Chapter 2
Developments in Space Policies, Programmes and Technologies Throughout the World and in Europe

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2.1 Space Policies and Programmes

All major space policy developments worldwide were presented in the previous section of Part I, in an attempt to clarify the principal space faring nations' strategies in 2010 and 2011. In the section bellow, there will be a brief discussion on developments in technology related areas, including access to space technologies and policies. The aim of this section is to clarify how the strategies already presented above interact with and influence specific space programmes and related research and development projects.

2.2 Space Transportation

2.2.1 Europe

European launcher development programmes are funded almost exclusively by ESA. These have been progressively decreasing since 2000, and there is considerable uncertainty about the way forward for European launcher technology.

The commercial operations of Arianespace led to significant losses in 2010 and a need for aid, said to be necessary to offset the adverse effect of currency movements.[1]

[1] De Selding, Peter B. "Arianespace Needs aid to avoid loss in 2010." 4 Jan. 2011. Space News 4 Jan. 2011 http://www.spacenews.com/civil/110104-arianespace-needs-aid.html

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2.2.2 United States

The new push of the U.S. government towards cooperation in space was made evident in the public discourse of NASA officials immediately after the new space policy's announcement. For example, Lori Garver, NASA's Deputy Administrator said, during the Berlin Air Show that NASA would see its budget reduced by 50 % in non-human spaceflight areas if the Obama's Administration had not cancelled the Moon-focused Constellation programme. On the contrary, she praised the new focus on international partnerships, which was very well received by its German audience and could be seen as intending to invite collaboration in space exploration in areas once reserved for U.S. technologies, including possible European contributions to a U.S. led space exploration programme. Garver affirmed that the policy to keep non-U.S. contributions off the critical path has not been fully put into practice and one example was the fact that the U.S. will rely on Russia to ferry U.S. astronauts to the ISS. As she said, any definition of "critical path" would certainly include crew-transport systems. The Deputy Administrator also qualified the ISS's life extension as a nod to the concerns of the NASA's space station partners. European and Japanese laboratories were among the last major station components to be launched to the orbital complex by the U.S. space shuttle and if the ISS life is not extended, they will have little time to operate facilities.[2]

At the same time, through its "Broad Area Announcement" (BAA) NASA issued a call for "affordable" heavy-lift launch vehicle concepts that could be used by multiple entities, such as the Department of Defence, commercial corporations and international space agencies. Proposals should be presented by 29 June 2010. The total funding for the project was around $8 million and no single contract was expected to exceed $625,000. The final selection was expected in 2015.[3]

In a separate development, on August 5, the U.S. Senate passed a NASA Authorization Bill that added a space shuttle flight to 2011 as well as $1.3 billion for the proposed commercial crew initiative over 3 years. This bill required NASA to start working on a heavy-lift rocket capable of supporting manned missions beyond low Earth orbit. Sen. Jay Rockefeller, Chairman of the Senate Commerce, Science and Transportation Committee considered this bipartisan bill to help in refocusing and reinvigorating NASA. The House Science and Technology committee approved a $3.3 billion investment in a commercial crew transportation system over the next 3 years. This House Bill would also permit the continuation of much of the work being done under NASA's constellation programme, an effort to build new rockets and spacecrafts optimized for lunar missions.[4]

On the other hand, however, efforts to increase space transportation commercialisation increased. For example, Armadillo Aerospace of Rockwell, Texas and Masten Space Systems of Mojave, Calif., were awarded a contract through

[2] "Garver: New NASA Direction Opens Door to Cooperation." Space News 14 June 2010: 13.

[3] "NASA Seeks Affordable Heavy-lift Rocket Ideas." Space News 5 July 2010: 8.

[4] "NASA Authorization Bill Passes Senate." Space News 9 Aug. 2010: 3.

NASA's commercial Reusable Suborbital Research Programme (CRuSR) (for a total of $475,000) to launch seven test flights.[5] NASA officials considered this contract as the beginning of an innovative teaming relationship with private industry, in order to provide affordable access to space. Armadillo is currently building three unmanned launches of its Super-Mod vehicle from Spaceport America in New Mexico. Masten Space System's Xaero vehicle made three unmanned test flights during the winter of 2010.[6] Super-Mod and Xaero vehicles would use the global navigation satellite systems to determine their position. They are also able to broadcast position data to ground stations. In order to advance their technology and business, Masten signed a deal with XCOR Aerospace to develop unmanned launchers that could be used for Moon, Mars and asteroids missions. On the other hand, Armadillo struck a deal with Vienna, Va.-based Space Adventures which booked space tourism flights to the ISS; planning to offer seats on suborbital rocket ships that Armadillo started developing. Each trip would cost $102.000.[7]

2.2.3 Russia

Improving its space transportation capabilities was a key plank of general Russian space policy in 2010 and 2011. Efforts to modernise relevant space and ground infrastructure continued, while use of the aging but reliable Soyuz rocket continued. The programme's budget has experienced a tenfold increase over the past decade, bringing it to $617 million in 2010, or over 20 % of the total space budget. Furthermore, the programme's total expenditures are believed to be even higher, as it also receives funding from the military. The core of the programme consists of the simultaneous development of the new Angara launcher and the construction of a spaceport certified for human space launch at Vostochny, in the Russian Far East.[8] Significantly, the $800 million long-planned launch facility in Vostochny started its construction already in 2011, ahead of schedule, and was expected to be completed by 2015. Vostochny will provide an alternative to Baikonur Cosmodrome, allowing Russia to launch from its own territory.[9] On the other hand, after a long development period the Angara launcher is expected to fly for the first time in 2013. The rocket will incorporate significant improvements compared to its predecessors that will bring it closer to European and U.S. standards, such as a modular design easily

[5] Space.com Staff. "NASA Funds Test Flights for Private Experimental Rockets." 31 Aug. 2010. Space.com 5 Aug. 2012 http://www.space.com/9042-nasa-funds-test-flights-private-experimental-rockets.html

[6] Werner, Debra. "Suborbital Spaceflight Gets a Boost from NASA, Congress." 18 Oct. 2010 Space News 5 Aug. 2012 http://spacenews.com/venture_space/101018-suborbital-spaceflight-boost-nasa-congress.html

[7] "NASA Grants Aim To Foster Manned Suborbital Flights." Space News 6 Sept. 2011: 8.

[8] Based on Euroconsult estimates.

[9] "Russia to Break Ground In 2011 for Spaceport." Space News 30 Aug. 2010: 3.

adaptable to different mission and payload profiles, as well as integration of the latter on the launch pad. These improvements are expected to allow Russia to extend its position in both government and commercial launch activities worldwide, by increasing its launching capabilities' performance and affordability.

2.2.4 Japan

Regarding Japan's launching capabilities, a significant development arose when JAXA announced that it would be now able to use its Tanegashima Space Centre all year around, lifting longstanding restrictions that limited its activities there. This was the result of an agreement between the agency and local fishing unions, which were concerned about the spaceport's impact on their local fishing grounds. JAXA policy called for a re-examination of those restrictions, blaming them for Japan's inability to be competitive in the global commercial launch market. However, a theoretical ceiling of 17 launches per year would be maintained, according to JAXA.[10]

From Tanegashima Space Centre, Japan launched the Quasi-Zenith satellite on 11 September 2010. The satellite, built by Mitsubishi Electric Corp., was designed to rebroadcast enhanced GPS navigation signals to hard-to-reach areas in Japan. It was launched aboard a Mitsubishi Heavy Industries- built H2A rocket.[11]

2.2.5 China

During the reporting period, Chinese space launch activities continued their medium-term growth. For example, on 15 June, a Chinese Long March 2D rocket launched the Shijian 12 scientific research satellite, from Jinquan Satellite Launch Centre in China's Gansu Province. This satellite was developed by the Shanghai Academy of Spaceflight technology.[12] In addition to this, on 22 September 2010, at 10:42 a.m., China launched the Yagon11 remote sensing satellite from Jinquan Satellite Launch Centre, the fifth launch in 7 weeks. The satellite was placed into orbit atop a Long March 2D rocket and is used to conduct scientific experiments and help with natural disaster response.[13]

Great Wall Industry Corp. recovered from its 2009 underperformance during the launch of Indonesia's Palapa-D telecommunications satellites. During 2011, China launched three satellites for non-Chinese customers: the W3C satellite for Eutelsat;

[10] "Deal Permits Year-round Launches from Japan." Space News 9 Aug. 2010: 9.

[11] "Japan's H2A Rocket Lofts Quasi-Zenith Sat." Space News 20 Sept. 2011: 8.

[12] "Long March 2D Rocket Lofts Chinese Research Satellite." Space News, 21 June 2010: 9.

[13] "China Launches 5th Satellite in 7 Weeks". Space News 27 Sept. 2011: 3.

Paksat 1R for Pakistan and Nigcomsat 1R for Nigeria. China Great Wall affirmed that the anomaly in the helium-propulsion on China's Sinosat 6 satellite could delay the launch of the Pakistani and Nigerian spacecraft. The Chinese launcher has proceed with upgrades that have increased the Long March 3B rocket's payload-carrying ability from 5,200 to 5,500 kg; they also reduced the amount of time needed for launching to 25 days, permitting the vehicle to launch 10 times per year. China Great Wall has enough business to conduct 20 launches per year in the next 5 years, counting only domestic launches.[14]

2.2.6 India

India's space launch programme is based around the development and exploitation of two rockets, the PSLV and the GSLV, capable of carrying payloads to Low and Geosynchronous Earth Orbits respectively. In 2010 and 2011 PSLV marked two successful launches. First, on 12 July 2010 it placed in orbit Cartosat 2B, an Indian Earth observation satellite of the IRS series, together with a cluster of experimental small satellites for scientific research purposes that included Algeria's ALSAT 2A, Canada's AISSAT 1 and Switzerland's TISAT 1. Second, on 20 April 2011 it launched RESOURCESAT 2, as well as two research satellites: YOUTHSAT 1, a joint project by Indian and Russian universities, and X-SAT, a technology demonstration small EO satellite from Singapore that was that country's first spacecraft.[15]

Contrary to the PSLV's successful and reliable record, ISRO has met with some technical difficulties in the development of the country's heavier launcher GSLV. In its present form, the rocket weights over 400 t and is capable of lifting up to 2.5 t of payloads into GTO, using two stages equipped with liquid fuel engines and a third stage with a solid fuel one. Its principal mission is to orbit India's new and heavier communication satellites of the GSAT series. Its inaugural flight took place in 2001, but progress with its development has been slow and uneven, a fact that is also demonstrated by its moderate success rate of three out of seven unsuccessful flights, with the last two consecutive. During the reporting period GSLV faced one such catastrophic failure on 25 December 2010, when it exploded 60 s into ascent, destroying the GSAT-5P spacecraft it was carrying. Despite the GSLV's mixed success rate, ISRO kept up the pace of development of its even heavier rocket GSLV Mk3, scheduled for flight for the first time in 2012. This new launcher would in fact be an almost entirely new rocket, and not a simple upgrade of the GSLV series, with which it would only share a certain number of components. With a lift-off weight of 630 t and a lift capacity of 5 t into GTO, the system would be the heaviest Indian rocket yet and would offer the country full autonomy in the launch

[14] "China Great Wall Shakes Off Satellite's Botched Launch". Space News 27 Sept. 2011: 8.

[15] PSLV. Indian Space Research Organization http://www.isro.org/Launchvehicles/PSLV/pslv.aspx

of its new generation INSAT communication spacecraft. Finally, it is noteworthy that GSLV Mk3 would field for the first time a second stage equipped with a re-startable liquid fuel engine that would greatly improve the system's operational flexibility and commercial attractiveness.[16]

2.2.7 Emerging Actors

On 10 June 2010, South Korea suffered a second space launch failure with the vehicle consisting of a modified Angara first stage manufactured by *Khrunichev*, and a South Korean solid-fuelled upper stage, launching from the Naro Space Center. After 136 s into the flight, the telemetry data downlink was terminated which demonstrates that an unexpected event occurred. A senior government official said that the vehicle was believed to have exploded. The cause of this incident was investigated by Korean and Russian experts. The Korea Space Launch Vehicle (KSLV)-1 featured a Korean-developed second stage and payload fairing.[17]

2.3 Space Science and Exploration

Space science goals include understanding the origin, evolution and future of the Universe, galaxies, our Solar System, stars, exoplanets, comets and asteroids. Exploration is understood to be human spaceflight, or robotic missions that prepare for it. These aspects of spaceflight often command the most prestige, visibility and funding. Therefore, they are dominated by publicly-funded projects carried out by the traditional governmental space agencies. However, the past year has also seen continued progress in commercial exploration, and emerging space powers have begun to demonstrate the technology needed to carry out such missions.

2.3.1 Human Spaceflight Activities

The focus of human spaceflight activities continued to be the International Space Station (ISS): with its use formally extended until at least 2020, it provides the opportunity for continued human presence in Low Earth Orbit (LEO) until that time. NASA continued to fly the Space Shuttle's last few missions, and authorised a

[16] GSLV MARK III. Indian Space Research Organisation http://www.isro.org/Launchvehicles/GSLVMARKIII/mark3.aspx; and Bergin, Chris. "FAILURE: Indian GSLV fails during launch with GSAT-5P satellite." 25 Dec. 2010. NASAspaceflight.com 25 Dec. 2010 http://www.nasaspaceflight.com/2010/12/indian-gslv-launch-with-gsat-5p-satellite/

[17] "South Korean Rocket Fails For the Second Time." Space News 14 June 2010: 3.

final mission, STS-135 launched on 8 July 2011. Roscosmos maintained its regular supply of cargo and crew to the ISS using Progress and Soyuz, with Europe's Automated Transfer Vehicle (ATV) and Japan's H-II Transfer Vehicle (HTV) complementing this.

ESA's six new astronauts, Samantha Cristoforetti, Alexander Gerst, Andreas Mogensen, Luca Parmitano, Timothy Peake and Thomas Pesquet, graduated from their basic training at the European Astronaut Centre (EAC) in Cologne, Germany on 22 November. Luca Parmitano was the first to be assigned to a flight, ISS Expeditions 36/37, scheduled for 2013.[18]

Two members of the ESA Astronaut Corps flew. Paolo Nespoli was launched on Soyuz TMA-120 on 15 December on the MagISStra mission. He carried out an intensive programme of experiments, ranging from radiation monitoring to measurements that could improve oil recovery in petroleum reservoirs.[19] Roberto Vittori was launched on STS-134 on 16 May on a flight opportunity provided by the Italian Space Agency (ASI), in agreement with NASA. His DArk MAtter (DAMA) mission had the primary objective of installing the Alpha Magnetic Spectrometer (AMS) on the ISS, a particle physics experiment designed to search for dark matter and antimatter by studying cosmic rays. During his 16-day mission Roberto worked as a mission specialist with the Space Shuttle and its robotic arm to complete six ASI-sponsored experiments, and conducted crew performance tests.[20]

The second Automated Transfer Vehicle (ATV-2), Johannes Kepler, was launched from Kourou on 16 February, and docked with the ISS 8 days later.[21] Whilst attached to the station, ATV-2 performed six releases of oxygen, six altitude control sequences, seven ISS reboosts, one debris avoidance manoeuvre, and delivered 850 kg of fuel and 1,600 kg of cargo to the orbital outpost.[22] After undocking on June 20, it was commanded to burn up in the atmosphere. The Advanced Re-entry Vehicle (ARV), a development of the ATV with the capability to return cargo to Earth and possibly eventually carry humans, underwent its Phase A preliminary requirements review during the summer.[23] However, the future of the vehicle remains unclear.

[18] "ESA – Human Spaceflight and Exploration – Astronauts – Graduation of Europe's new astronauts." 22 Nov. 2010. European Space Agency 25 Aug. 2011 http://www.esa.int/esaHS/SEMRFLIRPGG_ astronauts_0.html

[19] "ESA – MagISStra – About the MagISStra mission." 20 May 2011. European Space Agency 18 Aug. 2011 http://www.esa.int/esaMI/magisstra/SEM7E6QOHEG_0.html

[20] "ESA – DAMA mission– A DAMA for Roberto." European Space Agency 18 Aug. 2011 http://www.esa.int/SPECIALS/DAMA_mission/SEM4UE4SZLG_0.html

[21] "ESA – ATV – ATV-2: Johannes Kepler." 2 Mar. 2011. European Space Agency 18 Aug. 2011 http://www.esa.int/esaMI/ATV/SEM8HX6K56G_0.html

[22] Beskow, C. "ATV-2 is no more... | Edoardo Amaldi#more-3188#more-3188." 22 June 2011. European Space Agency 18 Aug. 2011 http://blogs.esa.int/atv/2011/06/22/atv-2-is-no-more%e2%80%a6/#more-3188

[23] "Annual Report 2010 of the International Space Exploration Coordination Group." International Space Exploration Coordination Group (ISECG) 25 Aug. 2011 http://www.globalspaceexploration.org/c/document_library/get_file?uuid=927d699a-2126-4205-b182-2fc8409eff88&groupId=10812

Within ESA, an Inter-Directorate Exploration Scenarios Working Group began defining a vision for space exploration, and awarded Exploration Scenario Studies contracts to various European companies. The end goal is a Strategic Plan for Human Spaceflight and Exploration by mid-2012.[19]

Besides ESA activities, national space agencies within Europe progressed in their exploration and space science efforts. Together with CNES, DLR developed a joint Report on Exploration, which was presented to the members of the ESA council meeting in Paris on 15 December 2010. Both agencies agreed that a European strategy considering both human and robotic missions should be proposed. In October 2010, the French government and CNES signed the "Contract between the State and CNES for the Period 2011–2015", which asked CNES to "make proposals to promote an international exploration programme of the Solar System in renewed governance." The French minister for Higher Education and Research proposed the creation of an international political forum on space exploration. The COmmittee for SPAce Research (COSPAR) meeting in Bremen from 18 to 25 July created a new panel which prepared a comprehensive report on robotic and human exploration of the Moon, Mars & near-Earth asteroids.[23]

NASA launched two space shuttles on ISS assembly flights. OV-103 Discovery was launched on the STS-133/ISS ULF 5 mission on 24 February 2011. The crew were Alvin Drew, Nicole Stott, Eric Boe, Steven Lindsey, Michael Barratt and Steve Bowen. The main payloads were the Permanent Multipurpose Module (PMM) and Express Logistics Carrier 4 (ELC4).[24] OV-105 Endeavour was launched on the STS-134/ISS ULF 6 mission on 16 May. The crew were Mark Kelly, Gregory Johnson, Michael Fincke, Greg Chamitoff, Andrew Feustel and Roberto Vittori. The payloads included the Alpha-Magnetic Spectrometer (AMS-02) and Express Logistics Carrier 3 (ELC3).[25]

In November, 10 years of permanent human presence on the ISS was celebrated. Over 600 science and technology experiments have been carried out in that time, leading to advances in medicine, environmental systems and scientific understanding of the Universe. The shift from assembly to utilisation also means that the ISS will be used as a testbed for research, technology and operations demonstrations related to exploration beyond LEO. As part of this, NASA has been directed, through the 2010 Authorisation Act, to select a research organisation to run a part of the U.S. segment as a national laboratory.[26]

JAXA launched its H-II Transfer Vehicle (HTV) Kounotori 2 on 22 January 2011, docking with the ISS on 27 January and undocking on March 28.[27] Russia

[24] "NASA – STS-133." NASA 25 Aug. 2011 http://www.nasa.gov/mission_pages/shuttle/shuttlemissions/sts133/main/index.html

[25] "NASA – STS-134." NASA 25 Aug. 2011 http://www.nasa.gov/mission_pages/shuttle/shuttlemissions/sts134/main/index.html

[26] ISECG. . .

[27] "H-II Transfer Vehicle "KOUNOTORI2" (HTV2)." 24 Aug. 2011 http://www.jaxa.jp/projects/rockets/htv/index_e.html

launched four Soyuz spacecraft: TMA-19 on 15 June with the Expedition 24/25 crew of Fyodor Yurchikhin, Shannon Walker and Douglas Wheelock, TMA-01M on 7 October with the Expedition 25/26 crew of Aleksandr Kaleri, Oleg Skripochka and Scott Kelly, TMA-20 on 15 December with the Expedition 26/27 crew of Dmitri Kondratyev, Catherine Coleman and Paolo Nespoli, and TMA-21 on 4 April with the Expedition 27/28 crew of Aleksandr Samokutyayev, Andrei Borisenko and Ronald Garan.[28] Russia also continued its regular resupply of the ISS with the launches of five Progress cargo transfer vehicles on 30 June 2010, 10 September 2010, 27 October 2010, 28 January 2011 and 27 April 2011,[29] While China did not launch any human missions this year, it continued to prepare for the launch of its first space station, Tiangong 1.

Looking to the future use of the ISS to prepare for human exploration beyond LEO, a "Call for Ideas: ISS for Exploration" was released on 15 October 2009 by ESA, attracting 181 proposals from 19 countries and ESA staff which covered a broad spectrum of areas of interest such as crew assistants, countermeasures for long-duration spaceflight, the monitoring of astronauts' health, robotics, maintenance, failure management and on-orbit repair, tele-operations as well as other topics. On 17 March 2011 ESA formally committed to extending Europe's participation in the ISS until 2020.

Analogue campaigns continued to be a feature of preparation for human exploration. The Mars500 520-day isolation study began on 3 June at the Institute of Biomedical Problems in Moscow. The crew was made up of two Europeans, one Chinese and three Russians. The six crewmembers, Romain Charles, Sukhrob Kamolov, Alexey Sitev, Alexandr Smoleevskiy, Diego Urbina and Yue Wang conducted simulated Martian surface operations beginning on 14 February 2011.[30]

ESA conducted field testing of the Eurobot Ground Prototype (EGP) and Long-Term Medical Survey system (LTMS) in association with the Austrian Space Forum (ÖWF) in Rio Tinto, Spain during April.[31]

NASA ran their Desert Research and Technology Studies (RATS) campaign from 31 August to 15 September in the Utah desert. Space Exploration Vehicles (SEVs), sample collection and communications tools, navigation systems, and the Habitat Demonstration Unit (HDU) were among the technologies tested.[32] The Haughton-Mars Project on Devon Island, Nunavut, Canada, concluded its 2010 field season on 10 August. The Mars Society continued its activities at the Mars

[28] "Starsem headlines." Starsem: The Soyuz Company 24 Aug. 2011 http://www.starsem.com/news/headlines.html

[29] "Spaceflight Now: Tracking Station: Launch Log." 1 Aug. 2011 http://spaceflightnow.com/tracking/launchlog.html

[30] "ESA – Mars500" European Space Agency European Space Agency 25 Aug. 2011 http://www.esa.int/esaMI/Mars500/

[31] "ESA Portal – Exploring Rio Tinto Eurobotically." 2 May 2011. European Space Agency 25 Aug. 2011 http://www.esa.int/esaCP/SEMT1DZGRMG_index_0.html

[32] "NASA – Desert Research and Technology Studies (RATS)" NASA 25 Aug. 2011 http://www.nasa.gov/exploration/analogs/desertrats/index.html.

Desert Research Station (MDRS) in Utah.[33] Technologies to support exploration, including Micro-Ecological Life Support System Alternative (MELiSSA) continued to progress, with study also continuing on Advanced Closed-Loop System (ACLS) and In-Situ Resource Utilisation (ISRU) technologies.

The Canadian Space Agency (CSA) continued to pursue its exploration efforts. Its robotic arm, Dextre, was fully certified on the ISS. The Exploration Core programme made significant progress due to the release of additional funds from the country's economic action plan. This programme funds the development of exploration technologies. The elaboration of a new Canadian Space Exploration Strategic Plan that will have a 25-year vision and a 10-year plan[34] has started.

2.3.2 Lunar Exploration

As the celestial body closest to Earth, science and exploration missions to the Moon remained active over the past year. Europe, along with India, China, and Japan progressed toward their first lunar landings. NASA continued its strong portfolio of lunar missions. Russia moved forward with plans to resume lunar exploration after a decades-long hiatus, mirroring the resumption of its robotic Mars exploration programme.

The ESA Lunar Lander programme took a significant step forward. The Phase B1 study contract was signed with EADS-Astrium in Berlin, Germany on 16 September. The contract will culminate in a Preliminary System Requirements Review in 2012, which will provide the basis for the final design of the mission and lander. The mission will land autonomously near the previously unexplored south pole of the Moon and is described as a precursor for future human exploration. The south pole is a region of interest due to the near-continuous illumination of the surface and potential access to water.[35]

The Lunar Reconnaissance Orbiter (NASA), launched in June 2009, was tasked with preparing for future lunar exploration, including finding landing sites, locating resources such as water ice and hydrogen, and investigating the long-term effects of the lunar environment. The mission brought an impressive list of achievements to a close, ending its exploration phase on 16 September. These included creating the most precise and complete topographic maps of the moon yet, finding the coldest spot ever discovered in the Solar System (−248 °C), and determining areas of the moon that are in near-continuous sunlight. Such areas could be valuable to power hardware in support of a robotic or human mission. New data was also announced

[33] "The Mars Society: Mars Desert Research Station." The Mars Society 24 Aug 2011 http://www.mdrs2011.com/

[34] ISECG. . .

[35] "ESA Portal – Next step for ESA's first Moon lander." 16 Sep. 2010. European Space Agency 19 Aug. 2011 http://www.esa.int/esaCP/SEMUV2KOXDG_index_0.html

from this mission, in collaboration with the Lunar CRater Observation and Sensing Satellite (LCROSS), which found that the soil in the shadowed parts of the Moon's craters is rich in water ice, and that the Moon is chemically active and has a water cycle.[36]

NASA re-tasked two spacecraft from the Time History of Events and Macroscale Interactions during Substorms (THEMIS) Earth-orbiting mission to take part in the Acceleration, Reconnection, Turbulence and Electrodynamics of Moon's Interaction with the Sun (ARTEMIS) mission. The spacecraft moved to two different Lagrange points, gravitationally semi-stable points near the Moon. The new mission focuses on the interactions between the solar wind and the Moon's surface.[37]

JAXA discussed the strategy for lunar exploration and issued a final report, "Lunar Exploration Strategy of Japan – World-Leading Robotic Lunar Exploration and Establishment of Technology Base towards Manned Space Activity" in July. This has the stated goal of assembling an exploration base at the South Pole of the moon. As a first step, Japan aims to demonstrate a soft landing by 2015.

China took major steps forward in its lunar exploration programme with the launch on 1 October of Chang'e 2, its second lunar orbiter. Flying in a lower orbit than its predecessor, it provided higher resolution images of the Moon's surface. The spacecraft completed its primary objectives within 6 months, including a low pass of 15 km altitude to image Sinus Iridum, or the Bay of Rainbows, the proposed landing site for future Chang'e missions.[38]

India announced the final payloads for its second lunar mission, Chandrayaan 2. It will consist of an orbiter and a rover, delivered by a Russian-supplied lander. Due to failures of the Geosynchronous Satellite Launch Vehicle (GSLV), however, the launch date has slipped to 2014.

Russia continued work on its Luna-Glob and Luna-Grunt series of missions, scheduled to begin in 2012. These missions include a lunar orbiter and surface penetrators, and will contribute to knowledge about the moon's formation.

The Google Lunar X PRIZE is a competition with a $30 million prize for the first privately-funded organisation to land a rover on the moon. To win, the rover must travel at least 500 m and send high-definition video and images back to the Earth. To provide additional impetus, the prize will reduce in value after a government-funded mission explores the lunar surface. Twenty-nine teams had registered by the deadline of 31 December. In press releases on 15 October and 20 December, NASA announced that it would purchase data and contract with some of the teams to

[36] "NASA – Lunar Reconnaissance Orbiter (LRO)." NASA 25 Aug. 2011 http://www.nasa.gov/mission_pages/LRO/main/index.html

[37] "NASA – ARTEMIS Mission Site." NASA 25 Aug. 2011 http://www.nasa.gov/mission_pages/artemis/

[38] "China announces success of Chang'e-2 lunar probe mission." 8 Nov. 2010. Xinhua News 25 Aug. 2011 http://news.xinhuanet.com/english2010/china/2010-11/08/c_13596211.htm

demonstrate technology in high technical risk areas associated with low-cost lunar missions.[39]

Upcoming missions of note include the Lunar Atmosphere and Dust Environment Explorer (LADEE), scheduled to launch in 2013, which will characterise the atmosphere and dust environment on the Moon,[40] and the Gravity Recovery And Interior Laboratory (GRAIL) mission was launched on 10 September 2011, with aims to determine the structure of the lunar interior.[41] Further in the future, an International Lunar Network (ILN) is proposed for 2018, that would involve operating all upcoming lunar landing missions as nodes in a geophysical network.[42]

2.3.3 Mars Exploration

The focus for Mars science remains the investigation of the planet's habitability, in particular the presence of water. A number of reports during the year suggested that Mars was once partially covered by large oceans, and that life would have been possible on many locations on its surface.

ESA's Mars Express mission, launched in June 2003, arrived at Mars in December of that year. It has the objectives of imaging the entire surface of the planet at high resolution, including maps of the mineral composition and atmosphere, and determining the structure of the sub-surface to a depth of a few kilometres, the effect of the atmosphere on the surface, and the interaction of the atmosphere with the solar wind. This year, the orbiter produced a unique video of an entire orbit, returned results that suggest that liquid water was once widespread over the surface of the whole planet, found evidence of debris from landslides, conducted a 100 km altitude flyby of the Martian moon Phobos, and returned high-resolution imagery of numerous craters, volcanoes and fractures on the surface of the planet.[43]

The joint NASA-ESA ExoMars mission, envisaged as an orbiter to be launched in 2016 with a rover following 2 years later, completed its payload selection on 2 August.[44] The orbiter features a 1000-fold increase in sensitivity over previous Mars orbiters, and will study the chemical composition of the planet. The System

[39] "Google Lunar X PRIZE." Google Lunar X Prize 25 Aug. 2011 http://www.googlelunarxprize.org/

[40] "Missions – LADEE – NASA Science." NASA 25 Aug. 2011 http://science.nasa.gov/missions/ladee/

[41] "Missions – GRAIL – NASA Science." NASA 25 Aug. 2011 http://science.nasa.gov/missions/grail/

[42] "Missions – ILN – NASA Science" NASA 25 Aug. 2011 http://science.nasa.gov/missions/iln/

[43] "ESA – Mars Express." European Space Agency. 25 Aug. 2011 http://www.esa.int/esaMI/Mars_Express/index.html

[44] "NASA – NASA and ESA's First Joint Mission To Mars Selects Instruments." 2 Aug. 2010. NASA 11 Aug. 2011 html://www.nasa.gov/home/hqnews/2010/aug/HQ_10-181_Joint_Mars_Mission.html

Preliminary Design Review for the orbiter and the rover was completed in December.[45] However, on 29 March, NASA advised ESA that it could not fund its rover, leading ESA to issue stop-work orders for all ExoMars contracts. Contract payments were expected to resume in July.[46]

The Mars Odyssey mission, launched in April 2001, continued. During its unprecedented length, it has returned the first global Martian maps of the amount and distribution of several chemical elements and minerals, provided evidence leading to the discovery of subsurface water ice, and recorded the radiation environment. The spacecraft also acts as a communications relay for the two Mars Exploration Rovers. During the last year, the orbiter expanded educational outreach programmes, with U.S. middle school students finding a lava tube using imagery from the orbiter.[47] The Mars Exploration Rover (MER) Opportunity continued to drive towards the Endeavour crater, stopping to examine various interesting scientific targets on the way. However, NASA stopped attempts to communicate with its twin rover, Spirit. The last communication was received from Spirit on 22 March 2010.[48]

The Mars Reconnaissance Orbiter (MRO) was launched in 2005 with the goals of determining whether or not life has existed on Mars, characterising the climate and geology, and preparing for future human exploration. During a very productive year, it returned detailed images of numerous different features; explained how wind changes the configuration of gullies at the polar ice caps; developed high-resolution 3D maps of the surface in collaboration with Microsoft; conducted a study of the atmosphere to prepare for the arrival of the Mars Science Laboratory (MSL) in August 2012; found hydrated silica deposits that provide the best evidence yet of prior hydrothermal environments such as a hot springs; provided mineral maps of areas near to the Mars Exploration Rover Opportunity, helping it to decide where to explore on the surface; observed changing sand dunes; provided new insights into buried carbonates, which may help to explain why Mars' atmosphere is much thinner that it used to be; and discovered that the total amount of atmosphere changes significantly as the tilt of Mars' axis changes.[49]

Development of the NASA Mars Science Laboratory (MSL) and its Curiosity rover continued, with a 26 November 2011 launch date. The rover will be the biggest ever landed on Mars, and will study Mars' habitability. Hardware assembly and testing continued, which was monitored by a public webcam watched by over

[45] ISECG...

[46] "ESA Expects by July To Restart Work on 2016 Mars Mission." Space News 30 May 2011: 6.

[47] "Mars Odyssey." NASA Jet Propulsion Laboratory, California Institute of Technology 25 Aug. 2011 http://mars.jpl.nasa.gov/odyssey/

[48] "Mars Exploration Rover Mission: Home." NASA Jet Propulsion Laboratory, California Institute of Technology 25 Aug. 2011 http://marsrover.nasa.gov/home/index.html

[49] "Mars Reconnaissance Orbiter." NASA Jet Propulsion Laboratory, California Institute of Technology 25 Aug. 2011 http://marsprogram.jpl.nasa.gov/mro/.

one million individuals.[50] Looking ahead to other future Mars missions, NASA awarded the launch services contract for the 2013 Mars Atmosphere and Volatile Evolution Mission (MAVEN) that aims to explore the planet's upper atmosphere, ionosphere and interactions with the Sun and solar wind.[51]

The Phobos-Grunt joint Russian-Chinese sample return mission to the Martian moon Phobos continued to progress towards a 8 November 2011 launch window. Its objective is to land on Phobos, collect 200 g of the Martian moon, and return them to Earth in 2014. The mission will also carry a Chinese sub-probe called Yinghuo-1, which will travel to Mars on the Russian spacecraft before separating and entering Mars orbit.[52]

2.3.4 Saturn Exploration

The Cassini-Huygens mission, a joint mission of NASA, ESA and ASI, was launched in 1997. After reaching Saturn in 2004, Cassini dropped the Huygens probe onto the Saturn moon Titan, where it made the first landing in the outer Solar System. The nominal Cassini mission ended in June 2008, however, the spacecraft continued to operate well on its extended Solstice mission and provided new insights, particularly into the plumes being emitted from the moon Enceladus. The scientific highlight of the year, reported on 22 June, was a flythrough of the plumes executed by Cassini. The scientific results provided strong evidence for the existence of large-scale saltwater reservoirs beneath the moon's icy crust.[53]

Other recent findings about Enceladus included the observation of distinctive coloured bands and patches on the inner, mid-size moons thought to be partially caused by material emitted from Enceladus; fissures, nicknamed 'tiger stripes', with warm edges and a heat output an order of magnitude higher than expected; and an electrical connection via magnetic field lines between Saturn and the moon, allowing electrons from the moon to create an auroral 'footprint' on the planet.[49] Cassini also provided new insights into Titan, including the detection of hydrogen molecules flowing down through the atmosphere and disappearing at the surface; a lack of acetylene, which could be the best candidate energy source for hypothetical methane-based life; the possible existence of cryovolcanism; and the observation of the seasonal methane precipitation.[49]

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[50] "Mars Science Laboratory." NASA Jet Propulsion Laboratory, California Institute of Technology 25 Aug. 2011 http://marsprogram.jpl.nasa.gov/msl/

[51] "MAVEN." University of Colorado at Boulder, Laboratory for Atmospheric and Space Physics 25 Aug. 2011 http://lasp.colorado.edu/home/maven/

[52] Friedman, Louis D. "Timeline for the Phobos Sample Return Mission (Phobos Grunt) – The Planetary Society Blog | The Planetary Society." 27 Oct. 2010. The Planetary Society 25 Aug. 2011 http://www.planetary.org/blog/article/00002738/

[53] "Cassini Solstice Mission." NASA Jet Propulsion Laboratory, California Institute of Technology 25 Aug. 2011 http://saturn.jpl.nasa.gov/index.cfm

2.3.5 *Venus Exploration*

Venus Express, an ESA mission, was launched in 1995. It reached Venus in 2006 with the objective of studying the atmosphere and clouds with unprecedented detail and accuracy. Amongst its discoveries, it detected the escape of ionic hydrogen and oxygen in the ratio of two to one. From this, it was inferred that solar ultraviolet radiation streams into the atmosphere and breaks up the water molecules into atoms. The results of several low polar passes, with the aim of measuring the density of the upper polar atmosphere, have shown that the atmosphere high above the poles is 60 % thinner than predicted. This could indicate that unanticipated natural processes are at work in the atmosphere, and may present a difficulty in using atmospheric drag to circularise Venus Express' elliptical orbit. This would be necessary to prevent fuel exhaustion due to manoeuvres needed to compensate for orbital perturbations caused by the Sun's gravity.[54]

The mystery of high-altitude sulphuric acid clouds was solved, with findings that may have implications for artificial mitigation of global warming on Earth. Venusian sulphuric acid clouds form at altitudes of 50–70 km, when sulphur dioxide from volcanoes combines with water vapour to make sulphuric acid droplets. Above 70 km, sulphur dioxide should be destroyed rapidly by intense solar radiation. However, another layer of sulphur dioxide was detected between altitudes of 90 and 110 km in 2008; the explanation being that some sulphuric acid droplets evaporate at high altitude, creating gaseous sulphuric acid that can then be broken apart by sunlight to release sulphur dioxide gas.

Based upon the global cooling of Earth caused by the ejection of sulphur dioxide into the Earth's atmosphere after the 1991 eruption of Mt. Pinatubo in the Philippines, it had been suggested that the artificial injection of sulphur dioxide, which would form sulphuric acid droplets, into the atmosphere may help to mitigate the effects of global warming by reflecting sunlight. However, this new evidence from Venus Express suggests that these droplets may be rapidly changed back into gaseous sulphur dioxide, which is transparent to sunlight, reducing their effectiveness in cooling the Earth.[50]

The JAXA Venus Climate Orbiter AKATSUKI (PLANET-C) was launched on 21 May 2010. On 7 December, it failed to inject into its planned 300 by 80,000 km elliptical orbit. JAXA maintained communication with the orbiter, and currently plans to reattempt orbit insertion during the next available opportunity, 6 years after the initial attempt. Results of the investigation into the failure have determined that it was most likely caused by damage to the thruster nozzle of the orbital manoeuvring engine. The mission was intended to make comprehensive observations of the planet's atmosphere and surface, in particular the particles escaping from the atmosphere, using five cameras operating at different wavelengths. In addition, the mission would have taken close-up photographs to

[54] "ESA – Venus Express." European Space Agency 25 Aug. 2011 http://www.esa.int/esaMI/Venus_Express/

observe the 'super-rotating' winds that blow on the surface, which can reach speeds of up to 100 m per second, faster than the planet itself rotates. It had also aimed to confirm the presence of active volcanoes and thunder.[55]

Included in the Russian Federal Space Programme is the Venera-D mission, its first Venus exploration mission in three decades, scheduled for a launch date in 2017. The mission has been simplified from a complex mixture of orbiter, two balloons at different altitudes, several microprobes delivered from the balloons, and a lander, to just a lander, orbiter and subsatellite. The lander will study the formation and evolution of Venus, in particular the elemental and mineralogical composition of the surface, geology, iron-containing phases and the distribution of iron oxidation states. During its descent, the lander will make meteorological measurements, record the isotopic composition of the atmosphere, measure the structure, chemistry and microphysics of clouds, and monitor electromagnetic radiation. The orbiter will be in a daily polar orbit and will study the atmosphere from the surface to an altitude of 160 km, using spectrometers from the ultraviolet to millimetre ranges. The subsatellite will allow the simultaneous measurements of plasma and magnetic fields. Europe and China have been invited to participate in the project.[56] The next Russian mission to Venus after Venera-D is called Venus Globe. It is targeted for a launch date of 2021. The major difference will be a long-lived lander.[52]

2.3.6 Mercury Exploration

BepiColombo will be Europe's first mission to Mercury, and it is a joint ESA-JAXA mission. Targeted for a launch in 2014 with arrival at Mercury in 2020 for a 1-year mission, it is currently in the implementation phase. The mission is made up of two spacecraft: the Mercury Planetary Orbiter (MPO), a three-axis stabilized spacecraft provided by ESA that will study the planet's geology, composition, inner structure, and exosphere, and the Mercury Magnetospheric Orbiter (MMO), a spin-stabilised spacecraft provided by JAXA that will study the planet's magnetic field, atmosphere, magnetosphere and inner interplanetary space. The MMO underwent testing in the European Space Technology and Research Centre (ESTEC)'s Large Space Simulator (LSS) in January.[57, 58]

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[55] "Venus Climate Orbiter mission of Japan." JAXA 25 Aug. 2011 http://www.stp.isas.jaxa.jp/venus/top_english.html

[56] "VENERA-D: ВЕНЕРА: Изучение продолжается." 3 Oct. 2011. Roscosmos 25 Aug. 2011 http://venera-d.cosmos.ru/index.php?id=692&tx_ttnews[tt_news]=1288&cHash=f9bfd2c6e7616171412b316d206d73a4

[57] "ESA Science & Technology: BepiColombo." European Space Agency 25 Aug. 2011 http://sci.esa.int/science-e/www/area/index.cfm?fareaid=30

[58] "ESA Science & Technology: ESA's Mercury mapper feels the heat." 18 Jan. 2011. European Space Agency 25 Aug. 2011 http://sci.esa.int/science-e/www/object/index.cfm?fobjectid=48254

MErcury Surface, Space ENvironment, GEochemistry and Ranging (MESSENGER), one of NASA's Discovery-class missions, was launched in August 2004. On 18 March, it became the first spacecraft to orbit the planet, following three flybys. Orbital data collection is scheduled to continue until March 2012. The mission is designed to address six broad scientific questions: why Mercury is so dense, the planet's geologic history, the nature of its magnetic field, the structure of its core, the nature of the unusual materials at the poles, and what volatiles are important at Mercury. MESSENGER is designed and built by the Johns Hopkins University Applied Physics Laboratory (APL).[59]

2.3.7 *Jupiter Exploration*

The Europa Jupiter System Mission (EJSM), a proposed joint NASA-ESA mission also known as Laplace, was placed under review due to the combined effect of not being ranked as a top priority in the U.S. National Research Council (NRC)'s decadal survey of astronomy and planetary science, and the overall U.S. budget outlook. It is now unlikely that EJSM/Laplace will be implemented as a NASA-ESA mission as originally planned.

Juno, a NASA New Frontiers mission to Jupiter, launched on 5 August 2011. The mission's objectives are to determine how much water is in Jupiter's atmosphere, measure the atmospheric composition, temperature, cloud motion and other properties, map the magnetic and gravitational fields, and explore the magnetosphere near the poles, especially the planet's aurorae.[60]

2.3.8 *Solar Observation*

Observations of the Sun continued to focus on improving understanding of the star's interior, corona and solar wind, as well as predicting 'space weather'. This included the monitoring of large Coronal Mass Ejections (CMEs), events in which the Sun emits larger than usual amounts of high-energy charged particles that travel towards Earth. Such CMEs often have negative effects on telecommunications and electrical infrastructure.

ESA's PRoject for OnBoard Autonomy (PROBA)-2 mission, part of the Agency's small, low-cost In-orbit Technology Demonstration Programme launched in November 2009, continued its solar observation. Proba-2 tracked CMEs,

[59] "MESSENGER: Mercury Surface, Space Environment, Geochemistry, and Ranging: Mercury Orbit Insertion." Press kit. NASA http://www.nasa.gov/pdf/525164main_Mercury MOI_PK.pdf

[60] "NASA – Juno." NASA 25 Aug. 2011 http://www.nasa.gov/mission_pages/juno/main/index.html

observed a partial solar eclipse, and an alignment of the Sun, Earth and Moon. As of 9 November, it had returned more than 180,000 images of the Sun in addition to solar and space weather information and demonstrated a range of technologies. Calibrated data was made available from several instruments, including a small solar ultraviolet radiometer that observes solar irradiance at least 20 times per second. Such rapid sampling enables the detailed analysis of how energy is released during solar events.[61]

Fifteenth of June saw the launch of the CNES solar metrology mission Picard. Its objectives are to improve our knowledge of how the Sun functions and the influence of solar activity on the Earth's climate. Picard will accomplish this by measuring absolute total and spectral solar irradiance, solar diameter and shape, and by probing the interior of the Sun using the helioseismology method. It is anticipated that the lifetime of the satellite will be between 2 and 3 years. The first image of the Sun was captured on 22 July, with subsequent images taken once per minute. In-flight commissioning ended on 8 October, and the system was declared ready for use. On 4 January, Picard observed a partial eclipse of the Sun by the Moon.[62]

The Solar Dynamics Observatory (SDO) is a NASA mission that is part of the Living With a Star (LWS) programme. It has the objectives of determining how the Sun's magnetic field is generated and structured, and how this stored magnetic energy is released in the form of the solar wind, energetic particles and variations in the solar irradiance. Launched in February 2010, the spacecraft comprises three scientific experiments: the Atmospheric Imaging Assembly (AIA), EUV Variability Experiment (EVE) and the Helioseismic and Magnetic Imager (HMI).[63]

The SOlar and Heliospheric Observatory (SOHO) continued to operate during the year. It was launched in December 1995, and has the scientific objectives of investigating the solar interior, explaining the high heating of the solar corona, and the mechanism by which the solar wind is produced and accelerated. Some of its key results include discovering new dynamic solar phenomena such as coronal waves and solar tornadoes, vastly improving our ability to forecast space weather, by giving up to 3 days' notice of adverse space weather, and monitoring the total solar irradiance, which is important in understanding the impact of solar variability on the Earth's climate. Having had the mission extended five times, SOHO has exceeded its expected lifetime of 2 years and is currently approved until the end of 2012.[64]

Along with SOHO, the Solar TErrestrial RElations Observatory (STEREO) spacecraft of NASA continued to operate. STEREO is made up of two spacecraft.

[61] "Proba-2's Lyra Solar Intensity Measurements Available." 11 Mar. 2011. ESA 11 Mar. 2011 http://www.esa.int/esaMI/Proba/SEMN91YTVKG_0.html

[62] "PICARD." CNES 25 Aug. 2011 http://smsc.cnes.fr/PICARD/

[63] "SDO | Solar Dynamics Observatory." NASA Goddard Space Flight Center 25 Aug. 2011 http://sdo.gsfc.nasa.gov/

[64] "Solar and Heliospheric Observatory Homepage." NASA 25 Aug. 2011 http://sohowww.nascom.nasa.gov/

They have provided new insights into CMEs, including detecting a CME heading for Earth on 2 August, and completing the processing of data that is intended to enable the tracking of CMEs all the way from the Sun to the Earth. STEREO also contributed to crowd-sourced data analysis, using data analysed by the public to make a prediction of a solar storm that reached Earth on 13 December, captured the first-ever images of the entire surface of the Sun, and has been used to discover more than 122 new eclipsing binary stars and hundreds more variable stars.[65] The Deep Space Climate ObserVatoRy (DISCOVR), originally built to conduct observations of the Earth's climate and never launched, may be re-purposed as a space weather and solar storm warning satellite.[66]

The Hinode (Solar-B) probe, led by JAXA in collaboration with NASA, the Science and Technology Facilities Council (STFC, U.K.) and ESA, was launched in September 2006, with the mission of studying the solar magnetic field; the project explores the solar magnetic fields of the Sun to better understand the mechanisms that power the solar atmosphere and drive solar eruptions.[67] The Advanced Composition Explorer (ACE), a NASA mission launched in August 1997, with its primary science objective of measuring the composition of the solar corona, wind, interplanetary particles, the interstellar medium and galactic matter, continued to collect data to improve forecasts and warnings of solar storms, and is expected to maintain its orbit until 2024.[68] The Reuven Ramaty High Energy Solar Spectroscopic Imager (RHESSI), a NASA SMall EXplorer (SMEX) mission with the objective of exploring the basic physics of particle acceleration and energy release in solar flares has also continued to operate. Data from the mission has led to several hundred publications, the first gamma-ray images of a solar flare, and the first measurements of terrestrial gamma-ray flashes.[69]

2.3.9 Outer Solar System Exploration and Observation

With near-Earth objects becoming a more widely-discussed target for human exploration, there was renewed interest in studying these asteroids and comets. This section also aims to cover some of the significant discoveries made about

[65] "NASA – STEREO." NASA 25 Aug. 2011 http://www.nasa.gov/mission_pages/stereo/main/index.html

[66] Clark, Stephen. "Spaceflight Now | Breaking News | NOAA taps DSCOVR satellite for space weather mission." 2 Feb. 2011. Spaceflight Now 25 Aug. 2011 http://spaceflightnow.com/news/n1102/21dscovr/

[67] "Hinode (Solar-B)." NASA 25 Aug. 2011 http://solarb.msfc.nasa.gov/

[68] "ACE Mission." California Institute of Technology 25 Aug. 2011 http://www.srl.caltech.edu/ACE/ace_mission.html

[69] "RHESSI Homa Page." NASA Goddard Space Flight Center 25 Aug. 2011 http://hesperia.gsfc.nasa.gov/hessi/index.html

celestial bodies outside the Solar System, including those in galactic astronomy and cosmology.

Rosetta completed a successful flyby of the asteroid Lutetia on 10 July, and also discovered that an object previously thought to be a comet is in fact a pair of colliding asteroids. In 2014, Rosetta will release a lander that will make the first landing on a cometary nucleus, that of 67P/Churyumov-Gerasimenko.[70] The Herschel infrared telescope made several significant discoveries. It confirmed that ultraviolet starlight is a key ingredient for making water in space, captured the most detailed infrared image of the Andromeda galaxy yet taken, revealed a population of galaxies shrouded by dust that do not need as much dark matter as previously thought to trigger bursts of star formation, found a link between star formation and shockwaves in interstellar clouds, and observed molecular gas streams emerging from galaxies at speeds of up to 1,000 km per second.[71] Herschel's counterpart Planck, a microwave observatory, was launched in May 2009 to study the Cosmic Microwave Background (CMB) – the ancient radiative 'fingerprint' of the Big Bang. Planck provided its first all-sky image, which gave scientists new insight into star and galaxy formation, and the formation of the infant universe soon after the Big Bang.[72]

The COnvection, ROtation and planetary Transits (COROT) space telescope operated by CNES is an astronomy mission that was launched in December 2006. It focused on probing the inner structure of stars using stellar seismology and detecting extrasolar planets. In June, the discovery of six new planets was announced.[73]

On 4 November, the Extrasolar Planet Observations and characterisation/deep impact eXtended Investigation (EPOXI) flew past comet Hartley 2. An extension of the Deep Impact mission, the spacecraft returned images of the comet that provided new information on the role comets may have in planetary formation.[74] NASA also announced its first asteroid sample return mission, the Origins Spectral Interpretation Resource Identification Security Regolith Explorer (OSIRIS-REx).[75] The JAXA Hayabusa mission successfully returned samples from the asteroid Itokawa on 13 May. About 1,500 particles were identified, most of them of extraterrestrial origin.[76]

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[70] "ESA – Rosetta." European Space Agency 25 Aug. 2011 http://www.esa.int/esaMI/Rosetta/

[71] "ESA – Herschel." European Space Agency 25 Aug. 2011 http://www.esa.int/SPECIALS/Herschel/

[72] "ESA – Planck." European Space Agency 25 Aug. 2011 http://www.esa.int/SPECIALS/Planck/index.html

[73] "Corot." CNES 25 Aug. 2011 http://smsc.cnes.fr/COROT/

[74] "NASA – EPOXI." NASA 25 Aug. 2011 http://www.nasa.gov/mission_pages/epoxi/index.html

[75] "NASA – NASA Selects OSIRIS-Rex as Next New Frontiers Mission." 25 May 2011. NASA 11 Aug. 2011 http://www.nasa.gov/centers/goddard/news/releases/2011/11-037.html

[76] "JAXA: Identification of origin of particles brought back by Hayabusa." 16 Nov. 2010. JAXA 11 Aug. 2011 http://www.jaxa.jp/press/2010/11/20101116_hayabusa_e.html

Exoplanets are planets orbiting stars other than the Sun. Until a few years ago their existence was hypothetical, but recent work has shown that they are quite common. Kepler is a NASA space telescope with the specific aim of finding exoplanets, particularly Earth-sized planets in the habitable zone of solar-like stars, where liquid water could exist on their surfaces. During the year several significant discoveries were made. On 26 August, Kepler discovered two planets transiting the same star for the first time, and followed up with the discovery of the first rocky exoplanet Kepler 10-b on 11 January, which is approximately 1.4 times the size of Earth and the smallest planet ever discovered outside of our Solar System. It also found candidate planets in the habitable zone of their stars.[77]

NASA's NEO Wide-field Infrared Survey Explorer (WISE) mission completed its survey of the sky for small bodies, asteroids and comets. Its list of discoveries includes 20 comets, more than 33,000 main belt asteroids, and 134 Near-Earth Objects (NEOs).[78]

The Spitzer infrared space telescope discovered 14 of the coldest stars known in our universe, leading to speculation that one of these brown dwarf stars could be a companion to the Sun, and contributed to observations of a dust cloud trailing Earth that may help astronomers to find Earth-like planets around other stars.[79]

The James Webb Space Telescope (JWST), the successor to the Hubble Space Telescope (HST), continued to progress towards a tentative 2018 launch date. It will investigate the formation of the first galaxies, planetary systems, and stars. Segments of the large primary mirror underwent cryogenic testing throughout the year.[80] However, the project is in political trouble, with an independent review finding, on 10 November, that its cost overrun was already $1.5 billion.[81]

2.3.10 International Cooperation in Space Exploration

It is almost universally acknowledged on a political level that future space exploration efforts will require international cooperation. However, the concept of 'autonomous' access to space remains a strong one. This has led, for example, to the

[77] "Kepler: Home Page." NASA Ames Research Center 25 Aug. 2011 http://kepler.nasa.gov/

[78] "NASA – NASA's NEOWISE Completes Scan for Asteroids and Comets." 1 Feb. 2010. NASA 25 Aug. 2011 http://www.nasa.gov/mission_pages/WISE/news/wise20110201.html

[79] "NASA Spitzer Space Telescope." NASA 25 Aug. 2011 http://www.spitzer.caltech.edu/

[80] "The James Webb Space Telescope." NASA 25 Aug. 2011 http://www.jwst.nasa.gov/

[81] Klamper, Amy. "JWST's Latest $1.5B Cost Overrun Imperils Other High-priority Projects." 12 Nov. 2010. Space News 25 Aug. 2011 http://www.spacenews.com/civil/101112-jwst-cost-imperils-priority-projects.html

U.S., Europe, Russia and Japan all developing their own methods of transferring cargo to the ISS.

At the second International Conference on Space Exploration, co-organised by ESA, attendees agreed that action was needed to make sure than Europe plays a significant role in future space exploration. EU Ministers and ESA Member States adopted the resolution "Global challenges: taking full benefit of European space systems" with section five dedicated to the European Vision on Space Exploration.[82]

The International Space Exploration Coordination Group (ISECG) continued to discuss architecture options for future human space exploration. On 23 June, senior managers from Canada, China, Europe, Japan, South Korea, Russia, Ukraine and the U.S. met to discuss human and robotic exploration, including the development of a Global Exploration Roadmap, that would constitute an international exploration architecture. Also released was the ISECG Reference Architecture for Human Lunar Exploration, which detailed a human Moon mission using the assets of many agencies.[83]

2.4 Satellite Applications

2.4.1 Space-Based Communications

Satellite communications operators continued to grow in 2010 and 2011, both qualitatively and quantitatively. With the help of improved financial results, the industry has undertaken significant space infrastructure modernisation efforts, especially in the field of new broadband technologies with the manufacturing of sizeable Ka-band spacecraft. Further investments were made in consolidating capabilities through the ordering or launch of larger spacecrafts with enhanced signal power and transponder capacity. The way the industry has reacted to the challenge of the 2008 financial crisis clearly demonstrates an acute rate of responsiveness to the changing conditions, as well as an increased sense of extrovert corporate behaviour and confidence in the sector's future prospects. Achieving the right mixture of investing in innovating technologies and new services on the one hand, while consolidating current operations on the other has boosted the industry's revenues for one more consecutive year.

[82] ISECG. . .

[83] "ISECG – Homepage." ISECG 25 Aug. 2011 http://www.globalspaceexploration.org/

2.4.2 Space-Based Positioning, Navigation and Timing Systems

During the reporting period, the development of GNSS systems continued, with all relevant actors increasing their efforts to complete their full satellite constellations as soon as possible.

In Europe, the European Commission continued the development of its Galileo GNSS constellation with the completion of four-in-orbit validation (IOV) satellites, constructed by a consortium led by Astrium Satellites and Thales Alenia Space. Construction of the IOV satellites were scheduled for launch well in advance of the initial 14 fully operational spacecraft that were already under order with OHB Technology of Bremen. However, in June 2010 IOV's contractors announced an additional 7-month delay to the programme, created by the need to replace Chinese-built search and rescue payloads that were already integrated to the nearly complete satellites. This departure form the spacecrafts' originally foreseen architecture was requested by the European Commission that reversed a previous decision and insisted that no non-European payloads would be allowed on the Galileo spacecraft. At that time, the IOV satellites were scheduled for a late 2010 launch, onboard two separate Soyuz flights.[84]

As mentioned above, the restoration of Russia's Glonass GNSS constellation to its full operational capacity remained a top priority in 2010 and 2011. The development of the system's new generation satellites was already underway in 2010. Known as the Glonass K series, the new spacecraft would most likely incorporate significant technical improvements, including a new more accurate timing device and a non-pressurized structure, bringing its operational performance close to U.S. and European standards. As mentioned above, their deployment was at that time scheduled to begin in 2013 and could be concluded as soon as 2016.

2.5 Technology Developments

New developments in space-related technologies merit discussion, as they indicate current trends in space technology and reveal the focus of relevant policy decisions. The following chapter provides an overview of recent activities, spanning across all major space faring powers and institutions, both established and emerging ones.

2.5.1 Propulsion

Significant advancements have occurred within Europe, the US, and China, in the field of propulsion. Improved rockets and other methods of propulsion are being explored with favourable results.

[84] "Galileo Validation Satellites Facing Another Launch Delay." Space News 14 June 2010: 3.

In Europe, Snecma's Vinci M4 engine, Europe's next generation upper-stage rocket, has reached the halfway milestone of its development. This cryogenic, liquid oxygen/hydrogen-fuelled expander cycle engine is designed to produce three times more thrust and increase payload capacity by 20 % more than the current upper stage rocket used by the Ariane 5. It can also be restarted up to five times while in flight, providing greater flexibility in meeting various orbit requirements.[85] Upon its completion, it is planned to be used in ESA's Ariane 5ME (Midlife Evolution) programme.

In the US, NASA is preparing to install a prototype 200-kw variable specific impulse magnetoplasma rocket (VASIMR) engine, produced by the Ad Astra Rocket Company, onto the International Space Station in 2014.[86] Using Argon gas as propellant, the VASIMR will convert electrical current (supplied by either a solar or a nuclear power source) into radio-frequency waves that ionize the argon gas to produce plasma; superconducting magnets then constrain and channel the super-heated plasma into thrust. While this experimental engine is designed to perform on 200-kw, the Ad Astra is working toward developing 100-MW larger plasma propulsion system that would have the capability of flying cargo and astronauts to Mars in less than 40 days.[87]

In another development, Pratt & Whitney Rocketdyne (PWR) has assembled the first complete J-2X upper-stage rocket engine for use by NASA's Orion spacecraft, designed to lift cargo, equipment, and science experiments into orbit.[88] Building on previous J-2 engines used on the Saturn V launch vehicle, the J-2X engine was originally planned for use on the decommissioned Ares I crew launch vehicle. Ares I was part of the Constellation programme that was terminated following the Obama administration's Fiscal 2011 NASA budget request. However, the J-2X continued to undergo tests while its future remained unclear, and PWR has already concluded that the engine can run on methane as an alternative to hydrogen fuel. Even if the J-2X was not selected for a heavy-lift launcher, PWR's $900 million investment could be salvaged by using the engine as a test-bed for turbine blade materials, avionics, and engine controls.[89]

Another promising propulsion technology development programme was the U.S. Navy's plan to launch a pair of small satellites in 2011 that would be able to use the Earth's magnetic field for propulsion.[90] Still in development, this

[85] Norris, Guy. "Validating Vinci – Next generation upper-stage rocket development effort nears halfway point." Aviation Week & Space Technology 28 Mar. 2011: 32.

[86] Klotz, Irene. "Flight-Test Engine – NASA preparing to demonstrate advanced plasma engine on ISS." Aviation Week & Space Technology 7 Feb. 2011: 56.

[87] Ibid; See also "VF-200." Ad Astra Rocket Company 16 Nov. 2011 http://www.adastrarocket.com/aarc/VF200

[88] Morring, Frank Jr. "Down To The Wire – J-2X engine ready for testing as funding comes to an end." Aviation Week & Space Technology 15 Nov. 2010: 49.

[89] Ibid.

[90] Matthews, William. "Experiment Designed To Harness Magnetic Field for Propulsion." Space News 12 July 2010: 14.

experiment involves tethering two small satellites together, where an electron collector from one end gathers electrons from the Earth's plasma (a low density cloud of electrons that exists in space) while an electron emitter on the other end of the tether discharges the electrons back into the plasma. This propulsion method would work best between the altitudes of 500–1,000 km. While this electrodynamic motor's capacity is limited to changes in altitude of about 5 km per day, it would operate significantly longer than standard liquid-fuelled thrusters, thus providing greater autonomy and longer operational life span to the spacecrafts that will use it.

At the same time, the U.S. Army is also looking into innovative and affordable access to space technologies for small payloads. One approach currently under development involves launching swarms of nanosatellites into orbit through the use of affordable nanomissiles that are designed to put 10 kg payloads into space.[91] Known as the 'Multipurpose Nanomissile System', the booster is 3.6 m tall and 60 cm in diameter, and would produce 3,000 lbs of thrust.[92] Upon successful development, this system will be available commercially for suborbital and orbital missions. However, as this nanomissile is part of Space Missile and Defence Command's (SMDC) Nanosatellite Technology Programme, its other objective is to produce battlefield-relevant satellites.[93] If produced in quantity, these nanomissiles could have a price tag as low as $150,000 per unit.

Across the Pacific, China is also advancing its propulsion technology with the development of a staged-combustion kerosene and liquid oxygen engine that is likely to offer greater performance for its Long March 6 and 7 launchers.[94] This engine provides 18 metric tons of thrust and will offer a high specific impulse, allowing for greater payloads to be launched into orbit. The Long March 6 may be operational before Long March 5, and the light launcher will be able to lift 1,000 kg to an orbit of 600 km.[95] The staged-combustion engine will also be used in the second stage of China's medium-heavy Long March 7 launcher.

[91] Brinton, Turner. "Nanomissile Being Designed To Launch the Smallest Satellites Affordably." Space News 9 Aug. 2010: 11.

[92] "2011 U.S. Commercial Space Transportation Developments and Concepts: Vehicles, Technologies, and Spaceports." Jan. 2011. Federal Aviation Administration 30 Nov. 2011: 20 http://www.faa.gov/about/office_org/headquarters_offices/ast/media/2011%20devcon%20report.pdf

[93] Ibid.

[94] Perrett, Bradley. "Next Stage – An advanced propulsion technology is readied for new Long Marches." Aviation Week & Space Technology 10 Jan. 2011: 35.

[95] Ibid.

2.5.2 Information Technology

In Europe, Eutelsat began providing commercial broadband service with its Ka-Sat satellite on May 31.[96] This satellite, the first of a fleet of high throughput satellites under development by Astrium, has a throughput of about 70 gigabits per second. Approximately 44,000 Surfbeam 2 terminals have already arrived in the Netherlands in anticipation of the demand for broadband capacity. Ka-Sat distributes its bandwidth through 82 spot beams, each carrying 900 megabits per second of capacity. These beams are evenly distributed to provide services in Europe and Africa. Yet despite the ability to shift bandwidth between nearby spotbeams, the satellite lacks the onboard processing capacity needed to maximize bandwidth and location flexibility. The population coverage of the satellite is about 800 million, nearly three times that of its U.S. counterpart, ViaSat's WildBlue consumer broadband service. It is expected that European demand for Ka-Sat might be higher in suburbs rather than rural areas, which are often the subject of government broadband stimulus programmes.[97]

2.5.3 Spacecraft Operations and Design

In Europe, UK developer Surrey Satellite Technology Ltd. (SSTL) is upgrading its constellation to improve its disaster monitoring capabilities. Its DCM3 will be optimized for commercial use, and will work along side SSTL's future medium-resolution constellation, Earthmapper, to attract additional non-disaster users. In addition to disaster monitoring, this system aims at natural resource and environmental monitoring, deforestation and forest fire applications, and land use mapping.[98] Earthmapper will get an entirely new bus, SSTL-100 v.3.0, allowing it to support higher resolution instruments and provide emergency response users with the ability to zoom in on disaster areas, while also meeting the needs of other users. The DCM3, expected to be operational in 2014, will be based on the SSTL-300S1, a new highly-agile submetric-resolution bus, which carries a new camera that provides a spatial resolution of 75 cm (the spatial resolution on Nigeriasat-2 is 2.5 m), and supports a high-speed downlink and 45° off-pointing slew rate.[99]

In another development, British imaging solutions company E2v was developing image sensors for Euclid, a dark-energy mapping mission currently under

[96] De Selding, Peter B. "Ka-Sat Enters Services as European Broadband Market Heats Up." 6 June 2011: 16.

[97] Ibid.

[98] Taverna, Michael A. "Remapping the Earth – New SSTL submetric smallsat concept could change economics for remote-sensing industry." Aviation Week & Space Technology 7/14 Mar. 2011: 58.

[99] Ibid.

development for ESA.[100] E2v was also awarded a contract with ESA to develop image sensors for Plato, a space telescope that searches for planets; this mission competed with two other space science missions, Euclid and Solar Orbiter, for two launch opportunities under ESA's CosmicVision program.[101] Euclid and Solar Orbiter were ultimately selected;[102] here, Euclid will be equipped with new front and back illuminated Charged Couple Device (CCD) image sensors. However, if Plato had been selected, it would have been equipped with 34 mini-telescopes, containing four back-illuminated charge-coupled devices on each of them. It would orbit the Sun 1.5 million kilometres beyond Earth for 6–8 years, and survey up to 40 % of the sky.[103]

Authorities at the Swedish Space Corp. report a near 100 % success rate for its Prisma formation flying mission.[104] Launched on a Russian-Ukrainian Dnepr rocket in June 2010, the two Prisma satellites conducted a year long mission to perform formation flying manoeuvres between the two spacecraft, while also testing several new technologies. One satellite operated in passive mode, while the other satellite operated around it autonomously, and made operational decisions on its own.[105] The Prisma mission paves the way for future formation-flying satellite missions, e.g. ESA's Proba-3. Analysis on Prisma also included tests on its High-Performance Green Propulsion (HPGP) system, developed by Ecological Advanced Propulsion Systems (Ecaps) of Sweden, which provided an alternative to conventional hydrazine fuel. At one third the cost of hydrazine, the HPGP system has a higher specific impulse, in addition to providing more thrust per fuel volume. It is also non-toxic, which allows fuelling to be conducted without the need for protective gear beyond standard clean room clothing.

The German DLR conducted its very first tandem mission, where ground controllers manoeuvred two radar satellites to within 350 m of each other in low Earth orbit.[106] Radar satellites TerraSAR-X, launched in 2007, and TanDEM-X, launched in 2010, originally had identical polar orbits 514 km in altitude, with a separation distance of 20 km. TanDEM-X's orbital period was reduced, letting it to move to a separation distance of 350 m from TerraSAR-X within 3 days. This separation enables the satellites to take simultaneous images of the same area, allowing for the production of three-dimensional digital evaluation models. This data provides a 12-m ground resolution, making objects this size or larger

[100] "E2v Tapped To Develop Image Sensors for Euclid." Space News 18 Oct. 2010: 8.

[101] "E2v Picked To Develop Image Sensors for Plato." Space News 25 Oct. 2010: 8.

[102] De Selding, Peter B. "Solar Orbiter, Euclid Chosen as ESA's Next Medium-class Missions." 5 Oct. 2011. Space News 6 Aug. 2012 http://www.spacenews.com/civil/111005-esa-selects-solar-orbiter-euclid.html

[103] Ibid.

[104] De Selding, Peter B. "Swedish Space Corp. Touts Success of Prisma Formation-flying Mission." Space News 6 Sept. 2010: 17.

[105] Ibid.

[106] "German Satellites Ready For Tandem Mission." Space News 18 Oct. 2010: 3.

distinguishable; the system also provides vertical accuracy of 2 m. The mission is managed by having one satellite transmit a radar signal to Earth, but both spacecraft would receive the reflected signal which is used to create the digital elevation models; this method also reduces power consumption and heat build-up, extending the transmission time for both satellites. While both satellites have a 5-year design life, the DLR is confident that TerraSAR-X will operate long enough to fulfil the tandem mission goal of 3 years of stereo collection.[107]

Across the Atlantic, Northrop Grumman Aerospace Systems has developed a pair of demonstration satellites that can track a ballistic missile launch through all phases of flight.[108] This unprecedented capability was achieved by the Space Tracking and Surveillance System (STSS) spacecraft, dubbed the "Holy Grail" for missile defence. Upon the launch of a missile, an STSS satellite will detect the heat signature of the launch with its acquisition sensor, and then use its gimballed tracking sensor to lock onto the boosting missile. The tracking data gets relayed to the other STSS satellite, which continues to observe the satellite as it re-enters the atmosphere toward its target. Future tests will involve attempts to cue the STSS system from the Defence Support Program missile warning satellites; determining if STSS satellites can produce missile tracking data good enough to cue the launch of ship-based interceptors; and, feeding data to the Aegis system while tracking a missile, to generate a "fire control solution" for an early interceptor launch.[109]

At the same time, a new squat, insect-like lander prototype underwent tests by engineers at NASA's Johnson Space Center.[110] They hope that the lander, named Morpheus, will 1 day enable manned missions to other planets or asteroids. The lander is equipped with an Automated Landing and Hazard Avoidance Technology (ALHAT) that uses lasers to spot dangerous craters or boulders that could make a landing spot unsafe. A safe landing spot can be determined quicker since the ALHAT lasers would image the surface of land area and identify hazards as it flies over. The lander is also being used to test a new lighter and safer mix of fuel; i.e. liquid oxygen and methane. While touted by NASA as a safer alternative to traditional propellants, it's also between 10 and 20 times less expensive, and potentially renewable on both the lunar surface and on Mars.[111] Current tests are being conducted using a crane and tether to maintain stability; despite some unexpected results, researchers are planning to test Morpheus in free flight up to an altitude of 30 m without a tether. If successful, Morpheus will have passed a significant milestone in its development.

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[107] Ibid.

[108] Brinton, Turner. "STSS Satellites Demonstrate 'Holy Grail' of Missile Tracking." Space News 28 March 2011: 10.

[109] Ibid.

[110] Moskowitz, Carla. "Johnson Space Center Engineers Test New Lunar Lander Design." Space News 23 May 2011: 17.

[111] Ibid.

Intelsat's Galaxy 15 communications satellite, aka Zombie Sat, has been secured. The wayward satellite went out of control in April 2010, causing 6 months of alarm about interference to the operators of satellites within its path. These other satellites underwent complex unprecedented manoeuvres to limit serious interference and service interruption. By Dec. 17, Galaxy 15 had lost Earth lock, which caused it to lose enough power to shut down its C- and L-band payloads; and soon afterward, its battery drained completely, shutting off the radio beacons and removing the remaining interference risk.[112] Intelsat, with the contribution of SES, Telesat and SatMex expertise, developed a three-pronged strategy in dealing with Zombie Sat's interference threat. When approaching another satellite, Galaxy 15's transmission was minimized by using the narrow beam of a large antenna in Clarksburg, Maryland (in some cases, through the Beach Earth station facility in Hawaii). The energy available to Galaxy 15 was also minimized by changing the sensitivity settings of the satellite at risk of interference. Next, in the final stages of the fly-by, a "leap-frog" manoeuvre would be performed by the at-risk satellite, permitting the two spacecraft to stay in sync and maintain a minimum spacing of at least 0.2° until Zombie Sat began moving away again.[113] As a result, while Galaxy 15 approached a dozen satellites, these manoeuvres kept it from creating a serious impact.

Bigelow Aerospace conducted tests on the life support system of its inflatable habitats, destined to provide research facilities and hotel accommodations in space.[114] On March 31, the prototype environmental control and life support (ECLS) system underwent testing within a 180 cubic-meter test chamber, designed to replicate the interior volume and shape of the company's Sundancer inflatable module. The ECLS system is unlike other systems that are used for short duration trips between Earth and the International Space Station, because it is geared toward regeneration capability through recycling water from the environment and from any waste treatment process, and generating oxygen from water. The test involved locking three Bigelow engineers within that structure for 8 hours while performing tasks which demonstrated the system's "ability to control temperature, humidity, pressure, oxygen content and the removal of carbon dioxide and trace-gas contaminants from the environment." Bigelow will conduct a 30-h and week-long demonstration of the ECLS system in subsequent months. In parallel with the building of ECLS, Bigelow is finishing work on an analytical chemistry laboratory that will expand real-time monitoring and analysis of gases and liquids within the chamber to identify the components present.[115]

[112] Taverna, Michael A. "End of an Odyssey – Engineers review options, operators relieved as Intelsat regains control of Zombie Sat." Aviation Week & Space Technology 3 Jan. 2011: 26.
[113] Ibid.
[114] Svitak, Amy. "Bigelow Tests Life Support System." Space News 11 April 2011: 24.
[115] Ibid.

Boeing is developing a commercial crew capsule that is designed to ferry people to and from the International Space Station and future private space stations.[116] Meant to fill the void left by retirement of NASA's space shuttle, the Crew Space Transportation-100 (CST-100) spacecraft could carry up to seven people, and would be larger than the Apollo spacecraft, but smaller than the Orion capsule.[117] Bigelow Aerospace will assist Boeing with demonstrations and design work in areas where Bigelow has experience from the construction of its own orbital facilities and commercial space complex.

The U.S. Air Force launched two X-37B unmanned space planes into Earth orbit between 2010 and 2011. The first drone, Orbital Test Vehicle 1 (OTV-1), returned from a 7-months orbit on December 3, while the second, Orbital Test Vehicle 2 (OTV-2) was launched just over 3 months later; both missions were classified. OTV-1 spent more than 220 days in orbit, with some analysts speculating that the spacecraft served as an unmanned orbital spy platform. Expert Brian Weeden, former U.S. Air Force orbital analyst, suggests the X-37B's sensor payload can be reconfigured for each mission, i.e. to meet the emerging needs of military commanders or intelligence agencies.[118] The X-37B also carries enough propellant to change orbit in the middle of a mission, allowing it to change the coverage area on short notice. The X-37B's orbit duration can last up to 270 days, where the craft can rely on its solar array power system for much of its journey. The spacecraft has an automated re-entry and landing system, with flight controls that are driven entirely by electro-mechanical actuators instead of bulky hydraulic circuits. New thermal tiles were needed because the X-37B's steeper incline while in re-entry would create an increased amount of heat, while the spacecraft would have less surface area to bleed off that heat.[119] Weighing about 5,000 kg, the craft is about 9 m in length, with a 4 m wingspan, and 3 m in height. OTV-2 launched from Florida on March 5 on another classified mission.[120] While the secrecy surrounding these missions has raised concerns by Russia and China that the X-37B is a space weapon of some sort, the U.S. Air Force denies this charge, stating that it is merely testing sensor, guidance and navigation control hardware for future spacecraft.[121]

Earlier in the year, developers of the Mars Science Laboratory (MSL) rover, known also as "Curiosity," were forced to cancel plans to attach a 3-D zoom camera system, developed with the help of filmmaker James Cameron, due to a lack of time

[116] Chow, Denise. "Boeing Unveils Design for Commercial Crew Capsule." Space News 26 July 2010: 15.

[117] Ibid.

[118] Malik, Tariq. "X-37B Wraps Up 7-month Mission Shrouded in Secrecy." Space News 6 Dec. 2010: 17.

[119] Ibid.

[120] "USAF's X-37B Minishuttle Returns to Space on Atlas 5." Space News 14 Mar. 2011: 8.

[121] Ibid.

to get it ready for launch in November.[122] While in its final stages as of April 2011, there wasn't enough time to complete the units and integrate them with the rover; 'a number of technical problems' were cited as the cause for the delay. Fixed focal length cameras will replace the 3-D zoom camera system, and are expected to achieve all of the primary science objectives of the rover's Mastcam investigation. Had the zoom cameras been installed, they would have provided increased operational flexibility, improved stereo imaging, and a 3-D motion imaging capability that would enhance the public's visual exploration of Mars. The 3-D zoom developers, Malin Space Science Systems, will continue working on the cameras for potential application on future missions to Mars, the Moon, or on an asteroid.[123] By June 2011, Curiosity began undergoing tests at NASA's Jet Propulsion Laboratory before being shipped to Kennedy Space Center.[124] The rover is twice as long and five times heavier than its predecessor; and it carries ten science instruments for use on Mars' surface.[125] The rover was launched on 26 November 2011; and was expected to reach Mars by August 2012.

Space Exploration Technologies (SpaceX) has three Commercial Orbital Transportation Services (COTS) capsules, named Dragons, in varying stages of assembly. These Dragons, along with their Falcon 9 medium-lift launchers, will undergo separate missions to demonstrate their space-worthiness.[126] The first demonstration was conducted on Dec. 8 2010, where the Dragon capsule orbited Earth twice, and executed a pre-programmed series of manoeuvres and system checks needed for future rendezvous and dockings with the International Space Station.[127] Four of the capsule's 18 Draco thrusters were fired for 6 min to re-enter Earth's atmosphere, followed by the use of drogue chutes and three parachutes to slow the craft down to 8 m per second before landing in the Pacific Ocean. Future versions of the spacecraft will use a propulsive landing system, with parachutes as a backup.[128]

NASA's Orion space capsule, part of the Constellation programme that was terminated following the Obama administration's Fiscal 2011 NASA budget request, was recommitted as NASA's Multi-Purpose Crew Vehicle (MPCV).[129] This repurposed vehicle will be slimmed down to function as a crew lifeboat at the International Space Station. While NASA considered changing Orion, by including the substitution of a composite crew cabin for the capsule's aluminium structure,

[122] David, Leonard. "NASA Nixes 3-D Camera for Mars Science Laboratory." Space News 4 Apr. 2011: 15.

[123] Ibid.

[124] "NASA's Next Mars Rover Touches Down in Florida." Space News 27 June 2011: 8.

[125] Ibid.

[126] "SpaceX's Second Dragon Powered up for 1st Time." Space News 27 June 2011: 8.

[127] Klotz, Irene. "Shear Magic – SpaceX's Dragon soars through test flight into record books after last-minute fix." Aviation Week & Space Technology 13 Dec. 2010: 22.

[128] Ibid.

[129] Berger, Brian. "NASA Makes It Official: Orion To Be Multi-Purpose Crew Vehicle." Space News 30 May 2011: 5.

and the use of a different kind of launch abort system, it decided to stick with the existing Orion design since it already met the needed requirements. Orion could carry four astronauts for 21-day missions before landing in the Pacific Ocean; and the craft would have nearly 9 cubic meters of habitable space.[130] When rendezvousing with the International Space Station, Orion's Relative Navigation System will utilize its Sensor Test for Orion Rel-Nav Risk Mitigation (STORRM) during the docking stage.[131] STORRM consists of an eye-safe Light Detection and Ranging Vision Navigation Sensor, a high-definition camera, along with avionics and flight software.[132]

Russia has upgraded its Soyuz spacecraft with new digital enhancements. The Soyuz TMA-01M, launched for the first time on Oct. 7, features a variety of avionics and computer upgrades that are designed to be less operator intensive, and to make flying it easier.[133] The new avionics system weighs 70 kg less than its predecessor, allowing a small increase in cargo capacity. Also, when docked with the International Space Station, the spacecraft's computer systems allow it to interface with the onboard computers in the Russian On-Orbit Segment, allowing continuous monitoring of the Soyuz by Mission Control in Moscow.[134]

2.5.4 Suborbital Activities

Development of suborbital activity has steadily increased in the U.S. as well as parts of Europe and Asia. While perceived by many as a sector for tourism, it can also be used for experimental purposes.

Virgin Galactic conducted drop tests and landing tests of its SpaceShipTwo spacecraft between 2010 and 2011. SpaceShipTwo completed its first piloted glide test on 10 October, first released from WhiteKnightTwo at an altitude of 13,700 m, and gliding down to the Mojave Air and Space Port.[135] The flight tested for a clean release of the spaceship from its mothership and whether the spacecraft could free fly and glide back and land.[136] The flight also tested SpaceShipTwo's ventral, belly-mounted speed break, which was used to help slow down SpaceShipTwo while in

[130] Ibid.

[131] David, Leonard. "Orion Development Continues at New Lockheed Martin Center." Space News 28 May 2011: 14.

[132] Ibid.

[133] Harwood, William. "Realtime coverage of Soyuz TMA-01M launch." 7 Oct. 2010. CBS News – Space 29 Nov. 2011 http://www.cbsnews.com/network/news/space/home/spacenews/files/7f8aa558a8d86128b00b2b8b7c8c6c43-80.html

[134] Ibid.

[135] David, Leonard. "Virgin Galactic's Private Spaceship Makes First Solo Glide Flight." Space News 18 Oct. 2010:12.

[136] Ibid.

descent.[137] SpaceShipTwo's third drop test used water ballast to achieve an aft centre of gravity, and the craft was flown to a more aggressive stall indication to evaluate its stability and control.[138] After successfully increasing its top speed to 246 KEAS (knots equivalent airspeed) and loads to 3.5 g, the next test phase involved higher-speed subsonic flight with a short 15 s burst of power from its Sierra Nevada RM2 hybrid rocket.[139] By May 2011, five successful drop/glide tests had been conducted in addition to the sixth hot-fire test of a full-scale flight design rocket motor performed at ground test facilities.[140] The next milestones to come will involve short, medium, and long blasts from SpaceShipTwo's RM2 rocket motor.

In a parallel development in the US, XCOR Aerospace began finalising the structure of its Lynx suborbital spacecraft.[141] While the Lynx has undergone a number of design refinements since its first launch in April 2008, it was now reaching its last stage of structural refinement. After finishing its final round of wind tunnel tests, XCOR was expected to conclude the Lynx's design phase and begin assembly.

In Europe, the German aerospace centre (DLR) hopes to expand on the thermal protection technologies validated by the Mach 6 Shefex 1 in 2005 for the purpose of developing a small sub-orbital re-entry vehicle in 2020.[142] The Sharp Edged Flight Experiment (Shefex 2) demonstrator incorporates nine different thermal protection system tests, an actively cooled segment and a hybrid navigation system, while performing at a target top velocity of nearly Mach 11. It expands on the Shefex 1 by increasing its flight duration to 50 from 15 s, resulting in an increased re-entry flight distance of around 100 from 20 km. The Shefex 2 will be launched on a Brazilian VS-40 sounding rocket and will detach at an altitude of 200 km. Shefex 2 is expected to reach a temperature of 2,000 °C while descending between 100 and 20 km. It will then engage a parachute system near the end of its descent and land in shallow water near the Arctic Circle for recovery and data analysis. The Shefex 3 will operate at near orbital flight with a velocity of Mach 24 in 2016; and Shefex 4 is expected to be orbit-capable by 2020.

Also in Europe, Thales Alenia Space is preparing two atmospheric re-entry test vehicles for launches in 2011 and 2013 under ESA's Future Launcher Preparatory

[137] Norris, Guy. "Flying Enterprise – First glide test for SpaceShipTwo begins buildup to powered, suborbital evaluation." Aviation Week & Space Technology 18 Oct. 2010: 37.

[138] "SpaceShipTwo Conducts Third Gliding Flight Test." Space News 22 Nov. 2010: 3.

[139] Norris, Guy. "Flying Start – Low-speed SpaceShipTwo tests pave way for powered evaluation." Aviation Week & Space Technology 20/27 Dec. 2010: 37.

[140] David, Leonard. "Virgin Galactic's Tourist Spaceship Makes Longest Test Flight." Space News 2 May 2011: 14.

[141] Norris, Guy. "Stable Supersonic – Designers focus on suborbital Lynx airframe, after wind tunnel tests verify stability margin." Aviation Week & Space Technology 20/27 Sept. 2010: 36.

[142] Norris, Guy and Robert Wall. "Speed Trial – Experiments prepared for expanded hypersonic test from Norwegian site." Aviation Week & Space Technology 25 April/2 May 2011: 74.

Program.[143] These vehicles are the 450 kg Expert suborbital capsule and the 1,815 kg Intermediate Experimental Vehicle (IXV). Expert will be launched mid-summer, and its 17-min flight will follow a ballistic trajectory to reach an altitude of around 100 km, re-entering Earth's atmosphere at about 5 km per second.[144] The conical, blunt-nose spacecraft is manoeuvred through four flaps that are positioned at its base.[145] It will run ten experiments during its hypersonic descent through Earth's atmosphere. IXV will be launched in 2013 onboard Italy's Vega small satellite launcher; its 21-min flight will reach an altitude of 430 km, re-entering Earth's atmosphere at about 7.5 km per second. This larger demonstrator will perform in-flight verifications of structures, materials, guidance and control systems, and other critical re-entry technologies.[146] An inflatable balloon will emerge upon alighting in the water to ensure vehicle recovery. These tests are being conducted in an effort to further develop its understanding of re-entry issues for future international exploration programs.

EADS Astrium teamed up with Singapore-based companies in an effort to develop a fleet of spaceplanes at Singapore's Changi International Airport.[147] While the Singapore companies are currently designing and building an engineless small-scale demonstrator spaceplane to test aerodynamics and glide capability, the real spaceplane will be operated using both turbofan engines and a rocket power-plant. The turbofan engines will have about 10,000 lbs of thrust, whereas the spaceplane's rocket engine, a derivative of Astrium's Vulcain rocket engines, will have 40 t of thrust. EADS Astrium plans to apply for EASA certification as the use of conventional turbofan engines allows this spaceplane to takeoff and land from commercial airports. During takeoff, the spaceplane will use its turbofan engines to ascend to an altitude of 12 km, before its rocket engine takes over. After reaching a maximum apogee at an altitude of 100 km, it will glide for a period while in descent, before reengaging its turbofan engines to land. The four passenger spaceplane concept reached maturity since first being conceived in 2006, and is now seeking money for development.[148]

[143] Taverna, Michael A. "From Dream To Reality – European hypersonic research shifts from drawing board to flight-preparation stage." Aviation Week & Space Technology 5 July 2010: 40.

[144] De Selding, Peter B. "Europe Prepares Two Atmospheric Re-entry Test Vehicles." Space News 29 Nov. 2010: 7.

[145] Taverna, Michael A. "From Dream To Reality…".

[146] Ibid.

[147] Francis, Leithen. "Launch Pad – Astrium hopes to base a fleet of spaceplanes at Singapore's Changi International Airport." Aviation Week & Space Technology 14 Feb. 2011: 52.

[148] Morrison, Murdo. "PARIS: EADS Astrium looking for funds to launch Spaceplane." 22 June 2011. Flightglobal 30 Nov. 2011 http://www.flightglobal.com/news/articles/paris-eads-astrium-looking-for-funds-to-launch-spaceplane-358289/

2.5.5 *Other Technologies*

New developments in technology and science have occurred within the 2010–2011 period, which have implications both within and outside the space sector.

European automakers may save weight on vehicles by using spinoff fasteners developed for the International Space Station and NASA's Mars Pathfinder. MST Aerospace, the European Space Agency's technology broker, is pushing bolts containing an internal strain-measurement sensor into the auto industry for use in drive trains and axles.[149] A small ultrasound sensor imbedded in the bolt heads provides direct uniform readings instead of the scattered results obtained when using a coupling liquid and external meter. These new bolts have less than a 3 % margin of error, whereas current bolts may have as much as a 30 % error margin.

On another note, an atomic clock test program will be conducted onboard the International Space Station, using two new generation atomic clocks. EADS Astrium Space Transportation will oversee the development of the Atomic Clock Ensemble in Space (ACES) system which will involve two types of atomic clocks. The French Space Agency is developing the first atomic clock, Pharao; a laser cooled caesium clock designed for use in a microgravity environment.[150] The second clock is a hydrogen master clock, developed by the Observatory of Neuchatel, Switzerland; master clocks are already used by the European Space Agency on the four Galileo In-Orbit Validation positioning, navigation and timing satellites slated for launch in 2011.[151] Researchers will compare the performance of the ACES clocks with each other, as well as with ground-based atomic clocks.

Across the Atlantic, Canada's MacDonald, Dettwiler and Associates (MDA) is developing a servicing satellite that has the ability to grapple 75 % of the commercial communications satellites in geostationary orbit and either refuel them or make simple repairs with its robotic arm.[152] After using lidar ranging to approach a target satellite, the servicing satellite will then locate the target's apogee kick motor nozzle via video and target recognition software and draw itself up to its docking ring. Refuelling will be conducted in the same way satellites are fuelled on ground.[153] However, while Intelsat has already signed up for a refuelling service by MDA's Space Infrastructure Services (SIS) vehicle, agreeing to purchase about half of the 2,000 kg of fuel on the vehicle, other satellite manufacturers are sceptical and believe that some type of heavy government backing, or a public-private

[149] Morring, Frank Jr. "Space Spinoffs – ESA pushes high-tech bolts to auto industry." Aviation Week & Space Technology 20/27 Dec. 2010: 22.

[150] "Astrium To Manage Atomic Clock Demo on Station." Space News 26 July 2010: 9.

[151] Ibid.

[152] Morring, Frank Jr. "Changing the Games – Canadian robotics may stretch commercial satellite lifetimes." Aviation Week & Space Technology 21 March 2011: 23.

[153] Ibid.

partnership, is needed to make the servicing model viable for the entire duration of its 10 year operational lifespan.[154]

In another development, NASA's Gravity Probe B was able to demonstrate two key aspects of Albert Einstein's General Theory of Relativity, despite unexpected system noise that obscured some measurements.[155] While this noise obscured the extremely subtle space-time "frame-dragging" effect to within a 20 % margin of error, researchers achieved a 1 % or better margin of error with a second measurement known as the geodetic effect. General relativity predicts that massive rotating objects should drag space-time around themselves when rotating; i.e. as the Earth rotates, it pulls the space-time in its vicinity around itself, shifting the orbits of near-Earth satellites.[156] At its core, the satellite houses four nearly perfect spheres of fused quartz and silicon, cooled with liquid helium to 1.8°K and spun in helium gas to 5,000 rpm, creating super-conducting gyroscope rotors that generated a magnetic pointer along the axis of rotation allowing for precise measurements by digital magnetometers.[157] But for the effect of gravity on space and time, rather than constantly pointing in the same direction while the craft was in polar orbit around Earth, these gyroscopes experienced small but measurable changes in the direction of their spin while being pulled by Earth's gravity.[158] While this technology has very unique applications, some components were already used in NASA's Cosmic Background Explorer which confirmed the Big Bang Theory.[159]

The U.S. Defense Advanced Research Projects Agency (DARPA) has developed a telescope that will provide wide-field views of objects in geostationary orbit.[160] Currently, a network of space-based assets, optical telescopes and radar sites around the world are used to catalogue more than 20,000 space objects. Radar signals generally track satellites and debris in low Earth orbit, while optical systems, e.g. US Air Force's Ground-based Electro-Optical Space Surveillance (GEODSS) system, track more distant objects in the geo-stationary orbit. Most telescopes have spherical mirrors that have a single radius of curvature throughout, and require additional optics to project an image of a curved field of view onto a flat charged coupled device sensor. On the other hand, DARPA's optical design does not require

[154] Cf. De Selding, Peter B. "Intelsat Signs Up for MDA's Satellite Refueling Service." Space News 21 March 2011: 5, and De Selding, Peter B. "Satellite Builders Not Enthusiastic About In-orbit Servicing Project." Space News 21 March 2011: 5.

[155] Morring, Frank Jr. "Space – Gravity Probe B pushed spacecraft technology to the limit – and perhaps a little beyond it." Aviation Week & Space Technology 9 May 2011: 38.

[156] See Cain, Fraser. "Frame Dragging Confirmed." 22 Oct. 2004. Universe Today 23 Nov. 2011 http://www.universetoday.com/9984/frame-dragging-confirmed/

[157] Morring, Frank Jr. "Space – Gravity Probe B . . .".

[158] "NASA's Gravity Probe B Confirms Einstein Theories." Space News 9 May 2011: 8.

[159] Morring, Frank Jr. "Space – Gravity Probe B . . .".

[160] Brinton, Turner. "DARPA Space Telescope Will Track Objects in Geostationary Orbit." Space News 2 May 2011: 6.

the use of other refractive optics to create a flat field for projection onto a flat sensor.[161] With an aspheric mirror and curved charged coupled device sensor, DARPA's design is simpler and more compact, enabling it to conduct faster and more accurate and sensitive searches than the GEODSS system. While still in the alignment phase, once calibration is complete the system will move onto its technology demonstration phase to better track objects in geostationary orbit.

2.5.6 Innovation Policy

In the United States, as the Constellation programme was terminated following the Obama administration's Fiscal 2011 NASA budget request, Orion's long term future remains uncertain. Rather than returning to the Moon, the White House is more in favour of commercial orbital developments, and the human exploration of an asteroid in 2025.[162] While the Orion capsule has already been recommitted as NASA's Multi-Purpose Crew Vehicle (MPCV),[163] it had the potential for asteroid exploration flights as early as 2016 with an adequate build-up of test flights prior to the endeavour.[164]

Commercial suborbital spaceflight is getting a boost from the U.S. Congress. President Obama signed the 3-year NASA Authorization Act into law on 11 October 2010, allowing NASA to devote millions of dollars annually to commercial suborbital transportation projects.[165] In an effort to spur development of new technologies, as well as improve microgravity research and support the fledgling commercial reusable suborbital transportation industry, the Act authorizes NASA to invest $15 million annually on its Commercial Reusable Suborbital Research (CRuSR) program, allowing NASA to fly research payloads on commercial suborbital vehicles. "These flights are expected to reduce the risk for use of overall space operations by demonstrating application in a relevant environment." While initial test flights will carry NASA payloads designed to monitor the flight environment and the FAA's Automatic Dependent Surveillance-Broadcast payload, later flights will carry educational experiments, technology demonstrations, and research payloads. CRuSR's main goal "... is to provide researchers with the opportunities to validate components of developmental systems in a variety of areas, including propellant management, autonomous operation, communication and navigation,

[161] Ibid.

[162] Norris, Guy. "Orion Options – Planners craft fast-track launch, funding and exploration survival strategy for Orion." Aviation Week & Space Technology 23 Sept. 2010: 28.

[163] Berger, Brian. "NASA Makes It Official: Orion To Be Multi-Purpose Crew Vehicle." Space News 30 May 2011: 5.

[164] Norris, Guy. "Orion Options...".

[165] Werner, Debra. "Suborbital Spaceflight Gets a Boost from NASA, Congress." Space News 18 Oct. 2010: 12.

in-situ resource utilization, and space manufacturing." Masten Space Systems and Armadillo Aerospace were already awarded $475,000 for flight demonstrations.[166]

A new space race has begun within the U.S. in regard to the successor to the retired space shuttle. The second stage of the Commercial Crew Development (CCDev-2) initiative is underway, with federal funding going toward five separate contenders, i.e. Lockheed Martin, Blue Origin, Boeing, Sierra Nevada Corp., and Space Exploration Technologies (SpaceX).[167] The goal of the NASA's CCDev effort is to seed a commercial industry that can fly crews to the ISS within this decade; CCDev-2 is meant to mature designs that have a chance of growing into a full-scale system. Lockheed Martin's Orion crew exploration vehicle will be retooled as the new Multi-Purpose Crew Vehicle, and will be funded for 3 years under the NASA Authorization Act.[168] Blue Origin received just over $22 million in CCDev-2 funding to provide sub-orbital space flight to tourists and for science experiments in a three seat biconic capsule launched on an Atlas V rocket; it later aims to develop a reusable launch vehicle that will carry a seven-seat capsule to low Earth orbit. Boeing received the most funding of the recipients, i.e. $92.3 million for a pressure test article for its CST-100 capsule, and to evaluate a lighter-weight engine for its pusher-type launch abort system, to evaluate its parachute and airbag inflation systems for water landings, and to conduct full-scale tests of the capsule's pyrotechnics used for separating its service module before re-entry. Sierra Nevada Corp. has already put $20 million into its Dream Chaser spaceplane, and it received $80 million in CCDev-2 funding for preliminary design reviews, and drop tests. And SpaceX will use its $75 million CCDev-2 award to speed development of its side-mounted pusher-type launch abort system, in addition to preparing its initial design for crew accommodation evaluations.[169]

[166] Ibid.

[167] Morring, Frank Jr. "The New Space Race – With funding freed, NASA and its partners crank up work on possible shuttle successors." Aviation Week & Space Technology 25 Apr./2 May 2011: 24.

[168] Ibid.

[169] Ibid.

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