EXPLORING OUR SOLAR SYSTEM: THE ASTEROIDS ACT AS A KEY STEP

HEARING

BEFORE THE

SUBCOMMITTEE ON SPACE

COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY

HOUSE OF REPRESENTATIVES

ONE HUNDRED THIRTEENTH CONGRESS

SECOND SESSION

September 10, 2014

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September 10, 2014

Appendix II: Additional Material for the Record

EXPLORING OUR SOLAR SYSTEM: THE ASTEROIDS ACT AS A KEY STEP

WEDNESDAY SEPTEMBER 10, 2014

HOUSE OF REPRESENTATIVES,
SUBCOMMITTEE ON SPACE
COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY,
Washington, D.C.

The Subcommittee met, pursuant to call, at 10:07 a.m., in Room 2318 of the Rayburn House Office Building, Hon. Steven Palazzo [Chairman of the Subcommittee] presiding.

LAMAR S. SMITH, Texas
CHAIRMAN

EDDIE BERNICE JOHNSON, Texas
RANKING MEMBER

Congress of the United States
House of Representatives
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Subcommittee on Space

Exploring Our Solar System: The ASTEROIDS Act as a Key Step

Wednesday, September 10, 2014
10 a.m. to 11:30 p.m.
2318 Rayburn House Office Building

Witnesses

***Dr. Jim Green,** NASA Planetary Science Division Director*

***Dr. Jim Bell,** Director, Acquisition and Sourcing Management, Government Accountability Office*

***Dr. Mark Sykes,** CEO and Director, Planetary Science Institute*

***Professor Joanne Gabrynowicz,** Professor Emerita, Director Emerita, Journal of Space Law Editor-in-Chief Emerita, University of Mississippi*

***Dr. Philip Christensen,** Co-Chair, NRC Committee on Astrobiology and Planetary Science (CAPS), Chair, Mars Panel, NRC Planetary Decadal Survey, Regents Professor, Arizona State University*

U.S. HOUSE OF REPRESENTATIVES
COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY
SUBCOMMITTEE ON SPACE

Exploring Our Solar System: The ASTEROIDS Act as a Key Step

Wednesday, September 10, 2014
10 a.m. – 11:30 p.m.
2318 Rayburn House Office Building

Purpose

This hearing will give the Committee an overview of the variety of issues facing the planetary science community, including challenges the community is facing due to the low inventories of Pu-238 for deep space missions, NASA's proposed budget for planetary science, and potential commercial interests. Witnesses will also be asked to comment on H.R. 5063, the American Space Technology for Exploring Resource Opportunities In Deep Space (ASTEROIDS) Act.

Witnesses

- **Dr. Jim Green**, NASA Planetary Science Division Director
- **Dr. Jim Bell**, Professor of Earth and Space Science Exploration, Arizona State University, and President, Board of Directors, The Planetary Society
- **Dr. Mark Sykes**, CEO and Director, Planetary Science Institute
- **Professor Joanne Gabrynowicz**, Professor Emerita, Director Emerita, Journal of Space Law Editor-in-Chief Emerita, University of Mississippi
- **Dr. Philip Christensen**, Co-Chair, NRC Committee on Astrobiology and Planetary Science (CAPS), Chair, Mars Panel, NRC Planetary Decadal Survey, Regents Professor, Arizona State University *(Minority Witness)*

Background

Science Mission Directorate

Budget Authority ($ in millions)	Actual 2013	Enacted 2014	Request FY15	FY14 Vs FY15	Notional 2016	2017	2018	2019
Science	4,781.6	5,151.2	4,972.0	(179.2)	5,021.7	5,071.9	5,122.6	5,173.9
Earth Science	1,659.2	1,826.0	1,770.3	(55.7)	1,815.4	1,837.6	1,861.9	1,886.3
Planetary Science	1,274.6	1,345.0	1,280.3	(64.7)	1,304.9	1,337.1	1,355.7	1,374.1
Astrophysics	617.0	668.0	607.3	(60.7)	633.7	651.2	696.8	933.0
James Webb Space Telescope	627.6	658.2	645.4	(12.8)	620.0	569.4	534.9	305.0
Heliophysics	603.2	654.0	668.9	14.9	647.6	676.6	673.3	675.5

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. The directorate has four divisions; Earth Science, Planetary Science, Astrophysics and Heliophysics. NASA is requesting $4.972 billion for SMD in FY15, which is a reduction of approximately $179.2 million (four percent) below the FY14 enacted.

The Administration continues to request a disproportionate amount of funding for Earth Science relative to Planetary Science and Astrophysics (including the James Webb Space Telescope), which have been used to fund other agency's priorities such as the National Oceanic and Atmospheric Administration's climate sensors and the US Geologic Survey's moderate resolution land imaging satellite.

The Planetary Science division is responsible for monitoring and analyzing data collected from NASA missions exploring the solar system and beyond in the search for the content, origin and evolution of the solar system as well as the potential for life. Additionally, Planetary Science is responsible for Near Earth Object Observations program. The Planetary Science division was again targeted this year for budget cuts as NASA prioritized missions in Earth Science and continued development of the James Webb Space Telescope (JWST). This trend has decreased the Planetary Science division from $1.485 billion in the FY11 request, to $1.280 billion this year.

In 2013, Planetary Science missions went to Mars (Mars Atmosphere & Volatile Evolution) and the Moon (Lunar Atmosphere and Dust Environment Explorer). In 2014 the ESA/NASA Rosetta comet rendezvous mission woke up from its ten-year journey to the asteroid belt and is expected to arrive at Comet Churyumov-Gerasimenko (Comet C-S) in the summer of 2014. Cassini continues to orbit Saturn, studying its rings and moons, including Titan and Enceladus. Work continues on the Origins-Spectral-Interpretation-Resource Identification-Security-Regolith Explorer (OSIRIS-Rex) mission to obtain a sample of near-Earth asteroid Bennu, and the Interior Exploration using Seismic Investigations, Geodesy and Heat Transport (InSight) mission to Mars, both of which are expected to launch in 2016. Work also continues on the Mars 2020 rover, NASA's next flagship mission to Mars.

The President's budget request included a line item of $15 million to begin designing a mission to Europa. Congress has long supported the National Academies' recommendation of this mission. The funding request is only for FY15, with no money budgeted for out-year activity. Further development of a mission concept beyond FY15 is uncertain.

FY2015 Budget

Generally, there has been bipartisan support for NASA funding in both chambers of Congress. In June, the House passed the NASA Authorization Act of 2014 by a vote of 401 to 2. In May, the House passed the Commerce-Justice-Science appropriations bill (H.R. 4660) by a bipartisan vote of 321 to 87. The bill would fund NASA at $435 million more than the President's FY15 budget request.[1]

[1] H.R. 4660 citation

H.R. 4660 provides $5.193 billion for SMD, an increase of $221 million from the President's FY15 budget request of $4.972 billion. Within that provision the Planetary Science Division would receive $170 million more than the budget request.

The Senate Appropriations Committee approved an appropriations bill in June for $17.9 billion, $440 million more than the President's budget request. Within that bill, SMD would receive $5.2 billion, an increase of $23 million, of which $1.3 would be for Planetary Science.

Current Planetary Missions

Planetary Science missions currently in operation and/or development include, in alphabetical order:

Cassini (Cassini Solstice Mission) – The Cassini mission has done numerous fly-bys of Saturn's moons, including Enceladus and Titan, which may harbor environments conducive to the existence of life. Cassini will end its third mission extension by examining the rings of Saturn and high-latitude mapping of Titan and Saturn.

Dawn – This mission is currently traveling between the oldest and largest bodies in the main asteroid belt between Mars and Jupiter. After launching in 2007, it orbited its first destination, the asteroid Vesta, in 2011, and is expected to reach the dwarf planet Ceres in February 2015. Dawn will compare and contrast each body to gain insights into the early years of the solar system.

Europa – For the first time, this year NASA has begun to formulate a mission to study Jupiter's icy moon Europa. Pre-formulation is under way, including releasing a call for instruments.

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.

Juno – Juno launched in 2011, and will orbit over Jupiter's poles to conduct remote sensing observations and take never-before-seen images of the Jovian planet. It will be the first solar-panel powered spacecraft to orbit Jupiter.

JUICE (Jupiter Icy Moons Explorer) – In a partnership with ESA, this mission will explore Jupiter and its moon Ganymede. It is expected to launch in 2022 and reach Jupiter in 2030.

LRO (Lunar Reconnaissance Orbiter) – LRO orbits the Moon, and was launched in 2009 as part of a precursor mission for preparations to send humans back 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.

MAVEN (Mars Atmosphere & Volatile EvolutioN) – Launched in 2013, MAVEN will orbit Mars and investigate the loss of its atmosphere and the possibility for habitability.

Opportunity Rover (Mars Exploration Rover/MER) – Opportunity landed on Mars in 2004, and continues to provide excellent science by making atmospheric observations and providing evidence of Mars' habitable past.

Mars Express – 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.

Mars Odyssey 2001 – Measurements made by 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.

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 rover.

MRO (Mars Reconnaissance Orbiter) – With its powerful camera, MRO captures detailed pictures of Mars' geology, which can be used for determining possible future landing sites. MRO has provided photographic evidence of the existence of liquid on Mars. It also serves as a communication channel between Mars and Earth.

Mars Rover 2020 – This year the Science Definition Team released the instruments expected to be included on the next Mars rover, when it launches 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.

Curiosity Rover (Mars Science Laboratory Curiosity Rover) – Curiosity is collecting soil and rock samples and analyzing them to determine if conditions have existed to support microbial life. It is the only rover to use Pu-238. It has already found evidence that water flowed on the Martian surface that could have supported microbial life.

MESSENGER (MErcury Surface, Space ENvironment, Geochemistry, and Ranging) – This mission to Mercury is attempting to answer six science questions: investigate why Mercury is so dense; map its geologic history; study its magnetic field; determine the size and make-up of its core; identify important volatiles in its exosphere; and better understand the unusual materials at its poles. MESSENGER is scheduled to complete its mission in the first half of FY 2015.

New Horizons – This is the first mission to examine Pluto and its moons Charon, Nix, Hydra, Kerberos and Styx. New Horizons was launched in 2006, and is expected to reach Pluto in July 2015. The mission will image Pluto, and gather information about its atmosphere and surface features. A potential extended mission could include traveling to the Kuiper Belt to examine study at least one icy mini-world.

OSIRIS-REx (Orginis-Spectral Interpretation-Resource Identification-Security-Regolith Explorer) – The spacecraft is expected to launch in 2016 and will examine the asteroid Bennu and return a physical sample of the asteroid to Earth.

Rosetta – Rosetta is a European Space Agency (ESA) led mission to rendezvous and land on Comet Churymov-Gerasimenko (C-CG) in 2014. Launched in 2004, the Rosetta spacecraft was placed in hibernation until it came close to intercepting C-CG this spring. In August, Rosetta successfully rendezvoused with C-CG, and is expected to place a lander on the comet's surface in November 2014.

2014 Planetary Mission Senior Review

On September 2, 2014, NASA released the results of the *2014 Planetary Mission Senior Review (PMSR).* Conducted every two years, Senior Reviews recommend which Planetary Science missions should be extended and which ones should not. Recommendations are based on presentations made by mission teams that show the scientific value of continuing the mission. Consideration is also given to how the costs of extending existing missions may impact the benefits of beginning new ones.

This year the Senior Review panel determined that the following missions should be extended:

- Cassini
- Lunar Reconnaissance Orbiter (LRO)
- Opportunity (Mars Exploration Rover/MER)
- Mars Reconnaissance Orbiter (MRO)
- Mars Express (MEX)
- Mars Odyseey (ODY)
- Curiosity (Mars Science Laboratory – MSL)

It should be noted that the older Opportunity Rover scored higher than the younger Curiosity Rover. Specifically, the panel felt that Curiosity's extended mission plan to take only eight samples in the next two years was not efficient and that "this is a poor science return for such a large investment in a flagship mission." The panel also found that "the proposal lacked specific scientific questions to be answered, testable hypotheses, and proposed measurements and assessment of uncertainties and limitations." Further, the panel expressed its concern that too much emphasis was placed on the distance the rover would travel, rather than the scientific analyses that could be conducted. Ultimately, the panel determined that the Curiosity team "felt they were too big to fail and that simply having someone show up would suffice."[2] The Mars Rover 2020 is expected to be designed to build upon Curiosity's science discoveries. Investigating the problems mentioned in the Senior Review could have important impacts on the Mars Rover 2020 program.

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[2] NASA's 2014 Planetary Senior Review, pp.5-6

Below is a table that illustrates how each mission was rated.

BUDGET	GUIDELINE	RECOMMENDED
Mission	**Rating**	**Rating**
Cassini	Excellent	
LRO	Very Good/Good	Excellent/Very Good
Opportunity	Excellent/Very Good	
MRO	Excellent/Very Good	
MEX	Good/Fair	Very Good
ODY	Very Good/Good	Very Good
Curiosity	Very Good/Good	Very Good/Good
Red = Recommended Grade and Budget. See individual mission reviews for details.		

Source: 2014 Planetary Mission Senior Review, p. 2

Discovery-class Planetary Mission Announcement of Opportunity

The Discovery-class missions in the Planetary Science division are cost-capped, competitively awarded, smaller and less-expensive missions that explore the Solar Sytem. Missions are proposed and led by a 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.

On July 2, 2014, NASA released their Draft Discovery-class Planetary Mission Announcement of Opportunity (AO). The deadline for submitting a proposal is December 2014. The selected mission will be announced in spring 2015, and will be awarded in 2016. The mission must be ready for launch no later than December 31, 2021.

The latest AO for Discovery-class missions is the thirteenth announcement. The cost cap for missions is $450 million, and does not include the launch vehicle required to launch the spacecraft. This year's announcement also features changes to past announcements. They include:

- Foreign instrument contributions are limited to one-third of the PI-Managed Instrument Cost.
- NASA will choose the launch vehicle, which will be provided as Government Furnished Equipment (GFE). If the mission chooses to use a higher performance launch vehicle than the one NASA has selected, the cost will be charged to the cost of the mission. If the mission chooses to use a less expensive (and potentially less reliable) launch vehicle of their choosing, the money will be credited to the mission.
- Mission payloads must include an experimental laser communications payload.
- Proposed missions should not require radioisotope power systems.

Radioisotope Power Systems and the Inventory of Plutonium-238

Plutonium-238 (Pu-238) is a by-product of nuclear weapons grade plutonium. When the Space Race began in the 1950s, Pu-238 was found to be an effective fuel for robotic spacecraft that needed longer-lasting electrical power than what traditional chemical batteries could supply. Space science missions increasingly began using radioisotope power systems (RPS) that used Pu-238.

Currently, there is not a substitute power system for RPS. NASA had been designing an Advanced Stirling Radioisotope Generator, which would use less plutonium for less expensive planetary science missions, but they cancelled the program. Without RPS missions, and without a RPS substitute, there will be limited future planetary science missions.

A memorandum of understanding has existed between the Department of Energy (DOE) and NASA for the production of Pu-238. The Department of Energy has traditionally been responsible for the design, development, fabrication, evaluation, testing and delivery of Pu-238 to NASA. The 2006 National Space Policy emphasizes DOE's role as manager of the nuclear infrastructure necessary for the production of Pu-238.[3] DOE had financial responsibility for the production facilities, and NASA has reimbursed DOE for the production cost of the Pu-238 NASA needed.[4]

In 1988, U.S. nuclear weapons production facilities were closed, ending the nation's ability to produce Plutonium. At the time production ended, there was believed to be a large enough stockpile of Plutonium to support NASA's RPS missions through the early 2000s.[5] In 1992, the stockpile was supplemented by purchasing Pu-238 from Russia. Russia no longer produces Pu-238, and no other country appears to be producing it.[6]

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[3] http://www.whitehouse.gov/sites/default/files/microsites/ostp/national-space-policy-2006.pdf

[4] Ibid.

[5] National Research Council. *Radioisotope Power Systems: An Imperative for Maintaining U.S. Leadership in Space Exploration.* Washington, DC: The National Academies Press, 2009.

[6] The European Space Agency (ESA) does not use nuclear powered planetary science missions, because the EU does not produce Pu-238. Their Mars rover, for instance, is solar powered.

Two upcoming flagship Planetary Science missions will require use of Pu-238: the Mars 2020 Rover and a possible mission to Europa. There is debate between Congress and NASA as to whether or not there is enough Pu-238 available for both missions.[7]

According to NASA, at this time the United States has 17kg of Pu-238 remaining for use in NASA RPS missions. Based on their calculations the Mars 2020 mission will use 4 kg and the Europa mission would use 13 kg. More Pu-238 would be needed for any RPS missions beyond Europa.[8]

In 2013, NASA entered into an agreement with DOE to begin producing more Pu-238. The Pu-238 will be generated at Oak Ridge National Laboratory in Tennessee and stored at Idaho National Laboratory in Idaho. The pellets needed for the RPS will be produced at Los Alamos Lab in Las Alamos, NM.

The production facilities are in need of significant updating before production of Pu-238 can begin (some of the press machines required to make pellets are 50 years old). NASA has been paying DOE $50 million per year to upgrade and repair the production facilities.

NASA has said that if production plans proceed as anticipated, they will be able to generate 1.5 kg of Pu-238 per year. In order to temper the hotter, new Pu-238 so that it meets the temperature requirements for RPS missions (too hot will melt the containment casing, while too cool will not provide the power needed), the newly generated Pu-238 will be blended with the older, cooler stockpile to achieve the optimal temperature.[9]

Congress has yet to receive a detailed plan from NASA outlining its agreement with DOE and how much Pu-238 it expects to need in coming decades. In a March 2014 article in *Space News*, NASA was quoted as saying that "there will not be enough plutonium-238 ready at the end of the decade to fuel comparatively inefficient Multi-Mission Radioisotope Thermoelectric Generators for both the Mars 2020 rover and the Discovery 13 mission." In the same article Jim Green was quoted in a NASA Advisory Council Planetary Science Subcommittee meeting as saying, "It will take approximately three-and-a-half years to replace that fully and get into production of the pellets." Once the pellets are produced, priority will be given to the Mars 2020 mission.[10] For the first time, a Planetary Science Announcement of Opportunity for Discovery-class missions (cost-capped, more frequent, and smaller, science focused missions) has told scientists that they should not submit proposals that require a radioisotope power system.[11]

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[7] http://www.spacenews.com/article/civil-space/39846nuclear-power-sources-nixed-for-nasa%E2%80%99s-next-discovery-mission

[8] Jim Green, NASA Planetary Science Division Director, NASA Mars Briefing for Committee staff, September 2, 2014. Dr. Green also informed Committee staff that research was being conducted to see if a solar powered Europa mission was feasible.

[9] Ibid.

[10] http://www.spacenews.com/article/civil-space/39846nuclear-power-sources-nixed-for-nasa%E2%80%99s-next-discovery-mission

[11] https://nspires.nasaprs.com/external/viewrepositorydocument/cmdocumentid=422861/solicitationId=%7BE688B67C-F571-CD88-D577-5DBEE9C425F6%7D/viewSolicitationDocument=1/Discovery2014draftAOFINAL.pdf

The American Space Technology for Exploring Resources Opportunities in Deep Space (ASTEROIDS) Act of 2014

In the past twenty years, the commercial space industry has begun to demonstrate viable operations in low Earth orbit (LEO). Currently, two American companies, SpaceX and Orbital Sciences, deliver cargo to the International Space Station. In fall 2014 NASA will announce its selection of the commercial companies that may eventually take U.S. astronauts and other passengers to the International Space Station and (LEO) – a selection that will eventually remove U.S. dependence on Russia to reach assets in space. Concurrently, several space tourism companies are testing spacecraft to take tourists on suborbital flights.

Advances in the commercial space industry have been accompanied by interest in exploring resources that exist in space, including asteroids and the Moon. Private companies recognize the potential for finding and extracting rare minerals and water in asteroids, and how the ability to access and retrieve these minerals may reduce U.S. dependence on foreign countries to supply domestic demand.

In order to establish legal precedence for asteroid mining activities, companies and policy makers have referenced the General Mining Act of 1872 (which authorized and governed mining claims made on federal lands), the Convention of the Law of the Sea (which governs resource collection in international waters), and Article 2 of The Outer Space Treaty of 1967 (which prohibits nuclear weapons in orbit around the Earth, on the moon, or other celestial bodies; establishes that the purposes of space exploration shall be peaceful; forbids any government from claiming moons or planets as sovereign property; and stipulates that said bodies are the "common heritage of mankind." Precedents established in the development of the oil and gas industry are also being examined.

The ASTEROIDS Act of 2014 expresses the desire of commercial and private entities in this burgeoning industry to address the challenges of staking claims to resources in outer space.

Chairman PALAZZO. The Subcommittee on Space will come to order.

Good morning. Welcome to today's hearing titled "Exploring Our Solar System: The ASTEROIDS Act as a Key Step." In front of you are packets containing the written testimony, biographies, and Truth in Testimony disclosures for today's witness. I recognize myself for five minutes for an opening statement.

Good morning. I would like to thank our witnesses for being here today to testify about future scientific exploration of our solar system and the recently introduced ASTEROIDS Act.

Planetary science has long inspired us to imagine what it would be like to visit another planet in our solar system. It has shown us that there are methane lakes on Saturn's moon, Titan, icy plumes on Jupiter's moon, Enceladus, and that humans can maintain a robotic presence on Mars.

However, over the last few years the Administration has consistently cut NASA's Planetary Science Division budget. Meanwhile, NASA's Earth Science program has grown by more than 40 percent. There are 13 other agencies throughout the Federal Government that currently fund over $2.5 billion in climate science research, but only one agency does space exploration and space science.

Congress has long been a supporter of planetary science, particularly as it pertains to asteroids. After the air burst over Chelyabinsk, Russia, that caused tens of millions of dollars in damage and injured nearly 1,500 people, this Committee held two hearings on NASA's near-Earth asteroid tracking program and its efforts to fulfill the requirements of the George E. Brown Near-Earth Object Survey Act.

Support for the detection and characterization of asteroids is not to be confused with the President's current proposed Asteroid Redirect Mission, or ARM. It is no secret that this Committee has expressed significant skepticism with regards to ARM. NASA's own experts have been critical of the plan. NASA's own Small Bodies Assessment Group recently said "its benefits for advancing the knowledge of asteroids and furthering planetary defense strategies are limited and not compelling." Additionally, the NASA Advisory Council has warned that "the ARM mission as currently defined may pose an unacceptable cost and technical risk." This is not the type of review you want to hear from the experts that NASA has chartered to provide advice. While I am indeed interested in the opportunities offered by near-Earth objects, I continue to be concerned that the Administration is not heeding the warnings of these experts for the mission that it has designed.

Today we will also be discussing the bipartisan efforts of two members of this Committee to offer a legal framework for the private sector to utilize celestial resources. The American Space Technology for Exploring Resource Opportunities in Deep Space Act, or ASTEROIDS Act, is a bipartisan bill introduced by Congressman Posey and Congressman Kilmer. The two of them have worked very hard to put this legislation together, and I am interested to hear what our witnesses have to say about the potential benefits offered by space resource utilization.

It is my sincere hope that the Administration will stop spending time on poorly designed and executed missions such as ARM, and look to the private sector and scientists for input on the best way to maximize our limited resources.

[The prepared statement of Mr. Palazzo follows:]

PREPARED STATEMENT OF SUBCOMMITTEE ON SPACE
CHAIRMAN STEVEN M. PALAZZO

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This is not the type of review you want to hear from the experts that NASA has chartered to provide advice. While I am indeed interested in the opportunities offered by near-Earth objects, I continue to be concerned that the Administration is not heeding the warnings of these experts for the mission that it has designed.

Today we will also be discussing the bipartisan efforts of two members of this committee to offer a legal framework for the private sector to utilize celestial resources. The "American Space Technology for Exploring Resource Opportunities In Deep Space Act" or ASTEROIDS Act, is a bipartisan bill introduced by Congressman Posey and Congressman Kilmer. The two of them have worked very hard to put this legislation together and I am interested to hear what our witnesses have to say about the potential benefits offered by space resource utilization.

It is my sincere hope that the Administration will stop spending time on poorly designed and executed missions such as ARM and look to the private sector and scientists for input on the best way to maximize our limited resources.

At this time, I yield my remaining time to Mr. Posey from Florida.

Chairman PALAZZO. At this time, I yield my remaining time to Mr. Posey from Florida.

Mr. POSEY. Thank you, Mr. Chairman, for holding this hearing, which will include discussion on H.R. 5063, the ASTEROIDS Act. I would like to thank my colleague and original cosponsor, Congressman Derek Kilmer, for his work on this bill and the 10 bipartisan cosponsors who we already have on this Committee.

Mr. Chairman, this is an exciting bill, both in subject matter and as a matter of practical legislation. Space exploration is inspiring, and today we will discuss the importance of a legal framework to encourage a new area of private space exploration. Today, private companies do not have legal certainty that if they obtain resources from an asteroid that they can own them. The ASTEROIDS Act would provide this certainty to American companies, and companies are empowered to conduct their operations without harmful interference. Asteroids can hold valuable minerals, some in impressive quantities, as well as resources essential for continued space exploration.

I look forward to further discussion on this topic. Again, if you want American commercial space companies to get off the ground, we need to create the proper legal framework for them to do so.

Thank you, Mr. Chairman. I yield back.

Chairman PALAZZO. Thank you, Mr. Posey.

I now recognize the Ranking Member, the gentlelady from Maryland, Ms. Edwards.

Ms. EDWARDS. Thank you very much, Mr. Chairman, for holding today's hearing on planetary science, and I hope we do focus on the science, and I want to welcome our distinguished panel of witnesses this morning.

The accomplishments in planetary science research and robotic exploration of the solar system are indicative of the exemplary work being done by NASA and its industry contractors, academia, and the non-governmental entities that comprise the planetary science community. The discoveries and advancements being enabled by NASA's planetary science program are in fact thrilling.

Just weeks from now, NASA's MAVEN spacecraft will enter into Mars orbit for its study of the Mars atmosphere. In October, just over a month from now, it will be "all hands on deck" for our Mars orbiters and rovers when NASA will have an unprecedented opportunity to use these assets to observe C/2013 A1—otherwise known as Comet Siding Spring—as it passes near Mars and bathes the planet in dust from its coma and tail. It is fortuitous that MAVEN, which will be a key observer of this event, will have arrived just weeks before Siding Spring's encounter with Mars. Finally, later this fall, the European-U.S. Rosetta comet mission will make the first attempt at a controlled landing of a robotic lander on a comet.

What this means to me is that we are getting real value from our investments, our current investments, in planetary science, and in fact, I would point out that the authorization bill that was approved unanimously out of this Subcommittee, and out of this Congress, balances those investments with other investments that we are making in the other important missions of NASA. Because a strong planetary science program is important not only to advancing our scientific understanding of the solar system but also to detecting potentially hazardous near-Earth objects, providing scientific insights relevant to the long-term goal of sending humans to Mars and to training of our future scientists and engineers, and I can't underscore enough the importance of NASA's programs including planetary science to inspiring the next generation. NASA's science missions provide concrete connections between learning science, technology, engineering, and math in the classroom and exciting projects in space, perhaps even ones that students dream to be a part of one day.

Mr. Chairman, I look forward to hearing from our witnesses on the many developments taking place in planetary science. I also look forward to working with you on ensuring that Congress provides the resources NASA needs for all of its mission areas, including planetary science, to enable a robust and innovative 21st century U.S. space program going forward.

And while my understanding is that the purpose of this hearing is to examine planetary science, as well I note that the majority has asked for discussion on H.R. 5063, the ASTEROIDS Act. The issues raised by the Act on resource utilization and property rights are important and interesting areas that I hope the Subcommittee will continue to explore more substantively in the next Congress.

Before I close, I also want to acknowledge the presence of our former chairman, Bart Gordon, with us here today and say hello to him and thank him for his continued public service even outside of Congress, and I want to take a moment to remember a key figure in NASA's planetary sciences, Dr. Noel Hinners, who passed away just this last Friday. Dr. Hinners was a Chief Scientist of NASA, Director of the Goddard Space Flight Center out in Prince George's County, where I live. He directed also the Smithsonian's National Air and Space Museum, and was Vice President of Flight Systems at Lockheed Martin where he was responsible for Lockheed's work on planetary science missions. NASA's planetary science program wouldn't be what it is today without the contributions of leaders such as Dr. Hinners, and our thoughts and prayers are with his family during this difficult time.

I want to say in closing that we have a lot of issues to explore, and they aren't just about the United States. They implicate our partners internationally, so as we move forward, let's think about our responsibility not just to U.S.-based companies, and we are concerned about those, but also to connecting our concerns with our international partners so that we can truly move forward in a 21st century manner for our space program, and I yield back.

[The prepared statement of Ms. Edwards follows:]

PREPARED STATEMENT OF SUBCOMMITTEE ON SPACE
RANKING MINORITY MEMBER DONNA F. EDWARDS

Thank you, Mr. Chairman, for holding today's hearing on planetary science, and welcome to our distinguished panel of witnesses.

The accomplishments in planetary science research and robotic exploration of the solar system are indicative of the exemplary work being done by NASA and its industry contractors, academia, and the non-governmental entities that comprise the planetary science community. The discoveries and advancements being enabled by NASA's planetary science program are thrilling.

Just weeks from now, NASA's MAVEN spacecraft will enter into Mars orbit for its study of the Mars atmosphere. And in October, just over a month from now, it will be "all hands on deck" for our Mars orbiters and rovers when NASA will have an unprecedented opportunity to use these assets to observe C/2013 A1—otherwise known as Comet Siding Spring—as it passes near Mars and bathes the planet in dust from its coma and tail. It is fortuitous that MAVEN, which will be a key observer of this event, will have arrived just weeks before Siding Spring's encounter with Mars. Finally, later this fall, the European-U.S. Rosetta comet mission will make the first attempt at a controlled landing of a robotic lander on a comet.

What this means to me is that we are getting real value from our investments in planetary science. Because a strong planetary science program is important not only to advancing our scientific understanding of the solar system, but also to detecting potentially hazardous nearEarth objects, providing scientific insights relevant to the long-term goal of sending humans to Mars, and to the training of our future scientists and engineers.

And I can't underscore enough the importance of NASA's programs, including planetary science, to inspiring the next generation. NASA's science missions provide concrete connections between learning science, technology, engineering, and math in the classroom and exciting projects in space, perhaps even ones that students dream to be a part of one day.

Mr. Chairman, I look forward to hearing from our witnesses on the many developments taking place in planetary science. I also look forward to working with you on ensuring that Congress provides the resources NASA needs for all of its mission areas, including planetary science, to enable a robust and innovative 21st century U.S. space program going forward.

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Before I close, I want to remember a key figure in NASA and planetary sciences, Dr. Noel Hinners, who passed away last Friday. Dr. Hinners was a chief scientist of NASA, director of the Goddard Space Flight Center, director of the Smithsonian's National Air and Space Museum, and vice president of flight systems at Lockheed Martin where he was responsible for Lockheed's work on NASA planetary science missions.

NASA's planetary science program wouldn't be what it is today without the contributions of leaders such as Dr. Hinners, and our thoughts are with his family during this difficult time.

Thank you, and I yield back.

Chairman PALAZZO. Thank you, Ms. Edwards.

I now recognize the chairman of the full Committee, Mr. Smith, for his opening statement.

Chairman SMITH. Thank you, Mr. Chairman.

Planetary science teaches us about how our solar system works and provides clues about how it was formed. Planetary missions search for scientific evidence that microbial life could potentially exist on planets within our solar system. They also map the locations of minerals and potential water sources on asteroids, comets, moons, and planets that could be extracted for use here on Earth.

One such mission called New Horizons is a robotic mission scheduled to reach Pluto next year. It will provide the first close-up images and measurements ever made of that dwarf planet. A mission to Europa could search for microbial life in the salty waters that lie underneath that moon's icy crust.

The President's budget requests have made it clear that this Administration does not consider planetary science a priority. Over the past two years, the Obama Administration has significantly cut funding for NASA's Planetary Science Division.

In June, the House passed the bipartisan NASA Authorization Act of 2014 by a vote of 401 to 2. In May, the House passed the Commerce-Justice-Science appropriations bill H.R. 4660 by a bipartisan vote of 321 to 87. The bill provides $170 million more to the Planetary Science Division than the President's budget request for Fiscal Year 2015. The Senate Committee on Appropriations also approved a bill that would provide $23 million above the President's request.

Congress has made it clear, on a bipartisan and bicameral basis, that we value the planetary science community and the important work that they do. Planetary science missions help lay the groundwork for manned missions. If the Administration does not support planetary science, how can they claim to have serious interest in human space exploration? I hope that the Administration is paying attention to today's discussion.

Planetary research also has significant commercial interest. We now know that asteroids contain rare minerals that are in short supply here on Earth. Several U.S. companies hope to someday develop business models that leverage the findings of planetary science to identify and extract these resources.

The legal framework to establish property rights to these resources has yet to be established. H.R. 5063, the American Space Technology for Exploring Resource Opportunities in Deep Space Act—ASTEROIDS Act—introduced by Representatives Bill Posey of Florida and Derek Kilmer of Washington, is the first bill to address important issues about the relatively new commercial intent to obtain resources from space. It discusses property rights for companies that find rare minerals and other materials in asteroids. It also directs the President to minimize barriers to growth of the industry.

And Mr. Chairman, I look forward to hearing from our witnesses today about their perspectives, especially on the ASTEROIDS Act, and the groundbreaking work that is being conducted in planetary science.

I thank you, and I yield back.

[The prepared statement of Mr. Smith follows:]

PREPARED STATEMENT OF FULL COMMITTEE CHAIRMAN LAMAR S. SMITH

Thank you, Chairman Palazzo, for holding this hearing. Planetary science teaches us about how our Solar System works and provides clues about how it was formed.

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It discusses property rights for companies that find rare minerals and other materials in asteroids. It also directs the President to minimize barriers to growth of the industry.

I look forward to hearing from our distinguished panel of witnesses today about their perspectives on the ASTEROIDS Act and the groundbreaking work that's being conducted in planetary science.

Thank you.

Chairman PALAZZO. Thank you, Mr. Smith.

I now recognize the Ranking Member of the full Committee, Ms. Johnson, for her opening remarks.

Ms. JOHNSON. Thank you very much, and good morning. I want to join Chairman Palazzo and Ranking Member Edwards in welcoming our witnesses to this morning's hearing.

Hearings such as today's provide a clear reminder of the amazing advantages—advances that are possible when this Nation makes a sustained commitment to investing in research and development. It is not an overstatement to say that the planetary science missions that will be discussed today would have been considered the stuff of science fiction not too many years ago.

As I speak, a spacecraft is circling the planet Saturn and imaging its moons, and a robotic rover is preparing to climb a mountain on Mars and even attempt to image a comet that will be visible to the Martian sky. A spacecraft is on its way to Pluto, and we are discovering and tracking asteroids that could potentially threaten the Earth.

Just this past weekend, in conjunction with the comments that are made by both the chairman and Mr. Posey, I visited Brownsville, Texas, and the University of Texas at Brownsville's astronomy program and the site for the new SpaceX launching station.

We are living in a wonderful time of scientific exploration, and I look forward to hearing more about NASA's planetary science program this morning, but we also need to hear about what problems need to be addressed to ensure that this record of achievement can continue.

And with that, I want to welcome you again and look forward to your testimony. Thank you, Mr. Chairman, I yield back.

[The prepared statement of Ms. Johnson follows:]

PREPARED STATEMENT OF FULL COMMITTEEE
RANKING MEMBER EDDIE BERNICE JOHNSON

Good morning. I want to join Chairman Palazzo and Ranking Member Edwards in welcoming our witnesses to this morning's hearing.

Hearings such as today's provide a clear reminder of the amazing advances that are possible when this nation makes a sustained commitment to investing in research and development. It is not an overstatement to say that the planetary science missions that will be discussed today would have been considered the stuff of science fiction not too many years ago.

As I speak, a spacecraft is circling the planet Saturn and imaging its moons, and a robotic rover is preparing to climb a mountain on Mars and even attempt to image a comet that will be visible in the Martian sky. A spacecraft is on its way to Pluto, and we are discovering and tracking asteroids that could potentially threaten the Earth.

We are living in a wonderful time of scientific exploration, and I look forward to hearing more about NASA's planetary science program this morning. But we also need to hear about what problems need to be addressed to ensure that this record of achievement can continue.

With that, I again want to welcome our witnesses, and I look forward to hearing your testimony.

Chairman PALAZZO. Thank you, Ms. Johnson.

If there are Members who wish to submit additional opening statements, your statements will be added to the record at this point.

At this time I would like to introduce our witnesses. Our first witness, Dr. Jim Green, has served in numerous capacities within NASA throughout his career and has served as NASA's Director of Planetary Science since 2006. Dr. Green, an expert in space physics, has written more than 100 articles in referred journals, primarily on the subject of Earth's and Jupiter's magnetospheres. He has also authored over 50 articles on the technical aspects of networks and data systems. Dr. Green received his Ph.D. in physics from the University of Iowa.

Our second witness, Dr. Philip Christensen, is Co-Chair of the National Research Council's Committee on Astrobiology and Planetary Sciences and Regents Professor at Arizona State University. His work in developing, building, and operating infrared cameras and spectrometers has been invaluable in studying the surface of Mars as equipment designed by Dr. Christensen has mapped the surface composition, search for habitable environments and helped to select the sites for future Mars landers and rovers. He served on the NRC Planetary Science Decadal Survey as the Chair of the Mars Panel. Dr. Christensen is a fellow of the American Geophysical Union and the Geological Society of America, and is the Co-Chair of the National Research Council's Committee on Astrobiology and Planetary Science. Dr. Christensen earned a B.S. in geology and an M.S. and Ph.D. in geophysics and space physics from the University of California-Los Angeles.

Our third witness today is Dr. Jim Bell. Dr. Bell is a Professor in the School of Earth and Space Exploration at Arizona State University, an Adjunct Professor of Astronomy at Cornell University, and President of The Planetary Society. His career has focused on robotic space exploration, and he has been involved in a number of NASA space exploration missions including serving as the Lead Scientist in charge of the Panoramic Camera Color Imaging System on the Mars rovers Spirit and Opportunity, and as the Deputy Principal Investigator of the Mass Cam Camera System on the Curiosity Mars rover. Dr. Bell is a markedly active and prolific planetary scientist, having authored or co-authored nearly 200 research papers in peer-reviewed scientific journals. His research is frequently featured in publications such as *Sky and Telescope* and *Scientific American*. Dr. Bell received his B.S. in planetary science and aeronautics from the California Institute of Technology and obtained his M.S. in geology and geophysics and his Ph.D. in planetary geosciences from the University of Hawaii.

Our fourth witness is Dr. Mark Sykes, CEO and Director of the Planetary Science Institute. Dr. Sykes is Co-Investigator of the NASA Dawn Mission to Vesta and Ceres, and has chaired many NASA review panels and advisory groups. Dr. Sykes received his B.A. in physics from the University of Oregon and a master of electronic science degree from the Oregon Graduate Center. He then went on to obtain a Ph.D. in planetary sciences and a juris doctorate from the University of Arizona.

Our final witness, Professor Joanne Gabrynowicz, is Professor Emerita at the University of Mississippi and was the Editor-in-

Chief of the Journal of Space Law. She currently serves on the National Geospatial Advisory Committee, the NASA Advisory Committee's Planetary Protection Subcommittee, and the U.S. Department of Commerce's National Oceanic and Atmospheric Administration's Advisory Committee on commercial remote sensing. She is also the Director of the International Institute of Space Law and the Chair of its publications committee. She received her B.A. at Hunter College and her J.D. from Yeshiva University.

Thanks again to our witnesses for being here today. As our witnesses should know, spoken testimony is limited to five minutes each after which the Members of the Committee will have five minutes each to ask questions.

I ask unanimous consent at this time to enter into the record a letter from Planetary Resources. Without objection.

[The information appears in Appendix II]

Chairman PALAZZO. I now recognize Dr. Green for five minutes to present his testimony.

TESTIMONY OF DR. JIM GREEN, DIRECTOR, NASA PLANETARY SCIENCE DIVISION

Dr. GREEN. Mr. Chairman and Members of the Committee, I would like thank you so much for the opportunity to appear today and discuss briefly the status of NASA's Planetary Science Program.

NASA'S planetary science missions continue to explore our solar system in unrivaled scope and depth. NASA's spacecraft have visited every planet as well as a variety of small bodies that have much to tell us about the solar system's formation and evolution.

We are seeking answers to fundamental science questions that guide NASA's exploration of the solar system. These questions are: how did our solar system form and evolve? Is there life beyond Earth? And what are the hazards to life on Earth from our solar system objects?

With an exploration strategy based on progressing from fly-bys to orbiting to landing to roving and, finally, to return samples from planetary bodies, NASA advances the scientific understanding of our solar system in extraordinary ways while pushing the limits of spacecraft and robotic engineering, design and operations.

Briefly, beginning in our inner solar system, NASA's Messenger spacecraft has been orbiting the planet Mercury now for more than two years. Mercury's surface has been shaped by impact and volcanic processes. We also find that Mercury harbors abundant volatiles in permanently shadowed craters. At the moon, the LADEE mission successfully studied the very tenuous lunar atmosphere and dust environment until its planned impact on April 17th. With LADEE, we also successfully tested high-speed optical communication back to Earth. This technology will be a critical element in our future Mars missions and beyond.

At Mars, the Curiosity rover has landed in an ancient river bed. It has determined the age of the surrounding Martian rocks. It has found evidence that the planet could have sustained microbial life and taken the first readings of radiation on the Martian surface.

Launched in November last year, the MAVEN spacecraft will arrive at Mars on September 21st and will explore the red planet's upper atmosphere, ionosphere, and their interaction with the sun and solar wind. MAVEN will also be in time to study a comet that will fly very close to Mars on October 19th.

From the furthest reaches of our solar system, comet Siding Spring has traveled for more than a million years, and for the first time since it was formed will come close to Mars, flying into the inner solar system. Siding Spring will pass within 130,000 kilometers of Mars blanketing it with cometary material. Many of NASA's space missions and ground-based assets will be studying this once-in-a-lifetime event.

Future NASA missions to Mars include a new Mars rover planned for launch in 2020. For the first time, NASA scientists and university scientists will use Mars 2020 Rover experiments to carefully select a collection of rock and soil samples that will be characterized and stored for potential return to Earth. The Mars 2020 rover will also help advance our knowledge of how human explorers could use natural resources available on the red planet.

Asteroids are important objects within our solar system, deserving intense study. After successfully orbiting the huge asteroid Vesta, in March next year Dawn will successfully get into orbit around Ceres, the largest object in the main asteroid belt.

We are also developing a robotic asteroid rendezvous and sample return mission called OSIRIS–REx. The first U.S. mission of its kind, OSIRIS–REx is on track for launch in 2016.

With recent Congressional support, NASA's enhanced funding for the near-Earth object survey and characterization activities necessary to protect our planet and also support human exploration and technology has made steady progress. In just over 15 years, we have found over 11,000 near-Earth objects. We are making great progress but we have a lot yet to do.

After nine years of travel, in July 2012, the New Horizon spacecraft will make its historic flyby of the dwarf planet Pluto and its moons. It will then venture into deep space and into the Kuiper Belt.

In summary, our future missions will continue along this path of exploration, discovery and innovation, allowing our scientists to answer questions I posed earlier.

Again, thank you for the opportunity to testify today and your continued strong support for NASA's Planetary Science Program. I look forward to responding to any questions you may have.

[The prepared statement of Dr. Green follows:]

Statement of
Dr. James Green
Director, Planetary Science Division, Science Mission Directorate
National Aeronautics and Space Administration

before the

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

Chairman Palazzo, Ranking Member Edwards and Members of the Subcommittee, thank you for the opportunity to appear today to discuss the status of NASA's Planetary Science program and our missions, both current and planned. NASA's Planetary Science missions continue to explore our solar system in unrivaled scope and depth. NASA spacecraft have visited every planet as well as a variety of small bodies that have much to tell us about the solar system's formation.

Status of Planetary Science Missions
NASA's Planetary Science program is engaged in one of the oldest scientific pursuits: the observation and discovery of our solar system's planetary objects. As noted in NASA's 2014 Science Plan, our strategic objective in planetary science is to ascertain the content, origin, and evolution of the solar system and the potential for life elsewhere. We pursue this goal by seeking answers to fundamental science questions that guide NASA's exploration of the solar system: How did our solar system form and evolve? Is there life beyond Earth? What are the hazards to life on Earth? NASA advances the scientific understanding of the solar system in extraordinary ways, while pushing the limits of spacecraft and robotic engineering design and operations.

Beginning in the inner solar system, NASA's MESSENGER spacecraft has changed our understanding of the planet Mercury. After entering Mercury's orbit in 2011, MESSENGER observations have shown that the planet's surface was shaped by volcanic activity and identified unique landforms molded by the loss of volatile materials. It has also provided compelling support for the long-held hypothesis that Mercury harbors abundant water ice and other volatile materials in its permanently shadowed polar craters. Given the incredible science returns thus far, we look forward to continued discoveries through the end of its mission in March 2015, when the spacecraft will have expended all of its fuel.

Our moon also continues to be a point of study. This past November, the Lunar Atmosphere and Dust Environment Explorer (LADEE) was successfully lowered into its science data collection orbit about the moon, and following the mission's final low-altitude science phase, impacted the surface of the moon, as planned, on April 17. In an incredible race with time, LADEE's Real Time Operations team queued and downloaded all science files just minutes prior to LADEE's impact. Further study of the returned data will reveal what the instruments saw at these low orbits, just a few kilometers above the surface. Early results suggest that LADEE was low enough to view new things, including increased dust density, with the spacecraft's unique position providing a full scope of the changes and processes occurring within the moon's tenuous atmosphere. A thorough understanding of the characteristics of our nearest celestial neighbor will help researchers understand a great deal about the Earth and other bodies in the solar system, such as large asteroids and the moons of outer planets.

At Mars, we have several missions in operation and in development. The current Mars portfolio includes the *Curiosity* and *Opportunity* rovers, the Mars Reconnaissance Orbiter, the Mars Odyssey orbiter, and our collaboration with the European Space Agency's (ESA) Mars Express orbiter. It also includes the new Mars Atmosphere and Volatile EvolutioN (MAVEN) orbiter, which will arrive at Mars later this month.

Building on the success of the *Curiosity* rover, NASA's Planetary Science program will continue its strategic, multi-mission approach to thoroughly investigating Mars. In a little more than two years on the Red Planet, the mobile Mars Science Laboratory has landed in an ancient river bed, determined the age of the surrounding martian rocks, found evidence the planet could have sustained microbial life, taken the first readings of radiation on the surface, and shown how natural erosion could be used to possibly reveal the building blocks of life protected just under the surface. NASA's *Curiosity* rover is providing vital insight about Mars' past and current environments that will aid plans for future robotic and human missions.

MAVEN will explore the Red Planet's upper atmosphere, ionosphere and interactions with the sun and solar wind. Scientists will use MAVEN data to determine the role that loss of volatiles from the Mars atmosphere to space has played through time, giving insight into the history of Mars' atmosphere and climate, liquid water, and planetary habitability. NASA is also in discussions with the Indian Space Research Organization (ISRO) regarding potential scientific collaboration with their Mars Orbiter Mission (MOM), due to enter Mars orbit about two days after MAVEN. While primarily a technology-demonstration mission, MOM includes five science instruments to study the martian atmosphere, mineralogy and surface features. With multiple data sets being collected, NASA and ISRO scientists will have a wealth of information to help solve mysteries regarding the Mars atmosphere. In addition, NASA and ISRO are talking about setting up a Joint Mars Working Group, under the auspices of the State Department's U.S.-India Civil Space Joint Working Group, that would coordinate our two agencies' plans for studying one of the Earth's nearest neighbors. Finally, both missions will arrive at Mars just in time to join the fleet of Mars-based spacecraft that could witness the effects of comet Siding Spring.

Since the formation of our solar system, comets have been bombarding our inner planets providing water and organic materials necessary for life. From the furthest reaches of our solar system, known as the Oort Cloud, comet Siding Spring has travelled for more than a million years, and for the first time since it was formed, will pass near the sun. Our Mars missions will give us the first opportunity to image and study the nucleus of a comet from the Oort Cloud region. Comets that we have encountered before have been short period comets (with orbital periods less than 200 years) from the region of our outer planets, not from the more distant Oort Cloud.

Comet Siding Spring will pass within 130,000 km of Mars, blanketing it with the comet's coma and tail. NASA's space observatories and ground-based assets will be studying this event and observing how the martian atmosphere will respond to the interaction with the comet, helping us to learn more about how comets may have seeded our planet with water and the organic material we call the building blocks for life. Using data based on prior observations by the Hubble Space Telescope, the Spitzer Space Telescope, Near Earth Object Wide-field Infrared Survey Explorer (NEOWISE), *Swift* and ground-based telescopes, experts modeled the dust ejected from the comet that could pose a risk to our orbiting Mars spacecraft. It was determined that the risk of affecting the orbital assets is low; however, the spacecraft will adjust their orbits as a precaution, placing them on the other side of Mars during the period of greatest risk.

Future missions to Mars include the Interior Exploration using Seismic Investigations, Geodesy and Heat Transport (InSight) mission, which will launch and land in 2016, providing our first look into the deep interior of Mars; participation on ESA's 2016 and 2018 ExoMars missions; and the new NASA Mars rover planned for launch in 2020. The Mars 2020 rover will carry seven carefully selected instruments to conduct unprecedented science and exploration technology investigations on the Red Planet. And, while the Mars 2020 rover is based on *Curiosity's* design, its new, sophisticated instruments will conduct geological assessments of the rover's landing site, determine the potential habitability of the environment and directly search for signs of ancient martian life. For the first time, scientists will use the Mars 2020 rover to identify and select a collection of rock and soil samples that will be stored for potential return to Earth by a future mission. The Mars 2020 rover also will help advance our knowledge of how human explorers could use natural resources available on the surface of the Red Planet. Designers of future human expeditions can use this mission to understand the hazards posed by martian dust and demonstrate technology to process carbon dioxide from the atmosphere to produce oxygen.

With an expected arrival date of March 2015, the Dawn spacecraft is nearing its next target, the dwarf planet Ceres, the largest object in the main asteroid belt between Mars and Jupiter. After completing more than a year in orbit around the asteroid Vesta, Dawn found that Vesta's southern hemisphere boasts one of the highest mountains in the solar system and that striations encircling Vesta and other features point to a giant impact with another body. Once Dawn reaches Ceres it will allow scientists to compare two large asteroids that appear to have dramatically different histories. By studying these two distinct bodies with the same complement of instruments, the Dawn mission hopes to compare the different evolutionary path each took as well as to create a picture of the early solar system. Data returned from the Dawn spacecraft could provide opportunities for significant breakthroughs in our knowledge of how the solar system formed.

Asteroids and other small bodies are important features within our solar system and NASA is currently developing a robotic asteroid rendezvous and sample return mission, dubbed OSIRIS-REx (for Origins-Spectral Interpretation-Resource Identification-Security-Regolith Explorer), which is planned to launch in 2016. The first U.S. mission of its kind, OSIRIS-REx will approach the near-Near Earth Asteroid 1999 RQ36 (Bennu), map the asteroid, and collect a sample of at least 60 grams for return to Earth in 2023. This mission will help scientists investigate how planets formed and how life began, as well as improve our understanding of asteroids that could impact Earth. The OSIRIS-REx mission will also help prepare and accumulate data for NASA's Asteroid Redirect Mission (ARM) in the areas of remote observation and proximity operations. ARM integrates several building blocks of human space exploration to initiate deep space exploration (our International Space Station experience, Orion and the Space Launch System, Solar Electric Propulsion and other technologies) and contributes significantly to the extension of the human exploration of space beyond Low Earth Orbit (LEO) in an affordable and sustainable way. The crewed mission segment of the ARM will operate a thousand times further than Low Earth Orbit, further from the planet than humans have ever traveled.

NASA leads the world in the detection and characterization of Near Earth Objects (NEOs), and is responsible for the discovery of about 98 percent of all known NEOs. NASA is leading a wide array of activities related to NEOs, including a long-standing ground-based observing campaign, focused flight missions to study both asteroids and comets, as well as conceptual studies and technology development to improve our ability to find NEOs. NASA uses radar techniques to better characterize the orbits, shapes, and sizes of observable NEOs, and funds research activities to better understand their composition and nature. NASA also funds the key reporting and dissemination infrastructure that allows for world-wide follow-up observations of NEOs as well as research related activities, including computer modeling, sample analysis and workshops to disseminate information about NEOs to the larger scientific and engineering community. The cumulative discovery of Near-Earth Asteroids, the largest subset of NEOs, started picking up dramatically in 1998 with the start of NASA's Spaceguard search program and the number of known NEOs has grown from a few hundred to over 11,000 in just 15 years.

NASA enhanced funding for the Near Earth Object survey and characterization activities in support of human exploration and to protect our planet. NASA has expanded our use of ground-based observatories to identify and characterize NEOs of all sizes, including those that are potential targets for the ARM mission. NASA's NEO Observation Program currently funds three survey teams that operate five ground-based telescopes involved in the NEO search effort. Each team conducts independent operations for 14 to 20 nights per month, as weather permits, avoiding approximately a week on either side of the full moon when the sky is too bright to detect these extremely dim objects from the ground. This year, the Wide-field Infrared Survey Explorer was reactivated, renamed NEOWISE and given a new mission to assist NASA's efforts to identify the population of potentially hazardous near-Earth objects (NEOs). While NEOWISE is not designed to discover a large number of NEOs, it will take infrared observations of previously discovered NEOs to produce more accurate size estimates, and to better determine the overall population size distribution.

At our outer planets, NASA's Cassini spacecraft continues its long reconnaissance of Saturn and its moons, and will do so through 2017, when it will fly a daring mission **between** the rings and the cloud tops, before finally plunging into the planet. Last summer, NASA's Cassini mission released a natural-color image of Saturn from space, the first in which Saturn, its moons and rings, and Earth, Venus and Mars, are all visible. It is also providing scientists with key clues about Saturn's moon Titan, and in particular, its hydrocarbon lakes and seas. Scientists working with the spacecraft's radar instrument have put together the most detailed multi-image mosaic of the region in Titan's northern hemisphere to date.

Other outer planet missions include the Juno mission to Jupiter and the New Horizons mission to Pluto. Launched in 2011, the Juno mission is on its way to Jupiter with an expected arrival in 2016. During its one-year mission in polar orbit, Juno will draw a detailed picture of Jupiter's magnetic field and find out whether there is a solid core beneath its deep atmosphere. After nine years of travel, in July 2015, the New Horizons spacecraft will flyby Pluto as the first mission to conduct a reconnaissance of Pluto and its moons and will then venture deeper into the distant Kuiper Belt, a relic of solar system formation that comprises many Pluto-like objects. This mission will help us understand worlds at the edge of our solar system and will explore how ice dwarf planets like Pluto have evolved over time.

Additionally, NASA's Planetary Science program includes pre-formulation activities for two potential new missions. In October, NASA plans to release a final Announcement of Opportunity for a new Discovery-class, Principle Investigator led mission, whose destination and science will be identified when selected. Most recently, NASA issued an Announcement of Opportunity (AO) for proposals for science instruments that could be carried aboard a potential future mission to Jupiter's icy moon, Europa. Selected instruments could address fundamental questions about the icy moon and the search for life beyond Earth. With compelling evidence of a liquid water ocean beneath its crust, exploration of Europa is vital to our understanding of the habitability of other planets.

Finally, NASA's commitment to planetary exploration research and analysis (R&A) activities also remains strong and the Planetary Science program continues to lead the world in this area, while ensuring that mission enabling activities are linked to the strategic goals of the agency. Broadly defined, R&A covers the concept studies that provide the science basis for a mission, the necessary technology and techniques for implementing the mission, the calibration, validation, and analysis of data as a mission is underway, and the analysis of archived data after a mission ends. The ultimate goal is to create new knowledge as we explore the Universe, and to use that knowledge for the benefit of all humankind.

One example of this successful strategy is the Solar System Exploration Research Virtual Institute (SSERVI), which is supported by NASA's Science and Human Exploration and Operations Mission Directorates. Recognizing that science and exploration go hand in hand, SSERVI aims to conduct basic and applied research fundamental to lunar and planetary sciences while advancing human exploration of the solar system. SSERVI research not only includes the Moon but also investigations related to NEOs, the martian moons Phobos and Deimos, and the near space environments of these target bodies. This broad approach encourages collaborative lunar and planetary research, while enabling cross-disciplinary partnerships throughout the science and exploration communities.

Conclusion

NASA Planetary Science program continues to expand our knowledge of the solar system, with spacecraft in place from the innermost planet to the very edge of our sun's influence. For decades, NASA has broadened its reach with increasingly capable missions and has produced a series of exciting achievements in planetary science. With your support, our future missions will continue along this path of exploration, discovery and innovation.

Again, thank you for the opportunity to testify today and your continued support of NASA's Planetary Science program. I look forward to responding to any questions you may have.

Biography

Dr. Jim Green, Planetary Science Division Director

Dr. Green received his Ph.D. in Space Physics from the University of Iowa in 1979 and began working in the Magnetospheric Physics Branch at NASA's Marshall Space Flight Center (MSFC) in 1980. At Marshall, Dr. Green developed and managed the Space Physics Analysis Network that provided scientists all over the world with rapid access to data, to other scientists, and to specific NASA computer and information resources. In addition, Dr. Green was a Safety Diver in the Neutral Buoyancy tank making over 150 dives until left MSFC in 1985.

From 1985 to 1992 he was the head of the National Space Science Data Center (NSSDC) at Goddard Space Flight Center (GSFC). The NSSDC is NASA's largest space science data archive. In 1992, he became the Chief of the Space Science Data Operations Office until 2005, when he became the Chief of the Science Proposal Support Office. While at GSFC, Dr. Green was a co-investigator and the Deputy Project Scientist on the Imager for Magnetopause-to-Aurora Global Exploration (IMAGE) mission.

He has written over 100 scientific articles in refereed journals involving various aspects of the Earth's and Jupiter's magnetospheres and over 50 technical articles on various aspects of data systems and networks.

In August 2006, Dr. Green became the Director of the Planetary Science Division at NASA Headquarters.

Over his career, Dr. Green has received numerous awards. In 1988, he received the Arthur S. Flemming award given for outstanding individual performance in the federal government and was awarded Japan's Kotani Prize in 1996 in recognition of his international science data management activities.

Chairman PALAZZO. Thank you, Dr. Green.

I now recognize Dr. Christensen for five minutes to present his testimony.

TESTIMONY OF DR. PHILIP CHRISTENSEN, CO-CHAIR, NRC COMMITTEE ON ASTROBIOLOGY AND PLANETARY SCIENCE (CAPS), CHAIR, MARS PANEL, NRC PLANETARY DECADAL SURVEY, REGENTS PROFESSOR, ARIZONA STATE UNIVERSITY

Dr. CHRISTENSEN. Mr. Chairman, thank you very much for the opportunity to speak with you today.

Three themes are going to run through my testimony today. The first is that planetary science has excellent opportunities for continuing the exploration of our solar system, and these opportunities have been clearly defined in the recent National Research Council's Planetary Science Decadal Survey. Second, the significant reductions in the level of funding from NASA's Planetary Science Division from the previous decade have dramatically slowed the pace of new missions and future discoveries. And third, the lack of year-to-year stability in funding is having a serious impact on our ability to develop a long-term plan for planetary exploration.

The NASA Planetary Science program has made a remarkable series of discoveries over the past several decades and is poised to continue to make major discoveries based on the plans outlined in the Decadal Survey. That report represented the consensus of the U.S. planetary science community and clearly defined a program centered around a suite of missions of differing sizes to explore the highest-priority objects in our solar system. The survey emphasized balance, both the importance of a balanced suite of small, medium and large missions, and also the importance of a balance of destinations.

In the three years following the release of the Decadal Survey, the key recommendations and priorities remain essentially unchanged and they continue to have the strong support of the planetary science community.

The primary challenge that the planetary program has faced in implemented the survey's recommendations have been the significant reduction in funding that occurred almost immediately after the report was completed. In Fiscal Year 2013, planetary funding was reduced by over 20 percent from previous years and has remained close to that level since then. Congress has worked extremely hard to increase the budget in each of the past two years but the funding remains well below what is needed to implement the Decadal Survey recommendations.

Equally important, year-to-year uncertainties in funding have made long-term planning extremely difficult. Planetary missions require many years to implement and operate, and without stable funding, these new missions either cannot be started or their development is stretched out with the inevitable increase in mission cost.

In spite of these stresses, there have been some major positive advances. In my view, the three key areas of progress and caution are the following. First, the highest-priority Decadal Survey recommendation to begin the campaign to return samples from Mars has been initiated with the approval of Mars 2020 rover. This first element will focus on collecting the samples. The follow-on missions will retrieve those samples and bring them back to Earth. In order for the sample return campaign to be successful and to remain true to the priorities laid out in the Decadal Survey, it is essential that this Rover remain focused on collecting and caching a suite of high-quality samples. Looking to the future, NASA also needs to start now to begin developing the technologies that will allow us to bring those samples back to Earth.

Europa was the second-highest-priority flagship recommendation in the Decadal Survey, and this mission has received support from Congress and NASA through the plans to request proposals for instruments to be carried on a future mission to explore Europa. This is a major step towards exploring that planet but it is only the beginning. The mission will require significant new funding to be implemented. In order to maintain a balance within the planetary science community, it is essential that the outer solar system remain a key part of NASA's portfolio. While the continued support for Europa from Congress is very encouraging, the commitment to start this mission needs to be made in earnest.

And finally, the reduction in planetary funding has led to a delay in starting the next New Frontiers and Discovery missions. The next new Discovery mission is being initiated but there are no plans to work on the next New Frontiers missions. These small- and medium-sized missions are key elements of the overall strategy for a balance of mission sizes.

With regard to human exploration, the robotic program at Mars, the Mars science program can and should play a major role in the long-term goal of sending humans to Mars. Much of the information that will be required to safely land and return humans from the surface is being obtained by the Robotic Science program. The properties of the surface, the nature of the atmosphere, the location of water, these are all areas of intense investigation by the ongoing Mars Science program.

In summary, planetary science and exploration have virtually unlimited opportunities. These opportunities have been very thoughtfully outlined. NASA is ready to explore the amazing places of Mars and Europa and we look forward to the opportunities to complete that exploration.

Thank you very much.

[The prepared statement of Dr. Christensen follows:]

Statement of
Dr. Philip R. Christensen
Ed and Helen Korrick Professor
School of Earth and Space Exploration
Arizona State University

before the

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

Mr. Chairman and Members of the Committee, thank you for the opportunity to appear today. My name is Philip R. Christensen, and my title is Ed and Helen Korrick Professor of Geological Science at Arizona State University. I have actively participated for the past 35 years in a range of NASA planetary science missions. I recently chaired the Mars Panel of National Research Council's Planetary Decadal Survey and currently co-chair the Committee on Astrobiology and Planetary Science for the NRC. The views that I present today are my own, and do not represent the opinions of the National Research Council or any other organization.

Three themes run through my testimony today:

- Planetary science has excellent opportunities for continuing the exploration of our solar system into the future. These opportunities have been clearly defined in the recent NRC Planetary Science Decadal Survey, Vision and Voyages in the Solar System (National Academies Press, 2011), and they remain the same today.

- Significant reductions in the level of funding for NASA's Planetary Science Division from the previous decade have dramatically slowed the pace of new missions and future discoveries.

- The lack of year-to-year stability in funding is having a serious impact on the ability to develop a long-term plan for planetary exploration.

Planetary science and the Decadal Survey

The NASA planetary science program has made a remarkable series of discoveries over the past several decades that have dramatically changed our views of the solar system we live in. This program is poised to continue to make major discoveries based on the plan and architecture outlined in the NRC's Planetary Science Decadal Survey report. That report represented the consensus of the U. S. planetary science community that was reached through over two years of effort on the part of hundreds of scientists and engineers. The Decadal Survey clearly defined a program centered around a suite of missions of differing sizes that will explore the highest priority objects in our solar system. These missions include the highest priority objective - a Flagship mission to begin the Mars sample return campaign by collecting and caching samples on the martian surface for return to Earth. The proposed suite of missions also includes a mission to explore Europa, a moon of Jupiter with a liquid water ocean beneath an icy crust, as well as a robust and balanced program of Discovery and New Frontiers missions. The report emphasized the importance of continued support for the research and analysis of the wealth of data returned from past missions, as well as the development of new technologies that will enable continued discovery into the future.

A key point of the Survey was its emphasis on program balance – the importance of a balanced suite of small-class Discovery, medium-class New Frontiers, and Flagship missions that will maintain the strength and world leadership of the planetary science and engineering communities. The Survey also stressed the importance of a balance of targets within the solar system, including Mars, the outer planets and their satellites, the inner terrestrial planets, and the diversity of comets and asteroids that are found throughout our solar system.

In the three years following the release of the Decadal Survey the key recommendations and scientific priorities remain essentially unchanged. The Decadal Survey continues to provide an excellent plan for planetary exploration. And the report continues to have the strong support of the planetary science community.

Challenges

The primary challenge that the planetary program has faced in implementing the Decadal Survey recommendations has been the significant reduction in planetary science funding that occurred after the report was completed. The detailed scientific rationales and plans laid out in the Decadal Survey were based on the continuation of planetary science funding at the level that had been provided during the previous 10 years. Almost immediately following the Report's release, the fiscal year 13 funding to planetary science was reduced by over 20% from the previous year – the cut to the Mars Program was 35% - and has remained at essentially this level in the President's budget proposed in the subsequent years. Not surprisingly this 20% reduction has had a dramatic effect on solar system exploration.

With the strong support of Congress the planetary science budget has been increased from the President's proposed budget in each of the past two years. Despite these increases, however, planetary science funding has remained well below the preceding years, and well below what is needed to implement the Decadal Survey recommendations.

Equally important, the uncertainties that exist in the year-to-year levels of support have made long-term planning extremely difficult. Planetary missions require many years, or even decades, to plan, develop, implement, and operate. As an example, the Voyager spacecraft now on the fringes of interstellar spa were launched in 1977 and their planning and development began even earlier. Without stable funding it is very difficult to implement these long-term missions, with the result that missions are either not begun or their development is extended, with a resultant increase in mission cost.

The reductions and uncertainties in planetary science funding that have occurred have resulted in significant slowing of the pace of new missions. These reductions also pose the threat of significant reductions in the scope of even the highest priority missions. And these reductions have placed stress on the programmatic and destination balance within planetary science – there simply hasn't been sufficient support to maintain the mix of mission sizes and destinations that had been the hallmark of NASA's planetary exploration program.

Where we are

In spite of these stresses, there have been major positive advances. In my view the key areas of progress, and concern, are the following:

- The highest priority Decadal recommendation - to begin the campaign to return samples from Mars - has been initiated with the approval of the Mars 2020 rover. This rover will carefully collect and cache a suite of high-quality samples to be returned to Earth by future missions. However, looking to the future, the planetary program needs to start now to begin developing the technologies required to return these samples. Without this development the return of these samples to Earth for study – which was the very element that made this mission the highest NRC priority – is in jeopardy of slipping well into the future. In addition, any increases in the development costs for Mars 2020 could threaten the capability of the caching system. In order to meet the goals laid out in the Decadal Survey, it is essential that Mars 2020 retain the capability to collect and cache a suite of high quality samples that will enable the extraordinary science payoff that will come when these samples are returned to Earth.
- Europa, the second highest Flagship recommendation in the Survey, has received support from Congress and NASA through the release of a request for proposals for science instruments that could be carried aboard a future mission. This is an important next step for exploring Europa. But it is only the beginning - the mission will require significant new funding to be implemented. In order to maintain balance within planetary science it is essential that the outer solar system remains a key part of NASA's portfolio. While the continued support for Europa from Congress and the Administration is very encouraging, it is important that the commitment be made to start this mission in earnest. Continued funding at levels below what are required to initiate the mission has the risk of adding to its overall cost.
- The planetary science Research and Analysis Program has managed to maintain a strong program during these times of rapid budget reduction. The research program is an essential part of the program, and in the past has been raided to make up shortfalls in the mission funding. This has not been the case in recent years.
- Perhaps the greatest difficulty that the planetary science program faces with the reduction in funding has been the delay in starting the next New Frontiers and

Discovery missions. These missions provide important opportunities for the planetary science community to follow up on new discoveries and pursue new directions. In many ways these missions provide lifeblood to the community by providing motivation and opportunities for early- and mid-career scientists and engineers. The selection process to identify the next Discovery mission is being initiated this year, but there are no plans to begin work on the next New Frontiers mission in the foreseeable future.

Human and Robotic Exploration of Mars

The Mars science program can, and should, play a major role in the long-term goal of sending humans to Mars. Much of the information that will be required to safely land and return humans from the martian surface is being obtained by the robotic program. The physical and chemical properties of the surface, the nature and state of the atmosphere, the occurrence of water and other critical resources, are all areas of intense investigation by the Mars science program. In addition, the robotic science program can make significant progress on several of the key technological and programmatic issues that human missions will eventually face, such as issues of how to land on and leave the martian surface, how to utilize the resources available on Mars, and how to deal with planetary protection and radiation hazards. All of these can be addressed by the ongoing scientific study of Mars and a robotic campaign to return samples from the surface.

Summary

In summary, planetary science and exploration have virtually unlimited opportunities. These opportunities have been thoughtfully outlined in the NRC's Planetary Science Decadal Survey, and the priorities described in that plan remain the same today. The current level of reduced funding, and the year-to-year uncertainties in that funding, have slowed the pace of new missions, but the U.S. planetary scientists and engineers remain engaged and committed to a balanced program of solar system exploration. Mars and Europa provide amazing opportunities for major discoveries regarding the possibility of habitable worlds in our solar system. NASA needs to remained focused on these highest priority targets, and remain on the path to return samples from Mars and to send a highly capable mission to explore Europa.

Dr. Philip Christensen is a Regents Professor of planetary geoscience in the School of Earth and Space Exploration at Arizona State University. His work is focused on developing, building, and operating infrared cameras and spectrometers, five of which have flown to Mars on NASA's Mars Observer, Mars Global Surveyor, Mars Odyssey, and the two Mars Exploration Rover missions. These instruments use infrared observations to map the surface composition, search for habitable environments, and help select the sites for future Mars landers and rovers. They have discovered ancient lake deposits, salt deposits evaporated from water early in Mars history, and sites of recent snow accumulation and melting. Most recently he has begun developing an infrared spectrometer for the OSIRIS-REx mission, which will study a small asteroid and return samples to the Earth. Over the past 10 years, Dr. Christensen has been working on concepts for Earth-orbiting cameras and sensors to study the urban environment of cities worldwide. Dr. Christensen is a Fellow of the American Geophysical Union and the Geological Society of America, received the Geological Society of America's G.K. Gilbert Award in 2008 and NASA's Exceptional Scientific Achievement Medal in 2003 and NASA's Public Service Medal in 2005. He served on the NRC Planetary Science Decadal Survey in 2010-2011 as the chair of the Mars Panel and is currently the Co-Chair of the NRC's Committee on Astrobiology and Planetary Science.

Chairman PALAZZO. Thank you, Dr. Christensen.

I now recognize Dr. Bell for five minutes to present his testimony.

TESTIMONY OF DR. JIM BELL,
PROFESSOR OF EARTH AND SPACE SCIENCE EXPLORATION,
ARIZONA STATE UNIVERSITY,
AND PRESIDENT, BOARD OF DIRECTORS,
THE PLANETARY SOCIETY

Dr. BELL. Thank you, Mr. Chairman, Members of the Committee for the opportunity to appear today to discuss the future of one of our Nation's crown jewels, which is NASA's Planetary Science and Solar System Exploration program. I am a Professor in the School of Earth and Space Exploration at Arizona State University, and I also serve as President of the Planetary Society, the world's largest public space advocacy organization, and today I am representing about 45,000 members of the Society. We are a nonprofit, independent organization of private citizens dedicated to advancing space science and exploration. The Planetary Society believes strongly that planetary exploration is a crucial program in a balanced NASA and that this exploration should follow the path recently defined by the National Academy of Science's Decadal Survey of Planetary Sciences.

I am also a professional planetary scientist so I brought some pictures. We can't talk about the beauty of our solar system without showing some examples. So let us put the next slide up, please.

[Slide.]

Our members, the members of the Planetary Society, respond to planetary exploration for many of the same reasons much of the public does. It is bold and daring like Curiosity here having landed on Mars in 2012. It tackles some of the most fundamental questions that humans have been asking for millennia: where did we come from, are we alone, how common is life, and can it take hold on other places besides Earth.

Next slide, please.

[Slide.]

As described in more detail in my written testimony, for the past 50 years, planetary science has made tremendous progress toward answering these questions, but like the tracks in the Curiosity rover here, we have only scratched the surface. Recent planetary science missions reveal a solar system filled with worlds begging for further exploration. Recent discoveries that you have heard about include water ice on the moon's poles, evidence from an early warm and wet climate on Mars, liquid water oceans under the surface of Jupiter's moon Europa shown in the next slide here, this gorgeous mosaic from the Galileo mission, and liquid hydrocarbon lakes on Saturn's moon Titan, shown in the next slide, one of those lakes showing here glinting in the sunlight from the Cassini mission view.

At the same time, astronomers have discovered hundreds of new planets orbiting other stars, allowing scientists to study how other planetary systems formed, what they are like and how they teach us about our own home. The Planetary Society is proud to support them and in many cases partner with NASA in these endeavors.

Among the requests in your invitation letter, you asked me to address concerns that we have about funding levels for NASA's Planetary Science program as well as to provide feedback on H.R. 5063. Next slide, please.

[Slide.]

Regarding NASA funding, NASA's Planetary Exploration program seems healthy today because of all the exciting missions and discoveries currently underway but it is important to note that today's successes were enabled by strong and consistent funding from the previous decade. It is the funding trajectory looking forward that is concerning, and that is where we believe there is a crisis for planetary exploration. The consistent stream of publicly exciting, scientifically compelling missions that we have all come to expect of NASA is coming to an end, largely because of proposed cuts to Planetary Science.

Now, to be clear, Congress has helped to restore some of that funding, and we thank you very much for that, but the long-term outlook for planetary science still remains at risk, and this chart that I just had up there shows that NASA had an average of about six new missions per year in the previous decade at a launch rate of about one per year, and that record of launches and missions is what has led to this golden age of planetary exploration that we are in. Over that time period, NASA's Planetary Science Division budget averaged about $1.5 billion per year, or less than ten percent of NASA's total annual funding. But since 2013, proposed planetary budgets have been cut below that historic average, and the average number of missions in the pipeline has plummeted in half, and indeed, only four launches are planned to occur before 2020, so the result is a de facto policy of withdrawal from some of the most exciting and scientifically compelling work that NASA does. We believe that there should be more of these missions, not fewer. Next slide.

[Slide.]

Regarding the ASTEROIDS Act, the issue of resources on asteroids is particularly compelling from the scientific perspective. Lots of interesting questions about the history of Earth's water, how do large impacts like from large asteroids like Eros seen here influence the development of life on our home planet, which asteroids represent impact hazards, and the issue is also compelling as we begin to imagine a future when humanity is moving outward beyond our home world. The Planetary Society recognizes that an agreed-upon policy regarding property rights for resources mined from asteroids will eventually be important for commercial investment. Since this is an area of current controversy among specialists, we advise careful thought and deliberation before moving forward in this area, and we embrace H.R. 5063's call to develop the frameworks necessary to attract commercial investment.

In closing, over the past half-century—next slide, please—discoveries in planetary science point to a rich and diverse solar system and provide tantalizing clues as to whether life exists elsewhere. The public, like the young people shown here who watched and rooted for Curiosity's daring landing on Mars in August 2012 in

Times Square, is clamoring for planetary exploration. Students and teachers are inspired to learn and share more about science and engineering and to search for deeper understanding of the worlds around us.

NASA's Planetary Science program has a clear plan in the Decadal Survey, has the people in place to continue the journey, and the question is whether we made a priority and given the resources to meet the challenge. We strongly believe it should.

On behalf of the members of the Planetary Society, I would like to again thank the Committee and the Congress in general for their solid support of America's planetary science exploration program over the past several years. I would also like to thank you personally for the opportunity to address you all today and to share my own thoughts on the importance of NASA's planetary exploration program for the Nation and for the world.

Thank you, Mr. Chairman.

[The prepared statement of Dr. Bell follows:]

Statement by
Dr. James F. Bell
President of The Planetary Society & Professor at Arizona State University

before the

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

10 September 2014

Mr. Chairman and Members of the Subcommittee, thank you for the opportunity to appear today to discuss the future of one of our nation's crown jewels: NASA's planetary science and solar system exploration program. My name is Jim Bell. I'm a Professor in the School of Earth and Space Exploration at Arizona State University and a planetary scientist involved in a number of NASA robotic planetary exploration missions, including the Opportunity and Curiosity rovers and the upcoming Mars-2020 rover.

I also serve as President of The Planetary Society, the world's largest public space advocacy organization, where today I am representing more than 45,000 current members, and more than half a million people total from around the world who have been members since we were founded in 1980. Our membership is comprised of individuals who are excited, inquisitive, and inspired by the bold missions that explore our solar system and beyond. We are a nonprofit, independent organization that seeks to know the Cosmos and our place within it. We work to empower citizens to advance space science and exploration. Promoting planetary exploration by NASA and other space agencies is one of the core goals of our organization.

Our members respond to planetary exploration for the same reasons much of the public does: it tackles some of the most fundamental questions we ask ourselves. Where did we come from? Are we alone? How common is life and can it take hold in places other than Earth?

The wonderful thing about planetary science is that we, the science and space community, have the power to attempt to answer these questions directly. We can build a spacecraft to search for hints of life on Jupiter's ocean moon, Europa. We can robotically grab samples from some of the solar system's oldest bodies—asteroids—and return them to Earth for analysis. We can drill into the ancient surface of Mars for clues to the past habitability of the red planet. We can send missions to Uranus or Neptune to better understand the enigmatic (and possibly similar) exoplanets discovered by the Kepler Space Telescope. For the first time in human history, our ambition is no longer bounded by limits in technology, but by self-imposed limitations on resources.

In the past half century, we have witnessed a revolution in our understanding of our planetary neighbors. This revolution has been motivated by human curiosity, by the urge to explore, and by the need to pursue answers to fundamental questions about our origins. And it was fueled by modest funding levels that never peaked at more than 12% of NASA's entire budget.

Robotic planetary exploration also provides crucial data and initial reconnaissance that support future human exploration. NASA followed this path during the 1960s, and is doing so again with its Mars and asteroids missions.

But, as I will discuss, the future of planetary exploration—and the ability to answer the compelling, fundamental questions mentioned above—has been severely undermined by disproportionate cuts initiated by the Administration in recent years. These cuts have dramatically reduced NASA's ability to explore the solar system, and have forced the United States into a unilateral retreat from both the outer and inner solar system. The near-term effects of this retreat can no longer be prevented, but a supportive Congress and a receptive White House can minimize its impact with a small adjustment in funding beginning next fiscal year.

In your invitation letter, you asked me to address the issues facing the planetary science community, NASA's proposed budget for planetary science, ways to encourage the development of deeper partnerships between space science and industry, as well as to provide commentary on the American Space Technology for Exploring Resource Opportunities In Deep Space (ASTEROIDS) Act.

I will begin by sharing The Planetary Society's concerns about funding levels at NASA for Planetary Science.

There are two important points to keep in mind when discussing the health of the planetary science program:

1. **Discoveries in planetary science depend on planetary exploration missions.** Missions are the lifeblood of the field. They directly measure a variety of phenomena that cannot be detected by Earth- or space-based telescopes or simulated in laboratories or computers, providing crucial data that cannot be gathered any other way. Without missions, new science is severely limited.
2. **Today's funding pays for tomorrow's missions.** Long lead times are required to plan, design, build, and launch planetary spacecraft, and the vast majority of their cost is incurred during these development stages. Current missions, or those about to launch, have already been paid for by significant previous investments. Cuts made today won't manifest themselves until years later.

With this in mind, we see that the impressive list of missions currently exploring our solar system from Mercury to Pluto and beyond is the result of strong funding from the previous decade. Looking at the period covered by the first National Academy of Sciences Planetary Decadal Survey (2003 – 2012), NASA's Planetary Science Division was funded at an average of $1.53 billion per year, adjusted for inflation.

Starting with its FY2013 budget request, the Administration began to levy disproportionate cuts on NASA's Planetary Science Division, initially proposing a 21% cut and pulling out of a joint Mars exploration mission with the European Space Agency. The Administration has continued to target planetary science in its FY2014 and FY2015 budget requests, despite Congressional resistance, with funding hovering around $230 million below the previous decade's average.

At the same time, NASA's Planetary Science Division has had to take on additional programmatic responsibilities. The crucial need for Plutonium-238 as an energy source in spacecraft drove NASA's Planetary Science Division to pay the Department of Energy (DOE) to restart production of this crucial isotope. And beginning in FY2014, the DOE's Radioisotope Power Systems infrastructure costs were also shifted to the planetary program. This works out to around $70 million per year to pay the DOE for services they had provided to NASA since the 1960s.

The Planetary Society is not arguing about who should pay for this important program. Plutonium-238 fuel is a requirement for planetary exploration and restarting production is one of the great success stories in modern space policy, but this must be acknowledged as a drain on already diminished resources.

The other issue is an increased number of operating missions. Now, this is a good problem to have, but the twelve currently-active missions combined consume hundreds of millions of dollars within the planetary budget. Many missions are already operating at severely scaled back levels and have sacrificed science to preserve continued operations.

These two developments have exacerbated the disproportionate cuts to NASA's Planetary Science Division, and we have already seen mission opportunities delayed and cancelled. The number of missions in development are dwindling [see Figure 1], reaching near-record lows by the end of this decade. In 2017, both the Cassini mission to Saturn and the Juno mission to Jupiter will reach their end, and NASA will "fade to black" in the outer solar system for the first time since the early 1970s[1]. The end of MESSENGER at Mercury in 2015 will cause a similar fade to black in the inner solar system. NASA has no official plans to return to either area of our solar system, though the Europa Clipper mission is a possible opportunity being discussed for an outer planets mission.

The current Decadal Survey, the National Academy's *Visions and Voyages for Planetary Science 2013 – 2022,* recommended a balanced planetary exploration program of small, medium, and flagship missions, with stable research funding and technology development. NASA's Planetary Science Division has done an admirable job in tough budgetary circumstances, and some priorities are being met—like the caching capability built into the Mars-2020 rover—but fundamentally, the budgets requested by the Administration since FY2013, as well as the increased programmatic commitments on the Planetary Science Division, do not support the recommended program by the Decadal Survey.

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[1] U.S. Planetary Science: Fading to Black, Hinners and Braun, Space News, April 22, 2013 – Attached.

The Planetary Society believes strongly that planetary exploration is a crucial program in a balanced NASA. The United States has invested billions over the decades to develop unprecedented capabilities in deep space exploration. There are fundamental questions that the scientific community can attempt to answer. And robotic exploration itself is a modest budget line within NASA, rarely approaching even 1/10th of the agency's total budget. Planetary science, along with NASA science programs in general, have clear, achievable, accepted goals defined by the Decadal Survey, and the potential to further revolutionize our understanding of the Universe around us.

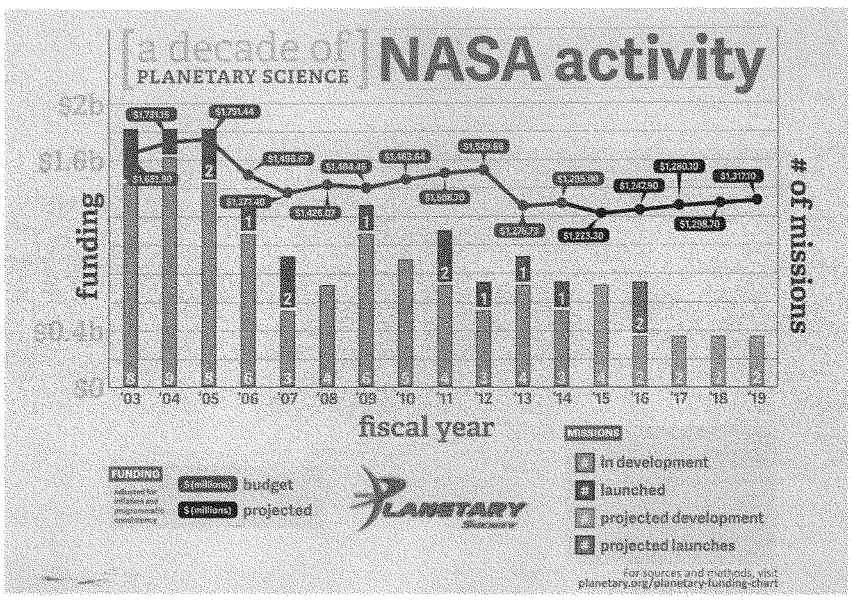

Figure 1. Funding level of NASA's Planetary Science Division from FY2003 – FY2019, in Real Year Dollars (adjusted for inflation) and displaying the number of missions in development according to NASA Budget requests during this period. The average budget for the Planetary Science Division from 2003 to 2013 was $1.53 billion per year. Note that by the end of this decade the NASA Planetary Science Division will be working on only two new missions (Mars 2020 and Discovery 13) while maintaining a diminishing set of aging spacecraft. The Administration has said it intends to begin Discovery 14 during this period, but no timeline is presented within the FY2015 President's Budget Request and thus not included here. Raw data and methods are available at http://planetary.org/planetary-funding-chart. Credit: Lori Dajose/Casey Dreier for The Planetary Society.

Fortunately, Congress, and this Subcommittee in particular, have strongly supported NASA's Planetary Science Division, and on behalf of the membership of The Planetary Society, we thank you for this. The 2014 NASA Authorization bill (H.R. 4412) passed by the House and drafted in this committee includes a clear policy provision (Section 321) supporting the Decadal Survey's recommended cadence of Discovery and New Frontiers missions, as well as a new flagship mission to Europa in the early 2020s. We strongly support this language in H.R. 4412, and thank you again for this support.

What are some of the ways in which The Planetary Society is contributing to upcoming planetary science missions, including Mars-2020 and a potential science mission to Europa?

The Planetary Society has a long history of official and unofficial contributions to a wide range of planetary science missions.

Since the early 1980s, we've held large public gatherings to support major planetary mission milestones. These "Planetfests" typically host thousands of people and have celebrated Voyager 2's encounters with the outer planets, every modern Mars landing, and the asteroid impact of the Deep Impact mission.

The Society also offers the most in-depth coverage of NASA's science missions on our website, radio show/podcast, and magazine. Our website and radio show are provided free, without advertisements, for members and non-members alike. The Society has also helped to foster an entirely new online community of amateur enthusiasts who work directly with the raw image data from NASA spacecraft.

Our members funded the construction of the first private instrument to fly on a NASA mission: a microphone on the ill-fated Mars Polar Lander. And getting a microphone on Mars (at no cost to the taxpayer) is one of our long-term goals and provides an added dimension to the mission.

The Planetary Society is the official outreach partner for the Mastcam-Z camera system on the Mars-2020 rover, and The Society plans to make a serious, long-term investment in building awareness with the public and finding a variety of ways in which they can become involved with the images from the next rover. And while The Society as yet has no official connections to the potential Europa mission, we will vocally support and promote that mission, if it is pursued.

The OSIRIS-REx mission launches in 2016 to the asteroid Bennu, where it will grab a sample of the asteroid's surface and return it to Earth. The name, Bennu, was the winning entry in a naming contest we ran here at the Society. We've also collected over 350,000 names and messages from around the world that will ride along with the spacecraft.

The Society has also maintained a strong relationship with the New Horizons mission team. We worked with them to create a digital time capsule that will be opened when the spacecraft flies by Pluto next year.

The Society actively promotes planetary science and space science in other ways, too. Our members donate the funds to support exoplanet observations of the Alpha Centauri system with a team from Yale. We engage with industry and help fund development of low-cost technological solutions for sampling the surfaces of other worlds. We also funded the effort that solved the so-called "Pioneer Anomaly" which was the unexpected deceleration of the Pioneer 10 and 11 spacecraft as they left our solar system.

All of these projects I just mentioned are paid for by donations from our membership. It's one thing to say that the public is interested in planetary science, and another to see people support these efforts with their hard-earned cash. They've voted with their dollars.

How is The Planetary Society encouraging the development of partnerships between science and industry?

The Planetary Society funds and carries out a number of science and technology projects that advance the development of technologies for future missions. We've worked with Honeybee Robotics to develop a simple sample acquisition hardware system that could fly on Discovery-class missions, have explored novel ways to deflect asteroids using lasers, and we are demonstrating solar sail propulsion for small spacecraft with our LightSail cubesat mission.

The Planetary Society, in its role as a nonprofit organization, has built and implemented partnerships with science institutions, government organizations, and private industry. Some of our science and technology projects such as our solar sail mission and our Living Interplanetary Flight Experiment (LIFE) have involved building teams of universities, private science entities, private industry, and NASA. In these activities, The Planetary Society connects scientists, engineers, and manufacturers, while also reporting to and engaging the public about our exciting projects and partnerships.

It is especially important to me personally that the Society engages the exciting "New Space" sector of the industry. In my role as a Professor at ASU, I interact with young engineers and scientists every day, and I witness their enthusiasm and excitement about the work being done by brash startups like SpaceX, Virgin Galactic, Bigelow Aerospace, Planetary Resources, and others. In fact, we've started a new program at ASU, the Space Technology and Science ("NewSpace") Initiative, that is designed to help directly connect the many ASU students, faculty, and staff across campus doing space science and engineering, with the goals and needs of these kinds of new space-related startup companies. As the Director of this Initiative at ASU, I am delighted to see NASA strongly support both large- and small-scale commercial space development activities across the nation, and as a working planetary scientist and President of The Planetary Society I am eager to see these new companies help to enable a wide range of exciting new solar system research and exploration opportunities.

What are your perspectives on the potential extraction of resources from asteroids? Provide feedback on H.R. 5063, the American Space Technology for Exploring Resource Opportunities In Deep Space (ASTEROIDS) Act.

Asteroids are the ancient leftover building blocks from which all of the planets were made. Early in the history of our solar system, they may have delivered some of the elements of life to our planet and others. A few of them also pose collision threats to our home world. By finding them and studying them, with telescopes, with space missions, or in laboratories when we study meteorites (some of which are tiny pieces of asteroids) we have begun to understand the details of how our planet and others formed and changed over time. Was Earth's water brought here by a steady rain of water-rich asteroids and comets early in the solar system's history? How did impacts by large asteroids influence the development of life on our home planet? Which asteroids out there represent future potential impact hazards? These questions are on the frontier of current planetary science research, and are among the kinds of asteroid-related studies recommended by the Decadal Survey. NASA's programs to answer these questions deserve full support.

The issue of resources on asteroids is particularly compelling, not only from the scientific perspective noted above, but also as we begin to imagine a future where humanity is moving outward beyond our home world, exploring and settling new frontiers in our solar system. Just like many of the settlers who moved to the American West in the 19th century, settlers moving outward from Earth in the 21st century and beyond will want to try to figure out how to "live off the land" as much as possible. Based on what we know now, there's good reason to believe that asteroids could provide many of the raw natural resources that humans will need to live and work beyond Earth. Some are water-bearing (and thus, oxygen-bearing), others have significant concentrations of metals and silicates useful as building materials. Based on meteorite studies, some are even likely to contain significant amounts of precious metals. All of these attributes make asteroids potentially economically attractive targets for future resource extraction.

While the extraction of space-based resources from asteroids is certainly still many years away, The Planetary Society believes that it would be wise to start making the required investments in technology, infrastructure, and transportation systems required to study asteroids in the level of detail needed to make truly informed future decisions about their individual resource potential. As such, we support investments, through both commercial and governmental programs, in the kinds of technologies needed for the exploration and utilization of asteroids as contemplated in H.R. 5063. Likewise, commercial and/or government investment in cataloging, characterizing, and mapping asteroids will enhance our ability to understand their potential for resource extraction as well for their potential as Earth-colliding objects. Investment to map and characterize asteroids should receive high priority, with an emphasis on identifying those near-Earth asteroids that could pose a collision threat.

The Society recognizes that a policy regarding property rights for resources mined from asteroids will eventually be important for commercial investment, but we believe that, since this is an area of current controversy among specialists, it is premature for us to take a position in support of the perspective on the property rights issues covered in the bill. Rather, we advise careful thought and deliberation before moving forward in this area, and embrace H.R. 5063's call to develop the frameworks necessary to attract commercial investment.

Closing remarks

Around midnight on August 6th, 2012, thousands of people gathered in Times Square to witness something that had never happened before (Figure 2). They were there to see the Curiosity rover attempt its landing on Mars, which was broadcast live on the Jumbotron. Pictures from that night capture the excitement, awe, and joy that the crowd experienced during the rover's seven minutes of terror as it landed on the red planet. This wasn't a scientific moment—though it would lead to great science; it was a human one. In that instant, the hopes of a nation were with a robotic spacecraft built by our best engineers and funded by the taxpayers to pursue a peaceful mission to uncover the secrets of another planet. Curiosity remains one of NASA's most popular missions, human or otherwise.

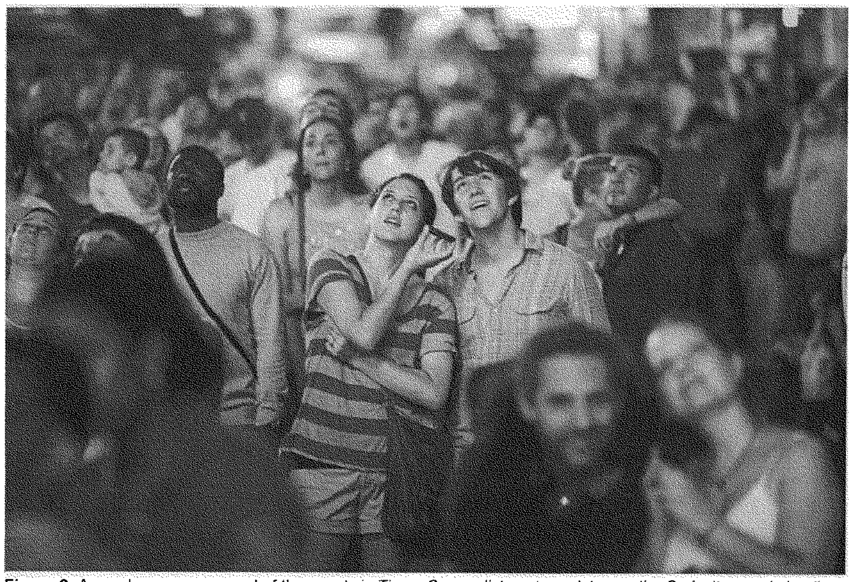

Figure 2. A couple among a crowd of thousands in Times Square listens to updates on the Curiosity rover's landing attempt. August 6th, 2012. Photo credit: Navid Baraty.

NASA is the most active, most capable, and most successful of all of the world's space agencies. As such, when NASA doesn't prioritize planetary science, no other agencies are presently capable of filling the gap. Other space agencies around the world are catching up, however. Europe and Russia have established planetary exploration programs with ambitious ongoing or near-term missions planned. China is building on its recent mission successes and rapidly advancing plans to explore beyond the Moon with robotic spacecraft. And even as I speak, India's first Mars orbiter is nearing the red planet.

The major NASA achievements in planetary exploration slated for the near future—the Curiosity rover arriving at Mt. Sharp, the new MAVEN orbiter arriving at Mars, the New Horizons flyby of Pluto and its moons, the Dawn mission going into orbit around the largest asteroid, Ceres—represent the best of space exploration. They are bold feats of engineering and scientific prowess. They are tangible manifestations of blatant optimism in the face of great odds, each one having faced immense challenges that were overcome by careful planning and outstanding

American engineering. They engage the public with their daring feats of discovery. And yet, planetary science is unique within NASA in having its budget cut dramatically despite its clear scientific and public successes.

Spacecraft take time to design, build, and fly. Our current set of missions were all initiatives begun during previous Presidential administrations. The future missions called for by the Decadal Survey need investment now, but they are not receiving it.

NASA already faces its biggest gap in solar system exploration in decades. But wise action by the Congress and the Administration can rejuvenate planetary science by supporting Decadal recommendations for a balanced mission portfolio. It is a worthy investment—$1.5 billion per year, less than 9% of NASA's total budget—to maintain a peerless program of exploration that inspires the country, reveals the mysteries of our solar system as well as our home planet, and searches for hidden abodes of life in the worlds around us.

On behalf of the members of The Planetary Society, I would like to again thank the Members of the Subcommittee, and of the Congress in general, for their solid support of America's planetary science exploration program over the past several years. I would also like to thank you personally for the opportunity to address you all today, and to share my own thoughts on the importance of NASA's planetary exploration program for the nation, and for the world.

APPENDIX.
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Space News

U.S. Planetary Science: Fading to Black

By Robert D. Braun, Noel W. Hinners | Apr. 22, 2013

By any objective measure, planetary science is one of America's crown jewels. A unique symbol of our country's technological leadership and pioneering spirit, this endeavor has consistently demonstrated that the United States is a bold and curious nation interested in discovering and exploring the richness of worlds beyond our own. In addition to informing our worldview, these missions are inspirational beacons, pulling young people into educational and career paths aligned with science, technology, engineering and mathematics, the foundation of continued U.S. economic competitiveness.

Beginning with the flight of Mariner 2 more than 50 years ago, the United States has consistently led the robotic exploration of our solar system. Decade by decade, we have created, flown and operated a balanced portfolio of missions to explore destinations across the solar system. For example, in the 1970s, the U.S. conducted the Viking missions at Mars, the Pioneer missions at Venus, and the Voyager and Pioneer missions to the outer planets. In the 1990s, the U.S. carried out multiple missions at Mars, Cassini to Saturn, as well as missions to our Moon, the asteroids and a comet. Today, U.S. spacecraft are en route to Jupiter and Pluto, two rovers trundle across the martian surface, and orbiters at Mars and Saturn are returning tantalizing insights.

Despite the success that has built up over decades, today we are on a path that relinquishes U.S. planetary science leadership. Starting in 2017, with the end of the Juno mission at Jupiter and the Cassini mission at Saturn, NASA will only have spacecraft at or on their way to one planet: Mars. Most striking is that after four decades of U.S. spacecraft operating in the vast outer solar system, there are currently no outer planet missions of any kind planned until after 2030 — when the European Jupiter Icy Moons Explorer is scheduled to arrive at its destination. In 2017, our insight into much of the solar system will go dark. Because it takes at least five years to conceive, design and implement a planetary science mission, this cliff is not only upon us, it is getting larger with each passing day. The next suite of planetary science missions should already be in development.

The emergence of the Chinese and Indian space programs and the continued successes of the European and Japanese programs illustrate that robotic exploration of space is an international priority — a way to gain scientific knowledge, global prestige and advance technological capability. In the coming decade, China is preparing a series of robotic lunar missions, Russia is preparing lunar, Venus and Mars missions, India has plans to go to the Moon and Mars, Japan is planning a second asteroid sample-return mission, and the Europeans are headed to Mercury, Mars, the asteroids and Jupiter.

Unfortunately, President Barack Obama's 2014 budget request for NASA continues the draconian path for planetary science laid out in the administration's 2013 request. Most striking, this budget line is reduced approximately $200 million relative to the 2013 level appropriated by Congress and signed into law by the president just three weeks ago. While a series of Mars missions is scheduled through 2020, NASA remains without plans for the development of missions to any other planets. Does the U.S. really want to cede leadership of the scientific exploration of the rest of the solar system to other nations?

Mars exploration can tell us much about our past and our potential future, but we have learned that our solar system and other planetary systems are exceedingly diverse. From the subsurface ocean of Jupiter's moon Europa to the vast hydrocarbon season Saturn's moon Titan to the mysterious ice giants Uranus and Neptune that stand like sentinels at the solar system's edge, there is much yet to discover in our cosmic backyard. A year ago, the National Academies put forward a roadmap for solar system science in the 2013-2022 decade. Balance was sought, both in the destination of the U.S. science missions and in their scope, to enable a steady stream of new discoveries and the capability to address grand challenges like sample return and outer planet exploration. However, driven by budget shortfalls and its own penchant for large, expensive missions, NASA has abandoned this balanced approach, resulting in a complete shutdown of missions to planets other than Mars after 2017.

For 50 years, NASA's program of robotic planetary science has been unparalleled in its successes and scope. Continuing this success requires action now, as these missions take years to develop and then to reach their destinations. We can continue U.S. leadership in this field or we can abandon an endeavor that inspires our children, builds the scientific and engineering literacy of our country, and increases our economic and technological competitiveness. Now is not the time to curtail the pace and scope of our planetary science program. This is a pursuit worthy of a great nation.

Robert D. Braun is the David and Andrew Lewis Professor of Space Technology at the Georgia Institute of Technology and served as NASA chief technologist in 2010 and 2011. Noel W. Hinners retired as vice president of flight systems for Lockheed Martin Space Systems and formerly served as associate deputy administrator and chief scientist of NASA, director of the NASA Goddard Space Flight Center, and NASA associate administrator of space science.

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Short Narrative Biography

Professor James F. Bell (Arizona State University)

Dr. Jim Bell is a Professor in the School of Earth and Space Exploration at Arizona State University in Tempe, Arizona, an Adjunct Professor in the Department of Astronomy at Cornell University in Ithaca, New York, and a Distinguished Visiting Scientist at NASA's Jet Propulsion Laboratory in Pasadena, California. He received his B.S. in Planetary Science and Aeronautics from Caltech, his M.S. and Ph.D. in Geology & Geophysics from the University of Hawaii, and served as a National Research Council postdoctoral research fellow at NASA's Ames Research Center. Jim's research group primarily focuses on the geology, geochemistry, and mineralogy of planets, moons, asteroids, and comets using data obtained from telescopes and spacecraft missions.

Jim is an active planetary scientist and has been heavily involved in many NASA robotic space exploration missions, including the Near Earth Asteroid Rendezvous (NEAR), Mars Pathfinder, Comet Nucleus Tour, Mars Exploration Rovers Spirit and Opportunity, Mars Odyssey Orbiter, Mars Reconnaissance Orbiter, Lunar Reconnaissance Orbiter, the Mars Science Laboratory Curiosity rover mission, and the Mars-2020 rover mission. Jim is the lead scientist in charge of the Panoramic camera (Pancam) color, stereoscopic imaging system on the Spirit and Opportunity rovers, is the Deputy Principal Investigator of the Mastcam camera system on the Curiosity rover, and is the Principal Investigator on the Mastcam-Z camera system on NASA's planned Mars-2020 rover. As a professional scientist, Jim has published 35 first-authored and more than 160 co-authored research papers in peer reviewed scientific journals, has authored or co-authored more than 525 short abstracts and scientific conference presentations, and has co-edited or edited two scientific books for Cambridge University Press (one on the NEAR mission: "Asteroid Rendezvous"; the other on Mars: "The Martian Surface: Composition, Mineralogy, and Physical Properties"). He has been an active user of the Hubble Space Telescope, and of a number of ground based telescopes, including several at Mauna Kea Observatory in Hawaii.

Jim is also an extremely active and prolific public communicator of science and space exploration, and is President of The Planetary Society, the world's largest public space advocacy membership organization. He is a frequent contributor to popular astronomy and science magazines like *Sky & Telescope, Astronomy, and Scientific American,* and to radio shows and internet blogs about astronomy and space. He has appeared on television on the NBC "Today" show, on CNN's "This American Morning," on the PBS "Newshour," and on the Discovery, National Geographic, Wall St. Journal, and History Channels. He has also written many photography-oriented books that showcase some of the most spectacular images acquired during the space program: *Postcards from Mars* (Dutton/Penguin, 2006), *Mars 3-D* (Sterling, 2008), *Moon 3-D* (Sterling, 2009), *The Space Book* (Sterling, 2013). Jim's latest book is "The Interstellar Age: Inside the Forty-Year Voyager Mission" (Penguin, 2015). He and teammates have received more than a dozen NASA Group Achievement Awards for work on space missions, and he was the recipient of the 2011 Carl Sagan Medal from the American Astronomical Society, for excellence in public communication in planetary sciences. The asteroid 8146 Jim Bell was named in his honor by the International Astronomical Union.

Chairman PALAZZO. Thank you, Dr. Bell.

I now recognize Dr. Sykes for five minutes to present his testimony.

TESTIMONY OF DR. MARK SYKES, CEO AND DIRECTOR, PLANETARY SCIENCE INSTITUTE

Dr. SYKES. Thank you. Mr. Chairman and Members of the Committee, thank you for the opportunity to appear before you today, and I would also like to express my deep appreciation for your continued support of solar system exploration and the support of Congress in these kind of recent turbulent times. It is much appreciated by the community.

I am going to focus on two topics in my remarks, the funding level for planetary missions and the asteroid retrieval mission. I am concerned that our planetary mission aspirations and goals seem disconnected from available resources at all levels and that priorities can only be inferred after the fact. For instance, it is very good news that after the latest review, all planetary missions and their extended phase that were reviewed will continue. This is not an unexpected outcome. However, the Administration's Fiscal Year 2015 NASA budget proposal did not include funds sufficient to cover this possibility. It is $35 million short. These funds are requested in a separate Opportunity, Growth and Security Initiative. What is the plan if we are in C.R. all year or this initiative is not passed?

On the larger scale, we would all like to see the recommendations of the NRC Planetary Decadal Survey implemented. These call for the restoration of a competed Discovery mission proposals every 24 month as it had in its first decade instead of the recent once or twice a decade. The Decadal Survey also calls for another round of competitive New Frontier proposals this decade.

If one adds to this the Administration's Mars 2020 flagship initiative, the desire among many to have flagship mission to Europa, the continuing missions, the foundational research and data analysis programs and technology development programs, it is simply not possible to do everything with the planetary budget of $1.3 billion a year or even if we go to two flagships, $1.5 billion a year. If our competed mission programs are not restored, the United States, as has just been mentioned, will have few assets operating in the solar system by the end of this decade and beyond. I am concerned about ongoing budget pressures on our continuing missions and losing our skills and capabilities or maintained and grown by our research programs, which has suffered a collapse in selection rates in recent years.

We need to have a transparently rational basis for a planetary budget that embraces in part a longer-term vision than the year-to-year chaos to which it has been subjected in recent years. I would suggest that this have two components: a predictable baseline program and a flagship program. A long-term baseline planetary program should be built on competed missions, competed research and technology programs consistent with the Decadal recommendations. This budget should be very predictable from one year to the next.

Flagships are a great value as well, but because of the large expense and cost volatility expected from ambitious projects, the cost of mission studies, instrument development, mission operations and science should be in a separate flagship program line. The mission target makes no difference.

I would like to go on to the asteroid retrieval mission, and I apologize for being a little negative perhaps on this. The NASA Advisory Council finds that this is not a substitute for a human mission to an asteroid in its native orbit and the NRC Committee on Human Spaceflight finds the retrieval part of ARM to be a dead-end element. The NASA Small Bodies Assessment Groups most recent findings state that ARM science and planetary defense benefits are not compelling and that significant uncertainties in our knowledge of the ARM targets—small asteroids or boulders on asteroids—contribute significantly to schedule and cost risk and the risk of mission failure. ARM is poorly conceived and poorly designed. It lacks fundamental knowledge of its target objects and strategically does not advance human exploration, does not advance science, does not advance planetary defense and does not advance understanding of the in situ resource utilization of near-Earth asteroids. In addition, the cost figure of less than $1.25 billion given at the most recent SBAG meeting strains credulity. The OSIRIS–REx mission, which has been mentioned previously, is returning 60 grams to 2 kilogram of near-Earth asteroid material to the surface of the Earth for a cost of $1.05 billion, which includes the launch vehicle and $60 million in headquarters-held reserves. We do not know what is in the ARM number but it is hard to believe that for an additional $200 million ARM is going to return 500 metric tons of asteroid material to retrograde lunar orbit using new technology not yet developed and tested on targets not identified and fully characterized to satisfy level I requirements not yet specified with an unknown level of risk acceptability. We can always find some benefit for whatever we do in space—it is what we do—but ARM sets an awfully low bar for rationalizing a major space initiative with a likely multibillion-dollar price tag.

Thank you.

[The prepared statement of Dr. Sykes follows:]

Statement of Mark V. Sykes
CEO and Director
Planetary Science Institute

Before the Subcommittee on Space
United States House of Representatives

September 10, 2014

Mr. Chairman and Members of the Committee, thank you for the opportunity to appear before you today. My name is Mark V. Sykes. I am CEO and Director of the non-profit corporation Planetary Science Institute, which celebrates 42 years of active participation in American solar system exploration. PSI supports more than 90 PhDs in 21 States and the District of Columbia and is involved with almost every NASA solar system exploration mission. I have been a member of the planetary community for more than 30 years and have had the honor of serving as Chair of the Division for Planetary Sciences of the American Astronomical Society, a member of the NASA Planetary Science Subcommittee, and as a founding Steering Committee member and Chair of the NASA Small Bodies Assessment Group from which I have now rotated off. I am also a Co-Investigator on the NASA Dawn mission to Vesta and Ceres and a member of the Board of Advisors of Planetary Resources, Inc. The views I express today are my own, and do not necessarily represent those of the Planetary Science Institute, the NASA Small Bodies Assessment Group, or any other organization or committee.

Summary of Comments to the Committee

The Committee has requested my testimony on several issues facing the planetary science community. My key points to the Committee are:

Draft SBAG Recommendations

- SBAG recognizes that the Asteroid Redirect Mission does not effectively advance our knowledge of asteroids or planetary defense strategies and that the uncertainties in our knowledge of the near-Earth object target population result in significant cost and schedule risk. I would further say that cost figures of $1.25B lack credibility and that this proposal undermines any long-term human exploration objective by this country.

- Achieving the Congressional goal of detecting and characterizing 90% of NEOs with diameters greater than 140m is achieved in the shortest time by a dedicated space-base survey telescope (and is not likely to meet the 2020 goal). SBAG has endorsed such a system several times since 2010 and recommended a competitive process for its selection. Concern has been expressed by SBAG that NASA's ability to move forward has been sidetracked by reliance on a private initiative seeking private funding. It notes that this company has been unable to meet schedule milestones under a Space Act Agreement with NASA.

- SBAG supports the recommendations of the planetary decadal survey with specific regard to the recommended cadence of missions in the competed Discovery and New Frontiers programs. Other findings include concern over maintaining US planetary radar capability and the need to establish a Planetary Defense Coordination Office within NASA in support of recommendations made in the 2005 and 2008 NASA Authorization Acts.

Concerns Regarding NASA Planetary Science Funding Levels

- US planetary science capability is significantly sustained by its research and data analysis programs. Instability in the funding of these programs threatens US leadership in this area. The $35.4M increase in the President's FY15 proposed budget for Planetary Science Research reflects a reorganization of budget lines and not a net increase in funding to these programs. The House proposes to increase this by a few million. A cut of $40.3M proposed by the Senate Appropriations Committee would have very negative consequences, which could include ending curation of NASA mission data and lunar and other samples or a sharp reduction in all new planetary research awards in FY15.

- The Planetary Science Division should be applauded for planning to fund new awards in its ROSES14 research programs within 6 months of proposal submission. This represents a new commitment to the GPRA standard. The new large amalgam program, Solar System Workings, is the exception at 1 year. This seems to be to afford the opportunity to shift funds for new awards from FY15 to FY16, thereby freeing up these funds for other purposes. Delays strain researchers and reduces funds for new awards in FY16.

- The pursuit of two flagship missions (Mars 2020 and Europa Clipper) is not possible within a budget profile of ~$1.3B/year. Even less so if planetary decadal recommendations for the competed Discovery and New Frontiers programs were followed, along with the recommendation for research and analysis programs. Cost overruns will cause even more disruption.

- A baseline budget for NASA planetary science should be established that consists of stable and modestly growing research and data analysis programs, technology programs, Discovery and New Frontiers missions at the cadence recommended by the planetary decadal survey, and continuing missions in flight. With the exception of continuing missions, all other baseline programs would be competed, ensuring the best return on taxpayer investment. Funding for any flagship mission or missions or their development should be an appropriation over and above this baseline budget.

Commercial Asteroid Resource Extraction

- Sustainable, long-term human activity beyond low-Earth orbit is not possible without the identification and cost-effective exploitation of resources, primarily water, from near-

Earth objects. Commercial exploitation requires a reasonable period of time between investment and return on that investment. The development of an NEO ISRU infrastructure is beyond the scope of private enterprise. No such infrastructure can be developed until we embrace a long-term vision requiring these resources and engage in a program to identify their sources, process them, develop the means to use them, and demonstrate that it can be done more cheaply than bringing everything up from the surface of the Earth.

H.R. 5063 – American Space Technology for Exploring Resource Opportunities In Deep Space (ASTEROIDS) Act

- The definition of property rights regarding resources obtained in outer space is useful. However, the provisions "Freedom from Harmful Interference" and "Relief from Harmful Interference" appears to be an attempt to lay the basis for a private company to assert property rights beyond "resources obtained in outer space." The scope of this right is unknown and could actually slow and discourage commerialization. Protection against actual damage or the demonstration of imminent damage to private property in space (e.g., a spacecraft or a resource recovery facility) would be of value, but only with language narrowly tailored to achieve that objective. This bill does not accomplish that.

When Nature is Inconvenient to Strategic Planning in Science

- The discovery of seasonal running water on Mars and the potential oceans on Ceres and what the Dawn mission will see when it arrives raises useful questions about how rigid we are in our thinking about important issues that feed into our strategic planning.

Draft SBAG Recommendations

Asteroid Redirect Mission

At the time this statement is being composed (August 28, 2014) the SBAG findings from its 11th meeting on July 29-31, 2014, in Washington DC, are still in draft form. The posted language is close to final form. The findings on the Asteroid Redirect Mission (ARM) refer to a draft report of the SBAG Asteroid Redirect Special Action Team (SBAG ARM SAT). SBAG was asked by NASA to create this team to provide specific input "on the likely physical composition of small (<10 meter diameter) near-Earth asteroids, the likelihood and nature of boulders on asteroids, relevant information gained from meteorites, the properties of asteroid regolith, and the potential for science, planetary defense, and resource utilization." This report may be undergoing significant revision.

At SBAG 11, an entire day was devoted to the discussion of the ARM mission. The overall finding [draft] is

> "The portion of the ARM concept that involves a robotic mission to capture and redirect an asteroid sample to cis-lunar space is not designed as an asteroid science mission and its benefits for advancing the knowledge of asteroids or furthering planetary defense strategies are not compelling and will be limited."

For a mission that is not a science mission, there is much effort to suggest potential science and planetary defense benefits. The finding indicates the degree to which SBAG finds that compelling.

There was much discussion about how our lack of knowledge of the physical characteristics of potential ARM target bodies in both the "capture and asteroid" scenario (Option A) and "pluck a boulder" scenario (Option B) equated to significant risks to the mission as well as to its expense. It was only short time ago that small asteroids were monolithic, strength dominated bodies. Now we know they could be rubble piles, even held together by Van der Waals forces with great uncertainty about the consequences of mechanical interaction. There is also the basic question of target mass, which still seems difficult to resolve with existing ground-based and space-based assets to with a factor of 4 from the earlier Target NEO 2 Workshop. The draft finding on these uncertainties is:

> "Limits in the current knowledge and large uncertainties in the properties of near-Earth asteroids contribute significantly to schedule and cost risk and ultimately to the likelihood of success or possibility of failure of either Option A (redirect an entire small asteroid) or Option B (capture and return a large boulder from a larger asteroid) of the robotic ARM concept. Current surveys, observing programs, and other projects are not positioned to sufficiently bridge this knowledge gap within the allotted schedule."

It is proposed to sharpen this up to relate identify the risk as the risk of mission failure.

One question for which a finding was not made was whether ARM is a part of the critical path for sending humans to Mars. While much was said about ARM having some relevance to future human Mars missions, no statement was made that I recall asserting that ARM was essential or even the most cost-effective way of demonstrating technology necessary for a future human Mars mission.

There is ongoing discussion on the SBAG ARM SAT report. The focus is primarily on whether ARM has anything more than notional relevance to planetary defense and resource utilization. My version of the summary regarding ARM and ISRU (which is a substantial rewrite of the draft report) is:

"Summary Findings: The value of ARM to ISRU is very limited.

- Detailed knowledge of a range of asteroid compositions within a given target taxonomic class is critical to developing a practical method of extracting a particular resource. ARM returns a single target.

- Knowledge of surface and subsurface mechanical properties are critical to a resource extraction processes.
- Small (ARM-class) targets provide limited information about the surface and subsurface mechanical properties of the larger asteroids that would be industrial ISRU targets.
- Once a technique is developed for extracting an identified resource from a likely range of compositions of target objects overlapping the composition of the returned ARM target, the ARM target could be used as a site for testing the deployment of a bulk processing demonstration, recognizing that it would not be testing for the range of potential mechanical properties of multiple ISRU targets.
- ISRU will require autonomous robotic operations. It is unclear on what timescale such a system can be matured for demonstration once the ARM sample is returned.
- ISRU experiments on ISS are essential precursors to any bulk processing experiments on the returned ARM sample."

Finally, I would note that at the meeting there was some vigorous opposition to ARM, but no complementary support by the non-ARM attendees at the meeting. I raised the concern that the only reported commitment of the ARM mission is to succeed in unfolding its solar panels – which might more cost-effectively be achieved in Earth orbit. Failing to commit to actually returning an asteroid to retrograde lunar orbit avoids the need to discuss levels of acceptable risk to mission success and how uncertainty in the target population of asteroid could drive cost in accommodating that uncertainty. NASA contends that the ARM mission will cost less than $1.25B (for comparison the OSIRIS-Rex mission will cost ~$800M). I think it is fair to say that this figure lacks any credibility with the SBAG community.

The Need for a Near-Earth Object Survey and *The B612 Sentinel Project*

Achieving the Congressional goal of detecting and characterizing 90% of NEOs with diameters greater than 140m is achieved in the shortest time by a dedicated space-base survey telescope (and is not likely to meet the 2020 goal). SBAG has endorsed such a system several times since 2010 and recommended a competitive process for its selection.

Concern has been expressed by SBAG that NASA's ability to move forward has been sidetracked by reliance on a private initiative seeking private funding (the B612 Sentinel project). Under the B612 Space Act Agreement with NASA, the schedule and milestones include: (1) Sentinel mission contract start date with Ball, November 2012; Preliminary design review, October 2013; Critical design review, October 2014; Launch, December 2016. There has been no PDR, without which a CDR cannot be held. The SBAG finding noted that this company has been unable to meet schedule milestones under the Space Act Agreement.

Other Findings

SBAG supports the recommendations of the planetary decadal survey with specific regard to the recommended cadence of missions in the competed Discovery and New Frontiers programs. Other findings include concern over maintaining US planetary radar capability and the need to establish a Planetary Defense Coordination Office within NASA in support of recommendations made in the 2005 and 2008 NASA Authorization Acts.

Concerns Regarding NASA Planetary Science Funding Levels

The budget for the NASA Planetary Science Division has been in difficult straights since the Administration suddenly reduced it by 20% from $1.5B to $1.2B from FY12 to FY13, using the difference to fund other agency priorities. Congress improved this situation in FY13 by appropriating $1.415B to planetary, but the Administration reduced this to $1.27B in its Operating Plan. Congress succeeded in raising this to $1.345B in FY14, which the Administration proposes to reduce to $1.28B in FY15. All this is in the context of the sudden desire of the Administration to commit to a new flagship mission, Mars 2020, and the desire of some in Congress to see a new start on a flagship Europa mission. There is also broadly declared support for the Planetary Decadal Survey, which calls for the restoration of the decimated Discovery program and an additional New Frontiers mission this decade in addition to growing funding for Research and Analysis programs. There is even a planetary balloon program that expended ~$12M in FY13 and continues in FY14 at ~$6M that appears nowhere in the President's budget. I am greatly concerned about the sustainability of our planetary programs. Even at $1.5B/year, there are insufficient funds to do everything. There is great unease across the planetary community about the future of the United States solar system exploration program.

Of particular note is the overwhelming focus on what flagships will prevail in a time of limited resources. Many people will to take the position that we need to have flagships (primarily), New Frontiers and Discovery missions under development because the decadal survey calls for "balance." I take the position that the decadal survey does not contemplate a suicide pact. Balance requires resources and the decadal gives specific guidance about what to do when there are insufficient funds to do everything

> "It is also possible that the budget picture could be less favorable than the committee has assumed. If cuts to the program are necessary, the first approach should be descoping or delaying Flagship missions. Changes to the New Frontiers or Discovery programs should be considered only if adjustments to Flagship missions cannot solve the problem. And high priority should be placed on preserving funding for research and analysis programs and for technology development."

This is a remarkable, fiscally responsible position, but it is largely rejected by vested interests and others. If the decadal recommendations for flagship missions were actually followed, we would probably be contemplating the modest Uranus Orbiter Probe option if any.

Over the years, I have advocated for competition in missions as a means of controlling cost and maximizing return. When the Europa Orbiter missions and Pluto-Kuiper Belt Express missions were cancelled because of huge cost overruns, I advocated along with others for NASA to set what it considered to be a reasonable cost and compete them. It did just that for the Pluto mission, which resulted in New Horizons mission, which won the competition, and the New Frontiers program. The first competed mission program was Discovery, which in its first decade selected two missions for flight every two years (excepting the initial NEAR and Mars

Pathfinder missions). We would do well to restore the vigor of the Discovery program and to ensure the twice a decade cadence of New Frontiers.

When it comes to the planetary budget and its management, my first concern, however, is always the small research programs, which are also competed. In a survey I conducted for the NASA Planetary Science Subcommittee in 2010, nearly half of the planetary community relied on these programs for at least half of their salaries. This makes sense. Modern planetary science is a creation of NASA, it has only modest penetration into academia, unlike astronomy. United States solar system exploration has not limited itself in its reach, sending missions from Mercury to beyond the edge of the solar system. Planetary science is incredibly rich in range of subjects it addresses across worlds – atmospheric science, geophysics and geology, celestial mechanic, particles and fields, and much more. The community engaged in this work has organically grown over the decades. The research programs are the primary means by which we support training the next generation of scientists, and they support the research we use to define the problems best addressed by missions and to analyze that mission data and integrate it back into our broader knowledge base. While missions are the peak of our endeavors, they rest on a mountain of work supported by the research programs. This is why the research programs are given probably the highest priority in the decadal survey – strive to keep stable under adverse economic conditions, and otherwise slowly grow.

Over the remainder of this decade, most of the NASA missions operating today are expected to come to an end: all of our Mars assets, MESSENGER, Cassini, Dawn, LRO and others. Perhaps Voyager will still be sending back signals! This will increase pressure on our research programs and the question must be raised about whether we are going to maintain our national capabilities, manage a retrenchment, or allow a more chaotic resolution. I anticipate the last.

Another pressure on the community is declining research program selection rates, which have dropped nearly 50% over the past five years, with more dramatic declines in specific programs, while average award sizes have stayed fairly constant and total numbers of proposals have actually declined. I think part of the problem has been the use of "rephasing" to free up money in the research programs in one year by shifting obligations of an award to the next year. Without money being added to the program to cover the obligations, funds available for new awards are reduced.

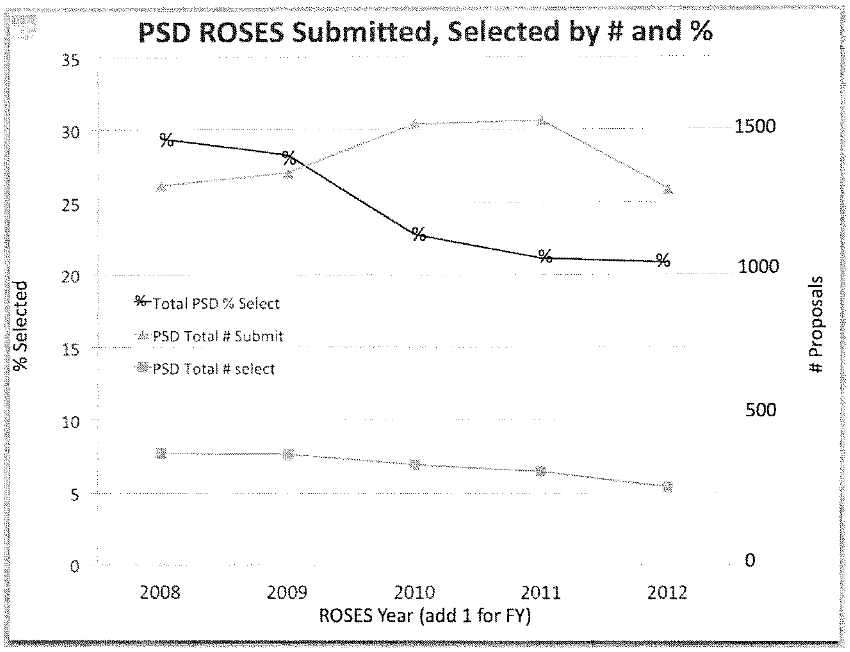


Figure from Jonathan Rall (NASA HQ) presentation to SBAG 11 (7/29/14). MVS calculation of success rates for planetary ROSES13 proposals, using data from sara.nasa.gov, is a new low of 19.5%.

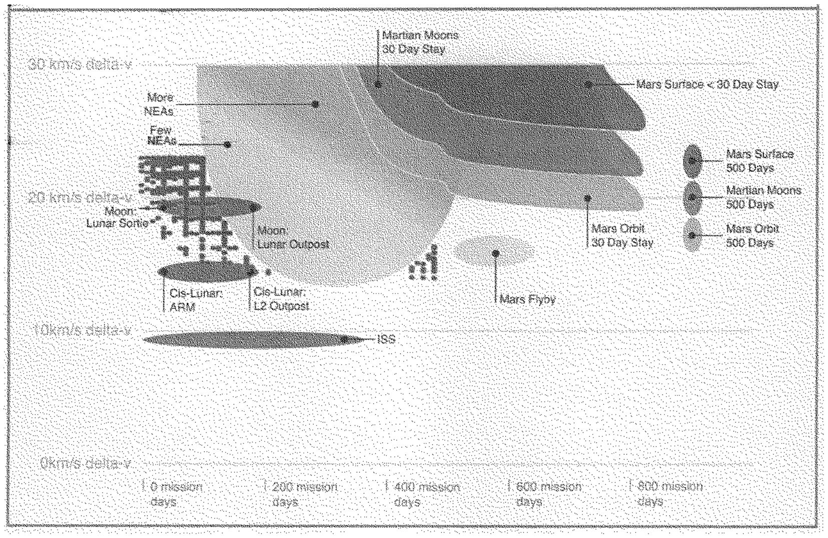
The current ROSES Year (2014) has marked the reorganization of established basic planetary research programs to in part align them more with the themes of the planetary strategic goals. The utility of the reorganization was not clear and estimated funding levels were not provided (though the funding levels of their merged programs were known), raising concerns at public venues (e.g., LPSC, AG meetings).

One point for which the Planetary Science Division should receive some credit is for planning to fund new awards in its ROSES14 research programs within 6 months of proposal submission. This represents a new commitment to the GPRA standard (Government Performance and Results Act), which calls for 150 days between proposal submissions and notifications of award. NASA procurement usually takes an additional month before the award is made and scientists can commence their work. The new large amalgam program, Solar System Workings, stands out, planning 1 year from proposal submission to funding. This seems to be to afford the opportunity to shift funds for new awards from FY15 to FY16, thereby freeing up these funds for other purposes. A statement by PSD Division Director Jim Green made at the December 3, 2013, "Virtual Town Hall Discussion of Restructuring of the Planetary Science Division R&A," indicated that the positioning allowed for the option of shifting all new awards from FY15 to FY16. Complaints about the artificially long gap (20 month) between the original program proposal due dates and the SSW due date resulted in a shift forward of 7 months of the SSW due date (from late February 2015 to late July 2014). However, by holding off funding for one year, PSD management is maintaining the option to rephase all new SSW awards to FY16. SSW should be held to the same 6 month standard as other programs.

Commercial Asteroid Resource Extraction

The future of human activity in space depends upon our ability to cost-effectively recover and utilize resources from near-Earth asteroids, primarily water, which would be used for propellant, life-support and radiation shielding. A human mission to the surface of Mars is estimated to be ~$1T, including development costs. This contemplates raising all the mass to be used (spacecraft components and fuel) from the surface of the Earth at great expense. This is not a number Congress is likely to fund over the next 20-30 years. To make human destinations beyond low-Earth orbit practical, we need to determine if we can offset costs by establishing an infrastructure that would provide necessary components such as fuel from near-Earth asteroids more cheaply than hauling it up from Earth.

NEOs offer easily accessible, low-energy targets with short mission times. This is illustrated in a figure generated by R. Binzel (below), which is a modification of an original figure from the recent NRC report *Pathways to Exploration— Rationales and Approaches for a U.S. Program of Human Space Exploration* (NRC 2014, prepublication draft). The red points were calculated by Binzel and shows the more accurate envelope of near-Earth object mission scenarios derived from known objects. NEOs can be more accessible than the surface of the Moon and can even be comparable to reaching lunar orbit. While these kinds of calculations have long fueled speculation that NEO in-situ resource utilization is practical, there are many other fundamental questions that need to be addressed in order for that to be demonstrated. However, wishing does not make it so, nor does invoking the magic of the private sector. There is much basic research that needs to be done.



It is recognized within the planetary science community that asteroids are intrinsically diverse. The population of near-Earth objects is also transient. It is fed by source populations throughout the asteroid belt and even by comet populations interacting with gravitational resonances and orbital perturbations by planets. The same gravitational effects result in their being ejected from the near-Earth population on timescales of ~7 million years. We have some idea of their composition from remote spectroscopic observations and by picking up meteorites on the surface of the Earth and analyzing them. However, while spectra provide important clues to composition, they do not necessarily provide detailed information on bulk minerals comprising an asteroid. Spectra measure the outermost microns of an asteroid surface and this may be subject to modification by space weathering, some minerals are not spectroscopically active. Likewise, meteorites represent only a small fraction of the mass of the asteroid entering the Earth's atmosphere and do not necessarily present a complete picture of its composition. These are good starting points, however. They tell us, for instance, that if we are interested in water, we want to look for dark carbonaceous asteroids, preferably those with spectral features indicating the presence of hydrated minerals. There are two missions that will be returning samples from such near-Earth objects: NASA's OSIRIS-Rex and JAXA's Hayabusa 2. These will provide some insight into the composition of the material that normally does not survive entry into the Earth's atmosphere. They will also provide some insight into linking remote spectra to meteorite samples.

Commercial asteroid resource extraction requires an understanding of the composition and mechanical properties of the material to be processed, and an understanding of how to do this under low-gravity conditions. The most dynamically accessible resource objects are likely to be small given that the population increases with number with decreasing size. Industrial level activity will probably require many resource targets and even within a taxonomic class (e.g., C-Type) there will be compositional variation. In fact, it is unknown the extent to which any asteroid is compositionally homogeneous (and there is evidence that some are quite inhomogeneous, such as the precursor of the Almahata Sitta meteorite that fell in Sudan in 2008). Extraction processes will have to be developed that accommodate a range of compositions within a target class. In the case of water, such processes would need to be tested and refined using a range of carbonaceous meteorites and simulants on the International Space Station. At some point there would have to be the demonstration of an autonomous resource recovery facility on a near-Earth asteroid. There is then the need to assess the resource that has been extracted, determine the need for subsequent processing into usable material (e.g., water may need to be purified and then converted to hydrogen and oxygen, liquefied, and stored).

All this basic science and engineering is something beyond the scope of reasonable investment by a commercial entity, because there would be no expectation of return in investment on a reasonable timescales. I expect it would take a couple of decades to get to the point when one could answer the question of whether, with some level infrastructure in place, the marginal cost of processing and returning water from an asteroid would be cheaper than bringing it up from the surface of the Earth. Given the potential long-term benefit of a positive outcome in opening up the solar system to expanded human activity, this is a logical area of governmental investment. Once the basic science is known and basic technologies supporting this effort are developed, this would be the logical time for the private sector to come in and see if it could do things more cost-effectively. They would also be in a much better position to create new industries, building on this infrastructure.

Ultimately, there can be no commercial enterprise without a market. For water, there is no market that exists today. In the near future, the primary customer will be the US government, and there is no and never has been a commitment to a long-term, open-ended vision of expanding human activity in space that would mandate the development of an asteroid ISRU infrastructure.

American Space Technology for Exploring Resource Opportunities In Deep Space (ASTEROIDS) Act (HR 5063)

HR 5063 desires "to promote the development of a commercial asteroid resources industry for outer space in the United States and to increase the exploration and utilization of asteroid resources in outer space." There are components of this bill that would support this, but on the whole I believe this bill could have the opposite effect.

On the positive side, this bill recognizes a personal property right of individuals and corporations in "any resources obtained in outer space from an asteroid." There is no incentive to invest in resource recovery if you do not own what you recover.

There is also a practical need to ensure that if you are engaged in resource recovery on an asteroid, that other private parties are discouraged from damaging your equipment, or interfering with your operations or the return of your recovered material. However, this bill focuses on "harmful interference" with a "right" to conduct operations and activities, not the activities themselves. The scope of this right is not defined and could lead to efforts to claim, and hold hostage, large numbers of potential resource targets long before the capability to exploit those targets is developed, not necessarily by the same parties. Under the current language, I could today take published observations of near-Earth objects by the NASA Wide-field Infrared Survey Explorer telescope, identify those with low albedo (enhancing their probability of being water sources), and lay claim to the 100 objects having the most favorable orbits for low-energy missions with good dynamical opportunities for returns of material to Earth orbit. Resource recovery may be decades in the future, but under the terms of this bill I can make an "assertion of superior right" by being "first in time, derived upon a reasonable basis" to have made that assertion and assuming it is "in accordance with all existing international obligations of the United States." I can effectively increase the future costs of those who might be compelled to pay me for access to "my" asteroids or go to a less dynamically favorable resource target.

As we expand commercial activities in space, we want to create a legal environment that establishes protections against interference with actual economic activity and the jurisdiction to which causes of action can be brought. This would include injunctive relief as well. For example, Company A establishes an automated resource recovery facility on the C-Type near-Earth asteroid 367248 (2007 MK13). Company B announces that it in the coming year it will be launching its own resource recovery facility to the same object and will operate on the opposite side of the asteroid. Company A seeks an injunction against Company A going to 367248, arguing that the debris necessarily ejected from the facility has a high probability of impacting their facility and causing irreparable damage. Company B, in turn, may provide detailed numerical simulations showing that by placing their facility on the opposite site of the asteroid, that the trajectory of all debris they would generate clearly avoids Company A's facility. Independent dynamical experts could be brought in to look at the details of Company A and Company B's simulations and offer their opinions. I would note that it would note that it would behoove Company A to bring its action as soon as possible even though it might be years from launch to the start of operation of Company B's facility. Company A has an obligation to mitigate Company B's losses. Company B may be able to launch its facility to a different target, but once launched towards 367248 it would be faced with total loss.

There is much that needs to be learned about the actual composition and the variation of that composition as well as mechanical properties across the near-Earth asteroid population – even within taxonomic types (e.g., "carbonaceous" C-Types) that are often referred to as primary targets for resource recovery activities. This information is critical to design the processes and methods that would be used for the industrial production of asteroid resources. It is not premature to establish protections against physical damage of private property in space, but we should be very cautious about establishing rights that are undefined and of uncertain scope that could have the unintended consequence of discouraging the development of a new important economic activity.

When Nature is Inconvenient to Strategic Planning in Science

I would like to say a few closing words about the inconvenience of the Universe when it comes to long held ideas in science and our efforts to lay out long term strategic plans in activities such as the Planetary Decadal Survey.

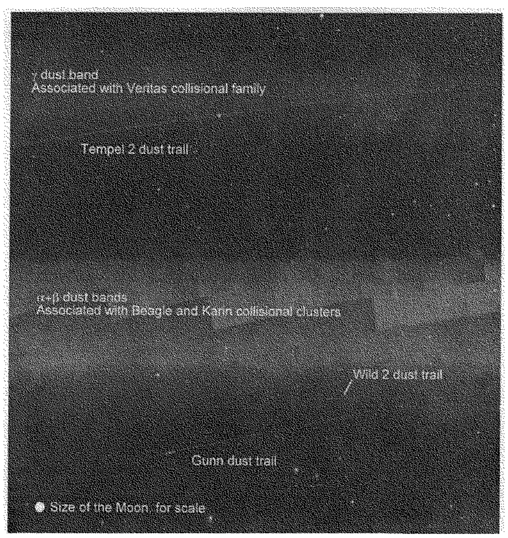
Three months after the release of the decadal survey, the Mars Reconnaissance Orbiter HiRISE team announced the discovery of seasonally flowing water on the walls of some Martian craters. Questions of aquifers arose, later whether it might be do to the accumulation and melting of ice **accumulated** from the atmosphere, but the first thought to come to most people's minds was whether there could be conditions on Mars today that would support life. Not whether conditions existed billions of years ago, but today. Scientists have dedicated their careers to asking questions about ancient conditions on the planet. This is the lynchpin of the rationale that is used to support the multi-flagship Mars sample return effort, which is their top priority. If put to an open discussion, I think more people and scientists would be excited by the question of life on Mars today, particularly if they thought there was some possibility that the answer might be positive.

In the mid-1990s, the discovery of subsurface oceans on Jupiter's moon Europa by the Galileo spacecraft triggered similar great excitement for similar reasons – could there be life beneath its surface? Does water equal life? Today another spacecraft, Dawn, is heading towards the dwarf planet Ceres, which orbits the Sun between Mars and Jupiter in the asteroid belt. It will be arriving in March 2015. Internal modeling of Ceres, with which I am involved along with other groups, indicates that it could have liquid water oceans in its interior today. The Herschel Space Telescope recently reported the episodic emergence of water vapor from its surface. As Dawn approaches this new world, our team will be looking for evidence of the emergence of mineralized water, geyser activity, and other possible explanations for the Herschel observations. If the Dawn mission discovers evidence for this subsurface reservoir of water, the question is again raised of whether there is life beneath the surface of Ceres. If water erupts and quickly evaporates from its surface, could we send another spacecraft to scoop up some of the evaporitic material and see if there are dead bugs? Now we have a target closer to Earth that is easier to reach and in a less hostile radiation environment. Some of the longer-term missions contemplated for Europa could be more cheaply and quickly executed at Ceres. But, many scientists have dedicated much of their careers and Congress has appropriated much funding for the study of future missions to Europa. Accessible oceans at Ceres is a very big IF, but it does bear contemplating how much flexibility we have in our planning to accommodate important if inconvenient discoveries.

Once a decadal survey is released, our knowledge of the solar system does not suddenly freeze. A mid-term review is good, but what if a major discovery is made right after that? We need to figure out ways of being flexible – both in our thinking as well as planning – when we are confronted with new information and insights.

Mark V. Sykes – Biography

Mark V. Sykes is Chief Executive Officer and Director of the Planetary Science Institute at its headquarters in Tucson, Arizona. He grew up in the in the United States Air Force, living in numerous places around the country before attending college at the University of Oregon. He spent summers studying the photometric and polarimetric behavior of eclipsing binary stars at Pine Mountain Observatory, writing his Bachelor thesis on a search for periodicities in the light-curve of the black-hole system, Cygnus X-1. He also studied music composition. In 1978, he received a Bachelor of Arts, Honors College, in Physics. He subsequently studied Fourier optics and laser physics at the Oregon Graduate Center from which he received a Master of Electronic Science in 1982. He received his PhD in planetary sciences from the University of Arizona in 1986, and was awarded its Gerard P. Kuiper Memorial Award for his research. He discovered cometary dust trails, which revealed comets to be far more rocky than previously thought, and discovered numerous rings of dust surrounding the inner solar system arising from recent asteroid collisions. He is a Co-Investigator on the NASA Dawn mission to Vesta and the dwarf planet Ceres. He has served as Chair of the Division for Planetary Sciences of the American Astronomical Society, and is a Fellow of the American Association for the Advancement of Science. He has served on and chaired numerous NASA review panels and advisory groups including the Small Bodies Assessment Group. Mark received his Juris Doctor in 1998 from the University of Arizona, and is admitted to the Arizona State Bar and to practice before the Federal District Court. In 1991 he was honored by the International Astronomical Union with the designation of Minor Planet 4438 Sykes for his discoveries and in 2007 was the first recipient of the NASA Planetary Science Division Distinguished Service Award. For the past 30 years, he has performed professionally with the Arizona Opera Company in its chorus and is actively involved with the American Guild of Musical Artists. Mark is married to Marilyn Guengerich, who is a Senior Program Coordinator at the MMT Observatory. His son Matthew and daughter-in-law Diana live in Ann Arbor, MI, where Matthew is working on his PhD in Material Science at the University of Michigan.



Wide-field Infrared Survey Explorer image of the sky courtesy F. Masci (IPAC/Caltech)

Chairman PALAZZO. Thank you, Dr. Sykes.

I now recognize Professor Gabrynowicz for five minutes to present her testimony.

TESTIMONY OF MS. JOANNE GABRYNOWICZ, PROFESSOR EMERITA, DIRECTOR EMERITA, JOURNAL OF SPACE LAW EDITOR-IN-CHIEF EMERITA, UNIVERSITY OF MISSISSIPPI

Ms. GABRYNOWICZ. Thank you. I would like to thank the Committee for the opportunity to address the ASTEROIDS Act. You have provided four specific questions, and I am delighted to respond. The entire text of my testimony has been submitted for the record.

Current law: Current law is an amalgam of laws that address existing commercial activities. United States law regulates launches and reentry; the technology, financing, and behavior of various payloads; as well as related activities, intellectual property, for example. Laws were passed for specific space-related applications as their technologies matured and were available for commercialization: communications satellites, launch vehicles, remote sensing and, GPS. To the extent that a private asteroid mission uses any of these applications, the law that governs the application will also govern that part of an asteroid mission that uses them.

There is one federal court case regarding an asteroid claim. The plaintiff alleged ownership of an asteroid based on a registration claim made by him on an online registry. He asserted that the United States infringed his property rights and sought compensation for parking and storage fees as well as special damages. The case was dismissed by the District Court and lost on appeal. The court held that the plaintiff appellant did not present a claim for which the District Court may provide relief.

Potential impacts of this kind of legislation on treaties: The potential legal impact of this kind of legislation is likely to be modest. The potential political impact is likely to be sizable. Opinio juris—legal opinion—is crucial to developing the meaning of treaties. There will be disagreement regarding the meaning of this kind of legislation and some of its terms will be challenged at law and in politics. This is because there is no legal clarity regarding some of the issues that the bill addresses. The treaty regime seems to allow private-sector entities to extract resources if those activities are consistent with international law and United States obligations. However, the ownership status of the extracted resources is unclear.

Space is a global commons. Unlike other global commons, there is no agreement as to whether title to extracted resources passes to the extracting entity. In the absence of an agreement, legal opinion is divided. No claims have ever been made in space. Therefore, the status of an intentionally asserted superior right based on a first claim is a question of first impression. The use of first-in-time claims were raised early as they apply to geosynchronous orbital slots.

Some nations champion a slot allocation system based on first come, first served. Others advocated using equity principles. These two positions continue to compete in a complicated and highly politicized legal regime. The competition has produced results such as distinguishing between access and appropriation as well as creating different categories of orbital allotments and assignments. Attempts may be made to apply these kinds of distinctions to asteroids.

There is need to clearly identify which federal agencies will be relevant to an asteroid industry and the specific responsibility of each agency. A private-sector asteroid industry is an unprecedented enterprise. It raises novel issues requiring a wide range of expertise. An interagency structure ought to be considered like the ones that formally govern GPS and commercial remote sensing. These feature a formal agreement among the lead agency and other agencies to work in coordination. Each agency has a particular expertise relevant to some specific aspect of the industry.

One of the greatest challenges is establishing the uniform licensing and regulation of activities on orbit and at the asteroid. At this time, no agency has a specific Congressional grant of on-orbit authority. Contemporary space issues such as orbital debris, space traffic management, planetary contamination, and satellite servicing have already caused some agencies to take regulatory action or make internal procedural requirements that go beyond licensing and operating satellites. These administrative actions demonstrate attempts at a nascent on-orbit authority. There needs to be a specific coordinated grant of on-orbit authority to agencies best suited to regulated an industry of this nature.

In conclusion, the bill addresses some unprecedented issues. If made into law, it should be expected that there will be both legal and political challenges to some of its terms. International space law contains many gaps and ambiguities. It is logical and appropriate to attempt to resolve those ambiguities in favor of U.S. national interest. At the same time, the final results must be consistent with international law and the obligations of the United States.

I thank the Committee for giving me this opportunity, and thank you for your work to further develop space law.

[The prepared statement of Ms. Gabrynowicz follows:]

Written Testimony of

Joanne Irene Gabrynowicz

Before the

Subcommittee on Space of the Committee on Science, Space, and Technology United States House of Representatives

September 10, 2014

Chairman Palazzo, Ranking Member Edward, Members of the Committee: Thank you for giving me the opportunity to address H.R. 5063, the American Space Technology for Exploring Resource Opportunities in Deep Space Act (ASTEROIDS). You have provided four questions on specific issues, and I am delighted to respond.

I. "Provide feedback on H.R. 5063, the American Space Technology for Exploring Resource Opportunities in (ASTEROIDS) Deep Space Act."[1]

All of this written testimony is my "feedback" on H.R. 5063. Under this particular question, I will address one issue.

The issue addressed under this section is the need to more clearly identify which Federal agencies will be relevant to private sector asteroid resource exploration and utilization and the specific responsibility of each agency. As written, the only standard used in H.R. 5063 to determine agency jurisdiction is "appropriateness."[2] It does not designate who determines which Federal agency is an "appropriate" agency and for what purpose. Jurisdictional disagreements are the reality of everyday Federal administration and politics. Resolution can be difficult and take a long time.

In general, Federal agencies can use the authority granted to them in Executive Orders and their organic statutes to reach agreements that define the

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[1] Letter from Rep. Steven Palazzo, Chair, Space Subcommittee of the U.S. House of Representatives Committee on Science, Space and Technology (August 22, 2014) to Joanne Irene Gabrynowicz, Prof. Emerita, on file with author.

[2] H.R. 5063, 113th Cong., § 51301, "The President, through the Administration, the Federal Aviation Administration, and other appropriate Federal agencies,..."

scope and implementation of their collaborative activities. These can take the form of interagency agreements, memoranda of understanding, etc. However, to be effective and to have the authority necessary to carry out an agreement's terms, the agreement ought to be entered into at a high level. To occur at a high level, there must be practical and political incentives strong enough to bring the agencies to discussions. An example of this is the *2012 Memorandum of Understanding Between the Federal Aviation Administration (FAA) and the National Aeronautics and Space Administration (NASA) for Achievement of Mutual Goals in Human Space Transportation.*[3] The *Shuttle* was retired and responsibility for transportation to the *International Space Station* (*ISS*) was shifting from the government to the private sector. The FAA had the authority to regulate; NASA had the human spaceflight expertise; the Nation needed transportation to the *ISS.* An agreement was reached at the level of associate administrator. It is unclear whether asteroid resource exploration and utilization will command this kind of attention when needed.

Private sector asteroid resource exploration and utilization is an unprecedented enterprise. It will raise novel issues requiring a wide range of entrepreneurial, technical, economic, legal, policy, space situational awareness, and diplomatic expertise. No one agency houses all that will be needed. Absent a clearer statement of which agency is responsible for what kind of regulation, an unpredictable over-regulated environment that relies on *ad hoc* dispute resolution could be created. It will produce unnecessary risk that is counterproductive to industry.

An interagency structure analogous to the ones that formally govern the Global Positioning System (GPS)[4] and commercial remote sensing[5] ought to be considered. These feature a formal agreement among a lead agency and other

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[3] *Available at* http://www.nasa.gov/pdf/660556main_NASA-FAA%20MOU%20-%20signed.pdf
[4] 51 U.S.C. § 50112.
[5] Licensing of Private Land Remote-Sensing Space Systems, 15 C.F.R. § 960 (2006).

agencies to work in coordination. Each agency houses a particular expertise relevant to some specific aspect of the industry.

II. "How does current law provide an industry whose purpose is to potentially extract resources from asteroids?"[6]

Current law that addresses an industry whose purpose is to potentially extract resources from an asteroid is an amalgam of space and nonspace laws that address existing commercial activities. United States law regulates launches and reentry; the technology, financing, and behavior of various payloads; as well as related activities, for example, intellectual property and export and import control. Laws were promulgated for specific space-related applications as their technologies matured and were available for commercialization: communications satellites; launch vehicles and services; remote sensing; and, GPS. To the extent that a private asteroid mission uses any of these applications, the laws that govern the applications will also govern the part of an asteroid mission that employs them. For example, an asteroid mission launched or operated by a U.S. citizen will require a launch license from the U.S. Department of Transportation/FAA/Office of Commercial Space Transportation.[7] Depending on its use of communications spectrum and equipment, it will likely also need a license from the Federal Communications Commission. If advertising in space is part of the business plan of an asteroid mission, the advertising must be "nonobtrusive".[8] The Department of Commerce/National Oceanic and Atmospheric Administration is responsible for licensing commercial remote sensing and has already determined that due to the profile of one planned private asteroid mission, it will not require a license. The license requirement could change for other missions with different profiles.

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[6] Palazzo, *supra* note 1 at 1.
[7] 51 U.S.C § 50901, et. seq.
[8] 51 U.S.C. § 50902 (9) and § 50911. " '[O]btrusive space advertising' means advertising in outer space that is capable of being recognized by a human being on the surface of the Earth without the aid of a telescope or other technological advice."

There is one Federal Court case regarding an asteroid claim.[9] The plaintiff alleged "ownership" of *Asteroid 433/Eros* based on a "registration" claim made by him at an online "registry". He asserted that NASA infringed his "property rights" and sought compensation for "parking" and "storage" fees as well as special damages. He sought declaratory judgment for five causes of action based on the Fifth, Ninth, and Tenth Amendments to the United States Constitution.[10] The plaintiff did not raise the issue of whether natural or juridical persons could claim asteroids.[11] The case was dismissed by the District Court and lost on appeal. The Court held that the plaintiff/appellant did not present a claim for which the District Court may provide relief.

Despite this relevant body of law there are "gaps" in the law that will have to be raised by private sector asteroid resource exploration and utilization. Some of them are known. Some are not. This will be addressed in the next section.

III. "What are the greatest challenges to legislating and regulating an industry of this nature?"[12]

One of the greatest known challenges to legislating and regulating an industry of this nature is establishing uniform licensing and regulations of the activities on-orbit and at the asteroid. This is often referred to as "on-orbit authority."

Space, itself, is a global commons and is governed by international law.[13] However, as a State-Party to the Outer Space Treaty the United States is

[9] Gregory William Nemitz, Plaintiff - Appellant, v. National Aeronautics And Space Administration; et al., Defendants – Appellees, No. 04-16223, United States Court of Appeals for the Ninth Circuit, 126 Fed. Appx. 343; 2005 U.S. App. Lexis 2350 (2005).
[10] Robert Kelly, *Case Note, Nemitz v. United States, A Case of First Impression: Appropriation, Private Property Rights and Space Law Before the Federal Courts of the United States*, 30 J. Space L. 297, 298 (2004).
[11] *See Id.* 309.
[12] Palazzo, *supra* note 1 at 1.
[13] Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, Including the Moon and Other Celestial Bodies, opened for signature Jan. 27, 1967, 18 U.S.T. 2410, 610 U.N.T.S. 205 [hereinafter

obligated to authorize and continually supervise the activities of non-governmental entities in outer space.[14] The United States meets this obligation through Federal licensing regulations. Objects that go into space are licensed, registered on the U.S. registry and are governed by U.S. law.

At this time, no agency has a specific Congressional grant of on-orbit authority. The FAA has authority to license launches and reentries. It does not have authority to license a private sector object that is intended to stay in orbit for a period of time.[15]

Some contemporary space issues such as orbital debris, space traffic management, planetary contamination by Earth-originating missions, and satellite servicing have caused some agencies to take regulatory action or make internal procedural requirements that go beyond licensing and operating satellites. For example, NASA promulgated a technical standard that seeks to limit the post-operational life of a space object to 25 years.[16] The FCC adopted this standard as a formal rule for satellites it licenses.[17] The FCC also requires license applicants to file a plan to avoid debris creation and deorbiting the satellite at the end of its life. Different procedures are required for satellites in low Earth orbit and those in geostationary orbit. NOAA reviews commercial remote sensing license applications for post-mission disposal on a case-by-case basis.[18] The Planetary Protection Subcommittee of the NASA Advisory Committee has

Outer Space Treaty]. Art. III.

[14] *Id.* Article VI.

[15] Timothy Robert Hughes & Esta Rosenberg, *Space Travel Law (and Politics): The Evolution of the Commercial Space Launch Amendments Act of 2004*, 31 J. Space L.1, at 49-50.

[16] NASA, *Process for Limiting Orbital Debris, NASA-STD-8719.14 (with Change 4)*, NASA, Washington, D.C., 2009, available at http:// www.hq.nasa.gov/office/codeq/doctree/871914.pdf.

[17] *In the Matter of Mitigation of Orbital Debris, Second Report and Order*, 19 FCC Rcd 1157, paragraphs 84-85 (2004). See http://hraunfoss.fcc.gov/ edocs_public/attachmatch/FCC-04-130A1.pdf; Federal Register publication, 69 FR 54581, 54585 (September 9, 2004).

[18] NOAA, *available at* http://www.nesdis.noaa.gov/CRSRA/licenseHome.html.

recommended reviewing commercial activities to prevent outbound contamination.[19]

Taken together, these administrative actions demonstrate attempts at a nascent on-orbit authority. There needs to be a specific coordinated grant of on-orbit authority to the agencies that are best suited to legislate and regulate an industry of this nature. Finally, as space law follows technological development,[20] legislation and regulations must be flexible to adapt to new technologies.

IV. "What particular issues should be considered in proceeding with legislation of this kind, i.e., potential impacts on international treaties?"[21]

The potential legal impact of this kind of legislation on international treaties is likely to be modest. The potential political impact of this kind of legislation on the international treaties is likely to be sizable. Disagreement should be expected as to the meaning of this kind legislation. *Opinio juris* is crucial to the development of international space law and the meaning of treaties.[22] Without it, potential legal results cannot be realized. The legal status of some of the issues contained in the proposed Bill is unclear and the concomitant international politics are highly contentious. It is to be expected that *opinio juris* will be further divided on some of the issues presented in this Bill.

The international space law legal regime contains a number of well-accepted legal principles: nonappropriation of space by Nation-States;[23] a liability regime;[24] and, national supervision of nongovernmental entities,[25] for example.

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[19]NAC Planetary Protection Subcommittee, http://science.nasa.gov/media/medialibrary/2010/03/31/NASArecommendationNov08_.pdf.

[20] *See* Joanne Irene Gabrynowicz, *One Half Century and Counting: the Evolution of U.S. National Law and Three Long-Term Emerging Issues*, 4 Harvard L. & Policy Rev., 405, 423-425 (2010)

[21] Palazzo, *supra* note 1 at 1.

[22] Leo Malagar, *International Law of Outer Space and the Protection of Intellectual Property Rights,* 17 B.U. Int'l L.J. 311, 341 (Fall 1999).

[23] Outer Space Treaty *supra*, Art. II note 13.

[24] Convention on International Liability for Damage Caused by Space Objects, opened for signature Mar. 29 1972, 24 U.S.T. 2389, 961 U.N.T.S. 187.

However, what constitutes customary legal principles of international space law beyond the well-accepted principles is uncertain. Only those issues most relevant to private sector asteroid resource exploration and utilization will be addressed here.

There is a distinction between the appropriation of territory and the appropriation of natural resources. The treaty regime is clear that appropriation of territory is prohibited.[26] The treaty regime[27] is unclear and contradictory regarding the appropriation of natural resources. Although there are specific provisions proscribing appropriation there are also specific provisions for the "exploitation of...natural resources"[28]. There are also specific provisions that permit the placement of "personnel, space vehicles, equipment, facilities, stations and installations..."[29] needed to extract resources. Further the appropriation of resources appears to be among the rights included in the "use" clauses of the treaties.[30] Taken together, the plain meaning of the word "use" in all of these provisions as well as the clearest and most important treaty provisions[31] indicates that the drafters and the signatories approved of the use, including extraction, of outer space resources.

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[25] Outer Space Treaty *supra*, Art. VI note 13.
[26] OST, Art. II; Moon Agreement, Art. 11 (2).
[27] The United States has not ratified the Agreement Governing the Activities of States on the Moon and Other Celestial Bodies, *opened for signature* Dec. 18, 1979, 1363 U.N.T.S.21 [hereinafter Moon Agreement]. Therefore the United States is not legally bound by it. However, to effectively address the lack of legal clarity regarding space-based resources the Moon Agreement must be included in a discussion of the full *corpus* of international space law. Further, it must be noted that the United States was a leading participant in the development of the Moon Agreement and its adoption by the U.N. General Assembly.
[28] Moon Agreement Art. 11 (5).
[29] Moon Agreement Art. 8 2. (b).
[30] OST, Art. I; Art. III, and, Art. IX. Moon Agreement, Art. 2, Art. 3, Art. 4, Art. 5, Art. 6, Art. 8, Art. 9, Art. 10, Art. 11, and, Art. 15.
[31] OST Art. 1; Moon Agreement, Art. 4.

What remains unclear is the ownership status of the resources when they are collected. Unlike other global commons[32], no agreement has been reached as to whether title to extracted space resources passes to the extracting entity. On the high seas, for example, it is long settled law that title to fish extracted from the ocean passes to the extracting entity. On the seabed "title to minerals shall pass upon recovery in accordance..." with the governing treaty.[33] In the Antarctic mineral resource activities are to be conducted in accordance with the terms of the Antarctic Treaty System.[34] In the absence of agreement legal opinion, *opinio juris*, is divided regarding the ownership status of extracted space resources.[35] Unsurprisingly, much of it divides along lines of political opinion.

In sum, the treaty regime does seem to allow asteroid resource exploration and utilization entities to extract resources if those activities are consistent with international law and United States obligations. There is no legal clarity regarding the ownership status of the extracted resources. It is foreseeable that an entity's actions will be challenged at law and in politics.

Related to the issue of extraction is the definition of "commercial". In the United States, the term "commercial" is defined by *who the actor is*. "Commercial" means the "private sector". In most of the rest of the world including in western, industrialized democracies, "commercial" is defined by *what the actor does*. In

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[32] A comparative analysis of the law applicable to terrestrial and space resource extraction is beyond the scope of this testimony. It is necessary to note however that agreements regarding extraction of resources from other global commons' have been reached.
[33] UN Convention on the Law Of the Sea III, Art. 1. Dec. 10, 1982, 1833 U.N.T.S. 3
[34] Chapter XI Regulation of Antarctic Mineral Resource Activities: CRAMRA, available at U.S. Department of State, http://www.state.gov/e/oes/rls/rpts/ant/.
[35] *Compare* Alan Wasser & Douglas Jobe, *Space Settlements, Property Rights, and International Law: Could a Lunar Settlement Claim the Lunar Real Estate it Needs to Survive?*, 73 J. Air L. & Commerce 72 (2008), *with* Press Release, International Institute of Space Law, Statement of the Board of Directors of the International Institute of Space Law (IISL) (Mar. 22, 2009), *available at* http://www.iislweb.org/html/20090322_news.html.

those Nations, "commercial" means "generates revenue".[36] In the systems that use this definition, governments can, and do, generate revenue through commercial activities. The definition of "commercial" as it applies to space has also been discussed in the United States Congress.[37] The draft Bill uses the term "commercial entities" and "private entity" interchangeably. This Bill, were it to become law, will draw the attention of the international space community. It would be prudent to clarify that the intent of the law is to facilitate the commercial activities of the United States private sector.

As with the ownership status of extracted resources, there is no legal clarity regarding the superior status of a claim found to be "first in time". World history is filled with examples of terrestrial land claims being perfected by making the first claim to a piece of land and then productively using it. No analogous claims have ever been made in space. Therefore the status of an intentionally asserted superior right to conduct specific commercial asteroid resource utilization activities is a question of first impression.

The world's most successful space-based commercial activity to date is satellite telecommunications. Telecommunications law had to address the issue of "first in time" claims as they applied to geosynchronous orbital slots early in its history. Some Nation-States championed a slot allocation system based on "first-come, first-served". Others advocated a slot allocation system based on principles of equity. Satellite telecommunications law is a complex and dynamic body of law the scope of which is beyond the invited testimony. Suffice it to say that these two positions—"first come first served" and equity—continue to compete in a complicated and highly politicized international legal regime. The competition between the positions has included producing some practical results such as distinguishing between access and appropriation as well as creating

[36] *See Frans von der Dunk, The Moon Agreement and the Prospect of Commercial Exploitation of Lunar Resources, 32 Annals Air & Space L.* 91, 93 *(2007).*
[37] See NASA Authorization Act, Pub. L. No. 106-391 §§ 303, 309, 114 Stat 1577, 1593 (2000); Human Space Flight Assurance and Enhancement Capability Act, H.R. 4804, 111th Cong. § 8 (2010)

different categories of orbital allotments and assignments. Attempts may be made to apply these kinds of distinctions to asteroids.

Telecommunications law, *per se*, is not a precedent for asteroid resource utilization rights. However, as both telecommunications satellite activities and asteroid resource utilization activities occur in space they both have to contend with some of the same international space law principles and international politics. It is to be expected that an assertion of a superior right to conduct commercial asteroid resource utilization activities will be challenged at law and in politics.

Conclusion

H.R. 5063 acknowledges and addresses some issues that arise from the unprecedented activity of private sector asteroid resource utilization. It also acknowledges and addresses some of the United States' existing international obligations regarding activities in space. Not all relevant issues are provided in the Bill, and given the ambiguities existing in space law, it is unlikely that it possible to do so. If made into law, it should be expected that there would be both legal and political challenges to its terms. International space law contains many gaps and ambiguities. It is logical and appropriate to attempt to resolve those ambiguities in favor of the U.S. national interest. At the same time, the final results must be consistent with international law and the obligations of the United States.

I thank the committee for giving me this opportunity and thank you for your work to develop the law of space.

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Prof. Gabrynowicz taught space law and remote sensing law for 26 years and was the Editor-in-Chief of the Journal of Space Law for 12 years. She was Research Professor and Director of the National Center for Remote Sensing, Air, and Space Law of the University of Mississippi School of Law (2001 – 2013) and Professor of Space Studies and Director of Graduate Studies at the Space Studies Department of the University of North Dakota (1987 – 2001).

Currently, Prof. Gabrynowicz serves on The National Geospatial Advisory Committee, a Federal Advisory Committee sponsored by the Department of the Interior under the Federal Advisory Committee Act; the NASA Advisory Committee Planetary Protection Subcommittee; and, the U.S. Department of Commerce National Oceanic and Atmospheric Administration's Advisory Committee on Commercial Remote Sensing.

She is a Director of the International Institute of Space Law (IISL) and the Chair of its Publications Committee. Prof. Gabrynowicz serves as an official observer for the IISL to the UN Committee on the Peaceful Uses of Outer Space Legal Subcommittee She was a member of the IISL delegation to the Unidroit Committee of Governmental Experts for the Preparation of a Draft Protocol to the Convention on International Interests in Mobile Equipment on Matters Specific to Space Assets and a delegate to the Group on Earth Observations. Prof. Gabrynowicz is also a member of the International Law Association Space Law Committee. She is a member of the Space Policy Editorial Board.

The UN Office of Outer Space Affairs invited Prof. Gabrynowicz to lecture on U.S. and international space law at all of its capacity building workshops for government officials and policymakers from new and emerging space capable nations. She briefed U.S. Secretary of the Interior Gayle Norton as part of the Secretary's preparation for the Earth Observation Summit. Prof. Gabrynowicz also briefed Deputy Assistant Secretary Frank A. Rose of the U.S. Department of State on the legal aspects of orbital debris.

Prof. Gabrynowicz was invited to serve as an expert member of the Permanent Court of Arbitration Advisory Group of Legal Experts on Optional Rules for Arbitration for Disputes Relating to Outer Space, The Hague. She previously served on the National Academy of Sciences Study on Assessment of NASA's Orbital Debris Programs; the Eisenhower Institute study, The Future of Space-the Next Strategic Frontier; and, was the organizer and chair of the Dept. of the Interior's Federal Advisory Committee for the National Satellite Land Remote Sensing Data Archive.

Prof. Gabrynowicz was the principle organizer and developer of the Eilene M. Galloway Critical Issues in Space Law Symposia from 2006 to 2012. She was a founding faculty member of the Space Studies Department at the University of North Dakota, where she also served as its Director of Graduate Studies. She taught traditional campus classes, on two U.S. Air Force bases, and, starting in 1995, via distance learning technologies. Her students include civilians, government, and industry aerospace professionals, and officers of the Air Combat, Air Mobility, and Space Commands. In 1999, she developed and taught a live, real-time, interactive Internet seminar, Landsat 7 Live: Past, Present, and Future that coincided with the satellite's launch. Speakers were the principals responsible for directing Landsat 7's science, technology, operations, and commercial activities. From 1992-94, Prof. Gabrynowicz was a member of The Congress of the United States Office of Technology Assessment Earth Observations Advisory Panel. From 1994-96, she was a member of the National Research Council Committee that produced Bits of Power: Issues in Global Access to Scientific Data. In 1994-95, Prof. Gabrynowicz was awarded a NASA/American Society of Engineering Education Summer Faculty Fellowship from Goddard Space Flight Center where she also served as the 1997 Dean of the NASA Space Academy. In 1996 she received a research fellowship from the USGS EROS Data Center. In 1999, the International Institute of Space Law invited Prof. Gabrynowicz to write and present the remote sensing law position paper at the Third UN Conference on the Exploration and Peaceful Uses of Outer Space. In 2000, she was invited by the National Research Council (NRC) to participate in a study on Diplomacy in a Transparent World: The Use of Civil Remote Sensing in the Development and Implementation of Foreign Policy. In 2003, the NRC asked Prof. Gabrynowicz to testify before the Committee on Licensing Geographic Data and Services and the Stepping Stones to the Future of Space Workshop on International Cooperation/Competition- Why, How, When? She was also asked to address the NASA Public Health Applications Program on Confidentiality and Geospatial Data. In 2001, Prof. Gabrynowicz was invited by the American Institute of Aeronautics and Astronautics to participate in the working group on Contribution of Space Systems to the Development, Implementation and Verification of International Environmental Agreements. She was invited by the University of Cologne Institute of Air and Space Law and the German Aerospace Center to serve as an expert for Project 2001, which produced, Legal Framework for the Commercial Use of Outer Space Working Group on Remote Sensing.

Before beginning her academic career in 1987, Prof. Gabrynowicz was the managing attorney of a law firm in New York City. She is a member of the American Bar Association (ABA), Forum on Aviation and Space Law, the New York State Bar, and the IISL, among other groups. In 2008 Prof. Gabrynowicz was profiled in the ABA Journal article *Making Space Matter*.

Chairman PALAZZO. Thank you, Professor Gabrynowicz, and I want to thank all the witnesses for their testimony, reminding Members that Committee rules limit questioning to five minutes. The chair will at this point open the round of questions. The chair recognizes himself for five minutes.

Dr. Green, NASA's 2014 Planetary Mission Senior Review Panel recommended continuing all seven missions that were up for review. However, the President's Fiscal Year 2015 budget request only included funding for the extension of the Cassini mission and the Mars Curiosity rover. The President's Opportunity, Growth and Security Initiative would provide an additional $35 million for mission extensions but is unlikely to pass Congress. Where will the money come from to pay for the extensions of the other five missions, and at what point does extending older missions threaten the creation of new missions?

Dr. GREEN. Well, that is a very good question, and of course, my understanding is that Congress will pass a Continuing Resolution, and it is within that Continuing Resolution that we have the framework to be able to continue our missions as we have in FY14. Congress, of course, goes through the appropriation for the overall budget of planetary and we will execute that and we will see at that time what the budget level is and the prioritization that we will have to do to be able to maintain our mission fleet and bring in the quality data that is currently coming in.

Chairman PALAZZO. So I guess as a follow-up to my second part of the question, at what point does extending older missions actually threaten the creation of new missions? Can you kind of elaborate a little more directly on that?

Dr. BELL. Of course. The very first recommendation of the Planetary Senior Review, which often gets overlooked, is that the seven missions that were reviewed were absolutely incredibly important. In other words, they provide outstanding value for the funding that we currently have that manages those missions. We don't have to launch them. They are on orbit. They are doing outstanding science, tackling some new questions that relate to the Planetary Decadal and are making excellent progress. So in the opinion of the community and certainly in the opinion of the senior review as represented by the community, these missions, we must find a way to continue on their operations.

Of course, funding that as appropriated will allow us then to determine the schedule of our next new opportunities and we are currently working on the Discovery Announcement of Opportunity as directed by Congress. We are happy to state that we anticipate getting the release of that announcement of opportunity in early October.

Chairman PALAZZO. Professor Gabrynowicz, the ASTEROIDS Act mentions the phrase "first in time." When describing property rights for resources extracted from an asteroid, would you please provide a definition of "first in time" and give a context for its use?

Ms. GABRYNOWICZ. Thank you, Congressman. Actually I can't because there is no definition in space law for "first-in-time." I haven't researched that specific question but I would look to other law, property law, for example. In the United States, the history of claims has been, if you are the first to claim land and you stay there and you work the land and you produce value from the land, then your claim is perfected. We see that in things like the Homestead Act and the Oklahoma Land Rush, and that is where my understanding of that comes from. But at international space law, that is a term of art that doesn't exist.

Chairman PALAZZO. Does the ASTEROIDS Act have an impact on international treaties that the United States is party to?

Ms. GABRYNOWICZ. Yes. The United States was a leader in developing the Outer Space Treaty, and the four core treaties. The United States is bound by the terms of those treaties, and something like the proposed legislation will catalyze a debate as to whether it is—whether its terms are consistent with the Outer Space Treaty and other relevant treaties, and the United States will definitely be a part of that process.

Chairman PALAZZO. In Section 51203 of the bill, subsections B and C talk about freedom from harmful interference and the need to avoid harmful interference when conducting resource extraction on an asteroid. Would you define the term "harmful interference" and provide the Committee again a better understanding of the context?

Ms. GABRYNOWICZ. The term "harmful interference" can be found in Article 9 of the Outer Space Treaty. When negotiated, that was intended to refer to things like contamination, environmental degradation, one country conducting experiments that precluded the ability of other countries to conduct experiments. It did not have any application to commercial entities or private-sector entities regarding claims. At that time it was only as it referred to nation-states and their national space programs.

Chairman PALAZZO. Thank you. I now recognize Ms. Edwards.

Ms. EDWARDS. Thank you very much, Mr. Chairman, and thank you—thank you, Mr. Chairman, and thank you to the witnesses.

I want to get a couple clarifications. I think it was Dr. Bell, when you talked about the up-and-down resourcing of planetary science, and I think that we share that concern and the authorization that passed in this Committee we established an authorization level that was actually consistent with what the appropriation was, and I noted on your chart, though—and maybe we could clarify this later—that it doesn't seem to reflect the actual dollars that were appropriated. And so for fiscal year 2014, for example, the actual appropriation was $1.345 billion, and I recognize that that is not what it had been at its peak but it is one higher than what the President's request was, but also reflects the notion that this Committee, I think, is trying to get back to some more consistent funding levels and a balanced mission approach to planetary science. And so maybe we could talk offline about your numbers and our numbers too.

Dr. BELL. Absolutely. I would be happy to do that.

Ms. EDWARDS. And then Dr. Green, if you could, on the continuing —on the issue of the Continuing Resolution, I just want to hear some clarity as to whether you believe that postponing new starts would have any impact on planned planetary missions that have required launch dates that are due to planetary alignments.

Dr. GREEN. You know, our current plan is indeed to release the next Discovery announcement. This keeps it on track for the community to be able to complete their development of their proposals and submit them by about the December-January time frame. We then go through an evaluation period with announcement later in that fiscal year. Our plan then is of course to keep our new missions on track to the best of our ability and as the budget will allow. Throughout this particular fiscal year, there is no need for a large influx of money for the Discovery program because we are primarily going through receiving proposals and going through the appropriate——

Ms. EDWARDS. For the next Fiscal Year or the current fiscal year?

Dr. GREEN. For the upcoming fiscal year.

Ms. EDWARDS. Okay.

Dr. GREEN. Because we will be going through the proposal evaluation and then selection.

Ms. EDWARDS. And so if a Continuing Resolution goes through December, you still are on track at least through the beginning of the year——

Dr. GREEN. Correct.

Ms. EDWARDS. —with the missions that are afoot and then you would wait to see what the actual appropriation is beyond the Continuing Resolution?

Dr. GREEN. Indeed.

Ms. EDWARDS. Thank you very much.

I want to go to the questions that Professor Gabrynowicz mentioned, and do you believe, given the things that you have outlined, the gaps that you have outlined in terms of our confluence of international law and domestic law and policy and relationships that it is premature to proceed with the ASTEROIDS Act at this point?

Ms. GABRYNOWICZ. My professional opinion is the ASTEROIDS Act as written is very, very vague and uses terms of art in novel contexts that I have not seen before. So without some groundwork, and by that I mean political, it could be premature.

Ms. EDWARDS. And have—are these, the discussions on the international context, are those ongoing right now in terms of the implications of international law and treaties at this point?

Ms. GABRYNOWICZ. Well, yes, there is the U.N. Committee on the Peaceful Uses of Outer Space that continues to meet every year. There is a counterpart in Geneva, the name of which is escaping me right now, but the discussion of international treaties and space law is an ongoing activity at the United Nations and elsewhere.

Ms. EDWARDS. But given the status, we could easily, this Committee, could postpone our consideration understanding the importance but to some additional more in-depth explorations in the next Congress?

Ms. GABRYNOWICZ. Well, with all due respect, I don't know the activities that brought it to the Committee today, so I don't know what is going on behind it. I don't know the urgencies or not. Strictly reading the text and based on legal knowledge, it definitely needs work.

Ms. EDWARDS. So we need to fill in some holes. Thank you very much, and thank you to the witnesses.

Chairman PALAZZO. I now recognize Mr. Brooks.

Mr. BROOKS. Thank you, Mr. Chairman.

This is for Dr. Green. What is the planetary science community's position on using the Space Launch System for planetary science missions?

Dr. GREEN. I am really happy to tell you that as our Europa mission is in its preformulation activity, we have indeed connected with human exploration and understand the status of the development of the SLS. The SLS can potentially provide us an enormous opportunity to rapidly reach an outer planet's target, and it may fit well for the very first time with our Europa initiative that will be launched in the 2020s. So it is understudy right now. There is no firm commitments but I am happy to say that it does look promising.

Mr. BROOKS. Dr. Sykes, what is the consensus in the planetary science community on whether there is a scientific value expected from the NASA Asteroid Redirect Mission?

Dr. SYKES. Well, I would say it is not a unanimous opinion but there is—it is not something that brings back the most bang for the buck, if you will, that there are higher priorities such as you want to characterize the near-Earth asteroid population to have a survey of that population from space in order to better understand what the real components are rather than an expensive mission to one small target that is not characteristic of the size of objects that represent a danger to Earth or the population of the asteroid—near-Earth asteroid population as a whole. So there is—the science support is weak.

Mr. BROOKS. Ms. Gabrynowicz, early on you state that "no one agency houses all that will be needed" to appropriately oversee private-sector asteroid resource recovery, going on to claim that the system as it stands "will produce unnecessary risk that is counterproductive to industry." Could you please expand upon what this risk might look like?

Ms. GABRYNOWICZ. Well, yes. The activities of asteroid mining have never been dealt with before, and at the same time, there are other activities like space situational awareness, space traffic management that are equally evolving and have aspects that are relevant to asteroid activities. So different agencies have different responsibilities regarding those other activities and there needs to be a coordinated discussion so information can go from one agency to the other, and when another activity or an event emerges which is a case of first impression, the agencies can discuss how to deal with that, and we have two very good models. One is the interagency MOU that is used for commercial remote sensing and also the interagency direction given by Congress for the governance of GPS. So I would suggest looking at those models and proceeding. That way a company will know who is responsible for what. Without it, a question will arise and only then do you start to look around to see who may know how to handle it, and that is unpredictable.

Mr. BROOKS. Thank you. This is for the entire panel. Whoever wishes to answer it, go ahead, and this is a GOP SST staff question. "Congress has been clear in its support for NASA's planetary science missions and continues to propose funding at higher levels than the President's budget request. Why do you think the Administration continues to cut NASA's planetary science division?" Whoever would like to address it in the time I have left?

Dr. SYKES. Well, I would just say that it has other priorities. I think it ranks other activities within the agency higher and that is how it chooses to allocate the resources. We might not agree with that—Congress certainly doesn't agree with that—but it is the hand that we are dealt with.

Mr. BROOKS. Any specific programs that you believe the Administration is placing as a higher priority rather than planetary science?

Dr. SYKES. I don't know. Everything?

Mr. BROOKS. That is pretty broad. Anyone else want to add to that? Hearing no additional response, Mr. Chairman, I yield back.

Chairman PALAZZO. At this time I recognize Mr. Kilmer.

Mr. KILMER. Thank you, Mr. Chairman, and thanks to the entire panel. I appreciate the comments about NASA's planetary science programs and your thoughts on ASTEROIDS Act. I want to also thank Representative Posey for the partnership on the ASTEROIDS Act.

And I guess I want to ask about two things, one, value, and second, principle. Those were the two things that got me interested in the ASTEROIDS Act. So I guess my first question to the panel is, what is there in an asteroid that would be worth the effort and expense of going to go get it?

Dr. BELL. So a variety of answers to that question. Some are purely scientific because we want to know how planets form and asteroids are the building blocks of planets. We know from telescopic surveys and missions that have gone on that there is a variety of kinds of objects out there—rocky, metallic, et cetera. So there are pure exploration goals associated with that.

And then there is a whole side of this business that cares about resources and the kinds of resources that future human explorers and settlers will need to live off the land, if you will, and asteroids are a potentially fruitful supply of those resources. You know, many people talk about metals and many asteroids based on the meteorites in our collection, which are from asteroids, have precious metals on them. But to me, I think maybe the most precious resource is probably water, H20, because we need the water to live, of course, the O to breathe. The H can be an important part of rocket fuel. And so perhaps in the near term—and of course, we are talking decades still for all this to happen—but perhaps the water inventory and water extraction efforts would be the most compelling.

Dr. SYKES. I would like to add to that. I fully agree. In fact, we had a lot of interest in humans to Mars. Humans to Mars is a very expensive proposition, you know, by the estimates that have been made, and I think that the only way that we are going to expand beyond low-Earth orbit in any kind of significant way for human activity is to find a way of living off the land, finding a way of reducing the amount of material we have to haul up the gravity well of the Earth at great expense, and asteroid resources, particularly water, I think offers that possibility. But just saying it doesn't make it so and there is a lot of homework that we need to do in order to determine whether that offers a cost-effective way of buying down the cost of expanding human exploration enabling our going to Mars.

Mr. KILMER. Thank you. The other thing I wanted to ask about, you know, my background was working in economic development and I worked with businesses professionally, and there was two things that drove my interest in this. One, we just talked about, the potential value of doing it, and the second is the sense that for businesses to make an investment, there needs to be some sense of certainty. My observation is, what business wants from government more than anything else is an environment of trust and predictability. So I would like to get some sense from you of, is there value in setting some rules of the road as private enterprise contemplates pursuing any of these valuable aspects of visiting mines—or mining asteroids for this purpose, and I guess relatedly, if a company fails in that endeavor, is there any risk to government or impact to NASA? Is there any downside?

Dr. SYKES. I would say that having that legal certainty, that when you go out there and acquire material at an asteroid, you are a private company, that you own it is very important, and at some point that framework needs to be created to give them, give private corporations that certainty so that if they make that investment and actually go out and do it, bring stuff back, somebody doesn't, you know, say thank you and take it away from them. So that is important.

In terms of risk to NASA, I guess I don't see—don't see that.

Mr. KILMER. Okay. Thank you. I yield back.

Chairman PALAZZO. I now recognize Mr. Hall.

Mr. HALL. I thank you, Mr. Chairman. There has been a lot of exacting questions asked. I will ask maybe some practical ones.

I guess the first question would be, how far away are the asteroids we are talking about and how long would it take to actually reach a target asteroid, not in inches or feet or half a mile, but just give a good guess.

Dr. SYKES. Congressman, asteroids are the easiest things to get to in the solar system. We swim in a cloud of near-Earth objects.

Mr. HALL. Does that mean they are easy, they are closer to us, or——

Dr. SYKES. They are closer to us. They are dynamically easier to get to. It takes less fuel to get to them—not all of them—I am talking about a portion of the population. And I think there is a little chart in my statement that shows how many you can get to with less energy than getting to the surface of the moon and you can do it with turnaround times of—you get there on time scales of, you know, weeks, days, depending on how close it gets. So they offer a great variety of opportunity of access-easy access.

Dr. BELL. I guess I would only add that that is true for a relatively random subset of them, and you know, we may have to go farther to get certain kinds of asteroids. The more water-rich ones may be concentrated out of the main belt Mars and Jupiter. So, you know, the answer is, it varies. Some are close, some are further away.

Dr. SYKES. Absolutely. There is thousands, tens of thousands that we know about, and it is a fraction of them, and their orbits are random within a range but we already know a large number that are easy to get to, and as we conduct space-based surveys to find these objects, you know, surveys designed to find these objects like the WISE mission that recently greatly expanded our knowledge of this class of objects, there are going to be even more targets, which is totally predictable.

Dr. BELL. And I think it is fair to say that no matter which ones we want to go to, we are going to need the sort of infrastructure capability to get out into deep space, whether it is government or a private company. It is not going to be the low-Earth orbit, medium-Earth orbit kind of activity. This is deep-space activity.

Mr. HALL. Mr. Brooks questioned what value you would put on that and why spend the money and are there specific goals. Even the chairman mentioned the question of harmful interference by either your testimony or our analysis of it, who is going to have to pay for it. We know who is going to have to pay for it.

But let me just ask another question. Is there any reason to think asteroid mining is not technically feasible? What is the danger in it? Why would it not be? We have talked about why it should be and what it is going to cost and how far away it is.

Dr. BELL. In terms of the activity of doing the mining? Is that what you are talking about? So it is a very challenging environment. There is almost no gravity on these bodies, and so most of mining technology on the Earth that we are used to involves gravity in some way, and at least being able to walk around and move equipment around, you are talking about very challenging environments, very small bodies where gravity it 1,000, 10,000 times less than what it is on the Earth. So I think there are some technical hurdles that need to be dealt with and how we operate, how do people even move around. Can we land on these objects? Do we actually docket with them? You know, very, very, very big challenges that need to get tackled.

Mr. HALL. Well, this Committee several years ago, maybe seven, eight or ten years ago had a hearing on the dangers involved and where the asteroids were. Somebody there even asked if they dropped something in the middle of America, could you split it and have half of it hit New York and another half hit Los Angeles. They couldn't answer that question either.

I guess—and we held hearings on asteroids about the one that exploded over Russia. If the asteroid mining industry develops, will the resulting technologies help us to understand and interact with asteroids better and perhaps protect against an asteroid threat?

Dr. SYKES. Congressman, I would say that yes, but we would need to be developing—we need to do a lot of homework before we do the asteroid mining because asteroids are characterized by their diversity. They are going to have a variety of internal makeup, surface properties and compositions. How do we work at the surface of an asteroid? There is a lot of homework that needs to be done, basic research that really is best done, I think, by us as a country.

Mr. HALL. I have just one more second and I just——

Dr. SYKES. Oh, sorry.

Mr. HALL. What recommendations—I will ask you this in a letter to you later—that you would make to provide rules and a level playing field and let the market operate form there? And I thank the witnesses for coming today, getting ready to come up here, arriving here and giving some testimony. I hope we use it wisely.

I yield back, Mr. Chairman. I thank you.

Chairman PALAZZO. I now recognize Ms. Bonamici.

Ms. BONAMICI. Thank you very much, Chairman Palazzo and Ranking Member Edwards, and thank you to this impressive panel of witnesses. We are always fortunate, particularly in this Committee and in this Subcommittee, to have experts like you help us inform our decisions.

One of the common themes that we hear about in this Subcommittee, especially when we are talking about planetary science and human space exploration, is the role that NASA has had in sparking imagination, especially in the next generation, and when we discussed missions before, we consider what NASA can do that will most effectively inspire the public so they can turn their interest to science and restore our sense of pride in our leadership role in space, and we have had some discussions already this morning about funding and budget levels, and it is my understanding that NASA's recent budget request for planetary science is low enough to force a withdrawal from the European Space Agency-led Mars mission in 2018 and focus instead on a U.S.-led mission in 2020.

So I want to ask Dr. Green, what might be the difference between a U.S. participation and a European-led mission and leading our own mission and would that negatively impact the collaborations that we have had with the European Space Agency or other international partners?

Dr. GREEN. We work very well with our international partners, and ESA in particular. In fact, as was earlier mentioned, the Rosetta mission has three U.S. experiments on it and a significant portion of another with more than 40 U.S. scientists that analyzing that fabulous data that is coming in that is really inspirational in terms of trying to understand what these cometary bodies are and how they interact with the inner part of the solar system.

As we move in other areas, ESA has a major desire to go to Mars. Their next Mars mission is an orbiter. It is in 2016. It is going to look for trace gases, and NASA actually has a part of that, a very small part of that in terms of providing some electrical equipment that allows that orbiter to communicate with our surface assets, whether they are ESA assets or NASA assets. And then in 2018, we have also—although we have scaled back our interaction on 2018, we still have part of a major experimental that we worked with the Germans on in 2018 rover.

What has happened mostly in our interactions is really the scale of those interactions. In the missions I mentioned, we were actually a minor partner. This is how we have worked the best. One agency leads the effort for which the other is a minor partner and participates and follows that lead.

Ms. BONAMICI. And I am sorry to cut you off. I want to allow time for another question but I am glad to see that there is still some role in those missions.

Dr. GREEN. And we have worked very hard to keep our role.

Ms. BONAMICI. I appreciate that.

And I want to ask Dr. Sykes a question. I see you went to the University of Oregon.

Dr. SYKES. Go, Ducks!

Ms. BONAMICI. I did as well. Go, Ducks. Thank you. So another issue that we talk about here and related to the point that I raised about inspiring the public again, I try to explain to our constituents why this is a priority, oftentimes I find that the public does not understand all the technologies that have been developed through the space program that have civilian uses. There are lists of them. You know. I think our constituents don't understand that GPS, memory foam, solar cells, radial tires, and the list goes on and on, communications, smoke detectors, water filters that they would not have those products to the extent that they do now without space exploration. So we are always trying to educate our constituency about why this is important.

But I wonder, with federal investment in NASA lagging oftentimes when there are tight budgets, some have suggested that the private sector could end up developing technologies that NASA could adopt, and so, analogous but different from asteroid mining. So are there good examples to date of private-sector technologies being adopted by NASA for planetary science research or other purposes? Is there anything we can do to spur innovation in the private sector?

Dr. SYKES. Well, I think the private sector is kicking off pretty with SpaceX and Virgin Galactic and XCOR developing systems, some of which—some of the SpaceX launch vehicles that will I am sure ultimately be used for solar system exploration missions at a reduced cost, and so I think that we are benefitting from that right now and it is opening up new activities in space through tourism. PSI is working with XCOR on the Atsa Suborbital Observatory human-tended telescopes up on—up into space to make observations, and I think that will be pretty exciting.

Ms. BONAMICI. Terrific, and I see my time is expired. I yield back. Thank you very much.

Chairman PALAZZO. I now recognize Mr. Rohrabacher.

Mr. ROHRABACHER. Thank you very much, Mr. Chairman, and I would like to compliment you and Ranking Member Edwards for your commitment to America's space program and keeping us the number one space-faring power in the world, so thank you very much.

Dr. Sykes, I was actually taken by your opening statement that you felt it necessary to apologize for being somewhat negative about a program. Now, let me just note, that attitude—and all I can say is, I commend you for then moving forward with being negative in expressing yourself on a program. What our problem has been in trying to set priorities has been that people on the witness stands have refused to tell us what is negative about specific programs. Over the years, I think I rarely have ever heard anybody say no, this is not worth the money and we should cancel that part and we should finance this. If we are going to have a successful space program, we need people to be very frank about what they believe not to be worth the money, and hopefully they won't need to apologize about pointing out that this program isn't worth as much as some other program. But again, rarely do we ever get that, and I always—they are willing to express what they really want the money for but never what they don't want money to be spent for.

Now, with this, let me note that in your testimony, you were very negative about asteroid retrieval. Let me just note that that was not a condemnation, however, to the ASTEROIDS Act nor was it in any way pooh-poohing or trying to throw cold water on the idea of asteroid mining and commercial activity dealing with asteroids. So that is a very important point to note here that you could have something that is a NASA program that deals with asteroids that may not be worth the money but certainly trying to encourage private investors in the initial steps that are going to be necessary for them to be involved is a very positive thing. So we do need—I think this could be the very first step that we will see 10, 20 years from now and then way beyond, maybe 50 years from now, we might see this as the first step towards something that was really valuable to humankind in that we have private sector people bringing minerals back to the Earth that we need for different types of industrialization.

And let me go to Mr. Green. One of the reasons why I just stressed that people won't say what they don't think is worthwhile is we have certain projects that I have strenuously said we need to reconsider and of course people know that the space—the SLS program is draining about a billion dollars a year out of the budget now. Could you tell me if—and I heard your answer earlier and it was kind of a little nebulous, but are there any planetary or space science missions that are at this point—that the SLS would be a prerequisite to them other than sending a manned mission to Mars?

Dr. GREEN. Yes, I will be happy to answer that. We have started interacting with human exploration which is developing the Space Launch System and we are finding that it has an opportunity to open up the outer part of our solar system, and what I mean by that is, because of its large-velocity injection from the Earth, it therefore enables a rapid transit from the Earth to objects such as Europa or other outer planets' objects. This is incredibly enabling for us.

Mr. ROHRABACHER. So there is no other rockets right now, that this multibillion-dollar effort, huge expenditure is necessary or we will not be able to send a mission by Europa? By the way, I said I eliminated the manned part of it.

Dr. GREEN. Currently, if you compare what our conventional rocket capability is today, we would have to do a number of gravity assists on the inner part of our solar system that will eventually then give the velocity necessary for a spacecraft to go to the outer solar system. This might take 6 or seven years. With the Space Launch System as currently being designed, we can cut that more than in half, and we can get to the outer solar system much quicker.

Mr. ROHRABACHER. I will have to admit that cutting the time in half does not necessarily justify the cutting of major space—other space-related programs to me. I mean, cutting things timewise in half is—I mean, it is interesting for me to hear that but I know that there are lots of endeavors, and if what you are complaining about mainly today is this declining amount of money that is going into space and what we see in this Administration a commitment to this mega project as well as to Earth science, to focus on Earth science rather than planetary science when we have got lots of other Federal Government agencies and departments focusing on

Earth science but NASA is the only one that focuses on space science. So I think that we have got to, number one, be very frank about what we think is not worthwhile and we have got to make sure that the money that we spend is spent wisely and maybe not just to cut the time frame in half at the expense of doing totally other programs.

Thank you very much, Mr. Chairman.

Chairman PALAZZO. I now recognize Mr. Posey.

Mr. POSEY. Thank you very much, Mr. Chairman, and I want to thank all of the witnesses for your excellent testimony here this morning, very informative and very inspiring, and we greatly appreciate it.

Professor Gabrynowicz, just a couple comments in your written testimony and just one quotation: "Given the ambiguities in existing space law, international space law contains many gaps and ambiguities."

Ms. GABRYNOWICZ. Correct.

Mr. POSEY. So, I mean, there is a lot of ambiguity already out there.

Ms. GABRYNOWICZ. Correct.

Mr. POSEY. You know, there will always be questions no matter what Congress does or doesn't pass right now.

Ms. GABRYNOWICZ. Correct

Mr. POSEY. And referring to this legislation, as you did, you know, in a way that you said it is logical and appropriate to attempt to resolve these ambiguities in favor of the U.S. national interest, I am deeply grateful to see that in print, and I am glad that we agree on that for certain.

Ms. GABRYNOWICZ. But we may not always agree as to what is in the national interest.

Mr. POSEY. Well, that is what is always debatable. I mean, you know, there will always be some people who would like to study this or anything else to death until the Russians, the Chinese or somebody else takes the lead on this as they have on some of the other things, and so my question was, if you agreed that this is a good starting point, you know, or in other words, you know, do you think it is time to conduct a full-scale regulatory framework upfront or do you think we should proceed with a draft regulatory framework that has the flexibility to allow the industry and technology to develop further before we start putting all the regulatory framework in cast iron, which some people want to do?

Ms. GABRYNOWICZ. I guess I would frame it differently, Congressman. I would frame it as follows. It needs to be recognized that what we are talking about is resource extraction, which is a very volatile and contentious issue at the international level. Therefore, it can be expected that there will be a great deal of political and legal discussion catalyzed by this. The language of the proposed bill will be analyzed in terms of current law and it will be years before there is any agreement on that. That will create the environment in which this activity needs to go forward, and I think it is appropriate to understand that.

Mr. POSEY. Well, if we wait years before we address the issue, the business just goes somewhere else, you know, and I guarantee you, the Russians and the Chinese will not give the rest of the world the thoughtful consideration that some people expect before we do anything.

Dr. Green, there is concern in the science community about the inventory of plutonium-238, the fuel which powers long-distance robotic spacecraft. How much plutonium-238 is on hand right now?

Dr. GREEN. Currently, the Department of Energy has allocated about 35 kilograms of plutonium. Seventeen kilograms of that is currently within specifications for us to use almost immediately, providing we have the manufacturing capability to put it in the appropriate form.

Mr. POSEY. Okay. How many missions will that supply?

Dr. GREEN. The missions are varied, depending upon the amount of power they have. For instance, the next nuclear mission that is currently being considered is indeed we are baselining radioisotope power for the Mars 2020 rover and that will need 4 kilograms. So we have adequate supply for that.

Mr. POSEY. Okay. How many upcoming planetary science missions will require the use of plutonium-238?

Dr. GREEN. Another one that we are considering, although it has also not been decided, is the potential Europa mission. That one again is in pre-phase A and undergoing intense study. I think it is also important to note that our program as delineated in the Planetary Decadal in the New Frontiers area has a number of targets that probably could not be accomplished without radioisotope power capability, and our intent would be at that solicitation to be able to facilitate that.

Mr. POSEY. Okay. What is the purpose for requesting proposals for Discovery-class missions that were not reliant on the use of radioisotope power systems reflective of the concern about the supply of plutonium-238?

Dr. GREEN. No, they were not. Our concern was the assurance by Department of Energy that they could develop the pellets of plutonium necessary to fuel our radioisotope power systems, and that is based on a production line that has not been fully maintained. We of course are now working closely with Department of Energy to turn that around, and we anticipate them getting back into production of these pellets that will allow our missions to move forward in the next several years.

Mr. POSEY. Thank you. Last year NASA canceled its program to design an advanced Stirling radioisotope generator that would use far less plutonium-238 per mission. Was that—what was the reasoning behind that, especially if there was concern about the amount of plutonium-238 available for long-distance science missions?

Dr. GREEN. Yes, I think it is important to recognize that what we canceled was the actual flight version of the Stirling capability. We currently have pulled that technology back into house. In other words, instead of having it manufactured, we are continuing to test that capability within the NASA centers, but we are anticipating that as we may need it, we will bring that technology back into the future.

Mr. POSEY. Thank you, Mr. Chairman. I see my time has expired. Thank you.

Chairman PALAZZO. I now recognize Mr. Schweikert.

Mr. SCHWEIKERT. Thank you, Mr. Chairman, and to Professors Christensen and Bell, it is nice to see ASU so well represented here. You know, it is—we often—I often talk to my associates here who are from back East who haven't seen the scale of what ASU has become, particularly in this last decade, and they don't understand, I believe we are now the largest university in the country and our hard sciences have done exceptional things.

Mr. Chairman and to the committee, this is sort of a one-off question but I think it actually really does move towards the underlying legislation, which I, you know, fully support the concept but, you know, we have seen throughout humankind, you know, ownership always is necessary for moving investment, but how do you do that in a world where there may be other treaty obligations, perception out there that these resources are sort of controlled either by the communal scientific community owned by sort of, shall we say, the collective of the populations of Earth with us moving forward on a piece of legislation like the ability to own those resources and therefore move forward and doing the investments. When you participate in international organizations, how is this discussion moving forward? Is there at least now a communal understanding that private ownership or individual ownership of those resources will be required to make particularly private investments? Anyone willing to delve into this with me? I am glad I created so much excitement. Professor Bell?

Dr. BELL. Well, I think it comes back to, maybe it was Mr. Kilmer and others who pointed out that companies need some assurance in order to make that investment. So if this is going to go forward, this problem has to be tackled. It is not clear, you know, from what we have heard from today, it is not clear that there is a straightforward solution but it is going to take time and it is going to have to be consistent with our international treaty obligations. So I don't think it is going to happen quickly.

Ms. GABRYNOWICZ. One thought that comes to mind is if we are going to talk about advancing an industry, that it be an industry and perhaps not individual companies. One thing in the language of the proposed bill when they use the term "harmful interference", it is referring to Company A or Company B. If Company A does something, then they are protected by this legislation from Company B's harmful interference. Harmful interference has never been used that way in the treaties. That is a completely novel application of that term of art, and it gives rise to the thought that maybe we are not talking about an industry here but we may be talking about the interest of individual companies, and if that is the case, then that is not going to get us what we want either.

Mr. SCHWEIKERT. To that point, forgive me, because in my reading through it, I actually took it as being even a little more complicated because for any of us to predict what this industry, what this is going to look like a decade, two decades from now, it may be cooperative ventures. It may be public-private. It may be a series of multinationals. Who knows? And so how do you design conceptually the framework in a fashion where we don't demonstrate a certain current arrogance that we know what the future is going to be? And that is sometimes very, very tricky to do.

Is there—and Professor Bell, particularly to you, unintended consequences, and the basic word "unintended" means we don't know, but can you think of any sort of cascade out there as we move forward on trying to build the framework for this discussion that may sneak up on us?

Dr. BELL. Well, I can't think of any technical one. I think the cascading effects are likely to be, as was pointed out, political and, you know, perhaps related to treaty obligations. I think, you know, another way forward, you know, historians would tell us to look to the past and we could look at, you know, analogs for development of the airline industry or development of the telecommunications industry and what we are seeing right now in commercial space is a lot of government seeding of these companies to help them with, you know, getting their footing, helping them to get some of the technologies under their belt that would help them attract investors. And so that is all moving out forward, and it is, you know, your guys' job to figure out the politics behind it.

Mr. SCHWEIKERT. And I know I am over time, and I would also ask you to add to that history the creation of the World Wide Web, which ultimately had very little government touch and actually may be our most successful in a century of reaching, touching and changing our lives.

With that, Mr. Chairman, thank you.

Chairman PALAZZO. Did you want him to answer any questions? I mean, even though we are short—I mean, you are out of time but we are coming close to the—okay.

At this time, for the purpose of being fair and inclusive to all our witnesses, we are going to open up a last round of questions, or question, and I will recognize Ms. Edwards.

Ms. EDWARDS. I just want to thank the chairman. We want to make sure that none of our witnesses, Dr. Christensen, gets to escape without answering a question, and so mine is for you, and it was prepared for earlier but in your prepared notes, you indicate that a sample caching system is a major new development of the Mars 2020 rover mission and should remain the focus of the mission, but in really simple terms what we know is that caching involves the rover carefully collecting a suite of high-quality samples to be returned to Earth by future missions. Are you concerned that the caching system is not a priority for Mars 2020, and then related to that, if you could give us an indication of the ways in which the planetary science is actually an enabler for human exploration missions because we like to see that there is some synergy between what we are doing in what I describe as the multi-mission focus of NASA, how is that planetary science related to the human exploration missions?

Dr. CHRISTENSEN. Sure. I think it is very important to remember the Decadal Survey spent two years looking at priorities across planetary science, and Mars came to the top of that not because of another Mars mission or another rover but because of those samples coming back to Earth, and there is a lot of pressure on actually fulfilling that series of missions. The first rover, its main goal is to collect that cache, and the concern is that if that is not kept at the highest possible priority, then the entire campaign is threatened, and then the whole rationale for making that mission the highest priority comes into question. So it is more of a cautionary note. It will be difficult. It is a complex system to create. We just need to make sure that NASA stays focused on that goal.

Ms. EDWARDS. You don't—I mean, it is not your view, though, that talking about human exploration missions or even investing in those is a distraction from those commitments?

Dr. CHRISTENSEN. I don't believe so. I think within the planetary science community, we have this very high priority, and that is to get samples back robotically from Mars. To tie to the humans, I think it is essential that robotic science program and the human programs are connected. We all wish there was a better connection between them. Everything we are learning is going to inform us so we can safely send humans to Mars. So we think of the science part as the precursor, the very beginning of eventually getting humans to Mars. They are closely tied.

Ms. EDWARDS. And do you think our budget, our budget considerations, I mean, where I mentioned now we are at $1.345 billion for planetary science is reflective of that commitment?

Dr. CHRISTENSEN. On the planetary side, we are concerned. In the previous decade, we could have fulfilled the goals and recommendations in the Decadal Survey. So planetary science doesn't need a vast amount of new money. It needs to be restored to where it had been for almost a decade. The scope of planetary exploration or robotic and human is so different that there is the threat that human exploration can take money from the planetary science side, but I think most of us believe that there is actually a very reasonable divide between those two, and planetary will continue forward successfully.

Ms. EDWARDS. Thank you.

And Dr. Green, do you share that?

Dr. GREEN. I do. I am also looking closely at Mars 2020 as we develop it further to ensure that it is Decadal compliant. I believe the Planetary Decadal is a fabulous document. You know, it is a consensus within the community and it is really part of my drive to make planetary science successful is to follow the Decadal to the best of our ability.

Ms. EDWARDS. Thank you, Mr. Chairman, and I yield.

Chairman PALAZZO. I now recognize Mr. Posey.

Mr. POSEY. Well, thank you, Mr. Chairman. I just wanted to make it again abundantly clear that the letter that you entered into the record at the beginning of this meeting makes it very clear that we have Americans ready actually waiting right now to pursue asteroids as we speak, not in two or three years when Congress finishes studying it together and then moves forward to the gridlock that won't do anything. I mean, this is imminent right now, and I am just so glad to see you take this action on it.

Dr. Green, currently, the United States is the only country able to produce plutonium-238 for use in long-distance science-based missions. If the United States fails to produce enough plutonium for our civilian space program, how likely is it that other countries will develop the capability to send missions to the outer planets of the solar system?

Dr. GREEN. I feel very confident in our relationship with the Department of Energy and the support of the Administration and the wonderful support that we get from Congress to be able to begin the production of plutonium. We are very much on track to be able to do that. Working with Department of Energy, we have actually started to test that process. We generated very small amounts of plutonium in one of their existing reactors. We have extracted that and we now are through Department of Energy developing the procedures and the processes to safely do that at about a kilogram and a half of plutonium oxide every year. That will meet our needs, and I believe that will secure our future, NASA and its approaches to going to places where there is very low light, whether it is the pole of Mars or crawling in a permanently shadowed crater on the moon or Mercury or going out to Pluto or Neptune or Uranus.

So I think we are poised now to be well positioned and good stewards of a planetary program by your support and getting the funding necessary for us to regenerate plutonium, and that is on track.

Mr. POSEY. Thank you, Mr. Chairman. I yield back.

Chairman PALAZZO. Thank you, Mr. Chairman. And I truly want to thank the witnesses for their valuable testimony and the Members for their questions.

The Members of the Committee may have additional questions for you, and we will ask you to respond to those in writing. The record will remain open for two weeks for additional comments and written questions from Members.

The witnesses are excused and this hearing is adjourned.

[Whereupon, at 11:52 a.m., the Subcommittee was adjourned.]

Appendix I

ANSWERS TO POST-HEARING QUESTIONS

ANSWERS TO POST-HEARING QUESTIONS

Responses by Dr. Jim Green

HOUSE COMMITTEE ON
SCIENCE, SPACE, AND TECHNOLOGY

"Exploring Our Solar System: The ASTEROIDS Act as a Key Step"

Questions for the record, Dr. Jim Green, Planetary Science Division Director Science Mission Directorate, NASA Headquarters
Questions submitted by Rep. Steven Palazzo, Chairman, Subcommittee on Space

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1) **The Mars Curiosity rover received critical reviews by NASA's 2014 Planetary Senior Review Panel. They say they "viewed [the team's proposal] as a poor science return for such a large investment," and that "the proposal lacked specific scientific questions to be answered..." The panel was also given the impression that the team thought the mission was "too big to fail."**

   a) **Would you explain the Review Panel's findings?**

Response: The Senior Review Panel recognized the overall science impact the Curiosity mission has had, noting it met its science goals and will likely continue making important discoveries in the extended mission.

The extended-mission proposal described a range of possible scenarios for the same operations budget. The panel's assessment that the proposal had a "poor science return for such a large investment" reflects its position that Curiosity should favor less driving and more sampling. Because Curiosity is an exploratory mission, it must balance the number of geological units it explores versus the intensity of its study for each unit. Put another way, Curiosity cannot explore everything in front of it. We believe the review panel's concern was that the proposal failed to highlight the most important scientific objectives. The proposal delineated ten science objectives and discussed approaches for addressing each of them. NASA does not view any mission as "too big to fail" and we will continue to monitor the scientific progress of Curiosity throughout its useful lifetime.

   b) **As the Mars Curiosity rover is expected to be the foundation for the Mars 2020 rover, how can Congress be assured that the Mars 2020 rover will [be] a worthwhile investment?**

Response: The Mars 2020 mission is being designed to satisfy the top-rated priority large mission recommendation of the current Planetary Decadal [Vision and Voyages, NRC 2013-2022]. To save costs, the Mars 2020 mission will use the architecture of the Curiosity mission as it is a proven delivery system to put a highly capable rover on Mars, and take advantage of hardware remaining from the Curiosity mission as well as existing vendors ready to replicate proven hardware. The Mars 2020 mission will be looking for signs of ancient life on Mars, a very different objective than Curiosity's, which was looking for signs of habitability. The Mars 2020 mission will host a suite of completely different instruments that have already been competitively selected, and a collaborative HEO/STMD involvement including NASA's first In-

Situ Resource Utilization (ISRU) instrument. Furthermore, the mission includes the capability to cache samples of extreme interest that could be returned to Earth. As an additional consideration, through Curiosity operations, we are learning ways to improve operational efficiency, thereby increasing the amount of science accomplished in any given time, which will be applied to the Mars 2020 mission.

c) **How has the Review Panel's critique changed how the Mars Science Lab will submit mission extension proposals in the future?**

Response: We fully expect future extended mission proposals will focus on the major questions the extended mission will address and will explain its science approach in appropriate detail for the senior review committee to completely assess its scientific merit.

2) **According to the Atomic Energy Act, the Department of Energy (DoE) is responsible for maintaining the facilities and infrastructure for the production of Plutonium-238, while NASA reimburses DoE for the cost of producing the plutonium needed for space missions.**

a) **What is the current agreement between the Department of Energy and NASA?**

Response: In April of 2014, NASA and DoE entered into an Interagency Agreement (IAA) under which NASA agreed to reimburse DoE for the cost of producing the plutonium needed for space missions. Under the IAA, DoE will maintain the facilities, equipment and key personnel necessary to fabricate radioisotope heat sources, to assemble and test Radioisotope Power Systems (RPS), to perform associated safety and other technical analysis, and to deliver and support the use of RPS at launch facilities. Furthermore, DoE will plan and execute a project to reestablish the capability to produce Pu-238 domestically.

b) **How much is NASA currently spending to refurbish DoE facilities?**

Response: NASA provided DoE $51.3M in FY2014 and requested $57.4M for FY2015 for DoE to maintain its capabilities to produce radioisotope power systems, to include maintaining specialized equipment and periodically replacing items that have exceeded their useful life. DoE is required to maintain these facilities in operational condition to support NASA's missions. Replacing aging equipment is incidental to that scope. NASA is not funding real property improvements.

c) **How much did NASA historically spend on Plutonium-238 prior to the shut-down of the production program in the 1980s?**

Response: DoE historically produced Pu-238 using DoE appropriations, and charged NASA for its use based on the then-current replacement cost, on the order of $1,200 per gram. Later missions were charged at the cost to purchase fuel from Russia, which ranged between $1,200 to $3,200 per gram over the duration of the Russian purchase contract that was suspended in 2009.

3) **This year an Announcement of Opportunity for a new Discovery-class mission will be**

released to solicit proposals for a smaller, cost-capped science mission.

a) Is there an expectation of the types of missions that will be proposed?

Response: We expect to see a diverse set of proposals in response to the Discovery 2014 Announcement of Opportunity (AO). Investigations could address the terrestrial planets (Mercury, Venus, and Mars) and their moons, Earth's moon, asteroids or comets.

b) How do you foresee the limit on foreign instrument contributions affecting mission proposals?

Response: We do not anticipate the new limit will pose an obstacle to most potential proposers.

4) Since the Draft Announcement of Opportunity states that radioisotope power systems should not be included in a proposal, what types of power systems do you expect to be included in proposed missions? How will this affect the science you expect to conduct?

Response: We expect all missions to propose using solar power. There are potential missions that cannot be supported using only solar arrays, such as to permanently shadowed craters, or orbits at Jupiter or beyond, but there is a large set of scientifically compelling missions that can be accomplished using only solar power, which has been the power source for every Discovery mission flown to date.

5) If the New Horizon's mission to Pluto does not survive beyond its primary mission life, there are currently no planetary science missions scheduled to operate in the outer solar system after 2017.

a) How will this impact U.S. competitiveness in space?

Response: Historically, we have led outer Solar System exploration, launching missions that address the unique challenges presented by this region of space and investigating the wealth of fascinating worlds present there. This exploration has caused us to revise our understanding of the universe at fundamental levels. Other nations are following the path created by the United States to further investigate discoveries made by U.S.-led missions such as Voyager, Galileo and Cassini. For example, the European Space Agency is building a mission to Ganymede, a moon of Jupiter. The U.S. space community continues to study potential new outer planets missions, and continues to conduct research using data already received from previous missions. NASA has been appropriated for the last three years to work on developing a mission to Europa. The multiple fly-by mission concept under development, orbiting through Jupiter's harsh radiation belts, is an example of a mission concept that can still only be pursued by the US Space program.

b) How will this impact scientific research?

Response: NASA missions typically return sufficient data to fuel productive research for a long period of time. We are still analyzing data from the Galileo mission, which ended in 2001, and we expect to continue analyzing data from the Cassini, Juno, and New Horizons missions for more than a decade after those missions are complete. However, at some point the research exhausts the data and productivity decreases. We are reaching that point now with Galileo mission data. In addition, our research allows us to pose new questions that build upon our data and discoveries, and answering these questions requires new types of data acquired by new missions.

6) What is the long-term plan for returning to Earth the Mars 2020 rover cached samples?

Response: There is currently no planned mission specifically to return cached samples from the Mars 2020 mission. However, future technology investments and strategic partnerships could make a future sample return feasible. To that end Mars 2020 will have a returnable cache with all the scientific and planetary protection considerations addressed. Caching a sample represents technical progress by demonstrating coring and sample handling capabilities, along with contamination-control techniques, whether or not the Mars 2020 samples are ever returned. In addition, studies have been conducted to identify future mission architectures for returning samples and to address technical challenges such as launching the samples from Mars and ways to encapsulate the cache for return to Earth. The architecture studies will enable us to make better decisions on landing sites for sample collection and will ensure cache designs are, in fact, returnable.

7) What is the likelihood that a flagship mission, like the Mars 2020 or a possible Europa Clipper mission, will be fully funded, developed, and launched in the next 10 years?

Response: The President's FY2015 Budget Request shows the full five-year funding plan for the Mars 2020 mission, which is planned to launch in 2020. Based upon that request, that mission is expected to launch on time. The President's request also includes $15M for work on a potential Europa mission. NASA has conducted significant pre-formulation activities to develop mission concepts for a Europa mission that could potentially be developed and launched in 10 years.

8) How have budget cuts to NASA's Planetary Science Division affected our cooperation with international partners?

NASA continues to have strong collaborations with international partners. As appropriations declined, the Administration decided not to proceed with a proposed partnership with the European Space Agency's (ESA) ExoMars missions. Since that time, we have focused on lower cost partnerships, primarily through instrument contributions and science team participation that provides access to mission data for significantly lower investments than stand-alone NASA missions. We have re-established cooperation with ESA on Trace Gas Orbiter (TGO) by providing Electra UHF radios and on the 2018 Rover by providing key components of the Mars Organic Molecule Analyzer (MOMA) instrument. We are providing an instrument on ESA's Bepi-Columbo's mission to Mercury, and have instruments on the Rosetta comet mission. We continue to partner with JAXA on their Venus and asteroid missions, and are beginning to work with ISRO on future collaborations.

9) What is the significance of finding water and other resources on asteroids?

Response: Finding water and other resources in sufficient quantities on asteroids could accelerate the exploration of the Solar System. We know from our analyses of meteorites (pieces of asteroids that have fallen to Earth) and remote sensing information from ground-based telescope observations that certain asteroids can contain substantial amounts of volatile materials (water-rich materials, organics, etc.) and metals (Platinum group metals, Iron, Nickel, etc.). The resources of most interest will probably be found on various types of carbonaceous asteroids and metallic asteroids. Space exploration and pioneering could be made much more sustainable by the ability to utilize resources already in space. Propellant mass, for example, is a significant percentage of all the mass that must be carried by a spacecraft and is often the limiting element for mission duration. If the raw materials for propellant and other consumption, such as water, could be extracted from asteroids then missions could survive longer and travel farther on less mass that must be launched from Earth by producing oxygen and other consumables from that water found along the way.

a) What potential market is there for these resources?

Response: There could be a significant market if more nations and commercial enterprises engage in deep space endeavors; once the capability to extract resources is fully developed, propellant production can extend space mission lifetimes without the need to launch additional mass to space from Earth. Additionally, capabilities such as future 3-D printing could use resources extracted from asteroids to manufacture parts. The most likely value is expected to be the utilization of materials extracted from asteroids for future exploration and settlements in space.

b) How would the ability to extract these resources benefit space exploration?

Response: Generally, once the technical challenges are overcome, using resources from asteroids could greatly reduce non-recoverable costs for launching excessive mass and could significantly extend mission capability. Extended robotic missions and future human exploration concepts appear to be much more feasible and at less cost when propellant and water mass can be acquired in space.

"Exploring Our Solar System: The ASTEROIDS Act as a Key Step"

Questions for the record, Dr. Jim Green, Planetary Science Division Director Science Mission Directorate, NASA Headquarters
Questions submitted by Rep. Donna Edwards. Ranking Member. Subcommittee on Space

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1) Please describe how the Mars 2020 mission, and its recently selected science instrument suite, is consistent with the planetary science decadal survey's recommendation for a Mars sample return mission as the highest priority large-class mission.

Response: The Mars 2020 mission is being designed to satisfy the highest-priority science objectives of the current Planetary Decadal Survey. The Mars 2020 rover will investigate Mars' geological processes and history, including the assessment of sampling geologic materials to assess Mars' past habitability and potential for preservation of biosignatures within accessible geologic materials. Additionally, current plans call for the rover to collect a set of scientifically compelling samples and to store them in a returnable cache. In addition, Mars 2020 is also supporting an instrument for the Human Exploration Mission Directorate (HEOMD) and Space Technology Mission Directorate (STMD) to aid future human exploration of Mars. This type of joint activity between the mission directorates is very synergistic with the robotic and human exploration of Mars as delineated in the Planetary Decadal Survey.

2) Has the implementation of the restructured planetary science Research and Analysis (R&A) program proceeded as planned? How do you balance initiating new missions with increasing the level of funding for analyzing existing data?

Response: Yes. The restructured R&A program was solicited under the 2014 Research Opportunities in Space & Earth Sciences (ROSES 2014) on February 18, 2014. Since then we have received proposals for four of our five core programs. The number of proposals received in the new structure has been consistent with our predictions based on the proposals received under the old structure. We have completed peer review panels for three of the five core programs and asked the panelists to complete a post-panel survey questionnaire regarding our performance in executing the new R&A program structure. So far, the trend in responses has been very positive. Once we have completed ROSES 2014, we will compile and analyze all of the survey data.

Planetary Science R&A programs create scientific value using data captured from current and previous planetary missions. It is essential that the R&A programs be adequately funded to take advantage of this investment. Based upon the research conducted through our R&A programs, new questions and new techniques are created that require new missions to pursue. Through our annual budget process, we strive to maintain a balance between analyzing existing data, and developing missions to answer new questions, to provide the greatest overall scientific benefit to the Nation.

3) How is NASA ensuring that its plans to have the Department of Energy restart the

domestic production of radioisotope material necessary for powering NASA deep space and rover missions are consistent with the requirements and timelines of NASA's future needs? With the improvements being made to solar array technology, could future reliance on radioisotope material by planetary science missions be reduced?

Response: NASA's Radioisotope Power System Program Office coordinates with DoE, NASA mission program offices, spaceflight centers, and other critical and related stakeholders to ensure adequate fuel is available to power NASA's planned deep space and rover missions. While working with the DoE to reestablish the capability to domestically produce Pu-238 at an average rate of at least 1.5 kg of Plutonium oxide per year, NASA is investigating opportunities for the development of more efficient Stirling power-conversion technology to lessen the future need for Pu-238. The targeted Pu-238 production rate was set based on a NASA assessment of its mission needs.

Radioisotope power systems are used when solar power is unavailable or infeasible to explore remote and challenging environments with complex missions. Recent advances in solar array technology have extended certain solar-powered missions to Jupiter's orbit, which previously was considered a destination that required radioisotope power systems. However, solar-powered missions remain infeasible beyond Jupiter for the foreseeable future, and radioisotope power systems are required for inner solar system missions where sunlight is obscured or infrequent, such as permanently or partially shadowed craters, high latitudes of Mars, and under the clouds of Venus. As a result, NASA will need to maintain its reliance on radioisotope material for planetary science missions.

4) **A number of international space agencies are now carrying out planetary science missions, including the European Space Agency, Japan, India, and China. To what extent does the international activity affect what the U.S. does with its planetary science program?**

Response: NASA actively pursues partnerships that will make progress in answering the science questions that are delineated in the Planetary Science Decadal (Vision and Voyages, NRC 2012). With many more questions than can possible be answered within NASA's planetary mission cadence, international partnerships provide an excellent opportunity to reach more destinations, and conduct more diverse investigations, than NASA can do alone. Additionally, one of NASA's primary objectives in partnering has been to make the data from these missions as widely available as possible, allowing access to the global research community.

NASA works to understand what the international community is doing in planetary science and is deliberate in its approach to participating in these missions as a minor partner. NASA is a minor partner on ESA's Rosetta, Jupiter Icy Moon Explorer (JUICE), ExoMars, and Bepi-Colombo missions. We are a minor partner in Japan's Hayabusa-2 mission providing a variety of science and sample management support for which we will obtain 10 percent of the returned sample from their targeted asteroid. In addition, we recently agreed to establish a joint NASA-Indian Space Research Organization (ISRO) working group to discuss potential future Mars missions. The joint working group gives NASA the opportunity to find a role in ISRO's future Mars missions that satisfies NASA's goals and objectives in alignment with the Planetary

Decadal and the desires of ISRO for doing Mars science. As certified to Congress under Public Law 113-76, we are working with the Chinese Academy of Sciences on the exchange of lunar science data and making it available through the Planetary Data System for access by U.S. planetary scientists.

5) **What are the challenges involved if NASA moves toward a private sector or public-private approach for providing telecommunications capabilities from Mars in the next decade?**

Response: There are a number of legal and policy considerations to defining a viable commercial telecommunications approach for Mars. NASA recently issued a request for information on this subject, and is just beginning to discuss these questions, and therefore does not yet have a specific set of challenges identified.

6) **Last July, NASA's Small Bodies Assessment Group (SBAG) stated in its findings that the private B612 Foundation, which is seeking to develop a space-based telescope mission named Sentinel to detect near-Earth objects, has been unable to meet scheduled milestones under its Space Act Agreement with NASA. SBAG stated that it is concerned that reliance on this initiative has delayed NASA's ability to move forward on a NEO survey telescope that is competed and optimally designed to address NASA strategic objectives across planetary defense, human exploration, and science. Has any progress been made by B612 with regards to the scheduled milestones?**

Response: The scheduled milestones as stated in the signed Space Act Agreement for "Joint Cooperation for the B612 Sentinel Mission" are as follows:

• Sentinel Mission contract start date with Ball	Nov 2012
• Preliminary Design Review	Oct 2013
• Critical Design Review	Oct 2014
• Launch	Dec 2016
• Initial on-orbit data delivery	NLT Launch + 6 months

None of these milestones have been completed.

a) **What will be the impact on NASA's ability to accelerate the detection of near-Earth objects from space if Sentinel is not available?**

Response: The NASA Near-Earth Object (NEO) Observation program has never specifically relied on the Sentinel project to achieve its goals. While we agree the Sentinel concept had the potential to contribute significant discoveries to the NEO catalog and we were prepared through the Space Act Agreement to benefit from that data should the project come to fruition, we did not assume it would succeed nor did we alter our approach for survey of the NEO population based on its potential success.

b) **What, if any, alternative plans does NASA have to accelerate the detection of near-Earth objects equal to or greater than 140m in diameter, consistent with**

Congressional direction?

Response: With the increased funding level provided in the FY2014 appropriations, the NEO Observation program has reactivated the Wide-field Infra-red Survey Explorer for a three-year mission dedicated to detection and characterization of NEOs, funded the completion of the Panoramic Survey Telescope and Rapid Response System (Pan-STARRS) second telescope and operations for both the Pan-STARRS 1 and 2 for near dedicated NEO detection and tracking, obtained the capability to access data from the new DARPA developed Space Surveillance Telescope for asteroid detection and tracking (in a background mode to its prime space surveillance mission), and funded the start of three new asteroid detection follow-up and characterization projects and four projects to improve capabilities at existing optical and radar facilities. We estimate these projects will at least double the current 1,000 per year discovery rate within the next two years. We have already seen a 42 percent increase in the discovery rate in 2014. In the future years we will support efforts with the National Science Foundation to establish an asteroid detection and tracking capability with the Large Synoptic Survey Telescope so that it can also contribute to the mission when it is projected to become operational in 2022.

7) **In FY 2014, the Science Mission Directorate lost $50 million in Education and Public Outreach (EPQ) funding. NASA's FY 2015 budget request calls for about $15 million to bring some EPO back. What education and outreach that was done in the past is no longer being done today because of the loss of $50 million?**

    a) **If the Science Mission Directorate receives the $15 million in FY 2015, what planetary science EPO activities could potentially be restored?**

Response: The NASA Science Mission Directorate took the FY2014 reduction as an opportunity to restructure its science education approach, and a competitive selection(s) is on track to be awarded late in FY2015.

The President's Budget Request of $15M for FY2015 is only for Science Mission Directorate education activities (which does not include public outreach). SMD's restructured education program will allow for more streamlined and effective implementation of SMD education efforts. The Directorate's restructured approach is to no longer fund mission-by-mission science education, but to fund along science themes or disciplines more aligned with educational standards. Planetary Science activities associated with solar system science-based questions and aligned with the Federal STEM Education Five-Year Strategic Plan will be supported under the new SMD education framework.

8) **To what extent are U.S. Federal agencies considering the issues regarding asteroid mining and resource extraction, including legal and any regulatory issues? What is the status of any interagency dialogue or review?**

Response: To our knowledge there has been no official interagency dialogue or review on the subject of asteroid mining and resource extraction. While there have been studies and significant research conducted on the feasibility of "in-situ resource utilization," to date there has only been informal discussion and academic study of the legal and regulatory issues that might be involved.

9) What is the status of international discussions on the legal issues associated with asteroid mining and property rights in relevant, formal international venues such as the U.N. Committee on the Peaceful Uses of Outer Space?

Response: To our knowledge there has been no official international discussions or review on the subject of asteroid mining and property rights in any international venue such as the U.N. Committee on the Peaceful Uses of Outer Space.

Responses by Dr. Philip Christensen

HOUSE COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY

"Exploring Our Solar System: The ASTEROIDS Act as a Key Step"

Questions for the record, Dr. Phillip Christensen, Regents Professor, Arizona State University
School of Earth and Space Exploration

Questions submitted by Rep. Steven Palazzo, Chairman, Subcommittee on Space

1. Currently, the United States is the only country able to produce Plutonium-238 for use in long-distance space science missions.
    a. If the U.S. fails to produce enough Plutonium-238 for our civilian space program, how likely is it that other countries will develop the capability to send missions to the outer planets of the solar system?

    I am not an expert in the production of Plutonium-238, so I am not qualified to answer questions regarding the likelihood that other countries will develop the capability to send missions to the outer planets.

    b. How would this affect U.S. leadership in space exploration?

    The U.S. is currently the leader in the exploration of the outer solar system. This leadership is based on several aspects, including the ability to navigate to the outer solar system, develop spacecraft and systems that are capable of operating at great distances and under extreme environments, and on the use of Plutonium-238 as a power source. Leadership in all of these areas is essential for the U.S. to maintain its leadership in the scientific exploration and in understanding the outer reaches of our solar system.

2. This year an Announcement of Opportunity for a new Discovery-class mission will be released to solicit proposals for a smaller, cost-capped science mission.

    a. Is there an expectation of the types of missions that will be proposed?

    The Discovery Program is open to any type of mission that can be completed within the $500 M cost cap. These missions provide the science community the opportunity to respond rapidly to new discoveries and to pursue mission concepts that are not part of NASA's core missions. As a result, it is difficult to predict the types of missions that will be proposed.

    b. How do you foresee the new limit on foreign instrument contributions affecting mission proposals?

NASA has placed limits on the total contribution cost of instruments that can be provided from international partners. While these limits may affect the science that can be provided by foreign sources, it does offer greater opportunities for the U.S. science and instrument development communities. Given that U.S. taxpayers are paying for the launch, spacecraft, and mission operations costs of the Discovery missions, it seems appropriate that the majority of the scientific instruments and the opportunities for discovery also remain available to U.S. scientists. One option that might be explored would be to have international partners who wish to provide instruments and participate in Discovery missions pay a proportional share of the mission costs. For example, if an international partner wishes to provide 40% of the science instruments, then 40% of the total launch, spacecraft, and operations costs would also be paid for by the international partner.

3. Since the Draft Opportunity Announcement states that radioisotope power systems should not be included as a power system, what types of power systems would you expect to be included in proposals? How will this impact the science conducted by these missions?

   Without the availability of radioisotope power systems for the upcoming Discovery missions, the power for these missions will be provided by solar-based systems. This limitation will preclude some types of missions – for example those that might go to the extreme outer solar system or to the polar regions of the Moon. However, a wide range of mission opportunities remain that can be achieved using solar power.

4. If the New Horizon's mission to Pluto does not survive beyond its primary mission life, there are currently no planetary science missions scheduled to operate in the outer solar system after 2017.
   a. How will this impact U.S. competitiveness in space?

   It is essential that the U.S. develop new missions to the outer solar system. Cassini at Saturn, Juno on its way to Jupiter, and Hew Horizons on its way to Pluto are the only operating U.S. outer solar system missions. And no new missions are currently in development. Several nations are currently developing mission to the Moon, Mars, comets, and asteroids, but the U.S. is currently the leader in outer solar system exploration. In order for the U.S. to retain its competitiveness in space and to maintain its leadership, it is essential that we remain the leaders in outer solar system exploration.

   b. How will this impact scientific research?

   Many of the exciting new scientific discoveries – from the search for life on icy moons to an understanding of exoplanets around other stars – will come from understanding the planets and moons in the outer regions of our own solar system.

U.S. leadership in these key scientific endeavors requires that we maintain our leadership in the engineering capability to explore these regions.

5. What is the likelihood that a flagship mission, like the Mars 2020 or a possible Europa Clipper mission, will be fully funded, developed, and launched in the next 10 years?

 The Mars 2020 sample caching mission is currently in development and is on track for a successful mission. The Europa Clipper mission continues to be studied and the selection of instruments for a Europa mission has been initiated. The National Research Council's Planetary Decadal Survey highly recommended both of these missions, and described in detail their scientific rationale. The decade-long plan outlined by the NRC was based on a funding level for the Planetary Division that was equivalent to the average yearly spending on planetary science over the previous decade. If the budget for the Planetary Division is restored to its prior level, then it is highly likely that both the Mars 2020 sample caching mission and a Europa mission that meets the criteria defined in the Decadal Survey can be achieved in the next 10-15 years. With restored funding levels it will also be possible to maintain the necessary programmatic balance that includes the smaller Discovery and New Frontiers missions as well as a healthy research and analysis programs.

6. How have budget cuts to NASA's Planetary Science Division affected our cooperation with international partners?

 The significant reductions in the budget of NASA's Planetary Science division have had a very negative impact on NASA's relationships with its international partners. Perhaps the most damaging was the ending of the joint NASA-ESA development of a Mars orbiter to study the state and composition of the atmosphere and a joint NASA-ESA partnership to land, rove, and collect surface samples from Mars. Joint exploration between NASA and ESA in the outer solar system has also been curtailed, with each organization now pursuing smaller independent programs to explore Jupiter and its moons. A larger budget for the Planetary Division would ensure that NASA's Europa mission occur in the near future, which would allow for planning and scientific coordination with ESA's JUpiter ICy moons Explorer (JUICE) planned for launch in 2022.

HOUSE COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY

"Exploring Our Solar System: The ASTEROIDS Act as a Key Step"

Questions for the record, Dr. Phillip Christensen, Regents Professor, Arizona State University
School of Earth and Space Exploration

Questions submitted by Rep. Donna Edwards, Ranking Member, Subcommittee on Space

1. Your prepared statement points out many challenges in implementing the current National Academies planetary science decadal survey as a result of reduced funding levels for the program, including a slowed pace of new missions, potential reductions in the scope of planned missions, and the potential loss of the mix of mission sizes and destinations that have been a cornerstone of the decadal survey. What specifically would be the impact to the health and future of planetary sciences if these challenges are not addressed?

   The National Academy's Planetary Science Decadal Survey called for a mixture of mission sizes and destinations as the critical requirement for maintaining the U.S. leadership in the scientific exploration of space. The current funding level for NASA's Planetary Division will not support the plans outlined in the Decadal Survey. Failure to implement the Survey's plans threatens the U.S. leadership in both the exploration of Mars and the exploration of the outer solar system. Dating back to the 1960's, the U.S. has led the exploration of Mars, and is currently the only country capable of landing and roving on the surface of that planet. The U.S. has made a substantial investment in developing this capability, and now stands to lose its leadership in the continuing exploration of Mars. The next critical step in understanding if life ever emerged on Mars will be the return of Martian samples for study in laboratories on Earth. NASA is poised to achieve this goal, and with it make perhaps the most important scientific discovery of our time by finding evidence of life outside our own planet. If the U.S. does not lead along this path, other nations will. Similarly, NASA is the world leader in exploring the remarkable worlds in our outer solar system. Europa, a moon of Jupiter, is another potential habitat for life, as are Titan and Enceladus, two moons of Saturn. If NASA does not continue its leadership role in the outer solar system, other countries will. Finally, the U.S. planetary science and engineering communities are world leaders. This leadership is also a risk if NASA does not continue to develop the next generation of major missions, and the future scientific discoveries and engineering developments will be made by scientists and engineers in other countries.

   a. Does the decadal survey make recommendations on how to address scenarios involving the challenges you describe?

The Decadal Survey strongly recommends maintaining a balance of mission sizes and recognizes that budget realities might mean a slowing in the pace of mission development and discovery. However, it clearly states that large ("flagship") missions must remain a key component of NASA's strategy. Therefore, the Decadal Survey's provides a clear plan for the science priorities, and recommends that these priorities be addressed in the priority order that is presented and at as rapid a pace as can be achieved within existing budgets. Within this strategy it is essential that large missions remain the key component of NASA's plan.

b. What do these challenges say about how the next planetary science decadal survey should be constructed?

The current Decadal Survey does not specify how the next Survey should be constructed. In the next decade the scientific priorities should once again be set by the science community, and the next Survey should assess these priorities and make adjustments to the current plan as appropriate.

2. How realistic is the prospect of developing both a Mars 2020 mission and a Europa mission that would be launched in the early 2020s, while also maintaining ongoing planetary science missions that were recently recommended for extension by the Planetary Science Senior Review process? What would be the impact on NASA's planetary science research grants program and on the planetary science Discovery missions?

The Mars 2020 mission is in development and appears to be on track for a successful completion. Sample caching remains the key element of that mission. If the Planetary Division funding level is restored to the level of the previous decade, then the Discovery and New Frontiers missions, as well as a robust research and analysis program, could also be accommodated. Without a restoration of the budget the pace of Discovery missions and the timing of a follow-on New Frontiers mission will likely be delayed. To date, the Planetary Division has been successful in maintaining the funding level for the research and analysis programs, although these programs have not increased their funding levels as recommended by the Decadal Survey. As stated in the Decadal Survey, a Europa mission will likely require additional funding to the Planetary Division.

3. To what extent is the Mars 2020 mission and its recently selected science instrument suite consistent with the planetary science decadal survey's recommendation for a Mars sample return mission as the highest priority large-class mission?

The Mars 2020 mission and its instrument suite is fully consistent with the Decadal Survey recommendations. As stated in the Decadal Survey, the primary goal of the Mars 2020 mission is to collect samples for subsequent return to Earth for analysis. Mars 2020 includes a robust sample collection and caching system, as well as a powerful suite of instruments to aid in the collection of a high-quality suite of samples. Thus, the current plan for Mars 2020, with its robust caching system, is fully compliant with the goals and requirements for the mission as specified by the Decadal Survey.

4. Earlier this year, NASA implemented a significant restructuring of the Planetary Science Division's Research and Analysis (R&A) Program. Initially, the science community expressed concern about the restructuring and lack of consistent guidance. Your prepared statement indicates that NASA is currently doing a good job balancing initiating new missions and increasing the level of funding for analyzing existing data. What, in particular, is NASA doing to strike this balance and what, if anything, is needed to maintain this balance?

   The Planetary Division's Research and Analysis program was restructured to better fit the goals of the Division and the needs of the community. This restructuring was based on several years of planning and extensive discussions with the science community. I believe that the program is working well, that the planetary science community is adjusting to the new program, and that the program should be allowed to develop in its current direction. It will likely be several years before the impact of the restructuring can be fully assessed and any necessary changes evaluated.

5. A number of international space agencies are now carrying out planetary science missions, including the European Space Agency, Japan, India, and China. What are your views on the trends internationally in planetary science? To what extent does the international activity affect what the U.S. does with its planetary science program?

   Planetary science and exploration is now being done by an expanding number of nations. The U.S. has long led the exploration of our solar system, and should continue to lead. However, it is exciting that other nations are now becoming involved. The U.S., through NASA, should develop close ties with these nations in order to maximize the return from planetary science, to collaborate where possible, and to avoid duplication of effort through overlapping, competitive programs.

6. In your opinion, how effective was NASA's Senior Review process for determining whether to extend planetary science missions and whether to recommend de-scoping?

   NASA's Senior Review process is designed to evaluate extended mission proposals and provide recommendations as to which missions should be continued. This is a very difficult task because of the differing objectives, both scientific and programmatic, of these missions. In my view the Senior Review process has worked well and has provided Jim Green with meaningful information on which to make decisions.

   a. Do you agree with the panel's concern about the need to balance science and operations in these extensions?

Yes, I agree with the decision to balance science and operations. Several of the missions perform key operations and infrastructure tasks, which in turn enable science from other missions.

b. What impact does the funding for extended operations have on NASA's ability to start the development of new science missions? What, if anything, should be done about the tension between extending missions and initiating new mission developments?

   There will always need to be a balance between maintaining existing missions and starting new ones. However, existing missions provide tremendous return on investment and should be maintained as long as they are making important contributions. While the cost of these missions is significant, they do provide the U.S. with a very cost effective way of producing new results. It is my opinion that the current process is working well and that NASA is achieving the appropriate balance between new and on-going mission support.

7. Given the extensive scientific data and knowledge that researchers have acquired about Mars, to what extent are the planetary science community and the human exploration community discussing and contributing jointly to planning for potential human exploration of Mars? How should the extensive planetary science data and knowledge of Mars be factored into long-term planning for potential human exploration of Mars?

   A tremendous amount of information has been obtained about Mars, and it is essential that this information play a key role in designing and developing future human missions to Mars. At the present time the exploration of Mars is led by the science and robotic missions. I believe that there needs to be expanding communication between the robotic and human exploration communities. It will be impossible to achieve a successful human mission to Mars without fully incorporating the planetary science data, and the planetary scientists, into the design of a human mission.

Responses by Dr. Jim Bell

Responses to Written Questions Submitted by
Chairman Palazzo and Ranking Member Edwards
Committee on Science, Space, and Technology
Subcommittee on Space
United States House of Representatives

Provided October 20, 2014 by Dr. Jim Bell
President, The Planetary Society
Professor, Arizona State University

Questions submitted by Rep. Steven Palazzo

1. In your written testimony, you said that "many missions...have sacrificed science to preserve continued operations."

(1a) Would you give examples of when this has occurred?

Science is the fundamental driver of mission operations. The team of scientists involved in daily mission operations evaluates data as it arrives to inform near-term activities in the mission. A geologist may see a particularly interesting type of rock near the Opportunity rover, for example, and argue for the team to investigate it further. This quick turnaround ensures a more complete return of promising data.

But since safety of the spacecraft is always the number one concern, the engineering team is given priority during rounds of operational cuts. Missions like Cassini and MER Opportunity have endured significant cuts to their operating budgets in their extended missions (for example, Cassini has dropped to about $56 million per year from an initial $80 million). What is often cut first is the number of science team members on the mission. With less science team involvement, there is less capability for quick and diverse analysis of tactical data, or for strategic planning of future observations, which means that promising areas of exploration could be missed as missions rove (or fly) on.

(1b) What is the best balance between extending missions and beginning new programs in the current budget environment?

The question is not just a matter of measuring the science return of an extended mission against the potential return of a new mission—there are also issues related to capability. Missions in extended operations do not challenge the industrial base in the same way a new mission might, and prolonged gaps in new missions can cause those capabilities to atrophy. Long gaps also reduce the opportunities for new researchers to propose new mission concepts and to lead new missions, which reduces experience in mission planning and design. Existing missions are also stuck with the instrumentation they were designed with, and, for the most part, cannot adapt to new discoveries. For example, Cassini's mass spectrometer was not specifically designed to look for astrobiologically interesting compounds, as no one expected it to encounter any. So when Cassini mission scientists discovered the plumes of water jetting off of the moon Enceladus, its instruments could only tell us limited information about the composition of this material.

For the most part, extended mission operations are so much less expensive than development of new missions that it almost always makes sense to continue them as long as they are producing good science. The established Planetary Science Senior Review process is an excellent means for providing this independent evaluation, and we believe it provides good guidance on how best to approach extended missions.

2.*Currently, the United States is the only country able to produce Pu-238 for use in long-distance space science missions.*

> *(2a) If the U.S. fails to produce enough Pu-238 for our civilian space program, how likely is it that other countries will develop the capability to send missions to the outer planets of the solar system?*

The European Space Agency plans to send a mission to Jupiter in 2022. No other space entity, including NASA, has yet made any commitments to develop new missions to explore planets beyond Jupiter. It is unlikely that any other country or space program would attempt to do so anytime in the next few decades.

Recent advances in the durability and efficiency of solar panels have released certain types of missions to Jupiter from the dependence of radioisotope power sources. ESA's mission, the Jupiter Icy Moons Explorer (JUICE), will utilize solar panels for its power generation, as will NASA's Juno mission to Jupiter (in transit and set to arrive in 2016) and its Europa Clipper mission concept (which, if approved, would likely not launch until the early 2020s).

There are many other destinations in the solar system that still require Plutonium-238 for power. These destinations are not just distant from the Sun, but are areas that do not have access to steady sunlight: planets beyond Jupiter, the dusty surface of Mars, cratered areas on Mercury, or the Moon's surface (requiring non-solar power to survive the long lunar nights).

Russia is the only other country to have demonstrated the ability to generate Plutonium-238, though, to the best of our knowledge, Russia no longer produces it. Throughout the 1990s and early 2000s, Russia provided Pu-238 for use in NASA missions, but stopped providing the isotope to the United States in the early 2000s to preserve its own stockpile. So, theoretically, Russia may have a reserve of Pu-238 available for an outer planets mission, but such a mission would be technically beyond anything Russia has ever attempted, and seems unlikely in the near term. Russia did attempt a Mars mission (Mars 96) using RTGs powered with Pu-238, but the mission failed due to problems with an upper stage of the launch vehicle.

China may be developing the capability to produce Pu-238, but this is not verified. The Chang'e-3 lander used small Plutonium-238 heater units, but most experts think that these were purchased from Russia. Europe is currently researching Americium-241 as a Plutonium-238 alternative, but this is limited to technical feasibility studies and is far from ready for use in space.

3. This year an AO for a new Discovery-class mission will be released to solicit proposals for a smaller, cost-capped science mission.

(3a) Is there an expectation for the types of missions that might be proposed?

One of the most compelling aspects of the Discovery program line is that scientists and engineers are free to dream up a variety of creative missions within the strict cost-cap. So in this sense, it's difficult to predict what will be proposed. Past Discovery AOs (this one will be the 13th) have received roughly 25 – 30 proposals each, spanning a wide range of destinations from the inner to the outer solar system, and a wide range of modalities from telescopes near Earth through flybys, orbiters, landers, rovers, and even airplanes and balloons that would study planets, moons, asteroids, and comets.

The details of the kinds of missions proposed to NASA are not publicly released. However, we can use recent publicly-available conference talks or web sites or research papers about missions that were proposed but not selected to get a sense of the variety NASA has to choose from (see, for example, Wikipedia's entry on the Discovery Program, at http://en.wikipedia.org/wiki/Discovery_Program). Among recent Discovery proposals, for example:

Titan-Mare Explorer (TIME): would have splashed down and floated on a sea of Titan, a moon of Saturn with a thick atmosphere and large bodies of of liquid methane.

Io Volcano Observer: would have performed seven flybys of Jupiter's moon Io, which exhibits active and spectacular volcanism.

Mars-Moon Exploration Reconnaissance and Landed Investigation (MERLIN): would have landed on Mars' moon, Deimos.

Icebreaker Life: would have landed in the polar regions of Mars and drilled three meters down into the ice to look for biosignatures.

Comet Hopper (CHOPPER): would have landed on an active comet nucleus to study the composition and organic chemistry of its surface and interior.

INSIGHT: a Mars lander that won the last Discovery competition and which will make the first seismic and geophysical measurements on Mars starting in 2017.

4. Since the Draft AO states that radioisotope power systems should not be included as a power system, what types of power systems would you expect to be included in proposals? How will this impact the science conducted by these mission?

The only other tested and available means of generating electricity for robotic spacecraft—besides radioisotope power systems—are solar panels. The science impact is difficult to quantify, but generally it means that the upcoming Discovery missions could not travel beyond Jupiter, or access permanently shadowed craters on the Moon or Mercury, or endure long lunar nights on the Moon, or survive for long in extreme polar environments on Mars.

5. If the New Horizons mission to Pluto does not survive beyond its primary mission life, there are currently no planetary science missions scheduled to operate in the outer solar system after 2017.

Indeed, there are currently no U.S. planetary science missions planned to operate in the outer solar system after 2017. The European Space Agency's Jupiter Icy Moons Explorer (JUICE) mission is scheduled to launch in 2022, and will orbit Jupiter in 2030 and then its large moon Ganymede in 2032.

(5a) How will this impact U.S. competitiveness in space?

For decades the U.S. has led the world in solar system exploration, with a major symbol of this leadership being that the United States is the only country in human history to have sent spacecraft significantly beyond the asteroid belt (indeed, five American spacecraft are the only human-made objects on course to leave the solar system entirely, led by *Voyager 1*, which was launched in 1977 and which recently crossed out of the Sun's protective magnetic cocoon and into interstellar space). The engineering requirements to design long-lived, durable, and reliable electronic equipment that can survive for decades without maintenance reflect significant investments in engineering systems, technology, and quality control that, so far, only the U.S. has developed. The U.S. has also led the world in the education and training of the highly specialized personnel needed for trajectory determination, deep space operations, and deep space communications.

These skills are critical for space-related missions and for commercial technology development right here on (and around) the Earth. NASA technologies and processes for deep space operations have had an enormous influence on the commercial terrestrial communications satellite, remote sensing, launcher, and mission operations industries, among others. The U.S. government has a long history of seeding investment in space-related technologies and components that, ultimately, have helped to fuel a significant part of the world's estimated $300 billion per year space economy.

If deep space missions are abandoned, the U.S. lead in these technical areas will atrophy and ultimately vanish, and the negative impact on future commercial—as well as governmental and academic—technology development will significantly diminish U.S. economic, engineering, and scientific competitiveness in space.

(5b) How will this impact scientific research?

The outer planets, particularly Uranus and Neptune, are the least-understood worlds in our solar system. Each planet has a swarm of moons and rings that help tell the story of how our solar system began and how it came to be. The Galileo orbital mission at Jupiter (1995 – 2003) and now the Cassini orbiter's mission at Saturn (2004 – 2017) ignited a revolution in our understanding of those gas giant planets. Similar missions are needed at Uranus and Neptune (which the initial *Voyager* flybys revealed to be a different kind of giant planet–ice giants) to revolutionize our understanding of those worlds as well. Additionally, exploring the outer planets would help develop a baseline to better understand the many similar types of exoplanets currently being discovered by astronomers. A flagship mission to explore Uranus was one of the top-ranked decadal recommendations (after Mars sample return and Europa), but no mission is under development.

The exploration of Venus provides a case-study of what happens when NASA pulls back from a destination of exploration. Magellan was the last NASA mission to Venus (1989 – 1994), making the first complete radar map of the planet's surface. But that was twenty years ago, and the scientists that led Magellan are retiring and those who were graduate students in the early 1990s have trouble attracting students to study Venus today. Without new data, there is little funding, and this drives developing scientists to look towards greener pastures for more promising research opportunities and funding support. A similar story will happen with the outer planets if NASA pulls back.

(5c) What impact could this have on the human spaceflight program?

The Planetary Science Division is uniquely positioned to help solve some major problems in human spaceflight, namely the low launch rate of the Space Launch System. Missions to the outer planets could greatly benefit from the heavy lift capability of the SLS to reduce travel times and radiation shielding required by current launch vehicles that must use Venus-Earth flybys. In turn, an increased number of outer planets missions would engage the industrial base of the SLS and maintain a higher frequency of launches that would help mitigate safety and performance concerns.

It is a well-known problem that NASA has not announced any specific plans for launches of the SLS beyond 2021, with an estimated rate of one SLS launch every two to four years after the EM-2 flight. The NASA Advisory Council has deemed this an unsafe rate of launch, recommending at least one launch per year. The problem is that human launches are generally very expensive. Robotic missions, however, are generally not as expensive.

A suite of planetary missions to explore the outer planets using the SLS architecture could help retain the industrial base capabilities required for future human missions while enabling researchers to significantly reduce the time between development and data return on science missions. But this could only happen if the Planetary Science Division has adequate funding to formulate, design, build, and conduct outer planets missions through flagships and the New Frontiers and Discovery competed program lines.

More frequent launches of the SLS will increase its reliability and its potential utility for human-crewed missions, and thus help significantly in promoting the Planetary Society's vision of NASA focusing its human exploration efforts on Mars. Without an outer planets program, the need for the SLS launch capability for planetary missions diminishes greatly, and NASA is once again stuck with the problem of maintaining a safe launch rate for its human SLS missions.

6. What is the likelihood that another flagship mission, like the Mars 2020 or a possible Europa Clipper mission, will be fully funded, developed, and launched in the next 10 years?

We at the Planetary Society believe that it is highly likely that both missions will be funded, developed, and launched over the next decade, due to the strong support that both Mars and Europa exploration receive from the public, the scientific community, and from pivotal members of Congress. The key is a consistent, stable funding environment.

If even a small increase up to or above the historical level of $1.5 billion per year for NASA's Planetary Science Division could be implemented and sustained, both Mars 2020 and the Europa Clipper could be built and launched within ten years. Both missions have been painstakingly designed to reduce risk and cost, and the pair together essentially represent two flagships for the price of one.

7. How have budget cuts to NASA's Planetary Science Division affected our cooperation with international partners?

Budget cuts led NASA to pull out of a joint series of Mars exploration missions with the Europeans, which ultimately drove ESA to partner with Roscosmos.

In 2009, NASA and the European Space Agency signed the *Mars Exploration Joint Initiative*, which led to two joint Mars missions collectively known as ExoMars. The first would have been an orbiting spacecraft called the Trace Gas Orbiter (TGO) set to launch in 2016, followed by a 2018 dual-rover mission featuring a U.S.-built robot called MAX-C and a European rover. NASA agreed to provide the launch vehicles for both missions.

In early 2011, NASA said it could no longer afford the rocket to launch the Mars 2016 mission, so the Europeans purchased a Proton rocket from the Russian space agency, Roscosmos. NASA further altered its commitment in late 2011 and negotiated with ESA to reduce the payload on the 2018 mission from two rovers to one, MAX-C, while also reducing NASA's—and increasing ESA's—proposed overall budgetary commitment. Finally, NASA's FY 2013 budget eliminated all NASA funds for both missions.

NASA spent $46 million for instruments on the Trace-Gas Orbiter mission before U.S. participation was cancelled, though NASA ultimately supplied relay radios that will fly on the orbiter and a science instrument on the European rover.

ESA was forced to scramble for a new partner and ultimately signed an agreement with Russia to continue the mission.

This was not the first time NASA had reneged on a deal with the Europeans. Between 2008 – 2011, ESA was evaluating three large-class missions (one planetary and two astrophysics) on which they hoped to collaborate with NASA. NASA pulled out of the planetary mission, which would have supplied two spacecraft to explore Jupiter's moons Europa and Ganymede. This decision led ESA to re-evaluate the reliability of its U.S. partner on the three large-class missions, and to re-engineer all three to remove dependendence on NASA.

Most recently, NASA has been unable to adequately fund some U.S. science team member's involvement in the ESA JUICE mission to Jupiter and Ganymede, despite European-led teams reaching out to try to involve U.S. scientists in their investigations. Such situations only further strain the relationship between NASA and other space agencies going forward.

Such actions by NASA reduce ESA's ability (and the ability of other national space agencies in Europe) to elicit funds from sponsor nations for future large collaborative efforts with NASA.

8. If NASA Planetary Science Division was funded at $1.5 billion a year, how would that funding affect planetary science missions?

We have calculated that a return to the recent historical average of $1.5 billion per year would be enough to restore Discovery mission selections to a three-year cadence, to maintain the New Frontiers mission cadence at one selection every five years, and to support the development and operation of both the Mars 2020 rover and a Europa Clipper-like mission by the mid 2020s. Research funding would be maintained, as would funding for Plutonium-238 and a stable, though more limited, technology development program. An increase above $1.5 billion for a few years in the late 2010s could help the Europa Clipper be ready sooner (peak funding periods for Mars 2020 and the Europa Clipper need to be staggered, otherwise) and increase scientific research and basic development on crucial technologies like a Mars Ascent Vehicle to return samples from the surface of the red planet to Earth.

Essentially, we believe that the $1.5 billion level is what is required for NASA to maintain a viable program that is fully responsive to the planetary science Decadal Survey.

9. How have the budget cuts to NASA's PSD affected our cooperation with international partners?

Please see answer to Question 7 above.

10. In your testimony you talked about the new program you started at ASU called the New Space Initiative that connects space science and engineering students, faculty, and staff with space start-ups.

(10a) Would you please elaborate on how the program works?

The Space Technology and Science (or "NewSpace") Initiative was started in 2013 to lead the integration of academic and commercial space enterprises using ASU's core strengths in space science, engineering, and education. The initiative's goals are to establish and foster partnerships between ASU and next-generation non-governmental space exploration science and technology companies (the NewSpace sector). Through participation in national conferences, local workshops, and face-to-face meetings, we work to enable the discovery of new research avenues, new partnerships, and new opportunities for student engagement. We actively research and survey both the ASU and NewSpace communities to identify opportunities for collaboration (for example, in submitting joint proposals for space-related research or projects to Federal agencies or private Foundations).

We are connecting ASU faculty, staff, and students with entrepreneurship opportunities on and off campus (for example, workshops, mentoring, and training through the ASU Startup Accelerator program), and we are also working with the WC Carey Business School at ASU and the Space Policy group in the ASU Law School to find ways to assist the commercial spaceflight industry through our membership in the Commercial Spaceflight Federation.

The ASU NewSpace Initiative is envisioned to be a precursor to a NewSpace Institute on campus that brings together established programs in space science, planetary science, and engineering to transform and define the future of academic-private space partnerships.

(10b) Have you seen an increase in students interested in staying in STEM fields after they graduate as a result of this program?

While the Initiative has not been running long enough to track graduating students, we have had significant student interest in the program. Specifically, this includes active engagement with approximately 100 students through a number of space and technology related student clubs at ASU (e.g., Students for the Exploration and Development of Space (SEDS), The Planetary Society student chapter, ASU Rocketry club, Sun Devil Satellite Laboratory, Student Space Law & Policy Society), as well as a seminar class (SES598: "Commercial Opportunities in Space") for approximately 30 students being offered by Profs. Bell and Mauskopf this semester. We have also worked to bring in high-profile female professionals in commercial space and STEM fields (for example from SpaceX and Qwaltec), and some have also interacted directly in mentoring roles with female undergraduate and graduate students through organizations like the ASU Women in Planetary Science. We believe that this kind of engagement will ultimately lead to significant student retention in STEM-related fields.

(10c) What kind of feedback have you received from industry about the program?

Initial feedback from industry has been positive, although we have only just begun working with companies on specific project and proposal ideas. For example, initial projects include work with Virgin Galactic to fly several ASU student microgravity research experiments on their SpaceShip Two suborbital flights in 2015 and 2016, work with SpaceX to identify opportunities for scientific-engineering collaborations in their nascent plans for Mars exploration, and research projects with Space Micro to help with the development of radiation-hardened electronics for use in the high-radiation environment at Jupiter and Europa. Additionally, industry participation in our "Commercial Opportunities in Space" seminar class has been impressive, with representatives from SpaceX, Virgin Galactic, Orbital, XM Radio, KinetX, Paragon, Planetary Resources, Qwaltec, and Space Micro participating in direct interactions with our students.

11. What is the significance of finding water and other resources on asteroids?

One of the most expensive aspects of human exploration, historically, has been the fact that we have initially had to bring all of our critical supplies – food, water, oxygen, fuel – with us on these voyages, whether they be near or far. As we look towards humans eventually traveling back into deep space, beyond the Moon to visit asteroids and eventually Mars, this issue will get even more acute. Longer voyages require longer stores of supplies, which in the traditional approach so far means that we'd have to launch more mass off of Earth to bring those supplies with us. This, of course, means that those missions will also be more expensive, and some could be prohibitively so.

However, it has long been realized that "living off the land," as it were, is possible in some sense for long-duration space travel. Specifically, stores of water within ices and minerals on asteroidal, cometary, and planetary surfaces could provide some of the most important resources required by future human space travelers and settlers. Liquid water could be used for drinking and as radiation shielding within spacecraft, and breaking down water into its constituent components could provide oxygen for breathing and rocket fuel, and hydrogen for energy generation and rocket fuel.

While water is likely to be the most precious resource humans can seek and extract in space, other resources could be of value as well. Specifically, silicate minerals and metallic ores could provide useful as construction supplies (cement, bricks, structures), and it is even possible that some asteroids harbor larger than average supplies of precious metals that could be economically useful back on Earth.

(11a) What potential market is there for these resources?

The most likely market for water, metals, and other resources in the future will be in space itself, on space stations, resupply depots, bases on the Moon or Mars, or on long-term missions to these or asteroidal destinations. The economics of this market would of course need to be worked out, but if prospecting can be made efficient and storage/delivery issues solved, it could easily be the case that in the latter half of the 21st century it could be more economically feasible to extract and purchase these resources directly and "live off the land" rather than having to bring them from Earth.

(11b) How would the ability to extract these resources benefit space exploration?

In the short term (next several decades), resource extraction efforts will be in their infancy, with governments and private organizations embarking on initial tests of a variety of techniques in a variety of environments (for example, NASA's Mars-2020 rover will carry an experiment designed to test methods of extracting oxygen from the Martian atmosphere). It is likely to take many decades not only to perfect resource extraction techniques, but also to prospect for and identify the best locations in near-Earth space and beyond to find those resources.

Looking to the far future (2nd half of the 21st century and beyond), developing the ability to subsist and to advance off-world exploration (both human and robotic) with the help of locally-extracted resources could be a significant benefit to space exploration. If the extraction can be sustainable, and the storage and distribution regularized, it could enable longer-duration stays at solar system destinations (compared to having to bring all supplies from Earth), and/or larger numbers of humans embarking on work, exploration, or settlement ventures. The ability to extract resources "locally" will almost certainly be a required part of establishing an economic sphere of influence that spans the entire solar system.

12. Would you please elaborate on your written testimony and explain what types of federal investment should be made into federal programs that would support the exploration and utilization of asteroids?

Federal investment is needed to continue and complete the catalog of potentially-hazardous Near-Earth Objects. The goals established under George E. Brown NEO Survey Act of 2005 to catalog NEOs down to 140 meters in diameter will provide a census of the population and types of nearby asteroids. In addition to the public safety benefits of properly cataloging potentially dangerous asteroids, it would also assist private endeavors looking for target asteroids for mining by doing some of the leg-work in identifying and characterizing the physical properties of these nearby asteroids.

In addition to completing the NEO survey, federal investment is needed to further mature and demonstrate autonomous proximity operations for space missions. Such technology is important for a wide variety of missions, including human spaceflight, and will be critical for approaching and grappling/landing/docking with asteroids.

And at even a more basic level, the government can continue to provide secondary launch opportunities on other government- or privately-funded launchers for small or secondary satellites (such as CubeSats) that can be used for scientific observations and technological advancements relevant to addressing the potential threats from NEOs.

> *(12a) How long would the development of such technologies take to make extraction of resources possible?*

This is a very difficult question to answer with any accuracy, as the timeline of technology development is nearly impossible to predict. Generally, the more resources that development projects have, the faster they will reach maturity. In this case, since private industry is attempting to develop much of the new techniques and technology, they are subject to the whims of investors and seed funding. Most experts agree that mining even the simplest of compounds (water ice) is decades away unless there is a major shift in fundamental research or private investment towards this area.

Questions submitted by Rep. Donna Edwards

1. Your prepared statement discusses the active role the Planetary Society has taken in outreach on planetary science and on certain planetary missions. How does your organization measure the effectiveness of its outreach efforts?

One of the most straightforward measures we use is the number of members of The Planetary Society. We are a public-facing Society, not a professional one, and our membership reflects that. We currently have nearly 45,000 members who pay a yearly fee to belong to our organization, including 10,000 international members. For the past two years, our membership has grown, and we expect that growth will continue. Each membership comes with a subscription to our magazine, which has unique and detailed reporting on the scientific side of space exploration.

Beyond that, we make extensive use of social media for our outreach. We have a specialized staff member who makes careful analysis of our cumulative two million-plus followers on Google+, Twitter, and Facebook, as well as on our website, which has millions of unique visitors per year.

2. A number of international space agencies are now carrying out planetary science missions, including ESA, Japan, India, and China. What are your views on the trends internationally in planetary science? To what extent does the international activity affect what the U.S. does with its planetary science program? To what extent should it?

There is a clear international trend of increased commitment to planetary exploration. As you noted, every major space program has developed ambitious goals for sending robotic spacecraft beyond Earth orbit. India recently demonstrated new capabilities with its Mars Orbiter

Mission, China with Chang'e-3 (and the upcoming Chang'e-5) lunar landers, and Russia with its failed Phobos-Grunt mission in 2012. The Japanese will launch another Near-Earth Object asteroid sample return mission, Hayabusa-2, later this year. ESA and Japan are working together to explore Mercury in the 2020s with BepiColombo. ESA also plans to orbit a moon of Jupiter, Ganymede, in 2030 with its Jupiter Icy Moons Explorer (JUICE) mission and to land on Mars in 2018 with its ExoMars rover.

However, international partnerships are not a panacea. They carry risks, such as intertwining multiple countries' budgetary limitations and politics, that can significantly complicate, delay, or even prematurely cancel missions.

We believe that the United States should seek international partnerships and coordinate scientific observations when it is possible to structure them in a way that minimizes the risks. Despite some recent negative experiences in international cooperation in space exploration, NASA does know how to do these kinds of partnerships well. Past and recent successes include supplying major instrument contributions on ESA's planetary missions, creating a Mars working group with India, and developing a working group for future Russian Venus exploration.

3. Your prepared statement notes that pressure on NASA's planetary science budget includes responsibility for funding the restart of domestic production of Pu-238 and funding needed to support an increasing number of operating missions. What do you propose to be done to address these tensions in the context of a fiscally constrained environment?

To ensure that Pu-238 is available for future missions, NASA should be given the appropriate resources to accomplish the restart through a partnership with DoE. The testimony simply serves to point out that a major shift in responsibility has occurred over the past few years; NASA is now required to carry the full burden of funding the U.S.'s radioisotope power systems infrastructure and restart of Pu-238 production, which for the past fifty years had been provided as a service by the DoE. This increase in scope, to the tune of $70 million per year, should be noted as an added pressure to an already constrained budget.

In an ideal world, we believe that the DoE would continue with its mandate to provide radioisotope power materials to NASA and other federal agencies, seeking a culture of partnership with those agencies for the betterment of the nation's science and technology enterprises, rather than promoting a culture more like that between a vendor and a customer and shifting money that could otherwise be spent in more direct service of NASA's scientific and exploration goals.

> (3a) *What, in concrete terms, is at stake if the U.S. defer on outer planet exploration for a period of time?*

If we abandon our leadership position in the exploration of the outer solar system, we will lose the institutional knowledge in engineering and technology required to conduct this kind of exploration, we will suffer a loss of the kinds of scientific output that spur a deeper understanding of all the worlds around us (including our own), and a loss of the intangible inspirational, educational, and national pride value that our nation's leadership brings to all of us. In more practical matters, we would also lose the opportunity to help solve a major problem facing NASA: namely the low flight rate of the Space Launch System.

Deferring outer planets missions will defer conducting science needed to answer fundamental questions about the origin of the solar system and the search for life. Outer planets research also contributes vital knowledge to the growing field of exoplanet research; to better understand the multitude of new planets being discovered by astronomers, we need to better understand those in our own solar system.

The ability to successfully conduct deep space missions to the outer planets requires highly specialized skills and facilities found nowhere else, including the design, development and operations of missions at extreme distances, spacecraft operations in high-radiation environments, deep space navigation and communications, and entry, descent, and landing technology. If these skills are not exercised they will atrophy and vanish, and the U.S. will no longer lead the world in this exciting area of science. Stepping back from outer solar system exploration would put our nation on a path that would take decades to rebuild.

NASA's Planetary Science Division is uniquely positioned to help solve a major problem in human spaceflight, namely the issue of the limited launch rate of the Space Launch System. Missions to the outer planets could greatly benefit from the heavy lift capability of the SLS to reduce travel times and radiation shielding required from Venus-Earth flybys required by current launch vehicles. For example, a mission to Europa launched by the SLS would take about three years, compared to nearly seven if launched from an Atlas-V.

It is a well-known problem that NASA has not announced any plans for launches of SLS beyond 2021, and has estimated just one SLS launch every two to four years afterwards. The NASA Advisory Council has deemed this an unsafe rate of launch, recommending at least one launch per year. The problem is that human launches are generally very expensive. Robotic missions, however, are generally not.

A suite of planetary missions to explore the outer solar system using the SLS architecture could help retain the industrial base capabilities required for future human missions while enabling researchers to significantly reduce the time between development and data return on science missions. But this only happens if the Planetary Science Division has proper funding to generate outer planets missions through flagships and the New Frontiers and Discovery competed program lines. Without an outer planets program, the need for the SLS launch capability for planetary missions diminishes greatly, and NASA is once again stuck with the problem of maintaining a safe launch schedule for its human SLS missions.

4. In your opinion, how effective was NASA's Senior Review process for determining whether to extend planetary science missions and whether to recommend de-scoping?

Overall, we find that the Senior Review process is effective at determining the value of scientific return from extending operations for planetary missions, and comparing that value against the cost of extending operations.

(4a) Do you agree with the panel's concern about the need to balance science and operations in these extensions?

In order to retain the best science teams for a project's extended operations, scientists will need to have the ability to engage in evaluation of the data, and not just data collection. Retaining the best scientists ensures that the data are collected properly, and that the data will address the most important scientific questions surrounding the mission. Therefore, we agree with the panel's assessment regarding a balance of science and operations.

(4b) What impact does the funding for extended operations have on NASA's ability to start the development of new science missions?

Fewer available funds for new mission starts can result in greater conservatism and selectivity in choosing the missions NASA is willing to evaluate at a high degree of technical detail, which in turn can stifle innovation for mission concepts, instruments, and technology.

(4c) What, if anything, should be done about the tension between extending missions and initiating new mission development?

We believe the current extended planetary missions are good return on investment, and NASA has done a good job of preserving balance in the planetary program. Perhaps the best action that Congress could take to help to maintain this situation would be to ensure adequate, stable funding for NASA's Planetary Science Division so that all aspects of the Planetary Decadal Survey, including continuity of productive extended missions, can be achieved.

5. Last July, NASA's SBAG stated in its findings that the private B612 Foundation, which is seeking to develop a space-based telescope mission name Sentinel to detect near-Earth objects, has been unable to meet scheduled milestones under its Space Act Agreement with NASA. SBAG stated that it is concerned that reliance on this initiative has delayed NASA's ability to move forward on a NEO survey telescope that is competed and optimally designed to address NASA strategic objectives across planetary defense, human exploration, and science.

(5a) Has any progress been made by B612 with regards to scheduled milestones?

The Planetary Society does not have any additional knowledge of this program beyond that which is made public. We hope they are making great progress.

(5b) What will be the impact on NASA's ability to accelerate the detection of near-Earth objects from space if Sentinel is not available? Does NASA have a "Plan-B"?

Yes, on several levels. First, JPL has proposed and is expected to propose again a Discovery mission called NEOcam, which would serve much the same purpose as the B612 Sentinel telescope. At the moment, NEOcam is just a mission concept and no money has been made available to pursue development of the mission, however. Secondly, continued operation and potential enhancements of NASA's ongoing NEO survey programs will help to generally advance the detection of NEOs, although not the particular potentially dangerous class of NEOs that missions like Sentinel and NEOcam are designed to detect.

6. How can Congress facilitate the potential acquisition of commercial telecommunications services in support of Mars spacecraft if they are proven to be needed and cost-effective?

NASA is indeed already looking into such options, attempting to make exactly that assessment: are there cost effective options that can fulfill a proven need? For example, this past summer, NASA issued a Request for Information (RFI) to investigate the possibility of using commercial Mars-orbiting satellites to provide telecommunications capabilities for future robotic missions to the Red Planet. While the results of that RFI have not yet been made public, it is likely that a number of companies, and perhaps some hybrid academic-commercial groups, have responded to this potential opportunity.

More broadly, continued Congressional support for NASA's technology development programs, including those that promote significant commercial involvement (for example, SBIR and STTR programs), could help to generally facilitate the deeper involvement of commercial service providers in NASA's solar system exploration program.

Responses by Dr. Mark Sykes

HOUSE COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY

"Exploring Our Solar System: The ASTEROIDS Act as a Key Step"

Questions for the record, Dr. Mark Sykes, CEO and Director, Planetary Science Institute

Questions submitted by Rep. Steven Palazzo, Chairman, Subcommittee on Space

1. This year an Announcement of Opportunity for a new Discovery-class mission will be released to solicit proposals for a smaller, cost-capped science mission.
   1. Is there an expectation for the types of missions that might be proposed?

These are missions by which the US planetary community really stretches its imagination to determine the most compelling science that can be proposed within the program cost-cap. Discovery class missions have gone to Mercury (MESSENGER), discovering ice at its poles and revealing strange geologic history; discovered ice at the lunar poles (Lunar Prospector) and probed its interior structure (GRAIL); pioneered putting the first rover on Mars (Pathfinder); collected dust from a comet (Stardust), revealing the early solar system to be more turbulent than had been thought; is conducting the first double rendezvous mission to the two largest objects in the asteroid belt (Dawn); and is discovering hundreds of solar systems around other stars (Kepler). This is neither exhaustive of the missions nor their accomplishments. We continue to expand the scope of what Discovery-class missions can do though improvements in propulsion technologies (particularly ion engines), power systems (e.g., efficient and lighter-weight solar power systems), communication systems (moving to optical from radio), and the capability and sophistication of instrumentation. Discovery mission proposals are also responsive to the latest discoveries arising from the accumulating analyses of data from prior and ongoing missions of all classes and the essential insights generated by the basic planetary research programs, which identify the boundaries of our understanding of the solar system, how it works, how it has evolved, and how it relates to Earth.

The new mission proposals will not want for targets. The near-Earth object population contains captured bodies originating from all parts of the solar system (including the outer solar system). Comets seem to be a highly diverse population of target objects. There are remnant cores from planet formation in the asteroid belt and populations of water-rich asteroids that may have supplied the Earth with its ocean. Mercury has many more mysteries to probe. Venus is still largely unexplored. Mars desperately needs more Discovery-class missions to further our fundamental understanding of this future destination for humans and to determine if life exists there today. Given improvements in solar power generation, it would not surprise me if Discovery expands its reach to Jupiter this call, to operate without nuclear power. There will certainly be numerous sample return missions from small bodies proposed – with the promise of providing detailed information about the early history of all parts of the solar system. I expect there will be survey telescopes proposed to probe the target-rich orbital environment of the

Earth and follow up on discoveries of planets around other stars. The most difficult problem will be to select only one of these proposals.

2. How do you foresee the new limit on foreign instrument contributions to affect mission proposals?

   Missions are not only a path to discovery, but a means by which we maintain and advance our own technical capabilities within the United States. It is not unreasonable for the taxpayer to invest in themselves. Other countries can supply free instruments, which may translate to more science return by affording more instruments within the cost cap. However, mission opportunities are few these days, making it increasingly difficult to sustain US expertise in some areas when foreign instruments on US missions further reduce those opportunities. So, it is worthwhile to find an appropriate balance.

2. Since the Draft Opportunity Announcement states that radioisotope power systems should not be included as a power system, what types of power systems would you expect to be included in proposals? How will this impact the science conducted by these missions?

   Radioisotope power systems allow for operations at large heliocentric distances where solar power is weak. Therefore, science will be limited to investigations requiring only solar power for powering batteries, instruments, operating systems and communications. This will exclude some novel science that was proposed in the last Discovery round, perhaps most dramatically to emplace a boat on the oceans of Saturn's moon Titan (Titan Mare Explorer, TiME). Of course, this was for higher net mission cost to NASA, since the nuclear systems were not included in the cost-cap. A great deal of critical science has yet to be undertaken by these modest cost-capped missions. Far more science has been lost due to the decimation of the Discovery program over the past nearly decade and a half than is not gained by not adding a nuclear power capability to the program. While adding that capability would be very valuable, it is not the end-all, and it does not compensate for reduced opportunities.

3. If the New Horizon's mission to Pluto does not survive beyond its primary mission life, there are currently no planetary science missions scheduled to operate in the outer solar system after 2017.
   1. How will this impact U.S. competitiveness in space?

      To my knowledge, there are no foreign missions to the outer solar system that are funded, so it will be an empty place indeed – except for the continuing signal from Voyager, in which we can take some pride! By the end of this decade almost all currently active US planetary missions are expected to come to an end: MESSENGER, Lunar Reconnaissance Orbiter, Mars Odyssey, MER Opportunity, Mars Reconnaissance Orbiter, MAVEN, Mars InSight, Mars Science Laboratory (Curiosity), Dawn, Juno, Cassini, and possibly New Horizons. OSIRIS-Rex will be launched before the end of the decade, returning a sample from a near-Earth object to Earth in 2023. It is difficult to remain competitive in an arena from which we are so dramatically withdrawing. The problem is way beyond US presence in the outer solar system. Taking together the recommendations of the recent NRC planetary decadal survey, a 'balanced' mission suite would consist of 5 Discovery missions per decade, 2 New Frontiers missions per decade and one Flagship mission per decade. The Discovery program originally envisioned more than 10 low-cost missions per decade. Mars is now included in the Discovery program, but used to have its own line, sending Discovery-class spacecraft to Mars every ~2 year opportunity. Even the decadal survey pulls back from the earlier ambitions of the US solar system exploration program. If the US wishes to be competitive in space exploration, it needs to commit to restoring the competed Discovery program and provide resources sufficient to fund the balanced program recommended by the decadal survey (the resources are not sufficient today after cuts by the Administration - and the decadal survey recommends descoping and delaying Flagships first). It would require only a modest uptick in the pre-2013 NASA Planetary Science Division budget. I hope at the end of this decade we will still be receiving Voyager's signal.

2. How will this impact scientific research?

The end of so many US planetary missions throughout the solar system by the end of this decade will have negative long-term consequences on scientific research, in part due to NASA's view of its own mission and the lack of new data against which we continually test our evolving understanding of the solar system. NASA officials are quick to point out that NASA is not a science agency. Their job is to launch missions. This hurts us by instilling from the beginning a minimalist approach to science return (e.g., mission success based on limited Level 1 requirements). Taxpayers invest significant dollars in these science missions, and it is the science return that should be maximized, not headlines (water-ice discovered on Mars - again) and drama ("seven-minutes of terror"). Science is obtained through analysis of mission data and the basic research required to understand it and put it in larger context. Collecting and transmitting data is just the beginning. There is an enormous amount of scientific research to be done to gain continuing benefit from missions past and still operating throughout the solar system. Even as our operating missions come to a nearly wholesale end, valuable scientific research will continue to the extent it is funded. However, new missions are an important tool we use to explore and open up new science and probe new questions arising from ongoing science. It keeps our science fresh and challenged. Our theories of the broader universe rest largely on remote observations of very distant events. We have the amazing opportunity to test and expand our knowledge and theories of our own solar system directly through robotic exploration. US planetary science needs both a sustained commitment to supporting planetary research and a steady cadence of small, medium and large missions (as prioritized across classes in the planetary decadal survey when resources are insufficient). As our missions die, I expect (if the past is any guide) that interest will begin to wane within the agency for supporting scientific research of worlds where missions no longer operate and to which mission are not being planned within an average residual career. American planetary research and American competitiveness will decline across the board.

4. What is the likelihood that a flagship mission, like the Mars 2020 or a possible Europa Clipper mission, will be fully funded, developed, and launched in the next 10 years?

   The intense focus on one or the other of these two Flagship mission concepts by the Administration and Congress makes it likely that one or the other, if not both, will be fully funded, developed and launched in the next 10 years, regardless of the consequences to the rest of US solar system exploration. I note that a misstatement of fact was made during testimony to this committee: The Mars Astrobiology Explorer-Cacher mission (MAX-C, to which Mars 2020 seeks to evolve) was not the top priority of the NRC planetary decadal survey. It was the top Flagship priority, under certain cost constraints. Flagships are not the top priority either. The budget of NASA's Planetary Science Division should be increased to a level that would allow a Flagship mission to be executed while at the same time restoring the Discovery program, maintaining the New Frontiers program, and preserving and modestly growing the research and data analysis programs and technology development as recommended by the planetary decadal survey.

5. How have budget cuts to NASA's Planetary Science Division affected our cooperation with international partners?

   The United States has been a successful and beneficial partner in cooperation with the space initiatives of other nations, and has benefitted from their cooperation on our own missions. We also have a long history of withdrawals from high-profile missions that have been very disruptive to our partners, going back decades to the Halley flyby/Tempel 2 rendezvous mission with ESA. Both the United States and other nations continue to take every opportunity afforded by law to find ways of cooperating with each other in space, despite the occasional negative drama. The potential science benefits continue to exceed the programmatic, budgetary and political risks. However, today there are a growing number of nations engaging in solar system exploration, and that increases options for partnership that did not earlier exist. The US is no longer indispensible. Our unreliability in major initiatives, most recently caused by substantial cuts to the NASA Planetary Science Division budget, gives incentive to other nations to look to other partners to advance their national exploration goals.

HOUSE COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY

"Exploring Our Solar System: The ASTEROIDS Act as a Key Step"

Questions for the record, Dr. Mark Sykes, CEO and Director, Planetary Science Institute

Questions submitted by Rep. Donna Edwards, Ranking Member, Subcommittee on Space

1. In your opinion, how effective was NASA's Senior Review process for determining whether to extend planetary science missions and whether to recommend de-scoping?

   I agree with the recent IG report that the Planetary Science Division's process has serious problems. Focusing narrowly on the short term (2 years instead of 4) and excluding projects impairs "the Planetary Science Division's ability to inform its budget formulation process and ensure the effectiveness and transparency of its Senior Review process." Per the report, there was a remarkable failure in PSD management's documentation of the rationale for its budget guidelines and its departure from estimates provided as part of NASA's Planning, Programming, Budgeting, and Execution (PPBE) process. Rationale for inclusion of some missions and not others in the process was not documented (except when queried by the IGO). The report that some missions felt they "did not have sufficient time between receipt of the budget target and the proposal due date" suggests a process not taken very seriously by PSD management. This is underscored by the late addition of the Deep Impact Project to the Senior Review, "when Division management verbally provided the Project management team with a budget target and requested a proposal." How can a process so flawed be effective?

    1. Do you agree with the panel's concern about the need to balance science and operations in these extensions?

       Rationalization for extending a mission will be based largely on the value of the science to be returned, balanced by operational risk and cost. There is no rational basis that I have seen for the "mission extension paradigm" - in particular to have a universal target of 33% cuts. It ignores the fact that operations take up a significant fraction of an extended mission's budget - often more than 50%. Operations also represent (with a few exceptions) a fixed cost. So, if you cut overall mission budget by 33% and operations stays fixed at 50%, you reduce science by 66%. That is a huge handicap.

    2. What impact does the funding for extended operations have on NASA's ability to start the development of new science missions? What, if anything, should be done about the tension between extending missions and initiating new mission developments?

       Extended mission costs should be built into their corresponding mission lines (and I have recommended to the committee that Flagships be grouped together, regardless of target). It is important to support extended missions when there is still good science to be returned for the marginal cost. Planetary missions are often to unique targets to do unique observations that are not going to be repeated.

One needs to consider the value of the science and the integrated marginal cost to the sunk cost of a mission from development through its prime mission phase. It is guaranteed that the cost of flying a new mission to conduct the extended science will be excessive. The cost of Cassini through its primary mission to US taxpayers was about $2.6B. While the President's budget does not parse out the cost of the Cassini extended mission (it should for all missions), news reports and the 2013 NASA Operations Plan gives a number near $60M/year. So, eight years of extended mission until it plunges into Saturn in 2017 sums up to around $480M (less than 20% of its original cost), and it will have been worth every penny. This is very close to the cost of a Discovery mission. So do we cancel Discovery calls to fund Flagship extensions? That would be silly. If anything, to maintain the kind of program balance envisioned by the planetary decadal survey, you put off commencing the next Flagship for a couple of years if there is a need. However, with a properly managed and executed Senior Review process with a longer horizon, the costs of these extended missions can better inform NASA budget requests – not at an arbitrary Procrustean level, but one informed by an assessment of the value of science to be returned for the cost and risk.

2. Last July, NASA's Small Bodies Assessment Group (SBAG) stated in its findings that the private B612 Foundation, which is seeking to develop a space-based telescope mission named Sentinel to detect near-Earth objects, has been unable to meet scheduled milestones under its Space Act Agreement with NASA. SBAG stated that it is concerned that reliance on this initiative has delayed NASA's ability to move forward on a NEO survey telescope that is competed and optimally designed to address NASA strategic objectives across planetary defense, human exploration, and science.
    1. Has any progress been made by B612 with regards to the scheduled milestones?

       Not to my knowledge.

    2. What will be the impact on NASA's ability to accelerate the detection of near-Earth objects from space if Sentinel is not available? Does NASA have a "Plan B"?

       Everyone loves something for nothing. It is appealing to think that the private sector will donate hundreds of millions of dollars for an asteroid survey mission. There is no evidence that after many years this will happen. To the extent that Sentinel has been NASA's Plan A, this survey is not happening. SBAG has called for this survey mission to be openly competed and satisfy criteria set by the agency, not a private party. It has been the opinion of SBAG, expressed in its published findings, that competition provides the best results. Such a survey has been proposed in response to previous Discovery calls and was highly ranked in the last call (and given technology development money for work on detectors), so we know there is at least one viable option. B612 and its partners would have an opportunity to participate in the competition if it wished. It is long past time that NASA move forward since the survey is important for human exploration, planetary defense, and science.

Responses by Ms. Joanne Gabrynowicz

HOUSE COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY

"Exploring Our Solar System: The ASTEROIDS Act as a Key Step"

Questions for the record, Professor Joanne Irene Gabrynowicz
Professor Emerita, Director Emerita, Journal of Space Law

Questions submitted by Rep. Steven Palazzo, Chairman, Subcommittee on Space

1. You state that "no one agency houses all that will be needed" to appropriately oversee private sector asteroid resource recovery, going on to claim that the system as it stands "...will produce unnecessary risk that is counterproductive to industry." Could you please expand upon what this risk might look like?

Commercial asteroid mining is an entirely new activity. The first few companies to engage in asteroid mining will be trailblazers in an unknown regulatory environment. They will proceed along a timeline that is required, in large part, by agreements made by a company with its investors and the stated expectations for returns on investment. As a company progresses, it should be expected that it will encounter novel regulatory questions that will take a long time for the appropriate regulatory bodies to sort out. Without specific regulations in place, it is likely that a company will be delayed until a decision is made. The delay is likely to have negative effects on investor confidence that could, in turn, lead to financial failures. Examples of this are the now defunct early innovators Geostar Corporation and O'Neill Communications. It was also the case with the commercial remote sensing industry until an interagency MOU was formalized among the relevant regulatory agencies that set out specific regulatory actions and timelines making many aspects of regulation more predictable.[1]

Another risk is the potential repercussions from political events. Resource extraction is a politically volatile issue. It should be expected that as company appears to be making progress toward extraction activities, there will be negative political reactions. These can range from heated arguments in international fora to Nations filing formal démarches with the United States Government to taking legal action in an appropriate court. Depending on where these reactions occur, by whom, and at what diplomatic level, it may be necessary for the United States to make a formal reply in some form. Again, depending on the specific facts of a given case, this could be as simple as a brief verbal or written reply from the appropriate United States Government entity. Or, it could be as complex and difficult as establishing an official, coordinated National position and/or an official, coordinated position with allies and like-minded Nations. The United States is legally obligated to authorize and continually supervise space activities of non-governmental entities and to assure that their activities are in conformity with treaty obligations.[2] Therefore, a company may encounter unpredictable periods of delay or

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[1] Licensing of Private Land Remote-Sensing Space Systems, 15 C.F.R. § 960 (2006).

[2] Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, Including the Moon and Other Celestial Bodies, opened for signature Jan. 27, 1967, 18 U.S.T. 2410, 610 U.N.T.S. 205, Art. VI.

examination of its activities to determine whether its activities conform to treaty obligations so that the United States can meet its legal obligations. Regarding other commercial space activities including telecommunications, remote sensing, and launches, the United States meets its obligations through Federal licensing regulations. Asteroid mining ought to have an analogous set of regulations to reduce risk and enhance predictability.

Finally, there are currently a number of interrelated issues that are growing in importance in the space community. They include space traffic management, space situational awareness, private space transportation to government on-orbit facilities, and orbital debris mitigation, among others. These have important national and international dimensions. Concepts and plans have been and continue to be proposed in a dynamic environment. They may or may not be relevant to an asteroid mining mission. Without a clear, transparent National asteroid mining regulatory regime that complies with international space law and defines an asteroid mining company's right and responsibilities, mining ventures can become unnecessarily entangled in the competing interests within these evolving issues.

2. You suggest an interagency structure analogous to that which governs GPS. You've mentioned jurisdictions of the Department of Transportation, the Federal Communications Commission, and the Department of Commerce. Can you approximately outline any other agencies that might be included in such a structure and in what capacities?

I also suggested that another model should be considered, specifically, the regulatory structure that governs commercial remote sensing.[3] These regulations govern private commercial entities that raise and deploy their own capital to generate revenue in a global market. In commercial terms, remote sensing activities are more analogous to commercial asteroid mining activities than are GPS activities. The remote sensing regulations address a wide variety of topics that range from licensing; data policy; monitoring and compliance programs; licensing new or advanced systems; operational recordkeeping; protecting United States national security; and honoring United States international obligations under the Outer Space Treaty, among others.

This model features an established interagency MOU that details the processes and timetables to be used for license applications.[4] It also includes processes and timetables to be used in the event of issues arising from interagency disagreements.

Unlike commercial remote sensing where the satellites are owned and operated by the private sector, GPS satellites are owned and operated by the United States Government. Therefore they are not regulated as commercial assets. However, Congress recognizes "that [GPS] is an essential element in civil, scientific and military space development...because of [the] emergence of [US] commercial industry which provides

[3] Written Testimony of Joanne Irene Gabrynowicz Before the Subcommittee on Space of the Committee on Science, Space, and Technology United States House of Representatives, September 10, 2014, page 2.
[4] Licensing of Private Land Remote-Sensing Space Systems, 15 C.F.R. § 960 (2006).

equipment and services".[5] These activities are regulated the same as other ground segment commercial activities, not as space activities, *per se.* The GPS model offers high level and coordinated oversight. If private sector asteroid mining is found to require this level of oversight due to its unique and unprecedented nature, then this part of the GPS model may provide part of a regulatory model.

Agencies that might participate in such an interagency governmental structure and the capacities they may exercise include:

1. *Department of Transportation/FAA*: In addition to its authority to license launches and reentries, it should be given a clear Congressional on-orbit grant of jurisdiction to license a private sector mission that is intended to stay in orbit or on an asteroid for a period of time. It must be recognized that this would be a substantial departure from previous jurisdictional grants because, unlike suborbital flights, orbital flights and asteroid mining will clearly operate in international territory. Therefore, national jurisdiction for commercial orbital operations must be considered within the context of international space law. Regulatory and license language will have to be crafted to acknowledge and address how international legal obligations are being met through national law. Examples of this are the language of the International Space Station Intergovernmental Agreement[6] and the commercial remote sensing regulations.[7]

2. *The National Aeronautics and Space Administration*: NASA is not a regulatory agency and lacks authority to regulate private asteroid mining missions. It is the Nation's space agency and has the space science and engineering expertise that will be needed in the national interest. NASA ought to have a formal consultative role in the licensing process. It can be consulted regarding whether the proposed mission profile will be compatible with existing National and international space activities.

Under the Outer Space Treaty, the United States is obliged to avoid harmful contamination of the space environment.[8] The Planetary Protection Subcommittee of the NASA Advisory Committee has recommended reviewing licenses for

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[5] 51 U.S.C. 50112

[6] "Nothing in this Agreement shall be interpreted as: (a) modifying the rights and obligations of the Partner States found in the treaties...(c) constituting a basis for asserting a claim to national appropriation over outer space or over any portion of outer space." Art. 2

[7] "In particular, it is important to note that the license requirement imposed on the licensee that it maintain 'operational control,' as the term is defined in Section 960.3, is an implementation of U.S. obligations under the United Nations Outer Space Treaty of 1967. That treaty provides that the U.S. Government, as a State party, will be held strictly liable for any U.S. private or governmental entity's actions in outer-space. Consequently, NOAA requires that licensees under this part maintain ultimate control of their systems, in order to minimize the risk of such liability and assure that the national security concerns, foreign policy and international obligations of the United States are protected."

[8] Art. IX.

commercial activities to prevent outbound contamination.[9] This ought to be part of the consultation
process.

3. *The Department of Commerce/NOAA*: If a mission will use remote sensing technology that is capable of sensing the Earth, it may be necessary for NOAA to review the asteroid mining license application to determine if a commercial remote sensing license will also be necessary.

4. *The Department of State*: A review by the State Department to determine what United States international interests and obligations may be effected by a commercial asteroid mining mission is essential.

5. The Federal Communications Commission: a review to ensure proper radiofrequency use.

6. The Department of Defense (DOD)/Joint Space Operations Center (JSpOC): The DOD/JSpOC operates situational awareness sensors and provides notice to satellite operators regarding potential collisions with other satellites or debris. It could review a license application to determine the proposed mission's near Earth operations as it relates to potential hazards in the space environment.

3. You indicate that the ownership status of collected space resources remains unclear. Do you consider the threat of this post-collection poaching to be greater from opposing private interests, or from rival national interests, or perhaps both?

The public record cites two private companies with plans to mine asteroids. They are both from the United States.[10] The record also contains a number of Nations that have conducted, or that have plans to conduct, scientific asteroid missions. Which entities are most likely to be successful at harvesting space resources is a question of science, engineering, and economics, not law. I therefore respectfully suggest that experts from these fields have this question posed to them.

However, in the absence of appropriate regulations both private and government actors can be motivated to be the first, or among the first, to harvest space resources for self-serving reasons without regard to the larger legal and political consequences. Historically, the United States has been the leader in developing national space law. One year to the day after *Sputnik I* orbited the Earth the United States issued the world's first national space law statute: the 1958 National Aeronautics and Space Act.[11] Since then, as activities and applications were developed statutes and regulations followed for telecommunications, launches, remote sensing, and GPS, among others. Legal principles

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[9] NAC Planetary Protection Subcommittee, http://science.nasa.gov/media/medialibrary/2010/03/31/NASArecommendationNov08_.pdf.
[10] Is Space Big Enough for Two Asteroid-Mining Companies?, SPACE.com, January 22, 2013, http://www.space.com/19380-asteroid-mining-spaceflightcompetition.html
[11] 51 USC 20101, et. seq.

were developed and applied. These became the *de facto* standard for other nations seeking to develop their own space law. Legal norms developed in United States law like "maximum probable loss" and "nondiscriminatory access" were adapted in laws of foreign nations.

Asteroid mining is once again presenting the United States with the opportunity to lead in the development of space law. It has the opportunity to set legal standards that serve the national interest, to be consistent with international law, and influence the development of space law in other nations.

4. In your written testimony you state that "as space law follows technological development, legislation and regulations must be flexible to adapt to new technologies." Would you provide us with an example of how that could be achieved?

   It would be important for asteroid mining regulations to codify the specific principle of revisiting the regulations, as new technological advances require. The regulations themselves ought to include language that acknowledges they will one day be applied to new or advanced technologies that will require reconsidering the basic provisions of the regulations with the intent of applying and incorporating new knowledge. Examples of this 9 approach can be found in arms control agreements[12] and the United States commercial remote sensing regulations.[13]

5. In your written testimony, you speak about the different definitions of "commercial" and "private entity," as they are used in an international context. Would you please expand on your statement and explain how these different definitions are reconciled in other international agreements?

   I am unaware of any space-related agreements where the precise definitions of "commercial" and "private entity" are specifically reconciled. The International Space Station Intergovernmental Agreement does provide that Partners may select users for its allocation of Station resources for any purpose consistent with the object of the Agreement.[14] These can include commercial and private entities. The Partner selecting the user is responsible for defining who or what the user is and whether it is engaged in peaceful purposes. The definition of the user is not a matter of joint agreement.

   I will expand on my statement with an excerpt of a law review article[15] written by me in which the "Evolving Definition of 'Commercial'" is addressed.

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[12] Treaty on the Limitation of Anti-Ballistic Missile Systems, U.S.-U.S.S.R., May 26, 1972,23 U.S.T. 3435, Agreed Statement D. "In order to insure fulfillment of the obligation not to deploy ABM systems...the Parties agree that in the event ABM systems based on other physical principles...are created in the future, specific limitations on such systems and their components would be subject to discussion..."
[13] Licensing of Private Land Remote-Sensing Space Systems, 15 C.F.R. § 960 (2006).
[14] Agreement Concerning Cooperation on the Civil International Space Station, art. 9, Jan. 29, 1998, T.I.A.S. No. 12927.
[15] Joanne Irene Gabrynowicz, One Half Century and Counting: the Evolution of U.S. National Law and Three Long-Term Emerging Issues, 4 Harvard L. & Policy Rev., 405. (2010)

The Evolving Definition of "Commercial"

The definition of the term "commercial" has a long and dynamic history in the aerospace industry. In the United States, the industry emerged from World War II, the necessities of which caused the dramatic growth of individual prewar companies like the McDonnell Aircraft Corporation and Douglas Aircraft Company.[16] In the postwar years, Cold War space and military activities created incentives for these entities to merge into aerospace manufacturers and defense contractors like the McDonnell Douglas Corporation.[17] But the end of the Cold War decreased demand, and a further wave of mergers left remaining only a few aerospace giants like the Lockheed Martin Corporation and The Boeing Company.[18]

Since the 1950s, the U.S. government and aerospace contractors have maintained a close relationship in which the government has awarded contract work through a complex mix of merit, technology, and politics in order to achieve both specific missions and to maintain a vibrant industrial base. All the while, both sides have maintained that the industry operates on a "commercial" basis—that is, the public and private sectors are separate, and the public sector sets work requirements that the private sector fulfills on a for-profit basis.[19] In comparison, since Europe's aerospace industry came of age in the 1970s with the Convention for the Establishment of a European Space Agency (Convention),[20] European governments have commonly engaged in commercial aerospace activities. For Europeans, a "commercial" activity is simply one that generates revenue, and is appropriate for governments to engage in commercial activities, too.[21] By contrast, in the United States, "commercial" activities are synonymous with the private sector, and there is a strong bias against governments engaging in commercial activities. As a result, the U.S. aerospace industry often calls for a level playing field—that is, a marketplace in which it does not have to compete with commercial activities conducted by governments.[22] The standing European response is to point out that the U.S.

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[16] *See* Boeing, McDonnell Aircraft Corp. . . . Preparing for the Phantom, www.boeing.com/history/narrative/n028mcd.html (on file with the Harvard Law School Library); Boeing, The Douglas Aircraft Co. . . . Building Up for War, http://www.boeing.com/history/narrative/n026dou.html (on file with the Harvard Law School Library).
[17] *See* Boeing, The McDonnell Douglas Corp. . . . Merging Talents, www.boeing.com/history/narrative/n063mcd/html (on file with the Harvard Law School Library).
[18] *See* Lockheed Martin, Lockheed Martin History, http://www.lockheedmartin.com/aboutus/history/index.html (on file with the Harvard Law School Library); Boeing, The Boeing Company . . . The Giants Merge, www.boeing.com/history/narrative/n079boe.html (on file with the Harvard Law School Library).
[19] *See* Frans von der Dunk, *The Moon Agreement and the Prospect of Commercial Exploitation of Lunar Resources*, 32 ANNALS AIR & SPACE L. 91, 93 (2007).
[20] Convention for the Establishment of a European Space Agency (ESA), May 30, 1975, 14 I.L.M. 864 [hereinafter ESA Convention], *available at* http://www.esa.int/convention/.
[21] von der Dunk, *supra* note 17, at 93.
[22] *See, e.g.*, U.S. GOV'T ACCOUNTABILITY OFFICE, U.S. AEROSPACE INDUSTRY: PROGRESS IN IMPLEMENTING AEROSPACE COMMISSION RECOMMENDATIONS, AND REMAINING CHALLENGES 26–29 (2006), *available at* http://www.gao.gov/new.items/d06920.pdf; TRENDS AND CHALLENGES IN AEROSPACE OFFSETS 33 (Charles W. Wessner ed., 1999).

government supplies and funds critical space infrastructure and provides exclusive contracts to U.S. aerospace companies, thus placing the companies in the same position as their European counterparts.

A variation on this theme relates to industrial policy. Industrial policy is a country's planned, strategic effort to develop a particular sector of industry. In the view of the U.S. aerospace industry, industrial policy is anathema to free market principles and results in misguided attempts by a government to choose winners and losers. In the European view, industrial policy is simply a cooperative effort between government and industry to promote the national interest. In fact, industrial policy is the legal reason for aerospace cooperation among nations within Europe.[23]

Some observers have noted the close and interrelated relationship between the U.S. government and aerospace industry and find relatively little difference between the two views.[24] Recent legislative efforts to define the term "commercial" lend credence to these observations as these efforts demonstrate that some lawmakers believe it is necessary to delineate a difference between government and private commercial activities.[25]

Historically, aerospace activities have, by and large, been segregated into national programs. International cooperative missions have consisted of discrete tasks and interactions that do not involve the exchange of funds. As a result, the debate over what is commercial has retained its familiar contours for decades. However, the debate is about to get more interesting. In 2010, the *Shuttle* is being retired,[26] and the Obama Administration's fiscal year 2011 budget for NASA's space exploration program envisions increased reliance on the U.S. private sector and innovative contracting practices to provide, among other things, transportation to and from the recently completed *ISS*.[27] The plan increases NASA's budget by billions of dollars and at the same time increases private sector involvement in national space programs. Predictably, the plan is very controversial, and its chance for success is uncertain.

Nonetheless, one can expect that this new direction and the need for new technologies will continue the globalization era transformation of the U.S. space program, including the relationship between NASA and the aerospace industry, and the contours of that industry. As for the NASA-industry relationship, in recent years both public and private entities have seen new forms of contracting in which procurements, payments, and performance milestones have been recast to "facilitate a smooth transition into

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[23] ESA Convention, *supra* note 90, art. VII.
[24] *See, e.g.*, ROBERT B. REICH, THE WORK OF NATIONS: PREPARING OURSELVES FOR 21ST CENTURY CAPITALISM 156–57 (1992).
[25] *See* NASA Authorization Act, Pub. L. No. 106-391 §§ 303, 309, 114 Stat 1577, 1593 (2000); Human Space Flight Capability Assurance and Enhancement Act, H.R. 4804, 111th Cong. § 8 (2010).
[26] Damien Cave, *Celebrating U.S. Future in Space, Hopefully*, N.Y. TIMES, Apr. 27, 2010, at A14.
[27] *See* President Barack Obama, Address at Kennedy Space Center (Apr. 15, 2010) (transcript and recording available at http://ww.nasa.gov/about/obama_ksc_pod.html).

commercialization."[28] Regarding the industry's makeup, the "buy national" policies of the Cold War have given way to an incremental inclusion of non-U.S. subcontractors that now provide important technologies for major U.S. general contractors, even for national security launches that have never before been commercially available to non-U.S. suppliers.[29]

These changes and the new space exploration direction suggest that business decisions will replace the geopolitical decisions that defined the Cold War space program. If so, then the debate surrounding the definition of "commercial" is about to take on new dimensions. It may be unlikely that a foreign entity will be designated as a prime contractor for critical U.S. needs, but yet unrecognized commercial arrangements are on the horizon.

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[28] Tiphany Baker Dickerson, *Patent Rights Under Space Act Agreements and Procurement Contracts: A Comparison by the Examinations of NASA's Commercial OrbitalTransportation Services (COTS)*, 33 J. SPACE L. 341, 343 (2007).

[29] *See, e.g.*, Press Release, Lockheed Martin, Atlas V Team Wins Achievement Award from U.S. Space Foundation (Apr. 1, 2003), *available at* http://www.lockheedmartin.com/news/press_releases/2003/AtlasVTeamWinsAchievementAwardFromU.html.

HOUSE COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY

"Exploring Our Solar System: The ASTEROIDS Act as a Key Step"

Questions for the record, Professor Joanne Irene Gabrynowicz
Professor Emerita, Director Emerita, Journal of Space Law

Questions submitted by Rep. Donna Edwards, Ranking Member, Subcommittee on Space

1. To what extent have U.S. Federal agencies considered the issues regarding asteroid mining and resource extraction, including legal and any regulatory issues?

   Response:

   "There's been a larger and ongoing discussion in the US government about how best to organize and supervise US space activities." [30] Asteroid mining and resource extraction have been one of a number of subjects that have catalyzed these talks. Other related issues include the use of commercial cargo spacecraft, space situational awareness, orbital debris mitigation, and space traffic management. The Department of State has taken a leading role in these discussions. They are addressing the basic questions of jurisdiction and more.

2. What is the status of international discussions on the legal issues associated with asteroid mining and property rights in relevant, formal international venues such as the U.N. Committee on the Peaceful Uses of Outer Space?

   Response:

   Currently, legal issues associated with asteroid mining and property rights are not formal agenda items in any relevant, formal international venues. However, the subject can be raised in the context of other fora agenda items. An example of this is the United Nations Committee on the Peaceful Uses of Outer Space Legal Subcommittee agenda item titled, the *Status and Application of the Five United Nation Treaties*.[31] Issues associated with asteroid mining and property rights are often addressed in professional conferences, workshops, and academic meetings.

3. In your view, what steps should the Subcommittee and Committee take to help inform its understanding of the policy and legal issues regarding space resource extraction and utilization and property rights?

   It must be appreciated that space resource extraction and utilization and property rights are arguably the most politically volatile issues in all of contemporary space law.

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[30] The quest for on-orbit authority, The Space Review, May 19, 2014
http://www.thespacereview.com/article/2514/1

[31] United Nations Journal, Committee on the Peaceful Uses of Outer Space, Legal Subcommittee, Fifty-Third Session, Tuesday, 25 March 2014, No. 3, Agenda item 6.

Positions regarding these issues often reflect a proponent's terrestrial values and politics and are filtered through the geopolitics on Earth. The body of academic literature is large and much of it also divides along political lines. It also contains objective legal analysis by scholars and other observers.

The most effective way for the Subcommittee and Committee to inform its understanding of the policy **and legal issues** regarding space resource extraction and utilization and property rights is to direct the appropriate Executive agency to commission the National Research Council to conduct a study on the legal status of space resource extraction and utilization and property rights.

The study could be organized into two parts: first, a survey of legal sources relating to resource extraction and utilization and property rights; second, an analysis of the survey results.

The survey would review:

a. Relevant international treaties, custom, and general principles of law
b. Relevant judicial decisions and the teachings of the most highly qualified publicists
c. Relevant National positions taken in international fora

The analysis would consider:

a. Taken together, does the literature contain a majority view? If so, what is it?
b. Taken together, does the literature contain a minority view? If so, what is it?
c. If possible, a breakdown of positions on a national basis.

Appendix II

Additional Material for the Record

LETTERS SUBMITTED BY SUBCOMMITTEE CHAIRMAN PALAZZO

DEEP SPACE INDUSTRIES

September 9, 2014

The Honorable Steven Palazzo
Chairman
Subcommittee on Space
Committee on Science, Space, and Technology
U.S. House of Representatives
2321 Rayburn House Office Building
Washington, DC 20515

Dear Mr. Palazzo:

Deep Space Industries' ("DSI") is honored to present its positions on the Asteroid Space Technology for Exploring Resource Opportunities in Deep Space Act H.R. 5063 ("Asteroids Act"). Too often there is a rush to inhibit the development of a new industry, something that can stifle creativity and destroy the very innovative drive that makes this nation the world's leader in so many areas. The Asteroid Act shows great wisdom since its intent is to achieve the opposite, and as such we support it whole-heartedly.

As one of only two firms in the world that is currently working on the issue of asteroid **resources** utilization, and one of only a handful of firms (all of which are located in the US) in terms of resource extraction of other bodies including the Moon, we believe it is of utmost urgency that this nation quickly take the lead in establishing our ability to harvest the resources of space via clear and understandable legislation and policy. If we succeed, not only will we be harvesting materials that will create new wealth and underpin a new economic arena for the United States, but by being out there and working with these objects we will be developing many of the same skills and abilities needed to help defend the planet from them, if needed.

In order to ensure the success of the Asteroids Act, DSI respectfully offers several suggestions that we believe will avoid unintended consequences that may inhibit the intent and viability of the Asteroids Act as it is currently drafted. The first suggestion is that the concept of "first in time" must mean actual physical contact with an object rather than simply looking at it using telescopes or other instruments – no matter how close they are. This will immediately ensure that only those groups and companies with sufficient ability to raise capital and develop spacefaring technology will be granted the right to profit from their investment and keep spurious and absurd claimants who use "looking at" an object in space as their basis for asserting a claim from clogging up the process. Our second recommendation is that this field is an area of commerce and as such should be overseen by an agency that has this as its primary focus.

Finally, we humbly request that as this bill and hearings or meetings related to this topic move forward in the committee, its members and staff understand and adopt the concept that we are entering a new era in space wherein a new perspective needs to be adopted based on human economic and other activities that may or may not have anything to do with science - even as the scientific community will benefit from our work in myriad ways. A new "slot" or category of investigation, opinion and indeed legislation must be adopted that is actually relevant to the questions at hand. We suggest therefore that in the future the committee reach out into those communities more appropriate to this new realm of activity. DSI's recommendations pertaining to the Asteroids Act are covered in greater detail in the attached document.

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The Honorable Steven Palazzo
Chairman
Subcommittee on Space
Committee on Science, Space, and Technology
U.S. House of Representatives

Working together with Congress, we are sure that we will be able achieve something incredible on the space frontier, and create a legacy that will transform the future of this great nation, enabling access to new resources, new industries and new hope for generations to come.

Sincerely,

Rick N. Tumlinson
Chair

Sagi Kfir
General Counsel

Attachment

Space Property Rights
Asteroids and Comets
DSI Policy Position on "ASTEROIDS ACT"

We are pleased to have been invited to comment on the recently introduced Asteroid Space Technology for Exploring Resource Opportunities in Deep Space Act H.R. 5063 ("Asteroids Act"). The following serves as Deep Space Industries' policy position on three material issues pertaining to the Asteroid Space Technology for Exploring Resource Opportunities in Deep Space Act ("Asteroids Act"), namely (1) the definition of "first in time"; (2) how does the Asteroids Act comply with the U.S.'s obligations to international law/treaties; and (3) what department of the U.S. government should regulate commercial asteroid utilization entities under the Asteroids Act.

I. First In Time

Section § 51302(b) of the Asteroids Act mandates legal protection to any commercial asteroid resource utilization entity from harmful interference by another commercial asteroid utilization entity and granting "superior right" to execute utilization activities if such an entity is "first in time".

Given the potential of asteroid utilization in terms of their potential economic value, we may expect that there will be many different "claims" to mine and harvest these resources. Clarifying this area will avoid unintended consequences based on legal challenges and battles regarding what constitutes "first in time" that may tie down development by real and credible companies and groups for years, drain millions in legal costs from the accounts of legitimate participants in the field and waste millions in taxpayer funds to serve the legal system as it deals with these cases.

The only guidance on how to determine "first in time" in the Asteroids Act is the requirement that first in time shall be "derived upon a reasonable basis" which provides little legal or "bright-line" clarity at the level of a "yes/no" answer in terms of claim validity. By not providing such critical guidance, the Act as written opens up an area of possible dispute that will complicate both the ability of companies to seek the investment needed to improve or utilize their claim and tie up the industry in a potential flood of legal actions, thus delaying the very goal the Act is supposed to support. This vagueness opens up the possibility of claims being staked based on being the "first to look at" such objects, thus requiring at what point "looking at" an object constitutes the right to legally claim to be "first in time". Rather than debates as to what instruments, distance or investment has been put into the viewing of asteroids, we propose the much simpler and obvious test of being "first to touch", and to emplace active technologies on those objects (the modern version of the prospector's stake in the ground).

DSI's Position in more detail:

- Looking at an object without being in contact with that object is not a valid means of establishing ownership or the right to further develop that object. The simple act of "looking at" something has not been considered a valid rationale for the assertion of rights pertaining to that object since early Roman times. The need for physical contact was codified in Latin as "pedis posessio" which loosely translated means "my foot is upon it".
- This is especially true in the realm of space resource utilization, where large investments of time and effort will be expended to achieve returns. A clear and reasonable definition for "first in time" should be "an entity that first establishes direct and continuing robotic or human physical contact" with the asteroid; "continuing contact" can be achieved by placing a beacon device on the object.
- Previous claims to extraterrestrial property unsubstantiated by physical act of possession have been invalidated by courts as non valid means of acquiring ownership; publicizing such a claim without actual presence on the object has no legal effect:
    - Greg Nemitz (and his company, Orbital Development) claiming ownership of Eros with the "Archimedes Institute Private Property Rights Registry"
    - Lunar Embassy
- The use of only remote sensing to assert a "first in time" claim to an asteroid or comet is unrecognized by customary international law, as stated above, since aerial observations alone do not substantiate a claim to a physical object. Therefore, the use of only remote sensing to assert a "first in time" claim is not a "reasonable basis".
- The use of only remote sensing to assert a "first in time" claim will lead to an immeasurable number of claims which will never lead to the exploration and utilization of asteroid resources, thereby leaving countless numbers of asteroids and comets dormant, unutilized and laying fallow. Therefore, the use of only remote sensing to assert a "first in time" claim is not a "reasonable basis".
- The use of only remote sensing to assert a "first in time" claim creates a dubious situation where there would be no limit on how distant the sensing could be – it even could be from terrestrial telescopes. Even if there was a requirement that the sensing had to be conducted in space, spacecraft in Earth orbit equipped with high-power telescopic abilities could make claims to asteroids at the farthest reaches of the solar system which would practically be impossible to explore and utilize for many years to come. Therefore, the use of only remote sensing to assert a "first in time" claim is not a "reasonable basis".

II. Compliance With International Law

The question arises whether Asteroids Act complies with international law and U.S. international treaty obligations as it is currently drafted as of September 9, 2014. While the Act's requirement of "first in time" without clear guidance and requirement of physical presence on the object leaves it open to valid legal scrutiny as stated above, the intent and scope of the Act does not conflict with international law or the U.S.'s international treaty obligations.

DSI's Position

A. Possible Issues with International Law

- The Act's current definition of "first in time" requirement without clear guidance and physical presence requirement may conflict with international law.

B. Allowed Under International Law and U.S. Treaty Obligations

- The Act correctly does not seek to change any terms of the Outer Space Treaty of 1967, which established that REAL property in space is not subject to claims of national sovereignty.
- The Act encourages the exploration and use of PERSONAL property in space, which is not prohibited either by the Outer Space Treaty or any other international law or U.S. treaty obligation.
- Planets and moons are considered non-movable objects and are therefore considered real property or celestial bodies; asteroids and comets are movable objects ("chattel") and therefore are considered personal property, much like oil, gas, minerals and metals. There is no claim to ownership of the real property or celestial bodies, just exploration and unfettered use of the objects or personal property.
- In the law, what is not prohibited is permitted. Therefore, the lack of any prohibition in international U.S. obligations to explore and utilize personal property (non-celestial bodies) allows the U.S. to set national guidelines for the exploration and use of personal property in space, much like the U.S. law of the Deep Seabed Hard Mineral Resource Act allows U.S. entities to explore and utilize deep sea minerals and resources.
- In fact, Article I of the Outer Space Treaty does explicitly encourage the "exploration and use of outer space".
- Personal property rights in space are not only consistent with international space law, but explicitly required by it.
    - Article VIII of the Outer Space Treaty explicitly recognizes that ownership of facilities and vehicles isn't changed by being in space and recognizes ownership rights in space in personal property (satellites, spacecraft, objects constructed in space or on celestial bodies).
    - The International Space Station Intergovernmental Agreement explicitly states in Articles 5 and 6 that each nation participating in ISS owns its own equipment and retains jurisdiction and control over the elements it registers. Additionally Article 21 of the ISS Agreement states that discoveries and work product on ISS are considered to occur in territory of elements (part of the ISS) of registered nation and each nation's law apply in their part of the ISS.

- On the issue of the Act's requirement of "freedom from harmful interference" - Article IX of the Outer Space Treaty implies that the United States could recognize a limited exclusive "safety" zone around such facilities to protect against harmful interference.
- The right to extract and utilize extraterrestrial resources should be: (i) limited in scope; (ii) contingent on physical presence and ongoing operations; (iii) operate without interference.
- Article VI of the Outer Space Treaty explicitly requires the United States to provide "authorization and continuing supervision" of what U.S. companies do in space to ensure compliance with the treaty, and therefore:
    - The Act will ensure compliance with Article VI and allow commercial space companies continue to grow and push the technological and legal envelope of the space economy.
    - The need for a beacon with continual telemetry as a physical presence on the asteroid will also ensure compliance with Article VI of "continuing supervision" of the activities of the U.S. entities on the asteroid.

III. U.S. Government Entity Overseeing Act

- Based on its historical role in the development of new industries and areas of economic opportunity, the U.S Commerce Department will be best able to shepherd the establishment of a vigorous, productive space resources economy under American leadership.
- This function is best provided by an entity that is able to grow with this field, and approaches it with a clean slate and a focus on the economics of the activities involved – which are separate from the purely scientific and military – even as they are mutually supportive.

PLANETARY RESOURCES™

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September 10, 2014

The Honorable Steven Palazzo
331 Cannon House Office Building
United States House of Representatives
Washington, D.C. 20515

The Honorable Donna Edwards
2445 Rayburn House Office Building
United States House of Representatives
Washington, D.C. 20515

Chairman Palazzo, Ranking Member Edwards, and distinguished Members of the Subcommittee, thank you for the opportunity to provide input on H.R. 5063, the ASTEROIDS Act. We are very grateful that the Subcommittee will discuss this timely and important matter. We strongly support the bill, and commend Representatives Posey and Kilmer for their foresight in introducing it. This legislation is timely, well constructed, and will help ensure that the United States will lead the development of this economically and strategically valuable new market.

BACKGROUND

Planetary Resources is a company based in Redmond, Washington that is developing the capabilities to explore and recover resources from asteroids. The company was founded in 2010 by two leaders in commercial and entrepreneurial space, Eric C. Anderson and Peter Diamandis. Our company has staff with world-class engineering, scientific and software knowledge. Several of our engineers are alumni of NASA's Jet Propulsion Laboratory and were lead engineers, mission managers, and flight directors for complex and successful Mars missions such as Spirit, Opportunity, Phoenix, and Curiosity. Other staff have been drawn from innovative industry leaders including Intel, Google, and Space X. Planetary Resources is a company that has the technical expertise to achieve its mission of asteroid resource exploration and recovery.

Planetary Resources is privately funded, with investment from noted technology leaders such as Eric Schmidt and Larry Page of Google, H. Ross Perot Jr. of the Hillwood Group, Sir Richard Branson of the Virgin Group, and Charles Simonyi, formerly Chief Architect at Microsoft. This support has given the company the financial means to accomplish its goals.

TIMELINE

Asteroid resource exploration and recovery may seem like a distant vision, but Planetary Resources has already completed construction of its first spacecraft and is awaiting launch. Once deployed, this satellite will demonstrate core technologies for Planetary Resources future missions. It will also be symbolically significant, because it will mark the beginning of private asteroid resource exploration and recovery. Planetary Resources will be launching a new spacecraft approximately every few months to discover and explore asteroids and ultimately to recover the valuable resources on those asteroids.

STRATEGIC AND ECONOMIC OPPORTUNITY
Asteroids are abundant in three classes of resources: volatiles and water (hydrogen, carbon, nitrogen, and oxygen); platinum group metals (ruthenium, rhodium, palladium, osmium, iridium, and platinum); and structural metals (iron, cobalt, and nickel).

WATER
Water has a number of high value uses in space, but it currently costs in excess of $23,000 per pound to transport from Earth. Water will be useful for human exploration, as it provides hydration and radiation shielding. Water can also be changed into fuel, through electrolysis, thereby turning the water into its elemental components of oxygen and hydrogen. One 75-meter water-bearing asteroid has enough hydrogen and oxygen to have launched all 135 Space Shuttle missions. Spacecraft are launched with all the fuel they will ever have and therefore their lifetime is limited by fuel – the equivalent of throwing away a car when the tank is empty. Being able to store water and fuel in space fundamentally changes the ways we can explore space and conduct national and commercial operations in space.

PLATINUM GROUP METALS
Platinum group metals are extremely rare resources – even rarer than rare-Earth elements – and are necessary for the construction of catalytic convertors, electronics, medical devices, glass, turbine blades, and jewelry. Today, the major sources of platinum group metals are South Africa and Russia. A single 500-meter platinum-rich asteroid contains more platinum than has been mined in the history of humanity.

STRUCTURAL METALS
It is extraordinarily expensive to launch heavy structures into space, and in most cases, the engineering design is optimized for the 9-minute journey to space, not for its use in space. Planetary Resources is developing the long-term capability to recover metals from asteroids and build specialized structures in space utilizing emerging technologies such as 3D printing. The capacity to build structures in space will fundamentally change commercial, civil, and scientific space activities.

Planetary Resources is not alone in this industry. There are other competitors here in the U.S. There is also strong competition coming from China and Russia. Both nations have stated their intent to begin developing the technologies to recover resources from outer space.

ASSURING U.S. LEADERSHIP
Planetary Resources believes the ASTEROIDS Act does three things critical to developing U.S. private asteroid resource exploration and recovery:

1. Provides a clear statement of resource ownership in full compliance with international obligations
2. Begins the discussion on oversight and regulation
3. Establishes U.S. leadership in policy and a new market

RESOURCE OWNERSHIP
The ASTEROIDS Act provides necessary clarity about who owns resources recovered in space by creating straightforward rules for U.S. courts to follow in adjudicating any future disputes between

entities subject to U.S. jurisdiction. This clarity permits and promotes increased investment throughout the private sector.

The existing UN Treaties recognize, encourage, and allow the use of space by nations, and by non-government entities. The recovery and ownership of resources in space has been recognized for several decades. Specifically, it has been over 40 years since the United States and the U.S.S.R. each returned samples from the Moon, and more recently Japan did the same from an asteroid, and no nation or entity has raised serious objections to those nations' right to use and control the property they have returned from space.

It was the intent of the nations negotiating the relevant treaties that space resource exploration and recovery should not be prevented by the treaties. In 1980, the then Legal Adviser to the Department of State, Robert Owen, provided testimony to Senate's Subcommittee on Science, Technology and Space. Mr. Owen noted that these treaties were negotiated with the understanding that it does not prevent the extraction of natural resources.[1]

Planetary Resources believes that the ASTEROIDS Act was carefully written to be in full compliance with all international obligations. The negotiating history of those obligations makes it very clear that commercial resource recovery in space and ownership of those resources is allowed and protected.

OVERSIGHT AND REGULATION

According to the UN Liability Convention, ratified by the United States in 1972, states are required to authorize and supervise the space-based activities of private entities to ensure they are complying with international obligations.

There are currently no U.S. oversight and regulation mechanisms that govern asteroid resource exploration and recovery. Planetary Resources believes the ASTEROIDS Act does an excellent job framing the potential development of these oversight mechanisms without being prescriptive – and without prematurely creating a new regulatory entity or spending new money. Writing legislation now that attempts to prescribe every operational scenario and technology that needs to be regulated would be impossible because many of this market's technologies and operations are new and still under development. The ASTEROIDS Act creates the framework for a productive exchange of ideas between Congress, the Executive Branch, and industry that can eventually lead to an informed, responsive, and productive regulatory regime.

LEADING THE INTERNATIONAL COMMUNITY

The ASTEROIDS Act is a domestic law and has no impact on non-U.S. concerns that may conduct asteroid resource exploration and recovery activities. However, Planetary Resources believes that the ASTEROIDS Act creates a foundation, in full compliance with existing international obligations, which could be easily adopted by other nations. The concepts of property rights, freedom from harmful interference, and safety of operations form the core components necessary for asteroid resource exploration and recovery companies from all nations to operate safely, predictably, and cooperatively in space. Planetary Resources firmly believes that the U.S. Government can use the ASTEROIDS Act to promote these core concepts in the UN and other international forums for international recognition and adoption.

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[1] *See* Hearings before the Subcommittee on Science, Technology and Space of the Committee on Commerce, Science and Transportation, United States Senate, 96th Cong. (July 29 and July 31, 1980)

SUMMARY

Private asteroid resource exploration and recovery activities are currently underway. Planetary Resources applauds the actions of Congress on this important and timely matter. With the ASTEROIDS Act, Congress has made clear that it is the intention of the United States to lead in this critical market.

The ASTEROIDS Act complies with all treaties, agreements and conventions to which the United States is a party; recognizes the need to develop applicable regulations at the appropriate time; and clarifies the right of U.S. entities to mine resources from asteroids. The ASTEROIDS Act provides a strong foundation for asteroid mining companies like Planetary Resources to begin commercial asteroid resource exploration and utilization in space, provides confidence to investors, stability to the industry, and builds upon a foundation of domestic and international law.

Respectfully,

Christopher A. Lewicki
President and Chief Engineer
Planetary Resources, Inc.