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 Chap. 1, above, to identify the principal space faring nations' strategies in 2012 and 2013. 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 these strategies interact with and influence specific space programmes, and related research and development projects.

2.2 Space Transportation

2.2.1 Europe

On the issue of future international cooperation, especially in the fields of space transportation and exploration, the retirement of the space shuttle in 2011 increased the potential for cooperation between Europe and the United States in terms of access to space vehicles. At the same time, it indirectly increased the value and relevance of ESA's Automated Transfer Vehicle (ATV). The combined use of the ATV and other similar spacecraft from the US (Dragon and Cygnus COTS missions), Japan (HTV) and Russia (Progress M) to serve ISS supply needs could create opportunities in the long term for the creation of common transportation policies among all participating space actors. Due to their technological proximity and operationally complementary nature, these spacecraft could also pave the way

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for future cooperation on a technology development level.[1] Indeed, on 16 January 2013, ESA had agreed to supply NASA with an ATV-derived service module to provide the Orion spacecraft with propulsion, power and thermal control, in addition to water and gas for the astronauts in the Orion module.[2] ESA's provision of ATV-technology for the Orion module is meant to pay for the space agency's 8.3 % share of the ISS's annual operating costs for the period 2018-to-2020; estimated at a total cost of 455 million Euros. The use of ESA's 5 ATV cargo supply vehicles has released ESA from paying further dues for the operation of the ISS until 2017.[3]

2.2.2 United States

On 21 November 2013, US President Obama signed the 2013 National Space Transportation Policy, intended to keep the US at the forefront of space activities by maintaining space transportation capabilities that are innovative, reliable, efficient, competitive, and affordable, and within US national interests. The new policy updated and replaced the 2004 US Space Transportation Policy, with the purpose of providing comprehensive guidance to all Federal Departments and Agencies on US priorities and on roles and responsibilities with respect to space transportation issues and programs.[4]

More specifically, the new Space Transport Policy seeks to: (1) promote and maintain a dynamic, healthy, and efficient domestic space transportation industrial base; (2) encourage and facilitate the US commercial space transportation industry to increase industry robustness and cost effectiveness, foster innovation-driven entrepreneurship and international competitiveness, and benefit the US economy; (3) conduct and promote technology research and development activities to improve the affordability, reliability, performance, safety, and responsiveness of US space transportation capabilities, while increasing collaboration and coordination among departments and agencies; (4) enable the capabilities to support human space transportation activities to and beyond low Earth orbit, including services to and from the International Space Station and the development of a deep-space-capable transportation system; and (5) foster the development of US commercial spaceflight capabilities serving the emerging nongovernmental human spaceflight

[1] Svitak, Amy. "U.S. And Europe Explore Common Space Transportation Needs." Aviation Week & Space Technology 27 June 2011: 41.

[2] "ESA Workhorse to Power NASA's Orion Spacecraft." 16 Jan. 2013. ESA 8 Apr. 2014. http://www.esa.int/Our_Activities/Human_Spaceflight/Research/ESA_workhorse_to_power_NASA_s_Orion_spacecraft.

[3] "France is Reducing Its Space Station Contributions." 20 Feb. 2013. SpaceNews 28 Apr. 2014. http://spacenews.com/article/civil-space/33755france-is-reducing-its-space-station-contributions.

[4] "Fact Sheet: 2013 National Space Transportation Policy." 21 Nov. 2013. Whitehouse.gov 19 May 2014. http://www.whitehouse.gov/sites/default/files/microsites/ostp/national_space_transportation_policy_fact_sheet_11212013.pdf.

market.[5] To implement this policy, a set of sector guidelines is laid out in the document, ranging from civil and national security space guidelines to commercial space guidelines. Moreover, cross-sector guidelines are listed in the fields of: space launch ranges; space transportation technology development, US space transportation industrial base; non-proliferation and excess intercontinental ballistic missile assets; and international collaboration.

Some of the differences from the previous 2004 US Space Transportation Policy relate to its emphasis on allowing new entrants to launch US government payloads, with the need to have available alternative US space transportation families. It also does not use the term 'operationally responsive space', and deemphasizes operationally responsive access to and use of space to support national security requirements, in favour of directing the Secretary of Defence to work with other agencies on "launch concepts, techniques, and technologies needed for augmentation or rapid restoration of national security space capabilities" without a specific goal or deadline. The policy clarifies the launch of US government hosted payloads on commercial spacecraft, and includes a provision to encourage increased technological innovation and entrepreneurship in the US commercial space transportation sector through the use of incentives such as non-traditional acquisition arrangements, competition, and prizes.[6]

2.2.3 Russia

Recently, Russian space policies have focused on improvement of the country's self-sufficiency, on technological and operational levels, with a drive to increase Russia's global market shares in the space sector. This was particularly true regarding the development of access to space systems, where over the course of 2012 and 2013, Russian authorities made a number of key government decisions on the development of the long-term space program. On 16 August 2012, the Russian government ordered the formation of the Directorate for the Vostochny Cosmodrome, currently under construction in the Russian Far East.[7]

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. In April 2013, NASA signed a deal with Roscosmos to continue sending American astronauts to the ISS aboard Soyuz space capsules until June 2017. As in the previous contract, spanning flights for

[5] National Space Transportation Policy. 21 Nov. 2013. NASA 20 May 2014. http://www.nasa.gov/sites/default/files/files/national_space_transportation_policy_11212013.pdf

[6] Foust, Jeff. "New national space transportation policy makes modest, not major, changes." 22 Nov. 2013. Space Politics 20 May 2014. http://www.spacepolitics.com/2013/11/22/new-national-space-transportation-policy-makes-modest-not-major-changes/.

[7] "Center to build of the Vostochny cosmodrome." TsENKI 20 May 2014. http://www.tsenki.com/en/about/leading_enterprise/division/build_spaceport/.

American astronauts through 2015, this agreement continues Russia's ferrying services for the United States through 2016 and into 2017. However the cost has increased by 12.8 % for the six American seats on the Soyuz, from $62.7 million per seat to $70.7 million per seat on a $424 million contract. With the retirement of its space shuttle fleet in July 2011, NASA is dependent on the Soyuz for launching its astronauts until its CCP programme has matured fully; now expected to be sometime in 2017.[8]

2.2.4 Japan

Japan's Epsilon 3-stage launcher, meant to be a lower-cost replacement for its M-5 solid-propellant rocket, has been in development since 2011.[9] While the launcher costs around ¥20.5 billion to develop, launch costs are projected to be ¥3.8 billion ($44.5 million) per vehicle, resulting in a cost about half as much as the M-5 per launch.[10] The tradeoff for the lower price is one-third less capability than the previous M-5 rocket.[11] While the Epsilon 1 was scheduled to debut on 27 August 2013, poor synchronization between flight and ground-based computers caused an anomaly reading on a sensor aboard the launcher which forced JAXA to abort the launch 19 s prior to liftoff.[12] The launch was postponed until 14 September 2013, when the rocket successfully lifted the Hisaki (SPRINT-A) satellite into elliptical orbit from the Uchinoura Space Center in Japan.[13]

Japan also plans to develop a lower-cost, commercially viable successor to its H-2A rocket. On 17 May 2013, Japan's Space Transportation Systems Subcommittee of its Cabinet-level Office of National Space Policy (ONSP) presented a

[8] "NASA to Pay $70 Million a Seat to Fly Astronauts on Russian Spacecraft." 30 Apr. 2013. Space.com 30 Apr. 2014. http://www.space.com/20897-nasa-russia-astronaut-launches-2017.html.

[9] Kallendar-Umezu, Paul. "Japan To Take Incremental Approach for New Epsilon Launcher." 11 Apr. 2011. SpaceNews 30 May 2014. http://www.spacenews.com/article/japan-take-incremental-approach-new-epsilon-launcher.

[10] "JAXA to launch solid fuel rocket." 31 Oct. 2012. SpaceNews 30 May 2014. http://www.spacenews.com/article/jaxa-launch-solid-fuel-rocket.

[11] Ferster, Warren. "JAXA's Epsilon Rocket Scheduled for Aug. 22 Debut." 21 May 2013. SpaceNews 30 May 2014. http://www.spacenews.com/article/launch-report/35427jaxa%E2%80%99s-epsilon-rocket-scheduled-for-aug-22-debut.

[12] Onuki, Misuzu. "Out-of-synch Computers Cited in Epsilon Launch Abort." 30 Aug. 2013. SpaceNews 30 May 2014. http://www.spacenews.com/article/launch-report/37014out-of-synch-computers-cited-in-epsilon-launch-abort.

[13] Ferster, Warren. "JAXA's Epsilon Small-satellite Launcher Makes Successful Debut." 23 Sept. 2013. SpaceNews 30 May 2014. http://www.spacenews.com/article/launch-report/37363jaxa%E2%80%99s-epsilon-small-satellite-launcher-makes-successful-debut.

draft midterm report recommending an H-3 successor launcher.[14] By 24 December 2013, the Japanese government approved initial funding of $70 million for 2014 for the development of the launcher, estimated to need $1.9 billion for full development. The two-stage H-3 is tentatively scheduled to have its first launch in 2020, and is projected to lift up to 6.5 metric ton payloads to GTO at a cost ranging between $50 million and $70 million per launch.[15] Mitsubishi Heavy Industries Corp. is expected to be the prime contractor of the launcher.

2.2.5 China

The Chinese government's latest Five-year plan for 2011–2016, entitled "China's Space Activities in 2011', was released in December 2011.[16] This document updates and extends the country's strategic and operational objectives in space, recounts the progress made since 2006 and lays down China's short term plans, divided into four main activity areas, including the field of space transportation. Therein, China is focusing on the development of three new launcher configurations by 2016, using more efficient engines and an entirely new upper stage. They include Long March 5 (with a 14 tons to GEO lift capacity), Long March 6 (1 tons to LEO), and Long March 7 (5.5 tons to LEO). The realisation of this programme will provide China with comprehensive and flexible access to space capability, in line with the current and prospective space rocket development plans of all other major space faring nations. This underpins China's willingness to improve its space capabilities on a peer-to-peer basis. Of particular interest is Long March 6, which is described as a "high-speed response launch vehicle". This lightweight launcher will provide China with an operationally responsive launch capability for the first time, with obvious national security and commercial applications.

China's intensive launching campaign continued in 2012 and 2013. For example, once again, within two consecutive days (25–27 November 2012) from two separate launch sites, China launched two satellites—the Yaogan 16 remote sensing satellite to LEO, and Chinasat 12 (APSTAR 7B) communications satellite.[17] Between 2012 and 2013, there were 6 occasions where Chinese launches occurred within 4 days of one another.

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[14] Kallendar-Umezu, Paul. "Japanese Government Recommends Developing H-2A Successor." 27 May 2013. SpaceNews 30 May 2014. http://www.spacenews.com/article/launch-report/35499japanese-government-recommends-developing-h-2a-successor.

[15] Onuki, Misuzi. "Japan Approves $1.9B for H-3 Rocket." 13 Jan. 2014. SpaceNews 30 May 2014. http://www.spacenews.com/article/civil-space/39069japan-approves-19b-for-h-3-rocket.

[16] White Papers of the Government of China. "China's Space Activities in 2011. "Beijing 29 Dec. 2011. 6 Mar. 2012. http://www.china.org.cn/government/whitepaper/node_7145648.htm.

[17] Federal Aviation Administration. Commercial Space transportation: 2012 Year in Review. Washington, DC: FAA, Jan. 2013: 32.

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]

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.[19] 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 will share a number of components. Its completion will enable full autonomy in launching heavier communications satellites of the INSAT-4 class. With its first flight test expected in January 2014, and commercial operations planned for 2016,[20] this launcher will be the first of its series to field a second stage equipped with a restartable liquid fuel engine that should greatly improve the system's operational flexibility and commercial attractiveness.[21]

2.3 Space Science and Exploration

In this section, space science is understood to mean using mainly remote observation to make discoveries on 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, on the other hand, involves human and robotic spaceflight missions. While traditional governmental space agencies dominate in both these fields, expanded progress in the latter category can be seen with the further development of exploration involving commercial players, and with new space powers demonstrating the technology needed to carry out such missions.

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

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

[20] "Heaviest rocket launch in 2014: ISRO." 10 Apr. 2013. The Hindu 30 May 2014. http://www.thehindu.com/sci-tech/technology/heaviest-rocket-launch-in-2014-isro/article4602878.ece.

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

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. Following the retirement of NASA's Space Shuttle, Roscosmos is the sole launch provider relied to transport crew regularly to the ISS and, using Progress and Soyuz, it provided ISS cargo resupply services with Europe's Automated Transfer Vehicle (ATV) and Japan's H-II Transfer Vehicle (HTV) providing auxiliary support.

ESA astronaut André Kuipers completed his 6-month mission on the ISS, returning to Earth on 1 July 2012.[22] With a background as a medical doctor, the astronaut of Dutch nationality began his PromISSe mission on 23 December 2011, conducting over 50 experiments in fields including biophysics, biology, and in improving computer models of fluids, in addition to carrying out maintenance and operational tasks, e.g. the rendezvous and docking of ESA's third ATV Edoardo Amaldi, and in berthing SpaceX's Dragon to the ISS.[23]

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 one assigned to ISS Expeditions 36/37 in 28 May 2013.[24] Alexander Gerst will fly to the space station as a flight engineer for Expeditions 40/41 in May 2014.[25] Samantha Cristoforetti has been assigned as the eighth ESA astronaut to fly to the ISS for a long-duration mission. The 6–7 month mission is planned to begin in 2014.[26] Timothy Peake has been assigned to join the crew of Expeditions 46/47 for 6 months in 2015. Andreas Mogensen, the first astronaut of Danish nationality, is scheduled to launch to the ISS in September 2015, for a brief 10 day mission intended to study the short duration impact of spaceflight on astronauts, in which he will test a new 'skinsuit' made from elastic material that will mimic Earth's gravity and thus passively mitigate the deconditioning of an

[22] "ESA Astronaut André Kuipers Returns to Earth." 1 July 2012. ESA 8 Apr. 2014. http://www.esa.int/Our_Activities/Human_Spaceflight/PromISSe/ESA_astronaut_Andre_Kuipers_returns_to_Earth.

[23] "André Kuipers." 3 Oct. 2013. ESA 13 Apr. 2014. http://www.esa.int/Our_Activities/Human_Spaceflight/Delta_Mission/Andre_Kuipers.

[24] "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.

[25] "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.

[26] "ESA Astronaut Samantha Cristoforetti Set for Space Station in 2014." 3 July 2012. ESA 8 Apr. 2014. http://www.esa.int/Our_Activities/Human_Spaceflight/ESA_astronaut_Samantha_Cristoforetti_set_for_Space_Station_in_2014.

astronaut's body during spaceflight.[27] Thomas Pesquet will be assigned for flight before mid-2015 for launch by 2017.[28] In the meantime, these newly selected ESA astronauts are undergoing extensive training in various facilities in the US, Russia, Japan, Canada and Germany, in addition to survival training in places such as the isolated and complex cave systems in the Mediterranean.[29]

Luca Parmitano, the first of the new astronauts from 2009, began a 5-month mission on the ISS on 28 May 2013.[30] Under the mission heading Volare, Luca Parmitano was the first European flight engineer to co-pilot the Soyuz spacecraft on an approach to the station that was eight times faster than the typical procedure, and conducted only once previously; he and the crew arrived at the station within 6 h of launch from Kazakhstan. With training as a flight engineer, the astronaut of Italian nationality took part in docking ESA's fourth ATV, Albert Einstein, which launched on 5 June 2013; he was also closely involved in berthing other supply vessels during his mission: Japan's HTV, SpaceX's Dragon and Orbital Science Corporations's new Cygnus. Other aspects of Luca Parmitano's Volare mission included more than 30 experiments, two spacewalks to replace a camera mounted on Japan's Kibo laboratory and retrieve science payloads, and other operational and maintenance tasks. On his second spacewalk, a malfunction in the spacesuit caused water to accumulate inside the helmet, forcing him and NASA astronaut Chris Cassidy to cut short their spacewalk and return to the airlock as quickly as possible.[31]

While the life cycle of the ISS has been extended by another 5 years, ESA is stopping the production of Automated Transfer Vehicles (ATVs) after 2015. Following the completion of the five ATV missions, ESA will have paid its share of dues for the use of the ISS through 2017. Following the extension, ESA 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.[32] Prior to the launch of the ATV-4, the ATV-3 had been the

[27] "Andreas Mogensen Set for Soyuz Mission to Space Station in 2015." 28 Aug. 2013. ESA 8 Apr. 2014. http://www.esa.int/Our_Activities/Human_Spaceflight/Astronauts/Andreas_Mogensen_set_for_Soyuz_mission_to_Space_Station_in_2015.

[28] "ESA Astronaut Timothy Peake Set for Space Station." 20 May 2013. ESA 8 Apr. 2014. http://www.esa.int/Our_Activities/Human_Spaceflight/ESA_astronaut_Timothy_Peake_set_for_Space_Station.

[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] "ESA Astronaut Luca Parmitano Arrives at Space Station." 29 May 2013. ESA 8 Apr. 2014. http://www.esa.int/Our_Activities/Human_Spaceflight/Astronauts/ESA_astronaut_Luca_Parmitano_arrives_at_Space_Station.

[31] "ESA Astronaut Luca Parmitano Lands Safely Back on Earth." 11 Nov. 2013. ESA 8 Apr. 2014. http://www.esa.int/Our_Activities/Human_Spaceflight/Volare/ESA_astronaut_Luca_Parmitano_lands_safely_back_on_Earth.

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

heaviest payload the Ariane 5 rocket had ever launched into space with a launch-mass of over 20 tons.[33] The ATV-3 completed its 6-month servicing mission on 28 September 2012, supplying nearly 7 tons of propellant, oxygen, air and water, scientific equipment, spare parts, and other necessities to the station, and performing nine reboosts to counteract atmospheric drag on the ISS.[34] ATV-4 Albert Einstein, now the heaviest payload that the Ariane 5 rocket has launched into space, brought supplies to the ISS, in addition to performing six reboosts during its 5-month servicing mission. Undocking on 28 October 2013, the ATV-4 carrying ISS waste material, burned up harmlessly in the upper atmosphere several days later.[35] Before the end of 2013, the final ATV-5 Georges Lemaître had already reached Europe's spaceport in French Guiana, and is scheduled to launch in late June 2014.

ESA's Inter-Directorate Exploration Scenarios Working Group which awarded Exploration Scenario Studies contracts to various European companies in 2010 to contribute to the development of a Strategic Plan for Human Spaceflight and Exploration, was concluded by an ESA internal review that took place in September 2012. Options for roadmaps, identifying and defining potential building block elements and their integration into these optional roadmaps have been presented and will inform future decisions.[36]

In this context, national space agencies within Europe progressed in their exploration efforts in addition to participating in ESA activities. DLR participated in a number of exploration activities in the 2012–2013 period; notable highlights included the successful flight of the Sharp Edge Flight Experiment (SHEFEX II) in June 2012, testing innovative ceramic tiles able to withstand temperatures reaching 2,000 °C, for the improvement of future spacecraft. Moreover, further results from the MARS 500 mission in 2011 led to the longest study on sodium intake in humans, allowing university researchers to determine that sodium metabolism follows a biorhythm of several days, rather than a cycle of 24 h; a result that is crucial for long duration human space exploration.[37] Also, in May 2013 the DLR

[33] 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.

[34] "Mission Accomplished for ATV Edoardo Amaldi." 3 Oct. 2012. ESA 8 Apr. 2014. http://www.esa.int/Our_Activities/Human_Spaceflight/ATV/Mission_accomplished_for_ATV_I_Edoardo_Amaldi_I.

[35] "A Fiery End to a Perfect Mission: ATV Albert Einstein." 2 Nov. 2013. ESA 8 Apr. 2014. http://www.esa.int/Our_Activities/Human_Spaceflight/ATV/A_fiery_end_to_a_perfect_mission_ATV_Albert_Einstein.

[36] "Annual Report 2012 of the International Space Exploration Coordination Group." 12 Nov. 2013. International Space Exploration Coordination Group (ISECG) 14 Apr. 2014. http://www.globalspaceexploration.org/wordpress/wp-content/uploads/2013/11/ISECG-Annual-Report-2012.pdf.

[37] Ibid.

provided the Omegahab payload on the BION-M1 mission; Omegahab is a designed to function as a bioregenerative life support system in microgravity.[38]

In 2012 and 2013, CNES continued to implement the contract between the French government 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. In that pursuit, France had actively contributed to defining the contents of the EU's technological programme Horizon 2020, particularly with regard to its part in exploration. CNES was also active in the preparation of the second version of the ISECG Global Exploration Roadmap, and of the White Paper—"Benefits stemming from Space Exploration", both released in the summer of 2013. CNES was also involved in discussions preparing European participation in the second high-level international conference on exploration which was scheduled to take place in January 2014, in Washington, DC.[39]

With NASA's Space Shuttle Programme retired in mid-2011, it took over 2 years before the agency could announce the success of its Commercial Orbital Transportation Services (COTS) programme in November 2013. With this achievement, the US can deliver supplies and science experiments to the ISS with the option of two space transportation systems (i.e. the SpaceX Falcon rocket/Dragon spacecraft, or Orbital Science's Antares rocket/Cygnus spacecraft).[40] SpaceX completed two demonstration missions in 2012, followed by another commercial mission to the ISS on 1 March 2013, opening the way for at least 10 additional cargo supply and return flights to the ISS under SpaceX's contract with NASA.[41] Similarly, Orbital Sciences completed its two launches of the Antares rocket, including its first Cygnus cargo demonstration supply mission to the ISS mission on 23 October 2013, it being notable that the Cygnus is designed to burn-up upon re-entry into the atmosphere.[42] In an effort to restore US capability to domestically launch astronauts into space by 2017, NASA's Commercial Crew Program (CCP) requested proposals from US companies to complete the development of crew transportation systems that meet NASA's certification requirements, and can launch crewed missions to the ISS. This 'Commercial Crew Transport Capability' (CCtCap) stage of the programme requires at least one crewed flight to the ISS

[38] Annual Report 2013 of the International Space Exploration Coordination Group." 20 Dec. 2013. International Space Exploration Coordination Group (ISECG) 14 Apr. 2014. http://www.globalspaceexploration.org/wordpress/wp-content/uploads/2013/12/Annual-Report_2013_FINAL.pdf.

[39] Ibid.

[40] "NASA Hails Success of Commercial Space Program." 13 Nov. 2013. NASA 8 Apr. 2014. https://www.youtube.com/watch?v=bj905HtsB-g.

[41] "Dragon Delivers." 3 Mar. 2013. SpaceX 8 Apr. 2014. http://www.spacex.com/news/2013/03/03/happy-berth-day.

[42] "Orbital Completes COTS Demonstration Mission to International Space Station." 23 Oct. 2013. Orbital Sciences 8 Apr. 2014. http://www.orbital.com/NewsInfo/release.asp?prid=1873.

before certification can be granted; NASA plans to have awarded CCtCap contracts by September 2014.[43]

In 2012 and 2013, Russia launched eight Soyuz spacecraft: TMA-04M on 15 May 2012 with the Expedition 31/32 crew of Joseph Michael Acaba, Gennady Padalka and Sergei Revin[44]; TMA-05M on 15 July 2012 with the Expedition 32/33 crew of Yuri Malenchenko, Sunita Williams, and Akihiko Hoshide[45]; TMA-06M on 23 October 2012 with the Expedition 33/34 crew of Oleg Novitskiy, Kevin Ford, and Evgeny Tarelkin;[46] TMA-07M on 19 December 2012 with the Expedition 34/35 crew of Roman Romanenko, Chris Hadfield, and Tom Marshburn[47]; TMA-08M on 28 March 2013 with the Expedition 35/36 crew of Chris Cassidy, Pavel Vinogradov, and Aleksandr Misurkin[48]; TMA-09M on 29 May 2013 with the Expedition 36/37 crew of Fyodor Yurchikhin, Karen Nyberg, and Luca Parmitano;[49] TMA-10M on 26 September 2013 with the Expedition 37/38 crew of Oleg Kotov, Michael Hopkins, and Sergei Ryazansky;[50] and TMA-11M on 7 November 2013 with the Expedition 38/39 crew of Mikhail Tyurin, Richard Mastracchio, and Koichi Wakata.[51] Russia also continued its regular resupply of the ISS with eight successful launches of the Progress cargo transfer vehicles: M-14M on 25 January 2012, M-15M on 20 April 2012, M-16M on 1 August 2012, M-17M on 31 October 2012, M-18M on 11 February 2013, M-19M on 24 April 2013, M-20M on 27 July 2013, and M-21M on 25 November 2013.[52]

In 2013, the US and Russia began exploring the concept of a 1-year mission aboard the ISS. Previously this was a Russian domain with four cosmonauts having spent more than a year in space between 1987 and 1995. Beginning in 2015, Russian cosmonaut Mikhail Kornienko and American astronaut Scott Kelly will

[43] "NASA Advances Effort to Again Launch Astronauts from U.S. Soil to Space Station." 19 Nov. 2013. NASA 8 Apr. 2014. http://www.nasa.gov/content/nasa-advances-effort-to-again-launch-astronauts-from-us-soil-to-space-station/#.U0QSuPmSwj4.

[44] "Soyuz TMA-04M." Russian Space Web 8 Apr. 2014. http://www.russianspaceweb.com/iss_soyuz_tma04m.html.

[45] "Soyuz TMA-05M." Russian Space Web 8 Apr. 2014. http://www.russianspaceweb.com/iss_soyuz_tma05m.html.

[46] "Soyuz TMA-06M." Russian Space Web 8 Apr. 2014. http://www.russianspaceweb.com/iss_soyuz_tma06m.html.

[47] "Soyuz TMA-07M." Russian Space Web 8 Apr. 2014. http://www.russianspaceweb.com/iss_soyuz_tma07m.html.

[48] "Soyuz TMA-08M." Russian Space Web 8 Apr. 2014. http://www.russianspaceweb.com/iss_soyuz_tma08m.html.

[49] "Soyuz TMA-09M." Russian Space Web 8 Apr. 2014. http://www.russianspaceweb.com/iss_soyuz_tma09m.html.

[50] "Soyuz TMA-10M." Russian Space Web 8 Apr. 2014. http://www.russianspaceweb.com/iss_soyuz_tma10m.html.

[51] "Soyuz TMA-11M." Russian Space Web 8 Apr. 2014. http://www.russianspaceweb.com/iss_soyuz_tma11m.html.

[52] "Spaceflight Now: Tracking Station: Launch Log." 14 Apr. 2014. http://spaceflightnow.com/tracking/launchlog.html.

participate in a year-long mission aboard the ISS—twice as long as a typical crew member—to gain knowledge on the medical, biomedical, and psychological challenges that explorers may face when they venture beyond cis-lunar distances, bound for deeper reaches such as a manned flight to an asteroid or Mars.

After launching only unmanned missions in 2011, successfully docking the Shenzhou 8 to the Tiangong 1 space laboratory,[53] China accomplished another historic milestone in 2012. After launching the first Chinese astronaut into space on 15 October 2003, aboard the Shenzhou 5,[54] and having another astronaut conduct China's first spacewalk on 27 September 2008, aboard the Shenzhou 7[55]; China accomplished two more milestones on 16 June 2012, when it successfully sent its first female astronaut, along with two male astronauts, aboard the Shenzhou 9 to dock with the Tiangong 1 on a 13-day mission—also making China the third nation to successfully dock a manned spacecraft to another in orbit.[56] China launched another three astronauts on a 15-day mission on 11 June 2013 aboard the Shenzhou 10 docking with Tiangong 1 on 13 June 2013.[57] China also plans to complete the construction and launch of its Tiangong 2 lab in 2015, followed by another experimental core module of the future space station around 2018.[58]

China's third Tianlian data-relay satellite, Tianlian I-03 was launched on 25 July 2012. It was preceded by the Tian-lian I-02 launched in July 2011, and the Tianlian I-01 launched in 2008. The Tianlian data-relay spacecraft support China's manned flights, in addition to being related to the development of China's Tiangong space station. China is now the third nation after the United States and Russia to build an operational data-relay service. This is viewed as being comparable to NASA's TDRS data relay satellites.[59]

While Japan has placed the development of human spaceflight capabilities at the forefront of its spending, attention is beginning to veer toward other areas including satellite navigation (with its QZSS constellation), and satellite reconnaissance systems. Under the government's updated Basic Plan on Space Policy, released

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

[54] "China puts its first man in space." 15 Oct. 2003. BBC News 15 Apr. 2014. http://news.bbc.co.uk/2/hi/asia-pacific/3192330.stm.

[55] Moskowitz, Clara. "Chinese Astronauts Complete First Spacewalk." 27 Sept. 2008. Space.com 15 Apr. 2014. http://www.space.com/5902-chinese-astronauts-complete-spacewalk.html.

[56] "Touchdown! Chinese Space Capsule With 3 Astronauts Returns to Earth." 28 June 2012. Space.com 8 Apr. 2014. http://www.space.com/16357-china-space-capsule-lands-shenzhou-9.html.

[57] "Three Chinese Astronauts Land After Record-Breaking Spaceflight." 25 June 2013. Space.com 8 Apr. 2014. http://www.space.com/21720-china-astronauts-land-shenzhou-10.html.

[58] "China plans to launch Tiangong-2 space lab around 2015." 27 June 2013. Space Daily 8 Apr. 2014. http://www.spacedaily.com/reports/China_plans_to_launch_Tiangong_2_space_lab_around_2015_999.html.

[59] Todd, David. "Chinese data relay satellite TianLian-1C is launched successfully on a Long March 3C." 26 July 2012. Seradata 19 May 2014. http://seradata.com/SSI/2012/07/chinese-data-relay-satellite-t/.

on 25 January 2013, the two new priority targets are (1) to expand its utilization of space—to create new services and products to improve the quality of life, and to offer effective measures for disaster management and national security; and (2) to ensure autonomy in space related activities by maintaining the manufacture, launch and operation of satellites for navigation, remote sensing (including meteorological observation and information gathering) and communications/broadcasting, along with maintaining, strengthening and developing the domestic industrial base that supports those activities.[60] In the new space plan, the human space activity programme is listed beneath the space science and space exploration programme as a priority area, marking a change in Japan's interests since Japan's earthquake in March 2011.

Following the maiden voyage of Japan's H-2 Transfer Vehicle (HTV) to the ISS in September 2009, the Japanese cargo tug made four deliveries to the ISS by the end of 2013. The HTV-3 launched to the ISS on 21 July 2012, delivering 3,600 kg of supplies to the station before undocking on 12 September 2012 to burn up shortly after in Earth's atmosphere.[61] The HTV-4 launched to the ISS on 4 August 2013, bringing with its supplies, a talking humanoid robot Kirobo, and an advanced camera to photograph comets; the HTV also had an 'i-Ball' device attached to record and transmit images of the tug's fiery re-entry into the atmosphere.[62]

In 2012, the Canadian Space Agency (CSA) continued to operate its Mobile Servicing System (MSS), providing robotic maintenance and resupply operations on the ISS. The CSA's Canadarm2 captured and berthed three spacecraft resupply missions: SpaceX's Dragon COTS second demonstration flight launched on 22 May; JAXA's HTV-3 cargo resupply tug launched on 21 July; and SpaceX's non-demonstration Dragon ISS 1-D resupply spacecraft launched on 7 October.[63] In 2013, Canadarm2 was used to capture and berth three more spacecraft resupply missions: SpaceX's second Dragon ISS 2-D resupply spacecraft launched on 1 March; JAXA's HTV-4 cargo resupply tug launched on 3 August; and Orbital Science's Cygnus COTS Demonstration resupply mission launched on 18 September.[64]Canadarm2 and the CSA's Dextre also performed flawlessly during

[60] Basic Plan on Space Policy. 25 Jan. 2013. Government of Japan 20 May 2014: 6. http://www8.cao.go.jp/space/plan/plan-eng.pdf.

[61] "Japanese Cargo Ship Re-enters over Pacific." 17 Sept. 2012. SpaceNews 8 Apr. 2014. http://www.spacenews.com/article/japanese-cargo-ship-re-enters-over-pacific.

[62] "Japanese Cargo Spacecraft Re-enters Atmosphere After Ending ISS Mission." 8 Sept. 2013. Astro Watch 8 Apr. 2014. http://www.astrowatch.net/2013/09/japanese-cargo-spacecraft-re-enters.html.

[63] "Annual Report 2012 of the International Space Exploration Coordination Group." 12 Nov. 2013. International Space Exploration Coordination Group (ISECG) 14 Apr. 2014. http://www.globalspaceexploration.org/wordpress/wp-content/uploads/2013/11/ISECG-Annual-Report-2012.pdf.

[64] Annual Report 2013 of the International Space Exploration Coordination Group." 20 Dec. 2013. International Space Exploration Coordination Group (ISECG) 14 Apr. 2014. http://www.globalspaceexploration.org/wordpress/wp-content/uploads/2013/12/Annual-Report_2013_FINAL.pdf.

the joint CSA-NASA Robotic Refuelling Mission (RRM), which resulted in the development of new flight products and procedures to support MSS operations, and expanded the boundaries of robotic operations on the ISS; the second phase is planned for some time in 2014. To maximise time for performing experiments, the MSS was also operated by ground control to relocate several On-orbit Replacement Units (ORUs) stowed on the ISS external storage platforms.

In addition to technological activities conducted on the station, the Canadian veteran astronaut Chris Hadfield began his third space mission and second trip to the ISS at the end of 2012. Launching to the station on 19 December 2012 for a 5-month period, Hadfield was on the ISS Expedition 34/35 mission where he worked as a flight engineer for 3 months during Expedition 34, and as a first for Canada, he assumed command of the ISS in March 2013. He returned from the ISS on 13 May 2013.[65] Also, Canada's two newly qualified astronauts, Major Jeremy Hansen and Dr. David Saint-Jacques, in addition to pursuing their pre-assignment training activities, were assigned to the Capcom/Training branch at NASA's Johnson Space Center. The two astronauts, both ready to be assigned to ISS missions and medically certified for ISS duties, were scheduled to complete their MSS robotics training at the CSA in early 2014.[66]

2.3.2 Lunar Science

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 a possible European Lunar Lander mission on 17 January 2012. This call was intended to support discussions with national agencies regarding potential contributions and to inform them of preparations for an Announcement of Opportunity (AO) in early 2013. The subsequent AO would lead to the formal selection of the

[65] "Chris Hadfield Safely Returns to Earth." 13 May 2013. CBCNews 8 Apr. 2014. http://www.cbc.ca/news/technology/chris-hadfield-safely-returns-to-earth-1.1403450.

[66] Annual Report 2013 of the International Space Exploration Coordination Group." 20 Dec. 2013. International Space Exploration Coordination Group (ISECG) 14 Apr. 2014. http://www.globalspaceexploration.org/wordpress/wp-content/uploads/2013/12/Annual-Report_2013_FINAL.pdf.

payload to be used as part of a Lunar Lander mission.[67] 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.[68]

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.[69]

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 or 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.[70] With extreme cold measurements from the Moon's poles, data from the LRO's Diviner instrument was paired with years of data collected by the Lunar Exploration Neutron Detector measuring the amount of hydrogen trapped in the Lunar soil, to locate hydrogen-rich areas in the poles. Such areas could be valuable to power hardware in support of a robotic or human mission. Moreover, high-resolution images from the LRO Camera revealed that the Moon is still retracting. Also, through measuring the Moon's radiation environment, the spacecraft's CRaTER instrument was able to show that lighter materials such as plastics can provide effective shielding against the radiation faced by astronauts in deep-space missions. The LRO is expected to continue transmitting data until October 2014, with the chance of continuing for an additional 2 years.[71]

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

[67] "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.

[68] "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.

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

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

[71] "NASA's LRO: Four Years in Orbit." 18 June 2013. NASA 7 Apr. 2014. http://www.nasa.gov/mission_pages/LRO/news/4th-anniv.html.

evolution. A secondary objective was to extend the knowledge gained from the Moon to the other planets of the solar system.[72] By the end of 2012, the twin NASA probes were able to generate the highest resolution gravity field map of a celestial body, revealing tectonic structures, volcanic landforms, basin rings and other details that indicate the Moon's gravity field is unlike any terrestrial planet in the solar system. With GRAIL, the Moon's crust was determined to be between 34 and 43 km, i.e. 10–20 km thinner than had been previously thought. This finding supports models where the Moon is derived from Earth materials that had been ejected from a giant impact near the beginning of our solar system's history.[73] With the success of the GRAIL mission, NASA capitalised on the end of its life by intentionally crashing the twin spacecraft into a mountain near the Moon's North Pole on 17 December 2012, within view of the LRO at the time of impact. This allowed the LRO to take measurements of the cloud of dust and gas that was pushed up with each impact, enabling the LRO's Lyman Alpha Mapping Project (LAMP) to register mercury and enhancements of atomic hydrogen in the ejected plumes using its ultraviolet imaging spectrograph.[74]

NASA's newly launched Lunar Atmosphere and Dust Environment Explorer (LADEE) lifted into space on 6 September 2013. Completing its development phase in reaching the Moon before the end of 2013, it has now begun its 100-day mission to study the Moon's exospheric dust environment and determine the composition of the lunar atmosphere, including the processes that control its distribution and variability.[75] 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 and other significant infrastructure contributions, will operate all upcoming lunar landing missions as nodes in a geophysical network.[76]

With 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 from July 2010, more details on JAXA's proposed roadmap became available.[77] In an abstract presented at the 44th Lunar and Planetary Science Conference (2013), an update on the status of Japan's SELENE-2 and SELENE-X missions was provided. SELENE-2 is expected to be in

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

[73] "NASA's GRAIL Creates Most Accurate Moon Gravity Map." 5 Dec. 2012. NASA 7 Apr. 2014. http://www.nasa.gov/mission_pages/grail/news/grail20121205.html.

[74] "Lunar Reconnaissance Orbiter Sees GRAIL's Explosive Farewell." 19 Mar. 2013. NASA 7 Apr. 2014. http://www.nasa.gov/mission_pages/grail/news/grail20130319.html#.U0JlN_mSwj4.

[75] "Missions—LADEE—NASA Science." NASA 16 Apr. 2014. http://science.nasa.gov/missions/ladee/.

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

[77] 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.

its phase-B within fiscal year 2013, with the earliest launch of the SELENE-2 lander and rover on the Moon's surface in 2018; it will be followed by a SELENE-X advanced lander for South Pole missions.[78]

China's lunar exploration programme accomplished another major technological and scientific feat when it became the third country in the world to soft land a spacecraft on the Moon. Launched on 1 December 2013, and alighting on 14 December 2013, the Chang'e 3 will operate for a 1-year mission, carrying cameras and an ultraviolet telescope to observe Earth's plasmasphere in addition to conducting astronomical observations from the Moon's surface. Chang'e 3's six-wheeled 'Yutu' lunar rover will operate for a 3-month mission, conducting scientific explorations of the geography and geomorphology of the landing spot and nearby areas.[79] Continuing on with the second phase of the lunar exploration programme, China's Chang'e 4, originally a backup to the Chang'e 3, is being adapted to verify technologies for the sample return initiative in the third phase of China's lunar exploration programme. China plans to return a sample of lunar soil to Earth with its Chang'e 5 to be launched in 2017,[80] in addition to sketch plans for a manned lunar landing sometime between 2025 and 2030.[81]

India's second lunar mission, Chandrayaan 2 was envisioned as a joint venture between India and Russia, featuring an ISRO orbiter and rover, and delivery by a Russian-supplied lander, and is expected to launch before the end of 2015.[82] However, problems arising from delayed construction and financial constraints resulted in Russia being unable to provide the lander within the planned 2015 timeframe. As a result, following a high-level review by ISRO, it was determined that India could provide a lander module on its own; though the configuration of the Chandrayaan 2 mission would need adjustment to take into account the weight, volume, and power constraints of an ISRO lander.[83] The Chandrayaan 2 mission has five primary payloads on the orbiter, two of which will be improvements on instruments that were on board the previous Chandrayaan 1 mission; the rover too

[78] Tanaka, S., et. al. "Present Status of the Lunar Lander Project SELENE-2." 26 Mar. 2013. 44th Lunar and Planetary Science Conference (2013) 16 Apr. 2014. http://www.lpi.usra.edu/meetings/lpsc2013/pdf/1838.pdf.

[79] "Chinese Rover Hibernating to Survive Frigid Lunar Night." 27 Dec. 2013. Spaceflight Now 7 Apr. 2014. http://www.spaceflightnow.com/china/change3/131227hibernation/#.U0KlqvmSwj4.

[80] "China Targets Moon Sample-Return Mission in 2017." 26 Dec. 2013. Space.com 7 Apr. 2014. http://www.space.com/24055-china-moon-sample-return-mission.html.

[81] "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.

[82] "Chandrayaan-2 Expected to Launch within 2 Years." 15 Dec. 2013. CCTV 7 Apr. 2014. http://english.cntv.cn/program/newsupdate/20131215/104199.shtml.

[83] "India to go Alone with Chandrayaan 2." 14 Aug. 2013. The Hindu 7 Apr. 2014. http://www.thehindu.com/sci-tech/india-to-go-alone-with-chandrayaan-2/article5022717.ece.

will carry two additional instruments. Chandrayaan 2 will be launched on a GSLV using an indigenous cryogenic engine.[84]

Russia continued work on its Luna-Glob and Luna-Grunt series of missions, with the former now scheduled to launch its first Luna-Glob 1 lander mission (Luna-25) in 2016.[85] With this first mission postponed by a year, the launch schedule of the follow-up Luna-Resurs orbiter (Luna-26) has been pushed to 2018, while the Luna-Resurs lander (Luna-27) is now planned for 2019. These missions, involving a lunar orbiter and surface penetrators, will contribute to knowledge about the moon's formation. Following the Luna-Glob missions, the Luna-Grunt mission will 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.[86] While Roscosmos will not provide a lunar lander in time for the launch of India's Chandrayaan-2 mission, that mission had been intended to be part of Roskosmos' Luna-Glob moon exploration programme, and hence, collaboration with India will likely continue.[87] Moreover, European investigators have exhibited an interest in participating in the upcoming Luna-Glob missions.[88]

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. Early in November 2013, in an effort to assist the competing teams by allowing them to access financing at a critical point in their mission timeline and raise public excitement and support for the teams, X PRIZE and Google announced a series of Milestone Prizes available to the competing teams. With amounts ranging from between $250,000 to $1 million available to several teams that demonstrate (via actual testing and analysis) robust hardware and software to combat key technical risks in the areas of imaging,

[84] 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.

[85] "First Russian Moon Mission Delayed." 17 Oct. 2013. Exploring Space 7 Apr. 2014. http://spaceexp.tumblr.com/post/64287200145/first-russian-moon-mission-delayed.

[86] 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/.

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

[88] "European-Russian Luna Mission Speed Dating." 3 Dec. 2013. Spaceports 7 Apr. 2014. http://spaceports.blogspot.co.at/2013/12/european-russian-luna-mission-speed.html.

mobility and lander systems, the awards can be won through the end of September 2014.[89] With 25 teams registered for the competition on 31 December 2010,[90] by the end of 2013, that number had reduced to 18 active teams, with several competitors leaving to pursue other business interests.[91] At the end of 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.[92]

2.3.3 Mars Science

The focus for Mars science has for decades remained the investigation of the planet's habitability, in a search 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. In June 2013, on its tenth anniversary, new global maps of Mars enabled researchers to compare a series of global maps showing the distribution and weathering of minerals found in water and from volcanic activity, allowing researchers to trace the evolution of the planet through time.[93] In previous years data generated by the spacecraft's radar showed that there may be glaciers hidden beneath the surface of Mars' Phlegra Montes mountain range; and it also detected sediments that are reminiscent of an ocean floor within the previously identified boundaries of ancient shorelines.

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[89] "Recognizing Giant Leaps: Google Lunar XPRIZE Establishes Milestone Prizes (Op-Ed)." 7 Nov. 2013. Space.com 7 Apr. 2014. http://www.space.com/23503-google-lunar-xprize-milestone-prizes.html.

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

[91] "As 2013 Comes To An End, Competition Intensifies In Private Race To The Moon." 19 Dec. 2013. Google Lunar X Prize 7 Apr. 2014. http://www.googlelunarxprize.org/blog/2013-comes-end-competition-intensifies-private-race-moon.

[92] 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.

[93] "Ten Years at Mars: New Global Views Plot the Red Planet's History." 3 June 2013. ESA 27 Mar. 2014. http://www.esa.int/Our_Activities/Space_Science/Mars_Express/Ten_years_at_Mars_new_global_views_plot_the_Red_Planet_s_history.

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.[94] Near the end of 2013, the spacecraft was expected to make its closest flyby of Mars' largest moon Phobos reaching a nadir distance of 45 km from its surface, allowing it to yield the most accurate details of the moon's gravitational field and provide new details of its internal structure.[95]

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.[96] On 13 February 2012, NASA announced 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 year.[97] Subsequently, in March 2013, ESA and Roscosmos signed a formal agreement to work in partnership on the ExoMars programme with launches of the two missions planned in January 2016 and May 2018.[98] ESA will provide the Trace Gas Orbiter (TGO) and the Entry, Descent and Landing Demonstrator Module (EDM) 'Schiaparelli' in 2016,[99] and the carrier and rover in 2018; while Roscosmos is responsible for the 2018 descent module and surface platform, and will provide launchers for both missions. Both partners will also supply scientific instruments and will cooperate closely in the scientific exploitation of the missions. The 2016 mission will search for evidence of methane and other atmospheric gases that could be signatures of active biological or geological processes, while the ExoMars rover, to be launched in 2018, will search the planet's surface for signs of life, past and present, and will be able to drill to a depth of 2 m.[100]

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

[95] "Mars Express Heading Towards Daring Flyby of Phobos." 23 Dec. 2013. ESA 27 Mar. 2014. http://www.esa.int/Our_Activities/Space_Science/Mars_Express/Mars_Express_heading_towards_daring_flyby_of_Phobos.

[96] "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.

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

[98] "ExoMars 2016 Set to Complete Construction." 17 June 2013. ESA 28 Mar. 2014. http://exploration.esa.int/mars/51931-exomars-2016-set-to-complete-construction/.

[99] "ExoMars Lander Module Named Schiaparelli." 8 Nov. 2013. ESA 28 Mar. 2014. http://exploration.esa.int/mars/53145-exomars-lander-module-named-schiaparelli/.

[100] "ExoMars: ESA and Roscosmos for Mars Missions." 14 Mar. 2013. ESA 28 Mar. 2014. http://exploration.esa.int/mars/51495-exomars-esa-and-roscosmos-set-for-mars-missions/.

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 October 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. The spacecraft also served as a communications relay for the two Mars Exploration Rovers.[101] 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.[102]

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. In previous years, it returned data that suggested that water still flows in some places on Mars, depicted as dark, finger-like features that appear and extend down some Martian slopes that change during the seasons.[103] In September 2012, the spacecraft returned the clearest evidence yet of carbon-dioxide snowfalls (i.e. 'dry ice') occurring around Mars' South Pole in its winter season.[104] Moreover, researchers at the California Institute of Technology (Caltech) have discovered evidence of an ancient delta where a river might once have emptied into a vast ocean that could have covered as much as a third of Mars, mainly located in the planet's northern hemisphere.[105] In December 2013, more evidence of flowing water was returned—slender dark markings, most likely due to salty water that advances seasonally down slopes surprisingly close to the Martian equator.[106] And a previous study has suggested that if Mars ever incubated life, the longest lasting

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

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

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

[104] "NASA Orbiter Observations Point to 'Dry Ice' Snowfall on Mars." 11 Sept. 2012. Jet Propulsion Laboratory 28 Mar. 2014. http://mars.jpl.nasa.gov/mro/news/whatsnew/index.cfm?FuseAction=ShowNews&NewsID=1341.

[105] "Evidence for a Martian Ocean." 17 July 2013. Jet Propulsion Laboratory 28 Mar. 2014. http://mars.jpl.nasa.gov/mro/news/whatsnew/index.cfm?FuseAction=ShowNews&NewsID=1493.

[106] "NASA Mars Spacecraft Reveals a More Dynamic Red Planet." 10 Dec. 2013. Jet Propulsion Laboratory 28 Mar. 2014. http://mars.jpl.nasa.gov/mro/news/whatsnew/index.cfm?FuseAction=ShowNews&NewsID=1567.

habitats were most likely below the surface, in the clay minerals that formed in the shallow subsurface all over the planet.

The NASA Mars Science Laboratory (MSL) rover, nicknamed Curiosity, reached Mars on 5 August 2012, completing an 8-month journey to the planet.[107] 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 4-billion-year timescale atmospheric evolution processes; determine the present state, distribution, and cycling of water and carbon dioxide; and characterize the broad spectrum of surface radiation, including galactic cosmic radiation, solar proton events, and secondary neutrons.[108] Since its arrival, Curiosity has transmitted results of initial experiments that show the mineralogy of Martian soil is similar to weathered basaltic soils of volcanic origin in Hawaii.[109] The rover was also the first to drill into a rock sample on Mars to collect a sample from its interior.[110] Analysis of similar samples has shown the presence of sulphur, nitrogen, hydrogen, oxygen, phosphorus, and carbon, all key elements that could have supported microbial life on ancient Mars.[111] Other samples collected from the planet's equator have shown a compound containing chlorine and oxygen, likely chlorate or perchlorate, a compound that had been previously found at Mars' North Pole, suggesting more global dispersion.[112] However, data from the rover surprised researchers when it revealed that the planet's environment lacks methane; contradicting positive detections that had been previously reported and reducing the probability of currently existing methane-producing microbes on Mars.[113]

[107] "NASA Lands Car-Size Rover Beside Martian Mountain." 5 Aug. 2012. NASA 31 Mar. 2014. http://www.nasa.gov/mission_pages/msl/news/msl20120805c.html.

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

[109] "NASA Rover's First Soil Studies Help Fingerprint Martian Minerals." 30 Oct. 2012. NASA 31 Mar. 2014. http://www.nasa.gov/mission_pages/msl/news/msl20121030.html.

[110] "NASA Curiosity Rover Collects First Martian Bedrock Sample." 9 Febr. 2013. NASA 31 Mar. 2014. http://www.nasa.gov/mission_pages/msl/news/msl20130209.html.

[111] "ASA Rover Finds Conditions Once Suited for Ancient Life on Mars." 12 Mar. 2013. NASA 31 Mar. 2014. http://www.nasa.gov/mission_pages/msl/news/msl20130312.html#.UzkhCPmSwj4.

[112] "Curiosity's SAM Instrument Finds Water and More in Surface Sample." 26 Sept. 2013. NASA 31 Mar. 2014. http://www.nasa.gov/content/goddard/curiositys-sam-instrument-finds-water-and-more-in-surface-sample/#.UzkiPfmSwj4.

[113] "NASA Curiosity Rover Detects No Methane on Mars." 19 Sept. 2013. NASA 31 Mar. 2014. http://www.nasa.gov/mission_pages/msl/news/msl20130919.html#.UzkiLfmSwj4.

NASA launched the Mars Atmosphere and Volatile EvolutioN (MAVEN) mission on 18 November 2013. It is expected to reach Mars on 22 September 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.[114] In other words, by studying the planet's upper atmosphere and measuring current rates of atmospheric loss, MAVEN scientists hope to understand how Mars transitioned from a warm, wet planet to its current dry desert state.[115]

ISRO's newly launched Mars Orbiter Mission (MOM) lifted into space on 5 November 2013. Its journey to Mars is expected to take 300 days, reaching the planet on 22 September 2014.[116] On reaching Mars, the spacecraft—carrying five indigenous scientific payloads consisting of a camera, two spectrometers, a radiometer, and a photometer—will observe Mars' surface, atmosphere and exosphere extending up to 80,000 km for a detailed understanding of the planet's evolution, especially its related geologic and possible biogenic processes.[117]

In 2011, the Russian Phobos-Grunt mission failed.[118] Russia now hopes to launch another probe Phobos-Grunt 2 to Mars's moon by 2022, to explore the theory that the moon might be a captured main-belt asteroid containing materials dating back to the formation of the solar system.[119]

2.3.4 Saturn Science

The Cassini-Huygens mission, a joint NASA, ESA and ASI mission, 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 to provide new insights on Saturn and its moons; it is now slated to explore Saturn

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

[115] "NASA Launches Mission to Study Upper Atmosphere of Mars." 18 Nov. 2013. NASA 31 Mar. 2014. http://www.nasa.gov/press/2013/November/nasa-launches-mission-to-study-upper-atmosphere-of-mars/#.Uzl3uvmSwj5.

[116] "Mars Orbiter Mission (MOM)—Manglayaan." Indian Space Projects 31 Mar. 2014. http://isp.justthe80.com/planetary-exploration/mars-obiter.

[117] "Indian Space Research Organisation | Mars Orbiter Mission." Indian Space Research Organisation 31 Mar. 2014. http://www.isro.org/mars/home.aspx.

[118] 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.

[119] "Phobos-Grunt-2: Russia to Probe Martian Moon by 2022." 18 Oct. 2013. Mars Daily 7 Apr. 2014. http://www.marsdaily.com/reports/Phobos_Grunt_2_Russia_to_probe_Martian_moon_by_2022_999.html.

until 2017.[120] In past years, the now 16-year old mission returned images of a storm that was 500 times larger than the storm Cassini witnessed between late 2009 and early 2010; the last storm covered approximately 4 billion square kilometres and was wrapped around the entire planet.[121] In June 2012, long-standing methane lakes, or puddles, in the "tropics" of Saturn's moon Titan were an unexpected finding because the models had assumed that these long-standing bodies of liquid would only exist at the poles.[122] Soon afterward, the spacecraft detected large tides on Titan, leading to the almost inescapable conclusion that there is a hidden ocean beneath the moon's ice crust.[123] The Cassini spacecraft was also able to observe small meteoroids breaking into streams of rubble and crashing into Saturn's rings. By studying the impact rate of meteoroids from outside the Saturnian system, scientists are better able to understand how the different planet systems in our solar system formed.[124]

On Enceladus, Cassini had previously observed plumes of 'dusty plasma' emanating from the icy geyser moon. 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 Pole region.[125] The complexity of the plasma was increased by the presence of ionised 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 situ.[126] Recent scientific results from a flythrough of the plumes also show strong evidence of the existence of large-scale saltwater reservoirs beneath Encelaus' crust.[127] Adding to this evidence of reservoirs beneath the moon's crust, data obtained by Cassini shows that the intensity of the jets of water ice and organic particles that shoot out from Enceladus depends on the moon's proximity to the ringed planet. Here, combining brightness data collected by Cassini's visual and infrared mapping spectrometer (VIMS) to previous models

[120] 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/.

[121] 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.

[122] "Cassini Sees Tropical Lakes on Saturn Moon." 13 June 2012. NASA Cassini 26 Mar. 2014. http://saturn.jpl.nasa.gov/news/newsreleases/newsrelease20120613/.

[123] "Cassini Finds Likely Subsurface Ocean on Saturn Moon." 28 June 2012. NASA Cassini 26 Mar. 2014. http://saturn.jpl.nasa.gov/news/newsreleases/newsrelease20120628/.

[124] "Cassini Observes Meteors Colliding with Saturn's Rings." 25 Apr. 2013. NASA Cassini 26 Mar. 2014. http://saturn.jpl.nasa.gov/news/newsreleases/newsrelease20130425/.

[125] "Enceladus Plume is a new Kind of Plasma Laboratory." 31 May 2012. NASA Cassini 30 May 2014. http://saturn.jpl.nasa.gov/news/newsreleases/newsrelease20120531/.

[126] Ibid.

[127] Ibid.

of Saturn's gravity on Enceladus, scientists deduced that the stronger gravitational squeeze near the planet reduces the opening of the tiger stripes and the amount of material spraying out. In turn, they surmise that the relaxing of Saturn's gravity farther away from planet allows the tiger stripes to be more open and the spray to escape in larger quantities.[128]

2.3.5 Venus Science

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. Previously, from the detected escape of ionic hydrogen and oxygen in the ratio of two to one from the planet, scientists inferred that solar ultraviolet radiation streams into the atmosphere and breaks up the water molecules into atoms. Venus Express has discovered an ozone layer high in Venus's atmosphere. 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.[129] Recently, an extremely cold region in the planet's atmosphere was observed, with temperatures reaching around –175 °C at an altitude of 125 km above the Venus's surface, leading researchers to suspect that carbon dioxide ice might form there, pinned between two comparatively warmer layers.[130] Moreover, the spacecraft was able to shed more light on the solar wind's interaction with the planet, wherein during a period of very low density solar outflow, the ionosphere of Venus was observed to become elongated downstream moving outward to at least 15,000 km from Venus, similar to a long-tailed comet.[131]

Previously, 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

[128] "NASA's Cassini Spacecraft Reveals Forces Controlling Saturn Moon Jets." 31 July 2013. NASA Cassini 26 Mar. 2014. http://saturn.jpl.nasa.gov/news/newsreleases/newsrelease20130731/.

[129] 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.

[130] "A Curious Cold Layer in the Atmosphere of Venus." 1 Oct. 2012. ESA 27 Mar. 2014. http://sci.esa.int/venus-express/50884-a-curious-cold-layer-in-the-atmosphere-of-venus/.

[131] "The Tail of Venus and the Weak Solar Wind." 29 Jan. 2013. ESA 27 Mar. 2014. http://sci.esa.int/venus-express/51315-the-tail-of-venus-and-the-weak-solar-wind/.

being studied, surface features on Venus have 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.[132] Operations of Venus Express have been extended until 2015, subject to a mid-term review and confirmation by ESA's Space Situational Awareness (SSA) programme in 2014.[133]

The Russian Federal Space Programme is planning to further build on its Venera programme—first initiated in the early 1960s. In the subsequent decades, the Venera programme launched a series of probes, landers, orbiters, and conducted repeated impact experiments and flybys up to 1985.[134] The Venera-D mission is currently being developed by the Russian Federal Space Programme, and it is now scheduled for launch in 2024. While previously projected to launch sometime in 2015–2016, the technical complexity of the project and the need to resume development of the lander technology resulted in the nearly 8-year schedule delay.[135] The mission will comprise of a lander, orbiter and a sub-satellite. The lander will study the formation and evolution of Venus, in particular the elemental and mineralogical composition of the surface, geology, iron-containing phases and the distribution of iron oxidation states. During its descent, the lander will make meteorological measurements, record the isotopic composition of the atmosphere, measure the structure, chemistry and microphysics of clouds, and monitor electromagnetic radiation. The orbiter will be in a daily polar orbit and will study the atmosphere from the surface to an altitude of 160 km, using spectrometers from the ultraviolet to millimetre ranges. The sub-satellite will allow the simultaneous

[132] 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.

[133] "ESA Science Missions Continue in Overtime." 20 June 2013. ESA 27 Mar. 2014. http://sci.esa.int/director-desk/51944-esa-science-missions-continue-in-overtime/.

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

[135] "RAS: Start "Venus-D" will take Place no earlier than 2024." 9 Apr. 2012. Gazeta 27 Mar. 2014. http://www.gazeta.ru/science/news/2012/04/09/n_2284249.shtml.

measurements of plasma and magnetic fields. Europe and China have been invited to participate in the project.[136]

2.3.6 Mercury Science

Running as a partnership between ESA and JAXA, BepiColombo will be Europe's first mission to Mercury. The mission's targeted launch date has been moved to July 2016 with arrival at Mercury in January 2024 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 stabilised 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. Enduring temperatures in excess of 350 °C, BepiColombo has been designed to provide the measurements necessary to study and understand the composition, geophysics, atmosphere, magnetosphere and history of Mercury.[137]

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 Mercury, following three flybys. After completing its year-long task to perform the first complete reconnaissance of the geochemistry, geophysics, geological history, atmosphere, magnetosphere, and plasma environment of Mercury by 17 March 2012, MESSENGER began its extended mission to build on its discoveries.[138] 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).[139] By 29 November 2012, a long-held hypothesis that Mercury harbours abundant water ice and other frozen volatile materials in its permanently shadowed polar craters gained compelling support from three

[136] "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.

[137] "BepiColombo Fact Sheet." 3 Dec. 2013. ESA 27 Mar. 2014. http://sci.esa.int/bepicolombo/47346-fact-sheet/.

[138] 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.

[139] "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.

independent lines of evidence: i.e. excess hydrogen at Mercury's north pole was measured with MESSENGER's Neutron Spectrometer; reflectance of Mercury's polar deposits at near-infrared wavelengths was measured with the Mercury Laser Altimeter (MLA); and the first detailed models of the surface and near-surface temperatures of Mercury's north polar regions that utilize the actual topography of Mercury's surface were measured by the MLA.[140] Dark patches with diminished reflectance were also recorded by the MLA, consistent with the theory that the ice in those areas is covered by a thermally insulating layer. By March 2013, in orbit for over 2 years, MESSENGER's +Mercury Dual Imaging System (MDIS) had imaged 100 % of the planet.[141] By that time, the spacecraft had completed its first year-long extended mission. In that time, the spacecraft completed 12 specialised measurement campaigns that led to new discoveries about surface volatiles on the planet, the duration of volcanism, the evolution of long-wavelength topography, the nature of localised regions of enhanced exospheric density, the effect of the solar cycle on Mercury's exosphere, and Mercury's energetic electrons.[142]

2.3.7 Jupiter Science

In May 2012, the proposed ESA Jupiter Icy moon Explorer (JUICE)[143] mission was selected by ESA's Space Programme Committee (SPC) as the first large (L-class) mission opportunity in ESA's Cosmic Vision 2015–2025 plan, with a foreseen launch date of 2022 and arrival in 2030. The proposed nearly 5 tons spacecraft will make a careful investigation of Jupiter's three biggest moons, i.e. it will use the gravity of Jupiter to initiate a series of close fly-bys around Callisto and Europa, and then finally to put itself in a settled orbit around Ganymede. As all three moons are suspected of having oceans of water beneath their icy crusts, scientists are trying to understand whether there is any possibility that these moons could host microbial life.[144] The final and formal adoption of JUICE is expected in 2014. At the time of JUICE's selection by the SPC, an agreement had already been established with

[140] "MESSENGER Finds New Evidence for Water Ice at Mercury's Poles." 29 Nov. 2012. NASA 27 Mar. 2014. http://www.nasa.gov/mission_pages/messenger/media/PressConf20121129.html#.UzQGLPldUj4.

[141] "MESSENGER Has Imaged 100 Percent of Mercury." 6 Mar. 2013. NASA 27 Mar. 2014. http://www.nasa.gov/mission_pages/messenger/media/Imaged100Percent.html#.UzQGLPldUj4.

[142] "MESSENGER Completes Its First Extended Mission at Mercury." 20 Mar. 2013. Space Daily 27 Mar. 2014. http://www.spacedaily.com/reports/MESSENGER_Completes_Its_First_Extended_Mission_at_Mercury_999.html.

[143] JUICE was renamed during its reformulation exercise from the designation Europa Jupiter System Mission (EJSM)–Laplace in 2011.

[144] "ESA Selects 1bn-Euro JUICE Probe to Jupiter." 2 May 2012. BBC News 27 Mar. 2014. http://www.bbc.com/news/science-environment-17917102.

NASA as a minor payload contributor, and negotiations on an agreement with Russia concerning payload provision for the JUICE spacecraft and the Russian Ganymede lander were in progress.[145]

Juno, NASA's new frontiers mission to Jupiter, 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.[146] The spacecraft performed two 30-min Deep Space Manoeuvres (DSM-1, -2) on 30 August and 14 September 2012, respectively, to refine the spacecraft's trajectory, allowing for a gravity assist from a flyby of Earth on Oct 9, 2013, with arrival expected on 4 July 2016. Once on orbit, the spacecraft will circle Jupiter 33 times, from pole to pole, and use its collection of eight science instruments to probe beneath the gas giant's obscuring cloud cover to learn about the planet's origins, structure, atmosphere and magnetosphere, and seek a potential solid planetary core.[147]

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.

[145] "Forthcoming Announcement of Opportunity for Scientific Instrumentation Onboard the JUICE Spacecraft." 30 May 2012. ESA 27 Mar. 2014. http://sci.esa.int/juice/50400-forthcoming-announcement-of-opportunity-for-juice-scientific-instrumentation/.

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

[147] "Juno's Two Deep Space Maneuvers are 'Back-To-Back Home Runs'." 17 Sept. 2012. NASA 27 Mar. 2014. http://www.nasa.gov/mission_pages/juno/news/juno20120917.html#.UzQtWPldUj4.

ESA's PRoject for OnBoard Autonomy (PROBA)-2 microsatellite continued its solar observation activity, having been given a programme extension in November 2012 by ESAs SPC, with the mission now extending until at least the end of 2014.[148] PROBA-2 tracks spikes in CMEs ejecting from the Sun that have previously been seen to just skim Earth, typically bringing with them a burst of radio energy.[149] 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.[150] ESA is also developing the Proba-3, as a pair of satellites maintaining a fixed configuration to form a 150 m long solar chronograph to study the Sun's faint corona closer to the solar rim than previously achieved.[151] Expected to launch in 2017, the satellite pair—separated by 150 m—will be capable of flying in formation to within a tolerance of a millimetre and one second of arc of one another to provide heightened clarity of the rim.[152]

CNES' solar metrology mission 'PICARD', launched on 15 June 2010, aims to improve knowledge of how the Sun functions and the influence of solar activity on the Earth's climate. PICARD will accomplish this by measuring absolute total and spectral solar irradiance, solar diameter and shape, and by probing the interior of the Sun using the helioseismology method. In the last reporting period, among additional findings, the spacecraft observed a partial Sun eclipse and an unusual Sun-spot that extended eight times Earth's diameter.[153] On 6 June 2012, PICARD tracked the Venus transit of the Sun, and it also witnessed a solar eclipse on 13 November 2012. By January 2013, PICARD's SODISM instrument had acquired its millionth image; and on 3 November 2013, PICARD was able to photograph the second solar eclipse of 2013.[154]

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),

[148] "ESA Science Missions Continue in Overtime." 20 June 2013. ESA 1 Apr. 2014. http://sci.esa.int/director-desk/51944-esa-science-missions-continue-in-overtime/.

[149] "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.

[150] "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.

[151] "About PROBA3." 19 Nov. 2012. ESA 1 Apr. 2014. http://www.esa.int/Our_Activities/Technology/Proba_Missions/About_Proba-3.

[152] "Proba-3 Mission will call on Satellites to Fly in Sub-Millimeter Precision." 17 Apr. 2013. Gizmag 1 Apr. 2014. http://www.gizmag.com/proba-3-satellite-mission/27124/.

[153] "PICARD NEWS." CNES 1 Apr. 2014. http://smsc.cnes.fr/PICARD/GP_actualites.htm.

[154] Ibid.

EUV Variability Experiment (EVE) and the Helioseismic and Magnetic Imager (HMI).[155] The SDO's global view of the Sun facilitates research that focuses on the previously unrecorded real fine structure of the star.[156] In August 2013, data from the HMI enabled scientists to show that, instead of a simple cycle of flow moving toward the poles near the sun's surface and then back to the equator, the writhing material inside the sun shows a double layer of circulation, with two such cycles on top of each, allowing for improved future predictions of the intensity of the next solar cycle.[157]

In June 2013, a NASA scientific balloon lifted the solar observatory mission SUNRISE from Kiruna, Sweden into Earth's atmosphere. Equipped with a one-metre mirror, SUNRISE is the largest solar telescope to fly above the atmosphere, drifting over the Atlantic Ocean for 5 days while gathering information about the Sun's chromosphere. SUNRISE provided the highest-resolution images to date in ultraviolet light of this thin corrugated layer, which lies between the sun's visible surface and the sun's outer atmosphere, the corona.[158] Initial findings show that the ultraviolet radiation from the chromosphere is highly suitable for visualizing detailed structures and processes.

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 kilometres from Earth, enabling an uninterrupted view of the star.[159] 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 impact of solar variability on the Earth's climate.[160] SOHO has helped to define

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

[156] 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.

[157] "NASA's SDO Mission Untangles Motion Inside the Sun." 28 Aug. 2013. NASA 1 Apr. 2014. http://www.nasa.gov/content/goddard/sdo-mission-untangles-motion-inside-sun/#.UzqOOvmSwj4.

[158] "SUNRISE Offers New Insight on Sun's Atmosphere." 27 Sept. 2013. NASA 1 Apr. 2014. http://www.nasa.gov/content/goddard/sunrise-offers-new-insight-on-suns-atmosphere/#.UzqORvmSwj4.

[159] 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.

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

what occurs during CMEs by providing simultaneous images of reactions on the sun and further out in the corona.[161] The SOHO mission has very significantly exceeded its expected lifetime of 2 years and on 19 June 2013, it was extended until 31 December 2016.[162]

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.[163] They provide new insights into CMEs, including detecting and processing data that enables the tracking of CMEs headed toward Earth. STEREO also benefits from crowd-sourced data analysis, using data analysed by the public to make 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.[164]

NASA's Interface Region Imaging Spectrograph (IRIS) satellite was launched on 26 June 2013, with the purpose of observing how solar material moves, gathers energy and heats up as it travels through the Sun's lower atmosphere. In addition to being where most of the Sun's ultraviolet emission is generated, this region between the Sun's photosphere and corona, powers the Sun's million-degree atmosphere, and drives the solar wind. For its 2-year mission, IRIS will enter a sun-synchronous polar orbit, making continuous solar observations throughout this time.[165] By December 2013, the spacecraft had revealed that this interface region was more violent than previously had been understood, finding even more turbulence and complexity than expected, helping scientists to understand the way energy moves through the lower levels of the Sun's atmosphere to drive solar winds and heat the Sun's corona.[166]

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

[161] "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/.

[162] "ESA Science Missions Continue in Overtime." 20 June 2013. ESA 27 Mar. 2014. http://sci.esa.int/director-desk/51944-esa-science-missions-continue-in-overtime/.

[163] "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

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

[165] "IRIS Solar Observatory Launches, Begins Mission." 28 June 2013. NASA 1 Apr. 2014. http://www.nasa.gov/content/iris-solar-observatory-launches-begins-mission/#.UzqYe_mSwj4.

[166] "IRIS Provides Unprecedented Images of Sun." 9 Dec. 2013. NASA 1 Apr. 2014. http://www.nasa.gov/content/iris-provides-unprecedented-images-of-sun/#.UzqYifmSwj4.

storm warning satellite,[167] to be launched early in 2015.[168] It is now designed to detect potentially Earth-threatening space weather that could harm electrical grids and communications systems, and disrupt air travel, satellites, and spaceflight. Its secondary mission has the spacecraft observe the Earth from the Sun-Earth Lagrange point 1 (where gravitational forces are in equilibrium), to measure ozone levels, cloud cover, vegetation changes, surface radiation, and atmospheric pollution.

The Hinode (Solar-B) probe, led by JAXA in collaboration with NASA, the Science and Technology Facilities Council (STFC, UK) 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. The spacecraft's mission has been extended until 31 December 2016.[169] The Advanced Composition Explorer (ACE), a NASA mission launched in August 1997, with the primary science objective of measuring the composition of the solar corona, wind, interplanetary particles, the local interstellar medium and galactic matter, continued to collect data to improve forecasts and warnings of solar storms, and is expected to maintain its orbit until 2024.[170] 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 five-week anneal procedure to rejuvenate its detectors from the effects of radiation damage, and had resumed collecting solar X-ray and gamma-ray data.[171]

2.3.9 Outer Solar Science

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

[167] 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/.

[168] "Long-Delayed Space Weather Satellite On Track for 2015 Launch." 13 Sept. 2013. Space.com 1 Apr. 2014. http://www.space.com/22740-mothballed-dscovr-satellite-2015-launch.html.

[169] "ESA Science Missions Continue in Overtime." 20 June 2013. ESA 27 Mar. 2014. http://sci.esa.int/director-desk/51944-esa-science-missions-continue-in-overtime/.

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

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

topic, the following section covers 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. By August 2014, Rosetta will reach the comet 67P/Churyumov-Gerasimenko, and by November 2014, it will release a lander that will make the first landing on a comet's nucleus.[172]

The Herschel infrared telescope continued to make significant discoveries in this reporting period, making the first detection of water vapour in a molecular cloud on the verge of star formation, finding enough water vapour to fill Earth's oceans more than 2,000 times over in the L1544 system within the Taurus constellation.[173] Herschel has also allowed astronomers to accurately 'weigh' a star's disc in the constellation of Hydrae with ten-times higher accuracy than previous telescopes, providing more insight into the planet building process.[174] Herschel also detected a cool layer in the atmosphere of Alpha Centauri A, a finding not previously seen beyond our own Sun. The data will aid in understanding the Sun's activity, in addition to the discovery of proto-planetary systems around other stars.[175]

By November 2012, Herschel's counterpart the Planck microwave observatory, launched in May 2009 to study the Cosmic Microwave Background (CMB), made the first conclusive detection of a bridge of hot gas connecting a pair of galaxy clusters, Abell 399 and Abell 401, across 10 million light-years of intergalactic space. The early Universe is believed to have had filaments of gaseous matter that had formed as a giant cosmic web, wherein clusters eventually formed the web's densest nodes.[176] By March 2013, Planck had revealed the most detailed map ever created of the cosmic microwave background radiation of the Big Bang, showing tiny temperature fluctuations that correspond to regions of slightly different densities at very early times, eventually forming the stars and galaxies of today.[177] Planck data also set a new value for the rate at which the Universe is expanding,

[172] "Wake Up, Rosetta!" 10 Dec. 2013. ESA 2 Apr. 2014. http://www.esa.int/Our_Activities/Space_Science/Rosetta/Wake_up_Rosetta.

[173] "Large Water Reservoirs at the Dawn of Stellar Birth." 9 Oct. 2012. ESA 2 Apr. 2014. http://www.esa.int/Our_Activities/Space_Science/Herschel/Large_water_reservoirs_at_the_dawn_of_stellar_birth.

[174] "Stars can be Late Parents." 30 Jan. 2013. ESA 2 Apr. 2014. http://www.esa.int/Our_Activities/Space_Science/Stars_can_be_late_parents.

[175] "A Cool Discovery about the Sun's Next-Door Twin." 20 Feb. 2013. ESA 2 Apr. 2014. http://www.esa.int/Our_Activities/Space_Science/A_cool_discovery_about_the_Sun_s_next-door_twin.

[176] "Planck Spots Hot Gas Bridging Galaxy Cluster Pair." 20 Nov. 2012. ESA 2 Apr. 2014. http://www.esa.int/Our_Activities/Space_Science/Planck/Planck_spots_hot_gas_bridging_galaxy_cluster_pair.

[177] "Planck Reveals an Almost Perfect Universe." 21 Mar. 2013. ESA 2 Apr. 2014. http://www.esa.int/Our_Activities/Space_Science/Planck/Planck_reveals_an_almost_perfect_Universe.

measuring a significantly slower expansion, and implying that the age of the Universe is really 13.82 billion years, rather than the previous assessments of 13.772 billion years by NASA's Wilkinson Microwave Anisotrophy Probe (WMAP), and 11 billion years derived from globular clusters.[178] The mission ended on 23 October 2013 after 4.5 years of operation where it completed five full-sky surveys with both its Low Frequency Instrument (LFI) and High Frequency Instrument (HFI), with the spacecraft put into permanent hibernation. The HFI exhausted its liquid helium coolant in January 2012, whereas the LFI was able to operate until 3 October 2013 at higher temperatures, before being switched off shortly thereafter.[179]

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.[180] By December 2013, data from the satellite provided the first clear photometric signature of the granulation in stars beyond our Sun. After operating twice as long as originally planned, the COROT mission is scheduled to end in late spring 2014.[181] While in operation, the COROT mission was the first to discover a confirmed Earth-like exoplanet orbiting a star similar to the Sun, and has since revealed 32 planets, while 100 more await confirmation.[182]

On 4 November 2010, NASA's Extrasolar Planet Observations and characterisation/deep impact eXtended Investigation (EPOXI) flew past comet Hartley 2, returning images of the comet that provided new information on the role comets may have in planetary formation.[183] The spacecraft was supposed to observe comet ISON's visit in 2013, however due to a malfunction with the spacecraft, communication was lost on 8 August, with the mission being declared lost on 19 September 2013.[184]

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

[178] Redd, Nola Taylor. "How Old is the Universe?" 20 Dec. 2013. Space.com 26 Apr. 2014. http://www.space.com/24054-how-old-is-the-universe.html.

[179] "Last Command Sent to ESA's Planck Space Telescope." 23 Oct. 2013. ESA 2 Apr. 2014. http://www.esa.int/Our_Activities/Space_Science/Planck/Last_command_sent_to_ESA_s_Planck_space_telescope.

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

[181] "Events." CNES 2 Apr. 2014. http://smsc.cnes.fr/COROT/GP_actualite.htm.

[182] "Mission Accomplished for CoRoT." 24 June 2013. CNES 2 Apr. 2014. http://smsc.cnes.fr/COROT/PDF/CP039-2013_mission_CoRoT_va.pdf.

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

[184] "Mission Status Report." NASA 2 Apr. 2014. http://epoxi.umd.edu/1mission/status.shtml.

oscillating stars, where liquid water could exist on their surfaces.[185] In August 2012, Kepler-47b and 47c were discovered to be the first transiting circumbinary system, i.e. multiple planets orbiting two stars, with one of those planets existing in the binary system's habitable zone.[186] Data from Kepler was also used to identify a four-star planetary system, the first known solar system of its kind.[187] It has also discovered a new planetary system that is home to Kepler-37b, the smallest planet yet found around a star like our Sun, in the constellation Lyra.[188] And through the use of Kepler and Spitzer space telescope data, astronomers have created the first cloud map of a giant gaseous planet known as Kepler-7b.[189] Kepler-78b was determined to be the first Earth-sized planet with a Measured Earth mass.[190] After losing two of its four reaction wheels in May 2013, resulting in the spacecraft losing its ability to precisely point at the original field of view, plans are underway to recover stability in the spacecraft using the Sun to maintain stability, under the designation Kepler 2; in December 2013, the mission concept was invited to the 2014 Senior Review at NASA.[191]

NASA's Wide-field Infrared Survey Explorer (WISE) mission completed its survey early in 2011, scanning the whole sky twice in infrared light. Capturing millions of images in that time, some of the most recent findings in 2012 and 2013 revealed 2.5 million super-massive black hole candidates in the universe, and 1,000 of the brightest infrared light emitting galaxies ever found, normally obscured by dust that blocks their visible light. While normally hidden, black hole activity warms the dust, causing it to glow in infrared light.[192] Moreover, WISE discovered a binary system of brown dwarfs at a distance of 6.5 light-years—taking the title as

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

[186] "Kepler-47: Our First Binary Star 2-Planet System." 28 Aug. 2012. NASA 2 Apr. 2014. http://kepler.nasa.gov/news/nasakeplernews/index.cfm?FuseAction=ShowNews&NewsID=228.

[187] "Planet Hunters Find Circumbinary Planet in 4-Star System." 16 Oct. 2012. NASA 2 Apr. 2014. http://kepler.nasa.gov/news/nasakeplernews/index.cfm?FuseAction=ShowNews&NewsID=233.

[188] "Discovery: Kepler-37b, a Planet Only Slightly Larger than the Moon." 20 Feb. 2013. NASA 2 Apr. 2014. http://kepler.nasa.gov/news/nasakeplernews/index.cfm?FuseAction=ShowNews&NewsID=256.

[189] "NASA Space Telescopes Find Patchy Clouds on Exotic World." 30 Sept. 2013. NASA 3 Apr. 2014. http://www.spitzer.caltech.edu/news/1564-ssc2013-08-NASA-Space-Telescopes-Find-Patchy-Clouds-on-Exotic-World.

[190] "Kepler-78b: First Earth-Size Planet with Measured Earth-Mass." 30 Oct. 2013. NASA 2 Apr. 2014. http://kepler.nasa.gov/news/nasakeplernews/index.cfm?FuseAction=ShowNews&NewsID=308.

[191] "NASA STATEMENT: Two-Wheel Kepler Mission Invited to 2014 Senior Review." 4 Dec. 2013. National Aeronautics and Aerospace Administration 2 Apr. 2014. http://www.nasa.gov/kepler/nasa-statement-two-wheel-kepler-mission-invited-to-2014-senior-review/.

[192] "NASA's WISE Survey Uncovers Millions of Black Holes." 29 Aug. 2012. NASA 3 Apr. 2014. http://www.nasa.gov/mission_pages/WISE/news/wise20120829.html.

the third closest star system to the Sun.[193] Although the spacecraft was placed into hibernation in February 2011, following the completion of its mission, it was reactivated in September 2013 for three more years of service with the goal of discovering and characterizing near-Earth objects (NEOs) with infrared light.[194] On 29 December 2013, this 'NEOWISE' mission detected the near-Earth asteroid '2013 YP139', found orbiting within 45 million km of Earth's path around the Sun.[195]

After running out of the coolant needed to chill its longer-wavelength instruments in 2009, NASA's Spitzer Space Telescope was repurposed to track exoplanets around other stars with the use of infrared light. As exoplanets cross in-front of their stars, they block out a fraction of the light, allowing the size of the planet to be revealed, in addition to giving clues about the planet's atmosphere by the infrared light that they also emit.[196] Spitzer has already observed infrared light emanating from a "super-Earth" planet in another solar system[197] and observed an unprecedented simultaneous elliptical galaxy with another thin disk existing in its interior.[198] And at the beginning of 2013, with the use of NASA's Spitzer and ESA's Herschel Space Observatory, a large asteroid belt was discovered around the star Vega.[199]

In July 2012, data from NASA's Hubble Space Telescope revealed the fifth known moon to orbit Pluto.[200] Hubble also discovered a new moon orbiting Neptune in July 2013, which is estimated to be less than 20 km in diameter.[201] It has also discovered the most distant galaxy to be found yet, with light that began

[193] "Closest Star System Found in a Century." 11 Mar. 2013. NASA 3 Apr. 2014. http://www.nasa.gov/mission_pages/WISE/news/wise20130311.html.

[194] "NASA Spacecraft Reactivated to Hunt for Asteroids." 21 Aug. 2013. NASA 2 Apr. 2014. http://www.jpl.nasa.gov/news/news.php?release=2013-257.

[195] "NEOWISE: The Wide-Field Infrared Survey Explorer (WISE)." NASA 2 Apr. 2014. http://neo.jpl.nasa.gov/programs/neowise.html.

[196] "How Engineers Revamped Spitzer to Probe Exoplanets." 24 Sept. 2013. NASA 3 Apr. 2014. http://www.spitzer.caltech.edu/news/1560-feature13-07-How-Engineers-Revamped-Spitzer-to-Probe-Exoplanets.

[197] "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-.

[198] "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.

[199] "NASA, ESA Telescopes Find Evidence For Asteroid Belt Around Vega." 8 Jan. 2013. NASA 3 Apr. 2014. http://www.spitzer.caltech.edu/news/1497-ssc2013-02-NASA-ESA-Telescopes-Find-Evidence-For-Asteroid-Belt-Around-Vega.

[200] "Hubble Discovers a Fifth Moon Orbiting Pluto." 11 July 2012. Hubble Site 3 Apr. 2014. http://hubblesite.org/newscenter/archive/releases/2012/2012/32/full/.

[201] "NASA Hubble Finds New Neptune Moon." 15 July 2013. NASA 3 Apr. 2014. http://www.nasa.gov/press/2013/July/nasa-hubble-finds-new-neptune-moon/.

700 million years after the Big Bang.[202] Hubble has also found faint signatures of water in the atmospheres of five distant planets,[203] in addition to observing water vapour above the south polar region of Jupiter's moon Europa, strongly suggesting that the vapour is generated by water plumes that erupted off Europa's surface.[204]

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.[205] And on 9 May 2012, NASA received the JWST's first completed instrument—the highly light-sensitive European-built Mid-Infrared Instrument (MIRI).[206] On 18 December 2013, the final three of 18 primary hexagonal mirror segments for the JWST arrived at NASA's Goddard Space Flight Center for integration prior to its launch. When in orbit, these hexagonal mirrors will fit together to form one unprecedented 6.5 m primary mirror, with the telescope stationed 1.5 million km from Earth, to be able to detect light from the first galaxies ever formed and observe planets in distant galaxies.[207]

2.4 Satellite Applications

2.4.1 Space-Based Communications

In 2012 and 2013, the satellite services industry continued to advance amid tepid global financial conditions. Yet while growth was positive, its rate diminished from 16 % in 2008 to 5 % in both 2012 and 2013. The growth can be credited to the industry's inherently global nature, allowing it to tap into the potential of emerging markets that had weathered the previous crisis with greater resilience. The industry continued to expand its technology development programmes with additional

[202] Texas Astronomer Discovers Most Distant Known Galaxy." 23 Oct. 2013. McDonald Observatory 3 Apr. 2014. http://mcdonaldobservatory.org/news/releases/2013/10/23.

[203] Hubble Traces Subtle Signals of Water on Hazy Worlds." 3 Dec. 2013. NASA 3 Apr. 2014. http://www.nasa.gov/press/2013/December/hubble-traces-subtle-signals-of-water-on-hazy-worlds/.

[204] "Hubble Space Telescope Sees Evidence of Water Vapor Venting off Jovian Moon." 12 Dec. 2013. NASA 3 Apr. 2014. http://www.nasa.gov/press/2013/December/hubble-space-telescope-sees-evidence-of-water-vapor-venting-off-jovian-moon/.

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

[206] 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.

[207] "Final James Webb Space Telescope Mirrors Arrive at NASA." 18 Dec. 2013. NASA 3 Apr. 2014. http://www.nasa.gov/content/goddard/final-james-webb-space-telescope-mirrors-arrive-at-nasa/.

investments in larger spacecraft with enhanced power and transponder capacity. Moreover, the industry exhibited the right mixture of investing in innovative technologies and new services while consolidating current operations, which boosted the industry's revenue for both reporting years.[208]

On radio frequency spectrum allocation, the ITU's World Radiocommunication Conference (WRC-15) is scheduled for 2015 and commercial satellite fleet operators have already begun preparing their defences, following their previous experience at WRC-07 when they struggled to prevent a raid on their C-band frequency allocations by terrestrial service providers. At the WRC-07, regulators agreed that the 3.4- to 4.2-GHz C-band frequencies should remain a priority allocation for satellite transmissions. Yet they also agreed that each nation could opt out of the agreement, and allocate these frequencies as it wished in its own territory (so long as resulting terrestrial wireless broadcasts did not interfere with satellite transmissions in a neighbouring country). Yet in practice, especially in the developing world, the decision by some nations to allow terrestrial wireless broadband services to operate more freely in C-band has produced multiple examples of satellite signals being wiped out. Now steps are being taken to coordinate with regional satellite broadcasting groups to try to develop a consensus position.[209]

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.

Russia's Glonass GNSS constellation was still being restored at the end of 2013, following the successful launch of one GLONASS-M satellite on a Soyuz launcher, and the launch failure of a Proton-M carrying three GLONASS-M satellites. Next-generation model GLONASS-K satellites will succeed the GLONASS-M model of which 24 were operational as of 26 April 2013, with additional spacecraft in production.[210] The new spacecraft will most likely incorporate significant technical improvements, including a new more accurate timing device and a non-pressurised structure, bringing operational performance close to US and European standards.

[208] See generally State of the Satellite Industry Report—October 2013.

[209] De Selding, Peter. "Another C-band Challlenge Expected at Upcoming Global Spectrum Conference." 15 Mar. 2013. SpaceNews 18 May 2014. http://www.spacenews.com/article/satellite-telecom/34362another-c-band-challenge-expected-at-upcoming-global-spectrum.

[210] Clark, Stephen. "Third Soyuz launch in a week bolsters Glonass system." 26 Apr. 2013. Spaceflight Now 19 May 2014. http://www.spaceflightnow.com/news/n1304/26soyuz/.

The constellation requires 24 operational satellites to provide complete global navigation coverage, with 3 sets of 8 satellites operating on three orbital planes.[211]

In Europe, following the milestone launches of the first two Galileo GNSS in-orbit validation (IOV) satellites on 21 October 2011 aboard a Europeanised Soyuz rocket launched from the Kourou, French Guiana, and an additional pair launched the next year on 12 October 2012, the IOV phase was another milestone determining the first position fix of longitude, latitude and altitude conducted on 12 March 2013, with an accuracy of 10–15 m. The 30-satellite constellation (27 operational and 3 spare) is expected to be completed by 2019.[212]

On 20 September 2012, in a summit between the EU and China in Brussels, Belgium, the two sides agreed to take their dispute over satellite navigation frequencies to the International Telecommunication Union (ITU) in December 2012.[213] The EU and China had been debating the issue of navigation signal conflicts for over 2 years without success in resolving the issue. While the ITU regulates satellite orbital slots and frequencies, its mandate does not extend to resolving issues such as that between Europe's Galileo and China's Beidou system. While the ITU was willing to provide a forum for discussions, it can do little given that Galileo and Beidou do not interfere with each other's operations. However, both sides see their overlapping frequency issue to be a problem, since China's Beidou system is designed to use a portion of radio spectrum that overlaps the Galileo frequencies the EU wants for its encrypted Public Regulated Service (both reserved for government and military use). If either the EU or China wanted to disable the other's secure signals in a time of conflict, due to the shared frequencies, they would be at risk of knocking out their own service as well.[214]

In late December 2012, China began fielding its regional satellite navigation capability offering services including positioning, navigation, time and text messaging to users in the Asia-Pacific region;[215] it plans to complete the deployment of its entire 35 satellite Beidou GNSS constellation by 2020. In light of that expedited development, Japan also began its development of the Quasi-Zenith Satellite System (QZSS), the country's future regional satellite navigation constellation. Following the first QZSS satellite launched in September 2010, the program slowed

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

[212] "Galileo: Satellite launches." 17 Jan. 2014. European Commission 18 May 2014. http://ec.europa.eu/enterprise/policies/satnav/galileo/satellite-launches/index_en.htm.

[213] De Selding, Peter. "China and Europe Taking Their Navigation Dispute to ITU." 8 Oct. 2012. SpaceNews 18 May 2014. http://www.spacenews.com/article/china-and-europe-taking-their-navigation-dispute-itu.

[214] De Selding, Peter. "EU, China Schedule Talks To Resolve Navigation Dispute." 15 Oct. 2012. SpaceNews 18 May 2014. http://www.spacenews.com/article/eu-china-schedule-talks-resolve-navigation-dispute.

[215] Associated Press. "China Satellite Navigation Starts Services to Asia." 27 Dec. 2012. SpaceNews 18 May 2014. http://www.spacenews.com/article/china-satellite-navigation-starts-services-to-asia.

due to unwillingness by the private sector to manage QZSS as a business without substantial government guarantees. In 29 March 2013, Mitsubishi Electric Co. was contracted to construct 3 additional QZSS satellites, i.e. one GEO satellite and two spacecraft following highly elliptical orbits, to complete the QZSS space architecture by 2017.[216] The QZSS system is designed to augment the regional accuracy of the GPS signal. The system scheme will provide Japanese authorities with a more accurate, secure and independent service. The future deployment of four spacecraft will allow for 24 h regional coverage, while deployment of the full seven satellite constellation will dramatically decrease Japan's dependence on GPS for regional coverage.[217]

On 2 July 2013, India also took a major stride in its regional navigation system launching its first dedicated navigation satellite, IRNSS-1A, into orbit. The first of 7 satellites, this autonomous regional system will consist of a ground segment, along with 3 IRNSS satellites in geostationary orbit and 4 satellites in inclined geosynchronous orbits. The system is expected to be completed be completed in 2015.[218]

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 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 February 2012. The Vega programme, approved by ESA

[216] De Selding, Peter. "Melco To Build Three QZSS Navigation Satellites." 3 Apr. 2013. SpaceNews 19 May 2014. http://www.spacenews.com/article/civil-space/34676melco-to-build-three-qzss-navigation-satellites.

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

[218] "India's first ever dedicated navigation satellite launched." 2 July 2013. DNAindia.com 30 May 2014. http://www.dnaindia.com/scitech/report-indias-first-ever-dedicated-navigation-satellite-launched-1855830.

in 1998, spent 9 years developing the launcher at a cost of 710 million Euros.[219] 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.[220]

ISRO's Geo-synchronous Satellite Launch Vehicle (GSLV-D5) is about to return to the launch platform, this time featuring an indigenous cryogenic engine in its third, final stage. It was planned to launch the GSLV-D5 on 19 August 2013, but this was aborted due to a leak in the rocket's second stage, which rained liquid fuel down the launcher, causing it to engulf in flames. The leak was due to the type of aluminium alloy used in the fuel tank, Afnor 7020, which was said to develop cracks over time. The GSLV-D5 has been refurbished since the incident, with a new second stage with its propellant tank made of aluminium alloy 2219.[221] If successful, this launcher will give India the capability to launch heavier satellites in the 2,000-plus kilogramme category into geosynchronous orbit, and launch interplanetary (or even lunar) spacecraft, while having been developed within ISRO's limited budget of around $1 billion per year.[222]

In the US, 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.[223] The engine, previously envisioned as the upper stage engine for the Ares 5 rocket to be used in the cancelled constellation programme, is now the upper stage of the heavy-lift US Space Launch System. However, upon completion of development testing in 2014, the engine with be shelved for several years before it is needed to launch humans to Mars. For precursor missions to the Moon, the all-cryogenic J-2X is somewhat over-powered, with the ability to lift a 130 metric ton SLS to LEO, whereas missions to the Moon simply need to lift a 105 tons SLS. Until NASA tests for a Mars mission, it will likely rely on the use of three or four RL-10 engines that could produce the dialled-back amount of force needed for lunar precursor missions.[224]

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

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

[221] "GSLV-D5 to Lift off on January 5." 22 Dec. 2013. The Hindu 9 Apr. 2013. http://www.thehindu.com/news/national/gslvd5-to-lift-off-on-January-5/article5487536.ece.

[222] "Cheaper Space Travel Technology." 11 Nov. 2013. Dawn.com 9 Apr. 2014. http://www.dawn.com/news/1055599/cheaper-space-travel-technology.

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

[224] "NASA's J-2X Engine To Be Mothballed After Testing." 4 Oct. 2013. Aviation Week 9 Apr. 2014. http://aviationweek.com/awin/nasa-s-j-2x-engine-be-mothballed-after-testing.

Space Exploration Technologies' (SpaceX) Falcon 9 launcher is the only currently operating launch vehicle that has engine out capability, able to lose 2 of its 9 Merlin engines in its first stage and still complete its mission.[225] In March 2013, SpaceX achieved flight qualification for its next generation Merlin-D engine, having accumulated a total test time of nearly 33 min, the equivalent of over 10 full mission durations.[226] The engine's 150 vacuum thrust-to-weight ratio, and enhanced design for improved manufacturability, makes it one of the most efficient booster engines ever built. Integrated on the upgraded Falcon 9 v1.1 launcher, the engines replaced the previous Merlin 1C engines and require a 60 % increase in the size of the rocket's propellant tanks; the Falcon 9 v1.1 had its debut launch on 29 September 2013.[227]

SpaceX developed a launch escape system engine to be used when eventually 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 re-entry. In the event of an emergency, at any stage in the launch, these "SuperDraco" engines can lift the astronauts' capsule out of danger with precise control, and can be restarted multiple times as needed.[228] The SuperDraco engines are built into the Dragon's side walls, and the 8 engines will produce up to 120,000 lb of axial thrust.[229] 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.

By the end of 2013, XCOR Aerospace and ULA had advanced substantially in their liquid hydrogen (LH2) engine development programme. Building on their earlier success with liquid oxygen and kerosene pumps, the group overcame the technical challenges presented with the extreme low temperature and small molecule size of liquid hydrogen to develop and successfully operate the engine's liquid hydrogen pump at full design flow rate and pressure conditions—opening the way for integrated testing of the LH2 demonstrator engine.[230] On 19 November 2013, the programme conducted the first successful hot fire of the subscale 2,500 lbf thrust XR-5H25 engine in the XCOR and ULA liquid hydrogen (LH2) engine

[225] "Merlin Engines." 29 July 2013. SpaceX 10 Apr. 2014. http://www.spacex.com/news/2013/03/26/merlin-engines.

[226] "SpaceX's Merlin 1D Engine Achieves Flight Qualification." 20 Mar. 2013. SpaceX 10 Apr. 2014. http://www.spacex.com/press/2013/04/13/spacexs-merlin-1d-engine-achieves-flight-qualification.

[227] "Upgraded Falcon 9 Mission Overview." 14 October 2013. SpaceX 9 Apr. 2014. http://www.spacex.com/news/2013/10/14/upgraded-falcon-9-mission-overview.

[228] "Draco Thrusters." 13 Apr. 2013. SpaceX 15 Apr. 2014. http://www.spacex.com/news/2013/04/04/draco-thrusters.

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

[230] "XCOR Aerospace and United Launch Alliance Announce Important Milestone in Liquid Hydrogen Engine Program." 23 Sept. 2013. XCOR Aerospace 14 Apr. 2014. http://www.xcor.com/press/2013/13-09-23_XCOR_ULA_announce_hydrogen_engine_milestone.html.

development programme.[231] The LH2 engine program is intended to produce a flight-ready cryogenic upper-stage engine in the 25,000 lbf thrust class with growth potential up to 50,000 lbf thrust or more, which should result in much lower cost and more capable commercial and government launch capabilities.

Reaction Engines is developing the Synergistic Air-Breathing Rocket Engine (Sabre) to power a planned single-stage-to-orbit (SSTO) spaceship, Skylon, as a part chemical rocket and part jet engine. Sabre will have the ability to use oxygen in airspace rather than from external liquid-oxygen tanks, and will eliminate the need for expendable boosters. When travelling at speeds of up to Mach 5.2, the super-heated air travelling through the engine is rapidly cooled to −150 °C, and then channelled through the engine's turbo-compressor, and into the thrust chambers, to be mixed with liquid hydrogen and ignited to produce thrust for the spacecraft.[232] ESA and the British government have invested a combined $92 million in the project, however completion of the engine will require an additional investment of $3.6 billion before it could be ready for flight tests. The Skylon itself would require a $14 billion investment.

NASA's Evolutionary Xenon Thruster (NEXT) Project has been operating for over 5.5 years, making it the longest space propulsion system demonstration project in history. The engine uses electricity generated by the spacecraft's solar panel to accelerate the xenon propellant to speeds reaching about 144,800 km/h. In an endurance test, the engine displayed a dramatic improvement in performance compared to conventional chemical rocket engines, consuming about 870 kg of xenon propellant to generate a total impulse that would require more than 10,000 kg of conventional rocket propellant for comparable applications.[233] The 7-kW class thruster could be used in a wide range of science missions, including missions in deep space.

Another strong potential propulsion system, in development for more than 25 years, is the Variable Specific Impulse Magnetoplasma Rocket (VASIMR). The VASIMR heats plasma to extreme temperatures using radio waves, which is then funnelled to the back of the engine with the use of strong magnetic fields, creating thrust. Plans are now underway to flight test a 200 kW variant of the

[231] "Hot Fire: XCOR Aerospace and United Launch Alliance Achieve Major Propulsion Milestone in Liquid Hydrogen Engine Program." 19 Nov. 2013. XCOR Aerospace 11 Apr. 2014. http://www.xcor.com/press/2013/13-11-19_XCOR_ULA_announce_hydrogen_milestone.html.

[232] "The Next Space Shuttle: Hybrid Engines Make Runway-To-Orbit Missions A Reality." 10 Sept. 2013. Popular Science 15 Apr. 2014. http://www.popsci.com/technology/article/2013-08/runway-orbit-and-back.

[233] "NASA Thruster Achieves World-Record 5+ Years of Operation." 24 June 2013. NASA 10 Apr. 2014. http://www.nasa.gov/home/hqnews/2013/jun/HQ_13-193_Ion_Thruster_Record.html.

VASIMR on the ISS as part of an electric-propulsion package on a commercial test bed that will operate as part of the station in the next few years. In addition to re-boosting space stations, the VASIMR could be used as a propulsion source in cleaning up space junk and powering superfast journeys that could reach Mars in less than 2 months.[234]

When selecting fuel for satellite propulsion, hydrazine with its highly energetic albeit equally toxic qualities has been the monopropellant of choice for over half a century. That may come to an end in the near future with the development of green propulsion fuel sources, and with the addition of hydrazine to the candidate list of "substances of very high concern" in the European Commission's Registration of Evaluation Authorization and Restriction of Chemicals (REACH) framework legislation in 2011. While some exemptions might be needed in the use of hydrazine for space, ESA is seeking industrial bids to study how propulsion system hardware might best be requalified to work with a less toxic 'green' propellant alternative as a replacement for hydrazine and other high toxicity propellants along with associated hardware. In ESA's pursuit, Sweden's ECAPS division of the Swedish Space Corporation Group (SSCG), with its High Performance Green Propulsion (HPGP) Ammonium DiNitramide (ADN)-based monopropellant designated 'LMP-103S', is considered to be most mature propellant option to serve as a hydrazine replacement.[235]

NASA is also evaluating alternative green propulsion technology, and has established a cooperative agreement with the Swedish National Space Board (SNSB) to test ECAPS' HPGP technology in the US. NASA will test and evaluate the 5-N and 22-N HPGP thrusters developed by ECAPS. LMP-103S is environmentally benign and significantly easier to transport and handle than hydrazine, while still being fully compatible with all of the traditional structural materials and commercial off-the-shelf (COTS) fluid control components that are typically implemented within hydrazine in-space propulsion system designs. In furtherance of the NASA-SNSB cooperative agreement, SNSB has contracted with ECAPS to mature both the 5 N and 22 N thrusters to Technology Readiness Level (TRL) 6, for demonstration purposes.[236]

[234] "High-Tech VASIMR Rocket Engine Could Tackle Mars Trips, Space Junk and More." 19 Nov. 2013. Space.com 10 Apr. 2014. http://www.space.com/23613-advanced-space-propulsion-vasimr-engine.html.

[235] "Considering Hydrazine-Free Satellite Propulsion." 14 Nov. 2013. Product Design & Development 16 Apr. 2014. http://www.pddnet.com/news/2013/11/considering-hydrazine-free-satellite-propulsion.

[236] "NASA to Test and Evaluate ECAPS Green Propulsion Technology." 30 Oct. 2013. SCC Space 10 Apr. 2014. http://www.sscspace.com/nasa-to-test-and-evaluate-ecaps-green-propulsion-technology.

In the US, Ball Aerospace & Technologies and other members of the Green Propellant Infusion Mission (GPIM) project are developing a green propellant demonstrator for NASA's Technology Demonstration Mission (TDM). To be integrated as a subsystem on a Ball BCP-100 spacecraft bus designed for easy integration of "ride-share" payloads, this mission will be the first time the US will use a spacecraft to test green propellant technology.[237] The propellant is a hydroxyl ammonium nitrate fuel/oxidizer blend known as AF-M315E, which offers nearly 50 % better performance than traditional hydrazine fuel, in addition to reducing the environmental impact during propellant loading, potentially increasing payload capacity, enhancing spacecraft manoeuvrability, and extending mission durations. On 20 September 2013, the GPIM project team achieved milestone when it was granted a successful Preliminary Design Review by NASA.

Innovative Space Propulsion Systems (ISPS) is also developing rocket engines that run on an environmentally benign propellant, "NOFBX". SpaceX now expects to fly the thruster test bed, 'ISPS NOFBX Green Propellant Demonstration', to the ISS sometime after 2013 for an up to 1-year placement on the European Columbus module, where it will undergo a series of in-space performance validation tests.[238] Developed in partnership by Odyssey Space Research and Firestar Technologies, NOFBX is a high-performance nitrous oxide/fuel/emulsifier blended mono-propellant that is non-toxic, low cost and easy to produce.[239] Capable of production from widely available chemicals, the fuel can be transported without excessive precautions.[240] In fact, NOFBX surpasses solid and bipropellants in many characteristics.[241] Also, due to its superior performance among competitors, NOFBX technology has been selected for development for low cost next generation tactical launch systems like DARPA's Airborne Launch Assist Space Access (ALASA) programme.[242]

And 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

[237] "Green Propellant Team Propels Itself Through Preliminary Design Review." 20 Sept. 2013. NASA 15 Apr. 2014. http://www.nasa.gov/mission_pages/tdm/green/green-propellant-preliminary-review.html.

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

[239] "Current Projects: Nitrous Oxide Fuel Blend (NOFBX)." Paragon 1 May 2014. http://www.paragonsdc.com/index.php?action=viewPost&postID=50.

[240] 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/.

[241] 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.

[242] "Stu Witt's Prepared Remarks to Congress on Commercial Space." 21 Nov. 2013. Parabolic Arc 16 Apr. 2014. http://www.parabolicarc.com/2013/11/21/stu-witts-prepared-remarks-congress-commercial-space/.

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.[243] 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.[244]

2.5.2 *Information Technology*

While the Ka-band radio-frequency allows higher bandwidth transfer in satellite communications, interest in the Ka-band spectrum has increased among terrestrial wireless broadband cellular network providers, wanting to expand their spectrum in the 30/20 GHz Ka-band range for their 5G terrestrial mobile systems. In this pursuit, the terrestrial wireless broadband industry, which competed with the satellite sector in 2007 over the use of C-band, is preparing to fight for new spectrum in the Ka-band at the World Radiocommunication Conference in 2015 (WRC-15), organised by the International Telecommunication Union (ITU). Should it be successful, Ka-band frequencies that now are reserved for satellite systems will be forced to share spectrum with terrestrial wireless operators. By the end of 2013, most of the 17 high-throughput satellites already in orbit used Ka-band, and another 30 satellites were scheduled for launch by 2022; while the revenue from these broadband satellites, which is expected to be less than $500 million in 2013, is expected to surpass $3 billion within 10 years. If spectrum is allowed to be shared, the satellite industry might find its services routinely violated in certain regions of the world, with broadband wireless networks causing interference with Ka-band satellite signals that in some nations are the main form of satellite communications.[245]

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[243] 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.

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

[245] "News from the High-Throughput Satellites London Roundtable | Terrestrial Operators Eyeing Ka-band Satellite Spectrum." 5 Dec. 2013. SpaceNews 10 Apr. 2014. http://www.spacenews.com/article/satellite-telecom/38517news-from-the-high-throughput-satellites-london-roundtable.

Inmarsat's first Global Xpress system satellite, Inmarsat-5, was launched on 8 December 2013, marking the beginning of the world's first globally available high-speed mobile broadband service for government and commercial users. With four satellites planned to be built by Boeing, the Inmarsat-5 satellite series will provide global mobile broadband communications for vessels at sea, in-flight connectivity on commercial aircraft, among other services.[246] Boeing is also building the Intelsat EpicNG high-throughput satellite, Intelsat 29e, to provide three to five times more capacity per satellite than Intelsat's traditional fleet.[247] By May 2013, four more Epic high-throughput satellites had been ordered from Boeing, with the Intelsat 29e expected to launch in 2015, while the other four will be launched on a yearly basis starting in 2016.[248]

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 that 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 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 Centre (ESOC) was to allow Rosetta to use more fuel than originally planned and fly a less-efficient route to the comet. Nevertheless,

[246] "1st Boeing-built Inmarsat-5 Global Xpress® Satellite Sends Initial On-Orbit Signals." 9 Dec. 2013. Boeing 10 Apr. 2014. http://boeing.mediaroom.com/1st-Boeing-built-Inmarsat-5-Global-Xpress-Satellite-Sends-Initial-On-Orbit-Signals.

[247] "Intelsat Epic^{NG}." Intelsat 10 Apr. 2014. http://www.intelsat.com/infrastructure/intelsat-epicng/.

[248] "Intelsat Buying Four More Epic Satellites from Boeing." 9 May 2013. SpaceNews 10 Apr. 2014. http://www.spacenews.com/article/satellite-telecom/35242intelsat-buying-four-more-epic-satellites-from-boeing.

with this approach, Rosetta will still have enough fuel to complete its comet rendezvous by mid-2014.[249]

ESA's Herchel science mission ended on 29 April 2013, following the exhaustion of its helium coolant reserves, having conducted more than 3 years of observations of the cool Universe.[250] Data from the Herchel's mission has been combined with the South Pole Telescope's measurements, to make the first detection of gravitational waves during the Universe's rapid 'inflation' period.[251] This result had previously been anticipated by Herschel's counterpart Planck mission. The spacecraft's final command, following a complex series of flight control activities and thruster manoeuvres, put Herschel on a course toward a safe disposal orbit around the Sun and placed its systems into passive mode.[252]

NASA's Mars Odyssey orbiter was put into safe-mode on 8 June 2012, when one of the three primary reaction wheels used for attitude control stuck for a brief period. Anticipating the potential occurrence of such a problem prior to the spacecraft's launch in April 2001, engineers had installed a spare reaction wheel skewed at right angles to all three others so that it could be used as a substitute for any one of them, to provide control in all directions. The satellite's reaction wheels control the way it faces the Sun, Earth or Mars. Increasing the rotation rate of a reaction wheel causes the spacecraft itself to rotate in the opposite direction. Through having the spare replacement wheel available, the longest running Mars obiter was returned to full, nominal operation mode on 27 June 2012, returning observation data with its Thermal Emission Imaging System and its Gamma Ray Spectrometer, and relaying data back to Earth from NASA's Mars Exploration Rover Opportunity and Mars Science Laboratory mission on the Red Planet.[253]

NASA's Orion Multi-Purpose Crew Vehicle (MPCV) will conduct its first mission, Exploration Flight Test-1 (EFT-1), in 2014. For its first mission, the Orion crew module will fly nearly 5,800 km above the Earth, where it will conduct two orbits before entering Earth's atmosphere to test the spacecraft's heat shield 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 will be to test whether

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

[250] "Herschel Closes its Eyes on the Universe." 29 Apr. 2013. ESA 2 Apr. 2014. http://www.esa.int/Our_Activities/Space_Science/Herschel/Herschel_closes_its_eyes_on_the_Universe.

[251] "Herschel Helps Find Elusive Signals from the Early Universe." 1 Oct. 2013. ESA 2 Apr. 2014. http://www.esa.int/Our_Activities/Space_Science/Herschel/Herschel_helps_find_elusive_signals_from_the_early_Universe.

[252] "Herschel End Operations as Orbiting Testbed." 17 June 2013. ESA 2 Apr. 2014. http://www.esa.int/Our_Activities/Operations/Herschel_ends_operations_as_orbiting_testbed.

[253] "Longest-Lived Mars Orbiter Is Back in Service." 27 June 2012. Jet Propulsion Laboratory 28 Mar. 2014. http://mars.jpl.nasa.gov/odyssey/news/whatsnew/index.cfm?FuseAction=ShowNews&NewsID=1242.

Orion's heat shield can withstand the forces of atmospheric re-entry at about 32,000 km/h, with temperatures reaching up to 2,200 °C.[254] While a total of 11 parachutes will be used to return the spacecraft to Earth, its 3 main parachutes, each weighing about 136 kg, will perform the major task of reducing Orion's speed to less than 32 km/h.[255]

In the private sector, following the permanent grounding of the NASA space shuttle fleet, NASA began the third phase of its Commercial Crew Development (CCDev) programme, called the Commercial Crew integrated Capability (CCiCap) initiative. In August 2012, following solicitations for proposals from US space industry participants to mature the design and development of an integrated crew transportation system (CTS) (which included spacecraft, launch vehicle, ground and mission systems), NASA awarded Boeing, SpaceX, and Sierra Nevada Corporation (SNC) funding to develop their vehicles to the next stage of providing domestic access to the ISS for US astronauts. Boeing was awarded $460 million, while SpaceX received $440 million, and SNC $212.5 million.[256] As at December 2013, the CCiCap award winners had the following milestone completion status: Boeing (14 of 20), SpaceX (11 of 17), and SNC (6 of 12).[257]

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 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.[258] During September 2013, the spacecraft passed its ninth milestone, where it successfully tested its orbital manoeuvring and attitude control (OMAC) system of 24 thrusters, which gives it the ability to perform critical manoeuvres in space (e.g. refining the CST-100's orbit), and its braking manoeuvre near the end of a mission to slow the spacecraft down before re-entry into the atmosphere.[259] By late October 2013, the CST-100's launch-abort engines completed their development testing milestone, clearing the way for

[254] 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.

[255] "Work on NASA's New Orion Spacecraft Progresses as Engineers Pivot to 2014." 23 Dec. 2013. NASA 15 Apr. 2014. http://www.nasa.gov/content/work-on-nasa-s-new-orion-spacecraft-progresses-as-engineers-pivot-to-2014/.

[256] "NASA CCiCAP Funding for SpaceX, Boeing and SNC's Crew Vehicles." 3 Aug. 2012. NASA Spaceflight 15 Apr. 2014. http://www.nasaspaceflight.com/2012/08/nasa-ccicap-funding-spacex-boeing-sncs-crew-vehicles/.

[257] "NASA's Return on Investment Report." 20 Dec. 2013. NASA 15 Apr. 2014. http://www.nasa.gov/sites/default/files/files/NASAROIReport_Dec2013_TAGGED.pdf.

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

[259] "NASA Commercial Partner Boeing Tests CST-100 Spacecraft Thrusters." 20 Sept. 2013. NASA 15 Apr. 2014. http://www.nasa.gov/press/2013/September/nasa-commercial-partner-boeing-tests-cst-100-spacecraft-thrusters/.

qualification tests of each engine requiring a firing duration of 11 s (double their design requirement). Similar to the SpaceX Dragon capsule, the CST-100 will have a pusher-style abort system, wherein four such engines would propel CST-100 and its crew to safety in the event of a launch problem.[260] Measuring 4.5 m across at its widest point, this seven-seat gumdrop-shaped capsule will be reusable for up to 10 flights.[261]

SpaceX is developing its Dragon 2.0 crew capsule, designed to send astronauts to the ISS, with two demonstration abort tests planned in 2014. SpaceX will flight-test its uncrewed 'DragonRider' to demonstrate the ability of the Dragon spacecraft abort system to lift the spacecraft clear of a simulated launch emergency. The second flight test involves simulating an in-flight emergency abort scenario during ascent at high altitude at maximum aerodynamic pressure at about 60 s into the launch. Both abort tests are essential for demonstrating that the spacecraft will activate its SuperDraco thrusters and separate in a split second from a potentially deadly exploding rocket fireball to save astronaut lives in the event of a real life emergency.[262] When crewed, the DragonRider will be able to lift up to seven astronauts to the ISS, and remain docked for at least half a year. SpaceX hopes to launch an initial crewed Dragon orbital test flight to the ISS as early as 2015.

The Sierra Nevada Corporation is developing the Dream Chaser, designed to send astronauts to the ISS on a winged, lifting-body spacecraft, with the capability of returning to Earth by landing on a conventional airstrip. The design of the reusable spacecraft is derived from NASA's HL-20 Personnel Launch System from the 1990s that had undergone years of development, analysis, and wind tunnel testing, along with related synergy with the retired US space shuttles. Capable of holding a crew of up to seven astronauts, the spacecraft would launch atop of an Atlas 5 rocket.[263] The first free flight of the Dream Chaser resulted in a milestone in successfully testing the spaceflyer's automated approach and landing system; although a malfunction in the Dream Chaser's left landing gear had it skidding off the runway at the end of the flight.[264] The landing gear door remained closed as the result of contamination in the hydraulic fluid that was used to power the system;

[260] "CST-100 Launch-abort Engines Complete Testing Milestone." 17 Dec. 2013. SpaceNews 15 Apr. 2014. http://www.spacenews.com/article/launch-report/38731cst-100-launch-abort-engines-complete-testing-milestone.

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

[262] "What's Ahead for Human Rated SpaceX Dragon in 2014—Musk tells Universe Today." 30 Dec. 2013. Universe Today 15 Apr. 2014. http://www.universetoday.com/107505/whats-ahead-for-human-rated-spacex-dragon-in-2014-musk-tells-universe-today/.

[263] "NASA CCiCAP Funding for SpaceX, Boeing and SNC's Crew Vehicles." 3 Aug. 2012. NASA Spaceflight 15 Apr. 2014. http://www.nasaspaceflight.com/2012/08/nasa-ccicap-funding-spacex-boeing-sncs-crew-vehicles/.

[264] "Private Dream Chaser Space Plane Skids Off Runway After Milestone Test Flight (Video)." 29 Oct. 2013. Space.com 15 Apr. 2014. http://www.space.com/23370-private-dream-chaser-space-plane-skidded-off-runway-after-milestone-test-flight.html.

its parts had been donated from a fighter jet, as opposed to the custom gear provided for missions in the future.[265] The Dream Chaser has attracted interest from Germany's DLR and OHB System AG, wishing to finance a study to explore ways in which the spacecraft can be used to cover German and European requirements for the transportation of payloads and astronauts to the ISS and for deployment as a manned or unmanned space vehicle allowing German and European scientists to conduct research under weightless conditions over extended periods of time. Moreover, given its capability of reaching orbits at a substantially greater altitude than the ISS, the study will determine the extent to which it is able to supply satellites or remove decommissioned satellites from their orbits.[266]

Notwithstanding the CCiCap awards given to Boeing, SpaceX, and SNC, Blue Origin is also in the running to develop its orbital reusable launch vehicle program outside of the CCiCap programme. In March 2013, NASA and Blue Origin signed an agreement to extend their CCDev2 partnership in an unfunded capacity, wherein until mid-2014, Blue Origin will continue to advance the subsystems of its biconic-shaped spacecraft.[267] In December 2013, Blue Origin test fired its hydrogen- and oxygen-fuelled BE-3 engine at full power for 145 s in its boost phase, shutting down to simulate coast through apogee, and then restarted and throttled down to 25,000 pounds thrust to simulate controlled vertical landing.[268] The BE-3 is planned to be a Reusable Booster System, which would be refurbished for another mission. The successful test of Blue Origin's BE-3 engine completed its Engine Mission Duty Cycle test milestone.[269]

2.5.4 Suborbital Activities

Virgin Galactic and similar US firms (e.g. XCOR Aerospace, Armadillo Aerospace, and Blue Origin, etc.) have been given a regulatory grace period extension on developing suborbital spacecraft without Federal Aviation Administration (FAA)

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[265] "Dream Chaser Receives CCDev-2 Green Light from NASA." 16 Dec. 2013. NASA Spaceflight 15 Apr. 2014. http://www.nasaspaceflight.com/2013/12/dream-chaser-ccdev-2-green-light-nasa/.

[266] "Contract Signed with DLR for the Study Phase for the Utilization of U.S. Company Sierra Nevada Corporation's Dream Chaser® Spacecraft." 13 Nov. 2013. OHB System 16 Apr. 2014. https://www.ohb-system.de/press-releases-details/items/contract-signed-with-dlr-for-the-study-phase-for-the-utilization-of-us-company-sierra-nevada-corporations-dream-chaser-spacecraf.html.

[267] "Blue Origin Signs New NASA Space Act Agreement." 2 Mar. 2013. Innerspace 16 Apr. 2014. http://innerspace.net/cotscommercial-crew/blue-origin-signs-new-nasa-space-act-agreement/.

[268] "NASA Commercial Crew Partner Blue Origin Test-Fires New Rocket Engine." 3 Dec. 2013. NASA 16 Apr. 2014. http://www.nasa.gov/press/2013/December/nasa-commercial-crew-partner-blue-origin-test-fires-new-rocket-engine/.

[269] "NASA's Return on Investment Report." 20 Dec. 2013. NASA 15 Apr. 2014. http://www.nasa.gov/sites/default/files/files/NASAROIReport_Dec2013_TAGGED.pdf.

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 has become established; the 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.[270]

On a related note, by late April 2013, Virgin Galactic completed the first rocket-powered flight of its suborbital space vehicle, SpaceShip Two.[271] This achievement officially marked the final phase of vehicle testing prior to commercial service from Spaceport America in New Mexico. The company cleared an important regulatory hurdle in 2012, when the US 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-US citizens on Virgin Galactic suborbital flights would have constituted an export activity requiring federal approval, and thus the need for export licenses that could take months for each case. However, as the spacecraft's 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 US, is treated as an 'export' of the technical data.[272] Virgin Galactic now expects to fly its first paying customers in 2014.[273]

Other groups have seen mixed results in their suborbital spacecraft development. Masten Space Systems, Armadillo Aerospace, and Blue Origin 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—these groups are required to carry NASA payloads within near-space altitudes. Near-space is the grey-zone

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

[271] "Virgin Galactic Breaks Speed of Sound in First Rocket-Powered Flight of SpaceShipTwo." 29 Apr. 2013. Virgin Galactic 11 Apr. 2014. http://www.virgingalactic.com/news/item/virgin-galactic-breaks-speed-of-sound-in-first-rocket-powered-flight-of-spaceshiptwo/.

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

[273] "Branson Ready for Lift Off With 700 Space Tickets Sold." 18 Sept. 2013. The Telegraph 11 Apr. 2014. http://www.telegraph.co.uk/finance/newsbysector/transport/10319028/Branson-ready-for-lift-off-with-700-space-tickets-sold.html.

where the delimitation between airspace and outer space is uncertain, i.e. between around 40 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. While the first experimental suborbital launcher was destroyed on 11 September 2012 during the spacecraft's 110th test-flight, when a stuck engine valve triggered the rocket's flight termination system during its descent,[274] a second slightly larger Xaero-B continued the programme's development.[275] Armadillo Aerospace was developing the SuperMod suborbital rocket; another vertical-takeoff, vertical-landing rocket, derived from Armadillo's Module 1 (Mod) vehicle, but by mid-2013 it had paused development in search for new investors. The company's January 2013 launch of its STIG-B rocket from Spaceport America in New Mexico resulted in a failure after a parachute failed to deploy.[276] Blue Origin's New Shepard suborbital spacecraft will be launched atop a rocket-powered Propulsion Module. In December 2013, Blue Origin, created by Amazon founder Jeff Bezos, completed a full-duration burn of a liquid hydrogen-fuelled BE-3 engine developed for both the New Shepard suborbital spaceship and planned orbital vehicles.[277]

Additionally, XCOR's Lynx suborbital spacecraft is the company's entry into the commercial reusable launch vehicle (RLV) market. The Lynx is a horizontal takeoff and horizontal landing vehicle that uses its own fully reusable rocket propulsion system to take off and land on runway. This two-seat, piloted space transport vehicle will take humans and payloads on a half-hour suborbital flight to 100 km (330,000 feet) and then return to a landing at the takeoff runway. The piloted, two-seat spacecraft can be used to lift humans and payloads on a 30 min suborbital flight up to four times in a day. Lynx will be FAA AST-licensed, and has already passed the AST licensing process with an earlier vehicle concept.[278] In March 2013, a significant milestone was reached when the first firing of a full piston pump-powered rocket engine was performed.[279] With interest already created among commercial industry and research institutes, XCOR's Lynx Mark I will

[274] "Masten's Xaero Rocket Lost During Mojave Test Flight." 17 Sept. 2012. SpaceNews 14 Apr. 2014. http://www.spacenews.com/article/masten%E2%80%99s-xaero-rocket-lost-during-mojave-test-flight.

[275] "Masten Unveils Xaero-B Reusable Suborbital Rocket." 26 Mar. 2013. Flight Global 14 Apr. 2014. http://www.flightglobal.com/news/articles/masten-unveils-xaero-b-reusable-suborbital-rocket-383662/.

[276] "Armadillo Aerospace Suspends Vehicle Development Work." 2 Aug. 2013. SpaceNews 14 Apr. 2014. http://www.spacenews.com/article/launch-report/36590armadillo-aerospace-suspends-vehicle-development-work.

[277] "Blue Origin Rocket Engine Test-fired for Simulated Suborbital Run." 4 Dec. 2013. SpaceNews 14 Apr. 2014. http://www.spacenews.com/article/launch-report/38495blue-origin-rocket-engine-test-fired-for-simulated-suborbital-run.

[278] "About Lynx." XCOR Aerospace 11 Apr. 2014. http://www.xcor.com/lynx/.

[279] "XCOR Aerospace Announces Significant Propulsion Milestone on Lynx Suborbital Vehicle." 26 Mar. 2013. XCOR Aerospace 14 Apr. 2014. http://www.xcor.com/press/2013/13-03-26_XCOR-lynx-propulsion-milestone.html.

begin commercial flights in 2015 and will carry payloads smaller than 1 kg as a "ride share" or "secondary payload", and up to one 120 kg "primary" mission payload [integrated into the Lynx by the Czech Space Office (CSO)]. Payloads may be placed inside the Lynx pressurised cabin or exposed to the vacuum and radiation conditions of space.[280]

2.5.5 Other Technologies

Developments in technology and science continued to advance both in 2012 and 2013, with implications reaching beyond the space sector.

In January 2013, NASA's Robotic Refuelling Mission (RRM) was used to demonstrate that remotely controlled robots using current-day technology could refuel satellites that were not designed to be serviced. Following this success, a second-phase RRM mission is planned in 2014 to demonstrate how space robots can replenish coolant in the instruments of similar legacy satellites.[281] NASA's RRM was launched to the ISS on 8 July 2011, and is mounted outside of the station. 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 uses a set of satellite-servicing tools to perform simulated refuelling tasks on the RRM. Initial activities to demonstrate this in-orbit capability were completed in 2012 wherein with the aid of the original RRM tools and activity boards Dextre was used to cut away protective thermal blankets, unscrew fuel caps and transfer simulated fuel from one reservoir to another. It is hoped that 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 commercial companies to conduct commercial refuelling operations on satellites.[282]

With Robonaut 2 (R2) already active on the ISS, NASA engineers are developing climbing legs to provide added mobility for regular and repetitive tasks within and outside the station. No longer considered to be superfluous add-ons, once the legs are attached to the R2 torso, the robot will have a fully extended leg span of 2.7 m. Each leg has seven joints and an end effector with a camera, allowing it to

[280] "Czech Space Office and XCOR Aerospace Sign Payload Integrator Agreement for Suborbital Flights." 21 Nov. 2013. XCOR Aerospace 14 Apr. 2014. http://www.xcor.com/press/2013/13-11-21_czech_space_office_xcor_payload_integrator.html.

[281] "Japanese Vehicle Delivers New Hardware for NASA's Robotic Refueling Mission." 2 Aug. 2013. NASA 15 Apr. 2014. http://www.nasa.gov/content/goddard/japanese-vehicle-delivers-new-hardware-for-nasa-s-robotic-refueling-mission/.

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

grasp handrails and sockets in and on the station. R2 will receive its legs early in 2014.[283] NASA is also developing another robot, Valkyrie (R5), which competed in DARPA's Robotics Challenge. In the challenge, this $7.6 million robot used standard tools and equipment commonly available in human environments (i.e. hand tools, vehicles, etc.) to demonstrate capabilities to execute complex tasks in dangerous, degraded, human-engineered environments.[284]

NASA's robotic exoskeleton (X1), jointly developed with the Florida Institute for Human and Machine Cognition (IHMC), is another spinoff derived from NASA's Robonaut 2 project and the IHMC's Mina exoskeleton designed for paraplegic users on Earth. The X1 is a 26 kg device that can be worn over a person's body either to inhibit or assist movement in leg joints. The inhibit mode would supply resistance against leg movement, allowing the X1 to be used as an in-space exercise machine. Moreover, the same technology could also be used to assist individuals to walk for the first time; and as the technology matures, it could also provide a robotic power boost to astronauts as they work on the surface of distant planetary bodies. The X1 is currently in the research and development phase, with primary focus on the design, evaluation and improvement of the technology. When completed, the X1 may help astronauts remain healthy in space, while also assisting paraplegics in walking on Earth.[285]

DARPA's Membrane Optical Imager for Real-Time Exploitation (MOIRE) program, currently in its final phase, aims to create technologies that would enable future high-resolution orbital telescopes to provide real-time video and images of the Earth from GEO orbit. The MOIRE programme recently demonstrated a ground-based prototype that included a new lightweight polymer membrane optics to replace glass mirrors, balancing the loss of efficiency with the use of much larger lighter-weight lenses that more than make up the difference. In the past, size and cost constraints prevented large-scale imaging satellites from being placed within GEO. A new system incorporating MOIRE optics would be roughly one-seventh the weight of a comparable traditional system, and could be tightly packed into a configuration roughly 6 m in diameter, wherein upon reaching GEO, it would unfold to create the full-size multi-lens optics reaching 20 m in diameter. If successful, the satellite could have a 40 % field of view of the earth's surface,

[283] "NASA Developing Legs for Space Station's Robonaut 2." 9 Dec. 2013. NASA 14 Apr. 2014. http://www.nasa.gov/press/2013/December/nasa-developing-legs-for-space-stations-robonaut-2/.

[284] "NASA JSC Has Developed A Girl Robot in Secret (Revised With NASA Responses)." 12 Dec. 2013. NASA Watch 14 Apr. 2014. http://nasawatch.com/archives/2013/12/nasa-jsc-has-de.html.

[285] "NASA's Ironman-Like Exoskeleton Could Give Astronauts, Paraplegics Improved Mobility and Strength." 2 Aug. 2013. NASA 14 Apr. 2014. http://www.nasa.gov/offices/oct/home/feature_exoskeleton.html.

and would be able to focus on a 10 km-by-10 km area at 1-m resolution, providing real-time video at 1 frame per second.[286]

In an effort to improve astronaut mobility both within and outside the ISS and other spacecraft, the Draper Laboratory is developing a spacesuit called a Variable Vector Countermeasure suit (V2Suit), which incorporates control moment gyroscopes (CMGs) into astronaut spacesuits and extravehicular Activity (EVA) jetpacks. CMGs are positioned on various parts of the spacesuit to create a network, which would then be attached to corresponding parts of the wearer, providing torque in movement to imitate gravity, and allow the wearer to develop a sense of egocentric coordination. By moving against resistance, the suit is expected to help prevent astronauts' loss of bone mass and muscle strength during extended stays in space. The project began in September 2011, funded by NASA's Innovative Advanced Concepts (NIAC) program, and it should complete its phase 2 by the end of 2014. Draper expects the suit to be ready for space sometime in the next 5–10 years. Additional plans involve the use of CMGs on EVAs to help stabilize an astronaut when working around an asteroid or other larger object in space. As current EVAs use gas thrusters to counter astronauts' motion in space, CMGs may help reduce the need for thrusters by compensating for angular motion, letting the thrusters control linear motion, instead of using thrusters for both.[287]

On 20 November 2013, the US Secretary of Defence completed a Memorandum of Understanding with Australia's Defence Minister to have DARPA's Space Surveillance Telescope (SST) fully relocated to Australia by 2016. The SST will be moved from its current mountaintop location in White Sands, New Mexico, USA where the system underwent operational testing and evaluation, to Australia, where it will provide key space situational awareness from the largely unexplored southern portion of the geosynchronous belt. The relocation process will begin in 2014, and is expected to resume operations sometime in 2016. From its new location, the SST—with ten times more sensitivity than current state-of-the-art systems—will transmit its observations into the Space Surveillance Network (SSN). The SSN is a US Air Force system charged with cataloguing and observing space objects to identify potential near-term collisions with space assets, providing data to spacefaring countries around the world. In addition to detecting debris, the SST will also continue to provide NASA and the scientific community with

[286] "First Folding Space Telescope Aims to "Break the Glass Ceiling" of Traditional Designs." 5 Dec. 2013. DARPA 14 Apr. 2014. http://www.darpa.mil/NewsEvents/Releases/2013/12/05.aspx.

[287] "When You Think Gyroscopes, Go Ahead and Think the Future of Spacesuits and Jet Packs, too." 1 June 2013. Washington Post 15 Apr. 2014. http://www.washingtonpost.com/blogs/innovations/wp/2013/06/01/when-you-think-gyroscopes-go-ahead-and-think-the-future-of-spacesuits-and-jet-packs-too/.

surveillance data on transient events such as supernovae and potentially hazardous NEOs.[288]

By August 2014, the ISS will have its first 3D printer on board with the capability of building an estimated 30 % of the spare parts on the station, in addition to specialty tools and experiment upgrades. Developed by 'Made in Space', the selected printer was one of three prototypes demonstrated by the company in parabolic flights. The result of collaboration with NASA's Marshall Space Flight Center, this 3D Printing in Zero G Experiment (3D Print) was meant to demonstrate that 3D printers can print in microgravity. As it is used on Earth, 3D printers use a technique called extrusion additive manufacturing to build objects layer by layer out of polymers, metals, composites and other materials. The main goal of the 3D Print experiment is to help jump-start an off-planet manufacturing capability, which could aid in deeper space exploration by making life in space easier and cheaper. In this pursuit, NASA has also recently funded the development of a prototype 3D printer designed to make space food products out of cheap raw materials that have a long shelf life; useful for long space journeys, such as the 500-day return trip to Mars.[289]

[288] "DARPA Space Surveillance Telescope Ready for Delivery." 9 Dec. 2013. SpaceRef 14 Apr. 2014. http://spaceref.com/nasa-hack-space/darpa-space-surveillance-telescope-ready-for-delivery.html.

[289] "3D Printer Passes Zero-Gravity Test for Space Station Trip." 19 June 2013. Space.com 16 Apr. 2014. http://www.space.com/21630-3d-printer-space-station-tests.html.