UNITED NATIONS
OFFICE FOR OUTER SPACE AFFAIRS

Highlights in Space 2008

Prepared in cooperation with the International Astronautical Federation, the Committee on Space Research and the International Institute of Space Law

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UNITED NATIONS OFFICE AT VIENNA

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Progress in space science, technology and applications,
international cooperation and space law

UNITED NATIONS
New York, 2009

UNITED NATIONS PUBLICATION
Sales No. E.09.I.4
ISBN 978-92-1-101190-6

ST/SPACE/42

INTRODUCTION

This publication has been compiled from reports prepared for the United Nations Committee on the Peaceful Uses of Outer Space. It was first published in 1992 as part of the United Nations activities undertaken for the International Space Year, with the objective of making all countries aware of the benefits of sound space activities.

The first part of the report on space technology and space applications was prepared by the International Astronautical Federation (IAF); the International Institute of Space Law (IISL) provided information for the second part of the report on international cooperation and space law; both parts cover the period from 1 November 2007 to 31 October 2008. The third part, focusing on space science and recent progress made regarding space research, was prepared by the Committee on Space Research (COSPAR) of the International Council for Science (ICSU) and covers the period from 1 November 2006 to 31 October 2008. Many international experts from various specialized fields have contributed to the drafting of this comprehensive report. The information contained therein indicates a wide variety of ongoing space activities in national as well as international space programmes. A list of coordinators and contributors can also be found at the end of the report. This publication is available in English only.

This 2008 review of latest developments in space science, technology, space applications, international collaboration and space law has the aim to inform a broad worldwide audience of recent advancements in the manifold field of outer space.

We hope that “Highlights in Space 2008” can significantly contribute to all the efforts undertaken by the United Nations family, in particular the Office for Outer Space Affairs, in attempting to disseminate information on space activities and on the benefits involved to all nations of the world.

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PART ONE

HIGHLIGHTS IN SPACE SCIENCE AND TECHNOLOGY FOR 2008

I. OVERVIEW

Space Transportation. United Launch Alliance (USA) conducted its first operational launch of the Delta-IV Heavy and the first Atlas-V launch from the U.S. west coast. Sea launch returned to flight after last year's failure, conducting five successful launches this year, and Land Launch orbited its first payload.

Launch failures this year included a Proton-M and the third Falcon-1. Proton-M returned to service in August, and the Falcon-1 was successful on its fourth launch attempt in September.

Development contracts were issued by NASA for all elements of the Ares-1 launcher and Orion module that will replace the crew-carrying function of the Space Shuttle after the Shuttle's planned retirement in 2010. Ares-1 passed its Preliminary Design Review, and design of the Ares-5 heavy lifter for subsequent Moon and Mars missions was modified to accommodate larger payloads.

NASA's Commercial Orbital Transportation Services (COTS) contract with Rocketplane Kistler was cancelled, and replaced by a contract with Orbital Sciences, which plans a new Taurus-2 launcher for cargo deliveries to the International Space Station. Space Exploration Technologies (Space-X) still holds the other COTS contract. A third team led by PlanetSpace has also bid for the COTS delivery contract.

Virgin Galactic unveiled models of the new SpaceShipTwo suborbital space-tourist vehicle and its WhiteKnightTwo carrier aircraft, and rolled out the first operational WhiteKnightTwo. Testing of both craft were begun in preparation for revenue flights planned to start in 2010.

Telecommunications. Inmarsat selected EADS Astrium to build Alphasat 1-XL, the test satellite selected by ESA to demonstrate the new Big GEO Alphabus platform. Planned for launch in 2012, the $365-million Alphasat 1-XL will weigh 6 tonnes and deliver 12 kW of power to its payload.

Viasat, Space Systems/Loral, and Eutelsat (France) announced a joint effort to invest in two high-bandwidth Ka-band satellites to provide high-definition television and broadband Internet services to both Europe and North America. Eutelsat's 5.8-tonne, $500-million KaSat is to be built by Astrium Satellites and launched in 2010. The first dedicated Ka-band satellite in Europe, it will generate 11 kW of power for its more than 80 spot beams, making it the biggest Ka-band satellite ordered to date. ViaSat's $535-million Ka-band ViaSat-1 will be built by Space Systems/Loral and launched in 2011.

JAXA's $490-million Kizuna (Winds) satellite was launched. The world's fastest Internet satellite, Kizuna enables Internet speeds of 1.2 GB/sec when transmitting to a 5-m ground antenna, and 155 MB/sec when transmitting to a 45-cm antenna. Japan's first indigenous communications satellite, Superbird-7, was also launched this year.

ProtoStar 1 was launched to Singapore's geostationary-orbit slot 9 days later than the United Nations' ITU deadline for beginning service. The ITU refused to grant Singapore an extension of the deadline, following which Singapore withdrew its regulatory support of ProtoStar 1. This left the satellite without regulatory ownership, a situation which had no precedent. The satellite was subsequently "adopted" by Intersputnik.

Africa's Rascom-QAF1 satellite failed to reach its operational orbit due to a leak in its onboard propulsion system, and had to use most of its propellant to get there. The resulting abbreviated lifetime justified an insurance claim, which was used to order a replacement spacecraft that is planned to be on orbit before Rascom-QAF1 expends all its propellant.

Vietnam's first communications satellite, Vinasat-1, was launched and is now delivering over 200 broadcast television channels, along with telecommunications, Internet access, weather information and navigation data to fishing vessels and oil rigs, and healthcare and education services to islands and other remote areas.

Cambodia's first nationwide satellite television service was launched, using Shin Satellite's IPSTAR broadband satellite system. It costs customers $75 to install the digital picture and sound service.

The ICO G-1 mobile communications satellite was launched this year. At 6.634 tonnes G-1 is the heaviest commercial satellite ever launched, and is the first system to offer nationwide two-way high-speed cell phone and wireless broadband service in the U.S.

The European Parliament finally approved implementation of the Galileo satellite navigation system by an almost unanimous vote. It will be the first European infrastructure that is commonly built and jointly owned. Private firms were called on to help build the system as contractors, and will help fund the system after 2013, but not as joint owners as was originally planned. Bids on the $5.4-billion operational system were submitted to the European Commission (EC). ESA will run the procurement competition, with the goal of deployment by 2013.

Remote Sensing. Earth observation satellite deployments this year were dominated by radar systems: Canada's Radarsat-2, Italy's Cosmo-Skymed 2 and 3, Germany's SARLupe 3, 4, and 5, and Israel's TecSar/Polaris-1.

The world's highest-resolution commercial imaging satellite, the 4.3-tonne GeoEye-1, was launched. It can simultaneously collect 0.41-m resolution black-and-

white (panchromatic) images and 1.65-m color (multispectral) images, but due to U.S. licensing restrictions, commercial customers can access only 0.5-m resolution imagery.

Environmental satellite launches featured the joint U.S.-French ocean-observation Jason-2 spacecraft and China's Fengyun-3, which was used to improve weather forecasts for the 2008 Olympic Games in Beijing.

Humans in Space. This year saw two major additions to the ISS: Europe's Columbus experiment module and both pressurized elements of Japan's Kibo experiment facility, along with Canada's Special-Purpose Dexterous Manipulator (Dextre) robot. The first flight of Europe's Automated Transfer Vehicle (ATV) to the station was so successful that Europe is considering human-rating it for future crew transport.

China launched its Shenzhou-7 space capsule. The mission carried China's first three-person crew, Jing Haipeng, Liu Boming, and Zhai Zhigang. Zhai also conducted China's first spacewalk during the mission.

Astronomy and Astrophysics. NASA's $690-million Gamma-ray Large Area Space Telescope (GLAST), renamed Fermi, was launched to its 550-km circular orbit, and its two telescopes are covering the entire sky every 3 hours in the energy range from 10 keV to over 300 GeV. Its mission is to discover the origins of cosmic rays; to investigate dark matter, supermassive black holes, neutron stars, supernova remnants, and pulsars; and to track gamma-ray bursts.

Space Exploration. NASA's $520-million Phoenix Mars lander discovered ice near the red planet's north pole, along with perchlorate salts, magnesium, sodium, potassium and chloride, and found a pH level of 8 to 9, which is on the alkaline side. That makeup of the soil, which is very similar to that of Earth soils, could support future manned exploration by growing vegetables such as green beans, turnips and asparagus. The discovery of Earth-like soil met the highest-priority goal of the Phoenix mission.

The Cassini spacecraft exploring the Saturnian system found carbon dioxide, carbon monoxide, and organic molecules of methane, propane, acetylene, and formaldehyde in the geyser plume from the moon Enceladus, a composition similar to that found in comets. Cassini also detected evidence that indicates the existence of a large internal water-ammonia ocean about 100 km below Titan's surface and found an ethane lake there, the first lake ever to be confirmed on another planet in the solar system.

India launched the Chandrayaan-1 lunar orbiter to the Moon, joining China's Chang'e and Japan's Kaguya, both launched last year.

Technology Advancement. Combustion instability was observed in NASA's first-stage Ares-1 solid-propellant rocket motor, Several mitigation prospects were identified and one was chosen for further testing next year.

Global Space Market Issues and Opportunities. Russia's Prime Minister announced that Russia will consolidate its leasing role in the space industry over the next three years by earmarking more than $7.68 billion from 2009 - 2011 federal budgets to develop the space industry.

Space-derived revenue in 2007 was $251 billion, an 11-percent growth over 2006. Of that total, the satellite industry claimed a 16% revenue growth in 2007 to a total of $123 billion; the satellite navigation hardware market placed 2007 sales at $33 billion, a $6-billion increase over 2006; and the first market survey of the budding personal spaceflight industry claimed 2007 revenues of $268 million.

The 2600 delegates to the UN International Telecommunications Union's World Radiocommunication Conference rejected the application of the terrestrial wireless broadband industry for access to C-band spectra in the range 3.4 – 4.2 GHz, which would have caused major interference problems with satellite communications.

The world's two largest satellite radio companies merged. XM Satellite Radio Holdings became a wholly owned subsidiary of Sirius Satellite Radio (both USA). The $3.9-billion merged company is operating under the name Sirius XM Radio, with 18.5 million subscribers as of July and combined 2007 revenues of $3.9 billion.

II. SPACE TRANSPORTATION

II.1. Current Launch Activities

The first operational launch of the United Launch Alliance's Delta-IV Heavy placed the 2.34-tonne U.S. Defense Support Programme satellite DSP-23 into the geostationary orbit on 10 November 2007.

The first Atlas-V launch from the newly refurbished 50-year-old Space Launch Complex-3 (SLC-3) at Vandenberg Air Force Base took place on 13 March, with the orbiting by the United Launch Alliance of a U.S. military satellite, L-28. The Atlas-V 411 configuration used a single Aerojet strap-on solid-propellant booster, a Centaur upper stage with a single Pratt & Whitney Rocketdyne RL-10 engine, and a 4-m payload fairing. Remodeling of SLC-3 to support the heavy-lift capability of the Atlas-V took 22 months and was accomplished at a cost of $500 million.

Sea Launch returned to flight status on 15 January with the successful launch of Thuraya-3 (United Arab Emirates) into its geostationary-orbit slot at 98.5 degrees east longitude, following more than two months of delays due to unfavorable sea conditions. Sea Launch's Zenit 3SL rocket had been grounded since its failure on 30 January 2007 (see last year's report). Extending Thuraya's mobile communications service to China and maritime services in Asia, Thuraya-3 was built by Boeing Satellite Systems International (USA).

Sea Launch conducted its second successful launch of the year on 19 March, placing DirecTV-11 into a geosynchronous transfer orbit from which the 5.9-tonne spacecraft boosted itself to its geostationary-orbit slot at 99 degrees west longitude and began two months of testing before commencing service. The 14-kW satellite is now delivering an additional 50 channels of high-definition television to DirecTVs customers nationwide in the U.S, for a total with DirecTV-10 of 150 channels. It also delivers an additional 750 channels of local high-definition channels via the satellite's spot beams, for a total with DirecTV-10 of 1,500 channels. DirecTV-11 was built by Boeing Satellite Systems International on the company's 702-model platform. Sea Launch also conducted three more successful launches this year: Intelsat's Galaxy-18 on 21 May, Dish Network's EchoStar 11 on 15 July, and Intelsat's Galaxy-19 on 24 September (see below).

On 28 April the inaugural flight of Land Launch placed Spacecom's 1.27-tonne Amos-3 (Israel) telecommunications satellite into an orbit whose apogee was slightly more than 1,000 km above its intended position because of a software-programming error in the rocket's Block-DM upper stage. However, while the error forced Amos-3 to use more of its onboard fuel than planned in order to reach its final position, the satellite still is expected to have 17 years of full in-orbit operations and there will be no insurance claim. The launch from the Baikonur Cosmodrome used a Land Launch Zenit-3SLB to carry the satellite directly into the geostationary orbit, from which its onboard propulsion system carried it to its final slot at 4 degrees west longitude, alongside the existing Amos 2 spacecraft.

Land Launch is a joint venture of Sea Launch (USA) and Space International Services (Russia and Ukraine), intended to meet growing demand for small telecommunications satellites in the 3-tonne, 4 kW range. The new rocket has a payload adapter and separation system supplied by Saab Space (Sweden). The $170-million, 1.2-tonne Amos-3, built by Israel Aircraft Industries with a payload provided by Thales Alenia Space (France and Italy), carries two 500-MHz Ka-band and 12 Ku-band transponders. It will provide service to parts of eastern North America, Europe, Russia, the Middle East and east-central Africa.

On 22 April NASA issued an indefinite-delivery, indefinite quantity (IDIQ) contract for launch services to Space Exploration Technologies (Space-X) for launches through 2012 using the company's Falcon-1 and Falcon-9 rockets. Total contract value could vary from $20,000 to $1 billion, depending on the number of missions flown. Payloads weighing 250 kg or more would be launched into 200-km, 28.5-degree circular orbits for NASA's Science, Space Operations, and Space Exploration directorates.

An International Launch Services Proton-M rocket launched from the Baikonur Cosmodrome on 14 March failed to deliver the AMC-14 communication satellite to its planned orbit. The satellite is owned by SES Americom and built by Lockheed Martin on the A2100AX platform, carrying 32 Ku-band transponders. It was left in an elliptical orbit with a 28,000-km apogee instead of the intended 36,000 km after the Proton-M's Breeze fourth stage shut down 32 minutes into its second burn, which was to have lasted

about 34-1/2 minutes. The failure was subsequently traced to rupture of an exhaust-gas conduit that caused shutdown of the Breeze-M's turbopump. It was attributed to the stress of long-term exposure to higher-than-expected temperatures, coupled with weakening of the conduit caused by oscillations during the 32-minute burn.

Although the satellite was still in operating condition, using its onboard propulsion system to raise it to the required 35,000-km geostationary orbit slot at 61.5 degrees west longitude would have seriously reduced its operating life. Hence on 11 April SES and Lockheed Martin declared the spacecraft a total loss and filed a claim for the $150-million insurance purchased by SES, along with a $42-million insurance claim by EchoStar (USA), which had covered part of the satellite's construction cost. AMC-14 had been fully leased by EchoStar to cover the entire North American continent, with a planned service life of 15 years. The insurance underwriters subsequently sold the satellite for $15 million to the U.S. Department of Defense for use in training, testing and augmentation of satellite communications capability. The terms of the sale forbid purposeful destruction of the satellite, to avoid any generation of orbital debris.

One consequence of the failure was the delay from its planned March launch of ESA's Goce satellite because its intended Russian Rockot launch vehicle uses a modified version of the Proton-M's Breeze-M upper stage engine. Goce is to measure Earth's gravity field, model the geoid, and study ocean circulation from an unusually low 250-km orbit. Goce is the first of ESA's Explorer satellites. It was built by a 45-company consortium led by Thales Alenia Space (Italy) at a total mission cost of $537 million including launch and 30 months of operation. The 1.1-tonne spacecraft is equipped with a gradiometer consisting of six accelerometers (built by Onera, France), each of which is capable of three-axis measurements, providing a gravity-field precision of one-millionth of Earth-normal gravity. The spacecraft has no moving parts, taking advantage of a unique electric propulsion capability (see below) to achieve near perfect compensation of the upper atmosphere drag effects, a large variation associated with the orbital period, and a high-frequency (~ 10 Hz) "juddering" effect.

On 8 September Goce's launch was again postponed first to 5 October, then to 27 October, then again to later in the year and eventually to early next year because of technical problems with the guidance and navigation subsystem of the launcher's upper stage.

On 23 June the Proton-M was deemed able to return to service following replacement of the existing exhaust conduit walls, which had been found to be thinner than the minimum specification and completion of a comprehensive quality improvement programme by Khrunichev that began in April. The result was a redesigned, retested and recertified flight engine equipped with a new thicker-walled conduit and a detailed quality assurance review, including an independent audit, that had been mandated under the quality improvement initiative. On 2 July ILS announced that a Proton-M would launch Inmarsat's 4F3 mobile communications satellite on 14 August; the launch was accomplished successfully on 19 August. Proton's next launch was Nimiq-4 (see below) on 20 September.

Arianespace (France) announced on 8 January that they will not seek an extension of the current five-year, $1.4-billion government launcher aid package that has provided about $300 million annually to support fixed costs at Europe's Guiana Launch Center at Kourou, French Guiana. Rising launch prices, signing a higher percentage of contracts in strong Euros rather than weak U.S. dollars and a reorganization of Europe's launcher sector will allow Arianespace to do without the European Access to Space (EGAS) support structure when it expires in 2009.

On 20 September Arianespace (France) ordered 10 Soyuz rockets from Roskosmos (Russia) for $500 million, including transport to the Guiana Space Center and refueling and launch operations to be conducted by a Russian work team there. The purchase follows an initial buy of four rockets in June 2007. The launches could be conducted from either Kourou in French Guiana or the Baikonur Cosmodrome in Kazakhstan beginning in 2009. Arianespace financed the purchase with a long-term loan from the European Investment Bank, to be repaid from commercial launch revenues.

On 12 November 2007 China's new Long March 4C rocket launched the 2.7-tonne advanced Yaogan-III remote-sensing satellite from Taiyuan into a 600-km Sun-synchronous orbit. The Long March 4C has an upgraded second stage that can be restarted in space. Both the launcher and the spacecraft were built by the Shanghai Academy of Space Flight Technology, a division of the China Aerospace and Technology Corporation. Yaogan-III is surveying land resources, aiding the estimation of crop yields, and assisting disaster prevention and relief efforts.

On 27 April India's Polar Satellite Launch Vehicle PSLV-C9 orbited ISRO's 690-kg Cartosat-2A remote sensing satellite from the Satish Dhawan Space Center on Sriharikota Island. The launch also lofted India's 83-kg mini-satellite IMS-1 and eight nanosats for various international customers. Cartosat-2A, with 1-m spatial resolution and panchromatic imaging capability, is generating maps for urban planning and other applications. IMS-1 carries a multi-spectral and a hyper-spectral camera with resolutions of 37 and 506 m respectively. The data it generates during its planned two-year life are being made available to developing countries as a way to build interest in the use of such information. The eight nanosats in the payload weighed only about 50 kg collectively. Seven were developed by various universities in Canada, Denmark, Germany, and the Netherlands, with input from Japan, and one was built by Cosmos International (Germany).

India's cabinet approved a budget of $300 million on 17 July for ISRO to fly six more Geostationary Satellite Launch Vehicles (GSLVs) over the next four years to meet India's increasing needs for satellite capabilities. The demand for transponders for the Indian National Satellite System is expected to increase from the current level of 211 to 500 by 2012. ISRO plans to increase the GSLV's payload capability to 2.4 tonnes through the use of an indigenous cryogenic upper stage slated for its first flight by the end of the year.

Brazil and Argentina launched a VS30 sounding rocket from Brazil's Barreira do Inferno launch center to an altitude of 120 km on 16 December 2007. The first joint space mission by the two nations, based on a 1998 agreement, carried experiments from both.

On 4 February Iran launched its second sounding rocket, Kavoshgar-1 (Researcher-1) into space from a new space center dedicated the same day. The launcher was Iran's Shahab-3B rocket, an upgraded version of the Shahab-3A that launched Iran's first sounding-rocket mission in February 2007. The payload's re-entry capsule was claimed to have reached an altitude of 200 km before falling back to Earth. Iran's president Mahmoud Ahmadinejad said the launch was in preparation for the subsequent launching of Iran's first satellite, the indigenously built Omid (Hope), later this year by an Iranian-built multi-stage space launch vehicle.

II.2. Development Activity

On 29 November 2007 the U.S. General Accountability Office (GAO) issued a report questioning NASA's ability to develop successfully the Ares-1 rocket that is slated to launch the Orion crew exploration vehicle (see last year's report). The report stated that NASA's $14.4-billion development budget "may be inadequate," and suggested that NASA postpone the planned July 2008 Preliminary Design Review in order to fix 51 as-yet unresolved issues, 31 of which the GAO considered to be of high risk.

A second GAO study, "NASA: Ares-1 and Orion Project Risks and Key Indicators to Measure Progress," released on 3 April, called on NASA to better define both Ares-1 and Orion requirements and risks before conducting their Preliminary Design Review (PDR), planned for August and September. Key potential roadblocks identified by the GAO report included cost uncertainties associated with as-yet incomplete requirements definition, thrust oscillations in Ares-1's first-stage engine (see below), development of the upper-stage's J-2X cryogenic engine, producibility of Orion's large ablating heat shield, schedule pressures imposed by early retirement of the Shuttle, and insufficient testing sites, especially for Orion's vibration and acoustic environment.

On 23 June NASA revised the design of the heavy-lift Ares-V launcher slated for lunar and Mars missions (see last year's report). The new design uses six Pratt & Whitney Rocketdyne RS-68 engines to power its core stage, and twin five-and-a-half segment versions of the four-segment ATK shuttle solid boosters. Previous Ares V concepts had five RS-68s and twin five-segment boosters that basically matched the first stage of its Ares I crew launch vehicle. Purpose of the design change was to increase the Ares-V payload capability to meet the requirements for the Altair lunar lander and the Orion crew exploration vehicle. The revised Ares-V can deliver over 71 tonnes to the Moon.

In July NASA also changed the nozzle of the Pratt & Whitney Rocketdyne J-2X engine, slated for use on both the Ares-1 upper stage and the Ares-5 Earth-departure stage, from the new composite-material structure planned to be built by Snecma (France) back to the original Haynes-230 high-temperature alloy. The nozzle size (2.4 m long by 3

m diameter) exceeded Snecma's furnace capacity and would have required a costly new furnace. The metallic nozzle will need a new coating to provide the necessary radiation-cooling capacity, but NASA did not consider this to be a serious problem.

NASA awarded the 9-year, $266-million contract for design, development, test and evaluation of the Ares-1 avionics ring on 12 December 2007 to Boeing Space Exploration, one of the two finalists in the competition. The other finalist was Ball Aerospace; the other three losing bidders were BAE Systems, Honeywell Technology Solutions, and Raytheon Missile Systems. The initial contract covered one ground-test unit, three flight-test units and six production units. Additional work not covered by the initial contract, plus another 12 flight units, could bring the total contract revenue to $800 million. This completed NASA's contracting for the entire Ares-1/Orion space exploration vehicle.

The Ares 1 passed its preliminary design review (PDR) on 10 September, clearing the way for detailed design work to begin. NASA targeted March 2011 for completing the Ares 1 critical design review (CDR). The Orion Crew Exploration Vehicle's PDR, previously planned for this fall, has been pushed off into 2009. A separate second PDR for Ares 1 will be held in the summer of 2009 to solidify NASA's technical solution for the thrust oscillation problem: outfitting the rocket's aft skirt with active reaction mass absorbers (see below).

The jettison rocket motor for the Orion Launch Abort System (LAS) that is to rescue the Orion crew in the event of a launch or early-ascent abort was tested successfully on 27 March and again on 17 July. The four-nozzle motor, weighing less than 150 kg, was run for two seconds, setting up the first full-scale pad abort test at the White Sands Missile Range later this year. The engine was designed and built by Aerojet for LAS prime contractor Orbital Sciences.

On 11 January Orion prime contractor Lockheed Martin (USA) issued a contract initially worth about $50 million to Alliant Techsystems (ATK, USA) to design, develop and build the spaceship's 5.84-m-diameter solar arrays (see below). Since the arrays are expendable and will require replacement after each Orion mission, ATK expects continuing production through at least 2029.

On 18 March NASA issued five small study contracts totaling $1.5 million to recommend approaches for increasing the technological maturity of the agency's conceptual designs of the Altair lunar lander for the Constellation programme's Moon vehicle. From the 30 proposals received, NASA selected Andrews Space, Boeing, Lockheed Martin, Northrop Grumman and Odyssey Space Research to receive the awards.

Thirteen companies submitted proposals to NASA on 21 November 2007 for the $175 million in the Commercial Orbital Transportation System (COTS) programme that was made available by Rocketplane Kistler's default on its contractual requirements (see last year's report). They included bids from Space X (which already had one of the two

COTS contracts awarded last year), SpaceDev, Spacehab, Transformational Space Corporation, PlanetSpace, Inc. (teamed with Lockheed Martin Space Systems and Alliant Techsystems), Andrews Space, Boeing, Orbital Sciences, and major spacecraft manufacturer Space Systems/Loral, teamed with Constellation Services International (see last year's report). NASA downselected five finalists in January: Andrews Space, Boeing, Orbital Sciences, PlanetSpace, and Spacehab.

NASA subsequently awarded Orbital Sciences a development contract on 19 February for a commercial launcher to deliver payloads to the space station. Orbital's Cygnus maneuverable spacecraft will be launched by the company's new Taurus-II rocket. Using interchangeable modules for pressurized and unpressurized cargoes, Cygnus will be able to carry payloads weighing 2,300 kg to the station and return 1,200 kg to Earth. It will not dock with the station, but will rendezvous sufficiently near it, using Orbital's Star-2 satellite platform as its propulsion and guidance module, to allow the station's robot arm to transfer payload cargoes. Cygnus is based on Orbital's spacecraft used for NASA's 2005 Demonstration of Autonomous Rendezvous Technology (DART) mission (see prior reports). Its pressurized cargo module will be based on the Leonardo Multipurpose Pressurized Logistic Module (MPLM), built specifically for space-station cargoes by Thales Alenia Space (Italy); the unpressurized cargo module is to be based on Orbital's own Express Logistics Pallet. Star-2 propulsion is to be a 400-N engine built by Ishikawajima Heavy Industries (IHI, Japan).

The Taurus-II, which will have the capacity to deliver 6 tonnes to low Earth orbit, will use Aerojet's Russian-built AJ-26 liquid oxygen-kerosene engines in its first stage, topped by a solid-propellant Alliant Techsystems Castor-30 upper stage. The first stage, including its main structure, pneumo-hydraulic system, and control and telemetry system is being developed by SDO Yuzhnoye (Ukraine) and will be manufactured at PA Yuzhny Machine-Building Plant (Ukraine). Orbital plans to invest $150 million of its own money to supplement the $170 million NASA contract. Other members of the winning team were Draper Laboratories, Science Applications International Corporation, and Odyssey Space Research (all USA). Orbital plans to launch Taurus-II from the commercial Mid-Atlantic Regional Spaceport at NASA's Wallops Space Flight Facility in Virginia, which was selected on 9 June over a competing bid from Florida. The first COTS demonstration flight to the space station, with no cargo aboard, is planned for December 2010, the year that the Shuttle fleet is currently scheduled to be retired.

On 28 February NASA issued a draft request for proposals (RFP) to deliver cargo to the space station between 2010 and 2015. The RFP calls for each selected team to deliver a minimum of 20 tonnes to the space station and return intact at least 3 tonnes, during the 7-year life of the contract. No minimum dollar value was specified but NASA identified a maximum contract value of $3.1 billion. A meeting of prospective contractors was held at the NASA Johnson Space Center on 17-18 March, and the final request for proposals for an indefinite-quantity indefinite-delivery contract was issued in April. Bids are due back to NASA on 7 November, with the award planned for December 2008.

In addition to Space-X and Orbital Sciences, a third consortium led by PlanetSpace (USA) announced its intent on 21 October to compete for the COTS cargo contract. Unlike competitors Space-X and Orbital Sciences, PlanetSpace has no government funding, but has been able to raise the necessary financing privately from U.S. banks. The team includes three large aerospace companies, Alliant Techsystems (ATK), Boeing (who joined the PlanetSpace team in October), and Lockheed Martin. ATK will provide the Athena III launch vehicle (see below) and ground processing; Lockheed Martin and Boeing will develop modular orbital transfer vehicles with about 2-tonne payload capability to serve as the cargo carriers. On 22 October PlanetSpace announced a proposal to launch a 48-m solid-propellant rocket by 2011 from Launch Complex 36 at Cape Canaveral, just hours after the pad was dedicated by the state of Florida as the state's premier commercial launch facility. ATK officials have said that work on this commercial venture will not interfere with the development of NASA's Ares I, for which ATK is the main-stage prime contractor (see prior reports).

Space Exploration Technologies (SpaceX) conducted a full launch dress rehearsal and hold-down firing of its third Falcon 1 rocket on 25 June at its launch site at Kwajalein Atoll. The test marked the first pad firing of SpaceX's new Merlin 1C reusable engine, an upgraded version of the Merlin 1A used for previous Falcon 1 launches (see below). The regeneratively cooled Merlin 1C operated at full power, with only the hold-down system keeping the rocket from lifting off. The test was the last major milestone before the launch, which was scheduled to take took place between 24 June and 3 July, but was postponed to 29 July due to discovery of a weld defect in one of the engine nozzles.

The launch was finally conducted on 2 August, but failed when unanticipated residual thrust from the newly redesigned Merlin-1C main engine following first-stage separation drove the first stage into the second stage just as its engine began to fire. Both stages and the payload fell into the Pacific Ocean well east of the Marshall Islands. Space-X claimed that correcting the anomaly required only a timing change in the separation sequencing, which could have an immediate effect and planned the next Falcon-1 launch for September. This decision was bolstered by successful firings of the Falcon 9's nine-engine cluster two months ahead of schedule, during the two days just preceding the third Falcon-1 failed flight.

The fourth Falcon-1 flight attempt was indeed successful, taking place from Kwajalein on 28 September. After the launch and a planned on-orbit engine restart, the rocket's second stage and the attached 165-kg dummy payload reached its initial 9-degree 330-km target orbit. The success of the launch and insertion, the goal of which was 330 km altitude and 9.0-degree inclination, was evidenced by the actual performance: 330.5 km altitude at 8.99 deg. inclination. The upper stage coasted for 43.5 minutes before the second burn of 6.8 seconds, which circularized the dummy payload's final orbit at 621 x 643 km with an inclination of 9.3 degrees.

Falcon-1 was the first privately developed liquid-propellant rocket to orbit the Earth. Space-X has set the price of a Falcon-1 launch at $7.9 million, much lower than

the typical cost of an orbital launch. Data from the flight indicated that the Merlin-1C engine, the highest-performance gas-generator-cycle kerosene-fueled engine ever built (specific impulse 304 seconds), could give the Falcon-1 the capability to deliver 420 kg to a 185-km circular orbit.

Among the Falcon-1 payloads lost on the vehicle's third launch failure was the U.S. Air Force's Trailblazer satellite, built by SpaceDev (USA), which actually succeeded in demonstrating its main goal: the ability to respond to an urgent military need by rapidly selecting, integrating, and launching a satellite. Also lost were two small NASA satellites mounted on an adapter ring being tested for future use on Malaysia's RazakSat remote sensing satellite, planned for a subsequent Falcon-1 launch, and the cremated remains of over 200 people, including those of Mercury-7 astronaut Gordon Cooper and television's Star Trek engineer "Scotty."

One of the NASA payloads was a technology demonstrator for PharmaSat, an orbiting micro-laboratory launched later in the year, and NASA claimed that by demonstrating partnering with industry and rapid development, it too, like Trailblazer, was not a total loss. The other NASA satellite was NanoSail-D, a gossamer fabric sail aluminized to capture solar photons for conversion into an electric-powered stationkeeping thruster. It was the only complete loss aside from the cremains.

Alliant Techsystems (ATK, USA) revealed plans on 16 January to develop Athena-III, a new all-solid-propellant launch vehicle. Its first stage would be a 2-1/2-segment version of the space shuttle's 4-segment 12.5-MN thrust booster; the second stage is a standard Castor-120 motor that is currently used on the Athena and Taurus commercial launchers; and the third stage is a 76-cm-diameter Castor-30 motor that ATK has been developing. Lockheed Martin's hydrazine liquid-monopropellant Orbit Adjust Module, which has flown on the Athena, would be used for in-space approach and docking.

The initial application cited by ATK for the new vehicle, which is claimed to be based totally on heritage elements, would be for NASA's Commercial Orbital Transportation System (COTS; see above and last year's report). The new Delta-II-class launcher could deliver 6 tonnes of cargo to the International Space Station by late 2010; with composite casings and propellant upgrades it is claimed to be able to increase that payload by over 700 kg. Subsequent applications could include lifting payloads into geosynchronous transfer orbits, translunar injection, and Mars science missions.

However, on 22 August ATK's ALV-X1 sounding rocket, an experimental vehicle developed by ATK to explore low-cost launchers, was destroyed by ground controllers 27 seconds into its first launch attempt from NASA's Wallops Island facility, depositing two NASA hypersonic research payloads into the Atlantic Ocean. The launch was contributed by ATK. The lost payloads, which cost an aggregate of $17 million including launch integration and range fees, were HYBOLT (Hypersonic Boundary Layer Transition) which was to have provided information about air flow and heating during hypersonic flight, and SOAREX, which was to have collected data on atmospheric

re-entry for the design of a Mars spacecraft. The unique and demanding trajectory imposed by the hypersonic research payloads overtaxed vehicle control systems, forcing range-safety destruction of the launcher.

On 23 January Virgin Galactic unveiled the design configuration of SpaceShipTwo and its carrier aircraft, WhiteKnightTwo, both of which began initial tests this summer following the 28 July rollout of the first operational WhiteKnightTwo at the Mojave Air and Space Port (USA). WhiteKnightTwo is the world's largest all-carbon-composite aircraft. The vehicle rolled out on 28 July was christened "Eve," in honor of Virgin Group chairman Sir Richard Branson's mother. At the time of the rollout, Virgin Galactic had invested $100 million in the project and had received $38 million in deposits by future customers.

During the 23 January unveiling at the American Museum of Natural History, Branson exhibited 1/16th-scale models of the two craft. WhiteKnightTwo, a twin-hulled aircraft with a 43-m wingspan powered by four jet engines, will carry the six-passenger, two-crew SpaceShipTwo between its hulls. It will also be capable of launching unmanned spacecraft into orbit. Each SpaceShipTwo is designed to fly twice daily and WhiteKnightTwo up to four times daily. Both craft are built wholly of composite materials. The cabins of WhiteKnightTwo are identical to that of SpaceShipTwo, so that the aircraft can be used as a training tool for the spaceship. Family members of space tourists will be able to watch the SpaceShipTwo launch from the cabin of WhiteKnightTwo. Virgin Galactic has stated that safety factors will be comparable to those of the airliners of the 1920s.

On 28 February NASA issued two Requests for Information (RFIs). One asked for ideas on using suborbital vehicles such as Virgin Galactic's for human-tended flight experiments on such tasks as atmospheric sampling and astronomical observations. This type of effort would provide Principal Investigators on projects for NASA's Science Mission Directorate with opportunities to develop and operate smaller projects early in their careers. The second RFI asked companies to provide NASA with information on buying flight services for these flight experiments.

Having received no viable responses to these RFIs, on 10 July NASA issued a call for proposals for up to eight one-year studies totaling $400,000 to develop human-tended experiments that would be flown on reusable suborbital spaceships. NASA plans up to two concept studies in each of its Science Mission Directorate's four divisions: astrophysics, Earth science, heliophysics, and planetary science.

On 2 October Virgin Galactic and the U.S. National Oceanic and Atmospheric Administration (NOAA) signed a letter of intent to use SpaceShipTwo and WhiteKnightTwo to carry instruments for climate research and other NOAA objectives. The tests, which provide NOAA with altitude capability about twice as high as that available for current NOAA experiments using commercial airliners, will be carried out during the crafts' flight-test programme in 2009 – 2010. The first tests will provide data on atmospheric composition, especially carbon dioxide and other greenhouse gases.

The explosion that killed three Scaled Composites employees during a cold-flow ground test of SpaceShipTwo's rocket engine in July 2007 (see last year's report) was traced on 7 February to failure of the oxidizer tank. The company claims that it will not affect the planned flight programme. On 18 August, Scaled Composites awarded SpaceDev (USA) a $15-million contract to assist in the development of SpaceShipTwo's production-ready hybrid rocket engine (see below). SpaceDev had a similar role in developing the engine for SpaceShipOne.

On 26 March Xcor Aerospace (USA) revealed its plans to develop and operate a rocketplane called Lynx as the company's entry into the space tourism market. Lynx is being designed to take off under its own power with a pilot and one passenger and fly to an altitude of 60 km. The initial Mk-1 version of Lynx will reach a maximum speed of Mach 2 when the engine cuts off at an altitude of about 42 km, where the passenger will then experience about 90 - 120 seconds of microgravity. Maximum deceleration will be 4 gravities at pullout after reentry. Testing is scheduled to begin at the FAA-licensed Mojave Air and Space Port (California, USA) in 2010, and is planned to comprise 20 to 50 test flights in addition to extensive engine ground-test firings and taxi tests.

The craft will be about the size of a small business jet and will use an engine powered by kerosene and liquid oxygen, whose subscale prototype, the 6.67-kN thrust 4K14 engine, has already been tested by Xcor, along with the baseline reaction control system that will steer the craft while it is above the atmosphere. Xcor's propellant pumps can operate with propellant stored in unpressurized containers, allowing the use of lightweight wing tanks. The price to the passenger will be $100,000, half that being charged by Virgin Galactic. Operational flights are planned to use New Mexico's Spaceport America complex, the same site as Virgin Galactic.

Rocketplane Global Incorporated (RGI, USA) announced completion of its separation from Rocketplane Inc. and Rocketplane Kistler (both USA) on 20 March, along with plans for a new variant of the Rocketplane XP suborbital space-tourist craft (see last year's report). The revised XP has canards for added control, a T-tail instead of a V-tail, for better control and reduced weight, and a more robust landing system. It will carry five passengers and a pilot, and will use two afterburning J-85 jet engines and a rocket engine burning liquid oxygen and kerosene. It will operate from a 4,000-m runway at the Oklahoma Spaceport's Burns Flat facility, climbing to an altitude of 12 km on jet power before turning on its rocket engine. Its coast period will provide three to four minutes of microgravity flight.

On 24 October Armadillo Aerospace (USA) successfully completed one contest in the Northrop Grumman Lunar Lander Challenge, winning a $350,000 prize. The vehicle launched vertically and moved sideways, hovering for over 90 seconds, before returning. NASA provided the prize money to push development of vehicles that can land instruments on the moon's surface. Armadillo tried the next day for the more difficult second challenge, worth $1.65 million. The rocket needed to fly for 180 seconds and then maneuver to a precise landing atop a crater-pocked and rock-laden look-alike of a lunar

landscape, but failed shortly after ignition, falling on its side. Because of the damage to the vehicle, the team did not make another attempt.

Lockheed Martin (USA) teamed with UP Aerospace (USA) to conduct a test flight of a subscale demonstration model of a prototype reusable launch system from Spaceport America in New Mexico on 19 December 2007. The test vehicle for the as-yet unnamed system was 2.4 m long, with a 1.8-m wingspan. It reached an altitude of about 915 m before being recovered. The project to develop a low-cost, rapid-response system is being funded by Lockheed Martin.

The European Aviation Safety Agency (EASA) announced its proposed regulatory approach for suborbital craft at a space safety conference in Rome, Italy on 27 October. Operators will have to be fully certificated before the first commercial flight, including operations, flight-crew and passenger licensing, and continued airworthiness. A follow-up policy paper will be based on the first round of applicants' feedback, while regulations are expected in the longer term.

On 16 January the South Korean Ministry of Science and Technology announced a new space budget of $338 million, with the key milestone to be the launch in December of the Korea Space Launch Vehicle-1 from the new Naro Space Center completed this year. It is expected to orbit a 100-kg technology demonstration satellite. Over a third of the 2008 budget will go for continued work on three multipurpose Earth observation satellites. South Korea plans to double its space expenditures over the next decade, to $3.8 billion.

On 11 April Russian President Vladimir Putin ordered Roskosmos to accelerate construction of a new cosmodrome and development of a new booster rocket. The Vostochny, or Eastern, cosmodrome will be built in the Amur region which borders China. Its launch pad will be built by 2015, and it is scheduled to begin handling all manned space launches in 2020. Russia would continue to use the Baikonur launch site in Kazakhstan until at least 2050. In addition to Vostochny, Russia is working with Kazakhstan to build a space complex at Baikonur, Baiterek, to launch Angara carrier rockets capable of delivering 26 tonnes of payload into low Earth orbits.

At the Global Space Development Summit held in Beijing on 23 – 25 April, China announced that multiple hot-fire tests have been conducted on new oxygen/kerosene and oxygen/hydrogen rocket engine systems for the forthcoming Long March 5 booster line, and are being integrated with their airframes and tankage for initial launches as early as 2010. Using a variety of strap-on boosters, the Long March 5 rockets will launch payloads of 10 to 25 tonnes to low Earth orbit and 6 to 14 tonnes into geosynchronous transfer orbits.

III. ROBOTIC EARTH ORBITAL ACTIVITIES

III.1. Telecommunications

III.1.1. Fixed-Base Communication Systems

The Star One C1 satellite, owned by Star One (Brazil), was launched on 14 November 2007 by an Ariane 5 ECA rocket from Kourou to its geostationary-orbit slot at 65 degrees west longitude. The 4.1-tonne spacecraft, built by Thales Alenia Space (France and Italy), carries 28 C-band and 10 Ku-band transponders, and one X-band transponder. The same launch also orbited the 4.7-tonne Skynet-5B satellite, built by Astrium Satellites for owner Paradigm Secure Communications (UK), which was subsequently moved to its geostationary-orbit slot at 53 degrees east longitude. The double payload, at 8.8 tonnes, was the heaviest ever launched by the standard Ariane 5 ECA configurations.

Satmex (Mexico) authorized Space Systems/Loral (USA) on 24 June to start work on the Satmex-7 satellite, a replacement for Solidaridad-2 in Satmex's geostationary-orbit slot at 119.4 degrees west longitude. Planned for launch in 2011, Satmex-7 will carry C-band and Ku-band transponders for television and broadband data services. A few days earlier, on 17 June, EchoStar Corporation (USA) requested permission from the U.S. Federal Communications Commission (FCC) to move two of its satellites to Mexico's orbital slot at 77 degrees west longitude, on behalf of its joint venture QuetzSat (Mexico) with SES Global (Luxembourg). When the license was subsequently granted, EchoStar-2 and EchoStar-8 replaced EchoStar-4 in the QuetzSat slot. Although the two companies plan to launch QuetzSat's first dedicated satellite QuetzSat-1 in 2011, a contract for its construction has yet to be signed.

The Land Launch anomaly on 23 April (see above) did not affect the 21 May launch of Intelsat's 4.6-tonne Galaxy-18 satellite by a Sea Launch rocket that uses the same upper stage; that launch was conducted successfully. The spacecraft, Intelsat's 54th satellite in orbit, was subsequently placed in a geostationary-orbit slot at 123 degrees west longitude, where it replaced Galaxy-10R. Built by Space Systems/Loral (USA), it carries 24 C-band and 24 Ku-band transponders for television and data transmission service to the U.S., Canada, and Mexico. Although designed for a 15-year lifetime, Galaxy-18 is expected to last for 20 years.

Intelsat (Bermuda) ordered its IS-18 satellite from Orbital Sciences (USA) on 21 August. To be built on Orbital's Star-2 platform, the new spacecraft will carry 24 C-band and 23 Ku-band transponders and will deliver 4.9 kW to the payload. It will replace IS-701 in Intelsat's geostationary-orbit slot at 180 degrees east longitude, from where it will cover the Pacific Ocean region and the western United States.

On 23 November 2007 Inmarsat (UK) selected EADS Astrium to build Alphasat 1-XL, the test satellite selected by ESA to demonstrate the new Big GEO Alphabus platform (see last year's report). The new satellite will provide increased capacity and

redundancy for Inmarsat's Broadband Global Area Network (BGAN), covering Asia, Africa, Europe and the Middle East from a geostationary-orbit slot at 25 degrees east longitude. Planned for launch in 2012, the $365-million Alphasat 1-XL will weigh 6 tonnes and deliver 12 kW of power to its payload. One new feature will be up to 750 channels of capacity in the extended L-band (1200 – 1600 MHz), which will provide better voice and data quality and higher download times. The spacecraft will also incorporate a $42-million second-generation laser communications terminal, provided by the German aerospace center DLR to test GEO-to-LEO data links with Germany's X-band radar satellite Tandem-X, to be launched in 2010-2011 (see last year's report).

On 7 January Viasat (USA), Space Systems/Loral (USA) and Eutelsat (France) announced a joint effort to invest in two high-bandwidth Ka-band satellites to provide high-definition television and broadband Internet services to both Europe and North America. Eutelsat's 5.8-tonne KaSat, which will cost over $500 million including launch, insurance, and an elaborate ground network, is to be built by Astrium Satellites (Europe) and launched in 2010 to Eutelsat's geostationary-orbit slot at 13 degrees east longitude. The first dedicated Ka-band satellite in Europe, it will generate 11 kW of power for its more than 80 spot beams, making it the biggest Ka-band satellite ordered to date. It will serve over 1 million subscribers in Europe and the Mediterranean basin.

ViaSat's ViaSat-1 Ka-band bird, to be built by Space Systems/Loral, is planned for launch in 2011 to Telesat Canada's geostationary-orbit slot at 115 degrees west longitude. It will cost about $535 million, including launch and insurance but not the ground segment, and will serve 3 million customers in North America. Both KaSat and ViaSat-1 will utilize ViaSat's next-generation SurfBeam/Docsis broadband ground-terminal technology. ViaSat claims that VisSat-1 will deliver twice as much throughput capacity as all eight of the other two-way C-band, Ku-band, and Ka-band fixed-service satellites over North America combined: 100 GB/sec *vs* 87 GB/sec., at a cost of $250 million *vs* the other satellites' combined cost of $1.5 billion.

Eutelsat also signed a contract with Thales Alenia Space (France and Italy) on 26 February for the 5.4-tonne W3B satellite, a large Ku/Ka-band bird to service Europe, northern and southern Africa, Turkey and the Middle East as well as the Indian Ocean region from Eutelsat's geostationary-orbit slot at 7 degrees east longitude, where it will be colocated with the company's W3A satellite. Delivery of W3B, which will carry 53 Ku-band and three Ka-band transponders and deliver 12 KW to its payload, is scheduled for mid-2010.

On 16 July a Sea Launch Zenit-3SL rocket launched the 5.5-tonne EchoStar-11, owned by Dish Network Corporation (USA), into a geosynchronous transfer orbit. It was then placed into a geostationary-orbit slot at 110 degrees west longitude, from where it broadcasts high-definition, direct-to-home television for customers in the U.S. Built by Space Systems/Loral (USA), the satellite generates 20 kW of power and has a design service life of 15 years.

Sea Launch subsequently orbited Intelsat's Galaxy 19 aboard a Zenit-3SL on 24 September. Galaxy 19 is now providing telecommunications services to the United States, Canada, Mexico and the Caribbean from its geostationary-orbit slot at 97 degrees west longitude, where it replaced Galaxy 25, launched in 1997. The 4.7-tonne spacecraft, built by Space Systems/Loral (USA) on the company's 1300 platform, carries 52 C-band and Ku-band transponders and is claimed to have sufficient on-board propellant for a 20-year operating lifetime.

Telesat Canada's Nimiq-4 satellite was launched by an ILS Proton-M rocket from the Baikonur Cosmodrome on 20 September to provide high definition television (HDTV) in North America over its planned life span of 15 years from Telesat's geostationary-orbit slot at 82 degrees west longitude. Built by Astrium Satellites (Europe), Nimiq-4 weighed 4.85 tonnes at launch. It carries 32 Ku-band and 8 Ka-band transponders for high-definition television service by lessee Bell TV (Canada).

Eutelsat shut down four of the 24 Ku-band transponders on board the W5 telecommunications satellite following a partial loss of power-generating capacity that occurred on 17 June. W5, built by Thales Alenia Space (France and Italy), was launched in November 2002 and has been operating at 70.5 degrees east longitude to provide communications links between Asia and Europe. The remaining payload is providing normal service, and traffic on the shut-down transponders was assumed by Eutelsat's W3 spacecraft and Israel's RRSat with no loss in service. The cause of the problem was malfunctioning of the drive mechanism for one of the spacecraft's solar panels due to reasons that were not identified. The failure will reduce W5's design service life of 15 years by one to three years,

On 4 August SES (Luxembourg) reported that a solar array problem had affected its AMC-4 and AMC-16 satellites and could affect more. The problem had caused varying degrees of power loss in some of SES's nine Lockheed Martin A2100 communications satellites, but had only resulted in a minor reduction in available commercial capacity on AMC-4 and AMC-16. Manufacturer Lockheed Martin said that corrective measures had been introduced on more recent A2100 models to prevent any reoccurrence of the problem.

On 25 May Hispasat (Spain) issued a preliminary authorization to proceed with industrial agreements for building the payload and bus of Hispasat-AG1. It is the first Small Geo satellite of the European public-private partnership initiative launched in December 2005 to create a new family of advanced small telecommunications satellites (see prior reports). It will use the new Luxor multipurpose bus design developed by OHB System (Germany) under ESA's Artes programme, which features a maximum takeoff mass of about 2.3 tonnes, a payload mass of 300 kg, 3 kW of power, a 15-year lifetime and a wide range of booster-rocket options. AG1 will carry up to 20 Ku-band transponders and 3 Ka-band transponders broadcasting via spot beams. ESA is contributing $300 million to cover the bus, system design, and innovative payload elements. Hispasat is investing $78 million for launch and insurance, and OHB about $30 million. 43% of ESA's funding is coming from Germany, 23% from Spain and $40

million from Italy. The OHB multinational development team includes Carlo Gavazzi Space, Luxspace, Oerlikon and the Swedish Space Corporation.

On 11 February an International Launch Services Proton M rocket from the Baikonur Cosmodrome launched Norwegian Telenor Satellite Broadcasting's Thor-5 satellite to its geostationary-orbit slot at 1 degree west longitude, where it replaces the aging Thor-2. It was the first commercial payload to be placed directly into the geostationary orbit by a Proton launcher. The 2.45-tonne spacecraft, built by Orbital Sciences Corporation (USA), carries 24 Ku-band transponders to provide high-definition television services in the Nordic region and Europe. Cost of the satellite, launch, and insurance was $217 million. Delivering triple the power of the Thor-2 bird it replaces, its design life after commencing service on 11 April is 15 years.

France and Italy signed a cooperative agreement on 30 November 2007 to jointly develop and build a dual-use broadband satellite for defense and other government communications. The agreement permits the French and Italian space agencies to initiate the design phase of a 3-tonne Ka-band spacecraft with a data rate of 2-3 GB/sec, to be launched in 2012 and costing $366-million to develop.

Thales Alenia Space (France and Italy) signed a cooperative agreement on 6 December 2007 with Russia's NPO-PM. The agreement covers satellite manufacturing and development, specifically the joint development of a new multi-mission satellite bus, Express 4000, which will be built by NPO-PM. Thales will supply avionics and star trackers. The new platform, planned for Express-AM4, can deliver 14.5 kW to the payload, *vs* the present Express-AM's 5 kW, and would have a longer service life. A second new satellite family planned by the Russian Satellite Communications Corporation (RSCC) using the new Thales bus, Express RV, will deliver 10 kW to the payload. The agreement also covered the supply by NPO-PM and other members of the Russian Information Satellite Systems Company (see last year's report) of components for Thales Alenia Space's Spacebus-4000 platform.

However, on 14 March RSSC selected a joint proposal by Khrunichev and Astrium Satellites to build Express-AM4, over the competing offer by Thales and NPO-PM. The satellite is being built on Astrium's Eurostar E3000 platform. Planned for launch in 2010 to RSSC's geostationary-orbit slot at 80 degrees east longitude, it will carry 63 C-band, Ku-band, Ka-band, and L-band transponders and deliver 14 kW to the payload. AM-4 will be the largest Express satellite ever built and the first to use a non-Russian platform.

RSSC's AM-33 was launched to a geostationary orbit at 96.5 degrees east longitude by a Russian government Proton-M-Breeze rocket from the Baikonur Cosmodrome on 28 January. The 2.6-tonne spacecraft was built by NPO-PM (Russia), with payload electronics supplied by Thales Alenia Space (France and Italy). AM-33 carries 10 C-band, 16 Ku-band, and one L-band transponder. It will serve customers in Russia and the Asia-Pacific region for its design service lifetime of 12 years.

RSCC's AM-22, launched in December 2003 into a geostationary-orbit slot at 53 degrees east longitude to service the Middle East and central Asia, suffered failure of its primary and backup stabilizing gyroscopes on 6 February. RSCC subsequently uploaded a software patch that appears to have been successful in keeping the satellite's transponders operating nominally. RSCC had originally intended filing an insurance claim for total loss of the satellite, which had been designed for a 12-year service life. Should AM-22 indeed fail later, RSCC plans to offload its customers, of whom Eutelsat is the primary one, onto AM-33 or AM-44, which was launched in June.

RSSC also announced on 10 January that its client, the Republic of Kazakhstan, had ordered KazSat-2 from Khrunichev State Research and Production Space Center (Russia), who had also been prime contractor for RSSC's KazSat-1, launched in June 2006. The second KazSat, like the first one, will use Khrunichev's platform with an electronic payload built by Thales Alenia Space (France and Italy). It will carry 16 Ku-band transponders *vs* 12 for KazSat-1, and is planned for launch from the Baikonur Cosmodrome directly into the geostationary orbit by a Khrunichev Proton rocket in late 2009.

On 15 January the Swedish Space Corporation (SSC) took over operational control of SES Sirius's Sirius-4 communications satellite, built by Lockheed Martin (USA) on the company's A2100 platform and launched on 18 November 2007 by an International Launch Services Proton rocket. The satellite is being used mainly for television broadcasting in the Nordic and Baltic regions. SES (Luxembourg) still owns 75% of Sirius-4 (SSC owns 25%) and continues to use it to boost capacity in Africa.

Japan's Kizuna, the Wideband InterNetworking engineering test and Demonstration Satellite (Winds), was launched successfully by an H-2A rocket from the Tanegashima space center on 23 February, completed its ascension to its 143-degree-east-longitude geostationary-orbit slot on 14 March, and then began a three-month checkout period. Claimed by developer Japan Aerospace Exploration Agency (JAXA) as the world's fastest Internet satellite, Kizuna can enable Internet speeds of 1.2 GB/sec when transmitting from its two Ka-band multi-beam transmission antennas to a 5-m ground antenna, and 155 MB/sec when transmitting to a 45-cm antenna. One of Kizuna's antennas is providing coverage for Japan and the other for southeast Asia. The spacecraft can divide up its service areas, providing extra power to rainy regions while economizing on those areas with good weather. Cost of the Winds mission, including development and launch, was $490 million. Its design life is 5 years.

On 12 June an Ariane-5 ECA rocket launched Turksat-3A from the Guiana Space Center at Kourou, French Guiana. The 3.1-tonne spacecraft, built by Thales Alenia Space (France and Italy) and owned by Turksat AS, carries 24 Ku-band transponders. It subsequently replaced the retired Turksat-1C in Turksat AS's geostationary-orbit slot at 42 degrees east longitude. The same launch also orbited the British Defence Ministry's 4.6-tonne Skynet-5C communications satellite, completing the Skynet-5 in-orbit fleet. The fleet is owned and operated for the U.K. Defence Ministry by Paradigm Secure Communications Ltd. (UK). Paradigm's unique $7-billion contract allows them to sell

excess Skynet capacity to other customers. The Skynet satellites were built by Astrium Satellites on their Eurostar E3000 bus.

Arabsat's Badr-6 satellite was launched on 7 July by an Ariane-5 ECA rocket from the Guiana Space Center in Kourou. The 3.4-tonne spacecraft, carrying 24 C-band and 20 Ku-band transponders, was built for Arabsat (Saudi Arabia) by Astrium Satellites and Thales Alenia Space (France). Badr-6 subsequently joined Badr-3, Badr-4, and Badr-C in Arabsat's geostationary-orbit slot at 26 degrees east longitude. Immediately following the successful launch, Arabsat announced the purchase of 11 Badr C-band transponders for five years by Sudasat (Sudan) and a 10-year, $85-million contract for C-band services with Emerging Market Communications (USA).

The same Ariane launch also orbited the 4.2-tonne ProtoStar 1, which was subsequently placed in Singapore's geostationary-orbit slot at 98.5 degrees east longitude. Built by Space Systems/Loral (USA) for Protostar (Bermuda), the satellite carries 38 C-band and 16 Ku-band transponders. It is the former Chinasat-8 spacecraft, built for Chinasat about ten years ago but denied shipment to China by U.S. export controls. It was intended for direct-broadcast television service by Dish TV India Ltd. and elsewhere in Asia. ProtoStar 2 has been ordered from Boeing Satellite Systems International (USA) and is planned for launch next year.

However, in an unprecedented series of actions, the United Nations' International Telecommunication Union (ITU) refused to grant Singapore an extension of the 28 June deadline for beginning service by the satellite, following which Singapore withdrew its regulatory support of ProtoStar 1. This left the satellite without regulatory ownership, a situation which had no precedent. China had previously expressed concerns about potential interference by ProtoStar 1 with China-registered satellites operating near the 98.5-degree slot that were preparing to broadcast the August Beijing Olympics, and the United Arab Emirates (UAE) had complained to the ITU that neither ProtoStar nor Singapore had undertaken sufficient coordination discussions to ensure that there would be no physical contact of their satellite with UAE's Thuraya-3 spacecraft operating at the same orbital location.

Despite these concerns, however, on 5 September ProtoStar Ltd. completed in-orbit testing and signed an agreement with Intersputnik (Russia) to deliver Ku-band and C-band satellite services to south and southeast Asia via ProtoStar-1. Commercial services there started on 1 October. As part of the agreement, Intersputnik accepted responsibility for ProtoStar-1 with the ITU and registered for frequency rights at the 98.5-degree slot. However, operators who registered between Singapore's registration date of 2001 and Intersputnik's protection date of May 2005 now take precedence over ProtoStar-1, so Intersputnik still has to coordinate with Chinese networks that now have seniority.

Superbird-7, Japan's first wholly home-designed and home-built communications satellite, was launched on 14 August by an Ariane 5 ECA from ESA's Guiana Space Center. Built by Mitsubishi Electric Corporation on the company's DS-

2000 bus, Superbird-7's 28 Ku-band transponders are delivering television and other services to Japan and the wider Asia-Pacific region from a geostationary-orbit slot at 144 degrees east longitude. The 4.8-tonne, 8-kW spacecraft is operated by Space Communications Corporation (Japan), which in October became a division of SkyPerfect JSAT Corporation (Japan). All previous Japanese broadcasters and commercial telecommunications carriers had used spacecraft made in the U.S.

The same launch also orbited SES Americom's 2.4-tonne AMC-21, built by Thales Alenia Space (France and Italy) on Orbital Science's (USA) STAR-2 platform. AMC-21's 24 Ku-band transponders are providing Internet services to the USA, the Gulf of Mexico, Central America and the Caribbean from its geostationary-orbit slot at 125 degrees west longitude, and are also delivering mobile broadband service to the maritime industry.

The 3.2-tonne Rascom-QAF1 satellite was launched from Kourou by an Ariane-5GS on 21 December 2007, but failed to reach its designated geostationary-orbit slot at 2.85 degrees east longitude due to a helium pressurization system leak that shut down its main onboard propulsion system. The most probable cause of the leak was traced to a 0.4-mm crack in a weld on a pressure regulator's low-pressure isolation device.

Built on the Thales Alenia Space Spacebus 4000B3 platform, Rascom-QAF-1's payload of 12 Ku-band and 8 C-band transponders was intended to serve African telecommunications companies in 45 nations who had previously relied on Intelsat, SES, Eutelsat, and other non-African operators. Financing of Rascom at $400 million was completed in 2003 after ten years of effort, with Rascom holding 26%, Libya's GPTC telecommunications service 29%, the Libyan African Investment Portfolio Bank 33%, and Thales Alenia Space the remaining 12%. The main tracking, telemetry, and control station is located in Gharyan, Libya; a second is in Abidjan, Cote d'Ivoire. Gateways are planned in Gharyan; Abidjan; Banjul, Gambia; and Douala, Cameroon.

Although Rascom-QAF1 was subsequently raised to its operational geostationary-orbit slot early in February through four weeks of apogee firings by using its onboard station-keeping thrusters, the consumption of propellant needed to do so reduced the satellite's life from its design value of 15 years to only about 2-1/2 years. The spacecraft's owner, RascomStar-QAF (Mauritius), had paid an 11.5% premium to insure the satellite for $365 million. Rascom filed a total-loss claim of $256 million, which the underwriter reduced to $236 million because of the satellite's truncated life expectancy.

On 8 June Rascom used the payment to order from Thales Alenia Space (France) an identical replacement satellite, Rascom-QAF 1R, which was contracted on 22 October to be launched by Arianespace (France) in the third quarter of 2010, thereby making it available when Rascom-QAF1's reduced lifetime expires in September 2010. Loss of Rascom-QAF1, coupled with previous 2007 launch failures of Sea Launch and Proton and the in-orbit failure of the GeoEye Orbview-3 satellite, have caused the satellite insurance industry a 2007 loss of $125 million - $200 million in excess of claims over premiums paid.

Nilesat (Egypt) ordered Nilesat 201 from Thales Alenia Space (France and Italy) on 5 June. The 3.2-tonne satellite, carrying 24 Ku-band and four Ka-band transponders, is due for launch in February 2010. To meet the growing demand until then, Nilesat has leased long-term capacity on Eutelsat's Atlantic Bird 4, which has been moved to Nilesat's geostationary-orbit slot at 7 degrees west longitude.

Angola's ministry of posts and communications approved the purchase and launch of a national telecommunications satellite in late August. Construction, launch, and operation of the $328-million Angosat will be managed by Russia's Rosoboronexport.

On 15 January Measat Satellite Systems (Malaysia) completed moving one of its satellites, Measat-1, originally deployed in 1996, to an inclined geosynchronous orbit over eastern Africa at 46 degrees east longitude to help meet the strong demand there for telecommunication services. Renamed Africasat-1, the satellite carries 12 C-band and 4 Ku-band transponders, but no longer can operate at full strength. It is being operated from Measat's facility near Kuala Lumpur. On 14 February Measat secured its first customer for Africasat-1, SkyVision Global Networks (UK), who will use the new capability to supplement their current Intelsat and SES services for communications between Europe and Africa and throughout Africa.

However, the launch of the company's Measat-3A satellite on a Land Launch Zenit-3SLB rocket, originally scheduled for 21 August, was delayed indefinitely due to damage incurred on 8 August when a crane operator at the Baikonur Cosmodrome struck it while moving a piece of ground equipment after the spacecraft had been mated with the launcher's upper stage. Measat-3A was built by Orbital Sciences (USA), who are repairing the damaged satellite for a planned launch early in 2009.

Vietnam's first communications satellite, Vinasat-1, was launched by an Ariane-5 on 18 April. The 2.6-tonne spacecraft carries 8 C-band and 12 Ku-band transponders. Built by Lockheed Martin (USA) for $180 million, it was placed in a geostationary-orbit slot at 132 degrees east longitude, from which owner Vietnam Post and Telecommunications Group is delivering over 200 broadcast television channels and both telecommunications and Internet access. Vinasat-1 is also providing weather information and navigation data to fishing vessels and oil rigs, as well as healthcare and education services to islands and other remote areas. Up to now Vietnam had been paying around $15 million a year to rent satellite capacity from Russia, Australia and Thailand.

The same launch also orbited Brazil's Star One C2 satellite to a geostationary-orbit slot at 70 degrees west longitude. The 4.1-tonne spacecraft, built by Thales Alenia Space (France and Italy) carries 28 C-band and 16 Ku-band transponders and one X-band unit for government use. It extends Star One's reach during its 15-year design life into Mexico, southern and northern California, and Florida, in addition to Latin America and Central America.

On 1 April Uruguay joined a communications satellite project based on a 2005 agreement between Venezuela and the China Great Wall Industry Corp, which was contracted to design, manufacture, test and put into orbit the VENESAT-1 for Venezuela. Uruguay has agreed to finance 10% of the $240 million cost of the project and has provided its geostationary-orbit slot, in exchange for 10% of its capacity. Renamed the Simon Bolivar Satellite, it was launched on 29 October from the Xichang Satellite Launch Center in southwest China atop a Long March 3B rocket and will begin carrying radio, television and other data transmissions in early 2009 after three months of tests. It is designed to have a service life of 15 years. Venezuela had an equal role in the development of the spacecraft, and the agreement for its launch involved technology transfer between the two countries. 90 Venezuelan specialists had worked on the satellite, and China is also helping Venezuela to build several satellite monitoring stations in that country.

On 3 April DTV Network Ltd. of Phnom Penh and the Cambodian government agency National Television of Kampuchea launched Cambodia's first nationwide satellite television service, Techo-DTV. Initial installation price of $75 for the digital picture and sound service, which uses Shin Satellite Plc's (Thailand) IPSTAR broadband satellite system, included a 60-cm Ku-band satellite dish, mounting hardware, a set-top box, and a remote control.

China launched its Tianlian-1 relay satellite from the Xichang space center on 25 April aboard a Long March 3C rocket. The flight was the first for the 3C launcher that combines two liquid strap-on boosters with the three-stage Long March 3A core vehicle. Tianlian-1, built on the DHF-3 bus, is the first of two relay satellites to increase communications coverage for manned Shenzhou spacecraft, about six months in advance of the three-person Shenzhou VII mission. It increased communications coverage to nearly 50 percent of each Shenzhou orbit compared with only about 12 percent coverage provided by Chinese ground stations and tracking ships. The second relay satellite, to be launched later this year, will eventually provide nearly 100 percent coverage for Shenzhou orbits.

China SatCom's Chinasat-9 was launched by a Long March 3B rocket on 12 June. Built by Thales Alenia Space (France and Italy) on the company's Spacebus-4000 platform, the $145-million satellite carries no U.S. components, so it did not have to conform to the U.S. export control regulations. With eighteen 36-MHz Ku-band transponders and four 54-MHz Ka-band transponders, the direct-broadcast satellite was used to broadcast the Beijing Olympics from its geostationary-orbit slot at 92.2 degrees east longitude. It has a design life of 15 years.

EchoStar (USA) advised China's State Administration of Radio, Film, and Television in April that work was suspended on the CMB-Star satellite, originally intended to broadcast the 2008 Olympics. The reason cited was that the satellite's performance specifications were not being met. However, EchoStar stated that the S-band satellite could be completed by another investor if the specifications were relaxed and sufficient funds were made available to meet them by reconfiguring the spacecraft.

III.1.2. Mobile Communication Systems

Inmarsat (UK) completed its new $1.5-billion 3-satellite Inmarsat 4 constellation on 19 August with the successful launch of Inmarsat-4F3 by an International Launch Services Proton Breeze M rocket (see above). The 6-tonne spacecraft was placed in a geostationary-orbit slot at 98 degrees west longitude. Its two companions were then moved to new slots to optimize global broadband service: Inmarsat 4F1 from 64 degrees east to 143.5 degrees east and Inmarsat 4F2 from 53 degrees west to 25 degrees west. The Inmarsat 4 constellation now offers global coverage for broadband data transmission and hand-held telephone service, compared with the 85% coverage of the previous 2-satellite system.

Globalstar (USA) signed a 30-year contract on 14 November 2007 with Open Range Communications (USA) to deploy a satellite-terrestrial broadband wireless network, beginning this year with service to 6 million customers in 500 rural U.S. communities and projecting expansion to a customer base of 50 million. The deal, in which Open Range paid $3.6 million to Globalstar and Globalstar bought $5 million in Open Range preferred equity, is the first time a value has been placed on the spectrum for future hybrid networks combining a satellite communication system with an Ancillary Terrestrial Component (ATC) of ground-based boosters. The U.S. Federal Communications Commission (FCC) granted Globalstar a license for the use of 27.85 MHz with an ATC network, stating that hybrid network operators should not have to pay for their terrestrial spectrum as long as they continue to offer nationwide satellite connectivity.

On 7 December 2007 Ondas Media (Spain) issued an authorization to Space Systems/Loral (USA) to initiate construction of three S-band radio broadcast satellites planned for elliptical orbits. The $1.1-billion contract to build, launch and insure the three spacecraft, and to deploy ground network facilities was signed in March. The use of S-band by Ondas Media will take advantage of in-car technology developed in the U.S by XM Satellite Radio and Sirius Satellite Radio, and the selection of elliptical orbits rather than the conventional geostationary orbit reflects the more northern location of the European market segment sought by Ondas Media.

The other companies seeking 18-year licenses from the European Commission in the available 30-MHz S-band spectrum are ICO Global (USA), Inmarsat (UK), Solaris Mobile Ltd. (Ireland; a joint venture of SES Global (Luxembourg) and Eutelsat (France)), and TerreStar Europe Ltd (UK; a subsidiary of TerreStar Corporation, USA), all of whom are planning geostationary-orbit satellites. The European Parliament proposed on 18 March that licensees will have to have their satellites launched and begin service within 22 months; hence the satellites would need to be either built or under construction well before the license is granted. There are likely to be up to two systems that could share the 30 MHz band that will become available. On 7 August the European Commission (EC) opened a competition to provide S-band mobile satellite service in Europe, including mobile television, high-speed data transfer, and emergency response service. The EC set

7 October as the deadline to receive bids from the four competitors, and expects a launch in time to begin operations in June 2011.

On 22 August Inmarsat (UK) issued to Thales Alenia Space (France and Italy) an Authorization to Proceed on building EuropaSat, to be based on the company's 4000C3 bus. The S-band satellite will weigh 5.7 tonnes and deliver 8.5 kW to its payload. Assuming the granting of the EC license, it will be launched in 2011 by an International Launch Services Proton Breeze M to a geostationary-orbit slot at 31.5 degrees east longitude. Thales is also building the competing Eutelsat W2A S-band spacecraft, planned to be launched in 2009, for Solaris Mobile (Ireland), a joint venture of Eutelsat (France) and SES (Luxembourg).

The ICO G-1 satellite was launched to its geostationary orbit slot by an Atlas-5 rocket from Cape Canaveral on 14 April. It is the first system to offer nationwide two-way high-speed cell phone and wireless broadband service in the U.S., and the second worldwide, after the Japanese-Korean MBSAT network. It uses a unique ground-based beam-forming technique developed by ground-segment-supplier Hughes Network Systems that will provide up to 250 transmit-and-receive S-band beams without imposing technical demands on the spacecraft.

At 6.634 tonnes G-1 is the heaviest commercial satellite ever launched, with solar arrays spanning 30 m and a 12-m Harris mesh antenna. It provides 8 to 15 channels of video at 500 kB/sec per channel for mobile television, bundled with roadside assistance and navigation for automobiles. The satellite has 2 GHz of S-band capacity via 20 MHz of bandwidth that was awarded by the U.S. Federal Communications Commission (FCC) for satellite-terrestrial mobile satellite service (MSS). The use of the DBS-SH standard protocol, the first in the U.S., maximizes the capacity of existing ground networks, limiting the number of Ancillary Terrestrial Component (ATC) towers required. The G-1 satellite deployed its 12-m antenna reflector on 1 May and was declared to be operational on 15 May. The system is expected to enter commercial service in late 2009, following the granting of ICO's ATC license by the FCC. Cost to ICO of the satellite and associated ground systems was $500 million; another $300 million to $800 million will be needed for the ATC. The satellite and launch were insured for $344 million; its in-orbit operations are insured for $300 million.

Construction of the 48-satellite second-generation fleet for GlobalStar (USA) began in August by manufacturer Thales Alenia Space (France and Italy), under an $860-million contract signed in November 2006 (see last year's report). The first six satellites are to be completed by June 2009 in time for a launch in September. The payload components are scheduled to be shipped in January 2009 from France to Thales' plant in Rome to be mated with their service modules. GlobalStar has continued to deposit the scheduled payments into an escrow account from which Thales Alenia Space makes regular withdrawals under the contract's provisions.

The new satellites will be merged into the existing constellation and eventually replace the current satellites. The 715-kilogram second-generation spacecraft are

designed to operate in a 1,414-km low Earth orbit for 15 years, twice the service life of the current satellites. They will feature downlink and uplink speeds of 1 MB/sec and 256 kB/sec respectively, providing Internet-compatible access, and will employ user-friendly 200-gram handsets. Arianespace (France) is under contract to launch 24 of the 48 second-generation satellites, with an option for the remaining 24 satellites. The launches will be via a modified Russian Soyuz rocket equipped with a new payload dispenser to launch six second-generation Globalstar satellites at a time.

On 8 September Thales Alenia Space also received an authorization-to-proceed contract worth about $500 million from a new startup company, O3B Networks Ltd (UK), for construction of a 16-satellite constellation designed for use by the world's less-developed nations. The name "O3B" denotes "the other 3 billion people" who do not have access to a broadband network. The 700-kg Ka-band spacecraft will fly in a low 8,000-km equatorial orbit to reduce time lag for high-speed two-way customers between 45 degrees south and 45 degrees north latitude. The spacecraft design is similar to that of the second-generation GlobalStar satellites (see above). Launch of the first eight satellites is planned for late 2010, with another eight to follow if funds are available. On 22 September Sea Launch (USA) received a contract for at least one launch of eight satellites for O3B and possibly two. Sea Launch will use a special dispenser to deploy eight O3B satellites in a single mission. Much of the required financing for the initial O3B constellation is being provided by Google (USA), Liberty Global (USA) and HSBC bank (UK).

In November 2007 Mobile Satellite Ventures (MSV, USA) created regional "talkgroups" that enable emergency responders to communicate using a push-to-talk button on the side of their handsets. Called Satellite Mutual Aid Radio Talkgroups (SMART), the service allows local firefighters and other fast-responders to disasters and other emergencies to communicate with members of other fast-responder teams such as police units or National Guardsmen on their MSV satellite phones without first dialing 10-digit phone numbers. Each talkgroup is designated by a call letter – for example, the U.S. Gulf states are SMART-G – and members of one regional group can also be members of another nearby group.

Six Orbcomm two-way messaging satellites were orbited on 19 June by a Russian Kosmos 3M rocket operating from the Kapustin Yar spaceport. Supplementing Orbcomm's existing fleet of 29 satellites, the new spacecraft are buttressing Orbcomm's existing machine-to-machine communications service and starting a new service for the U.S. Coast Guard called Automatic Identification System (AIS) for vessels in or near U.S. coastal waters. The six satellites were built by a U.S.-Russian-German team comprised of Orbital Sciences Corp (USA), which provided the satellites' electronics payload; Polyot (Russia), which built the satellites' platforms and arranged for the launch; and OHB System (Germany), which integrated the platforms and payloads and performed pre-launch testing.

On 7 October KVH Industries and ViaSat (both USA) began deployment of the first increment of a global mobile satellite system (MSS) network based on ViaSat's

ArcLight spread-spectrum technology. The lower-cost, lighter-weight Ku-band ArcLight airborne antennas and ship-based Very Small Aperture Terminals (VSATs) are expected to be competitive with Inmarsat's L-band satellite system and superior to the failed Connexion by Boeing for aircraft communications (see prior reports). Airborne antennas for the new system are only 27 cm in diameter, and the system is claimed to make more bandwidth available than Inmarsat's BGAN (see above and last year's report): up to 10 MB/sec on the downlink and 512 kB/sec on the uplink. The first customers for KVH and ViaSat, who signed their initial agreement in July, are maritime vessels and business aircraft, although ViaSat terminals were ordered by France's high-speed rail system TGV on 1 October and initial talks with the commercial airline Lufthansa (Germany) took place on 6 October.

JSAT Corporation (Japan) announced a new joint venture with Stratos Global (USA) on 21 August. JSAT Mobile Communications Inc. will provide mobile satellite service to Japanese corporate and government maritime and aeronautical users beginning early next year, using links from the low-orbit constellation of Iridium Satellite LLC (USA) and from Inmarsat's (UK) new 3-satellite Inmarsat-4 geostationary-orbit constellation (see above).

On 22 May the United Nations' International Telecommunications Union (ITU) deployed 100 Thuraya satellite telephones to support rescue and relief operations following the major earthquake near Chengdu, China that occurred on 12 May. The telephones, which incorporate Global Positioning System (GPS) satellite navigation equipment, were donated by Thuraya Satellite Telecommunications Company (United Arab Emirates) and were shipped free of charge by Federal Express Switzerland. All other costs were covered by the ITU. The Chinese government agencies also requested and received U.S. government maps derived from satellite imagery to help guide their recovery efforts from the magnitude-8 earthquake.

III.1.3. Navigation and Position Location

The first use of the Global Positioning System (GPS) to track mailed letters was instituted by the U.S Postal Service in March. The system, designed and developed by Tracking the World (USA), is less than 7 mm thick, fits into a standard No. 10 envelope, provides the envelope's location at all times and records those data for future analysis. Since mail travels often by air, the system is "receive-only" because transmissions are not permitted aboard commercial aircraft during takeoff and landing. The "Letter Logger" uses a GPS receiver manufactured by uBlox (Switzerland) and a microprocessor built by Texas Instruments (USA). The Postal Service plans to order about 5,000 units at a cost of $3 million - $4 million.

On 23 November 2007 the finance ministers of the European Union (EU) finally agreed on a financing plan for the Galileo satellite navigation system (see prior reports). The EU would commit $3.36 billion by diverting unused farm subsidies and revising the budgets for research and development spending. The agreement dealt with the concerns of four EU members about "geographical distribution" of contracts by separating

contracts for Galileo into six segments covering satellites, launchers, computer programmes, ground stations, control stations and operation. No one company is allowed to head more than two of the segments and contractors are required to subcontract at least 40 percent of the work to open opportunities for smaller companies. Galileo will have two control stations, one in Germany and the other in Italy. This funding plan, along with the $2.5 billion previously spent or committed, now totals $5.86 billion for completion of the system and initial operations through 2013. It was approved by the EU transportation ministers on 29 November 2007, despite a last-minute objection by Spain, and by the European parliament at a meeting in mid-December 2007.

On 22 April the European Parliament's assent cleared the way for Galileo's implementation, providing the necessary legal basis for the system by an almost unanimous vote. It will be the first European infrastructure that is commonly built and jointly owned. Private firms will be called on to help build the system as contractors, and will help fund the system after 2013, but not as joint owners as was originally planned.

The 26 operational Galileo satellites will be purchased in three batches. The first 10-satellite batch could be contracted to a single development team or be split between two competitors. The European Satellite Navigation Industries, a consortium headed by Astrium Satellites and Thales Alenia Space that was created by ESA to develop the Galileo system under the original public-private financing plan, was dissolved in December 2007. Astrium and Thales maintained their organizational plan as new competitors, but Surrey Satellite Technology Ltd (UK) and OHB System (Germany) announced on 28 November 2007 that they will also compete as a team for Galileo satellite contracts.

Then on 12 June the European Union (EU) announced that since all funding for Galileo would come from EU public funds, the procurement rules would not follow ESA's principle of geographical return, in which contracts are issued in accordance with each country's contribution to the project, but would use EU rules, which stipulate strict best-value-for-the-money criteria.

Nevertheless, when the European Commission (EC) issued its 1 July request for industry to bid on the 28 Full Operational Capability (FOC) Galileo satellites (26 operational units plus two spares) and the related Galileo ground segments, non-European Union contractors were barred from bidding as prime contractors except in "exceptional circumstances." Final contracts, estimated to total about $3.4 billion, are expected to be awarded in June 2009. Although the EC tender made clear that it is managing Galileo under commission rules of "value for money," and that non-EU subcontractors would be allowed, the prime contracts for five of the six main work packages will be limited to companies established in the 27-nation European Union. The sixth package deals with launching of the Galileo satellites, which could be done outside the EU. Galileo's $5.4-billion budget was divided into six segments with contracts for satellites, launchers, computer programmes, ground stations, control stations and the system's operation. The work packages have strict rules governing how much work can go to each company and how much of that work must then be subcontracted. EU's partner ESA will run the

procurement competition, with the aim of having Galileo fully operational by 2013. Although $4.6 billion has been set aside for Galileo through 2013 by the EU finance ministers, the procurement process is not expected to exceed $3.4 billion.

ESA and the European Commission (EC) selected 11 finalists on 26 September from among the 21 bidders on the six work packages, two for each of the five system packages and only one, Arianespace (France) for the launches. Ariane and Soyuz vehicles, both operated by Arianespace from the Guiana Space Center, will be considered. The other competitor for the launch contract, valued at about $1.5 billion, was Surrey Satellite Technology Ltd (SSTL, UK). The SSTL bid was rejected because they proposed the use of non-European launch vehicles, the Russian-Ukrainian Zenit and the U.S. Rascal-9, neither of which was to have been launched from European territory.

Competitors for construction of the 28 Galileo satellites are Astrium Satellites (Germany) and OHB Technology (Germany), the latter teamed with Surrey Satellite Technology Ltd (UK); the system support work will go to either Thales Alenia Space (Italy) or Logica (Netherlands); the ground mission system competitors are Thales Alenia Space (France) and Logica (UK); Astrium Ltd (UK) and the G-Nav consotium, led by Lockheed Martin (UK), will vie for the ground control system; and operations will go to either Nav-up, led by Inmarsat (UK), or a consortium led by DLR (Germany) and Telespazio (Italy).

The first plenary session of representatives of the United States and Europe, held at the U.S. Naval Observatory on 27 October, reaffirmed their commitment to the interoperability between GPS and Galileo. The working groups established under the agreement updated their progress and ideas for future work, discussing possible short- and long-term priorities. At the top of their agenda are safety of life services and interoperability of new civil signals.

At the meeting in Brussels on 26 September research and industry ministers from 29 European governments also endorsed a growing role for ESA and the EC in space-based security and defense and opened the Galileo system to use by the military forces of European nations. The ministers endorsed ESA's proposal to create a Space Situation Awareness system, which will federate European military and civil ground-based space surveillance assets into a single dual-use network comparable to those in the U.S. and Russia for cataloging and identifying objects in orbit. ESA plans to request $145 million in November to begin assembling the network

ESA's 500-kg Giove-B satellite was launched by a Starsem Soyuz-Fregat rocket from the Baikonur Cosmodrome on 27 April. The long-delayed launch (see previous reports) allowed Europe to keep access to a frequency reserved for Galileo with the International Telecommunications Union. Delays in the launch of Giove-B forced ESA to sign a contract in March 2007 with Surrey Satellite Technology Ltd (SSTL) SSTL, the builder of Giove A, to manufacture a nearly identical spacecraft to fill a potential operations void if Giove-B had been delayed further. Meanwhile, Giove-A had been operating flawlessly and on 31 March ESA signed an agreement with SSTL to operate it

for another year.

After Giove-B separated from the Soyuz-Fregat's upper stage an anomaly in the satellite's four reaction wheels caused it to spend its first 24 hours in safe mode. Ground controllers used the spacecraft's small thrusters to point the satellite to the sun, and then sent new software to Giove-B which appeared to solve the problem, believed to have been the result of a mistaken calibration and prolonged exposure to the cold during the flight to orbit. Subsequently, on 7 May the satellite successfully transmitted its first signals.

Giove-B is testing the key technologies that will eventually be built into the 30 operational platforms that form the Galileo network. Its passive hydrogen maser atomic clock, the first ever to fly in space, has an unparalleled stability of one nanosecond per day, *vs* the 10-nanosecond-per-day stability of Giove-A's rubidium clock. Also, Giove-B, unlike Giove-A, is transmitting in all three frequency bands assigned to Galileo and the U.S. GPS: 1.20, 1.28, and 1.575 GHz; and can transmit signals in the modulation format that assures compatibility between the two systems. Its mass (530 kg), power (1.1 kW), and dimensions are very close to those of the four In-Orbit Validation (IOV) satellites currently under construction (see last year's report). Giove-B is planned to operate until at least 2010, when the IOV spacecraft are scheduled for launch, to be followed in 2013 by the 26 Full Operational Capability (FOC) satellites.

On 7 September, however, Giove-B was shut down and placed in "safe" mode following a radiation incident that affected silicon chips in its computer. After determining that the failure was a single-upset event, controllers reactivated the spacecraft on 24 September, and it is now operating normally. Lessons learned from the event, which involved a period of several days to shut down and restart the atomic clock, are being applied to the first four in-orbit validation spacecraft to reduce their susceptibility to radiation hazards.

ESA's fifth annual European Satellite Navigation Competition (ESNC), seeking ideas for satellite navigation usage in non-space businesses, was conducted from 1 May to 31 July. The competition was open to companies, entrepreneurs, research institutes, universities and individuals from around the world. The winner will receive direct support at one of the three ESA business incubation centers, will be assisted by ESA's top experts, and will have access to space technologies.

On 24 September Russia orbited three Glonass navigation satellites, bringing the orbital constellation to 17 working spacecraft, plus one down for maintenance and another waiting to be deorbited. Three more are scheduled to be launched by the end of the year. The government has allocated another $2.7 billion to continue upgrading the system's space and ground segments, creating digital mapping capability and producing receivers for commercial use.

III.2. Remote Sensing

III.2.1. Earth Observations

On 26 November 2007, DigitalGlobe's Worldview-1 satellite, launched on 18 September 2007 (see last year's report), began delivering operational imaging to its primary customer, the U.S. National Geospatial Intelligence Agency. Worldview-1, at 0.5-m ground resolution, was then the world's highest-resolution commercial imaging satellite.

General Dynamics Advanced Information Systems (USA) received a $116-million delivery order on 23 April for the Landsat Data Continuity Mission, a gapfiller satellite. Awarded under the NASA Rapid Space Development Office's Rapid-II Indefinite Delivery/Indefinite Quantity (IDIQ) spacecraft catalog, the satellite is scheduled for launch in July 2011 to continue the delivery of the 36-year-old Landsat data set during its 5-year design lifetime. The other bidders, who had received $600,000 study contracts for the procurement (see last year's report), were Ball Aerospace, Orbital Sciences and Space Systems/Loral (all USA). Ball had won the $128-million contract for the satellite's primary instrument, the Operational Land Imager, in July 2007.

On 29 August GeoEye (USA) contracted with Google (USA) to provide exclusive mapping services from GeoEye-1, orbited by a United Launch Alliance Delta-2 from Vandenburg Air Force Base on 6 September. The vehicle's first stage carried a Google logo on its side, although Google did not purchase a financial interest in the satellite or in GeoEye. Google began receiving images with 0.5-m resolution from GeoEye-1 in October, following up a prior agreement with GeoEye for images from the company's Ikonos satellite (see prior reports). GeoEye continues to sell Ikonos images to other companies, and Google continues to purchase images from GeoEye competitor DigitalGlobe and other vendors.

On 15 October GeoEye signed a multi-year agreement with Telespazio SpA (Italy), giving Telespazio exclusive rights, as GeoEye's new Commercial Regional Affiliate for the region of Europe and North Africa, to produce, market and sell Earth imagery and related products and services from GeoEye-1 to customers in that region.

Now the world's highest-resolution commercial imaging satellite, GeoEye-1 can simultaneously collect 0.41-m resolution black-and-white (panchromatic) images and 1.65-m color (multispectral) images. Due to U.S. licensing restrictions, commercial customers can access only 0.5-m resolution imagery. The 4.3-tonne spacecraft was placed in a 681-km orbit, and following its calibration and checkout period began delivering images in November. It was built by General Dynamics Advanced Information Systems and the imaging system by ITT (both USA), at a total cost of $502 million including launch, development of four ground stations and insurance of up to $320 million.

Canada's 2.2-tonne Radarsat-2 was launched from the Baikonur Cosmodrome into an 800-km Sun-synchronous orbit by a Starsem Soyuz rocket on 14 December 2007.

It provides 3-m ground resolution, a significant improvement over the 10-m resolution of Radarsat-1, launched in 1995. Radarsat-2, which cost the Canadian Space Agency $420 million plus an additional $90 million provided by the satellite prime contractor, MacDonald Detwiler and Associates, also has a steerable antenna which enables it to cover both sides of its ground track and thereby attain a ground swath of 100 km. Its design life is 7 years, *v*s Radarsat-1's 5 years. Thales Alenia Space (France and Italy) provided the satellite platform.

On 15 February ESA's governments approved financing terms for Europe's Global Monitoring for Environment and Security (GMES) programme (see prior reports). The agreed-upon rules for ESA's management of the programme, re-named Kopernikus this year, specify a European Commission (EC) investment of $629 million, which was signed off on by the EC on 28 February. ESA has committed the balance of the $1.9-billion cost of GMES's Segment 1, less a deficit of $350 million that requires approval at the November meeting of the ESA governments. On 30 September Director-General David Williams of the British National Space Centre agreed to support Kopernikus to the tune of up to $146 million, with the *quid-pro-quo* that ESA will create a center for space expertise, most likely in robotic technologies, in the UK.

The ESA-EC contract was signed on 28 February for development of the GMES system, which consists of four satellites, payloads on two other spacecraft and access to spacecraft owned by several European countries. The first satellite, the C-band radar observation Sentinel-1 spacecraft, is due to be launched in 2012 (see prior reports). On 14 April ESA awarded Thales Alenia Space (France and Italy) a $475 million contract for the 1.2-tonne Sentinel 3, which will be launched by a Vega-class rocket in 2012 to provide oceanography and land vegetation-monitoring data. It will be equipped with an ocean/land color instrument, a sea/land temperature radiometer, a radar altimeter and a microwave radiometer. The altimeter will provide high-inclination data to ensure continuity with ESA's Envisat spacecraft, but at higher performance and availability levels. Thales Alenia Space will be responsible for the color monitor and altimeter, as well as satellite integration. Later that week, on 17 April, ESA awarded a $304-million contract to EADS Astrium for the 1.1-tonne Sentinel 2, a 13-band multispectral optical land-imaging satellite, also planned for launch in 2012. It will prolong some of the functions of France's Spot 5, but will utilize an all-new bus developed specifically for GMES.

Italy's second Cosmo-Skymed X-band radar satellite, Cosmo Skymed-2, was launched successfully on 9 December 2007 by a United Launch Alliance Delta-2 rocket from Vandenberg Air Force Base. The spacecraft was built by Thales Alenia Space (France and Italy). Cosmo Skymed-3, built by the same manufacturer, was launched by another Delta-2 from Vandenberg on 24 October. It increased the number of images 900 a day to 1,350 a day. The four-satellite constellation, which will cost the Italian space agency about $1.5 billion, is to be used by Italy as part of a programme for environmental monitoring and mitigation of natural disasters. It will monitor coastlines, seas and internal waters; check on harvests and manage treatment cycles; and conduct cartography. The 1-m resolution system, each of whose satellites has a five-year lifespan, was declared

operational by the Italian space agency in October 2007.

The third satellite in Germany's SARLupe radar observation system was launched from the Plesetsk Cosmodrome on 1 November 2007 by a Russian Cosmos-3M rocket. The 720-kg spacecraft, with 1-m ground resolution, joined its two predecessors in a near-polar 500-km orbit and enabled the system to be declared operational on 3 December 2007. The fourth spacecraft in the 5-satellite system was launched on 27 March, and the final one on 22 July. Prime contractor for SARLupe is OHB System AG; satellite system testing was managed by the German space agency DLR's Oberpfaffenhofen satellite control facility. The system reached full deployment status in August, when a data-sharing agreement with France allowed the fusing of SARLupe's radar data with France's Helios-2 optical images to provide timely, all-weather day/night intelligence as needed. The SARLupe system's design lifetime is 10 years.

The $250-million five-satellite RapidEye constellation was launched successfully on 29 August aboard a silo-based ISC Kosmotras Dnepr rocket from Russia's Baikonur Cosmodrome. All five satellites sent signals and were healthy in a 650-km low Earth orbit following the launch and three months of in-orbit testing and final satellite positioning.

The satellites are owned by RapidEye AG (Germany), but were co-funded by the German Aerospace Center DLR to the tune of $40 million, as part of Germany's national space programme. They were built by Surrey Satellite Technology Ltd. (SSTL, UK), with their five-band multispectral optical imagers provided by Jena-Optronik (Germany). The prime contractor was MacDonald, Detwiler and Associates (Canada). The 150-kg spacecraft have a ground resolution of 6.5 m and an image width of about 78 km. They are stationed 19 minutes apart in their orbit, which is near-polar but will image areas between 75 degrees north and 75 degrees south latitude. Primary markets for the constellation are insurance, forestry and agriculture.

On 18 February the Infoterra Group of Astrium Services (UK, France, Germany, and Hungary) created a joint venture with Cartographic Institute of Catalonia and Hisdesat (both Spain) to distribute high-resolution TerraSAR-X satellite radar data services to agricultural, environmental, and defense-related customers. The new company, Infoterra Servicios de Geoinformacion SA (Infoterra SGSA), is owned 60% by Astrium and 20% each by Hisdesat and the Cartographic Institute of Catalonia.

On 15 October the French space agency CNES unveiled plans for a microsatellite constellation to deliver low-cost, high-resolution, frequently refreshed imagery of the whole Earth to Internet users. The space segment would be deployed in multiple planes deployed incrementally, with 13 satellites in each plane to provide revisit times that could refresh imagery once a week. The e-Corse concept (electronic continuous observing system relayed by cellular processing environment) envisions a total of eight planes, providing daily refreshment of imagery to 50 ground stations. The spacecraft would weigh less than 300 kg, with a 6-year design life. The 40-kg payload would draw 120W of power and transmit data at 80 MB per second, using a 300-mm 14-row imager with

four 7,000-pixel charged-coupled-device detectors and a 3-mirror Korsch telescope. CNES studies indicate that the initial 13-satellite constellation, in a 600-km orbit, would cost as little as $540 million, including a test satellite, six spares, launch, insurance and the ground segment, and could be ready for launch by a Soyuz rocket in 2014. CNES is currently seeking a company or consortium to develop, deploy and operate the system under the code-name Blue Planet. The agency has developed and patented key technologies for e-Corse, most significantly an image-compression technique with a compression ratio of 50.

ESA and China's Ministry of Science and Technology opened the second phase of the Dragon programme in May. The first phase of Dragon, which calls for the sharing of Earth observation data and technology, began in 2004 with China receiving data from 16 ESA Earth observation satellite projects (see prior reports). During the second phase, ESA will access data from 25 Chinese Earth observation projects.

On 21 January Israel's TecSar/Polaris 1 imaging radar satellite was launched by an Indian Polar Satellite Launch Vehicle (PSLV) from the Satish Dhawan Space Center into a high-inclination (41-degree), 450 x 580-km elliptical orbit. The 300-kg spacecraft, built and operated by Israel Aerospace Industries, has electronically steered synthetic aperture radar with 1-m resolution.

Thailand's 715-kg THEOS Earth observation satellite was placed into a 690-km parking orbit on 1 October by a Russian-Ukrainian ISC Kosmotras Dnepr silo-launched rocket after nearly two years of delays related to launch-vehicle availability. The $130-million satellite, built by EADS Astrium (Europe), has two optical instruments, a panchromatic imager with 2-m resolution and a swath width of 22 km, and a multispectral imager providing color images with 15-m resolution and a 90-km swath width. It subsequently placed itself in an 822-km orbit inclined at 98.7 degrees, where it has sufficient propellant to operate for two years longer than its design life of 5 years. THEOS is operated by Thailand's Geo-Informatics and Space Technology Development Agency (GISTDA), which uses its imagery in cartography, land use, agricultural monitoring, forestry management, coastal zone management, flood risk management and defense-related applications.

India integrated its National Remote Sensing Agency (NRSA) into the Indian Space Research Organization (ISRO) on 1 September, where it became the National Remote Sensing Centre (NRSC). The NRSA had been a registered society for 34 years since its founding in 1974, but has now become a government organization under ISRO's Earth science division.

Chile ordered a high-resolution dual-use optical Earth observation satellite from Astrium Satellites on 25 July. Chile had solicited interest from 24 prospective prime contractors and requested nine to submit detailed proposals for the 1.5-m-resolution spacecraft, from which it had selected four finalists. The $72-million contract includes development of the satellite and its launch in 2010 as a secondary payload aboard a Russian Soyuz rocket from ESA's Guiana Space Center. The primary payload for the

launch, for which the French space agency CNES has already paid $63 million is France's Pleiades dual-use high-resolution optical Earth observation satellite. Chile's programme also includes sufficient training of Chilean engineers to enable indigenous construction of future Chilean satellites.

III.2.2. Atmosphere and Ocean Observations

Data from NASA's Upper Atmosphere Research Satellite and the agency's Aura satellite were used in February by St. Xavier's College (India) to calculate a 20% drop in stratospheric ozone concentration over the Jharia coal field in northern India, about 1,150 km southeast of New Delhi. The report suggested that the decrease was caused by smoke plumes from coal fires, which contain the ozone-depleting gases methane and the oxides and dioxides of carbon, nitrogen, and sulfur. The Jharia coal field consists of 23 large underground mines and 9 large open-pit mines in which about 70 fires are raging, fed by air that leaks in through large cracks in the underground seams.

On 27 May NASA announced results of observations by the multinational A-train constellation of five satellites: Aqua, Aura, Calipso, Cloudsat and Parasol (see prior reports). Clouds over South America infused with airborne pollution were observed to produce less rain than cleaner clouds during the dry season, but pollution was less of a factor during the wet monsoon season; detailed measurements of carbon monoxide concentrations in clouds implied the presence of smoke and other aerosols from polluting sources; and the effect of pollution on constraining ice-particle growth in clouds was measured.

ESA's Envisat transmitted data on 27 October showing that the thickness of Arctic sea ice had plummeted, thinning by as much as 49 cm in some regions. The data provided the first definitive proof that the overall volume of Arctic ice was decreasing; i.e., that the ice was not redistributed to other areas like coastlines and that the thinning is definitely caused by melting.

ESA issued a $415-million contract to Astrium Satellites (Germany) on 27 May for the agency's 1.7-tonne EarthCARE cloud- and aerosol-monitoring satellite. Planned for launch into a 400-km near-polar circular orbit in 2013, EarthCARE will carry four instruments: a cloud-profile radar provided by the Japan Aerospace Exploration Agency (JAXA) and three ESA instruments: an atmospheric lidar, a broadband radiometer and a multi-spectral imager. It is the sixth of ESA's Earth Explorer series, the first of which, the Goce gravity-wave measurement spacecraft, is scheduled to be launched early next year after several launcher-related delays (see below).

The U.S.-European Jason-2 ocean-altimetry satellite was launched to its 1,300-km orbit on 20 June aboard a United Launch Alliance Delta 2 rocket. The launch employed a video camera mounted on the Delta 2 rocket's upper stage that provided a live video feed of the satellite separating from the rocket and deploying its solar arrays. It was the first time a live camera aboard a launcher stayed trained on a satellite long enough to capture solar-panel deployment. Built by prime contractor Thales Alenia Space (France), the 506-

kg spacecraft was sponsored jointly by NASA (40%) and the French space agency CNES (60%), who cosponsored Jason-1 in 2001 and the Jason forerunner Topex-Poseidon in 1992. Additional financial support for Jason-2 was provided by the U.S. National Oceanic and Atmospheric Administration (NOAA) and Europe's Eumetsat (Germany). Total mission cost, including 5 years of operations, is $433 million.

On 5 July Jason-2 began delivering its first maps of the region between 66 degrees north and south latitude from its orbit at 1336 km, where it follows Jason-1 by 55 seconds. Jason-2 carries five main instruments: the Poseidon-3 radar altimeter, which measures sea-surface height, ocean-current speed, and wind velocity with an accuracy of 2.5 cm per second of ground tracking; the Advanced Microwave Radiometer, which corrects Poseidon's measurements for errors due to atmospheric water vapor; the Doppler Orbitography and Radio-positioning Integrated by Satellite (Doris), which measures the satellite's location; a Global Positioning System (GPS) payload, which validates and enhances Doris's measurements, and the Laser Retroreflector Array, which calibrates Doris and the GPS payload. Jason-2 also carries three "passenger" instruments: the Environmental Characterization and Modelization 2 (Carmen 2), which studies the effects of radiation on the satellite's environment; the Time Transfer by Laser Link, which compares and synchronizes ground clocks; and the Light Particle Telescope, provided by JAXA, which also studies radiation in the satellite's environment.

The Proteus bus for Jason-3, proposed by Eumetsat to its 21 member governments on 1 July and planned for launch in 2012 or 2013 to extend the data stream beyond Jason-2's nominal end-of-life in 2013, was funded by CNES and is already built and in storage at Thales. On 2 July Eumetsat agreed to provide $73 million toward Jason-3's total budget of $366 million. CNES has committed $73 million and NOAA has agreed to provide a $157 million in-kind contribution, including the launch. Commitment of the balance of Jason-3's $380-million budget must be secured by mid-2009, ostensibly by the European Commission, to ensure continuity of the Jason data stream. Eumetsat also agreed on 2 July that a Jason-4 satellite will be based on a German-built satellite bus of the type used for ESA's Cryosat, to be launched aboard a Vega rocket.

On 10 October the Eumetsat council approved the design of a Meteosat Third-Generation (MTG) system to be launched starting in 2015. Pending approval by the ESA ministers in late November, the $3.75-billion system will consist of six satellites: four imaging spacecraft (MTG-I) and two equipped with infrared and near-infrared sounding instruments (MTG-S). The MTG-I payloads will be a flexible combined imaging system, a lightning imager, a data-collection subsystem and a search-and-rescue subsystem. The MTG-S instruments will be an infrared sounder and a combined ultraviolet/visible/near-infrared sounder. MTG's first imaging satellite will be designed by ESA, which will bear 70% of its cost and that of the first sounder satellite. The MTG prototype is expected to cost $1.5 billion. The last of the four imaging satellites would be launched in 2028; the two sounders would be launched in 2018 and 2026.

On 7 July India announced that data from the joint Indian-French Megha-Tropiques environmental satellite would be made available to the global scientific

community at no cost and with no restrictions. The satellite, built by the Indian Space Research Organization (ISRO), will carry three main payloads: a microwave scanning radiometer to monitor rainfall, built jointly by ISRO and the French space agency CNES; a microwave sensor to take vertical profiles of atmospheric humidity, provided by CNES; and an Earth radiation budget sensor, also supplied by CNES. Megha-Tropiques is scheduled for launch in 2009 by an ISRO Polar Satellite Launch Vehicle into an 876-km orbit, inclined at 22 degrees for maximum coverage of the world's tropical regions.

On 6 June the Indian Space Research Organization (ISRO) announced an opportunity for scientists worldwide to submit proposals to utilize data from their Oceansat-2 satellite for atmospheric and oceanographic research. The spacecraft, due to be launched late this year into a 720-km Sun-synchronous orbit, is to carry two payloads: the Ocean Color Monitor, a solid-state camera with eight spectral bands and 360-m local resolution, using charge-coupled devices as detectors; and a Ku-band pencil-beam scatterometer for measuring ocean-surface wind speed and direction. Oceansat-2 also carries an Italian Space Agency payload, Radio Occultation Sounder for the Atmosphere, to measure atmospheric temperature and humidity profiles and electron density in the ionosphere.

The U.S. National Oceanic and Atmospheric Administration (NOAA) on 17 September awarded five U.S. companies eight contracts totaling $200,000 to study the possibility of obtaining environmental, space weather and climate data on a commercial basis. The awards went to GeoOptics, to study GPS radio occultation data; to Iridium LLC for solar irradiance and GPS radio occultation data; to Microsat Systems Inc. for solar irradiance data; to Orbcomm for solar irradiance, coronal mass ejection, and GPS radio occultation data; and to Space Services Inc. for solar wind and coronal mass ejection data.

China launched its 2.3-tonne Fengyun-3 (FY-3) weather satellite aboard a Long March-4C rocket from the Taiyuan Satellite Launch Center into a polar orbit on 27 May. Built by China Aerospace Corporation's Shanghai Academy of Spaceflight Technology, FY-3 is currently providing medium-range weather forecasts of between 10 and 15 days.

With a spatial resolution of 250 m and temperature accuracy of 0.05 Celsius, China's weather forecasting organization used it in conjunction with the older, less-capable FY-2 spacecraft to improve forecasting accuracy for the Summer Olympics. Detailed weather predictions were important for this because climatic conditions had a major impact on China's attempts to rid the Beijing skies of pollution for the Games. In the event that some endurance events might have had to be shifted if the air quality were not good enough, the earlier that possibility was known the easier it would have been to re-schedule. FY-3's data also helped with recovery from the major 12 May earthquake near Chengdu, and its three-dimensional sensors are monitoring the Earth's atmosphere and climate as well as the oceans and polar caps. China is sharing its data with the World Meteorological Organization for use in climate-change research.

Shortly following the 12 May earthquake, China had activated the International Charter on Space and Major Disasters that includes several international and national space agencies as members and provides access to Earth observation data to those affected by natural or man-made disasters.

On 15 September, China launched the first two of an eight-satellite optical and radar imaging constellation to support rescue and recovery from natural disasters. The 470-kg Huanjing-1A and Huanjing-1B Disaster Reduction and Environmental spacecraft were lofted into a high-inclination Sun-synchronous orbit by a Long March 2C rocket from the Taiyuan space center. The constellation will fly in a planned formation to enhance the coordination of data return. Although designed for disaster monitoring, the satellites will provide daily images of China and other areas.

The two satellites launched on 15 September were both optical, each carrying two charge-coupled-device (CCD) cameras with 30-m resolution and a swath width of 700 km, an infrared camera with 150-m resolution and a swath width of 720 km, and an ultralight image-formation meter with 100-m resolution, a swath width of 50 km, and a spectrum resolution of 9 km. China is one of the two charter members, along with the U.S., of the international Group on Earth Observations (GEO). GEO membership now consists of 74 governments and 52 intergovernmental organizations involved in environmental monitoring from space.

IV. HUMANS IN SPACE

IV.1. International Space Station Deployment and Operations

After moving the Harmony module to its final position on the front of the Destiny laboratory module during a spacewalk on 9 November 2007, Expedition-16 crewmembers Peggy Whitson and Dan Tani of the International Space Station (ISS) conducted two more spacewalks on 20 and 24 November to complete wiring of the module and install its ammonia cooling system. The Harmony module, delivered to the ISS in October 2007 (see last year's report), was then ready for delivery of ESA's Columbus module in December 2007. However, on 24 November the crew also discovered that damage to the Starboard Alpha Rotary Joint, detected in October 2007, was more extensive than had been first indicated, which required additional spacewalks that were to be made after spare parts were delivered by Shuttle Atlantis in February (see below).

Meanwhile the Columbus module was moved to the launch pad at the Kennedy Space Center on 6 November 2007 and was installed in Shuttle Atlantis's payload bay on 11 November. Atlantis's launch, originally scheduled for 6 December, was postponed twice, to 8 and 10 December, due to faulty readings of the fuel-depletion sensors in the external liquid-hydrogen fuel tank, However, the fault still could not be corrected, so the launch was postponed to 10 January, provided the fault could be located and fixed without moving the Shuttle from the launch pad.

On 18 December 2007 NASA located and identified the source of the anomaly as a faulty connector and subsequently found the root cause of the fault: freezing of air around the connector pin, which formed an insulating layer around the pin. This then caused a disconnection when shrinkage of the tank after being filled with liquid hydrogen moved the pin into the insulating layer. On 17 January the fault was corrected by soldering the connection so it could not move. Subsequent testing of the "fix" was carried out, and the launch, which carried ESA's Columbus laboratory to the ISS, was rescheduled for 7 February.

Instead of waiting for Atlantis's arrival, the ISS Expedition-16 crew conducted a spacewalk 18 December during which they made detailed examinations of the solar alpha rotary joint (SARJ) and a beta gimbal assembly (BGA) that rotates half the array wing to maintain proper solar orientation. The BGA had tripped its circuit breaker on 8 December. The crew found that the problem was in a slip ring known as the bearing rotor roll-ring module (BMRRM), a spare for which was on board the ISS. They pulled a number of the SARJ's thermal covers, took high-definition photographs of the mechanism, used mirrors to inspect areas that were not directly visible, collected samples of the ferrous debris that had fouled the SARJ and removed the most contaminated of the 12 trundle-bearing assemblies that hold the truss together as the outer section rotates, so that it could be returned to Earth for analysis.

Then in another 7-hr, 10-min spacewalk on 30 January Peggy Whitson and Dan Tani collected more information on the SARJ and Whitson replaced the BMRRM, reconnecting the four cables that link it to the station power grid. This fix enabled the forthcoming installation of Europe's Columbus and Japan's Kibo laboratory modules and the new Dextre "hand" for the Canadian robot arm.

On 4 February the Russian Progress-27 M-62 cargo craft left the space station loaded with waste and obsolete equipment, and was then used for a two-week Plasma-Progress test to explore the reflective properties, size and density of the plasma sheath that formed around the spacecraft during its destructive reentry into the atmosphere. Progress-28 M-63 arrived at the station on 7 February, carrying 2.1 tonnes of supplies comprising 528 kg of propellant, 45 kg of oxygen, 420 kg of water, and 1,327 kg of clothing, equipment and food that included honey, fruit and vegetables.

Space Shuttle Atlantis, finally launched on 7 February (see above), carried ESA's 12-tonne Columbus laboratory to the ISS, where Atlantis docked successfully following the now-routine examination of its thermal protection system for any launch damage. The only damage found was a small tear in the thermal blanket that was considered noncritical to safety during the forthcoming reentry and landing. Also, the parachute recovery systems on both solid-propellant boosters malfunctioned, one causing a water impact sufficiently severe to require replacement of the booster's aft skirt. Atlantis also brought ESA astronauts Hans Schlegel (Germany) and Leopold Eyharts (France) to the ISS.

The Columbus laboratory was transferred from Atlantis's payload bay to its berth on the ISS Harmony module on 10 February, following a day's delay due to the temporary illness of Hans Schlegel, who was scheduled to be one of the two spacewalkers to install the Columbus module. It was installed successfully during a 6-1/2-hour spacewalk by U.S. astronauts Rex Walheim and Stanley Love, who substituted for Schlegel. On 12 February Leopold Eyharts, the first to enter the Columbus module, declared it to be in good condition. The next day Walheim and Schlegel, then fully recovered, conducted a second spacewalk to attach a nitrogen tank and complete other work on Columbus's exterior.

Eyharts and Schlegel were able to begin science operations on Columbus's 20 experiments during their stay, because ESA's five racks of science hardware, weighing 500 kg but massing nearly 2 tonnes with their support systems, had been launched ready to operate. Other instruments, including a small solar telescope, were mounted on Columbus's exterior by Atlantis's crew during two subsequent spacewalks. Following the routine inspection of its thermal protection systems on 18 February, Atlantis subsequently returned to Earth on 20 February with Expedition-16 crewmember Tani, who was replaced on the ISS crew by Eyharts. Shortly afterward, Atlantis began the reconfiguration process needed for its next flight, the final servicing mission to the Hubble telescope, originally scheduled for October but delayed until 2009 due to an onboard Hubble failure (see below).

ESA's Jules Verne Automated Transfer Vehicle (ATV; see prior reports) was launched to the ISS by an Ariane-5 ES from Kourou, French Guiana on 9 March. At 19 tonnes the heaviest payload ever launched by an Ariane rocket, the ATV carried oxygen, food, water, and equipment for the ISS. One of the craft's four propulsion systems shut down shortly after launch, but flight controllers in Toulouse, France, sent new computer instructions to the ship, and then shut down and restarted the propulsion system successfully. The ATV then used its onboard engines to raise its orbit to 305 km and conduct a series of test maneuvers, including key tests on 14 March of its emergency-abort collision-avoidance sequence and its ability to switch to an independent backup computer.

It was then boosted on 18 March into a parking orbit about 2,000 km in front of the ISS. On 28 March the ATV edged to within 3.5 km of the ISS and then backed away as designed, in a test of its automated rendezvous systems. The ATV also established a two-way data link with the ISS using the Kurs radar system, and successfully delivered distance and speed information to the station's crew. The ATV was then instructed to remove itself to a safe distance for a second day of tests to demonstrate the optical sensors needed for close proximity maneuvers. It crept to within 11 meters of the ISS, successfully completing a test of satellite and laser guidance systems that set the stage for a docking of the two spacecraft. The exercise required close coordination between the ATV's control center in Toulouse, France, NASA's Mission Control in Houston, Russian's Mission Control outside Moscow and the space station's three crew members. During the tests, the ATV was stopped three times on command and was then positioned 38 km behind and 5 km below the station.

On 3 April the Jules Verne docked flawlessly and uneventfully with the ISS Zvesda module, and after scrubbing the air inside it to prevent contamination of the ISS, the station crew began unloading its 7.3 tonnes of supplies on 6 April. The successful docking unblocked $400 million in funds for follow-on ATVs and related investments in the Columbus laboratory, which were released to ESA on 4 April. The new funding was used to complete integration and testing of the second ATV, to be launched in 2010 and begin hardware purchases for the third unit, due for launch in 2011 – 2012.

The Jules Verne also boosted the ISS orbit by 4.6 km on 25 April via a 740-second burn by two of its four main engines, the first of four reboosts. The second, third and fourth firings were conducted on 12 June, 8 July and 6 August; but since the Jules Verne had an unused propellant reserve of 870 kg, its mission was extended by a month to perform a fifth reboost. The ATV also moved the ISS away from a cluster of space debris on 27 August (see below) with a 5-minute burn of its thrusters. It was the first such station maneuver since 30 May 2003.

The ATV was then loaded with 6.3 tonnes of trash, including some 900 kg of dry waste and 254 kg of liquid waste, and undocked from the ISS on 5 September. It was placed in a new orbit until 29 September, when it was sent on a re-entry path designed to cause it to burn up in the upper atmosphere over an uninhabited area of the Pacific Ocean east of New Zealand. Its destruction was scheduled to take place at night so that scientists could gain an insight into how large objects behave when they de-orbit. To that end, NASA deployed two aircraft laden with radar, ultra-violet, and other sensors to monitor the ATV burnup, which was also observed from above by the ISS crew using the Russian Fialka instrument for ultraviolet and spectrometric observations of the re-entry.

The 13.4-tonne Jules Verne entered the atmosphere at an altitude of 120 km and broke up into about 600 fragments 10-150 kg in mass at an altitude of 75 km. Most of these burned up in the atmosphere, with only about several dozen splashing down in a corridor 200 km wide about 2,000 km east of New Zealand and 2,500 km south of French Polynesia.

Shuttle Endeavour was launched to the ISS on 11 March, carrying the first piece of Japan's $1-billion Kibo laboratory, its Experiment Logistics Module – Pressurized Section (ELM-PS) and Canada's $209-million Special-Purpose Dexterous Manipulator (Dextre) robot for handling some of the maintenance duties formerly requiring the presence of spacewalking crews. ELM-PS, which carried eight experiment racks destined for installation in Kibo's Pressurized Module, was commissioned on 13 March by Japanese astronaut Takao Dai, who was lifted to the ISS by Endeavour as a mission specialist, and other members of the Shuttle crew. Endeavour also brought Leopold Eyharts' replacement on the ISS Expedition-16 crew, Garrett Reisman. Eyharts returned to Earth aboard Endeavour on 26 March (see below).

Endeavour's 16-day mission, the longest of any shuttle flight to date, included five spacewalks. During the first, on 13 March, Shuttle crewmembers Rick Linnehan and Garrett Reisman transferred Kibo's 8.4-tonne logistics module from the shuttle's payload

bay to the ISS Harmony module and began the assembly of the 1.5-tonne Dextre. The first attempt to power up Dextre failed, but the problem, which was corrected via a software patch transmitted to the ISS on 14 March, did not delay Dextre's fitting out, which continued during a second spacewalk by Linnehan and Shuttle crewmember Mike Foreman on 15 March. With power restored by the software patch, Dextre passed its initial operational testing successfully on 16 March.

During a third spacewalk on 17 March, Linnehan and Shuttle crewmember Bob Behnken provided Dextre with "eyes" (cameras and lights) and a set of tools. The robot's tool-belt holds some of the same hand tools used by astronauts. A final checkout resolved some minor problems encountered earlier with Dextre's joint brakes, completing Dextre's assembly work outside the ISS. On 18 March the crew moved Dextre from the truss where it was assembled to its permanent home on the American science lab Destiny. Before they could move the robot the astronauts had to fold up its arms, a slow process that took an hour for each arm.

On 20 March Behnken and Foreman conducted a fourth spacewalk to test a caulking gun and a new silicon-based sealing compound, Shuttle Tile Ablator-54 (STA-54), for repairing the Shuttle's thermal protection tiles in the event of a future damage incident like the one that doomed Columbia in 2003. During the final spacewalk of the mission, on 21 March, Behnken and Forman transferred the laser-tipped inspection boom from Endeavour's payload bay to the ISS, because Endeavour's next mission payload, Japan's Kibo pressurized experiment module, would not allow room for it in the payload bay. They also conducted one more inspection of the damaged starboard solar-array alpha rotary joint, which needed to be repaired before the full Kibo laboratory was activated. The now-routine inspection of the Shuttle's thermal protection system was conducted on 21 March. Endeavour landed successfully at the Kennedy Space Center on 26 March, following an initial diversion on its first attempt due to weather.

Two members of the Expedition 17 crew were launched to the ISS by a Russian Soyuz rocket on 8 April, along with the first South Korean astronaut Yi So-yeon (see above), and docked uneventfully with the station on 10 April. Oleg Kononenko and Sergei Volkov replaced Expedition 16 crewmembers Peggy Whitson and Yuri Malanchenko, who returned to Kazakhstan with Yi aboard the Soyuz TMA-11 spacecraft on 19 April. The landing was marred by an autopilot failure that caused the Soyuz vehicle to default to a ballistic re-entry, overshooting its targeted touchdown site by about 470 km. Although the crew were not injured by the excessive deceleration (about twice that of a normal Soyuz re-entry), it took 25 minutes for the pickup helicopter to locate the capsule. It was subsequently concluded that pyrotechnic bolts failed to fire as planned during the re-entry, leaving the propulsion module in place until its mechanical links burned through and released the capsule to swing around for the steeper trajectory. On 10 July Roskosmos identified the cause of the default to a ballistic reentry as failure of one of the five pyrobolts that separate the landing capsule from the equipment bay.

Volkov, the first second-generation space traveler, is the son of Alexander Volkov, the last Soviet Union cosmonaut to visit the space station before Russia took

over station activity. Expedition 17's research programme aboard the ISS comprised over 45 experiments, including studies into the growth of protein and polymers, forecasting earthquakes, and the influence of space on certain life forms, including humans.

A Russian Progress M-64/29P cargo capsule docked with the station on 16 May, delivering 2.1 tonnes of propellant, water, food, oxygen, life-support gear and other supplies, including a small stash of fruit and vegetables. The docking cleared the way for the successful 31 May launch of space shuttle Discovery, which brought Japan's Kibo laboratory module to the ISS. Following a brief inspection of the Shuttle's thermal protection system, which revealed four small "chinks" that were not expected to cause any problems during reentry, Discovery docked with the ISS on 3 June. The Progress M64/29P capsule was loaded with trash and undocked from the station on 1 September. It remained in space until 9 September in order to perform a series of experiments designed to study the plasma environment surrounding its rocket engines, as part of the Russian Plazma-Progress programme begun in 2007. Data from this programme were used in establishing the probable cause of the unexpected ballistic descent of two Soyuz capsules carrying ISS crewmembers back to Earth (see above and below).

Astronauts Michael Fossum and Ron Garan conducted a spacewalk on 4 June to move the orbiter boom sensor system from the ISS truss back to Discovery's's robot arm (it had been left at the ISS by Endeavour crew because the Kibo module was too big to allow it in Discovery's payload bay); to prepare the Kibo module for its move from Discovery's payload bay to its berth on the ISS; and to inspect the damaged starboard solar alpha rotary joint (see above and last year's report) to see if it would be possible to clean out the debris that fouled it. The Kibo module was then moved by the station's robot arm to its berth on the port side of the Harmony module.

At almost 16 tonnes, the Kibo module is the largest pressurized unit on the station, even without its 8.4-tonne pressurized logistics module. It added space for 23 more active experiment racks to the station's existing complement, and is equipped with a small airlock to move experiments between its pressurized interior and the external Kibo platform due to be launched next year to complete the Kibo facility. It will also be fitted with a 2-m "small fine robotic arm" next year, to place experiments on the airlock's sliding table.

On 24 September NASA finally determined the root cause of the contamination that had fouled the SARJ. Gold plating that had been added to the ring as lubrication had worn off prematurely, causing metal shavings to foul the geared mechanism. Also, the trundle bearings that hold the two halves of the joint together had been loaded with excessive force, resulting in a tighter squeeze than specified. NASA will therefore remove all 11 of the old trundle bearings and lubricate both the SARJ joints on a subsequent mission, and on one of the final Shuttle missions will cover the degraded race ring surface with an overlay.

On 4 June Japanese astronaut Akihiko Hoshide, who had been brought to the ISS aboard Discovery, opened the Kibo module and began its commissioning, that was

completed on 6 June by Fossum and Garan. The Kibo logistics module, which had been brought to the ISS by Endeavour (see above), was then moved from its temporary berth on Harmony to its final location on the Kibo module, and Kibo's 10-m robotic arm was activated and deployed on 8 June. Meanwhile cosmonaut Kononenko used a new pump delivered by Discovery to repair the station's Russian toilet, which had been inoperable for about ten days.

A final spacewalk by Fossum and Garan was conducted on 9 June to replace a failed nitrogen tank. Discovery undocked from the station on 12 June, and after a final, more-thorough inspection of its thermal protection system to check on the four "chinks" discovered earlier (see above), landed uneventfully at the Kennedy Space Center on 14 June with ISS Expedition 17 flight engineer Garret Reisman, having left astronaut Greg Chamitoff to replace him on the ISS.

Volkov and Kononenko of the Expedition 17 crew conducted a spacewalk on 10 July to cut into the thermal insulation on their Soyuz TMA-12 crew vehicle and remove an explosive bolt for analysis on the ground. This task was undertaken to help Russian engineers determine why the past two Soyuz descent modules failed to separate properly from their service modules during re-entry (see above and below). They conducted a second spacewalk on 15 July to start setting up the station to receive the first of two Russian Mini Research Modules, MRM2, in August 2009. It is to be launched on a Soyuz rocket and arrive at the station for an autonomous docking. Volkov and Kononenko installed a docking target on the Zvezda service module transfer compartment to accommodate the MRM2 docking. They also conducted several other tasks during the six-hour spacewalk.

Russian engineers subsequently identified electrical arcing between the space environment and the international space station most likely caused the problems with the explosive bolts used to separate Soyuz re-entry vehicles. The plasma environment around the space station appeared to have degraded the igniter wire in one of the bolts, apparently preventing the bolt from detonating. The phenomenon has been duplicated in a test chamber. Fixes for the problem include a new type of pyrotechnic bolt and a new Soyuz flight profile that may ease the phenomenon. In case the bolt issue isn't the root cause of the failures, Russian engineers addressed 25 other potential causes as well. The next Soyuz to carry a crew to the station was modified to minimize the threat of arcing.

JAXA's first experiment using the Kibo laboratory was conducted by remote control from the Tsukuba Space Center, beginning on 22 August. The research, which lasted until the end of October, gathered detailed data regarding the effects of gravity on convection patterns of liquid by heating oil in a special device. The experiment is aimed at the development of high-quality semiconductors through better control of the silicon melt crystallization process.

Russia's Progress M-65/P30 resupply spacecraft docked with the ISS on 17 September, five days later than planned because of Hurricane Ike. The Russian supply vehicle delivered 2,435 kg of cargo, including about 1,302 kg of food, spare parts and

science-experiment hardware; 864 kg of propellant for the station's Russian thrusters; 211 kg of water; and about 50 kg of oxygen and air. On 2 October the ISS crew moved experiment racks from the U.S. Destiny laboratory into Japan's Kibo module to make room for hardware needed to support the addition of three crew members in May 2009.

Space tourists Richard Garriott (USA) and Nik Halik (Australia) began training on 6 February for a trip in a Russian Soyuz capsule to the ISS. They started the main stage of their training on 11 February: studying the Russian language and undergoing the physical training needed for the launch. Garriott called on the ingenuity of British students to come up with a science experiment for his flight. He challenged primary school students in the U.K. between ages 7 and 10 to design an experiment that he could perform during his stay aboard the ISS, and he also challenged secondary school students ages 11-19 to envision how private enterprise may evolve for space tourism companies.

Garriott, Owen Garriott's son, is the first American second-generation astronaut. He was launched to the ISS on 12 October aboard Soyuz TMA-13/17S, along with U.S. astronaut Michael Fincke and Russian cosmonaut Yury Lonchakov. Fincke and Lonchakov, along with the third ISS Expedition-18 crewmember Greg Chamitoff, began the installing the internal life support equipment required by the station to house a full-time crew of six.

Garriott had created a substantial video game show business. He paid $30 million for his flight but expects to recoup much of that price through some of his experiments on the ISS. He hopes his trip might provide a viable model for financing private space travel in coming years. While aboard the ISS he made several paintings, being very careful not to let his paints fly loose in the microgravity environment. He left the ISS on 23 October with Expedition-17 commander Sergei Volkov, Russia's first second-generation cosmonaut, and crewmember Oleg Kononenko. The capsule landed on target, without any of the difficulties experienced by previous Soyuz returns (see above).

The European portion of the ISS will be operated from 2008 to 2010 by an industry team under a $439-million ESA contract awarded on 3 July. Headed by EADS Astrium (Germany), the team consists of about 40 companies from 10 nations, including Thales Alenia Space (Italy) and the German aerospace center DLR. Tasks include operation of the European ISS facilities, especially the Columbus module, as well as training, mission preparation and control, logistics, maintenance, ground communications, and payload engineering and supply.

NASA announced on 14 April that after the Shuttle fleet is retired in 2010, all U.S. cargo for the space station will be carried by commercial launchers, not on Russian Progress vehicles. However, when on 2 October the agency finally did obtain Congressional approval to continue the use of Russian Soyuz vehicles to carry U.S. astronauts for five more years after the current agreement expires in 2011, that approval also included the use of Progress cargo vehicles. Nevertheless, NASA announced its intention *not* to use the Progress vehicles for cargo transport, but to rely on U.S. launchers under the COTS programme (see above). As a backup for cargo deliveries,

NASA also plans to rely on prepositioned spares to be sent up before the shuttle retires. Two "contingency flights" to the ISS are planned among the remaining shuttle flights to deliver station spares too large to get to orbit on any other vehicle. Then on 15 October U.S. president George W. Bush signed legislation requiring NASA to add two Shuttle logistics flights to the current manifest and take all necessary steps to fly a third additional mission. The same legislation also requires the agency to take steps to ensure that the ISS remains viable until 2020.

On 1 October NASA issued a $650-million supplement to Boeing to continue as prime contractor for the ISS through 30 September 2010. This extension brought the total value of the ISS prime contract to $14.37 billion. The original contract covered engineering responsibility for all 18 major U.S. components as well as integration of elements built by the international partners.

On 11 June Space Adventures (USA) announced that the first commercial Soyuz flight to the ISS would carry Sergey Brin, co-founder of Google, who had placed a $5 million deposit toward his $35-million share of the flight's cost. That flight, planned for 2011, will differ from previous space-tourist flights to the ISS in that the Soyuz to be used for this and subsequent commercial missions will be a specially manufactured craft, separate from the other Soyuz vehicles designated for the transportation of the ISS crews. The Russian space agency claims that this private mission, with a Russian pilot flying two Space Adventures clients at once, will not interfere with the implementation of the ISS programme or the obligations of the Russian space agency.

Space Adventures subsequently announced on 29 September that Charles Simonyi, a space tourist who flew to the ISS aboard a Russian Soyuz launcher in April 2007 (see last year's report), had signed up for a repeat flight in the spring of 2009 and had begun his training in Star City.

A memorandum of understanding (MOU) between NASA and the U.S. Department of Agriculture was signed on 23 July, making experiment racks in the U.S. module on the ISS available to the U.S. Agricultural Research Service for research into biological cellular mechanisms. The MOU was part of NASA's response to a Congressional mandate to make the U.S. facilities on the ISS a national laboratory.

IV.2. Other Human Space Flight Operations

Following Shuttle Discovery's launch to the ISS on 31 May (see above), it was found that the launch had caused major damage to Launch Complex 39A at the Kennedy Space Center, including the loss of 5,300 refractory firebricks from the flame trench wall. Much of the construction material that was damaged had been laid down in the mid-1960s, and had served the launches of 12 Saturn-Vs and 70 space shuttles. Apparently none of the debris resulting from the damage had impacted Discovery during its launch.

Bigelow Aerospace (USA) announced on 1 February that they were ready to place an order with United Launch Alliance (ULA, USA) for six launches of human-rated

Atlas-5 rockets to begin assembly and early operations of the company's commercial space station, starting in 2011. The first two launches will deploy the Sundancer space-station module; the remaining four will transport crew and cargo. Bigelow had launched two subscale inflatable Genesis prototypes last year (see previous report), both of which remain in orbit.

NASA awarded Oceaneering International (USA) a $184-million contract on 12 June to design, develop and test a new modular spacesuit for use on the Orion crew exploration vehicle's trips to the International Space Station. The initial contract, which extends to 2014, also includes the manufacture of six spacesuits. It further specifies two options. The first, starting in 2010 and worth $302 million, would be for modification of the basic spacesuit to make it suitable for lunar missions. The second, running from October 2014 through September 2018 and worth up to $260 million, would be an indefinite-delivery, indefinite quantity contract for additional spacesuits beyond the first six. The losing bidder was Exploration Systems and Technology (EST), a joint venture of Hamilton Sundstrand and ILC Dover (both USA), who provided NASA with their current spacesuits.

However, on 14 July EST filed a formal protest with the U.S. General Accountability Office (GAO), claiming that NASA's 10 July debriefing did not provide sufficient information to them on the basis for the award decision. NASA terminated the contract with Oceaneering on 15 August due to a compliance issue, stating that the agency had failed to request a cost-accounting standards disclosure statement from them and therefore must re-examine both offerors' cost proposals. Following the GAO's dismissal of EST's protest at NASA's request, on the basis that Oceaneering's contract had been terminated, NASA stated that the agency would re-open the solicitation. Both companies subsequently announced their intention to re-bid.

ESA issued a call for new astronaut applications on 16 April. The announcement issued by the European Astronaut Center cited the challenges of ISS exploitation and human exploration of the solar system as the rationale for the call. Potential astronauts, male or female, would have to provide the same medical examination certificates as private pilots and would be subjected to medical, psychological, and professional aptitude evaluations. ESA was seeking candidates with good memory, reasoning ability, concentration, aptitude for spatial orientation, and manual dexterity, as well as competence in a science discipline such as life sciences, physics, chemistry or medicine.

The agency received nearly 10,000 responses and on 23 June provisionally accepted 8,413, based on their having provided a medical certificate and finalized their online application forms. Most of the applications were received from France (22.1%) and Germany (21.4%), followed by Italy, the U.K., and Spain. 16% were submitted by women. The next step was for ESA to begin psychological, physiological and technical testing in different fields, including visual memory and psychomotor aptitude. The agency will select four astronauts next year for a basic training cycle that ends in 2011.

On 30 April NASA Administrator Michael Griffin offered a position on one of NASA's future lunar missions to the U.K. if the U.K. provides an astronaut candidate to ESA.

NASA's acceptance period for new astronaut applications closed on 1 July. The agency was seeking trainees for long-duration stays on the ISS and for missions to the Moon. Applicant qualifications were a bachelor's degree in engineering, science, or mathematics and three years of related professional experience. Teachers and pilots with extensive experience flying high-performance jet aircraft had also been welcomed to apply.

ESA and the Russian federation space agency Roskosmos announced on 22 May that they had selected an Apollo-like conical manned capsule with a service module for their joint-programme Crew Space Transportation System (CSTS). In a departure from Russia's classical spherical configuration, ESA's industrial consortium will develop the service module, to be derived from ESA's ATV and designed to be compatible with Russia's and ESA's spaceports. Russia's Rocket and Space Corporation Energia will be the capsule's prime contractor and oversee service module-capsule integration. The vehicle could be launched on a human-rated EADS Astrium Ariane-5. A cargo CSTS variant may be announced later, but as yet there is only a crew version. On 21 July, at the Farnborough Airshow, RKK Energia (Russia) released the first official image of the CSTS spacecraft. The 18-to-20-tonne vehicle, which resembles NASA's Orion somewhat, is designed to carry a crew of six into low Earth orbit and four on missions to lunar orbit.

However, on 3 June ESA, Germany, and Italy indicated their interest in considering an alternative approach to human space transport. It too would be based on the highly successful Automated Transfer Vehicle (ATV), which had performed flawlessly on its first mission to the ISS (see above). ATV prime contractor EADS Astrium has conducted feasibility studies of an ISS cargo-download capsule with 1-tonne capacity that could later grow into a crew-carrying vehicle. Estimated cost of the initial Advanced Reentry Vehicle (ARV), which could be ready by 2013, is $775 million. RKK Energia (Russia) suggested that the ATV-based vehicle could be a "Plan B" to the CSTS design. Estimated total cost of the full-fledged human-rated space transportation capability is $7.25 billion.

China launched its Shenzhou-7 space capsule aboard a Long March 2F rocket from the Jiquan Satellite Launch Center on 25 September. China sold tickets to observe the night launch to viewers who had the endorsements of their employers. The $2,200 price included transportation to the remote launch site in the northwestern province of Gansu and a four-day stay in the area. The three-day mission carried China's first three-person crew, Jing Haipeng, Liu Boming, and Zhai Zhigang. Zhai also conducted China's first spacewalk on 27 September, a 40-minute sojourn during which he waved a Chinese flag and launched a small subsatellite that transmitted images of the event to Earth and performed a data relay test with the Tianlian-1 satellite. The 35-kg BX-1 subsatellite was equipped with two cameras and a maneuvering system, which was exercised six times

during the two weeks following the departure of the crew's descent module, placing the BX-1 in a 4 x 8-km orbit around the Shenzhou-7 orbiting module. The three taikonauts landed successfully on 28 September.

V. SPACE STUDIES AND EXPLORATION

V.1. Astronomy and Astrophysics

On 20 December 2007 ESA's Corot spacecraft, launched in November 2006 (see last year's report), discovered a gas-giant planet revolving around a star 800 light-years away. The planet is 1.4 times as big and 3.5 times as heavy as Jupiter, and circles its sun once every two days. It was discovered by its eclipsing of its sun. ESA announced in May that Corot had identified two more gas-giant exoplanets orbiting very close to their parent star, along with an unknown celestial object, Corot-Exo-3b, which is smaller than a superplanet but appears to be something between a planet and a brown dwarf.

Corot-Exo-3b could be the long-sought missing link between stars and planets. It is about the size of Jupiter, but 20 times more massive (about twice the density of lead), and orbits its parent star in 4-1/4 days. Corot also detected extremely faint signals of another exoplanet that appears to be 1.7 times the radius of Earth, the first rocky exoplanet to be found. On 24 July Corot discovered a new Jupiter-sized planet named Corot-Exo-4b. Its 9.2-day orbital period is the longest of any transiting exoplanet found to date.

NASA selected 19 science teams on 15 February to develop concept studies on possible future astronomy and astrophysics missions. The aggregate cost of the 19 studies, each of which is funded at $250,000 to $1 million, is about $12 million. The concepts include putting a telescope array on the lunar far side to study the roughly 1-billion-year period of the early universe following the "big bang;" two types of searches for extrasolar planets; and a census of black holes. Results are due in March 2009. On 25 March NASA also awarded the Massachusetts Institute of Technology a $12-million grant to study a farm of radiotelescopes that would be sited on the far side of the Moon to examine the ultra-low frequency signals generated during the universe's earliest years without interference from electronic sources on Earth.

On 4 June NASA awarded $750,000 six-month feasibility study contracts to six Small Explorer (SMEX) finalists, two of which will be picked in 2009 for full development. The six studies are the Coronal Physics Explorer, by the Naval Research Laboratory; Gravity and Extreme Magnetism SMEX, by NASA's Goddard Space Flight Center; Interface Region Imaging Spectrograph, by Lockheed Martin; Joint Astrophysics Nascent Universe Satellite, by Pennsylvania State University; Neutral Ion Coupling Explorer, by the University of California, Berkeley; and Transiting Exoplanet Survey Satellite, by the Massachusetts Institute of Technology.

NASA's $690-million Gamma-ray Large Area Space Telescope (GLAST) arrived at the Kennedy Space Center on 12 March for final processing by Astrotech (USA). Built by NASA's Goddard Space Flight Center and General Dynamics (USA), GLAST includes participation by the U.S. Department of Energy and research organizations in France, Germany, Italy, Japan and Sweden. It was launched from Cape Canaveral on 11 June by a United Launch Alliance Delta-II rocket to its 550-km circular orbit inclined at 25.5 degrees, following a three-week delay due to problems with the booster's second stage. GLAST's two telescopes are covering the entire sky every 3 hours in the energy range from 10 keV to over 300 GeV during its expected 5-10-year lifetime.

The 4.3-tonne spacecraft, renamed "Fermi" in August, is seeking to discover the origins of cosmic rays; to investigate dark matter, supermassive black holes, neutron stars, supernova remnants, and pulsars; and to track gamma-ray bursts. It can survey the entire sky every day, can see about 20% of the sky at any one moment and slews automatically to observe particularly bright gamma-ray events. On 1 July the Stanford Linear Accelerator Center's Instrument Science Operations Center (USA) began receiving data from the Large Area Telescope, one of Fermi's two instruments.

On 19 March the Burst Alert Telescope on NASA's Swift observatory detected the brightest gamma-ray burst ever recorded, about 2.5 million times more luminous than the previous record. It originated from GRB 080319B, a collapsing massive star in the constellation Bootes about 7.5 billion light-years distant, over halfway to the edge of the known universe. Then on 19 September Swift observed a gamma-ray burst from GRB 080913, near the edge of the universe about 12.8 billion light-years away, the farthest such event ever detected. Only the light from some faint galaxies has been detected beyond this burst, 100-300 million light-years further out.

On 20 June NASA selected the Goddard Space Flight Center (GSFC) proposal to build and fly a High-Resolution Soft X-ray Spectrometer on Japan's New exploration X-Ray Telescope (NeXT) mission, planned for launch in 2013. The $44-million GSFC proposal was one of two Exploration Programme Missions of Opportunity selected from the 17 proposals NASA had received earlier this year.

Construction and assembly of ESA's $1.6-billion Herschel infrared observatory (see prior reports) was completed in April, with the mating on 11 April of its sunshield and solar arrays to the cryostat and service module and attachment on 16 April of its ultra-light 320-kg telescope, the largest ever flown in space. Following mechanical testing, Herschel was shipped to the Kourou launch site, along with ESA's Planck cosmic background observer.

Since its launch on 23 April 2007 (see last year's report), Italy's orbiting gamma-ray detector AGILE this year revealed X-ray and gamma emissions coming concurrently from a gamma-ray burst. High-energy photons (over 50 MeV) originating from the gamma-ray burst 080514B were observed, together with X-ray emissions and an optical afterglow, enabling the measure of the distance and the "intrinsic power" of the explosion. In the same period gamma emissions measured from pulsar PSR J 2021

explain its nature as a rapidly rotating neutron star, much closer than previously thought according to radio data alone. This was the seventh pulsar of this kind observed to date.

On 27 September the Hubble space telescope suffered a failure of its 18-year-old science data formatting instrument, the Science Instrument Command and Data Handling (SIC&DH) unit, causing the spacecraft to lose its ability to record and send data. Efforts to bring it back on line from Earth did not work. NASA started up an onboard backup unit that had not been operational since 1990, and could have had it in use by 3 October. However, switching over to the backup unit permanently would endanger the observatory's long-term success and any effort to switch to the backup instrument onboard could blow a fuse. Also, a transition to the backup was not as simple as throwing a switch, because multiple other instruments had also to be commanded to make new connections to the formatter. There was a real risk that the switchover could disable the telescope permanently.

NASA therefore believed that it made more sense to delay the Shuttle's repair mission, originally planned for 14 October, until February 2009 or perhaps even later. NASA has a replacement data formatter that has been in storage since the early 1990s, but it has generated spurious commands and exhibited other anomalies that must be resolved before it can fly. Moreover, its installation on the Hubble telescope requires space-readiness acceptance testing that won't be complete until at least January. However, on 30 October the unit failed to operate properly, delaying its availability until at least April 2009. Hence NASA rescheduled the Atlantis repair mission again, this time until no sooner than May 2009. This delay also forced postponement of the Ares-1X test flight, which needs the same launch pad as the Atlantis Hubble repair mission.

Meanwhile NASA engineers conducted a successful simulation of the switchover to the onboard backup unit on 6 October. The actual switchover began on 14 October, a two-day process that involved 40 to 50 engineers in a tedious and challenging process. It was done entirely by remote control from Hubble's operations center at NASA's Goddard Space Flight Center. The change was concluded successfully on 16 October, but the computer that controls the instruments then shut down unexpectedly, apparently to protect all the equipment. On 25 October computers again began communicating properly with Hubble's Wide-Field Planetary Camera 2, and on 27 October the telescope transmitted its first picture, confirming that the observatory was back in action after a month of computer failures. Scientific observations resumed shortly thereafter.

V.2. Plasma and Atmospheric Physics

On 16 November 2007 the mission of the U.S. – European Ulysses solar-science spacecraft was extended by one year, to March 2009. This was the fourth extension of the spacecraft's two-decade mission. To compensate for the decreasing power available from the craft's nuclear radioisotope thermoelectric generator, controllers worked out a new operations scheme that limits power sharing by Ulysses' instruments. But on 1 July controllers had to shut Ulysses down due to insufficient electric power to keep its propellant from freezing. It had gathered data on the boundaries and impact of the Sun's

sphere of influence for 17 years, almost four times its expected lifetime. Launched in 1990 as the International Solar Polar Mission (ISPM), it was the first major collaboration between NASA and ESA. During its last months of operation, Ulysses recorded data indicating that the solar wind is significantly weaker, cooler and less dense than it has been in 50 years, finding that pressure and density of the overall solar wind are 20 to 25 percent lower than during the previous solar minimum.

NASA's five Themis spacecraft (see last year's report) were reported on 12 December 2007 to have discovered the mechanism responsible for the Aurora Borealis above the Earth's polar regions: geomagnetic storms powered by the solar wind racing at speeds of the order of 6,500 km/minute through twisted bundles of magnetic fields, which when destroyed in minutes by the solar-wind energy produce the spectacular auroral light displays. The first of these bundles to have been mapped by Themis was located in the Earth's magnetopause, about 65,000 km above the Earth's surface. The two-hour substorm created in it by the solar wind released about 500 million megajoules of energy in less than a minute.

On 30 April NASA authorized the Johns Hopkins University's Applied Physics Laboratory (JHUAPL) to begin work on a $750-million solar probe mission that will be launched around 2015 to fly within 7 million km of the Sun, measuring the stream of charged particles that move through the Sun's corona. JHUAPL received $13.8 million in pre-Phase A funding to begin addressing the mission's technical risks, including the design of a carbon-composite heat shield to protect the 450-kg spacecraft against a projected temperature of 1400 Celsius, and assessment of the necessary instrument accommodations.

NASA's Interstellar Boundary Explorer (IBEX) underwent testing at Vandenburg Air Force Base in August before being shipped to Kwajalein Atoll in September. It was launched on 19 October by an Orbital Sciences Pegasus XL. The 460-kg spacecraft was first launched into a low 208-km orbit, and then employed a unique onboard propulsion combination to achieve its operational orbit. An ATK Star-27 solid-propellant rocket motor boosted IBX to its apogee, and it then used a liquid hydrazine propulsion system to attain its final 320,000 x 7,000-km orbit. The $169-million mission thus demonstrated the ability to reach a high orbit via a low-cost launcher. IBEX is using its energetic neutral atom sensors to assemble for the first time global images of the interactions at the edge of the heliosphere where the solar wind meets interstellar dust and gas. Its high orbit takes it outside the Earth's magnetosphere, whose high density of energetic neutral atoms would otherwise have drowned out IBEX's observations. The spacecraft was developed by Southwest Research Institute (USA) for NASA's Goddard Space Flight Center.

On 26 August the U.S. National Science Foundation (NSF) selected SRI International and the University of Michigan to study radio auroras in the Earth's ionosphere. The three-year, $950,000 project includes development and operation of a small "CubeSat" spacecraft and its ground station, as well as purchase and testing of a small-satellite dispenser called P-POD, which can deploy three CubeSats as secondary payloads. NASA will provide project engineering and management support and in

December 2009 the U.S. Department of Defense will launch the P-POD and the satellite, both on a cost-reimbursable basis. Undergraduate and graduate students are participating in all aspects of the mission.

In February the Italian Space Agency awarded five Phase-A studies for small missions: SAGACE (Spectroscopic Active Galaxies and Clusters Explorer); POLARIX (X-band polarimeter); FLORAD (microsatellites FLOral constellation for RADiometric observations); MAGIA (Moon Altimetric Gravimetric geochemical mission); and ADAHELI (Advanced Astronomy for HELIophysics). The studies will be concluded by the end of the year, after which two could be selected for launch no earlier than 2012 and 2014.

On 25 October China deployed two research satellites: the third pair of Shijian 6 satellites, which study the harsh environment of space.

V.3. Space Exploration

China's Chang'e-1 lunar probe, launched on 24 October 2007 (see last year's report), was placed into a 200-km lunar orbit on 7 November 2007. The spacecraft and its launcher, a Long March 3A, were built by China Aerospace and Technology Corporation at a total mission cost of $188 million. Controllers at the Beijing Aerospace Control Center changed its orbit slightly on 27 January, raising it by 2 km, to reduce the time Chang'e had to spend in the dark during a 21-February lunar eclipse from 3 – 4 hours to 2 hours.

Both China and Japan announced at a programme meeting of the International Astronautical Federation in Paris on 26 March that their lunar orbiters, China's Chang'e and Japan's Kaguya (see last year's report), had operated flawlessly through the first half of their planned one-year missions. Their roles in meeting science objectives and serving as pathfinders for future lunar missions are therefore likely to warrant mission extensions of at least 6 months beyond their original one-year goals. This would also apply to Kaguya's two sub-satellites, the 50-kg Okina data-relay satellite and the 50-kg Ouna gravity-field-measurement spacecraft.

On 9 April Kaguya transmitted to Earth the most detailed global topographic map of the Moon ever assembled. The preview map includes two weeks of data taken by the Laser Altimeter (LALT) instrument, which was then analyzed by the National Astronomical Observatory of Japan (NAOJ) and processed into map form by the Japanese Geographical Survey Institute (GSI). It contained 1,127,392 point measurements of the lunar surface; JAXA expects more than 30 million points to be obtained after one full year of observation. Kaguya also succeeded in acquiring unique detailed global data on uranium, thorium, and potassium from its Gamma Ray Spectrometer and is still in the process of analyzing other elements from the data already acquired.

India launched its Chandrayaan-1 two-year lunar mission on 21 October from the Satish Dhawan Space Center aboard a modified Polar Satellite Launch Vehicle (PSLV). Most television channels in India covered the launch. The 1.38-tonne spacecraft (see prior reports) was placed in a 250-km x 23,000-km parking orbit, from which its onboard propulsion system performed a series of orbit-raising maneuvers that culminated in a 300-km x 387,000-km lunar transfer orbit. Another series of firings in November were to have brought the spacecraft into its final 100-km circular lunar orbit, which will take Chandrayaan-1 over the Moon's poles once every 118 minutes.

Chandrayaan-1 carries 11 experiments including three from ESA, two from NASA, one from Bulgaria and five developed by India. In addition to these instruments, which are designed to map the lunar surface and determine its mineral content, the spacecraft also includes a small Moon Impact Probe, which will be jettisoned to land on the lunar surface before the main mapping mission begins. The probe will give ISRO scientists experience to be used in subsequent lunar landing missions.

On 27 February NASA revealed models of two rovers that could be used by astronauts when they explore the Moon beginning about 2020. The Chariot design uses six independently moving wheels that provide the vehicle with 360-degree turning capability, allowing it to traverse very steep craters sideways if necessary. The Scarab rover will be designed to search for water, using a Canadian drill capable of boring a meter deep into the lunar regolith.

NASA selected 11 U.S. companies and one U.S. university on 28 July to conduct six 180-day, $250,000 studies on living and working in a lunar outpost. The awards went to Astrobic Technology and Honeybee Robotics for regolith-moving methods; to ATK Space Systems Group, Battelle Memorial Institute and Hamilton Sundstrand for energy storage studies; to Boeing, ILC Dover and the University of Maryland for minimum habitation functions; to the Charles Stark Draper Laboratory and United Space Alliance for software; to Honeywell International for avionics; and to Oceaneering Space Systems, for alternative packaging options.

On 10 December 2007, NASA selected the Gravity Recovery and Interior Laboratory (GRAIL) mission from among three proposals for Discovery-class missions. The $375-million mission will deduce gravity-field information from highly accurate measurements of the distance between two spacecraft flying in tandem orbits, enabling calculation of the Moon's subsurface structure all the way to its core. This technique for studying the Moon's interior is similar to that of the GRACE mission studying the Earth (see last year's report), and is likely to be used in the future to study Mars. The other two proposals were for an asteroid sample-return mission and a Venus orbiter. The winning proposal was by the Massachusetts Institute of Technology. GRAIL is planned to be launched in 2011.

Then on 9 April NASA added a secondary payload to the GRAIL mission: the $80-million Lunar Atmosphere and Dust Environment Explorer (LADEE), to explore the composition and structure of the Moon's tenuous atmosphere near the lunar surface

during a nominal 100-day mission. LADEE's data are expected to help assess how to develop future human exploration missions. It will separate from GRAIL while on its way to the Moon.

Representatives of ESA and eight national space agencies met on 14 March to create a new robotic International Lunar Network (ILN). Its goal is to build up a coordinated network of at least six small science stations on the lunar surface long before human flights would begin. ESA, NASA, Canada, India, Italy, Japan, South Korea and the UK agreed to place standardized, relatively small fixed robotic stations or simple rovers at several lunar surface locations beginning in 2013. Their function would be to form a seismic network to establish the nature of the Moon's core and to begin the process of lunar surface hardware cooperation with simple devices. NASA plans to begin the ILN with north and south polar landers in 2013-2014 and possibly two more in 2016-2017. ESA is planning a small 100-kg rover called MoonNEXT, to be launched in 2016 to the rim of Shackleton Crater near the lunar south pole.

On 19 December 2007 Anatoly Perminov, the head of the Russian space agency Roskosmos, announced an expansion of Russia's space programme, to be financed by recent growth in the nation's revenues, that features an orbiting base for human and robotic missions to the Moon and Mars after 2020. He indicated tentative plans for a human mission to Mars after 2035 that should be international in nature. The first of the new missions to be funded was the Luna-Glob 1 orbiter, planned for launch in 2012. On 13 October Russia's satellite and planetary probe specialist, the Lavochkin Association, began phase B design work as prime contractor. The probe will study the Moon's internal structure and look for mineral resources. It is the first of four missions planned before the creation of a fully robotic lunar base, scheduled after 2015. The second Luna-Glob mission, which also could launch in 2012, consists of a rover whose lander may become part of the International Lunar Network (see above), and could possibly employ a penetrator. Follow-on missions named Luna-Grount are currently scheduled for 2014 and 2015.

On 8 November 2007, Germany announced a proposal by the German space agency DLR to build and fly a lunar orbiter using all-German technology. The 2-tonne Lunar Exploration Orbiter (LEO), to be built by EADS Astrium and OHB System, would cost $508 million and would be launched into a 50-km lunar orbit in 2012. The project was approved on 2 October by the German parliament's economics committee, which allocated $414 million to begin work on the mission. The research ministry will contribute funding as well.

The first team to qualify for the $30-million Google Lunar X Prize (see last year's report), announced on 6 December 2007, was Odyssey Moon (Isle of Man), whose prime contractor for the vehicle is MacDonald Detwiler and Associates Ltd (Canada). The Planetary Society (USA), also a member of the Odyssey Moon team, will provide educational assistance and public involvement, and on 30 October the company contracted to pay NASA $500,000 over two years for design drawings, technical data and engineering support. The goal of the prize competitors is to land a privately funded robot

rover on the Moon, maneuver it to travel at least 500 m, and transmit video, images and data to Earth.

Nine more teams signed up for the competition on 21 February: Aeronautics and Cosmonautics Romanian Association (Romania); Astrobotic (USA), led by robotic expert William Whitaker of Carnegie Mellon University; Chandah (USA) led by Adil Jafry, CEO of Texas electricity company Tara; Frednet (USA), a team of engineers led by Fred Bourgeois, CEO of Applios, Inc; LunaTrex (USA), led by Peter Bitar, CEO of Xtreme Alternative Defense Systems; Micro-Space Inc. (USA), led by Richard Speck, CEO; Quantum3 (USA); Southern California Selene Group (USA); and Team Italia (Italy). Also on 21 February, the commercial Florida company Space Florida joined Google as a sponsor, offering the winner launch site services and an extra $2 million in prize money if they use a launch site in the state of Florida.

Four more teams joined the contest on 21 May: Jurban, from the Juxtobia Group (USA), a nonprofit research institution that focuses on educating minority students; Stellar, a team composed of North Carolina State University, Insight Technologies, and the Advanced Vehicle Research Center (all USA); Advaeros, a team led by Advanced Aerospace Industries (Malaysia); and a fourth team who chose to remain anonymous until July 20, 2009, the 40th anniversary of the first human landing on the Moon. Two more teams signed up on 6 October: Independence-X Aerospace (Malaysia) and Omega Envoy (USA). Analytical Graphics (USA) offered to provide each of the competing teams with about $200,000 worth of software and engineering services.

NASA celebrated the fourth anniversary of the landing on Mars of robot rovers Spirit and Opportunity on 4 January and 20 January, respectively. During those four years the rovers collectively traveled over 19 km and transmitted over 210,000 images, which formed the basis for more than 100 studies of the planet's geologic past, with many more still in progress. On 29 August Opportunity discovered evidence implying that a vast underground body of water once lay deep beneath Mars' surface. The rover detected under the rim of Victoria Crater water-formed minerals like iron, magnesium and calcium sulfates, as well as unidentified chlorides. Since the minerals were identical to those found in the Endurance Crater, the implication is that the same aquifer must have extended for thousands of square km.

NASA's Mars Reconnaissance Orbiter (MRO) collected images on 19 February from the spacecraft's High Resolution Imaging Experiment (HiRISE) showing large avalanches of soil mixed with water ice on the face of a 700-m-high slope at Mars latitude 84 degrees north. Possible causes cited for the avalanches include temperature-related resizing of the ice layer, a Mars quake or a meteor strike. On 19 March the Mars Odyssey Orbiter's thermal imaging camera observed what appear to be ancient salt deposits in Mars' southern highlands, whose configuration suggests that water once flowed there.

MRO's HiRISE camera also collected the highest-quality close-up images ever of the Martian moon Phobos on 9 April, showing the moon's most prominent feature, the

Stickney impact crater, along with grooves radiating outward from it. A composite of HiRISE images also provided the first three-dimensional images of Phobos.

NASA's $520-million Phoenix Mars lander, launched on 4 August 2007 (see last year's report), set down successfully near the red planet's north pole on 26 May. The final 7 minutes of the mission following separation from the cruise stage involved entry into Mars' atmosphere at an altitude of 125 km and a speed of 5.6 km/sec, resulting in deceleration at 9.2 g and a heat-shield temperature over 1400 Celsius; parachute deployment at 12.6 km altitude; and final descent via the spacecraft's twelve 300-N-thrust descent engines, nine of which fired up to 10 pulses/sec.

Phoenix's solar panels deployed successfully, and the first photographs were transmitted to Earth a few hours later, revealing two patches of what appeared to be water ice on the surface directly under the lander, but not within reach of the digging tool to be deployed later. Shortly following the landing, control was shifted from the Jet Propulsion Laboratory to The University of Arizona. The lander's 2.4-m robotic arm was deployed and its operation checked out successfully on 29 May. A major goal of the mission was to use the arm to dig soil and ice samples from its landing site, where Mars Reconnaissance Orbiter had detected the prospect of water ice at a depth of about 25 cm, easily reachable by Phoenix's digging arm.

The first digging task, preparing for this mission, was carried out satisfactorily on 1 June. Photos taken on 3 June by the craft's optical microscope revealed Martian soil particles as small as a tenth of a human hair, the best resolution ever returned from another planet. On 11 June, following six unsuccessful attempts, a soil sample was finally delivered to the first oven of the spacecraft's Thermal and Evolved-Gas Analyzer (TEGA). One of the soil samples scooped earlier had been delivered successfully to the Microscopy, Electrochemistry and Conductivity Analyzer (MECA), and its first images were transmitted to Earth on 12 June.

Then on 19 June a number of ice-like pieces scooped out by Phoenix's digger evaporated shortly after being retrieved, an almost certain indication that they were ice and not salt, which was the only other possibility. That conclusion was confirmed on 30 July, when a sample heated to 0 Celsius in Phoenix's oven gave off a puff of vapor. Analysis by the MECA instrument of soil samples collected by Phoenix's scoop on 25 and 26 June revealed the presence of perchlorate salts, magnesium, sodium, potassium and chloride, and found a pH level of 8 to 9, which is on the alkaline side. Some researchers had predicted an acid Martian pH of 1. That makeup of the soil, which is very similar to Earth soils, could support future manned exploration by growing vegetables such as green beans, turnips and asparagus. The discovery of Earth-like soil meets the highest-priority goal of the Phoenix mission.

One somewhat surprising finding, based on humidity measurements taken during the week of 1 September, was that although there was clear evidence that water vapor was settling on the Martian soil and then being released back into the atmosphere, sampling of the soil indicated that it was dry. On 28 September Phoenix's lidar

instrument detected snow in clouds about 4 km high and followed the precipitation as it fell more than a km, but could not tell if it reached the surface. The snow was not unexpected, because Phoenix had watched the clouds drifting across the horizon every morning after sunrise.

However, four insertions of Phoenix's probe on 3 and 4 September found no water, even though the probe can detect films of water only one molecule thick, and the relative humidity in the atmosphere was found to transition from zero to 100% with every day-night cycle. Nevertheless, all indications are that a "skating rink" of ice lies only a few cm below the surface. On 29 September, NASA extended the Phoenix mission until the spacecraft expires. The lander survived its first Martian dust storm on 11-12 October, but waning sunlight along with obscuration due to the dust storm drained Phoenix's power, forcing it to go into safe mode on 29 October. It failed to respond to two wake-up calls from Earth, but finally sent a signal the next day. However, controllers were unable to continue receiving signals, and on 31 October had to conclude that Phoenix was no longer active.

International partners on the Phoenix mission include the Canadian Space Agency, ESA, and components from Canada, Denmark, Finland, Germany, and Switzerland. Analysis tools include the most complex and capable set of mini-laboratories ever sent to another planet: eight tiny ovens equipped with a mass spectrometer, four wet-chemistry cells and two powerful microscopes.

On 16 July NASA released images from the Mars Reconnaissance Orbiter that show vast quantities of water-bearing clays on Mars' surface, particularly in the planet's highlands. MRO's Compact Reconnaissance Imaging Spectrometer for Mars (CRISM) instrument discovered several types of clay minerals, or phyllosilicates, including opal. The CRISM found hundreds of such sites, formed over 3.5 billion years ago, in which water altered rocks into the claylike materials that could have been friendly to simple life forms. An intriguing find was of deposits in the pointed peaks at the center of craters, which are believed to be underground material thrown up by impacting asteroids or comets from as much as five km below the planet's surface. The subsurface phyllosilicates were formed at relatively low temperatures, implying that Mars was not only wet but also relatively temperate at the time. The water transformed some rocks into the phyllosilicates, which include clays rich in iron, magnesium or aluminum, mica and kaolinite. The MRO images, from nine months of CRISM data, are the highest-resolution spectrometry ever taken from orbit.

On 15 May NASA released an image provided by Italy's SHARAD (Shallow Radar) aboard MRO implying that the crust and upper mantle of Mars are stiffer and colder than estimated previously. This suggests that environmental conditions adequate for living organisms requiring liquid water could be found at greater depths than previously thought.

NASA selected its second Mars Scout mission in mid-September from among 26 proposals. The $485-million Mars Atmosphere and Volatile Evolution (Maven) satellite,

proposed by the Laboratory for Atmospheric and Space Physics at the University of Colorado, is planned for launch in 2013 into an elliptical 145-km x 6,200-km Mars orbit to gain a better understanding of how Mars lost its dense early atmosphere. Carrying eight instruments for its one-year mission, Maven will be managed by NASA's Goddard Space Flight Center and is being built by Lockheed Martin Space Systems (USA). The other Maven team members are the University of California at Berkeley and the Jet Propulsion Laboratory.

ESA's Mars Express made five flybys of the Martian moon Phobos during July and August: 12 July, at an altitude of 563 km; 17 July, at 273 km; 23 July, the closest, at 97 km; 28 July, at 361 km; and 3 August, at 664 km. The purpose of the maneuvers was to gain insights into Phobos's surface, temperature, and geological past, using a battery of instruments that included a high-resolution stereo camera, an infra-red scanner and an atmospheric spectrometer.

Late in July the International Mars Architecture for the Return of Samples (iMARS) working group issued its report on the prospects for a Mars sample return mission. The group, which includes representatives from Australia, Canada, Europe, Japan, and the U.S., concluded that such a mission is technically feasible and scientifically worthwhile, although requiring the development of some enabling technologies and resolution of some science-engineering tradeoffs. It would require separate launches for a lander-rover-ascent module and an orbiter-return vehicle, and possibly a data-relay orbiter. The project could begin in 2013, launch in 2020, and return to Earth in 2023. The work could be divided into 20 separate tasks funded by different international teams, with a total rough cost estimate of $4.5 billion - $8 billion. A second one-year study was recommended to refine requirements, cost estimates and architecture, and to identify prospective partners and interfaces.

On 14 December 2007 ESA committed $117 million in 2008 funding toward development of the $1.5-billion ExoMars rover mission to enable its launch in 2013. Thales Alenia Space (Italy) has submitted a proposal for the spacecraft and integration of its 23 science instruments, most of which will be supplied by the national space agencies of Britain, France, Germany, and Italy. NASA and the Russian space agency Roskosmos are expected to join the mission via separate bilateral agreements. Tight schedule and funding problems led to postponement of the launch to the 2016 window. The ESA governments will decide the way forward and update their contribution to the mission in November 2008.

The Swiss Federal Institute of Technology built and flight-tested an unpiloted aerial vehicle (UAV) designed for continuous solar-powered flight in the atmosphere of Mars. The 27-hour test of the Sky-Sailor UAV on 26 June extended through the night, powered by a battery charged by solar energy. Wingspan of the Sky Sailor is 3 m. It was designed and developed under an ESA grant for a Mars flyer.

On 11 December 2007, NASA reported that the Voyager-2 spacecraft had passed through the "termination shock," where the solar wind meets interstellar space. Although other craft had passed through the shock previously (e.g., Pioneers 10 and 11 and Voyager-1), Voyager-2 was the first that carried a working instrument able to measure and transmit the speed and temperature of the solar wind as it passed through the shock. It transitioned the shock at 84 astronomical units (au) from the Sun, whereas Voyager 1 had done so in December 2004 at 94 au, indicating an asymmetry of the heliosheath.

NASA's Deep Impact spacecraft, originally reprogrammed to rendezvous with comet Boethin (see last year's report), was again reprogrammed on 13 December 2007 to an 11 October 2011 flyby of comet Hartley-2 at a distance of about 1,000 km. The decision was motivated by the disappearance of Boethin, which apparently broke up into pieces too small to detect. The renamed Extrasolar Planet Observation and Characterization and Deep Impact Extended Investigation (Epoxi) Mission was also programmed on 21 January, following the first of three gravity-assist flybys of Earth on 31 December 2007, to use its telescope in seeking smaller Earthlike planets in gas-giant planetary systems that have already been discovered around five stars.

On 13 March the Cassini spacecraft descended to within only 48 km of the surface of Saturnian moon Enceladus, where it passed through and sampled the moon's giant plume of water ice and dust (see last year's report) during a flyby near the moon's south pole at a lateral distance of 200 km from the core of the plume. Cassini's composite infrared spectrometer found carbon dioxide, carbon monoxide and organic molecules of methane, propane, acetylene, and formaldehyde in the plume; its infrared spectrometer measured "tiger stripe" temperatures of -93 Celsius, about 110 degrees warmer than the rest of the moon's surface; and its magnetometer looked for an induced magnetic field that could imply the existence of a subterranean ocean. The composition of the plume is similar to that found in comets. High-resolution images of Enceladus's north pole taken by Cassini's imaging system also revealed major topographical differences from the south pole. Cassini conducted subsequent flybys of Enceladus on 11 August, 9 October, and 31 October, adding more detailed information on the unique Saturnian moon. The 9 October encounter brought Cassini within 25 km of Enceladus, a breathtakingly close flyby at 64,000 km/hour, designed to gather dust and water particles from the geysers. The 31 October flyby focused on taking images of the "tiger-stripe" fractures that slash across the moon's south polar region.

On 13 October NASA released images of a massive cyclone at Saturn's north pole and a similar storm at the south pole, captured in June by Cassini in both infrared and visible-light wavelengths. The north-pole cyclone is rotating at 530 km/hour, and reaches out to 12,000 km from the planet's surface. The southern cyclone extends out to 15,000 km. They are believed to be powered by thunderstorms.

NASA announced on 20 March that Cassini's observations of the changes in the rotation of Saturn's moon Titan by the spacecraft's synthetic aperture radar during 19 separate Titan flybys between October 2005 and May 2007 indicate the existence of a large internal water-ammonia ocean about 100 km below the moon's ice and organic-rich

surface. This conclusion was inferred from the observed movement of 50 distinct surface features, some by over 30 km.

On 29 July Cassini detected an ethane lake on Titan, the first lake ever to be confirmed on another planet in the solar system. It could be as shallow as a few meters or as deep as tens of meters. It contains some of the same chemicals that preceded life on Earth, including nitrogen, methane, ethane, propane and butane. Previous Titan flybys had observed hundreds of dark, lake-like features, but could not distinguish liquid lakes from dark solid material. The 29 July flyby shows overwhelming evidence of evaporation, rain and fluid-carved channels draining into a liquid hydrocarbon lake. Named Ontario Lacus, the lake is located near Titan's south pole and covers an area of about 20,000 square km, making it slightly larger than Lake Ontario in North America. It is ringed by a dark beach, where the black lake merges with the bright shoreline.

On 15 April, NASA and ESA announced a two-year extension of Cassini's mission, originally scheduled to end in July. The extension will allow seven additional flybys of Enceladus, 26 of Titan, and one each of Saturnian satellites Dione, Helene and Rhea, as well as further studies of Saturn's ring system, atmosphere and magnetosphere during sixty more orbits around the planet.

ESA's Rosetta comet probe, launched four years ago (see prior reports) used an Earth gravity-assist maneuver on 13 November 2007 to gain velocity on its way to comet 67P/Churyumov-Gerasimenko, which it will reach in 2014. The flyby was supported by NASA and ESA Delta-DOR measurements, an interferometric method that precisely determines interplanetary trajectories using Quasar signals for compensation of signal disturbances caused by the ionosphere. Rosetta then flew by asteroid 2867 Steins on 5 September at a distance of about 800 km and a relative speed of 8.6 km/sec, providing new information about the asteroid and serving as a "dress rehearsal" for Rosetta's future encounters. The probe utilized 15 instruments for the flyby. Rosetta came within 805 km of the asteroid, which turned out to be slightly larger than expected: 5 km *vs* the previous measurement by NASA's Spitzer observatory of 4.6 km. Discovered in 1969, very little was known about this irregular-shaped body, which may be a fragment of a larger asteroid shattered in a collision long ago. Rosetta's images of 2867 Steins have provided clues to how the planets formed more than 4.6 billion years ago.

NASA's $446-million Messenger mission to Mercury (see last year's report) demonstrated its highly accurate mid-December trajectory correction maneuver on 6 January, when the agency decided to skip the next correction, originally planned for 10 January. The spacecraft's cameras began imaging Mercury on 9 January, and it flew by the planet for a gravity-assist maneuver on 16 January at a distance of 202 km, only 8.25 km from its aim point. During the flyby Messenger collected 500 MB of data on the composition of Mercury's surface and atmosphere and the properties of its magnetosphere, including 1,213 images of the planet's surface, many of previously unseen portions.

Findings published in the journal *Science* on 4 July indicated that the smooth plains on Mercury first observed by Mariner 10 in 1974 and 1975 are very likely the lava resulting from volcanic activity, a view supported by Messenger's images of a shield volcano 95 km in diameter within Mercury's Caloris basin. The spacecraft also spotted ions of silicon, sodium, sulfur and water during its pass through the planet's magnetosphere and established the nature of the planet's magnetic field as a dipole field generated by the churning of Mercury's molten iron-rich outer core, fed by energy from the solidifying inner core.

During Messenger's second gravity-assist flyby on 6 October, the spacecraft's cameras snapped 21,200 images of the planet. Along with images of the first flyby (see above) and Mariner 10's in 1974, U.S. spacecraft have now accumulated coverage of 95% of Mercury's surface. Besides the discovery that the planet's magnetosphere is highly symmetric, Messenger's Mercury Atmospheric and Surface Composition Spectrometer (MASCS) detected magnesium in Mercury's exosphere for the first time. Scientists have now concluded that the spatial distributions of sodium, calcium and magnesium offer an unprecedented window into the interaction of Mercury's surface and exosphere.

The 6 October flyby revealed more about the material spewed from past volcanoes. The material was all over the planet, leading to speculation that it is an important but as-yet unknown substance ejected from Mercury's large core, some probably by impacts. The current speculation is that the material is ilmenite or silicate rock with iron. Messenger's cameras spotted a "wrinkle ridge," about twice the height of similar features seen on Mars, suggesting that the planet contracted in on itself considerably as it cooled. The photos also show some empty craters on Mercury and some filled with solidified lava.

It was announced by *Nature* magazine on 29 November 2007 that ESA's Venus Express had confirmed the presence of lightning in Venus's atmosphere. Although lightning is known to occur in the atmospheres of three other planets, Earth, Jupiter and Saturn, the lightning there is associated with water-bearing clouds. On Venus, the lightning is associated with clouds of sulfuric acid. Venus Express data also revealed that the planet's complex three-dimensional wind fields, global temperature distribution, and cloud formations showed many similarities to conditions on Earth, reversing the formerly held belief that the two planets were totally dissimilar. On 4 April ESA announced that Venus Express data revealed major variations of sulfur dioxide in the planet's atmosphere, especially the upper atmosphere, suggesting the possibility of recent volcanic activity on Venus. A month later it was announced that the spacecraft's visible and infrared imaging spectrometer had discovered hydroxyl in a thin layer of Venus's atmosphere about 100 km in altitude, the first to be found on a nonterrestrial planet, sparking an intensive search for ozone.

On 14 July ESA began a series of maneuvers to lower the orbit of Venus Express to 185 – 300 km in order to study the northern polar region's magnetic field and the plasma environment deeper into the atmosphere and to measure the atmosphere's density.

The spacecraft reached the lower orbit on 4 August, and was later lowered still further into the atmosphere to measure the spacecraft's drag and evaluate the use of aerobraking to further adjust Venus Express's orbit.

ESA reported on 22 September that Venus Express had tracked cloud movements hidden within the murky depths of Venus' southern hemisphere and scoped out the huge hurricane-like vortices spinning over the planet's poles. The spacecraft's Visual and Infrared Thermal Imaging Spectrometer (VIRTIS) viewed visible cloud motions at the upper altitudes during the day, and switched to the infrared range to see lower cloud movements at night. The wind speed varied from almost 370 km/h at 65 km altitude to roughly 210 km/h at 45 km altitude. The last result from Venus Express was a 3-dimensional picture of the Venusian winds over an entire hemisphere. Beginning in September, data collected by Venus Express were made publicly available. The Venus Express Planetary Archive, now accessible online, is hosted at ESA's European Space Astronomy Centre in Spain (see below). The mission was designed to end in October 2007, but was then extended until at least May 2009. The spacecraft has sufficient propellant on board to last until 2013.

ESA signed a $515-million contract to Astrium GmbH (Germany) on 18 January for construction of the BepiColombo Mercury-orbiting satellite, to be launched in 2013 along with a sister spacecraft being developed by Japan. The total ESA budget for the mission is $975 million, including the Mercury Planet Orbiter spacecraft, launch and operations costs, and a contingency reserve. Japan is investing $147 million in the smaller Mercury Magnetospheric Orbiter, which will ride to Mercury on the ESA spacecraft before separating into its own Mercury orbit. Including the 11 instruments being built and financed by European laboratories, the total investment in the mission is about $1.42 billion.

A number of U.S. space-community leaders, meeting at Stanford University (USA) on 12-13 February, assembled an alternative programme to President Bush's Vision of Space Exploration (see prior reports). Their proposal featured deletion of the Vision's lunar base in favor of human missions to asteroids, greater emphasis on Earth environmental science, earlier human missions to Mars via landings on the Martian moons Deimos and Phobos, and human missions to place and service telescopes at the Earth-Sun Lagrange libration points. The all-invited meeting of scientists, engineers, and astronauts was cosponsored by Stanford University and The Planetary Society.

Plans by NASA and ESA to formulate a $3-billion outer-planet flagship mission were discussed at several workshops this spring: one in Vienna the week of 14 April, to refine concepts for a Saturn/Titan mission; one in Rome the week of 21 April to examine Jupiter/Europa concepts; reviews of both mission classes at NASA's Jet Propulsion Laboratory (JPL) the week of 8 May and Los Angeles the week of 12 May; and a final workshop to discuss major instrumentation options at JPL the week of 3 June. Final mission definition for selection of a mission was expected to culminate in November. NASA expects to commit $2 billion, with ESA and possibly Japan and Russia contributing $1 billion.

The Europa/Jupiter System Mission (EJSM) would use one orbiter to search Europa for signs of life in the oceans believed to underlie the moon's icy crust, while one or two other orbiters would survey Jupiter and its other moons. ESA's name for this mission is LaPlace. The Titan/Saturn System Mission (TSSM) would image Titan's lakes, streams, and other terrain, using a "hot air" balloon that would float in Titan's atmosphere for two years and would also deploy two or three surface or submarine probes with two-day lifetimes in areas of special interest; e.g., the subsurface of a methane lake. A companion TSSM orbiter would circle Saturn and focus on Enceladus to study its geysers (see above) in greater detail. Both missions would be launched in 2016 and would reach their target planets in 2023.

VI. TECHNOLOGY ADVANCEMENT

VI.1. Propulsion

VI.1.1. Earth to Orbit

Solid-Propellant Rockets

During testing in November 2007 of NASA's five-segment first-stage Ares-1 solid-propellant rocket motor, combustion instability was noted shortly before burnout of the motor. Exhaustive analysis of the resulting resonant thrust oscillation and vibration was conducted to determine how to mitigate these effects by bounding both the forcing function and the axial oscillation it produces. Initial estimates of that longitudinal vibration acceleration were 4.3 g rms (root-mean-square) at the Orion command module, well above the 0.6 g rms limit specified for the Orion crewmembers.

The team set up to deal with this potential problem had until March to come up with a solution, in order to accommodate the late-summer Ares-1 Preliminary Design Review schedule (see above). On 24 March NASA announced that the team's intensive study had concluded that the problem was far less severe than was indicated by the initial assessment projections, but that further analysis and extensive diagnostic instrumentation of engine ground tests and the similar space shuttle engines would nevertheless be pursued to help design any mitigation efforts that might be indicated. Several such prospects were identified that employed shock-damping spring mechanisms at various points on the first stage, which would not introduce significant weight penalties. However, tight budgets and seeking a better understanding of this and other technical issues motivated NASA on 15 August to postpone Orion's scheduled first piloted flight by a year, to September 2014.

On 20 August NASA selected a solution for further testing next year. Engineers will install 16 canisters in the bottom of the rocket with 45-kg weights attached to springs. Battery-powered motors will move the weights up and down to stop vibrations and a 17th shock absorber will be a ring of weights and springs near the middle of the

rocket. The system will be placed between the first and second stage of the Ares 1. It will reduce acceleration forces to 0.25 G, or about the same level that Mercury and Gemini astronauts were exposed to. Should all the actuators designed to move the 16 masses fail, the vibrations on the craft should only reach 1 G. However, the system will reduce the lift capacity of the Ares 1 rockets by 550 to 640 kg. Nevertheless, NASA claims that the rockets still will be powerful enough to fly missions to the space station and Moon.

On 1 May Alliant Techsystems (ATK) successfully test-fired the oldest 4-segment Shuttle solid-propellant booster ever fired (7 years old) at ATK's test site in Utah. Besides evaluating the performance of aging boosters, acoustic data from the 2-minute firing were used by NASA and ATK engineers to help overcome the potential thrust oscillation resonance of the 5-segment booster for the Ares-1 Orion vehicle (see above).

The P-80 first stage of ESA's new Vega launch vehicle, and also technology demonstrator, was successfully test-fired for the second and final time on 4 December 2007 at the Guiana Space Center. It delivered rated thrust of 190 tonnes for the full 111-second duration. Although 600 issues remain to be resolved, the P-80 stage was declared ready for its maiden flight next year. Vega's 23.6-tonne second-stage Zefiro-23 solid rocket motor passed its 75-second qualification firing on 27 March.

The third stage Z9 firing test, originally planned for the end of June, was delayed when the Z9 DM 2 was damaged in Sardinia during its transfer from the transport container to the erector. The test was conducted successfully on 24 October, with the engine consuming its 10.5 tonnes of solid propellant in 120 seconds and meeting all performance specifications. The second and final test firing of Z9, which will complete the Vega engine qualifications, is scheduled for February 2009.

In the frame of the ARTA Programme, as part of ESA's Ariane 5 and aimed at the continuing verification of the qualification status of the Ariane 5 launch system, the ARTA 4 MPS (Moteur Propergol Solide) test-firing took place on 5 April at the BEAP (Banc d'Essais des Accélérateurs à Poudre) in the Guiana Space Centre. The main objectives of the test were verification of the current production stability, efficiency of the pressure-oscillation reduction device, simplification of the manufacturing process, and the behavior of new products to solve current obsolescence.

Liquid-Propellant Rockets

The powerpack for NASA's J-2X engine which will power the Ares-1 upper stage was fired successfully for 36 seconds on 15 February, following a brief igniter test on 31 January. The 15 February firing was the first to run cryogenic propellant through the powerpack. The next test, a 450-second run, was delayed until 19 March due to damage to some ducting on the engine test stand. On that run the performance required for the 1.3-MN-thrust J-2X engine, a specific impulse of 448 seconds was demonstrated successfully. The last of nine hot-fire tests was run on 8 May; it lasted 401 seconds and included up-and-down throttling to generate data points for the J-2X upgrade.

On 25 September Pratt & Whitney Rocketdyne (PWR, USA) conducted a 40-second hot-fire test of the RS-68A upgrade to the main engine for the United Launch Alliance Delta IV space launch vehicle. It was the first in a 12-month series using three of the upgraded engines. The RS-68A boosts sea-level thrust on the three-engine Delta IV Heavy by more than 445 kN. Ultimately each RS-68A will deliver 3.12 MN of thrust, and will form the basis for the RS-68B slated for use on NASA's Ares V cargo rocket for Moon and Mars missions. Certification of the RS-68A is planned for mid-2010, and its first flight powering the Delta IV Heavy early in 2011.

On 18 January Space Exploration Technologies (Space-X, USA) completed the first two-engine firing of the first-stage Merlin-1C engine for the company's Falcon-9 launch vehicle (see above). No significant problems were encountered during the 14-second test of the gas-generator-cycle liquid oxygen-kerosene engine, which developed 800 kN thrust. In a subsequent 15-second test firing on 8 March, a three-engine cluster developed 1.2 MN thrust while consuming 477 kg/sec of propellant. Subsequent tests of five engines (on 3 June) and finally on 25 June the full nine-engine first-stage complement were conducted for the full first-stage burn time of 180 seconds, completing the qualification testing of the Merlin-1C. The nine-engine cluster was fired during successful full-propulsion-system testing on 31 July.

The Japanese H-IIB launcher was upgraded with 5.2-m diameter liquid oxygen and liquid hydrogen tanks and a cluster arrangement of two LE-7A engines to launch the H-II Transfer Vehicle (HTV). The key technology of the cluster propulsion system was successfully verified this year in a Battleship-tank Firing Test (BFT). The Japanese Aerospace Exploration Agency (JAXA) started a feasibility study on a next-generation 900-kN-class engine using the highly reliable, flight-proven open-expander-cycle technology. It is designated "LE-X" and is slated for use in the H-IIA family and a next-generation 21st-century launcher. As part of its "Propulsion for Exploration" programme, JAXA is also developing a liquid oxygen-liquid hydrogen engine with a wide throttling range for a reusable vertical ascent/vertical landing vehicle.

In the frame of the Future Launcher Preparatory Programme (FLPP), ESA and industry are conducting demonstration activities this year in order to meet the propulsion requirements for post-2020 launchers. These include high-thrust engines (gas-generator and staged-combustion engines) in the 1.5 – 3.0 MN thrust range. Subscale 40-kN liquid oxygen/liquid hydrogen demonstration tests were successfully completed this year with a coupled preburner-main combustion chamber arrangement representative of a future staged-combustion cycle system.

The first successful flight of a rocket engine powered by methane and liquid oxygen took place on 12 April, when a team of Garvey Spacecraft Corporation and California State University–Long Beach (both USA) launched their Prospector 14LM rocket to an altitude of 1,660 m. The Prospector vehicle and its 4.5-kN thrust rocket engine, developed and built by the University's students, were recovered intact by parachute after its 5-second burn.

Hybrid Rockets

SpaceDev (USA) announced in August 2008 that it had signed a multi-year contract with Scaled Composites to assist Scaled in the development of a production hybrid rocket motor for SpaceShipTwo (SS2, see above). The oxidizer is again expected to be nitrous oxide, despite the ground-test accident in July 2007 (see above and last year's report). Paraffin and asphalt based-solid fuels have been tested for the SS2 rocket motor. NASA's Glenn Research Center had published the results of research on paraffin hybrid motors in 2007.

In March 2008 SpaceDev was awarded a 6-month contract by NASA's Marshall Space Flight Center for research and development on its next-generation proprietary annular hybrid rocket motor design. The contract calls for development testing to validate performance parameters. This technology could offer significant improvements in hybrid-rocket performance and packaging efficiency that could broaden their overall applicability.

ESA conducted preliminary studies on hybrid propulsion this year. A project conducted by SNPE Matériaux Energetiques (France) and Avio (Italy) concluded that a technological breakthrough is needed to achieve major improvements in the solid fuel. Important mass gains are foreseen in lander or upper-stage applications with solid fuels that can provide a specific impulse greater than 350 seconds. This project is being supported via the ORPHEE programme funded by the European Union and led by SNPE. A parallel ESA study conducted by Thales Alenia Space (France and Italy) suggested that the most promising applications based on 'off-the-shelf' hybrid rocket technologies such as HTPB fuel used with nitrous oxide were a suborbital space vehicle and a small launcher capable of orbiting 100-kg payloads.

Air-Breathing Propulsion

The second flight test of the HyFly hypersonic dual-combustion ramjet engine failed on 16 January after reaching a speed of Mach 3.5 when its supersonic-combustion ramjet (scramjet) did not operate as expected. The test, which had been planned to demonstrate Mach 6 capability, ended in an ocean impact after only 58 seconds of flight. HyFly (see prior reports) is sponsored by the U.S. Defense Advanced Research Projects Agency (DARPA) and the U.S Office of Naval Research and is operated by Boeing and Aerojet (both USA). On 2 October DARPA awarded Boeing an $18.3-million contract to conduct a third Hyfly flight test.

The payload for the first flight of the U.S. – Australian HiFire hypersonic launcher programme (see prior reports) was completed in May and was shipped to Australia's Woomera test range, where it joined the launch rockets, delivered there on 29 April. The first flight will evaluate boundary-layer transition, aerodynamic heating, thermal expansion, and structural design data. That flight was originally scheduled for this spring but a decision to upgrade the system delayed it until late this year.

Testing of the Pratt&Whitney Rocketdyne (PWR, USA) dual-mode ramjet/scramjet engine began in the high-temperature wind-tunnel at NASA's Langley Research Center in August and was completed in September. The SJ61-2 flightweight engine, slated for use in September 2009 to power Boeing's $246-million X-51A Waverider hypersonic demonstrator (see last year's report), was tested at speeds of Mach 4.6 and Mach 5 over a range of dynamic pressures. It burns JP-7 hydrocarbon fuel, which is used to cool the engine prior to injection. Goal of the 2009 X-51A flight is for it to operate under scramjet power for 5-6 minutes after its release from a B-52 carrier aircraft operating out of Edwards Air Force Base, accelerating from Mach 4.7-4.8 to Mach 6.0-6.1. Its ultimate goal is Mach 7. The project is cosponsored by the U.S. Air Force Research Laboratory (AFRL) and the U.S. Defense Advanced Research Projects Agency (DARPA), with NASA contributing the wind-tunnel testing. DARPA had planned a follow-on flight demonstrator, Blackswift, which was to have taken off from a runway in 2012, accelerated to Mach 6, maneuvered, and then landed on the runway. However, the agency canceled Blackswift in October.

Advanced Propulsion Concepts

The first phase of the European Commission's (EC's) Long-Term Advanced Propulsion Concepts and Technologies (LAPCAT) programme was completed in April. Partly funded by the EC's Sixth Framework research programme, ESA researchers and their industry partners examined the core technical challenges to develop hydrogen-fueled Mach-5 and Mach-8 hypersonic transport aircraft. The four-year-long second phase of LAPCAT, with the EC contributing about $12 million toward a budget of $16 million, began on 16 October. Although LAPCAT's goal is a hypersonic aircraft that can fly from Brussels to Sydney in 2 – 4 hours, much of the propulsion technology has been developed for air-breathing orbital launchers and spaceplanes.

LAPCAT-I examined turbine-based and rocket-based combined-cycle engines burning kerosene or hydrogen, but LAPCAT-II is focusing on a hydrogen-burning engine called Scimitar that can accelerate from takeoff to Mach 5. Scimitar is derived from Reaction Engines' (UK) rocket-based Sabre engine concept that powers Reaction Engines' Skylon, a remote-piloted reusable spaceplane currently in the proof-of-concept phase, that is planned to carry a 12-tonne payload to Earth orbit in about ten years. A 3-year ESA study complementary to LAPCAT that began in 2006, the Aerodynamic and Thermal Load Interactions with Lightweight Advanced Materials for High-Speed Flight (Atllas), is focused on research into high-temperature materials for both the external structure and critical propulsion components. It involves a consortium of 13 partners from European industry, research institutions and universities.

Other European hypersonic research projects include the German Aerospace Center's (DLR's) Mach-11 Sharp Edge Flight Experiment (Shefex-II), scheduled to begin flight-testing at Norway's Andoya Rocket Range in March 2010; the Italian aerospace research center's (CIRA's) Pollux hypersonic testbed scheduled for its second flight test late this year (the first flight test, in February 2007, was discussed in last year's report); and the UK's Mach-6 Sustained Hypersonic Flight Experiment (Shyfe). Shyfe's

first flight test, planned for Australia's Woomera test range in August 2009, was to fly a 30-kg test vehicle at Mach 6 at an altitude of 32 km. However, the UK Defense Ministry, which was the project's sponsor, decided late in August not to pursue the flight test phase of Shyfe.

In other hypersonic propulsion research, the Russian Academy of Science is testing the application of magnetohydrodynamic plasma generators to control and reduce the drag of Mach-5 ramjets and scramjets (supersonic-combustion ramjets), and both China and Japan are involved in testing hypersonic propulsion technologies at Mach 6 and Mach 5 respectively. Joint U.S. – Australian flight testing of hypersonic research vehicles was discussed above and in prior reports.

VI.1.2. Orbit Transfer and In-space Operations

Upper-Stage Liquid Rockets

Pratt & Whitney Rocketdyne (PWR, USA) received in March a one-year extension of its December 2005 contract with NASA for a Common Extensible Cryogenic Engine (CECE), a descent engine for the future lunar lander. The extension's goal is to improve the stability of the modified RL-10 engine at low thrust levels. Recent testing by PWR in a vacuum chamber at a simulated altitude of 30 km demonstrated its repeatable throttleability from 100% of its 61-kN thrust down to 9.5%. The contract extension, which comes under the NASA Propulsion and Cryogenics Advanced Development (PCAD) project, part of NASA's Exploration Technology Development Program, calls for the design, manufacture and testing of a new injector aimed at eliminating the observed combustion instability at low thrust levels.

On 2 September PWR also completed hot-fire testing of liquid methane fuel in the storable-propellant RS-18 engine that had been last used 36 years ago to lift Apollo astronauts off the Moon. The engine, modified by PWR for NASA's current Constellation programme, demonstrated ignition under a wide range of conditions (including vacuum) and rapid startup and shutdown. The tests, conducted at the White Sands Missile Range, also measured specific impulse, chamber pressure, and combustion efficiency and stability.

Under the same NASA leadership, on 8 April Aerojet (USA) announced the award of a $6.9-million contract to mature a methane-fueled rocket engine that could be used to lift the future Altair lunar lander off the Moon. Aerojet will complete the evaluation of a 25-kN thrust pressure-fed engine assembly during the 21-month contract period. The company completed a test program for a 45-N liquid oxygen-liquid methane Reaction Control Engine (RCE) with testing at altitude conditions in NASA's White Sands Test Facility. More than 2,400 firings were conducted to evaluate steady-state and pulse performance over a wide mixture-ratio range. PCAD subsequently awarded Aerojet a contract to perform liquid oxygen-methane lunar-ascent main-engine technology development to reduce engine development risks. Project goals include high vacuum specific impulse, rapid start and multiple restart capability.

Aerojet also completed hot-fire testing of the 700-N thrust 104G monopropellant engine for the Orion crew exploration vehicle on 4 September. The vehicle will use 12 of these engines, which date back to NASA's Voyager and Magellan missions. The testing involved 87 engine starts, 2,118 engine pulses, and consumed over 180 kg of propellant.

On 2 September South Korean company Challenge & Space (C&S) announced the completion of the initial test phase of its 98-kN thrust Chase 10 engine, which they claim is the first methane-liquid oxygen regeneratively cooled engine to use a turbopump-fed design. C&S also announced the development of a 25-kN pressure-fed methane-fueled engine and a much larger (1.1-MN thrust) engine designated CH250.

In the frame of the ESA FLPP program, the VINCI expander engine was successfully test-fired during a new campaign from March to June 2008, with 4 test runs totaling 1327 sec. The tests confirmed the engine's suitability via a single-run duration of 565 sec; close to the targeted operational flight duration of 700 sec. Analyses subsequently confirmed that there is no limitation on operation at the full flight duration. A total of 4670 seconds of hot-fire tests on four different hardware configurations, including two refurbished engines, have been performed to date.

On 15 November 2007 the Indian Space Research Organization (ISRO) conducted a successful ground test of the new indigenous cryogenic upper-stage engine for the Geostationary Satellite Launch Vehicle (GSLV). The engine, which will replace the Russian engine used on prior GSLV launches, develops 69.5 kN of thrust. It will boost the GSLV's payload capability to 2.3 tonnes.

Solar Thermal Space Propulsion

On 27 May the U.S. Defense Advanced Research Projects Agency (DARPA) announced its support of two projects to develop and demonstrate solar thermal space propulsion systems suitable for very small satellites (e.g., 15 kg). SpaceDev and Pratt&Whitney Rocketdyne had received DARPA contracts last year of $3.7 million and $4.9 million respectively, under the High Delta-V Experiment satellite project. Both teams employ ammonia propellant heated directly by solar energy and expanded through a nozzle. SpaceDev's team includes General Atomics and BAE Systems; and Pratt&Whitney Rocketdyne is working with Boeing.

Electric Propulsion

The ion propulsion system for ESA's Goce spacecraft (see above) achieves the delicate control required by the mission via an unprecedented thrust range of 1 - 20 mN, ultra-precise thrust control (+/- 12 μN), and a rapid thrust response rate (> 2.5 mN/sec). It is designed for continuous cyclic operation with a total impulse up to 3 MN-seconds and more than 5500 on/off cycles. Developing the control software and algorithms to cycle, and to achieve the thrust response over the full operating range, presented a unique

system technical challenge. Others included accurate thrust alignment without a pointing mechanism and eliminating unwanted environmental effects such as magnetic torques.

The ion propulsion system for NASA's Dawn asteroid explorer, launched on 27 September 2007 (see last year's report), had successfully completed 6000 hours of operation as of 30 September, consuming 67 kg of its 425.2 kg propellant load. In October the spacecraft was 1.7 AU from the sun and had completed the first cruise phase of its mission. It has now begun the Mars Gravity Assist phase.

On 1 October the European Commission funded HiPER (High Power Electric Propulsion: A Roadmap for the Future). HiPER is a 3-year collaborative research programme led by Alta SpA (Italy) with 20 partners from 6 EU countries. With a total budget of $8.5 million, HiPER aims at consolidating technological and programmatic issues for future European space transportation needs, with activities ranging from the improvement of electric propulsion technologies (Hall-effect, gridded ion, and magnetoplasmadynamic [MPD] thrusters) to the development of the related power generation systems (advanced solar and nuclear power sources).

VI.2. Power

On 12 September a beamed-power experiment was conducted to demonstrate the feasibility of power transmission from a space solar power satellite through the atmosphere to Earth. The $1-million demonstration transmitted 20 watts of power 148 km between two islands in Hawaii (USA), which is claimed to simulate the full traverse of the atmosphere from a space-based solar power system to the Earth's surface. Each of the nine solar panels used in the experiment was capable of generating and delivering 20 W, but power levels were scaled back to 2 W each to comply with U.S. Federal Aviation Administration regulations. The test used a microwave frequency of 2.45 GHz, the value used in most prior system studies. The 4-month project was financed by the Discovery Channel, which broadcast a television programme about the results. The first demonstration of beamed power transmission through the atmosphere was conducted by NASA's Jet Propulsion Laboratory in 1975 over a distance of about 1.6 km.

On 22 October the U.S. Air Force Academy's Eisenhower Center for Space and Defense Studies announced plans to begin a project in December to build two small satellites that will test the space solar concept. Project "One Lightbulb" involves building two satellites concurrently to beam enough power between low Earth orbit and the Earth's surface to illuminate one 0.1W light-emitting diode (LED). One of the spacecraft, designated the "light" satellite mission, will receive power from a ground-based laser to light the LED; the other, designated the "heavy" satellite mission, will collect power in space and beam it via laser to a receiving station on Earth to light the LED. Each satellite will weigh less than 182 kg, and both are planned for launch in 2010.

NASA' Jet Propulsion Laboratory and Alliant Techsystems (ATK, USA) deployed a circular flexible solar array in a ground-based laboratory on 9 October. The 5.5-m diameter Ultraflex solar array development was funded under NASA's "New

Millennium Programme Space Technology 8" validation project. The technologies for the Ultraflex array, which weighs about half as much as conventional rigid-panel solar arrays, are being employed in the Orion spacecraft being developed for NASA's new space exploration programme (see above), whose array will be 5.84 m in diameter. The deployment test also verified the array's ability to meet the 2.7-g acceleration that would be imposed by a Moon departure. A smaller-scale circular array of similar design has operated successfully on the Phoenix spacecraft now on Mars.

VI.3. Spacecraft Design, Technology, and Development

The U.S. Defense Advanced Research Projects Agency (DARPA) selected Boeing, Lockheed Martin and Northrop-Grumman on 6 March to compete for the first phase of the agency's Future, Fast, Flexible, Fractionated, Free-Flying Spacecraft United by Information Exchange (System F-6), aimed at demonstrating the use of a team of small spacecraft to do the work of a single bigger, more expensive and less capable satellite. The agency had previously identified Orbital Sciences Corporation (OSC) as a competitor early in February. The System F-6 goal is that each 'fractioned' module will be able to contribute a unique capability to the rest of the network, such as computing, ground communications or payload functionality. The ultimate goal of the programme is to launch a fractionated spacecraft system and demonstrate it in orbit in approximately four years. The programme is budgeted at $37.3 million for Fiscal Year 2009; the one-year contracts allotted $13.6 million to OSC, $10.6 million to Boeing, $5.7 million to Lockheed Martin and $3.3 million to Northrop Grumman.

On 16 April the U.S. Air Force launched its 400-kg experimental Communication/Navigation Outage Forecasting System (C/NOFS) satellite aboard an Orbital Sciences Pegasus rocket from an L-1011 carrier aircraft based on Kwajalein Atoll in the Marshall Islands. Built and designed by General Dynamics for the USAF Space and Missile Center and the Air Force Research Laboratory, the satellite was successfully placed in its planned 285-km x 535-km elliptical orbit. Its mission is to predict communication outages caused by ionospheric scintillation.

Com Dev International Ltd. (Canada) announced on 17 June the initiation of a $7-million programme to develop with its own funds a micro-satellite platform weighing less than 150 kg to carry surveillance, environmental monitoring, science and communications payloads. The bus design meets micro-satellite specifications set by the Canadian Space Agency. On 23 June the company received an $8.6-million contract from the Canadian government to develop and build the Maritime Monitoring and Messaging MicroSatellite (M3MSat). Planned for launch in 2010, the technology-demonstration spacecraft will carry an Automatic Identification System (AIS) for ship identification and a low-data-rate communications payload for use by Canada's Defence and Space agencies as well as by commercial customers. It will be built on the Com Dev micro-satellite bus.

VI.4. Materials and Structures

On 18 February NASA's Glenn Research Center signed a Space Act Agreement with Improx Technology Corporation (USA) to develop silicon-carbide positioning sensors for use in high-temperature environments such as turbine-engine controls, spacecraft and engine components. Silicon carbide sensors can operate at temperatures up to 600 C, *vs* conventional silicon-based sensors' upper limit of about 350 C. The capability to embed sensors without having to cool them could be of significant benefit to many applications.

The Italian aerospace research center (CIRA) conducted plasma wind-tunnel tests in June and September on wing-box structures using advanced materials, for use on future hypersonic reusable spaceplanes and hypersonic aircraft. Sponsored by the Italian Space Agency, the full-scale wingbox elements tested were built by Thales Alenia Space (Italy). The carbon-carbon panels had a maximum thickness of 12 cm, with internal structures made of tungsten with ceramic coatings. They were designed for quick and easy assembly, disassembly and maintenance. Their metallic leading edge employed active fluid cooling, which kept the temperature below 100 C when heated by a thermal flux of 410 kW/sq. m during the first 15-minute test. Maximum temperature reached by the carbon-carbon panels was about 800 C. The September tests utilized a ceramic leading edge, which reached a temperature of 1500 C. The tests were applicable to Italy's robot FTB-X space vehicle.

VI.5. Information Technology

On 11 March the German TerraSAR-X radar Earth observation satellite (launched in April 2007) and the U.S. Missile Defense Agency's Near-Field Infrared Experiment (NFIRE; launched in June 2007), then 5,000 km apart in low Earth orbit, exchanged data by laser beams at a rate of 5.5 GB/sec. Subsequent tests were run successfully at separation distances from 2,000 to 8,000 km, including some transmissions through Earth's upper atmosphere. It took an average of only 25 seconds for the terminals to lock on to each other and begin two-way transmissions, which lasted as long as the satellites were within line-of-sight of each other, typically about 20 minutes. The bit error rate was less than one in a billion. The laser terminals, which weigh less than 30 kg, draw less than 130 W, and are qualified for speeds up to 16 GB/second, were built by Tesat-Spacecom (Germany). Tesat is building similar laser terminals for Germany's future TanDem-X radar Earth observation spacecraft and the Alphasat communications satellite (see above), and is seeking ESA approval to place laser terminals on several of ESA's future Earth observation satellites.

BAE Systems (USA) began delivering a new version of its radiation-hardened computer chip this year. The new 16-MB static random access memory (SRAM) chip is lighter, smaller, and four times more powerful than prior models, and can be stacked in multi-chip modules to provide 32-MB, 64-MB, and 80-MB radhard devices. Used in BAE Systems' upgraded RAD750 computer, which was space-qualified this year, the new chip provides the computer with a processing speed of 400 million instructions per

second (mips), as compared with the previous version's 250 mips, and a follow-on version will offer 500 mips. The RAD750 was flown on NASA's GLAST mission launched in June (see above), and is being installed in the Global Positioning System III (GPS-III) satellites, the Mars Science Laboratory (MSL), the Lunar Reconnaissance Orbiter (LRO), and the Lunar Crater Observation and Sensing Satellite (LCROSS).

Early in October Mobile Satellite Ventures (MSV, USA) were issued three patents on hybrid satellite and ground-based communication systems, and expected to receive three more in November. The company has applied for a total of about 100 patents, all based on MSV's Ancillary Terrestrial Component (ATC) concept of combining satellite signals with signals from terrestrial repeaters. MSV was granted the first license for such systems by the U.S. Federal Communications Commission (FCC) in 2003. Some of the patent applications are for hybrid communications between rovers – and eventually humans – on the Moon and Mars that can talk to each other and to Earth-orbiting satellites.

VI.6. Space Research Facilities

On 2 January NASA signed a $4.7-million indefinite-quantity, indefinite-delivery contract with Zero Gravity Corporation (USA) for simulated microgravity flights aboard the company's Boeing 727 G-Force One aircraft. The contract covers up to 80 flights, with a minimum commitment by NASA of four flights at a price of $300,000. It also includes four one-year options for a total potential value of $25.4 million. NASA also plans to continue flights aboard the agency's own C-9 aircraft, which operates out of NASA's Johnson Space Center in Houston, Texas. The first flights under the contract were conducted from Ellington Field in Texas on 28 August, 9 September, and 10 September. Five companies in NASA's Innovative Partnership Programme also flew experiments during these flights. Two additional flights had been scheduled, but were cancelled due to the incipient threat of Hurricane Ike.

Two Texus sounding rocket flights were conducted from Sweden's Esrange Space Center on 31 January and 7 February. Texus 44, the first Texus to use a new parachute recovery system, carried ESA metal alloy and biology experiments. Texus 45 contained fluid physics and biology experiments for the German aerospace center DLR. A third flight, on 21 February, carried three more DLR microgravity experiments, one to study the incidence of motion sickness among a flock of 72 small cichlid fish; the other two in hydrodynamics, fluid dynamics, and heat transfer, seeking improvements in industrial spray-cooling methods.

On 15 May the Maser-II mission launched four ESA microgravity experiments in fluid physics and metallurgy from Sweden's Esrange Space Center to an altitude of 252 km, providing 6-1/2 minutes of microgravity conditions. The two-stage rocket was based on Brazil's VSB-30 first stage.

ESA inaugurated the European Space Astronomy Centre (ESAC) near Madrid, Spain, on 6 February. ESAC is in charge of operations for ESA's astrophysics and solar-

system missions, including the current XMM-Newton, Integral, Mars Express, Venus Express, Rosetta, and Akari observatories and the forthcoming Herschel-Planck, Gaia, Lisa Pathfinder, James Webb Space Telescope, and BepiColombo Mercury missions. Then on 1 August ESA approved an engineering facility in the U.K. to specialize in robotic exploration, climate change, telecommunications, and other applications-oriented activities. Approval by the ESA ministerial summit in November will depend on a U.K. commitment to increase space expenditures.

On 21 January China announced plans for a commercial satellite research city in Xi'an. The multi-billion-dollar, 23-square-km National Civil Aerospace Industrial Base will focus on developing satellites, new materials, energies, intelligence technologies, and other civil-application technologies, with an expected annual revenue of $2.8 billion by 2012.

VI.7. Environmental Effects of Space Flight

VI.7.1. Orbital Debris

On 20 February a missile was fired from a U.S. Navy ship in the Pacific Ocean equipped with the Aegis missile-defense targeting system, impacting and destroying a failed U.S. military reconnaissance satellite that had been expected to undergo an uncontrolled reentry into the atmosphere early in March. The U.S. rationale for conducting the operation was that the 2.3-tonne satellite, launched in December 2006, was equipped with a propellant tank containing over 400 kg of frozen, highly toxic hydrazine, which could survive the reentry intact and therefore pose a danger to people on Earth if it landed in a populated area. The impact of the Standard Missile 3's non-explosive kinetic-kill warhead was subsequently determined to have shattered the tank and dispersed the propellant harmlessly in the upper atmosphere. Because the destroyed satellite was on an imminent reentry trajectory, all the debris from the impact reentered the atmosphere and burned up shortly after the event, leaving no potentially destructive pieces of debris in orbit.

A Russian Electronic Ocean Reconnaissance Satellite (Eorsat) exploded three times between March and June, spewing about 500 pieces of debris into a 390 – 415-km orbit, slightly higher than the 354-km orbit of the International Space Station (ISS). The satellite, also called Kosmos-2421, was the 50th and last of a series launched by Russia and the Soviet Union beginning in 1974. 22 of the satellites in this series have exploded at least once. Debris from the explosion could have been responsible for impacts on a handrail and a tool that occurred during a March ISS spacewalk and was also deemed a sufficient risk to the station (a 1-in-27-chance of collision) to warrant an evasive maneuver on 27 August using the thrusters of the Jules Verne ATV that was still attached to the ISS (see above).

VI.7.2. Near Earth Objects

The Planetary Society (USA) announced the winners of the Apophis Mission Design Competition on 26 February. The specified mission goal was to tag and track the Apophis asteroid. If Apophis reaches a near-Earth trajectory that takes it to 30,400 km altitude in 2029, the gravitational field of the Earth will change its trajectory in such a way that in 2036 there will be high probability of collision with the Earth. First prize of $25,000 was awarded to a team led by Spaceworks Engineering (USA) for a satellite called Foresight, carrying a laser altimeter, a camera, and an X-band tracking system, to be launched by an Orbital Sciences Corporation Minotaur-4 rocket in May 2012. It would then orbit Apophis for a month and then fly in formation with the asteroid at a distance of 2 km. Foresight would weigh 100 kg, and the estimated mission cost would be $137 million. SpaceDev (USA) was the second member of the winning team. The second and third place teams, each of whose mission designs would have an estimated price tag over $380 million and a 500-kg mass, were Deimos Space SI (Spain) and EADS Astrium (UK).

To prevent the Apophis asteroid from reaching the critical near-Earth trajectory, Yuzhnoye SDO (Ukraine) has proposed to deflect it with a kinetic module. Research studies conducted by Yuzhnoye demonstrated such a possibility, using a modified Sea Launch Zenit-3SL rocket

On 5 May Canada announced the forthcoming launch in 2009 of the 60-kg Near Earth Object Surveillance Satellite (NEOSSat), to spot potentially dangerous asteroids near Earth's orbit. Claimed to be the first space mission devoted to hunting asteroids, NEOSSat will use a 15-cm telescope, offering a clearer view of some areas of space than ground-based telescopes, particularly with regard to objects that stay close to the Sun in the sky.

Iowa State University (USA) established an Asteroid Deflection Research Center on 27 May to offer scientists from around the world a place to develop near-Earth object deflection technologies. These technologies, which include orbital guidance, navigation, and control, could have other applications in future advanced space vehicles as well.

VI.8. Life Sciences

On 2 October the Astrobiology Institute at NASA’s Ames Research Center awarded $70 million in five-year astrobiology research grants to ten U.S. interdisciplinary research teams to study the origins, evolution, distribution and future of life in the Universe. The ten new teams come from the Ames Research Center, Arizona State University, Carnegie Institution, Georgia Institute of Technology, NASA’s Goddard Space Flight Center, NASA’s Jet Propulsion Laboratory (two teams), Pennsylvania State University, Rensselaer Polytechnic Institute and the University of Hawaii. They also became members of the Astrobiology Institute, joining the four continuing members: Massachusetts Institute of Technology, Montana State University, University of Washington and University of Wisconsin.

VII. EDUCATION

VII.1. Teaching Programmes

A nine-day China Youth Space Academy programme was held in the Mars Space Flight facility at Arizona State University (USA), beginning on 27 January. 16 Chinese and 8 U.S. high-school students were intermingled and divided into two groups, each of which selected a question concerning Mars geology and answered it using images and other data from NASA's Mars Odyssey orbiter. The Chinese students were selected from over 12,000 applicants who registered to take an online test on the solar system and space exploration. Forty finalists then competed in designing a human outpost on Mars. Both tests were designed by staff at Arizona State University's School of Earth and Space Exploration.

A Space Experiment Competition in the UK was announced on 17 January for students aged 14 – 18. Five-page proposals were submitted on 28 February for experiments to weigh 1 kg or less, have a volume of 10 cubic cm or less, and consume an average of no more than 1 W of power on orbit. Six finalists were selected in March to prepare and submit more detailed proposals, with the help of judges. The winner, announced at the International Astronautical Congress in Glasgow in September, was granted a $195,000 budget to work on developing the experiment with engineers at Surrey Satellite Technology Ltd., one of the competition's sponsors. The other sponsor was the British National Space Centre.

The finals of the annual Team America Rocketry Challenge competition were held on 17 May. Sponsored by the Aerospace Industries Association (AIA) and the National Association of Rocketry, the contest involved 7,000 middle-school and high-school students on 643 teams from all over the U.S. Goal of the 100 finalists was to launch two raw eggs to an altitude of 228 m and return them unbroken in exactly 45 seconds. The winning team, from Enloe High School in Raleigh, North Carolina, won the competition and was sponsored by the Raytheon Company for a trip to the UK's Farnborough Air Show in July, where they competed with the winners of a similar contest in the UK. Lockheed Martin also awarded $5,000 scholarships to each of the top three teams, and $1,000 was given to each of the top ten schools by the U.S. Department of Defense, the American Association of Physics Teachers, and 34 member companies of AIA.

On 2 July NASA announced a new programme called the American Student Moon Orbiter, which will pair up college students and NASA mentors to build a small 180-kg satellite that would be placed in a highly elliptical "Frozen Lunar Orbit," carrying student-designed and -developed scientific instruments to perform lunar exploration activities of their choice. Its intent is for teams to learn directly from NASA mentors as they design, build and launch a spacecraft and its payload. NASA's Ames Research Center and Glenn Research Center are leading the initiative.

On 22 September NASA and the U.S. Air Force Research Laboratory announced a competition for university and industry partners to establish three national hypersonic science centers for the support of university-level basic science or engineering research to improve the understanding of flight at hypersonic speed. The agencies have set aside up to $30 million over five years to fund the centers, meaning a maximum grant of about $2 million a year. Papers are being solicited in air-breathing propulsion, materials and structures, and boundary layer control.

The city of Sheboygan, Wisconsin (USA) held a Pre-Launch Preview Education Week for its new spaceport early in May to build enthusiasm for the $21 million Great Lakes Aerospace, Science, and Education Center. Tied to the larger Rockets for Schools program, the event included space artifacts and hands-on demonstrations and presentations on the technology behind robots and spacesuits, the principles of aerodynamics and stability and the effects of microgravity on human physiology. The complex will transform a 66-year-old armory into an interactive education center that will include a mission control center, an IMAX theater, a planetarium, a NASA-affiliated museum, and exhibits allowing visitors to experience zero gravity, take a spacewalk and fly with a jet pack. Two former astronauts, Mark Lee and Winston Scott, attended the event.

During the summer Lockheed Martin (USA) hosted 20 elementary, middle and high school teachers as part of a fellowship programme to build a workforce with strong mathematicss, science and technology skills. The eight-week programme paired teachers with industry mentors and augmented their science and math skills by solving real-world problems. The teachers were expected to use the experience to stimulate student interest in math and science. The fellowship focused on technical challenges associated with space-based programmes, including satellite telecommunications and other advanced technologies.

On 27 July Lockheed Martin also launched an online programme for students and teachers to learn about NASA's missions to the Moon and Mars. Named "Orion's Path," the programme is an interactive, web-based lesson that consists of 41 short installments addressing such topics as how the Moon was formed, spacesuits and the Moon's environment. The programme is aimed at middle-school students and is designed so that teachers can use it as part of their curriculum. It describes the Orion vehicle and the other space vehicles astronauts will use to get to the Moon.

On 3 September NASA created the Carl Sagan Postdoctoral Fellowship to encourage research on planets and the possibility of life beyond the Solar System. NASA’s third postdoctoral fellowship programme, the new award joins the agency’s Einstein Postdoctoral Fellowship in Physics of the Cosmos and the Hubble Postdoctoral Fellowship in Cosmic Origins. Applications for the Sagan fellowships began being received in September, and selections will be announced in February 2009.

200 students from France, Japan, the Netherlands, and Spain attended the annual Student Space Rendezvous in La Courtine, France during July and August, testing their

own designs of suborbital sounding rockets and stratospheric balloons carrying a variety of imaging and other sensors. Organized by the French Planete Sciences association and the French space agency CNES, the session included several space industry and military programme managers. It also featured continued work on the French multi-year European University and Scientific Student Research Project (Perseus), whose goal is to design a low-Earth-orbit nanosatellite weighing one to 50 kg by 2012 and then pursue the construction and launch of a flight model.

VIII. GLOBAL SPACE MARKET ISSUES AND OPPORTUNITIES

VIII.1. Government Programmes

On 30 November 2007 Russian president Vladimir Putin launched a new $60-billion programme to capture 10% of the global market for information technology and office equipment over the next 10 years. Space is identified as a high-priority element in that programme, with the Russian space agency to receive $12.5 billion through 2015. One project identified in the programme statement is a lunar landing by 2025. On 21 October, Mr. Putin, then Russia's Prime Minister, announced that Russia will consolidate its leasing role in the space industry over the next three years by earmarking more than $7.68 billion from the federal budget for developing the space industry from 2009 to 2011. He identified the development of satellite navigation systems as a priority area, also citing geological research from space, environmental control and natural resource monitoring. He said that all the necessary legislation is already in place, adding that a programme for using Russian space technology is needed immediately and should be in force by 2010. Deputy prime minister Sergei Ivanov said that Russia may decide next year to create a state corporation for the rocket and space industry to help create conditions for the stable economic development of the space industry, and that all relevant departments were working on the proposal.

On 30 September Verkhovna Rada (Parliament) of Ukraine adopted legislation approving a national space programme for 2008-2012. It is the fourth space programme since the country's independence and the third one having the status of law. It aims at providing development and efficient use of the space potential of Ukraine for solving urgent problems in state security, introduction of high technologies, and advancement of science and education. It foresees, among other things, the launch of two Earth observation satellites (Sich-2 in 2009 and Sich-2M in 2012) and one communications spacecraft (Lybid in 2011); sustainable production of Zenith, Cyclone and Dnepr launchers; development of prospective space rocket complexes (e.g., Mayak); and new-generation spacecraft. The total program budget is $540 million.

VIII.2. Commercial Enterprises

On 6 April the Space Foundation (USA) released a report claiming that space-derived revenue in 2007 was $251 billion, an 11-percent growth from 2006. Commercial satellite products and services accounted for 55 percent of the global space economic

activity, at $138.8 billion, a 20% increase over 2006; commercial space infrastructure was 14%, at $34.6 billion; and infrastructure-support industries generated $700 million. U.S. government spending accounted for 25% of the total market, at $62.6 billion; the other spacefaring governments of the world spent $14.7 billion, or 6%.

The Satellite Industry Association (SIA, USA) on 11 June issued its annual report on the satellite industry, claiming a 16% revenue growth in 2007 to a total of $123 billion. Satellite services accounted for $79.3 billion, of which satellite television revenue was $55.4 billion and satellite radio $2.1 billion; satellite manufacture garnered $11.6 billion, launch services $3.2 billion and ground equipment $34.3 billion.

On 7 January *Space News* (USA) announced that 19 geostationary-orbit commercial satellites were ordered in 2007, a decline of seven from 2006's 26 spacecraft. Orbital Sciences (USA) garnered five orders, Astrium Satellites (Europe) and Space Systems Loral each received four, Thales Alenia Space (France and Italy) two, and Boeing Satellite Systems (USA), Israel Aircraft Industries, and Lockheed Martin (USA) one each. In the launch service industry, Arianespace (France) booked 13 launch orders in 2007, International Launch Services (USA) garnered 15, Sea Launch (USA) received two orders, and China Aerospace Corporation one.

Space News also reported on 14 January that an estimate by ABI Research (USA) of the satellite navigation hardware market placed 2007 sales at $33 billion, a $6-billion increase over 2006, and projected a market growth to $54 billion by 2011. The sharp increase in growth was attributed to both falling prices and booming European and North American sales increases in Portable Navigation Devices (PNDs) and mobile telephones equipped with satellite navigation capability. The two largest PND manufacturers, Garmin International (USA) and TomTom NV (Netherlands), who together hold about half the world market, shipped record quantities of 2.7 million and 2.2 million units, respectively, in the last quarter of 2007.

Global sales of PNDs more than doubled in 2007 *vs* 2006, from 12 million units to over 24 million, and so did sales of mobile telephones equipped with satellite navigation, to 5.1 million units in 2007. ABI predicts 2011 sales will grow to over 100 million PNDs, 62 million satellite navigation-equipped mobile telephones, 14 million manufacturer-installed automobile systems, and 4 million after-market automobile systems. On 2 July IN-Stat (USA) reported an even larger growth in PMD sales worldwide, from 13.3 million in 2006 to 30.7 million in 2007, with 68 million units predicted to be sold in 2012.

The first market survey of the budding personal spaceflight industry was released on 31 May by the Tauri Group (USA). Revenues in 2007 were $268 million, of which $206 million came from hardware sales, development, and support services. About $39 million came from personal spaceflight services, including Russian Soyuz flights booked through Space Adventures (USA), and $24 million was generated by non-spaceflight activities. Revenues from cargo delivery services by commercial operators were not included. The 19 member companies of the Personal Spaceflight Federation employ

1,227 people and had obtained about $1.2 billion in investments through 2007, about 25% of which has been spent.

The United Nations International Telecommunications Union's World Radiocommunication Conference concluded on 16 November. The 2,600 international delegates rejected the application of the terrestrial wireless broadband industry for access to C-band spectra in the range 3.4 – 4.2 GHz, which would have caused major interference problems with satellite communications (see last year's report). The support of the African and South American delegates was instrumental in reaching that decision, which was also supported by the satellite industry delegates and opposed by those of all the European governments except Luxembourg, home to SES Global.

The results of field tests on the interference of terrestrial broadband WiFi signals with satellite C-band transmissions, reported on 3 March, confirmed that such interference would indeed prevent effective satellite C-band communications. The tests, conducted by the Satellite Users Interference Reduction Group (SUIRG), demonstrated that both ground-based and tower-mounted WiMax units located as far away as over 12 km from a satellite antenna degraded the satellite signals by a ten-thousandfold increase in bit-error rate. Calculations indicated that fixed-satellite-service antennas cannot coexist with WiMax systems unless they are 50 – 200 km apart, depending on local terrain and WiMax output levels.

On 13 November 2007 shareholders of both XM Satellite Radio Holdings and Sirius Satellite Radio approved their merger plan (see last year's report). On 24 March the U.S. Department of Justice approved the merger, which would make XM a wholly owned subsidiary of Sirius. Sirius and XM extended their merger agreement for two weeks on 30 April, awaiting U.S. Federal Communications Commission (FCC) approval (the agreement had been due to expire on 15 May). That approval was granted on 25 July, and the $3.9-billion merger was announced on 28 July.

Conditions on the merger specified by the FCC include a requirement to field interoperable receivers within nine months; a three-year subscription price cap, a fine of $20 million for deploying 111 unlicensed signal repeaters, and a mandate to either remove those repeaters or bring them into compliance. Sirius XM Radio has already agreed to this last condition and has agreed to release the necessary technical specifications for construction of dual-compatible receivers. A new "Best of Both" subscription package combining XM and Sirius programmes was made available for $16.99 per month on 6 October and dual-compatible radios went on sale in the U.S. that week.

The merged company is operating under the name Sirius XM Radio, with 18.5 million subscribers as of 29 July. According to a 1 August filing with the U.S. Securities and Exchange Commission (SEC), XM and Sirius had a combined net loss of $287 million on revenue of $578 million during the three-month period ending 31 March. Sirius XM Radio has estimated $425 million savings in 2009 alone as a consequence of efficiencies resulting from the merger. The company operates two satellite fleets, one

consisting of four satellites in geostationary orbit deployed by XM and one with three satellites in a highly elliptical orbit launched for Sirius. A spare for each fleet is currently under construction.

Worldspace (USA) filed for bankruptcy on 22 October in an attempt to regroup before beginning to provide digital audio radio services in Europe next year. The company has 171,000 subscribers, mostly through its wholly owned affiliate in India, which is not covered by the bankruptcy filing. As of the date of filing Worldspace had assets of $307 million and a debt of $2.1 billion.

On 22 August space insurance company Aon (USA) announced the purchase of reinsurance specialist Benfield Group (UK) for $1.6 billion in cash, merging two of the top four space-insurance brokers, Aon and International Space Brokers, which had been owned by the Benfield Group. Customers of the merged company include Intelsat, Inmarsat, Arabsat, SES, Telesat and GlobalStar.

Alliant Techsystems (ATK, USA) announced its purchase on 8 January of the information systems and geospatial information services business of MacDonald Dettwiler and Associates (MDA, Canada) for $1.33 billion. ATK planned to combine the MDA division with previously acquired Swales Aerospace (see last year's report) to create ATK Space Systems Group. The acquisition would have added over 1,900 employees and annual revenues of $500 million to ATK. The new group and ATK's existing Launch Systems group would have had a projected combined annual revenue of $2 billion, making ATK the fifth largest U.S. space company.

However, on 8 April the Canadian government rejected Alliant Techsystems' bid, stating that the transaction was not likely to be of net benefit to Canada, and giving Alliant 30 days to appeal. Although not stated in the rejection letter, Canada's apparent concern was that besides giving the U.S. government access to classified technologies that MDA previously could not sell outside Canada, they would lose control of the Radarsat-2 imagery satellite.

The biggest single space-insurance package ever signed was secured by Eutelsat Communications (France) on 24 April, when insurance broker Willis Inspace engineered a $2.5-billion policy covering seven launches and two options, with fixed premiums guaranteed for launches that take place through 2011. The first four launches, Hot Bird 9, W2M, Hot Bird 10, and W2A are all scheduled for launches by Ariane-5 in 2008 and 2009 at a premium of 6.5%. W7 will be orbited by Sea Launch, at a 7.5% premium; W3B by a Chinese Long March at 7.9%, and Ka-Sat, which is to be launched either by Sea Launch or an ILS Proton, would have a 10.3% premium that could be reduced to 8.5% if Proton enjoys seven straight successes.

On 7 February TerreStar Corporation (USA) received commitments from EchoStar Corporation, Harbinger Capital (both USA), and other investors for $300-million in financing for the startup mobile satellite services provider. EchoStar has committed $150 million, Harbinger $100 million, and the other investors $50 million.

$200 million was made available immediately, permitting TerreStar to complete development and launch of TerreStar-1, being built by Space Systems/Loral for launch by Arianespace between 1 December 2008 and 28 February 2009. The remaining $100 million is to be used to begin work on TerreStar-2, the backup satellite required by the U.S. Federal Communications Commission to be available within one year of commercial operations startup.

On 28 February Liberty Media (USA) completed its acquisition of 41% of DirecTV (USA), not a controlling interest. Liberty exchanged its 16.3% stake in News Corporation (USA) for the DirecTV stock, regional sports networks, and $431 million in cash in a deal that was first announced in December 2006.

Iridium Holdings LLC (USA) agreed on 22 September to merge with an affiliate of investment bank Greenhill & Co. (USA), providing Iridium with a $500 million cash infusion to help finance a new satellite system. As a result of the deal Iridium claims it will be debt-free and in a good position to replace its fleet of 66 satellites. The company currently lists more than 305,000 subscribers and offers complete coverage of the entire Earth, including oceans, airways and polar regions. It will retain its current management, but will be renamed Iridium Communications when the deal goes through.

SES Global (Luxembourg) announced on 5 September the merger of its New Skies (Netherlands) and Americom (USA) divisions into a single unit. The company's third division, Astra (which services Europe), will remain independent, but SES has also created SES Engineering, which will handle procurement for the entire group. As part of the merger, Americom may also restructure its IP-Prime service, which delivers over 200 television channels to local telephone networks and other operators for distribution to customers via high-speed DSL links.

EADS Astrium Satellites (UK) announced on 4 April that the University of Surrey (UK) had agreed to sell to Astrium its majority ownership in Surrey Satellite Technology Ltd (SSTL; UK), retaining only a symbolic 1% share, and that Astrium would also purchase the 10% share owned by Space Exploration Technologies (USA) and the 5% share owned by SSTL employees. Total value of the purchase was estimated at $90 million. The agreement, which still requires approval by British and European regulatory authorities, stipulates that SSTL will continue as an independent entity, even when bidding against Astrium.

SSTL then announced on 12 August, while awaiting approval of company's sale to Astrium, that it would establish a U.S. subsidiary in Denver Colorado, with offices in Washington and Los Angeles. Expecting to grow the U.S. subsidiary to 250 employees by 2011, SSTL cited the burgeoning U.S. small-satellite market as having the greatest growth potential, and noted that capitalizing on that market would be greatly facilitated by being able to avoid U.S. export control restrictions on foreign manufacturers. SSTL also cited collaboration with Space-X, a former part owner of SSTL and builder of low-cost launchers, as an element in aiding penetration of the U.S. small-satellite market.

Space Adventures (USA) purchased Zero Gravity Corporation (Zero-G, USA) on 1 January for an undisclosed price. Zero-G has carried over 5,000 customers on over 175 flights of its G-Force-1 aircraft, providing them with up to 20 periods of microgravity on each 90-minute flight. U.S. retailer Sharper Image has exclusive marketing rights for Zero-G flights, offering them on its website at a price of $3,675. Space Adventures is the contractor for space-tourism flights to the International Space Station aboard Russia's Soyuz vehicles.

Sierra Nevada Corporation (USA) announced on 20 October the purchase of SpaceDec. Inc. (USA) for $38 million. Sierra Nevada is combining SpaceDev with its Microsat Systems Division (USA), purchased in January, into a new space technology unit that will provide space vehicle systems, propulsion systems, and components to both government and commercial customers. Microsat had already obtained a contract from Orbcomm (USA) to build from 18 to 48 second-generation messaging satellites. SpaceDev's revenues for 2007 were $35 million.

On 12 May satellite Earth station builder Comtech Communications Group purchased its competitor, Radyne Corporation, for $224 million. The deal included small-satellite manufacturer AeroAstro, purchased by Radyne in August 2007 (see last year's report). Combined earnings of the merged companies during the past year were about $650 million. All three companies are based in the U.S.

On 29 May Khrunichev (Russia) announced its purchase of an additional 51% of the shares in International Launch Services (ILS, USA) from Space Transport Inc. (British Virgin Islands), owned by long-time ILS board of directors member Mario Lemme. Lemme had bought his ILS shares from Lockheed Martin (USA) in October 2006 (see prior reports). Both U.S. and Russian regulatory agencies had approved the sale.

Astrium Services (France) purchased 41% of Spot Image (France) from the French space agency CNES on 14 July, increasing Astrium's ownership to 81%. The $30-million purchase was concluded on 5 August. Although CNES retained an interest in Spot Image as a public concession, to intercede in the event of any proposed sale to a non-French entity, the transaction transformed Spot Image from a quasi-governmental organization into a fully industrial company. The company's revenue in 2007 increased 30% over that of 2006, reaching $149 million, mainly from products generated by Spot 5. However, Spot 5 was launched in May 2002 and has now exceeded its planned 5-year lifetime, so Astrium will have to consider financing Spot 6, which could be launched in 2012 at a cost of about $320 million. Astrium's Satellite Division had already begun the design of Spot 6, which will be built on the company's Astrobus 250 lightweight imaging satellite bus and will have a resolution of 2 m.

Saab (Sweden) sold its space business, including subsidiary Austrian Aerospace, to RUAG Holding (Switzerland) for $56.3 million. The sale, announced on 15 July, still requires approval from regulatory authorities. Saab Space employs 500 people and generated 2007 sales of $113 million; RUAG, a supplier to ESA, has 150 employees

engaged in space activities.

Spacecom (Israel) rejected a 22 January takeover bid by SES (Luxembourg) on 7 February, claiming that SES's valuation of Spacecom at $350 million including debt, and $160 million excluding the debt and including only assets targeted by SES, was not sufficient. Spacecom also rejected the SES bid because it included only two of the company's satellites, Amos-2, and Amos-3 (with their revenues and their orbital-slot license at 4 degrees west longitude). The SES bid excluded Amos-4, currently on order from Israel Aerospace Industries for delivery in 2012. Spacecom claimed that although the Israeli government was financing $265 million of Amos-4's $365-million cost, the revenue from both the government and commercial customers for services of the single remaining Spacecom satellite would be insufficient to ensure the company's future.

On 31 March Gilat Satellite Networks (Israel), a builder of satellite ground terminals with 2007 revenues of $283 million, announced its purchase by private investors Mivtach Shamir Holdings (Israel), The Gores Group (USA), DGB Investments, Inc. (USA) and several shareholders of the LR Group Ltd. The purchase price was $475 million.

ANNEX
The Space Economy in Figures

Space is often about science and exploration, but some activities have reached such a maturity that many applications are now fully pervasive in citizens' daily lives. Modern societies rely more than ever before on telecommunications, meteorology and navigation tools using satellite technologies. In that context, the concept of "space economy" is useful to flag and investigate the space sector and its derived impacts as a potential source of economic growth.

Defining the space economy

In collaboration with the space community, the OECD Forum on Space Economics has developed a working definition of the space economy to encompass the different dimensions of programmes, services and actors.

"*The space economy is the full range of activities and the use of resources that create and provide value and benefits to human beings in the course of exploring, understanding, managing and utilising space.*

Hence, it includes all public and private actors involved in developing, providing and using space-related products and services, ranging from research and development, the manufacture and use of space infrastructure (ground stations, launch vehicles and satellites) to space-enabled applications (navigation equipment, satellite phones, meteorological services etc.) and the scientific knowledge generated by such activities.

It follows that the Space Economy goes well beyond the space sector itself, since it also comprises the increasingly pervasive and continually changing impacts (both quantitative and qualitative) of space-derived products, services and knowledge on economy and society."

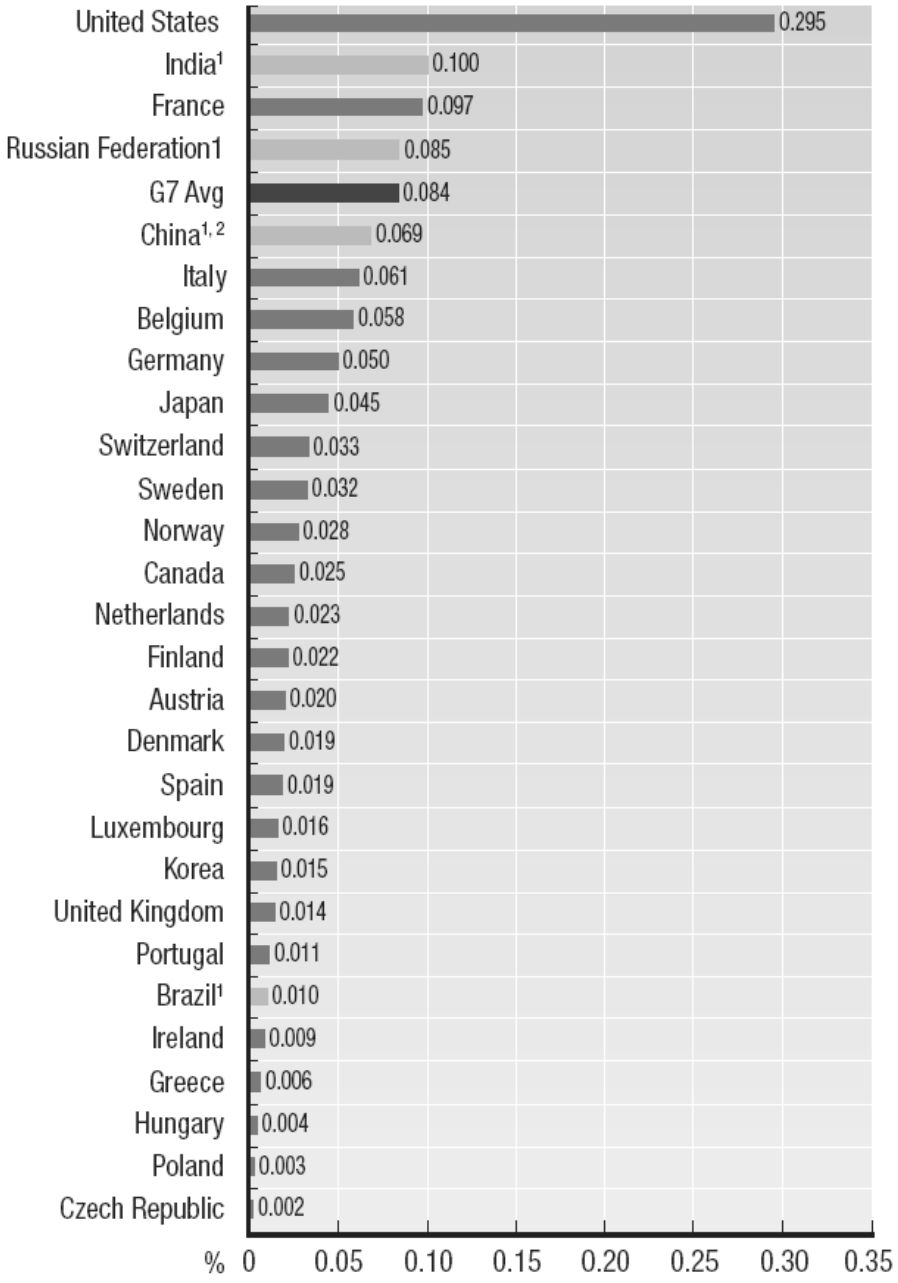
Estimating the space economy

Providing figures for the space economy is a complex exercise. However, the space economy shares some of the features of many other key new economic sectors, which can provide useful lessons learned (e.g. "information society", "security economy", "bioeconomy"). In order to provide a framework, the space economy can be divided into three main categories of indicators:

- The readiness factors (inputs) of the space economy consist mainly of the financial (e.g. budgets, capital stocks), R&D infrastructure and human resources that are employed in producing space-related hardware and the provision of relevant services (see Figure 1). For example, satellites are assets with strategic but also economic value. There were some 940 satellites operating in orbit in 2006, two-thirds of which for communication, with a replacement value of about USD 170-230 billion; the stock value of earth observation satellites launched in 2006 alone–considered to be a busy year–was at least USD 3.2 billion.
- The intensity factors (outputs) of the space economy describe the use that is made of space activities. Outputs may include products or services that are produced or provided in the realm of the space sector, including financial benefits (sales and trade revenues) and indications of future financial benefits (i.e. patents). Many useful estimates come from the private sector (see Figure 2).
- Finally, the impacts of the space economy, which can be sometimes more qualitative than quantitative, consist of the value-added created by space activities (e.g. productivity, cost avoidances). They are becoming more relevant and significant as space applications are deployed.

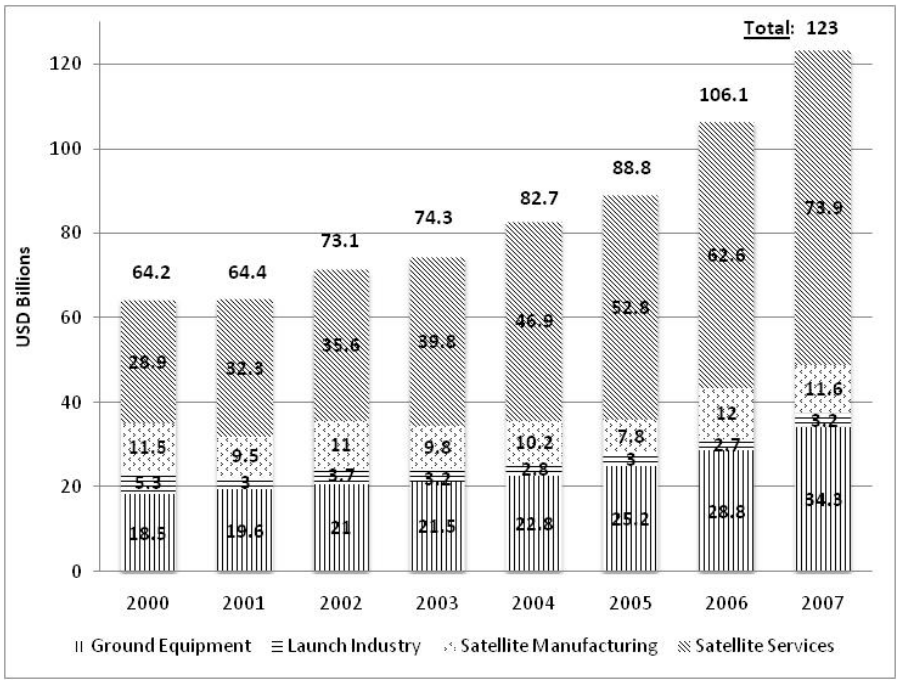
One key methodological aspect for both public and private data providers is the need to develop sound data series overtime, to allow better international comparability (i.e. taking into account inflation, changes in exchanges rates, purchase power parities), while making sure that users are informed about data caveats and changes in data series.

Figure 1. Public space budgets as a per cent of national GDP for selected OECD and non-OECD[1] countries (2005)



Notes: 1. Non-OECD countries are Brazil, Russia, India and China. 2. Chinese data based on unofficial estimates.
Source: OECD (2007), *The Space Economy at the Glance*. Data come from NASA, CSA, ESTP (Europe), JAXA, and other national sources.
GDP data: OECD (2007), *National Accounts of OECD Countries, Volume I – Main Aggregates.*

Figure 2. Partial Estimates of World Revenues Per Sector (2000-2007)



Source: Data aggregated from the US Satellite Industry Association / Futron, 2007 & 2008.
Note: Data not adjusted for inflation.

The way forward

Future space-related data collection efforts by both public and private actors will need to overcome obstacles in order to more accurately quantify the space sector and render data and statistics comparable across countries. To contribute to this effort, a new IAF Technical Committee on the Space Economy was launched in Glasgow in 2008, as a complement to other IAF and IAA Committees. It focuses on key economic aspects of space activities, particularly on metrics and methodologies for measuring the economic dimension of the sector. The Committee has two main missions: (1) offer a home to economists and other actors active in economic analysis of the space sector to allow international discussions on measurement issues (size of sector, impacts, etc) and (2) spread good practices and lessons learned to improve international data quality to all IAF members. The Committee welcomes members from the private sector (industry and services providers), representatives of consulting firms, industry associations, professional associations, academia and specialised journalists.

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PART TWO

INTERNATIONAL COOPERATION AND SPACE LAW

I. GLOBAL DEVELOPMENTS AND ORGANIZATIONS

I.1. New signatories, accessions to or ratifications of space treaties

Since 1987, the International Institute of Space Law (IISL) has compiled an annual report on the status of international agreements relating to activities in outer space. This report includes signature, ratification, as well as declaration of acceptance of rights and obligations that have taken place since January of the current year.

In 2008, the following accessions to, and /or ratifications of space treaties took place:

- **Bahrain** has ratified the 1974 Brussels Convention Relating to the Distribution of Programme-Carrying Signals Transmitted by Satellite;
- **Croatia** has ratified the 1983 Convention for the Establishment of a European Organization for the Exploitation of Meteorological Satellites (Eumetsat);
- **Honduras** has ratified the 1974 Brussels Convention Relating to the Distribution of Programme-Carrying Signals Transmitted by Satellite;
- **Luxembourg** has ratified the 1967 Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, including the Moon and Other Celestial Bodies (Outer Space Treaty);
- **Macedonia** (The former Yugoslav Republic of) has ratified the Agreement Relating to the International Telecommunications Satellite Organization (ITSO) with annexes and amendments(2001);
- **Montenegro** has ratified the 1968 Agreement on the Rescue of Astronauts, the Return of Astronauts and the Return of Objects Launched into Outer Space (Rescue Agreement); the 1972 Convention on International Liability for Damage Caused by Space Objects (Liability Convention); the 1963 Treaty Banning Nuclear Weapon Tests in the Atmosphere, in Outer Space and under Water (Nuclear Test Ban Treaty); the Convention on the International Mobile Satellite Organization, (IMSO) with annex (amended in April 1998 to provide for the restructuring of Inmarsat; the amendments entered into force on 31 July 2001);
- **Slovakia** has ratified the 1983 Convention for the Establishment of a European Organization for the Exploitation of Meteorological Satellites (Eumetsat);
- **Turkey** has ratified the 1972 Convention on International Liability for Damage Caused by Space Objects (Liability Convention);
- **Venezuela** has ratified the amended Convention on the International Mobile Satellite Organization, (IMSO);
- **Vietnam** has ratified the 1974 Brussels Convention Relating to the Distribution of Programme-Carrying Signals Transmitted by Satellite.

I.2. International Institute of Space Law (IISL)

The International Institute of Space Law has a new President as of January 2008. Tanja Masson-Zwaan, who had been the Secretary of the IISL since 1991, was unanimously elected President of the IISL during the IISL's General Assembly held at Hyderabad, India in 2007. Dr. Masson-Zwaan is currently the Deputy Director of the Institute of Air and Space Law, Leiden University, Leiden, The Netherlands. Corinne Contant-Jorgensen assumed the position of Secretary, and Professor Stephan Hobe replaces Frans von der Dunk as Treasurer.

The IISL was granted permanent observer status to the United Nations Committee on the Peaceful Use of Outer Space (UNCOPUOS) in March 2008. The IISL, in cooperation with the European Centre for Space Law (ECSL) has been providing symposia, seminars, and/or briefings for the UNCOPUOS delegates for several years.

The IISL held its 51st International Colloquium on the Law of Outer Space during the 59th International Astronautical Congress, Glasgow, Scotland. The Colloquium was divided into 5 topical sessions: 1) Private International Law Regarding Space Activities; 2) The 40th Anniversary of the Rescue Agreement: Looking Ahead; 3) Weaponization of Outer Space in light of Article 4 of the Outer Space Treaty; 4) Legal Aspects of Natural Near Earth Objects (NEO's); and 5) Other Legal Matters.

Manfred Lachs Space Law Moot Court Competition

Since 1992, the IISL has organized the Manfred Lachs Space Law Moot Court Competition. The 17th Space Moot Court competition was held in Glasgow, Scotland, during the IISL Colloquium. Three regions were represented: Europe (9 teams), Asia (26 teams) and North America (8 teams). Following past tradition, the judges from the International Court of Justice presided over the finals, held at Glasgow's City Chambers: H.E. Judge Abdul Koroma, International Court of Justice; H.E. Judge Peter Tomka, International Court of Justice, and Professor Francis Lyall, University of Aberdeen, Scotland, the latter replacing H.E. Judge Hisashi Owada, who was unable to be in Glasgow for the final rounds.

The winner of the 2008 world finals was the University of New South Wales, Sydney, Australia; the first runner up was the University of Augsburg, Germany; and the second runner up Georgetown University, USA. The Eilene M. Galloway award for best written brief was awarded to the University of Augsburg, Germany, while the Sterns and Tennen award for best oralist was given to Madeleine Ellicott, Australia. The newly established *Lee Love Award* for members of the winning team was given to the University of New South Wales, Sydney, Australia.

Eilene M. Galloway Symposium on "Critical Issues in Space Law

The third *Eilene M. Galloway Symposium on "Critical Issues in Space Law*, on the topic of Article VI of the Outer Space Treaty: Issues and Implementation", was held

on 11 December, 2008, in Washington, DC. The symposium is sponsored by the National Center for Remote Sensing, Air and Space Law of the University of Mississippi, and is held in honor of Dr. Galloway and her long-standing contribution to space law.

The *Isabella H.Ph.Diederiks-Verschoor Award and Prize for Best Paper* by a Young Author was not awarded in 2008 due to the lack of sufficient papers submitted. It is hoped that greater publicity will encourage young authors to submit their papers next year.

I.3. IISL/ECSL Symposium for UNCOPUOS

IISL/ECSL Symposium took place at the 47th Session of the Legal Subcommittee of the United Nations Committee on the Peaceful Uses of Outer Space (UNCOPUOS), held from 26 March to 5 April 2008 in Vienna, Austria. The topic of the 2-day symposium was "Legal Implications of Space Applications for Global Climate Change."

The first session, "Legal Implications of Space Applications for Climate Change: Principles and Rules", was chaired by Ambassador Peter Jankowitsch, and addressed the following issues: Legal Features of the Climate Change Convention: from Kyoto to Bali (*Gerhard Loibl*, University of Vienna, Austria); Space Applications and Climate Change (*Jorge Lafourcade);* Legal Aspects of Cooperation for Space Monitoring of Climate Change and Sustainable Development (*Jose Monserrat Filho,* Brazilian Society of Space Law, Brazil); Promoting Access to, and Exchange of, Data and Information related to Climate Change: the Legal Perspective (*Joanne Irene Gabrynowicz,* University of Mississippi School of Law, United States).

The second session, "Legal Implications of Space Applications for Climate Change: Institutions and Instruments" was chaired by Sergio Marchisio, President, European Centre for Space Law (ECSL), and included the following topics: Coordination Instruments and Satellite Observation of the Climate System: the Contribution of CEOS (*Evangelina Oriol Pibernat*, Centre for Earth Observation of the European Space Agency (ESA/ESRIN); Monitoring the Environment for Climate Change: the Case of GMES (*Gisela Süss,* European Space Agency (ESA); Monitoring the Kyoto Protocol: Greenhouse Gases Observation & the Global Forest Carbon Monitoring System (*Masami Onoda,* Japan Aerospace Exploration Agency (JAXA), University of Kyoto, Japan); Legal Aspects of Climate Monitoring by Means of Treaty Law (*Frans Von der Dunk,* University of Nebraska, United States). Concluding Remarks were made by *Vladimír Kopal,* University of Pilsen, Czech Republic.

I.4. International Law Association (ILA) and UNCOPUOS

The ILA's Space Law Committee, a permanent observer to the United Nations Committee on the Peaceful Uses of Outer Space (UNCOPUOS) since 1996, submitted its third Report on the *Legal Aspects of the Privatisation and Commercialisation of Space Activities*. The Report was discussed in depth and subsequently adopted at the Committee's working session, held during the ILA's 73rd Biennial Conference, held from

17 to 21 August 2008 in Rio de Janeiro, Brazil. The major topics addressed included the use of remote sensing, including satellite data and its value as evidence in international and national litigation; space debris revisited in light of the 2007 *UN Guidelines on Space Debris Mitigation;* links between the work of the ILA Space Law Committee and the UN International Law Commission (ILC) regarding responsibility of international organizations; national space legislation (NSL) with a view to drawing up a model law where special attention would be given to a regulatory framework for the compensation procedure and problems of insurance; national space legislation; and registration of space objects. The report is available on the ILA website at http: www.ila-hq.org.

I.5. UNIDROIT and UNCOPUOS

The International Institute for the Unification of Private Law (UNIDROIT) has been working on a *Draft Protocol on Matters Specific to Space Assets* for several years. In its most recent draft, the Protocol would apply only to the satellite itself, and not to more controversial items, such as licenses. In November 2007, UNIDROIT's Assembly of Parties decided to establish a new working group, with the aim of finalizing the Space Assets Protocol in a timely manner. At the 47th meeting of the Legal Subcommittee of the United Nations Committee on the Peaceful Uses of Outer Space (UNCOPUOS), held in Vienna from 26 March to 5 April various delegations agreed that, even though the Space Protocol is being drafted by UNIDROIT, UNCOPUOS should be kept informed about the matter and that this item should remain on the agenda of the Legal Subcommittee of COPUOS.

I.6. International Telecommunication Union (ITU)

The International Telecommunication Union (ITU) hosts World Radiocommunication Conferences (WRC) periodically, at which representatives from its member administrations and from the private sector meet to revise and update the ITU's Radio Regulations, to ensure that efficient and interference-free use is made of the radio frequency spectrum by communication systems throughout the world.

In 2007, WRC-07 was faced with a particular challenge of ensuring that the C-Band frequency spectrum remained for satellite systems. With the advent of many new satellite systems and providers of a growing array of communications, it is namely important to safeguard the use of certain frequencies. At the conference, the satellite industry scored a resounding victory as the meeting closed with delegates rejecting requests from terrestrial players that they have more access to C-band spectrum. The global satellite industry emerged from four weeks of successful negotiations to protect the users of its C-band spectrum from terrestrial interference. With its unequivocal 'No Change' campaign, the satellite industry at WRC-07 has ensured its uninterrupted, interference-free use of C-band for the future. Some countries around the globe signed a footnote that said they could offer IMT services within C-band, but they must ensure that the operations do not interfere with satellite ground stations within their borders or in neighboring countries.

II. AFRICA AND THE MIDDLE EAST

II.1. Africa

Africa is poised to enter the managed-service marketplace and mobile-service provider Contec Innovations is teaming with German consultancy Danet GmbH for a licensing and revenue-sharing agreement aimed at delivering mobile-data and managed-content services to that continent. Terms of the agreement provide Contec with both direct service-fee revenue and revenue-sharing income based on mobile subscription uptake. Danet is responsible for fulfilling systems integration and ongoing service delivery operations. The two will begin offering services at the end of 2008.

(a) Mauritius

The Rascom-QAF1, a satellite belonging to a Mauritius-based company, suffered a helium leak and operations were halted, satellite manufacturer Thales Alenia Space announced in December. Rascom-QAF1 satellite carries 12 Ku-band and eight C-band transponders intended to provide telecommunications services in rural parts of Africa as well as domestic and international connections, direct TV broadcast services and Internet access.

RascomStar-QAF signed an agreement with Arianespace for the launch of its Rascom-QAF 1R spacecraft, which will be built by Thales Alenia Space. The launch will be performed by an Ariane 5 or Soyuz vehicle during the second half of 2010. It will have 12 Ku-band and 8 C-band transponders, to provide services across the African continent.

Globalstar Inc. has taken a 30 percent stake in a company that provides satellite voice and data services to parts of Africa. GlobalTouch West Africa Ltd. (GWAL) provides services to customers in Nigeria, the surrounding portions of Western Africa as well as parts of the coastal Atlantic and Gulf of Guinea maritime region. Under the agreement, GWAL will provide satellite two-way voice and duplex and simplex data services throughout the region using a new ground station in Kaduna, Nigeria. Globalstar currently provides limited satellite services coverage in Northern Africa via two European satellite gateways located in Turkey and France.

(b) South Africa

Vodacom South Africa, the wireless carrier 50/50 owned by Telkom SA and Vodafone Group, has awarded Alcatel-Lucent nearly $30 million to design, build and deploy an upgrade of its existing 3G network. Vodacom is a Pan-African carrier providing GSM service to more than 34 million customers in South Africa, Tanzania, the Democratic Republic of the Congo, Lesotho and Mozambique. Vodacom South Africa launched its 3G network in December 2004, its 3G HSDPA network in March 2006 and its 3G HSDPA 3.6 with HSUPA network this past February. Vodacom's South African GSM and 3G networks cover more than 98 percent of the population.

A second South African satellite is scheduled to be launched in March 2009, according to a November statement from the South African Foreign Affairs Ministry**.** The Earth observation satellite, built at a cost of 25 million South African rand ($2.5 million), will be carried into space aboard a Russian rocket. The satellite will feed data to the Center for Scientific Research Institute**'s** application centre in Hartebeeshoek, South Africa. The satellite is expected to have a life span of between five and seven years and also will provide communications for amateur radio and scientific experiments. South Africa's first satellite, Sunsat, was launched in 1999 with assistance from NASA.

II.2. Middle East

In October, Omar Al-Emam of the Arab Science and Technology Foundation stated that Arab countries should create an integrated space agency to slash the cost of putting satellites into orbit. The agency should be civilian in nature, like the European Space Agency; such an agency which would substantially cut the cost of Arab states developing their own space programmes, would also contribute to one main goal: to monitor security and environmental developments in the region. Al-Emam said the biggest hurdle was the reluctance of countries to share potentially sensitive satellite images. He was less enthusiastic about the need for a regional space agency to develop its own rockets or put people in to space. This activity, he thought, was done more for publicity.

(a) Iran

In 2003, a bill was submitted by the Government to the Parliament of the Islamic Republic of Iran to establish a new regime for outer space issues; the bill received final approval in December 2003, and became a new law. It received the approval of the Guardian Council of the Constitution of the Islamic Republic of Iran in June 2005. The Government of the Islamic Republic of Iran officially took the first step in implementing the new law on 1 February 2004 by establishing the Iran Space Agency (ISA), which is now being setting up its organizational structure. To continue further development and implementation of the statutes and bylaws of the Iranian Space Agency, the Council of Ministers of the Islamic Republic of Iran approved amendments to the existing law on 15 June 2008, which received final approval on 2 July 2008.

(b) Israel

Israel successfully launched the Amos 3 communications satellite from Baikonur Cosmodrome, Kazakhstan, aboard a Zenit-3SLB Land Launch vehicle, Israeli Aerospace Industries and Sea Launch announced in April, after a delay of several days due to technical difficulties. The satellite, which joins the Amos 1 and Amos 2 in space, reportedly will provide broadcasting and communications services to Europe, the Middle East and the East Coast of the United States. It should last approximately 18 years. Amos 3 was built by the Israel Aerospace Industries' MBT Space Division, and it will replace the Amos 1, which has been operating on a borrowed time for at least a year.

III. Asia and the Pacific

(a) Australia

The Telecommunications Journal of Australia joined forces with Alcatel-Lucent to offer the Broadband Environment Challenge, awarding $10,000 in prize money for the best papers on broadband applications and solutions with potential to deliver benefits to environmental sustainability. The Eckermann-TJA Prize, named after the challenge's founder Prof. Robin Eckermann, will be awarded to the paper which best demonstrates how an existing use of broadband technology delivers environmentally sustainable benefits, or which proposes new ways of delivering eco-sustainability benefits. Papers are invited in such areas as consumption of natural resources, greenhouse gas emissions, waste production, and discharge into water and air from operations.

(b) China

China joined the Consultative Committee for Space Data Systems (CCSDS) on 26 June, becoming its eleventh member. The CCSDS, established in 1982, is an international forum for establishing space communications standards to enable joint operations. China and ESA have already used CCSDS protocols to transmit telemetry and commands through ESA tracking stations.

On 8 September China and the U.S. renewed space cooperation negotiations aimed at the formation of a potential landmark long-term and stable relationship, by adding a framework for broader cooperation to the previously established joint working groups on space science and Earth science.

China has now topped the United States in total number of broadband subscribers, the reason being China's size, as even a tiny broadband penetration results in a considerable increase in the total number of subscribers in the country. The total number of subscribers in China increased by 27.93 percent, compared to a 11.93 percent growth rate in the U.S. The only country to approach China's growth rate was Germany, where broadband users surged 23.39 percent year-over-year to 21,011,563. Germany sits just behind Japan, which is in third place with 28,694,000 broadband users and a tiny 4.02 percent growth rate, reflecting the high penetration rate of broadband in the country. It is predicted that China will continue to pull away from the USA, in terms of penetration.

China and Russia presented a joint proposal for an international treaty on the "Prevention of the Placement of Weapons in Outer Space, the Threat or Use of Force against Outer Space Objects" (PPWT) to ban the deployment of weapons in outer space. The proposal was presented at a plenary session of the Conference on Disarmament, the multilateral forum for disarmament negotiations, on 12 February.

(c) India

In September 2007, the National Remote Sensing Agency (NRSA) of India became the National Remote Sensing Centre (NRSC). As part of the Indian Space

Research Organization (ISRO), the NRSC will integrate with other ISRO centers in the development and operations of the ground segment of the large constellation of Indian remote sensing satellites, and will also take a larger role during research and development. The NRSC said it expects to fulfill its goals playing a major role in important national programs, through linkages with government departments and agencies.

On 12 November 2007, Russia and India signed a 10-year cooperative agreement under which Russia will provide a lander and a rover for India's Chandrayaan-2 robotic lunar exploration mission planned for launch in 2011-2012. The agreement also covers the use of India's Geostationary Satellite Launch Vehicle (GSLV) for joint missions to the Moon. India's cabinet approved Chandrayaan-2 on 18 September (lunar spacecraft Chandrayaan-1, the first unmanned moon mission by India was successfully launched in October 2007; see above) and allocated $93 million for the mission. Russia will supply the rover and lander; India is responsible for the orbiter and the GSLV launch.

India and the U.S. signed a new space accord on 1 February to work together on Earth and space science, exploration, human spaceflight, and other activities, replacing a previous agreement signed in 1997 that was limited to Earth and atmospheric sciences.

India and France also signed an agreement on 30 September to cooperate in the peaceful uses of outer space. The statement also mentions institutional linkages between the Indian Institute of Space Technology and Ecole Polytechnique. The countries' space agencies were already working as equal partners in Megha Tropiques Joint Satellite Mission, with SARAL (Satellite for Argos and Altika) slated to be launched in 2009-10. On the same day Europe's Astrium signed an agreement with India's Antrix organization for the launch of Astrium-built Earth observation satellites on India's Polar Satellite Launch Vehicle (PSLV) rocket starting in 2011.

ISRO finalized its project report on India's proposed first manned space mission in 2015 and was to submit it to the Government in late April for approval. The ISRO is keen on achieving the 2015 target, and may seek to cooperate on the manned mission with other competent space agencies. India is seeking funding for human spaceflight, according to press reports in May. ISRO will ask the Indian government to approve a human spaceflight mission by 2014-15 at a projected cost of $2.5 billion. ISRO Chairman G. Madhavan Nair said that India cannot be left behind in the space race, and added that man's presence is absolutely necessary in a spacecraft for conducting some experiments. A decision on the program by India's Space Commission is expected by the end of 2008. To acquire the skills necessary for future manned space missions India is considering sending one of its citizens into space on board a Russian spacecraft by having them trained in Russia and sent into space on board the Soyuz spacecraft. ISRO had been in talks on the issue with the Russian Federal Space Agency and received a positive response. RIA Novosti notes that India is planning to launch its first space shuttle in 2014 through the use of its successful Geosynchronous Satellite Launch Vehicle, a three-stage rocket with solid, liquid and cryo stages.

ISRO is looking to claim a growing share of the world's billion a year satellite launch market with the success of its recent launch, which placed 10 new satellites into orbit. The launch set a record for the heaviest load and biggest number of satellites ever put into orbit in a single mission, eclipsing a previous Russian record. India's space agency offers relatively cheap rates, a third lower than most of its competitors. This financial advantage should keep business growing for the country's increasingly reliable looking space effort.

India's launch of an Israeli satellite cements the two countries' already-close relations, even as ISRO downplayed assertions that the Israeli satellite, which has a resolution of 1 meter, would be used to spy on Iran. ISRO also denied there had been pressure from Persian Gulf countries to scrap the launch, which was originally scheduled for September 2007. New Delhi and Tehran have close economic and cultural relations and are negotiating at least two energy-supply contracts. Regardless, the launch cements Israel's position as one of the world's top countries for satellite technology and India's place as a world-class but relatively inexpensive launch option.

(d) Japan

Japan presented a bill in 2006 to the Diet (Parliament), setting forth comprehensive space policies for Japan. With the advent of a new Diet, the bill became law in May 2008, realigning Japan's apparatus for space policymaking and planning. The new legislation placed space development planning and administrative authority in the prime minister's cabinet office under a new Minister for Space reporting directly to the prime minister. It also changed the nation's emphasis from research and development to utilization and defense, the latter doing away with Japan's 40-year ban (since 1969) on using space for military purposes. However, the law restricts military use of space to defensive purposes only, in accordance with the United Nations' 1967 Outer Space Treaty. Under the new law, the Space Activities Commission in the Ministry of Education, Culture, Sports, Science, and Technology (MEXT), which had formerly overseen Japan's space activities, will become a technical oversight commission and MEXT will no longer have space budget authority.

NASA's May launch of shuttle Discovery carried a 17.5-ton Japanese laboratory that will be the largest science research facility at the International Space Station (ISS). This is the second section of the Japanese Kibo Laboratory. Japan's Kibo lab on the ISS presents a challenge to ISS capabilities and a future logistical challenge for JAXA and its space station partners, even with the imminent arrival of the European Space Agency's first Automated Transfer Vehicle. JAXA's H-II Transfer Vehicle (HTV) is planned to arrive at ISS next year.

(e) Korea

After sending its first astronaut into space, Korea is now building its own space launch vehicle in Russia. The Korea Space Launch Vehicle-1 is scheduled for launch in December.

(f) Sri Lanka

Futurist, scientist and author Arthur C. Clarke, who described the perfect orbit for communications satellites in a paper published in October 1945, died on 17 March at his home in Colombo, Sri Lanka. At the time, the concept of communication satellites was considered by many prominent scientists to be an impossible vision, but in October 1957 the Russians orbited Sputnik, and the United States followed in January 1958 with Explorer 1. The first commercial communications satellite, Early Bird, was launched in 1965 into precisely the orbit that Clarke had described two decades earlier, and today, hundreds of satellites provide various services around the globe. Geosynchronous orbits, which keep satellites in a fixed position relative to the ground, are called Clarke orbits.

In the 1940s, Clarke was one of the pioneers of ground approach radar, which today is a fundamental element of air traffic safety, and in the 1950s, he worked with Jacques Cousteau and others to help perfect scuba equipment. Clarke had also written about topics such as geothermal, solar and wind energy; the search for extra-terrestrial life; the development of the space elevator concept; and dozens of other innovative ideas. Clarke's non-fiction volumes on space travel and his explorations of the Great Barrier Reef and Indian Ocean earned him respect in the world of science, and in 1976 he became an honorary fellow of the American Institute of Aeronautics and Astronautics. Clarke became a household name with the film "2001- A Space Odyssey," which was based on one of his books.

IV. EUROPE

IV.1. Regional events/developments

(a) European Centre for Space Law (ECSL)

The 17th ECSL Summer Course on Space Law and Policy took place at the University of Genoa, Italy, from 1 to 12 September 2008, with 35 students from 13 countries and 15 different nationalities attending it. Four tutors guided the students in their personal and teamwork, and 36 speakers participated.

The ECSL's 2008 Practitioner's Forum with the topic "National space legislation in Europe – Issues of authorisation in the light of developments in European space cooperation" was held on 15 December 2008, at the ESA Hedquarters, Paris, France. The number and volume of national laws addressing the authorisation of private space activities is constantly growing in Europe. This raises legal issues with regard to European cooperation in space both in the context of ESA and in that of recent EU developments, most particularly the drafting of a Reform Treaty containing a few relevant clauses on this subject matter.

ECSL also participated in the International Workshop *"L'outil Spatial pour la Gestion des Catastrophes et des Situations d'urgence en Afrique: Aspects Techniques, Organisationnels et Juridiques"* at Rabat, Morocco, from 10 to 12 November 2008.

(b) Council of the European Union

The European Union (EU) is taking its steps forward in the development of its space policy. It should be recalled that a Framework Agreement between the European Space Agency (ESA) and the EU was reached in 2004, and the first European Space Council was held in November 2004. The Preliminary Elements of that policy were transmitted to the European Parliament in May 2005. The Fifth Space Council was held in 28 September 2008. At that meeting, the Council passed a resolution "Taking forward the European Space Policy" that aims at further strengthening the collaboration between the EU and the ESA on space policy matters.

The resolution recognized that the EU, ESA and their respective Member States were the three key actors of the European Space Policy, and highlighted the fact that the EU was taking increased responsibilities for space matters, especially related to space applications, consistent with those of a global actor and bringing an added-value to ESA and Member States while respecting roles and responsibilities of each of them. The resolution also stressed the importance of a coherent approach to international cooperation in space programmes in view of their global nature, while recognizing that Europe should be able to face global competition. Its aim is to promote the development of an appropriate regulatory framework to facilitate innovative and competitive downstream services, in particular with the objective of guaranteeing sustained access to spectrum for all space-based applications; the successful launch and in-orbit validation of GIOVE-B, demonstrating critical new technologies needed for the performance of the Galileo system. The resolution also sets four "New Priorities" in the implementation of the European Space Policy: Space and Climate Change; space as a high tech R&D domain and the economic exploitation of its results, Space and Security of European citizens; and Space Exploration. For a detailed account of the European Space Policy see also http://ec.europa.cu/enterprise/space/archives/publications.

(c) European Commission

The European Commission (EC) in July invited public comments regarding the future regulation of wireless "voice call termination rates" in the European Union (EU) based on a draft EC recommendation. The EC's draft proposal includes principles on which cost elements should be taken into account when national telecom regulators determine termination rates, a costing methodology and symmetric regulation (where the same price caps apply, within a country, to mobile and fixed operators, respectively).

Previous decisions of the various national regulators have resulted in divergent rates across the EU. Mobile termination rates range from $0.03 per minute (in Cyprus) to more than $0.28 per minute (in Bulgaria), and they are nine times higher than fixed-line termination rates (on average, less than one penny per minute for local call termination). Disparate termination rates across the EU and large gaps between fixed and mobile termination rates are serious barriers to achieving a single European telecoms market that benefits competition and consumers, who ultimately are the ones who pay the price for these gaps between national regulatory policies. The EC is expected to issue the final text

of the recommendation on the regulatory treatment of fixed and mobile termination rates in October. All this is in pursuance of the EC's goal to further harmonize the application of EU telecom rules in the single market to promote competition and consumer benefits. In turn, member states must ensure that national regulators take "the utmost account" of the EC recommendations.

The EC also seeks to reform its telecommunications regulatory framework, with the aim of improving competition in the provision of electronic communications, by encouraging efficient use of the radio spectrum, simplifying regulations. Eventually, the EC aims at having a single market in electronic communications. To achieve its goals, the EC is proposing to create a new, independent European Communications Market Authority to ensure regulatory consistency in the EU. However, some Member States are not entirely in favor of creating a new regulatory authority, and believe that the work undertaken by the current European Regulators Group (ERG) could be enhanced and improved instead.

The EC launched a competition on 7 August seeking satellite operators to provide mobile services across Europe. New regulations will allow the selected operators to provide their services over a specifically reserved spectrum without having to secure permission from individual countries. Mobile satellite services have the advantage of being able to cover most of the EU territory thereby reaching millions of EU citizens across borders. They represent an unprecedented opportunity for all Europeans to access new communication services, and this not only in metropolitan areas but also in rural and less populated regions. However, these satellite services depend on substantial investment and therefore need simple and swift procedures as well as long-term legal certainty. This is why the Commission, in close cooperation with the European Parliament and the Council of Ministers, set up, in a record time of only 10 months, a single EU procedure for selecting interested operators of mobile satellite services. There is now one market, not 27 in Europe for mobile satellite services. Companies had to submit unit October 7 applications to the EC, which will assess the technical and commercial ability of the candidates to launch their systems. The criteria in the second selection phase include: the speed at which all member states will be covered; range of services, including in rural areas; and the number of end-users to be served and the capacity of the system to fulfill public policy objectives and spectrum efficiency. The first satellite launches are expected to take place in 2009.

(d) European Space Agency (ESA)

Mauricio Lucena, Director General of Spain's Center for Industrial Technology Development (CDTI) will chair the European Space Agency (ESA) Council for the next two years, replacing Per Tegnér of Sweden in July. Lucena was appointed Director General of Spain's Centre for the Development of Industrial Technology (CDTI) in 2004 and has served as head of the Spanish delegation to ESA.

On 8 July NASA and ESA completed a six-month assessment of their potential space exploration programmes and technologies. Findings from the study included a

significant mutual interest in the potential development of lunar cargo landing systems, communication and navigation systems, lunar orbital infrastructures, and lunar surface systems such as habitats or mobility systems. The NASA/ESA study is expected to serve as a model for discussions with other potential partners.

ESA began its search for new astronauts on 16 May, calling for applications from talented individuals who wish to join the European Astronaut Corps. Almost 10 000 individuals registered to begin the application process. At the close of the application phase which lasted a month, 8413 aspiring astronauts provided a medical certificate and finalised the online application form. This qualifies them for the next step in the selection process. By September fewer than 200 candidates were on the "short list."

Galileo

ESA launched the second experimental satellite in its planned Galileo constellation, a competitor to the U.S. Global Positioning System (GPS) array. This second Galileo In-Orbit Validation Element (GIOVE-B) satellite, carrying what the agency says is the most accurate atomic clock ever flown into space, was built by a European industrial team led by Astrium GmbH, with Thales Alenia Space doing the integration and testing in Rome. Two years after the GIOVE-A mission, this orbiter will continue the demonstration of critical technologies for the navigation payload of future operational Galileo satellites. In addition to its technology-demonstration mission, GIOVE-B also will take over GIOVE-A's mission to secure the Galileo frequencies, as that first Galileo demonstration satellite launched in December 2005 is approaching the end of its operational life.

With the successful launch of GIOVE-B, the demonstration phase for Galileo is nearly completed. Strong cooperation between ESA and the European Commission (EC) has been instrumental in making progress in a difficult environment over the past few years; Galileo is thus progressing, with two satellites now in orbit, the next four in the construction phase and a fully qualified EGNOS service, all designed to serve citizens in Europe and all around the globe. The next step in the Galileo program will be the launch of four operational satellites, aimed at validating the basic Galileo space and related ground segment, by 2010. Once that In-Orbit Validation phase is completed, the remaining satellites will be launched and deployed to reach the full operational capability of 30 identical satellites. The $5.3 billion Galileo project is expected to be operational by 2013. Numerous applications are planned for Galileo, including positioning and other value-added services the telecom and transport industries, among others. According to the EC, Galileo will be Europe's own global navigation satellite system, providing a highly accurate, guaranteed global positioning service under civil control. It will be interoperable with the U.S. GPS and Russia's GLONASS, the two other global satellite navigation systems. Galileo will deliver real-time positioning accuracy down to the meter range.

In May, the U.K. government published the agreement signed with its fellow European governments and the United States of America, for the promotion, provision

and use of the Galileo and Global Positioning System (GPS) systems. The United States and the EU signed an agreement in June 2004 that GPS and Galileo signals would be interoperable, but it has taken several years for the agreement to be approved by member states. The current agreement specifies that while Galileo satellites will produce Galileo signals, and GPS satellites will produce GPS signals, both signals on the ground will be compatible and interoperable, allowing users in the future to use a device that contains both GPS and Galileo chipsets, which are still to be defined. However, this will mean that existing GPS-based sat-navigation devices will require a different chipset to utilize the Galileo signal.

In October, Europeans and United States representatives reaffirmed their commitment to the interoperability of the USA's GPS and Europe's Galileo. The representatives met at the US Naval Observatory, and reaffirmed their commitment to the implementation of the agreement and presented the current status of their respective systems. The working groups established under the agreement also updated their progress and ideas for future work. The working group designed to enhance cooperation for the next generation of GPS and Galileo discussed possible short- and long-term priorities in order to prepare its first work plan. In the first stage, this group plans to address safety of life services, and will also discuss interoperability of new civil signals.

IV.2. Europe –National Activities

(a) Belarus

The Administration of Belarus, the notifying Administration for the International Organization of Space Communications (INTERSPUTNIK) announced in October that ProtoStar I had been operating fully within applicable ITU rules and regulations since its successful launch on 7 July 2008. Intersputnik has followed the regulations to properly bring frequencies into use on the operationally-healthy ProtoStar I satellite at 98.5 degrees east under the Intersputnik-98.5ECK satellite network. The ITU also confirmed that ProtoStar has met all due diligence requirements of ITU Resolution 49. ProtoStar Ltd., a Bermuda company with subsidiaries in Bermuda, San Francisco, CA and Singapore, was formed to acquire and operate high-power geostationary satellites optimized for DTH satellite television, broadband Internet and GSM cellular backhaul service providers across the Asia-Pacific region.

(b) Czech Republic

On 24 June the Czech Republic became the first of the former communist-bloc countries to become a full-fledged member of ESA, following a four-year PECS membership stint.

(c) France

France enacted a new law on space activities in July 2008, *Loi sur les Opérations Spatiales* that includes, among others, provisions on authorizing the transfer of space

objects. Also included in the new law are articles related to responsibility/liability and the exemption of the French space agency CNES from certain provisions (see also: http://www.legifrance.gouv.fr).

French President Nicolas Sarkozy announced that during France's six-month term in the European Union (EU) presidency, which began on 1 July, he would seek to make space policy and investment a major EU theme. France will promote an ambitious effort to raise Europe's space profile and investment in environmental monitoring, space surveillance, and both human and robotic space exploration, as well as in military objectives.

One French initiative would be to create a space-monitoring network of currently independent European ground stations to locate and identify operating satellites and orbital debris, a capability for which Europe now depends on the U.S. Space Surveillance Network. Another would be to find an acceptable middle ground between U.S., Chinese, and Russian positions on making space an arms-free zone and to define an appropriate "code of conduct" that would reinforce each nation's right to use space without fear that its satellites would be damaged.

Alcatel-Lucent CEO Pat Russo and Chairman Serge Tchuruk, the Lucent and Alcatel executives responsible for the merger of the two companies in late 2006, handed in their resignations as the company took another massive write-down of its declining CDMA business. Former BT Group chief Ben Verwaayen took the helm at Alcatel-Lucent in September 2008, replacing embattled CEO Pat Russo who as Lucent's CEO co-engineered the "merger of equals" that has led the company to six quarters and $7 billion in the red. Verwaayen had served as Lucent's CEO and Vice Chairman from 1997 until going to BT in 2002. He returned to Alcatel-Lucent just three months after leaving BT, after a six-year stint during which he transformed the formerly staid, traditional landline phone company into a carrier with skyrocketing next-generation business growth, including broadband, online and international services. International media group Lagardere Co-Managing Partner Philippe Camus has been named non-executive chairman.

Arianespace

Arianespace confirmed a new launch date of June 12 for the Skynet 5C and Turksat 3A satellites. Based on a Thales Alenia Space Spacebus 4000B2, Turksat 3A has 24 Ku-band transponders and will replace the Turksat 1C satellite. Skynet 5 is the next-generation military satellite communications program for the U.K. Ministry of Defence. Secure communications services are being delivered by the owner and operator, Paradigm, part of Astrium Services, with the system, including the satellites, designed and built by Astrium Satellites.

Workers are beginning to install equipment and systems at Europe's new Soyuz launch pad in Kourou, French Guiana, in a race to have the facility ready by the middle of 2009. The new pad is needed to meet demand for medium-sized communications and

Earth observation satellites and to provide a backup for the Ariane 5 heavy-lift launcher. Another factor in the pad's construction is the recent entry into service of Land Launch, a medium-lift derivative of Sea Launch that will be the closest rival of the upgraded Soyuz 2.1 a/b rockets that will use the new facility. Three launches are planned in 2009 and four in 2010, although managers may increase this launch rate to meet growing demand.

Ariane 5's largest payload ever, the Automated Transfer Vehicle, was integrated on the launch vehicle, Arianespace announced in February. The spacecraft, which has a liftoff mass of more than 19 metric tons, was scheduled to be launched March 8 to deliver propellant, oxygen, equipment, systems, food and water for the International Space Station.

Eutelsat

Eutelsat and ViaSat ordered a pair of Ka-band satellites under collaboration to develop more satellite broadband capacity, the satellite operators announced in January. The infrastructure is specifically designed for interactive consumer services. Through the satellite infrastructure programs and the collaboration between the two companies, consumer satellite broadband is making exciting progress in terms of efficiency and competitiveness and can have a substantial impact in resolving the digital divide. More than 15 million homes in Europe and as many in North America will still be beyond range of terrestrial broadband networks in 2010.

EADS Astrium will manufacture the first all-Ka-band satellite for Eutelsat. The spacecraft is scheduled to be placed into orbit in the 2010 to provide consumer broadband services across Europe and the Mediterranean basin. The procurement of the satellite and associated ground system is part of the investment objective Eutelsat laid out in October 2007. Space Systems/Loral (SS/L) will build ViaSat-1 for ViaSat. The spacecraft, intended to serve the North American market, is planned for launch in 2011. ViaSat has secured financial commitments of more than $100 million from partners toward ViaSat-1 and will finance the remainder from cash on hand, future cash flows and available borrowing capacity. Loral is investing in the Canadian coverage portion of the satellite in anticipation of Telesat using this capacity to provide broadband services throughout Canada. Telesat will provide telemetry, tracking and control operations.

ViaSat and Eutelsat are cooperating around ViaSat's Ka-band SurfBeam networking system and a similar wholesale business model that works through ISPs, telecommunications companies and pay-TV platforms to serve subscribers. This strategic partnership combines the companies' expertise and economies of scale in broadband modems and Ka-band MMICs, with the benefit of our partners' extensive experience in designing, launching, and operating satellite systems.

(d) Germany

Germany passed a new law on remote sensing, the Act on Satellite Data Security (*Satellitendatensicherheitsgesetz* – SatDSiG), which entered into force on December 1,

2007. The SatDSiG has two purposes. Firstly, it aims to safeguard the security and foreign policy interests of Germany in relation to the dissemination and commercial marketing of satellite-based Earth observation data, in particular on the international marketplace. Secondly, it creates a framework of legal certainty for commercial satellite data marketing entities, enabling the calculation of operating terms and business risks. The operation of, and data sales from the German radar satellite TerraSAR-X, which was launched in June 2007, will be the first system affected by the SatDSiG. The text of this Act is available in German at http://www.bgblportal.de/BGBL/bgbl1f/bgbl107s2590.pdf; for an unofficial English translation see "Current Status and Recent Developments in German Remote Sensing Law", (2008) 34(1) Journal of Space Law 97, p. 115.

The German Aerospace Center (DLR) in cooperation with the Institute of Air and Space Law, University of Cologne has undertaken a five-year project, The Cologne Commentary on Space Law (CoCoSL). The project aims to produce a three-volume commentary on the written legal norms of international space law. Volume 1 focuses on the 1967 Outer Space Treaty, and is expected to be published in the fall of 2009. Volume 2 will address the 1968 Rescue and Return Agreement, the 1972 Liability Convention, the 1975 Registration Convention and the 1979 Moon Agreement. Volume 3 provides a commentary on six United Nations General Assembly Resolutions: the 1982 Direct Broadcasting Principles, the 1986 Remote Sensing Principles, the 1992 Nuclear Power Sources Principles, the 1996 Space Benefits Declaration, the 2004 Declaration on the Definition of the "Launching State" and the 2007 Registration Resolution. Volumes 2 and 3 are expected by fall 2011. The CoCoSL project is the first commentary on the written international norms relating to space activities, and is targeted at legal practitioners and academics, as well as other technicians and professionals involved in space activities. More information on the CoCoSL project is available online at http://www.cocosl.com.

EUMETSAT

At its 2 July meeting, the European Organisation for the Exploitation of Meteorological Satellites, EUMETSAT (Germany) acted to strengthen its cooperation with the environmental-data organizations of other nations, and also agreed to make all its satellite data products available free of charge to the European Space Agency's and the European Commission's Global Monitoring for Environment and Security (GMES) programme. Specific coordination actions included an agreement to fly the U.S. National Oceanic and Atmospheric Administration's (NOAA's) Space Environment Monitor instrument, currently aboard EUMETSAT's Metop-A, on a future Metop-C satellite; data exchanges with the China Meteorological Administration; and data exchanges with Russia's Roshydromet organization, which plans to launch three Geostationary Orbiting Meteorological (Electro) Satellites between 2009 and 2015 and six new polar-orbiting Meteor meteorology and oceanography satellites, beginning late this year with Meteor-M.

(e) Greece

Greek Information and Communications Technology (ICT) house and Software as a Service (SaaS) solutions provider Globo, until now little noticed outside of its home market, is offering what it says can turn almost any cellphone into a Blackberry challenger. Globo said that its "CitronGO!" enables almost any cellphone to receive push e-Mail and handle a long list of other enterprise-class capabilities. The Greek firm's theory is that while enterprise users, and consumers may covet enterprise-type capabilities they're not about to simply throw away their existing phones and buy expensive smartphones in order to get such features. Users want an 'all-in-one solution' that provides an instant email experience, but are unwilling to change their handset for one of the specialized handheld devices, argues Globo. The company, based in the Athens suburb of Halandri but traded on the London Stock Exchange, also said that "CitronGO!" can run on other platforms including laptops, PDAs and desktops, in essence uniting all of those screens.

(f) Luxemburg

SES Astra revealed details of its latest contract for a new satellite, stating that it had awarded the contract for the design and construction of its Astra-3B spacecraft to Astrium in November 2007. Astra 3B will be a Ku- and Ka-band satellite designed to distribute both direct-to-home (DTH) broadcast services and two-way broadband services across Europe. Astra 3B will have 52 transponders, 32 of them creating new capacity and the other 20 to replace existing in-orbit capacity. Overall it will strengthen 23.5 degrees East as the third orbital hotspot for European DTH services. Astra 3B is expected for launch in early 2009.

SES is weighing its options for the AMC-14 satellite, which was left short of its intended orbit by a March 15 Proton launch failure. Since the spacecraft is stable and performing nominally, albeit in the wrong orbit, SES has had some time to carefully evaluate the consequences of it and to carefully evaluate all available alternatives to whatever maneuver it will be conducting. This is an ongoing process between SES and the manufacturer, Lockheed Martin until SES takes the decision on what corrective action it will take. In all of the various scenarios to redirect the spacecraft, onboard fuel will have to be used so there is likely to be an impact on the expected lifetime of the satellite. The spacecraft, under contract to EchoStar, was intended to operate at the orbital position of 61.5° West and is insured for partial and total loss.

SES Astra has initiated a new orbital position at 31.5° East as it looks to make more of an impact in the Middle East and Eastern Europe, the company announced in April. The new position will allow SES Astra to operate satellite services at up to 40 new broadcasting frequencies. The Sirius 2 satellite, now part of the SES fleet and renamed Astra 5A, has been moved from 5° East to the new position and will allow the commercialization of up to 26 transponders. With the new position, SES Astra and SES Sirius operate five orbital positions, with their fleet of 13 Astra and 2 Sirius satellites.

(g) Poland

Poland joined the ESA Plan for European Cooperating States (PECS) programme on 8 May, the fourth nation to join the PECS. Although Polish scientists and engineers have already served as co-principal investigators and suppliers of components on ESA space missions such as Herschel and ExoMars, this new status allows Poland to participate fully in ESA science missions, human spaceflight, navigation and communications satellite projects, and technology initiatives for a period of five years.

(h) Russian Federation

A new $60-billion programme to capture 10% of the global market for information technology and office equipment over the next 10 years was launched on 30 November 2007 by the Russian president Vladimir Putin. Space is identified as a high-priority element in that programme, with the Russian space agency Roskosmos to receive $12.5 billion through 2015; among projects identified in the programme is a lunar landing by 2025.

Russia is building a new space center, Vostochny, in the Far East, in the Amur region of southeast Russia, bordering China, as an alternative to the Baikonur base, a Soviet-built facility that Russia now leases from Kazakhstan. Vostochny should be ready for rocket launches of any type by 2016 and manned launches specifically by 2018. The Russian agreement to lease Baikonur from Kazakhstan was renewed in 2004 and will continue through 2050.

A boost to the Russian space programme and to space tourism may come from the latest U.S. space tourist, Richard Garriott who is of view that government space agencies like NASA, Roscosmos and others need to give private entrepreneurs broader access to the orbiting station and encourage private space travel. Garriott flew to the International Space Station (ISS) together with 2 Russian cosmonauts aboard a Russian Soyuz capsule on 6 February. However, in April Russia announced that it may stop selling seats on its spacecraft to “tourists” starting in 2010 because of the planned expansion of the ISS crew, which could reach six or even nine in 2010. Because of additional astronauts, Russia will have fewer extra seats available for tourists on its Soyuz spacecraft. The Soyuz spacecraft has taken five wealthy private citizens on trips to ISS over the past eight years. Despite the future change in policy, Russian space agency Roskosmos has no opposition to space tourism in general, as long as tourists on board the Soyuz spacecraft do not interfere with the ISS.

In January, Russian media reported that the first 1,000 units that can receive signals from Russian Glonass and the U.S. GPS navigation systems had sold out. Glonass is a dual–purpose global navigation system designed to serve the Russian Ministry of Defense and civil users. The Federal Industry Agency is in charge of the production of the units, while the Russian Federal Space Agency operates the Glonass program. Glonass is the Russian equivalent of the U.S. Global Positioning System (GPS), which is designed for both military and civilian use, and allows users to identify their positions in

real time. Currently, Glonass constellation consists of 18 satellites and is capable of providing navigation and positioning data covering the whole territory of the Russian Federation. When completed in 2010, Glonass will consist of 24 Glonass-M and Glonass-K satellites, with 21 used for transmitting signals and three for on-orbit spares, deployed in three orbital planes.

A Russian Proton rocket placed the Sirius 4 satellite into orbit for SES Sirius on 18 November. This is the first commercial Proton mission since a September launch failure. Sirius 4 will be located at 5° East and deliver broadcast and broadband services across Europe as well as transmit high-definition TV channels. Sirius 4 will lead to even more revenues being derived from Eastern Europe, a key target for the company. Eastern Europe represents around 20 percent of SES Sirius' current revenues, but over the next few years it is expected to grow beyond 50 percent. Sirius 4 also will carry an African beam which will be marketed by SES Astra. Commercial operations are expected to begin in January.

Russia is testing a second stage URM-2 booster for a new Russian carrier rocket that was delivered to an engine test facility in the Moscow Region for 'cold' firing tests, the Khrunichev Space Research and Production center. The booster will allow the Angara rocket now being developed to insert heavy payloads into orbit from the Plesetsk launch enter in order to reduce Moscow's dependence on Kazakhstan's Baikonur, as well as to complement, and eventually replace, the existing line of Rockot and Proton launch vehicles. The Khrunichev center stated that flight tests of the Angara rocket are due to start in 2010. In early 2011, a lighter version of Angara is to be launched and by the end of the same year a heavy-class, Angara-5, vehicle will lift off.

(i) Slovenia

The European Space Agency (ESA) announced in June details of a new cooperation agreement with Slovenia. The agreement is a first step for Slovenia as it becomes more involved in space activities in Europe. It is expected that Slovenia will, in a few years, become a European Cooperating State, making an increased financial contribution to space activities. Slovenia is the second recent EU Member State to sign a Cooperation Agreement with ESA, following Estonia in June 2007.

(j) Spain

The year 2008 was the second year of the multi-year Spanish Space Plan, which spans 2007-2011 and is aimed at increasing the size and capabilities of Spain's space industry. One of the pillars of the Spanish Space Plan is the Spanish Earth Observation Satellite Program, approved in 2007, aimed at developing a national system capable of acquiring optical and radar Earth images. The satellites are being designed following the requirements set by the Spanish user community, both civil and military. In addition, Ingenio will be part of Spain's contribution to the Global Monitoring for Environment and Security (GMES) - the European Union initiative for Earth observation. Spain is also participating in international missions, such as NASA's Mars Science Laboratory and

SNSB's PRISMA, in cooperation with the French space agency CNES. Spain has continued the cooperation with Russia in the development of the World Space Observatory, a geosynchronous astronomical observatory to be launched early in the next decade.

Mauricio Lucena, Director General of the Centre for Industrial Technology Development (*Centro para el Desarrollo Tecnológico Industrial* (CDTI)) is now the President of the Council of the European Space Agency. CDTI serves as a conduit for international cooperative agreements with various space agencies, such as Roskosmos, NASA, CNES and ESA. In addition, Spain intends to further its cooperation with these agencies and space agencies of other countries as well to develop space programs of mutual interest.

Spain's National Institute of Aerospace Technology (*Instituto Nacional de Técnica Aeroespacial* (INTA)) is a public research centre that promotes international cooperation and raises awareness among the public about the socioeconomic benefits of space applications. INTA participates in the Mars Met Net Precursor Mission, which is a joint project between the Finnish Meteorological Institute, the Russian Academy of Sciences and the Babakin Space and Research Centre. INTA also participates in the implementation of the National Plan of Earth Observation: Ground segment and some developments of the space one are under the aegis of INTA. The Institute is developing new concepts for offering more affordable solutions to space science and other applications, such as exploring further uses of nanotechnology and developing new concepts for on-board software.

Two Spanish organizations joined forces with Astrium to create an Earth observation joint venture. In February Astrium announced that it had entered into a joint venture with the Cartographic Institute of Catalonia (ICC), the Catalan official mapping agency, and Hisdesat, a space services provider, to create Infoterra Servicios de Geoinformación SA (Infoterra SGSA), which will form part of the Infoterra Group, a provider of geoinformation products and services based on Earth observation data. Infoterra SGSA will offer customers a portfolio ranging from data acquisition and processing to geo-information services. The new company will expand an already strong European organization present in France, Germany, Hungary and in the U.K.

(k) Sweden

Saab AB of Sweden is in exclusive negotiations with Thales Alenia Space over the purchase of Saab Space. Saab Space was advertised as available in 2007, but parent company Saab AB cautioned at the time that it would hold out for a deal "at the right price with the right buyer" and might end up keeping the division if it could not secure satisfactory terms. Saab Space is Sweden's largest space contractor, specializing in satellite payload electronics and in systems used to release satellites from launch vehicles. The company's biggest customer is the European Space Agency.

(l) The Netherlands

The Netherlands' Space Activities Act entered into force in January, and consists of three main points: 1) The licensing and authorisation régime, its requirements and conditions applicable to legal and physical nationals of the Netherlands; 2) A national register of space objects; and 3) Insurance liability and indemnification procedures.

The law serves to regulate space activities that fall under Dutch jurisdiction. The most important provisions of the law concern the establishment of a mandatory licensing system for the performance of space activities (e.g. launches or navigational and operational activities) and the inclusion of a redress provision in the event of State liability. The law does not set out to lay down rules for activities that can be undertaken with the aid of space technology (e.g. telecommunications, Earth observation or geo informatics). Products and services of this kind are principally governed by the statutory regulations in the field of telecommunications and broadcasting.

(m) United Kingdom

On 14 February the British National Space Center (BNSC) codified a series of prior strategic space proposals (see last year's report) into a formal "Civil Space Strategy: 2008 – 2012 and Beyond." The new strategy identifies space as a strategic economic center; commits the UK to establishing a National Space Technology Programme; espouses the creation of an international space facility with ESA at Harwell; states that it is time to review the 1986 UK policy eschewing human space missions; and espouses a BNSC study of programme options that takes into account their scientific, technological, and economic costs and benefits, as well as the UK's existing strengths in robotic space exploration.

Then on 9 October the minister of Britain's new Department for Innovation, Universities and Skills, Lord Drayson, gave the strongest sign yet that the government will soon drop its longstanding opposition to funding manned space flight, stating that he will lobby for the recruitment of a national astronaut corps. He called manned spaceflight projects "iconic" and said that they could inspire students and have benefits in business. He pointed out that space tourism was being commercialized through Virgin Galactic and others, adding that maybe in the past human space flight did not make sense but now it does.

In April, the European Space Agency (ESA) was scheduled to begin a year-long astronaut selection process, and faced the possibility that a British citizen would emerge among the best candidates. In the past, the U.K. government has remained firmly, and vocally, outside of all astronaut-related programs in Europe, concluding that human spaceflight is more expensive than it is worth. It is not clear whether ESA's policy of distributing contracts according to each nation's financial participation in a program applies to selecting astronauts as well.

U.K.-based satellite imaging company DMCii Ltd. provided data to the United Nations to assist in relief efforts in Myanmar in the wake of the devastation created by Cyclone Nargis, DMCii announced in May. Images collected by DMCii's UK-DMC satellite are being used by the United Nations Institute for Training and Research Operational Satellite Applications Programme (UNOSAT) to detect floodwater and estimate the likely impact on villages and townships. The images, which have a ground resolution of 32 meters, are compared with those recorded prior to the cyclone in order to predict the spread of post-disaster floodwaters. Imagery acquired by DMCii, a subsidiary of Surrey Satellite Technology Ltd., is also being supplied to project managers of the International Charter "Space and Major Disasters", an initiative to provide free satellite imagery to relief organizations of areas affected by disasters, to be processed into information products that determine flood extents. DMCii also supplied pre-disaster archived imagery to enable comparisons and for the production of emergency maps.

Surrey Satellite Technology Ltd. (SSTL), located at the University of Surrey, was acquired by EADS Astrium. SSTL, which specializes in the design and manufacture of small and micro satellites, is joining EADS Astrium following a decision by the University of Surrey to sell its majority stake of about 80 percent in the company. Financial terms of the deal were not disclosed and the deal is subject to regulatory approval. This acquisition contributes to strengthening SSTL and is also significant from the University of Surrey's perspective, as it will represent one of the largest cash spin-outs from any U.K. university. It will also allow the company to realize its full potential as a rapidly growing and leading supplier of small and micro satellites, whilst the university retains the benefit of close interaction with SSTL and its new partner EADS Astrium. By retaining a small stake in SSTL the University shows its commitment to both the future of the company and space research itself.

In February, OmniGlobe Networks was acquired by Bandwidth Technologies International Group Limited, a U.K.-based international provider of satellite communications systems. OmniGlobe specializes in the provision of telecommunications services in areas of the world where the conventional telecoms infrastructure is often non-existent. Bandwidth Technologies' management, staff, offices and technical center in Frimley, Hampshire, England will be renamed the OmniGlobe International Satellite Communications Division and become the operations and sales center for OmniGlobe's planned expansion of its existing business in the Middle East and Africa.

V. THE AMERICAS

(a) Brazil

Brazil and Argentina decided to create and construct jointly a new satellite, Sabiá-Mar, for coastal and oceanographic observation; the decision was adopted by the presidents of both countries, in a declaration on 22 February.

The Brazilian Space Agency (AEB) has a new chair, Carlos Ganen and the directors.

Brazil and the U.K. agreed to establish a programme for space cooperation. The U.K. will put an image sensor with 12m definition on the Brazilian satellite Amazonia-1 to monitor the Amazonian region.

In December 2007, Brazil announced the launch of the CBERS Program for Africa, at the Group on Earth Observation (GEO) meeting. CBERS is the Chinese-Brazilian Earth remote sensing satellite initiative. In 2008, the China-Brazil Space Program – CBERS celebrated its 20th anniversary, as it was in 1988 when the first Brazilian - Chinese agreement was signed. On this occasion an illustrated book with the complete CBERS history and a special post stamp were issued, and an exposition was held in all the major cities of Brazil.

Brazil and Russia signed an agreement in April to jointly develop top-line jet fighters and satellite launch vehicles. According to the Brazilian Ministry of Strategic Affairs, the agreement will lead to the development of rockets capable of hurling several kinds of satellites into space.

Innova S. de R.L. de C.V. and Sky Brasil Serviços Ltda. have reached an agreement with Intelsat Corp. to build and launch a 24-transponder satellite. The satellite will provide backup services for both Sky Mexico Innova and Sky Brasil, and will also double Sky Mexico's current capacity. Innova plans to use this extra capacity for HD and other value-added services. The satellite, which will be manufactured by Orbital Sciences Corp., is expected to be launched in the fourth quarter of 2009.

(b) Canada

In December 2007, Loral Space and Communications and the Public Sector Pension Investment Board (PSP Investments) completed their acquisition of Telesat Canada, resulting in the consolidation of the largest fixed satellite services operators, and leaving few options in the consolidation of the FSS market. These options are further limited, as the regional operators continue to be supported by governments that seek the prestige of owning their own (smaller) satellites, which they can acquire for $100 million instead of $200 million or $300 million.

Canada faced a potential sale of the space division of MDA, its largest space company, this year. Several lawyers in Ottawa have been promoting the need for a Canadian National Space Policy, and organized a roundtable in February. In March, a former Canadian astronaut urged the federal government not to sell a space technology company to American interests, saying it threatens the country's sovereignty. Former head of the Canadian Space Agency Marc Garneau discouraged handing over this first-class Canadian technology as it would prevent the country from controlling its own technology, and argued against the sale of MacDonald Dettwiler and Associates (MDA) to Alliant Technosystems. MDA makes the Radarsat 2, a device that can see through

clouds and allow Canadian authorities to monitor possible incursions onto Canadian land. In May, Canada confirmed its decision to block a U.S. company's takeover of the space and satellite division of MacDonald, Dettwiler and Associates Ltd. (MDA), Canada's leading space technology firm. Industry Minister Jim Prentice blocked the sale of MDA to Alliant Techsystems (ATK) last month under the Canada Investment Act. The sale of MDA's taxpayer-subsidized space and satellite division would not benefit Canada. Shortly after confirming the blocked sale, Prentice announced the renewal of a major contract between MDA and the Canadian Space Agency (CSA) to provide logistics and engineering and technology services for the Canadian-made Mobile Servicing System on the International Space Station over the next four years.

Canada's spectrum auction, held earlier in 2008, finished its second week with bids unexpectedly topping $3 billion - almost twice the total expected. The auction was expected to conclude in June. As the auction entered "Stage Two", the country could see two new national wireless carriers emerge. Globalive Communications, already optimistically listing itself as "Globalive Wireless", was Number Three in the standings with top bids for 16 spectrum blocks covering virtually all of Canada and totaling $490.8 million ($499,879,500 in Canadian dollars). The question was how Globalive would get all the cash it needs and still comply with Canadian foreign-investment limits. It would seem that Globalive crafted an equity/loan deal, rather than all equity, that technically remains within the legal limits. Another strong bidder was Québecor, which maintained the top bids on 27 blocks of spectrum, totaling $388.8 million. Like Globalive, Québecor is a newcomer to wireless but a well-known player in the Canadian market with diverse offerings. It also emerged as the leading bidder for a block covering Toronto that, if it wins, would catapult it to national status. The Toronto spectrum where Québecor was winning is part of the spectrum the Canadian government set aside for wireless newcomers. Wireless service in Canada is considered to be among the most expensive in the world, particularly for data, and the government hopes that by encouraging new market entrants competition will result in lower prices. Currently, Canada's three incumbents - Rogers Communications, Bell Canada and Telus - hold 94 percent of the market.

Canada-based In Motion's onBoard Mobile Gateway reportedly provides first responders with mobile, secure, wireless local area networks, called "vehicle area networks". The gateway enables a range of first responder devices, including laptops, video surveillance equipment, vehicle diagnostics and such medical devices as ECGs to communicate with others. The gateway automatically senses and selects the best available wireless network - cellular, 3G, 4.9 GHz or 700 MHz - to send voice, video and data from a moving emergency vehicle. The company says public-safety organizations that have deployed the gateway have seen improved communications and emergency operations, and reduced response times.

In May Public Safety Canada activated the International Disasters Charter "Space and Major Disasters" to use the two Radarsat satellites to monitor flooding in New Brunswick. According to the Canadian Space Agency (CSA), this was the first time the advanced capabilities of Radarsat-2 were used in an emergency context,

In late October, the Big Sky Astronomical Society of Canada held the grand opening of its observatory in Alberta. The press stated that “stargazing events" are to begin next year at the Big Sky Observatory, to coincide with the International Year of Astronomy, which is a United Nations initiative designed to rekindle world-wide interest in astronomy on the year marking the 400th anniversary of the first use of an astronomical telescope by Galileo Galilei.

(c) Colombia

Ciro Arévalo Yepes was elected Chairman of the United Nations Committee on the Peaceful Uses of Outer Space (UNCOPUOS). Ambassador Arévalo has been the delegate of Colombia to UNCOPUOS for several years.

(d) Ecuador

The Ecuadorian Civilian Space Agency - *Agencia Espacial Civil Ecuatoriana* (EXA) was established on 1 November 2007. It is the organization in charge of administering and executing the Ecuadorian civilian space programme and conducting scientific research on space and planetary sciences; and is a mixed capital non-profit organization (50% civilian and 50% of the Ecuadorian government through the Ecuadorian Air Force). Among its staff members, EXA includes the first Ecuadorian trained astronaut, Ronnie Nader.

The Ecuadorian Civilian Space Program has three phases: Suborbital, Orbital and Lunar; in the Suborbital phase three manned missions are planned; in the Orbital phase at least two manned missions and three unmanned missions are envisaged; and the Lunar phase consists of four unmanned and one manned mission. ESAA-01, the first suborbital mission is set for 2009 and the experiments for this mission have been assigned to the Ecuadorian Air Force. All the manned and unmanned missions in the Ecuadorian space programme involve scientific experiments developed in the country with the objective, according to EXA, to encourage the scientific and technological development of the country and to inspire the next generations of Ecuadorian scientists, engineers and explorers (see also http: www.exa.ec).

Ecuador became a member of the International Astronautical Federation during the 59th IAF’s Congress held in Glasgow, Scotland from 29 September to 3 October 2008.

(e) Mexico

Mexico passed a law in November, allowing for the establishment of the Mexican Space Agency, Agencia Espacial Mexicana (AEXA). The agency was first proposed in April 2006, but was not approved at that time. A vote of approval by the Mexican Chamber of Senators was expected in December 2007 but the law creating this entity received full approval on 4 November. AEXA intends to continue the research of the

former National Commission for Outer Space - *Comisión Nacional del Espacio Exterior* (CONEE), which existed between 1962 and 1977. AEXA will function as a public entity, with technical autonomy; its management will be under the *Secretaría de Comunicaciones y Transportes.*

The Mexican Space Agency is intended as an organization specializing in technology, charged with the promotion, coordination and encouragement of all matters relating to the research, exploration and use of outer space, in the interest of preserving this knowledge as a heritage to the Mexican nation. The space agency also aims to benefit educational institutions as it will raise academic standards, which in turn can have a positive impact in the industrial sector and for society as a whole. AEXA enjoyes the support of an interdisciplinary group formed by institutions such as the National Autonomous University of Mexico (UNAM), the Science and Technology National Council (CONACYT), the National Polytechnic Institute (IPN), as well as many other companies and entrepreneurs who continue to join the initiative.

In May, Satélites Mexicanos, S.A. de C.V. (Satmex) announced the appointment of Patricio Northland as its new Chief Executive Officer (CEO) in another step to strengthen the company as a leading satellite operator in the Western Hemisphere. With a long history of success in the worldwide telecommunications and satellite industries, Northland has the global experience and knowledge that will enable him to firmly establish Satmex's leadership position, according to Luis Rebollar, Chairman of the Board of Satmex.

(f) Peru

The National Aerospace Research and Development Commission of Peru - *Comisión Nacional de Investigación y Desarrollo Aeroespacial* (CONIDA), is in charge of Peruvian aerospace activities, and is the headquarters of Peruvian space agency. Its scope of work involves research and development of work programmes that contribute to the country's overall progress; promotion of cooperation with other national and international entities in studies as well as in technical and practical research work; and building-up capacity (training personnel) to work in the space sector. CONIDA also forms proposals of national legislation regarding outer space activities. CONIDA has recently undergone a process of restructuring, to boost its international cooperation, and is currently focusing on national capacity building in aerospace sector, while seeking to reactivate earlier agreements with other space agencies**.**

(g) United States

Government

One of the most publicized, and perhaps controversial events in 2008, was the US's destruction of a non-responsive spy satellite that allegedly could pose a danger if it fell down to Earth. The US's action was criticized by China, Russia, and other nations, who remained skeptical as to the real motive for shooting down the satellite. One result of

the destruction was a call from Russia and China to ban the development of weapons in space, something the White House has resisted.

The plan to destroy the satellite was designed to protect populated areas from hazardous rocket fuel aboard the dead satellite, but the attempt again threw into sharp relief the Administration's antipathy to treaties limiting anti-satellite weapons, which put the United States opposite China and Russia, which in February proposed a new pact banning space weapons.

The U.S. notified members and observers to the United Nations Committee on the Peaceful Uses of Outer Space (UNCOPUOS) about the plans prior to and after the interception, that took place on 20 February 2008, including information that almost all of the resultant space debris had fallen to Earth and had not survived re-entry.

A Pentagon report cites effort to counter anti-satellite technologies, with the military increasing its efforts to gather intelligence, fend off cyber-attacks and improve relations with other nations as part of a strategy for keeping the U.S. safe. Defense Secretary Robert Gates's plan maps out six broad areas where improvements must be made. Among these is an imperative to invest in new and improved ways to counter cyber-attacks and anti-satellite technologies that could knock out vital U.S. surveillance spacecraft. Additionally, Gates noted that the Pentagon is funding other improved technologies, including technologies related to fighter jets.

Another issue that is gaining more attention is the amount of space debris, and the need to know what is in orbit. There are now at least 18,000 observable objects orbiting the earth, much of it debris, calling for heightened international co-operation to share information about what was orbiting the Earth.

In January, U.S. President George W. Bush signed a package of directives that will ensure the U.S. export control policies and practices better support the National Security Strategy of 2006. These new directives are aimed at advancing a more efficient and transparent export licensing process and enhance dispute resolution mechanisms, the White House said in a press release. They will also help ensure proper levels of control for continued U.S. economic competitiveness and innovation while protecting national security. The result will be a quickened process for issuing licenses, and a requirement that the State Department make a decision on a license application within 60 days. However, some experts were unconvinced that the measures were sufficient, as the reform fails to address the principal deficiencies of the current system, which are adversely impacting U.S. technology companies.

A report by the Center for Strategic and International Studies, Washington D.C., issued in February, argued that, far from blocking the rise of foreign space capabilities, U.S. export controls tightened nearly 10 years ago, had the opposite effect in some cases. The report found that since the U.S. tightened space technology-transfer rules in 1999 after congressional investigators found China had acquired sensitive technologies from U.S.-built commercial satellites then being launched by the Chinese, the U.S.'s share of

global space markets has been steadily declining and U.S. companies are increasingly hard-put to cash in on foreign markets. However, the study also said that the overall financial health of the top manufacturers in the U.S. space industrial was 'good' despite the U.S. industry's loss of share overseas; and that the U.S. space industrial base was largely dependent on U.S. national-security spending.

Federal Communications Commission (FCC)

The FCC adopted a Third Further Notice of Proposed Rulemaking (NPRM) in November that proposes licensing the 700 MHz D-block spectrum as part of a revised 700 MHz public/private partnership. In doing so, the Commission believes it can maximize the public-safety and commercial benefits of a nationwide, interoperable broadband network in the 700 MHz band. The FCC sought comment in May on whether it should revise the 700 MHz public/private partnership and to re-auction this spectrum. These rules included the creation of a 10-megahertz license in the D block to be part of a public/private partnership with the adjacent 10 megahertz of spectrum dedicated to a public-safety broadband license. To help ensure that all aspects of this critical initiative are given careful consideration, the FCC now seeks additional public comment on this latest proposal, which was largely developed from the input, ideas and recommendations received from public-safety organizations and officials, government representatives, wireless carriers and manufacturers across the country.

A primary goal of the Commission is to promote the deployment of a broadband network that provides maximum coverage to first responders across the country. This notice proposes to retain a public/private partnership framework for the 700 MHz band absent other sources of funding. The FCC also proposes to use the competitive bidding process to determine whether, based on greatest population coverage and highest bid(s), the D-block spectrum would be licensed to a single licensee on a nationwide basis or to regional licensees on the basis of 58 public-safety regions. The notice also proposes that the public-safety broadband licensee should remain a non-profit entity, and that certain restrictions be imposed on its business relationships to avoid the potential for conflicts of interest.

NASA

NASA celebrated its 50th anniversary this year, as it was in 1958 when President Lyndon B Johnson signed “The NASA Act”, creating this agency. Many articles in aerospace journals and other events were dedicated to this milestone anniversary. Unfortunately NASA is also facing some financial problems. According to the Agency's latest report to Congress, two-thirds of NASA's major new programmes are significantly over budget or behind schedule. NASA is facing a budget that is nearly stagnant, and 4 of its 12 new major projects are over budget. A further eight are behind schedule to the point where lawmakers needed to be notified. Under threat of cancellation is the Glory climate satellite, due in part to a 31 percent cost overrun in Glory and rise in development costs of the Mars Science Laboratory. While some of the problems are not NASA's fault, as a result of the budgetary shortfall, NASA could reduce pre-flight testing; strip planned

scientific sensors from over-budget spacecraft and scale back operations of older space missions.

In October, President Bush signed into law the 2008 NASA Authorization Act. The Act stipulates, among others that a report on the U.S. industry's ability to develop rocket engines has to be supplied to the U.S. Congress by 15 January 2009, assessing the capacity of the U.S. industrial base for development and production of engines to meet requirements for space launch vehicles. The report also has to include information on engine developments for suborbital and small, medium, and heavy lift rockets. The full text of the Act can be found at http://thomas.loc.gov/.

On 16 July NASA announced the establishment with the China National Space Administration (CNSA) of joint Earth and space science working groups, following up on NASA Administrator Michael Griffin's September 2006 visit to China (see prior reports). The focus will be on data from missions already being pursued; no new joint missions are contemplated. The goal of the cooperative effort is to reduce mission cost and duplication and advance scientific knowledge. On 8 September China and the U.S. renewed space cooperation negotiations aimed at the formation of a potential landmark long-term and stable relationship, by adding a framework for broader cooperation to the previously established joint working groups on space science and Earth science.

On 29 July eight countries signed a landmark agreement with the United States to carry out lunar exploration. The agreement allows NASA to share the costs of a multinational fleet of robot spacecraft returning to the Moon in coming years. Signing the agreement were Canada, France, Germany, India, Italy, Japan, South Korea, and the United Kingdom. They will work with NASA on building and operating a network of sensor-stuffed robotic lunar probes that will monitor, measure, and analyze the moon's surface and subsurface. Japan is expected to launch the first of the spacecraft, a rover, by 2012, with two American landers, called the NASA Anchor Nodes, following soon after.

NASA, together with the Massachusetts Institute of Technology, is designing a U.S. satellite mission to map the Earth's soil moisture. The NASA Soil Moisture Active-Passive satellite will also obtain freeze-thaw measurements - all data essential to the accuracy of weather forecasts and predictions of global carbon cycle and climate. The satellite is scheduled for a December 2012 launch.

A lunar base could be built from waterless concrete composed entirely of moon dust, according to U.S. researchers. Engineers at the University of Alabama, Huntsville, and the Marshall Space Flight Center, developed a new method that involved mixing sulfur to lunar dust, which was heated to form concrete. The mixture was strengthened when silica was added. NASA's Goddard Space Flight Center previously developed its own concrete method, which would require a supply of epoxy to be shipped to the moon, but once that is done it is simpler to make, because it does not require a power source to bake sulfur out of lunar soil, and melt the concrete mixture.

A NASA-funded study of mice found that so-called high linear-energy-transfer (LET) radiation in space can do more harm to living cells than the low-LET radiation that people encounter more commonly on Earth, and also saw evidence of premature aging. Researchers plan to continue studying the issue of radiation and cancer risk, as understanding if high-energy radiation affects living cells the same way as low-energy radiation should help NASA begin to plan around the problem and develop appropriate medical or shielding technologies.

NASA awarded a launch contract to SpaceX, separate from the COTS contract SpaceX already has. The new agreement allows SpaceX to compete to be the launch provider for NASA's science and exploration missions. The contract also allows NASA to order services from SpaceX through 2010 for flights that will take place through 2012. The contract is an indefinite delivery/indefinite quantity contract for launch services on the company's Falcon 1 and planned Falcon 9 launch vehicles that would support NASA's Science, Space Operations and Exploration Systems directorates.

NOAA

The U.S. National Oceanic and Atmospheric Administration (NOAA) will lead an international effort to pinpoint the location more than 40 GPS satellites in orbit, NOAA announced in January. For the next four years, NOAA's National Geodetic Survey will serve as the analysis center coordinator for the International Global Navigation Satellite Systems Service, a voluntary federation of more than 200 organizations that provide continuous global satellite-tracking data. NOAA personnel will compile and analyze data from 10 analysis centers around the globe to ensure the accuracy of GPS information at the centimeter level, which is necessary for scientific work, rather than the current meter-level data. The information, which will not be available in real-time, will be used for such disparate jobs as measuring levee height and plate tectonic movement.

US Government and Commercial Space Transportation

A commercial human spaceflight safety report for Congress has recommended that new legislation should be passed to put the US government's National Transportation Safety Board's (NTSB) role of lead agency for space vehicle accident investigations on a legal footing. The safety report, which was a requirement of 2004 Commercial Space Launch Act Amendment, was to be submitted to the relevant US Senate and House of Representatives committees in December.

The Federal Aviation Administration’s (FAA) Commercial Space Transportation Office has taken a higher profile over the past several years, thanks to the rise of private-sector space ventures. In an interview in August, the Administrator for this Office discussed the potential future transition to commercial space transportation, and how the FAA might balance between airplanes and spaceships in the next 50 years. He also addressed the FAA's regulatory authority involving spaceflight, as well as the FAA's role in the Commercial Orbital Transportation Services program and the Google Lunar X Prize, among other topics.

US Public/Private Sector

New Mexico's effort to build the world's first commercial spaceport is nearly on schedule to open in late 2010, and Virgin Galactic already has more than 275 customers who have paid $35 million total to book seats on spaceships that would launch from the high desert site, once the federal government grants the permits, according to New Mexico Spaceport Authority. The authority has the $200 million it needs from the state and county governments. There is debate over the spaceport's proposed location and what effect it will have on the local El Camino Real trail. Officials have tried to address the concerns with a design that would make the main spaceport facility invisible from the trail, but what the final environmental impact statement will say will not be known until the end of the year.

In January, Sir Richard Branson and the aerospace designer Burt Rutan unveiled a model of SpaceShipTwo, the vehicle they hope will be able to take passengers about 62 miles above Earth for the fun of it, with test flights possibly beginning later this year. Rutan said his firm, Scaled Composites, is building at least five of the suborbital vehicles and two WhiteKnightTwo carriers for Virgin Galactic, and hopes to build at least 40 SpaceShipTwos and 15 carrier craft over the next 12 years. Each spacecraft is designed to fly twice a day, with their WhiteKnightTwo carriers capable of up to four daily launches.

Dish Network Corp.

In March Dish Network Corp. suffered a setback after AMC-14, a newly launched satellite aboard a Proton rocket failed to reach its intended orbit. This resulted in fewer HD channels for Dish and potentially lower revenue to EchoStar. Although it could use its rockets to correct the orbit, doing so would substantially reduce its service life. SES officials were optimistic that, with the help of satellite builder Lockheed Martin Commercial Space Systems, AMC-14 could be raised to its operational orbit to meet its customers' requirements. EchoStar has fully leased the AMC-14 satellite. The Russian press noted that AMC-14 was unlikely to reach the designated orbit from its current position, and that fuel supplies on board the satellite and the power of its engines were not enough to raise its orbit another 8,000 kilometers above the Earth to provide effective signal coverage for the designated regions of the U.S. Proton's failure could affect launch industry, since satellite operators again face a dearth of launch capacity, and International Launch Services (ILS) faces new questions about the reliability of manufacturing and launch processes. The failure could push up satellite insurance rates and lead to a new increase in launch prices, and set back ILS plans to orbit six or seven satellites in 2008. The accident will probably delay the following launches of Rokot and Soyuz (commercial modification).

Globalstar

In February Globalstar Inc. signed an agreement to provide customers of Atmospheric Systems Corp. (ASC) with data. Under the agreement, ASC will integrate the Globalstar GSP-1620 satellite data modem as part of ASC's Doppler Sodar (Sonic

Detection and Ranging) product line, which is designed to monitor and collect data within the atmospheric boundary layer. The system emits acoustic pulses and records the corresponding atmospheric echo to determine wind speed, wind direction and turbulence profiles at as many as 50 user-selected altitudes. Using the Globalstar satellite network, these readings are then relayed to the customer via e-mail.

The Globalstar constellation of satellites is a quantum improvement in the transfer of critical atmospheric wind and system status information in a timely manner for our customers, according to ASC. The ability to work with one communications provider to cost effectively support our worldwide customer base is a unique capability that is only available through the Globalstar network.

In October, Globalstar awarded Ericsson Federal Inc., which offers technology and services to telecom operators, a $22.7 million contract to develop, implement and maintain a ground interface or core network system to be installed at Globalstar's satellite gateway ground stations. Globalstar is one of two mobile satellite systems providing global coverage via non-geostationary satellites.

ICO Global Communications

The long-awaited trial between ICO Global Communications and Boeing Satellite Systems International (BSSI) began on 16 June. ICO sued BSSI's parent company for over $2.4 billion, claiming default on a 13-year-old contract to build and launch ICO's 12-satellite constellation. Ten of the spacecraft are still in storage at BSSI's plant; six are claimed to be 98% completed and the other four from 75% to 95% finished. Only one was launched, and is in a medium-altitude Earth orbit. Boeing filed a countersuit against ICO, claiming that the contract's collapse was ICO's fault, not BSSI's. The jury found in ICO's favor on 21 October, awarding ICO $370.6 million in damages, including $279 million for breach of contract and fraud with regard to satellite pricing and $91.6 million for fraud with regard to launches. The jury also awarded ICO $91.6 million in damages against parent company Boeing for tortuous interference, subject to further proceedings. Furthermore, it found that Boeing should pay prejudgment interest and could be liable for punitive damages as well. The jury convened on 28 October to determine whether punitive damages should be awarded, and on 31 October awarded ICO another $237 million in such damages. Boeing filed an appeal; the appeal process can be expected to take several years.

Iridium

In September, Iridium was purchased by an investment bank, Greenhill & Co., in a complex $591 million reverse-merger deal. This deal will erase the last of Iridium's debt and will provide the cash needed to fund the satellite communications company's launch of a new constellation of satellites to create an IP network in the sky.

Iridium's venture into mobile satellite communications cost it at least US $5 Billion; the company defaulted on $1.5 billion in loans and filed for bankruptcy in

August 1999. Motorola and the current Iridium Holdings took over the Iridium satellite venture from the bankruptcy court for a token $25 million in 2001. The biggest impact of this purchase is the fact Iridium not only clears its debt, but it won't have to go deeper into debt to launch its planned "Iridium NEXT" satellites, which are to replace the current fleet. NEXT, announced in February 2007 and currently in design, is to have 66 cross-linked, secure satellites using end-to-end IP technology. Iridium had some $261 million in revenue last year; about 11 percent of its revenue came from U.S. Department of Defense contracts and the rest from commercial customers.

Lockheed Martin

The sixth GPS 2R satellite built by Lockheed Martin was launched on March 15. The satellite, placed in orbit by a United Launch Alliance Delta 2 rocket, carries a modernized antenna panel to provide increased signal power to receivers on the ground, two new military signals for improved accuracy, enhanced encryption and anti-jamming capabilities for the military, and a second civil signal. This was the third launch of a GPS 2R-M satellite in less than five months and is one of the final three Block II2-M satellites planned for launch in 2008. The final satellite, which includes a demonstration payload that will provide a temporary on-orbit demonstration for the new L5 civil signal completed final integration testing in preparation for a launch in June.

NextGen Mobile LLC

NextGen Mobile LLC, comprised of 28 independent U.S. wireless carriers and commercial wireless licensees, aims to help promote the existence of small and rural wireless companies throughout the country. The company grew out of a year-long dialog between existing mobile operators and winners of Advanced Wireless Services (AWS) and 700 MHz licenses in recent FCC auctions. All members of NextGen Mobile operate, or anticipate operating, GSM networks, including UMTS and, eventually, LTE.

According to the new company, one of its first goals is to decrease the operational costs associated with deploying and maintaining a next-generation, high-speed wireless network. Another top priority is to buy “leading edge” UMTS devices as they come to market. NextGen Mobile wants to grow; prospective members, while not required to own any spectrum, must be in sync with the group’s goals of building wireless networks in small and rural markets.

NextWave Wireless Inc.

NextWave Wireless Inc. plans to sell its Advanced Wireless Service (AWS) licenses, its Wireless Communication Service (WCS) licenses and its Educational Broadband Service (EBS) and Broadband Radio Service (BRS) licenses and leases. The San Diego-based company retained Deutsche Bank and UBS Investment Bank to explore the sale of its extensive spectrum holdings in the U.S.

Since the completion of the recent 700 MHz auction by the Federal Communications Commission (FCC), NextWave received multiple offers for its U.S. spectrum assets. Monetizing the value of its substantial spectrum assets would allow the company to further strengthen its balance sheet by retiring debt, and continuing the commercial introduction of a wide range of innovative wireless broadband and multimedia solutions and platforms that are now being deployed commercially worldwide, with many of the largest mobile operators and device manufactures in the world. NextWave's North American spectrum holdings represent an asset that will be highly complementary with the current or planned spectrum holdings of a number of mobile and new entrants who are planning to extend their 3G coverage or acquire spectrum for their 4G rollouts.

The Nasdaq agreed to NextWave's $100 million bail-out plan, allowing the company to proceed without the normal required shareholder approval. NextWave was required to demonstrate to Nasdaq that the delay associated with the effort to secure stockholder approval would have seriously jeopardized the company's financial viability. As of June 28, NextWave had more than $330 million in long-term notes outstanding. Its accumulated deficit was $650.56 million, for a total of about $1billion in liabilities; the global economic downturn affecting even the telecom sector.

Orbcomm

Orbcomm received new regulatory approvals and began offering low earth orbit (LEO) satellite services in El Salvador, Guatemala and Panama, the company announced in January. Orbcomm had already received regulatory authorizations in Argentina, Bolivia, Brazil, Chile, Colombia, Mexico, Paraguay, Peru, Uruguay and Venezuela. Latin America represents an important market for Orbcomm's Resellers, who have been eagerly awaiting this announcement. Orbcomm is now able to offer very high quality low-cost services in even more countries and expects additional new country regulatory approvals to be issued in the near future.

Satellite broadband

Satellite broadband witnessed success in the market, with offerings by WildBlue and Hughes reaching thousands of customers in North America, bolstered by a recent deal struck between ViaSat and Eutelsat to launch an all-Ka-band satellite covering Europe. One of the biggest problems facing satellite companies who want to work in Ka-band is the lack of capacity. WildBlue, which provides broadband Internet access for customers in the rural United States and Canada, announced last year that it had sold out capacity in some regions.

Sea Launch

Sea Launch resumed its launches in January, putting the Thuraya-3 mobile communications satellite in orbit. Sea Launch was forced to abandon an earlier attempt to launch the satellite when unusually strong currents forced the ship to return to port. Sea

Launch's Zenit-3SL rocket resumes operations with this flight, following an unsuccessful launch in January 2007.

SES Americom

Ed Horowitz resigned as president and CEO of SES Americom, parent company to SES announced in May. Mr. Horowitz will join Global Entertainment and Media Holdings Corp. In the interim, Romain Bausch, SES CEO and chairman of the SES Americom board will oversee SES Americom in conjuction with the company's Americom's management committee, Horowitz was instrumental in the further integration of SES Americom into the SES family and in developing new market areas such as IP-Prime.

X Prize

X Prize will expand the scope of competitions, according to co-founder Peter Diamandis, who says he's aiming for two new prizes every year, focusing on five fields, one of them being lunar exploration. The X Prize Foundation has also been involved with other projects, ranging from a feasibility study for an orbital space prize to the Northrop Grumman Lunar Lander Challenge, which carries a $2 million purse put up by NASA.

(n) Uruguay

The Law School of the Universidad de la República has created a website for the virtual Regional Center of Space Law Studies (CREDE) that was established pursuant to the Declaration of Montevideo, signed by Argentina, Brazil and Uruguay in 2007.

In April Uruguay hosted several NASA-sponsored competitions, geared towards the technical and engineering aspects of space activities. These included the Space Settlement Design Competition (SSDC) and the Latin American Space Challenge - *Desafío Espacial Latinoamericano* (DESLA); 27 projects from several countries were presented, mostly from Argentina, Chile, Paraguay, Peru, Brazil and Uruguay. *The Centro de Investigación y Difusión Aeronáutico-Espacial* (CIDAE) was host to the semifinals of the SSDC and the finals of the DESLA competitions. In the NASA Ames Research competition, in which 840 students from 12 countries participated, Uruguay's "ECÓPOLIS" project won first prize.

Dr. Martha Gaggero of CIDAE participated in the 18th UN/IAF Workshop on "Integrated Space Technology Applications – Support to Managing Potentially Hazardous Events", which took place during the 59th International Astronautical Congress in Glasgow, Scotland, end September; with the presentation entitled "Risks: from disaster to opportunity".

Spaceweek Uruguay 2008 took place from 4 to 10 October, with the participation of numerous pre-university students from many schools.

(o) Venezuela

Venezuela's first satellite, Simon Bolivar (Venesat-1) was launched on 30 October, on board a Long March 3B launch vehicle from the Xichang Satellite launch center in Sichuan province. The satellite, manufactured by China Aerospace Science and Technology Corp. (CASC), is based on the DFH-4 bus. It was built pursuant to an agreement signed in November 2005. The satellite consists of 12 C-band and 14 Ku-band transponders, and will be used for government and military communications and to give remote areas of Venezuela access to telephone communications, fax, videoconferencing, high-speed Internet, radio, tele-medicine and tele-education. Venesat 1 has a design life of 15 years and will operate at the 78º E orbital position, ceded to Venezuela by Uruguay in an agreement signed several years ago by which Uruguay ceded its orbital location to Venezuela in exchange for the use of 10% of Venezuelan satellite capacity.

PART THREE

PROGRESS IN SPACE RESEARCH 2007-2008

I. SPACE STUDIES OF THE EARTH'S SURFACE, METEOROLOGY AND CLIMATE

This chapter provides an overview of the contributions and main scientific achievements related to the studies of the Earth's surface, meteorology and climate from space for the period covering 2007-2008.

Monitoring of global change requires space-borne observations of the Earth and associated co-ordinated international collaborations. We provide an overview of the most relevant international committees, groups, and partnerships, relevant for Earth Observation. It is important to stress that there is currently a steadily increasing effort in this area, and most notably, several parallel groups and initiatives have started to pool their efforts in order to establish a most efficient strategy for space-based observations. COSPAR Commission A is present in all these activities as a member or partner (via the COSPAR Secretariat) and through several of its officers who play an active role in these initiatives.

In addition to these policy-related activities, in 2007-2008, several new satellites were launched for the study of the atmosphere, of terrestrial surfaces and/or clouds; some of these were principally devoted to meteorological applications and to climate studies. Relevant satellites launched into space in this period are discussed in this chapter together with their characteristics and their primary application domains.

A selection of scientific highlights is then given to provide some examples of the latest findings for which remote sensing data from space proved to be crucial. This is followed by some concluding remarks in the last section.

I.1. Earth Observation Policy: Overview and current developments

I.1.1. GEO and GEOSS

The Group on Earth Observations (GEO) is co-ordinating efforts to build a Global Earth Observation System of Systems (GEOSS). GEO was launched in response to calls for action by the 2002 World Summit on Sustainable Development and by the G8 (Group of Eight) leading industrialized countries. These high-level meetings recognised that international collaboration is essential for exploiting the growing potential of Earth observations to support decision making in an increasingly complex and environmentally stressed world. GEO is a voluntary partnership of governments and international organizations. It provides a framework within which these partners can develop new projects and co-ordinate their strategies and investments. As of July 2008, GEO's Members include 74 Governments and the European Commission. In addition, 51 inter-governmental, international, and regional organizations (including COSPAR) with a

mandate in Earth observation or related issues have been recognised as Participating Organizations.

GEOSS is the focus of the GEO effort and includes Earth observations, Earth system models and information products and services. The GEO plan envisions major advances in the GEOSS over the next ten years accomplished by collaboration and co-ordination of investments by nations around the world. The Committee on Earth Observation Satellites (CEOS, see below) is responsible for co-ordinating the development of the space segment of the GEOSS.

An important initiative resides in the concept of Virtual Constellations for GEO, which has been established with a view to harmonise and maximise efforts among space agencies to deploy Earth observation missions as part of GEOSS and to address emerging data gaps. A Virtual Constellation is a set of ground or space-based assets from different partners that are mobilized in a co-ordinated manner for greater efficiency. The Virtual Constellation concept also provides a process by which international cooperation among space agencies is stimulated to define a co-ordinated response to the space-based observation needs focusing on a particular thematic area. A series of four prototype Virtual Constellations (namely, Land-Surface Imaging, LSI; Constellation for Precipitation, PC; Ocean Surface Topography, OST; and Atmospheric Composition, AC) are currently under definition by CEOS members and participating organizations, in consultation with their respective user communities. Two more Virtual Constellations (Ocean Colour Radiometry, OCR, and Ocean Surface Vector Winds, OSVW) are in preparation.

The 4th Plenary Session of the Group on Earth Observations (GEO-IV) took place in Cape Town (South Africa) in November 2007. The 5th Plenary Session of the Group on Earth Observations (GEO-V) and its side events took place in Bucharest (Romania) in November 2008. For more information see: http://earthobservations.org.

I.1.2. CEOS

The Committee on Earth Observation Satellites (CEOS) is an international mechanism charged with co-ordinating international civil space-borne missions designed to observe and study planet Earth. Comprising 26 Members (most of which are space agencies) and 20 Associates (associated national and international organisations), CEOS is recognised as the major international forum for the co-ordination of Earth observation satellite programmes and for interaction of these programmes with users of satellite data worldwide. CEOS was created in 1984 in response to a recommendation from the Economic Summit of Industrialised Nations Working Group on Growth, Technology, and Employment's Panel of Experts on Satellite Remote Sensing. This group recognized the multidisciplinary nature of satellite Earth observation and the value of co-ordination across all proposed missions. Convened under the original name of International Earth Observations Satellite Committee (IEOSC), the organisation combined the previously existing groups for Co-ordination on Ocean Remote-Sensing Satellites (CORSS) and Co-

ordination on Land Observing Satellites (CLOS) and established a broad framework for co-ordinating all space-borne Earth observation missions.

The three primary objectives of CEOS are as follows: (1) to optimise benefits of space-borne Earth observations through co-operation of its participants in mission planning and in development of compatible data products, formats, services, applications, and policies; (2) to serve as a focal point for international co-ordination of space-related Earth observation activities; and (3) to exchange policy and technical information to encourage complementarity and compatibility of observation and data exchange systems.

The 21st CEOS Plenary Meeting took place in Hawaii (USA) in November 2007. The 22nd CEOS Plenary Meeting was held in November 2008 in George (South Africa). For more information see: http://www.ceos.org.

I.1.3. IGOS

The Integrated Global Observing Strategy (IGOS) Partnership was established in June 1998 by a formal exchange of letters among the 13 founding Partners (CEOS, FAO, GCOS, GOOS, GOS/GAW, GTOS, ICSU, IGBP, IGFA, IOC-UNESCO, UNEP, UNESCO, WCRP, WMO) for the definition, development and implementation of the Integrated Global Observing Strategy.

The principal objectives of the IGOS are to address how well user requirements are being met by the existing mix of observations, including those of the global observing systems, and how they could be met in the future through better integration and optimisation of remote sensing (especially space-based) and in-situ systems. The IGOS serves as guidance to those responsible for defining and implementing individual observing systems. Implementation of the Strategy, i.e. the establishment and maintenance of the components of an integrated global observing system, lies with those governments and organisations that have made relevant commitments, for example, within the governing councils of the observing systems' sponsors.

To aid the development of the Strategy, the Partners have adopted an incremental "Themes" approach based on perceived priorities. Approved IGOS Themes are (as of October 2008): Atmospheric Chemistry, Carbon, Geohazards, Ocean, and Water Cycle. In preparation are: Coastal, Cryosphere, and Land. These IGOS Themes are currently transferred to GEO.

The 14th IGOS-P Session took place in Paris (France) in May 2007. The IGOS P14-bis meeting took place in Cape Town (South Africa) in November 2007. The last meeting of IGOS-P took place in Paris in May 2008. Together with the transfer of the IGOS Themes to GEO a closure of the Partnership has been proposed.
For more information see: http://www.igospartners.org.

I.1.4. GMES (Kopernikus)

Kopernikus, formerly known as the Global Monitoring for Environment and Security (GMES) initiative, is the European participation in the worldwide monitoring and management of planet Earth, and the European contribution to the Group on Earth Observation (GEO). Kopernikus is based on observation data received from Earth Observation satellites and ground based information. These data will be co-ordinated, analysed and prepared for end-users. Kopernikus represents a concerted effort to bring data and information providers together with users, so they can better understand each other and make environmental and security-related information available to the people who need it through enhanced or new services.

Kopernikus is being built up gradually: it starts with a pilot phase which targets the availability of a first set of operational GMES services by 2008 followed by the development of an extended range of services which meet user requirements. In the period 2004-2008, the following services where implemented: (1) "Fast Track Services" (FTS) - Emergency Response Core Service (ERCS), Land Monitoring Core Service (LMCS), and Marine Core Service (MCS); (2) "Pilot Services" in particular in two areas, namely, Atmospheric Composition and Dynamics Monitoring, and Information Services for Security-related Activities.

The Forum GMES 2008 held in Lille on 16-17 September 2008 marked the launch of the first Kopernikus services in pre-operational mode: Marine Environmental Services, Atmospheric Environmental Services, Land Environmental Services, Support to Emergencies and Humanitarian Aid, and Support to Security-related Activities. For more information see: http://www.gmes.info/.

I.2. Earth Observation space missions in 2007-2008 (selection)

I.2.1. Calipso (launch 28.04.2006)

The Calipso (Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observation) satellite was launched on 28 April 2006. Calipso is a joint NASA and CNES satellite mission designed to provide new information on the role that clouds and atmospheric aerosols play in the Earth's weather, climate, and air quality. Calipso consists of three co-aligned nadir-viewing instruments: (1) the Cloud-Aerosol Lidar with Orthogonal Polarization (CALIOP) is a 2-wavelength polarization-sensitive lidar that provides high-resolution vertical profiles of aerosols and clouds; (2) the Imaging Infrared Radiometer (IIR) is a nadir-viewing, non-scanning imager with a 64 km by 64 km swath and a pixel size of 1 km; (3) the Wide Field Camera (WFC) which is a fixed, nadir-viewing imager with a single spectral channel covering the 620-720 nm region, selected to match band 1 of the MODerate resolution Imaging Spectro-radiometer (MODIS) instrument on Aqua (launched in May 2002). The last two years have demonstrated that Calipso provides data of unprecedented quality and vertical resolution concerning clouds and aerosols.

I.2.2. CloudSat (launch 28.04.2006)

The NASA/CSA CloudSat was launched on 28 April 2006 at the same time as Calipso becoming part of the A-Train constellation. CloudSat's primary goal is to furnish data needed to evaluate and improve the way clouds are parameterised in global models thereby contributing to better predictions of cloud development and thereby improving understanding of their role in influencing climate change through what is referred to as cloud-climate feedback. The CloudSat Mission was jointly developed by NASA, JPL, CSA, the Colorado State University, and the US Air Force. CloudSat's payload, the Cloud Profiling Radar (CPR), is the first spaceborne 94-GHz (W-band) radar, which provides unique information about the vertical cloud profiles over the globe.

CPR has been acquiring the first-ever, continuous global time series of vertical cloud structures and vertical profiles of cloud liquid water and ice content and precipitation incidence. The vertical resolution is 485 m and the spatial resolution is defined in terms of the antenna 3 dB footprint being 1.4 km. In order to take full advantage of observations by other types of space-borne atmospheric remote sensing instruments, the CloudSat spacecraft flies in formation as part of the Afternoon Constellation of satellites (the so called A-Train). In particular CloudSat flies in close formation with CALIPSO, which carries a lidar system, so that their respective beams cover the same vertical column within about 15 seconds.

I.2.3. MetOp (launch 19.10.2006)

Launched on 19 October 2006, MetOp is Europe's first polar-orbiting satellite dedicated to operational meteorology. It represents the European contribution to a new co-operative venture with the USA providing data to monitor climate and improve weather forecasting. MetOp is a series of three satellites to be launched sequentially over 14 years, forming the space segment of EUMETSAT's Polar System (EPS). MetOp carries a set of 'heritage' instruments provided by the USA and a new generation of European instruments that offer improved remote sensing capabilities to both meteorologists and climatologists. The new instruments will augment the accuracy of temperature humidity measurements, readings of wind speed and direction, and atmospheric ozone profiles.

MetOp flies in a polar orbit corresponding to local 'morning' while the USA will be responsible for 'afternoon' coverage. The series will provide data for both operational meteorology and climate studies. The combination of instruments on board MetOp has remote sensing capabilities to observe the Earth by day and night as well as under cloudy conditions.

The instruments aboard MetOp that provide data with very high spatial and temporal coverage include: an Infrared Atmospheric Sounding Interferometer (IASI) to derive humidity and atmospheric temperature profiles in the troposphere and lower stratosphere; a Global Navigation Satellite System Receiver for Atmospheric Sounding (GRAS) providing a minimum of 500 atmospheric profiles per day through a process of

Global Positioning Satellite (GPS) radio occultation; an Advanced Scatterometer (ASCAT) that measures wind speed and direction over the ocean; the Global Ozone Monitoring Experiment-2 (GOME-2), a spectrometer that collects light from the Sun to derive the atmospheric profiles of ozone, nitrogen dioxide, water vapour, oxygen, bromine oxide and other gases. The meteorological instruments also include AMSU-A1 and AMSU-A2, HIRS/4, AVHRR/3, MHS and SEM-2.

I.2.4. TerraSAR-X (launch 15.06.2007)

TerraSAR-X is an X-band SAR (Synthetic Aperture Radar) mission for scientific research and applications. It is the first satellite to be built in a public/private partnership in Germany. It carries the experimental Tracking, Occultation and Ranging (TOR) package provided by GFZ and CSR. TOR consists of a two-frequency CHAMP type GPS receiver and a CHAMP Laser Retro-Reflector (LRR). The mission's objectives are: (1) the provision of X-band SAR-data for scientific research and applications as well as (2) the establishment of a commercial EO-market and to develop a sustainable EO-service business, based on TerraSAR-X derived information products.

TerraSAR-X was launched on 15 June 2007 with the expected lifetime 5 years and has the following instrumentation onboard: (1) Active phased array X-band SAR, (2) Tracking, Occultation, and Ranging (TOR) package (GPS receiver, retroreflector array), and (3) Laser Communication Terminal (LCT).

I.2.5. COSMO-SkyMed (launch 08.06.2007 and 09.12.2007)

COSMO-SkyMed (Constellation of Small Satellites for Mediterranean basin Observation) is planned as a constellation of four Synthetic Aperture Radar satellites for primarily military surveillance, but with products made available to civilian users as well. The system is funded by the Agenzia Spaziale Italiana and the Italian Ministry of Defense. The first satellite uses an X-band radar; later satellites are to be equipped with more sophisticated multi-mode X-, C- L- and P-band instruments. The constellation and associated ground segment are to provide global, all-weather, day-night surveillance coverage of the Earth's surface. Stereo imaging will be possible in a single pass, and ground track repeatability will be better than 1 km. The spacecraft are three-axis stabilized. The Carbon Fibre Reinforced Plastic bus is equipped with two deployable solar arrays and the SAR antenna. A star tracker and a high-quality GPS receiver provide the necessary positional and pointing accuracy. The SAR antenna points 38º to the right of the satellite ground track. The satellites are deployed in Sun-synchronous dawn-dusk orbits, all spacecraft in the same orbital plane. The full constellation will achieve a revisit time of a few hours on a global scale. The COSMO-SkyMed constellation can be operated in a nominal stand-alone configuration or pairs can be operated in an interferometric configuration. The interferometric configuration allows acquisition of 3D SAR imagery by combining radar measurements from two satellites of the same target from slightly different incidence angles. It requires control of the baseline distance between the two satellites with an accuracy of tens of meters. The SAR-2000 radar was built by Alcatel Alenia Space. A swath width of between 10 and 200 km is available,

depending on mode, with any target within 650 km left or right of the ground target being observable.

I.2.6. WorldView-1 (launch 18.09.2007)

WorldView-1 is a commercial Earth observation satellite owned by DigitalGlobe. It was launched on 18 September 2007, and DigitalGlobe plans to launch another, similar, satellite after its construction is finished in late 2008. First imagery from WorldView-1 is expected to be available prior to October 18, the six-year anniversary of the launch of QuickBird, DigitalGlobe's current satellite. WorldView-1 was built by Ball Aerospace & Technologies. Ball Aerospace built the spacecraft bus and the camera (instrument) using the unique off-axis camera design identical to QuickBird with the instrument's focal plane being supplied by ITT Corporation. The camera is a panchromatic imaging system featuring half-metre resolution imagery. With an average revisit time of 1.7 days, WorldView-1 is capable of collecting up to 750,000 square kilometres per day of half-metre imagery.

I.2.7. CARTOSAT-2A and IMS-1 (launch 28.04.2008)

Using ISRO's Polar Satellite Launch Vehicle (PSLV-C9), CARTOSAT-2A and IMS-1 were launched on 28 April 2008 into a 637 km Sun-synchronous orbit.

CARTOSAT-2A is a state-of-the art remote sensing satellite with a spatial resolution of about one metre and swath of 9.6 km. The satellite carries a panchromatic camera (PAN) capable of taking black-and-white pictures in the visible region of the electromagnetic spectrum. The highly agile CARTOSAT-2A is steerable along as well as across the direction of its movement to facilitate imaging of any area more frequently. High-resolution data from CARTOSAT-2A will be invaluable in urban and rural development applications calling for large scale mapping.

The Indian Mini Satellite (IMS-1), flown as an auxiliary payload on board PSLV-C9, has been developed by ISRO for remote sensing applications. Weighing 83 kg at lift-off, IMS-1 incorporates many new technologies and has miniaturised subsystems. IMS-1 carries two remote sensing payloads: (1) A Multi-spectral camera (Mx), and (2) a Hyper-spectral camera (HySI), operating in the visible and near infrared regions of the electromagnetic spectrum. The spatial resolution of the Mx camera is 37 m with a swath of 151 km, while that of HySI is about 506 m with a swath of about 130 km. The data from this mission will be made available to interested space agencies and the student community from developing countries to provide necessary impetus to capacity building in using satellite data. The versatile IMS-1 concept has been specifically developed to carry different payloads in future without significant changes and has a design life time of two years.

I.2.8. OSTM/Jason-2 (launch 20.06.2008)

OSTM/Jason-2 was launched on 20 June 2008 with a United Launch Alliance Delta II launch vehicle from California's Vandenberg Air Force Base. The spacecraft orbit has an altitude of 1,336 km, the same orbit as Jason-1, where it maps 95 percent of the world's ice-free oceans every 10 days. Once OSTM/Jason-2 was in orbit and its data had been calibrated and validated, Jason 1 was moved into a parallel ground track, midway between two OSTM/Jason-2 ground tracks, and the two spacecraft have conducted a tandem mission to further improve tide models in coastal and shallow seas and improve our understanding of the dynamics of ocean currents and eddies. OSTM/Jason-2 is designed to operate for at least three years. At the end of that time, if useful data are still being collected, the mission may be extended by two years, or any additional period agreed upon by the mission partners. The science objectives of Jason-2 are: (1) Extend the time series of ocean surface topography measurements beyond Topex/Poseidon and Jason-1 to complete two decades of high-precision altimetry observations; (2) Determine how ocean circulation varies over long time periods using the combined data record from Topex/Poseidon and Jason-1; (3) Improve the knowledge of ocean circulation that does not change with time; (4) Measure global sea level change; and (5) Improve ocean tide models, including coastal tides.

OSTM/Jason-2 carries five primary science instruments that are similar to or upgraded versions of those flown on Jason-1. The Poseidon 3 altimeter, provided by CNES, is the mission's main instrument. It measures the distance from the satellite to Earth's surface by sending radar pulses to the sea surface and measuring how long they take to bounce back. The speed of ocean surface currents is derived from the dynamic topography measurements. The Advanced Microwave Radiometer, provided by NASA, measures the amount of water vapour in the atmosphere, which can delay the return of radar pulses to the satellite, interfering with sea level measurement accuracy. Three location-finding systems are used to measure the spacecraft's precise position in orbit. These include the following: The Doppler Orbitography and Radio-positioning Integrated by Satellite (Doris) is provided by CNES; the Global Positioning System Payload is provided by NASA, and the Laser Retroreflector Array, is also provided by NASA. Advances in OSTM/Jason-2's instruments will allow scientists to monitor the ocean in coastal regions with increased accuracy, almost 50 percent closer to coastlines than previously possible. Three "passenger," or experimental, instruments are also included on OSTM/Jason-2. In addition to their own scientific objectives, these instruments improve the performance of the Doris location-finding system. The Environmental Characterization and Modelisation-2 (Carmen-2) is provided by CNES. It allows study of the effects of radiation in the satellite's environment on advanced components. The Time Transfer by Laser Link instrument is provided by CNES. It uses a laser link to compare and synchronise remote ground clocks with high accuracy. The Light Particle Telescope is provided by Japan. It enables studies of radiation in the satellite's environment.

I.2.9. RapidEye (launch 29.08.2008)

On August 29, 2008, a DNEPR-1 rocket (a refurbished Inter-Continental Ballistic Missile), was successfully launched from Baikonur cosmodrome in Kazakhstan carrying RapidEye's constellation of five Earth observation satellites designed and implemented by MDA of Richmond, Canada. Since then, the satellites have been undergoing their initial testing and calibration phase, which will last until approximately the end of 2008. RapidEye is a commercial small satellite mission that enables global monitoring of the Earth's surface. The constellation is designed to provide insurance and food companies, farmers, government and other agencies and institutions throughout the world with valuable, up-to-date, customised information products and services of the highest quality. The five satellites are placed in a common Sun-synchronous orbit of 630 km, with the satellites equally spaced about 19 minutes apart in their orbit, ensuring frequent imaging of particular areas of interests. The RapidEye system images any area in the World at all latitudes between +/– 75 degrees within one day and cover the entire agricultural areas of North America and Europe within an average of five days. The multi-spectral push broom style imager onboard each spacecraft provides images of the Earth in five spectral bands, scanning a 78 km swath at 6.5m resolution.

I.3. Selected scientific achievements (atmosphere, ocean, ice, land)

I.3.1. Stratosphere: Global distribution of mean age of stratospheric air from MIPAS

Sulphur hexafluoride (SF_6) is the end product of the photochemistry of man-made fluorine-containing molecules that are injected into the stratosphere (chlorofluorocarbons, CFCs). Global distributions of profiles of SF_6 have been retrieved from limb emission spectra recorded by the Michelson Interferometer for Passive Atmospheric Sounding (MIPAS) on Envisat covering the period September 2002 to March 2004. For the tropical troposphere an increasing trend of 0.230±0.008 pptv/yr has been derived from the MIPAS data.

From the global SF_6 distributions, global daily and monthly distributions of the apparent mean age of air are inferred by application of the tropical tropospheric trend. The inferred mean ages which are a measure of the strength of the Brewer-Dobson Circulation are provided for the full globe up to 90° N/S. The seasonal variation of the mean age indicates episodes of severe intrusion of mesospheric air during polar winter, long-lasting remnants of old, subsided polar winter air over the spring and summer poles, and a rather short period of mixing with mid-latitude air.

This study shows the great potential of long-term observations of the stratosphere using mid-infrared limb sounders for understanding and monitoring of atmospheric dynamics.

See the following references for further information:

Stiller, G. P., T. von Clarmann, M. Höpfner, N. Glatthor, U. Grabowski, S. Kellmann, A. Kleinert, A. Linden, M. Milz, T. Reddmann, T. Steck, H. Fischer, B. Funke, M. López-

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Fischer, H., M. Birk, C. Blom, B. Carli, M. Carlotti, T. von Clarmann, L. Delbouille, A. Dudhia, D. Ehhalt, M. Endemann, J. M. Flaud, R. Gessner, A. Kleinert, R. Koopmann, J. Langen, M. López-Puertas, P. Mosner, H. Nett, H. Oelhaf, G. Perron, J. Remedios, M. Ridolfi, G. Stiller and R. Zander, MIPAS: an instrument for atmospheric and climate research, Atmos. Chem. Phys., 8, 2151-2188, 2008.

I.3.2. Mesosphere: Airglow measurements of OH with the OSIRIS instrument aboard the Odin satellite

The OSIRIS instrument on the Odin satellite was designed to measure scattered sunlight in the atmospheric limb in order to derive trace gas profiles in the upper troposphere and throughout the stratosphere. However, the instrument also detects the airglow and although it only has 1 nm spectral resolution it is possible to detect OH (A-X) resonance emission at 308 nm through a comparison of the band envelope with synthetic model spectra. The initial observations were used to derive the water vapour concentration and to compare the profile with that obtained from solar occultation. The accuracy of the derived profile is dependent on a chemical model. Recently it has been possible to identify the OH prompt emission that is excited in the Lyman-alpha dissociation of water vapour and so obtain a direct measure of the water vapour profile in the mesosphere. Thus the OSIRIS instrument is continuing to provide new information throughout the mesosphere and so improve our knowledge of the terrestrial atmosphere.

For further information, see:

E.J. Llewellyn, N.D. Lloyd, D.A. Degenstein, R.L. Gattinger, S.V. Petelina, A.E. Bourassa, J.T. Wiensz, E.V. Ivanov, I.C. McDade, B.H. Solheim, J.C. McConnell, C.S. Haley, C. von Savigny, C.E. Sioris, C.A. McLinden, E. Griffioen, J. Kaminski, W.F.J. Evans, E. Puckrin, K. Strong, V. Wehrle, R.H. Hum, D.J.W. Kendall, J. Matsushita, D.P. Murtagh, S. Brohede, J. Stegman, G. Witt, G. Barnes, W.F. Payne, L. Piché, K. Smith, G. Warshaw, D.-L. Deslauniers, P. Marchand, E.H. Richardson, R.A. King, I. Wevers, W. McCreath, E. Kyrölä, L. Oikarinen, G.W. Leppelmeier, H. Auvinen, G. Mégie, A. Hauchecorne, F. Lefèvre, J. de La Nöe, P. Ricaud, U. Frisk, F. Sjoberg, F. von Schéele and L. Nordh, The OSIRIS Instrument on the Odin Spacecraft, Can. J. Phys., 82, 411-422, 2004.

R.L. Gattinger, C.D. Boone, K.A. Walker, D.A. Degenstein, P.F. Bernath and E.J. Llewellyn, Comparison of Odin-OSIRIS OH A2Σ+-X2Π Mesospheric Observations and ACE-FTS Water Vapor Observations, Geophys. Res. Letts., 33, L15808, doi:10.1029/2006GL026425, 2006.

M.H. Stevens, R.L. Gattinger, J. Gumbel, E.J. Llewellyn, D.A. Degenstein, M. Khaplanov and G. Witt, First UV satellite observations of mesospheric water vapor, J. Geophys. Res., 113, D12304, doi: 10.1029/2007JD009513, 2008.

R.L. Gattinger, D.A. Degenstein, E.J. Llewellyn, and M.H. Stevens, OH A2Σ+-X2Π band ratios observed in the mesosphere by OSIRIS, Can. J. Phys., 86, 857-862, doi:10.1139/P08-13, 2008.

I.3.3. Troposphere: Distribution of tropospheric O_3 over Europe during the heat wave in the summer of 2007

The first distributions of tropospheric ozone during the heat wave over Europe in the summer of 2007 were observed from mid-infrared spectra recorded by the IASI instrument aboard MetOp (launched in October 2006). The results were validated with balloon sonde measurements and compared with predictions of a numerical model of tropospheric photochemistry. The measurements show very high ozone concentrations over South-Eastern Europe indicating both strong pollution and solar radiation (leading to photo smog).

This demonstration of the feasibility of near-real time tropospheric ozone measurements is an important milestone in the preparation of operational services focusing on Air Quality.

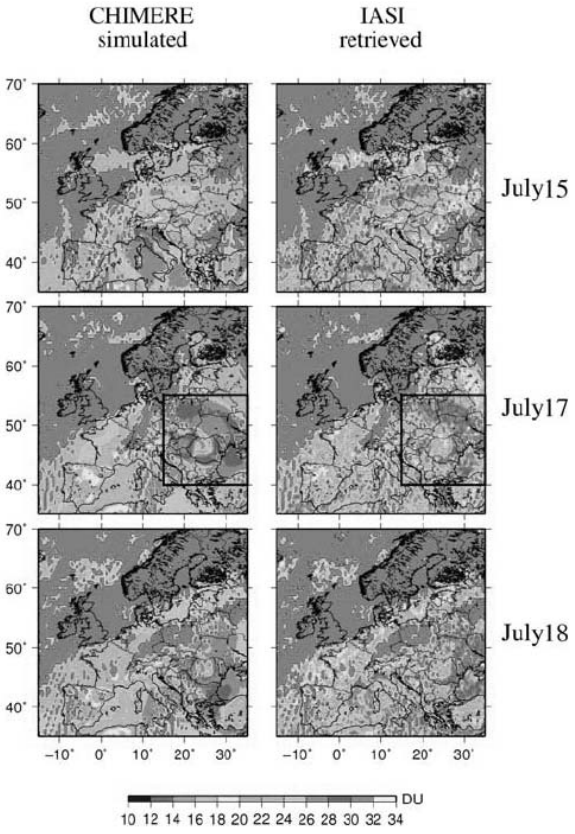

Figure I-1: Tropospheric ozone over Europe (in Dobson Units DU) in July 2007, measured with the IASI instrument aboard MetOp (launched in October 2006); the right panel shows the measured ozone, the left panel shows a prediction using the CHIMERE air quality model developed in France. There are very high values of O_3 over South-Eastern Europe (red and orange colors). Image credit: LISA/CNRS.

For more information, see the following reference:

Eremenko, M., G. Dufour, G. Foret, C. Keim, J. Orphal, M. Beekmann, G. Bergametti, and J.-M. Flaud, Tropospheric ozone distributions over Europe during the heat wave in July 2007 observed from infrared Nadir spectra measured by IASI, Geophys. Res. Lett. 35, L18805, doi:10.1029/ 2008GL034803, 2008.

I.3.4. Oceans: Jason-2 (launched in July 2008) providing complete maps of ocean height

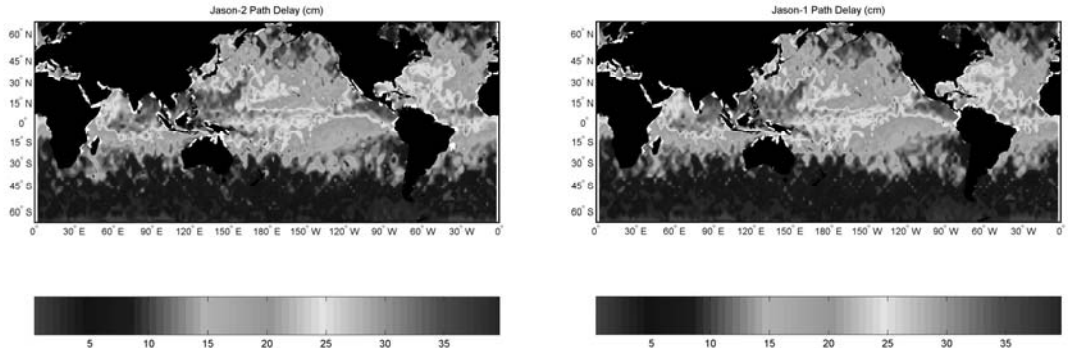

Figure I-2: Images of the path delay from Jason-2 (left) and Jason-1 (right) over the oceans, showing excellent agreement. Image credit: NASA/CNES.

Less than a month after the launch of the Jason-2 ocean altimetry satellite, the Jason-2/OSTM (Ocean Surface Topography Mission) produced its first complete maps. The maps were calculated from the first 10 days of Jason-2's operational orbit starting on 4 July. After reaching its operational orbit some 1,336 km above the Earth at a 66º inclination, Jason-2 and its experimental predecessor, Jason-1, began flying in formation some 55 seconds apart, making nearly simultaneous measurements to allow scientists to precisely calibrate Jason-2's instruments. Comparisons of the data from the two satellites show very close correlation of all measured parameters. Just 48 hours after the launch of Jason-2 from Vandenberg Air Force Base in California on a Delta II launcher on 20 June, the first waveforms were acquired from Jason-2 and the Centre National d' Etudes Spatiales (CNES), the French space agency, processed the first Operational Geophysical Data Record test product. Thus, Jason-2/(OSTM) is clearly providing a vital contribution to the monitoring of climate change, ocean circulation and weather.

Once it has been calibrated by the partners, the satellite will provide oceanographic products on an operational basis to the large EUMETSAT user community using the European weather satellite organisation's proven dissemination capabilities. The main instrument onboard Jason-2 is the Poseidon 3 dual frequency altimeter. Jason-2 provides the much-needed data continuity which is essential when measuring the sea level trend, one of the key indicators of climate change. Of equal importance is the contribution Jason-2 will provide for meteorology and oceanography, in the area of long-term and seasonal predictions. Jason-2 is the continuation of the existing successful cooperation between the USA and Europe. It is a global endeavour with responsibilities for satellite development and launch shared between CNES and NASA. CNES and the US National Oceanic and Atmospheric Administration (NOAA) are responsible for satellite operations, while the Jet Propulsion Laboratory is managing the mission for NASA. Data processing is being carried out by CNES, EUMETSAT and NOAA, depending on the type of product, with EUMETSAT acting as an interface for near-real-time product distribution to European users.

See also: http://www.eumetsat.int/Home/Main/Media/Press_Releases/706771?l=en.

I.3.5. Ice: Satellites monitor the acceleration of ice loss in Antarctica

Ice loss in Antarctica increased by 75 percent in the last 10 years due to a speed-up in the flow of its glaciers and is now nearly as great as that observed in Greenland.

In a first-of-its-kind study, an international team led by E. Rignot of NASA's Jet Propulsion Laboratory, and the University of California, Irvine, estimated changes in Antarctica's ice mass between 1996 and 2006 and mapped patterns of ice loss on a glacier-by-glacier basis. They detected a sharp jump in Antarctica's ice loss, from enough ice to raise global sea level by 0.3 mm (0.01 inches) a year in 1996, to 0.5 mm (0.02 inches) a year in 2006. Rignot said the losses, which were primarily concentrated in West Antarctica's Pine Island Bay sector and the northern tip of the Antarctic Peninsula, are caused by ongoing and past acceleration of glaciers into the sea. This is mostly a result of warmer ocean waters, which bathe the buttressing floating sections of glaciers, causing them to thin or collapse. Rignot notes that "Changes in Antarctic glacier flow are having a significant, if not dominant, impact on the mass balance of the Antarctic ice sheet".

To infer the ice sheet's mass, the team measured ice flowing out of Antarctica's drainage basins over 85 percent of its coastline. They used 15 years of satellite radar data from the European Earth Remote Sensing-1 and -2 (ERS-1 and ERS-2), Canada's Radarsat-1 and Japan's Advanced Land Observing satellites to reveal the pattern of ice sheet motion toward the sea. These results were compared with estimates of snowfall accumulation in Antarctica's interior derived from a regional atmospheric climate model spanning the past quarter century. The team found that the net loss of ice mass from Antarctica increased from 112 (+/- 91) gigatonnes a year in 1996 to 196 (+/- 92) gigatonnes a year in 2006. A gigatonne is one billion metric tons, or more than 2.2 trillion pounds. These new results are about 20 percent higher over a comparable time frame than those of a NASA study of Antarctic mass balance last March that used data from the NASA/German Aerospace Center Gravity Recovery and Climate Experiment (GRACE). This is within the margin of error for both techniques, each of which has its strengths and limitations.

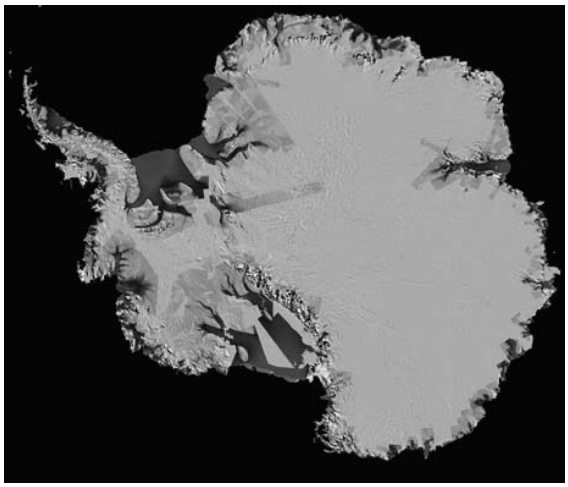

Figure I-3: Antarctic ice loss between 1996 and 2006, overlaid on a Moderate Resolution Imaging Spectroradiometer (MODIS) mosaic image of Antarctica. The colors indicate the speed of the ice loss. Purple/red is fast. Green is slow. Image credit: NASA

See also:

E. Rignot, J. L. Bamber, M. R. van den Broeke, C. Davis, Y. Li, W. J. van de Berg, E. van Meijgaard, Recent Antarctic ice mass loss from radar interferometry and regional climate modeling, Nature Geoscience Vol. 1, 106-110, 2008.
(http://www.jpl.nasa.gov/news/news.cfm?release=2008-010)

I.4. Concluding remarks

The observation of our planet Earth is an important activity in the context of climate change and of the great impact of man-made emissions on stratospheric ozone and tropospheric air quality.

Satellites are extremely useful to monitor changes in atmospheric composition, ocean parameters and properties, and of the Earth's surface. There is an ongoing effort to integrate observations from different instruments and platforms in a global system (GEOSS). The data provided by Earth observation satellites are required today by a great variety of users and applications, and have become a significant economic and political element. The data have been used in many landmark studies of international panels (e.g. the IPCC or the WMO). The CLRTAP Task Force on Hemispheric Transport of Air Pollution is currently developing the integration of satellite observations into chemical models on air quality ("chemical weather forecast").

It is important to stress here that this field of space research needs continuous support to maintain and improve scientific and operational activities in the future. In particular, observations of ocean properties and of atmospheric composition from geostationary orbits need stronger support. There are several research missions that need to be continued by new projects in order to provide long-term monitoring of the Earth, like concerning atmospheric composition in the upper troposphere and lower stratosphere (using Limb-measurements in the mid-infrared), or concerning sea level measurements, to give just two examples. For existing missions, it is very important to stress that data gaps with future missions will lead to great difficulties with the cross-calibration of instruments and thus problems with long-term trends.

The time that is required to propose and prepare new missions is rather long (5-10 years) compared to the time scales of technological changes, but rather short for the scales of global change (several decades); this requires that a great number of preparatory studies must be carried out in parallel – a problem which is today clearly the bottleneck of Earth Observation from space. There are only very few new projects being prepared, and most of them are in strong competition with other space programmes. The cost of preparatory studies is much lower than the cost of new missions. The funding of a significantly larger number of preparatory studies is essential for the future of Earth Observation.

In conclusion, there is urgent need for a much greater number of preparatory studies to develop the future space segment of Earth Observation, in particular concerning global and regional climate.

II. SPACE STUDIES OF THE EARTH-MOON SYSTEM, PLANETS AND SMALL BODIES OF THE SOLAR SYSTEM

II.1 Lunar Exploration

SMART-1, the first ESA Small Mission for Advanced Research in Technology, was launched on 27 September 2003. As its name implies, it was principally a technology mission aimed at demonstrating electric propulsion in deep space. After a 14-month cruise, SMART-1's lunar capture took place on 15 November 2004, followed by a spiralling down to a lunar orbit with 450 km perilune and 3000 km apolune, reached on 15 March 2005. This was followed by a nominal 5-month science operations phase, with a reboost using electric propulsion (2 Aug to 17 Sept 2005), allowing a possible extension until August 2006. The spacecraft carried a small scientific payload (AMIE - Advanced Moon micro-Imaging Experiment, D-CIXS - Demonstration of Compact X-ray Spectrometer, SIR - SMART-1 Infrared spectrometer, SPEDE/EPDP - Spacecraft Potential Electron and Dust Experiment/Electric Propulsion Diagnostic Package, KATE/RSIS - Ka-band Telemetry and telecommand Experiment/Radio Science for SMART-1 experiment) in order to study surface composition, formation and evolution of the Moon, and to survey resources for future exploration. SMART-1 lunar science investigations include studies of the chemical composition of the Moon, of geophysical processes (volcanism, tectonics, cratering, erosion, deposition of ices and volatiles) for comparative planetology, and high resolution studies in preparation for future steps of lunar exploration. The mission addresses several topics such as the accretional processes that led to the formation of rocky planets, and the origin and evolution of the Earth-Moon system.

The SMART-1 mission ended with a controlled impact in the Lunar Lake of Excellence on 3 Sept 2006. A world wide observing campaign was organized to study the flash and debris in real time.

The integration of the data from SMART-1, Lunar Prospector and the Clementine missions into a global database is continuing. The joint interpretation of these data together with the analyses of lunar samples has given new views on the composition and evolution of the Moon. The comparison of element abundance from SMART-1 and previous orbiters and surface sample missions, has given new information on lunar mare, highlands and impact basins, such as the giant South Pole-Aitken basin.

The 2,350 kg Chinese Chang'E1 spacecraft was launched on 24 October 2007 and relayed the first images of the Moon on 26 November 2007. The spacecraft includes a payload comprising: a CCD stereo camera, an imaging interferometer, a laser altimeter, a gamma/x-ray spectrometer, a microwave radiometer, a solar high-energy particle detector and a low-energy ion detector. The launch of the lunar probe is the first step in China's three-stage moon mission, which will lead to a landing and launch of a rover vehicle around 2012. In the third phase, another rover will land and return to the Earth with lunar soil and stone samples for scientific research around 2017.

The JAXA Japanese orbiter mission SELENE (Selenological and Engineering Explorer) was launched on 14 September 2007 by an H-IIA rocket, and inserted into lunar orbit on 4 October 2007. It carries a comprehensive set of instruments for multi-spectral remote sensing of the lunar surface (X-ray and gamma-ray spectrometers, multi-band imager and spectral profiler, terrain camera, radar sounder), gravity studies (VLBI and data relay), and for lunar environment studies (magnetometer/plasma imager, charged-particle spectrometer and plasma analyser, radio science). In the framework of the Japanese lunar exploration programme, the SELENE-B mission (with a lander element and demonstration of technologies for future lunar exploration) is under discussion.

The Indian ISRO mission Chandrayaan-1 was launched aboard a PSLV launch vehicle on 22 October 2008, with objectives of studying the origin and evolution of the Moon, and producing a 3D atlas and chemical mapping of the lunar surface. Its core payload includes: a terrain mapping stereo camera, a hyperspectral wedge filter, laser ranging, a low energy x-ray spectrometer, a solar X-ray monitor, a high energy X-ray instrument, and a Descent system "ranger module". It carries international instruments from ESA (SIR2, CIXS, SARA) and from US (Moon mineralogy Mapper, Radar).

A proposal for a sample return mission from the South Pole Aitken Basin, recommended as part of the US Decadal plan, has been studied within NASA's New Frontiers programme. It is expected to be one of the candidate missions for an anticipated New Frontiers selection in 2009.

A new mission, the Lunar Reconnaissance Orbiter, is being developed by NASA for launch in April 2009 to perform survey measurements of the lunar surface as a preparation for future exploration. From a 50 km orbit, it will study the lunar surface environment, produce high resolution maps and a geodesic grid , and survey lunar resources. Its instruments include Laser Altimeter, Camera, Neutron Detector, Diviner Radiometer, Lyman Alpha mapper, Cosmic ray sensor. LCROSS, including an impactor of 2 ton followed by a shepherd spacecraft, will target a polar crater to characterise polar ice deposits.

As part of the Discovery Program, NASA has selected the GRAIL mission. GRAIL's primary objective is to map the lunar gravity field with unprecedented precison, using the two spacecraft tracking techniques similar to those of highly successful Earth-orbital GRACE mission. The data are expected to provide new insight into the structure of the lunar crust and interior as well as giant impact structures.

II.2 Mercury and Venus Exploration

ESA launched Venus Express in November 2005, a mission to conduct investigations of the Venusian atmosphere and surface. It re-utilised hardware developed for the Mars Express spacecraft. Instruments developed for other ESA planetary missions were adapted to enable a faster and cheaper payload development. The Venus Express payload comprises a combination of spectrometers, spectro-imagers and imagers

covering a wavelength range from ultraviolet to thermal infrared, a plasma analyser and a magnetometer. This set of instruments has been able to study the atmosphere, plasma environment and surface of Venus in great detail. The investigation aims to enhance our knowledge of the composition, circulation and evolution of the atmosphere of Venus. The surface properties of Venus and the interaction between the atmosphere and the surface will be examined and evidence of volcanic activity will be sought. Venus Express performed its Venus Orbit Insertion on 11 April 2006 and a steady stream of data has been returned since. These data have formed the basis of numerous publications (including a special issue of Nature). The data are being archived in ESA's Planetary Science Archive. The mission is expected to continue until at least 2010.

Japan has also approved the Venus Climate Orbiter to Venus, concentrating on plasma and atmospheric studies. It is hoped that the spacecraft will launch in 2011 allowing co-ordinated observations and cross-calibration with an extended Venus Express mission.

On 3 August 2004, NASA launched the MESSENGER (MErcury Surface, Space ENvironment, GEochemistry, and Ranging) mission – a Mercury orbiter – as a part of its Discovery programme. A significant part of its instrumentation is dedicated to geological studies of this innermost terrestrial planet. MESSENGER completed two swing-bys of Venus (on 24 October 2006 and 5 June 2007) to use the pull of the planet's gravity to guide it closer to Mercury's orbit. The encounter offered opportunities for new observations of the Venus atmosphere and cloud structure and some co-ordination with Venus Express was also made.

At 19:04:39 UTC on 14 January 2008, MESSENGER made its first fly-by of Mercury at an altitude of 200 km above Mercury's surface. The fly-by was completely successful. The Mercury Dual Imaging System (MDIS) cameras imaged almost half of the planet including terrain that had never previously been viewed by spacecraft. The encounter added another 21% of Mercury's surface to the total imaged close-up by spacecraft. The first laser ranging experiments were carried out. The very first measurements of ions in Mercury's magnetosphere revealed a remarkable richness in the species present. In addition to the solar wind protons that make up the bulk of the solar wind and are ubiquitous in planetary magnetospheres throughout the Solar System, the plasma analyser discovered that Mercury's magnetosphere is host to a plethora of heavy ions. Data from MESSENGER's first flyby of Mercury have been released to the public by the Planetary Data System (PDS).

The MESSENGER spacecraft flew by Mercury for the second time at 10:40 UT on 6 October 2008, gaining a gravity assist that will tighten its orbit and keep it on its course to pass the planet one last time in 2009 before becoming the first spacecraft ever to orbit Mercury, beginning in 2011.

ESA and JAXA are just entering the flight model build phase for the BepiColombo mission to Mercury. BepiColombo will contribute to our understanding of the evolution and dynamics of Mercury and its magnetospheric processes. The mission

consists of a Mercury Planetary Orbiter (for high resolution multi-wavelength geophysical and geochemical observations, and gravimetry/fundamental physics studies), and a Mercury Magnetospheric Orbiter (dedicated to particles and fields). The latter will be provided by JAXA to ESA for integration and launch on an Ariane 5 launcher in August 2014. With the innovative combination of electric propulsion and gravity assists, the planned cruise duration is about 6 years. A 1 Earth year primary mission is planned.

NASA's New Frontiers Program is expected to include Venus missions with atmospheric and surface science objectives as possible candidates for 2009 selection.

II.3 Mars EXPLORATION

NASA's Mars Global Surveyor, in orbit since September 1997, continued to operate well until November 2006, and to provide impressive images of the surface of Mars. Clear evidence has been found for a 'sapping' origin of many channels probably from melting of subsurface ice, suggesting the possible existence of liquid water in the recent past of Mars. Mars Global Surveyor has fulfilled all of its science objectives.

The mission has studied the entire Martian surface, atmosphere, and interior. One of the most exciting observations of the spacecraft's wide-angle camera system, known as the Mars Orbital Camera, is that the red planet has very repeatable weather patterns. Each day the camera operated, it collected images that were used to build up a daily global map. These maps provided a record of changing meteorological conditions on Mars. Weather patterns observed by the spacecraft included some dust storms that repeated in the same location within a week or two of the time they occurred in the previous year. A panoply of high-resolution images from the Mars Global Surveyor has documented gullies and debris flows suggesting that occasional sources of liquid water, similar to an aquifer, were once present at or near the surface of the planet. Magnetometer readings have shown that the planet does not have a global magnetic field but has localised magnetic fields in particular areas of the crust.

Temperature data and close-up images of the Martian moon Phobos have determined that the moon is covered by a layer of powdery material - the pulverized output of millions of years of meteoroid impacts - at least 1 m thick. By studying Mars for several Martian years (a Mars year is about twice as long as an Earth year), Mars Global Surveyor has observed gully formation, new boulder tracks, recently formed impact craters, and diminishing amounts of carbon dioxide ice within the south polar cap.

Data from the spacecraft's laser altimeter has given scientists their first 3-D views of Mars' north polar ice cap. Changes in radio transmissions as they are refracted by the Martian atmosphere have enabled scientists to create vertical profiles of atmospheric temperature and pressure. Spacecraft accelerations due to gravity have given scientists a better understanding of the interior of Mars. Findings such as these have shown that Mars is a dynamic planet with a history of seasonal and long-term change recorded in the planet's surface.

Principal goals for the orbiter's latest mission extension included continued weather monitoring to form a continuous set of observations with NASA's Mars Reconnaissance Orbiter; imaging of possible landing sites for the Phoenix 2007 Mars Scout lander and 2009 Mars Science Laboratory rover; continued mapping and analysis of key sedimentary-rock-outcrop sites; and continued monitoring of changes on the surface due to wind and ice. After studying Mars four times as long as originally planned, Mars Global Surveyor last communicated with Earth on 2 November 2006.

The NASA Mars Odyssey, mainly devoted to the mapping of chemical elements and minerals on the surface, was launched on 7 April 2001, and arrived on 24 October 2001. After a manoeuvre into a 25-hour capture orbit, aerobraking was used to achieve a low Mars orbit. The orbiter carries three science instruments (THEMIS – Thermal Emission Imaging System, GRS – Gamma-Ray Spectrometer, and MARIE – Mars Radiation Environment experiment). THEMIS maps the mineralogy and morphology of the Martian surface using a high-resolution camera and a thermal infrared imaging spectrometer. The GRS, a rebuild of the instrument lost with the Mars Observer mission, achieves global mapping of the elemental composition of the surface and determines the abundance of hydrogen in the shallow subsurface. Evidence has been found for a widespread distribution of water ice, buried to a depth of at least one meter and mixed with rocky material. The MARIE characterizes aspects of the near-space radiation environment as related to the radiation-related risk to human explorers. The primary science mission continued through August 2004 and Odyssey is currently in its extended mission. Mars Odyssey is still orbiting the red planet, collecting scientific data and relaying communications from NASA's two Mars rovers to Earth. Mars Odyssey has made global observations of Martian climate, geology, and mineralogy. The spacecraft's Gamma Ray Spectrometer has allowed scientists to make maps of the elemental distribution of hydrogen, silicon, iron, potassium, thorium, and chlorine on the Martian surface. A global map of minerals associated with water, essential to life, as we know it, guided NASA in its selection of Meridiani Planum, the landing site for NASA's Opportunity rover, an area rich in hematite. Odyssey supported landing site selection for the Phoenix Scout Mission, launched in 2007, using data showing that surface areas near the poles of Mars consist of more than 50 percent water ice by volume. Other Odyssey accomplishments include measurement of radiation, a pre-requisite for future human exploration because of its potential health effects, and a groundbreaking programme in education outreach that has allowed students to take pictures of Mars and conduct scientific investigations with cameras on Odyssey. The spacecraft has collected more than 130,000 images and continues to send information to Earth about Martian geology, climate, and mineralogy.

The ESA Mars Express mission, launched on 2 June 2003, arrived at Mars on 25 December 2003. Mars Express consists of an orbiter with eight experiments (HRSC – High Resolution Stereo Camera, OMEGA – IR mineralogical mapping spectrometer, SPICAM UV and IR – atmospheric occultation spectrometer, PFS – Planetary Fourier spectrometer, ASPERA – Analyser of Space Plasma and Energetic Atoms, MaRS – Mars Radio Science experiment, MARSIS – Mars Advanced Radar for Subsurface and Ionosphere Sounding), and a lander. The lander, Beagle 2, was planned to be a valuable

complement to the main mission with in-situ analysis of the Martian subsurface chemistry relevant to exobiology, using a suite of cameras, spectrometers, and gas and environment analysis sensors. The Beagle-2 lander, after a nominal separation from the Mars Express orbiter and nominal injection, entered the Martian atmosphere on 25 December. However, no contact could be established with the lander.

Following the Mars Express spacecraft commissioning at Mars in January 2004, most experiments on board began their calibration and testing phase while already acquiring scientific data. This phase lasted until June 2004 when all the commissioned instruments started their routine operations. The MARSIS radar antenna deployment was postponed for technical reasons until May 2005, and it became operational in July 2005.

Since the start of science operations in early 2004, Mars Express has delivered new science results related to the water ice in polar caps, the presence of sulphates, the evidence for recent volcanic and glacial activity, methane detection in the atmosphere and signatures of atmospheric escape. Mars Express has started mapping water in its various states. In building up a global data set for composition and characteristics of the surface and atmosphere, Mars Express has revealed that volcanic and glacial processes are much more recent than expected. It has confirmed the presence of glacial processes in the equatorial regions, and mapped water and carbon dioxide ice, either mixed or distinct, in the polar regions. Through mineralogical analysis, it found out that large bodies of water, such as lakes or seas, might not have existed for a long period of time on the Martian surface.

Mars Express has also possibly detected methane in the Martian atmosphere. This, together with the possible detection of formaldehyde, suggests either current volcanic activity on Mars, or, more excitingly, that there are current active 'biological' processes. This hypothesis may be reinforced by the fact that Mars Express saw that the distribution of water vapour and methane, both ingredients for life, substantially overlap in some regions of the planet. Furthermore, the mission detected aurorae for the first time on the Red Planet. It has made global mapping of the density and pressure of the atmosphere between 10 and 100 km altitude, and studied atmospheric escape processes in the upper layers of the atmosphere. This is contributing to our understanding of the weather and climate evolution of the planet.

There is still much to be discovered by the set of instruments on board Mars Express. MARSIS will continue its subsurface studies mainly in the search for liquid and frozen water. By combining subsurface, surface and atmospheric data, Mars Express should provide an unprecedented global picture of Mars and, in particular, its water. So far, the High Resolution Stereo Camera has imaged only 19% of the Martian surface at high resolution. In the extended phase, it will be able to continue the 3D high-resolution colour imaging. Thanks to the extension, Mars Express will also be able to study for a second year the way the atmosphere varies during different seasons, and to observe again variable phenomena such as frost, fog or ice. Finally, Mars Express will be able to revisit those areas where major discoveries, such as new volcanic structures, sedimentary

layering, methane sources, nightglow and auroras, have been made, thus allowing us to confirm and understand all aspects related to these discoveries.

Further to providing an impressive wealth of scientific results on its own, Mars Express has also successfully co-operated with NASA's Mars Exploration Rovers, in terms of co-ordinated scientific observations and to test Mars Express in relaying the rover data to Earth. Further scientific collaboration between Mars Express and both rovers and Mars Odyssey is expected, and with NASA's Mars Reconnaissance Orbiter mission during the extended mission. ESA's Mars Express mission was extended by one Martian year, or about 23 months, from the beginning of December 2005. Mars Express is currently in the middle of its first extension period which shifted the mission end date to 31 October 2007 by adding one Martian year of 687 days to the mission's nominal end date in November 2005. The nominal mission lifetime of one Martian year (January 2004 to November 2005) for the orbiter has already been extended twice, up to May 2009). The extensions give priority to fulfilling the remaining goals of the nominal mission (including gravity measurements and seasonal coverage), to catch up with the delayed MARSIS observations, to complete global coverage of high-resolution imaging and spectroscopy, and subsurface sounding with the radar, to observe atmospheric and variable phenomena, and to revisit areas of discoveries.

Two identical lander missions (Mars Exploration Rovers) were launched by NASA on 10 June and 7 July 2003, and arrived on 4 and 25 January 2004. Pathfinder-derived airbag technology was used for landing the rover vehicles *Spirit* and *Opportunity* onto the surface. The rovers are considerably larger and more sophisticated than the Sojourner/Pathfinder rover, and include multiple camera systems as well as a variety of compositional investigations in an integrated science payload. The primary science instruments carried by the rovers include:

- Panoramic Camera (Pancam) for determining the mineralogy, texture and structure of the local terrain;
- Miniature Thermal Emission Spectrometer (Mini-TES) for identifying promising rocks and soils for closer examination and for determining the processes that formed Martian rocks. The instrument will also look skyward to provide temperature profiles of the Martian atmosphere;
- Mössbauer Spectrometer (MB) for close-up investigations of the mineralogy of iron-bearing rocks and soils;
- Alpha Particle X-Ray Spectrometer (APXS) for close-up analysis of the abundances of elements that make up rocks and soils;
- Magnets: for collecting magnetic dust particles. The Mössbauer Spectrometer and the Alpha Particle X-ray Spectrometer will analyze the particles collected and help determine the ratio of magnetic particles to non-magnetic particles. They will also analyse the composition of magnetic minerals in airborne dust and rocks that have been ground by the Rock Abrasion Tool;
- Microscopic Imager (MI) for obtaining close-up, high-resolution images of rocks and soils;

- Rock Abrasion Tool (RAT) for removing dusty and weathered rock surfaces and exposing fresh material for examination by instruments onboard.

The findings from the Mars Exploration rovers have been largely reported in the refereed literature (*Science* special issues) and in the media. Major results to date include evidence for evaporated minerals in exposed rock layers, and other signs strongly suggesting the presence of standing bodies of water on Mars when the rocks formed. The project has been extended due to the rovers' survival through the depth of Martian winter. Two and a half years after landing, both rovers are still working and have far exceeded their initial 90-day warranties on Mars.

To date, Spirit has driven 7.26 km (4.51 miles) and has returned more than 102,000 images. Opportunity has driven 11.57 km (7.19 miles) and has returned more than 94,000 images. They both sent spectacular, high-resolution, full-colour images of Martian terrain as well as detailed microscopic images of rocks and soil surfaces to Earth. Four different spectrometers have amassed unparalleled information about the chemical and mineralogical makeup of Martian rocks and soil. Special rock abrasion tools, never before sent to another planet, have enabled scientists to peer beneath the dusty and weathered surfaces of rocks to examine their interiors.

Opportunity observations have revealed evidence for past inter-dune playa lakes that evaporated to form sulfate-rich sands. The sands were reworked by water and wind, solidified into rock, and soaked by groundwater. During the extended mission, Opportunity has detected more sedimentary bedrock exposures where an even broader, deeper section of layered rock is likely exposed that could reveal new aspects of Martian geologic history.

While Spirit's initial travels revealed a more basaltic setting, the rover found a variety of rocks indicating that early Mars was characterised by impacts, explosive volcanism, and subsurface water. Unusual-looking bright patches of soil turned out to be extremely salty and affected by past water. Spirit discovered finely layered rocks that are as geologically compelling as those found by Opportunity and that may hold clues to a history of past water. Both rovers have found metallic meteorites on Mars. Opportunity discovered one rock with a composition similar to a meteorite that reached Earth from Mars.

NASA has extended, for a fifth time, the activities of the two Mars Exploration Rovers. The decision keeps the two rovers active on opposite sides of Mars, possibly through 2009. This extended mission and the associated science are dependent upon the continued productivity and operability of the rovers. Now that Opportunity has finished exploring Victoria Crater and returned to the surrounding plain, the rover team plans to use tools on the robotic arm in the coming months to examine an assortment of cobbles -- rocks about fist-size and larger -- that may have been thrown from impacts that dug craters too distant for Opportunity to reach.

The NASA's Mars Reconnaissance Orbiter, launched in August 2005, arrived at Mars on 10 March 2006. The aim is to characterise the surface, subsurface, and atmosphere of Mars, and to identify potential landing sites for future missions. The Mars Reconnaissance Orbiter carries six science instruments, three engineering instruments that will assist in spacecraft navigation and communications, and two more science-facility experiments. The science package includes:

- High Resolution Imaging Science Experiment (HiRISE) able to reveal small-scale objects in the debris blankets of mysterious gullies and details of geologic structure of canyons, craters, and layered deposits.
- Context Camera (CTX) for providing wide area views to help provide a context for high-resolution analysis of key spots on Mars provided by HiRISE and CRISM.
- Mars Color Imager (MARCI) for monitoring clouds and dust storms.
- Compact Reconnaissance Imaging Spectrometer for Mars (CRISM) for identifying minerals, especially those likely formed in the presence of water.
- Mars Climate Sounder (MCS) for detecting vertical variations of temperature, dust, and water vapor concentrations in the Martian atmosphere.
- Shallow Radar (SHARAD) for probing beneath the Martian surface to see if water ice is present at depths greater than 1 m.

The Mars Reconnaissance Orbiter carries the most powerful camera ever flown on a planetary exploration mission for homing in on details of Martian terrain with extraordinary clarity. This capability has not only provided an astoundingly detailed view of the geology and structure of Mars, but it also contributed to identify obstacles that could jeopardise the safety of future landers and rovers. The Mars Reconnaissance Orbiter also carries a sounder to find subsurface water, an important consideration in selecting scientifically worthy landing sites for future exploration.

Other science instruments on this multitasking, multipurpose spacecraft will identify surface minerals and study how dust and water are transported in the Martian atmosphere. A second camera will provide medium-resolution images to provide a broader geological and meteorological context for more detailed observations from higher-resolution instruments. The Mars Reconnaissance Orbiter will also serve as the first installment of an “interplanetary Internet”, a crucial service for future spacecraft. As the first link in a communications bridge back to Earth, several international spacecraft will use the Mars Reconnaissance Orbiter in coming years. The Orbiter's primary mission is planned to end on December 31, 2010.

The Phoenix mission is the first chosen for NASA's Scout programme, an initiative for smaller, lower-cost spacecraft. Phoenix was launched in August 2007. It uses a lander that was intended for use by 2001's Mars Surveyor lander prior to its cancellation. It also carries a complex suite of instruments that are improved variations of those that flew on the lost Mars Polar Lander. Phoenix landed on the icy northern pole of Mars between 65 and 75 degrees north latitude. During the course of the 150 Martian day mission, Phoenix deployed its robotic arm and dig trenches up to half a metre into the

layers of water ice. These layers, thought to be affected by seasonal climate changes, could contain organic compounds that are necessary for life. To analyse soil samples collected by the robotic arm, Phoenix carries an "oven" and a "portable laboratory". Selected samples will be heated to release volatiles that can be examined for their chemical composition and other characteristics. Preliminary analyses of samples confirm that they are alkaline, and composed of salts and other chemicals such as perchlorate, sodium, magnesium, chloride and potassium. In the near future, the Phoenix team will also fill the final four of eight single-use ovens on another soil-analysis instrument, the Thermal and Evolved Gas Analyzer, or TEGA. The team's strategy is to deliver as many samples as possible before the power produced by Phoenix's solar panels declines due to the end of the Martian summer.

The Mars Science Laboratory is NASA's next rover mission being planned for travel to Mars before the end of the decade (planned launch in the Autumn of 2009). Twice as long and three times as heavy as the Mars Exploration Rovers Spirit and Opportunity, the Mars Science Laboratory would collect Martian soil samples and rock cores and analyse them for organic compounds and environmental conditions that could have supported microbial life now or in the past. The mission is anticipated to have a truly international flavour, with a neutron-based hydrogen detector for locating water provided by the Russian Federal Space Agency, a meteorological package provided by the Spanish Ministry of Education and Science, and a spectrometer provided by the Canadian Space Agency.

The Mars Science Laboratory is intended to be the first planetary mission to use precision landing techniques, steering itself toward the Martian surface similar to the way the Space Shuttle controls its entry through the Earth's upper atmosphere. In this way, the spacecraft will fly to a desired location above the surface of Mars before deploying its parachute for the final landing. As currently envisioned, in the final minutes before touchdown, the spacecraft will activate its parachute and retro rockets before lowering the rover package to the surface on a tether. This landing method will enable the rover to land in an area 20 to 40 km (12 to 24 miles) long, about the size of a small crater or wide canyon and three to five times smaller than previous landing zones on Mars.

Like the twin rovers now on the surface of Mars, Mars Science Laboratory will have six wheels and cameras mounted on a mast. Unlike the twin rovers, it will carry a laser for vaporising a thin layer from the surface of a rock and analyzing the elemental composition of the underlying materials. It will be able to collect rock and soil samples and distribute them to on-board test chambers for chemical analysis. Its design includes a suite of scientific instruments for identifying organic compounds such as proteins, amino acids, and other acids and bases that attach themselves to carbon backbones and are essential to life as we know it. It can also identify features such as atmospheric gases that may be associated with biological activity.

Using these tools, Mars Science Laboratory will examine Martian rocks and soils in greater detail than ever before to determine the geologic processes that formed them;

study the Martian atmosphere; and determine the distribution and circulation of water and carbon dioxide, whether frozen, liquid, or gaseous.

NASA plans to select a landing site on the basis of highly detailed images sent to Earth by the Mars Reconnaissance Orbiter, in addition to data from earlier missions. The rover will carry a radioisotope power system that generates electricity from the heat of plutonium's radioactive decay. This power source gives the mission an operating lifespan on Mars' surface of a full Martian year (687 Earth days) or more while also providing significantly greater mobility and operational flexibility, enhanced science payload capability, and exploration of a much larger range of latitudes and altitudes than was possible on previous missions to Mars.

ExoMars (planned launch, 2013), ESA's Aurora Flagship mission, is currently being assessed. Its aim is to further characterize the biological environment on Mars in preparation for robotic missions and then human exploration. Data from the mission will also provide invaluable input for broader studies of exobiology - the search for life on other planets. This mission calls for the development of a Mars orbiter, a descent module and a Mars rover.

II.4. Dwarf Planets and Small Solar System Bodies Exploration

II.4.1. Kuiper Belt Objects and Dwarf Planets (Plutoids)

Following the official IAU definition from 2006, additional dwarf planets have been added to the ranks, joining Pluto, Ceres (the largest member of the asteroid belt), and Eris (discovered in 2003 and thought to be larger than Pluto at about twice its distance from the Sun). These new members include Makemake (discovered in 2005 and about three-fourths the size of Pluto) and Haumea (originally discovered in 2004 and is thought to be distinctly ellipsoidal in shape with its long axis exceeding the size of Pluto). The IAU introduced the term, *plutoid*, to describe a trans-Neptunian *dwarf planet* or an object that is likely to be such a body.

Other large bodies in this region (known as the Kuiper Belt) and ranging in sizes between Makemake and Ceres are Varuna and Quaoar (both classical trans-Neptunian objects), Orcus (a plutino), and Sedna (a distinctly red planetoid). Whether these objects qualify as dwarf planets is not yet clear. During this reporting period, two small moons were reported orbiting Haumea (Hi`iaka and Namaka) but none have been found at Makemake. It is anticipated that many more plutoids will be discovered in this region of our Solar System within the next decade. More than 60 smaller Kuiper Belt Objects (KBOs) have been discovered since the last report, bringing the rapidly growing total to more than 1200. The orbital ensemble of these bodies displays an incredible amount of structure and includes classifications such as Plutinos, Scattered Disk Objects, Resonance Objects, Cubewanos, and other dynamical classes. A new model suggests that the large planets Jupiter and Saturn entered a temporary orbital resonance in the early history of the Solar System, pushing the orbits of Uranus and Neptune into the outer protoplanetary disk and gravitationally scattering large icy planetesimals throughout the Solar System

while at the same time scattering planetesimals from the asteroid belt. This idea accounts for many observations in the inner as well as the outer Solar System. The total mass of the Kuiper Belt is currently estimated to be less than one-tenth Earth's mass but is still quite uncertain.

New Horizons, NASA's New Frontiers one-way journey to the Pluto system (and then to one or more Kuiper Belt Objects) launched in January 2006, encountered Jupiter in early 2008 for a gravity assist and scientific studies (see Outer Planets section below). New Horizons is well past the orbit of Saturn at the time of this report and is expected to arrive at Pluto in July 2015. Seven scientific instruments onboard the spacecraft include imaging spectrometers (ultraviolet to infrared spectral ranges), energetic particle spectrometers (solar wind interactions), a radiometer for radio science investigations, and a dust counter operated by students. New Horizons' primary goals are to characterize the geology, morphology, and chemical compositions of the surfaces of Pluto and Charon and to characterize Pluto's neutral atmosphere with many lower priority objectives including a search for additional satellites and rings.

II.4.2. Asteroids and the Dwarf Planet Ceres

The JAXA Hayabusa ("peregrine falcon", formerly MUSES-C) mission was launched in May 2003 to investigate a near-Earth asteroid and to return a sample of its surface to Earth. Using solar electric propulsion, Hayabusa arrived at the asteroid 25143 Itokawa in September 2005 and observed it at an altitude of 20 km to 3 km through November 2005. Many new results using its four science instruments (imagers, X-ray and near infrared spectrometers) were obtained concerning the asteroid's shape, geographical features, surface altitude variation, albedo, spectrum, mineral composition, gravity, and the main chemical composition. A miniature rover (MINERVA) failed to reach the asteroid but the spacecraft successfully landed on the surface and collected samples. After some technical difficulties with the spacecraft, these samples will be returned to Earth in June 2010. Results from the Hayabusa mission are expected to provide insights into our current understanding of asteroids by returning pristine samples from a well-characterized asteroid, bridging the gap between ground-based observations of asteroids and laboratory analyses of meteorites (thought to originate from asteroids) and cosmic dust collections.

The Dawn mission, developed in NASA's Discovery series, was successfully launched on September 27, 2007. Dawn is designed to characterize the conditions and processes of the solar system's earliest epoch by investigating in detail two of the largest protoplanets remaining intact since their formations, Ceres and Vesta. They are considered two of the most interesting large bodies in the main asteroid belt: Vesta seems to be highly evolved, while Ceres, the newly designated dwarf planet, may be water-rich, in the form of ices and/or hydrated minerals. The payload comprises two framing cameras, a visual and infrared mapping spectrometer, and a gamma ray and neutron spectrometer. After a successful commissioning phase, the next important step will be a Mars gravity assist in February 2009. The arrival at Vesta is scheduled on August 2011.

II.4.3. Comets

After travelling nearly 5 billion km during its seven-year round-trip odyssey to comet 81P/Wild 2, NASA's Stardust sample return mission safely returned to Earth. The capsule, carrying cometary and interstellar particles, became an artificial meteor on 15 January 2006 and successfully touched down in the desert salt flats of Utah. Two days later, the sample return capsule's science canister and its cargo of comet and interstellar dust particles were transferred to the Johnson Space Center (Clear Lake, Texas, USA) where it was opened for scientific investigation and curation. The Stardust project has delivered to the international science community material that has been unaltered since the formation of our solar system to help provide answers to fundamental questions about comets and the origins of the solar system.

Samples from comet 81P/Wild 2 have surprised scientists, showing a remarkable range of minerals with some of these particles containing minerals that form only at extremely high temperatures that could not have existed where the comets formed, indicating the formation of at least some comets may have included materials ejected by the early Sun to the far reaches of the solar system. Many of the comet particles are built like loose dirt-clods composed both of "large strong rocks" as well as very fine powdery materials. The public has been invited to join in the search for tiny particles of interstellar dust at the interactive, internet-based website, Stardust@home, where the aerogel collector can be examined. During its flyby, Stardust returned high-resolution images of the nucleus of comet 81P/Wild 2, expanding our knowledge of these small solid bodies that are the source of cometary activity. In the mean time, the Stardust spacecraft was placed into hibernation mode for possible use in an extended mission to another target.

The current renaissance in cometary science continues with NASA's Discovery-class Deep Impact mission. Its goal was to study the pristine material of a cometary nucleus by excavating an artificial crater to release subsurface materials. It was launched on 12 January 2005, and delivered a 370 kg copper projectile travelling at a velocity of 10.2 km/s into the nucleus of comet 9P/Tempel 1 on 4 July 2005. This spectacular event resulted in the formation of a crater, and ejection that was observed by an extensive network of ground-based and Earth-orbiting telescopes as well as from the Deep Impact spacecraft and ESA's Rosetta spacecraft (see below). The results seem to indicate that the crating process was gravity-dominated, lending to the notion that the comet nucleus consists of porous, pristine, unprocessed material of very low tensile strength. Spectra taken shortly after impact revealed emission lines of water, HCN, carbon monoxide and dioxide, and several organics in the hot volatile-rich vapour plume. The amount of dust released was greater than expected, consisted of very fine particles, and contained crystalline and amorphous (glassy) silicates, amorphous carbon, carbonates, and clay minerals (phyllosilicates). Images of the nucleus of comet 9P/Tempel 1 revealed a rugged surface with relatively flat areas, scarps, and circular features thought to be impact craters. Small patches of water ice were detected for the first time on the surface of a comet. Analysis and interpretation of the results of this mission are ongoing.

The Rosetta mission, an ESA Cornerstone project to rendezvous with comet 67P/Churyumov-Gerasimenko in 2014, was launched on 2 March 2004 using an Ariane-5 rocket from Kourou (French Guiana). The Rosetta project consists of an orbiter with eleven experiments and a lander with nine further experiments. The spacecraft and instruments have successfully undergone initial testing and evaluation. One of the major objectives of the orbiter is to study the development of cometary activity and the processes in the surface layer of the nucleus as the solar distance of the nucleus decreases. The near-nucleus phase will start at a heliocentric distance of about 3.25 AU and continue until perihelion passage at about 1 AU. To gain enough orbital energy to reach the cometary target, gravity assists (and accompanying science studies) with Mars and Earth were successfully executed in late 2005, with one additional Earth assist scheduled for November 2007. The orbiter will deploy the lander after the first year of operation. It will focus on elemental and molecular determinations. In addition, the properties of the near surface will be studied and the coarse internal structure will be revealed. Various onboard instruments have already acquired scientific data of the Earth and many comets. In particular, Rosetta participated in the observation campaign that accompanied the Deep Impact event on July 2005, obtaining many useful data.

On 5 September 2008, the first of two asteroid fly-bys has been performed. Asteroid 2867 Steins was selected as a scientific target to be observed because is a rare, E-type asteroid of which little is known. The Rosetta fly-by provided a unique opportunity to perform the first in-situ exploration and characterise the surface and environment of this member of the E-type asteroid class. A third Earth-gravity assist will occur in November 2009 leading to the second asteroid fly-by in July 2010 when Rosetta will encounter 21 Lutetia, a larger body of about 100 km diameter. Afterwards, it is on course to rendezvous with comet 67P/Churyumov-Gerasimenko in May 2014.

II.4.4. Space-based Observatories and Small Bodies Research

The JAXA Akari ("Light", formerly ASTRO-F) mission to produce a second-generation survey of the entire infrared sky was launched 22 February 2006. It will improve on its predecessor IRAS with better sensitivity, spatial resolution, and wider spectral coverage ranging from 1.7 to 180 micrometres. Akari has a 68.5-cm IR telescope cooled to 6K. After achieving a Sun-synchronous polar orbit of about 700 km, it returned the first images in April 2006 and a portion of the observing time will be devoted to solar system studies, including small bodies.

The Hubble Space Telescope is continuing to actively participate in small bodies research. In the last two years HST was used to image Ceres, possibly finding impact features on its surface, the Kuiper Belt Object Sedna, and the dwarf planet Eris with its moon Dysnomia. Extraordinary views were also provided of the fragments of the comet 73P/Schwassmann-Wachmann 3 and of the effect of the collision between the projectile released by the Deep Impact spacecraft and comet 9P/Tempel 1.

The Spitzer Space Telescope joined observers around the world in the Deep Impact campaign, observing the cloud of material that was ejected when the impactor struck the surface of 9P/Tempel 1 with its infrared spectrograph.

Through various automated, ground-based observational programmes, asteroids are being discovered at a rate of about 5000 per month. A total exceeding 400,000 are registered as minor planets at the time of this report, more than 190,000 of these having well-determined orbits and given permanent official numbers, and some 14,698 bearing offical names. Roughly 4700 Near-Earth Asteroids with orbits close to Earth's orbit are presently known.

An astronomical survey called Pan-STARRS (Panoramic Survey Telescope And Rapid Response System) will continuously conduct astrometry and photometry of much of the sky. Its primary mission is to detect near-Earth objects that threaten Earth with impact events. However, it is expected to discover many new asteroids, comets, variable stars, and other celestial objects visible from its location in Hawaii (about three-quarters of the entire sky).

II.5. OUTER SOLAR SYSTEM SPACE PROBES

II.5.1. Jupiter

NASA has selected a Jupiter mission, named Juno, as the second of its New Frontiers missions - the first being the New Horizons mission on its way to Pluto and the Kuiper Belt. Juno is an orbital mission, scheduled for launch about 2010. The mission will utilise a highly elliptical, near polar orbit to permit very low altitude observations whilst minimising exposure to Jupiter's radiation belts. The primary objectives of Juno are to determine the internal structure of the giant planet through detailed study of the magnetic and gravity fields with unprecedented precision, and determination of the abundance of water, and therefore oxygen, deep in the Jovian atmosphere, a key measurement not accomplished by the Galileo atmospheric Probe, which descended in a dry portion of the atmosphere where water was highly depleted.

New Horizons conducted a highly successful flyby of the Jupiter system in early 2008. The new data returned included spectacular time lapse images of volcanic eruptions on Io, some at locations which have been active since the Voyager and Galileo missions. Observations of Jupiter also identified lightning in shear zones in the atmosphere.

II.5.2. Saturn

The Cassini-Huygens mission, a joint programme between NASA and ESA, was launched in October 1997. It was designed to provide an intensive investigation of the Saturn system including Titan, the chemical environment of which may resemble that of the primordial Earth and thus provide valuable clues as to the chemistry of the early Earth. The Cassini spacecraft with the Huygens probe attached went into orbit around

Saturn on 1 July 2004. A major goal of the mission was achieved when ESA's Huygens probe successfully completed its mission, becoming the first spacecraft to land on Titan. The only anomaly in the technical performance of the probe was the loss of one of the two redundant radio channels to the Orbiter due to a commanding error. One of the main science experiments on the lost channel was the Doppler-Wind radio experiment, but fortunately the objectives of this experiment were achieved using an experimental direct-to-Earth tracking channel and an extensive international effort by radio astronomers to detect and measure the probe's radio signal from Earth-based radio telescopes.

During its approximately three hour descent through Titan's cold, thick nitrogen atmosphere, the Huygens probe sent back data on the composition and structure of the moon's atmosphere and took panoramic images of its dimly lit surface. Images taken below about 12 km altitude show the surface of Titan in unprecedented detail, including hills over 100 m in height, with channel and valley networks apparently carved by flowing liquid, probably liquid methane.

Huygens landed on a solid, icy pebble-strewn plain, possibly the outflow deposits from the channels seen in the nearby hills. Although no liquid was detected on the surface in the vicinity of the landing site, data from the Mass Spectrometer experiment on board showed a sharp increase in methane gas following the landing and heating of the surface by the probe, indicating that the soils may contain liquid methane below the surface. Another major discovery from the chemical analysis of the atmosphere was the lack of primordial noble gases (Kr, ^{36}Ar, and Xe), a finding that strongly suggests the origin of Titan's nitrogen atmosphere is the break down of ammonia rather than delivery of nitrogen trapped in very cold icy planetesimals during Titan's formation.

The Cassini Orbiter has also made extensive studies of Titan, performing close flybys, typically within a few thousand km altitude. As of October 2006, nineteen targeted flybys had been successfully achieved. The Orbiter carries out remote visual, infrared and radar observations of the atmosphere and surface and can also perform *in situ* analyses of Titan's atmosphere during close encounters. Synthethic aperature radar (SAR) images of Titan's surface have revealed a geologically young surface, with only a few large impact craters detected. In addition to channel systems similar to those seen in the Huygens descent images, the radar has also mapped extensive dune fields in the equatorial regions, likely composed of solid hydrocarbon particles. Observations near Titan's north pole show extensive dark lake-like features, interpreted as liquid methane/ethane lakes which may be part of a seasonal exchange of methane from the south to the north poles as well as supplying methane to the atmosphere to create the rainstorms recorded in the erosion channels seen by Huygens.

Detailed comparisons of features seen by the Cassini Radar have shown the satellite's icy crust is apparently rotating at a slightly different rate from the body of the satellite, which is locked in synchronous rotation with Saturn. This is interpreted as strong evidence for a low viscosity, probably liquid water, and layer decoupling the crust from the deep interior. Preliminary models for causing the non-synchronous spin suggest that it may be due to interactions with seasonally variable zonal winds in Titan's thick

atmosphere, analogous to small changes in the Earth's rotation induced by atmospheric coupling.

In addition to observing Titan, the Cassini Orbiter is making extensive measurements of Saturn's ring system, the smaller icy satellites and Saturn's magnetic and plasma environment. One of the major discoveries of the mission to date has been the detection of huge geyser-like eruptions from cracks in the south polar region of tiny Enceladus, an icy moon close to Saturn and only ~500 km in diameter. These plumes are composed primarily of water vapour and tiny ice particles and appear to be responsible for creating the huge, extended E-ring around Saturn. The source of the heat to produce these eruptions is still unknown, probably a combination of radioactive heating from the rocky portion of the satellite and tidal heating. The preliminary interpretation of the data on the plumes suggests strongly that there may be liquid water at shallow depths beneath at least the south polar region on Enceladus, and simple hydrocarbons have been detected on the surface and in the plume gas. Enceladus is thus of major interest to astrobiologists, as yet another planetary environment (along with Mars, Jupiter's moon Europa, and Titan) where the basic requirements for terrestrial life (water, organic material and energy) may be present currently or in the past.

Cassini's nominal mission ended in July of 2008. The spacecraft is still fully operational and NASA has approved a three year extended mission phase, ending in 2011. A further extension, possibly through 2017, is being studied.

II.5.3. Future Missions to the Jupiter and Saturn Systems

As a result of Galileo and Cassini/Huygens discoveries, several studies of future missions to Jupiter and Saturn have been conducted by NASA and ESA (as part of the Cosmic Vision solicitation). From these, two specific mission proposals were selected by NASA and ESA in 2008 for future study for a possible NASA-ESA joint mission. These included a Jupiter system exploration mission involving a Europa orbiter and a Jupiter system exploration ending with a Ganymede orbiter, and a Saturn system mission including a Titan orbiter and descent and *in situ* exploration, as well as future study of the Saturn system. Possible additional contributions from JAXA and other national space agencies are also being considered as part of the effort. A selection of the first mission to be implemented is expected in early 2009, with a possible launch in 2018 – 2022.

II.5.4. Other Studies, including Remote Space Studies of Exo-Planets

The solar system observations with the NASA-ESA HST (Hubble Space Telescope) have continued to be very productive with, for example, the observation that several Kuiper Belt Objects are actually binary systems, most likely as a result of mutual encounters and collisions.

The ESA-NASA Solar and Heliospheric Observatory (SOHO) has completed half a solar cycle of observations during which it discovered more than 800 comets.

The Odin sub-mm satellite, led by Sweden and involving Canada, Finland and France, was launched in February 2001, and is contributing to the study of water vapour in weakly active comets.

The current generation of X-ray space telescopes like Chandra have continued to provide important information for the study of solar wind-comet interaction and the X-ray spectroscopy of cometary comas. Key measurements of the auroral X-ray emissions of Jupiter and of Saturn have also been made by Chandra and XMM-Newton. The XMM observations showed that the Jovian aurora is likely to be produced by the precipitation of captured solar wind ions.

Ground-based activities (observations, laboratory measurements, modelling studies), of major interest for the preparation of future space missions, have been and are being performed in various parts of the world. A new trend has appeared with the development of 'laboratory' experiments under microgravity conditions on-board rockets, spacecraft, and the International Space Station (e.g., the International Microgravity Plasma Facility and the facility for Interactions in Cosmic and Atmospheric Particle Systems), to study dusty plasmas, dust aggregation, planetesimal formation and the light scattering properties of dust particles.

Several Earth-orbiting satellites are expected to provide results on exo-planets and exo-planetary systems. The NASA SIRTF (Space Infra-Red Telescope Facility) now called the Spitzer space telescope, was launched in August 2003, and will facilitate the study of Kuiper-belt dust out to 50-100 AU around nearby stars.

The French-European Corot mission, launched in December 2006, is being used to search for signatures of the transits of telluric-type and giant planets passing in front of stars. In extended observation periods of 150 days some 30,000 stars are observed continuously. The NASA Kepler Discovery class mission, to be launched in early 2009, consists of a space telescope that will use photometric transit measurements, also to search for Earth-like planets. The NASA SIM (Space Interferometer Mission) is being studied as a 5-year operational mission to complete a census of nearby stellar systems, using ultra-high precision, micro-arcsec interferometry to detect several Earth-mass planets around nearby stars (and larger planets around more distant stars). Finally, the ESA Cornerstone Gaia astrometric observatory mission, to be launched before 2012, is expected to detect the astrometric signatures of tens of thousands of Jupiter-type planets around stars in our galactic neighbourhood. In addition, it should provide a large, uniform census of minor planet kinematics, Near Earth Objects, trojans, trans-neptunians, and give information on galactic perturbations to the Oort cloud.

III. SPACE STUDIES OF THE UPPER ATMOSPHERES OF THE EARTH AND PLANETS, INCLUDING REFERENCE ATMOSPHERES.

III.1. The Earth's Middle Atmosphere and Lower Ionosphere

The Earth's middle atmosphere and lower ionosphere form an active and diverse region that couples the lower terrestrial atmosphere with the near Earth space environment. This region of the atmosphere is driven by waves and tides propagating upward from the lower atmosphere, and can be significantly perturbed by solar particle and radiative inputs from above. These external forcing mechanisms are of similar magnitude and importance in driving the global structure of the middle atmosphere and lower ionosphere.

The mesopause is the coldest place in the terrestrial environment and the turbopause, where the atmosphere makes the transition from well mixed to diffusive equilibrium, is located in this region. While dynamics play a major role in forcing the summer mesopause out of radiative equilibrium, chemistry also plays a significant role in this region. The constant ablation of meteors creates metallic layers.

The scientific community is working to understand the processes present in the middle atmosphere and lower ionosphere along with their impact on the region and coupling to other regions above and below. Topics relevant to understanding the region have grown out of recent symposia, including COSPAR. These areas include: understanding the processes that couple the lower atmosphere to the middle atmosphere and then into the lower ionosphere; the global distribution of waves from small scale gravity waves to large scale planetary waves and their influence on the system; co-ordinated ground and space based observations; meteoric input and its influence on the region; understanding the impact of geomagnetic storms on the region; understanding the processes that control the polar regions; layered phenomena such as noctilucent clouds (NLC, but also called polar mesospheric clouds or PMC); climatic impact of changes in trace constituents and solar input; impact of cosmic forcing; and the global electric circuit.

III.1.1. Progress on Selected Scientific Topics

It is not practical to cover all of the many and diverse topics of current interest to COSPAR sub-Commission C2, however, certain of the key activities from 2007 and 2008 are highlighted.

Network for the Detection of Mesopause Change

A Network for the Detection of Mesopause Change (NDMC) has been set up to co-ordinate long-term observations of the terrestrial mesopause region (80 to 100 km). It focuses on optical observations of OH and O_2 airglow that permit the spectroscopic determination of mesospheric temperature. Thus it exploits the combined expertise of the different research groups specialising in these studies, to improve the quality of available

and future data sets suitable for analysis of the issue of long-term change. Activities in May 2007 used a diverse network including 47 instruments/observation sites in some twenty-one countries. These instruments and observation sites are operated by Associates of COSPAR Commission C (see http://wdc.dlr.de/ndmc). In order to expand the scope of NDMC, links to the communities representing other observing techniques as well as modelling relevant to the mesopause region, are being established. NDMC is affiliated with the WMO programme Global Atmosphere Watch and the Network for the Detection of Atmospheric Composition Change. It now also forms part of the Global Earth Observation System of Systems (see http://earthobservations.org/geoss_cl_ea.shtml).

The Advanced Modular Incoherent Scatter Radar

The Advanced Modular Incoherent Scatter Radar (AMISR) is a modular, mobile radar facility that will be used by scientists and students from around the world to conduct studies of the upper atmosphere and to observe space weather events. When completed, AMISR will consist of three separate radar faces, with each face comprised of 128 building block-like panels over a 30 m x 30 m roughly square surface. AMISR is being constructed in two stages: the first face in Poker Flat, Alaska, was completed in early 2007 and is already being used for scientific investigations. The remaining two faces are under construction in Resolute Bay, Nunavut, Canada.

The locations of future AMISR Sites will be determined by a Scientific Advisory Panel. Since each face of AMISR functions independently, AMISR can be deployed in up to three separate locations at the same time. In February 2007, the Poker Flat AMISR system completed a year-long run associated with the International Polar Year (IPY). Since 1 March 2007, when not running for other experiments, PFISR operated almost continuously in a low-duty cycle mode. The resulting large dataset, combined with that from the year-long run of the EISCAT Svalbard radar at full-power and the bi-weekly 30 hr runs of the EISCAT Tromsø, Sondrestrom and Millstone Hill radar, provides an unprecedented volume of high quality high-latitude measurements during the IPY.

Aeronomy of Ice in the Mesosphere

The Aeronomy of Ice in the Mesosphere (AIM) spacecraft was launched on 25 April 2007. AIM has the goal of explaining why polar mesospheric clouds (PMC, or NLC) form, and understanding the detailed mechanisms that cause the apparently mysterious changes in their behaviour. By making measurements of PMCs and the thermal, chemical and dynamical environment of the mesosphere in which they form, AIM will quantify the connection between these clouds and the meteorology of the polar mesosphere. This has been accomplished by a complement of three dedicated instruments mounted on a SORCE follow-on spacecraft placed into a 600 km, Sun-synchronous orbit. The Cloud Imaging and Particle Sizes (CIPS) instrument measures backscattered solar radiation at 265 nm to provide panoramic ultra-violet (UV) images. It displays the effects of gravity wave activity and PMC particle properties with a horizontal resolution of ~ 2km x 2km. The Solar Occultation for Ice Experiment (SOFIE) uses infrared solar occultation measurements to provide 2 km vertical resolution profiles of temperature,

H_2O, CH_4, O_3, CO_2, NO, aerosols and particle size distribution from the stratosphere to ~120 km altitude (in the case of temperature). The Cosmic Dust Experiment (CDE), mounted on the zenith side of the spacecraft provides the daily input of cosmic dust flux to the atmosphere by measuring depolarization signals created by dust impact on polyvinyldifluoride (PVDF) films. An important objective of AIM is to establish the basis for study of long-term changes in mesospheric climate and their relationship to global change by firstly providing a comprehensive observation baseline and secondly through validation of predictive models that can be used to assess future changes.

AIM has already made measurements of the cold summer mesopause region for two northern hemisphere seasons and one winter season. New results from the AIM mission include:

1. The most detailed images of the PMC collected thus far. These show that PMC are present every day; that they are widespread and that they are highly variable on time scales of hours to days.
2. That PMC brightness varies over horizontal scales of about 3 km; and over small regions, clouds measured by AIM are ten-times brighter than those measured by previous space-based instruments.
3. One unexpected result is that mesospheric ice has been found to occur in a continuous layer extending from below the main peak at 82 km altitude and extending up to around 88 km.
4. Observations of a previously suspected, but never before observed optically, population of very small ice particles. These are believed to be responsible for the strong radar echoes observed in this altitude region within the summertime mesosphere. This was made possible because of the unprecedented sensitivity of the AIM optical measurements.
5. PMC structures have been resolved fully for the first time. They exhibit complex features remarkably similar to those present in normal tropospheric clouds. This startling similarity suggests that the mesosphere may share some of the same dynamical processes responsible for tropospheric weather. If this similarity is supported by further and more detailed analysis, this opens up an entirely different view of potential mechanisms that can explain why the PMC are formed and how they vary with time and space.

CAWSES

The Climate and Weather in the Sun Earth System (CAWSES) is an international programme sponsored by the Scientific Committee on Solar-Terrestrial Physics (SCOSTEP), established with the aim of significantly enhancing our understanding of the space environment and its impacts on life and society. The main functions of CAWSES are to help co-ordinate international activities in observations, modelling, and applications crucial to achieving this understanding; to involve scientists in both developed and developing countries; and to provide educational opportunities for students of all levels. Theme three of CAWSES specifically focuses on solar and

magnetospheric inputs which propagate downward through the atmosphere and on tropospheric effects which propagate upward into the thermosphere-ionosphere system.

CAWSES is of great interest to the COSPAR Commission C-2 community as illustrated by the Scientific Meetings supported by C-2 at the most recent 2008 COSPAR Assembly in Montreal, Canada. Significant activities have occurred in the interest area of the "Global Tidal Group" with dedicated workshops held during 2007 and 2008 to analyse and interpret data collected from a network of ground-based radar and optical instrumentation in addition to the space-based observations.

Virtual Observatories

The observations required to investigate and understand the complex problems in the middle atmosphere and lower ionosphere are provided by many scientists and research groups of investigators distributed all around the world. Data collected from individual instruments are often held at the home institution of the principal investigator and are made available more widely either via the web or by request. In the case of the more complex space missions, such as those sponsored by NASA and ESA, these data are disseminated widely via national data centres. While the data centre model is viable for large projects, such as a satellite mission, there are great difficulties and challenges in handling and distributing the many modest-sized and diverse data sets from these ground-based instruments. A new concept, called the virtual observatory (VO), has recently been developed. Under the VO scheme, data can be shared around the world via the web through a "virtual observatory". Under the VO concept, all data is served to the web locally and the VO provides powerful search and recovery capabilities through this distributed network of data.

The Virtual Solar Terrestrial Observatory (VSTO) is currently under development. The VSTO will provide a mechanism for researchers in the ionosphere-thermosphere-mesosphere (ITM) community to share their data. VSTO will comprise a system that provides virtual access to specific data, models, tools, and material archives containing items from a variety of space- and ground-based instruments and experiments, as well as individual and community modelling and software efforts bridging research and educational use. The overall goal is to integrate a balance of extensive holdings of observational data and results from model simulations; portals; diverse and powerful client software; and a semantically-rich framework that provides an environment that researchers can use without undue effort, just as if all of the materials and powerful tools for analysis and display were available on his/her local computer.

III.2. Earth's Ionosphere, Thermosphere and Mesosphere

The Ionosphere, Thermosphere, and Mesosphere (ITM) region, including much of the Exosphere, extends from 70 to approximately 1500 km in altitude and continues to be the focus of active research by international space-based and ground-based teams and facilities. The region has become critically important to human presence in space and is

the arena in which dynamical processes dramatically affect communication, navigation, power, aviation, defence, and space transportation systems.

The density, composition, and dynamics of this region are highly responsive to variable energy inputs from above (the Sun and magnetosphere) and from below (the middle atmosphere). The ionosphere is generally coincident with the mesosphere, thermosphere and exosphere and is created by two overall processes. These include 1) the direct absorption of solar extreme ultraviolet (EUV) radiation by neutral atoms and molecules and 2) the impact ionisation of neutral species by the precipitation of energetic electrons at high latitudes into the thermosphere. Both the ionised and neutral gases are closely linked through collisions and dynamics. They respond to energy and momentum forcing from both the magnetosphere above and the middle atmosphere below.

The ITM is studied by a variety of techniques ranging from ground optical and radio instruments to sounding rockets and satellite platforms. Research activity has expanded beyond individual or national investigations to include large, international, focused study projects and campaigns. In the 1990's, research was co-ordinated by the Solar Terrestrial Energy Program (STEP) and the Coupling, Energetics and Dynamics of Atmospheric Regions (CEDAR) programmes. From 1998 through 2002, the Scientific Committee for Solar Terrestrial Physics (SCOSTEP), SRAMP (STEP Results, Applications and Modelling Phase) programme and the PSMOS (Planetary-scale Mesopause Observing System) programme were active. The EPIC (Equatorial Processes Including Coupling) programme studied the ITM coupling processes at low latitudes. These programmes worked in conjunction with the International Solar Cycle Study (ISCS) programme that was also under the direction of SRAMP. Since 2002 SCOSTEP has emphasized the importance of space weather (the highly variable impact of the Sun's photons, particles, and fields upon the Earth and our technological systems) and implemented a major programme for the period 2004-2008 called Climate and Weather of the Sun-Earth System (CAWSES; see above). These programmes provide a global network of observing systems and study projects to understand the Sun's affects upon the Earth's ITM and to determine the global scale solar, chemical, and dynamical influences on the ITM region.

III.2.1. Progress on Selected Scientific Topics

The large number of individual and national projects that study and characterise the processes and variability of the ITM are now too numerous to list in a single article. However, some important highlights can be described.

Ground-Based Radar and Optical Programmes

These include Fabry-Perot measurements of thermospheric winds and temperatures, ionosonde programmes providing raw ionograms and summary reports, ground-based nightglow observations to monitor variability of the mesopause region, coherent radar for studying the auroral zone electrodynamics including plasma convection, and GPS-based technology to monitor and understand the ionosphere.

Examples include a multi-instrumental atmosphere observation programme, CPEA (Coupling Processes in the Equatorial Atmosphere), which used the Equatorial Atmosphere Radar (EAR) from Indonesia. The study of onset conditions of plasma bubbles was conducted by using data from ionospheric soundings obtained using the Southeast Asia Ionospheric Network (SEALION) while SEEK-2 (Sporadic E Experiment over Kyushu 2) studied sporadic E layers. The effect of thunderstorms on the upper atmosphere and ionosphere has been studied using co-ordinated optical and electromagnetic (VHF/ELF) measurements of sprites' optical emissions in the mesosphere. Earthquake effects on the ionosphere have been studied in the great Sumatra earthquake (26 December 2004) as changes in the ionospheric total electron content were detected by a GPS receiver network and as geomagnetic pulsations were generated through the dynamo action of an atmospheric pressure pulse. A precursor of ionospheric perturbations to the Sumatra earthquake was found in a sub-ionospheric VLF propagation signal. Observations of geomagnetic storm effects on the ionosphere disturbances used magnetometers from the Pacific sector and an ionosonde network along the Japan meridian as well as data from the Brazilian sector to study global characteristics. GPS receiver networks over Japan (GEONET) have been used to study travelling ionospheric disturbances with simultaneous observations in Australia.

Rocket Systems, Results and Campaigns

Rocket programmes are providing data on thermospheric and ionospheric parameters, high-resolution EUV irradiances, atmospheric density, temperature and winds, electric and magnetic fields, as well as chemical composition, including minor constituents. Many rocket campaigns are co-ordinated with co-located facilities such as lidar and radar systems, so that information on the background atmospheric and ionospheric conditions can be determined during the period surrounding the time of specific rocket flights. Examples include polar atmosphere-ionosphere studies by the Dynamics and Energetics of the Lower Thermosphere in Aurora (DELTA) rocket campaign from the Andøya Rocket Range, Norway.

Satellite Systems

Major spacecraft continue to make ITM-related measurements. ACE continues to measure the composition of the solar wind at the L1 position; COSMIC makes GPS occultation measurements of the total electron content for 3-D ionospheric tomography; C/NOFS was launched in 2008 to make observations of equatorial scintillation; CHAMP and GRACE provide accelerometer and GPS data for neutral density specification; GOES satellites in geosynchronous orbits monitor solar X-rays and solar particles; POLAR completed its observing of both high- and low-altitude perspectives of the polar region of geospace; ROCSAT-1 continues to study ionospheric phenomena, including field-aligned irregularities; SDO will be launched in 2009-2010 to understand and, ideally, predict the solar variations that influence life on Earth and humanity's technological systems; SOHO continues to provide information on the structure of the solar interior, surface magnetic fields, inner corona, coronal mass ejections, and the solar wind; SORCE provides measurements of the 0.1-34 nm and 115-2000 nm solar

irradiances with four instruments; the Solar Platform was attached to the International Space Station to make complementary solar irradiance measurements; STEREO provides 3-D views of solar phenomena and disturbances travelling in the inner heliosphere; TIMED continues to study the energy balance (solar heating, IR cooling, transport) and basic state (density, composition, temperature, wind) of Earth's atmosphere between 60 and 180 km while UARS completed its observations of the upper atmosphere and, interestingly, was impacted by a debris object to become part of the space debris field itself.

Models and Modelling Activities

There have been substantial advances in both empirical and first principles models that describe the Earth's upper atmosphere, ionosphere, magnetosphere, and solar radiative and particle inputs. Models are now being included in systems-level characterisations of the Sun-Earth environment. These coupled models are the basis for climatological research as well as space weather operations:

Physics-based Thermospheric Models: CISM (Center for Integrated Space Weather Modelling) is a consortium of ten US institutions whose vision is to understand the Sun's effects on the Solar System, life, and society by developing the first comprehensive community model for space weather; **NCAR TIEGCM,** the thermosphere-ionosphere-electrodynamic general circulation model continues to be updated and used for comparative studies with measurements and other models; the **CTIP, CTIM, and SUPIM** models are global, three-dimensional, time-dependent, non-linear models for the neutral thermosphere and mid- as well as high-latitude ionosphere; and **Global Numerical Model** describes the mesosphere, thermosphere, ionosphere and inner part of the magnetosphere of the Earth as a single system by means of numerical integration of the time-dependent three-dimensional continuity, momentum and heat balance equations for neutral, ion and electron gases as well as the equation for the electric field potential. The Global Ionosphere Thermosphere Model (**GITM**) removes the assumptions of hydrostatic equilibrium, which is present in the other models, and solves on an altitude grid, as opposed to pressure-levels. A new initiative to develop a data-assimilative, physics-based neutral atmosphere model for use by operational communities has been started and is called **NADIR**.

Empirical Thermospheric Models: NRLMSISE-00 incorporates new AFRL accelerometer data sets and the CEDAR Database (Millstone Hill incoherent scatter radar and Arecibo) data sets. NRLMSIS will be part of the new COSPAR International Reference Atmosphere (CIRA); **JB2006** and **JB2008** are modified Jacchia-type models, with improved description of the semi-annual variation and using new solar and geomagnetic activity indices that reduce the uncertainties of previous MSIS and Jacchia-type models by almost 50%. **JB2008** will be part of the new COSPAR International Reference Atmosphere (CIRA), which is the basis for ISO's New Work Item for "Air Density Models" of the Earth's thermosphere.

Physics-based Ionospheric Models: GAIM (one version each by USU and USC/JPL) continues to extend the capabilities of first principles/data assimilation for the ionosphere by assimilating a variety of data types including total electron content (TEC) from ground and space-based GPS receivers, and data from orbiting ultraviolet imagers. The USU GAIM model has been implemented operationally by the USA.

Empirical Ionospheric Models: The International Reference Ionosphere (**IRI)** model continues to be developed and updated, which is the basis for ISO TS 16457.

Plasmasphere Models: These are becoming increasingly important in order to specify the electron densities in the higher altitudes of the ionosphere and include the following: **FLIP** describes the seasonal and solar cycle behaviour of the mid-latitude ionosphere during most quiet periods; the **La Trobe** plasmasphere global electron density model for analyzing TEC measurement variability is based on GPS data; the **Sheffield** model provides an understanding, through physics-based modelling, of the complex physical processes of the plasma flows along the magnetic field lines; **GCPM** includes the IRI electron density below 500-600 km and demonstrates sophisticated dependencies of the plasmasphere on the solar and magnetic indices; **GPID** includes IRI below 500-600 km extended with theoretical plasmasphere electron density description along the field lines; the **IZMIRAN** empirical plasmasphere model based on whistler and satellite observations is smoothly fitted to IRI electron density profile at 1000 km altitude and extends towards the plasmapause (up to 36,000 km); the **IMAGE** plasmaspheric model is based on Radio Plasma Imager (RPI) measurements of the electron density distribution along magnetic field lines.

Solar Irradiance Models: The Solar Irradiance Platform (**SIP**) has evolved from the SOLAR2000, VUV2002, and SOLARFLARES models into a hybrid (empirical, physics-based, and data assimilative) system producing research and operational full solar spectrum irradiances between X-ray and radio wavelengths (1-1,000,000 nm) with up to 1 minute time resolution and 0.1 nm spectral resolution; the Flare Irradiance Spectral Model (**FISM**) empirical model estimates 0.1 to 190 nm solar irradiances at 1 nm resolution with a time cadence of 60 s to model irradiance variations due to solar flares; the Solar Radiation Physical Model (**SRPM**) has evolved from the SunRISE solar synthesis model to create a physics-based solar atmospheric spectral model at high spectral resolution to compute the emergent intensity and irradiance spectrum of IR, VIS, UV, and EUV wavelengths; the **HEUVAC** solar EUV flux proxy model is used for calculating upper atmosphere densities and temperatures; **NRLEUV** utilizes differential emission measure distributions derived from spatially and spectrally resolved solar observations, full-disk solar images, and a database of atomic physics parameters to calculate the solar EUV irradiance.

3D-MHD Models: Thermosphere/ionosphere disturbances can be generated by solar wind shock waves and coronal mass ejections as a result of dynamic pressure pulses and interplanetary magnetic field polarity and magnitude changes. An ensemble of four physics-based Sun-to-Magnetosphere models is being extended to include a three-dimensional MHD model. Complementary to these are the statistical solar wind models

developed for precipitating electrons and based on 10 years' worth of NOAA-12 Space Environment Monitor (SEM) data.

International Programmes

CAWSES: In the 2004-2008 period SCOSTEP implemented a programme called Climate and Weather of the Sun-Earth System (CAWSES; see above) as a systems approach in solar terrestrial physics. CAWSES fosters a scientific approach to understanding the short-term (Space Weather) and long-term (Space Climate) variability of the integrated solar-terrestrial environment and for its societal applications. These include human activities in space, the need for increased reliability of technological systems whose performance depends on variations in the solar-terrestrial environment, and global changes in climate and ozone. Education also plays an important part in CAWSES. CAWSES is organized to accomplish the following specific objectives:

1. Articulate timely outstanding scientific questions in the connected Sun-Earth system, particularly in cooperation with other ICSU programmes.
2. Coordinate international aspects of specific national programmes when the participating nations find this desirable.
3. Provide a forum to bring together the international solar-terrestrial science community to help define future programmes.
4. Continue to help developing nations to participate meaningfully in international solar-terrestrial programmes.
5. Provide scientific inputs for the purpose of specifying the environment for technological systems whose performance critically depends on solar-terrestrial variations.
6. Provide a co-ordinated environment in which computer modellers work within observational and analytical programmes to achieve validated, reality-based end-to-end models of the entire Sun-Earth system, and then assist in the transition to applications.
7. Provide scientific inputs that help ensure human safety in space, since humans will be spending increasing amounts of time there.
8. Contribute solar-terrestrial information to the Global Change community.
9. Actively help international science education by providing solar-terrestrial information to the international educational community and promote scientist-and student interactions.
10. Systematically review the quality of solar-terrestrial databases and derived information and improve metadata for solar-terrestrial products so that they meet scientific community needs.
11. Guide the World Data Center system of ICSU in providing needed STP data and information collecting, processing and archiving services in the modern Internet era.

TIGER: The primary objective of the TIGER programme is to determine the variable solar EUV/UV and X-ray fluxes, to improve the existing and future thermospheric-ionospheric (T/I) models and to derive EUV/UV indices or proxies for various applications in space research and space-related fields such as navigation and

communication. In 2004, 2006, and 2008 TIGER Symposia were held as COSPAR sessions to emphasise the unique but interrelated contributions of solar irradiance effects upon the terrestrial thermosphere and ionosphere (T/I). Specific presentations and publications included reports on solar irradiance measurements, reference spectra, models, and proxy developments for thermosphere/ionosphere uses, particularly emphasising solar products that are compliant with ISO 21348 (Solar Irradiance Standard). Airglow emissions correlate well with T/I parameters such as densities or temperatures and reports of airglow modelling results, especially from the TIMED mission, were included.

Solar Measurements on-board the ISS: A new instrumentation system for COLOMBUS on the ISS, named "SOLAR" (or Solar Platform) consists of three instruments dedicated to absolute solar spectral and total irradiance. These are SOL-ACES measuring from 17 to 200 nm, SOLSPEC measuring from 165 to 3000 nm and SOVIM measuring the total solar irradiance. These new measurements are highly relevant to atmospheric physics and those in the shortest wavelength range are particularly important for the upper atmosphere. SOLAR was launched in early 2008 and nominal measurements started by the end of July 2008.

Space Weather: The US National Space Weather Program (NSWP) is devoted to improving predictive services for the near-Earth environment. Its Assessment Committee report was published in 2006 to update the status of US space weather activities and identify, assess and help predict the risks to ground-based and space-based technological systems. The NSWP programme derives particular benefit from the GEM (Geospace Environment Modelling) programme of the US National Science Foundation, which continues to develop methodologies for the accurate modelling of space weather events in the magnetosphere and the ever more accurate measurement/modelling of important inputs to the Ionosphere-Thermosphere-Mesosphere (ITM) region (aspects as critical as high latitude ion convection patterns, integrated hemispheric heating rates, solar wind and interplanetary magnetic field configurations, etc.).

ISO TC20/SC14/WG 4 (Space environment – natural and artificial) and ECSS: Space environment standards continue to be produced by ISO TC20/SC14 Working Group 4. There are several draft standards or technical specifications currently in process or recently published and these are: ISO 15390:2004 (Galactic cosmic rays), ISO 21348:2007 (Determining solar irradiances), ISO 15856 (Ionising radiation tests of materials), TS 16457 (Earth's ionosphere/plasmasphere), and ISO 22009 (Earth's magnetosphere). In addition, new work items are being considered for the orbital debris environment, guidelines and standards for Earth atmosphere densities, geomagnetic and solar activity prediction, radiation belt characteristics, charging of GEO solar array panels, and lunar dust simulants, creation, and transport. Working Group 4 held special sessions at the 2002, 2004, 2006, and 2008 COSPAR Scientific Assemblies to review standards activities related to the space environment, and will have a further scientific session at the 2010 COSPAR Assembly. The ECSS European standards community has made a major upgrade to the ECSS 10-04E document on the space environment.

III.3. Planetary Atmospheres and Aeronomy

III.3.1. Mercury

The study of Mercury is considered to be very important for comparative planetology since this planet is the closest to the Sun and in many respects is the "end member" among the terrestrial planets. Our knowledge about Mercury is far from being complete. Even the surface is not fully mapped. The Messenger spacecraft, designed and built as part of the NASA Discovery Programme, was successfully launched on 3 August 2004. After one Earth, two Venus, and three Mercury flybys, the spacecraft will reach Mercury in 2011. Results from the first of the Mercury fly-bys have been presented recently, providing some surprising new information on the surface, and on the gravity field.

Mercury has a tenuous atmosphere (exosphere) created by intense interaction of the solar wind with the surface. A spectrometer onboard Messenger will study the atmosphere of Mercury in great detail.

BepiColombo – an ESA cornerstone mission – is also planned for studies of Mercury, and is now scheduled for launch in 2013. The mission is a joint effort of the European and Japanese space agencies. It will consist of two orbiters: the first one, the Mercury Planetary Orbiter (MPO), will study the surface and exosphere of the planet and the second one, the Mercury Magnetospheric Orbiter (MMO) will investigate the magnetic field and plasma environment of the planet. The Instruments selected for the ESA (MPO) and JAXA (MMO) payloads are now being constructed by several consortia of research groups with very wide international representation and co-operation.

III.3.2. Venus

In April 2006 ESA's Venus Express spacecraft arrived at Venus and began making observations. The nominal mission lasted till October 2007 and the first extension until May 2009 was approved. The mission is based on re-use of the Mars Express spacecraft and the instruments available from the Mars Express and Rosetta missions with the main goal of carrying out a global and systematic remote sensing survey of the atmosphere, plasma environment, and the surface of Venus from polar orbit. Venus Express continues and extends the investigations of earlier missions by providing detailed monitoring of processes and phenomena in the atmosphere and near-space environment of Venus.

Many observation techniques are being used for the first time at Venus, including radio, solar and stellar occultation, together with thermal emission spectroscopy, sounding of the atmospheric structure in the altitude range from 150 to 40 km with vertical resolution of few hundred metres, revealing strong temperature variations all over the planet driven by radiation and dynamical processes. Multi-spectral imaging is being performed to investigate the cloud morphology at different levels and its latitudinal and temporal changes. It shows vigorous convection in the cloud layer at low latitudes that

ceases towards the poles. Sequences of images are being used to track motions of the cloud features and to derive wind speeds in the 50-70 km altitude range. The polar orbit of Venus Express provides near-nadir viewing of middle and high latitudes in the southern hemisphere, enabling the first detailed observations of the cloud morphology and dynamics, leading to the discovery and characterisation of the complex "eye" of the southern polar vortex. The imaging instruments also perform thermal mapping of the surface in the near IR spectral windows on the night side, searching for surface emissivity anomalies and signs of active volcanism.

The chemistry and dynamics of the mesopause region (~100 km altitude) is being studied by observing non-LTE emission from O_2 and NO molecules in the UV and near-IR. Composition measurements over a wide range of altitudes are providing for the first time vertical profiles of CO, H_2O, HDO, HCl, HF, and SO_2 in the mesosphere (70-100 km), and global mapping of CO, COS, H_2O, and SO_2 in the lower atmosphere at heights around 35 km.

The Venus Express instruments measure the magnetic field and densities of neutral atoms, ions and electrons *in situ*. These observations determine the structure and properties of the circum-planetary plasma and characterize escape processes at Venus. They cover the time of solar minimum, and thus complement Pioneer Venus investigations at solar maximum. Interestingly, the H/O ratio was found to be ~2 thus suggesting that these ions are escaping in the stochiometric ratio of water. The magnetometer detects whistler signals in ~10% of the pericentre passes. This is interpreted as evidence of lightning and the rate is estimated to be at least as frequent as on Earth.

The Venus Express observations significantly contribute to the field of comparative planetology and, in particular, to our understanding of the Earth climate and its evolution. The success of the mission has revived a worldwide interest in our neighbouring planet. The Japanese mission to Venus (Planet-C) is scheduled for launch in the summer of 2010 to join Venus Express. In 2008 the Venus Science and Technology Definition Team (VSTDT) was formed by NASA to formulate the science goals and technology challenges for the future Flagship mission to the planet.

III.3.3. Mars

A flotilla of spacecraft is now working in orbit around Mars, unveiling mysteries of the Red Planet. In March 2006 NASA Mars Reconnaissance Orbiter (MRO) joined the Odyssey (NASA) and Mars Express (ESA) Orbiters to continue investigations of the Martian surface, subsurface layers and atmosphere. Of particular importance is global long-term monitoring of the main meteorological parameters like temperature and pressure fields, dust and water content that provides details about climate and weather on the planet. Accumulation of the observational data by the spacecraft goes hand in hand with numerical modelling of the Martian environment by sophisticated General Circulation Models (GCM). The seasonal changes of global temperature fields on Mars appear to be rather similar to that of the Earth and are driven by changes in solar

insolation. Dust "devils" – small Martian tornados - were found to be one of the main suppliers of dust into the atmosphere.

The water cycle shows strong changes of atmospheric water content which are dominated by condensation/sublimation processes on the polar caps. Monitoring of the abundance of minor constituents like H_2O, CO, HDO, CH_4 and others has shed light on the complex chemistry that occurs in the thin but very interesting Martian atmosphere.

Two NASA Mars Exploration Rovers (MERs – Spirit and Opportunity) continue their journeys investigating the surface of Mars *in situ*. During their mission of ~1500 days the rovers have travelled ~10 km each. They have studied different types of rocks and sediments that provided important clues about the geology and history of Mars. The rovers also carry out meteorological and optical observations. In May 2008 the Phoenix lander joined the MERs to study in detail the processes in the northern polar regions. Two sophisticated mobile laboratories – MSL (NASA) and Exomars (ESA) are being prepared now to investigate exobiological aspects of the Martian environment.

III.3.4. Jupiter and its moons

The next step in the exploration of Jupiter will be done by the NASA Juno mission which is under development now and is scheduled for launch in August 2011. The spacecraft will be inserted in a polar orbit and will investigate gravity and magnetic field, atmosphere and satellites of the giant planet.

III.3.5. Saturn and its system

In July 2004 the NASA/ESA Cassini spacecraft reached Saturn and was successfully inserted into orbit. In January 2005 the Huygens probe entered Titan's thick atmosphere and successfully landed on Titan. The instruments provided unique data about the atmosphere and the surface of the moon. The probe discovered a cold exotic world governed by chemistry and physics of various hydrocarbons. Photochemical reactions give rise to the formation of dense aerosols that precipitate on the surface, resulting in a hydrological cycle which is similar to the water cycle on Earth. Titan has given scientists a glimpse of what Earth might have been like before life evolved. We now believe Titan possesses many geological parallels to Earth, including lakes, rivers, channels, dunes, rain, snow, clouds, mountains and possibly volcanoes. The Cassini Orbiter continues to make remote sensing investigation of Saturn and its moons.

III.3.6. Pluto

On 19 January 2006 NASA's Pluto-Kuiper Belt mission was launched. After passing Jupiter in early 2007, the spacecraft will reach the Pluto-Charon system in 2015. Both objects belong to the category of "dwarf planets" according to the new IAU classification accepted in 2006. Pluto's surface is mainly composed of ices that tend to sublime when the planet comes closer to the Sun in its orbital motion, thus creating a

tenuous atmosphere. During the flyby, the probe will study the surfaces and atmospheres of these remote icy planets.

III.3.7. Theoretical Studies and Numerical Modelling

A vigorous programme of theoretical studies of planetary atmospheres and plasma environments is continuing. Some of these activities are associated with the interpretation of past data sets. However, a wide range of predictive studies and simulations are associated with providing essential support for future planetary missions.

III.4. Task Groups for Reference Models of the Atmosphere and Ionosphere

COSPAR Commission C is charged with the responsibility for developing Reference Models of the Atmospheres and Ionospheres of the Earth, Planets and Satellites. In order to undertake these activities, Task Groups are set up that report directly to Commission C. Currently, there are three Task Groups – the International Reference Ionosphere (IRI), COSPAR International Reference Atmosphere (CIRA) and Reference Atmospheres for the Planetary System (RAPS). The COSPAR International Reference Atmosphere (CIRA) and the International Reference Ionosphere (IRI) are joint projects of COSPAR and URSI.

International Reference Ionosphere (Joint COSPAR / URSI Task Group)

The main event during the reporting period was the release of the new and improved version of the model, IRI-2007. This latest version includes several new options and new parameters: (a) two new options for the topside electron density profile (a correction based on topside sounder data developed by Bilitza, USA and the NeQuick-model of Radicella, Italy and Leitinger, Austria), (b) a Neural-Network model for the electron density in the auroral E-region based on the work of McKinnell, South Africa, and Friedrich, Austria, using EISCAT incoherent scatter radar measurements and rocket data, (c) plasmaspheric electron temperatures are included for the first time (Akebono model of Kutiev, Bulgaria and Oyama, Japan), (d) a much improved model for the topside ion composition (Triskova and Truhlik, Czech Republic), and for the first time a specification of spread F probability (de Souza, Brazil).

During the COSPAR 2006 General Assembly in Beijing, China a special IRI-related session was held entitled “Modelling the Solar Activity Variations of Ionospheric Parameters (session C4.2)”. Close to 60 papers were presented during the 2-day session including oral and poster presentations. Of special interest is the good correlation of topside parameters with indicators of solar variation like the F10.7 radio flux when allowing for a 1-2 day delay.

A special IRI workshop was held in October of 2006 in Buenos Aires, Argentine focusing on an improved representation of Total Electron Content (TEC) with IRI. The meeting was exceptionally well organised by Dr. M. Mosert and her team from CASLEO, San Juan with help from the ionospheric groups from the Universidads

Nacional of Tucuman and La Plata. An excellent global coverage was provided by participants (Argentina, Czech Republic, Italy, USA, Spain, Russia, Austria, Peru, Cuba, South Africa, Brazil, Nigeria, and Mexico) as well as the many different data sources (ionosondes, GPS, incoherent scatter radars, TIMED, DMSP, Hinotori, Akebono and a few other satellites). Presentations showed how on one hand the data from the Global Navigation Satellite Systems (GNSS) can benefit the representation of TEC with IRI both in terms of model improvements as well as real-time updating, and on the other hand showed how usage of the IRI model helps to initiate and fine-tune the GNSS data mapping techniques. A more detailed description can be found at http://iri.gsfc.nasa.gov/docs/iri_06_report.html.

For its 2007 Workshop the IRI team joined forces with the European Co-operation for the Mitigation of Ionospheric Effects on Radio Systems (COST 296) one of the major pan-European projects in ionospheric physics supported by the European Co-operation in the Field of Scientific and Technical Research (COST). The special focus of this combined IRI/COST workshop was a better representation of the forcing from below and from above in ionospheric models with special emphasis on the IRI model and regional European models. Naturally the workshop had a strong orientation towards application of ionospheric models and specifically on their effects on radio systems. The 1-week meeting was held in Prague, Czech Republic in July 2007, expertly organized by the Local Organizing Committee of the Institute of Atmospheric Physics (Lastovicka, Buresova, Sauli, Truhlik, Triskova) and attended by 103 participants from Africa, Asia, Europe, and North and South America giving 67 oral and 50 poster papers. An important outcome of the presentations and discussions at the meeting was the initiation of a special F-peak Mapping Task Force that will work towards the development and inclusion in IRI of an improved representation of F-peak density and height. The models currently in use are more than 25 years old and urgently in need of improvement. The task group will also co-ordinate with the F-peak mapping needs of the International Telecommunication Union (ITU) in supporting worldwide radio-communication. Very promising is an effort at Rhodes University in South Africa by McKinnell and her colleagues. They have successfully applied a Neural Network technique to the large volume of globally available ionosonde data. An article summarizing workshop results was published in the Space Weather journal (Bilitza, D., B. Reinisch, and J. Lastovicka (2008), Progress in Observation-Based Ionospheric Modeling, Space Weather, 6, S02002, doi:10.1029/2007SW000359).

All three IRI meetings received financial support from a number of international and nationalorganizations including COSPAR and URSI. Refereed papers from the IRI meetings will be published in the COSPAR Scientific Journal Advances in Space Research. A combined issue with ~30 papers from the Beijing and Buenos Aires meetings was just published as a special issue of Journal Advances in Space Research (Volume 42, Number 4, 2008). Editorial work is under way for the papers from the Prague IRI Workshop. Because of the large number of contributions the papers will be distributed over two issues of Advances in Space Research. Two ASR issues with papers from earlier IRI workshops were published during this reporting period: (1) Bilitza D., B. Reinisch, (eds.), Advances in Specifying Plasma Temperatures and Ion composition in

the Ionosphere, Advances in Space Research, Volume 37, Number 5, 2006. (2) Reinisch B., D. Bilitza, and D. Altadill (eds.), New Satellite and Ground Data for IRI and Comparison with Regional Models, Advances in Space Research, Volume 39, Number 5, 2007.

COSPAR International Reference Atmospheres (CIRA) Task Group

During the COSPAR Assembly at Warsaw in July 2000, Commission C re-organised the Task Groups concerned with development of future Reference Atmosphere models. Subsequent scientific meetings held during the COSPAR Assemblies in Houston (October 2002) Paris (July 2004) Beijing (2006) and Montreal (2008) have been used to present and review the very wide range of new data on minor constituent densities in the middle and upper atmosphere, and new empirical models describing atmospheric density, temperature and constituent densities. A further meeting is planned for the 2010 COSPAR Assembly to be held in Germany.

During the 2008 COSPAR Assembly in Montreal, the components of the CIRA-2008 Model were presented and discussed during a very successful dedicated scientific meeting. The considerable progress with semi-empirical models for atmospheric density was noted. For the first time in some 30 years, there has been a real improvement in the prediction of thermospheric density, so essential for the understanding of satellite orbit lifetime and decay and the prediction of satellite re-entry.

The new J-B-2008 model also aids preparation for safe manned flight re-entry manoeuvres. Further major progress has been made in the future prediction of solar and geomagnetic parameters, leading to new indices that are far more representative of the heating and energisation of the upper atmosphere and ionosphere. In particular, it is now possible to consider the prediction of thermospheric density, with moderate accuracy, for future epochs. This is of particular use in planning certain future space missions.

Reference Atmospheres for the Planetary System (RAPS)

The RAPS task group has held successful meetings during each of the recent COSPAR Assemblies. An International Reference Model for the Martian atmosphere has been prepared, and will be published shortly. This activity has benefited greatly from the new measurements made by the well-instrumented spacecraft that have visited Mars recently. The next priority of the Task Group is to update and complete an International Reference Model for the Venus atmosphere, exploiting data from the very successful Venus Express Mission. By the time of the COSPAR Assemblies in 2010 and 2012, the vast range of high quality data now being assimilated from the recent space missions to Jupiter and Saturn will be used to create the first detailed and comprehensive models describing the structure, composition and behaviour of the atmospheres of Jupiter, Saturn and Titan.

Development of Standards for the International Standards Organisation.

The IRI model has been proposed to the International Standards Organisation (ISO) as the Standard Model for the ionosphere. This was supported by a resolution of URSI Commission G during the URSI General Assembly in Toronto, Canada in 2004. The new COSPAR International Reference Atmosphere Model (CIRA-2008), now under final preparation, has been endorsed by resolutions of COSPAR and URSI and will also be the basis of a new ISO Standard on "Air Density". Updated versions of IRI and Atmospheric Models have also been used as components of the new ECSS-E-10-04C standard, due to be published in December 2008.

III.5. Dusty Plasmas

The observable universe consists mostly of plasma. Plasma is a low density gas consisting of charged particles that may attain high energies. Our Sun, which has a vital influence on life on Earth, and the near-Earth space environment where energetic particles create a hazard for human and satellite spaceflight, also consists primarily of plasma. Unfortunately, it is difficult to create realistic plasma conditions on Earth, since even experiments inside vacuum chambers are not entirely realistic because of their small size and the effects of chamber walls. The only near-by place where natural unbounded plasma can be observed is within the Earth's ionosphere, above about 100 km altitude. A range of diagnostic systems, typically radar and night-vision optics, has been developed over the decades to study ionospheric plasma and so gain insights into the plasma of the universe. Facilities that can temporarily modify the ionospheric plasma, typically high-power radio wave transmitters, allow controlled experiments to be undertaken.

Significant advances have been realised in the past 2 years including, for example: Imaging of the plasma irregularities that cause scintillations in the ionosphere that degrade radio communications and satellite navigation signals. Several radio wave plasma interactions can occur simultaneously, causing electrons to be accelerated to high energies, which are dangerous to spaceflight. The angle and strength of the magnetic field is critical to wave-plasma interactions. An artificial radio wave reflector can be produced in the ionosphere to focus radio waves up to 1000 times their original strength.

Ionospheric modification research using high-power radio waves is experiencing a major expansion. The new HAARP facility in Alaska has been expanded to its design power capability. The EISCAT facility in northern Norway is being upgraded with new digital control electronics and software and plans exist to extend its working frequency range. A new ionospheric modification facility is under construction at the Arecibo radar facility in Puerto Rico. Planning is underway to propose new ionospheric modification facility at the Jicamarca radar facility in Peru. The existing facilities in Alaska (HIPAS), Russia (Sura) and Svalbard (SPEAR) continue to operate. The different locations of ionospheric modification facilities is important because the angle the Earth's magnetic field subtends relative to the radio wave beam fundamentally influences the interactions and phenomena induced. The continuation and expansion of ionospheric modification

facilities around the world clearly demonstrates their usefulness in ionospheric as well as fundamental wave-particle interaction research in plasmas.

A major recent advance in studying dusty space plasmas has been the launch of the AIM (Aeronomy of Ice in the Mesosphere) satellite. AIM has made substantial contributions to understanding Polar Mesospheric Clouds (PMCs). PMCs form perhaps the most well known dusty plasma in the near-Earth space environment. AIM provides insight into the creation and composition of these clouds which many believe are directly linked to global climate change. This connection is currently a fore-front issue in space science. There have also been significant advances studying the relationship between Noctilucent clouds (which are PMCs observed from the ground) using *in situ* sounding rocket measurements and Polar Mesospheric Summer Echoes (which are radar echoes from the associated dusty plasma source region).

Several important experiments (e.g. ECOMA/MASS) have been performed which are continuing to provide important insight through high quality scientific data. Active dusty space plasma experiments have also begun to play a more important role. A major upcoming experiment (Charged Aerosol Release Experiment, CARE), will involve creating a dusty space plasma in the Earth's ionosphere. It will provide insight into turbulence processes in dusty space plasmas as well as possible connections to the turbulence observed in natural dusty space plasmas (i.e. PMCs). Finally modification of dusty space plasmas using high power radio waves is continuing to provide insight into charging and diffusion processes which govern the evolution of phenomenon in dusty space plasmas. Overall there have been significant recent advances in the dusty space plasma field and substantial future growth and important new contributions are expected.

IV. SPACE PLASMAS IN THE SOLAR SYSTEM, INCLUDING PLANETARY MAGNETOSPHERES

COSPAR commission D is devoted to the study of plasmas in the solar system, from the Sun's corona to the outermost regions of the heliosphere where the solar wind meets with the local interstellar medium. This also includes the magnetosphere and ionised atmosphere of each of the planets as well as the extended plasma environments of comets. Our knowledge of the physics of plasmas in space comes mainly from *in-situ* and remote-sensing measurements made on space probes, but important information also comes from sample return missions, sounding rockets, balloons, and ground-based facilities.

IV.1. Sun's Corona and Heliosphere

The successful launches of both the NASA STEREO and the Japanese Hinode missions have provided us with particular highlights in their first years of operation.

The twin STEREO (Solar TErrestrial RElations Observatory) spacecraft were launched on 26 October 2006. It is the third mission in NASA's Solar Terrestrial Probes

programme (STP). This two-year mission provides a unique and revolutionary view of the Sun-Earth System. The two nearly identical observatories - one ahead of Earth in its orbit, the other trailing behind – traces the flow of energy and matter from the Sun to Earth as well as reveals the 3D structure of coronal mass ejections and help us understand why they happen. STEREO also provides alerts for Earth-directed solar ejections, from its unique side-viewing perspective adding it to the fleet of Space Weather detection satellites.

Coronal mass ejections (CMEs), are powerful eruptions that can blow up to 10 billion tonnes of the Sun's atmosphere into interplanetary space. Travelling away from the Sun at speeds of approximately 1.6 million km/h, CMEs can create major disturbances in the interplanetary medium and trigger severe magnetic storms when they collide with Earth's magnetosphere. Large geomagnetic storms directed towards Earth can damage and even destroy satellites, are extremely hazardous to astronauts when outside of the protection of the Space Shuttle or the International Space Station, performing Extra Vehicular Activities (EVAs), and they have been known to cause electrical power outages. Solar ejections are the most powerful drivers of the Sun-Earth connection. Yet despite their importance, we don't fully understand the origin and evolution of CMEs, nor their structure or extent in interplanetary space. STEREO's unique stereoscopic images of the structure of CMEs now enable us to determine their fundamental nature and origin.

Coronal jets are small-scale transient ejections of hot gases, or plasma, occurring in the solar atmosphere. During a typical event, about a million tonnes of matter are ejected at speeds reaching a 1.6 million km/h for a duration of a few minutes. The jets are believed to contribute significantly to the mass flow constantly ejected by the Sun, known as the solar wind. Despite their relative simplicity, jets may serve as a paradigm for more complex and far larger events originating in the solar atmosphere, such as coronal mass ejections. Until recently, all jet observations suffered from an inherent limitation: because they were observed from a single viewpoint, their complete geometry could not be determined unambiguously. This situation improved dramatically once the stunning images from the SECCHI instruments onboard the twin NASA/STEREO spacecraft became available from early 2007. A unique polar coronal jet observation was made on 7 June 2007. Analysis of the images from the two distinct viewpoints of the STEREO spacecraft reveals an unmistakable helical structure in the jet. These pioneering, multi-viewpoint observations from STEREO provide the first conclusive evidence for the jet's helical geometry.

STEREO also detected particles from the edge of the solar system last year. This helped scientists map the energized particles where the hot solar wind slams into the cold interstellar medium. Sensors aboard both STEREO spacecraft detected energetic neutral atoms originating from the same spot in the sky, where the Sun plunges through the interstellar medium. Mapping the region by means of neutral, or uncharged, atoms instead of light heralds a new kind of astronomy using neutral atoms. The heliosphere is a bubble in space produced by the solar wind. It stretches from the Sun to beyond the orbit of Pluto. The solar wind streams off the Sun in all directions at great speeds. Once

beyond the orbit of Pluto, this supersonic wind must slow down to meet the gases in the interstellar medium. As the solar wind slows, it changes direction to form a comet-like tail behind the Sun. This subsonic flow region is called the heliosheath. The STEREO results now clear up a discrepancy in the amount of energy dumped into space by the decelerating solar wind.

The Japanese Hinode spacecraft (formerly Solar-B) is a highly sophisticated observational satellite equipped with three advanced solar telescopes. It was launched on 22 September 2006. Its solar optical telescope (SOT) has an unprecedented 0.2 arcsec resolution for the observation of solar magnetic fields. It would resolve a feature the size of 50 cm, if it was used to observe the Earth. The X-ray telescope (XRT) has a resolution of three times better than an earlier instrument on the Yohkoh spacecraft, and the EUV imaging spectrometer (EIS) has a sensitivity ten times as high as the equivalent spectrometer aboard ESA's SOHO spacecraft. These X-ray and EUV telescopes can reveal much about the heating mechanism and dynamics of the active solar corona. With this suite of telescopes, we can address the following key questions in solar physics: Why does a hot corona exist above the cool atmosphere? What drives explosive events such as solar flares? What creates the Sun's magnetic fields?

Images from Hinode have already shed new light about the Sun's magnetic field and the origins of solar wind. The data show that magnetic waves play a critical role in driving the solar wind into space. The solar wind is a stream of electrically charged gas that is propelled away from the Sun in all directions at speeds of almost 1.6 million km/hr. Better understanding of the solar wind may lead to more accurate prediction of damaging radiation waves before they reach satellites. How the solar wind is formed and powered has been the subject of debate for decades. Powerful magnetic Alfvén waves in the electrically charged gas near the Sun have always been a leading candidate as a force in the formation of solar wind since Alfvén waves in principle can transfer energy from the Sun's surface up through its atmosphere, or corona, into the solar wind. In the solar atmosphere, Alfvén waves are created when convective motions and sound waves push magnetic fields around, or when dynamic processes create electrical currents that allow the magnetic fields to change shape or reconnect. Until now, Alfvén waves have been impossible to observe because of limited resolution of available instruments. Using Hinode's high resolution X-ray telescope, it is now possible to peer low into the corona at the Sun's poles and observe record numbers of X-ray jets. These observations show a clear relationship between magnetic reconnection and Alfvén wave formation in the X-ray jets. The large number of jets, coupled with the high speeds of the outflowing plasma, lends further credence to the idea that X-ray jets are a driving force in the creation of the fast solar wind.

Launched in December 1995, and after a short cruise phase, the Solar and Heliospheric Observatory (SOHO) has been stationed near the first Lagrange point 1.5 million km away from the Earth. The SOHO mission is a joint project of ESA and NASA. It is a space-based observatory, viewing and investigating the Sun from its deep core, through its outer atmosphere - the corona - and the domain of the solar wind, out to a distance ten times beyond the Earth's orbit. Discoveries from SOHO include complex

currents of gas flowing beneath the visible surface of the Sun, and rapid changes in the pattern of magnetic fields. SOHO has made the largest and most detailed database of solar surface features, and has become the most prolific discoverer of comets in the history of astronomy, although it was not designed for that purpose.

On 4 January 2008, the first reversed-polarity sunspot appeared, signaling the start of Solar Cycle 24. Images of the first sunspot of Solar Cycle 24 have been taken by SOHO. Solar activity waxes and wanes in 11-year cycles. Lately, we've been experiencing the low ebb, very few flares, sunspots, or activity of any kind. The previous solar cycle, Solar Cycle 23, peaked in 2000-2002 with many furious solar storms. That cycle decayed as usual to the present quiet level leaving solar physicists little to do other than wonder, when would the next cycle begin? The answer is now.

New solar cycles always begin with a high-latitude, reversed polarity sunspot. "Reversed polarity" means a sunspot with opposite magnetic polarity compared to sunspots from the previous solar cycle. High-latitude refers to the Sun's grid of latitude and longitude. Old cycle spots congregate near the sun's equator. New cycle spots appear higher, around 25 or 30 degrees latitude. The onset of a new solar cycle is significant because of our increasingly space-based technological society. Solar storms can disable satellites that we depend on for weather forecasts and GPS navigation. Radio bursts from solar flares can directly interfere with cell phone reception while coronal mass ejections (CMEs) hitting Earth can cause electrical power outages. Air travel can be affected, too. Every year, intercontinental flights carry thousands of passengers over Earth's poles. It's the shortest distance between, say, New York and Tokyo or Beijing and Chicago. In 1999, United Airlines made just twelve trips over the Arctic. When airplanes fly over the poles during solar storms, they can experience radio blackouts, navigation errors and computer reboots all caused by space radiation. Avoiding the poles during solar storms solves the problem, but it costs extra time, money and fuel to "take the long way around".

Recently, SOHO has confirmed a 36-year-old solar theory. Data from the VIRGO instrument on SOHO have been used to show that solar flares drive global oscillations in the Sun. This confirms a prediction made more than 30 years ago. The result has implications for our understanding of flares on the Sun and on solar-like stars.

Ten years of data from the VIRGO instrument on SOHO are used to construct frequency/time diagrams of integrated sunlight. The temporal behaviour of solar flares, for the same period, is represented by the 1-8 Å X-ray flux measured by the GOES satellite. Analysis of the data shows a strong correlation between the energy at high frequencies (above 5.3 mHz) and the appearance of solar flares. As the number of solar flares increases so too does the strength of the high-frequency oscillations. The idea that solar flares could excite free global oscillations in the Sun was proposed in the early 1970's. The phenomenon is similar to what happens on Earth in the aftermath of a large earthquake. A recent example is the 2004 Sumatra-Andaman Earthquake; this quake set the Earth ringing for several weeks afterwards. The Karoff and Kjeldsen study shows that this is also true for the Sun. This result will bring new insight into the phenomenon of solar flares. It may also be applicable to studies of solar-like stars. High-frequency waves

have already been detected in beta Hydri and in alpha Cen A & B (Karoff 2007). If telescopes, such as COROT or Kepler, can measure the time variation of the amplitude of these waves then it may be possible to infer the existence of flares on these stars.

The Reuven Ramaty High Energy Solar Spectroscopic Imager (RHESSI) is a NASA Small Explorer that was launched on 5 February 2002. Its primary mission is to explore the basic physics of particle acceleration and explosive energy release in solar flares.

A rather unexpected observation outside its primary mission was the detection of a mysterious “Earth energy”. The satellite detected flashes of gamma ray energy in Earth's upper atmosphere in greater detail than ever before, called terrestrial gamma ray flashes (TGFs). TGFs are very short blasts of gamma rays, lasting about one millisecond, emitted into space from Earth’s upper atmosphere. They are thought to be emitted by electrons traveling at 99.99 percent of the speed of light (186,000 mps), when they scatter off of atoms and decelerate in the upper atmosphere. The Burst and Transient Source Experiment (BATSE) on the Compton Gamma-Ray Observatory first discovered TGFs in 1994. However, BATSE's ability to count the TGFs or measure their peak energies was limited. Observations from RHESSI raised the maximum recorded energy of TGFs by a factor of 10, and indicate Earth gives off approximately 50 TGFs or more daily. This is a very interesting process involving extreme physics right here on Earth. If we can understand the process here, it might give us insights into similar processes in less accessible parts of the universe. The energies we see are as high as those of gamma rays emitted from black holes and neutron stars. While it remains unknown exactly how electron beams accelerate fast enough to produce TGFs, it may involve the build-up of electric charge at the tops of thunder clouds due to lightning discharges. This results in a powerful electric field between the cloud tops and the ionosphere, the outer layer of Earth’s atmosphere. Regardless of the exact mechanism, there is some enormous particle accelerator in the upper atmosphere that is accelerating electrons to these very high energies, so they emit gamma rays when they hit the sparse atoms of the upper atmosphere. There is excitement in the fact that we are getting data good enough for the theorists to really test their models. TGFs have been correlated with lightning strikes and may be related to visible phenomena that occur in the upper atmosphere over thunderstorms. RHESSI investigators plan to collaborate with other researchers to investigate how various phenomena are related.

Launched in October 1990, the joint ESA/NASA Ulysses mission continues to provide a wealth of new information concerning the heliosphere from the unique perspective of this solar polar orbit, onto which it was injected with a Jupiter fly-by in February 1992. With the completion of the second polar orbit in mid-2004, Ulysses has provided the first, and for the foreseeable future the only, survey of the high-latitude heliosphere within 5 astronomical units (AU) of the Sun over the full range of solar activity conditions.

Now Ulysses is about to complete its 18th year of operations in space and is well underway on its third polar orbit. For the last two years the spacecraft has been fully

immersed in the fast solar wind from the coronal hole that covers the Sun's polar caps around solar minimum. Comparisons of these recent observations with those made during the same phase on its first orbit (1993-94) have shown that Ulysses encountered continuous fast flow from the southern polar coronal hole later in the solar cycle than during the first orbit. It seems that the solar wind stream structure at the same distance and latitude is less regular and more variable than during the first orbit. This indicates that the heliospheric current sheet topology is more complex, having a larger tilt with respect to the Sun's rotation axis, and having a significant warp, or non-planar shape.

Recent Ulysses spacecraft data indicate that the solar wind is currently hitting at a 50-year low, reaching the lowest levels since accurate readings have become available. This current state of the Sun could reduce the natural shielding that envelops our Solar System. A number of recent studies have concluded that the solar wind observed in Ulysses' third orbit is about 25 percent less powerful than that measured during the spacecraft's first orbit. While the wind speed is almost the same during both orbits, the density and pressure measured during the third orbit are significantly lower. The Ulysses data cover high latitude regions of the Sun. In order to determine whether or not the apparent weakness in the solar wind was a phenomenon limited to these regions the study authors compared the Ulysses data with observations from the Advanced Composition Explorer (ACE) spacecraft (which observes in the ecliptic plane). Data from the two spacecraft correlated extremely well for comparable regions leading the authors to conclude that the observed weakness in the solar wind is a global phenomenon. Overall, the measurements indicate significant, long-term variations in solar wind output from the entire Sun. The marked long-term trend to lower dynamic pressures implies that the heliosphere has been shrinking and as a consequence the distance to the heliopause is reduced. Since the heliopause acts as a shield for our solar system, warding off a significant portion of the cosmic rays outside the Galaxy, a reduction in size and strength could mean an increase in the number of Galactic cosmic rays that enter the inner part of the solar system.

For five days in early February 2007, when Ulysses was at its highest southern latitude, four of its instruments measured cometary ions and key properties of the interaction of the ion tail of Comet McNaught (C/2006 P1) with the high-speed polar solar wind. During this encounter of record-breaking duration the data are unusually comprehensive. O3+ ions were detected for the first time at a comet, coexisting with singly charged molecular ions with mass in the range 28-35 amu. The presence of magnetic turbulence and of ions with energies up to ~200 keV indicate that at a distance of ~1.6 AU from the comet nucleus, the ion tail of comet McNaught had not yet reached equilibrium with the surrounding solar wind.

The Voyager 2 spacecraft has followed its twin Voyager 1 into the solar system's final frontier, a vast region at the edge of our solar system where the solar wind runs up against the thin gas between the stars. However, Voyager 2 took a different path, entering this region, called the heliosheath, on 30 August 2007. Because Voyager 2 crossed the heliosheath boundary, called the solar wind termination shock, about 15 billion km away from Voyager 1 and almost 1.5 billion km closer to the Sun, it confirmed that our solar

system is “squashed” or “dented” – that the bubble carved into interstellar space by the solar wind is not perfectly round. Where Voyager 2 made its crossing, the bubble is pushed in closer to the Sun by the local interstellar magnetic field. Voyager 2 continues its journey of discovery, crossing the termination shock multiple times as it entered the outermost layer of the giant heliospheric bubble surrounding the Sun and joined Voyager 1 in the last leg of the race to interstellar space. Voyager 1 was the first spacecraft to explore this outer layer, when it crossed into the heliosheath in December 2004. As Voyager 1 made this historic passage, it encountered the shock wave that surrounds our solar system called the solar wind termination shock, where the solar wind is abruptly slowed by pressure from the gas and magnetic field in interstellar space.

Even though Voyager 2 is the second spacecraft to cross the shock, it is scientifically exciting for two reasons. The Voyager 2 spacecraft has a working Plasma Science instrument that can directly measure the velocity, density and temperature of the solar wind. This instrument is no longer working on Voyager 1 and estimates of the solar wind speed had to be made indirectly. Secondly, Voyager 1 may have had only a single shock crossing and it happened during a data gap. But Voyager 2 had at least five shock crossings over a couple of days (the shock “sloshes” back and forth like surf on a beach, allowing multiple crossings) and three of them are clearly in the data. They show us an unusual shock. In a normal shock wave, fast-moving material slows down and forms a denser, hotter region as it encounters an obstacle. However, Voyager 2 found a much lower temperature beyond the shock than was predicted. This probably indicates that the energy is being transferred to cosmic ray particles that were accelerated to high speeds at the shock. The two Voyager spacecraft will be the only source of local observations of this distant but highly interesting region for years to come.

The Advanced Composition Explorer (ACE) is an Explorer mission launched on 25 August 1997. It is designed to study of energetic particles that constantly bombarded the Earth not only from the Sun, but also from interstellar and galactic sources, thus contributing to our understanding of the formation and evolution of the solar system as well as the astrophysical processes involved. The ACE spacecraft carrying six high-resolution sensors and three monitoring instruments samples low-energy particles of solar origin and high-energy galactic particles with a collecting power 10 to 1000 times greater than past experiments. ACE orbits the L1 libration point which is a point of Earth-Sun gravitational equilibrium about 1.5 million km from Earth and 148.5 million km from the Sun. From its location at L1 ACE has a prime view of the solar wind, interplanetary magnetic field and higher energy particles accelerated by the Sun, as well as particles accelerated in the heliosphere and the galactic regions beyond. The spacecraft provides near-real-time continuous coverage of solar wind parameters and solar energetic particle intensities (space weather). When reporting space weather, ACE provides an advance warning (about one hour) of geomagnetic storms that can overload power grids, disrupt communications on Earth, and present a hazard to astronauts. The spacecraft has enough propellant on board to maintain an orbit at L1 until ~2024.

IV.2. Solar-Terrestrial Connection and Earth Magnetosphere

Since the 1980s, the collaborative efforts by NASA, ESA, and the Institute of Space and Astronautical Science (ISAS) of Japan have led to the conception of the International Solar-Terrestrial Physics Science Initiative consisting of a set of solar-terrestrial missions to be carried out during the 1990s and into the 21st century. The primary science objectives of the ISTP Science Initiative are: Determining structure and dynamics in the solar interior and their role in driving solar activity; Identifying processes responsible for heating the solar corona and its acceleration outward as the solar wind; Determining the flow of mass, momentum and energy through geospace; Gaining a better understanding of the turbulent plasma phenomena that mediate the flow of energy through geospace; Implementing a systematic approach to the development of the first global solar-terrestrial model, which will lead to a better understanding of the chain of cause-effect relationships that begins with solar activity and ends with the deposition of energy in the upper atmosphere. The ISTP Science Initiative uses simultaneous and closely co-ordinated measurements from GEOTAIL, WIND, POLAR, SOHO and Cluster. These measurements of the key regions of geospace are being supplemented by data from equatorial missions such as the Geosynchronous Operational Environmental Spacecraft (GOES), and ground-based investigations.

The Cluster mission has just passed successfully the recent long eclipse season - the most critical period of the mission since launch in 2000. Before that, constellation manoeuvres were executed putting C3 and C4 at a mere 17 km from each other, their closest separation distance in the Cluster lifetime. This constellation allows the investigation of very small plasma structures in the tail of the magnetosphere. The four spacecraft and instruments are all operating nominally.

A recent study reports the first statistical investigation of outflowing oxygen ion beams collected over a three-year period by the four Cluster satellites flying in constellation at between 5 and 12 Earth radii over the polar regions. For the first time, the role of a specific acceleration process for such outflowing oxygen ions, called centrifugal acceleration was quantitatively assessed in the polar cap at high altitude without any assumptions related to observations by a single satellite. Four spacecraft was exactly what was needed to fully estimate all terms of a textbook equation describing the centrifugal acceleration mechanism, a well known physical process to accelerate outflowing oxygen ions along magnetic field lines towards the plasma sheet. Centrifugal acceleration can be regarded as a sling-shot effect that occurs when ions are moving across magnetic field lines, whose shape changes in the presence of an electric field. When ions move over a polar cap of Earth, the changing shape of the magnetic field lines bends the drift path induced by the electric field normal to the magnetic field. The centrifugal acceleration associated with this bending shoots the ions away from the Earth along the magnetic field lines. This effect provides more energy to heavy ions like oxygen compared to the lighter helium ions and protons. It is the changing shape of the field-lines that can be resolved by the use of the four Cluster spacecraft. And it turns out that the role of the centrifugal acceleration mechanism is significant and may explain a large fraction of the parallel velocities observed at high altitude above the polar caps.

This scientific discovery is an excellent example of what can be done with the four satellites of the Cluster mission.

Cluster results also have impacts on future missions. Magnetic reconnection is a universal process able to drive explosive phenomena such as solar flares. At the heart of this process is a small zone called the electron diffusion region, where reconnection is thought to be triggered. In a recent article, Cluster investigators report the first observational evidence for the overall size of this region and find that it is 300 times larger than previously thought. This means that future missions will have a much better chance of detecting and resolving this region than previously estimated, profoundly impacting mission design and scientific operations.

NASA's Time History of Events and Macroscale Interactions during Substorms (THEMIS) was successfully launched on 17 February 2007. The mission aims to resolve one of the oldest mysteries in space physics, namely to determine what physical process in near-Earth space initiates the violent eruptions of the aurora that occur during substorms in the Earth's magnetosphere. THEMIS is a 2-year mission consisting of 5 identical probes that will study the violent, colourful eruptions of Auroras.

What causes the shimmering, ethereal Northern Lights to suddenly brighten and dance in a spectacular burst of colourful light and rapid movement? THEMIS investigators have discovered that an explosion of magnetic energy a third of the way to the moon powers substorms, sudden brightenings and rapid movements of the aurora borealis, called the Northern Lights. The culprit turns out to be magnetic reconnection, a common process that occurs throughout the universe when stressed magnetic field lines suddenly “snap” to a new shape, like a rubber band that’s been stretched too far. Substorms produce dynamic changes in the auroral displays seen near Earth’s northern and southern magnetic poles, causing a burst of light and movement in the Northern and Southern Lights. These changes transform auroral displays into auroral eruptions. As they capture and store energy from the solar wind, the Earth’s magnetic field lines stretch far out into space. Magnetic reconnection releases the energy stored within these stretched magnetic field lines, flinging charged particles back toward the Earth’s atmosphere. These particles then create halos of shimmering aurora circling the northern and southern poles. Investigators directly observe the beginning of substorms using five THEMIS satellites and a network of 20 ground observatories located throughout Canada and Alaska. The five identical satellites line up once every four days along the equator and take observations synchronized with the ground observatories. Each ground station uses a magnetometer and a camera pointed upward to determine where and when an auroral substorm will begin. Instruments measure the auroral light from particles flowing along Earth’s magnetic field and the electrical currents these particles generate. These observations have now confirmed for the first time that magnetic reconnection triggers the onset of substorms. The discovery supports the reconnection model of substorms, which asserts a substorm starting to occur follows a particular pattern. This pattern consists of a period of reconnection, followed by rapid auroral brightening and rapid expansion of the aurora toward the poles. This culminates in a redistribution of the electrical currents flowing in space around Earth.

IV.3. Space Plasma Missions under Development

At the edge of our solar system in December 2004, the Voyager 1 spacecraft encountered something never before experienced during its then 26-year cruise through the solar system — an invisible shock formed as the solar wind piles up against the gas in interstellar space. This boundary, called the termination shock, marks the beginning of our solar system's final frontier, a vast expanse of turbulent gas and twisting magnetic fields.

A NASA-sponsored team is developing a way to view this chaotic but unseen realm for the first time. Just as an impressionist artist makes an image from countless tiny strokes of paint, NASA's new Interstellar Boundary Explorer (IBEX) spacecraft will build up an image of the termination shock and areas beyond by using hits from high-speed atoms that are radiating out of this region. Thus IBEX will let us make the first global observations of the region beyond the termination shock at the very edges of our solar system. This region is critical because it shields out the vast majority of the deadly cosmic rays that would otherwise permeate the space around the Earth and other planets. IBEX will let us visualize our home in the galaxy for the first time and explore how it may have evolved over the history of the solar system. Ultimately, by making the first images of the interstellar boundaries neighbouring our solar system, IBEX will provide a first step toward exploring the galactic frontier. Beyond the orbit of Pluto, the solar wind gradually slows as it interacts with inflowing neutral gases from interstellar space, and then abruptly drops in speed at a thin, invisible boundary around our solar system called the termination shock. The turbulent region beyond the shock boundary corresponds to a layer in the outer heliosphere of turbulent plasma flows and magnetic fields called the heliosheath. The boundary of this turbulent layer with the interstellar plasma environment is called the heliopause – this is the end of our Solar System's frontier. Beyond that is interstellar space.

IBEX will make pictures of the heliosheath region and determine the termination shock's strength. It will also discover what happens when the solar wind clashes with interstellar space by observing how the solar wind is flowing in the heliosheath and how the interstellar gas interacts with the heliopause. IBEX will determine how high-speed atoms are accelerated within the termination shock and heliosheath. IBEX is scheduled to be launched on a Pegasus rocket in October, 2008. It needs to go beyond the region of space controlled by Earth's magnetic field, called the magnetosphere, because this region generates radiation and the same high-speed atoms (ENAs) that IBEX will use to make its pictures. To avoid contamination from local ENAs produced in the magnetosphere, IBEX's orbit will take it up to 200,000 miles from Earth.

Scheduled for launch in 2009 is the Solar Dynamics Observatory (SDO), which will be taking a closer look at the Sun, the source of all Space Weather. Space Weather affects not only our lives here on Earth, but the Earth itself, and everything outside its atmosphere (astronauts and satellites out in space and even the other planets). The Sun, our closest star, is still a great mystery to scientists. SDO will help us understand where the Sun's energy comes from, how the inside of the Sun works, and how energy is stored

and released in the Sun's atmosphere... yes, the Sun has an atmosphere! By better understanding the Sun and how it works, we will be able to better predict and better forecast the "weather out in space" providing earlier warnings to protect our astronauts and satellites floating around out there. SDO is the first satellite under the Living with a Star (LWS) programme at NASA. The spacecraft has been designed to fly for five years or more. SDO will be collecting huge amounts of data everyday, filling the equivalent of a single CD every 36 seconds.

A candidate for a new NASA mission is Solar Probe Plus, an extraordinary and historic mission, exploring what is arguably the last region of the solar system to be visited by a spacecraft: the Sun's outer atmosphere or corona as it extends out into space. Solar Probe Plus will repeatedly sample the near-Sun environment, revolutionising our knowledge and understanding of coronal heating and of the origin and evolution of the solar wind and answering critical questions in heliophysics that have been ranked as top priorities for decades. Moreover, by making direct, *in-situ* measurements of the region where some of the most hazardous solar energetic particles are energised, Solar Probe Plus will make a fundamental contribution to our ability to characterise and forecast the radiation environment in which future space explorers will work and live.

We now know more about the corona and the solar wind than ever before. And yet the two fundamental questions, raised in the 1940s by the discovery of the corona's million-degree temperature and in the early 1960s by the proof of the supersonic solar wind's existence, remain unanswered: Why is the solar corona so much hotter than the photosphere? And how is the solar wind accelerated? The answers to these questions can be obtained only through *in-situ* measurements of the solar wind down in the corona. A mission to provide these measurements, to probe the near-Sun particles-and-fields environment, was first recommended in 1958, at the dawn of the space age, and might now become reality.

Quite complementary to Solar Probe, an ESA mission candidate called Solar Orbiter is intended to brave the fierce heat and carry its telescopes to just one-fifth of the Earth's distance from the Sun, where sunlight will be twenty-five times more intense than we feel it. The spacecraft must also endure powerful bursts of atomic particles from explosions in the solar atmosphere. But the reward will be images significantly sharper than the best available today. The pictures of the weird solar landscapes, where glowing gas dances and forms loops in the strong magnetic field, will be stunning. They will show details down to 100 km wide, which can be compared with the width of the Sun's visible disc, 1.4 million kilometres. After launch the Solar Orbiter will manoeuvre into an orbit around the Sun. It will perform a close approach every five months. Around closest approach, when travelling at its fastest, the Solar Orbiter will remain roughly positioned over the same region of the solar atmosphere as the Sun rotates on its axis. Just as geostationary weather and telecommunications satellites are stationed over particular spots on the Earth's surface, so the spacecraft will seem to 'hover' for a while over the Sun. The Solar Orbiter will therefore be able to watch storms building up in the atmosphere over several days. The Solar Orbiter will exploit new technologies being developed by ESA for the BepiColombo mission to Mercury, the closest planet to the

Sun. These include heat-proofing for all the equipment and instruments and the communications system. Over extended periods the Solar Orbiter will deliver images and data of the polar regions and the side of the Sun not visible from Earth.

V. RESEARCH IN ASTROPHYSICS FROM SPACE

V.1. Astronomy

The use of space techniques continues to play a key role in the advance of astrophysics by providing access to the entire electromagnetic spectrum from radio to gamma rays. The increasing size and complexity of large space-based observatory missions places a growing emphasis on international collaboration. This is particularly marked by the increasing range of joint missions involving the large space agencies in the U.S. (NASA), Europe (ESA), Japan (JAXA) and Russia (RKA). A major future contribution is foreseen for the Indian and Chinese space agencies. It is important that the space agencies coordinate their mission plans for both large and smaller scale enterprises. The co-ordination of existing and future datasets from space-based and ground-based observatories is an emerging mode of powerful and relatively inexpensive collaboration to address problems that can only be tackled by the application of large multi-wavelength datasets.

As in previous reports, an updated overview of worldwide space programmes in astronomy and astrophysics is summarised in Tables 1 and 2. The tables list the missions which are operating in space or have continuing data analysis efforts, and those which are approved and either awaiting a start or already under construction.

Tables 1 and 2 (see below) include:

- The main responsible agency or nation;
- Launch dates (actual or scheduled)
- A brief description of the main characteristics of the mission

Comments on the content of the tables and on the situation in each of the principal spectral regions are given below.

X-rays and Gamma-rays

The NASA Rossi-XTE mission (high resolution timing studies of X-ray sources over the 1 to 200 keV range) continues to operate successfully producing key findings on variable, pulsed and quasi-periodic sources. The world-wide gamma-ray burst monitoring capability has been enhanced enormously with the launch of the Swift mission in November 2004. Bursts have been detected from the early universe at redshifts in the range of the most distant objects known. The mission is managed by NASA, and has significant instrument contributions from Italy and the UK.

Following the successful launch and operation of NASA's Chandra observatory in June 1999, the ESA X-ray Multi-mirror Mission (XMM/Newton) was launched in December 1999 and is operating successfully. With their complementary emphasis on high angular resolution and high throughput spectroscopy, these observatory missions continue to generate major advances in astrophysics. The two missions have been particularly effective in studying distant galaxies, including galactic mergers, the massive black holes at their centres, and the billion-degree gas that permeates the medium in clusters of galaxies. Japan's Suzaku X-ray mission was launched in 2005. It has X-ray and hard X-ray telescopes that are producing high-quality broad-band observations of accreting and jetted sources.

At the relatively low gamma-ray energies associated with nuclear spectral lines, ESA's Integral (International Gamma Ray Astrophysics Laboratory) observatory, launched in 2002, is now supplying the world gamma-ray astronomy community with an important imaging and spectroscopic capability. At the higher energies that will facilitate investigation of the highest energy processes in the universe, Italy's AGILE (Astro-rivelatore Gamma a Immagini Leggero) was launched in 2007 and the major Gamma-ray Large Area Space Telescope (GLAST) developed by NASA & the Department of Energy in the US plus universities and agencies in France, Germany, Italy, Japan and Sweden and was launched in 2008 and is now called the Fermi Gamma Ray Space Telescope.

The Indian ASTROSAT mission is an X-ray and multiwavelength satellite in development for launch in 2009. The Nuclear Spectroscopic Telescope Array (NuSTAR) is a hard X-ray mission with focusing of hard X-rays. It is a NASA SMEX in development for a launch in 2011. The Space-based multi-band astronomical Variable Objects Monitor (SVOM) mission is a gamma-ray burst mission in development in China and France for a launch in 2012.

For the next generation of X-ray observatories, two projects involving large X-ray telescope systems are being studied intensively. The US Constellation-X is envisaged as a set of four telescopes, in orbits around the L2 point, working together as a single observatory. The European Xeus, a 10 m diameter X-ray telescope that will involve separate spacecraft for the telescope and focal plane packages, is now also being studied for a single launch to the L2 point. Recently these two efforts plus Japanese involvement were combined in the International X-ray Observatory (IXO).

UV/Extreme UV and Visible

The Hubble Space Telescope (HST) continues to operate successfully producing spectacular images. Instruments and key sub-systems are replaced on orbit by astronauts during serving missions, with the last one planned for 2008. NASA's GALEX (Galaxy Evolution Explorer), is conducting the first deep all-sky survey in the ultraviolet, and has detected more than one million hot stars and galactic cores since launch in 2003.

Infrared

NASA's Spitzer Observatory is detecting tens of millions of infrared point sources and probing the dust and gas in star-forming regions in the Milky Way and in other galaxies. Its extensive legacy programmes are devoted to specific large-scale surveys. NASA is intensifying work on HST's successor mission with extended near-IR capability, this being the James Webb Space Telescope (JWST), in which ESA is playing a significant role.

Sub-Millimetre

NASA's Wilkinson Microwave Anisotropy Probe (WMAP) Explorer mission has reported the spectacular results of its sky survey. While pinning down the age of the universe to approximately 1%, these results also offer powerful confirmation of all the measurable predictions of the 'hot big bang with inflation' history of the early universe. An added surprise of these first WMAP results is the apparent evidence for the earlier appearance of the first stars than was expected from the standard model of galaxy formation.

The ESA Herschel/Planck mission involves a large general-purpose observatory and a specialist spacecraft to attack the microwave background angular distribution problem. Development is proceeding towards a launch in 2009.

Sweden's Odin mission was launched in February 2001 into a Sun-synchronous 600 km orbit. Designed to study the interstellar medium and the Earth's atmosphere at mm and sub-mm wavelengths, the mission continues to operate successfully.

Radio

Halca (formerly VSOP), launched by Japan's ISAS in 1997, has produced maps with a resolution of 0.3 milli-arc seconds at an operating frequency of 5 GHz. The mission ended in 2005.

Complementary Research

Gravitational wave astronomy continues to grow in importance. The LISA mission is being studied by both ESA and NASA. Both agencies are working on technology development, and ESA is developing the LISA Pathfinder technology demonstration mission currently planned for a launch in 2010.

Table 1. Missions in Operation/Data Analysis Phase

Year	radio	sub-mm	*IR*	visible/UV	EUV/X-ray	hard X-ray/ gamma ray
1990				*HST*		
1996						*Rossi-XTE*
1997	*Halca*					
1999					*Chandra*	
					XMM-Newton	
2000						
2001		*Odin*				
		WMAP				
2002						*Integral*
2003			*Spitzer*	*GALEX*		
2004				□	*Swift*	□
2005					*Suzaku*	□
2006			*Akari*			
2007						*AGILE*
2008						*Fermi (GLAST)*

HST	(NASA/ESA) Observatory mission with 2.4 m telescope for imaging and spectroscopy of galactic and extragalactic sources.
XMM/Newton	(ESA) Observatory mission. High throughput spectroscopy and imaging in the soft X-ray range.
Rossi XTE	(NASA) Temporal studies and broadband spectroscopy of compact X-ray sources (1-200 keV). PI mission with GI programme.
Halca	(Japan) Observatory mission. 10 m antenna for orbiting VLBI imaging 1.3, 6, 18 cm.
Odin	(Sweden/Finland/Canada/France) 1.1 m telescope for mm (119 GHz) and sub-mm (420-580 GHz). Interstellar chemistry and atmospheric ozone.
WMAP	(NASA) Explorer to study anisotropy in the cosmic microwave background radiation.
Integral	(ESA) Imaging and spectroscopy from 20 keV to 10 MeV.
GALEX	(NASA) Galactic Evolution Explorer. UV all-sky survey mission.
Spitzer	(NASA) Observatory mission. Space Infrared Telescope Facility. IR telescope of 0.85 m aperture.
Swift	(NASA/UK/Italy) Medium Explorer. Gamma-ray burst detection with X-ray and optical telescopes for rapid follow-up.
Suzaku	(Japan/NASA) X-ray and hard X-ray telescopes.
Akari	(ISAS) 0.7 m cooled telescope for second generation IR all-sky survey. Previously called Astro-F.
AGILE	(ASI) high energy gamma-ray mission.
Fermi	(NASA/DOE/France/Germany/Italy/Japan/Sweden)

Table 2. Approved Projects

gravity waves	sub-mm	IR	visible/UV	EUV/ X-ray	hard X-ray/ gamma ray
LISA Pathfinder	*Planck*	*Herschel*			*T NuSTAR, ASTROSAT SVOM*

ASTROSAT (India) X-ray observatory.

Planck (ESA) Medium-size mission to study the spectrum and anisotropy of the diffuse cosmic microwave background radiation relic of the 'Big Bang'. To be launched together with *Herschel* to L2.

Herschel (ESA) Observatory mission 3 m warm Cassegrain telescope for high throughput heterodyne and far IR spectroscopy and imaging.

LISA Pathfinder (ESA) Technology test mission for future *Laser Interferometer Space Antenna* mission.

SVOM (China/France) Gamma-ray bursts mission.

Conclusions

Astronomy from space is a model for international scientific cooperation. Most missions have some international hardware collaboration, and virtually all feature extensive data sharing. International astronomical databases now include ground-based as well as space-based archival data in standard formats, so that astronomers anywhere in the world can access all results after brief proprietorial periods, and can perform extensive multi-wavelength investigations of large data samples from their desktops.

V.2. Solar and Heliospheric Physics

The Sun is a relatively ordinary star by cosmic standards, but its proximity offers us a unique astronomical laboratory. Because of the high temperatures reached in the upper chromosphere and corona, the solar atmosphere is best observed at shorter wavelengths: ultraviolet (UV), extreme ultraviolet (EUV), X-ray and gamma ray. Work at these wavelengths must be undertaken from space since the radiation cannot penetrate the atmosphere of the Earth. Even at visible and infrared wavelengths, observations from space eliminate the distorting effects of the Earth's atmosphere. This allows imaging of fine structures on the Sun's surface (photosphere) at size scales of approximately 100 km, and possibly below this eventually. Also visible-light observations of the outer corona, say several solar radii above the Sun's surface, are only made possible with spacecraft-borne coronagraphs thanks to the absence of scattered light from the Earth's atmosphere.

At the present time, we are enjoying a 'golden age' in solar physics from space; a fleet of advanced solar observatories, namely the Solar and Heliospheric Observatory (SOHO), the Transition Region and Coronal Explorer (TRACE), the Reuven Ramaty High Energy Solar Spectroscopic Imager (RHESSI), Hinode ('Sunrise'; formerly Solar-

B), and the Solar TErrestrial RElations Observatory (STEREO), etc, are all in space, observing the behaviour of the Sun in unprecedented detail.

'Living With a Star' (LWS) was initiated by NASA in 2001 and has evolved into the 'International Living With a Star' (ILWS) programme. This includes the Solar Dynamics Observatory (SDO: launch planned for 2009), which will continue the successful space-based helioseismology observations of the convection zone begun by SOHO, along with imaging studies of the photosphere and corona. A set of four Solar Sentinel spacecraft are being studied to be placed on the far side of the Sun and in the inner heliosphere to work with SDO on studies of CMEs and other disturbances passing through the interplanetary medium with special reference to those that impact the Earth.

Understanding the outer layers of the solar atmosphere and the transfer of energy to these regions from the interior represents a major intellectual challenge that is of substantial cultural significance. It also has a huge potential impact both on our economies and, through the Sun's influence on climate, and our quality of life on Earth. Thus, work in solar physics needs to be undertaken on a worldwide basis. The requirement for simultaneous ground-based observations at optical, infrared and radio wavelengths must also be fulfilled and can be achieved gradually by the construction and commissioning of several facilities in countries that do not possess directly the appropriate infrastructure for implementation of space-based observations. However, many nations do work with space data and make an immensely valuable contribution to the subject given the increasingly open access to these datasets that is currently possible. This emphasis on co-ordination is one of the key elements in most of the major programmes for solar physics. Furthermore, from lengthy experience in solar observing and the need for collaboration with colleagues in many countries, the solar physics community has a long and successful history of international collaboration, which is fully exploited in planning space missions.

Currently Operating Solar Programmes

Current solar programmes are directed at three broad areas of solar-terrestrial science: (1) the solar interior; (2) the solar atmosphere; and (3) the influence of the solar wind and large solar events, such as CMEs and solar flares, on the Earth and the interplanetary medium.

Work continues using the imaging telescopes, spectrometers, and coronagraphs on SOHO, TRACE, and other spacecraft. These instruments address a broad range of scientific questions concerning the Sun's magnetic activity cycle, solar flares, the nature of the inner and extended corona, CMEs, and the acceleration of the solar wind.

SOHO, a joint ESA-NASA mission, is one of the most ambitious solar physics missions so far deployed. The SOHO spacecraft was launched in December 1995 and has been observing the Sun and the heliosphere for more than ten years from the Lagrangian point, L1, between the Earth and the Sun. From this unique vantage point, 1.5 million km in front of the Earth, SOHO observes the Sun continuously without day/night cycles and

without serious effects from the orbital motion inevitably present in low Earth orbiting missions. L1 also lies outside range of the geocorona ultraviolet emission. Consequently, SOHO has an unprecedented view of solar phenomena and is able to detect solar oscillations and solar UV emission with minimum noise. SOHO's scientific payload consists of 12 instruments, including six built by ESA member countries in collaboration with groups in the USA. These instruments study the Sun, from the solar interior using helioseismology, to the outer atmosphere by remote sensing in the visible and the ultraviolet. The solar wind is simultaneously probed by *in-situ* measurements. The twelfth instrument observes hydrogen Lyman-alpha emission from the interplanetary medium to monitor the mass flow of the solar wind. The ESA-NASA cooperation on SOHO includes the staffing of a common operations centre at the NASA/Goddard Space Flight Center for day-to-day operational decisions and collaborative research.

SOHO is successfully probing the interior of the Sun. It does so with several instruments observing the solar surface oscillations that can be detected almost completely free of noise. The measurements are of small periodic variations in emission intensity or in surface velocity. The short-range oscillations are due to sound waves generated by gas motions occurring just below the solar surface. Analysis can determine solar rotation in and below the convection zone. Rotation below the surface has been found to be less dependent on latitude than on the solar surface.

The surface of the Sun turns out to be highly dynamic even in periods of low solar activity, with the continuous emergence and cancellation of magnetic fields, as shown by the high-resolution telescopes observing the solar disk and the inner corona. A class of phenomena ('blinkers') has been identified, which along with other new variable phenomena may provide an important input to the problem of heating the solar atmosphere. These telescopes can locate the onset of CMEs near the solar surface, and identify large global disturbances caused by flares. These large disturbances are in the form of waves propagating from the site where the flare occurs throughout the entire solar atmosphere.

The white light and UV coronagraphs on SOHO are continuing to provide dramatic images of CMEs, during the course of which the Sun releases large amounts of hot material into the heliosphere. It has been found that the mass input in the solar wind during mass ejections is much greater than expected as is the frequency of these phenomena. CMEs disturb the entire solar system, can affect the Earth's own space environment, and can have devastating effects on telecommunication satellites.

The fast and slow solar wind flows in the outer solar atmosphere have been mapped by SOHO for the first time thereby making it possible to relate the flows to the topology of the solar magnetic fields. The solar wind acceleration has now been traced back to a few solar radii from the solar surface and has been shown to be much more effective at the solar poles and in other regions where magnetic fields are open. Here the solar wind speed reaches 800 km s^{-1} at about three solar radii out from the solar surface. Acceleration is less effective near the solar equator where closed magnetic field lines underlie the streamers, which are probably the source of the slow solar wind.

The Transition Region and Coronal Explorer (TRACE), a NASA Small Explorer mission, was launched in April 1998 into a Sun-synchronous polar orbit to allow eight months of continuous solar observation without satellite nights. It is being operated in co-ordination with SOHO and RHESSI (see below). The objective of the TRACE mission is to observe directly the connections between the small-scale features that characterize the photospheric magnetic field and the larger-scale structures that are seen in the solar corona, thereby following up on the discovery by Yohkoh that the corona is a continuously dynamic atmosphere which responds to impulses from the photosphere. TRACE has been surveying this connection from the photosphere into the corona with unsurpassed temporal and spatial resolution. Discoveries have included active region outflows, the oscillation of entire coronal magnetic loop structures, and the predominance of non-uniform magnetic footpoint-heating in coronal loops in the temperature range 0.8-1.6 million K. With these revelations, TRACE is making major contributions to current understanding of the coronal heating mechanism. The TRACE instrument is designed to isolate narrow UV and EUV spectral bands containing emission lines formed in the chromosphere, transition region, and corona. As TRACE is an open mission, all its data and related analysis software are freely available to the entire solar physics community.

The Reuven Ramaty High Energy Solar Spectroscopic Imager (RHESSI) mission, one of NASA's Programme for Small Explorers, is an advanced hard X-ray imager of the rotating modulation collimator type for flare observations. Equipped with cooled germanium detectors, RHESSI provides hard X- and gamma-ray images of solar flares with unprecedented high spatial and non-dispersive energy resolution over the energy range from 3 keV to 10 MeV. From just after its successful launch on 5 February 2002, the RHESSI satellite has provided and continues to provide numerous new results on electron and ion acceleration in solar flares. RHESSI, like TRACE, is an open mission; all data and related analysis software are freely available to the entire solar physics community.

As a successor to the highly successful Yohkoh mission, JAXA launched the Hinode spacecraft on 22 September 2006. The mission involves collaboration with solar groups in the USA and UK, supported, respectively, by NASA and PPARC (now STFC). The payload includes an optical telescope capable of producing photospheric images with a spatial resolution of 150 km on the solar surface and of measuring vector magnetic and velocity fields in the photosphere. An X-ray imager for the diagnosis of plasmas having temperatures of 0.5 to 10 million K is also included in Hinode's payload. Line broadening in the transition region and coronal emission lines, which may be manifestations of energy input into the corona, are being observed with an EUV imaging spectrometer. With the co-ordinated set of these instruments, Hinode aims to unveil the coupling of coronal activity with the underlying photospheric magnetic and velocity fields and, furthermore, reveal more about the mechanism of coronal heating – one of the largest puzzles in solar physics. A Sun-synchronous, polar orbit was chosen to avoid the orbital temperature variation due to day/night cycles and to minimise the effects of observing time gaps and of line shifts due to the orbital motion. First light for the

instruments, the Solar Optical Telescope, the EUV Imagine Telescope, and the X-Ray Telescope, was October 2006.

STEREO is the third mission in NASA's Solar Terrestrial Probes programme (STP). This mission employs two nearly identical space-based observatories - one ahead of Earth in its orbit, the other trailing behind - to provide the first-ever stereoscopic measurements to study the Sun and the nature of its coronal mass ejections, or CMEs. The twin spacecraft were launched on 26 October 2006 and took first light images on 15 December 2006. STEREO's scientific objectives are to: understand the causes and mechanisms of CME initiation; characterise the propagation of CMEs through the heliosphere; discover the mechanisms and sites of energetic particle acceleration in the low corona and the interplanetary medium; and improve the determination of the structure of the ambient solar wind. Both STEREO spacecraft are currently performing as expected and taking science data.

Koronas is a series of Russian satellites designed to observe the solar atmosphere from near-Earth orbit, and to observe solar activity and magnetospheric solar effects. They carry instruments developed by groups from Russia, in collaboration with researchers from the Ukraine, Georgia, Poland, Germany, France, the UK and USA. The instruments include X-ray spectrometers, multi-layer imaging telescopes and coronagraphs, as well as detectors for helioseismology. The first of the series, Koronas-I, was launched in March 1994 with a scientific payload of eleven instruments designed to cover a wide region of the electromagnetic spectrum and to measure particles. The second Koronas-F, was launched on 31 July 2001 and was operated successfully for more than five years. The twelve instruments on board have observed solar radiation from radio waves to gamma rays, facilitating studies of solar oscillations, the properties of the *in-situ* particle flux, and energy deposition and transport processes in quiet and active conditions. The mission has broad scientific objectives associated with observational solar physics, much like SOHO.

All the missions mentioned above have been operated in close collaboration In addition, simultaneous observations of the Sun with other experiments such as those borne on other satellites, sounding rockets and balloons, as well as ground-based telescopes, are organised regularly and prove particularly fruitful for investigating solar activity.

Other solar physics oriented experiments include operational satellite-, sounding rocket- and balloon-borne experiments. For example, a hard X-ray spectrometer, provided by the Czech Republic, now monitors the Sun from the Multispectral Thermal Imager satellite, which is a US Department of Defense Earth observing satellite. Similarly, the Solar X-ray Spectrometer (SOXS) on board an Indian application satellite has been monitoring solar flares continuously since June 2003. In addition, many spacecraft, designed for the study of the heliosphere and the geomagnetosphere, such as Ulysses, Wind, ACE, Cluster, Double Star, carry instruments that provide relevant data to be analysed together with those from the solar physics missions described above.

Missions Currently in Development

NASA is also developing the Solar Dynamics Observatory (SDO), a successor to SOHO. SDO is the first Space Weather Research Network mission in NASA's 'Living With a Star' (LWS) programme of NASA and will carry a suite of instruments to provide the observations that should lead to a more complete understanding of the solar dynamics that drive variability in the Earth's environment. The instruments include the Helioseismic and Magnetic Imager, Atmospheric Imaging Assembly, Extreme Ultraviolet Variability Experiment. The next of the Koronas series, Koronas-Photon, which is mainly aimed at detecting gamma rays as well as neutrons, is under preparation for launch in 2008.

Conclusions

As may be seen from the above, solar physics activities in space include extensive international cooperation and a rich variety of research goals over the next decade. These involve both the continued operation of existing spacecraft as well as preparation and planning for future missions. Studies of the Sun have a dual importance in that the Sun is not only a prototypical object for much of astrophysics, but also has the driving role in defining the heliosphere, in influencing the Earth and in controlling the near-Earth environment. It is to be hoped that the long-standing tradition of international co-operation in solar research will be strengthened still further.

VI. LIFE SCIENCES AS RELATED TO SPACE

VI.1. Gravitational Biology

COSPAR Scientific Commission F considers Life Sciences as Related to Space, and sub-commission F1 is concerned gravitational and space biology. The sub-commission focuses on gravity perception, genetic and physiological modifications in response to microgravity or simulated gravity. Genetic studies are typically paired with physiological manipulations and space flight experiments. The research relies on, unfortunately limited, chances for flight experiments, either in sounding rockets or on board of the Space Shuttle. The objective is to provide a broad framework for gravitational biology, particularly with reference to spaceflight, applicable to humans, animals, and plants, including micro-organisms and cell preparations. The terms of reference include: spaceflight low-G effects; effects of ground-based low-G simulation; gravity perception and orientation; gravity scale effects; centrifuge high-G effects; vibration effects.

Recently, the main activities of this sub-commision were centred on the 37th COSPAR Scientific Assembly held in Montreal, Canada on July 13-20, 2008. There were two symposia in this field, first, on Gravitational Effects on Plants, Fungi, and Unicellular Systems (organised by John Z. Kiss and Karl H. Hasenstein), and, second, on

Co-ordination of Arabidopsis Gravitation-related Research (organised by Ruediger Hampp).

The symposium on Gravitational Effects on Plants, Fungi, and Unicellular Systems considered gravity effects in plants, protists, and fungi. Presentations ranged from responses to and effects of gravity in higher plants (gravitropism) to the directional movements of unicellular systems and dealt with morphological, physiological, developmental, and genetic effects in response to changes in magnitude or direction of the gravity vector. The presented papers discussed molecular events related to gravity perception, gene expression during the graviresponse and signal transduction events as influenced by mutations, competing stimuli, or time. Despite the scarcity of flight opportunities, some presentations gave data from recent and older flight experiments, but the focus was on ground-based studies.

Hypergravity effects contrasted effects of microgravity in new hardware that was used to examine light and gravity interactions as well as endogenous movements that often confound the analysis of the gravitational effects. Gene expression studies included light and gravity interactions and gravity induced changes in gene activation. Technological advances were reported on, and ranged from telemetric analysis of space induced stress to sophisticated image analysis of stimulus-response interactions to gravity and auxin. Poster presentations reported effects of magnetic fields, novel greenhouse designs, and susceptibilities of plants to pathogens in altered gravity conditions.

The presentations at this truly international meeting were of excellent quality and involved most laboratories working on gravitational effects, including those in the U.S., Canada, Europe Asia, and especially Japan. The technologies were innovative but also accommodated classical morphological studies and included solid justifications why limitations to a few plant model systems may not be the best approach to achieve a comprehensive understanding of gravity effects. The load bearing and thus gravity effect of short and short-lived organisms differs considerably from long-lived and large organisms.

The second symposium was on the Co-ordination of Arabidopsis Gravitation-related Research. In order to investigate gravitational effects on organisms, model systems are used. In the case of plants, Arabidopsis thaliana has become a model system for higher plants which is widely used within the scientific community. Arabidopsis is thus also playing an increasing role in gravitation-related studies. Having participated in the previous COSPAR meeting in Beijing, the idea came up to bring together people who have experience with this plant system, with the aim of comparing data and knowledge about the experimental systems used (e.g. whole plants, cell cultures) and their responses. In Montreal a short workshop was arranged with 20 highly interested participants. The talks addressed hypo (clinorotation; random positioning; sounding rocket μg) and hypergravity (centrifugation) related responses of Arabidopsis plants as well as cell cultures.

Different aspects of gravity responses of Arabidopsis were covered in this "round table" which was extremely important and valuable, and they were also covered during the ESA Meeting "Life in Space for Life on Earth" in Angers (France) this summer. Other topics envisaged included considering the chances for eventually sharing exposed material for additional analysis, and developing concepts for further (possibly co-ordinated) experiments.

VI.2. Radiation Environment, Biology and Health

The principle objective of COSPAR sub-commission F2 is to study the biological effects of space radiation to living organisms. The natural radiation environment outside the magnetic shielding of the Earth is rather complex and consists of a mixed field of high energy protons, electrons, alpha particles and heavy ions. As the era of manned space exploration of our Solar System becomes increasingly a reality rather than a myth, the potential exposure of astronauts to these high linear energy transfer (LET) radiations and the subsequent short and long term health effects on the crews become a major concern of the space agencies. The focus of subcommittee F2 includes the influence of external factors such as radiation quality, weightlessness and environmental stress on radio-biological processes; radiation risk and protection in solar particle events; dosimetry in manned spaceflight; radiation standards and radiation protection in manned spaceflight.

Traditionally, our knowledge of biological effects of cosmic radiation in deep space is almost exclusively derived from ground-based accelerator experiments with heavy ions in animal or in vitro models. In an effort to gain more information on space radiation risk and to develop counter-measures in preparation for manned missions to the Moon and Mars, NASA initiated several years ago a Space Radiation Health Program, which is currently supporting biological experiments performed at the Brookhaven National Laboratory. The NASA Space Radiation Laboratory (NSRL), a $34-million facility, jointly managed during a four-year construction project by the office of Science of the US Department of Energy and NASA's Johnson Space Center, employs beams of heavy ions extracted from Brookhaven's Booster accelerator to simulate the cosmic and solar radiation environment found in space. Through the Ground Based Research in Space Radiation Biology programme, NASA has funded 25 research projects in the past two years. More recently, studies have been conducted aboard the International Space Station to ascertain the radiobiological effects of space radiation using a variety of in vitro and in vivo endpoints.

An international consortium of scientists from space agencies and universities launched the Anomalous Long Term Effects in Astronauts (ALTEA) project to ascertain the effects of space environment and cosmic rays on the central nervous system aboard the International Space Station. Endpoints including particle flux, electrophysiology and behavioural patterns of brain functions are measured. Based on the final recommendation of Investigations into Biological Effects of Radiation (IBER) (http://iber.na.infn.it), an European Accelerator-based space Radiation biology Program (EARP) has been devised to support safe human exploration of the Solar System and is

described herein. EARP should develop the database and the knowledge required by ESA to accurately predict and to manage efficiently radiation risk for manned interplanetary missions. The knowledge will be acquired by means of a peer-reviewed, ground-based and investigator-initiated science research programme in way similar to that of NASA. The ultimate goal of EARP should be to allow human colonisation of the Moon and exploration of Mars with acceptable risk from exposure to space radiation. A first suite of experiments has been selected by an international peer review committee recently. NASA, CSA, ESA, JAXA and RSA support activities in the field of radiation biology as part of their space medicine programmes.

Major conferences in this field include the 13th International Congress of Radiation Research (ICRR) held in San Francisco from 8-12 July 2007. The International Workshop on Microbeam Probes and Cellular Radiation Response was held in New York on 15-17 March 2006. The 12th Workshop on Radiation Monitoring for the International Space Station (WRMISS) (www.wrmiss.org) was held at Oklahoma State University on 10-12 September. This annual meeting is considered to be one of the best opportunities to discuss the results in space radiation dosimetry. One of the major topics this year was an update on the MATROSHKA (Facility for radiation measurements under extra vehicular activity conditions) results and the development of new technologies for space application. Twenty international groups participate in the MATROSHKA experiment which has the objective of determining organ absorbed radiation doses in a human phantom as a measure for the exposure of astronauts and cosmonauts outside and inside the ISS.

VI.3. Astrobiology

The principal areas of interest of sub-commission F3 are the study of: the pathway (chemical) by which life may have arisen - extraterrestrial organic chemistry, chemical evolution; the early geological record (pre-Cambrian) as it pertains to the origin and early evolution of life; the interaction of life with the planet in physical-chemical and evolutionary terms, terrestrial life forms in unusual and extreme environments; and finally, the search for life (including intelligence) in the universe. Also included is the development of planetary protection plans in solar system exploration and sample return missions.

The main recent conferences in this area of research are listed in the following paragraphs:

The 37th COSPAR Scientific Assembly held in Montreal, Canada on 13-20 July 2008 included four symposia in the field of astrobiology: (1) Circumstellar, Interstellar, and Protostellar Organic Chemistry (organised by Max Bernstein and Sun Kwok); (2) Chemical Evolution and the Origins of Life in the Solar System and Other Planetary Systems: Exo-, Astrobiological Aspects (organised by R. Navarro-Gonzalez and F. Raulin); (3) Limits of Life: Lessons for Astrobiology (organised by Daniel Prieur and Petra Rettberg); and (4) Instrumentation for In Situ Life Detection in Harsh Environments (organised by Jay Nadeau and Kenneth H. Nealson).

The 15th International Conference on the Origin of Life and 12th ISSOL Meeting (ISSOL '08), were held at the Palazzo dei Congressi, Florence, Italy on 24-29 August 2008. More than 150 papers were presented either in oral sessions or in poster sessions with 350 attendees. The papers presented treated a wide variety of aspects of origins of life, one of the main subjects of astrobiology: Past, present and future.

The Federation of Astrobiology Organisations (FAO) meeting took placed on 31 August 2008 in Neuchâtel, Switzerland. FAO encompasses an ever widening set of individual astrobiology networks, associations, institutes, research groups, and societies; linking them together to assist in the implementation of co-operative international activities. All astrobiology networks, associations, institutes, research groups, and societies are invited to participate in this federation. A primary focus of the FAO is broadening the opportunities available to talented students from all countries and supporting activities that develop their academic and research potentials.

VI.3.1. Astrobiology Activities around the world

The key goals for the Australian Centre for Astrobiology (http://aca.unsw.edu.au/) include contributing to the understanding of the origin of life on Earth and to set an Australian life-seeking instrument on the surface of Mars. The Centre also has a strong media, education and outreach programme related to its research, and which has attracted Australian Federal funding. In association with NASA, the Centre developed a "virtual field trip" that allows students to join scientists in the field in the Pilbara and Shark Bay areas, and to understand the relevance of Australian science in understanding our origins and in searching for life elsewhere in the universe.

The Astrobiology Society for Britain (www.astrobiologysociety.org) serves its members and the astrobiology community as a whole in the UK in fostering links between the various and many disciplines that comprise the science of astrobiology in order to ensure that astrobiology research in the UK is vigorous, progressive and successful. It seeks to provide a mechanism for members of the astrobiology community to meet, collaborate, make the community aware of UK astrobiology activities, and encourage new students and researchers into the field. It seeks to act as a professional society to organise and co-sponsor meetings and provide an environment favourable for the development of inter-disciplinary connections between biological and space sciences. The Astrobiology Society for Britain meets biannually; the 3rd conference took place in 2008.

The Centro de Astrobiología (CAB) in Madrid, Spain (www.cab.inta.es), has a formal centre, with buildings, staff, budget and research. There is a wide range of activities on-going. Particularly relevant to Education and Outreach are: (i) an annual international summer school of astrobiology which attracts about 40 students per year; (ii) invited talks/seminars to museums, university societies (40-50 per year); (iii) Science Fairs and the annual Spanish Week of Science; (iv) hosting visits to CAB - schools come

every week; (v) holding thematic exhibitions; and (vi) hosting national and international expos, e.g. Zaragoza.

The Groupement de Recherché en Exobiologie (GdR Exobiologie), France (http://www.exobio.cnrs.fr/), supports workshops, meetings, seed funding for cross-disciplinary collaborations. Apart from organizing summer schools for students on specific disciplines, it also supports a large summer school every two years that is open not only to students but to established academics and teachers, therefore cementing links between the different communities. GdR Exobiologie is to become a scientific society "Societie Francais d'Astrobiologie."

Bioastronomy: Search for Extraterrestrial Life was established as Commission 51 of the IAU in 1982 (http://www.ifa.hawaii.edu/~meech/iau/). The objectives of the commission include: The search for planets around other stars; The search for radio transmissions, intentional or unintentional, of extraterrestrial origin; The search for biologically relevant interstellar molecules and the study of their formation processes; Detection methods for potential spectroscopic evidence of biological activity; The co-ordination of efforts in all these areas at the international level and the establishment of collaborative programmes with other international scientific societies with related interests. There is a large IAU general assembly every 3 years. The IAU structure includes many divisions, and 53 commissions (i.e. subfields). Bioastronomy has been included since 1982 and was originally named "SETI" (Search for ExtraTerrestrial Intelligence). The commission hosts meetings every 3 years; the recent one was held in San Juan de Puerto Rico on 16-20 July 2007. Meetings play an important role in integrating the broader interests and techniques of both astronomy and biology to understand the origin of our solar system and the origin and evolution of living systems; as well as in generating a context for exploration in our solar system and in extrasolar planetary systems. The theme of the 2007 meeting was "Molecules, Microbes and Extraterrestrial Life".

The Israel Society for Astrobiology and the Study of the Origin of Life (http://www.ilasol.org.il/) runs annual meetings; the recent one was the 20th annual meeting of the society that took place on 4 January 2007 at the Weizmann Institute of Science in Rehovot.

ISSOL (http://www.issol.org) changed its name in Beijing 2005 to "ISSOL: The International Astrobiology Society". Its most recent meeting was in Florence in 2008, with 350 attendees and 38 travel grants to young scientists. ISSOL sponsored COSPAR 2007.

The field of astrobiology, covering chemical evolution and the origin and distribution of life in the universe, continues to prosper and expand in the USA. The academic science community, basic science funding agencies, NASA and the general public all show increased interest in, and support for, the inherently exciting questions being asked by this interdisciplinary endeavour. A number of academic institutions, such as the University of Washington and Pennsylvania State University, have developing

programmes in astrobiology that include ever more formalised curricula and degree/certification opportunities. Particularly promising, the field of astrobiology continues to attract excellent young undergraduate and graduate students.

In April 2008, the astrobiology community came together at the Astrobiology Science Conference in Santa Clara, California, to exchange research results and develop new collaborations, and plans for the future. The conference attracted more than 500 participants from across the USA and around the world. The conference proved that the science of astrobiology shows exciting growth and maturity, with particular focus on the concepts of planetary habitability, the source and delivery of prebiotic, precursor material to the Earth and other bodies, and the search for planets beyond our solar system. Publications in this new discipline, as indicated by submissions to journals, such as "Astrobiology", continue to increase in number and impact to the wider science community. Perhaps more importantly, astrobiology has become an integrating theme for the science and space missions being conducted by and planned for by NASA. Current missions, such as the Phoenix Lander, which landed in the high northern latitudes of Mars, as well as future missions, such as the Mars Science Laboratory, are being designed to address many of the objectives fundamental to astrobiology: for example, are the conditions on Mars now, or were they ever in its past, conducive to life as we know it?

The Astrobiology Program at NASA follows a community-generated roadmap that was updated in 2008. The programme is increasing in scope and budget, with timely new research being funded in all four of its sub-elements: Exobiology and Evolutionary Biology, its instrument (Astrobiology Science and Technology Instrument Development: ASTID) and technology (Astrobiology Science and Technology for Exploring Planets: ASTEP) programmes, and the NASA Astrobiology Institute (NAI). In addition, a new initiative is offering flight opportunities for astrobiological research as part of a small-payloads programme (Stand Alone Mission of Opportunity Notice: SALMON). In 2007, NASA announced the selection of four new NAI teams: at the Massachusetts Institute of Technology, Montana State University, the University of Wisconsin and the University of Washington. Additional 10 NAI teams were awarded funding in 2008 (http://astrobiology.nasa.gov/nai). The year 2007 also saw the completion of a formal review of the NAI by the US National Research Council. The Institute was judged as being very successful, or in the words of the committee's report, "overall, the committee is unanimous in finding that the NAI has fulfilled its original mandate. The NAI has played a key role in supporting the development of astrobiology, has positively affected NASA's current and future missions, and should continue to be supported." This judgment reflects a very positive and enthusiastic view of astrobiology by the science community, of its significance to the advancement of fundamental objectives in science, and to its future growth in the US and beyond.

The Sociedad Mexicana de Astrobiología (SOMA) (www.nucleares.unam.mx/~soma/) aims to promote the study and development of life sciences as related to space, and provides a mechanism for members of the astrobiology community to meet, collaborate, raise awareness in public about the Mexican

astrobiology activities, and encourage new students and researchers into the field. It has held annual meetings since 2001; the most recent took place on 16-17 June 2008 at the Universidad Nacional Autonoma de Mexico in Mexico City.

The Nordic Network of Astrobiology (http://www.nordicastrobiology.net/) aims to create a Nordic Research and Education area in Astrobiology; provides funding for Nordic students to attend Astrobiology courses at other universities in the Nordic Countries and funds travels of Nordic Scientists to teach Astrobiology at other Nordic Institutions; it also organises events for young astrobiologists and collaborates with other astrobiology institutions worldwide.

The European Astrobiology Network (www.astrobiology.pl/eana/) was founded in 2001 to bring together European researchers; 17 nations are represented, including Russia. It has created an Astrobiology Lecture Course Network (ABC net) which has run a course via video conferencing and published a Complete Course in Astrobiology, edited by Herda Horneck and Petra Rettberg. The published course includes a CD with lectures that were broadcasted to the participants in the course. The lectures are also available as video on demand http://streamiss.spaceflight.esa.int. In the academic year 2007/08 11 universities took part in the second course. European credits are awarded for the course.

The Society for the Study of the Origin and Evolution of Life (SSOEL) and the Japanese Society for Biological Sciences in Space (JSBSS) are two major societies covering the field of astrobiology in Japan. They continued their activities by holding annual meetings, publishing journals, etc. Recent meetings include: the 35th Annual Meeting of SSOEL, held at Kobe University, Kobe, Japan on 14-16 March 2007; the "Astrobiology Symposium", held at the Japanese Geoscience Union Meeting 2007, Makuhari Messe, Chiba, Japan on 22-23 May 2007; and the 21st Annual Meeting of JSBSS, held at Ochanomizu Women's University, Tokyo, Japan on 27-28 September 2007. SSOEL also founded "SSOEL Friends" and its first public event, the "Historical significance of Stanley Miller's spark discharge experiment" took place on 8 October 2007 at Osaka Science Museum.

JAXA maintains support for working groups on Space Utilisation Researches, among them three working groups related to astrobiology were selected. Based on their activities, Wideband Global SATCOM (WGs), a novel astrobiology mission on the Japanese Experimental Module of the International Space Station (named "Tanpopo") was proposed to JAXA, and selected as a candidate mission. The Tanpopo Mission aims to capture and measure the exposure of microorganisms and extraterrestrial organics in low Earth orbit to evaluate the panspermia hypothesis.

VI.4. Natural and Artificial Ecosystems

Artificial ecosystems with different degrees of complexity and closure are being developed to study both the particular laws of development of individual elements and components of an ecosystem, and the general regularities in the development of the entire biotic turnover. Different experimental ecosystems are regularly discussed at COSPAR

Scientific Assemblies and mainly published in ASR issues devoted to Life Sciences. These experimental ecosystems include: the Experimental Complex at the Institute of Biomedical Problems in Moscow, Russia; Bios-3 in Krasnoyarsk, Siberia at the Institute of Biophysics; Advanced Life support System Test Bed at the NASA Johnson Space Research Center in Houston, Texas; the NASA Kennedy Space Center "Breadboard" Plant Growth Facility in Florida; Biosphere 2 in Oracle, Arizona; the "Laboratory Biosphere" in Santa Fe, New Mexico; the aquatic ecosystems at the Ruhr University of Bochum in Germany; the Closed Ecology Experiment Facility (CEEF) complex at the Institute of Environmental Sciences in Japan; the Pilot Plant that is being constructed in the framework of the European program MELISSA (Micro-Ecological Life Support System Alternative).

At the 37th COSPAR Scientific Assembly held in Montreal in July 2008, seven sessions (symposia) were held in the area of "Natural and Artificial Ecosystems Studies for Earth and Space Applications" with about 30 countries represented. These sessions discussed new experimental and theoretical and high technologies' findings presented by ESA, NASA, and other space agencies, research institutes and universities from Bulgaria, China, India, Japan, Russia, Ukraine and other countries.

Comparisons of the problem of the sustainable development of humanity on Earth and the problem of supporting human life in space proves that they have the same scientific and methodological grounds. The key to solving both problems is a long-term maintenance of balanced material cycle. As a whole, natural or artificial ecosystems are to be more closed than open, but their elements (links of systems) are to be substantially open in interactions with each other. Prolonged stable interactions of different links have to have unique joint results – closed material cycling or biotic turnover. Possible uncontrolled evolution of links, their self development is to be a matter of special attention for the maintenance of prolonged stable functioning. These questions and some problems of information approach development for CES investigations were discussed in papers presented by researchers from China, Russia, and the U.S.

The MELISSA project, ESA's multi-component project of a closed life support system, was also discussed in papers presented by an international team of researchers. In particular, special attention was drawn, at the Assembly, to the Canadian role in advanced life-support test-bed development: an integration of a higher plant chamber into the MELISSA project.

NASA's researchers have continued theoretical and experimental investigations of different variants of bio-regenerative LSS testing at NASA's space centres. Closed Aquatic Systems – AquaHab – as a possible important part of a CELSS for exploration, Earth and Space applications has been developed by German researchers. Data on the circulation of waste material, water, CO_2 and O_2, and production of food and animal feed within a closed and controlled system comprised of humans, goats, crops, and physical/chemical systems were presented by a team of researchers of Japanese associated with the CEEF facility.

Different prospects for innovation in space agriculture have been mainly discussed by Japanese and Chinese researchers. Special sessions at the COSPAR Assembly were devoted to the influence of spaceflight environments on artificial ecosystems and their elements. Space effects on biological objects on genomic, proteomic, transcriptomic, chromosomal, and cellular levels were discussed thoroughly in seven sessions of the F4 Sub-commission.

In general, papers, presented by researchers from different countries, dealt with new findings in physical/chemical, biotechnological and experimental studies of the main features of artificial and natural ecosystems and their links for both Earth and space applications.

Finally, we note that a major international conference on "Life Support Systems as a Means of Human Exploration of Outer Space" was held in Moscow (Russia) on 24-28 September in 2008.

VI.5. Human Physiology in Space

The aim of COSPAR sub-commission F5 is on the one hand to understand the adaptation processes and mechanisms taking place in humans in the microgravity environment and on the other hand to develop counter-measures based on the achieved data to ensure health of the astronauts even during long-duration spaceflight. Hence, the physiological as well as the psychological system should be covered noting that those interact and affect each other. Taking into consideration that any stay in space might be up to years when thinking of missions to Mars, the physiological processes should be well understood and measures should be in place counteracting potentially negative adaptation processes. Besides focusing on space missions, simulation studies which in some way mimic the physiological changes in microgravity are also taken into account to gain knowledge in physiological reactions of humans in altered gravity. The latter include weakening of the musculoskeletal system, the cardiovascular system as well as psychological modifications when being in a confined environment far away from loved ones.

As part of the counter-measure development, different exercise regimes, and potential nutritional counter-measures, as well as gender differences when applying those counter-measures, are currently being examined. ESA has supported several studies in past years and intends to continue to focus particularly on artificial gravity, exercise regimes and nutritional counter-measures as well as combination of these in the upcoming years. An entire session was dedicated on "Integrative Physiology: Nutritional aspects" during the Joint ESA-Life Sciences, ISGP and ELGRA conference which took place in Angers, France, in 2008.

The IAA is planning a meeting in 2009 in Moscow, where new results on human physiological studies from the ISS as well as simulation studies will be presented by and to the International scientific community.

The first short-term ESA studies of 5 days bed rest plus artificial gravity or artificial gravity and exercise as a counter-measure will be launched in 2009 at two different sites, namely, the German Aerospace Center (DLR), Cologne, and the Institut Médicine Physiologie Spatiale (MEDES), Toulouse, France.

In preparation of further long-term missions, in particular Mars missions, the Institute of Biomedical Problems (IBMP) in Moscow, Russia is planning a 500-day confinement study as well as a 105-day preparatory study. International agencies and scientists from CNES, DLR, ESA, NSBRI and others will participate in this very impressive IBMP study investigating psychological and physiological questions as well as working on technical challenges. The onset of the preparatory study is planned for spring 2009.

China launched another manned mission in the autumn of 2008 with three taikonauts, with one of the taikonauts performing the first Chinese extravehicular activity (EVA) during their stay in space. This is another step, for China, towards a potential Chinese space station or a landing on the Moon.

VII. MICROGRAVITY RESEARCH

In recent decades as humans we have found that we can survive without gravity for brief periods. We have shown that plant and animal reproduction are possible in orbit. We have observed changes in virtually every system of the body and tested approaches for keeping these changes within safe limits. In the physical sciences, we have tested fundamental physical theories to degrees of precision not possible in Earth-bound laboratories. These findings and accomplishments have been based on brief visits to space using the Space Shuttle, the International Space Station and supplemented by substantial Earth-based research.

Microgravity research involves the study of low gravity on physico-chemical phenomena as applied to materials science, fluid physics, combustion and biotechnology. Microgravity materials scientists seek to use microgravity to study the processes by which materials are produced and the relationships between the formation of a material and its properties. Various research programmes attempt to advance the fundamental understanding of the physics and chemistry associated with phase changes (when a material changes from one phase - liquid, solid, or gas - to another). The materials science programmes in most countries support both fundamental research and applications-oriented investigations of electronic and photonic materials, glasses and ceramics, metals and alloys, and polymers. Consequently both ground-based and flight research is necessary. A fundamental objective of microgravity materials science research is to gain a better understanding of how buoyancy-driven convection (fluid flow resulting from density differences) and sedimentation (settling of heavier constituents in a liquid) affect the processing of materials. In microgravity, these gravity-driven phenomena are significantly suppressed, allowing researchers to study underlying events and phenomena that are obscured by the effects of gravity and difficult or impossible to study quantitatively on Earth. For example, in microgravity, the significant reduction of

buoyancy-driven convection makes it possible for scientists to study segregation, a phenomenon that influences the distribution of a material's components as it forms from a liquid or gas.

Fluid physics is the study of the motion of fluids and the effects of such motion. Since three of the four states of matter (gas, liquid and plasma) are fluid and even the fourth (solid) behaves like a fluid under many conditions, fluid physics is vital to understanding, controlling, and improving all of our industrial as well as natural processes. The engines used to propel a car or an airplane, the shape of the wings of an airplane that allow it to fly, the operation of boilers that generate steam used to produce over 90% of the World's electric power, the understanding of how cholesterol is transported in our bloodstream and how it affects heart disease, and how pollutants are transported and dispersed in air and water, are just a few examples of how fluid physics affects our everyday life and forms the very basis for an industrial society. A low-gravity environment nearly eliminates buoyancy and sedimentation and provides scientists near ideal conditions to probe into flow phenomena otherwise too complex to study on Earth. It also allows study of flows (such as surface tension driven flows) that are nearly masked in Earth's normal gravity. This has the potential to enable tomorrow's information technology. Understanding of liquid-vapour flows and heat transfer in microgravity is also vital to the design of spacecraft and life support systems needed for humans to explore and exploit the unlimited potential of space.

The application of biotechnology research results range from the design of new drugs, to protein engineering, synthetic vaccines, and biochip technology for the electronics industry. Biotechnology under microgravity conditions has focused on the study of isolated bio-macromolecules, such as proteins and the study of cells in controlled fluid and chemical environments.

The International Space Station represents a major leap in our capability to conduct research in orbit. It serves as a laboratory for exploring basic research questions in commercial, science, and engineering research disciplines, and as a test bed and springboard for exploration.

The research programmes in Europe and Japan are examples of space utilisation for microgravity research. Much work has been accomplished in the last two years in the fields of fluid and materials sciences. Research has been conducted in space as well as on the ground. Many fluid science problems test fundamental ideas of fluid motion but also have applications to Earth based technologies and space enabling technologies. Microgravity experiments have been conducted on recoverable satellites. The principal platforms supported by ESA are the drop tower in Bremen, parabolic flights using an Airbus and Russian recoverable FOTON satellites, in addition to the ISS. Most of the experiments on the drop tower have been related to combustion. The recoverable satellites have been used for studies of protein structures and diffusion in liquids. Parabolic flights provide low gravity for a few seconds and have been used to study quick responding fluid physics associated with foams and emulsions.

The Japanese Space Agency, JAXA, has supported and continues to support research for the planning of future space experiments. Some of this research utilises drop towers and parabolic flights to carry out microgravity experiments and is obtaining significant results, especially in combustion sciences. JAXA has recently started a microgravity experiment aboard the Japanese Experiment Module, KIBO. The first experiment is a fluid science study concerning surface tension gradient flows called Marangoni convection.

The Chinese microgravity research programme has been involved with experiments relating to physics and life sciences in several runs on board a Chinese recoverable satellite, SJ-8, which was launched in November 2006 and operated in orbit for 18 days. Results of the space experiments were published in a special issue of the journal Microgravity Science and Technology (Vol.20, no.2, 2008). The main programmes related to space experiments in China are the Manned Space Engineering and Space Science programmes. Studies in ground laboratories, including the preparation of space experiments during the next few years will continue.

In 2006-2008 drastic changes have occurred in the USA's microgravity science programme. The severe reductions in the content and extent of the ground and space programmes of the microgravity fluids and combustion programmes has caused the expertise resident in these areas to move to NASA's Exploration Systems programmes.

VIII. FUNDAMENTAL PHYSICS

The arena of fundamental physics continues to encompass some of the most pressing and exciting problems in physics including the interaction of quantum mechanics and gravitation, the nature of space-time and the understanding of complex systems. Better knowledge of the laws of the universe is as much a part of scientific exploration as a visit to the surface of a planet. Understanding the development and content of the universe is the basic objective of COSPAR science, and the frontiers of fundamental physics contribute significantly to our ability to do this.

GP-B was NASA's second independently launched mission in fundamental physics, GP-A having been launched in 1976 to confirm the gravitational red-shifting of light. GP-B was designed to test the effects of gravitational forces on the motion of a spinning body. Two effects are predicted by General Relativity: one is the geodetic motion of the spin axis in the plane of the satellite orbit and the other is caused by frame dragging produced by the rotating source of gravitation-in this case the Earth.

The launch of GP-B in 2004 demonstrated a number of outstanding technical achievements such as charge control of free masses, SQUID readout systems, patch field control, precise dynamics of spinning masses, and 10-11 g drag-free control. Not surprisingly for an instrument of such precision the analysis and interpretation of the data has thrown up detailed issues which have taken some time to resolve. The geodetic effect has been determined to ~ 1% accuracy. The frame dragging measurement currently has a

statistical bound of ~ 25%, consistent with General Relativity prediction, but rigorous evaluation of potential systematic effects is required before this result can be accepted. Advances in the removal of spurious polhode motions and various other improvements suggest that these limits will be substantially reduced later this year. The ultimate precision might be 2% for frame dragging and 0.02% for the geodesic effect. This work is being done in the USA.

The foundations of General Relativity rest on the equivalence of the gravitational force and accelerations, originally observed by Galileo and Newton. Tests of the Equivalence Principle in space should exceed the sensitivity of ground based experiments which have reached upper limits on Equivalence Principle violation of the order of parts in 10^{12}. The Microscope experiment being developed by CNES aims at a sensitivity of parts in 10^{15} whereas the design studies for STEP indicate that 10^{18} might be possible. Microscope is under development and a launch in 2010 is expected. This work is being performed in France with assistance from ESA.

The properties of black holes are an important outcome of General Relativity as well as a defining issue in the structure and development of the universe. The probing of space-time local to black holes can be carried out by studying the gravitational waves emitted during binary interactions or the in-fall of condensed objects. The LISA mission will be able to make these studies with high precision and the technological development is proceeding via the LISA Pathfinder mission due for launch in 2010 and by means of laboratory programmes in institutes in Europe and the USA. LISA technology is close to the required readiness level and favourable programmatic decisions could result in a launch in 2018. The countries involved include France, Germany, Italy, Spain, Switzerland, the Netherlands, the UK and the USA.

The AMS experiment (Alpha Magnetic Spectrometer) has been designed to search for the presence of antimatter in Cosmic Rays. A fundamental issue for particle cosmology is to provide an explanation of why the Universe is so polarised in favour of matter when so many basic interactions generate equal numbers of particles and anti-particles. AMS has flown on the Space Shuttle in 1998 and is being prepared for a long duration flight on the International Space Station. The countries involved in this include the USA, Taiwan China, France, Italy, Germany, Spain, Denmark, Portugal, Russia and Finland.

Fundamental Physics is an extremely fruitful field of technical development and training for young instrumentation scientists with the opportunity to work on experiments of exquisite precision. After receiving higher degrees or project training in this field many go on to other employment in the space sector providing a considerable transfer of techniques and skills. The good relations between these aerospace industry employees and their previous institutes also contribute to the development of future opportunities for knowledge exchange and joint project ventures. The intellectual excitement of fundamental physics can thus be a pathway for recruiting highly skilled scientists and engineers to work on space programmes of wider applicability. This recruitment path has

to be stimulated constantly by effective outreach programmes in order to maintain the technical capabilities of universities and industry alike.

IX. SATELLITE Dynamics

The central theme of the COSPAR Panel on Satellite Dynamics is the precise determination of the motion of artificial satellites, including satellites orbiting Earth, the Sun, the Moon, the planets, planetary moons and inter-planetary satellites. Moreover, the Panel addresses activities in support of POD, such as the establishment and maintenance of reference frames, improved modeling of gravitational and non-gravitational forces (for example atmospheric drag, solar radiation pressure, albedo, and thermal infra-red perturbing forces), and development and application of tracking systems (such as SLR, GNSS, DORIS) and new technologies (for example, RF and optical (laser) satellite-to-satellite tracking, space-borne accelerometry and gradiometry).

In recent years, significant advances have been made in many areas associated with the field of satellite dynamics. An overview is given below including a summary of selected highlights. This overview has been divided into a part addressing Low Earth Orbiting (LEO) satellite missions, Global Navigation Satellite Systems (GNSS), and solar system missions (to the Moon, Sun, planets and inter-planetary).

IX.1. Low Earth Orbiting satellites

The ESA ENVISAT, German DLR CHAMP, the NASA/GFZ GRACE and NASA/CNES Jason-1 satellites continue to operate nominally and provide unprecedented results in the fields of geopotential modelling (Earth's gravity and magnetic fields), oceanography (altimeter-based), glaciology (for example by InSAR), seismology (also InSAR) and atmospheric research (radio occultation, SCIAMACHY). All these results have been enhanced by further improving the precise orbit determination for these satellites, which has been achieved by a combination of better treatment of tracking data (GPS satellite-to-satellite tracking, DORIS, SLR), improved modelling of non-gravitational forces (based on comprehensive satellite models and satellite-atmosphere interaction models) and also better understanding/treatment of space-borne accelerometer observations (CHAMP and GRACE). The precision of determined orbits for these satellites is now at the 1 cm level, especially for the radial direction (enhancing for example altimeter products and applications).

The latest re-release (RL04) of six years of high-quality GRACE L2 data in 2007 resulted in a wealth of scientific results related to hydrology, global change, oceanography, POD for LEO, etc. Other missions (e.g. CHAMP) continue to release more data, contributing to studies of the geopotential fields and the atmosphere. Significant progress has been made with better interpreting and processing of the observations taken by the KBR instrument onboard GRACE and the accelerometers, improved background modelling (tides, atmosphere, ocean mass changes) and improved estimation of both, local and global time series of gravity field changes. These temporal

gravity variations are highly correlated with continental hydrology, ocean mass redistribution, and tides in Arctic areas.

Despite the reduced intermittent operation of the laser altimeters onboard ICESat, unique results have been obtained which along with those from the re-analysis of GRACE data and Jason-1 altimetry have led to unprecedented documentation of global change.

Also relevant to this topical area is that ESA continues the development of CryoSat-2, with a possible launch date in late 2009.

The 1st MetOp satellite (launched on 19 October 2006) has continued to provide excellent global data sets for operational meteorology: from (near) real-time atmospheric profiling by radio occultation with a newly developed European GRAS receiver (GPS Receiver for Atmospheric Sounding) to atmospheric sounding with the most sophisticated instrument in orbit, the Infrared Atmospheric Sounding Interferometer (IASI). MetOp offers a challenging environment for near-real time very precise orbit determination and it is operated by the EUMETSAT organization (with support from ESA, CNES and NOAA).

The US/Taiwan COSMIC constellation reached operational status in 2007 and produces consistently global soundings maps on a daily basis with near-real time delivery. The primary objective of COSMIC is to study Earth's atmosphere and track climate change. All the six satellites carry a high-quality GPS receiver that allows a very precise orbit determination, a prerequisite for atmospheric profiling by GPS radio occultation. In addition, the constellation might offer unique opportunities for formation flying and relative positioning concepts.

In early 2007 the first data were collected from JAXA's geostationary ETS-8, an experimental communications, timing and positioning satellite. After a successful tracking campaign for almost a year, the Naval Research Laboratory's (NRL) ANDE-RRA (Atmospheric Neutral Density Experiment Risk Reduction - Active) mission re-entered the atmosphere on Christmas day of 2007. The other half of the mission, the passive spacecraft ANDE-RRP followed on 25 May 2008. On 15 June 2007, the German TerraSAR-X mission was successfully launched. It carries an X-band SAR antenna, occultation GPS, a Laser Retroreflector Array (LRA), as well as a Laser Communication Terminal (LCT).

On 20 June 2008 the Ocean Surface Topography Mission (OSTM)/Jason-2 was successfully launched from California's Vandenberg Air Force Base aboard a United Launch Alliance Delta II rocket. OSTM/Jason-2 is the follow-on to Jason-1 and TOPEX/POSEIDON, the two extremely successful NASA-CNES collaborative oceanographic missions. Standard products are already available to the scientific community, while Jason-2 is still undergoing the usual calibration/validation phase. Amongst the improvements between the two Jason's the DORIS DIODE navigator stands out, as it can now track up to seven beacons simultaneously (vs. two) and thus improve

the quality of the positioning results and enable operational oceanography in near-real time.

Finally, intensive last minute preparations are being made for the ESA GOCE mission. GOCE aims at providing observations for modelling Earth's (pseudo-static) gravity field with unprecedented precision and resolution making use of space-borne gravity gradiometry (based on an instrument that consists of an orthogonal triad of 3 pairs of accelerometers) and tracking by GPS. The launch date of this very challenging satellite originally set for 10 September 2008, was moved to October 2008, onboard a Eurockot launcher from Plesetsk.

IX.2. Global Navigation Satellite Systems

A continuously growing number of users and applications benefit from the US Global Positioning System (GPS). The International GNSS Service (IGS) continues to – very reliably – provide precise ephemeris and clock products for the GPS satellites, continuously improving the precision of these products and decreasing the latency.

An important development is the commitment by the Russian Space Agency to re-establish the full GLONASS constellation in the upcoming years. This will open the possibility to enhance the GPS system and further improve the reliability, integrity and precision of navigation by GNSS. This will likely happen soon after the implementation of the European Galileo system that was recently approved by the EU. In a recent news release, Russia states that it will soon launch six additional spacecraft for GLONASS, expecting to reach a 30-satellite constellation by 2011. Furthermore, production of the modernized K-series of GLONASS satellites has begun, with a first launch scheduled in 2010. An important milestone for Galileo was reached in 2008, when on 27 April GIOVE-B was placed in orbit onboard a Soyuz Rocket from the Baikonur cosmodrome. Keeping apace, China has launched the Compass M-1 satellite on 14 April 2007. This satellite, different from the previous Beidou spacecraft, is the first of a 35-spacecraft constellation that will form the Chinese global navigation satellite system. Unlike prior Chinese navigation satellites, Compass M-1 broadcasts in L-band, using signal structures similar to other GNSS systems and sharing frequencies near to or overlapping those of GPS, Galileo, and GLONASS.

IX.3. Solar System and Interplanetary Missions

Major and impressive advances have been made in recent years in the field of precise orbit determination of Lunar and Mars orbiters, in conjunction with gravity field modeling of these celestial bodies. Analysis and re-analysis of Earth-based tracking of Lunar and Mars orbiters has resulted in improved orbit solutions for Clementine, Lunar Prospector, and Mars Global Surveyor. In addition, successful attempts have been made to increase the resolution of lunar gravity field models and even observe temporal variations in Martian gravity. On 4 August 2007, Phoenix, a NASA mission to Mars was launched aboard a Delta II rocket from Cape Canaveral Air Force Station, Florida. The Phoenix lander targeted the circumpolar Martian regions, where using a robotic arm to

dig through the protective top-soil layer, reached the water ice below and delivered both soil and water ice to the lander platform for sophisticated scientific analysis. The exciting news came on 31 July 2008, when NASA announced that Phoenix confirmed the presence of water ice on Mars (predicted in 2002 by the Mars Odyssey orbiter).

Closer to Earth, the Japanese Kaguya/SELENE mission to the Moon was successfully launched on 14 September 2007. SELENE carries more than 10 instruments and the mission included a number of sub-satellites that aim at modelling for the first time the global lunar gravity field (including the so-called far side) with high precision and resolution, making use of a combination of Earth-based and satellite-to-satellite tracking between Kaguya and the relay satellite Okina. Recent results include the observation of the lunar dichotomy in the form of vastly different gravity anomalies between the near and far side of the Moon, and the first observation of the Apollo landing site halo from space.

The Russian space interferometer mission RadioAstron is nearing its final stages in 2008. The RadioAstron Space Observatory (the Spectr-R project) equipped with a 10 m antenna, is dedicated to investigating the structure of various objects in the universe at cm and dm wavelengths with an angular resolution of up to a few millionths of an arc-second (i.e. millions of times better than a human eye's resolution). The radio interferometer consists of an Earth-orbiting space telescope with an apogee of up to 350,000 km, and the largest ground-based radio telescopes on Earth. The Spectr-R project has been included in Russia's Federal Space Program for 2006-2015. The possibility of tracking this spacecraft with SLR will certainly present challenging opportunities for further experiments and the extension of the two techniques (SLR & VLBI), as well as a new "tie" of the reference frames realised by the two.

NASA is also steadily progressing in readying the Lunar Reconnaissance Orbiter (LRO) for an early 2009 launch. LRO carries multiple laser technology components: a laser altimeter (LOLA) for topographic mapping and a laser transponder for one-way laser ranging (LR). It is anticipated that a significant number of the ground-based tracking sites will participate in tracking LRO-LR. This will be the first global scale application of optical one-way tracking for POD. Along with LRO, NASA will launch LCROSS, the Lunar CRater Observation and Sensing Satellite, managed by NASA's Ames Research Center in California. LCROSS will search for water ice in a permanently shadowed crater near one of the lunar poles.

A new regime of satellite dynamics will be reached by the new technology of satellite-to-satellite tracking by laser interferometry, Laser Doppler Interferometry or LDI. Ranging precisions of the order of nano- to pico-meter might be achieved by this technology, offering the possibility to study new phenomena, especially in the field of fundamental physics. Currently, ESA and NASA are studying the LISA concept, a constellation of three satellites separated by some 5 million km (in a triangle with equal legs) flying in an Earth-like orbit at 1 AU from the Sun. Early studies indicate that LISA is not only a very challenging mission concerning the required precision level for inter-satellite tracking, but also concerning attitude, and constellation control and maintenance.

A rigorous assessment of perturbing and control forces has been made, taking into account accelerations with amplitudes many orders of magnitude smaller than typically required for the orbit determination of existing satellites and their applications.

IX.4. Outlook

Satellite dynamics and precise orbit determination continue to play an important, crucial role in the exploitation of artificial satellites, be it scientific or commercial. An important development is the design, development and realisation of more and more multi-satellite missions, requiring not only absolute precise position solutions for single satellites, but also relative ones for which the precision requirements are often more stringent. It is fair to state that many future satellite missions will rely on the availability of precise orbit solutions, in many cases in near-real time. For certain missions even further advances need to be made, not only concerning precise orbit determination methodology, but also concerning models (gravitational and non-gravitational) and tracking technology (both Earth-based and space-borne). Many efforts are currently being undertaken to achieve such improvements. One of the most promising approaches is to improve the modelling of system Earth on the basis of the many global models that are now becoming available thanks to the very same satellite missions that collect global observations on a daily basis now.

X. SCIENTIFIC BALLOONING

Scientific balloon programmes around the world in 2007-8 continued to play a vital role in providing a low-cost alternative vehicle for carrying out space research using payloads lifted to heights of 20-50 km. The research disciplines have included atmospheric sciences, aeronomy, cosmic rays, and astronomy and astrophysics. Progress has continued in developments in technology and materials to achieve the important and ultimate goal of observation periods of several weeks with state of the art payloads that could be flight ready in a relatively short space of time. Balloon-borne observations of the Earth's atmosphere have continued with high quality instruments. Such future observations will play a pivotal role in assessing environmental and atmospheric changes attributed to human activity. Balloon flights have maintained their role in providing quasi-space conditions for the validation of new concepts for satellite missions. These programmes have also served as an excellent training ground for students and young researchers, and for public outreach activities.

X.1. Flight Programmes and Missions

The NASA balloon programme has continued to provide high altitude platforms for science investigations and technology development. Their five standard balloon sizes range from 113,000 m^3 to 1,130,000 m^3, supporting a maximum payload of 3,600 kg. A total of 32 heavy payload flights were conducted in 2007-2008. The launch sites (and numbers of flights) included McMurdo Station, Antarctica (6), Fort Sumner, USA (19), Palestine, USA (4) and Kiruna, Sweden (3).

Working with the University of New South Wales, Australia, NASA is adding a new payload staging building at the Balloon Launching Station in Alice Springs, Australia. NASA is planning a conventional campaign (line-of-sight missions of 6 to 36 hours duration) to be conducted from Alice Springs in April – May 2010.

NASA and the US National Science Foundation (NSF) have successfully completed the launch of three heavy payloads from McMurdo during both the 2006-7 and 2007-8 southern summer seasons. NASA and ESRANGE (Kiruna, Sweden) continued planning toward campaigns for Long Duration Balloon (LDB) missions in June-July 2009 and beyond. Fort Sumner remained the principal launch site for all NASA test flights in USA, the site being used for conventional missions during turnaround for the testing of instruments prior to their flights on LDB missions.

The NSF manages the US Antarctic Program and provides logistic support for all US scientific operations in Antarctica. NSF and NASA conduct annual scientific balloon campaigns during the Antarctic summer, when the unique atmospheric circulation allows balloon launches from McMurdo Station, with payload recovery from nearly the same spot weeks later. Antarctic balloon flights last much longer than flights in other places because constant daylight means no day-to-night temperature fluctuations of the balloon, which helps it stay at a nearly constant altitude during the flight. Each balloon circles the continent from one to three times between launch and recovery.

The Indian National Balloon Facility (INBF) has conducted 6 flights carrying heavy payloads, from Hyderabad. Four of these flights involved X-ray astronomy payloads, one flight an infrared astronomy telescope, and the sixth was an engineering flight which carried an assortment of newly developed technology experiments and sub-systems.

INBF continued to provide support for high altitude wind profiling to other agencies. It conducted a test flight with a 4000 m^3 high balloon made out of ultra thin polyethylene from the Satish Dhawan Space Centre (SDSC) at Shar in April 2006 for measuring meteorological parameters at altitudes up to 42 km. An agreement has been signed between SDSC and INBF for the supply of further 50 high altitude balloons and expert manpower support for this programme.

ISAS/JAXA has conducted 14 balloon flights from the Sanriku Balloon Center (SBC) in Iwate in 2006-7. In addition to scientific observations in the fields of cosmic-ray physics, astronomy and geophysics, some technical verification of space engineering was carried out during these flights. Four additional flights were conducted to investigate new technologies such as high altitude balloons fabricated from ultra-thin film, and prototypes of pumpkin-shaped super-pressure balloons.

ISAS/JAXA has decided to move their domestic balloon base from Sanriku to Taiki, Hokkaido. Thus, the SBC was closed in September 2007 and balloon operations at the Taiki Aerospace Research Field (TARF) started in May 2008. A new dedicated

balloon operation building was constructed at TARF, and a unique sliding launcher was developed which enabled the inflation of balloons inside a huge hanger. These developments will enhance the TARF capability to launch much larger balloons carrying heavier payloads.

The Brazilian Balloon Launching Center of the National Institute for Space Research – (INPE) has continued to conduct high altitude balloon launches for science investigations and technology development. The center provides technical support and infrastructure for INPE projects as well as for other national and international organizations. Its main launch facility is located at INPE´s campus in Cachoeira Paulista, São Paulo, with the capacity to launch balloons of volumes up to 700,000 m^3. The centre's launch vehicle can handle payloads of up to 700 kg weight and 6 m height. In a collaborative programme with ISAS/JAXA, INPE has developed a new semi-dynamical technique that allows launches of larger balloons from Cachoeira Paulista.

X.2. Technology and Mission Concepts

NASA's Super-Pressure Project (formerly called ULDB for Ultra Long Duration Balloon) continues toward development of a heavy-lift vehicle capable of supporting extended duration flights up to 100 days. Small scale testing and model updates have been completed in order to enhance deployment and ensure material integrity. NASA remains on track to provide a large super-pressure balloon to carry 2,700 kg to an altitude of 34 km. A 56,600 m^3 volume super-pressure balloon was successfully test flown in June 2008, which incorporated recent design enhancements. NASA plans to launch a 198,218 m^3 volume super-pressure test flight from McMurdo, Antarctica in December 2008.

NASA has implemented significant enhancements to its balloon recovery systems. Through engineering support from NASA's prime contractor at Columbia Scientific Balloon Facility (CSBF), a new parachute shock reduction system was successfully tested and now implemented as standard equipment on all flights. This system has reduced opening parachute shock loads by an order of magnitude. CSBF also made enhancements to the parachute separation system that better ensures parachute separation from the payload once it touches ground at the end of each mission. In addition, CSBF has developed light weight – low power electronic flight support systems for balloon control and recovery of data for both line-of-sight and over-the-horizon global missions.

Southwest Research Institute and Aerostar International have continued their development efforts of a small payload stratospheric airship. A test flight was conducted in early summer 2008 of a technology demonstrator and work is continuing.

Balloon fabrication is an integral part of the INBF. The balloons are designed and manufactured to experimental requirements of payload weight and required float altitude. Eight balloons ranging in volume from 32,613 to 738,947 m^3 were fabricated during 2007-8 for experiments in astronomy and astrophysics. Fifty-five balloons of volume

4000 m^3 were fabricated for probing the upper atmosphere up to 42 km. Three further custom-designed balloons were manufactured for Scientific Instruments Limited, Saskatoon, Canada.

The extrusion of thin film was carried out in industry under the direct supervision of the INBF team. Experimentation with extrusion protocol has resulted in the successful production of thinner film with an average thickness of ~4.8 μm, compared with the earlier average of ~ 6.2μm. The resulting reduction in balloon weight enabled INBF to attain an Indian record altitude of 43.25 km. Other technical innovations at INBF have included improved balloon gore sealing techniques, new launch equipment, and a new portable bank of hydrogen balloon inflation gas. A new balloon load line package was developed which included S-band telemetry and flight termination subsystems. This package, which was successfully deployed in flight, weighed 20 kg compared to the previous package weight of 54 kg.

ISAS/JAXA has conducted two technical flights for a drag-free micro-gravity experiment system. To provide a microgravity environment of good quality, adequate time duration with moderate cost, a balloon-based free-fall capsule was developed. The flight capsule consists of an outer shell, an inner shell containing an experiment module, and a propulsion system. In order that the inner shell is isolated from the outer shell and no disturbance force is worked to it, the propulsion system controls the outer shell so that it does not collide with the inner shell. The first successful test flight with a fluid dynamics experiment lasted a few seconds in 2006. The second flight for a combustion experiment was also successful and it achieved a microgravity environment for 35 s. ISAS/JAXA also carried out a technical flight to test solar sail membrane deployment, and an engineering flight to evaluate fuel cell system for long duration balloon flights.

ISAS/JAXA has continued to develop ultra-thin polyethylene films for high altitude balloons floating in the mesosphere. In November 2007, three balloon flights with technical objectives were launched by INPE from Cachoeira Paulista in collaboration with ISAS/JAXA and the University of Nagoya, Japan. The flights were intended to validate a new telemetry system and also to test a 300,000 m^3 super-pressure balloon, developed by ISAS/JAXA, carrying a 500 kg payload. The launch of this new type of lobed-pumpkin shaped balloon took place using a new semi-dynamical technique developed by the two collaborators.

X.3. Scientific Research

NASA and NSF have achieved a new milestone in conducting scientific observations from balloons by launching three long-duration flights within a single Antarctic summer in two consecutive seasons. The Antarctica Impulsive Transient Antenna (ANITA), the Balloon-borne Large-Aperture Sub-millimeter Telescope (BLAST), and the Solar Bolometric Imager (SBI) were launched during the 2006-2007 season. ANITA successfully employed an ultra-broadband quad-ridged horn antenna array for ~ 35 days in a search for ultra-high energy cosmogenic neutrinos. Data analysis is underway, and the payload is being integrated for its second flight during the

2008-2009 season. With a 2 m primary mirror and large-format bolometer arrays operating at 250, 350 and 500 μm, BLAST conducted a sensitive, large-area (>10° × 10°) sub-mm survey during a 11-day flight to address galactic and cosmological questions regarding the formation and evolution of stars, galaxies and clusters. SBI was planned to study irradiance variations at the upcoming sunspot minimum, when the local fields would be at their weakest, but it experienced an operational problem with the flight computer on ascent.

The 2007-2008 season has been NASA's most successful ballooning campaign by far. The three science payloads were all successful, and collectively they gathered about 79 days of data. The three investigations were the University of Maryland's Cosmic Ray Energetics And Mass (CREAM) experiment, the Balloon-borne Experiment with a Superconducting Spectrometer (BESS) developed jointly by the NASA's Goddard Space Flight Center, Greenbelt, Maryland USA and Japan's High Energy Accelerator Centre, Tsukuba, Japan, and Louisiana State University's Advanced Thin Ionization Calorimeter (ATIC) experiment.

The CREAM experiment measured elemental composition and energy spectra of very high-energy energy (~10^{10} to > 5×10^{14} eV) cosmic rays with better precision and higher statistics than any previous experiment. It is searching for characteristic changes associated with a limit to particle acceleration in supernovae, a goal that requires a series of long duration flights. Their third flight was launched in December 2007, and flew for 28 days. Combined with two previous flights of 42 days and 28 days, about 100 days of exposure have already been accumulated.

The BESS investigation obtained definitive measurements of low-energy cosmic-ray antiprotons in solar minimum conditions, when the sensitivity of the measurements to the possible presence of an exotic source is greatest. Its precise data will constrain models for dark matter, primordial black holes and cosmological antimatter. This second Antarctic flight of BESS, a Japanese – US co-operative project, was launched in December 2007, and flew for ~ 30 days, during which 4.7 billion cosmic-ray events were recorded.

The ATIC investigation is focusing on cosmic-ray electrons, the only component for which there is direct evidence of acceleration in supernova remnants. Electrons are of particular interest because they are subject to synchrotron energy loses that limit the distance they can travel through space. ATIC also measures high-energy (< 5×10^{10} to ~10^{14} eV) cosmic-ray proton and helium spectra. The third and last flight of ATIC was launched on 26 December 2007, and recovered near the South Pole after a 19-day flight.

Research in the fields of Environmental Sciences and Payload Engineering commenced at INBF in 2006 and experimental work has begun on ozone measurements, space weather, aerosol chemistry, and tropospheric and stratospheric exchange. Regular observations have started on the spectral study of aerosols and their radiation forcing over India. Sudden ionospheric disturbances are studied using low frequency wavelength propagation. An ionospheric tomography experiment is under way using multi-station

interferometery. A pilot experimental programme titled "Investigation of atmospheric dynamics over a tropical station, Hyderabad, India using high altitude balloon data and stratosphere-troposphere exchange and gravity wave characterisation" has been completed. The project involved simultaneous probing of stratospheric winds and temperature up to 43 km using high altitude balloons carrying GPS sondes and Light Detection and Ranging (LIDAR) observations from Tirupathi.

Regular public outreach programmes are held at INBF. About 50 undergraduate students along with their faculty members from 6 to 7 tertiary institutions are invited for one day learning sessions in stratospheric ballooning.

ISAS/JAXA provided a flight for VLF (Very Low Frequency) observations of radio and optical radiation emitted from lightning related phenomena. Several Transient Luminous Events, such as sprites and elves, were observed during the 6-hour flight. Two balloon flights for stratospheric cryogenic sampling were carried out for systematic observation of the minor constituents, such as CO_2, CH_4, CFCs, and isotope ratios of CO_2. Prototypes of X-ray polarimeter and gaseous gamma-ray detectors have been tested successfully. A cosmic electron and gamma-ray measurement was also conducted.

In 2008, a large campaign named SCOUT 2008 was organized in Teresina, in northeast Brazil. This was a collaboration programme between the Brazilian Space Agency and CNES to launch scientific balloons in the equatorial region of Brazilian territory. Seven launches of zero-pressure balloons were conducted from May to June, 2008, carrying experiments of several European institutions. Some of these experiments have INPE scientists as collaborators. The main scientific objectives of the experiments were monitoring the ozone layer, climate change studies and validation of the ESA satellites ENVISAT and METOP.

In November 2008 INPE organized the 4th campaign of the INPE/ISAS/University of Nagoya co-operation programme. The Far Infrared Interferometric Telescope (FITE) is to launch from Cachoeira Paulista. Two infrared mirrors separated by 8 m are part of the payload and the experiment will provide imaging with 2.5 arcsec resolution. The attitude control system has a 0.2 arcsec precision.

XI. POTENTIALLY ENVIRONMENTALLY DETRIMENTAL ACTIVITIES IN SPACE

In this report we only address space debris issues, which represent the current focus of the COSPAR Panel on Potentially Detrimental Activities in Space (PEDAS).

At the 37th COSPAR Scientific Assembly, held in Montreal, Canada, on 13-20 July, 2008, a total of 26 oral presentations in three sessions were made on a wide variety of space debris topics, ranging from measurements and orbit predictions, to space debris environment modeling, to mitigation aspects, and to hypervelocity impact research.

Most of the deterministic knowledge on objects orbiting the Earth is obtained from the US Space Surveillance Network (SSN), which can detect and track objects down to 5 cm in size in low-Earth orbit altitudes (LEO), and down to about 30 cm in size at geostationary orbit altitudes (GEO). On 1 January 2008, the SSN catalogue of tracked objects had a total count of nearly 12,500, an increase of 25% from the previous year. Nearly all of this increase is attributed to the debris generated by the 11 January 2007 anti-satellite (ASAT) test conducted by the People's Republic of China. More than 2,700 objects larger than 5 cm have been identified associated with this event, and the number of debris objects larger than 1 cm is estimated to be more than 150,000.

In response to the imminent reentry of an uncontrolled spacecraft containing materials hazardous to human life, the USA destroyed its own USA-193 satellite at an altitude of approximately 250 km on 21 February, 2008. The majority of the debris created by this engagement reentered the atmosphere within a few days. Within four months only two trackable debris objects from this event remained in orbit. Temporarily, however, for a few weeks, the risk of shield penetrations or severe damage on the ISS from USA-193 fragments increased notably.

In the time frame March to June 2008 the Russian Cosmos 2421 satellite experienced three fragmentations in an orbit of altitude near 400 km, which produced more than 500 trackable debris objects. The reason for the series of breakups is unknown, but 22 out of 50 satellites of this class have suffered breakups since 1975. The debris will be relatively short-lived. However, their passage through the ISS orbital regime significantly increased collision risk assessments and prevention efforts.

Collision avoidance manoeuvres were conducted twice in 2008 by satellites of the international Earth Observation System, operating at an altitude of 705 km. The Aura spacecraft manoeuvred on 26 June to avoid a piece of debris which had been in orbit for more than 30 years. The Cloudsat spacecraft manoeuvred on 20 July to ensure a miss by a piece of fragmentation debris which had also been in orbit for more than three decades. On 27 August 2008, the ISS performed a manoeuvre to avoid a close conjunction with a piece of debris of the Cosmos 2421 series of fragmentations. This was the 8th ISS avoidance maneuver, and the first one since May 2003. At the time of the ISS manoeuvre, 87 trackable Cosmos 2421 fragments were crossing the ISS altitude shell. This corresponds to 15% of all SSN catalogue objects that could pose a risk to the ISS.

In 2007 a total of 23 spacecraft and 2 orbital stages were launched and deployed into the GEO regime. Only 12 GEO spacecraft reached their end of life in 2007, and all were manoeuvred to higher disposal orbits, except for one that was clearly non-compliant with international GEO disposal guidelines. Nearly 75% of the more than 1,300 known objects in the vicinity of the GEO regime are orbital debris. Observations of the GEO region are routinely performed by the US and Russian space surveillance networks, with resolutions down to 30 cm. On an experimental basis such observations are also carried out by other entities at a national level, or through international co-operation, with resolutions down to 15 cm.

To preserve the long-term stability of the space debris environment, the removal (de-orbit) of mass from the LEO region is essential. Initially, this refers to operational payloads and rocket stages after their mission completion. Later, this should also include the removal of inert objects from orbit. Such a mitigation activity is denoted as "space debris environment remediation". A related study is in progress at the International Academy of Astronautics (IAA). An informal working group on the "long-term sustainability of space activities", formed in February 2008 on the initiative of UNCOPUOS, and led by Gérard Brachet (UNCOPUOS chair at the time) shares some of the objectives of the IAA study group.

Space debris is a global problem, which requires international co-operation and co-ordination for the elaboration and implementation of effective mitigation measures. The leading instance in this respect is the Inter-Agency Space Debris Coordination Committee (IADC). IADC has eleven members from all major space faring nations. They meet annually to facilitate technical information exchange. The 26th meeting of the IADC was held in April 2008 at Moscow, Russia, hosted by Roscosmos.

Since 1994 space debris has been an official agenda item in the Scientific and Technical Sub-Committee (STSC) of the United Nations Committee on the Peaceful Uses of Outer Space (UNCOPUOS). Several national delegations, ESA, and the IADC regularly report on their space debris activities at the STSC.

Principles on space debris mitigation are also important for the design, procurement and operation of spacecraft and launch systems. ISO (the International Organisation for Standardisation, TC20/SC14) is working on a set of standards governing the implementation for space debris mitigation measures. These will serve as guidelines for manufacturers and operators of space systems.

XII. RADIATION BELT ENVIRONMENT MODELLING

Radiation belt modelling is in continuous progress. This is mainly due to the increasing number of simultaneous multi-point in-situ measurements and also due to the combination of complementary measurements (particles, waves, magnetic and electric fields etc.).

Since it has been made clear that wave-particle interaction plays a major role in radiation belt electron dynamics ("killer electrons"), most efforts have concentrated in describing all waves present in the radiation belts and their detailed interactions with trapped electrons. Thus, recent studies have allowed us to understand global electron dynamics. Nevertheless it is still difficult to reproduce, in detail, *in-situ* observations because the magnetic field and waves can vary very quickly. Of course more investigations are required and will be conducted in the future to refine the global description of the entire system (magnetic field topology, wave distribution etc.).

Thanks to our increasing understanding of the global inner radiation belt system, and also because important outstanding questions have been well identified, it is possible to envisage new dedicated missions in the radiation belts. To enable progress in this field, several new missions are being planned in various countries. The Radiation Belts Storm Probe (part of the NASA "Living with a Star" programme) has been defined in term of optimum orbits and required measurements. Also because having simultaneous multiple measurements available is crucial, other countries have considered how to provide complimentary measurements. In Japan, Russia and in Canada, the ERG, RESONANCE and ORBITALS missions have been proposed, respectively. Progress and mission planning is such that most of them should fly at the same time, with a launch scheduled in 2011-2012. In most cases, instrument design is already completed and they achieve the prime science requirement. In parallel, science teams have been set up to work out how the large amount of data will be made available to the community and how data-sets will be stored. At this stage the COSPAR Panel on Radiation Belt Environment Modelling provides guidelines for standard particle data file format and particle measurement analysis.

XIII. SPACE WEATHER

Developments in the field of Space Weather that occurred in 2007-2008 are reported in this section. Space weather refers to the dynamic conditions in space that impact systems both in space and on the ground. Commercial satellites as well as scientific satellites encounter hazardous situations in orbit. Large geomagnetic storms cause problems in ground systems such as power grids and radio wave propagation. Ionospheric disturbances impact the accuracy of our global positioning systems. Solar X-rays and energetic particles disrupt radio propagation needed for commercial airline operations, and the particle radiation presents a hazard for astronauts.

Space weather includes many aspects from science through to applications including effects on infrastructure and the resulting need for operational services. The Sun is the main cause of space weather, and space weather effects occur throughout the entire region of space between the Sun and the upper atmosphere. Disturbances propagate through the many regions, and unique physical processes occurring within each region are important for the study of space weather. In order to report recent space weather activities to readers we first would like to concentrate on the main scientific aspects. This will be followed by recent developments in operational dissemination of space weather information and news relating to areas of international co-operation.

XII.1. Sun

One of the most distinguished recent achievements has been made by the Hinode (Solar-B) satellite, which was designed and manufactured by JAXA. At the end of 2007, results from Hinode were published in Science. Hinode discovered twist-like motions and small scale jets in Sunspot Penumbra. It also found continuous plasma outflows from the edge of active regions, which are likely a possible source of the solar wind, and strong

Alfvén waves in X-ray observations. Studies of chromospheric anemone jets are thought to reveal evidence of magnetic reconnection in the solar chromosphere.

Studies of CMEs (Coronal Mass Ejections) are being performed using the NASA STEREO satellites. The STEREO mission consists of two satellites, one ahead of the Earth and the other behind the Earth, in solar orbits, instrumented to study the 3D structure and evolution of CMEs and to obtain STEREO pictures of the Sun's atmosphere during solar activity. Joint studies between several solar observing satellites are being made to improve our understanding of solar eruptions and their consequences at the Earth. The STEREO real-time beacon has also proved very valuable allowing use of these data in the context of operational space weather monitoring.

XII.2. Heliosphere

Studies of interplanetary space and the solar wind using IPS (Inter Planetary Scintillation) techniques are being performed at the STE Laboratory at Nagoya University, using four large UHF antennas located in Japan. They show long term variation of the solar wind 3D structure, which is applicable to space climatology.

Another recent result has been provided using the GMD (Global Muon Detector Network). The study of the muon anisotropies has brought new insights on the interaction of cosmic rays with ICMEs (Interplanetary Coronal Mass Ejections). The geometry of ICMEs has been revealed in several cases where a large Forbush decrease was observed.

Significant progress is also being made in modelling solar processes and the propagation of CMEs from the Sun to the Earth. Results presented at the annual Solar, Heliospheric, and Interplanetary Environment (SHINE) workshop have indicated that whereas significant uncertainties still exist in defining many of the key input parameters to solar and interplanetary models, our computational capabilities are advancing and could soon lead to improved predictive capabilities.

XII.3. Magnetosphere

One of the highlights of magnetospheric space weather studies has been brought about by the NASA THEMIS mission. THEMIS was launched early 2007, employing five spacecraft with ideal instruments for a co-ordinated constellation. THEMIS serves as a science and a technology pathfinder for STP (Solar Terrestrial Physics) especially in the magnetosphere. THEMIS passed through its dawn phase in late 2007, where the apogee of the orbits was on the dawn side of the magnetosphere. In early 2008, THEMIS was in its magnetotail phase, where the apogees of the orbits were in the magnetotail and then proceeded to the dusk phase and dayside phase. THEMIS has allowed the study of tail reconnection, which triggers substorm onsets, and propagating features of substorms both in space and with complementary ground observations, many of which are located in Canada. THEMIS has detected plasma penetration into the ring current region during a magnetic storm. By determining the onset location of energy release in the magnetotail

and the subsequent propagation of substorm flows, these results eventually will contribute to a better space weather prediction capability.

Another important space weather topic in the magnetosphere is the radiation belt. The STE Laboratory group has examined outer belt electron flux enhancements associated with solar wind stream interaction. They found that the Bz component of the IMF (Interplanetary Magnetic Field) plays an important role in the enhancement of outer belt electrons. Utilising solar wind data they have started radiation belt forecasting on a daily basis.

XII.4. Ionosphere

The ionosphere is an important region for space weather since the disturbances in the ionosphere can interrupt radio wave propagation and degrade the accuracy of GPS. Some disturbances are initiated by high latitude effects such as high-latitude energy deposition and the electric field dynamo. The National Institute of Information and Communications Technology (NICT) has utilised observatories in the middle and low latitude regions. They studied conditions of intense ionospheric disturbances in the mid-latitude region and found that the midnight disturbance dynamo can cause expansion of ionospheric storms to lower latitudes.

Another effect of the ionosphere on radio waves is a propagation delay in the ionosphere. This delay depends on the TEC (Total Electron Content). The NICT group made an empirical TEC model over Japan, which will be helpful in determining the position with high accuracy. Similar modelling activities are occurring worldwide, many utilising data assimilation techniques to improve our specification and forecasting of ionospheric disturbances.

XII.5. Operational Data and Service Provision

NOAA space-based assets have continued to provide continuous publicly available space environment data. This is complimented by a space environment monitor onboard the EUMETSAT MetOp-A spacecraft, the data from which is also available via the NOAA Space Weather Prediction Centre (formerly Space Environment Centre). Space weather monitoring continues to make extensive use of data collected from networks of ground-based observatories (solar, geomagnetic, ionospheric) and scientific space-based instruments.

Service provision continues to be primarily supported through the International Space Environment Service (ISES). Members of ISES currently comprise 12 Regional Warning Centers (RWCs) and ESA, which acts as a collaborative expert centre and continues to support co-ordinated pilot service provision in Europe through SWENET (Space Weather European Network).

In 2008, The Hermanus Magnetic Observatory (HMO) in Hermanus, South Africa, became an RWC of ISES, responsible for Space Weather in Africa. HMO is a

national facility of the South African National Research Foundation (NRF), and has primarily focussed on magnetospheric and ionospheric measurements and modelling. Within the instrumentation network of Southern Africa HMO has access to 4 permanent magnetic observatories, 4 ionosondes and some 40 GPS receivers. To fulfil its mandate as the RWC for Africa, HMO plans to make data from these instruments available in real time as well as creating access to predictions, forecasts and other space weather information of relevance to the African region. See: http://spaceweather.hmo.ac.za.

XII.6. International Cooperation and Cross-disciplinary projects of interest

In June 2007, the chairman of the United Nations Committee on the Peaceful Uses of Outer Space (UNCOPUOS) presented a note in which he raised concern over the long-term sustainability of human space activities in Earth orbit. To properly address this issue, an informal working group was set up, with a mission to exchange views with the industrial and scientific communities and draft an outline resolution. This informal working group, as well as a resolution drafting committee, met on several occasions since then. Although not included at the very start, it was rapidly realised that Space Weather is one of the important items to be studied in this context. The International Space Environment Service (ISES) was therefore invited to make a presentation about these effects, and it was subsequently decided to include this field in the resolution to be drafted.

There is also a growing interest in space situational awareness in particular in Europe and the US as the importance of space objects and environment effects on key assets is increasingly being recognised. It can be noted that current European and US development in this area address space weather issues.

In addition, the World Meteorological Organization secretariat is investigating together with the International Space Environment Services the possibility to enhance international co-operation between activities related to terrestrial weather and the ones related to space weather. Activities such as these are crucial for ensuring that our space weather research and applications take full advantage of the complementary efforts that are occurring internationally.

It is important to participate in projects that are integrated around the world. The recently concluded SCOSTEP CAWSES (Climate and Weather in Sun-Earth System, 2004-2008) programme was a good example of significant international co-ordination of space weather data and model results. In October 2007 the International CAWSES symposium was held in Kyoto with the help of Grant-in-Aid for Creative Scientific Research from the Japanese government. From all over the World, results of space weather modelling and simulations were presented, showing improvements in our ability to model space weather from the Sun to the upper atmosphere of the Earth. For example, the Kyoto University group showed interesting results in their simulations of the acceleration of radiation belt electrons by low frequency plasma waves and the reconnection process which is applicable to solar flares.

The International Heliophysical Year (IHY) is a programme of international scientific collaboration, organised to coincide with the 50th anniversary of the 1957 International Geophysical Year. Through a range of activities including providing a framework for co-ordinated scientific programmes, this programme has contributed significantly to furthering our understanding of the heliosphere, crucial for producing reliable space weather services.

In Europe, the COST Action, Developing the Scientific Basis for Monitoring, Modeling and Predicting Space Weather, concluded in 2007. This action has been very successful in focusing scientific research in the area of space weather over its 4 year duration and has led to the formation of a strong European space weather research community. Following this action, a new European COST Action ES0803 titled 'Developing Space Weather Products and Services in Europe' will start in late 2008. This action will focus on further development of our understanding of underlying phenomena, together with model development with a view towards user requirements for products and services. The new COST action will continue the task of focusing scientific input to the European Space Weather Week workshops. These meetings are jointly organized with ESA, who focus on the applications elements and over the last few years have grown into a key focal point for European space weather activities.

The ILWS (International Living With a Star) programme continues to co-ordinate scientific programmes of various space agencies. The end users task group is active in ensuring that end users views are represented.

In Europe, several space weather related projects have recently been accepted for funding through the EU's 6th and 7th Framework Programme. These include:

SOTERIA (Solar –Terrestrial Investigation and Archives) which is expected to start in 2008 and will focus on scientific data availability with a view towards furthering scientific research into space weather phenomena and facilitating the development of new service-oriented products

NMDB: real-time database for high resolution neutron monitor measurements began in 2008 and the aims of making neutron monitor data available in high resolution from many stations in real-time

ULISSE will focus on the exploitation of scientific data, including space weather data, from previous and future space experiments onboard the International Space Station as well as data from other space platforms, increasing the involvement of the scientific community and the awareness of the general public

SWEETS (Space Weather and Europe – an Educational Tool with the Sun) took place during 2007 and included the organisation of a number of space weather public events, a mobile exhibition and educational DVD.

XIV. PLANETARY PROTECTION

Planetary protection is concerned with biological interchange in the conduct of solar system exploration, including: (1) possible effects of contamination of planets other

than the Earth, and of planetary satellites within the solar system by terrestrial organisms; and (2) contamination of the Earth by materials returned from outer space carrying potential extraterrestrial organisms. This area of space policy and its implementation accord with the provisions of Article IX of the United Nations Outer Space Treaty of 1967, which states that:

…parties to the Treaty shall pursue studies of outer space including the Moon and other celestial bodies, and conduct exploration of them so as to avoid their harmful contamination and also adverse changes in the environment of the Earth resulting from the introduction of extraterrestrial matter and, where necessary, shall adopt appropriate measures for this purpose…

The recent discoveries about the adaptations of Earth life to extreme environments, data suggesting the potential for liquid water to exist on and near the surface of Mars in recent times, and the continuing evidence supporting the existence of a liquid water ocean on Europa all suggest that the contamination of other solar system bodies is possible. Furthermore, the potential for life elsewhere in this Solar System demands prudence in the planning and execution of missions that will return to Earth materials from some bodies in the Solar System.

During the period from September 2006-2008, a variety of missions to other solar system bodies were launched in compliance with the planetary protection policy that is maintained by COSPAR (http://www.cosparhq.org/scistr/PPPolicy.htm) in support of the objectives of the UN Outer Space Treaty. In the COSPAR policy, the concern for contamination is given from Category I (no concern) through Category IV (greatest concern; landing spacecraft), with Category V reserved for Earth-return missions.

XIII.1. COSPAR Panel on Planetary Protection Activities

Solar System exploration has entered a new era of activity and multi-national co-operation. A number of the missions under consideration are targeted to bodies that have significant interest with respect to the origin of life and chemical evolution, and the potential for biological studies. This last year, the International Mars Exploration Working Group chartered a study team to develop an international sample return mission from Mars, and international cooperative missions are in operation to comets, asteroids, the giant planets and their moons.

COSPAR has an important role as the standard-setting international organisation in the area of planetary protection - a required reference for international missions to such bodies. The Panel on Planetary Protection was formed in 1999 to consolidate and further develop the COSPAR planetary protection policy. As initially envisioned in the early 1960s, the COSPAR policy has come to form the basis for international agreements on provisions to protect other Solar System bodies from Earth-source biological contamination, and to protect the Earth from potential extraterrestrial biological contamination. Accordingly, the Panel (with the assent of the COSPAR Bureau and

Council) has become the forum within which the de facto international standard for planetary protection is forged and promulgated.

In addition to providing specific guidelines that incorporate policy requirements for solar system bodies that merit protection, the COSPAR policy recommends that launching parties provide information to COSPAR about the procedures and computations used for planetary protection for each flight. The COSPAR policy forms the basis for planetary protection measure to be undertaken consequent to bilateral or multilateral agreements for joint Solar System exploration missions, and has been employed for agreements between space agencies including ESA, NASA, CNES, CSA, DLR, RSA, and JAXA.

Recent activities of COSPAR focus on two areas of planetary protection. One is on further policy development and the explicit maintenance and promulgation of the COSPAR policy. At the COSPAR Scientific Assembly held in Montreal on 13-19 July 2008, the Panel on Planetary Protection adopted several additions to the policy that were subsequently approved by the COSPAR Bureau. It was concluded that both Venus and the Earth's Moon merit Category II protection, being of interest for understanding the evolution of organic materials in the Solar System. In recognition of the renewed interest in human planetary exploration, language was added to the policy that provides general guidelines on planetary protection requirements for human missions beyond low-Earth orbit, based on conclusions from international workshops convened to prepare for the development of a formal policy and requirements. Finally, language was added to the policy that defines "Special Regions" on Mars, the result of multilateral efforts over the past several years to develop requirements for planetary bodies where emerging scientific evidence suggests that not only are there contamination concerns, but that the body may have different prospects for Earth-source contamination depending on the specific location that is being explored on the planet's surface.

A second activity involves the dissemination of knowledge about the COSPAR policy and its implementation. This has been undertaken under the broad charter of the Panel on Planetary Protection, which continues as an essential meeting ground for space agencies conducting Solar System exploration missions intent on understanding the potential for life, and life-related molecules within Earth's own neighbourhood. At the 2008 COSPAR Scientific Assembly, it was agreed that one or more workshops on the ethical implications of planetary protection should be sponsored (at least in part) by the COSPAR Panel on Planetary Protection.

XIII.2. Significant Mission Events (Category II and Above Missions)

NASA's Phoenix mission, a Category IVc lander, was launched on 6 August 2007, using a Delta-II launch vehicle, from Cape Canaveral Air Force Station in Florida. The Phoenix spacecraft landed on Mars on 25 May 2008, on the north polar plains of Mars. The Phoenix mission has confirmed that high concentrations of water ice are present cm below the surface of the northern plains of Mars, and data suggest the presence of perchlorates, energy-carrying compounds that could be used as food by Earth

organisms. The mission is accessing the Martian subsurface via vertical mobility, with a robot arm that was sterilised prior to launch and kept sterile until reaching Mars.

NASA's Dawn mission (Category III due to a Mars gravity assist) was launched on 27 September 2007, and is using an ion propulsion drive to reach the two main-belt asteroids Ceres and Vesta. Dawn is expected to reach Vesta in August of 2011, and is planned to depart Vesta in May of 2012 for an insertion into orbit around Ceres in February 2015. Dawn's goal is to characterize the conditions and processes of the solar system's earliest epoch by investigating in detail two of the largest protoplanets remaining intact since their formations.

NASA's Stardust spacecraft was re-targeted to perform the Category II mission of opportunity New Exploration of Tempel-1 (NExT), which will visit the comet P/Tempel 1 into which the Deep Impact mission released a projectile during a close encounter that occurred on 4 July 2005. The NExT investigation will provide the first look at the changes to a comet nucleus resulting from its close approach to the Sun, and will mark the first time a comet has ever been revisited. NExT also will extend the mapping of Tempel 1, making it the most mapped comet nucleus to date, and refining our view of what comets are, and where and how they formed.

NASA's Deep Impact spacecraft (Category II) has been re-targeted to encounter Comet Hartley 2, performing two mission-of-opportunity investigations under the combined mission name EPOXI. On the journey to Hartley 2, the Extrasolar Planet Observations and Characterisation (EPOCh) mission is using the larger of the two telescopes on the Deep Impact spacecraft to search for Earth-sized planets around five stars selected as likely candidates for such planets. The Deep Impact Extended Investigation (DIXI) will investigate Hartley 2 using all three of its instruments, with closest encounter planned for 11 October 2010.

The NASA MErcury Surface Space ENvironment, GEochemistry, and Ranging (MESSENGER) mission, set to become the first spacecraft to orbit the planet Mercury, continues enroute, having completed its two Venus flybys and the first of three Mercury flybys before it enters orbit around Mercury in March 2011. Data from the first Mercury flyby have provided new views of the planet, including confirmation of extensive volcanism in its history. MESSENGER is the second spacecraft sent to Mercury, with the third (BepiColombo) being prepared by ESA for launch early in the next decade (2013).

NASA's New Horizons mission to Pluto (Category II) performed a flyby of the Jupiter system on 28 February 2007 on its way to encounter Pluto in July 2015. The seven science instruments on the piano-sized New Horizons probe allowed it to explore Jupiter as no spacecraft had done before, returning data on lightning near Jupiter's poles, the life cycle of fresh ammonia clouds, boulder-size clumps speeding through the planet's faint rings, the structure inside volcanic eruptions on its moon Io, and the path of charged particles traversing the previously unexplored length of Jupiter's long magnetic tail. Upon reaching Pluto and Charon, New Horizons will return the first detailed data on the bodies' surface properties, geology, interior makeup and atmospheres. After the

Pluto/Charon flyby, New Horizons has the potential for an extended mission to investigate other Kuiper-Belt objects during the period 2016-2020.

NASA's Mars Global Surveyor mission (Category III) last communicated with Earth on 2 November 2006, and the mission has been ended after lasting more than four times longer than the planned prime mission. The spacecraft is expected to meet its 50-year orbital lifetime requirement in good order.

XIII.3. Other Missions in Operation

Other missions currently in operation and of primary interest for planetary protection are listed below. Additionally, in consideration of the recent reassignment by COSPAR of missions to Venus and the Earth's Moon (from Category I to Category II), information is provided on operating missions around those bodies, though the missions were originally designated Category I:

The NASA/ESA Cassini mission (Category II), continues in orbit around Saturn for an extended mission that will permit multiple close encounters with a number of Saturn's moons, including Titan and Enceladus. Warm regions at Enceladus' south pole have been found by Cassini to spout water ice that forms the Saturnian E ring, and detailed investigation of this phenomenon continues to be a high priority from the standpoint of both science and planetary protection.

The NASA Mars Reconnaissance Orbiter (MRO) continues its prime science mission. This initial science orbit is incompatible with orbital lifetime restrictions, so MRO has met total bioburden requirements, per the COSPAR policy. Data returned by MRO provided critical information to identify a safe landing site for the Mars Phoenix mission and will be used to similarly support other Mars lander missions. Data from MRO have dramatically increased our understanding of conditions on early Mars, which may even now be a more hospitable place for life than was previously suspected.

The JAXA-launched Hayabusa mission continues on its return to Earth after visiting the asteroid 1998/Itokawa (formerly 1998 SF36) in August 2005. Despite some anomalies with spacecraft operations, it is still possible that a sample of that asteroid will be returned to Earth in June of 2010. The return phase of this mission (Category V) has been assessed as "unrestricted Earth return" in the current COSPAR policy framework.

The NASA Mars Odyssey mission (planetary protection Category III) continues its mission science phase in orbit around Mars. Additional results from Odyssey continue to document widespread hydrogen beneath the surface at medium to high Martian latitudes, which was confirmed as water ice by the Phoenix lander. The spacecraft also continues to act as a communications relay for landers on the planet's surface. Over 80% of all Mars Exploration Rover data has been relayed through Mars Odyssey, as well as a significant fraction of Phoenix data.

The ESA Mars Express orbiter (Category III) continues is mission science activities in polar orbit around Mars, providing high resolution views of Mars through its stereo camera system and other instruments, and sounding the Martian subsurface with its long-wave radar.

The two NASA Mars Exploration Rover (MER) missions (planetary protection Category IVa) continue in operation on the Martian surface. Initial results from Opportunity demonstrated the past presence of standing liquid water on Mars, while Spirit, on the other side of Mars, has also detected liquid water in the distant past on Mars. The two spacecraft completed all science objectives within their nominal (90-sol) missions, and continue on extended missions now in their fifth Earth year.

The ESA Rosetta mission (Category II) continues on its 10.5 year cometary odyssey to 67P/Churyumov-Gerasimenko. The mission will include the first soft landing, *in situ* analysis, and panoramic images from a comet's surface, reaching the 4 km diameter comet in May 2014.

ESA's Venus Express mission, which launched on 9 November 2005, entered orbit around Venus on 11 April 2006. Venus Express's science objectives are to study the atmosphere, the plasma environment, and the surface of Venus in great detail. Data provide by Venus Express are contributing to an improved understanding of atmospheric evolution on Venus, Earth, and Mars.

JAXA's SELenological and ENgineering Explorer "KAGUYA"(SELENE) was launched by the H-IIA rocket on 14 September 2007, and entered lunar orbit on 4 October. The major objectives of the KAGUYA mission are to obtain scientific data on the Moon's origin and evolution.

CNSA's Chang-e 1 spacecraft was launched in October 2007, and entered its working orbit around the Moon on 7 November. Science goals for the mission include production of a three-dimensional survey of the Moon's surface. Chang-e 1 will also analyze the abundance and distribution of elements on the lunar surface and investigate characteristics of the lunar regolith.

XIII.4. Missions in Development/Planning

The RSA's Phobos-Grunt sample return mission is planned for launch in 2009 and includes a mini-satellite from CNSA, as well as experiments provided by ESA and The Planetary Society, a private organization based in the USA. The mission's objectives are to collect soil samples from Phobos, a satellite of Mars, and to bring the samples back to Earth for comprehensive scientific research into Phobos, Mars and Martian space. The Phobos-Grunt mission is expected to meet COSPAR's orbital lifetime requirements for missions to Mars, and the sample return portion is expected to meet requirements for Category V 'unrestricted Earth return'. Plans by RSA and The Planetary Society to send viable Earth organisms and tundra communities on the round-trip mission are of considerable concern from the standpoint of planetary protection.

Work continues at NASA's Jet Propulsion Laboratory for the Category IVc Mars Science Laboratory (MSL) scheduled for the 2009 launch opportunity to Mars. This multi-instrument-carrying rover is anticipated to soft-land on Mars in 2010, and is intended to drill into Martian rocks. The plan for MSL to carry a cache that could store interesting samples for a potential future return mission has resulted in additional planetary protection assays that are intended to permit identification of Earth organisms that might be found in returned samples after a round-trip journey.

NASA's next Discovery-class mission, the Gravity Recovery and Interior Laboratory (GRAIL), was selected in October 2006 and receives a Category II designation based on the recent alterations in COSPAR planetary protection policy. GRAIL is scheduled to launch in 2011, and will map the gravitational field of the Moon using paired orbiting spacecraft.

NASA's Lunar Atmosphere and Dust Environment Explorer (LADEE) mission is also expected to launch in 2011, and will orbit the Moon to characterise the atmosphere and lunar dust environment. As Category II missions, both GRAIL and LADEE will generate an inventory of organic materials (>1kg) carried by the spacecraft, as well as provide documentation of mission operations and the final disposition of the spacecraft.

NASA's Juno mission (Category II) will launch in 2011, fly by Earth for a gravity assist in 2013, and arrive at Jupiter in 2016. Juno will map the gravity field, magnetic field and atmospheric structure of Jupiter from a unique polar orbit. These observations will lead to a better understanding of the formation of our solar system and planetary systems discovered around other stars. To avoid contamination of Europa and other icy Jovian satellites, it is planned to deorbit the spacecraft into Jupiter at the end of the mission.

In September 2008, NASA selected the Mars Atmosphere and Volatile EvolutioN (MAVEN) mission as the next Mars Scout activity. The mission is scheduled for launch in late 2013, and will provide detailed information about the Martian atmosphere and climate history, as well as potential habitability.

ESA's Aurora programme for future Mars exploration is envisioned to include a series of missions to land on Mars and ascertain its suitability for future human exploration. ESA has completed payload selections for an instrument suite for their "ExoMars" mission, now planned for the 2013 launch opportunity. ExoMars could end up being either Category IVc, or Category IVb (mission planning life detection experiments that could be compromised by the presence of Earth organisms), but is expected to provide necessary ground truth for the presence of life-related organics on and below (up to 2m depth) the Martian surface.

A number of lunar missions currently being planned or developed would be designated Category II under the new COSPAR planetary protection policy, although

these missions retain the Category I designations that were provided previous to the 2008 COSPAR policy revision. These include:

The Chandrayaan I spacecraft which was launched in October 2008 by the Indian Space Research Organization (ISRO), carrying instruments provided by a number of international partners. The mission is intended to survey the lunar surface to produce a complete map of its chemical characteristics and 3D topography. The polar regions are of special interest, as they might contain water ice.

NASA's Lunar Reconaissance Orbiter (LRO) will launch on 27 February 2009, with the objectives of finding safe landing sites for future human missions, locating potential resources, and characterizing the radiation environment of the Earth's Moon. The Lunar CRater Observation and Sensing Satellite (LCROSS) is planned to launch on the same vehicle with LRO. LCROSS will guide the launching rocket's upper stage to impact into the lunar surface, and will make observations while flying through the debris plume to provide data about the composition of the Moon.

XV. CAPACITY BUILDING

The principal activities of the COSPAR Panel for Capacity-Building are to manage COSPAR's capacity-building programme and to organise sessions on this and related topics at COSPAR assemblies. The capacity-building programme is collaborative with IAU, UNOOSA and UNESCO.

XIV.1. COSPAR Capacity-Building Workshops

These workshops are primarily intended to enable young developing-country scientists to use the huge archives of space data from current and past missions which are readily available to all comers *via* the internet and which are an indispensable asset for world class research in most areas of space science. The workshops are strongly practical in nature and aim to provide direct experience of accessing the archives and of the analysis tools required to use them. Whilst those attending are selected on a regional basis, they are jointly funded by COSPAR, the host country, and a variety of other agencies. Generally speaking, an effort is made to relate them to a project or government initiative of the host country.

There have been four workshops in the period covered by this report, as detailed below:

Sinaia, Romania— Solar-Terrestrial Interactions (STIINTE), 4-16 June 2007
(Organisers: Joachim Vogt and Octav Marghitu)

This workshop was dedicated to the analysis of data from multi-satellite space missions such as Cluster. It was attended by 24 very motivated PhD students and post-docs coming from Central and Eastern Europe, including, Armenia, Bulgaria, Czech

Republic, Georgia, Hungary, Poland, Romania Russia and Ukraine. The scientific programme focussed on various aspects of multi-satellite missions, ranging from data analysis and instrument design to kinetic modelling, the analysis of boundaries, and the analysis of auroral processes.

After a first and already quite intensive week, the work culminated in the preparation of scientific projects by five teams. Each team had to address a specific problem in magnetospheric physics, leading to very intensive team-work and providing an excellent opportunity for the students to interact, put together their competences and apply what had been learnt. On the last day of the school, each team defended its project to a panel of senior scientists who were participating at the simultaneous STIMM-2 (Solar Terrestrial Interactions from Microscales to global Models) meeting.

The workshop took place in the framework of the Plan for European Co-operating State (PECS) agreement between Romania and ESA, which is designed to prepare for full Romanian membership of ESA.

Montevideo, Uruguay—Planetary Science, 23 July - 3 August 2007
(Organiser: Gonzalo Tancredi)

In recent years, the community of scientists working in planetary sciences in Latin America has been growing. Collectively, it was decided to pursue a new step in the academic development of this community by promoting the use of data from planetary space missions in its every day research. This workshop, the first in the series related to planets and small bodies of the Solar System and devoted to the use of planetary missions' data bases, was designed to meet this objective. It focussed on missions to comets, asteroids, satellites, rings and planets, like Mars. The participants worked for two weeks with real data from the missions and ideally started a research project with the data that they could continue after returning to their home institutes.

Alexandria, Egypt—X-ray astronomy using Chandra, XMM/Newton and Swift, 19 January - 1 February 2008
(Organisers: Alaa Ibrahim and Peter Willmore)

This workshop took place in the prestigious new library of Alexandria, the first activity of this nature to take place in the region. The workshop activities were attended by the science minister, Professor Hany Helal, the deputy minister Professor Maged El Sherbiney and the president of the Egyptian Academy of Science Professor Tarek Hussein who chaired the opening session and the closing ceremonies, reflecting a recent decision to strengthen astronomy in Egypt.

31 participants from Egypt, India, Morocco, Nigeria, South Africa, Turkey and Ukraine were admitted to the full programme while 5 more from local institutions were offered two-day participation. There was a public outreach day during which 100 high school students from Cairo and Alexandria attended a planetarium show and three public lectures. The programme consisted of morning lectures and afternoon practical computer

sessions. After the first few days the students started to work on research projects and they presented their results in a poster session at the end.

Kuala Lumpur, Malaysia—Space Optical and UV astronomy, 1 - 14 June 2008 (Organiser: Martin Barstow)

The workshop programme included lectures on a range of topics in UV and optical astronomy, on-line data products and data processing pipelines, data reduction and analysis and analysis software, data archives, search for targets and display quick-look data for inspection purposes. Participants carried out a major project and also produced a draft guest observer proposal.

A total of 30 "student participants" and 8 lecturers took part. The former included 9 from Malaysia, 9 from India, 4 from China, 3 from Indonesia 2 from Iran, 2 from Vietnam and 1 from Pakistan. One of the IAU's International Schools for Young Astronomers was held in Malaysia in 2007. The COSPAR workshop was intended to build on this as part of a general plan to strengthen Malaysian astronomy. A number of the Malaysian participants were in the early stages of research degree programmes, so their supervisors took part in the formulation of their project topics with the workshop lecturers and in discussion of possible follow-up activities after the workshop.

COSPAR's thanks are due to the organisers of these four workshops and their lecturing teams - about 35 COSPAR associates have taken part as lecturers over this period. The financial sponsors of this programme during this period were ANGKASA, CLAF, CONAE, ESA, IAU, ICTP, INPE, MOSTI, NASA, ROSA, UN/OOSA, URSI, National University of Malaysia, Universities of Cairo (Egypt), de la Republica (Uruguay), and Leicester (UK). The total number of developing country scientists who have participated in the programme is now around 270, and they are now appearing in increasing numbers at COSPAR assemblies to give papers. One further workshop has been approved, on Planetary Science, to be held in Harbin, China in September, 2009.

XIV.2. COSPAR Fellowship Programme

An extension of COSPAR's programme to include follow-up to the workshops so that they become firmly embedded in the receiving community has been under consideration for some time, and has resulted in an important new activity starting in 2008. There has been a continuing need for some way in which participants who have started research projects with supervisors as part of the workshop activities could visit their laboratories subsequently to continue the collaboration. To meet this need, a new COSPAR Fellowship programme was agreed by the Bureau in March, 2008 for a trial period of 2 years. Details can be found on the COSPAR website, but it provides for young scientists who have attended a workshop to pay visits lasting 2-4 weeks to their supervisors' laboratories. The funding for this will be a joint effort between the receiving laboratories, COSPAR and their home country. So far 11 laboratories in the USA, Europe and India have signed up to the programme. Two countries, India and Egypt, have also agreed to support travel costs and Turkey is also expected to do so. We hope to run at a

level of 5-10 fellowships each year. The first round of applications was received in September, 2008 and the selection of the first fellows is under way.

XIV.3. Montreal COSPAR Scientific Assembly

Two one-day sessions were held at the Montreal Scientific Assembly, namely:

PCB1 - Capacity-Building through the construction of National Small Satellites and Space Instruments.

Over a considerable period of time, many countries have constructed or have commissioned the construction of small satellites with the objective (among others) of enhancing their technological and scientific capabilities. During this session, representatives of various such countries were invited to describe their experiences, including both their objectives before the event, and an assessment of the extent to which they had been achieved by the project. Some contributed papers relating to the enhancement of national technological capacity through satellite construction were also presented.

PCB2 - Capacity-Building Strategies for Success.

Various international organisations which conduct capacity-building programmes described their programmes and their strategies.

XVI. EDUCATION ACTIVITIES RELATED TO SPACE SCIENCE

Space education activities in the world have been principally connected with K-12, public outreach and graduate education.

In the USA the major funding and effort for education for K-12 students comes from NASA and subsidiary agencies from Space Grant Consortia. NASA websites have published lessons for students and teachers on the Solar System, spectra and black holes. In other efforts by NASA, summer space camps have encouraged young scientists. Efforts funded by NASA and the National Science Foundation have led to public awareness programmes, notably the NOVA programs.

For nearly 20 years an international venture called the Challenger Center's network has created Learning Centers throughout the United States, Canada, and the United Kingdom with an emphasis on teacher training programmes.

Several space science programmes in Europe also aim at K-12 education. The first European Space Education Resource Office (ESERO) was opened at NEMO, the National Science and Technology Centre (NCWT) in Amsterdam in 2006. Here, as in the Challenger centres, a major aim is teacher training.

Japan's space agency JAXA established a Space Education Centre in 2005 which serves as a base for working with school teachers. The Space Education Centre is located within Sagamihara Campus of JAXA. A recent international conference on space technology and utilization ISTS (2008) has featured several exciting projects by Japan on space science outreach at various levels.

The Space Technology and Research Students program S*T*A*R*S was launched several years ago to enable US and Chinese students to collaborate on science studies and space research, via the Internet. This programme will provide a unique blend of space-originated news, information and, education content.

Efforts by a fast growing economy such as India have led to several activities. There are centres of space education awareness. A community science centre has been established in Ahmedabad and also an education satellite (EDUSAT) has been launched. The centre in Admedabad "caters to all branches of science but its activities have a very significant component of space education."

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The report submitted by the International Astronautical Federation (IAF) for Part One (Highlights in Space Technology and Applications for 2008) was prepared by Jerry Grey, President Emeritus of IAF (for Tetsuo Yasaka, Vice-President, Technical Activities of IAF and Madhavan Nair, Vice-President, Scientific Activities of the International Academy of Astronautics (IAA) and was approved by Berndt Feuerbacher, President of the IAF.

The report submitted by the International Institute of Space Law (IISL) for Part Two (International cooperation and space law) was prepared by Sylvia Ospina, Member of the IISL Board of Directors, with the assistance of Rafael Moro Aguilar. Information was compiled from submissions of IISL Members and other sources. The IISL contribution is intended to highlight important events, and does not pretend to be all-inclusive. The IISL regrets any inconsistencies and/or omissions it may contain.

Part Three of the report (Progress in Space Research 2007-2008) was prepared by the Committee on Space Research (COSPAR) in response to a request from the Scientific and Technical Subcommittee of the United Nations Committee on the Peaceful Uses of Outer Space, and provides an overview of the progress in the various disciplines of space research science during the years 2007 and 2008. The report is organized in a manner that reflects the scientific domains of COSPAR's Scientific Commissions and Panels. Although many people contributed to this report, the major part of the scientific input was provided by the following persons:

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COSPAR expresses its gratitude to all those who contributed to the report but particularly to the above named persons and to R.A. Harrison (UK) and C. Argent (UK) who edited the report.

ACRONYMS, ABBREVIATIONS AND DEFINITIONS

ACE	Advanced Composition Explorer
ABC net	Astrobiology Lecture Course Network
AGILE	Astro-rivelatore Gamma a Immagini Leggero
AIM	Aeronomy of Ice in the Mesosphere
ALTEA	Anomalous Long Term Effects in Astronauts
AMIE	Advanced Moon micro-Imaging Experiment
AMS	Alpha Magnetic Spectrometer
ANDE-RRA	Atmospheric Neutral Density Experiment Risk Reduction - Active
ANDE-RRP	Atmospheric Neutral Density Experiment Risk Reduction - Passive
ANGKASA	National Space Agency of Malaysia
ANITA	Antarctica Impulsive Transient Antenna
APXS	Alpha Particle X-Ray Spectrometer
Ar	Argon
ASI	Agenzia Italiana Spaziale
ASPERA	Analyser of Space Plasma and Energetic Atoms
ASTEP	Astrobiology Science and Technology for Exploring Planets
ASTID	Astrobiology Science and Technology Instrument Development
ATIC	Advanced Thin Ionization Calorimeter
AU	Astronomical Unit
BATSE	Burst and Transient Source Experiment
BESS	Balloon-borne Experiment with a Superconducting Spectrometer
BIOS-3	Closed ecosystem at the Institute of Biophysics in Krasnoyarsk, Siberia
BLAST	Balloon-borne Large Aperture Sub-millimeter Telescope
C/NOFS	Communication/Navigation Outage Forecasting Satellite
CAWSES	Climate and Weather in Sun-Earth System
CEEF	Closed Ecology Experiment Facility
CELSS	Closed Ecological Life Support Systems
CEOS	Committee on Earth Observation Satellites: http://www.ceos.org/
CHAMP	Challenging Minisatellite Payload (for Geophysical Research)
CLAF	Centro Latinoamericano de Fisica
CLRTAP	Convention on Long-Range Transport of Air Pollutants: http://www.unece.org/env/lrtap
CME	Coronal Mass Ejection
CNES	Centre National d'Ètudes Spatiales (French Space Agency)
CNSA	China National Space Administration
CONAE	Comisión Nacional de Actividades Espaciales (Argentina)
Coronas	Complex Orbital Near-Earth Observations of the Solar Activity
COROT	Convection, Rotation et Transits planétaires
COSMIC	Cosmic Observing System for Meterology, Ionosphere and Climate
COSPAR	Committee on Space Research: http://cosparhq.cnes.fr/
COST	Cooperation in the field of Scientific and Technical research – a European initiative to support cooperation among scientists and researchers across Europe and a network for coordination of nationally funded research activities
CREAM	Cosmic Ray Energetics And Mass
CRISM	Compact Reconnaissance Imaging Spectrometer for Mars
CSA	Canadian Space Agency
CSBF	Columbia Scientific Balloon Facility
CTIM	Coupled Thermosphere-Ionosphere Model
CTIP	Coupled Thermosphere-Ionosphere-Plasmasphere Model
CTX	Context Camera
D-CIXS	Demonstration of Compact X-ray Spectrometer
DIODE	Détermination Immédiate d'Orbite par DORIS Embarqué

DIXI	Deep Impact EXtended Investigation
DLR	Deutsches Zentrum für Luft- und Raumfahrt (German Space Agency)
DORIS	Doppler Orbitography and Radiopositioning Integrated by Satellite
EARP	European Accelerator-based space Radiation biology Program
EC	European Commission
ECOMA	Existence and Charge state Of Meteoric smoke particles in the middle Atmosphere (Sounding Rocket Experiment)
EDUSAT	Education Satellite
EIS	EUV Imaging Spectrometer
ELGRA	European Low Gravity Research Association
ENA	Energetic Neutral Atoms
ENVISAT	ENVIronment SATellite
EPOCh	Extrasolar Planet Observations and Characterization
EPOXI	Combined DIXI/EPOCh mission
ERG	Energization and Radiation in Geospace
ESA	European Space Agency
ESERO	European Space Education Resource Office
EUMETSAT	European Organization for the Exploitation of Meteorological Satellites
EUV	Extreme Ultraviolet
EVA	Extra Vehicular Activity
FAO	Federation of Astrobiology Organizations
FITE	Far Infrared Interferometric Telescope
G	Gravity
GALEX	Galaxy Evolution Explorer
GAW	Global Atmospheric Watch - see in particular the "WMO Global Atmosphere Watch (GAW) Strategic Plan: 2008–2015": http://www.wmo.int/pages/prog/arep/gaw/documents/gaw172-26sept07.pdf
GCOS	Global Climate Observing System: http://www.wmo.int/pages/prog/gcos/
GdR	Groupement de Recherche
GEO	Geostationary Orbit
GEO	Group on Earth Observations: http://earthobservations.org/
GEOSS	Global Earth Observation System of Systems: http://earthobservations.org/
GEOTAIL	ISTP magnetotail mission (ISAS/NASA)
GIOVE	Galileo In-Orbit Validation Element
GITM	The Global Ionosphere Thermosphere Model
GLAST	Gamma-ray Large Area Space Telescope
GLONASS	(Russian) Global Navigation Satellite System
GMD	Global Muon Detector Network
GMES	Global Monitoring for Environment and Security: http://www.gmes.info/
GNM	Global Numerical Model
GNSS	Global Navigation Satellite System
GOCE	Gravity field and Ocean Circulation Explorer
GOES	Geostationary Operational Environmental Satellites
GOOS	Global Ocean Observing System: http://www.ioc-goos.org/
GP-B	Gravity Probe B
GPS	Global Positioning System
GR	General Relativity
GRACE	GRAvity recovery and Climate Experiment
GRAIL	Gravity Recovery and Interior Laboratory
GRS	Gamma-Ray Spectrometer
HCN	Hydrogen Cyanide
HiRISE	High Resolution Imaging Science Experiment
HMO	Hermanus Magnetic Observatory
HRSC	High Resolution Stereo Camera
HST	Hubble Space Telescope
IAA	International Academy of Astronautics

IADC	Inter-Agency Space Debris Coordination Committee
IASI	Infrared Atmospheric Sounding Interferometer
IAU	International Astronomical Union
IBER	Investigations into Biological Effects of Radiation
IBEX	Interstellar Boundary Explorer
IBMP	Institute of Biomedical Problems
ICESAT	Ice, Cloud and land Elevation Satellite
ICME	Interplanetary Coronal Mass Ejections
ICRR	International Congress of Radiation Research
ICTP	International Centre for Theoretical Physics
IGOS-P	Integrated Global Observing Strategy Partnership: http://www.igospartners.org/
IHY	International Heliophysical Year
ILWS	International Living With a Star
IMF	Interplanetary Magnetic Field
INPE	Instituto Nacional de Pesquisas Espaciais (Brazil)
InSAR	Interferometric Synthetic Aperture Radar
Integral	International Gamma Ray Astrophysics Laboratory
IPCC	Intergovernmental Panel on Climate Change: http://www.ipcc.ch/
IPS	Inter Planetary Scintillation
IR	infrared
IRAS	Infrared Astronomy Satellite
ISAS	Institute of Space & Astronautical Science, Japan
ISES	International Space Environment Service
ISGP	International Society for Gravitational Physiology
ISO	International Organization for Standardization
ISRO	Indian Space Research Organization
ISS	International Space Station
ISSOL	The International Astrobiology Society
ISTP	International Solar Terrestrial Physics
ISTS	International Symposium on Space Technology and Science
IXO	International X-ray Observatory
JAXA	Japan Aerospace Exploration Agency
JSBSS	Japanese Society for Biological Sciences in Space
KATE/RSIS	Ka-band Telemetry and telecommand Experiment/Radio Science for SMART-1 experiment
KBO	Kuiper Belt Object
KIBO	Name, meaning “hope,” of the Japanese Experiment Module built for the ISS
Koronas	See Coronas
Kr	Krypton
LADEE	Lunar Atmosphere and Dust Environment Explorer
LCROSS	Lunar CRater Observation and Sensing Satellite
LCT	Laser Communication Terminal
LDB	Long Duration Balloon
LEO	Low-Earth Orbit
LEO	Low Earth Orbiting (satellite)
LET	Linear Energy Transfer
LIDAR	Light Detection and Ranging
LISA	Laser Interferometer Space Antenna
LOLA	Lunar Orbiter Laser Altimeter
LRA	Laser Retroreflector Array
LRO	Lunar Reconaissance Orbiter
LWS	Living With a Star
MARCI	Mars Color Imager
MARIE	Mars Radiation Environment experiment

MaRS	Mars Radio Science experiment
MARSIS	Mars Advanced Radar for Subsurface and Ionosphere Sounding
MASS	Dust MASS Analyzer (NASA Sounding Rocket Experiment)
MATROSHKA	Facility for radiation measurements under extra vehicular activity conditions
MAVEN	Mars Atmosphere and Volatile EvolutioN
MB	Mössbauer Spectrometer
MCS	Mars Climate Sounder
MDIS	Mercury Dual Imaging System
MEDES	Institut Médicine Physiologie Spatiale
MELISSA	Micro-Ecological Life Support System Alternative
MESSENGER	MEcury Surface Space ENvironment, GEochemistry, and Ranging mission (Applied Physics Laboratory; launched by NASA)
MetOp	Meteorological Operational satellite
MI	Microscopic Imager
MINERVA	MIcro/Nano Experimental Robot Vehicle for Asteroid
Mini-TES	Miniature Thermal Emission Spectrometer
MOSTI	Ministry of Science, Technology and Innovation of Malaysia
MRO	Mars Reconnaissance Orbiter
MSL	Mars Science Laboratory
NADIR	Neutral Atmosphere Dynamics Interdisciplinary Research
NAI	NASA Astrobiology Institute
NASA	National Aeronautics and Space Administration
NCWT	National Science and Technology Centre (Amsterdam)
NEMO	The science center at the NCWT
NExT	New Exploration of Tempel-1
NICT	National Institute of Information and Communications Technology
NMDB	Neutron Monitor Database
NOAA	National Oceanic and Atmospheric Administration
NOVA	NASA Opportunities for Visionary Academics
NRF	National Research Foundation (South Africa)
NRL	Naval Research Lab (USA)
NSBRI	National Space Biomedical Research Institute
NSF	National Science Foundation
NSRL	NASA Space Radiation Laboratory
NuSTAR	Nuclear Spectroscopic Telescope Array
OMEGA	Observatoire pour la Mineralogie, l'Eau, la Glace et l'Activité
ORBITALS	Outer Radiation Belt Injection, Transport, Acceleration and Loss Satellite
Pancam	Panoramic Camera
Pan-STARRS	Panoramic Survey Telescope and Rapid Response System
PDS	Planetary Data System
PFS	Planetary Fourier Spectrometer
PMCs	Polar Mesospheric Clouds
POD	Precise Orbit Determination
POLAR	Polar Orbiting Satellite (NASA)
PRBEM	(COSPAR) Panel on Radiation Belt Environmental Modelling
PSD	(COSPAR) Panel on Satellite Dynamics
PSLV	Polar Satellite Launch Vehicle
RAT	Rock Abrasion Tool
RF	Radio Frequency
RHESSI	Reuven Ramaty High Energy Solar Spectroscopic Imager
RKA	Russian Space Agency
ROSA	Romanian Space Agency
RSA	Russian Space Agency
RWC	Regional Warning Center
S*T*A*R*S	Science Technology and Research Students program
SARA	Sub KeV Atom Reflecting Analyser

SBC	Sanriku Balloon Centre
SBI	Solar Bolometric Imager
SCIAMACHY	SCanning Imaging Absorption spectroMeter for Atmospheric CHartographY
SCOSTEP	Scientific Committee On Solar-Terrestial Physics
SDO	Solar Dynamic Observatory
SDSC	Satish Dhawan Space Centre
SECCHI	Sun-Earth Connection Coronal and Heliospheric Investigation
SELENE (KAGUYA)	SELenological and ENgineering Explorer
SETI	Search for ExtraTerrestrial Intelligence
SHARAD	Shallow Radar
SHINE	Solar, Heliospheric, and Interplanetary Environment
SIR	SMART-1 Infrared Spectrometer
SIRTF	Space Infra-Red Telescope Facility
SJ-8	ShiJian-8, a Chinese seed-breeding satellite
SLR	Satellite Laser Ranging
SMART	Small Mission for Advanced Research in Technology
SOHO	Solar and Heliospheric Observatory
SOMA	Sociedad Mexicana de Astrobiología
SORCE	Solar Radiation and Climate Experiment
SOT	Solar Optical Telescope
SOTERIA	Solar-Terrestrial Investigation and Archives
SOX	Solar X-ray Spectrometer
SPEDE/EPDP	Spacecraft Potential Electron and Dust Experiment/Electric Propulsion Diagnostic Package
SPICAM	Spectroscopy for Investigation of Characteristics of the Atmosphere of Mars
SQUID	Superconducting Quantum Interference Device
SSN	Space Surveillance Network (USA)
SSOEL	Society for the Study of the Origin and Evolution of Life
STE	Solar-Terrestrial Environment (Laboratory, Nagoya, Japan)
STEREO	Solar Terrestrial Relations Observatory
STP	Solar Terrestrial Probes
STP	Solar Terrestrial Physics
STSC	Scientific and Technical Sub-Committee (of UNCOPUOS)
SUPIM	Sheffield University Plasmasphere Ionosphere Model
SVOM	Space-based multi-band astronomical Variable Objects Monitor
SWEETS	Space Weather and Europe - an Educational Tool with the Sun
SWENET	Space Weather European Network
TARF	Taiki Aerospace Research Field
TEC	Total Electron Content
TEGA	Thermal and Evolved Gas Analyzer
TGF	Terrestrial Gamma-ray Flash
THEMIS	Time History of Events and Macroscale Interactions during Substorms
THEMIS	Thermal Emission Imaging System
TIEGCM	Thermosphere-ionosphere-electrodynamic general circulation model
TOPEX	(Ocean) TOPography EXperiment
TRACE	Transition Region and Coronal Explorer
UHF	Ultra High Frequency
ULDB	Ultra Long Duration Balloon
ULISSE	An EC program focusing on the exploitation of scientific data including space weather data
UN	United Nations
UNOOSA	United Nations Office for Outer Space Affairs: http://www.unoosa.org/
UNCOPUOS	United Nations Committee on the Peaceful Uses of Outer Space
UNEP	United Nations Environment Programme: http://www.unep.org/
URSI	International Union for Radio Science

UTC	Coordinated Universal Time
UV	ultraviolet
VIRGO	Variability of solar IRradiance and Gravity Oscillations
VLBI	Very Long Baseline Interferometry
VLF	Very Low Frequency
VSOP	VLBI Space Observatory Programme
WACCM	"Whole Atmosphere Community Climate Model"
WGs	Wideband Global SATCOM
WIND	NASA spacecraft to study solar wind and terrestrial plasma
WMAP	Wilkinson Microwave Anisotropy Probe
WMO	World Meteorological Organisation: http://www.wmo.int/
WRMISS	Workshop on Radiation Monitoring for the International Space Station
Xe	Xenon
XMM	X-ray Mutli-Mirror Mission
XRT	X-ray Telescope
XTE	X-ray Timing Explorer

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The United Nations Office for Outer Space Affairs (OOSA) is responsible for promoting international cooperation in the peaceful uses of outer space and assisting developing countries in using space science and technology.

United Nations publication
Sales No. E.09.I.4
ISBN 978-92-1-101190-6
ST/SPACE/42

FOR UNITED NATIONS USE ONLY
Printed in Austria
V.08-59018—February 2009—825