Opportunities for NASA and the New Administration

Near-term recommendations for the U.S. space program

prepared for the new President by The Planetary Society

Cover: In the early hours of August 6th, 2012, crowds spontaneously gathered in New York City's Times Square to watch NASA's Curiosity rover attempt to land safely on Mars. Curiosity's landing was successful and continues to explore the Red Planet in 2017. Photo credit: Navid Baraty. Used with permission.

The Planetary Society is the world's largest independent non-profit space organization, with more than 50,000 dues-paying members in 100 countries worldwide. The Society is primarily funded by these members—not by government or industry. They support a nonpartisan organization devoted to promoting space science and exploration to the public.

The Society was founded in 1980 by visionary scientist Dr. Carl Sagan, then-Director of NASA's Jet Propulsion Laboratory (JPL) Dr. Bruce Murray, and JPL engineer Dr. Lou Friedman.

Bill Nye, leading science educator and advocate, is CEO of The Planetary Society. He serves a growing and diverse Board of Directors that includes top scientists, business leaders, space policy experts, educators, and entertainers.

More information is available at *planetary.org*.

Introduction

Decisions made by the new Administration have the potential to define NASA's future for generations to come. These decisions can define the direction of humanity's exploration of the cosmos, potentially lead to the discovery of life elsewhere in the universe, and return invaluable scientific data of our origins and future direction of our planet and our species.

The Planetary Society provides five recommendations for the new Administration to pursue in its space policy agenda, recommendations that will provide a stable path to success for NASA and the larger space industry. These are:

- Maintain the exploration of Mars as the organizing principle for NASA's human spaceflight program (page 3)
- Direct NASA to plan an executable, affordable path for sending humans to Mars orbit by 2033 (page 5)
- Expand NASA's highly successful science portfolio (page 7)
- Initiate annual five percent increases to NASA's budget for five years (page 9)
- Continue to grow and support the commercial space industry (page 11)

In addition, The Planetary Society provides perspective on how NASA can be considered as a tool to achieve national priorities in modern workforce development, encourage STEM engagement, and engage domestic and international allies (page 12). A brief summary of major programs in human spaceflight and science is also provided (page 14).

These recommendations, at their core, endorse the goal to send humans to Mars and to increase investment in NASA's scientific programs. While refinements and reprioritizations of certain elements are required—and a clear strategic framework to achieve the Mars goal is a necessity—the Society recommends against another major reset of the space program's direction.

A high-level integrated strategy to explore Mars and to search for life within our solar system and beyond is proposed in Figure 1. Many of these missions must be started or sustained over the next four years in order to succeed in a near-term timeframe. Decisions made by the new Administration will determine whether the next decade will see Europa and Mars explored for life, humans develop deep-space endurance capability for Mars, and the direct imaging of exoplanets. These decisions, made early on in this new Administration, could impact its legacy for generations.

NASA is the best brand the United States government has. It represents the nation's spirit of adventure, demonstrates our technological capability, and engages our citizens and the world through peaceful exploration. The new Administration has the opportunity to provide the vision and stability needed to set it on an historic path of discovery.

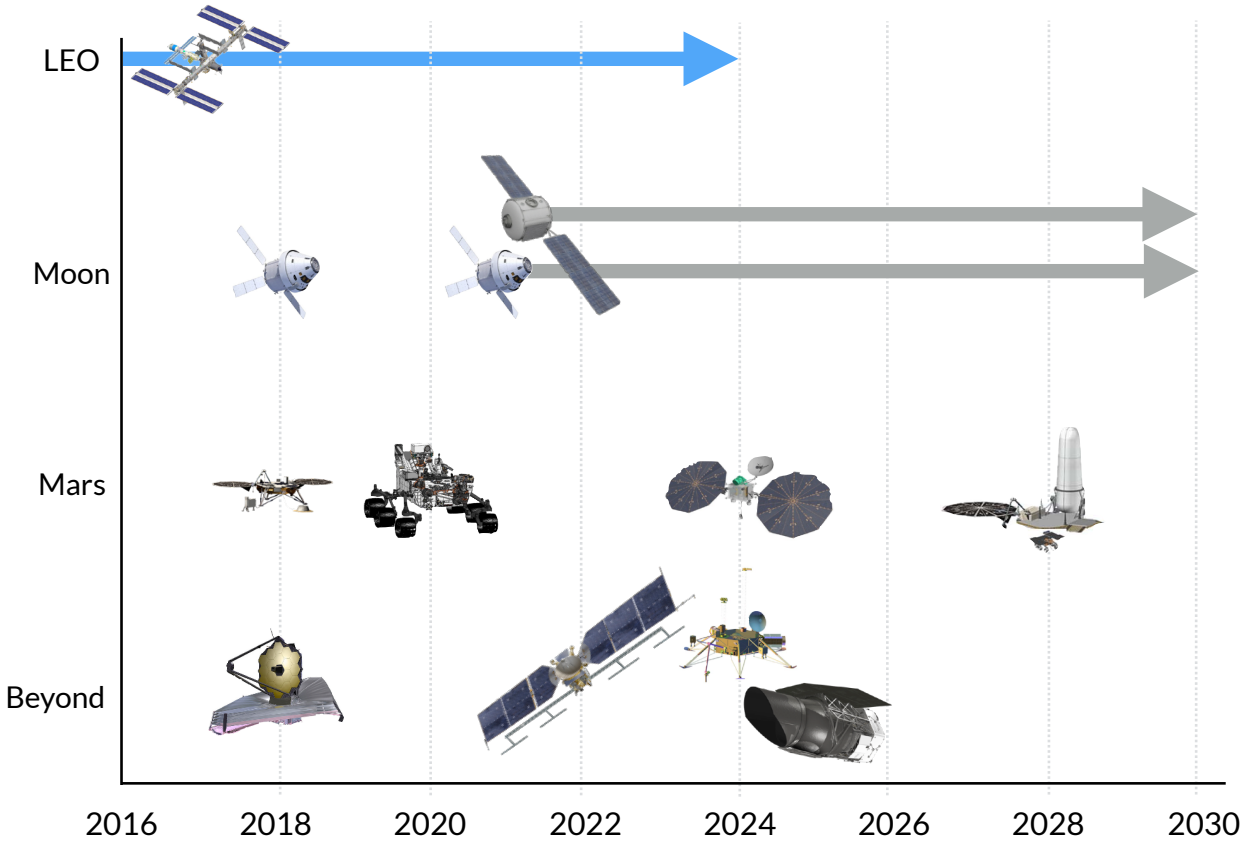

Figure 1. *A high-level overview of major NASA missions relevant to the new Administration with a focus on paving the way to send humans to Mars (via human missions near the Moon and robotic precursors to Mars) and searching for life beyond Earth (missions to Europa, Mars, and highly-capable space telescopes). These missions and schedules are consistent with recommendations made by NASA, the National Academy of Sciences, the NASA Advisory Council, The Planetary Society's Humans Orbiting Mars report, and Congressional directives.* ***LEO****: the ISS through 2024;* ***Moon****: Uncrewed Orion, 2018; Crewed Orion places Deep Space Habitat in cis-lunar space, 2021; ongoing crew visits to habitat in preparation for Mars missions;* ***Mars****: InSight, 2018; Mars 2020, 2020; Mars science/telecom orbiter, 2024; Mars Sample Return, late 2020s;* ***Beyond****: James Webb Space Telescope, 2018; Europa Multi-Flyby, 2022; Europa Lander, 2024; WFIRST, 2025.*

Figure 2. *Curiosity took the images for this panoramic view of one of the Murray buttes with its left Mastcam on sol 1419 (August 3, 2016). Seán Doran added a figure of an astronaut into a panorama assembled by Thomas Appéré in order to provide a sense of scale. Credit: NASA / JPL / MSSS / Thomas Appéré / Seán Doran.*

Recommendation: Maintain the exploration of Mars as the organizing principle for NASA's human spaceflight program

The Planetary Society recommends that the new President continue the focus of sending humans to Mars as the ultimate goal of NASA's human spaceflight program. This goal is widely supported by members of Congress, major industry partners, the past two presidential administrations, and by multiple reports from the National Academies of Sciences, Engineering, and Medicine. While there are compelling arguments in support of human exploration of asteroids and the surface of the Moon, NASA is working with constrained resources. In such conditions, NASA cannot afford a broad focus for its human spaceflight program. It should instead limit development of new hardware and execute only the missions deemed essential to the Mars goal.

A habitat to sustain human life for long durations in deep space is on the critical path of any successful exploration of Mars. In fiscal year (FY) 2016, Congress directed NASA to begin work on a deep space habitat for use near the Moon.[1] NASA has engaged six industry partners in early development studies, and requested a formal new start for this program in the FY 2017 budget request.[2]

A cis-lunar (near the Moon) habitat provides critical opportunities to validate life-support, communications, and other important systems beyond Earth orbit, but provides easy Earth-return capability. It also provides a destination and focus for the near-term work of NASA astronauts to test long-duration spaceflight beyond low-Earth orbit and a clear

[1] 114th Congress of the United States of America, *Consolidated Appropriations Act of 2016 (H.R. 2029)*. December 18, 2015. Available at: https://www.congress.gov/bill/114th-congress/house-bill/2029/text

[2] National Aeronautics and Space Administration, *FY 2016 Budget Proposal*. Washington, D.C.: Government Printing Office, February 2, 2016. Available at: http://www.nasa.gov/feature/fy-2016-budget-proposal

mission for the Space Launch System rocket and Orion crew capsule throughout the 2020s.

Additionally, a cis-lunar habitat allows NASA to provide logistical, communications, and launch support for commercial and international partners who have ambitions to reach the lunar surface, as well as for potential future lunar science missions by NASA itself. While NASA focuses on a lean, cost-efficient architecture to send humans to Mars, it can, at the same time, enable complimentary leaps in exploration with smart infrastructure investments that can spur economic development of lunar resources, scientific exploration, and crewed missions led by NASA's partners in exploration.

Solar electric propulsion (SEP)—a highly efficient means of moving large amounts of material in space—is a valuable technology. As the Administration assumes office in 2017, NASA is planning to use SEP to retrieve a boulder from the surface of an asteroid and place it in lunar orbit. The Society agrees with a recent finding by the NASA Advisory Council that SEP technology can be better integrated into the overall program by demonstrating the capability within the Mars system directly.[3] The robotic science program provides a scientifically compelling opportunity to test this technology. The planetary science community agrees that returning samples of the Martian surface is the highest priority strategic mission of the decade.[4] Such an undertaking requires a spacecraft that can relay data from Martian surface assets, rendezvous with samples launched from Mars, and return them back to Earth. The next Mars rover, which will launch in 2020, will select and prepare samples of Mars for return to Earth. Using SEP to return a spacecraft carrying those samples, or to provide a critical communications relay for the Mars 2020 rover, presents an opportunity to demonstrate this technology where it will be used—the Mars system—while serving an important scientific goal.

[3] Squyres, Steven W, Chair of the NASA Advisory Council, letter to NASA Administrator Charles Bolden, April 16, 2015. Available at: https://www.nasa.gov/sites/default/files/atoms/files/april9-10_finalrecom-tagged.pdf

[4] Committee on the Planetary Science Decadal Survey, Space Studies Board, Division on Engineering and Physical Sciences, National Research Council. *Vision and Voyages for Planetary Science in the Decades 2013-2022*. Washington, D.C.: National Academies Press, 2012. Available at: https://www.nap.edu/catalog/13117/vision-and-voyages-for-planetary-science-in-the-decade-2013-2022

Recommendation: Direct NASA to plan an executable, affordable path for sending humans to Mars orbit by 2033 as a critical step in the journey to the Martian surface, and strengthen the emerging Mars coalition of industry, science, and Congress

NASA has been on a "Journey to Mars" for a few years, though the agency has yet to specify detailed plans or define its strategy to achieve this goal. The Administration should direct NASA to release a strategic framework for human spaceflight to Mars in order to properly engage our international and commercial partners in this endeavor, as well as provide a means to measure progress, budgetary requirements, and to plan the long-term technology development necessary for this endeavor to succeed.

The most promising path forward to Mars does not require significant increases to NASA's budget or politically costly restructuring of NASA's major programs. In 2015, The Planetary Society hosted a workshop of space policy experts, astronauts, industry partners, and scientists to study a sustainable pathway to send humans to Mars. The subsequent workshop report[5] highlighted the promise of a strategic approach to sending humans to Mars, beginning with cis-lunar demonstration flights in the 2020s, an orbit-only mission to Mars in 2033, and landing humans on the surface later in that decade. This so-called "minimal architecture" used existing hardware and limited new development of unproven systems. This Mars concept was created by a study team from NASA's Jet Propulsion Laboratory and included an independent cost analysis performed by the Aerospace Corporation.[6]

This independent analysis suggested that NASA could send humans to Mars by the 2030s if NASA's budget grows only to match inflation, provided that NASA relinquishes primary funding responsibility for the International Space Station (ISS) by the mid-2020s. In no feasible future budgetary scenario can NASA maintain a balanced portfolio of science, aeronautics, and technology research while pursuing two major human spaceflight efforts: the ISS and the Journey to Mars. In the interests of advancing the frontier of human exploration, we recommend that the Administration work with NASA to find ways to hand off primary funding responsibilities for the ISS in order to apply these resources toward sending humans to Mars.

There is an emerging coalition of support for this stepwise approach to Mars. A major aerospace company has released a human exploration concept embracing the same principles (Figure 3),[7] Congress has added support for exploring the moons of Mars as a

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[5] The Planetary Society, *Humans Orbiting Mars: A Critical Step Toward the Red Planet*. September 2015. Available at: http://hom.planetary.org

[6] Price, Hoppy; John Baker; and Firouz Naderi. "A Minimal Architecture for Human Journeys to Mars." *NewSpace Journal*, Volume 3, Number 2. 2015. Available at: http://online.liebertpub.com/doi/pdf/10.1089/space.2015.0018

[7] Lockheed-Martin's proposal for an orbiting science laboratory, *Mars Base Camp* is available at: http://lockheedmartin.com/us/ssc/mars-orion.html

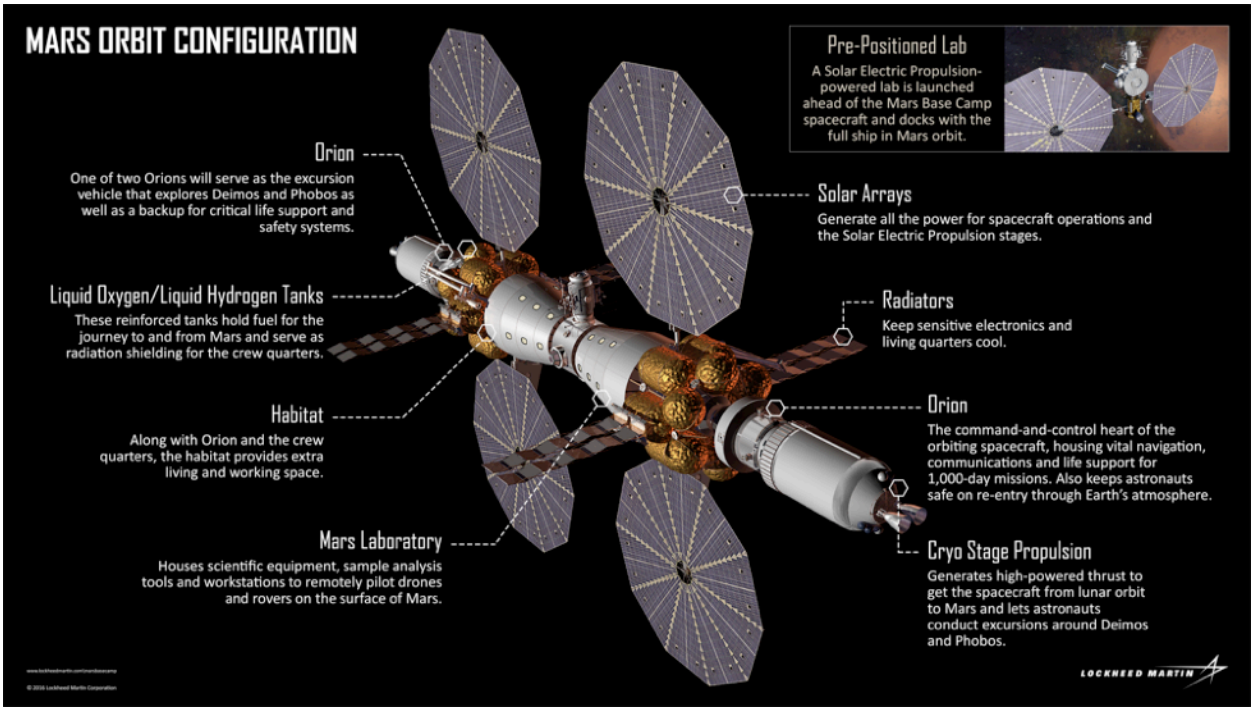

Figure 3. *Mars Base Camp, developed by Lockheed Martin, would leverage existing NASA programs to send humans to an orbiting science laboratory around the Red Planet as early as 2028. Multiple industry and NASA study teams have proposed strategic exploration frameworks that would send humans near the Moon and then on to Mars by the 2030s. Image credit: Lockheed-Martin.*

step toward the surface in a proposed NASA authorization bill,[8] and there is growing scientific interest in exploring the surface of Mars with telerobotic operations from orbiting astronauts as well as exploring the moons of Mars themselves.[9]

The Planetary Society urges the transition team to embrace a stepwise, orbit-first approach to sending humans to Mars in order to create a sustainable goal for NASA's human exploration program. There is ample opportunity to engage private industry and international partners in this endeavor, and Congress is already broadly supportive of this goal. This is an opportunity to define the legacy and vision of the new Administration—taking steps that could ultimately be responsible for landing humans on Mars and sustaining a long-term presence there.

[8] Senate Committee on Space, Science, and Competitiveness, *NASA Transition Authorization Act of 2017 (S.442)*. Introduced February 17, 2017. Available at: https://www.congress.gov/bill/115th-congress/senate-bill/442

[9] Workshop on the Space Science Opportunities Augmented by Exploration Telepresence. Oct 3 - 7, 2016. Keck Institute for Space Science, California Institute of Technology. Workshop website: http://kiss.caltech.edu/new_website/workshops/telepresence/telepresence.html

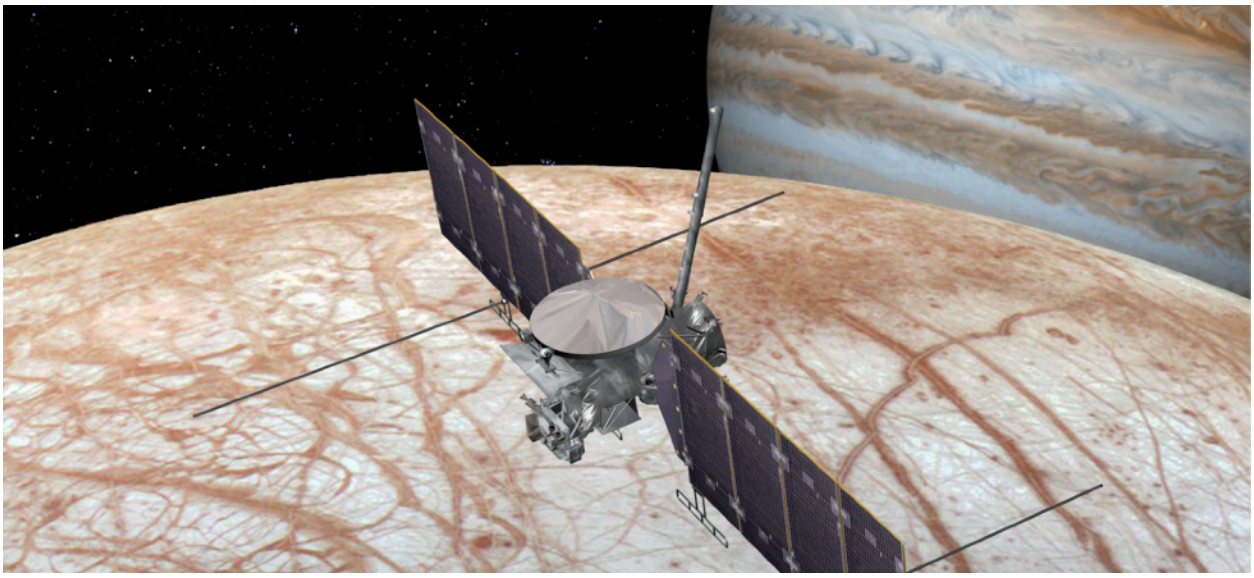

Figure 4. *Europa, a moon of Jupiter with a likely global ocean, is one of the highest-priority destinations for NASA planetary exploration as defined by the scientific community. Under congressional direction, NASA began developing the Europa Multi-Flyby Mission in 2015, and could launch as early as 2022 . Credit: NASA / JPL.*

Recommendation: Expand NASA's highly successful science portfolio to enable the search for life and the pursuit of critical scientific questions as recommended by the National Academies

Many of NASA's biggest successes are the result of its science program. Crowds cheered in Times Square as they watched the Curiosity rover's daring landing on Mars. The world saw Pluto's surface revealed when NASA's New Horizons spacecraft flew by. Thousands of planetary systems have been discovered by the Kepler mission. And humanity finds deeper meaning as it probes the limits of the cosmos with new discoveries from the Hubble Space Telescope.

NASA's science program has the potential to usher in some of the greatest revolutions in humanity's understanding of the cosmos. NASA's four science divisions, Astrophysics, Earth Science, Heliophysics, and Planetary Science, have clear programmatic direction provided by their respective Decadal Survey reports produced by the National Academies of Sciences, Engineering, and Medicine. These reports represent a scientific consensus for the near- and medium-term goals of each science that will help humanity better understand its origins, protect us from solar

	FY 2018	FY 2019	FY 2020	FY 2021	FY 2022
Proposed SMD	$6.1 billion	$6.5 billion	$6.8 billion	$7.1 billion	$7.5 billion
- PSD	$1.9 billion	$2.0 billion	$2.1 billion	$2.3 billion	$2.2 billion

Table 1. *Recommended funding levels for a Science Mission Directorate receiving 30% of a NASA budget that grows at an annual rate of 5%. The recommended budget for the Planetary Science Division (PSD) supports a balanced program with missions to Europa and sample return from Mars.*

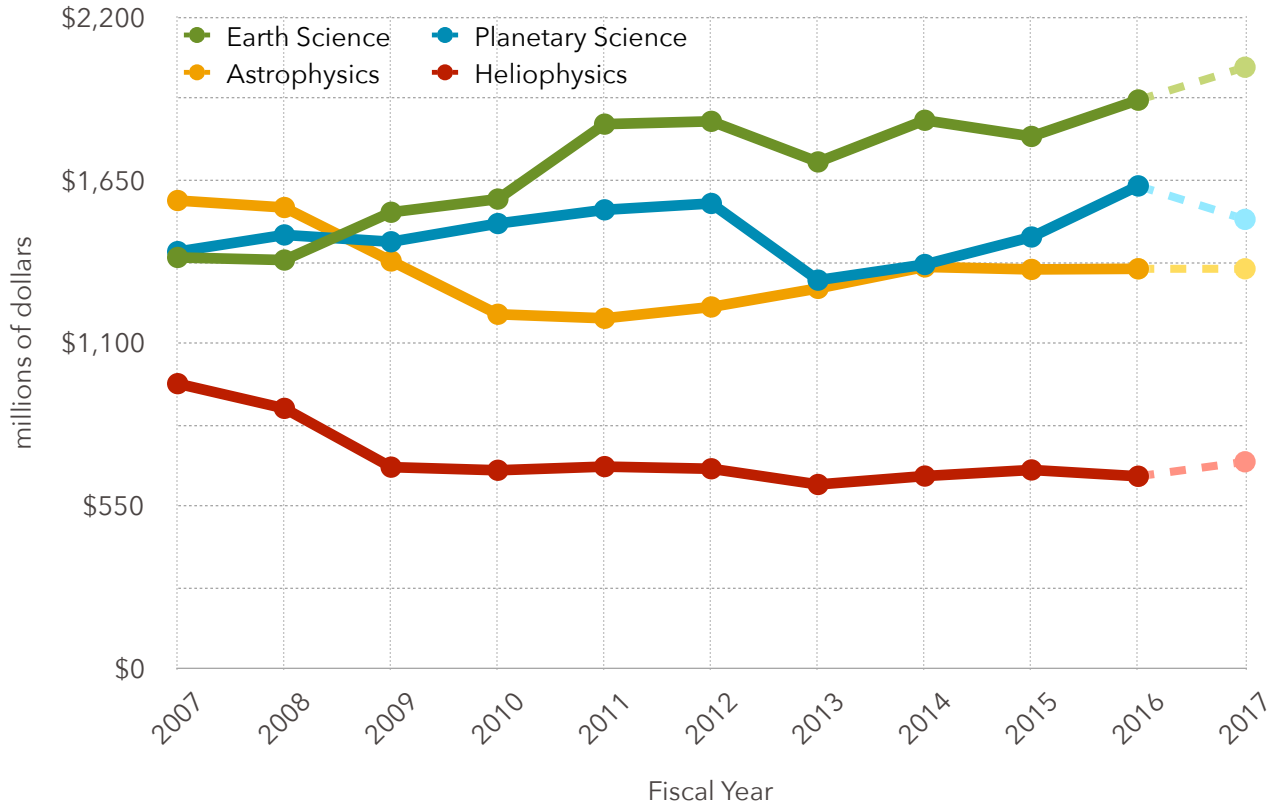

Figure 5. *Approved budget levels for each of NASA's four science divisions during the Obama administration as reported in NASA budget requests for FYs 2008 - 2017. FY 2017 numbers reflect budgets requested by the President and have not yet been appropriated. Adjusted for inflation.*

storms, search for life beyond Earth, as well as understand our changing climate.

The Planetary Society urges the new Administration to support and fund the recommendations made in the Decadal Surveys. While Earth Science has seen welcome budgetary growth in the last administration, the other three science areas have struggled under flat or shrinking budgets (see Figure 5). Planetary Science, in particular, endured significant cuts in FY 2013 which resulted in cancellations and delays of important missions. With bipartisan support from Congress, the program is rebuilding itself to address some of the top scientific priorities in the solar system. This effort would be greatly enhanced by complimentary support from the White House.

Our recommendation is that at least 30 percent of NASA's total budget be committed to its Science Mission Directorate, and that the budget for the Planetary Science Division grows beyond $2 billion by 2019 in order to rebuild a balanced program that addresses the top scientific priorities for Mars, Europa, and other ocean worlds in the solar system (see Table 1). Earth Science and other science divisions—not to mention the large scientific community in the United States—would benefit from this modest increase by an increased number of missions and scientific research funding.

Recommendation: Initiate the "5 over 5" plan—annual five percent budget growth over five years

A recent National Academies report[10] stated that, without increases to NASA's budget at least matching the rate of inflation, NASA would soon be unable to afford to send humans anywhere beyond the space station. As discussed previously, the budgets for many of NASA's science programs over the previous eight years have been flat or diminished. The nation has asked NASA to do too much while providing it with too little.

Fortunately, the new Administration will find Congressional support for NASA on both sides of the aisle. Since 2015, Congress has worked in a bipartisan fashion to appropriate a total of nearly $2 billion above the Presidential requests for NASA (see Figure 6). This additional funding has been generally split between human spaceflight, aeronautics, and science programs.

In conjunction with a broad coalition of industry, scientific, and educational partners,[11] The Planetary Society proposes the "5 over 5" plan: five percent annual increases to NASA's budget for the next five years (see Table 2). Five percent would match inflation growth with an additional three percent to help NASA invest in several critical areas that have been underfunded in recent years. These include the development of a deep space habitat for use near the Moon in the 2020s, and the testing of life support, operations, and safety systems for use in a crewed Mars mission, as well as a reinvigorated science portfolio as discussed in the previous recommendation.

The Planetary Society recommends small annual adjustments to NASA's top-line budget in order to enable the goal of sending humans to Mars and supporting growth in its critical science programs (see Table 2 and Figure 6).

	FY 2018	FY 2019	FY 2020	FY 2021	FY 2022
NASA	$20.5 billion	$21.5 billion	$22.6 billion	$23.7 billion	$24.9 billion

Table 2. NASA budgets under the "5 over 5" plan, assuming a $19.5 billion initial budget in FY 2017.

[10] Committee on Human Spaceflight; Aeronautics and Space Engineering Board; Space Studies Board; Division on Engineering and Physical Sciences; Committee on National Statistics; Division of Behavioral and Social Sciences and Education; National Research Council, *Pathways to Exploration: Rationales and Approaches for a U.S. Program of Human Space Exploration*. Washington, D.C.: National Academies Press, 2014. https://www.nap.edu/catalog/18801/pathways-to-exploration-rationales-and-approaches-for-a-us-program

[11] The Coalition for Aerospace and Science, letter to Representatives John Culberson and Michael Honda and Senators Richard Shelby and Barbara Mikulski, February 26, 2016. Available at: https://sciencepolicy.agu.org/files/2013/07/CAS-FY-2017-Appropriations-Request.pdf

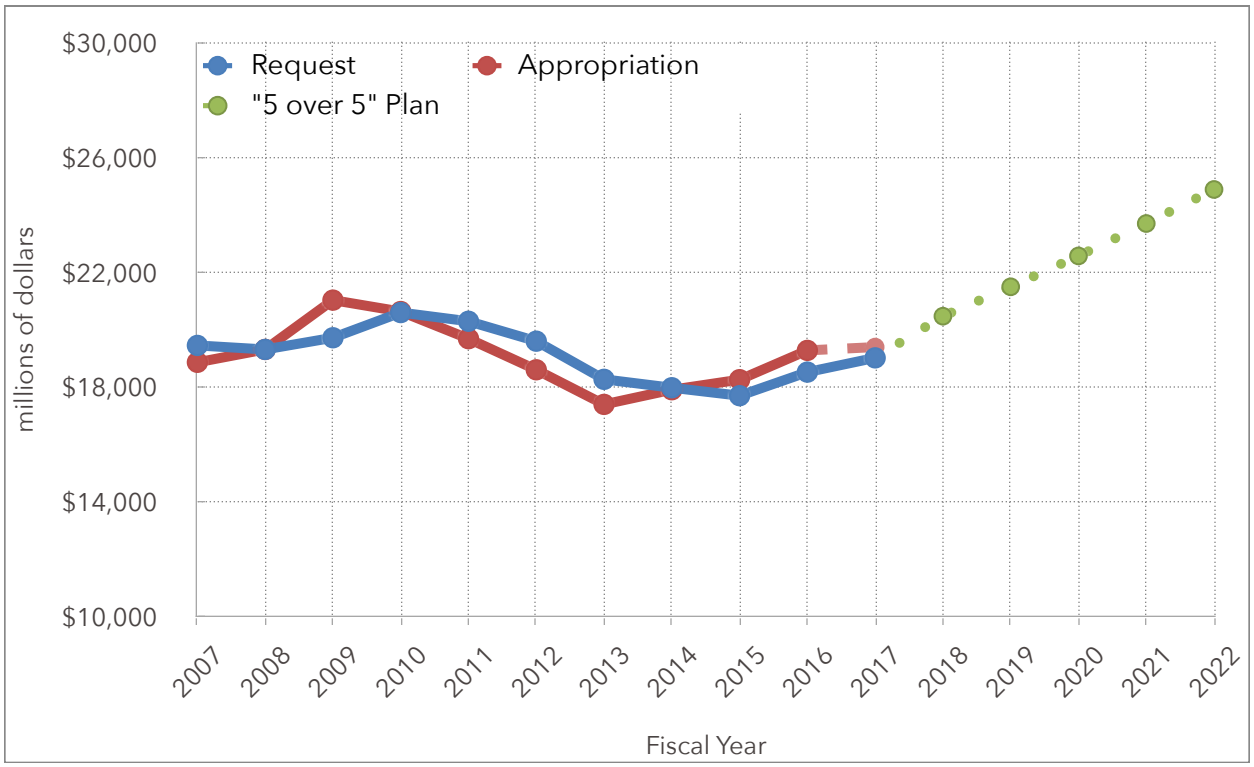

Figure 6. *NASA's top-line funding as requested by the President and appropriated by Congress, with the recommended "5 over 5" plan continuing the recent budget growth beginning in FY 2015. The FY 2017 appropriation amounts are not finalized, so the average from the proposed Senate and House CJS bills is used as a placeholder. Source: NASA budget requests, FY 2007 - FY 2017. Adjusted for inflation.*

Recommendation: Cultivate the commercial space industry to enable rapid growth in national capability

While private industry has always been a critical partner in NASA's exploration efforts, policies initiated during the George W. Bush administration and expanded under President Obama created a new relationship between private aerospace companies and NASA. Beginning with cargo resupply services to the ISS (and soon to expand to transit services for astronauts), private companies have developed independent access to low-Earth orbit that promises to be more affordable than previous NASA-directed efforts.

Many of these new companies are leveraging these capabilities to pursue their own exploratory ambitions beyond the immediate needs of NASA. Notably, there are several companies that have ambitions to colonize Mars, create a space tourism industry, mine asteroids, or enable millions of people to live and work in space. There is a growing venture capital market that funds these private companies. NASA has provided (and continues to provide) critical funding in a public-private partnership that enables novel new capabilities for access to space.

As the commercial sector continues to serve the needs of NASA in low-Earth orbit and grow its own private sector economy, we urge the Administration to enact regulatory and contracting policies that enable the growth of the private space sector and to continue to support NASA in its use of competitive contracting awards to ensure increased capability and ambition in this exciting new economy.

Figure 7. *A SpaceX Falcon 9 first stage lands on an autonomous "drone ship" in the Atlantic ocean. Credit: SpaceX*

Addendum

Opportunities presented by NASA for the new Administration

The Planetary Society encourages the new Administration to utilize the space program as a powerful means to address national priorities in creating high-quality jobs, to positively engage other nations, to help alleviate partisanship, and to inspire our nation and the world

Jobs: Turbocharging the Industrial and High-Tech Workforce

NASA and a strong commercial space sector present unique opportunities to propel the best and brightest minds into tech-sector jobs in engineering and science. A clear vision to send humans to Mars and to engage in other highly challenging space endeavors, as well as a commensurate expansion of NASA-supported opportunities for associated development, will motivate young Americans to pursue careers in these critical areas. Many will inevitably direct their energy, skills, and entrepreneurship, into other industries as work progresses in the grand goal of exploration, helping to spur the economy beyond the aerospace sector. NASA already supports some 17,000 civil servants and tens of thousands of private-sector contractors throughout the country. An agency focused on exploring Mars in partnership with a vibrant commercial sector has the potential to engage many more of our citizens in a 21st-century workforce.

Diplomacy: Peaceful engagement of allies and adversaries alike

The space program has served as a tool of international diplomacy since the earliest days of the space age. Nearly every NASA science mission includes non-U.S. hardware supplied by other countries and provides worldwide dissemination of scientific data. The Apollo-Soyuz rendezvous mission in 1975 helped to demonstrate the potential of peaceful coexistence in space between the U.S. and the Soviet Union. NASA currently has 750 active agreements with more than 120 nations around the world.[12] The 15-nation-strong International Space Station is perhaps the grandest example of the diplomatic potential of space-based cooperation between nations, and serves as a blueprint for how NASA, with strong Presidential and congressional support, can shape a broad international coalition for a campaign to send humans to Mars.

Bipartisanship: Space exploration provides a bridge between the parties

The space program can provide a critical bridge between our divided political parties. NASA has historically enjoyed bipartisan support from Presidents and members of Congress. Citizens of all political orientations support NASA and space exploration.[13] Engaging Congress on a bipartisan basis with respect to the future of NASA can serve to build stronger connections and trust between

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[12] Bolden, Charles, NASA Administrator, "International Cooperation: Critical on Our Human Journey to Mars." Posted October 20, 2016 at: https://blogs.nasa.gov/bolden/2016/10/20/international-cooperation-critical-on-our-human-journey-to-mars/

[13] Motel, Seth. “NASA Popularity Still Sky-High.” Pew Research Center. Published February 3, 2015, at: http://pewresearch.org/fact-tank/2015/02/03/nasa-popularity-still-sky-high/

the Administration and congressional members on both sides of the aisle.

Optimism: Supporting space exploration reinforces a positive view of the future and the capabilities of the nation

In the past decade, NASA has been a consistent source of major success stories that have captured the public's imagination, particularly the robotic missions that landed on Mars and flew by Pluto, the financial support that enabled a vibrant new commercial launch industry, and beginning a journey to send humans to Mars. These achievements have incalculable impact on the national mood, particularly with regard to optimism for the future. Many great achievements are yet to come, including advances in the search for life within our solar system and in planetary systems beyond our own, and in pushing the boundaries of human presence beyond the Earth. The Administration has the opportunity to create a positive legacy through the vision and resources it will provide to the space program.

Current State of Selected NASA Programs

Science

NASA's four science divisions account for less than 30 percent of the agency's budget and are actively exploring Earth, the Sun, the Solar System, and the cosmos beyond. The science divisions have clear direction provided by periodic Decadal Survey reports from the National Academies of Sciences, Engineering, and Medicine. Several major science missions are in development and are on track to launch within the next four years. In 2018, NASA will launch the successor to the Hubble Space Telescope, named the James Webb Space Telescope, as well as a mission that will fly closer to the Sun than any other spacecraft in history—Solar Probe Plus. NASA is preparing a new Mars lander in 2018 that will study the Red Planet's seismology. In 2020, NASA will launch a new rover to gather samples of Mars for future retrieval and return to Earth. Also in development in the next four years are missions to explore Jupiter's ocean moon of Europa, which could launch as early as 2022, and a major new space telescope, WFIRST, which would help unravel mysteries of dark matter and the atmospheres of exoplanets. A number of smaller missions are expected to be selected and begin development over the next four years as well.

Many important missions are in early phases of study and development. However, due to budget restrictions, NASA's ability to address high-priority scientific questions has been slowed. Earth Science has seen a welcome increase of its budget during the previous Administration. Unfortunately, the other three science divisions have experienced stagnant or deeply cut budgets over the past eight years.

Human Spaceflight

NASA is in the midst of a significant transition within its human spaceflight program. The agency retired the Space Shuttle in 2011 after nearly 30 years of service and has since relied on purchasing seats aboard Russian Soyuz spacecraft to launch astronauts to the International Space Station.

NASA is investing in two different efforts to send humans into space: one is a public-private partnership focused on low-Earth orbit; the second is a NASA-led development program to create a large new rocket, the Space Launch System (SLS), and a new deep space crew vehicle, Orion. Both programs have significant milestones planned for 2018.

While the commercially provided spacecraft will ferry astronauts to and from the space station, NASA plans to use the SLS and Orion on a "Journey to Mars"—the current organizing goal of the human exploration program. NASA has not publicly released a detailed framework for how it intends to land humans on Mars by the 2030s, though it has stated its intention to test new hardware and technologies near the Moon throughout the 2020s and, via its Asteroid Redirect Mission (ARM), to robotically place a boulder from an asteroid in orbit around the Moon. Astronauts would then visit this sample of a primitive solar system body in the late 2020s. NASA has also engaged industry partners in early design work on deep space habitats—critical to any long-duration journey to Mars. Much of this effort must continue if the goal of humans reaching Mars in the 2030s is to be achieved.