U.S. House of Representatives
Committee on Science, Space, and Technology

Exploration of the Solar System: From Mercury to Pluto and Beyond

HEARING CHARTER

Tuesday, July 28, 2015
10:00 a.m.
2318 Rayburn House Office Building

Purpose

At 10:00 a.m. on Tuesday, July 28, 2015, the Science, Space, and Technology Committee will hold a hearing titled *Exploration of the Solar System: From Mercury to Pluto and Beyond.* The purpose of this hearing is to review recent NASA achievements in exploring our solar system, including the exploration of Pluto and the asteroid Ceres, as well as assess future NASA missions under development, including a flagship mission to conduct a detailed survey of Jupiter's moon Europa.

Witnesses

- **Dr. John Grunsfeld,** Associate Administrator, Science Mission Directorate, NASA
- **Dr. Alan Stern,** Principal Investigator, New Horizons Mission, Southwest Research Institute
- **Dr. Christopher Russell**, Principal Investigator, Dawn Mission, and Professor of Geophysics and Planetary Physics, University of California Los Angeles
- **Dr. Robert Pappalardo,** Study Scientist, Europa Mission Concept, Jet Propulsion Laboratory, NASA
- **Dr. Robert Braun,** David and Andrew Lewis Professor of Space Technology, Georgia Institute of Technology

Background

Budget for NASA's Science Mission Directorate[1]

	Actual	Enacted	Request	FY15 Vs FY16	Appropriations		Authorizations
					House	Senate	H.R. 2039 (Sec. 101)
Budget Authority ($ in millions)	FY14	FY15	FY16		FY16	FY16	FY16
Science	5,148	5,245	5,289	44	5,238	5,295	4,952
Earth Science	1,825	1,773	1,947	174	1,683	1,932	1,450
Planetary Science	1,346	1,438	1,361	(77)	1,557	1,321	1,500
Astrophysics	678	685	709	24	736	731	731
James Webb Space Telescope	658	645	620	(25)	620	620	620
Heliophysics	641	662	651	(11)	642	650	651

[1] Congressional Research Service, *NASA Appropriations and Authorizations a Fact Sheet* (22 June 2015) <https://www.fas.org/sgp/crs/space/R43419.pdf >

The Science Mission Directorate (SMD) conducts scientific exploration enabled by the observatories and probes that view Earth from space, observe and visit other bodies in the solar system, and gaze out into the galaxy and beyond.[2] SMD has four divisions; Astrophysics, Earth Science, Heliophysics, and Planetary Science. NASA is requesting $5.288 billion for SMD in FY16, an increase of approximately $43.9 million (0.8 percent) above the FY15 enacted level.

The Planetary Science Division is responsible for monitoring and analyzing data collected from NASA missions exploring the solar system in the search to ascertain the content, origin, the evolution of the solar system and potential for life on other worlds as well as the search for potentially hazardous Near Earth Objects. The budget for the Planetary Science division has decreased from $1.485 billion in the FY11 request to $1.361 billion in the FY16 request.[3] The Committee approved a two-year authorization of $1.5 billion in FY16 and FY17 for the Planetary Science division in H.R. 2039, the National Aeronautics and Space Administration Authorization Act of 2016 and 2017.[4] The House Representatives passed an FY16 appropriation for NASA's Planetary Science funding of $1.557 billion.[5] The Senate Committee on Appropriations reported $1.321 billion for NASA's Planetary Science division.[6]

NASA's FY16 budget request includes a line item of $30 million to support formulation of a new mission to explore Jupiter's moon, Europa, one of Jupiter's moons that is covered with frozen water. Since water is one of the fundamental ingredients for life on Earth, Europa holds promise that life may exist beyond Earth. Congress continues to demonstrate support for a Europa mission, one of the priorities from the National Academies of Science decadal survey for planetary science.[7]

New Horizons Mission

New Horizons is an interplanetary space probe that was launched as part of NASA's New Frontiers program to flyby at close range and image Pluto, gathering information about its atmosphere and surface features.[8] This is the first mission to examine Pluto and its moons Charon, Nix, Hydra, Kerberos, and Styx.

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[2] National Aeronautics and Space Administration FY16 Budget Estimates – Science Mission Directorate (p. SCMD-4) <http://www.nasa.gov/sites/default/files/files/NASA_FY_2016_Budget_Estimates.pdf >

[3] Congressional Research Service, *NASA Appropriations and Authorizations a Fact Sheet* (22 June 2015) < https://www.fas.org/sgp/crs/space/R43419.pdf >

[4] H.R. 2039, *NASA Authorization Act of 2016 and 2017* < https://www.congress.gov/bill/114th-congress/house-bill/2039/text>

[5] H.R. 2578, *Commerce, Justice, Science and Related Agencies Appropriations Act, 2016* < https://www.fas.org/sgp/crs/space/R43419.pdf >

[6] Congressional Research Service, *NASA Appropriations and Authorizations a Fact Sheet* (22 June 2015) < https://www.fas.org/sgp/crs/space/R43419.pdf >

[7] National Research Council. *Vision and Voyages for Planetary Science in the Decade 2013-2022*. p. 268, Appendix C, p. 345. Washington, DC: The National Academies Press, 2011. <http://www.nap.edu/catalog/13117/vision-and-voyages-for-planetary-science-in-the-decade-2013-2022>

[8] New Horizons was the first New Frontiers program selected. Others include Juno (a mission to Jupiter) and Osiris-Rex (a mission to return an asteroid sample to Earth). All New Frontiers programs are principal-investigator led mission that are cost capped at approximately $1 Billion.

New Horizons was launched in 2006, and flew 12,500 kilometers/7,800 miles above Pluto on July 14th. The spacecraft is already to transmitting data recorded during the flyby. It will take 16 months for all data to be transmitted.[9] The total cost of New Horizons is approximately $700 million.[10]

New Horizons carries seven scientific instruments to study the surfaces of Pluto, its moons, and any Kuiper Belt objects that New Horizons encounters: a visible and infrared imager/spectrometer (RALPH), an ultraviolet imaging spectrometer (ALICE), a radio science experiment for studying atmospheres (REX), a telescopic camera (LORRI), a solar wind and plasma spectrometer (SWAP), an energetic particle spectrometer (PEPSSI) and a space dust counter (SDC).[11]

New Horizons scientific objectives are ranked into three categories, called Group 1, Group 2, and Group 3.[12]

- Group 1 objectives: (required)
  - Characterize the global geology and morphology of Pluto and Charon
  - Map chemical compositions of Pluto and Charon surfaces
  - Characterize the neutral (non-ionized) atmosphere of Pluto and its escape rate
- Group 2 objectives: (expected)
  - Characterize the time variability of Pluto's surface and atmosphere
  - Image select Pluto and Charon areas in stereo
  - Map the terminators (day/night border) of Pluto and Charon with high resolution
  - Map the chemical compositions of select Pluto and Charon areas with high resolution
  - Characterize Pluto's ionosphere (upper layer of the atmosphere) and its interaction with the solar wind
  - Search for neutral species such as molecular hydrogen, hydrocarbons, hydrogen cyanide and other nitriles in the atmosphere
  - Search for any Charon atmosphere
  - Determine bolometric Bond albedos for Pluto and Charon
  - Map surface temperatures of Pluto and Charon
  - Map any additional surfaces of outermost moons: Nix, Hydra, Kerberos, and Styx
- Group 3 objectives: (desired)
  - Characterize the energetic particle environment at Pluto and Charon
  - Refine bulk parameters (radii, masses) and orbits of Pluto and Charon
  - Search for additional moons and any rings

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[9] Greg Rienzi, *How exactly does New Horizons send all that data back from Pluto?* John Hopkins University Hub <http://hub.jhu.edu/2015/07/17/new-horizons-data-transmission>.

[10] NASA New Horizons website: <http://solarsystem.nasa.gov/missions/profile.cfm?MCode=PKB&Display=ReadMore>

[11] NASA New Horizons website: <http://solarsystem.nasa.gov/missions/profile.cfm?Sort=Target&Target=Dwarf&MCode=PKB&Display=ReadMore>

[12] Harold A. Weaver and S. Alan Stern, *New Horizons: NASA's Pluto-Kuiper Belt Mission* at <http://web.gps.caltech.edu/~mbrown/out/kbbook/Chapters/Weaver_NewHorizons.pdf>

A potential extended mission could include traveling to the Kuiper Belt to study at least one Kuiper Belt object.

Current Planetary Missions[13]

In addition to New Horizons, Planetary Science missions currently in operation and/or development include, in alphabetical order:

Cassini-Huygens (Cassini Solstice Mission) – Cassini-Huygens was launched in 1997 and entered orbit around Saturn in 2004. Cassini is an orbiting spacecraft and Huygens is an atmospheric entry probe that landed on Saturn's moon Titan in 2005. The Cassini mission continues to conduct numerous fly-bys of Saturn's moons, including Enceladus and Titan, which may harbor environments conducive to the existence of life. Cassini is currently in its second mission extension called the Cassini Solstice Mission, examining the rings of Saturn and high-latitude mapping of Titan and Saturn. The total cost of the Cassini-Huygens mission is about $3.26 billion. The U.S. contributed $ 2.6 billion, the European Space Agency $500 million and the Italian Space Agency $160 million.[14]

Dawn – The Dawn mission's goal is to characterize the conditions and processes of the solar system's earliest eon by investigating in detail two of the largest proto-planets remaining intact since their formation. After launch in 2007, it orbited its first destination, the asteroid Vesta, in 2011, and reached its final destination the dwarf planet Ceres last March. The total cost of the Dawn mission (not including launch vehicle) is approximately $357.5 million.[15]

Europa –NASA recently initiated a mission to study Jupiter's icy moon Europa. The mission would send a solar-powered spacecraft into a long, looping orbit around the gas giant Jupiter to perform repeated close flybys of Europa over a three-year period. Last May, NASA selected nine science instruments for a mission to Jupiter's moon Europa, to investigate whether the mysterious icy moon could harbor conditions suitable for life.[16]

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[13] Please note that the cost numbers provided in this section are designed to give an accurate understanding of program costs, but may not include mission extension costs or other costs that have been incurred since the mission launched. Also, the cost numbers cited are not recalculated to account for current value of money. For example, the cost to a mission cited from a press kit in 2005 will not be recalculated into 2015 dollars.

[14] NASA Cassini website: <http://saturn.jpl.nasa.gov/faq/FAQMission/>

[15] NASA Dawn website <http://solarsystem.nasa.gov/missions/profile.cfm?InFlight=1&MCode=Dawn&Display=ReadMore>

[16] The instruments NASA selected are: Plasma Instrument for Magnetic Sounding (PIMS) -- principal investigator Dr. Joseph Westlake of Johns Hopkins Applied Physics Laboratory (APL), Laurel, Maryland; Interior Characterization of Europa using Magnetometry (ICEMAG) -- principal investigator Dr. Carol Raymond of NASA's Jet Propulsion Laboratory (JPL), Pasadena, California; Mapping Imaging Spectrometer for Europa (MISE) -- principal investigator Dr. Diana Blaney of JPL; Europa Imaging System (EIS) -- principal investigator Dr. Elizabeth Turtle of APL; Radar for Europa Assessment and Sounding: Ocean to Near-surface (REASON) -- principal investigator Dr. Donald Blankenship of the University of Texas, Austin; Europa Thermal Emission Imaging System (E-THEMIS) -- principal investigator Dr. Philip Christensen of Arizona State University, Tempe; MAss SPectrometer for Planetary EXploration/Europa (MASPEX) -- principal investigator Dr. Jack (Hunter) Waite of the Southwest Research Institute (SwRI), San Antonio; Ultraviolet Spectrograph/Europa (UVS) -- principal investigator Dr. Kurt Retherford of SwRI; SUrface Dust Mass Analyzer (SUDA) -- principal investigator Dr. Sascha Kempf of the University of Colorado, Boulder.

There is no firm cost estimate yet for the Europa mission, but it is likely to be a "flagship" class mission for NASA over $1 billion.

InSight (Interior Exploration using Seismic Investigations, Geodesy and Heat Transport) – InSight is a Mars lander mission, and is expected to launch in spring 2016. It will study the interior of Mars to understand how rocky planets (like Earth and Mars) were formed, and investigate possible tectonic activity. The mission (not including launch vehicle) is cost-capped at $425 million.[17]

Juno – Juno will orbit over Jupiter's poles to study Jupiter's composition, gravity field, magnetic field, and polar magnetosphere and search for clues about how the planet formed, including whether it has a rocky core, the amount of water present within the deep atmosphere, and how its mass is distributed. It will be the first solar-powered spacecraft to orbit Jupiter. Juno launched in 2011 and is scheduled to arrive at Jupiter in 2016. Total cost is approximately $1.1 billion.[18]

JUICE (Jupiter Icy Moons Explorer) – In a partnership with the European Space Agency (ESA), this mission will explore Jupiter and its moon Ganymede. NASA's contribution will consist of one U.S.-led science instrument and hardware for two European instruments to fly on ESA's Jupiter Icy Moons Explorer (JUICE) mission. It is expected to launch in 2022 and reach Jupiter in 2030. NASA's total contribution to the JUICE mission is $100 million.[19]

LRO (Lunar Reconnaissance Orbiter) – LRO orbits the Moon, and was launched in 2009 as a precursor to future human and robotic missions to the lunar surface. One of its primary purposes was to map potential landing sites for future human Moon exploration, but it also has provided more information about the Moon's geological features and the potential presence of ice and water. LRO is currently active on an extended mission. The total cost is approximately $500 million.[20]

MAVEN (Mars Atmosphere & Volatile EvolutioN) – MAVEN is part of NASA's Mars Scout program to study Mars's upper atmosphere, ionosphere and interactions with the sun and solar wind. MAVEN reached Martian orbit in 2014. Mission goals include determining how the atmosphere of Mars and water, presumed to have once been substantial, were lost over time. The total cost is approximately $671 million.[21]

Opportunity Rover (Mars Exploration Rover/MER) – Opportunity is one of two Mars Exploration Rovers (the other being named Spirit). landed on Mars in 2004 and continues to move, gather scientific observations (including evidence of Mars' habitable past), and

[17] NASA InSight website: <http://www.nasa.gov/mission_pages/mars/news/mars20120820.html>
[18] NASA Juno website <https://solarsystem.nasa.gov/missions/profile.cfm?InFlight=1&MCode=Juno&Display=ReadMore>
[19] NASA JUICE website: <http://www.nasa.gov/home/hqnews/2013/feb/HQ_13-060_JUICE_Instruments.html>
[20] NASA LRO website: <https://solarsystem.nasa.gov/missions/profile.cfm?InFlight=1&MCode=LRO&Display=ReadMore >
[21] NASA Maven website: <http://mars.nasa.gov/files/resources/MAVEN_PressKit_Final.pdf >

report back to Earth for over 4075 sols,[22] 40 times longer than originally planned. The total cost for the Mars Exploration Rover program is approximately $820 million.[23]

Mars Express – Mars Express is a European Space Agency (ESA) mission, launched in 2003 and successfully orbiting Mars in 2004. The U.S. contributed components for the Mars Advanced Radar for Subsurface and Ionospheric Sounding (MARSIS) and the Analyzer of Space Plasmas and EneRgetic AtomS (ASPERAS). These instruments examine the ionosphere and atmosphere of Mars to determine the potential for life on the planet. The mission is operational. Mars Express cost approximately $300 million euros, including scientific payloads and launch.[24]

Mars Odyssey 2001 – Measurements made by the orbiting spacecraft Mars Odyssey have enabled scientists to create a mineralogical map that provides future missions with target areas in which to search for the potential existence of water, microbial life, and possible landing sites for human missions to the surface of Mars. It is still operating on an extended mission. Total cost is approximately $297 million.[25]

MOMA (Mars Organic Molecule Analyzer) – This instrument is the U.S. contribution to the ESA ExoMars program (Exobiology on Mars). It is the astrobiology instrument on Europe's 2018 Mars rover. ExoMars is expected to cost approximately $1.2 billion euros.[26]

MRO (Mars Reconnaissance Orbiter) – Launched in 2005, MRO has a powerful camera with which it captures detailed pictures of Mars' geology. The pictures are being used to determine possible future landing sites. MRO has provided photographic evidence of the existence of liquid on Mars. It also serves as a communication relay between Mars and Earth for the Mars rovers. Total cost is approximately $720 million.[27]

Mars Rover 2020 – This mission is part of NASA's Mars Exploration Program, scheduled to be launched in 2020. The rover will collect core samples for future return to Earth, conduct fine-scale imaging, determine mineral and chemical compositions, and determine the existence of past or present organic material. It will also conduct tests to determine if the right ingredients exist on Mars for production of oxygen for human use. Preliminary estimate of project life cycle cost is $2.14-$2.35 billion.[28]

Curiosity Rover (Mars Science Laboratory Curiosity Rover) – Curiosity is NASA's largest rover on Mars and is collecting soil and rock samples and analyzing them to determine if conditions have existed to support microbial life. It has already found

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[22] The term sol is used by planetary astronomers to refer to the duration of a solar day on Mars.
[23] NASA MER website: <https://solarsystem.nasa.gov/missions/profile.cfm?InFlight=1&MCode=MER&Display=ReadMore >
[24] ESA Mars Express press kit <http://www.esa.int/esaSC/SEMTV8374OD_0_spk.html >
[25] NASA Odyssey press kit <http://www.jpl.nasa.gov/news/press_kits/odysseyarrival.pdf >
[26] Stephen Clark, *Facing Funding Gap, ExoMars Rover is on Schedule for Now*, Spaceflightnow.com <http://www.spaceflightnow.com/news/n1403/03exomars/#.Va_M0PlVhBc >
[27] NASA MRO press kit < http://www.nasa.gov/pdf/124378main_mro-launch-Aug051.pdf >
[28] GAO, *NASA Assessments of Selected Large-Scale Projects* (GAO-15-320SP) <http://www.gao.gov/products/GAO-14-338SP>

evidence that water flowed on the Martian surface that could have supported microbial life. The total cost is approximately $2.5 billion.[29]

MESSENGER (MErcury Surface, Space ENvironment, GEochemistry, and Ranging) – MESSENGER was a robotic NASA spacecraft which orbited the planet Mercury between 2011 and 2015. The scientific objectives of the mission were to characterize the chemical composition of Mercury's surface, to study the planet's geological history, to elucidate the nature of the global magnetic field, to determine the size and state of the core, to determine the volatile inventory at the poles, and to study the nature of Mercury's exosphere. Operations are complete but scientists are still analyzing data from the mission. Total cost is approximately $460 million.[30]

NEOWISE (Near Earth Object Wide-field Infrared Survey Explorer) - NEOWISE is a NASA infrared-wavelength astronomical space telescope launched in December 2009, and placed in hibernation in February 2011 when its transmitter turned off. It was re-activated in 2013 on a new three-year mission to search for potentially hazardous near-Earth objects. Total cost is approximately $300 million.[31]

OSIRIS-REx (Origins-Spectral Interpretation-Resource Identification-Security-Regolith Explorer) –The spacecraft is scheduled to launch in 2016 and will examine the asteroid Bennu and return a physical sample of the asteroid to Earth. It is the third planetary science mission selected in the New Frontiers Program, after Juno and New Horizons. The development cost of Osiris-Rex is estimated at $709.7 million.[32]

Rosetta – Rosetta is a European Space Agency (ESA) led mission that rendezvoused and landed *Philae* on Comet Churymov-Gerasimenko (C-CG) in 2014. NASA contributed three instruments to Rosetta. After escorting comet C-CG past its perihelion (closest point to the Sun), Rosetta will terminate its mission. The total cost is close to $1.4 billion Euros.[33]

Planetary Decadal Survey Recommendations

The most recent decadal survey, Visions and Voyages for Planetary Science in the Decade 2013- 2022 was issued in March 2011 ("2013 Planetary Science Decadal Survey"). Requested by NASA, and managed and written by the National Academy of Sciences, the report develops a comprehensive strategy for U.S. planetary science in the coming decade. Per the report, the recommended program "will achieve long-standing scientific goals with a suite of new missions across the solar system. It will provide fundamental new scientific knowledge, engage a broad segment of the planetary science community, and have wide appeal for the general public whose support enables the

[29] NASA Curiosity website <http://solarsystem.nasa.gov/missions/profile.cfm?InFlight=1&MCode=MarsSciLab&Display=ReadMore>
[30] NASA Messenger website <http://solarsystem.nasa.gov/missions/profile.cfm?MCode=MESSENGER&Display=ReadMore>
[31] NASA NEOWISE website <https://solarsystem.nasa.gov/missions/profile.cfm?InFlight=1&MCode=WISE&Display=ReadMore>
[32] GAO, *NASA Assessments of Selected Large-Scale Projects* (GAO-15-320SP)
[33] ESA Rosetta website <http://www.esa.int/Our_Activities/Space_Science/Rosetta/Frequently_asked_questions >

program."[34] The 2013 Planetary Science Decadal Survey committee utilized four main criteria to measure proposed missions as a means of selecting and prioritizing future missions. First and foremost was the ability to provide high science return per dollar. Programmatic balance across mission targets throughout the solar system as well as the appropriate mix of small, medium and large missions was the second criteria. The other two criteria were technological readiness and the availability of trajectory opportunities within the timeframe discussed.

Discovery-class Planetary Mission Announcement of Opportunity

Discovery-class missions in the Planetary Science division are cost-capped, competitively awarded, smaller and less-expensive missions that explore the Solar System. Missions are proposed and led by a senior scientist who serves as the Principal Investigator (PI) for the mission. In selecting Discovery missions, consideration is given to the priorities outlined in the latest planetary science decadal survey issued by the National Academies of Science.[35] The 2013 Planetary Science Decadal Survey does not make specific recommendations on the small Discovery program missions. It does register its continued support for these missions as a valuable asset to the overall program and recommends that it continue at its current level capped at $500 million (FY2015) and a cadence of 24 months for selections.

Last November, NASA released their Discovery-class Planetary Mission Announcement of Opportunity (AO). The deadline for submitting proposals was February 2015. The latest AO for Discovery-class missions is the thirteenth announcement. The cost cap for Discovery missions is $450 million, not including the cost of the launch vehicle. The mission must be ready for launch no later than December 31, 2021.

To date, NASA has not announced a selected mission for the 2014 Discovery-class Planetary Mission AO.

New Frontiers-class Planetary Mission Announcement of Opportunity

Medium missions, known as New Frontiers, are capped at $1 billion (FY2015) per mission (excluding launch vehicle costs) with a goal of selecting two such missions in the decade. Based on their science value and projected costs, the 2013 Planetary Science Decadal Survey committee recommended NASA select two additional New Frontiers missions in the decade 2013-2022 (referred to as New Frontiers Mission 4 and New Frontiers Mission 5). "To achieve an appropriate balance among small, medium, and large missions, NASA should select two New Frontiers missions in the decade 2013-2022."[36] The report identifies five candidate missions and two alternates for which

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[34] *Vision and Voyages for Planetary Science in the Decade 2013-2022*, National Academies of Science, Washington, DC, March 2011. ES-1 <http://www.nap.edu/catalog/13117/vision-and-voyages-for-planetary-science-in-the-decade-2013-2022>

[35] *Visions and Voyages for Planetary Science in the Decade 2013-2022*, National Academies of Science, Washington, DC, March 2011. <http://www.nap.edu/catalog/13117/vision-and-voyages-for-planetary-science-in-the-decade-2013-2022>

[36] *Visions and Voyages for Planetary Science in the Decade 2013-2022*, National Academies of Science, Washington, DC, March 2011. Pg. 15. <http://www.nap.edu/catalog/13117/vision-and-voyages-for-planetary-science-in-the-decade-2013-2022>

NASA should select based on competitive peer review. Candidate missions include Comet Surface Sample Return, Lunar South Pole-Aitken Basin Sample Return, Saturn Probe, Trojan Tour and Rendezvous and Venus In Situ Explorer. The alternates would be Io Observer and Lunar Geophysical Network.

NASA's FY16 budget requests funding for a 2016 New Frontiers AO. NASA plans to announce the next opportunity by the end of FY 2016.[37]

Flagship Missions

Flagship missions are the largest and most expensive of NASA's solar system exploration programs, costing more than $1 billion each. The 2013 Planetary Science Decadal Survey identified five candidate flagship missions for the decade 2013-2033. In alphabetical order, they are as follows:[38]

- **Enceladus Orbiter:** This mission would investigate the saturnian satellite's cryovolcanic activity, habitability, internal structure, chemistry, geology, and interaction with other bodies of the Saturn system.
- **Jupiter Europa Orbiter (JEO):** This mission would characterize Europa's ocean interior, ice shell, chemistry and composition, and the geology of prospective landing sites.
- **Mars Astrobiology Explorer-Cacher (MAX-C):** This mission is the first of the three components of the Mars Sample Return campaign. It is responsible for characterizing a landing site selected for high science potential, and for collecting, documenting, and packaging samples for return to Earth.
- **Uranus Orbiter and Probe:** This mission's spacecraft would deploy a small probe into the atmosphere of Uranus to make in site measurements of noble gas abundance and isotopic ratios and would then enter orbit, making remote sensing measurements of the planet's atmosphere, interior, magnetic field, and rings, as well as multiple flybys of the larger uranian satellites.
- **Venus Climate Mission:** This mission is designed to address science objectives concerning the Venus atmosphere, including carbon-dioxide greenhouse effects, dynamics and variability, surface-atmosphere exchange, and origin. The mission architecture includes a carrier spacecraft, a gondola and balloon system, a mini-probe, and two dropsondes.

The survey concludes that the top-priority large flagship mission for the coming decade would be MAX-C, which will begin the NASA-ESA Sample Return campaign – one that would not be completed into the decade beyond 2022. However, MAX-C, a joint ESA-NASA mission, was cancelled. In its place, NASA is developing MARS 2020, a rover that will conduct in-situ scientific studies and core, collect, and cache (store) geological samples for a future yet-to-be determined sample return mission to Earth.[39] The second

[37] NASA FY16 Budget Request. Pg. PS-32 <http://www.nasa.gov/sites/default/files/files/NASA_FY_2016_Budget_Estimates.pdf >

[38] *Vision and Voyages for Planetary Science in the Decade 2013-2022*, National Academies of Science, Washington, DC, March 2011. Pg. 16-17 <http://www.nap.edu/catalog/13117/vision-and-voyages-for-planetary-science-in-the-decade-2013-2022>

[39] NASA MARS 2020 website <http://mars.jpl.nasa.gov/mars2020/mission/overview/>

highest priority Flagship mission for the decade 2013-2022 is the Jupiter Europa Orbiter (JEO).