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

The major space policy developments worldwide were presented in Chap. 1, above, to identify the principal space faring nations' strategies in 2014. In the section below, there will be a brief discussion of 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

With the conclusion of the 2 December 2014 ESA Ministerial Council meeting, ESA has decided to proceed with the Ariane 6 as the next generation launcher, to be developed by 2020. A major distinction of the Ariane 6 from its progenitors is in its governance arrangement, wherein industry partners Airbus and Safran, under a joint venture called Airbus Safran Launchers, will take over as the launcher's design authority, in addition to taking on the responsibility of the commercial exploitation of these launchers. Meanwhile, ESA member states have agreed to continue supporting the Ariane 5, Vega, and Europeanized-Soyuz launchers until the 2016 ESA Ministerial Council meeting. At the next meeting, ESA will decide

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whether to continue with these three distinct launchers, or to rely solely on the two configurations of the Ariane 6 for future launches.[1]

On the issue of future international cooperation in space transportation and space exploration, the combined use of the ATV and other similar spacecraft from the U.S. (Dragon and Cygnus COTS missions), Japan (HTV) and Russia (Progress M) to serve ISS supply needs provides an example of the opportunities in the creation of common transportation policies among all participating space actors. While ESA began its final ATV-5 mission in mid-2014, to pay for its contribution to the operation of the ISS until 2017, ESA's dues for the utilization of the ISS on its extended operation will be paid by supplying NASA with an ATV-derived service module for NASA's Orion spacecraft.[2] The provision of ESA's ATV-technology for the Orion module will cover ESA's 8.3 % share of the ISS's annual operating costs for the period 2018–2020; estimated at a total cost of 455 million euros. At the International Astronautical Congress (IAC) held on 29 September to 3 October 2014, it was suggested that the Progress, ATV, and HTV cargo spacecraft would likely be welcome to fly to the upcoming Chinese space station; although some political and export control barriers need to be overcome before U.S. commercial supply services are able to launch to the Sino-space station.[3]

Seeking to increase its space exploration capability, ESA has been developing its entry, descent, and landing technology through its Intermediate Experimental Vehicle (IXV) since 2006. Having narrowly escaped cancellation following the previous financial crisis, the Italian led programme was scheduled to complete final integration in May 2014, and was planned to undergo a suborbital test launch on a Vega launcher by 18 November 2014.[4] However, the launch had to be pushed to 2015, to allow for additional analyses of the Vega flight trajectory.[5]

[1] Henry, Caleb. "ESA Hands Reins to Industry on New Launchers." 3 Dec. 2014. Satellite Today 22 June 2015. http://www.satellitetoday.com/launch/2014/12/03/esa-hands-reins-to-industry-on-new-launchers/.

[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] Foust, Jeff. "SN Blog | The Role of International Cooperation in China's Space Station Plans." 14 Oct. 2014. SpaceNews 30 June 2015. http://spacenews.com/42183sn-blog-the-role-of-international-cooperation-in-chinas-space-station-plans/.

[4] Foust, Jeff. "65th International Astronautical Congress | European Re-entry Demonstrator Ready for November Test Flight." 3 Oct. 2014. SpaceNerws 14 July 2015. http://spacenews.com/4207765th-international-astronautical-congress-european-re-entry-demonstrator/.

[5] "Vega launch of ESA spaceplane postponed." 28 Oct. 2014. ESA 15 July 2015. http://www.esa.int/Our_Activities/Launchers/IXV/Vega_launch_of_ESA_spaceplane_postponed.

2.2.2 United States

Despite the success of NASA's Orion Multi-Purpose Crew Vehicle (MPCV) Exploration Flight Test 1 mission on the Space Launch System (SLS) on 5 December 2014, the ongoing White House and Congress debate on funding levels and prioritisation has resulted in missed opportunities, with the debut of the SLS probably delayed by a year. While NASA had aimed to have the SLS ready by December 2017, it seems more likely to have the launcher ready only in November 2018.[6] However a revised launch date awaits the completion of design reviews expected early in 2015. Other factors contributing to the expected delay come from the analyses of the 5 December launch, which tested many of the MPCV's key subsystems (e.g. its heat shield, electronics, and parachutes); and from ESA's inclusion into the programme by providing its ATV-derived service module.[7]

In broad policy matters, at the 30th Space Symposium in Colorado Springs, U.S., held on 19–22 May 2014, U.S. congressional staffers revealed that the U.S. government is preparing to update the Commercial Space Launch Act, last amended in 2004. Expected to come by 2015, the new legislation will address: whether the FAA will be allowed to begin writing human spaceflight safety regulations after October 2015, when the current regulatory grace period expires; in addition to changes to the formula FAA uses to determine how much insurance commercial launch providers must carry; and some changes to the National Oceanic and Atmospheric Administration's (NOAA) licensing regime for commercial remote sensing satellites. However, it not clear whether the new law will allow the FAA to regulate what commercially launched spacecraft can do while they are on orbit; that hot-button issue is currently being reviewed by congress.[8]

2.2.3 Russia

Russia is making progress in line with recent national space policies that have focused on improvement of the country's self-sufficiency, on technological and operational levels, to increase Russia's global market shares in the space sector. Development of the Vostochny Cosmodrome, located in the Far Eastern region of Russia, is continuing—to ensure the completion of the spaceport's Soyuz-2 and

[6] Foust, Jeff. "Looming SLS Delay To Rekindle Debate about NASA's Priorities." 29 Aug. 2014. SpaceNews 14 July 2015. http://spacenews.com/41710looming-sls-delay-to-rekindle-debate-about-nasas-priorities/.

[7] Foust, Jeff. "Next Orion Flight To Slip to 2018." 3 Dec. 2014. SpaceNews 14 July 2015. http://spacenews.com/42825next-orion-flight-to-slip-to-2018/.

[8] Leone, Dan. "Hill Staffers: Commercial Space Launch Bill Is Coming This Year." 26 May 2014. SpaceNews 14 July 2015. http://spacenews.com/40694hill-staffers-commercial-space-launch-bill-is-coming-this-year/.

Angara launch pads by 2016; which should also coincide with the completion of its Angara launcher.[9] The final construction stage of the Vostochny Cosmodrome, taking place between 2016 and 2018, will develop facilities for a super-heavy launch vehicle that will be capable of delivering 120–150 tons into space by 2020.[10]

On 9 July 2014, Russia succeeded in test launching its new indigenous Angara launcher, the first new rocket designed by Russia's space industry in over 20 years.[11] The inaugural sub-orbital flight of the Angara 1.2 was postponed from its intended 27 June 2014 launch date due to a drop in oxidizer pressure that stemmed from a poorly sealed valve on the launcher's liquid oxygen tank.[12] The Angara is a two stage launcher, with a main core that burns kerosene and liquid oxygen, which can be supplemented with additional boosters to increase power; while different upper stage designs can be used depending on the intended orbit altitude. The 9 July test launch was of the Angara 1—its simplest configuration—that should be capable of launching up to 4 tons to LEO orbit. The variants are planned to extend to a heavy-lift Angara 5 version intended to carry up to 7.5 tons to GEO orbit. The Angara will launch from both the Plesetsk spaceport and the soon to be built Vostochny Cosmodrome.[13] The Angara is meant to replace Russia's somewhat unreliable Proton M launcher to remain competitive with commercial launcher providers such as SpaceX.

2.2.4 Japan

Japan 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 draft midterm report recommending an H-3 successor launcher.[14] On 24 December 2013, the

[9] Nowakowski, Tomasz. "Putin pledges $1.5 billion for completion of Vostochny Cosmodrome, OKs plans for creating super-heavy rockets." 9 Sept. 2014. Spaceflight Insider 16 July 2015. http://www.spaceflightinsider.com/organizations/roscosmos/putin-pledges-1-5-billion-completion-vostochny-cosmodrome-oks-plans-creating-super-heavy-rockets/.

[10] Bodner, Matthew. "Putin Pledges $1 Billion for Completion of New Cosmodrome." 2 Sept. 2014. The Moscow Times 16 July 2015. http://www.themoscowtimes.com/business/article/putin-pledges-1-billion-for-completion-of-new-cosmodrome/506321.html.

[11] De Selding, Peter B. "Russia's Angara 1.2 Rocket Succeeds in Inaugural Flight, Khrunichev Says." 9 July 2014. SpaceNews 16 July 2015. http://spacenews.com/41184russias-angara-12-rocket-succeeds-in-inaugural-flight-khrunichev-says/.

[12] Bodner, Matthew. "Angara Launch Troubles Reflect Russia's Struggling Space Industry." 1 July 2014. The Moscow Times 16 July 2015. http://www.themoscowtimes.com/business/article/angara-launch-troubles-reflect-russias-struggling-space-industry/502809.html.

[13] Amos, Jonathan. "Russia's Angara rocket 'makes debut'." 9 July 2014. BBC.com 16 July 2015. http://www.bbc.com/news/science-environment-28058633.

[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.

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. was selected by JAXA as the prime contractor, with the launcher expected to feature a liquid hydrogen/liquid oxygen core stage with up to six solid-fuel strap-on boosters to offer a wide range of payload-to-orbit capabilities.[16]

2.2.5 *China*

In line with its latest five-year plan for 2011–2016, released in December 2011,[17] China has continued to make incremental progress in the field of space transportation. It plans to develop three new launcher configurations by 2016, i.e. Long March 5 (with a 14 tons to GEO lift capacity), Long March 6 (1 ton to LEO), and Long March 7 (5.5 tons to LEO), using more efficient engines and an entirely new upper stage. China is also developing a new launch centre in the Northeastern corner of Hainan Island, far south of the mainland; its completion is expected to coincide with the completion of China's Long March 5, 6, and 7 launch systems. The use of the Hainan spaceport will allow China to free itself from the limitations of using its curving rail lines, and transporting vehicles through the narrow width of its train tunnels.[18]

The Long March 5 is expected to conduct its first launch sometime in 2015, from the Hainan spaceport. By the end of 2014, it was undergoing final testing and assembly.[19] The Long March 5 will be used to lift component modules of China's space station into orbit over the next decade. Comparable to other heavy launchers, such as the U.S. Delta IV Heavy and Europe's Ariane 5, the Long March 5 will be

[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] Onuki, Misuzu. "MHI Formally Selected as H-X Prime Contractor, Operator." 25 Mar. 2014. SpaceNews 30 May 2014. http://www.spacenews.com/article/financial-report/39971mhi-formally-selected-as-h-x-prime-contractor-operator.

[17] 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.

[18] David, Leonard. "China's New Spaceport to Launch Country's Largest Rocket Yet." 2 Apr. 2014. Space.com 16 July 2015. http://www.space.com/25323-china-new-spaceport-rocket-launches.html.

[19] Lin, Jeffrey and P.W. Singer. "China Is Building One Of The World's Largest Space Launch Vehicles." 11 Dec. 2014. Popular Science 16 July 2015. http://www.popsci.com/long-march-goes.

powerful enough to launch a lunar or Mars mission spacecraft with a total thrust at sea level of 1080 tons.

On 21 November 2014, China conducted the second launch of its Kuaizhou mobile satellite launch vehicle (SLV), meant to be a rapid satellite repopulation capability, following the first launch on 25 September 2013.[20] Also, China is developing a second emergency response launch vehicle, Long March 11, to allow it to rapidly enter space and meet the emergency launching demand in case of disasters and contingencies. It is expected to launch sometime before 2016.[21]

Moreover, China is also developing an even larger launcher, comparable to the U.S. SLS system, called the Long March 9. Up to December 2014, China had been conducting preliminary research, considering the technological feasibility and requirements needed for the launcher to be capable of exploration beyond the Moon. Similar to the SLS, the Long March 9 is expected to have a maximum payload of 130 tons, but its first launch will occur in the decade following the SLS's first launch.[22] At the International Astronautical Congress held in Beijing on 23–-27 September 2013, the CALT published the main specifications of the two possible configurations. The first concept would have four YF-660 engines mounted in the core first stage and one in each of four side-mounted boosters. In the second concept, most of the initial thrust would come from four solid-propellant boosters, each generating 1000 tons of thrust, while four YF-220 concept engines would be mounted in the first stage. While work is underway on the engines, Chinese industry is still awaiting permission to begin developing the Long March 9.[23]

2.2.6 India

India's space launch programme primarily relies on the use of its Polar Satellite Launch Vehicle (PSLV), capable of carrying 3700 kg payloads to Low Earth Orbit and 800 kg to Geosynchronous Transfer Orbits (GTO).[24] However the successful launch of its Geosynchronous Satellite Launch Vehicle (GSLV)-Mark II on 5 January 2014 makes room for ISRO to develop its new GSLV Mark III rocket, capable of launching around 4000 kg into GTO. The GSLV-Mark II can launch up

[20] Fisher (Jr.), Richard D. "China launches second Kuaizhou mobile SLV." 26 Nov. 2014. HIS Jane's 360 16 July 2015. http://www.janes.com/article/46360/china-launches-second-kuaizhou-mobile-slv.

[21] Profiles of Government Space Programs. Paris: Euroconsult, 2014: 18.

[22] Lei, Zhao. "New Long March launcher on the drawing board." 9 Dec. 2014. SpaceDaily 16 July 2015. http://www.spacedaily.com/reports/New_Long_March_launcher_on_the_drawing_board_999.html.

[23] "Chinese Super-Heavy Launcher Designs Exceed Saturn V." 30 Sept. 2013. Aviation Week 2 May 2014. http://aviationweek.com/awin/chinese-super-heavy-launcher-designs-exceed-saturn-v.

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

to 2500 kg into GTO, using two liquid fuel stages, and a new indigenous cryogenic upper stage. Prior to the successful January 2014 launch of the GSAT 14 communications satellite, the Mark I and II had had mixed results over the past decade, exhibiting a trend of launch failures from 2006, and were not used following launch failures in 2010.[25] The GSLV-Mark III will share a number of components with its predecessor GSLV-Mark I and II launchers, but it 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.[26] The first experimental sub-orbital test of the GSLV-Mark III was conducted on 18 December 2014.[27] ISRO plans to market its GLSV to launch heavier commercial communications satellites through its Antrix commercial arm beginning in 2017.[28]

At the International Astronautical Congress held in Toronto from 29 September to 3 October 2014, India's intention to expand its presence in the global launch market became more apparent. Representatives from Antrix announced that India's PSLV had five slots available for commercial Earth observation and research customers, i.e. one in 2015, three in 2016, and one in 2017, to launch missions to sun-synchronous orbit. And one GSLV-Mark III launcher should be available per year for commercial sale starting in 2017.[29]

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, progress in the latter category can be seen with the development of exploration involving commercial players, and with new space powers demonstrating the technology needed to carry out such missions.

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

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

[27] "First Experimental Flight of India's Next Generation Launch Vehicle GSLV Mk-III Successful." 18 Dec. 2014. ISRO 15 July 2015. http://www.isro.gov.in/update/18-dec-2014/first-experimental-flight-of-indias-next-generation-launch-vehicle-gslv-mk-iii.

[28] De Selding, Peter B. "65th International Astronautical Congress | India Poised To Expand Presence in Global Launch Market." 1 Oct. 2014. SpaceNews 14 July 2015. http://spacenews.com/4205565th-international-astronautical-congress-india-poised-to-expand-presence/.

[29] Ibid.

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 upon to transport crew regularly to the ISS and, using Progress and Soyuz, it also provided ISS cargo resupply services with Europe's Automated Transfer Vehicle (ATV) and Japan's H-II Transfer Vehicle (HTV) providing auxiliary support.

On 22 November 2010, ESA's newest batch of astronauts, Luca Parmitano, Alexander Gerst, Samantha Cristoforetti, Timothy Peake, Andreas Mogensen, and Thomas Pesquet, graduated from the European Astronaut Centre (EAC). After Luca Parmitano completed his 5-month ISS Expeditions 36/37 mission on 11 November 2013, Alexander Gerst flew to the space station as a flight engineer for Expeditions 40/41 in May 2014. In November 2014, Samantha Cristoforetti began her mission to the ISS as the eighth ESA astronaut to participate in a long-duration visit.

Alexander Gerst began his 6-month 'Blue Dot' mission on the ISS on 28 May 2014. Serving as a flight engineer, Alexander assisted in the docking and unloading of five visiting cargo spacecraft, and was the prime operator for the final ESA Automated Transfer Vehicle (ATV), George Lemaître, where he monitored the arrival and docking of the vessel and took responsibility for the distribution of the contents of its cargo bay.[30] The German astronaut also tested the Electromagnetic Levitator, a furnace that can melt and solidify metal alloys away from the container's walls, helping to gain insight into the solidification and physical properties of molten alloys, and intended to improve industrial casting processes and permit finer and more delicate metal castings.[31] Gerst performed over 50 other experiments covering materials physics, human physiology, radiation biology, solar research, biotechnology, fluid physics and astrophysics, and a series of technology demonstrations.[32] Gerst also participated in NASA's Ocular Health research into how astronauts' eyes adapt to space conditions, and assisted with general maintenance on the station, such as repairing a xenon lamp in JAXA's SAIBO rack, for experiments aiming to grow more effective crops on Earth.[33] Further he participated in a 6.25 h spacewalk on 7 October with NASA astronaut Reid Wiseman, and

[30] "ESA astronaut Alexander Gerst arrives at Space Station." 29 May 2014. ESA 26 May 2015. http://www.esa.int/Our_Activities/Human_Spaceflight/Blue_dot/ESA_astronaut_Alexander_Gerst_arrives_at_Space_Station.

[31] "Ask astronaut Alexander anything." 11 Mar. 2014. ESA 26 May 2015. http://www.esa.int/Our_Activities/Human_Spaceflight/Blue_dot/Ask_astronaut_Alexander_anything.

[32] "ESA astronaut Alexander Gerst arrives at Space Station." 29 May 2014. ESA 26 May 2015. http://www.esa.int/Our_Activities/Human_Spaceflight/Blue_dot/ESA_astronaut_Alexander_Gerst_arrives_at_Space_Station.

[33] "Alexander's first week in space." 5 June 2014. ESA 26 May 2015. http://www.esa.int/Our_Activities/Human_Spaceflight/Blue_dot/Alexander_s_first_week_in_space.

choreographed a second 6.5 h spacewalk in the following week.[34] Gerst completed his Blue Dot mission on 10 November 2014, and returned to Earth along with Russian commander Maxim Suraev and NASA astronaut Reid Wiseman on the same Soyuz TMA-13M spacecraft that brought them to the station.[35]

Shortly afterward, on 24 November, ESA Astronaut Samantha Cristoforetti began a 5-month mission on the ISS under the mission banner 'Futura'.[36] In addition to helping to berth regular supply vessels such as the American Dragon, the Italian astronaut will be the prime operator for the undocking of ESA's final ATV from the ISS. Cristoforetti will run an extensive scientific programme including experiments in physical science, biology, human physiology, and radiation research and technology demonstrations, in addition to maintenance of the station.[37]

Although the life of the ISS has been extended by another 5 years, ESA is stopping the production of Automated Transfer Vehicles (ATVs) after 2015. The fifth and final ATV, George Lemaître, was launched to the ISS on 29 July 2014 on an Ariane 5 ES launcher from French Guiana. The ATV-5 carried on its exterior a Laser InfraRed Imaging Sensors (LIRIS) test demonstrator as a step toward future rendezvous with 'uncooperative' targets, such as orbiting debris or a Mars sample capsule. Using infrared cameras and lidar sensors (i.e. the light equivalent of radar), such future missions will scan the targets while onboard computers process the data using new guidance navigation and control software.[38] The ATV-5 was the heaviest of its progenitors, carrying over 6602 kg of experiments, spare parts, clothing, food, fuel, air, oxygen and water to the station—including the 400 kg Electromagnetic Levitator.[39] By the end of 2014, the ATV-5 had conducted more than three reboost/deboost manoeuvres,[40] including an unprecedented event in November where the ISS required urgent action to avoid a piece of Cosmos-2251 space debris.[41]

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[34] "Wiseman and Gerst Complete First Spacewalk of Expedition 41." 7 Oct. 2014. NASA 27 May 2015. http://www.nasa.gov/content/wiseman-and-gerst-complete-first-spacewalk-of-expedition-41.

[35] "ESA astronaut Alexander Gerst returns to Earth." 10 Nov. 2014. ESA 26 May 2015. http://www.esa.int/Our_Activities/Human_Spaceflight/Blue_dot/ESA_astronaut_Alexander_Gerst_returns_to_Earth.

[36] "ESA astronaut Samantha Cristoforetti arrives at Space Station." 24 Nov. 2014. ESA 26 May 2015. http://www.esa.int/Our_Activities/Human_Spaceflight/Futura/ESA_astronaut_Samantha_Cristoforetti_arrives_at_Space_Station.

[37] "Futura mission in brief." 27 Oct. 2014. ESA 27 May 2015. http://www.esa.int/Our_Activities/Human_Spaceflight/Futura/Futura_mission_in_brief.

[38] "ATV-5 set to test new rendezvous sensors." 18 Mar. 2014. ESA 26 May 2015. http://www.esa.int/Our_Activities/Human_Spaceflight/ATV/ATV-5_set_to_test_new_rendezvous_sensors.

[39] "ATV-5: loaded and locked." 23 July 2014. ESA 26 May 2015. http://www.esa.int/Our_Activities/Human_Spaceflight/ATV/ATV-5_loaded_and_locked.

[40] "ATV-5 Mission Updates." 1Oct. 2014. Spaceflight101.com 27 May 2015. http://www.spaceflight101.com/atv-5-mission-updates.html.

[41] "ESA space ferry moves Space Station to avoid debris." 4 Nov. 2014. ESA 26 May 2015. http://www.esa.int/Our_Activities/Human_Spaceflight/ATV/ESA_space_ferry_moves_Space_Station_to_avoid_debris.

DLR continued to develop and implement the German Space Programme, based on its National Space Strategy published in 2010, with strong involvement in the ISS, ExoMars and lunar preparatory activities at ESA level, and scientific instrumentation, robotics contributions and data analysis in the National Programme and cooperatively for international exploration missions. The flight of astronaut Alexander Gerst to ISS in May 2014 was strongly supported by Germany's national research and outreach programme.[42]

In 2014, Russia launched four expeditions to the ISS on its Soyuz launcher: TMA-12M on 26 March 2014 with the Expedition 39/40 crew of Steve Swanson, Alexander Skvortsov, and Oleg Artemyev[43]; TMA-13M on 28 May 2014 with the Expedition 40/41 crew of Reid Wiseman, Maxim Suraev, and Alexander Gerst[44]; TMA-14M on 26 September 2014 with the Expedition 41/42 crew of Aleksandr Samoukutyaev, Elena Serova, and Barry Wilmore[45]; and TMA-15M on 24 November 2014 with the Expedition 42/43 crew of Terry Virts, Anton Shkaplerov, and Samantha Cristoforetti.[46] In addition to conducting a 6.5 h space-walk outside the ISS, and launching a Russo-Peruvian nanosatellite, Chasqui I (Messenger), Russian cosmonauts Aleksandr Skvortsov and Oleg Artemyev carried out a number of technical operations on the ISS.[47] Elena Serova is the first Russian woman to work on the ISS, and the fourth Russian woman to fly in space; Serova will work on or help to plan a variety of ongoing experiments on the station.[48] Russia also conducted four successful resupply launches to the ISS with its Progress cargo transfer vehicles: M-22M on 5 February 2014, M-23M on 9 April 2014, M-24M on 24 July 2012, and M-25M on 29 October 2014.[49]

[42] 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.

[43] "Russia launches Expedition 39 to ISS." Russian Space Web 26 May 2015. http://www.russianspaceweb.com/iss_soyuz_tma12m.html.

[44] "Russia launches fresh crew to ISS." Russian Space Web 26 May 2015. http://www.russianspaceweb.com/iss_soyuz_tma13m.html.

[45] "Mission of Soyuz TMA-14M." Russian Space Web 26 May 2015. http://www.russianspaceweb.com/iss_soyuz_tma14m.html.

[46] "Mission of Soyuz TMA-15M." Russian Space Web 26 May 2015. http://www.russianspaceweb.com/iss_soyuz_tma15m.html.

[47] Burke, Myles. "Russian cosmonauts make six-and-a-half-hour spacewalk outside ISS." 18 Aug. 2014. The Telegraph 21 Aug. 2015. http://www.telegraph.co.uk/news/science/space/11041065/Russian-cosmonauts-make-six-and-a-half-hour-spacewalk-outside-ISS.html.

[48] Allen, Nick. "Zebrafish, athlete's foot and 3D printing: 10 far out experiments on the International Space Station." 26 Sept. 2014. The Telegraph 21 Aug. 2015. http://www.telegraph.co.uk/news/science/space/11122637/Zebrafish-athletes-foot-and-3D-printing-10-far-out-experiments-on-the-International-Space-Station.html.

[49] "A complete chronology of ISS missions." Russian Space Web 26 May 2015. http://www.russianspaceweb.com/iss_chronology_flights.html.

Following the success of the Tiangong 1 space laboratory and associated milestones in docking its Shenzhou spacecraft to the station, and repeatedly sending Chinese astronauts to the station in 2012 and 2013, China did not conduct human spaceflight missions in 2014. China plans to complete the construction and launch of its Tiangong 2 space lab in 2015, followed by another experimental core module of the future space station around 2018.[50] However, the launch of the Tiangong 2 space lab has been pushed to 2016. The Shenzhou-11 spacecraft and Tianzhou-1 cargo spacecraft will be launched shortly afterward to dock with the space lab. China's full space station is to be completed by 2022.[51]

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 progress toward a robotic and human lunar presence, however budget constraints had the potential to delay well-intentioned initiatives. The U.S. and Russia also maintained their interest in exploring the Moon, and its potential benefit for future Mars exploration.

At ESA's Ministerial Council meeting held on 2 December 2014, the agency gained approval and funding to investigate participation with Russia in robotic missions for the exploration of the Moon; Russia intends to place a lander and a rover on the Moon's South Pole. Discussions of a partnership with Russia's Roscosmos on the project have been ongoing following ESA's inability to gather enough support for its own proposed ESA Lunar Lander mission at the Ministerial Council held in 2012. The project had been passed over in favour of launcher development, EO, ISS operations, and the joint ExoMars mission with Russia.[52] In the new proposed partnership, ESA would contribute technologies to Roscosmos' Luna-Resource Lander, also known as Luna 27, which is scheduled for launch in 2019, as well as the Lunar Sample Return, planned for the early 2020s. Pursuing lunar missions is strategically important for ESA, not only to secure access to the Moon's surface for European scientists, but also to ensure that European expertise and technology is involved in future lunar exploration—including, ultimately, international crewed missions and even a permanent lunar base.[53]

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[50] "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.

[51] "China's space station to be established around 2022." 10 Sept. 2014. English.news.cn 11 June 2015. http://news.xinhuanet.com/english/china/2014-09/10/c_133633441.htm.

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

[53] Gibey, Elizabeth. "Europe proposes joint Moon trips with Russia." 9 Dec. 2014. Nature 28 Feb. 2015. http://www.nature.com/news/europe-proposes-joint-moon-trips-with-russia-1.16517.

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, including the largest high resolution mosaic of the Moon's North polar region to date,[54] and has determined areas of the Moon that are in perpetual darkness or in near-continuous sunlight. The LRO helps scientists study the deformation of the Moon due to Earth's pull, which provides clues about the Moon's interior. Earth's distorting effect on the Moon, i.e. the lunar body tide, provides enough force to raise a 51 cm bulge on the near side of the Moon and a corresponding dip on the far side, with the bulge shifting according to the Earth's movements.[55]

In a study published in August 2014, it was proposed that high-energy particles from uncommon, large solar storms penetrate the Moon's polar regions and electrically charge the soil potentially significantly altering soil properties, which could have important implications for current understanding of the evolution of planetary surfaces in extremely cold regions that are exposed to harsh radiation from space.[56] Moreover, the LRO has provided researchers strong evidence that the moon's volcanic activity slowed gradually instead of stopping abruptly a billion years ago, having observed distinctive rock deposits that are estimated to be less than 100 million years old, with some areas appearing less than 50 million years old.[57] Also, through measuring the Moon's radiation environment, the spacecraft's CRaTER instrument was able to show that in shielding against the radiation faced by astronauts in deep-space missions, tissue-equivalent plastics and other lightweight materials can provide even more effective protection than standard shielding, such as aluminium.[58] The LRO completed its first extended science mission on 15 September 2014, beginning its second 2 year extended science mission slated

[54] Press Release. "NASA Releases First Interactive Mosaic of Lunar North Pole." 18 Mar. 2014. NASA 28 Feb. 2015. http://www.nasa.gov/press/2014/march/nasa-releases-first-interactive-mosaic-of-lunar-north-pole/.

[55] Zubritsky, Elizabeth. "NASA Missions Let Scientists See Moon's Dancing Tide From Orbit." 29 May 2014. NASA 28 Feb. 2015. http://www.nasa.gov/content/goddard/nasa-missions-let-scientists-see-moon-s-dancing-tide-from-orbit/.

[56] "Electric Sparks May Alter Evolution of Lunar Soil." 21 Aug. 2014. NASA 28 Feb. 2015. http://www.nasa.gov/content/goddard/electric-sparks-may-alter-evolution-of-lunar-soil/.

[57] Release. "NASA Mission Finds Widespread Evidence of Young Lunar Volcanism." 12 Oct. 2014. NASA 28 Feb. 2015. http://www.nasa.gov/press/2014/october/nasa-mission-finds-widespread-evidence-of-young-lunar-volcanism/.

[58] Zubritsky, Elizabeth. "Internet Radio Provides Musical Space-Weather Reports from NASA's LRO Mission." 9 Jan. 2014. NASA 28 Feb. 2015. http://www.nasa.gov/content/goddard/musical-space-weather-reports-from-nasas-lro/.

for completion in September 2016[59]; even so, the LRO retains sufficient fuel to maintain its current orbit for around more 8 years.[60]

NASA's newly launched Lunar Atmosphere and Dust Environment Explorer (LADEE) lifted into space on 6 September 2013. After completing its development phase in reaching the Moon at the end of 2013, the satellite began 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.[61] LADEE uses a set of three instruments to measure the chemical composition of the atmosphere, and collect and analyse samples of lunar dust particles in the atmosphere. Its Neutral Mass Spectrometer, measuring atoms and molecules in the lunar atmosphere, has already recorded noble gases helium, neon, and argon-40. The Ultraviolet-Visible Spectrometer views the lunar horizon seeking the glow of atoms, molecules and dust in the lunar atmosphere and has made measurements of atmospheric sodium and potassium at lunar sunset, sunrise and noon. LADEE's Lunar Dust Experiment (LDEX) has measured the dust tossed up by a fairly steady "rain" of meteoroids on the lunar surface, due to meteoroid showers and "dust bursts" that may be from LADEE flying through plumes kicked up from nearby meteoroid impacts. [62] While the 100-day mission was completed on 1 March 2014, it had been extended for an additional lunar day (29.5 Earth days) to gain a further understanding of the sources and drivers of the tenuous lunar atmosphere, as they are subject to change from month to month.[63] LADEE's final manoeuvre was performed on 11 April, adjusting its trajectory to avoid any previous lunar mission landings; and following a total lunar eclipse on April 14 to 15, LADEE impacted the surface of the moon on 17 April 2014.[64]

China's Chang'e 3 Lunar lander and rover mission successfully soft-landed on the Moon on 14 December 2013, making it the third country in the world to soft land a spacecraft on the Moon. Shortly afterward, the Yutu rover, 'Jade Rabbit', began its planned 3-month mission, using ground-penetrating radar and spectrometers to inspect the composition of the Moon's soil and the structure of the much

[59] Keller, J. "The Lunar Reconnaissance Orbiter and the New Moon: Mission Highlights and Two More Years of Science From Lunar Orbit!" 22 Nov. 2014. LRO—Lunar Planetary Institute 16 Mar. 2015. http://www.lpi.usra.edu/meetings/leag2014/presentations/keller.pdf.

[60] Petro, Noah E., and John W. Keller. "The second extended science mission for the lunar reconnaissance orbiter: Status, science goals, and data deliveries." 15 Sept. 2014. LPSC 16 Mar. 2015. http://www.hou.usra.edu/meetings/lpsc2015/pdf/2278.pdf.

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

[62] Hoover, Rachel. "NASA Extends Moon Exploring Satellite Mission." 31 Jan. 2014. NASA 28 Feb. 2015. http://www.nasa.gov/ames/nasa-extends-moon-exploring-satellite-mission/.

[63] Elphic, Rick. "LADEE Project Scientist Update: Citius, propius, occupatus." 10 Apr. 2014. NASA 28 Feb. 2015. http://www.nasa.gov/ames/ladee-project-scientist-update/.

[64] "NASA Completes LADEE Mission with Planned Impact on Moon's Surface." 18 Apr. 2014. NASA 28 Feb. 2015. http://www.nasa.gov/ames/nasa-completes-ladee-mission-with-planned-impact-on-moons-surface/.

deeper lunar crust.[65] While the rover was able to activate all of the scientific tools within days of deployment, it experienced a myriad of challenges from the outset of its mission. Those challenges stemmed from the extreme lunar environment and mechanical control problems that eventually kept the rover from entering normal dormancy and folding its mast and solar panels by its second 14-day lunar night. The rover completed its first examination of the lunar soil on 16 January 2014.[66] In the following weeks, communication with the rover became more difficult as the rover's solar panels began to degrade due to the colder than anticipated temperatures on the Moon; the rover became immobile from 25 January 2014,[67] however it was still able to send signals to Earth for the remainder of the year.

Following the continued success of Chang'e 3 lander and the Jade Rabbit rover, the country pressed on with the 23 October 2014 launch of its test capsule Chang'e 5-TI, which looped around the Moon as a test-run for an eventual lunar sample return mission.[68] The mission was to verify technologies for the sample return initiative in the third phase of China's lunar exploration programme; it also accommodated a mini-satellite called the Manfred Memorial Moon Mission (4M) developed by LuxSpace.[69] China plans to return a sample of lunar soil to Earth with its Chang'e 5 to be launched in 2017,[70] in addition to sketching plans for a manned lunar landing sometime between 2025 and 2030.[71]

The Google Lunar X PRIZE is a competition for a total of $30 million in prizes for the first privately funded team to safely land a rover on the Moon. 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

[65] "Chang E III launch next year will achieve lander and rover joint probe." 14 June 2012. News. Xinhuanet.Com 21 Aug. 2015. http://news.xinhuanet.com/politics/2012-06/14/c_112217044.htm.

[66] "China's Jade Rabbit rover explores Moon soil." 16 Jan. 2014. BBC News 21 Aug. 2015. http://www.bbc.com/news/science-environment-25763168.

[67] Chen, Stephen. "Last-ditch efforts to salvage mission of China's stricken Jade Rabbit lunar rover." 18 Apr. 2014. South China Morning Post 21 Aug. 2015. http://www.scmp.com/news/china/article/1486425/last-ditch-efforts-salvage-mission-chinas-stricken-jade-rabbit-lunar.

[68] Spudis, Paul D. "China is Now Positioned to Dominate the Moon." 6 Nov. 2014. Air & Space Smithsonian 28 Feb. 2015. http://www.airspacemag.com/daily-planet/china-now-positioned-dominate-moon-180953267/?no-ist.

[69] Lakdawalla, Emily. "UPDATED: China successfully launched test mission for Chang'e 5 program today." 23 Oct. 2014. Plantary.org 28 Feb. 2015. http://www.planetary.org/blogs/emily-lakdawalla/2014/10230750-china-to-launch-test-mission.html.

[70] "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.

[71] "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.

teams. With amounts ranging from between $250,000 to $1 million available to teams that demonstrate (via actual testing and analysis) robust hardware and software to combat key technical risks in the areas of imaging, mobility and lander systems, the awards can be won through the end of September 2014.[72] With 25 teams registered for the competition on 31 December 2010,[73] by the end of 2013, that number had reduced to 18 active teams, with several competitors leaving to pursue other business interests.[74] On 16 December 2014, the Lunar X Prize was competition deadline was extended to 2016.[75]

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 October 2014, the orbiter was repositioned to view the comet Siding Spring as it streaked past Mars at a distance reaching 139,500 km; i.e. just over a third of the distance from the Moon to the Earth. The flyby presented the opportunity for close-up observations of the comet, the influence of the comet's gas and dust on Mars atmosphere, and the complex three-way interaction between Mars, the comet and the solar wind.[76]

The ExoMars mission, now a joint endeavour between ESA and Russia, continued its development into 2014. ESA will provide the Trace Gas Orbiter (TGO) and the Entry, Descent and Landing Demonstrator Module (EDM) 'Schiaparelli' in

[72] "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.

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

[74] "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.

[75] Foust, Jeff. "Google Lunar X Prize Extends Competition Deadline." 17 Dec. 2014. SpaceNews 23 July 2015. http://spacenews.com/google-lunar-x-prize-extends-competition-deadline/.

[76] "Mars Express ready for comet encounter." 17 Oct. 2014. ESA 1 Mar. 2015. http://www.esa.int/Our_Activities/Operations/Mars_Express_ready_for_comet_encounter.

201,[77] 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. The ExoMars mission will address whether life has ever existed on Mars by drilling the surface of the planet and analyzing the samples in situ. By February 2014, the orbiter's core TGO module was completed, and will be launched in the 2016 mission to search for evidence of methane and other atmospheric gases that could be signatures of active biological or geological processes.[78] 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.[79] In October 2014, an ESA-appointed panel formally recommended further analysis of four possible landing sites for the rover, i.e. Mawrth Vallis, Oxia Planum, Hypanis Vallis, and Aram Dorsum—each located relatively close to Mars' equator. The candidate sites will need to satisfy the technical constraints of the mission, meeting the operational and engineering requirements for safe landing and roving on the surface. The first certification is expected by the end of 2016, while a final decision on the landing site will be taken sometime in 2017.[80]

NASA's Mars Odyssey mission, launched on 7 April 2001, is the longest-operating spacecraft to be sent to Mars. The satellite orbited the planet's poles at about 5 am/pm local Mars time for the first 6 years of its mission, providing optimal temperature for its Gamma Ray Spectrometer search for evidence of water near the Martian surface (e.g. how widely water ice and other elements are distributed on Mars). In the next 3 years, a 4 am/pm orbit allowed the orbiter's Thermal Emission Imaging System (THEMIS) to more easily identify the infrared signatures of minerals. By 2012, after providing radio-relay support for the landing of the Curiosity Mars rover, the orbit was manoeuvred on a slow drift to later times of the day to aid in preserving battery life. In February 2014, it was proposed to have the orbiter moved to a 6:45 am/pm orbit that will have the Odyssey make daylight observations from South-to-North, which could present seasonal differences; the orbit-adjustment locking manoeuvre will be conducted on 15 November 2015.[81] On 5 August 2014, the orbiter was manoeuvred to place it behind Mars during the 30 min when the comet Siding Spring's dust particles were most likely to reach Mars, avoiding a potential impact that might have ended the Odyssey mission a

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

[78] "ExoMars orbiter core module completed." 3 Feb. 2014. ESA 1 Mar. 2015. http://exploration.esa.int/mars/53642-exomars-orbiter-core-module-completed/.

[79] "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/.

[80] "Four candidate landing sites for ExoMars 2018." 1 Oct. 2014. ESA 1 Mar. 2015. http://exploration.esa.int/mars/54708-four-candidate-landing-sites-for-exomars-2018/.

[81] Press Release. "NASA Moves Longest-Serving Mars Spacecraft for New Observations." 12 Feb. 2014. NASA 1 Mar. 2015. http://mars.jpl.nasa.gov/odyssey/news/whatsnew/index.cfm?FuseAction=ShowNews&NewsID=1602.

decade too early.[82] On 19 October 2014, the orbiter's THEMIS was used to observe the comet's arrival, while its Neutron Spectrometer and High Energy Neutron detector were used to assess possible effects on Mars' atmosphere of dust and gas from the comet.[83]

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,[84] in addition to finding evidence of carbon-dioxide snowfalls (i.e. 'dry ice') occurring around Mars' South Pole in its winter season.[85] In February 2014, a possible explanation for the dark, finger-like slopes came from clues corresponding to the seasonal changes in iron ore minerals and a survey of ground temperatures and other traits that supported a suggestion that the slopes may be brines with an iron-mineral anti-freeze, such as ferric sulfate, that flow seasonally.[86] Images from the spacecraft's High Resolution Imaging Science Experiment (HiRISE) camera also helped to reveal more detail about the changing Martian seasons, such as showing the formation of a new gully channel that broke out from an older route and eroded its new path; an activity that generally tends to occur in the planet's winter period where temperatures are cold enough to keep carbon dioxide in its liquid state.[87] The MRO was also manoeuvred on 2 July and 27 August to place the satellite in the right position to view the gases in comet Siding Spring's coma, in addition to detailed views of the comet's small nucleus and potentially its rotation rate and surface features.[88]

[82] "Orbiter Completes Maneuver to Prepare for Comet Flyby." 6 Aug. 2014. NASA 1 Mar. 2015. http://mars.jpl.nasa.gov/odyssey/news/whatsnew/index.cfm?FuseAction=ShowNews&NewsID=1689.

[83] "NASA's Mars Odyssey Orbiter Watches Comet Fly Near." 19 Oct. 2014. NASA 1 Mar. 2015. http://mars.jpl.nasa.gov/odyssey/news/whatsnew/index.cfm?FuseAction=ShowNews&NewsID=1736.

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

[85] "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.

[86] "NASA Mars Orbiters See Clues to Possible Water Flows." 10 Feb. 2014. NASA 1 Mar. 2015. http://mars.jpl.nasa.gov/mro/news/whatsnew/index.cfm?FuseAction=ShowNews&NewsID=1599.

[87] "NASA Orbiter Finds New Gully Channel on Mars." 19 Mar. 2014. NASA 1 Mar. 2015. http://mars.jpl.nasa.gov/mro/news/whatsnew/index.cfm?FuseAction=ShowNews&NewsID=1613.

[88] "NASA's Mars Spacecraft Manoeuvres to Prepare for Close Comet Flyby." 25 July 2014. NASA 1 Mar. 2014. http://mars.jpl.nasa.gov/mro/news/whatsnew/index.cfm?FuseAction=ShowNews&NewsID=1675.

The NASA Mars Science Laboratory (MSL) rover, nicknamed Curiosity, reached Mars on 5 August 2012, and is currently studying Mars's habitability.[89] 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; interpreting the processes that have formed and modified rocks and soils; assessing 4-billion-year timescale atmospheric evolution processes; determining the present state, distribution, and cycling of water and carbon dioxide; and characterizing the broad spectrum of surface radiation, including galactic cosmic radiation, solar proton events, and secondary neutrons.[90] By 6 May 2014, Curiosity had drilled into its third rock sample, a sandstone slab designated as Windjana, to be studied by the rover's internal instruments. Whereas the two previous rock-drilling sites, conducted on mudstone targets, revealed evidence of an ancient lakebed environment that held key chemical elements and a chemical energy source that long ago provided conditions favourable for microbial life, the Windjana site is expected to reveal the cementing material that holds together sand-size grains in sandstone.[91] On 5 August 2014, Curiosity celebrated its second year on Mars; while in its first year, Curiosity's major science goal was in determining whether Mars ever offered environmental conditions favourable for microbial life, its second year was meant to determine how the environmental conditions on Mars evolved.[92] After bypassing a fourth drilling target for safety concerns in August, the rover reached Mount Sharp on 24 September, where it began to sample the base layer of the mountain.[93] There, Curiosity confirmed the presence of the mineral hematite, an iron-oxide mineral that gives clues about ancient environmental conditions from when it formed, first mapped from orbit by the NASA MRO in 2010.[94] On 16 December 2014, after a year of analysing a drilled sample of the Sheepbed mudstone in the Gale crater, the team responsible for the Sample Analysis at Mars (SAM) instrument made the first definitive detection of organic material on Mars—i.e. short of finding signs of life at the Gale crater, the discovery shows that the ancient environment offered a supply of

[89] "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.

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

[91] "NASA's Curiosity Rover Drills Sandstone Slab on Mars." 6 May 2014. NASA 1 Mar. 2015. http://www.nasa.gov/jpl/msl/drill-hole-20140506/.

[92] "NASA Mars Curiosity Rover: Two Years and Counting on Red Planet." 5 Aug. 2014. NASA 1 Mar. 2015. http://www.nasa.gov/jpl/msl/curiosity-20140805/.

[93] "NASA Rover Drill Pulls First Taste From Mars Mountain." 25 Sept. 2014. NASA 1 Mar. 2015. http://www.nasa.gov/jpl/msl/nasa-rover-drill-pulls-first-taste-from-mars-mountain/.

[94] "NASA's Curiosity Mars Rover Finds Mineral Match." 4 Nov. 2014. NASA 1 Mar. 2015. http://www.nasa.gov/jpl/msl/nasas-curiosity-mars-rover-finds-mineral-match/.

reduced organic molecules for use as building blocks for life and an energy source for life.[95]

NASA's Mars Atmosphere and Volatile EvolutioN (MAVEN) mission, launched on 18 November 2013, successfully entered Mars's orbit on 21 September 2014.[96] 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.[97] 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.[98] The satellite was also manoeuvred to avoid the high-velocity dust released by comet Siding Spring, while its Imaging Ultraviolet Spectrograph observed intense ultraviolet emissions from magnesium and iron ions high in the atmosphere in the aftermath of the meteor shower, and its Neutral Gas and Ion Mass Spectrometer detected eight different types of metal ions, including sodium, magnesium and iron.[99] By 16 November 2014, MAVEN had completed its commissioning activities, and formally began its 1-year primary science mission[100]; and by the end of the year new insight was gained about the depth of penetration solar wind makes in a planet's atmosphere.[101]

ISRO's Mars Orbiter Mission (MOM) lifted into space on 5 November 2013, entering Mars' orbit on 24 September 2014.[102] Shortly thereafter, the spacecraft began its science activities fully, activating its five indigenous scientific payloads

[95] "NASA Goddard Instrument Makes First Detection of Organic Matter on Mars." 16 Dec. 2014. NASA 1 Mar. 2015. http://www.nasa.gov/content/goddard/mars-organic-matter/.

[96] "MAVEN spacecraft enters orbit around Mars." 22 Sept. 2014. University of Colorado Boulder 1 Mar. 2015. http://lasp.colorado.edu/home/maven/2014/09/22/maven-spacecraft-enters-orbit-around-mars/.

[97] "MAVEN." University of Colorado Boulder 14 Jan. 2013. http://lasp.colorado.edu/home/maven/.

[98] "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.

[99] "Mars Spacecraft Reveal Comet Flyby Effects on Martian Atmosphere." 7 Nov. 2014. University of Colorado Boulder 1 Mar. 2015. http://lasp.colorado.edu/home/maven/2014/11/07/mars-spacecraft-reveal-comet-flyby-effects-on-martian-atmosphere/.

[100] "MAVEN Completes Commissioning And Begins Its Primary Science Mission." 17 Nov. 2014. University of Colorado Boulder 1 Mar. 2015. http://lasp.colorado.edu/home/maven/2014/11/17/maven-completes-commissioning-and-begins-its-primary-science-mission/.

[101] "MAVEN Identifies Links in Chain Leading to Atmospheric Loss." 15 Dec. 2014. University of Colorado Boulder 1 Mar. 2015. http://lasp.colorado.edu/home/maven/2014/12/15/maven-identifies-links-in-chain-leading-to-atmospheric-loss/.

[102] "Mars Mission: India creates history as Mangalyaan successfully enters Mars orbit in first attempt." 24 Sept. 2014. The Economic Times 22 Mar. 2015. http://economictimes.indiatimes.com/news/science/mars-mission-india-creates-history-as-mangalyaan-successfully-enters-mars-orbit-in-first-attempt/articleshow/43299562.cms.

consisting of the Mars Colour Camera, the Methane Sensor For Mars, the Thermal Infrared Imaging Spectrometer, the Mars Exospheric Neutral Composition Analyser, and the Lyman Alpha Photometer. Also, at the end of September, NASA and ISRO officials signed an agreement to establish a working group to explore potential coordinated observations and science analysis between the MAVEN orbiter and MOM.[103] MOM will observe the surface of Mars and its atmosphere and exosphere extending up to 80,000 km for a detailed understanding of the planet's evolution, especially its related geological and possible biogenic processes.[104]

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 until 2017.[105] In May 2014, data from the now 17-year old mission provided a new technique to understand the atmospheres of exoplanets by comparing sunsets seen through Titan's hazy atmosphere; due to a similarity between exoplanet transits and Titan's sunsets as seen by the Cassini spacecraft, the solar occultations effectively allowed the scientists to observe Titan as a transiting exoplanet without having to leave the solar system. With Titan as an example, scientists found that hazes high above some transiting exoplanets might strictly limit what their spectra can reveal to planet transit observers. Moreover, as with Titan's hazes, which more strongly affect shorter wavelength colours of light, exoplanet spectra hazes may not affect colours of light uniformly.[106] Titan's ocean beneath its outer ice shell showed that it was relatively high in density, and likely to be an extremely salty brine of water mixed with dissolved salts likely composed of sulphur, sodium and potassium.[107] On Titan's south pole, the emergence of a giant polar vortex containing frozen particles of the toxic compound hydrogen cyanide (HCN) suggests that the

[103] Laxman, Srinivas. "Mars Orbiter Mission activates all science instruments as NASA, ISRO form joint Mars working group." 1 Oct. 2014. Planetary.org 22 Mar. 2015. http://www.planetary.org/blogs/guest-blogs/2014/10010914-mars-orbiter-mission.html.

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

[105] 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/.

[106] "Sunsets on Titan Reveal the Complexity of Hazy Exoplanets." 27 May 2014. NASA 1 Mar. 2015. http://saturn.jpl.nasa.gov/news/newsreleases/newsrelease20140527/.

[107] "Ocean on Saturn Moon Could be as Salty as the Dead Sea." 2 July 2014. NASA 1 Mar. 2015. http://saturn.jpl.nasa.gov/news/newsreleases/newsrelease20140702/.

nitrogen-rich atmosphere of Titan's southern hemisphere is cooling much faster than expected; HCN forms frozen particles only if the atmospheric temperature is as cold as minus 148 °C—while predictions from current theoretical models of Titan's upper atmosphere were anticipated to be about minus 48 °C.[108] The nitrogen in Titan's atmosphere appears to have originated in conditions similar to the comets from the Oort cloud rather than from the relatively warmer disk of material surrounding Saturn during its formation or from comets born in the Kuiper belt.[109]

By July 2014, scientists using Cassini mission data had identified 101 distinct geysers erupting from the four tiger stripe fractures on the icy Enceladus. Moreover, the location of the greatest geyser activity coincided with the location of greatest thermal emissions. The size of hotspots was too small to be caused by the rubbing of opposing walls of the fractures; however they were the right size to come from the condensation of vapour on the near surface walls of the fractures, and thus the geyser process was actually causing the heat. As a sea is known to exist beneath the ice shell, and narrow pathways through the ice shell can remain open from the sea all the way to the surface, if filled with liquid water, it is the only plausible source of the material forming the geysers.[110]

2.3.5 Venus Science

ESA's Venus Express mission was launched in 1995 and reached Venus in April 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. On 16 May 2014, after 8 years in orbit around Venus, and after concluding its routine science operations, the satellite began preparations for a final mission involving aerobraking in Venus' atmosphere, conducted from 18 June through 11 July 2014. Through short drag campaigns in the upper atmosphere layers, progressively dipping to an altitude of around 130 km, researchers gained new insights into the inaccessible regions of Venus's atmosphere, and how the spacecraft and its components respond to such a hostile environment. Moreover, the spacecraft conducted some limited science measurements with its magnetic field, solar wind and atom analysing instruments, while temperature and pressure sensors recorded the conditions that the spacecraft

[108] "Swirling Cloud at Titan's Pole is Cold and Toxic." 1 Oct. 2014. NASA 1 Mar. 2015. http://saturn.jpl.nasa.gov/news/newsreleases/newsrelease20141001/.

[109] "Titan's Building Blocks Might Pre-date Saturn." 23 June 2014. NASA 1 Mar. 2015. http://saturn.jpl.nasa.gov/news/newsreleases/newsrelease20140623/.

[110] "Cassini Spacecraft Reveals 101 Geysers and More on Icy Saturn Moon." 28 July 2014. NASA 1 Mar. 2015. http://saturn.jpl.nasa.gov/news/newsreleases/newsrelease20140728/.

experienced.[111] Full contact with the spacecraft was lost on 28 November 2014, as it had exhausted its propellant and only limited information could be retrieved from the telemetry and telecommand links; the mission came to an end by December 2014.[112] Through its eight-year mission, its major discoveries included the further understanding of Venus' shape-shifting polar vortices; thousands of volcanoes and widespread volcanic plains suggesting a planet-wide resurfacing during the last 500 million years; that the planet appears to be slowing in its rotation, while the atmosphere rotation is accelerating; that a region in Venus' atmosphere is cold enough for dry-ice snow to form; the existence of an ozone layer on the planet; the loss of water from the planet into space over billions of years; and instead of an internal magnetic field, the existence of an elongated magnetotail on the side of Venus that points away from the Sun.[113]

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 one-year mission, with a possible 1-year extension. To be executed under ESA leadership, BepiColumbo is currently in the implementation stage, to be eventually launched on the Ariane 5 launch vehicle. The mission is made up of two spacecraft: the Mercury Planetary Orbiter (MPO), a three-axis stabilized spacecraft provided by ESA that will study the planet's geology, composition, inner structure, and exosphere, and the Mercury Magnetospheric Orbiter (MMO), a spin-stabilised spacecraft provided by JAXA that will study the planet's magnetic field, atmosphere, magnetosphere and inner interplanetary space. 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.[114] On 21 July 2014, the protoflight models of the Mercury Transfer Module (MTM), the MPO, and the MMO were completed at the Thales Alenia Space facility in Turin, Italy, and were sent to ESTEC where final integration tasks, and environmental testing will be performed.[115]

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[111] "Venus Express gets ready to take the plunge." 16 May 2014. ESA 1 Mar. 2015. http://www.esa.int/Our_Activities/Space_Science/Venus _Express/Venus_Express_gets_ready_to_take_the_plunge.

[112] "Venus Express goes gently into the night." 16 Dec. 2014. ESA 1 Mar. 2015. http://www.esa.int/Our_Activities/Space_Science/Venus_Express/Venus_Express_goes_gently_into_the_night.

[113] "Major Discoveries by Venus Express: 2006–2014." 4 July 2014. ESA 1 Mar. 2015. http://sci.esa.int/venus-express/54062-1-shape-shifting-polar-vortices/.

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

[115] "#13: BepiColombo integration and functional testing completed at Thales Alenia Space in Turin." 21 July 2014. ESA 1 Mar. 2015. http://sci.esa.int/bepicolombo/54364-13-bepicolombo-integration-and-functional-testing-completed-at-thales-alenia-space-in-turin/.

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.[116] On 16 March 2014, based on global imaging and topographic data from MESSENGER, it was determined that Mercury had contracted far more than had been previously estimated.[117] In the course of 3 years, MESSENGER's +Mercury Dual Imaging System (MDIS) had imaged 100 % of the planet[118]; and in June 2014, its orbit was modified to prepare for a low-altitude campaign that would extend its mission. Two additional manoeuvres were conducted in September and October, along with an additional manoeuvre early in 2015, to raise the minimum altitude above the planet.[119] In previous years, 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 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.[120] On 15 October 2014, the first optical images of ice and other frozen volatile materials within permanently shadowed craters in Mercury's north pole were revealed, which also hold clues as to when the ices were trapped and how they have evolved.[121]

[116] "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.

[117] "Mercury's Contraction Much Greater Than Thought." 16 Mar. 2014. MESSENGER 1 Mar. 2015. http://messenger.jhuapl.edu/news_room/details.php?id=254.

[118] "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.

[119] "Third of Four Planned Maneuvers Extends MESSENGER Orbital Operations." 24 Oct. 2014. MESSENGER 1 Mar. 2015. http://messenger.jhuapl.edu/news_room/details.php?id=267.

[120] "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.

[121] "MESSENGER Provides First Optical Images of Ice Near Mercury's North Pole." 15 Oct. 2014. MESSENGER 1 Mar. 2015. http://messenger.jhuapl.edu/news_room/details.php?id=266.

2.3.7 Jupiter Science

In May 2012, the proposed ESA Jupiter Icy moon Explorer (JUICE)[122] 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 tonne 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.[123] On 20 November 2014, the mission gained approval from ESA's Science Programme Committee to begin its implementation phase. Moreover, the multilateral agreement for JUICE was also approved, which provides the legal framework for provision of payload equipment and ongoing mission support between funding agencies.[124]

2.3.8 Solar Observation

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

ESA's PRoject for OnBoard Autonomy (PROBA)-2 microsatellite continued its solar observation activity, with its programme extended again on 20 November 2014 by ESAs SPC, with the mission now operating until at least the end of 2016.[125] 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.[126]

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

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

[124] "JUICE mission gets green light for next stage of development." 27 Nov. 2014. ESA 1 Mar. 2015. http://sci.esa.int/juice/55055-juice-mission-gets-green-light-for-next-stage-of-development/.

[125] "Working life extensions for ESA's science missions." 20 Nov. 2014. ESA 1 Mar. 2015. http://sci.esa.int/director-desk/54999-working-life-extensions-for-esas-science-missions/.

[126] "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.

The mission has gathered over 400,000 images of the Sun, and made nearly 20 million in-situ ionospheric observations.[127] 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.[128]

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. PICARD received is final telecommand on 4 April 2014.[129]

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), the EUV Variability Experiment (EVE) and the Helioseismic and Magnetic Imager (HMI).[130] The SDO's global view of the Sun facilitates research that focuses on the previously unrecorded real fine structure of the star.[131] A new technique to probe the Sun's interior came from using the HMI instead of the more commonly applied technique of tracking the time it takes for waves to travel from one side of the Sun to the other. The research published in April 2014 showed that it is possible to track the size of different magnetically-balanced areas on the Sun, which corresponded to the size of the Sun's granules and supergranules, and reveal spotted areas much larger than previously noted.[132]

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

[127] "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.

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

[129] "PICARD News." Cnes 1 Mar. 2015. http://smsc.cnes.fr/PICARD/GP_actualites.htm.

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

[131] 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.

[132] "Bright Points in Sun's Atmosphere Mark Patterns Deep In Its Interior." 17 Apr. 2014. NASA 1 Mar. 2015. http://www.nasa.gov/content/goddard/bright-points-mark-patterns-inside-sun/.

1.5 million kilometres from Earth, enabling an uninterrupted view of the star.[133] 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. The SOHO mission has very significantly exceeded its expected lifetime of two years and on 19 June 2013, it was extended until 31 December 2016.[134] In 2014, new analysis of data from SOHO's Solar Ultraviolet Measurements of Emitted Radiation (SUMER) instrument revealed that the comet ISON had stopped producing dust and gas, and disintegrated shortly prior to its closest approach to the Sun, which provided an exceptional chance to see the entirety of the comet.[135]

NASA's Solar TErrestrial RElations Observatory (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.[136] They provide new insights into CMEs, including detecting and processing data that enables the tracking of CMEs headed toward Earth. In June 2014, STEREO showed that the corona (or atmosphere) of the Sun extended further than previously thought, i.e. around 8 million km from the Sun's surface, which will have implications for NASA's close-orbiting Solar Probe Plus mission that is due to launch in 2018.[137] STEREO continued to operate for the remainder of 2014. On 20 August and 1 December 2014, the mission underwent side lobe repointing operations that will provide lower resolution data; the mission will remain in this state until January 2016.[138]

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.[139] IRIS

[133] 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.

[134] "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/.

[135] "Comet ISON's dramatic final hours." 16 July 2014. ESA 1 Mar. 2015. http://sci.esa.int/soho/54344-comet-ison-dramatic-final-hours/.

[136] "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

[137] "NASA's STEREO Maps Much Larger Solar Atmosphere Than Previously Observed." 25 June 2014. NASA 1 Mar. 2015. http://www.nasa.gov/content/goddard/nasas-stereo-maps-much-larger-solar-atmosphere-than-previously-observed/.

[138] "Q & A for Operations of STEREO During Superior Conjunction." 3 July 2014. NASA 1 Mar. 2015. http://www.nasa.gov/content/goddard/q-a-for-stereo-during-superior-conjunction/.

[139] "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.

caught its first CME on 9 May 2014, which hurled a giant cloud of particles, several times the size of Earth into space.[140] It also witnessed dozens of solar flares in 2014, including two X-class flares and numerous M-class flares that are a tenth as strong. One X-class flare was fortuitously caught by both IRIS and SDO, allowing IRIS to view the relatively lower temperature lower atmosphere of the Sun, called the transition region, while SDO viewed the hotter material higher up in the Sun's corona.[141]

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 1 September 2014, the spacecraft had completed its fourth annual procedure to rejuvenate its detectors from the effects of radiation damage, and had resumed collecting solar X-ray and gamma-ray data.[142]

2.3.9 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.

ESA's Rosetta mission turned out to be a stunning success, following its mid-2014 rendezvous with the comet 67P/Churyumov-Gerasimenko, and the release of its lander Philae which accomplished the first soft-landing on a comet's nucleus. While en route to the comet, Rosetta's Optical, Spectroscopic and Infrared Remote Imaging System (OSIRIS) camera observed variable activity around the comet, as its coma rapidly increased in brightness and then died down during that period.[143] Rosetta made its first observations of water vapour streaming out on 6 June; using its Microwave Instrument for Rosetta Orbiter (MIRO) it was estimated that the water vapour was being ejected into space at about 300 ml/s.[144] And between 13 and 21 July, at a distance of over 5000 km from the comet, Rosetta's visible, infrared and thermal imaging spectrometer (VIRTIS) collected the infrared light emitted by the comet, which enabled scientists to determine that its average

[140] "A First for NASA's IRIS: Observing a Gigantic Eruption of Solar Material." 30 May 2014. NASA 1 Mar. 2015. http://www.nasa.gov/content/goddard/a-first-for-nasas-iris-observing-a-gigantic-eruption-of-solar-material/.

[141] "NASA Releases IRIS Footage of X-class Flare." 17 Sept. 2014. NASA. http://www.nasa.gov/content/goddard/nasa-releases-iris-footage-of-x-class-flare/.

[142] "RHESSI Resumes Observations." 1 Sept. 2014. RHESSI Science Nuggets 24 Mar. 2015. http://sprg.ssl.berkeley.edu/~tohban/wiki/index.php/RHESSI_Resumes_Observations.

[143] "Rosetta arrives at comet destination." 6 Aug. 2014. ESA 9 Mar. 2015. http://www.esa.int/Our_Activities/Space_Science/Rosetta/Rosetta_arrives_at_comet_destination.

[144] "Rosetta's comet 'sweats' two glasses of water a second." 30 June 2014. ESA 9 Mar. 2015. http://www.esa.int/Our_Activities/Space_Science/Rosetta/Rosetta_s_comet_sweats_two_glasses_of_water_a_second.

surface temperature is about –70 °C, providing clues about the composition and physical properties of the comet's dusty surface. While comet 67P/Churyumov-Gerasimenko was already known to have a low reflectance from ground-based observations, which indicated that it lacked a 'clean' icy surface, the surface temperature was found to be around 20–30 °C warmer than for a comet at that distance covered exclusively in ice, as darker material heats up and emits heat more readily than ice when it is exposed to sunlight.[145] By November, following Philae's successful landing on the comet, and prior to its hibernation, the lander had utilized its instruments including a sampling drill to penetrate the dust covered surface ice and collect a soil sample. However, further analysis of the data is needed before it can be confirmed whether a sample was collected and put into Philae's micro-oven for analysis.[146] Nevertheless, some findings from the Rosetta mission are providing insight into the origin of Earth's oceans, as Rosetta's Orbiter Spectrometer for Ion and Neutral Analysis (ROSINA) measured the comet's deuterium/hydrogen (D/H) ratio to be more than three times greater than for Earth's oceans and for other recorded Kuiper Belt comets; it also measured higher than previous Oort cloud comets as well, potentially indicating that comets in the Kuiper belt may have formed over a wider range of distances than previously thought.[147]

NASA's reboot of the Wide-field Infrared Survey Explorer (WISE) mission, this time to discover and characterize near-Earth objects (NEOs) with infrared light, was reactivated in September 2013 for three additional years of service.[148] The original WISE mission was completed early in 2011, following the completion of surveying the whole sky twice in infrared light the space telescope had been placed in 31 months of hibernation.[149] Now dubbed NEOWISE, the new mission commenced at the start of 2014, detecting 857 minor bodies in our solar system, including 22 NEOs and four comets in the first 25 days of its operation.[150] NEOWISE was also used to observe the active and dusty comet Siding Spring prior to its dramatically-close flyby of Mars, both for characterization and to study dust particle sizes and amounts produced by the comet to understand the potential

[145] "Rosetta takes comet's temperature." 1 Aug. 2014. ESA 9 Mar. 2015. http://www.esa.int/Our_Activities/Space_Science/Rosetta/Rosetta_takes_comet_s_temperature.

[146] De Selding, Peter B. "Philae Managers Say Recovery Possible as Comet Approaches Sun." 18 Nov. 2014. SpaceNews 14 May 2015. http://spacenews.com/42586philae-managers-say-recovery-possible-as-comet-approaches-sun/.

[147] "Rosetta fuels debate on origin of Earth's oceans." 10 Dec. 2014. ESA 9 Mar. 2015. http://www.esa.int/Our_Activities/Space_Science/Rosetta/Rosetta_fuels_debate_on_origin_of_Earth_s_oceans.

[148] "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.

[149] "NASA's Asteroid Hunter Spacecraft Returns First Images after Reactivation." 19 Dec. 2013. NASA 9 Mar. 2015. http://www.jpl.nasa.gov/wise/newsfeatures.cfm?release=2013-373.

[150] "NEOWISE Celebrates First Month of Operations After Reactivation." 23 Jan. 2014. NASA 9 Mar. 2015. http://www.jpl.nasa.gov/wise/newsfeatures.cfm?release=2014-023.

risks to the Mars orbiters.[151] NEOWISE also discovered its first new comet since coming out of hibernation, officially named "C/2014 C3 (NEOWISE)" at a distance of 230 million kilometres from Earth; however its orbit is still a bit uncertain.[152] Another comet, "C/2013 UQ4 (Catalina)" was observed by NEOWISE a day after passing through its closest approach to the sun; due to its inactivity when observed in 2013, it was originally thought to be an asteroid, but it became highly active as it closed in on the Sun in 2014. Its next approach to the Sun will be in 450 years.[153]

2.3.10 Outer Solar Science

ESA launched its Gaia mission on 19 December 2013 to measure the positions and motions of a billion stars of the roughly 100 billion stars in our galaxy to create the most accurate map yet of the Milky Way.[154] Gaia followed a trajectory to the L2 Lagrangian point 1.5 million km beyond Earth's orbit, where it is spared from sweeping in and out Earth's shadow, heating up and cooling down the telescope, and distorting its view. It also has a sunshield to protect its instruments from the light and heat that comes from the Sun, Earth and Moon simultaneously.[155] It shares this position with the Herschel infrared telescope, and the Planck microwave observatory. After a series of tests and calibrations, Gaia began its 5-year scientific mission on 25 July 2014, spinning slowly as it repeatedly scans the sky with its two telescopes, and focuses their light simultaneously onto a single digital camera to create an extraordinarily precise 3D map of these stars, also mapping their motions, luminosity, temperature and composition.[156] Already on 30 August, Gaia observed its first super nova, a Type Ia supernova that was detected in the form of a sudden spike in the brightness of light coming from another distant galaxy that had appeared much dimmer when Gaia first looked at it in July.[157]

While ESA's Herchel science mission ended on 29 April 2013, following the exhaustion of its helium coolant reserves, data from Herchel's mission is continuing

[151] "NASA Preparing for 2014 Comet Watch at Mars." 28 Jan. 2014. NASA 9 Mar. 2015. http://www.jpl.nasa.gov/wise/newsfeatures.cfm?release=2014-026.

[152] "NEOWISE Spies Its First Comet." 28 Feb. 2014. NASA 9 Mar. 2015. http://www.jpl.nasa.gov/wise/newsfeatures.cfm?release=2014-067.

[153] "NEOWISE Spots a Comet That Looked Like an Asteroid." 23 July 2014. NASA 9 Mar. 2015. http://www.jpl.nasa.gov/wise/newsfeatures.cfm?release=2014-241.

[154] "ESA PR 44-2013: Liftoff for ESA's billion-star surveyor." 19 Dec. 2013. ESA 9 Mar. 2015. http://sci.esa.int/gaia/53536-esa-pr-44-2013-liftoff-for-esas-billion-star-surveyor/.

[155] "The experts behind Gaia's arrival at nothingness." 15 Jan. 2014. ESA 9 Mar. 2015. http://www.esa.int/Our_Activities/Operations/The_experts_behind_Gaia_s_arrival_at_nothingness.

[156] "Gaia overview." 23 Apr. 2014. ESA 9 Mar. 2015. http://www.esa.int/Our_Activities/Space_Science/Gaia/Gaia_overview.

[157] "Gaia discovers its first supernova." 12 Sept. 2014. ESA 9 Mar. 2015. http://sci.esa.int/gaia/54630-gaia-discovers-its-first-supernova/.

to make significant findings. In January 2014, the first unambiguous detection of water vapour was discovered around Ceres, the dwarf planet orbiting between Mars and Jupiter, providing proof that Ceres has an icy surface and an atmosphere; estimates approximate 6 kg of water vapour being produced per second.[158] By March 2014, researchers had produced the largest census of dust in local galaxies, wherein observing the light emitted by the dust as a function of wavelength provides a means to study the physical properties of the dust, and provides a local benchmark for quantifying the role dust has played in galaxy evolution throughout the history of the Universe.[159] Moreover, Herschel helped researchers to discover that the molecule, OH+ (a positively charged combination of single oxygen and hydrogen atoms), vital for creating water, can be formed by the ultraviolet radiation poured out from white dwarfs even while the same radiation may destroy molecules that had previously been ejected by the star.[160]

While ESA's Planck microwave observatory mission to study the Cosmic Microwave Background (CMB) ended on 23 October 2013, research continued on into the following year. Scientists are now assessing CMB data to measure the polarisation of the light, which could provide evidence of gravitational waves generated in the Universe immediately after its birth.[161] After 4.5 years of operation where Planck completed five full-sky surveys with both its Low Frequency Instrument (LFI) and High Frequency Instrument (HFI), the spacecraft was 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.[162]

CNES' COnvection, ROtation and planetary Transits (COROT) space telescope ended its mission on 17 June 2014. The mission, operating for more than 7 years, probed the inner structure of stars using stellar seismology and was 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.[163, 164] While in operation, the COROT mission was the first to discover a

[158] "Herschel discovers water vapour around dwarf planet Ceres." 22 Jan. 2014. ESA 9 Mar. 2015. http://www.esa.int/Our_Activities/Space_Science/Herschel/Herschel_discovers_water_vapour_around_dwarf_planet_Ceres.

[159] "Herschel completes largest survey of cosmic dust in local Universe." 18 Mar. 2014. ESA 9 Mar. 2015. http://www.esa.int/Our_Activities/Space_Science/Herschel/Herschel_completes_largest_survey_of_cosmic_dust_in_local_Universe.

[160] "New molecules around old stars." 17 June 2014. ESA 9 Mar. 2015. http://www.esa.int/Our_Activities/Space_Science/Herschel/New_molecules_around_old_stars.

[161] "Planck takes magnetic fingerprint of our Galaxy." 6 May 2014. ESA 9 Mar. 2015. http://www.esa.int/Our_Activities/Space_Science/Planck/Planck_takes_magnetic_fingerprint_of_our_Galaxy.

[162] "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.

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

[164] "CoRoT Events." Cnes 2 Mar. 2015. http://smsc.cnes.fr/COROT/GP_actualite.htm.

confirmed Earth-like exoplanet orbiting a star similar to the Sun, and has since revealed 32 planets, while 100 more await confirmation.[165]

NASA's Kepler space telescope mission was recently extended to 2016 with the continued aim of finding Earth-sized planets in the habitable zone of other solar-like oscillating stars, where liquid water could exist on their surfaces.[166] In February 2014, Kepler-413b was found to wobble wildly on its spin axis, varying as much as 30° over 11 years; by comparison, Earth's spin axis varies by 23.5° over 26,000 years, resulting in much less rapid and erratic changes in weather patterns.[167] In April 2014, the first Earth-sized planet, Kepler-186f, was validated to orbit a distant star in the habitable zone. Whereas Kepler-186f is less than 10 % larger than Earth, the next closest Earth-like planet is Kepler-62f, which is 40 % larger than Earth and also orbits its habitable zone.[168] By July 2014, the number of confirmed exoplanets exceeded 1800,[169] with 715 exoplanets verified to orbit 305 stars.[170] Through the use of Kepler and Spitzer space telescope data, scientists have made the most precise measurement to date of an exoplanet, Kepler-93b, with an uncertainty of 119 km on either side of the "super-Earth" planetary body.[171] And data from the duo, in addition to the Hubble telescope's Wide Field Camera 3, helped to identify that exoplanet HAT-P-11b, a Neptune-sized planet that orbits the star HAT-P-11, had clear skies and water vapour, through a technique called transmission spectroscopy which observed the distinct signatures made by starlight as it is filtered through the rim of a planet's atmosphere containing the vapour.[172] And 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

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

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

[167] "Kepler Finds a Very Wobbly Planet." 4 Feb. 2014. NASA 9 Mar. 2015. http://kepler.nasa.gov/news/nasakeplernews/index.cfm?FuseAction=ShowNews&NewsID=319.

[168] "First Earth-Size Planet in 'Habitable Zone'." 17 Apr. 2014. NASA 9 Mar. 2015. http://kepler.nasa.gov/news/nasakeplernews/index.cfm?FuseAction=ShowNews&NewsID=330.

[169] "Kepler-421b: An exoplanet orbiting near its star's "snow line"." 21 July 2014. NASA 9 Mar. 2015. http://kepler.nasa.gov/news/nasakeplernews/index.cfm?FuseAction=ShowNews&NewsID=347.

[170] "715 Newly Verified Planets More Than Triples the Number of Confirmed Kepler Planets." 26 Feb. 2014 NASA 9 Mar. 2015. http://kepler.nasa.gov/news/nasakeplernews/index.cfm?FuseAction=ShowNews&NewsID=324.

[171] "Kepler-93b: The Most Precise Measurement of an Alien World's Size." 23 July 2014. NASA 9 Mar. 2015. http://kepler.nasa.gov/news/nasakeplernews/index.cfm?FuseAction=ShowNews&NewsID=348.

[172] "NASA Telescopes Find Clear Skies and Water Vapor on Exoplanet." 24 Sept. 2014. NASA 9 Mar. 2015. http://kepler.nasa.gov/news/nasakeplernews/index.cfm?FuseAction=ShowNews&NewsID=355.

were underway to recover stability in the spacecraft using the Sun to maintain stability, under the designation Kepler 2 (K2)[173] In May 2014, the K2 mission was approved by NASA, which repurposed Kepler to accurately point at target sky fields along the ecliptic plane of Earth's orbit.[174] And by year end, the K2 mission succeeded in discovering its first exoplanet HIP 116454b, in addition to having observed more than 35,000 stars and collected data on star clusters, dense star-forming regions, and several planetary objects within our own solar system.[175]

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.[176] Spitzer has already observed infrared light emanating from a "super-Earth" planet in another solar system[177] and observed an unprecedented simultaneous elliptical galaxy with another thin disk existing in its interior.[178] By the beginning of 2014, with the use of NASA's Spitzer and ESA's Herschel Space Observatory, the evolutionary sequence of compact elliptical galaxies that erupted and burned out early in the history of the universe was pieced together; i.e. from their initial burst of star formation through their development of dense stellar cores to their ultimate reality as giant ellipticals. It was determined that compact ellipticals voraciously consumed the gas available for star formation, to the point where they could not create new stars, and then merged with smaller galaxies to form giant ellipticals.[179] In August 2014, Spitzer observed the eruption of dust around the star NGC 2547-ID8, when it surged in the amount of observable

[173] "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/.

[174] "Kepler Begins K2 Mission Field 1 Observing." 30 May 2014. NASA 9 Mar. 2015. http://kepler.nasa.gov/news/nasakeplernews/index.cfm?FuseAction=ShowNews&NewsID=341.

[175] "NASA's Kepler Reborn, Makes First Exoplanet Find of New Mission." 18 Dec. 2014. NASA 9 Mar. 2015. http://www.nasa.gov/press/2014/december/nasa-s-kepler-reborn-makes-first-exoplanet-find-of-new-mission/.

[176] "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.

[177] "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-.

[178] "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.

[179] "NASA and ESA Telescopes Help Solve Mystery of Ultra-Compact, Burned-Out Galaxies." 29 Jan. 2014. NASA 9 Mar. 2015. http://www.spitzer.caltech.edu/news/1607-ssc2014-01-NASA-and-ESA-Telescopes-Help-Solve-Mystery-of-Ultra-Compact-Burned-Out-Galaxies.

dust between August 2012 and January 2013, possibly the result of two large asteroids colliding.[180]

NASA's Hubble Space Telescope provided significant findings throughout 2014. Hubble and Spitzer were used to discover and characterize four unusually bright galaxies as they appeared more than 13 billion years ago, with luminosities that are about 10–20 times greater than anything seen previously. Hubble first detected the galaxies with its sharp imaging, while Spitzer allowed researchers to estimate the stellar masses by measuring the total luminosity of the galaxies.[181] The pair were also used to find one of the youngest galaxies in the universe, Abell2744_Y1 within the Abell 2744 cluster of galaxies, using gravitational lensing where specific foreground galaxy clusters are used to amplify the faint light from far more distant background objects.[182] Hubble also enabled astronomers to precisely measure the rotation rate of the galaxy Large Magellanic Cloud (LMC) for the first time. By recording its stars' slight movements over a 7-year period, it was determined that the LMC galaxy completes a rotation every 250 million years.[183] Hubble data also showed that the largest known galaxy cluster in the distant universe, ACT-CL J0102-4915 (or El Gordo), is roughly 43 % more massive than earlier estimates based on X-ray and dynamical studies.[184] Another first for the Hubble telescope occurred when it viewed a binary star system that later produced an unusual and weaker Type Iax supernova explosion of a white dwarf, SN 2012Z, providing clues about the similarities between normal Type Ia supernovas and their Type Iax progenitors.[185] And a companion star to a rare Type IIb supernova occurring in the galaxy M81 enabled astronomers to put constraints on the properties of the surviving star in estimating its luminosity and mass, which provides

[180] "NASA's Spitzer Telescope Witnesses Asteroid Smashup." 28 Aug. 2014. NASA 9 Mar. 2015. http://www.spitzer.caltech.edu/news/1696-ssc2014-06-NASA-s-Spitzer-Telescope-Witnesses-Asteroid-Smashup.

[181] "NASA Great Observatories Team Up to Discover Ultra-Bright Young Galaxies." 7 Jan. 2014. Hubblesite 9 Mar. 2015. http://hubblesite.org/newscenter/archive/releases/cosmology/2014/2014/05/full/results/100/.

[182] "Hubble and Spitzer Space Telescopes Find One of the Youngest Galaxies in the Universe." 7 Feb. 2014. Hubblesite 9 Mar. 2015. http://hubblesite.org/newscenter/archive/releases/galaxy/2014/2014/17/results/100/.

[183] "Hubble Watches Stars' Clockwork Motion in Nearby Galaxy." 18 Feb. 2014. Hubblesite 9 Mar. 2015. http://hubblesite.org/newscenter/archive/releases/galaxy/2014/2014/11/full/results/100/.

[184] "Hubble Finds That Monster 'El Gordo' Galaxy Cluster Is Bigger Than Thought." 3 Apr. 2014. Hubblesite 9 Mar. 2015. http://hubblesite.org/newscenter/archive/releases/galaxy/2014/2014/22/full/results/100/.

[185] "NASA's Hubble Finds Supernova Star System Linked to Potential 'Zombie Star'." 6 Aug. 2014. Hubblesite 9 Mar. 2015. http://hubblesite.org/newscenter/archive/releases/galaxy/2014/2014/32/full/results/100/.

insight into the conditions that preceded the explosion.[186] Hubble also helped to find the smallest known galaxy, with 140 million stars grouped in a diameter of about 300 light-years, that has a supermassive black hole that is five times the mass of the black hole at the centre of our 100,000 light-year diameter Milky Way.[187]

2.4 Satellite Applications

2.4.1 Space-Based Communications

The industry continued to expand its technology development programmes with additional investments in larger spacecraft with enhanced power and transponder capacity.[188]

On radio frequency spectrum allocation, the ITU's biennial World Radiocommunication Seminar 2014 (WRS-14) was held on 8–12 December 2014. The seminar provided deeper insight into the revised ITU radio regulations following the World Radiocommunication Conference 2012, and addressed the application of the provisions of those regulations with respect to the use of radio-frequency spectrum and satellite orbits. The seminar aimed at providing its 400 participants from over 90 countries with technical and regulatory background information to aid in preparation for the World Radiocommunication Conference (WRC-15) to be held on 2–27 November 2015 in Geneva, Switzerland.[189] Prior to the WRS-14 seminar, representatives from the top satellite operators expressed concern over an ITU demand study for C-band spectrum; they believed the study exaggerated the demand by 10 or even more than 100 times, which might result in skewed estimates of how much spectrum will be required for terrestrial wireless broadband when distributed at the WRC-15.[190] Nevertheless, on 9 October, it was confirmed that the European Commission had decided to authorise terrestrial broadband operators to use a portion of the C-band spectrum normally reserved exclusively for satellite

[186] "Hubble Finds Companion Star Hidden for 21 Years in a Supernova's Glare." 9 Sept. 2014. Hubblesite 9 Mar. 2015. http://hubblesite.org/newscenter/archive/releases/galaxy/2014/2014/38/full/results/100/.

[187] Hubble Helps Find Smallest Known Galaxy with a Supermassive Black Hole." 17 Sept. 2014. Hubblesite 9 Mar. 2015. http://hubblesite.org/newscenter/archive/releases/galaxy/2014/2014/41/full/results/100/.

[188] See generally "State of the Satellite Industry Report—September 2014." 10 Sept. 2014. SIA 9 Apr. 2015. http://www.sia.org/wp-content/uploads/2014/09/SSIR-September-2014-Update.pdf.

[189] "ITU World Radiocommunication Seminar focuses on regulatory aspects of the use of the radio-frequency spectrum and satellite orbits." 8 Dec. 2014. ITU 6 Apr. 2015. http://www.itu.int/net/pressoffice/press_releases/2014/CM11.aspx.

[190] De Selding, Peter B. "News from Satellite 2014 | Satellite Operators On Guard Against Ground Attack at 2015 Spectrum Conclave." 11 Mar. 2014. SpaceNews 9 Apr. 2015. http://spacenews.com/39819news-from-satellite-2014-satellite-operators-on-guard-against-ground/.

use; but that it would not extend to frequency used by satellites in the upper part of the band.[191] The European Commission Decision 2008/411/EC[192] on the harmonisation of the 3400–3800 MHz frequency band for terrestrial systems capable of providing electronic communications services in the Community was modified through the Implementing Decision 2014/276/EU[193] of 2 May 2014.[194]

As had occurred in the World Radiocommunication Conference of 2007 (WRC-07), the satellite sector will have to compete with the terrestrial wireless broadband industry over the use of C-band radio spectrum and of Ka-band spectrum at the World Radiocommunication Conference in 2015 (WRC-15). In addition to the loss of spectrum, the satellite sector is concerned about the risk of having Ka-band frequencies shared with the terrestrial wireless industry as it is bound to cause frequency interference at a time when satellite operators are heavily investing in Ka-band systems that allow higher bandwidth transfer in satellite communications for use in high-throughput satellite systems.[195] Moreover, a disinterested opinion by the 48-nation European Conference of Postal and Telecommunications Administrations (CEPT) remarked that sharing radio frequency without interference does not appear to be an option (at least for Wi-Fi and radar Earth observation signals), since the prevention of interference would need radio wireless broadband devices (Radio LANS) to operate at ten times lower levels than are being used in adjacent bands. Moreover, the strength of satellite signals are already depleted by the time they reach Earth, making them even more vulnerable to Wi-Fi networks. If allowed to be shared, Europe's Sentinel 1 radar satellite system, and Canada's Radarsat Constellation Mission are just two examples of what is at stake for the space sector.[196]

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[191] De Selding, Peter B. "European Commission Backs Reallocation of C-band Spectrum to Terrestrial Broadband." 9 Oct. 2014. SpaceNews 9 Apr. 2015. http://spacenews.com/42136european-commission-backs-reallocation-of-c-band-spectrum-to/.

[192] Commission of the European Communities. on the harmonisation of the 3400–3800 MHz frequency band for terrestrial systems capable of providing electronic communications services in the Community. European Commission Decision C (2008) 1873 of 21 May 2008. 2008/411/EC. Brussels: European Union. http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2008:144:0077:0081:EN:PDF.

[193] Commission of the European Communities on amending Decision 2008/411/EC on the harmonisation of the 3400–3800 MHz frequency band for terrestrial systems capable of providing electronic communications services in the Community. European Commission Implementing Decision C (2014) 2798 of 2 May 2014. 2014/276/EU. Brussels: European Union. http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32014D0276&from=EN.

[194] Viola, Roberto. "Keynote speech on: Interference and telecommunication services." 9 Oct. 2014. Secure World Foundation 3 Sept. 2015. http://swfound.org/media/178605/Roberto%20Viola%20Keynote.pdf.

[195] SpaceNews Editor. "Editorial | Facing Down the Next Spectrum Challenge." 13 Jan. 2014. SpaceNews 9 Apr. 2015. http://spacenews.com/39077editorial-facing-down-the-next-spectrum-challenge/.

[196] De Selding, Peter B. "European Government Group Says Radar Satellites and Wi-Fi Cannot Coexist." 29 Jan. 2014. SpaceNews 9 Apr. 2015. http://spacenews.com/39322european-government-group-says-radar-satellites-and-wi-fi-cannot/.

2.4.2 Space-Based Positioning, Navigation and Timing Systems

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

In 2014, Russia's Glonass GNSS constellation was still in the midst of fleet replenishment, following the successful launches of a GLONASS-M satellite on 23 March and on 14 June on a Soyuz launcher. One of Russia's next-generation model GLONASS-K satellites was also launched on 30 November on a Soyuz launcher. The -K series will succeed the -M predecessor, and will most likely incorporate significant technical improvements, including a new more accurate timing device and a non-pressurized structure, bringing operational performance close to U.S. and European standards. The constellation requires 24 operational satellites to provide complete global navigation coverage, with 3 sets of 8 satellites operating on three orbital planes.[197]

At the beginning of 2014 Europe's four Galileo GNSS in-orbit validation (IOV) satellites were reported to have exceeded their expected level of accuracy, marking a substantial milestone for the European Commission's flagship navigation system.[198] Nevertheless, an unexplained brief power drop in one of the IOV satellites early on 27 May required the satellite to be shut down for the following month.[199] As a precaution, ESA reduced the broadcast power on all four satellites, as its ground team continued to investigate the cause of the anomaly.[200] On 22 August the first pair of Galileo's fully operational satellite models were launched from the Guiana Space Center in French Guiana aboard a Europeanized Soyuz launcher; yet shortly thereafter it was determined that the Soyuz' Fregat upper stage had injected the satellites in the wrong orbital perigee and inclination.[201] The cause of the Fregat malfunction was determined to be due to the installation position of its hydrazine fuel line, which put it in too close proximity to a supercold helium line, which caused the hydrazine to freeze long enough to upset the Fregat stage's orientation

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

[198] De Selding, Peter B. "ESA Says It Won't Be Penalized for Galileo Delays." 17 Jan. 2014. SpaceNews 19 May 2015. http://spacenews.com/39141esa-says-it-wont-be-penalized-for-galileo-delays/.

[199] De Selding, Peter B. "Sudden Power Loss Leaves a Galileo Satellite in Safe Mode." 3 July 2014. SpaceNews 19 May 2015. http://spacenews.com/41130sudden-power-loss-leaves-a-galileo-satellite-in-safe-mode/.

[200] De Selding, Peter B. "ESA Proceeding with Galileo Launches Despite In-orbit Satellite Issues." 20 Aug. 2014. SpaceNews 19 May 2015. http://spacenews.com/41616esa-proceeding-with-galileo-launches-despite-in-orbit-satellite-issues/.

[201] De Selding, Peter B. "Galileo Launch, Initially Hailed as Success, Is a Failure." 23 Aug. 2014. SpaceNews 19 May 2015. http://spacenews.com/41650galileo-launch-initially-hailed-as-success-is-a-failure/.

and premature payload release.[202] Correcting both satellites' orbital positions without exhausting operational fuel reserves initially appeared futile; however, following a series of 11 firings to raise one of the satellites to a higher orbit in the following months, it was deemed to have sufficient fuel to operate for 12 years, and could be reinserted into the planned broader Galileo constellation.[203] By late December, ESA had begun to repeat the process for the second wayward satellite, and expected it to be also suitable for inclusion into the nominal 30-satellite Galileo navigation constellation.[204]

China's development of its Beidou navigation system has been accelerated with its 21 May announcement that it will begin launching the third generation of its navigation satellites in 2015. China began fielding its regional satellite navigation capability offering services including positioning, navigation, time and text messaging to users in the Asia-Pacific region in December 2012.[205] It now expects to complete its third phase, deploying its entire 35 satellite Beidou GNSS constellation by 2017 instead of 2020.[206]

In light of China's expansion in the Asia-Pacific maritime region, and North Korea's missile launch activity, Japan's Committee on the National Space Policy outlined a draft proposal which includes increasing its regional Quasi-Zenith Satellite System (QZSS) to a total of four satellites, to increase Japan's overall surveillance systems by supplementing its surveillance satellites with positioning information.[207] Following the first QZSS satellite launched in September 2010, the program slowed due to unwillingness by the private sector to manage QZSS as a business without substantial government guarantees. On 29 March 2013, Mitsubishi Electric Co. was contracted to construct three additional QZSS satellites, i.e. one GEO satellite and two spacecraft following highly elliptical orbits, to

[202] De Selding, Peter B. "65th International Astronautical Congress | Fregat Plumbing Blamed for Soyuz Failure that Stranded Galileo Satellites in Wrong Orbit." 30 Sept. 2014. SpaceNews 19 May 2015. http://spacenews.com/4204365th-international-astronautical-congress-%e2%80%8bfregat-plumbing-blamed-for/.

[203] De Selding, Peter B. "Galileo Satellite Left in Bad Orbit Reaches Operating Position." 5 Dec. 2014. SpaceNews 19 May 2015. http://spacenews.com/42861galileo-satellite-left-in-bad-orbit-reaches-operating-position/.

[204] De Selding, Peter B. "Galileo Satellite Left in Bad Orbit Reaches Operating Position." 5 Dec. 2014. SpaceNews 19 May 2015. http://spacenews.com/42861galileo-satellite-left-in-bad-orbit-reaches-operating-position/.

[205] 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.

[206] Gibbons, Glen. "China Plans to Complete BeiDou Ahead of Schedule." 21 May 2014. InsideGNSS 21 May 2015. http://www.insidegnss.com/node/4040.

[207] GPS World staff. "QZSS May Expand to Meet Japan's Surveillance Needs." 22 Aug. 2014. GPS World 20 May 2015. http://gpsworld.com/qzss-may-expand-to-meet-japans-surveillance-needs/.

complete the QZSS space architecture by 2017.[208] 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.[209]

In 2014 India continued to achieve several milestones in its regional navigation system launching its second regional navigation satellite, IRNSS-1B, into orbit on 4 April, followed by the launch of IRNSS-1C on 16 October.[210] The regional system will consist of a ground segment, along with 3 IRNSS satellites in geostationary orbit and 4 satellites in inclined geosynchronous orbits. The remaining IRNSS satellites are to be launched in 2015.[211]

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

In Europe, following the December 2014 Ministerial Council meeting, ESA Member States agreed on funding the development of the Ariane 6 next generation launcher, in addition to an enhanced Vega launcher. The Ariane 6 main stage will

[208] De Selding, Peter B. "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.

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

[210] Javaraman, K.S. "India Launches Third Satellite for Regional Navigation Constellation." 16 Oct. 2014. SpaceNews 20 May 2015. http://spacenews.com/42206india-launches-third-satellite-for-regional-navigation-constellation/.

[211] "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.

be based on the Ariane 5 liquid oxygen/liquid hydrogen Vulcan engine, while its P120 solid rocket boosters are of a similar type to the next evolution of the four-stage Vega launcher series, Vega-C. 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.[212] The Ariane 6 will also have a cryogenic liquid oxygen/liquid hydrogen upper stage propelled by a Vinci engine, which will be adapted from the Ariane 5ME upper stage.[213]

On 5 January 2014, ISRO's Geo-synchronous Satellite Launch Vehicle (GSLV-D5) powered by an indigenous cryogenic engine in its third stage was successfully launched.[214] And ISRO successfully test launched its newest and largest GSLV variant, the GSLV Mk.III on 18 December 2014. The GSLV Mk.III is a two-stage rocket, with its first stage powered by two French Vikas engines that burn unsymmetrical dimethylhydrazine (UDMH) propellant oxidised by dinitrogen tetroxide (N2O4). Its intended C25 second stage engine was not tested, and was replaced instead by a CE30 engine which normally burns liquid hydrogen and liquid oxygen, but for demonstration purposes was loaded with liquid nitrogen to simulate the full second stage.[215]

In the U.S., Aerojet Rocketdyne completed testing its J-2X upper-stage rocket engine on 26 June 2014.[216] Nine liquid oxygen/liquid hydrogen fuelled J-2X engines had been built, i.e. seven for development tests and two for certification tests.[217] 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 U.S. Space Launch System. For now, following the completion of development testing, the engine will be shelved for several years before it is needed for the Mars effort. 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 ton SLS. Until NASA tests for a Mars mission, it will likely rely on the use of three or four RL-10 engines

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

[213] Ariane 6. 3 Dec. 2014. ESA 13 May 2015. http://www.esa.int/Our_Activities/Launchers/Launch_vehicles/Ariane_6.

[214] Ram, Arun. "Isro successfully launches indigenous cryogenic engine-powered GSLV-D5." 5 Jan. 2014. The Times of India 12 May 2015. http://timesofindia.indiatimes.com/india/Isro-successfully-launches-indigenous-cryogenic-engine-powered-GSLV-D5/articleshow/28437867.cms.

[215] Graham, William. "India debuts GSLV Mk.III with prototype crew capsule." 17 Dec. 2014. NASA spaceflight.com 12 May 2015. http://www.nasaspaceflight.com/2014/12/india-gslv-mk-iii-prototype-crew-capsule/.

[216] "Aerojet Rocketdyne Completes J-2X Testing." 26 June 2014. Aerojet Rocketdyne 12 May 2015. https://www.rocket.com/article/aerojet-rocketdyne-completes-j-2x-testing.

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

that could produce the dialled-back amount of force needed for lunar precursor missions.[218]

The 28 October 2014 failure of Orbital Science's third Commercial Resupply Services (CRS) mission to the ISS brought into question the future of the Antares launcher—particularly in regard to its first stage AJ-26 engines. Supplied by Aerojet Rocketdyne as refurbished versions of the NK-33 engines, the AJ-26 has experienced several failures in recent times, including a failed test at the NASA Stennis Space Center in Mississippi, USA in May 2014, and another failed test in June 2011 due to a fuel leak in the engine.[219] The latest failure, attributed to the engine's turbo-pump machinery,[220] accelerated Orbital's plans to replace the engine with a derivative of the RD-180 engine from Russian manufacturer NPO Energomash, and on 17 December 2014 it was confirmed that the RD-181 would begin to be delivered starting from 2015, with a launch already scheduled for some time in 2016.[221]

With relations between the U.S. and Russia deteriorating following Russia's annexation of Crimea, subsequent sanctions by the U.S., and the resulting Russian ban in using its RD-180 engine for U.S. military purposes; the U.S. government has begun seeking a replacement for the RD-180 engine and its derivatives.[222] On 16 September 2014, the United Launch Alliance (ULA) selected Blue Origin to develop a new main engine for a future rocket that would combine elements of the Atlas 5 and the Delta 4 launchers. Blue Origin has been developing its BE-4 engine for more than 3 years, giving it a head start against other developers, and it is meant to be relatively inexpensive to develop and build through the use of liquefied natural gas as its propellant. Liquefied natural gas was preferred over kerosene as the engine's propellant due to its cost and engine reusability; similar to methane, the fuel is cheaper than rocket-grade kerosene and leaves less burn residue, making the engine easier to refurbish and reuse.[223] However, as this fuel source is less dense than the kerosene fuel that is used in the RD-180, larger fuel tanks than are available

[218] "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.

[219] Foust, Jeff. "Antares Failure Raises Questions About Vehicle's Future." 31 Oct. 2014. SpaceNews 9 Apr. 2015. http://spacenews.com/42395antares-failure-raises-questions-about-vehicles-future/.

[220] Foust, Jeff. "Turbopump in AJ-26 Engine Implicated in Antares Failure." 10 Nov. 2014. SpaceNews 9 Apr. 2015. http://spacenews.com/42502turbopump-in-aj-26-engine-implicated-in-antares-failure/.

[221] De Selding, Peter B. "Orbital Sciences Orders RD-181 Engines for Antares Rocket." 17 Dec. 2014. SpaceNews 9 Apr. 2015. http://spacenews.com/orbital-sciences-orders-rd-181-engines-for-antares-rocket/.

[222] Gruss, Mike, and Warren Ferster. "Senate Defense Bill Provides $100M To Develop New U.S. Rocket Engine." 23 May 2014. SpaceNews 9 Apr. 2015. http://spacenews.com/40676senate-defense-bill-provides-100m-to-develop-new-us-rocket-engine/.

[223] Ferster, Warren. "ULA To Invest in Blue Origin Engine as RD-180 Replacement." 17 Sept. 2014. SpaceNews 9 Apr. 2015. http://spacenews.com/41901ula-to-invest-in-blue-origin-engine-as-rd-180-replacement/.

on the Atlas 5 launcher would be needed, which would call for substantial design changes if it is to replace the Atlas 5 main stage RD-180 engine. The BE-4 engine will be capable of providing 550,000 lbs of thrust and is a variant of the BE-3 engine that is used on Blue Origin's New Shepard experimental suborbital rocket that will launch and land vertically.

In the meantime, following the request by the U.S. Air Force for information on RD-180 replacement options, Aerojet Rocketdyne responded on 29 September 2014 by announcing it is developing a kerosene-fuelled main engine propulsion concept designated AR-1 as a potential replacement for the Atlas 5 RD-180 main stage engine. The announcement also clarified that the AR-1 would require minimal changes to the Atlas 5 launcher, including its ground system and launch infrastructure. The AR-1 is a liquid-oxygen/kerosene-fuelled engine, and will be capable of generating 500,000 lbs of thrust and could be ready to fly by 2019 for an investment of less than $1 billion, making it a low-risk transition engine for multiple launch vehicles.

On 20 November 2014, XCOR Aerospace announced the completion of another milestone in the development of its liquid oxygen and liquid hydrogen (LH2) programme. Being developed for the ULA, XCOR successfully performed hot fire testing of the XR-5H25 engine's regeneratively cooled thrust chamber, with both liquid oxygen and liquid hydrogen propellants supplied in pump-fed mode.[224] Building on their earlier success with liquid oxygen and kerosene pumps, the group has overcome 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.[225] The LH2 engine program is intended to produce a flight-ready cryogenic upper-stage engine in the 25,000 lb thrust class with growth potential of 50,000 lb of thrust or more, which should result in much lower cost and more capable commercial and government launch capabilities. It is intended as a potential successor to the Delta and Atlas series upper stage engines that are currently used.

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.[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

[224] Press Release. "XCOR Aerospace Announces Latest Milestone in ULA Program." 20 Nov. 2014. XCOR Aerospace 12 May 2015. http://www.xcor.com/press/2014/14-11-20_XCOR_announces_ULA_milestone.html.

[225] "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.

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

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] By 22 October 2014, eighty Merlin 1D engines had been launched, exceeding the propulsion heritage of the RS-68/68A engine (41 flown) on the Delta and the RD-180 engine (55 flown) on Atlas variants.[228]

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.[229] 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. The Skylon could begin test flights in 2019.[230]

In the U.S., Ball Aerospace and 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 used on a Ball BCP-100 spacecraft designed for easy integration of "ride-share" payloads, this mission will be the first time the U.S. will use a spacecraft to test green propellant technology.[231] 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. As milestone progress is continuing to be made, following supplier Aerojet Rocketdyne's successful test of its 1 Newton (1 N) thruster in July 2014, the completed small satellite is expected to launch sometime in 2016.[232]

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[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] "SpaceX Completes 100th Merlin 1D Engine." 22 Oct. 2014. SpaceX 12 May 2015. http://www.spacex.com/news/2014/10/16/spacex-completes-100th-merlin-1d-engine.

[229] "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.

[230] Passary, Sumit. "Sabre Jet can Fly Mach 5 and Bring You Anywhere in the World in Just Four Hours." 18 Dec. 2014. TechTimes 13 May 2015. http://www.techtimes.com/articles/22463/20141218/sabre-jet-can-fly-mach-5-and-bring-you-anywhere-in-the-world-in-just-four-hours.htm.

[231] "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.

[232] "GPIM Spacecraft to Validate Use of "Green" Propellant." 19 Aug. 2014. NASA 13 May 2015. https://www.nasa.gov/content/gpim-spacecraft-to-validate-use-of-green-propellant/.

On 28 March 2014 Boeing was selected by the U.S. Defense Advanced Research Projects Agency (DARPA) to build and demonstrate a low-cost, airborne satellite launching system that is capable of relocating and launching from any major runway around the globe. DARPA's Airborne Launch Assist Space Access (ALASA) programme started in 2012, when it awarded design contracts to Boeing, Lockheed Martin, and Virgin Galactic, in addition to related technology development contracts to three other companies.[233] Boeing's cost-effective design moved the rockets engines forward, allowing both the first and second stages to be powered by the same engines, thereby enabling a reduction in weight and system complexity. Upon being released from a F-15E fighter aircraft at an altitude of 12 km, the rocket would be capable of lifting a microsat weighing up to 45 kg satellite to low Earth orbit, at a cost of $1 million per launch; amounting to a 66 % launch cost reduction when compared to Orbital Science's Pegasus XL air-launched rocket system. A demonstration launch of the ALASA system is expected sometime in 2015.[234]

2.5.2 Telecoms

In April 2014 the information security firm IOActive released a technical white paper on the vulnerabilities of satellite communications security.[235] The report found multiple high-risk vulnerabilities in satellite ground terminal equipment from Harris Corp., Hughes, Thuraya, Cobham, JRC, and Iridium; these flaws included hardcoded credentials, undocumented protocols, insecure protocols, backdoors, and weak password reset features.[236] Those vulnerabilities have implications for many critical services e.g., such as revealing the location of units and soldiers in military communications, or by being open to a malicious hacker to block or disrupt emergency communications to aircraft and ships.[237]

[233] Gruss, Mike. "DARPA Picks Boeing To Demonstrate Airborne Launcher Concept." 25 Mar. 2014. SpaceNews 9 Apr. 2015. http://spacenews.com/39967darpa-picks-boeing-to-demonstrate-airborne-launcher-concept/.

[234] Gruss, Mike. "Boeing Targets 66 Percent Launch Cost Reduction with ALASA." 28 Mar. 2014. SpaceNews 9 Apr. 2015. http://spacenews.com/40023boeing-targets-66-percent-launch-cost-reduction-with-alasa/.

[235] Santamarta, Ruben. "A Wake-up Call for SATCOM Security." 17 Apr. 2014. IOActive 22 Aug. 2015. http://www.ioactive.com/pdfs/IOActive_SATCOM_Security_WhitePaper.pdf.

[236] Higgins, Kelly Jackson. "Satellite Communications Wide Open To Hackers." 17 Apr. 2014. Information Week 22 Aug. 2015. http://www.darkreading.com/vulnerabilities---threats/satellite-communications-wide-open-to-hackers/d/d-id/1204539.

[237] Lever, Rob. "Satellite telecom vulnerable to hackers, researchers find." 17 Apr. 2014. Phys.org 22 Aug. 2015. http://phys.org/news/2014-04-satellite-telecom-vulnerable-hackers.html.

2.5.3 Spacecraft Operations and Design

In Europe, the European Space Agency's (ESA) Rosetta comet chasing spacecraft was awoken from a 31 month hibernation period on 20 January 2014, while on course to rendezvous with the 67/P Churyumov-Gerasimenko comet by mid-2014.[238] Rosetta arrived within a 100 km distance from the comet on 6 August, and proceeded to manoeuvre itself in triangle-shaped paths to stay mainly between the Sun and the comet to view its illuminated terrain. The spacecraft berthed its own lander, Philae, which has its own suite of instruments, including a drill capable of penetrating as much as 23 cm beneath the surface. Upon reaching within 20 km of the comet, Rosetta deployed Philae on 12 November; yet as both the lander's two harpoons and its Active Descent System failed to function as planned, the lander bounced by an elevation of 1 km before alighting in a rocky and less illuminated region of the comet. From there, its solar panels receive only 90 min of sunlight every 12 h, rather than the anticipated 6 and 7 h of sunlight per 12-h day expected.[239] Nevertheless, on 15 November, following attempts to better orient Philae's solar array by lifting the lander by 4 cm and rotating it about 35°, the lander was put into hibernation. Yet before expending Philae's 72 h battery life, the lander managed to complete all the measurements planned for the final block of experiments on the comet's surface, and relayed the data to Earth via Rosetta, marking the unprecedented success of the Rosetta mission in exploring the surface of a comet.[240] While Philae's hibernation is likely to be permanent, there is a chance that it can be reawakened as the 67/P Churyumov-Gerasimenko comet nears the Sun.[241]

NASA's Orion Multi-Purpose Crew Vehicle (MPCV) conducted its first mission, Exploration Flight Test-1 (EFT-1), on 5 December 2014. Prior to the penultimate mission, the Orion's parachutes were tested on 25 June 2014, to test how they would respond at higher speeds in the final stages of the spacecraft's descent, and in the case where one of the three main parachutes were to expand quicker than intended. Another drop in August was to test the combined failure of one drogue parachute, which opens ahead of the three main parachutes to slow Orion down

[238] De Selding, Peter B. "Rosetta Probe Revived after 31-month Slumber for Comet Rendezvous." 20 Jan. 2014. SpaceNews 14 May 2015. http://spacenews.com/39185rosetta-probe-revived-after-31-month-slumber-for-comet-rendezvous/.

[239] De Selding, Peter B. "Rough Landing Putting Comet Probe's Science Team to the Test." 13 Nov. 2014. SpaceNews 14 May 2015. http://spacenews.com/42541rough-landing-putting-comet-probes-science-team-to-the-test/.

[240] De Selding, Peter B. "Philae Mission May be Done." 15 Nov. 2014. SpaceNews 14 May 2015. http://spacenews.com/42565philae-mission-may-be-done/.

[241] De Selding, Peter B. "Philae Managers Say Recovery Possible as Comet Approaches Sun." 18 Nov. 2014. SpaceNews 14 May 2015. http://spacenews.com/42586philae-managers-say-recovery-possible-as-comet-approaches-sun/.

before the spacecraft's final landing phase, and one main parachute, as well as new parachute design features.[242] On its December flight test, the Orion crew module reached an apex orbit of nearly 5800 km above Earth, conducting two revolutions before entering Earth's atmosphere to test the spacecraft's heat shield when re-entering the atmosphere at speeds verging on those that would occur during a return from deep space. The key purpose of this launch was to test whether Orion's heat shield can withstand the forces of atmospheric re-entry at about 32,000 km/h, with temperatures reaching up to 2200 °C.[243] On landing in the Pacific Ocean, 1015 km off the coast of California, the spacecraft had recorded only a minor problem with the system that inflates the five airbags that are to keep the module upright after splashdown, as only three of those airbags inflated fully. Orion is now expected to fly again in 2018 on the first launch of the Space Launch System heavy-lift rocket, followed by the first crewed Orion launch on the SLS in 2021.[244]

Boeing is developing its own Commercial Space Transportation-100 (CST-100) crew capsule, designed to send astronauts to the ISS as early as 2015.[245] On 17 October 2014 Boeing reached its final milestone, having undergone an extensive battery of tests on its mission flight software, including launch, docking, on-orbit, and re-entry and landing manoeuvres; mission simulations to advance communications and mission operations planning; wind tunnel testing of both the CST-100 and the Atlas V launch vehicle; and test-firings of the spacecraft's launch abort engines and thrusters used for manoeuvring in space.[246] Similar to the SpaceX Dragon capsule, the CST-100 has 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.[247] Measuring 4.5 m across at its widest point, this seven-seat gumdrop-shaped capsule will be reusable for up to 10 flights.[248]

In November 2014, SpaceX completed an additional two milestones in the development of its Dragon 2.0 crew capsule, designed to send astronauts to the ISS, including the Dragon Primary Structure Qualification, and the Delta Crew

[242] Leone, Dan. "NASA Tests Orion Parachutes Ahead of First Space Launch." 30 June 2014. SpaceNews 9 Apr. 2015. http://spacenews.com/41075nasa-tests-orion-parachutes-ahead-of-first-space-launch/.

[243] 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.

[244] Foust, Jeff. "Orion Aces First Flight Test." 5 Dec. 2014. SpaceNews 9 Apr. 2015. http://spacenews.com/orion-aces-first-flight-test/.

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

[246] "Boeing Finishes Commercial Crew Space Act Agreement for CST-100/Atlas V" 17 Oct. 2014. NASA 15 May 2015. http://www.nasa.gov/content/boeing-finishes-commercial-crew-space-act-agreement-for-cst-100atlas-v.

[247] "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.

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

Vehicle Critical Design Review, along with additional critical design reviews of systems and operations. However, SpaceX still needs to conduct two abort tests for the Dragon 2.0 in 2015, as required under the CCiCap.[249] 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 to save astronaut lives in the event of a real life emergency.[250] 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 U.S. space shuttles. Capable of holding a crew of up to seven astronauts, the spacecraft would launch atop an Atlas 5 rocket.[251] In December 2014 SNC announced the successful completion of milestone 15a, relating to the spacecraft's Reaction Control System (RCS) which provides on-orbit control for many critical manoeuvres such as docking to the ISS. This marked the successful completion of 12 out of 13 critical milestones.[252] 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

[249] Rhian, Jason. "SpaceX completes first CCtCap milestone as pace of Commercial Crew accelerates." 22 Dec. 2014. Spaceflight Insider 15 May 2015. http://www.spaceflightinsider.com/organizations/space-exploration-technologies/spacex-completes-first-milestone-commercial-crew-transportation/.

[250] "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/.

[251] "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/.

[252] "Sierra Nevada Corporation Successfully Tests Critical Dream Chaser® Spacecraft Propulsion System, Completes CCiCap Milestone 15a." 2 Dec. 2014. PRWeb 15 May 2015. http://www.prweb.com/releases/2014/12/prweb12367203.htm.

determine the extent to which it is able to supply satellites or remove decommissioned satellites from their orbits.[253]

Blue Origin is also in the running to develop its orbital reusable launch vehicle program outside of the CCiCap programme, participating with NASA in an unfunded partnership. In October 2014, NASA and Blue Origin signed an agreement to extend their CCDev2 partnership into 2016. Three additional unfunded milestones were added to the agreement to continue the development work and partnership, involving Blue Origin's propellant tank, BE-3 engine, and pusher escape system.[254]

2.5.4 *Suborbital Activities*

In mid-2014, U.S. lawmakers began preparations to update the U.S. Commercial Space Launch Amendments Act of 2004. The new legislation *will inter alia* address whether the FAA can begin to write human spaceflight safety regulations.[255] Up to October 2015 suborbital spacecraft developer Virgin Galactic and similar U.S. firms have a regulatory grace period extension on developing suborbital spacecraft without Federal Aviation Administration (FAA) imposed passenger and crew safety rules. Across the Atlantic, on 15 July 2014, the British government unveiled a broad strategy document designed to create the necessary regulatory regime to permit suborbital spaceplane flights by 2018 as part of a long term goal of establishing a domestic small-satellite launch capability. The UK Civil Aviation Authority (CAA) has selected eight existing airports as potential suborbital spaceports, six of them in Scotland. The U.S. FAA and UK CAA signed an MOU on the following day for better coordination between the two regions, yet the UK-based industry has some challenges to overcome especially in the areas of U.S. ITAR restrictions, flight safety regulations, and liability exposure.[256]

In the first half of 2014, Virgin Galactic was on the verge of completing the final phases toward upgrading its FAA experimental permit to also include a commercial

[253] "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.

[254] Money, Stewart. "Blue Origin, NASA Add Three More Unfunded Milestones." 14 Nov. 2014. Innerdpace.net 15 May 2015. http://innerspace.net/cotscommercial-crew/blue-origin-nasa-add-three-more-unfunded-milestones/.

[255] Leone, Dan. "Hill Staffers: Commercial Space Launch Bill Is Coming This Year." 26 May 2014. SpaceNews 9 Apr. 2015. http://spacenews.com/40694hill-staffers-commercial-space-launch-bill-is-coming-this-year/.

[256] De Selding, Peter B. "News from the Farnborough International Airshow | Britain Plots Course for Domestic Small-satellite Launcher." 18 July 2014. SpaceNews 9 Apr. 2015. http://spacenews.com/41296news-from-the-farnborough-international-airshow-britain-plots-course-for/.

launch licence for SpaceShipTwo, following a successful third rocket-powered test flight on 10 January. In the first launch, the spacecraft reached a top altitude of 21 km and top speed of Mach 1.4, in addition to testing the vehicle's reaction control system and a thermal coating on its tail boom.[257] Following Virgin Galactic's May announcement that it will change the fuel used in the vehicle's hybrid rocket motor from hydroxyl-terminated polybutadiene (a form of rubber) to a polyamide-based plastic, the company held its next flight test on 28 August. This time it was an unpowered release from the WhiteKnightTwo to conduct a "cold flow" test of the spacecraft's rocket engine, which ran liquid oxidizer through the motor without igniting it.[258] Tragically, on its next powered flight test on 31 October 2014, SpaceShipTwo experienced an 'inflight anomaly' shortly after release from the WhiteKnightTwo and ignition of its hybrid rocket engine; SpaceShipTwo was destroyed, killing one of its pilots, and injuring the other. Investigations of the accident attributed the cause of the explosion to the premature unlocking of the spacecraft's feathering mechanism that, subject to subsequent aerodynamic forces, resulted in the in-flight separation of the wings and the vehicle. Following this disaster Virgin Galactic stated that it plans to continue the construction of a second SpaceShipTwo, and that it was about 65 % complete. It expects the second SpaceShipTwo to be ready for test flights in 2015 and commercial service in 2016.[259]

In a continued effort to foster a viable market for American commercial reusable suborbital platforms that allow testing of new space technologies within Earth's atmosphere, in September 2014 NASA selected Virgin Galactic and three other companies (Masten Space Systems, Paragon Space Development Corp., and UP Aerospace Inc.) to integrate and fly technology payloads on commercial suborbital reusable platforms. The new 3-year contracts for integration and flight services build on previous contracts awarded by NASA in 2011; they also carry 2-year extension options and a minimum value of $100,000. As part of the contracts, the flights will carry a variety of payloads during five diverse flight profiles to help meet NASA's research and technology needs while also maturing cross-cutting technologies to flight readiness status for future space missions.[260]

[257] Ferster, Warren. "SpaceShipTwo Reaches Highest Altitude to Date in Test." 10 Jan. 2014. SpaceNews 9 Apr. 2015. http://spacenews.com/39031spaceshiptwo-reaches-highest-altitude-to-date-in-test/.

[258] Foust, Jeff. "Virgin Galactic Delays First Commercial Flights to 2015." 11 Sept. 2014. SpaceNews 9 Apr. 2015. http://spacenews.com/41837virgin-galactic-delays-first-commercial-flights-to-2015/.

[259] Foust, Jeff. "SpaceShipTwo Investigation Expands To Include Human Factors." 4 Nov. 2014. SpaceNews 9 Apr. 2015. http://spacenews.com/42445spaceshiptwo-investigation-expands-to-include-human-factors/.

[260] "NASA Selects U.S. Firms to Provide Commercial Suborbital Flight Services." 8 Sept. 2014. NASA 17 May 2015. https://www.nasa.gov/press/2014/september/nasa-selects-us-firms-to-provide-commercial-suborbital-flight-services/.

Masten is developing the Xaero; a vertical-takeoff, soft 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,[261] a second slightly larger Xaero-B has continued the programme's development, and completed four successful launches on 16 September 2014.[262] Also, Paragon Space Development Corp. is developing a passenger-carrying stratospheric balloon that will be operated by its World View subsidiary.[263] The vehicle, a 40 million cubic-foot (1.1 million cubic-meter) helium balloon and a steerable parafoil, is expected to carry six passengers and two pilots on a two hour journey; and its initial demonstration tests claimed a world record for the highest parafoil flight when its parafoil was inflated at about 15 km during the balloon's descent.[264] In addition, UP Aerospace Inc. has operated expendable solid-fuelled suborbital rockets from Spaceport America, New Mexico since 2006; its latest mission conducted on 23 October 2014 carried four payloads for NASA's Flight Opportunities Programme.[265]

Finally, 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 a runway. This two-seat, piloted space transport vehicle will take humans and payloads on a half-hour suborbital flight to 100 km 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.[266] XCOR announced rapid progress towards final assembly on 18 December 2014, following the bonding of both the Lynx' cockpit and carry-through spar to its fuselage. The next integration

[261] "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.

[262] Commercial Space Transportation Advisory Committee (COMSTAC) Systems Working Group. "DARPA XS-1 | MSS XEPHYR" 16 Sept. 2014. Masten 18 May 2015. http://www.faa.gov/about/office_org/headquarters_offices/ast/advisory_committee/meeting_news/media/2014/sep/Dennis_Poulos.pdf.

[263] SpaceNews Staff. "NASA Awards 4 Companies Suborbital Flight Contracts." 15 Sept. 2014 SpaceNews 18 May 2015. http://spacenews.com/41867nasa-awards-4-companies-suborbital-flight-contracts/.

[264] Brooks, Karen. "Balloon space flight company completes small-scale test flight." 25 June 2014. Reuters 18 May 2015. http://www.reuters.com/article/2014/06/25/us-space-ballooning-idUSKBN0F01MK20140625.

[265] "Welcome to UP Aerospace Past Missions." 23 Oct. 2014. UP Aerospace Inc. 18 May 2015. http://www.upaerospace.us.com/Past-Missions.html.

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

step involves attaching the strakes to the spacecraft.[267] With interest already created among commercial industry and research institutes, XCOR's Lynx Mark I will 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 pressurized cabin or exposed to the vacuum and radiation conditions of space.[268]

2.5.5 Other Technologies

Developments in general technology and science continued to advance in 2014, with implications reaching beyond the space sector.

In mid-2014, NASA's Satellite Servicing Capabilities Office (SSCO) had achieved several critical milestones involving its continuing Robotic Refuelling Mission (RRM), such as the ground-based Remote Robotic Oxidizer Transfer Test (RROxiTT) in February, which tested how robots can transfer hazardous oxidizer at flight-like pressures and flow rates through the propellant valve and into the mock tank of a satellite.[269] The RRM mission is being used to demonstrate that remotely controlled robots using current-day technology could refuel satellites that were not designed to be serviced. Now entering its second phase, following the 29 July delivery of its fourth mock satellite task board and the Visual Inspection Poseable Invertebrate Robot (VIPIR) tool, the RRM mission will demonstrate how space robots can replenish coolant in the instruments of similar legacy satellites.[270]

NASA's Robonaut 2 (R2) had its climbing legs attached to its torso by September 2014, for added mobility in conducting regular and repetitive tasks within and outside the ISS.[271] The legs were delivered to the station on 18 April

[267] Press Release. "In Pictures: XCOR announces Further Progress on XCOR Lynx Spacecraft." 18 Dec. 2014. XCOR 18 May 2015. http://www.xcor.com/press/2014/14-12-18_Lynx_development_in_pictures_carry_through_spar.html.

[268] "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.

[269] Washington, Dewayne and Adrienne Alessandro. "NASA Tests New Robotic Refuelling Technologies." 5 Mar. 2014. NASA 18 May 2015. http://www.nasa.gov/content/goddard/nasa-tests-new-robotic-refueling-technologies/.

[270] Alessandro, Adrienne. "NASA's Space Station Fix-It Demo for Satellites Gets Hardware for 2.0 Update." 12 Aug. 2014. NASA 18 May 2015. http://www.nasa.gov/mission_pages/station/research/news/rrm_update/#.U-o_jCQcB9U%EF%BF%BD%EF%BF%BD.

[271] Howell, Elizabeth. "Space Station's Robonaut 2 Is Getting More Astronaut-Like By The Day." 5 Sept. 2014. UniverseToday 18 May 2015. http://www.universetoday.com/114346/space-stations-robonaut-2-is-getting-more-astronaut-like-by-the-day/.

2014.[272] With a fully extended leg span of 2.7 m, each leg has seven joints, giving it great flexibility, and an end effector with a camera, allowing it to grasp handrails and sockets in and on the station.[273] Earlier in the year, the R2 underwent tests to show how its dexterity could be used to perform telemedical procedures, through the application of an appropriate level of force and tracking of progress using R2's vision system.[274] The same technology could foreseeably also be used by doctors to conduct complex medical procedures on humans in remote locations.

Other technological advances inspired by NASA's R2 include the RoboGlove. The RoboGlove was developed by NASA in collaboration with General Motors (GM), as a wearable human grasp assist device, to help reduce the grasping force needed by an individual to operate tools for an extended time or when performing tasks having repetitive motion.[275]

DARPA's Membrane Optical Imager for Real-Time Exploitation (MOIRE) program, currently in its second 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. In May 2014, the final tests on MOIRE's components were completed, with both the primary mirror's composite back structure and the deployment hinges having undergone environmental tests designed to simulate the temperature range and vacuum of a space environment.[276] 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, 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.[277]

On 20 November 2013, the U.S. Secretary of Defence completed a Memorandum of Understanding with Australia's Defence Minister to have DARPA's Space

[272] Hall, Loura. "A Step Up for NASA's Robonaut: Ready for Climbing Legs." 23 Apr. 2014. NASA 18 May 2015. http://www.nasa.gov/content/a-step-up-for-nasa-s-robonaut-ready-for-climbing-legs.

[273] "Robonaut 2 | Robonaut 2 Getting His Space Legs." 27 Aug. 2014. NASA 18 May 2015. http://www.nasa.gov/mission_pages/station/main/robonaut.html.

[274] Gannon, Megan. "NASA Teaches Humanoid Robonaut 2 Medical Skills for Space Emergencies (Video)." 18 Feb. 2014. Space.com 18 May 2015. http://www.space.com/24717-nasa-robonaut-telemedicine-training.html.

[275] "Robo-Glove." 1 Sept. 2014. NASA 19 May 2015. http://technology.nasa.gov/media/NP-2014-08-1136-HQ_JSC_RoboGlove_1_Web.pdf.

[276] "Final tests completed on giant surveillance telescope components." 23 May 2014. Optics.org 18 May 2015. http://optics.org/news/5/5/43.

[277] "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.

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 began in 2014, and the telescope 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 to the Space Surveillance Network (SSN).

The ISS received its first 3D printer on 23 September 2014, having been delivered aboard a Dragon supply ship that had launched on a Falcon 9 rocket 2 days earlier. The printer was installed aboard the ISS on 17 November, and over the following weeks it underwent testing to produce an initial set of more than 20 demonstration parts, including tools and test coupons that will also be printed by a duplicate printer on Earth for comparison.[278] The 3D printer has the capability of building an estimated 30 % of the spare parts on the station, in addition to specialty tools and experiment upgrades. 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.[279]

[278] Clark, Stephen. "3D printer activated aboard the International Space Station." 18 Nov. 2014. Spaceflight Now 10 May 2015. http://spaceflightnow.com/2014/11/18/3d-printer-activated-aboard-the-international-space-station/.

[279] "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.

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