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 2015. 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

As Europe's launch sector begins its substantial reorganisation to make it more competitive in the global market, the Arianespace launch consortium aims to increase the launch rate of its Vega launcher to benefit from economies of scale and increased demand. The per-launch cost of the Vega launcher is expected to decrease as its prime contractor Avio SpA ramps up production to enable three launches per year. Yet as favourable EU/U.S. exchange rates are likely to have helped grow the Vega's backlog to 11 launches for a total of 13 satellites as of June 2015, the demand for Vega has also allowed Arianespace to increase its launch price. Whereas in 2013, Vega's backlog of four satellite launches was valued at

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130 million euros, or 32.5 million euros per launch, the value of this new backlog has grown to 400 million euros, or 36.4 million euros per launch.[1]

On 12 August 2015, ESA and CNES signed a contract to develop the Ariane 6 launch pad and horizontal launcher integration facilities in Europe's Guiana Space Centre in French Guiana. Valued at 600 million euros, construction of the new launch installation will need to be completed before the intended demonstration launch of the Ariane 6 in 2020. French industry can expect to receive 52 % of the value of the contract in proportion to its government's investment in the ESA Ariane 6 launcher programme. Likewise, Germany's industry will receive a 23 % share of the contract, while the remaining 25 % will be spread among Italy, and other Ariane 6 participating member states under ESA's geographic return policy.[2]

Until now an Ariane 5 launcher has sold for 150 million euros; however, its launch cost is 170 million euros, requiring institutional support of Arianespace of around 100 million euros annually.[3] With orders for the Ariane 5 launcher booked into 2017, Arianespace and ASL aim to decrease the cost of the Ariane 5 by 5–6 % in the next batch of launch orders starting in 2019 through improvements in production and operation. They also plan to raise the price for heavier satellites intended for the Ariane 5's upper-berth, as demand for that slot has increased following the recent failed launches by competitors ILS and Sea Launch. With a total of 69 consecutive successful launches as at the end of 2015, the Ariane 5's reliability is a strong motivator for commercial satellite operators. Moreover, the price for the Ariane 5's lower berth, targeted for small satellites and telecom satellites using electric propulsion to reach geostationary transfer orbit, will be reduced to make it more competitive with SpaceX prices. Another advantage exists in the current EU-U.S. exchange rate that will allow customers to purchase an Ariane 5 launch with a lower value Euro.[4] Yet, once the Ariane 6 becomes operational in 2020, the Ariane 5 will undergo a 3-year phase out.[5]

ASL's first priority in developing the Ariane 6 launcher is to reduce the cost of launching a heavy telecomm satellite to geostationary transfer orbit by 50 % in

[1]De Selding, Peter B. "Vega Launches Sentinel-2A Observation Satellite." 23 June 2015. SpaceNews 5 Jan. 2016 <http://spacenews.com/vega-launches-sentinel-2a-observation-satellite/>.

[2]De Selding, Peter B. "ESA Inks $3.8 Billion in Contracts for Ariane 6, Vega-C and Spaceport Upgrades." 12 Aug. 2015. SpaceNews 13 Jan. 2016 <http://spacenews.com/esa-inks-3-8-billion-in-contracts-for-ariane-6-vega-c-and-spaceport-upgrades/>.

[3]De Selding, Peter B. "With Revenue Looking Up, Arianespace Seeks To Bring Ariane 5 Costs Down." 21 Oct. 2015. SpaceNews 13 Jan. 2016 <http://spacenews.com/with-revenue-looking-up-arianespace-seeks-to-bring-ariane-5-costs-down/>.

[4]De Selding, Peter B. "Arianespace Assures French Parliament it Can Outcompete SpaceX." 13 May 2015. SpaceNews 5 Jan. 2016 <http://spacenews.com/arianespace-assures-french-parliament-it-can-outcompete-spacex/>.

[5]De Selding, Peter B. "With Revenue Looking Up, Arianespace Seeks To Bring Ariane 5 Costs Down." 21 Oct. 2015. SpaceNews 13 Jan. 2016 <http://spacenews.com/with-revenue-looking-up-arianespace-seeks-to-bring-ariane-5-costs-down/>.

comparison to the Ariane 5.[6] In addition to its modernized and simpler design, and the reshaped role of industry, expenditures on the Ariane 6 will be reduced by integrating the launcher horizontally; a notable departure from the vertical integration of previous Ariane launchers.[7] Capable of lifting two telecom satellites with a combined mass of 9500 kg to geostationary transfer orbit at a total cost of around 90 million euros, the 64 configuration of the Ariane 6 with four boosters will be sold for 96.34 million euros per launch (or 48.17 million euros per customer).[8] The 62 configuration of the Ariane 6 with two boosters for small satellites will cost around 75 million euros.[9]

ESA's ties with China have grown throughout the year, with the ESA actively working on eventually placing a European astronaut on China's space station by its completion in 2022. While no specific plans have been made for an ESA astronaut mission, ESA astronauts have visited China's astronaut facilities, while some have begun learning to speak Chinese in collaboration with China's Manned Space Flight Office.[10] As the year progressed, it was increasingly realised by European stakeholders that China's inclusion in the global space exploration endeavour would be an asset.[11] Chinese officials echoed those sentiments, inviting international participation in the form of foreign modules on its space station, along with foreign cargo and crewed visits, at the 66th IAC held on 12–16 October 2015 in Jerusalem, Israel. Europe and Russia have each already signed initial space station cooperation agreements with China.[12] Yet, an open question remains as to whether China's space station will use the same international docking system standard used by Europe and the U.S. on the ISS, or whether a docking adapter will be needed.

[6]De Selding, Peter B. "ESA Approval Paves Way for Ariane 6, Vega-Contracts." 17 July 2015. SpaceNews 13 Jan. 2016 <http://spacenews.com/esa-approval-paves-way-for-ariane-6-vega-contracts/>.

[7]De Selding, Peter B. "ESA Inks $3.8 Billion in Contracts for Ariane 6, Vega-C and Spaceport Upgrades." 12 Aug. 2015. SpaceNews 5 Jan. 2016 <http://spacenews.com/esa-inks-3-8-billion-in-contracts-for-ariane-6-vega-c-and-spaceport-upgrades/>.

[8]De Selding, Peter B. "With Revenue Looking Up, Arianespace Seeks To Bring Ariane 5 Costs Down." 21 Oct. 2015. SpaceNews 13 Jan. 2016 <http://spacenews.com/with-revenue-looking-up-arianespace-seeks-to-bring-ariane-5-costs-down/>.

[9]Gallois, Dominique. "Ariane 6, un chantier européen pour rester dans la course spatiale." 1 Dec. 2014. Le Monde 9 Mar. 2016 <http://www.lemonde.fr/economie/article/2014/12/01/les-europeens-s-appretent-a-mettre-ariane-6-en-chantier_4532259_3234.html>.

[10]De Selding, Peter B. "ESA Hikes Budget, Takes Steps To Send Astronaut to Chinese Space Station." 16 Jan. 2015. SpaceNews 8 Jan. 2016 <http://spacenews.com/esa-hikes-budget-takes-steps-to-send-astronaut-to-chinese-space-station/>.

[11]C.f. De Selding, Peter B. "Dordain Says ESA Cannot Go it Alone in Debris Mitigation." 21 May 2015. SpaceNews 22 Dec. 2015 <http://spacenews.com/dordain-says-esa-cannot-go-it-alone-in-debris-mitigation/>.

[12]De Selding, Peter B. "China's Space Station Planners Put out Welcome Mat." 13 Oct. 2015. SpaceNews 11 Jan. 2016 <http://spacenews.com/chinas-space-station-planners-put-out-welcome-mat/>.

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 resulted in missed opportunities, with the debut of the SLS delayed by a year. NASA estimates given in November 2015 place both the SLS and its ground systems on schedule to support a first launch in June 2018, while Orion could be launched as soon as September 2018. Moreover, while NASA announced in September 2015 that the first crewed Orion launch on SLS could be delayed to as late as April 2023, there was still a hope that it can be advanced to August 2021.[13]

On 16 December 2015, the U.S. Congress approved the National Defense Authorization Act for 2016 (NDAA-16) which lifted the ban on the Russian-built RD-180 engine that was enacted in the previous year's NDAA. Amid continuing tensions between the U.S. and Russia following Russia's 2014 incursion in Ukraine, the act prohibited U.S. companies from contracting with Russian suppliers of rocket engines or renewing current contracts for space launch activities.[14] The act directly affected United Launch Alliance (ULA) that has had the U.S. government launch services market to itself since its formation in 2006 but now faces increasing competition from SpaceX. Since ULA uses RD-180 engines for the first stage of its Atlas 5 launcher, the restriction limited its use before ULA's follow-on Vulcan launcher—powered by Blue Origin's BE-4 engine—is ready in 2020. While ULA was granted an exemption of 5 RD-180 engines that were already on order at the time of the law's enactment, in addition to a batch of 29 RD-180 engines that were ordered while the NDAA-15 was still pending,[15] it needed access to at least 13 more RD-180 engines in order to remain competitive with SpaceX.[16] By 23 December 2015, ULA had ordered 20 more RD-180 engines, in addition to the 29 RD-180 engines it had ordered before Russia's annexation of Crimea from Ukraine.[17] The reversal had mixed responses in the Senate Armed Services Committee, with some considering whether to place a complete and indefinite restriction on RD-180

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[13]Foust, Jeff. "NASA Counting on Budget Increase for SLS and Orion." 5 Nov. 2015. SpaceNews 10 July 2016 <http://spacenews.com/nasa-counting-on-budget-increase-for-sls-and-orion/>.

[14]Section 1608. Carl Leven and Howard P. "Buck" McKeon National Defense Authorization Act for Fiscal Year 2015, Pub. L. no 113-291 (2014) <http://www.gpo.gov/fdsys/pkg/CPRT-113HPRT92738/pdf/CPRT-113HPRT92738.pdf>.

[15]Gruss, Mike. "House-Senate Conference Measure To End Pentagon Use of RD-180." 5 Dec. 2014. SpaceNews 22 July 2015 <http://spacenews.com/42701house-senate-conference-measure-to-end-pentagon-use-of-rd-180/>.

[16]Ferster, Warren. "Defense Bill Curbs ULA Use of Russian Engines but Draws Veto Threat." 30 Sept. 2015. SpaceNews 24 Dec. 2015 <http://spacenews.com/defense-bill-limits-ula-to-9-more-russian-built-engines/>.

[17]Shalal, Andrea. "ULA Orders 20 More RD-180 Rocket Engines." 23 Dec. 2015. SpaceNews 14 Jan. 2016 <http://spacenews.com/ula-orders-20-more-rd-180-rocket-engines/>.

engines in the NDAA for 2017. The NDAA-16 also provided $143 million in addition to the $84 million requested by the US Air Force to accelerate the development of a U.S. made replacement engine expected to be ready to fly by 2019.[18]

2.2.3 Russia

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 Angara launch pads by 2016; which should also coincide with the completion of its Angara launcher.[19] 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 low Earth orbit by 2020.[20]

Russia's Proton launcher, manufactured by Moscow-based Khrunichev State Research and Production Space Centre, and marketed in the U.S. by its commercial-arm International Launch Services (ILS), has suffered a string of failures since 2012. Uncertainty over the Proton M's reliability has led to more commercial contracts seeping to SpaceX and to Arianespace. Both launch providers split evenly the commercial launch contracts in 2014, each winning nine contracts for geostationary satellites,[21] while also ahead in 2015. To overcome its recent failure record and resulting unfavourable insurance rates, Khrunichev aims to introduce its Angara rocket family to replace its Proton launcher. In the near future, as the SpaceX has a large backlog and Arianespace's backlog for its Ariane 5 is booked into 2017, ILS might want to consider charging its consumers a lower price for its Proton launcher in light of the lower-valued rouble to offset the increased price customers must pay for insurance.[22]

[18] Gruss, Mike. "Spending Bill Lifts RD-180 Ban, Puts ULA Back in Competitive Game." 16 Dec. 2015. SpaceNews 7 Jan. 2016 <http://spacenews.com/spending-bill-lifts-rd-180-ban-puts-ula-back-in-competitive-game/>.

[19] 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/>.

[20] 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>.

[21] De Selding, Peter B. "Arianespace Assures French Parliament it Can Outcompete SpaceX." 13 May 2015. SpaceNews 5 Jan. 2016 <http://spacenews.com/arianespace-assures-french-parliament-it-can-outcompete-spacex/>.

[22] De Selding, Peter B. "ILS Mission Assurance VP Replaces Slack as President." 11 Sept. 2015. SpaceNews 13 Jan. 2016 <http://spacenews.com/ils-mission-assurance-vp-replaces-slack-as-president/>.

Until SpaceX's commercial crew capsule begins service in late 2017, Russia's Soyuz launcher is currently the sole vehicle capable of sending astronauts and cosmonauts to the ISS. By August 2015, the cost of sending six astronauts to the ISS had grown to $490 million, or $82 million per seat, up from $70.7 million per seat in 2013.[23] In contrast, the average cost of sending an astronaut to the ISS on a U.S. crewed vehicle is expected to cost on average $58 million per seat.[24]

2.2.4 Japan

JAXA has increased its funding toward the development of a lower cost H-3 successor to Japan's workhorse H-2A launcher. Of the ¥182 billion accorded to JAXA's 2015 fiscal year budget ending 30 March 2016, funding for the new development of the launcher increased by ¥5.5 billion in 2015, amounting to a total of ¥12.5 billion for 2015. The H-3 is estimated to need $1.9 billion (¥194.46 billion) for full development by 2020. The two-stage H-3 should be able to lift up to 6.5 metric ton payloads to GTO at a cost ranging between $50 million (¥5.12 billion) and $70 million (¥7.16 billion) per launch.[25] The H-3 launcher is 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.[26]

As Japan starts developing its H-3 launcher, the status of its recent three-stage solid-fuel Epsilon launcher remains unclear. Likewise developed to cut launcher costs, the Epsilon launcher uses the same solid-fuel strap-on booster used by the H-2A.[27] The first launch of the Epsilon-1 was conducted on 14 September 2013, yet Japan has sought to perfect the launch capability of the launcher in the following years. In 2015, JAXA's development of an Enhanced Epsilon Launch Vehicle continued smoothly, which included the completion of a static firing test of the sub-sized upper-stage motor in March 2015, followed by a pyro-shock test of the shocks and behaviour due to the payload separation impact conducted in June

[23]"NASA: Seats on Russian rockets will cost U.S. $490 million." 6 Aug. 2015. CBS 7 Sept. 2016 <http://www.cbsnews.com/news/nasa-seats-on-russian-rockets-will-cost-u-s-490-million/>.

[24]Kermer, Ken. "These Astronauts Will be the First to Launch With SpaceX and Boeing." 10 July 2015. Io9 7 Sept. 2016 <http://io9.gizmodo.com/these-astronauts-will-be-the-first-to-launch-with-space-1717036938>.

[25]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>.

[26]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>.

[27]Matsuda, Shogo. "Japan's Epsilon rocket shoved aside?" 16 Jan. 2015. Nikkei Asian Review 21 Jan. 2016 <http://asia.nikkei.com/Tech-Science/Tech/Japan-s-Epsilon-rocket-shoved-aside>.

2015.[28] Another combustion test of the enhanced engine was conducted on 21 December 2015.[29] The Epsilon launcher is designed to be capable of placing a 1.2 tons payload in low Earth orbit (LEO), and 700 kg payload into sun-synchronous orbit (SSO).[30]

2.2.5 China

China conducted the maiden launch of its three-stage Long March 6 on 19 September 2015 from the northern Taiyuan Satellite Launch Centre in China. With a launch capacity of 1500 kg into a low earth orbit (and 1080 kg into a 700 km sun synchronous orbit), the launcher lifted 20 small to cube-sized satellites to an sun-synchronous orbit of around 524 km.[31] Long March 6 is part of a new family of more environmentally friendly launchers being developed in China, including the Long March 5 (with a 14 tons to GEO lift capacity) and Long March 7 (5.5 tons to LEO). The launcher's first and second stages are fuelled by a liquid oxygen and kerosene mixture which is less toxic than the hypergolic propellants used in the earlier generation of its launchers, while its restartable third stage uses unsymmetrical dimethylhydrazine in combination with dinitrogen tetroxide as an oxidizer. In addition to the Taiyuan launch site, China plans to launch the Long March 6 from the newly constructed Wenchang Satellite Launch Centre on the north-eastern coast of Hainan Island.[32]

2.2.6 India

By the end of 2015, India's workhorse Polar Satellite Launch Vehicle (PSLV) had conducted its 31st successful launch out of 32 launches in total.[33] Capable of lifting 3700 kg to Low Earth Orbit and 800 kg to Geosynchronous Transfer Orbits (GTO),

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[28]"Development progress for Enhanced Epsilon." 6 Aug. 2015. JAXA 21 Jan. 2016 <http://global.jaxa.jp/projects/rockets/epsilon/>.

[29]"JAXA tests improved Epsilon rocket engine." 21 Dec. 2015. NHK World 21 Jan. 2016 <http://www3.nhk.or.jp/nhkworld/english/news/20151221_28.html>.

[30]Federal Aviation Administration. The Annual Compendium of Commercial Space Transportation: 2014. Washington, DC: FAA, Feb. 2015: 10.

[31]"China's Long March 6 Rocket successfully completes Maiden Flight." 23 Sept. 2015. Spaceflight101.com 28 Jan. 2016 <http://spaceflight101.com/chinas-long-march-6-rocket-successfully-completes-maiden-flight/>.

[32]"CZ-6 (Chang Zheng-6)." 21 Dec. 2015. Gunter's Space Page 28 Jan. 2016 <http://space.skyrocket.de/doc_lau/cz-6.htm>.

[33]"PSLV." 6 Feb. 2016. Gunter's Space Page 15 Feb. 2016 <http://space.skyrocket.de/doc_lau/pslv.htm>.

the PSLV has launched a total of 51 satellites for customers in 20 countries. In addition to its successful track record, having one initial failure in 1993, and a partial success in 1997, another draw card of the launcher is its low cost; its latest 16 December 2015 launch of six satellites cost Singapore's government 26 million euros ($30 million).[34] Incidentally, India's low cost launch capacity, and India's refusal to sign a commercial launch accord with the U.S. government to ensure fair market-based pricing, had been the reason U.S. companies have been restricted from using the PSLV in the past decade.[35]

India is also nearing the completion of its Geosynchronous Satellite Launch Vehicle (GSLV)-Mark III. Following the GSLV-Mark III's first sub-orbital test on 18 December 2014, ISRO tested the launcher's indigenous restartable upper-stage engine on 28 April 2015.[36] On 27 August 2015, ISRO launched the GSLV-Mark II variant to place the GSAT-6 satellite in orbit. This third launch of the GSLV-Mark II enabled ISRO to test its upgraded indigenous cryogenic upper stage engine.[37] The engine used in the GSLV-Mark II's previous launch in 2014 was an older version of its indigenous cryogenic upper stage, while earlier GSLV launcher variants used a cryogenic system provided by Russia. The new GSLV Mark III rocket will be able to launch 4000 kg into GTO, while the GSLV-Mark II can lift 2500 kg into GTO. Aside from the GSLV-Mark III's restartable liquid fuel engine, it shares a number of components with its predecessor GSLV-Mark I and II launchers.[38] The next GSLV-Mark II launcher is expected to be developed and launched by July 2016, while the GSLV-Mark III should be ready for institutional and commercial launches by 2017.[39]

By 28 November 2015, ISRO announced that it was ready to conduct the initial test flight of its Reusable Launch Vehicle (RLV) Technology Demonstration Program. First conceived by ISRO in 2009, the long delayed first flight test of the scramjet propulsion system was to occur sometime in January or February 2016 from the Sriharikota spaceport in India.[40] Sitting aboard two RH 560 sounding rockets in a two-stage to orbit configuration, the 1500 kg technology demonstrator

[34]Jayaraman, K.S. "ISRO Launches Six Satellites for Singapore." 16 Dec. 2015. SpaceNews 6 Jan. 2016 <http://spacenews.com/isro-launches-six-satellites-for-singapore/>.

[35]SpaceNews Editor. "Getting the Cubesat Revolution Out of Low Gear." 24 Nov. 2015. SpaceNews 6 Jan. 2016 <http://spacenews.com/getting-the-cubesat-revolution-out-of-low-gear/>.

[36]SpaceNews Staff. "India Test Fires New Engine for GSLV." 29 Apr. 2015. SpaceNews 5 Jan. 2016 <http://spacenews.com/india-test-fires-new-engine-for-gslv/>.

[37]De Selding, Peter B. "Successful Indian GSLV Launch Features Domestic Upper Stage." 27 Aug. 2015. SpaceNews 5 Jan. 2016 <http://spacenews.com/successful-indian-gslv-launch-features-homemade-upper-stage/>.

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

[39]Ibid.

[40]"'Scramjet Propulsion' Technology Test in Jan." 28 Nov. 2015. The New Indian Express 11 Feb. 2016 <http://www.newindianexpress.com/cities/thiruvananthapuram/Scramjet-Propulsion-Technology-Test-in-Jan/2015/11/28/article3150688.ece>.

will ascend to an altitude of 70 km, and will autonomously test the RLV's hypersonic aerodynamic properties, avionics, thermal protection and control systems, and its mission management. This initial mission is the first of four flights of the technology demonstrator, which will be followed by a landing experiment, a launch to orbit and return mission, and a scramjet propulsion demonstration.[41]

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.

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 2024. 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, along with U.S. commercial resupply missions provided by SpaceX and Orbital ATK, Europe's Automated Transfer Vehicle (ATV) and Japan's H-II Transfer Vehicle (HTV) providing auxiliary support.

Among ESA's newest batch of astronauts selected on 22 November 2010, Samantha Cristoforetti, Andreas Mogensen, and Timothy Peake, journeyed to the ISS in 2015; ESA astronauts Luca Parmitano and Alexander Gerst participated on the station in Expeditions 36/37 and 40/41 respectively in 2013 and 2014, while ESA astronaut Thomas Pesquet was scheduled to join the ISS for Expedition 50/51 in November 2016.

ESA astronaut Samantha Cristoforetti began a 5-month Expedition 42/43 mission on the ISS under the mission banner 'Futura' on 24 November 2014.[42] While

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[41] Jayaraman, K.S. "India To Fly RLV Tech Demo by June." 5 Mar. 2015. SpaceNews 1 Jan. 2016 <http://spacenews.com/india-to-fly-rlv-tech-demo-by-june/>.

[42] "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>.

Samantha expected to return to Earth by mid-May 2015, the Futura mission was extended until 11 June 2015 due to the failure of the Russian Progress M-27M cargo resupply mission on 28 April 2015, which burned up in the atmosphere in an uncontrolled re-entry; the incident also placed further launches to the ISS on hold pending the results of an investigation into the failure.[43] On January 2015, ESA astronaut Samantha Cristoforetti assisted NASA astronaut Butch Wilmore in capturing the Dragon CRS spacecraft, which brought an assortment of experiments involving fruit flies, flatworms, human, and shellfish immune cells.[44] In March 2015, Cristoforetti and NASA astronaut Terry Virts participated in their final session of the Airway Monitoring experiment which measured the amount of nitric oxide expelled by the two astronauts while they were inside the station's cylindrical Quest airlock as air was being pumped out to reduce air pressure by 30 %—equivalent to being on a mountain at 3000 m altitude. The experiment was meant to test the use of nitric oxide as a tool for monitoring lung inflammation as well as charting lung health in astronauts as their lungs are at risk of harm due to ever-floating dust on the station; dust might be an even greater concern when astronauts return to the Moon and probably Mars, as it will likely stick to astronauts through static electricity and have sharp edges.[45] Other experiments performed by ESA astronaut Samantha Cristoforetti involved studying gene changes over generations of fruit flies, investigating small particles behaviour in liquids without gravity's interference, looking at microscopic worms that appear to thrive in weightlessness, and observing how plants grow in weightlessness compared to Earth. Samantha was the prime operator for the undocking of ESA's final Automated Transfer Vehicle (ATV) 'George Lemaître' on 14 February 2015,[46] and also captured a second Dragon CRS spacecraft to the station with the assistance of NASA astronaut Terry Virts on 17 April 2015.[47]

ESA astronaut Andreas Mogensen began a short-duration visit to the ISS, for an ESA science mission named 'IrISS', on 4 September 2015.[48] Andreas Mogensen, Europe's first Danish astronaut, and Kazakh cosmonaut Aidyn Aimbetov, spent

[43]"Samantha's longer stay on Space Station." 12 May 2015. ESA 27 May 2016 <http://m.esa.int/Our_Activities/Human_Spaceflight/Futura/Samantha_s_longer_stay_on_Space_Station>.

[44]"Fresh supplies and experiments for Samantha." 13 Jan. 2015. ESA 27 May 2016 <http://m.esa.int/Our_Activities/Human_Spaceflight/Futura/Fresh_supplies_and_experiments_for_Samantha>.

[45]"Testing astronauts' lungs in Space Station airlock." 9 Mar. 2015. ESA 27 May 2016 <http://m.esa.int/Our_Activities/Human_Spaceflight/Futura/Testing_astronauts_lungs_in_Space_Station_airlock>.

[46]"Futura Mission In Brief." 30 Sept. 2015. ESA 27 May 2016 <http://www.esa.int/Our_Activities/Human_Spaceflight/Futura/Futura_mission_in_brief>.

[47]"Second Dragon, fruit flies and fresh coffee for Samantha." 22 Apr. 2015. ESA 27 May 2016 <http://m.esa.int/Our_Activities/Human_Spaceflight/Futura/Second_Dragon_fruit_flies_and_fresh_coffee_for_Samantha>.

[48]"ESA astronaut Andreas Mogensen begins busy International Space Station tour." 4 Sept. 2015. ESA 27 May 2016 <http://www.esa.int/Our_Activities/Human_Spaceflight/iriss/ESA_astronaut_Andreas_Mogensen_begins_busy_International_Space_Station_tour>.

10 days in space delivering a new Soyuz spacecraft intended to return NASA astronaut Scott Kelly and Roscosmos cosmonauts Mikhail Kornienko and Sergei Volkov to Earth in March 2016. Kelly and Kornienko are the 1-year mission crew members, while Volkov is the Soyuz commander who flew to the ISS with Mogensen and Aimbetov.[49] While on the ISS, ESA astronaut Andreas Mogensen tested ESA's 'SkinSuit' for 2 days to test its effectiveness in preventing astronauts' spines stretching in weightlessness.[50] Andreas Mogensen also worked on around 20 European experiments, which focussed on Mogensen's blood vessels and muscles, bones and brain to see how they fared in space. He also helped to test new ways of interacting with ESA mission control to improve operations by relying on just-in-time-training from 3D software and wearing a headset to stream live video to mission control to conduct tasks, instead of training on the ground. Mogensen also participated in the Meteron project, which aims to control robotic systems from space, by operating a rover in the Netherlands from the ISS using a feedback joystick to move its twin on Earth which allowed him to 'feel' objects remotely.[51] Mogensena and Aimbetov returned to Earth with Russian cosmonaut Gennady Padalka aboard the Soyuz TMA-16M spacecraft on 12 September 2015.[52]

ESA astronaut Tim Peake began his 6-month Expedition 46/47 mission on the station under the mission banner 'Principia' on 15 December 2015. Peake is the first British astronaut to travel to the ISS; while serving as Flight Engineer, he plans to conduct dozens of experiments for researchers on Earth including growing crystals and blood vessels in space, simulating atomic structures, and charting areas in the brain as they adapt to stressful situations.[53] ESA astronaut Tim Peake is scheduled to return from the station on 5 June 2016.[54]

ESA's final Automated Transfer Vehicle (ATV) mission, ATV-5 George Lemaître, ended on 15 February 2015, following its separation from the ISS a day earlier.[55] Prior

[49] "Three Soyuz Crew Members Wrap Up Mission on Space Station." 11 Sept. 2015. NASA 30 May 2016 <https://blogs.nasa.gov/spacestation/2015/09/11/three-soyuz-crew-members-wrap-up-mission-on-space-station/>.

[50] *See further* "Suit up for Skinsuit." 10 Jan. 2014. ESA 30 May 2016 <http://m.esa.int/Our_Activities/Human_Spaceflight/Astronauts/Suit_up_for_Skinsuit>.

[51] "100 days to Andreas Mogensen's mission." 25 May 2015. Phys.Org 30 May 2016 <http://phys.org/news/2015-05-days-andreas-mogensen-mission.html>.

[52] "Andreas Mogensen lands after a busy mission on Space Station." 12 Sept. 2015. ESA 27 May 2016 <http://www.esa.int/Our_Activities/Human_Spaceflight/iriss/Andreas_Mogensen_lands_after_a_busy_mission_on_Space_Station>.

[53] "ESA astronaut Tim Peake begins six-month stay on Space Station." 15 Dec. 2015. ESA 27 May 2016 <http://m.esa.int/Our_Activities/Human_Spaceflight/Principia/ESA_astronaut_Tim_Peake_begins_six-month_stay_on_Space_Station>.

[54] "Tim Peake: British astronaut's space mission at a glance." 15 Dec. 2015. The Guardian 27 May 2016 <https://www.theguardian.com/science/2015/dec/15/tim-peake-british-astronauts-space-mission-at-a-glance>.

[55] "Last ATV reentry leaves legacy for future space exploration." 15 Feb. 2015. ESA 30 May 2016 <http://m.esa.int/Our_Activities/Human_Spaceflight/ATV/Last_ATV_reentry_leaves_legacy_for_future_space_exploration>.

to undocking, ESA astronaut Samantha Cristoforetti had installed the Break-Up Camera prototype within the capsule's cargo area and trained it on the forward hatch to record the ATV's death throes in the infrared as it plummeted through the atmosphere. During the fall, the camera recorded nearly 6000 pictures at a rate of 10 frames per second; it also took accelerometer and magnetometer readings, details of the sphere rotation and a temperature reading, and successfully transferred those results to the SatCom heat shield-protected sphere.[56] The SatCom survived the break-up of the capsule, and managed to broadcast at least one message to the Iridium telecom satellite constellation as it fell to Earth, indicating that the internal temperature of the sphere remained moderate and there were no signs of any thermal issues. However, the SatCom team was unable to retrieve all the data, and they are investigating why further data packets didn't make it through the scorching plasma—known for blocking radio signals.[57] ESA is using the knowledge gained from the ATV programme to build its European Service Module for NASA's Orion spacecraft that will fly astronauts to the Moon and beyond.[58]

Japan launched its fifth H-2 Transfer Vehicle (HTV) to the ISS on 19 August 2015; while it was supposed to launch to the station in July 2014, it incurred numerous and multifaceted external delays that pushed its launch to the later date. The HTV-5, also known as Kounotori 5, was launched on a H-IIB rocket from the Tanegashima Space Centre in Southern Japan, carrying 5.7 tons of cargo, including water and food supplies, crew commodities, system components, and science experiments.[59] Its cargo also included the CALorimetric Electron Telescope (CALET), which will be placed on the exposed facility attached to Japan's Kibo module for a period of 2–5 years, to search for signatures of dark matter and provide the highest energy direct measurements of cosmic rays and high energy gamma rays.[60] Other equipment included a new Fluids Control and Pump Assembly for the Urine Processor Assembly, Water Processing Assembly Multifiltration Beds, a new SAFER (Simplified Aid For EVA Rescue) unit, and an assortment of satellites to be released from the station. The HTV5 was released from the ISS on 28 September 2015; it burned up in Earth's atmosphere carrying the station's

[56] "Camera to record doomed ATV's disintegration – from inside." 6 Feb. 2015. ESA 30 May 2016 <http://m.esa.int/Our_Activities/Space_Engineering_Technology/Camera_to_record_doomed_ATV_s_disintegration_from_inside>.

[57] "ATV's internal camera delivered data, but not images." 20 Feb. 2015. ESA 30 May 2016 <http://m.esa.int/Our_Activities/Space_Engineering_Technology/ATV_s_internal_camera_delivered_data_but_not_images>.

[58] "Last ATV reentry leaves legacy for future space exploration." 15 Feb. 2015. ESA 30 May 2016 <http://m.esa.int/Our_Activities/Human_Spaceflight/ATV/Last_ATV_reentry_leaves_legacy_for_future_space_exploration>.

[59] Gebhardt, Chris, and Chris Bergin. "HTV-5 Kounotori sets sail for the ISS." 18 Aug. 2015. NASASpaceFlight.com 28 Jan. 2016 <http://www.nasaspaceflight.com/2015/08/htv-5-kounotori-launch-space-station/>.

[60] "CALorimetric Electron Telescope (CALET)." 24 Apr. 2014. JAXA 28 Jan. 2015 <http://iss.jaxa.jp/en/kiboexp/ef/calet/>.

refuse.[61] The next HTV6 mission is expected to launch near the end of 2016, along with four additional HTV missions that are intended in subsequent years.[62]

In 2015, Russia launched four expeditions to the ISS on its Soyuz launcher: TMA-16M on 27 March 2015 with the Expedition 43/44 crew of Gennady Padalka, Mikhail Kornienko, and Scott Kelly[63]; TMA-17M on 22 July 2015 with the Expedition 44/45 crew of Oleg Kononenko, Kimiya Yui, and Kjell Lindgren[64]; TMA-18M on 02 September 2015 with the Expedition 45/46 crew of Sergei Volkov, Andreas Mogensen, and Aidyn Aimbetov[65]; and TMA-19M on 15 December 2015 with the Expedition 46/47 crew of Yuri Malenchenko, Timothy Kopra, and Timothy Peake.[66] Russian cosmonaut Gennady Padalka became the first four-time ISS commander, and now holds the record for having spent the most time in space; adding 168 mission days to increase his total number of days in space to 879 over five trips.[67] Cosmonaut Mikhail Kornienko and NASA astronaut Scott Kelly are both participating in the first 1-year crew mission to the ISS, covering Expeditions 43–46.[68] Cosmonaut Oleg Kononenko, along with JAXA astronaut Kimiya Yui and NASA astronaut Kjell Lindgren spent 141 days aboard the space station, and conducted two landing simulations to refresh their knowledge of necessary procedures in their final week in orbit.[69] Russian cosmonaut Sergei Volkov stayed aboard the ISS for Expeditions 45/46, supporting various scientific activities and maintenance aboard the Russian segment, while crewmates ESA astronaut Andreas Mogensen and Kazakh Space Agency (KSA) cosmonaut Aidyn Aimbetov completed a 10-day mission returning to Earth with Gennady Padalka on 12 September 2015.[70] Prior to reaching the ISS on

[61] Bergin, Chris. "HTV-5 departs ISS – following slight glitch – ahead of fiery demise." 28 Sept. 2015. NASASpaceFlight.com 28 Jan. 2016 <http://www.nasaspaceflight.com/2015/09/htv-5-departs-iss-fiery-demise/>.

[62] Gebhardt, Chris, and Chris Bergin. "HTV-5 Kounotori sets sail for the ISS." 18 Aug. 2015. NASASpaceFlight.com 28 Jan. 2016 <http://www.nasaspaceflight.com/2015/08/htv-5-kounotori-launch-space-station/>.

[63] "Soyuz TMA-16M: Starting "Year in Space" mission." 29 Feb. 2016 Russian Space Web 25 May 2016 <http://www.russianspaceweb.com/iss_soyuz_tma16m.html>.

[64] "Soyuz TMA-17M mission." 12 Dec. 2015. Russian Space Web 25 May 2016 <http://www.russianspaceweb.com/iss_soyuz_tma17m.html>.

[65] "Soyuz TMA-18M mission." 3 Mar. 2016. Russian Space Web 25 May 2016 <http://www.russianspaceweb.com/iss-soyuz-tma18m.html>.

[66] "Soyuz crew in close-call docking with ISS." 29 Apr. 2016. Russian Space Web 25 May 2016 <http://www.russianspaceweb.com/iss-soyuz-tma19m.html>.

[67] "Russian cosmonaut record-breaker Padalka returns to Earth." 12 Sept. 2015. BBC News 25 May 2016 <http://www.bbc.com/news/science-environment-34231700>.

[68] Kramer, Miriam. "One-Year Crew Begins Epic Trip on International Space Station." 28 Mar. 2015. Space.com 25 May 2016 <http://www.space.com/28960-one-year-space-station-trip-begins.html>.

[69] "Soyuz TMA-17M mission." 12 Dec. 2015. Russian Space Web 25 May 2016 <http://www.russianspaceweb.com/iss_soyuz_tma17m.html>.

[70] "Sergei Volkov." 25 Aug. 2015. Spaceflight 101 27 May 2016 <http://spaceflight101.com/iss-expedition-45/sergei-volkov/>.

15 December 2015 for Expedition 46/47, following the failure of the Soyuz capsule's Kurs automated rendezvous system, Russian cosmonaut Yuri Malenchenko had to manually dock the spacecraft to the station, succeeding on his second attempt just 3 min from entering Earth's shadow, and another 15 min from going out of range of communications with Russia's mission control centre in Korolev.[71] Russia also conducted five resupply missions (including one failure) to the ISS with its Progress cargo transfer vehicles: M-26M on 17 February 2015, M-27M on 28 April 2015 (which failed to reach the ISS due to an anomaly experienced at orbit insertion—it re-entered the atmosphere out of control), M-28M on 3 July 2015, M-29M on 1 October 2015, and MS on 21 December 2015.[72]

An example of the softening U.S. hard-line position toward China can be found in the recent arrangement to have a Chinese experiment ferried to the ISS. Brokered by NanoRacks, which facilitates the use of the ISS for businesses, the commercial arrangement was seen to fall outside the ambit of Congress' 2011 restriction that continues to prohibit NASA and the White House Office of Science and Technology Policy (OSTP) from bilaterally cooperating with China. The experiment will investigate how the space environment affects DNA, with particular focus on whether space radiation and microgravity can cause mutations to gene encoding antibodies. The experiment, conducted by the Beijing Institute of Technology, will be lifted to the ISS on a SpaceX cargo supply mission in 2016, and will be housed in Japan's Kibo module for a 15-day duration.[73] The experiment will be performed by astronauts aboard the ISS, while China will receive only the data and experiment samples via NanoRacks.[74] It is hoped that the experiment can serve as a bridge for greater cooperation between the space powers in the future.

After nearly 2 years of inactivity for China's human spaceflight programme, China plans to launch its Tiangong 2 space lab in 2016 aboard a Long March 2F/G rocket. The space lab will use the same basic module as the Tiangong 1 space lab, but will include a new regenerative life support system and will be resupplied by China's first cargo spacecraft, Tianzhou.[75] As China's second space habitat, with the first space lab to be eventually de-orbited,[76] the Tiangong 2 will receive a single

[71]"Soyuz crew in close-call docking with ISS." 29 Apr. 2016. Russian Space Web 25 May 2016 <http://www.russianspaceweb.com/iss-soyuz-tma19m.html>.

[72]"A complete chronology of ISS missions." 10 Apr. 2016. Russian Space Web 27 May 2016 <http://www.russianspaceweb.com/iss_chronology_flights.html>.

[73]David, Leonard. "US-China Space Freeze May Thaw with Historic New Experiment." 21 Aug. 2015. Space.com 22 Jan. 2016 <http://www.space.com/30337-chinese-experiment-international-space-station.html>.

[74]Cowing, Keith. "Commercial Payload From China to Fly on ISS." 3 Aug. 2015. NASA Watch 22 Jan. 2016 <http://nasawatch.com/archives/2015/08/commercial-payl.html>.

[75]Jones, Morris. "Progress for Tiangong 2." 1 Sept. 2015. SpaceDaily.com 31 May 2016 <http://www.spacedaily.com/reports/Progress_for_Tiangong_2_999.html>.

[76]Wenz, John. "China to Launch a New Space Station in 2016." 10 Mar. 2015. Popular Mechanics 31 May 2016 <http://www.popularmechanics.com/space/a14480/china-space-station-2016-tiangong-2/>.

crew of Chinese astronauts on board the Shenzhou 11 for up to 1 month. China will attempt an automatic docking of its Tianzhou cargo spacecraft to the Tiangong-2 shortly after the launch of the Shenzhou 11.[77] China plans to launch another experimental core module of the future space station around 2018, while China's full space station is to be completed by 2022.[78]

2.3.2 Lunar Science

Interest in the Moon is ongoing for both its science and exploration value, in addition to being the finish line for several private space companies competing to win the Google Lunar X Prize. This year, the U.S. and China continued to progress toward a robotic and human lunar presence, however budget constraints still have the potential to delay well-intentioned initiatives. Moreover, Google Lunar X-Prize competitors have begun to partner up to better their odds of winning the symbolic award.

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 LRO is in the midst of its second 2-year extended science mission, which began on 15 September 2014 and is slated for completion in September 2016.[79] By 4 February 2015, a research team using the LRO's Lunar Exploration Neutron Detector (LEND) instrument, which detects hydrogen by counting the number of neutrons flying off the lunar surface, discovered that there is a greater abundance of hydrogen on the Moon's Pole-Facing Slopes (PFS) than on its Equator-Facing Slopes (EFS), by an average of about 23 parts-per-million-by-weight (ppmw). There is also a greater abundance of hydrogen in the Moon's southern hemisphere, beginning at between 50 and 60 degrees south latitude, wherein slopes closer to the South Pole show a larger hydrogen concentration difference. The presence of hydrogen could help reduce the need to transport it from Earth to the Moon's surface, it being an important component for fuel and drinking water.[80] On 4 May 2015, NASA completed a manoeuvre, consisting of two station keeping burns to lower the LRO's orbit to

[77] Whittington, Mark. "China preparing to send crewed Shenzhou 11 to Tiangong 2 space station in 2016." 2 Sept. 2015. Examiner.com 31 May 2016 <http://www.examiner.com/article/china-preparing-to-send-crewed-shenzhou-11-to-tiangong-2-space-station-2016-1>.

[78] Jones, Morris. "The Last Tiangong." 20 Oct. 2015. SpaceDaily.com 31 May 2016 <http://www.spacedaily.com/reports/The_Last_Tiangong_999.html>.

[79] 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>.

[80] "NASA's LRO Discovers Lunar Hydrogen More Abundant on Moon's Pole-Facing Slopes." 4 Feb. 2015. NASA 24 Apr. 2016 <http://www.nasa.gov/content/goddard/lro-lunar-hydrogen>.

within 20 km of the Moon's South Pole and 165 km from its North Pole, to enable improved measurements of the LRO's Lunar Orbiter Laser Altimeter (LOLA) and its high resolution Diviner instrument over the South Pole. By magnifying the sensitivity of the LRO instruments, researchers will be able to better understand the mechanisms by which water or other volatiles might be trapped there.[81]

China's Chang'e 5-TI test capsule returned to lunar orbit in the week of 12 January 2015.[82] Launched on 23 October 2014, the prototype sample-return capsule reached the Moon within a day, circling it before returning to eject its sample capsule at a higher than average velocity into Earth's atmosphere. Following the successful release of the capsule on 1 November 2015, Chang'e 5-TI began making its way to the Earth-Moon Lagrange (L2) point on the opposite side of the Moon. Reaching L2 by late November 2015, the service module then completed three circles around that point prior to returning to lunar orbit.[83] In addition to testing critical breaking manoeuvres, the Chang'e 5-TI carries a camera system that will help to identify future landing sites for the Chang'e 5 robotic sample-return mission planned for launch in 2017 or 2018. This later Chang'e 5 mission will involve a soft landing on the Moon and the collecting of 200 g of samples prior to bringing them to Earth.[84]

China is also planning to launch a second lunar lander mission, Chang'e 4, after the Chang'e 5 mission. Following the success of the Chang'e 3 lunar lander and rover mission conducted at the end of 2013 and into 2014, China wants to send a similar upgraded version of the mission to the Moon in 2020. This second mission will use a more powerful launcher, allowing for the use of a heavier spacecraft, and will land in a different region of the Moon.[85] China is also developing plans for a manned lunar landing sometime between 2025 and 2030.[86]

The Google Lunar X Prize is a competition for a grand prize of $20 million and a second prize of $5 million for the first two privately funded teams to safely land on the Moon, travel at least 500 m across its surface, and send high-definition video, images, and data back to the Earth. In late 2013, the X Prize Foundation and Google announced a series of interim 'milestone' prizes available to assist the competing teams in accessing financing at a critical point in their mission timeline and to raise public excitement and support for the teams. By 26 January 2015, the X Prize

[81]"NASA's LRO Moves Closer to the Lunar Surface." 5 May 2015. NASA 24 Apr. 2016 <http://www.nasa.gov/feature/goddard/nasas-lro-moves-closer-to-the-lunar-surface>.

[82]David, Leonard. "Chinese Spacecraft Enters Orbit around the Moon." 20 Jan. 2015. SpaceNews 8 Jan. 2016 <http://spacenews.com/chinese-spacecraft-enters-orbit-around-the-moon/>.

[83]"Service Module of Chinese Probe Successfully Enters Lunar Orbit." 11 Jan. 2015. Sputnik News 22 Jan. 2016 <http://sputniknews.com/science/20150111/1016776437.html>.

[84]Foust, Jeff. "China's Mars Exploration Program Facing Delays." 1 Apr. 2015. SpaceNews 8 Jan. 2016 <http://spacenews.com/chinas-mars-exploration-program-facing-delays/>.

[85]Foust, Jeff. "China's Mars Exploration Program Facing Delays." 1 Apr. 2015. SpaceNews 8 Jan. 2016 <http://spacenews.com/chinas-mars-exploration-program-facing-delays/>.

[86]"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>.

Foundation had awarded a total of $5.25 million in awards to 5 of the 18 teams in the competition as rewards for demonstrating progress in landing system technologies, imaging systems, and mobility systems.[87] The awards can also be seen as a litmus test to see where competitors are in achieving their self-defined milestone goals; i.e. here Astrobiotic Technology won $1.75 million for its progress in all three areas, while Moon Express won $1.25 million for its progress in landing system technologies and imaging systems. Team Indus won $1 million for its landing system technologies, while Part-Time Scientists won $750,000 for demonstrating their mobility and imaging systems; and Hakuto won $500,000 for its mobility system.[88]

In the follow-up to those awards, Astrobiotic Technology and Hakuto decided to partner up to share risks and rewards, in an arrangement where both teams will share the costs of the launch of the overall spacecraft, and then share the winning proceeds if one of their teams wins the grand prize. Upon reaching the Moon's surface, Astrobiotic Technology's lander will release its one rover along with the two rovers developed by Hakuto; the three rovers will then race to achieve the 500 m requirement, with the winning team splitting the proceeds according to an undisclosed ratio.[89] As Astrobiotic Technology plans to launch its lander on the SpaceX Falcon 9 rocket, it is expected to have an estimated 1250 kg of the 2500 kg launch capacity available for other customers. By 27 October 2015, Astrobiotic Technology had signed on another Google Lunar X Prize competitor, Team AngelicvM of Chile, along with two non-competing payloads (one from the Mexican Space Agency, and one from the British crowd-sourced Lunar Mission One).[90]

The Google Lunar X Prize competition was extended to the end of 2017, after two teams had met the X Prize Foundation's 16 December 2014 stipulation requiring at least one team to have made launch arrangements by the end of 2015.[91] An Israeli team, SpaceIL was the first to be confirmed by the foundation on 7 October 2015, after purchasing a spot on SpaceX's Falcon 9 launcher.[92] On

[87]The five teams considered are the following: Astrobiotic of Pittsburgh, USA; Moon Express (Mountain View, USA); Team Indus (Bengaluru, India); Hakuto (Tokyo, Japan); Part-Time Scientists (Multinational).

[88]Foust, Jeff. "5 Lunar X Prize Teams Land Payday; Only 2 Landed Hardware." 30 Jan. 2015. SpaceNews 8 Jan. 2016 <http://spacenews.com/5-lunar-x-prize-teams-land-payday-only-2-landed-hardware/>.

[89]Foust, Jeff. "Google Lunar X Prize Teams Partner To Share Risks and Rewards." 24 Feb. 2015. SpaceNews 8 Jan. 2016 <http://spacenews.com/google-lunar-x-prize-teams-partner-to-share-risks-and-rewards/>.

[90]Foust, Jeff. "Astrobotic Adds Another Google Lunar X Prize Team to Its Lander." 27 Oct. 2015. SpaceNews 11 Jan. 2016 <http://spacenews.com/astrobotic-adds-another-google-lunar-x-prize-team-to-its-lander/>.

[91]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/>.

[92]Foust, Jeff. "Israeli X Prize Team Announces Launch Contract for Lunar Mission." 7 Oct. 2015. SpaceNews 5 Jan. 2016 <http://spacenews.com/israeli-x-prize-team-announces-launch-contract-for-lunar-mission/>.

8 December 2015, the X Prize Foundation confirmed a second launch agreement by Moon Express, which has purchased three launches on Rocket Lab's still in development small Electron launcher. If Moon Express wins the competition with one of its two launches planned 2017, the team plans to sell the remaining capacity on later missions to scientists or space agencies.[93] Astrobiotic Technology is waiting to finish signing up launch customers before finalizing its launch contract with SpaceX for a late 2017 mission. By the end of 2015, only 16 teams remained in the competition; these teams now have until the end of 2016 to submit their own launch documentation to remain in the competition.[94]

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 its 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. On 15 January 2015, images taken by the MRO helped to reveal the location of the UK-led Beagle-2 Mars lander, which hitched a ride on ESA's Mars Express mission, but went radio silent after successfully touching down on Mars' surface on 25 December 2003.[95] Images taken by the high-resolution stereo camera on Mars Express on 12 July 2015 just to the south of the mouth of Minio Vallis, near volcanic giants such as Olympus Mons in the south-western portion of the Tharsis bulge, helped to show how volcanic activity may have triggered the melting of subsurface ice, and consequently the formation of the water-carved channels in the region.[96] Additionally, the course of the Mars Express mission has revealed that the planet has its own ultraviolet aurora despite not having a global magnetic field. Likely caused by weak residual magnetism in the crust, such as in the highlands of the southern hemisphere, the ultraviolet auroras last only a few seconds and tend to be rare and

[93]Foust, Jeff. "Moon Express Buys Rocket Lab Launches for Lunar Missions." 1 Oct. 2015. SpaceNews 5 Jan. 2016 <http://spacenews.com/moon-express-buys-rocket-lab-launches-for-lunar-missions/>.

[94]Foust, Jeff. "X Prize Verifies Moon Express Launch Contract." 8 Dec. 2015. SpaceNews 6 Jan. 2016 <http://spacenews.com/x-prize-verifies-moon-express-launch-contract/>.

[95]"Beagle-2 lander found on Mars." 16 Jan. 2015. ESA 25 Apr. 2016 <http://www.esa.int/Our_Activities/Space_Science/Mars_Express/Beagle-2_lander_found_on_Mars>.

[96]"Flash floods in Mangala Valles." 15 Oct. 2015. ESA 25 Apr. 2016 <http://www.esa.int/Our_Activities/Space_Science/Mars_Express/Flash_floods_in_Mangala_Valles>.

transient. A total of 16 detections were made from following 113 night side orbits since the beginning of the mission in 2003.[97]

The ExoMars mission is a joint endeavour between ESA and Russia that addresses whether life has ever existed on Mars by drilling the surface of the planet and analyzing the samples in situ. ESA is providing the Trace Gas Orbiter (TGO) and the Entry, Descent and Landing Demonstrator Module (EDM) 'Schiaparelli' in 2016,[98] 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. Near the end of 2015, ExoMars' orbiter and entry, descent and landing module mission, slated for launch in January 2016, was delayed by 2 months due to the presence of leaky pressure transducers. The same lot of transducers also forced delays in six other ESA missions currently in development, including ESA's Solar Orbiter and Cheops. While the transducers were meant to monitor pressure in the entry, descent and landing module's hydrazine fuel tank and its helium pressurization tank, ESA chose to remove them without replacement, as their role was non-critical to the lander's functioning, and only increased the risk to the mission's descent stage. ESA was made aware of the defective components by their manufacturer Moog Inc. of Aurora New York in the summer of 2015, after the company had found that a welding machine defect had made cracks in the transducers, making them at risk of leakage. ExoMars new launch date is expected to take place sometime between 14 and 25 March 2016.[99] The second part of the ExoMars mission will be launched in 2018, and will involve increased Russian participation. That mission is still missing over 175 million euros for development, yet the mission partners might be willing to pay more to avoid schedule delays.[100]

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. A study of Mars' largest known carbonate deposit revealed merely twice the amount of carbon as in the current Mars

[97]"Shining a light on the aurora of Mars."

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

[99]De Selding, Peter B. "Faulty Component that Delayed ExoMars Affects Other ESA Programs." 22 Sept. 2015. SpaceNews 11 Jan. 2016 <http://spacenews.com/faulty-component-that-delayed-exomars-affects-other-esa-programs/>.

[100]De Selding, Peter B. "ExoMars Work at Frenzied Pace To Make 2016 Launch Date." 25 Nov. 2015. SpaceNews 11 Jan. 2016 <http://spacenews.com/exomars-work-at-frenzied-pace-to-make-2016-launch-date/>.

atmosphere, and that the combination of all known carbon reservoirs would not have been enough for Mars to have had a thick atmosphere at the time when rivers flowed on the planet. Rather than being a warm and wet planet at the time of its valley network formation, Mars might have been cold and wet with an atmosphere that had already thinned. There is also uncertainty about how much of that loss of carbon from the atmosphere occurred before the period of valley formation, which NASA hopes its MAVEN orbiter will help to uncover.[101]

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. By 7 February 2015, the MRO had completed 40,000 orbits of Mars, while in its fourth extended mission, and ninth year of returning data; it reached its tenth year on 12 August 2015.[102] The MRO is now investigating seasonal and longer-term changes in Mars' atmosphere, surface and subsurface, including some warm-season flows that are the strongest evidence so far of liquid water on Mars today.[103] From 7 to 21 June 2015, the Mars solar conjunction occurred, wherein the Sun was directly between the Earth and the Red Planet, and blocked any signals from being sent to the MRO and other Mars' spacecraft. As the Sun disrupts radio communications between the planets during the conjunction period, commands to these spacecraft during that time were reduced, though data continued to be collected.[104] The MRO helped to reveal the presence of glass deposits in impact craters on Mars, which could preserve bio signatures and other evidence about whether Mars ever had life at the time of impact; on Earth, similar research has shown organic molecules and plant matter entombed in glass formed by an impact that occurred millions of years ago in Argentina.[105] And on 28 September 2015, data from the MRO's imaging spectrometer provided the strongest evidence yet for NASA to confirm that a briny liquid water flows intermittently on present-day Mars.[106]

[101] "What Happened to Early Mars' Atmosphere? New Study Eliminates One Theory." 2 Sept. 2015. NASA 25 Apr. 2016 <http://mars.jpl.nasa.gov/odyssey/news/whatsnew/index.cfm?FuseAction=ShowNews&NewsID=1852>.

[102] "One Decade after Launch, Mars Orbiter Still Going Strong." 10 Aug. 2015. NASA Jet Propulsion Laboratory 16 May 2016 <http://mars.nasa.gov/mro/news/whatsnew/index.cfm?FuseAction=ShowNews&NewsID=1849>.

[103] "NASA Spacecraft Completes 40,000 Mars Orbits." 9 Feb. 2015. NASA Jet Propulsion Laboratory 16 May 2016 <http://mars.nasa.gov/mro/news/whatsnew/index.cfm?FuseAction=ShowNews&NewsID=1778>.

[104] "Mars Conjunction." 3 June 2015. NASA Jet Propulsion Laboratory 16 May 2016 <http://mars.nasa.gov/mro/news/whatsnew/index.cfm?FuseAction=ShowNews&NewsID=1824>.

[105] "NASA Spacecraft Detects Impact Glass on Surface of Mars." 8 June 2015. NASA Jet Propulsion Laboratory 16 May 2016 <http://mars.nasa.gov/mro/news/whatsnew/index.cfm?FuseAction=ShowNews&NewsID=1827>.

[106] "NASA Confirms Evidence That Liquid Water Flows on Today's Mars." 28 Sept. 2015. NASA Jet Propulsion Laboratory 16 May 2016 <http://mars.nasa.gov/mro/news/whatsnew/index.cfm?FuseAction=ShowNews&NewsID=1858>.

NASA's Mars Science Laboratory (MSL) rover, Curiosity, 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.[107] By 5 February 2015, Curiosity had begun to analyse its second drilled rock sample at Mount Sharp, after using a new low-percussion-level drilling technique more suited for fragile rock. Using its Chemistry and Mineralogy (CheMin) instrument to analyse sample powder from the "Mojave 2" rock target, preliminary results showed a significant amount of jarosite, an oxidized mineral containing iron and sulphur that forms in acidic environments. The powder was also delivered to the internal Sample Analysis at Mars (SAM) suite of instruments for chemical analysis.[108] By 25 February 2015, Curiosity had collected another sample at its third drilling site at the base of Mount Sharp called "Telegraph Peak", finding higher ratios of silica to magnesium and silica to aluminium, which would be expected if there has been some acidic leaching.[109] By 24 March 2015, Curiosity's SAM instrument suite had made its first detection of nitrogen, in the form of nitric oxide, on Mars' surface.[110] By the end of 2015, the abundance of silica found in samples during the year was a contrast to what had been seen in the first 2 years of Curiosity's mission, highlighting considerable variability in minerals within very short distances.[111]

NASA's Mars Atmosphere and Volatile EvolutioN (MAVEN) mission 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'

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

[108] "NASA's Curiosity Analyzing Sample of Martian Mountain." 5 Feb. 2015. NASA Jet Propulsion Laboratory 16 May 2016 <http://mars.nasa.gov/msl/news/whatsnew/index.cfm?FuseAction=ShowNews&NewsID=1777>.

[109] "NASA's Curiosity Mars Rover Drills at 'Telegraph Peak'." 25 Feb. 2015. NASA Jet Propulsion Laboratory 16 May 2016 <http://mars.nasa.gov/msl/news/whatsnew/index.cfm?FuseAction=ShowNews&NewsID=1782>.

[110] "Curiosity Rover Finds Biologically Useful Nitrogen on Mars." 24 Mar. 2015. NASA Jet Propulsion Laboratory 16 May 2016 <http://mars.nasa.gov/msl/news/whatsnew/index.cfm?FuseAction=ShowNews&NewsID=1791>.

[111] "Rocks Rich in Silica Present Puzzles for Mars Rover Team." 17 Dec. 2015. NASA Jet Propulsion Laboratory 16 May 2016 <http://mars.nasa.gov/msl/news/whatsnew/index.cfm?FuseAction=ShowNews&NewsID=1879>.

habitability.[112] 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.[113] From 10 to 18 February 2015, MAVEN conducted its first of five deep-dip manoeuvres designed to gather measurements closer to the lower end of the Martian upper atmosphere. The campaign placed MAVEN at an altitude of 125 km, allowing scientists to make measurements at atmospheric densities more than ten times greater than recorded from its normal altitude of 150 km.[114] From the beginning of 2015, MAVEN had detected an unexplained high-altitude dust cloud using its Langmuir Probe and Waves (LPW) instrument, which has been present throughout MAVEN's operation. MAVEN also detected an aurora spanning Mars' northern hemisphere using its Imaging Ultraviolet Spectrograph (IUVS) instrument, which surprisingly occurred much deeper than on Earth or elsewhere on Mars.[115] By 21 September 2015, MAVEN had been in orbit around Mars for an entire year, carrying out 10 months of observations during MAVEN's primary mission, along with four deep-dip campaigns.[116] And by 5 November 2015, NASA announced that MAVEN measurements indicate that the solar wind strips away gas at a rate of about 100 g (equivalent to roughly 1/4 pound) every second; atmospheric erosion also increases significantly during solar storms, as observed following a series of dramatic solar storms affecting Mars' atmosphere in March 2015.[117]

ISRO's Mars Orbiter Mission (MOM) lifted into space on 5 November 2013, entering Mars' orbit on 24 September 2014.[118] Shortly thereafter, the spacecraft began its science activities fully, activating its five indigenous scientific payloads consisting of the Mars Colour Camera, the Methane Sensor For Mars, the Thermal

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

[113] "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>.

[114] "NASA's MAVEN Spacecraft Completes First Deep Dip Campaign." 19 Feb. 2015. NASA Mars Exploration 17 May 2016 <http://mars.nasa.gov/news/whatsnew/index.cfm?FuseAction=ShowNews&NewsID=1780>.

[115] "NASA Spacecraft Detects Aurora and Mysterious Dust Cloud around Mars." 18 Mar. 2015. NASA Mars Exploration 17 May 2016 <http://mars.nasa.gov/news/whatsnew/index.cfm?FuseAction=ShowNews&NewsID=1789>.

[116] "NASA's MAVEN Celebrates One Year at Mars." 21 Sept. 2015. NASA Mars Exploration 17 May 2016 <http://mars.nasa.gov/news/whatsnew/index.cfm?FuseAction=ShowNews&NewsID=1855>.

[117] "NASA Mission Reveals Speed of Solar Wind Stripping Martian Atmosphere." 5 Nov. 2015. NASA Mars Exploration 17 May 2016 <http://mars.nasa.gov/news/whatsnew/index.cfm?FuseAction=ShowNews&NewsID=1869>.

[118] "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>.

Infrared Imaging Spectrometer, the Mars Exospheric Neutral Composition Analyser, and the Lyman Alpha Photometer.[119] MOM observes 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.[120] On 11 November 2015, ISRO announced the first science results of the mission, noting that science data collected by all instruments of the spacecraft was currently being studied and prepared for publication. The Methane Sensor for Mars (MSM) instrument required further calibration of its measurements, but so far has contributed to other studies including a published paper in which the dust patterns in the high-altitude regions of Valles Marineris were discussed. MOM's Mars Exospheric Neutral Composition Analyser (MENCA) conducted mass spectrometry measurements in the outer layers of the atmosphere and detected a number of species of particles in the range of 1–300 amu (atomic mass unit) and also studied the variation in exospheric composition with altitude. Science data from MOM's Thermal Infrared Spectrometer is being used to map the surface composition of Mars, and has already shown a temperature dip to 10–15° in zones of Martian dust storms. MOM's Lyman Alpha Photometer has made over 80 measurements of Mars' ratio of deuterium to hydrogen to trace atmospheric loss at Mars, and will enable the Lyman Alpha intensity to be mapped as a function of altitude. And lastly, MOM's Mars Colour Camera provided images of the backside of Mars' moon Deimos, inaccessible by the other spacecraft currently orbiting Mars, finding that the anti-Mars side of Deimos is smoother than the near side without any major craters or surface irregularities.[121]

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.[122]

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[119] 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>.

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

[121] "India's Mars Orbiter Mission delivers first Science Results, looks at future Challenges." 11 Nov. 2015. Spaceflight 101 17 May 2016 <http://spaceflight101.com/mom/indias-mars-orbiter-mission-delivers-first-science-results-looks-at-future-challenges/>.

[122] 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/>.

In late January 2015, new research published in the journal Geophysical Research Letters, provided a glimpse of how Saturn's moon Titan would behave if it orbited around the Sun directly. Data collected by Cassini-Huygens magnetometer instrument on 1 December 2013 while Titan was observed beyond the region of Saturn's magnetosphere[123] showed that Titan interacted with the solar wind similar to Mars, if Mars was moved to the distance of Saturn. That finding surprised researchers as they could use the same tools to study both celestial bodies' response to solar wind, rather than having to develop a unique approach for the complex chemistry of the Titan's dense hazy atmosphere.[124] Another study of Titan's surface found that two large depressions holding 'lakes' of liquid methane and ethane likely formed over 50 million years by raining hydrocarbons that slowly eroded the dissolvable minerals lining the pools, in a process that's similar to the creation of caves and sinkholes on Earth.[125] And by 11 November 2015, new observations of Titan's South Pole made by Cassini-Huygens' Composite Infrared Spectrometer (CIRS) instrument showed the substantial growth of an ice cloud first seen in 2012. As Titan enters its 7.5 year winter season, the build-up of these southern clouds indicates that the direction of Titan's global circulation of gases is changing.[126]

By March 2015, Cassini-Huygens mission data had provided scientists with the first clear evidence that Saturn's icy moon Enceladus showed signs of present-day hydrothermal activity that may resemble that seen in the deep oceans on Earth, i.e. where hot water from the interior meets the relatively cold water at the ocean bottom.[127] Research using data from the Cassini-Huygens mission also revealed that a global ocean lies beneath Enceladus' icy crust, as researchers found a tiny, but measurable wobble as it orbits Saturn; that wobble would have been dampened significantly if the moon's surface and core were rigidly connected.[128] By October 2015, Cassini-Huygens had made two close flybys of Enceladus, along with a final close flyby in mid-December. The first of those flybys began on 14 October 2015, for a close-up look at the North Pole region of Enceladus to find signs of ancient geological activity similar to the geyser-spouting, tiger-stripe fractures in the moon's South Pole region.[129] On 28 October 2015, Cassini-Huygens made its deepest-ever dive through Enceladus' plume of ice spray, reaching an altitude of

[123]Titan spends about 95 % of the time within Saturn's magnetosphere.

[124]"Cassini Catches Titan Naked in the Solar Wind." 28 Jan. 2015. NASA Jet Propulsion Laboratory 17 May 2016 <https://saturn.jpl.nasa.gov/news/2528/>.

[125]"The Mysterious 'Lakes' on Saturn's Moon Titan." 19 June 2015. NASA Jet Propulsion Laboratory 17 May 2016 <https://saturn.jpl.nasa.gov/news/2796/>.

[126]"NASA's Cassini Finds Monstrous Ice Cloud in Titan's South Polar Region." 11 Nov. 2015. NASA Jet Propulsion Laboratory 17 May 2016 <https://saturn.jpl.nasa.gov/news/2800/>.

[127]"Spacecraft Data Suggest Saturn Moon's Ocean May Harbor Hydrothermal Activity." 11 Mar. 2015. NASA Jet Propulsion Laboratory 17 May 2016 <https://saturn.jpl.nasa.gov/news/2529/>.

[128]"Cassini Finds Global Ocean in Saturn's Moon Enceladus." 15 Sept. 2015. NASA Jet Propulsion Laboratory 17 May 2016 <https://saturn.jpl.nasa.gov/news/2542/>.

[129]"Cassini Begins Series of Flybys with Close-up of Saturn Moon Enceladus." 13 Oct. 2015. NASA Jet Propulsion Laboratory 17 May 2016 <https://saturn.jpl.nasa.gov/news/2543/>.

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