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 Chap. 1, in an attempt to clarify the principal space faring nations' strategies in 2011 and 2012. In the section below, there will be a brief discussion on developments in technology related areas, including policies and access to space technologies. The aim of this section is to clarify how the above presented strategies interact with and influence specific space programmes, and related research and development projects.

2.2 Space Transportation

2.2.1 Europe

Europe's launcher development programmes are funded primarily by ESA. This funding has progressively decreased in the past decade, and as the Ministerial Conference in November 2012 approached, there was considerable uncertainty about the way forward for European launcher technology.

Germany wanted to commit funding toward upgrading Europe's Ariane 5 rocket, instead of developing a next-generation launcher. It argued that key decisions must first be made on Galileo and GMES prior to addressing launcher development, as Galileo lacks over €1 billion necessary to develop and launch the 30-satellite constellation, and financing for GMES was completely removed from the European Commission's 7-year budget proposal. Meanwhile, Germany and France agreed

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tentatively to update the Ariane 5 with a re-startable upper stage that uses the Vinci engine, now in development. With a total upgrade cost of €1.5 billion, this launcher would be capable of launching 10,500 kg into geostationary transfer orbit, an increase of 1,000–1,200 kg from the present Ariane 5 model.[1] France released a space strategy report that reiterated its position on investing in space capacity, but was unclear on whether to enhance the current Ariane 5 launcher or to develop a successor to the Ariane 5 launch vehicle. Whatever the decision, the report argued for an overhaul of the Ariane 5 launcher.[2] The launcher's development was to be decided at the 2012 Ministerial Conference, with the choice between an Ariane 5 Mid-life Evolution (ME) and an Ariane 6 depending to a large extent on the demands of government and commercial customers.

While commercial operations of Arianespace led to significant losses in 2010 and 2009, and a need for aid to offset the adverse effect of currency movements,[3] Arianespace expected to post a 10 % revenue increase in 2011 and to report a slight profit. The company's backlog stood at an unprecedented combined amount of €4.5 billion ($5.9 billion) for its heavy-lift Ariane 5 series and medium-lift Soyuz 2 ST vehicles. Whereas in 2011, the Soyuz 2 ST conducted two launches, 2012 was to have three Soyuz launches from French Guiana, with two additional commercial launches conducted from its original Baikonur location. Arianespace had also scheduled seven launches of the Ariane 5 series launch vehicle, and conducted the inaugural launch of the Vega small-satellite launcher in 2012. Last year, following an audit of Arianespace and its contractors (a condition for injecting about €240 million ($312 million) into Arianespace over 2 years), ESA determined that additional savings related to the Ariane series would not be possible without wholesale restructuring. Hence, ESA released €217 million ($282 million) allocating half to Arianespace's 2011 accounts, with the remaining funds scheduled to be made available in 2012.[4]

2.2.2 United States

The implementation of the new NASA direction continued to preoccupy the Agency in 2011 and 2012. One of the most controversial aspects of its progress was the Agency's efforts to manage the further development of the cancelled

[1] De Selding, Peter B. "Germany Reaffirms Commitment to $2B Ariane 5 Upgrade." 28 Oct. 2011 Space News 8 May 2012 http://www.spacenews.com/civil/111028-germany-reaffirms-commitment-ariane.html.

[2] De Selding, Peter B. "French Strategy Paper Says ESA Should Fall Under EU Authority." Space News 2 Apr. 2012: 4.

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

[4] De Selding, Peter B. "Arianespace Expects to Post 2011 Profit After 2 Years of Losses." Space News 9 Jan. 2012: 10.

Constellation programme's technological spin offs, the centrepiece of which was the implementation of its 2010 Authorisation Act that mandated the development of a new spacecraft and heavy-lift vehicle. The new Multi-Purpose Crew Vehicle (MPCV) would be based on the groundwork conducted on the Orion capsule, while the launcher would draw upon components designed for the Ares rocket. Throughout the reporting period, NASA's decisions regarding the implementation of this project came under intense legislative scrutiny. For example, Congress members from states where the Constellation was to be manufactured pressed NASA to make use of the programme's existing sub-contractors to develop the new spacecraft and launcher. NASA officials, on the other hand, demonstrated a clear preference to re-open the competition in an effort to cut down development costs for the Constellation spin offs, and avoid an indirect "resurrection" of the cancelled programme. Nevertheless, the cost cutting potential of using already developed components for the new spacecraft and launcher remained an important factor.[5]

In the course of the year, the large divergence of views between the executive and legislative branches of government regarding the future of the U.S. access to space programme became apparent, adversely affecting NASA appropriations. Indeed, in its 2012 NASA spending bill, Congress effectively proposed the nullification of the new NASA direction by multiplying funding for the development of the Constellation spin offs to the point of resurrecting it. For example, it recommended a tenfold increase (to $1.95 billion) to the budget for the development of the Space Launch System (SLS), NASA's future launcher mandated by its 2010 Authorisation Act. These funds were to be used for related research and development alone, meaning that total spending on the project out of NASA's budget would have been even higher. At the same time, it slashed appropriations to develop innovative access to space technologies and fund private spaceflight companies by two thirds, limiting them to $375 million.[6] According to NASA sources, if the spending bill were to be fully implemented, the development of the MPCV and SLS tandem would cost between $41.6 and $63 billion through 2025, depending on the programme's progress and the evolution of NASA's budget. In addition to this, it was foreseen that SLS would not fly before 2018, which would be too late to meaningfully support ISS operations that were scheduled to be terminated in 2020. At the same time, development of the even heavier SLS variant

[5] Leone, Dan. "Senators Call for Competitive Heavy-Lift Propulsion Procurement." 2 June 2011. Space News 25 Jan. 2012 http://www.spacenews.com/civil/110602-senators-competitive-heavy-lift-procurement.html.

[6] Leone, Dan. "Committee Cuts NASA Budget, Adds Cash for SLS, Crew Capsule." 11 July 2011. Space News 25 Jan. 2012 http://www.spacenews.com/policy/110711-committee-cuts-nasa-budget.html; Leone, Dan. "Support for Commercial Crew Transports Also Singled Out for Less Funding in 2012." 18 July 2011. Space News 25 Jan. 2012 http://www.spacenews.com/policy/110718-commercial-crew-transports-less-funding.html.

foreseen in the bill would not be completed before 2030. However, several Congress members doubted the accuracy of these estimates, qualified as an attempt to "sabotage" SLS.[7]

In an indirect reply to these accusations, on 15 September 2011 NASA announced its SLS development plans. The new rocket would have two stages, the first one making extensive use of Space Shuttle components (including its external fuel tank and spacecraft engines), and the second one based on the prototype J-2X engine developed for Ares. According to NASA, the entire development project for SLS, MPCV and their required ground infrastructure was not expected to cost more than $18 billion through 2018. Based on tested and reliable technologies, the development process was not expected to create delays or budget overruns, except in the case of the SLS first stage that would be based on an entirely new concept.[8] Congress's encouragement to rely as much as possible on existing Shuttle and Ares components and their subcontractors in order to minimise technological and budgetary risks was fully reflected in the NASA SLS procurement plan. Nevertheless, experts and some members of Congress questioned whether the adopted approach would in fact be less expensive than opening the contract to competition. In addition to this, the approach could be found in violation of U.S. federal procurement laws that laid down open market procurement rules for all public purchases.[9]

While NASA was struggling to meet Congressional demands on the exploitation of existing Space Shuttle and Constellation components for its future space transportation programme, it also moved toward exploring new propulsion technologies, as required by its new direction. Nuclear propulsion technology was one of the options under study, with an initial budget of $7.5 million allocated to it. Such technologies would prove especially useful to planetary science and exploration missions. For the realisation of further conceptual and development work in this field, NASA asked that plutonium-238 production be restarted by the Department of Energy. However, the programme faced difficulties receiving Congressional approval.[10]

NASA efforts to maximise the gains from technology spin offs during 2011 and 2012 were not limited to the field of space transportation, but also included the exploitation of the ISS. In the interest of maximising the use of in-orbit experiments

[7] Leone, Dan. "Obama Administration Accused of Sabotaging Space Launch System." 9 Sept. 2011. Space News 25 Jan. 2012 http://www.spacenews.com/policy/110909-obama-admin-accused-sabotaging-sls.html.

[8] Leone, Dan. "NASA Commits To Building Mandated Heavy-lift Rocket." 19 Sept. 2011. Space News 25 Jan. 2012 http://www.spacenews.com/civil/110919-nasa-commits-heavy-lift.html.

[9] Leone, Dan. "NASA's SLS Procurement Plans Prompt Call for GAO Investigation." 3 Oct. 2011. Space News 6 Feb. 2012 http://www.spacenews.com/civil/111003-sls-procurement-gao-investigation.html.

[10] Werner, Debra. "NASA Presses on with Pu-238 Restart Despite Congressional Resistance." 26 Sept. 2011. Space News 25 Jan. 2012 http://www.spacenews.com/civil/110926-nasa-presses-pu238-restart.html.

onboard the ISS, NASA increased its outreach activities to the scientific community at large, multiplying opportunities for researchers. In order to do so, it set up a non-governmental organisation to run the ISS National Lab established since 2005. Space related research areas included the creation of an analogue spacecraft for deep-space missions, as well as an engineering lab to test new materials. Other potential research objectives included work on robotic tools and systems, as well as on advanced propulsion, habitation and radiation protection technologies. In addition to this, particular emphasis was placed on broader technological spinoffs that would be able to produce benefits for society at large. Such experiments included the development of satellite application technologies through the onboard testing of cubesats, as well as pharmaceutical research.[11]

2.2.3 Russia

A key plank of Russian space policies during 2011 and 2012 was to improve the country's self-sufficiency across the board, on technological and operational levels. This was particularly true regarding the development of access to space systems, where Russian authorities expressed their desire to maintain their country's forefront position by developing an entirely new space transportation system that would include a new crew/cargo transport vehicle and a medium-class launcher to be used at the new spaceport under construction in the Russian Far East. Although the launcher was expected to be a variation of the Zenith or Angara rockets, the spacecraft would be an entirely new design, in the area of 12–14 t in weight. For the latter, a very tight development schedule was foreseen, with the first automated flight taking place in 2015 and the first manned flight in 2018, possibly with a crew of six.[12]

Another characteristic of Russian space policies during the review period was its increased involvement in international cooperation, especially regarding the present and future of ISS operations. Indeed, in June 2011 the Russian space agency announced its plans to improve ISS exploitation and multiply the scientific experiments conducted onboard. In order to do so, it engaged in improving the scientific facilities of the Russian ISS module, notably with the addition of two new science power platforms and an improved docking module. This modernisation would also end the Russian segment's reliance on the U.S. segment for supplying the power required to conduct experiments on the ISS.[13]

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[11] Morring, Jr., Frank. "Exploration, Earth Spinoffs Planned For NASA At ISS." Aviation Week & Space Technology 20 June 2011: 130.

[12] Wall, Robert. "Russian Industry Eyes New Space Concepts."Aviation Week & Space Technology 22 Aug. 2011: 31.

[13] Pyadushkin, Maxim. "Russia To Increase Research On ISS."Aviation Week & Space Technology 20 June 2011: 135.

2.2.4 Japan

During the reporting period JAXA unveiled its long-term human space exploration strategy. Its objective is to develop a vehicle capable of human spaceflight based on the HTV cargo spacecraft created to support ISS operations. However, neither a budget was allocated to the programme, nor has it received the green light from Japan's Space Activities Committee. Since the original HTV spacecraft was operationally conceived as a part of the ISS programme, development of its human spaceflight capable variant could face a tight programmatic timeline, in view of the possible retirement of the ISS in 2020.[14]

2.2.5 China

It is noteworthy that China explicitly positions itself between industrialized and developing countries. This approach implies a twofold strategy seeking to exploit the country's comparative technological advantages vis-à-vis the latter and remedying its weaknesses compared to the former. It therefore implies that the Chinese officials are keenly aware of their country's unique position on the global space activities' scene, and they are hopeful to fully exploit it. Presumably, this would involve providing affordable space applications to their developing country partners, and engaging in high profile missions with more established space faring nations. In this context, the areas of scientific research, satellite applications, human spaceflight, technological cooperation and satellite services' commercialisation are identified as principal future cooperation areas. When considering this list, it is indeed probable that Chinese officials aspire to establish their country as a satellite applications' provider to emerging economies, and a peer partner to developed space powers for innovative space science, technology and spaceflight missions.

On 11 July 2011 China successfully launched its second data relay satellite Tianlian 1–02. The spacecraft joined the Tianlian 1–01 data-relay satellite, launched in 2008, that supports China's manned flights, while its launch was also considered related to the deployment of its first space station. Thus, China became only the third nation after the United States and Russia to build an operational data-relay service.[15]

In 2011 and 2012 China continued its intensive launching campaign. On 27–29 July 2011 for example, it orbited two satellites in two consecutive days, with the orbiting of a Beidou/Compass navigation satellite, and the experimental

[14] Perrett, Bradley. "Japan Charts Path for Manned Space Missions." Aviation Week & Space Technology 8 Aug 2011: 48; see also "Japan's H2A Rocket Lofts Quasi-Zenith Sat". Space News 20 Sept. 2011: 8.

[15] "2nd Chinese Data-Relay Satellite Reaches Orbit." Space News 18 July 2011: 9.

Shijian SJ-11-02 spacecraft, both built by China Space Co. Ltd.[16] This frantic pace continued throughout the reporting period, undeterred by temporary setbacks, such as the failure of the SJ-11-04 experimental satellite, due to a malfunction of the Long March 2C rocket that carried it.[17]

2.2.6 India

India's space launch programme primarily relies on the use of its Polar Satellite Launch Vehicle (PSLV), capable of carrying 3,700 kg payloads to Low Earth Orbit and 800 kg to Geosynchronous Transfer Orbits (GTO).[18] In 2011, ISRO performed three PSLV launches, deploying the GSAT-12 communications satellite into GEO in July 2011; the two other launches deployed seven scientific, remote sensing, and communications satellites in LEO and SSO in April and October 2011.[19] In 2012, two additional PSLV launches were performed, placing the RISAT 1 remote sensing satellite and France's SPOT 6 remote sensing satellite into SSO in April and September, respectively.[20]

ISRO has also developed its Geosynchronous Satellite Launch Vehicle (GSLV)-Mark I & II over the past decade with mixed results. Capable of launching up to 2,500 kg into GTO, the launch vehicle uses two stage liquid fuel engines and a third stage with a solid fuel one. These launch vehicles are meant to orbit India's new and heavier communication satellites of the GSAT series. The GSLV has exhibited a trend of launch failures from 2006, and has not been used following launch failures in 2010.[21] In the meantime, ISRO has been developing its new GSLV Mk III rocket, meant to launch heavier communication satellites, reaching up to 5,000 kg in weight, into GTO. Rather than upgrading the current GSLV series, this new launcher would merely share a number of components. Its completion will enable full autonomy in launching heavier communications satellites of the INSAT-4 class. This launcher will be the first of its series to field a second stage equipped with a restartable liquid fuel engine that would greatly improve the system's operational flexibility and commercial attractiveness.[22]

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[16] "China Launches Two Satellites in Two Days." Space News 1 Aug. 2011: 8.

[17] "Long March Failure Mars China's Launch Tempo." Space News 22 Aug. 2011: 8.

[18] Federal Aviation Administration. Commercial Space transportation: 2011 Year in Review. Washington DC: FAA, Jan. 2012: 15.

[19] Id. at 14.

[20] Federal Aviation Administration. Commercial Space transportation: 2012 Year in Review. Washington DC: FAA, Jan. 2013: 18.

[21] "GSLV." ISRO 19 Apr. 2013 http://www.isro.org/launchvehicles/GSLV/gslv.aspx.

[22] "GSLV MARK III." ISRO 19 Apr. 2013 http://www.isro.org/Launchvehicles/GSLVMARKIII/mark3.aspx.

2.2.7 Emerging Actors

South Korea did not launched its Korea Space Launch Vehicle (KSLV) in 2011 or 2012, following the vehicle's second launch failure on 10 June 2010. The KSLV consists of a modified Angara first stage manufactured by Khrunichev, and a South Korean solid-fuelled upper stage, and is launched from the Naro Space Center.[23]

In 2012 North Korea conducted two launches of its Unha rocket with a 50 % success rate. The Unha debuted in 2009, and by 2012, had conducted three launch attempts in total. Its latest launch in December 2012 appeared to have successfully placed North Korea's first payload into Low Earth Orbit.[24]

Iran conducted a successful launch of its Safir 2 rocket on 15 June 2011.[25] In the following year, the Persian space power would made three more launch attempts, with a 33 % success rate. With a total of six launches of its Safir 2 rocket since its debut in 2009; by the end of 2012, the total success rate of the launcher stood at 50 %.[26]

2.3 Space Science and Exploration

In this section, space science covers new developments in the origin, evolution and future of the Universe, its galaxies, our Solar System, and other celestial bodies e.g. stars, exoplanets, comets, and asteroids. Space exploration reflects both human and robotic spaceflight missions in process or still developing. While traditional governmental space agencies dominate in both these fields, expanded progress in the latter category can be seen with the further development of commercial exploration, and with the new space powers demonstrating the technology needed to carry out such missions.

2.3.1 Human Spaceflight Activities

Human spaceflight was focused in Low Earth Orbit (LEO), with the International Space Station (ISS) at centre stage, following its formal extension to at least 2020. NASA retired its US Space Shuttle after its final STS-135 mission, launched on 8 July 2011. Roscosmos is the sole launch provider relied on to transport crew regularly to the ISS and, using Progress and Soyuz, it provided ISS cargo resupply

[23] Federal Aviation Administration. Commercial Space transportation: 2010 Year in Review. Washington DC: FAA, Jan. 2011: 15.

[24] Commercial Space transportation: 2012 Year in Review, 18.

[25] Commercial Space transportation: 2011 Year in Review, 14.

[26] Commercial Space transportation: 2012 Year in Review, 19.

services, along with Europe's Automated Transfer Vehicle (ATV) and Japan's H-II Transfer Vehicle (HTV) adding auxiliary support.

ESA's newest batch of astronauts, Samantha Cristoforetti, Alexander Gerst, Andreas Mogensen, Luca Parmitano, Timothy Peake, and Thomas Pesquet, graduated from the European Astronaut Centre (EAC) on 22 November 2010; with Luca Parmitano as the first assigned to ISS Expeditions 36/37 in 2013.[27] Alexander Gerst will fly to the space station as a flight engineer for Expeditions 40/41 in 2014.[28] However, the newly selected astronauts continued their survival training in places such as isolated complex cave systems in the Mediterranean.[29] Meanwhile, ESA astronaut Paolo Nespoli completed a 6-month mission on the ISS, between December 2010 and May 2011, carrying out an intensive programme of experiments, ranging from radiation monitoring to taking measurements that could improve oil recovery in petroleum reservoirs.[30]

ESA astronaut André Kuipers began a 6-month mission on the ISS on 23 December 2011.[31] The first Dutch astronaut to return to space, André Kuipers participated in about 50 experiments covering a wide range of disciplines, while also involved in the rendezvous and docking of ESA's third ATV Edoardo Amaldi, and in berthing SpaceX's Dragon to the ISS.[32] André Kuipers returned to Earth on 1 July 2012.

While the life-cycle of the ISS has been extended by another 5 years, ESA has cancelled the development of Automated Transfer Vehicles (ATVs) from Thales Alenia Space after 2015. Instead, the space agency has directed Thales to look for ways to supply a service module for the Multi-Purpose Crew Vehicle (MPCV) that Lockheed Martin started building under the old Constellation program.[33] Three ATVs had resupplied the ISS by 2012, with the ATV-1 Jules Verne launched in 2008, the ATV-2 Johannes Kepler launched in February 2011, and the ATV-3 Edoardo Amaldi launched on 23 March 2012. With a mass of over 20 t, the ATV-3

[27] "ESA – Human Spaceflight and Exploration – Astronauts – Graduation of Europe's new astronauts." European Space Agency 25 Aug. 2011 http://www.esa.int/esaHS/SEMRFLIRPGG_astronauts_0.html.

[28] "ESA Astronaut Alexander Gerst To Fly To Space Station in 2014." 18 Sept. 2011. ESA 18 Apr. 2013 http://www.esa.int/Our_Activities/Human_Spaceflight/ESA_astronaut_Alexander_Gerst_to_fly_to_Space_Station_in_2014.

[29] "Mission Accomplished: Cave Crew Returns to Earth." 19 Oct. 2011. ESA 18 Apr. 2013 http://www.esa.int/Our_Activities/Human_Spaceflight/Mission_accomplished_cave_crew_returns_to_Earth.

[30] "About the MagISStra Mission." 18 Mar. 2013. ESA 20 Apr. 2013 http://www.esa.int/Our_Activities/Human_Spaceflight/MagISStra/About_the_MagISStra_mission.

[31] "ESA Astronaut André Kuipers Arrives at the Space Station." 23 Dec. 2011. ESA 18 Apr. 2013 http://www.esa.int/Our_Activities/Human_Spaceflight/PromISSe/ESA_astronaut_Andre_Kuipers_arrives_at_the_Space_Station.

[32] "André Kuipers." 30 July 2012. ESA 18 Apr. 2013 http://www.esa.int/Our_Activities/Human_Spaceflight/Delta_Mission/Andre_Kuipers.

[33] Morring, Jr., Frank. "Spacefaring Nations Regroup For Push Beyond LEO." Aviation Week & Space Technology 10 Oct. 2011: 46.

is the heaviest payload the Ariane 5 rocket has ever launched into space.[34] ATV-4 Albert Einstein will launch in 2013, with the final ATV-5 scheduled in 2014.[35]

ESA's Inter-Directorate Exploration Scenarios Working Group which awarded Exploration Scenario Studies contracts to various European companies with the end goal of developing a Strategic Plan for Human Spaceflight and Exploration by mid-2012, has made significant progress in identifying and defining optional building blocks elements and their integration into seven optional roadmaps.[36]

In this context, national space agencies within Europe progressed in their exploration and space science efforts in addition to participating in ESA activities. DLR participated in a number of space activities in the 2011 period; its highlight involved the ATV-2 Johannes Kepler's automated docking to the ISS, with EADS of Bremen in the industrial lead in this ESA Project. And in September 2011, the DLR met with a JAXA delegation to discuss German participation in Japan's Hayabusa-2 mission; the DLR and JAXA agreed on the inclusion of the German small surface lander science package MASCOT in the mission. MASCOT has been developed with CNES science instrumentation.

In 2011, CNES began work on the 'Contract between the State and CNES for the period 2011–2015', signed in October 2010, which tasks CNES to 'make proposals to promote an international exploration programme of the Solar System in renewed governance,' with the aim of an increased role for the European Union in exploration matters. CNES participated in the writing of the ISECG Global Exploration Roadmap, released in September 2011; and was also active in the preparation of the high-level international conference on exploration which took place in November 2011, in Lucca, Italy. France has also participated in the development of ExoMars programme in addition to the exploitation and utilization of the ISS.[37]

NASA launched its final three space shuttle missions in 2011, with Discovery launching on 24 February, Endeavour on 16 May, and Atlantis on 8 July. Discovery was launched on the STS-133/ISS ULF 5 ISS assembly mission; the main payloads were the Permanent Multipurpose Module (PMM) and Express Logistics Carrier 4 (ELC4).[38] Endeavour was launched on the STS-134/ISS ULF 6 ISS assembly mission; its payloads included the Alpha-Magnetic Spectrometer (AMS-02) and

[34] Botta, Oliver. "Factsheet – ATV-3 Edoardo Amaldi begins its journey to the ISS." 19 Mar. 2012. Swiss Space Office 6 May 2012 http://www.sbf.admin.ch/htm/dokumentation/publikationen/raumfahrt/FactSheet_ATV3-e.pdf.

[35] "Ariane 5 ES." ESA Launch Vehicles. 24 Apr. 2012 http://www.esa.int/esaMI/Launchers_Access_to_Space/SEM20W67ESD_0.html.

[36] "Annual Report 2011 of the International Space Exploration Coordination Group." 16 Nov. 2012. International Space Exploration Coordination Group (ISECG) 20 Apr. 2013 http://www.globalspaceexploration.org/c/document_library/get_file?uuid=757abb46-0e23-4bfc-8c1c-dde1320faadc&groupId=10812.

[37] Id.

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

Express Logistics Carrier 3 (ELC3).[39] And Endeavour was launched on the STS-135/ISS ULF 7 mission, the final mission of the US Space Shuttle fleet, carrying astronauts Chris Ferguson, Doug Hurley, Rex Walheim, and Sandy Magnus. Its payloads included the Raffaello Multi-Purpose Logistics Module (RPLM); a Robotic Refuelling Mission (RRM) experiment; and a Pump Module (PM) for the station's Active Thermal Control System (ATCS) that maintains temperatures among avionics, crew members and payloads.[40]

Russia launched four Soyuz spacecraft: TMA-02M on 7 June 2011 with the Expedition 28/29 crew of Mike Fossum, Satoshi Furukawa, and Sergei Volkov[41]; TMA-22 on 14 November 2011 with the Expedition 29/30 crew of Dan Burbank, Anatoly Ivanishin, and Anton Shkaplerov[42]; TMA-03M on 21 December 2011 with the Expedition 30/31 crew of Oleg Kononenko, André Kuipers, and Don Petit[43]; and TMA-04M on 15 May 2012 with the Expedition 31/32 crew of Joseph Michael Acaba, Gennady Padalka and Sergei Revin.[44] Russia also continued its regular resupply of the ISS with four out of five successful launch attempts of the Progress cargo transfer vehicles: M-11M on 21 June 2011, M-12M on 24 August 2011 (launch failure), M-13M on 30 October 2011, M-14M on 25 January 2012, and M-15M on 20 April 2012.[45]

China launched only unmanned missions in 2011 – on 31 October 2011, following the launch of the Tiangong 1 space station, China successfully launched and later docked Shenzhou 8 to the station.[46] Shenzhou 9 will be a manned mission that launches in June 2012.

Analogue campaigns provide safe and affordable environments to test and train in conditions that are similar to those on the Moon and on Mars. In addition to aiding researchers directly in planning for future human exploration, these campaigns have also stimulated a large amount of media interest. The Mars500 520-day isolation study began on 3 June 2010 at the Institute of Biomedical Problems in Moscow. The crew was made up of two Europeans, one Chinese and three

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

[40] "NASA – STS-135." NASA 20 Apr. 2013 http://www.nasa.gov/mission_pages/shuttle/shuttlemissions/sts135/main/index.html.

[41] "Soyuz TMA-02M Crew." Russian Space Web 20 Apr. 2013 http://www.russianspaceweb.com/iss_soyuz_tma02m.html.

[42] "Soyuz TMA-22." Russian Space Web 20 Apr. 2013 http://www.russianspaceweb.com/iss_soyuz_tma22.html.

[43] "Soyuz TMA-03M." Russian Space Web 20 Apr. 2013 http://www.russianspaceweb.com/iss_soyuz_tma03m.html.

[44] "Soyuz TMA-04M." Russian Space Web 20 Apr. 2013 http://www.russianspaceweb.com/iss_soyuz_tma04m.html.

[45] "Spaceflight Now: Tracking Station: Launch Log." 20 Apr. 2013 http://spaceflightnow.com/tracking/launchlog.html.

[46] Federal Aviation Administration. Commercial Space transportation: 2011 Year in Review. Washington DC: FAA, Jan. 2012: 26.

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.[47] The mission ended on 4 November 2011, with the crew having faithfully followed all phases of a real mission, and having performed more than 100 experiments, all linked to the problems of long-duration missions in deep space.[48]

The Canadian Space Agency (CSA) continued operating its Mobile Servicing System (MSS), providing robotic maintenance and resupply operations on the ISS. Dextre and Canadarm2 were utilized in the transfer of cargo from the Japanese HTV vehicle onto the station, and also performed flawlessly during a robotic refuelling demonstration in cooperation with NASA. Canadian robotics successfully replaced critical equipment on the station, and the CSA also continued the upgrade of its ground control operations for Canadarm2 to enable the handling of heavier payloads. In addition to technological upgrades, the CSA also qualified two new Canadian astronauts, Major Jeremy Hansen and Dr. David Saint-Jacques, who completed their Basic Training course requirements and are now eligible for long-duration flight assignment on the ISS.[49]

2.3.2 Lunar Exploration

The Moon stimulated a great deal of interest in this reporting period in regard to the science and exploration activities that were planned or already underway. Europe, China, Japan and India made steady progress toward a robotic and human lunar presence, however budget constraints had the potential to delay well-intentioned initiatives. The US and Russia also maintained their interest in exploring the Moon, and its potential benefit for future Mars exploration.

Looking to future interests in potential surface payloads on the Moon, ESA released a "Call for Declarations of Interest (CDI)" inviting members of the Science and Exploration community to register their interest in proposing a surface payload for the European Lunar Lander mission on 17 January 2012. This call was meant to support discussions with national agencies regarding potential contributions and to inform of preparations for an Announcement of Opportunity (AO) in early 2013. The subsequent AO would lead to the formal selection of the payload to be used as

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

[48] "Welcome Back and Thank You, Mars500." 4 Nov. 2011. ESA 21 Apr. 2013 http://www.esa.int/Our_Activities/Human_Spaceflight/Mars500/Welcome_back_and_thank_you_Mars500.

[49] "Annual Report 2011 of the International Space Exploration Coordination Group." 16 Nov. 2012. International Space Exploration Coordination Group (ISECG) 20 Apr. 2013 http://www.globalspaceexploration.org/c/document_library/get_file?uuid=757abb46-0e23-4bfc-8c1c-dde1320faadc&groupId=10812.

part of the Lunar Lander mission.[50] The mission would land autonomously near the previously unexplored South Pole of the Moon and was 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.[51]

Unfortunately, despite experiencing steady development in the previous reporting period, with Germany backing the ESA Lunar Lander as a top priority, by the end of 2012 funding issues forced the programme to be shelved. The project was put on hold in favour of launcher development, EO, ISS operations, and the joint ExoMars mission with Russia.[52]

NASA's Lunar Reconnaissance Orbiter (LRO), launched in June 2009, is scouting the Moon in preparation 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 has created the most precise and complete topographic maps of the moon yet, and has determined areas of the moon that are in perpetual darkness and in near-continuous sunlight. Helium has been detected in the Moon's atmosphere, and the LRO's mini-RF radar instrument detected small patches of ice in the permanently shadowed craters with temperatures cold enough to permit ice to accumulate. Such areas could be valuable to power hardware in support of a robotic or human mission.[53]

NASA's Acceleration, Reconnection, Turbulence and Electrodynamics of Moon's Interaction with the Sun (ARTEMIS) mission utilized two of the five spacecraft from the Time History of Events and Macroscale Interactions during Substorms (THEMIS) Earth-orbiting mission to orbit the moon to study its lunar environment. The first ARTEMIS spacecraft was inserted into lunar orbit on 27 June 2011; the second on 17 July 2011. Using minimal amounts of fuel and some complex orbit manoeuvres, involving numerous gravity assists from the Moon and the Earth, the spacecraft moved to two different Lagrange points, gravitationally semi-stable points near the Moon. The mission will collect data about the Moon's core, surface composition, and magnetic field, to understand the Moon's environment in space.[54]

NASA's Gravity Recovery And Interior Laboratory (GRAIL) mission was launched on 10 September 2011, with the primary goal of determining the total structure of the lunar interior and advancing understanding of the Moon's thermal

[50] "European Lunar Lander – Call for Declarations of Interest." 17 Jan. 2012. ESA 20 Apr. 2013 http://www.esa.int/Our_Activities/Human_Spaceflight/Human_Spaceflight_Research/European_Lunar_Lander_-_Call_for_Declarations_of_Interest.

[51] "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.

[52] Clark, Stephen. "ESA lunar lander shelved ahead of budget conference." 20 Nov. 2012. Spaceflight Now 21 Apr. 2013 http://spaceflightnow.com/news/n1211/20moonlander/.

[53] "NASA – Lunar Reconnaissance Orbiter (LRO)." NASA 21 Apr. 2013 http://www.nasa.gov/mission_pages/LRO/main/index.html.

[54] "Two NASA Probes Tackle New Mission: Studying the Moon." 19 Jul. 2011. NASA 21 Apr. 2013 http://www.nasa.gov/centers/goddard/news/releases/2011/11-042.html.

evolution. A secondary objective was to extend the knowledge gained from the Moon to the other planets the solar system.[55] Upcoming missions of note include NASA's Lunar Atmosphere and Dust Environment Explorer (LADEE) that will study the Moon's exosphere and dust environment, was scheduled to launch in late summer or early autumn 2013.[56] Further in the future, an International Lunar Network (ILN) is in its study phase, and is expected to launch in March 2018; the mission, involving robotic landers, orbiters, instrumentation, or other significant infrastructure contributions, will operate all upcoming lunar landing missions as nodes in a geophysical network.[57]

In respect to JAXA's lunar strategy and its "Lunar Exploration Strategy of Japan – World-Leading Robotic Lunar Exploration and Establishment of Technology Base towards Manned Space Activity" report published in July 2010, more details on JAXA's proposed roadmap became available. Japan aims to land its SELENE-2 lander and rover on the Moon's surface in 2016, followed by a SELENE-X advanced lander for South Pole missions in 2020.[58]

China's lunar exploration programme proceeded with the launch of its Chang'e-2 second lunar orbiter on 1 October 2011. 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.[59] The Chang'e-3 lunar rover was expected to launch in 2013 as part of phase II of the lunar exploration programme; and China planned to bring 2 kg of lunar soil back to Earth sometime in 2017–2018 as part of phase III of its programme.[60] China was also considering a manned lunar landing sometime between 2025 and 2030.[61]

India's second lunar mission, Chandrayaan 2, was originally envisioned as a joint venture between India and Russia, featuring an ISRO orbiter and rover, and delivered by a Russian-supplied lander. However, following the failure of the Russian Phobos-Grunt mission in December 2011, Russia had to delay construction of the lander, and financial problems that arose afterward made Russia unable to

[55] "Missions – GRAIL – NASA Science NASA 26 Mar. 2013 http://science.nasa.gov/missions/grail/.

[56] "Missions – LADEE – NASA Science." NASA 26 Mar. 2013 http://science.nasa.gov/missions/ladee/.

[57] "Missions – ILN – NASA Science" NASA 26 Mar. 2013 http://science.nasa.gov/missions/iln/.

[58] Sato, Naoki. "JAXA Status of Exploration and Human Space Program." 14 Nov. 2011. JAXA 21 Apr. 2013: 9 http://www.nasa.gov/pdf/605307main_JAXA-Status-(Final)-A-Sato.pdf.

[59] "China announces success of Chang'e-2 lunar probe mission." 8 Nov. 2010. Xinhua News 21 Apr. 2013 http://news.xinhuanet.com/english2010/china/2010-11/08/c_13596211.htm.

[60] Laxman, Srinivas. "China's Unmanned Moon Mission To Bring Back Lunar Soil To Earth." 21 Mar. 2012. Asian Scientist 21 Apr. 2013 http://www.asianscientist.com/topnews/china-unmanned-moon-mission-to-bring-back-lunar-soil-2012/.

[61] "China considering manned lunar landing in 2025–2030." 24 May 2009. China View 21 Apr. 2013 http://news.xinhuanet.com/english/2009-05/24/content_11425131.htm.

provide the lander even if the Chandrayaan 2 were to be launched in 2015. The natural consequence of this factor will mean that the mission profile will have to change moderately. The Chandrayaan-2 mission has five primary payloads on the orbiter, two of which will be improvements on instruments that were onboard the previous Chandrayaan-1 mission; the rover too will carry two additional instruments. And Chandrayaan-2 will be launched on a GSLV using an indigenous cryogenic engine.[62]

Russia continued work on its Luna-Glob and Luna-Grunt series of missions, with the former scheduled to launch in 2014. These missions include a lunar orbiter and surface penetrators, and will contribute to knowledge about the moon's formation. The Luna-Grunt mission would comprise a lunar rover and the Earth return vehicle. The Luna-Glob probe will study the Moon's Polar Regions following NASA's LRO discovery of the presence of water ice in polar craters that are constantly in the sun's shadow. Four high speed penetrators, and a polar probe equipped with a radio beacon to facilitate future landings will be deployed on the Moon's surface.[63] While Roscosmos was unable to provide a lunar lander in time for the 2015 launch of India's Chandrayaan-2 mission, that mission was intended to be part of Roskosmos' Luna-Glob moon exploration programme, and hence, collaboration with India will likely be ongoing.[64]

The Google Lunar X PRIZE is a competition for a total of $30 million in prizes for the first privately-funded teams to safely land a rover on the moon by the end of 2015. To win, the rover must travel at least 500 m on the Moon's surface and send high-definition video, images, and data back to the Earth. To provide additional incentive for accelerated development, the prize will reduce in value after a government-funded mission explores the lunar surface. Team registration closed on 31 December 2010, and there are now 25 teams fundraising, mission planning, and building robots for this race.[65] In press releases on 15 October and 20 December 2010, NASA announced that it would purchase data and contract with some of the teams to demonstrate technology in high technical risk areas associated with low-cost lunar missions.[66]

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[62] Ramachanran, R. "Chandrayaan-2: India to go it alone." 22 Jan. 2013. The Hindu 21 Apr. 2013 http://www.thehindu.com/news/national/chandrayaan2-india-to-go-it-alone/article4329844.ece.

[63] Pavlishev, Boris. "Lunar probe to search for water on Moon." 18 Oct. 2011. radio – The Voice of Russia 21 Apr. 2013 http://english.ruvr.ru/2011/10/18/58931510/.

[64] Ramachanran, R. "Chandrayaan-2: India to go it alone."

[65] "Google Lunar X PRIZE." Google Lunar XPRIZE 26 Mar. 2013 http://www.googlelunarxprize.org/.

[66] Braukus, Michael, Lynnette Madison, and Josh Byerly. "NASA Awards Contracts For Innovative Lunar Demonstrations Data." 15 Oct. 2010. NASA Press Releases 26 Mar. 2013 http://www.nasa.gov/home/hqnews/2010/oct/HQ_10-259_ILDD_Award.html; *see also* Harrington, J.D., and Josh Byerl. "NASA Selects Companies for Further Lunar Demonstrations Data." 20 Dec. 2010. NASA Press Releases 26 Mar. 2013 http://www.nasa.gov/home/hqnews/2010/dec/HQ_10-344_ILDD_Selections.html.

2.3.3 Mars Exploration

The focus for Mars science has for decades remained the investigation of the planet's habitability, in searching for the presence of water. The collected data continues to suggest that Mars was once partially covered by large oceans, and that life could have been possible in many locations on the planet's surface.

ESA's Mars Express orbiter, launched in June 2003, continued its mission 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 winds. The spacecraft observed a crater that was deemed to have once been filled by a lake, revealed by the presence of a delta of dark sediments on the crater's edge. Radar has shown that there may be glaciers hidden beneath the surface of Mars' Phlegra Montes mountain range; and it has also detected sediments that are reminiscent of an ocean floor within the previously identified boundaries of ancient shorelines. Moreover, a planetary alignment between Earth and Mars, both passing through a gust of the same solar wind, allowed researchers to compare the protective effects of Earth's magnetic field with Mars' lack of a magnetic field, showing that the existence of a magnetic field is vital for keeping an atmosphere in place. And gravity mapping data collected over a period of 5 years allowed researchers to determine that Martian volcanic lava grew denser over time and that the thickness of the planet's rigid outer layers varies in Mars' Tharsis volcanic region.[67]

The ESA ExoMars mission continued its development, undergoing a revision in spring 2011 following the uncertainties in funding that arose from NASA's constraints and eventual withdrawal.[68] Envisaged as an orbiter to be launched in 2016 with a rover following 2 years later, its payload selection was completed on 2 August 2010.[69] The orbiter features a 1,000-fold increase in sensitivity over previous Mars orbiters, and will study the chemical composition of the planet. The System Preliminary Design Review for the orbiter and the rover was completed by NASA in December 2010.[70] On 29 March 2011, NASA advised ESA that it

[67] "ESA – Mars Express." European Space Agency. 26 Mar. 2013 http://www.esa.int/esaMI/Mars_Express/index.html.

[68] "Annual Report 2011 of the International Space Exploration Coordination Group" International Space Exploration Coordination Group (ISECG) 26 Mar. 2013 http://www.globalspaceexploration.org/c/document_library/get_file?uuid=757abb46-0e23-4bfc-8c1c-dde1320faadc&groupId=10812.

[69] "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.

[70] "Annual Report 2010 of the International Space Exploration Coordination Group" International Space Exploration Coordination Group (ISECG) 26 Mar. 2013 http://www.globalspaceexploration.org/c/document_library/get_file?uuid=927d699a-2126-4205-b182-2fc8409eff88&groupId=10812.

could not fund its rover, leading ESA to issue stop-work orders for all ExoMars contracts. Contract payments were expected to resume in July.[71] By 13 February 2012, NASA announced on that it would have to withdraw entirely for budgetary reasons, with Roscosmos replacing the NASA as a main partner in the mission at the end of the reporting period.[72]

NASA's Mars Odyssey mission, launched on 7 April 2001, is the longest-operating spacecraft to be sent to Mars. Orbiting the planet since 24 Oct. 2001, some of its contributions include: confirming the mineral exposure that was selected as the landing site for NASA's Mars Exploration Rover Opportunity and helping to identify safe landing sites for NASA's Mars Phoenix lander; discovering carbon-dioxide gas jets at the south polar ice cap during the spring season; finding chloride salt deposits across the planet; and producing the best available global image map of Mars. At the end of this reporting period, the spacecraft put itself into temporary standby safe mode after unexpected characteristics of movement in one of its reaction wheels were detected. The spacecraft also served as a communications relay for the two Mars Exploration Rovers.[73] The Mars Exploration Rover (MER) Opportunity reached the Endeavour crater, examining scientific targets in the surrounding area and finding mineral veins that were deposited by water. NASA's MER Spirit, was deemed to have completed its mission on 25 March 2011, following failed attempts to communicate with the rover beyond the last transmission received on 22 March 2010.[74]

NASA's Mars Reconnaissance Orbiter (MRO) continued to provide valuable data for the purpose of determining whether or not life has existed on Mars, characterising the climate and geology, and preparing for future human exploration. Launched in 2005 and undergoing a 7 month journey to the red planet, the MRO reached its 5-year mark orbiting Mars on 10 March 2011. During a very productive year, it returned data that suggests that water still flows in some places on Mars, depicted as dark, finger-like features which appear and extend down some Martian slopes that change during the seasons. The MRO's highest resolution camera was shut down for a period of 2 weeks as a precaution due to improperly received commands for an observation by the memory module controlling one of the instrument's 14 electronic detectors; the camera began making do with 13 detectors while running diagnostics on the malfunctioning detector. A new study suggests that if Mars ever incubated life, the longest lasting habitats were most likely below the surface, in the clay minerals that formed in the shallow subsurface all over the planet. Sand dunes, once thought stationary when observed with lower resolution cameras in previous decades, were caught migrating by several meters per year in

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

[72] De Selding, Peter. "ExoMars Wins One-month Reprieve." SpaceNews 21 May 2012: 8.

[73] "Mars Odyssey." NASA Jet Propulsion Laboratory, California Institute of Technology" 26 Mar. 2013 http://mars.jpl.nasa.gov/odyssey/.

[74] "Mars Exploration Rover Mission: Home." NASA Jet Propulsion Laboratory, California Institute of Technology 26 Mar. 2013 http://marsrover.nasa.gov/home/index.html.

dozens of locations on the planet, following years of monitoring the Martian surface. In fact, some dunes similar in scale to those on Earth, i.e. some as thick as 61 m, were observed to be moving as coherent units across the landscape.[75]

The NASA Mars Science Laboratory (MSL), nicknamed Curiosity, launched on 26 November 2011. On completing its 8-month journey, the rover reached Mars in August 2012. As the largest rover to ever land on Mars, its mission will run for at least 687 Earth days (a full Martian year), and will study Mars's habitability. The rover has eight scientific objectives, i.e. determining the nature and inventory of organic carbon compounds; conducting an inventory of the chemical building blocks of life; identifying features that may represent the effects of biological processes; investigating the chemical, isotopic, and mineralogical composition of Martian geological materials; it will interpret the processes that have formed and modified rocks and soils; assess four-billion-year timescale atmospheric evolution processes; determine the present state, distribution, and cycling of water and carbon dioxide; and it will also characterize the broad spectrum of surface radiation, including galactic cosmic radiation, solar proton events, and secondary neutrons.[76]

Next, NASA was to launch the Mars Atmosphere and Volatile EvolutioN (MAVEN) mission on 18 Nov. 2013, to reach Mars on 22 Sept. 2014. MAVEN aims to explore the planet's upper atmosphere, ionosphere and interactions with the Sun and solar wind, which will be used to determine the role that the loss to space of volatile compounds from the Mars atmosphere has played in the history of Mars' habitability.[77]

The Phobos-Grunt mission missed its window in travelling to Mars, as it did not perform its scheduled burn to begin the needed trajectory. The joint Russian-Chinese Phobos-Grunt and Yinghuo-1 mission aimed at collecting approximately 100–200 g of samples from the moon Phobos, to be deposited in a return capsule and launched back to Earth.[78] Since missing its further burn, thus only reaching an elliptical Earth orbit, it re-entered the atmosphere on 15 Jan. 2012.[79]

[75] "Mars Reconnaissance Orbiter." NASA Jet Propulsion Laboratory, California Institute of Technology 26 Mar. 2013 http://marsprogram.jpl.nasa.gov/mro/.

[76] Mars Science Laboratory (MSL). 14 May. 2012. NASA NSSDC 14 Jan. 2013 http://nssdc.gsfc.nasa.gov/nmc/spacecraftDisplay.do?id=2011-070A.

[77] "MAVEN." University of Colorado at Boulder, Laboratory for Atmospheric and Space Physics 14 Jan. 2013. http://lasp.colorado.edu/home/maven/.

[78] Phobos-Grunt. 14 May. 2012. NASA NSSDC 14 Jan. 2013 http://nssdc.gsfc.nasa.gov/nmc/spacecraftDisplay.do?id=2011-065A.

[79] Amos, Jonathan. "Phobos-Grunt: Failed probe 'falls over Pacific'." 15 Jan. 2012. BBC News 14 Jan. 2013 http://www.bbc.co.uk/news/science-environment-16491457.

2.3.4 Saturn Exploration

The Cassini-Huygens mission, a joint mission of NASA, ESA and ASI, was launched in 1997. Reaching Saturn in 2004, Cassini went on to drop the Huygens probe onto Saturn's moon, Titan. The renamed Cassini Solstice Mission was supposed to end in June 2008, however, funding was provided to allow continued operation providing new insights on Saturn and its moons; it is now slated to explore Saturn until 2017.[80] By 2011, the 14 year old mission had returned images of a storm that was 500 times larger than the storm Cassini witnessed between late 2009 and early 2010; this storm covered approximately four billion square kilometers and was wrapped around the entire planet.[81]

On Enceladus, plumes of 'dusty plasma' emanating from the icy geyser moon were believed to have been observed. In addition to recording the results that were previously only theoretical, Cassini's instruments showed that the 'heavy' and 'light' species of charged particles in normal plasma were actually reversed near the plume spraying from the moon's south polar region.[82] The complexity of the plasma was increased by the presence of ionized water vapour that attached to dust particles; changing its properties and producing a new collective behaviour. Being a rare opportunity, as dusty plasma is thought to exist in comet tails and dust rings around the Sun, Cassini flew through the dusty plasma and directly measured its characteristics in place.[83] Moreover, recent scientific results from a flythrough of the plumes also show strong evidence of the existence of large-scale saltwater reservoirs beneath Encelaus' crust.[84]

2.3.5 Venus Exploration

ESA's Venus Express mission was launched in 1995 and reached Venus in 2006. It studies Venus's atmosphere, including its dynamics and chemistry, atmosphere-surface interactions, and interactions with solar wind, to address open questions such as the workings of the complex global dynamics of the planet, its cloud system, processes that govern the chemical state of the atmosphere, and the 'green-house effect' in its global climate. While Venus Express already detected the escape of ionic hydrogen and oxygen in the ratio of two to one in the previous

[80] Mason, Betsy. "Cassini Gets Life Extension to Explore Saturn Until 2017." 3 Feb. 2010. WIRED 18 Dec. 2012 http://www.wired.com/wiredscience/2010/02/cassini-life-extension-2017/.

[81] SpaceNews Staff. "NASA's Cassini Spacecraft Witnesses Big Saturn Storm." 11 Jul. 2011. SpaceNews 18 Dec. 2012 http://www.spacenews.com/article/nasas-cassini-spacecraft-witnesses-big-saturn-storm.

[82] "Enceladus plume is a new kind of Plasma Laboratory." 31 May 2012. NASA Cassini 18 Dec. 2012 http://saturn.jpl.nasa.gov/news/newsreleases/newsrelease20120531/

[83] Id.

[84] Id.

reporting period; from this, it was inferred that solar ultraviolet radiation streams into the atmosphere and breaks up the water molecules into atoms. Now, Venus Express has discovered an ozone layer high in Venus's atmosphere. Previously detected only on Earth and Mars, this discovery offers a useful comparison for searching for life outside of Earth. Three oxygen atoms make up the ozone molecule, which in the Venus atmosphere is thought to be formed when sunlight breaks up carbon dioxide molecules, releasing oxygen atoms which are then swept to the dark side of the planet by atmospheric winds; they subsequently combine to form two-atom oxygen molecules, and occasionally, three-atom ozone molecules.[85]

Moreover, Venus Express discovered that the planet rotated at a slower rate than first determined by NASA's Magellan orbiter in the early 1990s. Since last being studied, surface features on Venus had been displaced by up to 20 km from where they were expected. Over a 4 year period, Magellan enabled scientists to determine the length of the day on Venus to be equal to 243.0185 Earth Days. Nearly two decades later, those surface features could only be lined up with those observed by Magellan if the length of the Venus day is on average 6.5 min longer than Magellan's measurements. These measurements help to determine whether Venus has a solid or liquid core; if it had a solid core, the planet's rotation would react less to external forces because its mass would be more concentrated towards the centre. Venus's dense atmosphere (i.e. more than 90 times the pressure of Earth's) and high-speed weather systems are the most important of those forces, and they are believed to change the planet's rotation rate by causing friction with the planet's surface. Earth experiences a similar but vastly diminished effect (largely caused by wind and tides), where the length of a day can change by roughly a millisecond, depending on wind patterns and temperatures occurring over the course of a year.[86]

The Russian Federal Space Programme is planning to further build on its Venera programme – first initiated in the early 1960s. Throughout the following decades, the Venera programme launched a series of probes, landers, orbiters, and conducted repeated impact experiments and flybys up to 1985.[87] The Venera-D mission is currently being developed by the Russian Federal Space Programme, and it is scheduled for launch in 2017. The mission will comprise of a lander, orbiter and a 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

[85] Venus Express. "ESA finds that Venus has an ozone layer too." 6 Oct. 2011. ESA 9 Jan. 2012 http://www.esa.int/Our_Activities/Space_Science/Venus_Express/ESA_finds_that_Venus_has_an_ozone_layer_too.

[86] Venus Express. "Could Venus be shifting gear?" 10 Feb. 2012. ESA 9 Jan. 2012 http://www.esa.int/Our_Activities/Space_Science/Venus_Express/Could_Venus_be_shifting_gear.

[87] Williams, David R. "Chronology of Venus Exploration." 29 Jun. 2011. NASA 10 Jan. 2013 http://nssdc.gsfc.nasa.gov/planetary/chronology_venus.html.

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.[88] 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-life lander.[88]

2.3.6 Mercury Exploration

Running as a partnership between ESA and JAXA, BepiColombo will be Europe's first mission to Mercury. The mission is targeted for a launch in 2015 with arrival at Mercury in 2022 for a 1-year mission with a possible 1-year extension. To be executed under ESA leadership, BepiColumbo is currently in the implementation stage, to be eventually launched on the Ariane 5 launch vehicle. 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.[89]

MErcury Surface, Space ENvironment, GEochemistry and Ranging (MESSENGER), a NASA discovery-class mission, was launched in August 2004. On 18 March 2011, it became the first spacecraft to orbit the planet, following three flybys. By 17 March 2012, MESSENGER had completed its year-long campaign to perform the first complete reconnaissance of the geochemistry, geophysics, geological history, atmosphere, magnetosphere, and plasma environment of Mercury. On 18 March 2012, it began its extended mission to build on its discoveries.[90] The mission is designed to address six broad scientific questions: why Mercury is so dense, the planet's geological 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 on Mercury. MESSENGER was designed and built by the Johns Hopkins University Applied Physics Laboratory (APL).[91]

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[88] "VENERA-D: ВЕНЕРА: Изучение продолжается." 10 Mar. 2011. Roscosmos 25 Aug. 2011 http://venera-d.cosmos.ru/index.php?id=692&tx_ttnews[tt_news]=1288&cHash=f9bfd2c6e7616171412b316d206d73a4.

[89] BepiColombo. ESA Science & Technology 13 Jan. 2013 http://sci.esa.int/science-e/www/area/index.cfm?fareaid=30.

[90] MESSENGER Completes Primary Mission at Mercury, Settles in for Another Year. 19 Mar. 2012. MESSENGER 13 Jan. 2013 http://messenger.jhuapl.edu/news_room/details.php?id=197.

[91] "MESSENGER: Mercury Surface, Space Environment, Geochemistry, and Ranging: Mercury Orbit Insertion." Press kit. NASA 25 Aug. 2011 http://www.nasa.gov/pdf/525164main_MercuryMOI_PK.pdf.

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. The mission has been placed in the L-class mission category, to be launched in the early 2020s. The primary goals of the mission are to characterize Ganymede as a planetary object including its potential habitability and to study the Jupiter system as an archetype for gas giants.[92]

NASA's new frontiers mission to Jupiter, Juno, was launched on an Atlas V55 on 15 August 2011. The $1.1 billion spacecraft carries an assortment of instruments, including a Gravity Science Experiment, a Magnetometer (MAG), a Microwave Radiometer (MWR), a Jupiter Energetic Particle Detector Instrument (JEDI), Jovian Auroral Distributions Experiment (JADE), Waves, a Jovian Infrared Auroral Mapper (JIRAM), Ultraviolet Imaging Spectrograph (UVS), and a JunoCam. 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 auroras.[93]

2.3.8 Solar Observation

Continued observation of the Sun's external activity has the benefit of improving our understanding of its interior, its corona, the monitoring of solar wind and its consequences on Earth and its neighbouring planets. Coronal mass ejections (CMEs) from the Sun emit surges of charged particles in directions that may cross Earth's path and can damage satellites, impede space-based services and affect the terrestrial electrical infrastructure.

ESA's PRoject for OnBoard Autonomy (PROBA)-2 microsatellite continued its solar observation activity, tracking spikes in CMEs ejecting from the Sun at the beginning of the reporting period that just skimmed Earth on 9 June 2011, and brought with it a burst of radio energy.[94] It also tracked Comet Lovejoy's 120,000 km perigee with the Sun, providing a close-up extreme ultraviolet view

[92] Mission Summary. ESMJ-Laplace. 16 Mar. 2012. ESA Science & Technology 14 Jan. 2013 http://sci.esa.int/science-e/www/area/index.cfm?fareaid=107.

[93] "NASA – Juno." NASA 4 Mar. 2013 http://www.nasa.gov/mission_pages/juno/main/index.html.

[94] "Small Sun-Watcher Proba-2 Offers Detailed View of Massive Solar Eruption." 9 June 2011. ESA 17 Apr. 2013 http://www.esa.int/Our_Activities/Technology/Small_Sun-watcher_Proba-2_offers_detailed_view_of_massive_solar_eruption.

of the comet's survival.[95] By the end of 2011, the mission had gathered about 400,000 images of the Sun, and made nearly 20 million in-situ ionospheric observations.[96]

CNES' solar metrology mission 'PICARD', launched on 15 June 2010, aims to improve our knowledge of how the Sun functions and of 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. In this reporting period, among additional findings, the spacecraft observed a partial Sun eclipse and an unusual Sun-spot that extended eight times Earth's diameter.[97]

The Solar Dynamics Observatory (SDO) is the first NASA mission to operate under its Living With a Star (LWS) programme. Launched on 11 February 2010, its objectives are to determine 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. The spacecraft is comprised of three scientific experiments: the Atmospheric Imaging Assembly (AIA), EUV Variability Experiment (EVE) and the Helioseismic and Magnetic Imager (HMI).[98] The SDO's global view of the Sun facilitates research that focuses on the previously unrecorded real fine structure of the star.[99]

The SOlar and Heliospheric Observatory (SOHO) continued to operate during this reporting period. As an international cooperation project between ESA and NASA, this EADS Astrium-et al.-built spacecraft was launched on 2 December 1995. The spacecraft orbits around the Sun in step with the Earth, at a distance of 1.5 million km from Earth, enabling an uninterrupted view of the star.[100] Its scientific objectives are to investigate the solar interior and explain the extreme 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

[95] "Proba-2 Tracks Comet Lovejoy Through Sun's Fiery Corona." 22 Dec. 2011. ESA 17 Apr. 2013 http://www.esa.int/Our_Activities/Technology/Proba-2_tracks_Comet_Lovejoy_through_Sun_s_fiery_corona.

[96] "ESA's Space Weather Station Proba-2 Tracks Stormy Sun." 2 Dec. 2011. ESA 17 Apr. 2013 http://www.esa.int/Our_Activities/Technology/ESA_s_space_weather_station_Proba-2_tracks_stormy_Sun.

[97] "PICARD NEWS." CNES 17 Apr. 2013 http://smsc.cnes.fr/PICARD/GP_actualites.htm.

[98] "SDO | Solar Dynamics Observatory." NASA Goddard Space Flight Center 4 Mar. 2013 http://sdo.gsfc.nasa.gov/.

[99] SpaceNews Staff. "NASA Boasts Big Results from 5-minute Spaceflight." 28 Jan. 2013 SpaceNews 4 Mar. 2013 http://www.spacenews.com/article/nasa-boasts-big-results-from-5-minute-spaceflight.

[100] About the SOHO Mission. "SOHO Fact Sheet." SOHO – Solar and Heliospheric Observatory 4 Mar. 2013 http://sohowww.nascom.nasa.gov/about/docs/SOHO_Fact_Sheet.pdf.

impact of solar variability on the Earth's climate.[101] SOHO has helped to define what occurs during CMEs by providing simultaneous images of reactions on the sun and further out in the corona.[102] The SOHO mission has very significantly exceeded its expected lifetime of 2 years and on 19 November 2010, it was extended until 31 December 2014.[103]

In addition to SOHO, NASA's Solar TErrestrial RElations Observatory (STEREO) continued to operate. STEREO is made up of two space-based observatories, i.e. STEREO-A travelling in a smaller and faster orbit (ahead of Earth's orbit), and STEREO-B trailing behind with a larger and slower orbit; these spacecraft are now 180° apart relative to the Sun.[104] They provide new insights into CMEs, including detecting and processing data that enables the tracking of CMEs headed toward Earth. STEREO also contributes to crowd-sourced data analysis, using data analysed by the public to make a predictions of solar storms that can reach Earth, it has 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.[105] The Deep Space Climate ObserVatoRy (DSCOVR), originally built to conduct observations of the Earth's climate will be re-purposed as a space weather and solar storm warning satellite,[106] to be launched by SpaceX in 2014.[107]

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. In this period, its solar optical telescope followed a special observation programme taking images of Comet Lovejoy as it passed by the Sun.[108] 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

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

[102] "Approaching 17 Years Of Observations For ESA/NASA's SOHO Spacecraft." 5 Dec. 2012. redOrbit 4 Mar. 2013 http://www.redorbit.com/news/space/1112742788/17-years-observations-esa-nasa-soho-spacecraft-120512/.

[103] SOHO. The Project Main Steps. 29 Nov. 2012. CNES 5 Mar. 2013 http://smsc.cnes.fr/SOHO/.

[104] "First Ever STEREO Images of the Entire Sun." 6 Feb. 2011. NASA 5 Mar. 2013 http://www.nasa.gov/mission_pages/stereo/news/entire-sun.html.

[105] "NASA – STEREO." NASA 5 Mar. 2013 http://www.nasa.gov/mission_pages/stereo/main/index.html.

[106] 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/.

[107] Leone, Dan. "SpaceX To Launch Two Military Satellites." 5 Dec. 2012. SpaceNews 5 Mar. 2013 http://www.spacenews.com/article/spacex-to-launch-two-military-satellites.

[108] "Hinode – News Archive." 16 Jan. 2012. NASA 17 Apr. 2013 http://solarb.msfc.nasa.gov/news_resources_2012.html.

particles, the local interstellar medium and galactic matter, continued to collect data to improve forecasts and warnings of solar storms, and continues to be expected to maintain its orbit until 2024.[109] 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 also continued to operate. By 22 Feb 2012, the spacecraft had undergone its third 5-week anneal procedure to rejuvenate its detectors from the effects of radiation damage, and had resumed collecting solar X-ray and gamma-ray data.[110]

2.3.9 Outer Solar System Exploration and Observation

Near-Earth Objects continue to be widely discussed as a target for human exploration, with renewed interest in the study of comets and asteroids. In addition to this topic, the following section aims, to cover some of the significant discoveries made about celestial bodies outside the Solar System.

Following Rosetta's successful flyby of the asteroid Lutetia on 10 July 2010, and its discovery that an object previously thought to be a comet is in fact a pair of colliding asteroids, the probe was put into hibernation while transiting in deep space on 8 June 2011. In 2014, Rosetta will release a lander that will make the first landing on a cometary nucleus, that of 67P/Churyumov-Gerasimenko.[111] The Herschel infrared telescope continued making significant discoveries in this reporting period, finding Saturn's moon Enceladus to be the only moon in the solar system to influence the chemical composition of its parent by continuously expelling jets of water into Saturn's upper atmosphere.[112] It made the first confirmed detection of oxygen molecules created in the nearby Orion star-forming complex.[113] In one finding, Herschel detected water in a comet with nearly the exact level of deuterium as water on Earth, adding support to the idea of comets as the primary source of Earth's oceans,[114] while further observations revealed evidence of a vast amount of water vapour emanating from ice on dust grains in a disc around the TW Hydrae

[109] "Advanced Composition Explorer (ACE) Mission Overview." California Institute of Technology 17 Apr. 2013 http://www.srl.caltech.edu/ACE/ace_mission.html.

[110] "RHESSI STATUS." 22 Feb. 2012. NASA 17 Apr. 2013 http://hesperia.gsfc.nasa.gov/rhessi2/home/news-ressources/status/.

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

[112] "Enceladus rains water onto Saturn." 26 July 2011. ESA 17 Apr. 2013 http://www.esa.int/Our_Activities/Space_Science/Herschel/Enceladus_rains_water_onto_Saturn.

[113] "Astronomers Searching for Oxygen Can Breathe More Easily." 1 Aug. 2011. ESA 17 Apr. 2013 http://www.esa.int/Our_Activities/Space_Science/Herschel/Astronomers_searching_for_oxygen_can_breathe_more_easily.

[114] "Did Earth's Oceans Come From Comets?" 5 Oct. 2011. ESA 17 Apr. 2013 http://www.esa.int/Our_Activities/Space_Science/Herschel/Did_Earth_s_oceans_come_from_comets.

star.[115] 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. In this reporting period, Planck completed its survey of the remnant light from the Big Bang, revealing previously undiscovered islands of cold gas and a haze of microwaves throughout the galaxy.[116]

The COnvection, ROtation and planetary Transits (COROT) space telescope operated by CNES probes the inner structure of stars using stellar seismology and is used to detect extrasolar planets. This astronomy mission, launched on 27 December 2006, announced the discovery of ten new planets at the beginning of this reporting period.[117]

On 4 November 2010, the Extrasolar Planet Observations and characterisation/deep impact eXtended Investigation (EPOXI) flew past comet Hartley 2, returning images of the comet that provide new information on the role comets may have in planetary formation.[118]

Exoplanets are planets that orbit stars other than our solar system's Sun. NASA's Kepler space telescope mission was recently extended to 2016 with the continued aim of finding Earth-sized planets in the habitable zone of other solar-like oscillating stars, where liquid water could exist on their surfaces.[119] This reporting period resulted in the discovery of Kepler-14b, a planet 8.4 times the mass of Jupiter with an orbital period of nearly 7 days.[120] The recently discovered TrES-2b was found to be the darkest known exoplanet reflecting less than 1 % of the starlight falling on it; believed to be due to extremely high temperatures and tidal lock with its star.[121] Kepler-22b was found to be the first planet in the habitable zone of a sun-like star.[122] And a new class of circumbinary planets was established when the Kepler-

[115] "Herschel Detects Abundant Water in Planet-Forming Disc." 20 Oct. 2011. ESA 17 Apr. 2013 http://www.esa.int/Our_Activities/Space_Science/Herschel/Herschel_detects_abundant_water_in_planet-forming_disc.

[116] "Planck Steps Closer to the Cosmic Blueprint." 13 Feb. 2012 ESA 17 Apr. 2013 http://www.esa.int/Our_Activities/Space_Science/Planck/Planck_steps_closer_to_the_cosmic_blueprint.

[117] "CaRoT discovers 10 new extra-solar planets." 14 June 2011. CNES 17 Apr. 2013 http://smsc.cnes.fr/COROT/GP_actualite.htm.

[118] "SOHO Watches a Comet Fading Away." 28 Jul. 2011. NASA 17 Apr. 2013 http://www.nasa.gov/mission_pages/epoxi/index.html.

[119] "NASA Approves Kepler Mission Extension." 4 Apr. 2012. NASA 16 Apr. 2013 http://kepler.nasa.gov/news/nasakeplernews/index.cfm?FuseAction=ShowNews&NewsID=199.

[120] "Kepler-14b." 25 Oct 2011. NASA 16 Apr. 2013 http://kepler.nasa.gov/Mission/discoveries/kepler14b/.

[121] "Alien World is Blacker than Coal." 11 Aug. 2011. Harvard-Smithsonian Center for Astrophysics 16 Apr. 2013 http://www.cfa.harvard.edu/news/2011/pr201121.html.

[122] "Kepler-22b, our first planet in the habitable zone of a Sun-like Star." 5 Dec. 2011. NASA 16 Apr. 2013 http://kepler.nasa.gov/news/nasakeplernews/index.cfm?FuseAction=ShowNews&NewsID=165.

35 planet was found to orbit two sun-like stars that eclipsed one another at irregular intervals.[123]

In the reporting period, NASA's NEO Wide-field Infrared Survey Explorer (WISE) mission observed Earth's first Trojan asteroid that shares its orbit at a stable distance.[124] It also discovered the coolest class of stars yet, with some of its confirmed 100 brown dwarfs bearing estimated atmospheric temperatures that are near 25 °C.[125] And data from the WISE mission has lead to the best estimate of potentially hazardous asteroids (PHAs) that represent an impact hazard with Earth; finding roughly 4,700 ± 1,500 PHAs with diameters larger than 100 m.[126]

In addition to discovering 14 of the coldest stars known in our universe,[127] and contributing to observations of dust clouds that may help identify Earth-like planets around other stars,[128] the recently-extended Spitzer infrared space telescope mission observed infrared light emanating from a "super-Earth" planet in another solar system[129] and observed an unprecedented simultaneous elliptical galaxy with another thin disk existing in its interior.[130]

The James Webb Space Telescope (JWST), the successor to the Hubble Space Telescope (HST), survived the broad US budget cuts that threatened to derail the spacecraft from its planned 2018 Ariane 5 launch date. The spacecraft will investigate the formation of the first galaxies, planetary systems, and stars. Segments of the large primary mirror already underwent cryogenic testing throughout 2011.[131] And on 9 May 2012, NASA received the JWST's first completed instrument – the highly light-sensitive European-built Mid-Infrared Instrument (MIRI).[132]

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[123] "Kepler Discovery Establishes New Class of Planetary System." 11 Jan. 2012. NASA 16 Apr. 2013 http://kepler.nasa.gov/news/nasakeplernews/index.cfm?FuseAction=ShowNews&NewsID=180.

[124] "NASA's WISE Mission Finds First Trojan Asteroid Sharing Earth's Orbit." 27 Jul. 2011. NASA 16 Apr. 2013 http://www.nasa.gov/mission_pages/WISE/news/wise20110727.html.

[125] "NASA's WISE Mission Discovers Coolest Class of Stars." 23 Aug. 2011. NASA 16 Apr. 2013 http://www.nasa.gov/mission_pages/WISE/news/wise20110823.html.

[126] "NASA Survey Counts Potentially Hazardous Asteroids." 16 May 2012. NASA 16 Apr. 2013 http://www.nasa.gov/mission_pages/WISE/news/wise20120516.html.

[127] "The Coolest Stars Come Out of the Dark." 24 June 2010. NASA 15 Apr. 2013 http://www.spitzer.caltech.edu/news/1137-feature10-08-The-Coolest-Stars-Come-Out-of-the-Dark.

[128] "Catch a Planet by the tail." 9 July 2010. NASA 15 Apr. 2013 http://www.spitzer.caltech.edu/news/1150-feature10-10-Catch-a-Planet-By-the-Tail.

[129] "NASA's Spitzer Sees The Light of Alien 'Super Earth'." 8 May 2012 NASA 16 Apr. 2013 http://www.spitzer.caltech.edu/news/1419-ssc2012-07-NASA-s-Spitzer-Sees-The-Light-of-Alien-Super-Earth-.

[130] "NASA's Spitzer Finds Galaxy with Split Personality." 24 Apr. 2012. NASA 16 Apr. 2013 http://www.spitzer.caltech.edu/news/1412-ssc2012-06-NASA-S-Spitzer-Finds-Galaxy-with-Split-Personality.

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

[132] SpaceNews Staff. "First JWST Instrument Handed Over to NASA." 14 May 2012. SpaceNews 15 Apr. 2013 http://www.spacenews.com/article/first-jwst-instrument-handed-over-nasa.

The 'Peter and Patricia Gruber Foundation', in association with Yale University, awarded the 2011 Gruber Cosmology Prize to four astronomers for finding evidence of dark matter. The team, led by Marc Davis of the University of California, Berkeley, with George Efstathiou (Cambridge, England), Carlos Frenk (Durham University, England), and Simon White (Max Planck Institute, Germany), created key computer simulations in the 1990s that mapped the large-scale distribution of matter in the universe. On realising that the universe was not just a uniform scattering of galaxies, but a cosmic web of galaxies grouped into filaments separated by expansive voids, Davis and his team developed computer models that conducted vast calculations to simulate billions of years of galaxy evolution; these models show that a type of cold dark matter could produce the topography observed in space. These 20+ year old simulations convinced most experts of the existence of dark matter, despite the subsequent fruitless search to find out what dark matter is. Ten years later, "dark energy" was discovered to permeate the universe. Today, cosmologists estimate that the universe is composed of 4.6 % 'ordinary' matter (i.e. stars, planets, life, etc.), 23.3 % dark matter, and 72.1 % dark energy.[133]

In late 2010, NASA's Rossi X-ray Timing Explorer (RXTE) satellite detected what astronomers believe is the first neutron star to burst the way that models predict. Researchers had developed models to theoretically predict how a neutron star bursts, but the X-ray observations from nearly 100 exploding neutron stars over a period of three decades failed to validate those predictions. Neutron star bursts were mostly seen at low mass-accretion rates, while bursts at high-mass accretion rates were rare, i.e. they had not observed more plasma exiting at a more frequent rate in these bursts. However, the RXTE satellite detected X-ray spikes from a binary star system in Terzan 5, whose data showed evidence of higher mass-accretion rates, validating the theoretical prediction. It should be noted that the rotation of a neutron star may affect its thermonuclear burning, possibly causing friction between layers of plasma and the neutron star's surface, thereby affecting the rate of nuclear burning. In this latest case, the observed neutron star had a much slower rate of rotation than previously observed neutron stars, i.e. 11 rotations per second compared with typical neutron stars rotating between 200 and 600 times per second. Newer models may need to consider rotation when predicting how a neutron star bursts.[134]

[133] Sanders, Robert. "Gruber Cosmology Prize honors 'dark matter' astronomers." 1 June 2011. UC Berkeley News Center 18 Mar. 2013 http://newscenter.berkeley.edu/2011/06/01/gruber-cosmology-prize-honors-dark-matter-astronomers/.

[134] SpaceNews Staff. "In a First, Neutron Star Bursts as Models Predicted." SpaceNews 5 Mar. 2012: 8.

2.3.10 International Cooperation in Space Exploration

While most states desire autonomy in space, the benefits of shared capabilities, including efficiencies of scale in component development make international cooperation the better approach in the current age of space exploration. This realization is almost universally acknowledged on a political level, despite the fact that the U.S., Europe, Russia and Japan have developed their own cargo transfer vehicles for the ISS.

The Third International Conference on Space Exploration, jointly organised by ESA, the European Commission, the Polish Presidency of the EU; and hosted by the Italian government, highlighted the importance of international cooperation in the pursuit of sustainable space exploration for the benefit of humankind.[135] From that conference, government representatives committed to begin a continued open structured high-level policy dialogue on space exploration at the intergovernmental level for the benefit of humankind.[136]

The International Space Exploration Coordination Group (ISECG) continued to discuss architecture options for future human space exploration. On 30 August 2011, senior managers representing 10 of its 14 member space agencies, met to advance the group's Global Exploration Roadmap (GER) for coordinated space exploration. The GER's first iteration will inform and help focus planning in the areas of planetary robotic exploration, advanced technology development and use of the ISS to help in preparation for future exploration.[137]

2.4 Satellite Applications

2.4.1 Space-Based Communications

In 2011 and 2012, the satellite services industry continued to function with remarkable resilience in view of the adverse global financial conditions. The industry's upward trend is credited to its inherently global nature, allowing it to profit from the quick economic recovery of emerging markets (e.g. in South East Asia and South

[135] "Europe opens the way for a political dialogue on space exploration." 10 Nov. 2011. European Commission – Enterprise and Industry 15 Apr. 2013 http://ec.europa.eu/enterprise/newsroom/cf/itemdetail.cfm?item_id=5555&lang=en.

[136] "Third International Conference on Exploration – First meeting of the High-level International Space Exploration Platform – Declaration." 10 Nov. 2011. European Commission – Enterprise and Industry 15 Apr. 2013 http://ec.europa.eu/enterprise/newsroom/cf/_getdocument.cfm?doc_id=7040.

[137] "Space Agency Senior Managers Meet to Discuss a Global Exploration Roadmap." 30 Aug. 2011. International Space Exploration Coordination Group 15 Apr. 2013 http://www.globalspaceexploration.org/web/isecg/news/2011-08-31.

America). The industry continues to expand its technology development programmes with further investments through the ordering or launch of larger spacecraft with enhanced signal power and transponder capacity. This industry demonstrates an acute ability to achieve the right mixture of investing in innovative technologies and new services while consolidating current operations, which has boosted the industry's revenue for one more consecutive year.[138]

2.4.2 *Space-Based Positioning, Navigation and Timing Systems*

The development of GNSS systems continued during this period, with the relevant actors increasing their efforts to complete their full satellite constellations.

In Europe, a milestone was reached in the second half of 2011, with the launch of the first two Galileo GNSS in-orbit validation (IOV) satellites onboard a Europeanized Soyuz rocket launched from the European spaceport in French Guiana on 21 October 2011. Four Galileo IOV satellites were being developed during the reporting period, with the other two IOV satellites set for launch on 12 October 2012. The system, with the European Commission as a major stakeholder, is being constructed by a consortium led by Astrium Satellites and Thales Alenia Space. The successful launch signified the opening of the system's operational deployment phase, with the scheduled launch of 14 satellites out of a total of 30 required to achieve full operational capability.[139]

Russia's Glonass GNSS constellation is being restored, with its operational capacity increasing by five satellites in 2011. Next-generation model GLONASS-K satellites will succeed the GLONASS-M model of which 23 were operational as at November 2011, with additional spacecraft in production.[140] 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. The constellation requires 24 operational satellites to provide complete global navigation coverage, with three sets of eight satellites operating on three orbital planes.[141]

China intended to field its regional satellite navigation capability by the end of 2012 and to complete the deployment of its entire 35 satellite Beidou GNSS constellation by 2020. In light of that expedited development, Japan decided to proceed with the development of the Quasi-Zenith Satellite System (QZSS), the

[138] See generally State of the Satellite Industry Report.

[139] De Selding, Peter B. "Soyuz Lofts Two Galileo Satellites In Debut from European Spaceport." Space News 24 Oct. 2011: 1.

[140] Clark, Stephan. "Proton rocket replenishes Russian navigation system." 4 Nov. 2011. Spaceflight Now 12 May 2012 http://www.spaceflightnow.com/news/n1111/03proton/.

[141] "Glonass System." Glonass.it 12 May 2012 http://www.glonass.it/eng/glonass-story.aspx.

country's future regional satellite navigation constellation. QZSS is likewise scheduled to be fully operational by 2020, but is designed to augment the regional accuracy of the GPS signal. The system scheme would provide Japanese authorities with a more accurate, secure and independent service. The future deployment of four spacecraft would allow for 24 h regional coverage, while deployment of the full seven satellite constellation would dramatically decrease Japan's dependence on GPS for regional coverage.[142]

2.5 Technology Developments

The 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 and the US in the field of propulsion. Newly developed rockets and other methods of propulsion are being explored with favourable results.

In Europe, the Italian-led Vega small-satellite launcher made its successful inaugural launch on 13 Feb, 2012. The Vega programme, approved by ESA in 1998, spent 9 years developing the launcher at a cost of 710 million Euros.[143] Vega is a single body launcher with three solid propulsion stages and an additional liquid propulsion upper module used for attitude and orbit control, and satellite release. The launcher is capable of placing a 1,500 kg satellite in a 700 km low Earth orbit.[144]

And ESA's Proba-2 micro-satellite demonstrated a whole new space technology when its experimental xenon gas 'resistojet' engine was re-pressurized with nitrogen gas produced from a solid material rather than itself being stored in a pressurized state. The four 'cool-gas generators' containing the solid material are on the

[142] Kallender-Umezu, Paul. "Japan Commits To Deploying Satellite Navigation System by 2020." Space News 17 Oct. 2011: 14.

[143] De Selding, Peter. "Europe's Italian-led Vega Rocket Succeeds in Debut." SpaceNews 20 Feb. 2012: 10.

[144] Launch Vehicles – Vega. 30 Oct. 2012. ESA 8 Mar. 2013 http://www.esa.int/Our_Activities/Launchers/Launch_vehicles/Vega.

Proba-2, and once triggered, each produces more than 250 times its own volume in pure nitrogen gas.[145]

In the U.S., Pratt & Whitney Rocketdyne (PWR) began test-firing its J-2X upper-stage rocket engine in mid-July. The liquid propellant rocket engine maker is building nine J-2X engines: seven for development tests and two for certification tests.[146] The engine, previously envisioned as the upper stage engine for the Ares 5 rocket to be used in the cancelled constellation programme, is the upper stage of the heavy-lift U.S. Space Launch System.

Space Exploration Technologies (SpaceX) developed a launch escape system engine to be used when flying astronauts in its Dragon capsule to the International Space Station. The engine is an advanced version of the Draco engines that the Dragon uses to manoeuvre while in orbit and on reentry. These "SuperDraco" engines are built into the Dragon's side walls, and the eight engines will produce up to 120,000 lb of axial thrust. [147] While the propellant used in its hypergolic engines spontaneously ignites when coming in contact with an oxidizer; hypergolic propellants tend to be corrosive and/or extremely toxic to handle.

In an effort to move away from harmful fuel sources, Innovative Space Propulsion Systems (ISPS) is developing rocket engines that run on an environmentally benign propellant, "NOFBX". SpaceX will the fly the thruster test bed, 'ISPS NOFBX Green Propellant Demonstration', to the ISS in mid-2013; which will be placed on the outside of the European Columbus module to undergo a series of in-space performance validation tests.[148] Developed by Firestar Technologies, NOFBX is a high-performance nitrous oxide/fuel/emulsifier blended monopropellant that is non-toxic, low cost and easy to produce. Capable of production from widely available chemicals, the fuel can be transported without excessive precautions.[149] In fact, NOFBX surpasses solid and bipropellants in many characteristics.[150] The current fuel used on most types of spacecraft is hydrazine, a highly toxic chemical that produces environmental hazards and pollution in addition to operational hazards and longer launch processing times.[151]

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[145] "Proba-2 Fuel Tank Refilled from 'Solid Gas'." 24 Aug. 2011. ESA 17 Apr. 2013 http://www.esa.int/Our_Activities/Technology/Proba_Missions/Proba-2_fuel_tank_refilled_from_solid_gas.

[146] SpaceNews Staff. "J-2X Engine Test Fired at NASA Stennis Space Center." SpaceNews 1 Aug. 2011: 9.

[147] SpaceNews Staff. "SpaceX Test Fires SuperDraco Engine for Dragon Launch Escape System." SpaceNews 6 Feb. 2012: 9.

[148] SpaceNews Staff. "ISS-bound Propellant Demo Passes NASA Safety Review." SpaceNews 28 May 2012: 9.

[149] Messier, Doug. "A Non-Toxic Fuel From the Mojave Desert." 9 Aug. 2011. Parabolic Arc 8 Mar. 2013 http://www.parabolicarc.com/2011/08/09/a-non-toxic-fuel-from-the-mojave-desert/.

[150] Mungas, Greg. "NOFBX® Monopropulsion Overview." 14th Annual FAA Commercial Space Transportation Conference 9 Feb. 2011 https://www.aiaa.org/uploadedFiles/About-AIAA/Press_Room/Key_Speeches-Reports-and-Presentations/Greg_Mungas.pdf.

[151] SpaceNews Staff. "NASA Seeks Green Alternative to Highly Toxic Hydrazine." SpaceNews 13 Feb. 2012: 8.

While many telecommunications satellites have relied on electric propulsion to maintain steady orbit in the last decade, a new trend involves the use of electric thrusters to carry the satellite from transfer orbit to final geostationary position. In order to obtain a significant reduction in weight at launch, Boeing's ABS and Satmex satellites will carry between 300 and 350 kg of xenon propellant for the electric thrusters, rather than use 2,000 kg of conventional fuel, as used with comparable satellites. Its 25 cm xenon-ion propulsion systems are installed on 18 larger satellites that are already in orbit, while subsequent systems will be upgraded with more fuel capacity. However, a downside in relying on electric thrusters stems from the extended time delay in getting a satellite into its final orbital position.[152] Nevertheless, the European Space Agency has also pursued electric propulsion in recent years, with missions including ESA's Smart satellite, and its Artemis technology demonstration satellite. And Astrium Satellites has electric thrusters on six commercial telecommunications satellites, purely for orbit maintenance.[153]

2.5.2 *Information Technology*

At the beginning of the reporting period, concerns on the possible interference by LightSquared's hybrid satellite-terrestrial broadband network on L-band signals had already raised concern among the GPS Community. LightSquared is licensed to use two specific 10-MHz blocks within the L-band frequency range; however GPS signals are also transmitted using the L-Band spectrum.[154] The ground-based transmissions by the former overpower the generally weak GPS signals from space. The consequence of such interference could result in aviation users losing GPS capabilities around densely populated areas with stations spaced out 400–800 m apart, and aircraft below 3,040 m in altitude could not rely on GPS in some areas; additionally, police cars could not acquire GPS signals within 182 m of a LightSquared tower that broadcasts at 15 kW.[155] Of the various mitigation options considered, the only viable option would be for LightSquared to acquire rights to another part of the electromagnetic spectrum.[156] On 14 May 2012, LightSquared

[152] De Selding, Peter. "ABS, Satmex Banding Together for Boeing Satellite Buy 13 Mar. 2012. SpaceNews 8 Mar. 2013 http://www.spacenews.com/article/abs-satmex-banding-together-boeing-satellite-buy.

[153] De Selding, Peter. "Europeans Vow To Check Boeing Advantage in All-electric Sats." SpaceNews 14 May 2012: 4.

[154] Leone, Dan. "LightSquared Says Altered Plan Would Limit GPS Disruption." Space News 27 June 2011: 14.

[155] Brinton, Turner. "Reports: LightSquared Plan Poses Unacceptable Risk to GPS Service." Space News 13 June 2011: 1.

[156] Id. at 4.

filed for bankruptcy protection following earlier FCC license restrictions on the proposed mobile satellite-terrestrial broadband network.

ViaSat Corp.'s ViaSat-1 satellite, launched on 20 Oct. 2011, will deliver a total of 140 gigabits per second of throughput capacity by employing the largely unused Ka-band portion of the radio spectrum and by separating coverage into dozens of spot beams, i.e. 63 spot beams directed at the US.[157] In Europe, Eutelsat's Ka-Sat satellite was launched on 26 Dec. 2010, and began providing commercial broadband service on 31 May 2011.[158] This satellite, the first of a new generation of high throughput satellites under development by Astrium, has a throughput of about 70 gigabits per second. 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. The throughputs of these satellites are respectively 14 and 7 times that of the Spaceway 3 satellite, the previous broadband capacity record-holder.[159] Advantages from the use of high capacity satellite systems include the economic delivery of Internet media with 100 times the capacity of Ku-band and 10 times the throughput of any previous Ka-band satellite, and in-orbit costs per gigabyte at a fraction of even the newest satellites in orbit.[160]

Raytheon Space and Airborne Systems has increased its rate of data exploitation from its new space-based Advanced Responsive Tactically Effective Military Imaging Spectrometer (ARTEMIS) payload. Operating as the primary instrument on the TacSat-3 satellite, ARTEMIS's hyperspectral imaging capability enables the U.S. military to identify materials on the ground based on the way they reflect and absorb sunlight. The imaging capability is applicable to both military and humanitarian uses, e.g. while conducting a 13-month demonstration of its imaging capability, TacSat-3 was also used to aid in relief efforts following devastating earthquakes in Haiti and Chile in 2010. Operating in the short-wave infrared region of the electromagnetic spectrum, the ARTEMIS payload develops about 100 hypercube data products per month, where each hypercube is composed of 400 image slices; since its launch in May 2009, hypercube processing speed has increased tenfold, providing useful information to troops in a dramatically reduced timeframe. This improved analysis of space-based hyperspectral data is partly attributable to Raytheon's work on exploitation algorithms for aerial hyperspectral data. While the short-wave infrared region of the magnetic spectrum makes the ARTEMIS capable of observing solid materials, a future upgrade to the sensor to

[157] De Selding, Peter. "Long-awaited ViaSat-1, Touted As DSL Competitor, is in Orbit." SpaceNews 24 Oct. 2011: 4.

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

[159] De Selding, Peter. "Long-awaited ViaSat-1, Touted As DSL Competitor, is in Orbit." SpaceNews 24 Oct. 2011: 4.

[160] "High-Capacity Satellite System and ViaSat-1." ViaSat 9 Mar. 2013 http://www.viasat.com/broadband-satellite-networks/high-capacity-satellite-system.

also collect long-wave infrared imagery would enable it to detect and characterize gas plumes and atmospheric content as well.[161]

2.5.3 Spacecraft Operations and Design

In Europe, the European Space Agency's (ESA) Rosetta comet chasing spacecraft had to be put into hibernation for a period lasting 2.5 years on 8 June 2011. Now switched off and placed into an unprecedented 90 s rotation, the satellite's two 14-m-long solar arrays produce about 500 W of power to keep the thermal-control system and the on-board computer functioning as the spacecraft journeys to a point some 790 million km from the sun. The spacecraft was launched in March 2004 to rendezvous with the 67/P Churyumov-Gerasimenko comet in mid-2014. While en route, Rosetta developed attitude-control and propulsion system problems: two of its four reaction wheels started showing signs of degradation; and there was a leak in a helium-pressurization system which enables the propellant reservoir to direct fuel to Rosetta's on-board thruster engines. In response to the former issue, the Rosetta operations team will spend the hibernation period developing software to operate the satellite with three, and even two reaction wheels if necessary. Currently, the Rosetta spacecraft needs only three wheels to function, so when awakened in January 2014, one of the degraded wheels can be used as a spare. With the latter propulsion problem, ESA's first plan involved re-pressurizing Rosetta for future operations, allowing for maximum fuel efficiency; however that route had the potential to aggravate the current leak. The alternate approach adopted by ESA's European Space Operations Center (ESOC) was to allow Rosetta to use more fuel than originally planned and fly a less-efficient route to the comet. Nevertheless, with this approach, Rosetta would still have enough fuel to complete its comet rendezvous by mid-2014.[162]

ESA's Planck space observatory reached the end of its operational ability, completing five full-sky surveys of the cosmic microwave background (CMB) since its launch in May 2009. Viewed as a strong success, the mission had called for a minimum of two such surveys to collect data that might allow scientists to get a better understanding of the Big Bang and the very early universe. Planck uses two key sensors, the High Frequency Instrument (HFI) and Low Frequency Instrument (LFI), which require cooling the sensors to one-tenth of a degree above absolute zero (minus 273.05 °C) in order to detect the faint CMB. As expected, the HFI's coolant ran out around 14 Jan. 2012, ending the instrument's ability to detect faint CMB. The LFI will continue to gather calibration data throughout 2012 until its

[161] Brinton, Turner. "Raytheon Touts Progress on Hyperspectral Data Exploitation." SpaceNews 13 Jun. 2011: 14.

[162] De Selding, Peter. "ESA Controllers Buy Time To Fix Glitches on Comet Chaser." SpaceNews 20 Jun. 2011: 10.

coolant reservoir is likewise depleted. Planck findings about the Big Bang and CMB will be released in two stages between 2013 and 2014; i.e. observations from the first 15.5 months of operation will be published in early 2013, with a full data release of the entire mission occurring in the following year.[163]

In the last reporting period, the British imaging solutions company E2v had been developing image sensors for Euclid, a dark-energy mapping mission currently under development for ESA.[164] E2v was also awarded a contract with ESA to develop image sensors for Plato, a space telescope that searches for planets; the Plato mission competed with the Euclid and Solar Orbiter space science missions for two launch opportunities under ESA's Cosmic Vision program.[165] Euclid and Solar Orbiter were ultimately selected; 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. Plato would have orbited the Sun 1.5 million km beyond Earth for 6–8 years, and surveyed up to 40 % of the sky. Euclid is set for a launch in 2019 aboard a Europeanized version of Russia's medium-lift Soyuz rocket. Equipped with a 1.2 m-aperture telescope and other observing instruments furnished mainly by European laboratories, this spacecraft will study the universe's quickening expansion and its dark energy catalyst. Solar Orbiter will study solar phenomena from an unprecedented orbit altitude of 41.9 million km beyond the sun's surface. Slated to launch in 2017, ESA will develop the spacecraft as a bilateral endeavour with NASA; where the former will provide a majority of the spacecraft's payload and instruments, and the latter will provide part of the satellite's payload and the use of an Atlas rocket.[166]

Across the Atlantic, since the retirement of the U.S. Space Shuttle Fleet in July 2011, NASA has focused on destinations that extend deeper in space. NASA's Technology Demonstration Missions programme selected three pioneering technology demonstrations to aid in this pursuit, i.e. a deep space atomic clock project, a solar sail demonstration mission, and an optical in-space communication system. The first mission will launch and validate a miniature mercury-ion atomic clock that is ten times more accurate than today's systems; its precision timing will be vital to the navigation and performance of any deep space mission. The second technology is an expansion of the NanoSail-D's concept project; here, the Solar Sail demonstration mission will deploy and operate a sail that is seven times larger than any ever flown in space (38-by-38 m in area). In addition to its use in deep space missions that travel through space without the need of traditional propellant, solar sails may help set up systems to monitor space weather and clean up orbital debris. The third sponsored demonstration is the optical in-space communication system

[163] SpaceNews Staff. "Key Sensor Aboard Planck Runs Out of Vital Coolant." SpaceNews 23 Jan. 2012: 9.

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

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

[166] De Selding, Peter. "Solar Orbiter, Euclid Chosen as ESA's Next Medium-class Missions." SpaceNews 5 Oct. 2011: 11.

that sends information with the use of encoded laser beams, thus allowing a spacecraft to transmit data at speeds up to 100 times faster than current capabilities. Whereas this latter project should be developed sometime in 2015, its two former projects are planned to debut 1 year earlier. The synergistic results of the clock and laser duo should greatly enhance navigation and communication capabilities on future spacecraft, and the additional benefit of a solar sail when travelling vast distances should reduce the need for heavier alternative propellant sources.[167]

NASA planned to launch its PhoneSat mission onboard Orbital Science Corp.'s Antares medium-lift rocket on its inaugural launch in early 2013. The PhoneSat project, led by the Ames Research Center, intends to demonstrate that cubesats can be produced at a cost below $10,000 using only commercial off-the-shelf components. Three identical PhoneSat 1.0 cubesats were made at a cost of about $3,500 each. At 10 cm in length per side, each cubesat holds an HTC Corp. Nexus One smartphone running Google's Linux-based Android operating system, and does not have propulsion capability. When launched, these cubesats will be released by an Isipod cubesat deployer, developed by Innovative Solutions in Space of the Netherlands. The cubesats will then drift in low Earth orbit for about 2 weeks sending data to its ground controllers on the health of its system, batteries, and sensors, and will also take photos and attempt to send them through its transmission, prior to re-entering Earth's atmosphere.[168]

The space agency also wants to conduct an unmanned test flight of its Orion Multi-Purpose Crew Vehicle (MPCV) aboard a Delta 4 Heavy rocket by 2014. If the undertaking can be secured by funds in the MPCV budget, the test flight would be 3 years ahead of its intended carrier rocket, the U.S. Space Launch System. The test would occur following the completion of two orbits around the Earth, when Orion would then re-enter the atmosphere at speeds verging on those that would occur during a return from deep space. The key purpose of this launch would be to test whether Orion's heat shield can withstand the forces of atmospheric re-entry at about 32,000 km/h.[169]

In the private sector, following the permanent grounding of the NASA space shuttle fleet, Boeing is developing its own Commercial Space Transportation-100 (CST-100) crew capsule, designed to send astronauts to the ISS as early as 2015. Boeing intends flight-testing CST-100 on three expendable Altas 5 rockets; four tests are planned, the first of which is a launch pad abort test planned for 2014. In 2015, three additional tests will be conducted involving an unmanned orbital flight

[167] Wall, Mike. "NASA Picks 3 Pioneering Tech Missions for Deep Space." SpaceNews 22 Aug. 2011: 10.

[168] Leone, Dan. "Smartphone-powered Cubesats To Fly on Antares Maiden Launch." SpaceNews 6 Feb. 2012: 10.

[169] Leone, Dan. "NASA Proposes Orion Test Flight in 2014." 8 Nov. 2011. SpaceNews 12 Mar. 2013 http://www.spacenews.com/article/nasa-proposes-orion-test-flight-2014>.

of the CST-100, an in-flight test of the capsule's abort system, and the first manned flight of the CST-100 at the end of the year.[170] During October 2011, Boeing applied hundreds of small sensors on a 7 % scale aluminium model of the CST-100 space capsule, and subjected it to ultra-high-speed winds. Over 20 different positions will be used when measuring the airflow across the model, to simulate aborted landing stages, with the goal to ensure structural soundness and safe operation.[171] Drop tests of the real CST-100 capsule were conducted in April and May 2012, whereupon after release from an altitude of 3.3 and 4.2 km, the capsule's three main parachutes deployed to slow its descent before six airbags inflated to cushion the landing. The second drop test added a drogue parachute which deploys first in order to pull the main parachute into full deployment, to demonstrate the full normal parachute deployment sequence.[172] Measuring 4.5 m across at its widest point, this seven-seat gumdrop-shaped capsule will be reusable for up to ten flights.[173]

Notwithstanding Boeing's progress in the development of the CST-100 under NASA's Commercial Crew Development program; as of 26 April 2012, Blue Origin had completed a series of wind tunnel tests to validate the shape of its reusable spacecraft under development. Blue Origin's spacecraft has a bi-conic shape to provide greater cross-range and interior volume than traditional gumdrop-shaped capsules without the need to use winged spacecraft. Over 180 wind tunnel tests were conducted in March and April 2012 to validate the spacecraft's aerodynamics during re-entry, including its ability to change its flight path to increase the number of landing opportunities available to the vehicle. Blue Origin is also testing its thrust chamber assembly for the BE-3, a liquid oxygen-liquid hydrogen engine, capable of producing 100,000 lb of thrust; and the company will also conduct a test of a pusher escape system, that will control the flight path of the capsule by use of a new thrust vector control system, later in 2012.[174]

Finally, in the previous reporting period, Space Exploration Technologies (SpaceX) had three Commercial Orbital Transportation Services (COTS) capsules, named Dragons, in varying stages of assembly. Despite expected cost increases and delays, as of 25 May 2012, following the successful launch and birthing of its cargo-carrying Dragon capsule to the International Space Station, SpaceX could now be cleared to begin commercial cargo operations to the station. Upon clearance, SpaceX could make its ISS deliveries under a fixed-price NASA contract

[170] SpaceNews Staff. "Boeing Picks Atlas 5 for CST-100 Test Flights." SpaceNews 8 Aug. 2011: 3.

[171] SpaceNews Staff. "Boeing CST-100 Model Undergoes Wind Tunnel Testing." SpaceNews 24 Oct. 2011: 9.

[172] SpaceNews Staff. "Boeing Drop Tests CST-100 Over the Nevada Desert." SpaceNews 9 Apr. 2012: 3; *see also* SpaceNews Staff. "Boeing Conducts Second CST-100 Parachute Test." SpaceNews 7 May 2012: 8.

[173] Chow, Denise. "Boeing's CST-100 Capsule Shooting for 2015 Debut." SpaceNews 30 Apr. 2012: 14.

[174] SpaceNews Staff. "Blue Origin's Space Vehicle Completes Wind Tunnel Tests." SpaceNews 7 May 2012: 9.

worth $1.6 billion. Having already received $336.7 million as an advance of the contract award, upon the completion of development and demonstration of the milestones, SpaceX will receive the final instalment of its $396 million COTS portion of its contract agreement with NASA. SpaceX launched Dragon aboard its Falcon 9 rocket on 22 May 2012, to which over the course of just over 3 days and 6 h, the capsule conducted a series of automatic orbital manoeuvres adjacent to the ISS prior to gradually entering within the range of capture of the station.[175]

2.5.4 Suborbital Activities

Virgin Galactic and similar US firms have been given a regulatory grace period extension on developing suborbital spacecraft without Federal Aviation Administration (FAA) imposed passenger and crew safety rules. The 2004 Commercial Space Launch Amendments Act barred the FAA from imposing those rules for a period of 8 years, unless an operator experienced a serious accident or an especially dangerous close call. In either circumstance, the FAA would be limited to restricting or prohibiting the craft's design features or operating practices resulting in those events. Whereas this grace period was due to finish by the end of 2012, with the expectation that commercial suborbital spaceflight had become established; this extension to September 2015 allows the fledgling commercial human spaceflight industry to develop without being weighed down with regulation, and allows operators to establish a base of safety-related best practices that the FAA could later-on convert into regulations.[176]

On a related note, Virgin Galactic planned to begin powered test flights of its SpaceShip Two suborbital launch vehicle in early 2012. While it previously planned to begin in 2011, the suborbital spacecraft had experienced a problem following a clean release from its carrier during its 16th glide test, held on 16 Sept. 2011. Experiencing a tail-stall due to an excessive downward pitch, the pilot was able to stabilize the craft at an altitude above 6 km and make a safe runway landing.[177] The company cleared an important regulatory hurdle in 2012, when the U.S. government granted Virgin Galactic a favourable EAR99 ruling, removing its suborbital operations from ITAR control. Without this ruling, the training and/or launching of non-U.S. citizens on Virgin Galactic suborbital flights would have constituted an export activity requiring federal approval, and thus the need for export licenses which could take months for each case. However, as the spacecraft's

[175] Ferster, Warren and Dan Leone. "SpaceX's Successful Mission Boosts Commercial Credibility." SpaceNews 25 May 2012: 1 + .

[176] Leone, Dan. "Private Spaceflight 'Learning Curve' Extension Approved." SpaceNews 13 Feb. 2012: 4.

[177] Leonard David. "Virgin Galactic's SpaceShipTwo Powered Flights Expected To Begin in 2012." SpaceNews 31 Oct. 2011: 13.

flight hardware is still under ITAR's export control, any disclosure of controlled technical data to a foreign national, regardless of whether disclosed within the U.S., is treated as an 'export' of the technical data. The company expects to fly its first paying customers in 2013.[178]

Other groups have seen mixed results in their suborbital spacecraft development. Both Masten Space Systems and Armadillo Aerospace are developing spacecraft to rival Virgin Galactic's SpaceShip Two. Funded in-part with seed money from NASA's Commercial Reusable Suborbital Research program – a programme intended to mature experimental suborbital launch technology and help create a commercial suborbital launch industry – during agency-funded flights, these groups are required to carry NASA payloads within near-space altitudes. Near-space is the grey-zone where the delimitation between airspace and outer space is uncertain, i.e. between 20 and 107 km in altitude. Masten is developing the Xaero; a vertical-takeoff, vertical-landing vehicle, that uses the firm's isopropyl alcohol- and liquid oxygen-burning Cyclops-AL-3 engine. Its successful first flight test, held on 29 June 2011, had the vehicle ascend to 1.8 m above ground level (its maximum altitude is intended to reach 30 km), hover briefly, and then descend to land. Armadillo Aerospace is developing the SuperMod suborbital rocket; another vertical-takeoff, vertical-landing rocket, derived from Armadillo's Module 1 (Mod) vehicle. Eleven seconds into its 11 June 2011 launch, the rocket veered sharply off course and thus an abort was triggered at 1.5 km in altitude. The failure was likely caused by a cracked standpipe that broke off inside the rocket's fuel tank. The companies shared a NASA Commercial Reusable Suborbital Research award in August 2010.[179]

And in an effort to reduce launch costs, NASA and the Pentagon's Operationally Responsive Space Office have developed and are testing an inexpensive microsatellite platform aboard a Terrier-Improved Orion suborbital rocket. Measuring 40 cm in diameter, the primary payload is a modular reconfigurable microsatellite bus that can be integrated and readied for launch in as few as 7 days at a cost of less than $1 million. The Small Rocket/Spacecraft Technology microsatellite bus, dubbed SMART, can be used for a variety of missions, e.g. optical imaging and radio-frequency applications. Following the launches, the payload may be recovered for data analysis.[180]

[178] Leone, Dan. "Virgin Galactic Granted License Exemption for Spaceflight Experience." SpaceNews 16 Apr. 2012: 22.

[179] SpaceNews Staff. "Suborbital Firms Have Mixed Results in Tests." SpaceNews 5 Jul. 2011: 3.

[180] SpaceNews Staff. "NASA Sounding Rocket Tests New Technology." SpaceNews 13 Jun. 2011: 3.

2.5.5 *Other Technologies*

Developments in technology and science continued to advance within the 2011–2012 period, with implications both within and outside the space sector.

Sweden's ACC Microtec, in association with the Swedish Defense Materiel Administration and the U.S. Air Force Research Laboratory, has developed plug-and-play avionics meant for use in the University of Tokyo's nanosatellite research programme. With technology on par with the U.S. Space Plug-and-play Avionics standard, the spinoff from Uppsala University's Angstrom Laboratory has developed remote terminal units and distributed power control units, which are designed to permit satellite builders to integrate their hardware with increased speed, and at a decreased cost, allowing for cost-effective development of the technology.[181]

NASA planned to demonstrate on-orbit satellite refuelling and repair technology with its Robotic Refuelling Mission (RRM) satellite mock-up in November 2011. With the aide of the Special Purpose Dexterous Manipulator (Dextre), a twin-armed Canadian-built robot that has been onboard the ISS since 2008, and with specially updated software, Dextre will use a set of satellite-servicing tools to perform simulated refuelling tasks on the RRM. The mock-up was lifted to the ISS on the final U.S. Space Shuttle launch on 8 July 2011, and it is mounted outside of the station. As the RRM is fitted with the same valves, caps and connectors found on many commercial and government satellites, Dextre will be used to cut away protective thermal blankets, unscrew fuel caps and transfer simulated fuel from one reservoir to another. The aim of the mission is to demonstrate that existing technology can be used to perform such work. Moreover, the RRM might also spark a private satellite-servicing industry, which might also encourage satellite owners to put additional sensors, electronics and fuel-carrying capacity onto future spacecraft, as the potential to extend operational life would be seen as sufficiently worthwhile to make up for a higher up-front investment. However, the RRM is only meant to be a demonstrator, and it will be left to companies like MacDonald Dettwiler and Associates to conduct commercial refuelling operations on satellites.[182]

The humanoid robot, Robonaut 2, has been activated on the International Space Station. The product of a joint project between NASA and car manufacturer General Motors, this $2.5 million robot is designed to assist humans in complex tasks, either in on the space station or on Earth. Weighing about 150 kg on Earth, and with an upright height of 1 m, Robonaut 2 has the configuration of a head, torso, arms and super-dexterous hands; and as the need for legs and feet onboard the ISS is superfluous, an anchor-like pole is used to attach the robot to the wall of the U.S. Destiny module. A second Robotnaut 2 is undergoing tests in different terrains

[181] SpaceNews Staff. "Swedish Firm Tapped for Nanosatellite Components." SpaceNews 13 Jun. 2011: 9.

[182] Leone, Dan. "Space Station-bound Refueling Demo Won't Start Before November." SpaceNews 5 Jul. 2011: 6.

on Earth as part of a space exploration technology demonstration test program called Desert Research and Technology Studies.[183]

In an effort to assist astronauts in adjusting to weightlessness, the Draper Lab group in Cambridge, Massachusetts, is developing a concept for a gravity imitating spacesuit that will simulate the resistance experienced while moving against a gravitational acceleration – applicable for use on the ISS, asteroids, Mars and beyond. This action could be done with the use of an inertial measurement unit that would help to gauge movement, enabling flywheel gyroscopes to vary spacesuit resistance for every movement, by increasing speed or changing direction. Astronauts might also benefit from maintaining muscle coordination while operating in resistance-free microgravity; and spinoff uses with physical rehabilitation are also foreseeable. While still in development, Draper Lab is looking to make a prototype for a spacesuit arm by 2012, and a full-body wearable suit within a decade.[184]

High-radiation environments have a degrading effect on the susceptible and increasingly sophisticated microelectronics within spacecraft. To lessen the harm caused by this radiation, the U.S. Air Force Research Laboratory and BAE Systems are developing powerful radiation-hardened RAD750 microprocessors that are modified for better use in space applications. While the first generation of RAD750 microprocessors were radiation-tolerant with modest processing speeds, strategic radiation-hardened versions with higher processing speeds are now available.[185]

The Pentagon's Defense Advanced Research Projects Agency (DARPA) wants to recycle the still-functioning components of non-operational satellites to be refitted on cheaper-to-launch small- and nano-satellites that have entered geosynchronous orbit. Dubbed the Phoenix programme, the intent is to use a tender vehicle – equipped with grasping mechanical arms and remote vision systems – to act like a robotic satellite servicing station, attaching the salvaged antennas to the antenna-less satellites placed into orbit at a reduced launch cost. As existing hardware is usually molded or welded onto satellites, accomplishing this task requires advanced remote imaging and robotics technology and special tools to capture, detach, and modify complex systems. If successful, the Phoenix programme could have the dual benefit of reducing space debris and saving money by not having to launch satellites with large and bulky antennas.[186]

Draper Laboratory has also developed the Guidance Embedded Navigator Integration Environment (GENIE) for NASA's Autonomous Landing and Hazard

[183] SpaceNews Staff. "Humanoid Robot Powers Up on Space Station." SpaceNews 29 Aug. 2011: 9.

[184] SpaceNews Staff. "Spacesuit To Imitate Gravity on Long NASA Missions." SpaceNews 12 Sep. 2011: 9.

[185] SpaceNews Staff, "BAE and Air Force Fielding Hardened Microprocessors." SpaceNews 10 Oct. 2011: 8.

[186] SpaceNews Staff. "DARPA Project Aims To Turn Space Junk into Satellites." SpaceNews 24 Oct. 2011: 8.

Avoidance Technology (ALHAT) project, which has since been integrated into Masten Space Systems' Xombie rocket for initial testing prior to testing GENIE at high altitudes. The GENIE achieved Technology Readiness Level 6, i.e. achieving a successful demonstration in a relevant environment, by vertically flying 50 m, laterally moving 50 m while maintaining altitude, before landing within 12 cm of its target. The next test flight will be conducted on Masten's Xaero suborbital rocket in 2013, to further mature the technology intended for landers by imitating the landing trajectories that spacecraft would follow when landing on other celestial bodies.[187]

2.5.6 *Innovation Policy*

Near Earth LLC conducted a study for NASA on opportunities and obstacles inherent in attracting private capital to commercial space ventures. The study found that institutional investors desire adequate assurance that the risks and rewards of commercial space investments are in line with their overall investment goals.[188] As public-private partnerships (PPPs) help spur innovation, NASA has already taken important steps in establishing its Commercial Orbital Transportation Services and Commercial Resupply Services contracts, meant to support private industry efforts to develop space transportation services. However, in light of the unique and inherent risks in developing space technology, additional steps are needed to make commercial space ventures attractive to cautious investors; e.g. developing business plans that include incremental steps toward a goal. Another way that NASA could attract private capital and build the market is by serving as the first customer for a new space-based product, or by functioning as an anchor tenant ensuring enough purchases to make commercial businesses viable. Tier awards for achieving milestones could also be deemed to be more useful than winner-take-all competitions. Additional recommendations included: the continued use of seed money and Centennial Challenge programmes; the need for a roadmap identifying the types of jobs NASA would like to turn over to industry; the development of an innovative technology programme like the CIA's 'In-Q-Tel' non-profit programme, which could provide funding for commercial technology to meet the space community's needs; and loan guarantees to enable private space companies to borrow money at low interest rates for programs that have reached a level of maturity where the risk of default is low.[189]

[187] Leone, Dan. "Draper, Masten Test Guidance System." SpaceNews 13 Feb. 2012: 12.

[188] Werner, Debra. "Institutional Investors Seek Profit Potential in Commercial Space." SpaceNews 22 Aug. 2011: 7.

[189] Davidson, Hoyt. "Near Earth Report – Supporting Commercial Space Development." Near Earth LLC. Presentation. NewSpace 2011 Space Conference. NASA-Ames Research Center, San Jose, USA. 29 July 2011 http://www.youtube.com/watch?v = ySc SEV-Mqh8.

NASA, desiring the long-term cryogen storage capability needed for deep-space exploration, will invest up to $600,000 a piece in four companies that study concepts that demonstrate the storage and uniform transfer of liquid oxygen with "zero boil-off" and liquid hydrogen with "minimal boil-off" in space. In managing storage difficulties associated with the very small size of the hydrogen molecule, the current state-of-the-art for liquid hydrogen storage only lasts for several hours prior to leakage; NASA would like the ability to store liquid hydrogen for several months. In addition to demonstrating the concept, awardees must ensure that the mission costs remain between $200 and $300 million.[190]

The U.S. Air Force (USAF) would like to find new launch service providers to compete in launching small- and medium-class military payloads. Having relied solely on Minotaur rockets, with repurposed ICBM solid-rocket motors, since 1997, the USAF's 2003 Orbital/Suborbital Program (OSP)-2 fixed-price contract will end earlier than expected due to higher-than-anticipated demand for the Minotaur 4 launch vehicle. The USAF planned to award multiple indefinite-delivery, indefinite-quantity contracts to several new U.S. launch providers by February 2012, for the cost-effective purchase of as many as 16 launches during the next 8-year period. With a desire to have at least two launch vehicles available for any given mission, contract eligibility requires launchers to have already undergone critical design review; while Minotaur rockets still remain a viable option in lower tier launches, potential options for the heaviest missions might be SpaceX's Falcon 9 rocket or Orbital Sciences' Taurus 2 rocket.[191]

[190] Leone, Dan. "NASA Invests in Cryogen Storage Mission Concepts." SpaceNews 22 Aug. 2011: 6.

[191] Brinton, Turner. "USAF To Allow Competition for Small- and Medium-lift Rockets." SpaceNews 13 Jun. 2011: 4.

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