Review of NASA's Planetary Science Division's Restructured Research and Analysis Programs

DETAILS

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Review of the Restructured Research and Analysis Programs of NASA's Planetary Science Division

Committee on the Review of NASA's Planetary Science Division's
Restructured Research and Analysis Program

Space Studies Board

Division on Engineering and Physical Sciences

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Preface

The 2011 National Research Council[1] (NRC) planetary science decadal survey, *Vision and Voyages for Planetary Science in the Decade 2013-2022*,[2] noted that while "NASA's planetary missions are the most visible aspect of the agency's solar system exploration program . . . they are supported by an infrastructure and research program that are vital for mission success." Such research activities "generate much of the planetary program's science value on their own, independent of individual missions" (p. 283). The survey report continues by noting that funding from NASA's research and analysis (R&A) programs "allow the maximum possible science return to be harvested from missions" (p. 284). R&A programs support a diverse portfolio of activities in addition to the analysis of data from past and current spacecraft; laboratory research; theoretical, modeling, and computational studies; geological and astrobiological fieldwork in planetary analog environments on Earth; geological mapping of planetary bodies; the analysis of data from Earth- and space-based telescopes; and development of technologies for instruments, missions, and laboratories.

The 2009 NRC report *An Enabling Foundation for NASA's Earth and Space Science Missions*[3] (also known as the Fisk report) highlighted the importance of R&A programs to all of the activities undertaken by NASA's Science Mission Directorate (SMD), including those undertaken by the Planetary Science Division (PSD). The 2009 report recommended, in part, that

> NASA should ensure that SMD mission-enabling activities are linked to the strategic goals of the agency and of SMD and that they are structured so as to: encompass the range and scope of activities needed to support those strategic goals; provide the broad knowledge base that is the context necessary to interpreting data from spaceflight missions and defining new spaceflight missions; maximize the scientific return from all spaceflight missions; supply a continuous flow of new technical capabilities and scientific understanding from mission enabling activities into new spaceflight missions; and enable the healthy scientific and technical workforce needed to conduct NASA's space and Earth science program. (p. 47)

From 2011 to 2014, NASA's PSD undertook a process of community discussion and analysis leading to the restructuring of its portfolio of R&A programs, in response to the above recommendation from the *Enabling Foundation* report. This process considered input from the Planetary Science Subcommittee of the NASA Advisory Council's Science Committee and input from other U.S. government stakeholders. The restructured program was announced in late 2013 and initially implemented in the agency's Research Opportunities in Earth and Space Sciences (ROSES) 2014 solicitation. Implementation has continued in the ROSES 2015 and ROSES 2016 solicitations.

On August 13, 2015, following the completion of the reorganization of PSD's R&A programs, SMD Associate Administrator John M. Grunsfeld approached the Space Studies Board (SSB) with a request to convene an ad hoc committee to examine the elements of PSD's R&A programs, as they currently exist following restructuring, for their consistency with past advice from the National

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[1] Effective July 1, 2015, the institution is called the National Academies of Sciences, Engineering, and Medicine. References in this report to the National Research Council are used in an historical context identifying programs prior to July 1.

[2] National Research Council (NRC), *Vision and Voyages for Planetary Science in the Decade 2013-2022*, The National Academies Press, Washington, D.C., 2011.

[3] NRC, *An Enabling Foundation for NASA's Earth and Space Science Missions*, The National Academies Press, Washington, D.C., 2009.

Academies of Sciences, Engineering, and Medicine. Following discussions between NASA and the SSB, it was agreed that the committee would address the following questions:

1. Are the PSD R&A program elements appropriately linked to, and do they encompass the range and scope of activities needed to support the NASA strategic objective for planetary science and the Planetary Science Division's science goals, as articulated in NASA's *2014 Science Plan*?
2. Are the PSD R&A program elements appropriately structured to develop the broad base of knowledge and broad range of activities needed both to enable new spaceflight missions and to interpret and maximize the scientific return from existing missions?

It was also agreed that in conducting its task, the committee would

- Not examine the PSD R&A programs as they were prior to the restructuring;
- Conduct its review in the context of current budgetary realities that have differed from projections assumed prior to the release of the most recent planetary science decadal survey; and
- Not comment on the strategic science goals and objectives of PSD, SMD, or NASA.

The National Academies established the Committee on the Review of NASA's Planetary Science Division's Restructured Research and Analysis Program in April 2016 to address the tasks described above. The committee held its first meeting in Washington, D.C. on May 12-13, 2016. The committee met twice more—in Washington, D.C., on August 16-18 and in Woods Hole, Massachusetts, on September 21-23—and assembled the first, full draft of its report in late-November. A revised draft of the report was sent to external reviewers on December 2, 2016, and revised in response to reviewer comments in February 2017.

The work of the committee was greatly assisted by the input and other contributions made by many individuals, including the following: Max Bernstein (NASA Headquarters), Michael Bicay (NASA Ames Research Center), Nancy Chabot (Johns Hopkins University Applied Physics Laboratory), Lennard Fisk (University of Michigan), James Green (NASA Headquarters), Robert Grimm (Southwest Research Institute), Colleen Hartman (NASA Goddard Space Flight Center), Jeffrey Johnson (Johns Hopkins University Applied Physics Laboratory), Janet Luhmann (University of California, Berkeley), Alfred McEwen (University of Arizona), Clive Neal (University of Notre Dame), Michael New (NASA Headquarters), Jani Radebaugh (Brigham Young University), Jonathan Rall (NASA Headquarters), Christophe Sotin (NASA Jet Propulsion Laboratory), James Spann (NASA Marshall Space Flight Center), Eileen Stansbery (NASA Johnson Space Center), Ellen Stofan (NASA Headquarters), Timothy Swindle (University of Arizona), Mark Sykes (Planetary Science Institute), Meagan Thompson (NASA Headquarters), and Andrew Westphal (University of California, Berkeley).

In addition, the committee gives its special thanks to Nobumichi Shimizu (Woods Hole Oceanographic Institution) for stepping in and accepting appointment as a consultant at a key phase in the development of this report.

This report has been reviewed in draft form by individuals chosen for their diverse perspectives and technical expertise. The purpose of this independent review is to provide candid and critical comments that will assist the institution in making its published review as sound as possible and to ensure that the report meets institutional standards for objectivity, evidence, and responsiveness to the study charge. The review comments and draft manuscript remain confidential to protect the integrity of the deliberative process.

The committee wishes to thank the following individuals for their participation in the review of this report: Steven Battel (Battel Engineering, Inc.), Richard Binzel (Massachusetts Institute of Technology), Robin Canup (Southwest Research Institute), John Casani (Jet Propulsion Laboratory, retired), Anita Cochran (University of Texas, Austin), Timothy J. McCoy (Smithsonian Institution

National Museum of Natural History), Harry Y. McSween (University of Tennessee), David Morrison (NASA Ames Research Center), Gerald Schubert (University of California, Los Angeles), and Norman Sleep (Stanford University).

Although the reviewers listed above have provided comments and suggestions, they were not asked to endorse the conclusions or recommendations, nor did they see the final draft of the report before its release. The review of this report was overseen by Charles F. Kennel (University of California, San Diego), who was responsible for making certain that an independent examination of this report was carried out in accordance with institutional procedures and that all review comments were carefully considered. Responsibility for the final content of this report rests entirely with the authoring committee and the institution.

Contents

Executive Summary

The Research and Analysis (R&A) program managed by NASA's Planetary Science Division (PSD), supports a broad range of planetary science activities, including the analysis of data from past and current spacecraft; laboratory research; theoretical, modeling, and computational studies; geological and astrobiological fieldwork in planetary analog environments on Earth; geological mapping of planetary bodies; analysis of data from Earth- and space-based telescopes; and development of flight instruments and technology needed for future planetary science missions. The primary role of the PSD R&A program is to address NASA's strategic objective for planetary science and PSD's science goals, which are derived in part from the 2011 National Research Council (NRC) planetary science decadal survey.[1] The R&A program is composed of a number of thematic program elements that solicit proposals from the planetary science community under the NASA Science Mission Directorate's annual Research Opportunities in Space and Earth Sciences (ROSES) NASA Research Announcement (NRA).

Recently, PSD reorganized the R&A program to provide better alignment with the strategic goals for planetary sciences, following the recommendations of a study by the NRC[2] and a report by the Planetary Science Subcommittee of the NASA Advisory Council.[3] This reorganization was implemented in the ROSES 2014 NRA and first supported using fiscal year (FY) 2015 funds. The major changes in the R&A program involved consolidating a number of prior program elements, many of which were organized by subdiscipline, into a smaller number of thematic core research program elements. Other R&A program elements underwent changes before, during, and after the reorganization but these modifications were not on the scale of those made to the core research program elements. Despite numerous efforts by PSD to communicate the rationale for the reorganization and articulate clearly the new processes, there has been significant resistance from the planetary science community and concerns in some sectors regarding the major realignment of funding priorities.

As described in the Preface and Appendix A, the Committee on the Review of NASA's Planetary Science Division's Restructured Research and Analysis Program was charged by NASA to look closely at the new R&A program and determine if it appropriately aligns with the agency's strategic goals, supports existing flight programs, and enables future missions. In particular, the committee investigated whether any specific research areas or subdisciplinary groups that are critical to NASA's strategic objectives for planetary science and PSD's science goals are not supported appropriately in the current program or have been inadvertently disenfranchised through the reorganization. In order to collect the data necessary for this investigation, the committee solicited input from NASA PSD management. NASA provided information on the detailed structure of the current program, the procedures involved in funding under the new program elements, and the tools used to ensure appropriate balance across and within program

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[1] National Research Council (NRC), *Vision and Voyages for Planetary Science in the Decade 2013-2022*, The National Academies Press, Washington, D.C., 2011.

[2] NRC, *An Enabling Foundation for NASA's Earth and Space Science Missions*, The National Academies Press, Washington, D.C., 2009.

[3] Planetary Sciences Subcommittee, *Assessment of the NASA Planetary Science Division's Mission-Enabling Activities*, NASA Advisory Council Science Committee, August 29, 2011.

elements. The committee also solicited community perspectives from representatives of the various planetary science analysis/assessment groups and the NASA center leads[4] for planetary science.

In response to the first of the two questions in the charge, the committee finds that **the current R&A structure is properly aligned with scientific priorities of the decadal survey and the Planetary Science Division 2014 science goals**. In particular, the committee finds that, despite early community concerns, keyword analyses of the type of task, target body, and science discipline revealed no evidence that restructuring has led to deleterious effects on the planetary science R&A program or on specific segments of the community. Furthermore, in response to the second of the two questions in the charge, the committee finds that, in general, **the structure of the program elements will allow NASA PSD to prepare for future spaceflight missions and to maximize science value from existing missions**.

Nonetheless, the committee has concerns about some components of the current program—for example, in aspects of the proposal-review process and in support of future technology and instrumental and infrastructure capabilities—and found several areas that could be improved. The committee is strongly of the opinion that its concerns provide important input to NASA on how to improve the existing program and clearly address how well the current elements of the R&A program are appropriately structured to develop the broad base of knowledge and broad range of activities needed both to enable new spaceflight missions and to interpret and maximize the scientific return from existing missions. These concerns resulted in the recommendations listed below. With respect to the procedures followed by PSD in the implementation of the current program, the committee recommends the following:

> ***Recommendation:*** In conducting scientific peer reviews of research proposals, NASA's Planetary Science Division should engage the services of several (at least two or three) external (mail) reviewers well in advance of panel reviews. These reviews are critical to a fair and effective proposal evaluation process, particularly when the review panels have a more interdisciplinary character. The panel chair and group chiefs, if recruited early, can take the lead in identification of appropriate external reviewers. (Additional details may be found in section "Proposal Submission and Review" in Chapter 2.)

> ***Recommendation:*** NASA's Planetary Science Division should expeditiously complete establishment of the process for reconsideration of proposal selection decisions, develop and implement a formal mechanism to track debriefing and reconsideration requests across program elements, and inform the community about the process. More transparency in this area can provide the planetary science community with greater confidence that NASA has appropriate checks and balances in the selection process. (Additional details may be found in the section "Proposal Decision Reconsideration" in Chapter 2.)

With respect to how effectively the current R&A program elements align with PSD science goals, and whether specific research areas or subdisciplinary groups that are critical to NASA's mission are not supported appropriately in the current program, the committee makes the following recommendations:

> ***Recommendation:*** NASA needs to investigate appropriate mechanisms to ensure that high-risk/high-payoff fundamental research and advanced technology-development activities receive appropriate consideration during the review process. (Additional details may be found in the section "High-Risk/High-Payoff Research Activities and Advanced Technology" in Chapter 3.)

> ***Recommendation:*** A formal assessment by NASA of how well the program structure and funding are aligned with the Planetary Science Division's science goals should be conducted at

[4] The center leads were asked for input because the NASA centers host research and mission activities that are quite distinct from those generally found in the academic research community and civil servant scientists frequently work under different constraints than academic scientists.

least every 5 years, appropriately phased to the cycle of decadal surveys and midterm reviews. (Additional details may be found in the section “Funding Distribution Among Program Elements” in Chapter 3.)

With respect to whether the current R&A program adequately supports existing missions and prepares the way for future missions, the committee recommends the following:

***Recommendation*:** NASA should support the development of the technologies required to return astrobiological and cryogenic samples to Earth and the appropriate containment, curation, and characterization facilities consistent with the Planetary Science Division’s science goals and planetary protection requirements. (Additional details may be found in the section “Enable New Spaceflight Missions” in Chapter 4.)

***Recommendation*:** In making funding decisions for the various research and analysis program elements, NASA should consider the need to sustain critical scientific and technical expertise and the instrumental and facility capabilities required for scientific return on future missions, as discussed in the 2011 planetary science decadal survey. (Additional details may be found in the section “Enable New Spaceflight Missions” in Chapter 4.)

1
Introduction

Planetary science encompasses a broad range of scientific disciplines that address questions such as how planets form, how they work, and why life developed and is sustained on at least one planet in the solar system. The Planetary Science Division (PSD), one of four divisions within NASA's Science Mission Directorate (SMD), addresses these questions through scientific investigations that include robotic space missions, ground-based observations, modeling activities, and experimental, analytical, and theoretical studies. All of these investigations follow NASA's strategic goals for planetary science, which are rooted in community-based input and periodic review by the National Academies of Sciences, Engineering, and Medicine,[1] beginning with reports from the Committee on Lunar and Planetary Exploration (COMPLEX) from the early-1970s to the late-1990s. Building on this history, NASA's strategic goals for planetary science are currently addressed by the planetary science decadal surveys. These surveys are performed approximately every 10 years by an ad hoc committee and rely heavily on community input and engagement. The most recent planetary science decadal survey, *Vision and Voyages for Planetary Science in the Decade 2013-2022*,[2] identified three cross-cutting themes (Box 1.1)[3] for investigation over the decade 2013-2022. While these themes are generally similar to those from the prior planetary science decadal survey, *New Frontiers in the Solar System: An Integrated Exploration Strategy*,[4] the questions underlying these themes had evolved over the previous decade as new discoveries were made, mission activities retired key questions, and new technologies became available.

Although the planetary science decadal survey themes and questions provide a consensus perspective from the planetary science community, they provide only one of several inputs into NASA's strategic plan for planetary science. In particular, NASA weighs issues, such as synergy with other mission directorates (notably the Human Exploration and Operations Mission Directorate and its human exploration goals), defense of the human race against threats from asteroids and comets, and characterization and utilization of space resources that may enable further robotic or human exploration. For that reason, NASA's planetary science questions and goals (Box 1.2), as articulated most recently in NASA's *2014 Science Plan*,[5] are more expansive than those of the decadal survey. Nevertheless, clear linkages can be drawn between the decadal survey's cross-cutting themes and the planetary science goals in the NASA science plan (Figure 1.1).

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[1] Effective July 1, 2015, the institution is called the National Academies of Sciences, Engineering, and Medicine. References in this report to the National Research Council are used in an historical context identifying programs prior to July 1.

[2] National Research Council (NRC), *Vision and Voyages for Planetary Science in the Decade 2013-2022*, The National Academies Press, Washington, D.C., 2011.

[3] Ibid, p. 11.

[4] NRC, *New Frontiers in the Solar System: An Integrated Exploration Strategy*, The National Academies Press, Washington, D.C., 2003.

[5] NASA, *2014 Science Plan*, Washington, D.C., 2014, pp. 60-61.

BOX 1.1
Planetary Science Decadal Survey: Cross-Cutting Themes

Vision and Voyages for Planetary Science in the Decade 2013-2022[1] identified three cross-cutting science themes and 10 priority questions relating to them to guide research activities in the current decade. These themes and related questions are quoted verbatim below.

1. *Building new worlds—understanding solar system beginnings*
   a. What were the initial stages, conditions, and processes of solar system formation and the nature of the interstellar matter that was incorporated?
   b. How did the giant planets and their satellite systems accrete, and is there evidence that they migrated to new orbital positions?
   c. What governed the accretion, supply of water, chemistry, and internal differentiation of the inner planets and the evolution of their atmospheres, and what roles did bombardment by large projectiles play?
2. *Planetary habitats—searching for the requirements for life*
   a. What were the primordial sources of organic matter, and where does organic synthesis continue today?
   b. Did Mars or Venus host ancient aqueous environments conducive to early life, and is there evidence that life emerged?
   c. Beyond Earth, are there contemporary habitats elsewhere in the solar system with necessary conditions, organic matter, water, energy, and nutrients to sustain life, and do organisms live there now?
3. *Workings of solar systems—revealing planetary processes through time*
   a. How do the giant planets serve as laboratories to understand Earth, the solar system, and extrasolar planetary systems?
   b. What solar system bodies endanger Earth's biosphere, and what mechanisms shield it?
   c. Can understanding the roles of physics, chemistry, geology, and dynamics in driving planetary
   atmospheres and climates lead to a better understanding of climate change on Earth?
   d. How have the myriad chemical and physical processes that shaped the solar system operated, interacted, and evolved over time?

[1] National Research Council, *Vision and Voyages for Planetary Science in the Decade 2013-2022*, The National Academies Press, Washington, D.C., 2012, pp. 69-83.

The questions and goals in NASA's *2014 Science Plan* guide NASA's planetary science activities, including robotic missions, infrastructure support, technology development, and research and analysis (R&A) activities. Activities under the rubric of R&A usually include new science instrument technology development; suborbital research flights on aircraft, balloons, and sounding rockets; analysis and interpretation of spaceflight data; development of theory and computer simulations; and ground-based telescopic measurements and laboratory investigations—all in support of spaceflight missions. Within this report, the term R&A is specifically used to encompass all program elements that are solicited through the annual Research Opportunities in Space and Earth Sciences (ROSES) NASA Research

Announcement (NRA),[6] which includes core research, core technology, and strategic and focused program elements (as detailed in the section "Planetary Science Division R&A Program Elements" later in this chapter). The data analysis activities are largely contained within the strategic and focused research program elements. Historically, R&A has also been referred to as research and data analysis (R&DA).

BOX 1.2
NASA's *2014 Science Plan*—Planetary Science Questions and Goals

NASA's *2014 Science Plan*[1] identified three key questions and five related goals to guide the current activities of its Planetary Science Division research activities in the current decade. These questions and goals are quoted verbatim below.

Planetary Science Questions

1. How did our solar system form and evolve?
2. Is there life beyond Earth?
3. What are the hazards to life on Earth?

Planetary Science Goals

1. Explore and observe the objects in the solar system to understand how they formed and evolve;
2. Advance the understanding of how the chemical and physical processes in our solar system operate, interact and evolve;
3. Explore and find locations where life could have existed or could exist today;
4. Improve our understanding of the origin and evolution of life on Earth to guide our search for life elsewhere; and
5. Identify and characterize objects in the solar system that pose threats to Earth, or offer resources for human exploration.

[1] NASA, *2014 NASA Science Plan*, Washington, D.C., 2014, pp. 60-61.

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[6] NASA, *Research Opportunities in Space and Earth Sciences—2016 (ROSES-2016)*, NASA Research Announcement (NRA) NNH16ZDA001N, February 2016.

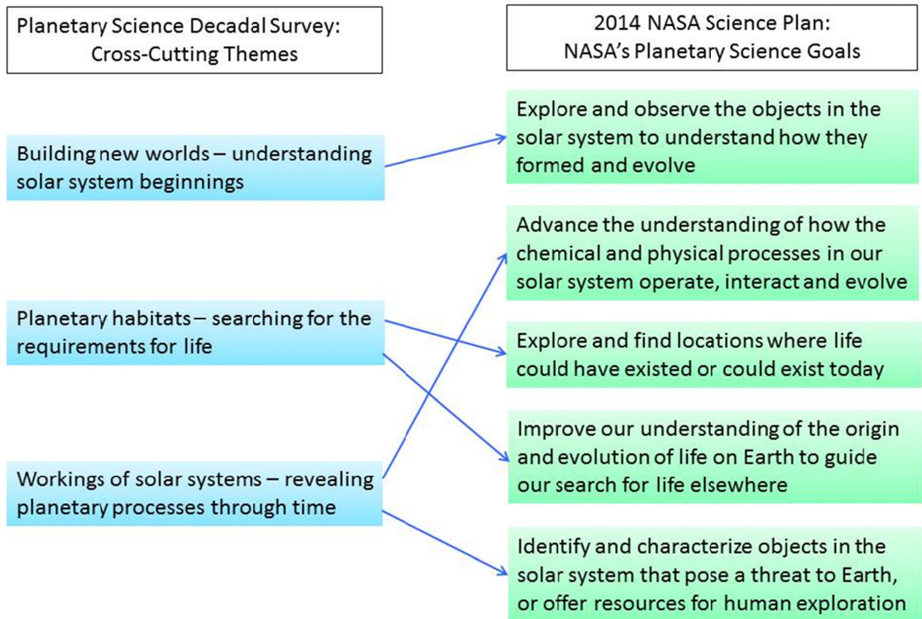

FIGURE 1.1 Clear connections can be drawn between the cross-cutting science themes identified in the 2011 *Vision and Voyages* planetary science decadal survey (*left*) and the planetary science goals listed in NASA's *2014 Science Plan* (*right*).

PRIOR RELATED STUDIES ON PLANETARY R&A

Several prior advisory reports are directly relevant to the committee's current study. In 1998, the National Research Council (NRC) examined the full range of R&DA activities being conducted by NASA's Office of Space Science and Applications. The 1998 report[7] discussed the roles and characteristics of different elements of the R&DA program, illustrated how they contribute to NASA's overall science mission, and examined funding trends and other measures of program content and balance for the 5- to 10-year period leading up to the study. The first recommendation in the report addressed principles for taking a strategic approach to managing R&DA, saying that NASA should

- Regularly evaluate the impact of R&DA on progress toward the goals of NASA's strategic plans;
- Link NASA research proposal solicitations to addressing key scientific questions that can be related to the goals of the strategic plans;
- Regularly evaluate the balance between the funding allocations for spaceflight programs and the R&DA activities required to support those programs;
- Regularly evaluate the balance amongst various subelements of the R&DA program; and
- Use broadly based, independent, scientific peer review panels to define suitable metrics and review the agency's internal evaluations of balance.

The 1998 NRC report[8] also recommended that NASA explicitly consider how R&DA programs address needs for infrastructure (e.g., including facilities and institutions) and human capital (e.g.,

[7] NRC, *Supporting Research and Data Analysis in NASA's Science Programs: Engines for Innovation and Synthesis*, National Academy Press, Washington, D.C., 1998.
[8] Ibid.

graduate students), and it recommended that NASA improve its capabilities for using funding data as tools in managing the R&DA program strategically.

In 2007, Congress directed NASA to task the NRC conduct a new analysis of the SMD's R&A programs, particularly regarding factors relevant to managing the balance between resources for spaceflight missions and supporting research activities. The report from that study[9] again outlined and illustrated the various important roles that R&A programs perform as enablers of NASA's science missions, and it presented a set of principles, metrics, and recommendations for effective strategic management of R&A programs. The report's first recommendation was that NASA should ensure that its mission-enabling activities are linked to the strategic goals of the agency and of NASA's SMD and that they be structured so as to

- Encompass the range and scope of activities needed to support those strategic goals;
- Provide the broad knowledge base that is the context necessary to interpreting data from spaceflight missions and defining new spaceflight missions;
- Maximize the scientific return from all spaceflight missions;
- Supply a continuous flow of new technical capabilities and scientific understanding from mission-enabling activities into new spaceflight missions; and
- Enable the healthy scientific and technical workforce needed to conduct NASA's space and Earth science program.[10]

The 2009 NRC report also emphasized the importance of taking a strategic approach to managing NASA's portfolio of mission enabling activities. Such an approach would include the following attributes:

- Clearly defined mission-enabling objectives, strategies, and priorities that can be traced back to the overall strategic goals of NASA, SMD, and the relevant discipline division;
- Clearly articulated relationships between mission-enabling activities and the ensemble of ongoing and future spaceflight missions that they support;
- Clear metrics that permit program managers to relate mission-enabling activities to strategic goals, evaluate the effectiveness of mission-enabling activities, and make informed decisions about priorities, programmatic needs, and portfolio balance;
- Provisions for integrating support for innovative high-risk/high-payoff research and technology,[11] interdisciplinary research, and scientific and technical workforce development into mission-enabling program strategies;
- Active involvement of the scientific community via an open and robust advisory committee process; and
- Transparent budgets that permit program managers to effectively manage mission-enabling activity portfolios and permit other decision makers and the research community to understand the content of mission-enabling activity programs.[12]

In 2011, NASA PSD established a Supporting Research and Technology Working Group under the auspices of the Planetary Sciences Subcommittee of the NASA Advisory Council's Science Committee to provide advice about implementing the recommendations of the 2009 NRC report. The working group's charge included the following tasks:[13]

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[9] NRC, *An Enabling Foundation for NASA's Earth and Space Science Missions*, The National Academies Press, Washington, D.C., 2009, often referred to as the Fisk report.

[10] Ibid., p. 47.

[11] For the definition of high-risk/high-payoff research and technology, see NRC, *An Enabling Foundation,* 2009, p. 40.

[12] NRC, *An Enabling Foundation*, 2009, p. 48.

[13] Planetary Sciences Subcommittee, *Assessment of the NASA Planetary Science Division's Mission-Enabling Activities*, 2011.

1. Identify those mission-enabling research and analysis activities that are required to support the strategic goals of the NASA SMD Planetary [Science] Division;
2. Map these activities to existing PSD program elements and identify activities that overlap multiple elements and activities unsupported by any element; and
3. Provide recommendations to PSD regarding the application of "active portfolio management" to meet its strategic goals.[14]

In its report, the working group concluded that the then current mission-enabling activities "can be mapped clearly to the specific scientific objectives contained in the NASA 2010 Science Plan."[15] However, the working group also concluded that "many of the research and analysis programs overlap" and that PSD "should consider consolidating programs to eliminate overlap as a part of the portfolio management strategy."[16] While the working group report presented a number of examples of how a detailed mapping could be constructed to link broad scientific objectives to program elements and then to specific research activities, the authors found that to be much too ambitious a task for the working group to perform within its available time and resources. Consequently, the report recommended that NASA carry out such an endeavor as part of its regular response to decadal survey reports. Finally, the working group offered a large number of specific findings and recommendations regarding both near-term and recurring actions that NASA could take to improve program management and execution.

PLANETARY SCIENCE DIVISION R&A PROGRAM ELEMENTS

NASA PSD reorganized its R&A program in 2013, resulting in a revised set of program elements for which research proposals were first solicited in the 2014 ROSES NRA. Selections under this NRA were first awarded using fiscal year (FY) 2015 funding, such that approximately 33 percent of FY2015 R&A funding was awarded to proposals submitted under these revised program elements, with the rest supporting ongoing research activities. The current PSD R&A program elements fall largely within four groups as follows:[17]

- Core research program elements,
- Core technology program elements,
- Strategic program elements, and
- Focused program elements.

These program elements are detailed in Appendix C of the ROSES-2016 NASA Research Announcement.[18] A brief synopsis of the major ongoing program elements is given below, drawn from the ROSES-2016 NRA and presentations to the committee.[19]

Core Research Program Elements

Each of the following core research program elements have a broad science scope that directly addresses PSD science goals:

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[14] NRC, *An Enabling Foundation*, 2009, p. 28.

[15] Planetary Sciences Subcommittee, *Assessment of the NASA Planetary Science Division's Mission-Enabling Activities*, 2011, p.1.

[16] Ibid.

[17] Jonathan Rall, PSD R&A Lead at NASA Headquarters, *Restructuring Planetary Science's Research & Analysis Program*, Planetary Science Subcommittee, January 2014, slide 23.

[18] NASA, *ROSES-2016*, 2016.

[19] Rall, *Restructuring Planetary Science's Research & Analysis Program*, 2014.

- *Emerging Worlds (EW)*—Research in the area of Emerging Worlds aims to understand the formation and early evolution of the solar system, as well as planetary systems in general. The central goal of this program element is to understand how the Sun's family of planets, satellites, and minor bodies (including small bodies and planetary rings) form and evolve.
- *Solar System Workings (SSW)*—The Solar System Workings program element supports research into atmospheric, climatological, dynamical, geologic, geophysical, and geochemical processes occurring on planetary bodies, satellites, and other minor bodies (including rings) in the solar system. This program element seeks to address the physical and chemical processes that affect the surfaces, interiors, atmospheres, exospheres, and magnetospheres of planetary bodies.
- *Habitable Worlds (HW)*—Research supported in Habitable Worlds seeks to use knowledge of the history of Earth and the life upon it to determine the processes that create and maintain habitable environments, search for ancient and contemporary habitable environments, and explore the possibility of extant life beyond Earth.
- *Exobiology (EXO)*—The goal of research in Exobiology is to understand the origin, evolution, and distribution of life on Earth. Research is centered on the origin and early evolution of life on Earth and the potential of life to adapt to different terrestrial environments. This research is conducted in the context of NASA's ongoing exploration of Earth's stellar neighborhood and the identification of biosignatures for in situ and remote sensing applications.
- *Solar System Observations (SSO)*—Within the Solar System Observations program element, Near Earth Object Observations (NEOO) supports NASA's commitment to discover and inventory potentially hazardous near Earth objects with sizes down to ~100 meters and to characterize that population through determination of their orbital elements. This program element also considers proposals that characterize a representative sample of these objects by measuring their sizes, shapes, and compositions. Planetary Astronomy (PAST) supports both ground-based astronomical observations and suborbital investigations of the solar system involving sounding rockets and balloons. Proposals are solicited for observations over the entire range of wavelengths—from the ultraviolet to radio—that contribute to the understanding of the solar system.

Core Technology Program Elements

Each of the following core technology program elements provides funding for technologies that support PSD science and mission activities:

- *Maturation of Instruments for Solar System Exploration (MatISSE)*—The MatISSE program element supports the advanced development of spacecraft-based instruments that show promise for use in future planetary missions (Figure 1.2). The goal of the program element is to develop and demonstrate planetary and astrobiology science instruments to the point where they may be proposed in response to future announcements of flight opportunity without additional extensive technology development (i.e., to advance the technology readiness level (TRL) from three to six [Figure 1.3][20]).

[20] A technology readiness level (TRL) 6 technology is defined by NASA as having a fully functional prototype or representational model that has yet to be demonstrated in a space environment.

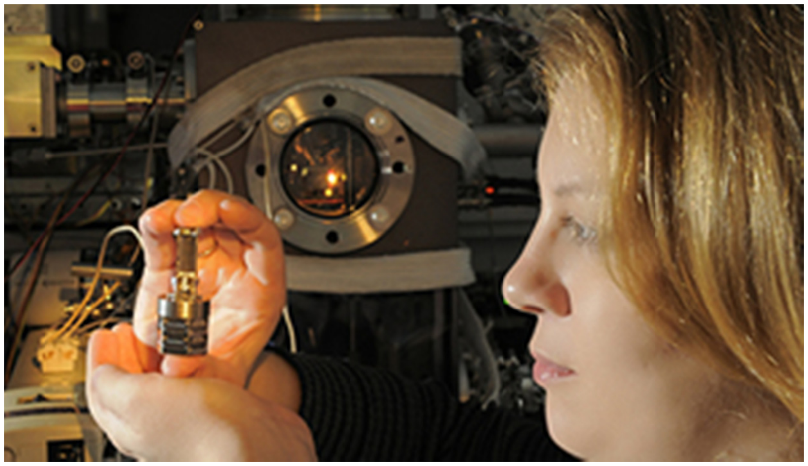

FIGURE 1.2 A NASA scientist holds a piece of the sensor for the Linear Ion Trap Mass Spectrometer, a highly compact mass spectrometer funded under the MatISSE (Maturation of Instruments for Solar System Exploration) program. SOURCE: Pat Izzo/NASA.

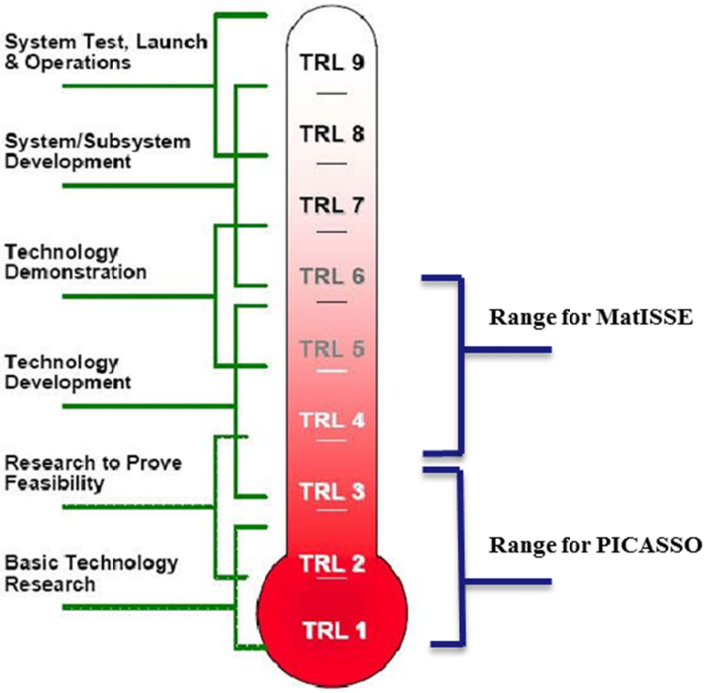

FIGURE 1.3 Technology readiness levels (TRLs) for space missions. SOURCE: NASA.

- *Planetary Instrument Concepts for the Advancement of Solar System Observations (PICASSO)*—The PICASSO program element supports the development of spacecraft-based instrument systems that show promise for use in future planetary missions. The goal of the program element is to conduct planetary and astrobiology science instrument feasibility studies, concept formation, proof of concept instruments, and advanced component technology development to the point where they may be proposed in response to the MatISSE program element (i.e., to advance the TRL from one to three).

- *Planetary Major Equipment (PME)*—The PME program provides funding for the purchase or development of new or upgraded non-flight analytical, computational, telescopic, and other instrumentation required by investigations in eligible planetary science research program elements.

FIGURE 1.4 Utilization of CheMin prototype instruments in a Mars-analog arctic environment in Norway's Svalbard Archipelago. SOURCE: Courtesy of NASA/JPL

Strategic Program Elements

The following strategic program elements, which are generally narrower in scope than the core program elements, sustain for multiple funding cycles and address current PSD strategic needs:

- *Planetary Data Archiving, Restoration, and Tools (PDART)*—The PDART program element solicits proposals to generate higher-order data products, archive and restore data sets or products, create or consolidate reference databases, generate new reference information, digitize data, and develop or validate software tools.
- *Planetary Science and Technology from Analogue Research (PSTAR)*—The PSTAR program element addresses the need for integrated interdisciplinary field experiments as an integral part of preparation for planned human and robotic missions. Furthermore, the program element solicits proposals for investigations focused on exploring the Earth's extreme environments in order to develop a sound technical and scientific basis to conduct astrobiological research on other solar system bodies (Figure 1.4).
- *Exoplanets Research (XRP; joint with Astrophysics Division)*—The Exoplanets research program element solicits basic research proposals to conduct scientific investigations related to the research and analysis of extrasolar planets (exoplanets). Its broad objectives include the determination of compositions, dynamics, energetics, chemical behaviors of extrasolar planets, and the detection and characterization of other planetary systems.
- *New Frontiers Data Analysis Program (NFDAP)*—The objective of NFDAP is to enhance the scientific return from New Frontiers[21] missions by broadening scientific participation in the

[21] New Frontiers missions are competed principal investigator (PI)-led missions selected from a set of candidate missions identified by the 2011 planetary science decadal survey. For the most recent competition, total mission cost

analysis and interpretation of data returned by these missions

- *Discovery Data Analysis Program (DDAP)*—The objective of DDAP is to enhance the scientific return of Discovery[22] missions by broadening scientific participation in the analysis of data, both recent and archived, collected by these missions.
- *Laboratory Analysis of Returned Samples (LARS)*—The goal of the LARS program element is to maximize the science derived from planetary sample-return missions. Activities supported by LARS fall into two categories: (1) development of laboratory instrumentation and/or advanced techniques required for the analysis of returned samples and (2) direct analysis of samples already returned to Earth.
- *Mars Data Analysis Program (MDAP)*—The objective of MDAP is to perform analysis of mission data sets to enhance the scientific return from missions to Mars conducted by NASA and other space agencies.
- *Planetary Protection Research (PPR)*—Planetary protection involves preventing biological contamination on both outbound and sample return missions to other planetary bodies. Numerous areas of research in astrobiology and exobiology are improving understanding of the potential for survival of Earth microbes in extraterrestrial environments, which is relevant to preventing contamination of other bodies by organisms carried on spacecraft. Research is required to improve NASA's understanding of the potential for both forward and backward contamination, how to minimize it, and to set standards in these areas for spacecraft preparation and operating procedures.

Focused Program Elements

The following focused program elements, which are narrower in scope than the core program elements, are solicited only for a limited time usually associated with the end of a flight mission or series of missions:

- *Lunar Data Analysis Program (LDAP)*—The objective of this limited-term program element is to take full advantage of the wealth of lunar data from recent and ongoing missions.
- *Cassini Data Analysis Program (CDAP)*—The objective of this limited-term program element is to take full advantage of the wealth of data from the Cassini mission to Saturn (Figure 1.5).

NASA PSD also establishes program elements that address topical needs or targeted technology requirements. Such program elements are often of short duration and include the following:

- *New Frontiers Homesteader*—This program element was released in ROSES 2015 to support the advanced development of technology, including instruments, relevant to mission concepts for the next two New Frontiers Announcements of Opportunity, the first of which will be selected in 2019.
- *Concepts for Ocean Worlds Life Detection Technology (COLDTech)*—This program element supports the development of spacecraft-based instruments and technology for surface and subsurface exploration of ocean worlds such as Europa, Enceladus, and Titan.
- *Small Innovative Missions for Planetary Exploration (SIMPLEx)*—This program element

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is capped at $850 million (FY 2015) for Phases A through D, not including the cost of the Expendable Launch Vehicle (ELV) or any contributions.

[22] Discovery missions are competed PI-led missions that are not specifically identified by the 2011 planetary science decadal survey. For the most recent competition, total mission cost was capped at a Phase A-D cost of $450 million (FY 2015), excluding standard launch services.

supports the formulation and development of science investigations that can be accomplished using small spacecraft.

- *Planetary Science Deep Space SmallSat Studies (PSDS3)*—This program element supports the study of spacecraft mission concepts that can be accomplished using small spacecraft, including CubeSats.
- *Dynamic Power Converters for Radioisotope Power Systems*—The goal of this program element is to investigate new dynamic power-conversion technologies for radioisotope power systems that can enable future spacecraft missions.
- *Hot Operating Temperature Technology (HOTTech)*—This program element supports the advanced development of technologies for the robotic exploration of high-temperature environments, such as the surfaces of Venus and Mercury, or the deep atmosphere of the gas giant planets.

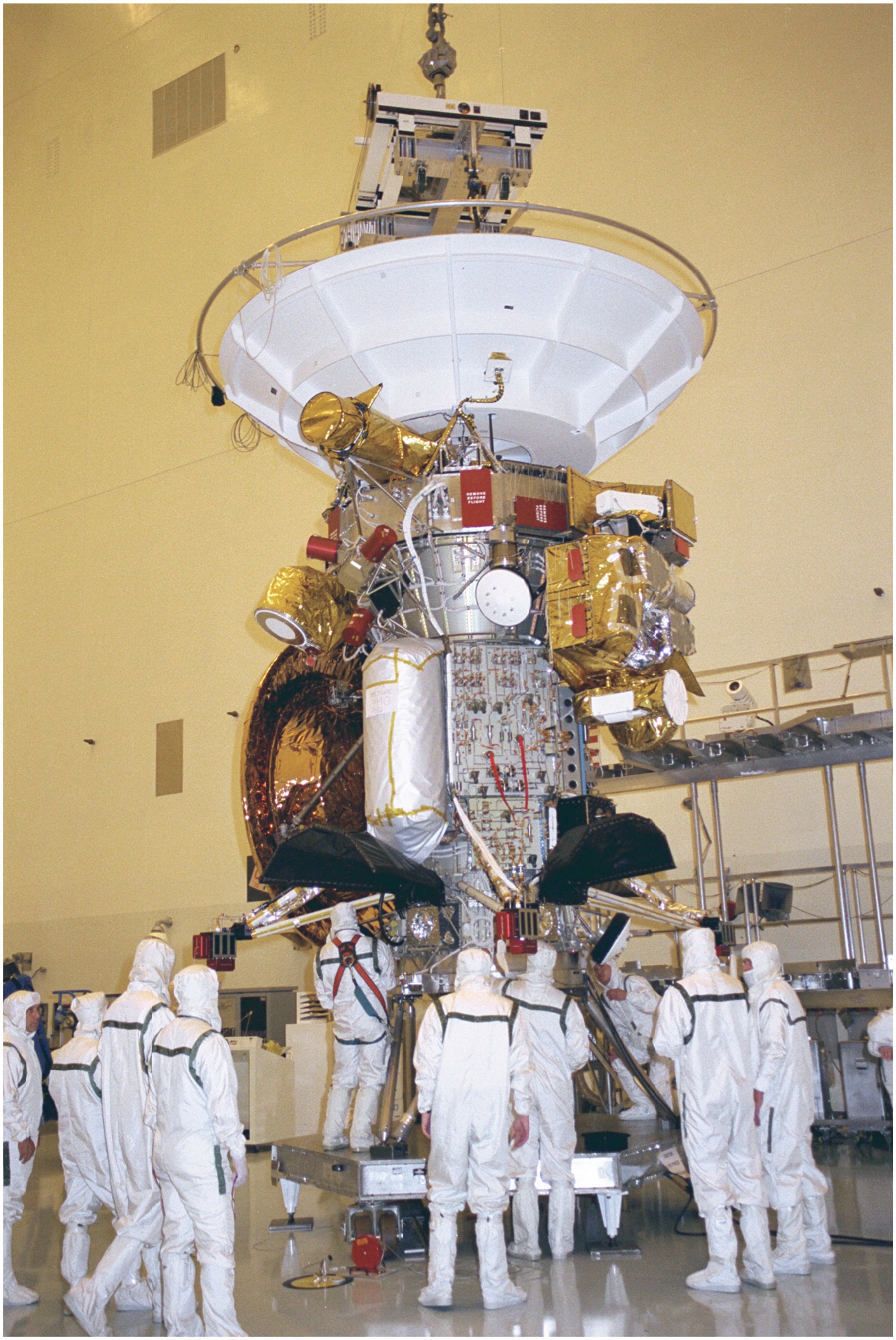

FIGURE 1.5 The Cassini-Huygens spacecraft during preparation for launch at the Kennedy Space Center in October 1997. SOURCE: Courtesy of NASA.

2
NASA's Planetary Science Division R&A Process

The processes by which NASA PSD selects proposals for funding bear directly on how effectively the current R&A program aligns with NASA's strategic objectives for planetary science and the Planetary Science Division (PSD) science goals, as articulated in NASA's *2014 Science Plan*[1] (Figure 2.1). As these processes have been retooled in response to the recent reorganization of the program elements, it is important to review the current approach and how it accommodates the challenges associated with implementing an R&A program structure with new, more encompassing program elements.

The current organization of NASA's PSD R&A program was designed to map specific core research program elements directly to NASA's planetary science goals. The presentations by NASA PSD senior staff that characterized the restructuring devoted considerable attention to the much improved ability of NASA to satisfy congressional and administration mandates such as the Government Performance and Results Modernization Act (GPRAMA). However, as one might expect from any such large-scale re-ordering, and despite what appeared to be a good-faith effort on the part of PSD to explain the reorganization, the restructuring also generated a number of concerns in the planetary science community. Many of these concerns reflect on the processes now used by PSD to review and make funding decisions on proposals.

Under the reorganized R&A structure, PSD has modified the processes associated with submission, review, and selection of R&A proposals for funding. Any resultant inconsistencies and inefficiencies in the mechanisms used to submit, review, and select proposals have direct bearing on the linkage between the R&A program elements, PSD goals and objectives (i.e., items directly pertinent to the first question in the committee's statement of task), and the planetary science community's ability to interpret and maximize the scientific return from NASA missions (i.e., items directly pertinent the second question in the committee's statement of task). As such, issues associated with submission, review, and selection of R&A proposals have a direct bearing on the two questions posed to the committee by NASA. Consequently, the committee asked PSD to provide details concerning the R&A proposal process. The material provided by PSD, as informed by the committee's subsequent discussions and deliberation, forms the basis of the following sections of this chapter. The issues identified by the committee in the following pages are clearly the source of some of the concerns expressed during its data-gathering activities (Appendix C). The committee also notes that the material provided by PSD is not clearly delineated elsewhere.

Although these processes vary somewhat amongst the various program elements within PSD R&A, all program elements use the same basic approach, following *SMD Policy Document SPD-22: Management of ROSES Peer Review and Selection Process*[2] and the guidelines for peer review from the *Guidebook for Proposers*.[3] To enable consistency of process across program elements, PSD uses a management structure with overall responsibility for R&A residing with PSD's R&A lead.

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[1] NASA, *2014 Science Plan*, Washington, D.C., 2014.

[2] NASA Science Mission Directorate, *SMD Policy Document SPD-22: Management of ROSES Peer Review and Selection Processes*, http://www.lpi.usra.edu/PSD-RandA/SPD-22-SMD-Peer-Review-Policy.pdf, accessed April 17, 2017.

[3] NASA, "NASA Guidebook for Proposers 2016," https://www.hq.nasa.gov/office/procurement/nraguidebook/, pp. B6-B7.

FIGURE 2.1 Cover of NASA's *2014 Science Plan*. SOURCE: Courtesy of NASA.

A general overview of the current processes, illustrated in Figure 2.2, can be broken down into (1) activities leading up to and including the panel review, (2) activities involving selection of reviewed proposals for funding, and (3) activities associated with principal investigator (PI) requests for debriefings and reconsiderations.

PROPOSAL SUBMISSION AND REVIEW

NASA PSD has established approaches to proposal submission and review that were summarized in a presentation to the committee (Box 2.1). PSD currently uses a two-step proposal submission process utilizing the NASA Solicitation and Proposal Integrated Review and Evaluation System (NSPIRES). The Step-1 proposal is required by NASA and has to be submitted by an Authorized Organizational Representative (AOR) of the PI's institution. It includes only the names of the PIs and co-investigators, their institutional affiliations and a brief summary of the research to be performed. The Step-1 proposal allows NASA to plan for the panel review process and to provide feedback, as appropriate, to PIs when proposed research appears to be inappropriate to the solicitation. While a Step-1 proposal is required before submission of a Step-2 proposal, it is not a commitment on the part of the PI's institution to submit a Step-2 proposal, which contains all NRA-required elements for peer review.

Under the new organizational structure, the review of proposals submitted to each program element is managed by a caucus of PSD program officers representing the disciplinary breadth of the program element. Additional support for proposal review management, but not funding decisions, is provided by community members who act as panel chairs and group chiefs. These scientists are recruited from the planetary science community by the appropriate program officer for each program element. The panel chairs provide oversight of the panel review process, while the group chiefs chair individual subpanels that provide panel reviews of subdisciplinary groups of proposals for each program element.

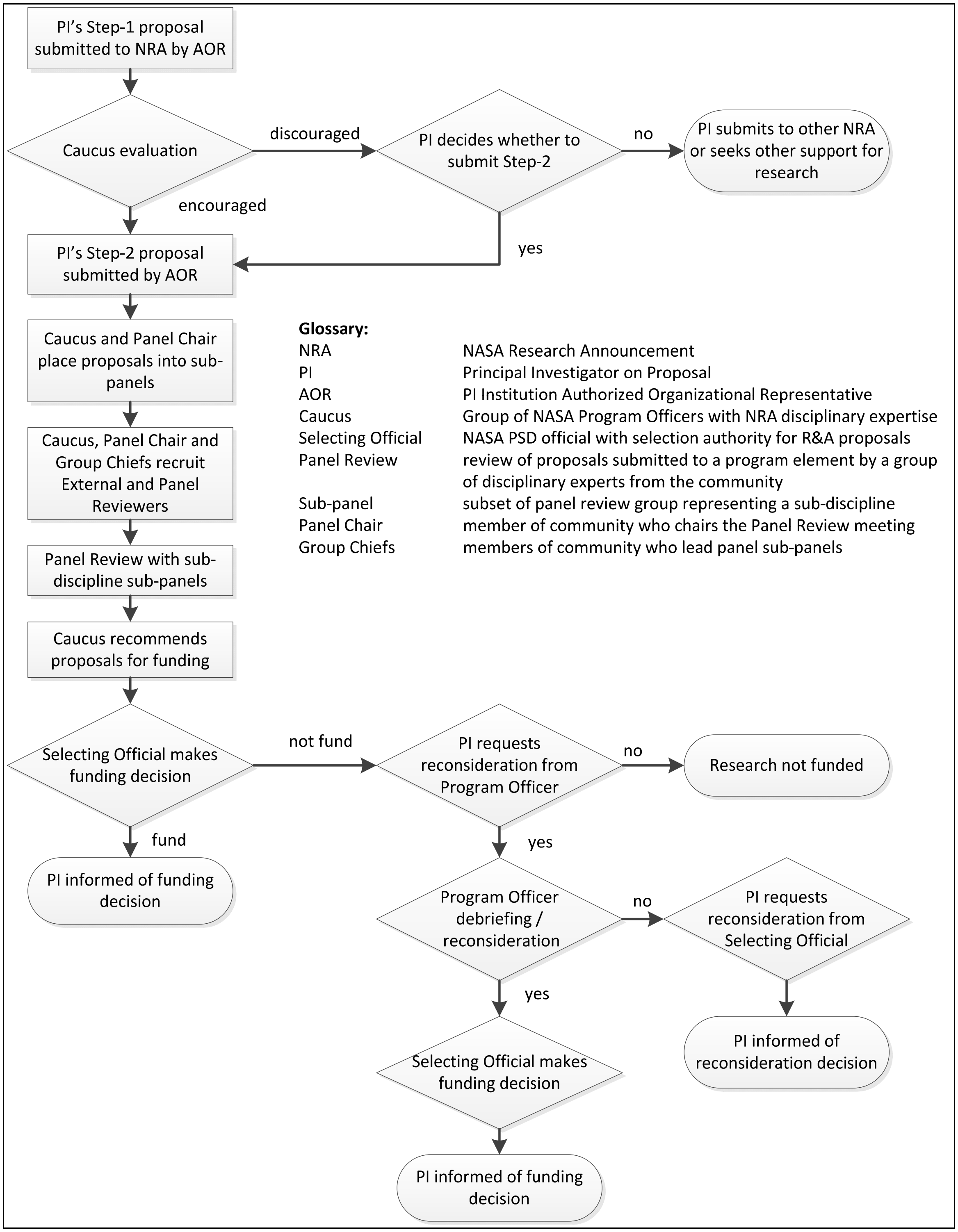

FIGURE 2.2 Flow chart for the processing of proposals submitted to R&A program elements in NASA's Planetary Science Division (PSD), showing the multiple steps and decision points between submission (*top left*) and final disposition (*bottom*). NOTE: AOR, Authorized Organizational Representative; NRA, NASA Research Announcement; PI, principal investigator.

BOX 2.1
NASA PSD Current Processes: Proposal Submission and Review

- Step-1 proposals are submitted by authorized organizational representative (AOR) to the NSPIRES system prior to the published deadline. A master list of all submitted proposals is provided to the discipline scientist (caucus lead) who shares with his/her caucus.
- Caucus meets to discuss encourage/discourage decisions for all compliant Step-1 proposals.
- Encourage and discourage letters are uploaded in NSPIRES and released to proposers.
- Caucus meets to sort proposals into "like sub-panels" of generally similar size—that is, similar number of proposals—typically less than 20 but with a common theme or discipline. Sometimes, a panel chair has already been identified and participates in the sorting.
- Caucus members and panel chair identify candidates for group chiefs (also referred to as subpanel chairs) and then start populating panels and making reviewer assignments.
- The panel chair typically has conference calls with the group chiefs and there is some discussion of the distribution of proposals between subpanels. The search for panelists almost always identifies external reviewers who cannot attend in person but will agree to submit a mail review. This process is iterated until each proposal has at least two assigned panel reviewers and 1 to 3 external reviewers.

SOURCE: NASA PSD R&A lead, presentation to the committee, August 17, 2016.

As an example, PSD also provided the committee with the briefing materials that are used in plenary session at the beginning of the SSW panel review, which are largely representative of the materials used across all of the program elements. These presentations provide a uniform approach across all subpanels within the panel review process for each program element and directly mitigate concerns about variability in approach to proposal scoring and preparation of panel summaries. The subpanels are specifically asked to evaluate the merit of each proposal based on the following criteria:[4]

- Are the stated scientific goals compelling?
- Is the approach (including proposed techniques) appropriate, sound and likely to succeed?
- Does the proposal acknowledge potential pitfalls and propose alternatives?
- How much will the proposed research program advance the field if successfully executed?
- Does the team have the necessary expertise?
- Can the proposed research program achieve the stated goals on the proposed schedule?

Materials presented to the committee by NASA suggest that the panels were not specifically sensitized to issues of unconscious bias, where proposals by female and/or minority PIs may be reviewed differently from those of their white male colleagues. Nonetheless, PSD program officers do receive training in unconscious bias, and they watch for any such behavior during panel review discussions. While NASA has not traditionally collected demographic information from proposers, and consequently does not know the extent of any bias in proposal reviews, unconscious bias in reviewing has been demonstrated by other funding agencies. The committee is pleased to note, based on the presentation by NASA Chief Scientist Ellen Stofan, that NASA has moved forward with a plan to collect demographic data to assess any disparity in review and selection of proposals. Absent such demographics, it would seem prudent to make the panelists aware of the issue of unconscious bias as part of the introduction to the panel review process.

[4] See also NASA, "NASA Guidebook for Proposers 2016," p. C2.

The committee was impressed by the current implementation of the panel review process. Although the panel reviews for several of the program elements are larger and more interdisciplinary than for prior program elements, the presentations by NASA and the community representatives suggest that the implementation of the new program elements has been quite effective. In particular, the use of multiple subpanels for each program element, a uniform evaluation process across subpanels, and the use of caucus members having broad disciplinary coverage in both the subpanels and subsequent funding decisions largely alleviated committee concerns with respect to the larger number of proposals in each program element. Nonetheless, the committee retains concerns that the subpanels do not always have sufficient members with appropriate expertise for all proposals and that insufficient use has been made of external reviewers to fill that expertise gap. Some outreach by NASA to the broader reviewer community, to encourage timely and thorough review of proposals, may be warranted. Both NASA and community representatives noted that requests for external reviews were often unheeded, and reviews were frequently late and of insufficient quality to aid in the review process.

The committee is pleased with the addition of an early career planetary scientist as executive secretary for each subpanel. The use of these early career scientists is viewed as an effective way to provide training and experience in proposal preparation and review for the next generation of researchers. These executive secretaries take notes in every panel and subpanel session and are empowered to contact a NASA R&A manager should any untoward or prejudicial behavior be noted. Furthermore, the use of a caucus of program officers for these large program elements also allows the presence of a program officer as an observer in most of the panel discussions. Besides the obvious advantages of being able to provide on-the-spot responses to logistical questions and ensure a fair and balanced review process, the presence of a caucus member can provide first-hand knowledge of the panel discussion in the event of a later PI request for debriefing and/or reconsideration. With these larger, more thematic program elements, interdisciplinary proposals can be reviewed more effectively, potentially including reviewers from other concurrent review panels to cover expertise shortfalls.

> ***Finding:*** The committee finds the selection process for the R&A program elements to be reasonable and consistent. The committee finds that by virtue of utilizing multiple subpanels, a rating and selection process was implemented that met the standard of fairness and thoroughness. Nonetheless, challenges remain in maintaining an optimal selection of proposals that meet NASA’s current and future needs.

> ***Finding:*** Although NASA PSD has a target of one to three external reviewers per proposal, the committee is concerned that this target is not always met and that not all external reviews were of sufficient quality to assist in the review process. Given the broader disciplinary coverage of the new program elements and resultant subpanels, it is critical that there are sufficient qualified external reviews for effective review of all proposals. The critical role of external reviews needs to be communicated to the reviewer community to ensure timely return of high-quality, fair reviews.

> ***Finding:*** A greater diversity of expertise is now available during the panel review process for the core research program elements due to the broader disciplinary makeup of its panels. Such diversity directly addresses concerns about insufficiently qualified peer reviewers for interdisciplinary research proposals.

> ***Recommendation:*** The NASA Planetary Science Division should engage the services of several (at least two to three) external (mail) reviewers well in advance of panel reviews. These reviews are critical to a fair and effective review process, particularly when the review panels have a more interdisciplinary character. The panel chair and group chiefs, if recruited early, can take the lead in identification of appropriate external reviewers.

PROPOSAL SELECTION FOR FUNDING

NASA PSD has established approaches to proposal selection for funding that were summarized in a presentation to the committee (Box 2.2). These approaches follow the guidelines in *SMD Policy Document SPD-08: Requirements for Selection Decision Documents for NASA Research Announcements including ROSES*.[5]

The committee was impressed by the attempts by NASA PSD to adapt their decision-making process for the new funding program elements. In particular, the use of a caucus of program officers allows greater disciplinary coverage in decision-making and increased oversight of selection of proposals that, for a variety of reasons, may not have ranked highly during panel discussions but still warrant funding. Such proposals should still be responsive to NASA's *2014 Science Plan* but might include high-risk/high-payoff research, research by early career scientists who are less experienced in proposal preparation, interdisciplinary research, mission-enabling research, research that sustains critical functionality for planned missions or anticipated missions, and research that enables future human missions.

BOX 2.2
NASA PSD Current Processes: Proposal Selection for Funding

- Within 4 weeks of the end of the review panel, the caucus lead and caucus members prepare the selection requirements package (SRP), including a draft selection decision document (SDD), and the caucus lead signs the SRP and presents the SRP to the selection official.
- The SDD contains a brief rationale for the selection based upon the expert evaluation of proposals by a peer review panel in accordance with the evaluation criteria defined in the NRA, and incorporating programmatic factors; and a brief description of the post-panel decision-making process used to arrive at the selection. In particular, the SDD contains a rationale for the selection of proposals identified by the peer review as having a lower evaluation result than some that were not selected.
- The selecting official selects a subset of the submitted proposals, fully or partially, and declines to select the rest, and signs the SDD.
- Once the review panel is done, the roles of panel chair and group chief are complete; they do not participate in the preparation of the selection requirements package. They may however be contacted to participate in a request for reconsideration at the caucus lead's discretion.
- Programmatic and discipline balance is discussed during the selection meeting with the selection official. Typically in preparing the SDD, the caucus lead in conjunction with the caucus would identify any imbalance, either extant in the program or one that would result from the selection recommendation, and make adjustments.

SOURCE: Jonathan Rall, PSD R&A Lead at NASA Headquarters, presentation to the committee, August 17, 2016.

> ***Finding:*** The use of a caucus of R&A program officers at all stages of the proposal review and selection process for the new core research program elements brings greater disciplinary breadth and increased ability to assess alignment with strategic goals, innovative or high-risk endeavors, and mission-enabling character.

[5] NASA Science Mission Directorate, *SMD Policy Document SPD-08: Requirements for Selection Decision Documents for NASA Research Announcements including ROSES,* Washington, D.C., 2007, http://www.lpi.usra.edu/PSD-RandA/SPD-08-NRA-Selection-Documents.pdf.

PROPOSAL DECISION RECONSIDERATION

NASA PSD has established approaches to proposal decision reconsideration that are currently being implemented (Box 2.3).

The committee discussed concerns about non-responsiveness of some NASA program officers to requests for debriefings or reconsiderations, and the apparent lack of awareness in the community about the official procedures for debriefings and reconsiderations. During the presentations by PSD, it became clear that such procedures are still in the process of being implemented. Nonetheless, these need to be communicated clearly to proposers. Because initial requests for debriefing and reconsideration come through email, phone calls, or in person to the lead program officer for each of the program elements, and may later be elevated to the PSD R&A lead, there needs to be some formal mechanism in place to track such requests. Only through such a mechanism can NASA adequately document the numbers of such requests and their outcomes.

> ***Finding:*** NASA PSD is establishing a uniform, formal process for reconsideration of funding decisions. Once promulgated and fully implemented, this process can provide fairness as well as transparency and improved communication with the planetary science community.

> ***Recommendation:*** The NASA Planetary Science Division should expeditiously complete establishment of the reconsideration process, develop and implement a formal mechanism to track debriefing and reconsideration requests across program elements, and inform the community about the process. More transparency in this area can provide the planetary science community with greater confidence that NASA has appropriate checks and balances in the selection process.

BOX 2.3
NASA PSD Current Processes: Proposal Decision Reconsideration

- After final selection of the awards for each program element by the selecting official on the recommendation of the program officer (in consultation with the caucus), the panel summary and decision letter are provided to the proposer. Any proposer may request a formal debriefing on the positive and negative aspects of the proposal from the program officer within 60 days of being notified of the final selection decision.
- If the proposer has issues with the panel evaluation or review process that he/she feel may have resulted in unfair declination, the proposer may request a reconsideration from the program officer within 60 days of being notified of the final selection decision. Program officers are expected to respond to such requests within 4 weeks, either with a decision or an explanation that more time is needed.
- If the proposer is not satisfied with the final decision of the program officer, they can request a reconsideration from the selecting official within 60 days of being notified of the final selection decision or 30 days of the last communication from the program officer, whichever was later. The selecting official has 30 days to respond with a decision or an explanation that more time is needed.

SOURCE: Jonathan Rall, PSD R&A Lead at NASA Headquarters, presentation to the committee, August 17, 2016.

3
Linkage Between Planetary R&A and NASA PSD Science Goals

The committee was charged with addressing two questions related to the Planetary Science Division's (PSD's) current research and analysis (R&A) program elements. The first of two questions posed to the committee asks:

> *Are the PSD R&A program elements appropriately linked to, and do they encompass the range and scope of activities needed to support the NASA strategic objective for planetary science and the Planetary Science Division science goals, as articulated in the 2014 NASA Science Plan?*

As noted in Chapter 1, the current PSD R&A program encompasses core research and core technology program elements, as well as some strategic and focused program elements.[1] The committee looked at all of these program elements and the range and scope of activities that they support, with a view to assessing their alignment with NASA's strategic objectives and PSD's science goals. Particular attention was given to whether the current program elements provide suitable support for all research activities critical to PSD's mission. The committee also looked at how well PSD balances funding both within and between program elements as it works to optimize its use of scarce resources.

In its deliberations, the committee discussed assertions by several of the chairs of the analysis/assessment groups (Appendix C) highlighting concerns that certain planetary science subdisciplines or areas of research were not adequately funded under the new program element structure to support PSD's science goals. There was additional concern that as the new program elements become fully implemented, there will be a loss of both expertise and technical capability that will be needed to support future missions. While the alignment between NASA's planetary science goals and the PSD R&A program elements prior to the 2014 reorganization is outside the charge of this committee, the committee examined implementation of the reorganization in terms of whether critical capabilities have been lost in the transition to the current program. The loss of critical capabilities would potentially impede PSD's ability to address its strategic goals.

REORGANIZATION OF PSD R&A PROGRAM

As noted in Chapter 1, prior studies both by the National Research Council (NRC)[2] and the Planetary Science Subcommittee of the NASA Advisory Council[3] recommended that PSD reorganize the R&A budget structure to align more closely with NASA's planetary science goals. When the reorganization was implemented for ROSES 2014, the appropriate NASA document was NASA's 2010

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[1] More detail on the current program elements can be found in the section "Planetary Science Division R&A Program Elements" in Chapter 1.

[2] National Research Council (NRC), *Supporting Research and Data Analysis in NASA's Science Programs: Engines for Innovation and Synthesis*, National Academy Press, Washington, D.C., 1998.

[3] Planetary Sciences Subcommittee, *Assessment of the NASA Planetary Science Division's Mission-Enabling Activities*, NASA Advisory Council Science Committee, August 29, 2011.

science plan.[4] This document identified five fundamental science questions that guided NASA's solar system exploration. These questions were used by PSD to structure a new set of R&A core research program elements, which are described in the section "Planetary Science Division R&A Program Elements" in Chapter 1. While NASA's *2014 Science Plan*[5] reworded these science questions as planetary science goals (Box 1.2), they remain fundamentally the same. The mapping of the science questions to the new program elements is illustrated in Figure 3.1. Thus, the reorganization followed the first recommendation of the 1998 NRC report[6] on NASA's research and data analysis activities: "Link NASA research [proposal solicitations] to addressing key scientific questions that can be related to the goals of the strategic plans" (p. 3).

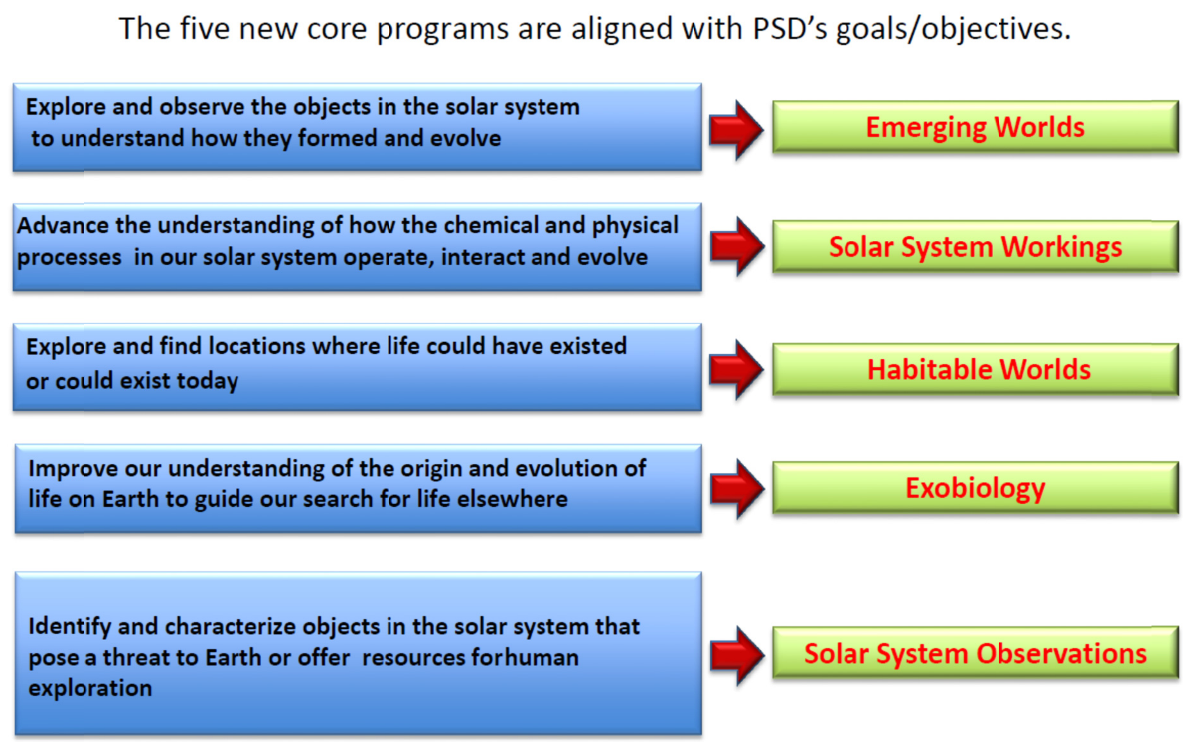

FIGURE 3.1 Alignment of the Planetary Science Division's science goals from NASA's *2014 Science Plan* (*left*) to the new core research program elements (*right*).

MAPPING OF PRIOR PROGRAM ELEMENTS TO NEW CORE RESEARCH PROGRAM ELEMENTS

The R&A program elements prior to the 2014 ROSES solicitation included subdisciplinary elements (e.g., Cosmochemistry,[7] Planetary Geology, and Geophysics), target-oriented elements (e.g., Lunar Advanced Science and Exploration Research, Outer Planets Research, and Mars Fundamental

[4] NASA, *2010 Science Plan for NASA's Science Mission Directorate*, NASA Headquarters, NP-2010-08-669-HQ, Washington, D.C., July 2010.
[5] NASA, *2014 Science Plan*, Washington, D.C., 2014.
[6] NRC, *Supporting Research and Data Analysis in NASA's Science Programs*, 1998.
[7] Cosmochemistry is the study of the chemical composition of matter in the universe and the processes that led to these compositions.

Research) and elements that have components of both. As illustrated in Figure 3.2, these older program elements do not map simply into the new core research program elements, which are more thematic in character. Proposals appropriate to the new core elements may have been previously submitted to a variety of the older elements. In addition, not all proposals traditionally submitted to one of the older program elements are appropriate to the same new program element. Thus, for example, most Cosmochemistry proposals would now be submitted to either Emerging Worlds or Solar System Workings, depending on the research focus. It was this many-to-many mapping of the previous-to-new program elements (Figure 3.2) that created challenges for PSD in maintaining programmatic balance through the transition and in demonstrating to the planetary science community that no research activities that are critical to NASA's science mission had been inadvertently disenfranchised.

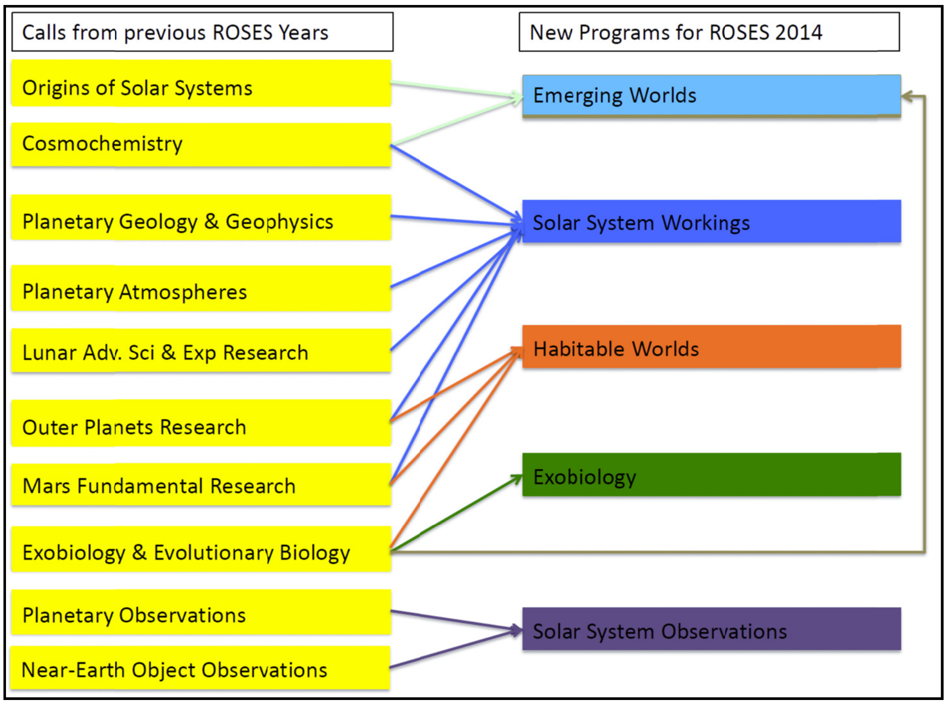

FIGURE 3.2 Mapping of the older (i.e., prior to ROSES 2014) R&A program elements (*left*) to the new core research program elements (*right*). SOURCE: Jonathan Rall, PSD R&A Lead at NASA Headquarters, presentation to the committee, May 12, 2016.

MAPPING OF PRIOR RESEARCH ACTIVITIES TO NEW STRATEGIC AND FOCUSED PROGRAM ELEMENTS

While the reorganization mostly focused on mapping the old research programs into new core research program elements that are aligned with NASA's science goals, some restructuring of the strategic and focused program elements also occurred (Figure 3.3), so that all proposals submitted under ROSES would have an appropriate home in the new structure. In particular, the formation of an Exoplanets program element, jointly with the SMD Astrophysics Division, provides a home for studies relevant to both solar system science and exoplanetary research. Planetary Science and Technology Through Analog Research (PSTAR) and Planetary Data Archiving, Restoration, and Tools (PDART) (see the section "Planetary Science Division R&A Program Elements" in Chapter 1) provide funding for some research activities that are integral to understanding our ability to conduct the scientific exploration of other planets by both robotic and human explorers (PSTAR), or to generate higher-order data products, archive and restore data sets, create or consolidate databases, or digitize data and make improved software tools available to researchers (PDART). The committee notes that such research activities did not always fare well in the traditional funding program elements.

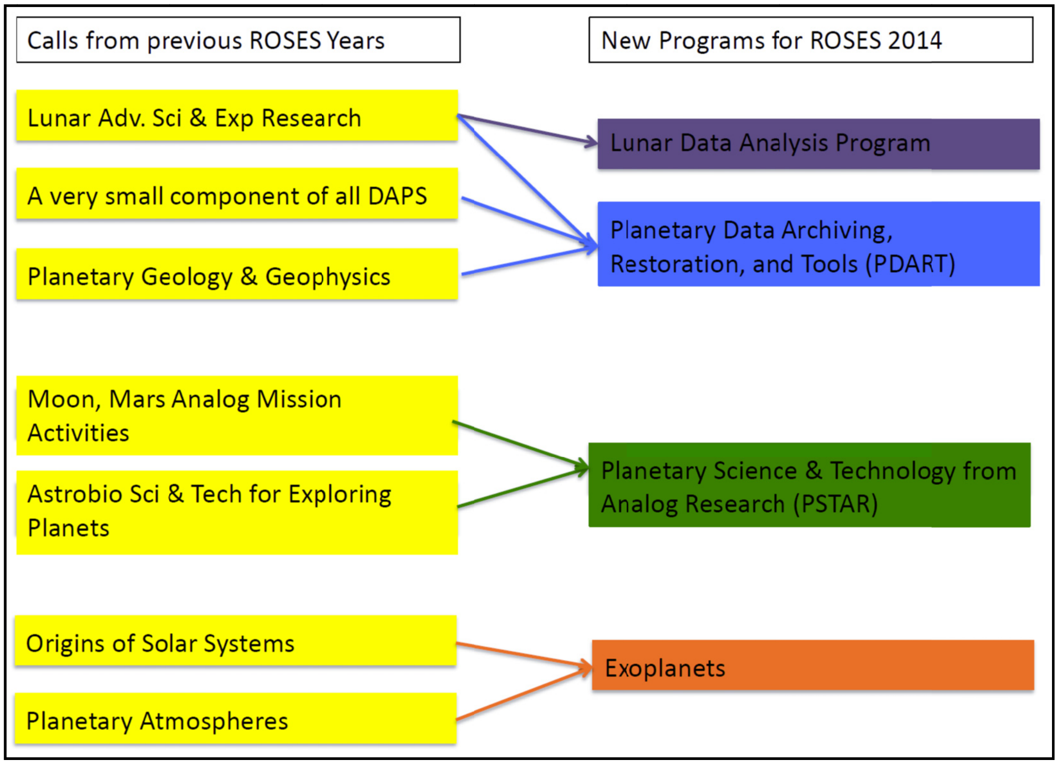

FIGURE 3.3 Mapping of components of some of the older (i.e., prior to ROSES 2014) program elements (*left*) to the other new, strategic and focused program elements (*right*). SOURCE: Graphic from presentation by NASA PSD R&A Lead to the committee, May 12, 2016.

ALIGNMENT BETWEEN PSD R&A PROGRAM ELEMENTS AND NASA'S STRATEGIC OBJECTIVE FOR PLANETARY SCIENCE AND PSD'S SCIENCE GOALS

Based on their assessment of the breadth and scope of the current R&A program elements, the committee finds that these program elements are appropriately linked to and encompass the range and scope of activities needed to support NASA's strategic objective for planetary science and PSD's science goals. Presentations to the committee from the chairs of the analysis/assessment groups and the NASA center leads for planetary science largely concurred with this finding.

> ***Finding:*** The new R&A structure is properly aligned with scientific priorities of the decadal survey and Planetary Science Division's 2014 science goals and is consistent with the recommendations of the 2009 National Research Council report *An Enabling Foundation for NASA's Earth and Space Science Missions*.

The transition from the old to the new R&A structure has been phased in over the last 3 years (fiscal year (FY) 2015 to FY2017), covering several ROSES proposal cycles to accommodate the budget process and varying grant expiration dates. The process understandably provided some initial confusion among proposers and disruptions in the funding process. Investigators had to determine to which of the new program elements they should submit proposals, and on what deadlines, and how many proposals were needed. Bridging or sustaining funding was needed in some cases to adjust to new schedules. PSD had to decide how to deal with continuing grants and how to optimize the review process for the new thematic program elements. The ensuing confusion produced considerable concern for some investigators. Nonetheless, the committee concludes that NASA has successfully addressed these issues and that the program is now operating well under the new structure.

> ***Finding:*** There were some start-up issues with program implementation during and following the reorganization. For example, there was uncertainty about the boundaries of the core program elements and about the possibility of funding gaps due to shifting timelines for proposal submission. NASA appears to have resolved these transient problems.

KEYWORD ANALYSIS

Even as the appropriated budget for NASA's PSD has fluctuated significantly in recent years, including a decrease of some 22 percent from FY2012 to FY2013, PSD has protected the funding for R&A awards from such fluctuations. However, because the number of proposals has increased significantly while R&A budgets have received only modest increases, proposal success rates have fallen. Continuous adjustment has been needed to maintain appropriate balance within and between program elements to ensure the health of the PSD program of activities, including spaceflight mission lines, R&A and technology development. Data analysis tools to measure programmatic balance—for example, analyses of keywords identified for proposals—have thus become increasingly necessary for effective program management.

As the reorganization of the planetary science R&A programs involved many-to-many mapping of old-to-new program elements, it was difficult for the committee to assess whether appropriate support for subdisciplinary activities critical for PSD's science goals was maintained through the reorganization. Certainly, some changes would be anticipated given the stronger focus on linkages to and alignment with NASA's strategic goals. In order for the committee to assess balance within and across program elements and alignment of the current program with NASA's strategic goals, appropriate data was needed on funding distributions by scientific discipline, target body, and type of task.

Over the last several years, PSD has implemented the use of keyword characterization of individual projects as a tool to better assess the program and provide more transparency about where the money is flowing in terms of subject areas. Upon request of the committee, PSD expanded analysis of the keyword data and provided several presentations to the committee on the results of this analysis. NASA's initial dependence on proposers to assign keywords proved less than ideal (early attempts at using keywords provided by proposers had a disappointingly small response), so that PSD elected to use program officers to assign keywords for all proposals under their purview. While there remain challenges when changes in PSD staffing result in differing perspectives on meanings of individual keywords, the organization of caucuses of program officers within PSD to provide input on proposal selection has helped to make the keyword use more uniform and more completely utilized.

NASA assigns keywords in four fields, the first three of which are relevant to the committee's analysis—*type of task*, *target body*, and *scientific discipline*. Program officers can fill in up to five keywords in each of these fields. When the PSD program officer assigns more than one keyword to a particular field for a proposal, the total awarded funding is divided evenly among the assigned keywords. This approach can lead to some distortions and limits the use of the keywords to broad conclusions. Similarly, changes in the personnel assigning the keywords can lead to shifts in the results, also limiting one to rather broad conclusions. Nevertheless, the committee considers that the analysis presented by NASA PSD[8] is now sufficiently robust to draw broad conclusions about impacts of the reorganization.

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[8] Presentation to the committee on September 22, 2016, by Meagan Thompson, NASA Headquarters, based on input prepared by Thompson and Jonathan Rall, PSD R&A Lead at NASA Headquarters.

Figure 3.4 shows the distribution of funding awarded by target body/bodies for each fiscal year from 2011 through 2015 (data were not final for FY2016 at the time of report preparation). It is important to remember that data awarded for a given fiscal year are based on proposals to the previous year's ROSES announcement. Because the reorganization of R&A core research program elements first appeared in ROSES 2014, proposals selected for funding under this NRA were first supported using FY2015 funds. Similarly it is important to recall that a typical grant has a duration of 3 years so that the funding awarded in any given year is a mix of new awards with second- and third-year renewals. Thus, the FY2014 funding data is totally under the old program elements. Because the FY2015 data contains renewals from previous years and funding for program elements that remained through the reorganization, only roughly one-third of the funding went to proposals submitted under the new program elements. It is also important to recognize that external factors, such as congressional designation of specific tasks—for example, the near Earth object and the Europa programs—influence annual distribution of funding. Finally, the declining phases of data analysis program elements that are narrowly targeted to a specific mission can also introduce year-to-year fluctuations in funding allocations.

Absent final data for FY2016, the keyword data have not been collected over a long enough period since reorganization for the committee to make firm conclusions. However, some broad conclusions are possible. In particular, there is no clear indication in the keyword data shown in Figure 3.4 that research support for certain classes of target body has been significantly reduced due the reorganization of the PSD R&A program.

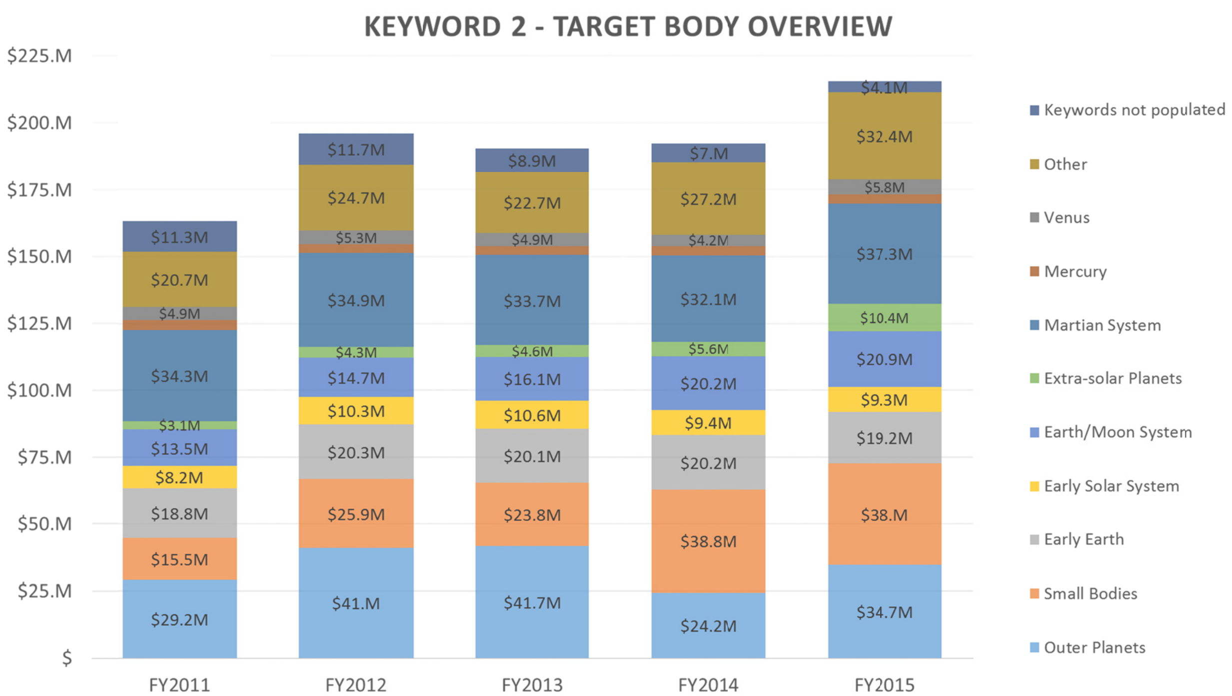

FIGURE 3.4 Distribution of awarded funding by target for fiscal year (FY) 2011 through FY2015. FY2015 contains roughly one-third of the proposals awarded under the reorganized program (ROSES 2014) and two-thirds renewals of programs started under the previous organization.

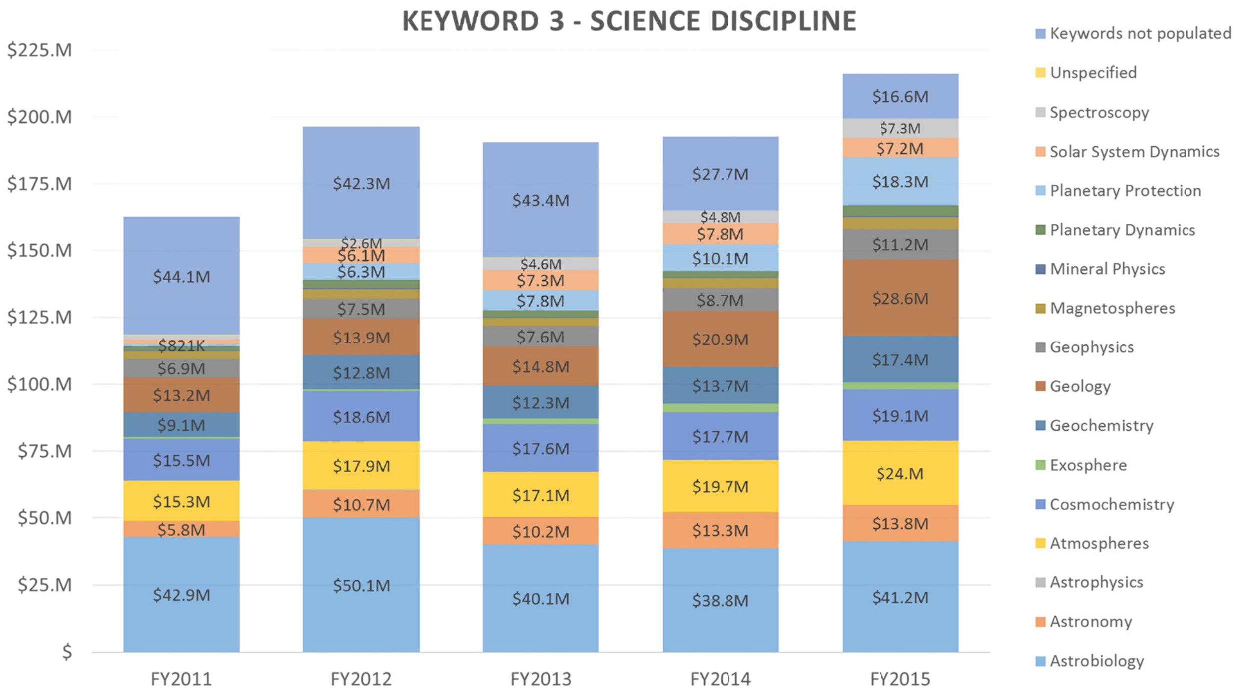

FIGURE 3.5 The distribution of awarded funding by scientific discipline in fiscal year (FY) 2011 through FY2015. FY2015 contains roughly one-third of the proposals awarded under the reorganized program (ROSES 2014) and two-thirds of renewals of the programs started under the previous organization.

Similarly, Figure 3.5 shows the distribution of awarded funding by scientific discipline. As with the distribution by target, there are year-to-year fluctuations, and the impact of the reorganization is yet to be fully demonstrated. However, there is no indication that funding for any particular science discipline has been dramatically reduced. In particular, the committee heard during presentations by several chairs of the analysis/assessment groups and NASA center planetary leads that the cosmochemistry community had seen severe cuts in funding through the reorganization. The committee is thus surprised to see funding associated with both the cosmochemistry and geochemistry keywords increase from FY2014 to FY2015. In fact, the most dramatic change in Figure 3.5 is the significant decrease in unpopulated keywords as program officers make better use of the keywords to monitor their programs.

> ***Finding:*** The committee finds that keyword analyses of the type of task, target body, and science discipline revealed no evidence that restructuring is leading to deleterious effects on the planetary science R&A program or on specific segments of the community.

The keyword analyses presented above can also be extremely useful as a management tool in assessing allocations relative to PSD's science goals, but perhaps more importantly, they can be a very effective way of communicating NASA's allocation of funds to the community. In the past, various presentations to different communities have seemed to be contradictory because the presentations were made as the reorganization was progressing and data were not complete. As the number of unpopulated keywords is further reduced and the uniformity of assigning keywords by program officers is improved, the principal evolution over the next 2 years will be due to the move from a year in which only one-third of the budget is for proposals under the new organization (FY2015) to a year in which the budget is entirely for proposals under the new organization (FY2017). If these charts are used in the future to communicate with the community about NASA's R&A program, it is crucially important that they be consistently explained and that the limitations to their interpretability be spelled out. As the committee has noted in this report, it is easy to be led astray by a variety of artifacts in the data.

> ***Finding:*** In addition to providing a strategic management tool, keyword analyses can be used to promote increased transparency between NASA and the planetary science community with respect to trends in proposal selection decisions and program content.

HIGH-RISK/HIGH-PAYOFF RESEARCH ACTIVITIES AND ADVANCED TECHNOLOGY

Prior to the 2014 reorganization, the PSD R&A program already included specific technology development activities (e.g., PICASSO and MatISSE) focused on future instrument technology needs. However, the program did not explicitly encourage or make room for including high-risk/high-payoff advanced technology projects beyond PSTAR-supported field tests of advanced instrumentation. The current program structure remains unchanged in this regard. The same point can be made about other research initiatives beyond technology development. High-risk/high-payoff research proposals submitted to core research program elements face challenges in review that are exacerbated in times of tight budgets and low selection rates.

Many past studies have emphasized the importance of such activities. For example, the 2009 NRC report[9] on mission-enabling research commented that

> While most of the SMD mission-enabling research budget should be clearly directed at supporting specific goals of the various science divisions, NASA can benefit from separately funded and protected mission-enabling activities that pursue high-risk/high-payoff advanced technologies or other research activities that could produce game-changing results. (p. 40)

The report explained that

> Where mission development times can run as long as 7 to 10 years, such an approach is especially important because the phasing-in of new technologies can be 5 to 10 times longer than time to market in the commercial and university research sectors. Thus, one can envision progressively falling behind the state of the art in many technical areas unless technology is purposefully captured and utilized through an active mission- enabling research program. (p. 40)

The 2009 NRC report drew on observations from the highly regarded 2007 report *Rising Above the Gathering Storm: Energizing and Employing America for a Brighter Economic Future*[10] to explain why high-risk/high-payoff research often struggles to gain management support.

> It is not necessarily a matter of providing additional resources for high-risk research, but rather providing incentives for program managers to fund high-risk research out of a discretionary portion of the existing budget. Lack of incentives for (or barriers to) performing high-risk research include (1) a peer review system that tends to favor established investigators using well-known methods; (2) pressure from customers and management for short-term results; and (3) risk averseness, since high-risk projects are prone to failing and increased government and public scrutiny make "projects that fail" increasingly untenable. (p. 41)

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[9] NRC, *An Enabling Foundation for NASA's Earth and Space Science Missions*, The National Academies Press, Washington, D.C., 2009.

[10] National Academy of Sciences, National Academy of Engineering, National Research Council, *Rising Above the Gathering Storm: Energizing and Employing America for a Brighter Economic Future*, The National Academies Press, Washington, D.C., 2007.

> ***Finding:*** The PSD R&A program elements have not been optimized to support high-risk/high-payoff fundamental research and advanced technology-development activities.
>
> ***Recommendation:*** NASA needs to investigate appropriate mechanisms to ensure that high-risk/high-payoff fundamental research and advanced technology-development activities receive appropriate consideration during the review process.

FUNDING DISTRIBUTION AMONG PROGRAM ELEMENTS

Data presented to the committee by NASA PSD staff shows that the proposal success rates for the five core research program elements are all ~20 percent, consistent with funding allocations between program elements largely driven by proposal pressure, rather than an assessment of strategic importance to NASA PSD science goals. As noted in Box 2.2, PSD does have mechanisms in place to identify proposals that may not have reviewed highly but warrant consideration for funding based on strategic and other criteria. However, these mechanisms operate within a program element and have little impact on the distribution of funds between program elements.

> ***Finding:*** Funding difference between program elements does not appear to be determined to any significant extent by strategic priorities. Rather, the funding distribution among program elements appears to be defined predominantly by proposal pressure.

The committee notes in Chapter 2 that prior advisory studies of R&A programs have recommended that the programs should not only be *structured* to match strategic goals but that they should also be *managed* strategically. PSD's recently developed keyword system (see the section "Keyword Analysis" earlier in this chapter) for characterizing research activities can serve as a useful strategic management tool. Analysis of keywords is now possible at sufficient depth and breadth to provide the basis for assessing relationships between such factors as program element size and funding levels, proposal demand and success rates, and investigator demographics—all in terms of how well they can support NASA PSD science goals.

The 2011 Planetary Science Subcommittee (PSS) report on supporting research and technology explicitly recommended that PSD should regularly conduct such an across-the-board review of such factors.

> The PSD should consider implementing division-wide coordination and evaluation of the mission-enabling activities by NASA and the community by holding a "senior review" at least every 10 years, which could be linked to the NRC Surveys. The review should include articulation by the PSD of the current priorities, budget allocations for all mission-enabling activities (including supporting activities), and how the various activities have met their specific program objectives in the past. Such a review should become part of the PSD "portfolio management" process to ensure that resources are apportioned appropriately.[11]

This committee endorses the 2011 PSS recommendation but is not convinced that a "senior review" every 10 years is sufficiently frequent given the rate of discovery in the field.

> ***Finding:*** No formal mechanism exists to periodically review funding distribution among program elements based on strategic goals.

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[11] Planetary Sciences Subcommittee, *Assessment of the NASA Planetary Science Division's Mission-Enabling Activities*, 2011, p. 24.

Recommendation: A formal assessment by NASA of how well the program structure and funding are aligned with the Planetary Science Division's science goals should be conducted at least every 5 years, appropriately phased to the cycle of the planetary science decadal surveys and midterm reviews.

4
Linkage Between Planetary R&A and NASA PSD Missions

The committee was charged with addressing two questions related to PSD's current R&A program elements. The second of the two questions posed to the committee asks,

> *Are the PSD R&A program elements appropriately structured to develop the broad base of knowledge and broad range of activities needed both to enable new spaceflight missions and to interpret and maximize the scientific return from existing missions?*

The committee elected to address separately the role of PSD R&A program elements in (1) interpreting and maximizing the scientific return from existing missions (see the section "Interpret and Maximize the Scientific Return from Existing Missions" later in this chapter) and (2) the enabling of new spaceflight missions (see the section "Enable New Spaceflight Missions" later in this chapter). Moreover, the committee interprets "existing missions" to include not only planetary missions that are currently operating, but also recent missions where primary data analysis is still being performed.

For their presentations to the committee, the chairs of the analysis/assessment groups and the NASA center leads for planetary science were asked, in particular, to provide their perspectives and those of their communities on how effectively the current program elements enable research based on current and past missions, as well as pave the way for future missions (Appendix C). In its discussion of this question, the committee assessment is that the present program elements perform well in enabling new missions and supporting existing missions, although there was a feeling that improvements could be made, particularly in preparation for future missions. Notable among these improvements, as delineated later in this chapter, are adequate support for development of instruments and facilities, and maintenance of scientific/technical expertise and analytical instrument capability for sample-return missions.[1] Based on their deliberations, the committee concludes that the answer to the second question was a qualified "yes."

> ***Finding:*** In general, the structure of the program elements will allow NASA PSD to prepare for future spaceflight missions and to maximize science value from existing missions. While there is room for improvement, no recommended mission concept identified in the planetary science decadal survey remains out of reach.

INTERPRET AND MAXIMIZE THE SCIENTIFIC RETURN FROM EXISTING MISSIONS

The availability of sufficient resources to support the analytical effort required to extract knowledge from raw mission data is a key component of planetary science research that extends beyond the activities of the mission science team. In addition, maximizing scientific return from existing missions entails more than just data analysis and involves a range of other activities within Planetary R&A, such as modeling and theoretical studies, cartographic work, laboratory-based analysis and experimentation, ground-based telescopic observations, and field-based (analog) studies.

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[1] The committee notes that while the present study was in progress, NASA's Planetary Science Division commissioned the National Academies of Sciences, Engineering, and Medicine to undertake a review of the current status of sample-science facilities and the likely future needs of the U.S. sample-science community.

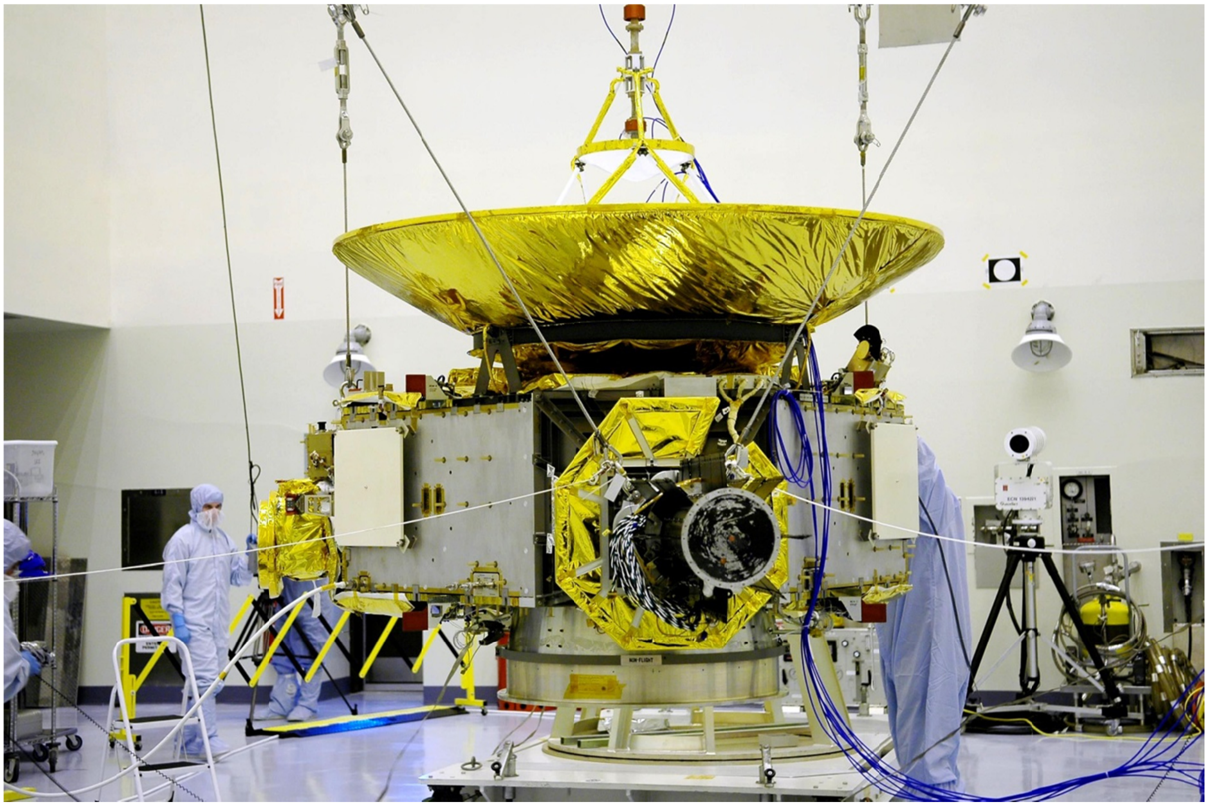

FIGURE 4.1 The New Horizons spacecraft under preparation for its historic mission to Pluto and the Kuiper belt. Planning for optimal mission success includes understanding the critical science issues and building a spacecraft with the appropriate instruments, especially for targets like Pluto that may not get visited again for decades. Non-mission scientists can apply to the New Frontiers Data Analysis Program for funding to work with the wealth of data returned by New Horizons during its July 2015 flyby of Pluto and its five satellites. SOURCE: Courtesy of NASA.

Adequacy of Support for Data Analysis

As described in the section “Planetary Science Division R&A Program Elements” in Chapter 1, the R&A program elements include both core research programs and a collection of technology, instrumentation, data analysis, laboratory and field-based efforts. The committee’s approach was to examine the current structure of the R&A program (see Figure 3.2) and determine whether there were data analysis programs (DAPs) that serve all existing missions.

As background, it should be noted that NASA policy requires that for each flight mission and investigation, some funding is allocated for the mission’s principal investigator (PI) and co-investigators to calibrate, validate, and publish the initial data set from the project. The funding for these efforts is not generally contained in the R&A program, but rather within the mission budget and contracts negotiated with the mission’s scientific team. To further maximize the scientific return from the set of ongoing missions, NASA long ago created so-called DAPs. The intent of these DAPs is to allow a broader group of science community researchers to collaborate with mission PIs and coinvestigators using the mission data set to explore and interpret the planetary data produced. The committee finds that, whether the mission is from the Discovery Program,[2] New Frontiers Program[3] (e.g., the New Horizons mission to the Pluto system, Figure 4.1), a strategic mission[4] (e.g., the Cassini Saturn orbiter, see Figure 1.5) or a mission of opportunity,[5] there is a corresponding data analysis program in ROSES that would allow a scientist to propose to conduct research using a current data stream. The ROSES NRA also provides guidance for where to propose when a proposal addresses data from multiple missions or does not seem to have an obvious home in the current set of DAPs. Thus, the committee concludes that the current R&A program does, in fact provide proposal opportunities that the community can utilize to maximize the data return from existing missions.

> ***Finding:*** The current R&A program elements are appropriately structured to interpret and maximize the scientific return from existing space missions. In particular, there is sufficient scope and level of support in the current data analysis program elements to enable maximum return on the raw data from the present suite of missions.

Adequacy of Support for Broader Range of Activities to Maximize Science Return from Existing Missions

The charge to the committee involves an evaluation as to whether the current R&A program is "appropriately structured to develop the … broad range of activities needed… to interpret and maximize the scientific return from existing missions." The committee's analysis paid particular attention to whether the scope of the current R&A program was sufficiently broad to encompass research derived from all mission data, past or present, and whether the scope of the current program elements allows that essentially any scientifically credible planetary research idea can be funded. In order to answer this question, the committee used the keyword analysis (see the section "Keyword Analysis" in Chapter 3) to assess whether the traditional range of planetary objects and disciplines was still addressed subsequent to the R&A reorganization. The committee did not concern itself with the absolute level of the funding, since that can vary with time and be a function of a given strategic imperative. As seen in Figures 3.4 and 3.5, which are derived from NASA PSD's keyword analysis, all historically relevant target bodies and disciplines have continued to be supported both before and after the reorganization of the R&A program, with no indication of significant changes in funding levels above the statistical variance in the data.

> ***Finding:*** The range of current R&A program elements is broad enough to address the full scope of credible research activities resulting from current and past missions.

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[2] Discovery missions are competed principal investigator (PI)-led missions that are not specifically identified by the planetary science decadal survey. For the most recent competition, total mission cost was capped at a Phase A-D cost of $450 million (fiscal year [FY] 2015), excluding standard launch services.

[3] New Frontiers missions are competed PI-led missions selected from a set of candidate missions identified by the planetary science decadal survey. For the most recent competition, total mission cost is capped at $850 million (FY 2015) for Phases A through D, not including the cost of the Expendable Launch Vehicle (ELV) or any contributions.

[4] PSD strategic missions, often referred to as flagship missions, are capability-driven missions that are directed to a NASA center and have total mission costs that exceed $1 billion.

[5] Missions of opportunity allow the U.S. scientific community the chance to participate in non-NASA missions by providing funding for a science instrument or hardware components of an instrument. They also offer the possibility to use an existing NASA spacecraft for a new science investigation.

ENABLE NEW SPACEFLIGHT MISSIONS

Adequacy of Support for Research that Enables Future Missions

As detailed in Chapter 2, the committee received presentations from NASA PSD staff on procedures involved in the PSD evaluation of R&A proposals since the reorganization. The committee also received commentary from the chairs of the analysis/assessment groups and from the NASA center planetary science leads on the types of proposals submitted and funded through the current programs and their communities' perceptions of the current procedures. These proposals included a number that address the science issues that support future missions, including fundamental research to enable those missions. Such research activity includes the following: explaining current observations, testing hypotheses, refining the questions and explanations, and proposing tests to be addressed by future missions. The results of this research and analysis provide the basis for the most important goals and objectives for future missions and determine the desired measurements and the instruments to address them.

Overall, the committee heard no specific stakeholder concerns about insufficient scope in the current R&A program to fund appropriate mission-enabling research activities. Certainly, the committee assesses, there is no shortage of proposals for compelling science missions, firmly rooted in sound scientific research, for any of the planetary science mission announcements of opportunity (AOs). Nonetheless, NASA does not have the metrics to quantify the R&A impact on the development of future mission concepts, so it is difficult to assess whether highly innovative mission concepts fail to reach proposal stage for lack of precursory scientific research.

> ***Finding:*** The scope of the current planetary R&A program appears to be sufficient to adequately support scientific research activities that enable future planetary science missions. Nonetheless, it was not possible to determine whether innovative mission concepts are adequately supported.

While there is sufficient scope in the current R&A program to support a broad range of mission-enabling activities, the committee is concerned that some essential research areas do not receive the appropriate priority in merit reviews. These research areas include general surveys of targets such as near-Earth objects (NEOs), trans-neptunian objects (TNOs), and Kuiper belt objects (KBOs); laboratory investigations; focused technical studies; research requiring substantial equipment investments; and cartography.

> ***Finding:*** The committee has concerns that some activities that are critical components in addressing PSD science goals for future missions, which include long-term synoptic surveys (e.g., NEO, TNO, and KBO surveys), laboratory investigations, and planetary cartography, often receive a lower priority in science merit reviews.

Adequacy of Support for Technology Development that Enables Future Missions

Instrument technology development and instrument field-testing are part of the R&A program included in the annual ROSES solicitations. Such activities are critical for optimizing the science return from PSD missions, which often involve complex technologies (Figure 4.2). The most general and frequently utilized technology development programs[6] are MatISSE (Maturation of Instruments for Solar System Exploration) and PICASSO (Planetary Instrument Concepts for Advancement of Solar System Observations), for both high and low technology readiness levels, respectively. Program elements[7] also exist for the development of instrument technology for future New Frontiers missions (Homesteader),

[6] See also the section "Planetary Science Division R&A Program Elements" in Chapter 1.
[7] See also the section "Planetary Science Division R&A Program Elements" in Chapter 1.

future astrobiological instrumentation for Europa and other “ocean worlds[8]” missions (COLDTech—Concepts for Ocean worlds Life Detection Technology), missions to study the interiors of the gas giants and the surface of Venus and Mercury (HOTTech—Hot Operating Temperature Technology), planetary studies through emerging platforms such as CubeSats (SIMPlEx—Small, Innovative Missions for Planetary Exploration; PSDS3—Planetary Science Deep Space SmallSat Studies), and research activities in environments on Earth that are analogous (Figure 4.3) to those on other planetary bodies (PSTAR—Planetary Science and Technology Through Analog Research). Other technology development opportunities exist for laboratory instrumentation through the Planetary Major Equipment (PME) and Laboratory Analyses of Returned Samples (LARS) program elements, which support efforts in the development of laboratory instrumentation and advanced techniques required for the analysis of returned samples and direct analysis of samples already returned to Earth. The evolution, and much of the current set of instrument technology programs, are shown in Figure 4.4. PSD has invested in new targeted technology development programs, when required by a compelling scientific case, based on new discoveries or by strategic priorities.

The objectives of these programs are aligned with the technology needs for future missions to address the science priorities in the 2011 planetary science decadal survey,[9] and the breadth of programs provides a general structure that can support the development of technology and instrumentation needed to address NASA’s strategic goal for planetary science. However, the committee has concerns, based on their experiences and input from stakeholders, that the funding levels for these programs are not adequate to meet the needs of future missions. In particular, the committee is concerned about the level of funding for instrument development, sample-return technology development, research in environments on Earth that are analogous to those on other planetary bodies, and in situ resource utilization. The technical challenges of future missions, as outlined in the 2011 planetary science decadal survey, and the resources required to prepare technologies for flight and to maintain the needed scientific and technical expertise on mission timelines are considerable. The committee is concerned that while technology development is included in the R&A program it is not sufficiently prioritized by PSD.

FIGURE 4.2 Artist impression of the OSIRIS-REx spacecraft as it approaches the surface of the asteroid 101955 Bennu to collect samples, which will be returned to Earth for analysis in September 2023. A variety of technical challenges with sample collection and handling need to be addressed for future, more challenging, sample-return missions. Image courtesy of NASA.

[8] The ocean worlds are planetary bodies (other than Earth) that have liquid oceans either on the surface or in the interior. Obvious examples include Europa, Enceladus and Titan, although recent spacecraft observations suggest that Ceres and Pluto may also qualify.

[9] National Research Council, *Vision and Voyages for Planetary Science in the Decade 2013-2022*, The National Academies Press, Washington, D.C., 2011.

FIGURE 4.3 Scientists conduct field tests for the NASA funded robotic explorer VALKYRIE (Very-deep Autonomous Laser-powered Kilowatt-class Yo-yoing Robotic Ice Explorer), created by Stone Aerospace on Matanuska glacier in Alaska as an analogue for Europa. VALYYRIE was funded via a predecessor of the current Planetary Science and Technology Through Analog Research program element for field testing of mid-technology readiness level instrumentation in analogue environments on Earth.

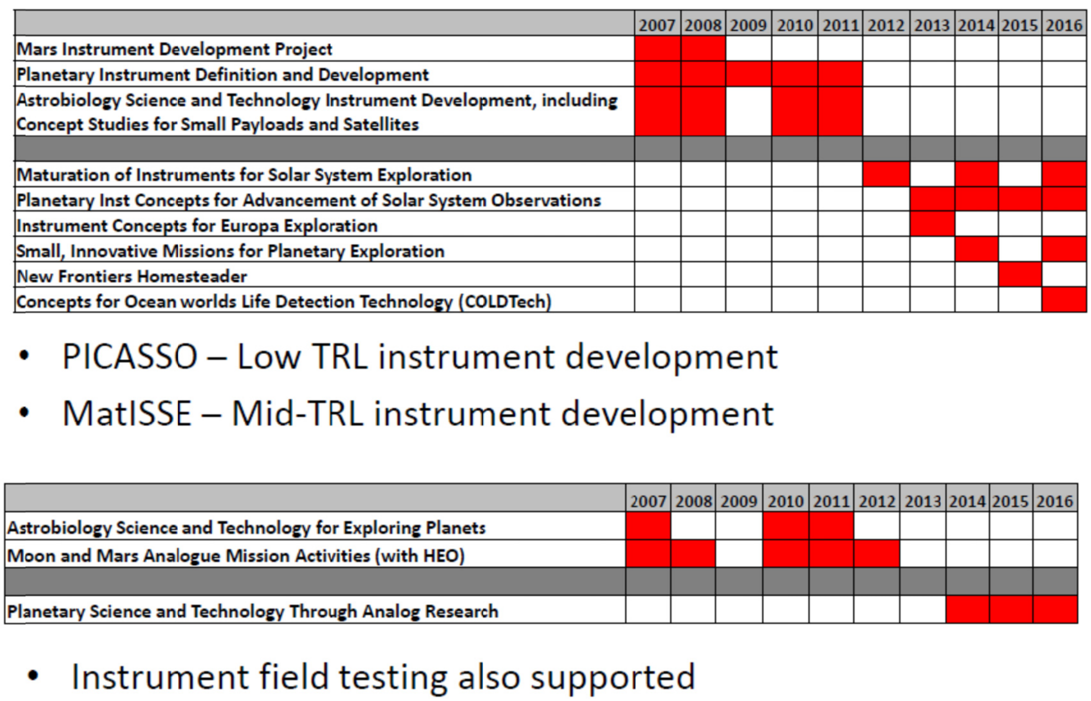

FIGURE 4.4 Evolution of the various technology programs supported by NASA's Planetary Science Division Research and Analysis program since 2007. The diversity of activities demonstrates NASA's flexible approach to technology development. The currently active programs are described briefly in the section "Planetary Science Division R&A Program Elements" in Chapter 1. NOTE: MatISSE, Maturation of Instruments for Solar System Exploration; PICASSO, Planetary Instrument Concepts for the Advancement of Solar System Observations; TRL, technology readiness level. SOURCE: James L. Green, presentation to the committee on May 12, 2016, slide 13.

> ***Finding:*** In addition to scientific research, PSD's planetary R&A supports the development of technology and instrumentation that enables future mission investigations. The variety of current technology and instrument programs is intended to address the breadth of technology development needs for the planetary sciences. However, future technically challenging missions recommended in the 2011 planetary science decadal survey justify enhanced priority for appropriate technology development.

In its deliberations about the LARS program, which supports laboratory instrumentation and advanced techniques required for the analysis of returned samples, the committee is concerned that it is not being sufficiently funded to meet the requirements of future missions that are clearly anticipated by NASA PSD in its Mars (especially Mars sample return) and New Frontiers programs (particularly in the ocean worlds area). Although the first mission in a Mars sample-return architecture is approaching its critical design review, and the New Frontiers program was recently expanded to allow for missions to Enceladus and Titan (which may or may not include some form of sample return), the LARS program text in ROSES 2016 mentions both New Frontiers and Mars sample return as missions that "are expected to have low priority for LARS funding."[10] That "low priority," especially for development of techniques required for the analysis and handling of returned samples, including cryogenic ones, could result in NASA being unable to develop required capabilities and community expertise to effectively and safely implement these compelling sample-return missions. Working with such returned samples will necessitate advanced technical and analytical capability to make the required measurements. Furthermore, it is important to retain the capacity to design and implement the investigations on samples both in space and on Earth. Given planetary protection requirements and the needs for receiving laboratories and curation facilities (with appropriate instrumentation) that protect the samples from Earth contamination while also protecting Earth from potential extraterrestrial organisms, the committee notes that the timelines for this development are already challenging.

> ***Finding:*** NASA has not demonstrated that its PSD R&A programs can enable future spacecraft missions that will return samples of biological interest from Mars or cryogenic samples from icy bodies and receive, curate, and analyze them on Earth.

> ***Recommendation:*** NASA should support the development of the technologies required to return astrobiological and cryogenic samples to Earth and the appropriate containment, curation, and characterization facilities consistent with the Planetary Science Division science goals and planetary protection requirements.

Adequacy of Support for High-Risk/High-Payoff Research that Enables Future Missions

NASA encourages high-risk/high-payoff technology development through programs such as Concepts for Ocean Worlds Life Detection Technology (COLDTech), Hot Operating Temperature Technology (HOTTech), and Small Innovative Missions for Planetary Exploration (SIMPlEx), and with the MatISSE and PICASSO programs that address TRL advancement in order to move beyond the "valley of death."[11] However, while the current R&A structure does not prevent high-risk/high-payoff

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[10] NASA Science Mission Directorate, NASA Research Announcement: Research Opportunities in Space and Earth Sciences 2016, Solicitation: NNH16ZDA001, https://nspires.nasaprs.com/external/solicitations/summary.do?method=init&solId=%7B68C12087-132D-3814-9A87-5323BCE6CAB6%7D&path=open, accessed April 12, 2017.

[11] The technology development "valley of death" is the dip in the curve of available funding versus technology maturity, where the incremental cost to advance the technology increases and funding availability drops. This

technology development proposals from being funded, in reality such proposals are at a disadvantage due to risk aversion in the review and selection process. The committee deliberated on this topic at considerable length and, based on its own experience, concurs with their conclusion. This risk aversion is similar to that discussed for high-risk/high-payoff science (see the section "High-Risk/High-Payoff Research Activities and Advanced Technology" in Chapter 3).

Finding: R&A technology investments needed for future missions, as identified in the 2011 planetary science decadal survey, require innovative approaches that may be high-risk/high-payoff and are less likely to be supported under the existing program.

Adequacy of Long-Term Support of Scientific and Technical Expertise and Instrumental Capabilities

Because of the intrinsic relationship between PSD's R&A program and the successful definition and operation of planetary missions, the program comprises more than a pure science examination of a list of questions about the universe, or the development of clever and capable technology for those missions. It is essential for PSD's R&A program to have as one of its goals the sustainment of support for special-purpose instruments and other facilities on Earth that can enhance multimission investigations and continuing post-mission science and engage the appropriate technical and scientific expertise to operate them. These capabilities are essential, but often their preservation is not formally acknowledged in the development of R&A programs elements, research announcements, or mission AOs.

The committee acknowledges that this is not an easy problem to solve. Various approaches have been attempted over the years that balance the maintenance of current capabilities against the development of new approaches and methods and the ebb and flow of mission opportunities. Each approach known to the committee has had its shortcomings—largely because different timelines are associated with R&A grants and new mission development and flight (particularly to the outer solar system). The challenges of planning for an emerging emphasis on sample-return missions—especially sample-return missions from bodies like Mars, Europa, and Enceladus that may support their own life forms—add further complications to achieving balance between near- and long-term needs. Such sample-return missions will have even longer timelines, and more comprehensive post-mission demands, than have been seen by NASA since the return of lunar samples in the late 1960s and early 1970s. Nonetheless, NASA has a need (and in the case of sample-return missions, a critical responsibility) to rise to those challenges.

Finding: The reliance of PIs on R&A awards (normally offered every 3 years) alone to sustain the critical scientific and technical expertise and infrastructure needed for current and future planned missions can be a challenge. This issue is a particular concern for sample-return missions where laboratory analytical techniques and expertise may need to be sustained so that they remain available when samples are finally returned.

Recommendation: In making funding decisions for the various R&A program elements, NASA should consider the need to sustain critical scientific and technical expertise and instrumental and facility capabilities required for scientific return on future missions, as discussed in the 2011 planetary science decadal survey.

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frequently occurs as technology evolves from prototype to pilot stages. The MatISSE program element was specifically designed to bridge this gap.

Appendixes

A
Statement of Task

The Space Studies Board will convene an ad hoc committee to examine the program elements of NASA's Planetary Science Division (PSD) Research and Analysis (R&A) programs, as they currently exist following restructuring, for their consistency with past advice from the Academies. In conducting its review, the committee will address the following questions:

1. Are the PSD R&A program elements appropriately linked to, and do they encompass the range and scope of activities needed to support the NASA strategic objective for planetary science and the Planetary Science Division science goals, as articulated in the 2014 NASA Science Plan?
2. Are the PSD R&A program elements appropriately structured to develop the broad base of knowledge and broad range of activities needed both to enable new spaceflight missions and to interpret and maximize the scientific return from existing missions?

In conducting its task, the committee will:

- Not examine the PSD R&A programs as they were prior to the restructuring;
- Conduct its review in the context of current budgetary realities that have differed from projections assumed prior to the release of the most recent planetary science decadal survey; and
- Not comment on the strategic science goals and objectives of PSD, SMD, or NASA.

B
Letter of Request

National Aeronautics and Space Administration
Headquarters
Washington, DC 20546-0001

AUG 1 3 2015

Reply to Attn of: SMD/Astrophysics Division

National Research Council
Dr. David Spergel
Chair, Space Studies Board
500 5th Street NW
Washington, DC 20001

Dear Dr. Spergel:

The 2010 SSB report, *An Enabling Foundation for NASA's Earth and Space Science Missions*, stated that the Research and Analysis (R&A) programs of the National Aeronautics and Space Administration (NASA) Science Mission Directorate (SMD) divisions, including the Planetary Science Division (PSD), comprise a key element of NASA's mission-enabling activities. The report recommended, in part: "NASA should ensure that SMD mission-enabling activities are linked to the strategic goals of the agency and of SMD and that they are structured so as to: encompass the range and scope of activities needed to support those strategic goals; provide the broad knowledge base that is the context necessary to interpreting data from spaceflight missions and defining new spaceflight missions; maximize the scientific return from all spaceflight missions; supply a continuous flow of new technical capabilities and scientific understanding from mission enabling activities into new spaceflight missions; and enable the healthy scientific and technical workforce needed to conduct NASA's space and Earth science program."

From 2011 to 2013, PSD undertook a process of community discussion and analysis leading to the restructuring of its R&A programs, in response to the above recommendation from the *Enabling Foundation* report. This process considered input from the Planetary Science Subcommittee of the NASA Advisory Council's Science Committee and input from other U.S. Government stakeholders. The restructured program was announced in late 2013, and initially implemented in the Research Opportunities in Space and Earth Sciences (ROSES) 2014 solicitation. Implementation has continued in the currently open ROSES 2015 solicitation.

It would be very helpful if the NRC were to convene an ad-hoc committee to examine the program elements of the PSD R&A programs, as they currently exist following restructuring, for their consistency with past NRC advice. In conducting its review the committee would address the following questions:

1. Are the PSD R&A program elements appropriately linked to, and do they encompass the range and scope of activities needed to support, the NASA Strategic Objective for Planetary Science and the Planetary Science Division Science Goals, as articulated in the 2014 *NASA Science Plan*?

2. Are the PSD R&A program elements appropriately structured to develop the broad base of knowledge and broad range of activities needed both to enable new spaceflight missions and to interpret and maximize the scientific return from existing missions?

The review should not examine the PSD programs as they were prior to the restructuring nor examine the strategic science goals and objectives of PSD, SMD, or NASA. The review should operate from the premise that the science goals of PSD are themselves intrinsically linked with the strategic goals of SMD and NASA; hence linkage with PSD goals implies linkage with SMD and NASA goals. Also the NRC should conduct its review in the context of the current budgetary realities which have differed from projections assumed prior to the release of the most recent planetary science decadal survey.

PSD would be able to provide, at your request, informational briefings and reference materials on the SMD and PSD strategic goals, the R&A program elements, and statistical data on proposals submitted and selected. We request that a report from the Board expressing its findings and suggestions be submitted in December 2016.

I would like to request that the NRC submit a plan for execution of the proposed review by the Space Studies Board. Once agreement on the scope, cost, and schedule of the proposed study has been achieved, the Contracting Officer will issue a task order for implementation.

We look forward to having the Board's inputs to this vital activity. SMD's point of contact for this study will be Dr. Thomas Statler, who can be reached at (202) 358-0272 or by email at Thomas.S.Statler@nasa.gov, if any questions arise.

Sincerely,

John M. Grunsfeld
Associate Administrator for
Science Mission Directorate

C
Center Leads and Analysis Group Commonalities

As part of its data-gathering process, the committee solicited perspectives from representatives of the various planetary science analysis/assessment groups and the NASA center leads for planetary science. The analysis/assessment groups (AGs) comprise members of the planetary-science community whose research is broadly aligned with specific solar system bodies and/or research themes. The AGs meet several times each year and provide input to the NASA Advisory Council through the Planetary Science Subcommittee. The center leads were asked for input because the NASA centers host research and mission activities that are quite distinct from those generally found in the academic research community. Moreover, civil servant scientists at NASA centers frequently work under different constraints than their counterparts in academia. Representatives of the AGs and several NASA centers gave presentations to the committee on the concerns expressed by their colleagues concerning the R&A reorganization and current structure. The committee heard community perspectives from representatives of the following organizations:

- *Analysis/Assessment Groups:*
  — CAPTEM: Curation and Analysis Planning Team for Extraterrestrial Materials
  — LEAG: Lunar Exploration Analysis Group
  — MAPSIT: Mapping and Planetary Spatial Infrastructure Team
  — MEPAG: Mars Exploration Program Analysis Group
  — OPAG: Outer Planets Assessment Group
  — SBAG: Small Bodies Assessment Group
  — VEXAG: Venus Exploration Analysis Group

- *NASA Center Leads for Planetary Science:*
  — ARC: Ames Research Center, California
  — GSFC: Goddard Space Flight Center, Maryland
  — JPL: Jet Propulsion Laboratory, California
  — JSC: Johnson Space Center, Texas
  — MSFC: Marshall Space Flight Center, Alabama

The representatives of the AGs and NASA science centers were provided with the charge to the committee and asked to provide their communities' perspectives on the questions in the charge. The committee also encouraged the representatives to provide input on other aspects of the current program and the R&A reorganization that they felt were pertinent to the charge of the committee. The committee notes than some of the issues raised by representatives of the AGs and the NASA centers (and reported below) in response to the committee's request could be described as anecdotal. Other responses relate to long-standing issues having been brought to the fore by, but unrelated to, the reorganization of the R&A program. As such, a detailed examination of them is far beyond the limited scope of the current study. The committee appreciates all these community perspectives as inputs in their deliberations, but notes that all findings and recommendations resulted directly from committee discussions.

Based on the presentations made by the representatives of the AGs and the NASA science centers and their subsequent discussions with the committee, their responses were formatted as seven tables

(Tables C-1 to C-7). The perspectives from the representatives of the AGs and the science centers are to be found in the left and right columns, respectively.

TABLE C.1 Are PSD R&A Program Elements Linked to NASA PSD Goals and Objectives?

Analysis Group		NASA Center	
CAPTEM	Yes in principle, no in practice	ARC	Better aligned with NASA science goals and the decadal survey
LEAG	Mostly yes	GSFC	Better aligned with NASA goals enabling better program balance and resource direction
MAPSIT	No specific comment	JPL	No specific comment
MEPAG	Appear to be linked but it is all very broad. Not appropriately divided among program elements	JSC	Maps well to the stated science goals and resources allocated accordingly. Great for search for life and habitability
OPAG	Yes, however a one-to-one matching doesn't work. Most grants contribute to multiple top-level themes	MSFC	Better mapped to decadal survey
SBAG	Many of the "new" programs are based on very broad questions, while "old" programs were often technique-based		
VEXAG	Yes, but current elements are broad		

TABLE C.2 Community Perspectives on the Current R&A Program Structure

Analysis Group		NASA Center	
CAPTEM	Structured well in principle, but not in practice. Low selection numbers are a red flag	ARC	Uncertainties about program boundaries, leads researchers to submit similar proposals to multiple programs (SSW, HW, and EW)
LEAG	The five major programs need to be separated into subprograms. MatISSE and PICASSO programs are welcomed	GSFC	Anticipate positive effects associated with interdisciplinary programs, specifically HW and XRP
MAPSIT	PDART is a strong addition but oversubscribed and underfunded. PG&G is a big loss	JPL	SSW too large, cumbersome, ill-understood catch-all
MEPAG	Reasonable job of making sure there was a home for every relevant proposal	JSC	Reevaluate scope of SSW. Fewer programs, fewer opportunities to propose, timing is more critical, greater likelihood for a gap year
OPAG	Structured well in terms of ocean worlds technology development, not for fundamental research (declined 32.5 percent)	MSFC	SSW is too big, greater likelihood for gap year in funding in some programs
SBAG	No specific comment		
VEXAG	The current R&A structure is process-based. R&A program overall lacks specific structure to develop target-oriented knowledge base		

TABLE C.3 Perspectives on the Effectiveness of Review Panels in the Current R&A Structure

Analysis Group		NASA Center	
CAPTEM	Systematic cross-calibration may be difficult between subpanels in broad programs like EW or SSW	ARC	Ensure that interdisciplinary proposals are reviewed by interdisciplinary scientists, not by multiple specialists
LEAG	Some programs (e.g., SSW) encompass such a broad range of topics that it becomes impossible to find qualified, non-conflicted reviewers to adequately assess proposals	GSFC	No specific comment
MAPSIT	No specific comment	JPL	Reviewers with adequate breadth of knowledge required to evaluate SSW proposals are rare and conflict of interest policies restrict pool of reviewers
MEPAG	The current structure creates large elements creating a challenging environment to identify qualified, un-conflicted, review panels	JSC	SSW is too large of a catch-all, makes it challenging to assemble a properly qualified panel for proposal review
OPAG	Going to be even more difficult to find un-conflicted people for the review panel	MSFC	Reviewer pool is more limited since the scope of program element is increased, greater potential for conflict of interest
SBAG	Large programs may create issues finding knowledgeable reviewers		
VEXAG	Programmatic imbalance—main issues are reviewer burden (clear) and viability of multiple submittals (need stats). Proposal vetting and timing is incomprehensible		

TABLE C.4 Effectiveness of PSD Communication and Transparency of Current Processes

Analysis Group		NASA Center	
CAPTEM	Common perception in the community that the decline in selected proposals is a direct (but perhaps unintended) consequence of the HQ decision to apply equal selection rates of 20 percent to all new programs	ARC	Reorganization has been transparent
LEAG	No specific comment	GSFC	Lacking clear published data on funding allocations within R&A programs across the reorganization boundary
MAPSIT	Unclear among community how and what types of maps should be done under PDART or other programs	JPL	No specific comment
MEPAG	No specific comment	JSC	Lacking good communication of what is expected to be funded. Reorganization was not well advertised
OPAG	Many SSW grants contribute significantly to habitability. If just grants in Habitable Worlds contribute to the Habitability theme, they are under-reporting by at least 2X. There is more habitability research done in SSW (80 grants) than in Habitability (14 grants)	MSFC	Reorganization is transparent, but the priority of each program and its various elements is not
SBAG	As stated in the PSS report, restructuring of R&A Program should be required to pass a formal Senior Review prior to implementation. SBAG finds that the submission of a draft ROSES 2014 document to the PSS does not constitute sufficient review and assessment		
VEXAG	Perceptions that restructuring was essentially a money-saving exercise without regard to community burden		

TABLE C.5 Selection Rates for Funding of Proposals in the Current R&A Program

Analysis Group		NASA Center	
CAPTEM	PSD should prioritize its critical needs and not necessarily be tied to equal selection rates for the various defined programs	ARC	Decreasing selection rates, researchers need to write too many proposals to secure salary support
LEAG	No specific comment	GSFC	Selection rates declined to 1/5
MAPSIT	No specific comment	JPL	Low selection rates specifically in cosmochemistry and geochemistry
MEPAG	No specific comment	JSC	Selection rates declined to 1/5
OPAG	14 percent reduction in number of new OPAG-centric R&A grants and 32.5 percent reduction of fundamental research grants	MSFC	No specific comment
SBAG	Low selection rates weaken astromaterial research, which motivates and enables new missions. and may drive knowledgeable, experienced US scientists out of the field		
VEXAG	Low success rates induced negative feedback and decrease workforce efficiency		

TABLE C.6 Level of R&A Support of Field-Based and Analog Investigations

Analysis Group		NASA Center	
CAPTEM	No specific comment	ARC	No specific comment
LEAG	Decrease in funding PSTAR does not appear to translate to what gets funded	GSFC	No specific comment
MAPSIT	No specific comment	JPL	Negative impacts felt in programs that require significant infrastructure and support personnel (i.e., laboratory cosmochemistry)
MEPAG	The R&A programs need to support field research and general research on impact crater materials, to elucidate fundamental processes relevant to Mars	JSC	Priority appears to be to diminish sample studies; perception is that contributions not valued
OPAG	No specific comment	MSFC	No specific comment
SBAG	No specific comment		
VEXAG	No specific comment		

TABLE C.7 Do the Current PSD R&A Program Elements Adequately Support Existing and Enable Future Missions

Analysis Group		NASA Center	
CAPTEM	No specific comment	ARC	No specific comment
LEAG	The current lack of focus on theoretical modeling, laboratory work, and new software development is severely hindering our ability to understand new data and apply it to future mission studies	GSFC	Technology support for flight programs is critical for NASA success, but stable and long-term infrastructure support not integrated well in the programs
MAPSIT	Should proposals supporting current and future missions be given priority?	JPL	No specific comment
MEPAG	Loss of MFRP seriously diminishes the ability to perform investigations crucial to framing questions for future missions	JSC	No specific comment
OPAG	No spacecraft data from Outer Planets between end of Cassini Saturn orbiter and Juno Jupiter orbiter and arrival of Europa Clipper multi-flyby mission (approx. 10 year gap)	MSFC	No specific comment
SBAG	No specific comment		
VEXAG	No specific comment		

D
Committee Members and Staff Biographies

STEPHEN J. MACKWELL, *Chair*, is the corporate director, science programs, for the Universities Space Research Association. Most recently, he served as the outgoing director of the Lunar and Planetary Institute. Prior to that appointment, Dr. Mackwell served as the director of the Bayerisches Geoinstitut at the University of Bayreuth, Germany. He has served as program director for geophysics, Division of Earth Sciences, National Science Foundation (NSF); as member, group chief, and panel chair of the review panel for NASA's Planetary Geology and Geophysics and Solar System Workings Programs; as expert reviewer for the Department of Energy's (DOE's) Geosciences Research Program; and as expert consultant for the NSF Division of Earth Sciences. Dr. Mackwell conducts laboratory-based research into the physical, chemical, and mechanical properties of geological materials under conditions relevant to the mantle and crust of Earth and other terrestrial planets. He received his Ph.D. from the Australian National University. His past committee service for the National Academies of Sciences, Engineering, and Medicine includes the Committee on New Opportunities in Solar System Exploration, the Committee to Review Near-Earth-Object Surveys and Hazard Mitigation Strategies, the Committee on the Planetary Science Decadal Survey, the Committee on Lessons Learned in Decadal Planning in Space Science: A Workshop, the Committee on Assessment of NASA Science Mission Directorate 2014 Science Plan, and the Committee on Survey of Surveys: Lessons Learned in Decadal Planning in Space Science., He currently serves on the Committee on Astrobiology and Planetary Science.

MICHAEL F. A'HEARN is a distinguished university professor emeritus and research professor of astronomy at the University of Maryland, College Park (UMCP). His research is aimed at the small bodies of the solar system, particularly comets, and what they tell us about the origin of the solar system. At UMCP, he was the principal investigator (PI) for both the Deep Impact mission and the EPOXI mission in NASA's Discovery Program. He is the PI for the Small Bodies Node of NASA's Planetary Data System and is a member of two instrument teams on ESA's Rosetta mission (the ALICE UV spectrometer and the OSIRIS cameras). Dr. A'Hearn has been at the University of Maryland since 1966 (with visiting positions elsewhere). He has received the NASA Medal for Exceptional Scientific Achievement twice, the Kuiper Prize of the AAS's Division for Planetary Sciences, and the Space Science Award of the American Institute of Aeronautics and Astronautics. He received his Ph.D. in astronomy from the University of Wisconsin. His prior National Academies service includes the Committee to Review Near-Earth Object Surveys and Hazard Mitigation Strategies, the Panel on Primitive Bodies of the Committee on a New Science Strategy for Solar System Exploration (the first planetary science decadal survey), and the Task Group on Sample Returns from Small Bodies.

JOSEPH K. ALEXANDER is a consultant in science and technology policy at Alexander Space Policy Consultants. He was a senior program officer with the National Academies' Space Studies Board (SSB) from 2005 until 2013, and he served as SSB director from 1998 until November 2005. Prior to joining the National Academies, he was deputy assistant administrator for science in the Environmental Protection Agency's Office of Research and Development where he coordinated a broad spectrum of environmental science and led strategic planning. He has also served as associate director of space sciences at the NASA Goddard Space Flight Center (GSFC) and, concurrently, as acting chief of the Laboratory for Extraterrestrial Physics (1993-1994); assistant associate administrator for space sciences and applications in the NASA Office of Space Science and Applications where he coordinated planning and provided oversight of all scientific research programs (1987-1993); and acting director of life sciences (1992-1993). Prior positions have included deputy NASA chief scientist, senior policy analyst at the White House Office of Science and Technology Policy, and research scientist at the GSFC. His research interests were in radio astronomy and space physics.

JOSEPH A. BURNS is the Irving Porter Church Professor of Engineering, Theoretical and Applied Mechanics and a professor of astronomy at Cornell University. Dr. Burns has also served as dean of the faculty at Cornell since 2012. His research interests center on using the principles of mechanics and classical physics to understand various aspects of the current structure of the solar system. He is particularly interested in the structure and dynamics of planetary rings. Dr. Burns is a member of the Cassini Imaging Team. He has curated exhibits of those images simultaneously being shown at the American Museum of Natural History and the National Air and Space Museum. Dr. Burns is a fellow of the American Geophysical Union (AGU), the American Association for the Advancement of Science (AAAS), and the Royal Astronomical Society. He is an elected member of the Russian Academy of Sciences and the International Academy of Astronautics. He has been a vice president of the American Astronomical Society (AAS) and has chaired their divisions for Planetary Sciences and Dynamical Astronomy (DDA). He received the DDA’s Brouwer Prize in 2013. His National Academies experience includes membership on the Committee on Planetary and Lunar Exploration, the Space Studies Board, the Committee on a New Science Strategy for Solar System Exploration, and the Panel on Ultraviolet, Optical, and Infrared Astronomy from Space of the Astronomy and Astrophysics Survey Committee.

LARRY W. ESPOSITO is a professor at the University of Colorado, Boulder, and at the Laboratory for Atmospheric and Space Physics. He is the PI of the Ultraviolet Imaging Spectrograph (UVIS) experiment on the Cassini space mission to Saturn. He was chair of the Voyager Rings Working Group and, as a member of the Pioneer Saturn Imaging Team, he discovered Saturn’s F ring. His research focuses on the nature and history of planetary rings. Dr. Esposito has been a participant in numerous U.S., Russian, and European space missions and used the Hubble Space Telescope for its first observations of Venus. He was awarded the Harold C. Urey Prize from the AAS, the Medal for Exceptional Scientific Achievement from NASA, and the Richtmyer Lecture Award from the American Association of Physics Teachers and the American Physical Society. Dr. Esposito has extensive National Academies experience, including service on the Task Group on the Forward Contamination of Europa and the Committee on Planetary and Lunar Exploration.

G. SCOTT HUBBARD is an adjunct professor in the Department of Aeronautics and Astronautics at Stanford University, the director emeritus of the Stanford Center of Excellence for Commercial Space Transportation (COE CST), and the editor-in-chief of the peer-reviewed journal *New Space*. Dr. Hubbard has been engaged in space-related research, as well as program, project, and executive management, for more than 40 years, including 20 years with NASA—culminating as director of NASA’s Ames Research Center. At Stanford, Dr. Hubbard’s research interests include the study of both human and robotic exploration of space with a particular focus on technology and missions for planetary exploration, especially Mars. Examples include novel hybrid propulsion for applications such as a Mars Ascent Vehicle and drilling techniques for a future Mars sample-return mission. Dr. Hubbard served as NASA’s first Mars program director and successfully restructured the entire Mars program in the wake of mission failures. His book entitled *Exploring Mars: Chronicles from a Decade of Discovery* describes his work on NASA’s Mars program. Dr. Hubbard previously served as the sole NASA representative on the Columbia Accident Investigation Board and directed the impact testing that established the definitive physical cause of the accident. He was the founder of NASA’s Astrobiology Institute; conceived the Mars Pathfinder mission with its airbag landing, and was the manager for NASA’s highly successful Lunar Prospector Mission. Prior to joining NASA, he was a staff scientist at the Lawrence Berkeley National Laboratory and directed a high-tech start-up company. He chairs the SpaceX Commercial Crew Safety Advisory

Panel. Within the COE CST, Dr. Hubbard led research to enable, facilitate, and promote commercial space. He has received many honors, including NASA's highest award, the Distinguished Service Medal. Dr. Hubbard has received several honorary doctorates. He earned his B.A. in physics-astronomy at Vanderbilt University. He has served on the National Academies' Decadal Survey for Planetary Science 2013-2022 and the Committee for Astrobiology and Planetary Science. He is a NASA Advisory Council at-large member.

TORRENCE V. JOHNSON is a senior research scientist at Jet Propulsion Laboratory (JPL). He is also a visiting associate in planetary science at the California Institute of Technology. At JPL, his most recent position was chief scientist for Solar System Exploration. His research interests include the study of the satellites of outer planets, the dynamics and chemistry of Io using both spacecraft and ground-based telescopic observations, and laboratory studies of silicates and ices, and interpretation of planetary spacecraft data. He was an imaging team member during the Voyager mission's planetary phase, and he was the project scientist for the Galileo mission from 1977 to end of mission. Currently, he is an imaging team member and co-investigator on the Cosmic Dust analyzer on the Cassini mission. He is a fellow of the AGU, a member of the American Academy of Arts and Sciences, and has an honorary doctorate from the University of Padua in Italy. He earned his Ph.D. in planetary science from the California Institute of Technology. Dr. Johnson's National Academies service includes membership on the U.S. National Committee for the International Union of Geodesy and Geophysics and the Working Group on Planetary Science.

PETER B. KELEMEN is the Arthur D. Storke Memorial Professor at Columbia University. He also serves as the chair of the Department of Earth and Environmental Sciences. His current research interests are in the geologic capture and storage of CO_2 (CCS) via mineral carbonation, the subduction zone carbon cycle, and reaction-driven cracking processes in natural and engineered settings, with application to CCS, geothermal power generation, hydrocarbon extraction, and in situ mining. In addition, he is working on reactive transport of melt and fluids in Earth's upper mantle and crust, genesis and evolution of oceanic and continental crust, subduction zone processes, and viscous mechanisms for earthquake initiation in the mantle and beneath glaciers. Dr. Kelemen was a founding partner of Dihedral Exploration, a mineral exploration consultancy specializing in field work requiring technical climbing skills, with whom he searched for ore deposits in British Columbia, Alaska, and Greenland. He is a member of the National Academy of Sciences and a fellow of the AGU, the Mineralogical Society of America, and the Geochemical Society. He has received the AGU Bowen Award and Columbia University's Lenfest Distinguished Faculty Award. He has participated in a broad range of NSF-based workshops and planning meetings related to Earth sciences and marine geology and geophysics. He received his Ph.D. in geological sciences from the University of Washington.

MAKENZIE LYSTRUP is the director of advanced systems and business development at Ball Aerospace civil space. At Ball, Dr. Lystrup leads the new business organization that addresses customers that include NASA, NOAA, and other civil government agencies. She also leads strategic planning for the Civil Space business unit. Her research interests have been in infrared spectroscopic observations of giant planet upper atmospheres and planetary ionosphere-magnetosphere interactions. Previously, Dr. Lystrup was a science policy congressional fellow and a NSF astronomy and astrophysics postdoctoral fellow at the University of Colorado's Laboratory for Atmospheric and Space Physics. She received her Ph.D. in astrophysics from University College London.

JUAN PEREZ-MERCADER is a senior research fellow and PI of a large group at Harvard University in the Department of Earth and Planetary Sciences. His current research interests are in the physics and chemistry of self-organizing behavior, information in non-equilibrium physico-chemical systems, chemical computation, origins of life, theoretical biology, and life detection. He previously served as the first director of Spain's Centro de Astrobiologia (CAB), which he helped found in Association with the

NASA Astrobiology Institute. He is also profesor de investigación in Spain's National Research Council (CSIC) and an external faculty member at the Santa Fe Institute. Dr. Perez-Mercader has authored about 150 research papers and five books, including a best-selling popular science book in Spanish. He has two patents in biotechnology and one pending in chemical computing. He is an elected member of the International Academy of Astronautics and of the European Academy of Sciences and Arts. He is the recipient of many honors and distinctions. Among these are one of the prizes given in 1994 by the Gravity Research Foundation, the European Physical Society Lecturer for the 2005 Celebrations in Bern of Einstein's 1905 work there, and the NASA Public Service Medal, as well as NASA's Group's Achievement Award for exceptional achievement on Rover Environmental Monitoring Station (REMS). He received his Ph.D. in physics from the City College of New York.

JOHN D. RUMMEL is a senior scientist with the SETI Institute, where he works on astrobiology and planetary protection science and policy issues. He is currently a visiting scholar at the McGill University Institute of Air and Space Law, working on models of future space governance for protection and use of space environments. Dr. Rummel was formerly the director of the Institute for Coastal Science and Policy and a professor of biology at East Carolina University, where he continued his interests in ecosystems ecology, community ecology, and evolutionary biology. He maintains an active interest in the ecology and biogeography of deep sea hydrothermal vents and the potential for life elsewhere in the universe. Dr. Rummel previously worked as both the planetary protection officer and the senior scientist for astrobiology at NASA and as director of research administration and education at the Marine Biological Laboratory in Woods Hole, Massachusetts. He is the recipient of numerous performance and achievement awards for his work at NASA, and is a fellow of AAAS, and the recipient of the Life Sciences Award from the International Academy of Astronautics. He received his Ph.D. from Stanford University for research in community ecology and evolution. Dr. Rummel is a former member of the National Academies' Committee on Planetary and Lunar Exploration and served as the chair of the Panel on Planetary Protection of the International Council for Science's Committee on Space Research (1999-2014). He was also a member of the NASA Advisory Council's Planetary Protection Subcommittee until 2015.

Staff

DAVID H. SMITH, *Study Director*, joined the SSB in 1991. He is the senior staff officer and study director for a variety of activities at the National Academies in planetary science, astrobiology, and astrophysics. He also organizes SSB's Lloyd V. Berkner Summer Policy Internship program and supervises most, if not all, of the interns. He received a B.Sc. in mathematical physics from the University of Liverpool in 1976, completed Part III of the Mathematics Tripos at Cambridge University in 1977, and earned a D.Phil. in theoretical astrophysics from Sussex University in 1981. Following a postdoctoral fellowship at Queen Mary College, University of London (1980-1982), he held the position of associate editor and, later, technical editor of *Sky and Telescope*. Immediately prior to joining the staff of the SSB, Dr. Smith was a Knight Science Journalism Fellow at MIT.

CHARLIE HARRIS was a research associate for the SSB and the ASEB through August 2016. He graduated from the University of North Carolina, Chapel Hill, in 2014 with a double major in public policy and communication studies, and a minor in astronomy. He has served as an intern with NASA's Space Technology Mission Directorate at NASA Headquarters and with the Committee on Science, Space, and Technology in the U.S. House of Representatives. He has also worked as a junior associate with an independent policy firm focused on providing clients in the commercial space sector with government relations services and strategic consulting.

DIONNA J. WISE is a program coordinator with the SSB, having previously worked for the National Academies' Division of Behavioral and Social Sciences and Education for 5 years. Ms. Wise has a long career in office administration, having worked as a supervisor in a number of capacities and fields. She attended the University of Colorado, Colorado Springs, and majored in psychology.

CHERIE ACHILLES was a Lloyd V. Berkner Space Policy Intern with the SSB. She is a Ph.D. student studying geosciences at University of Arizona. Her research focuses on martian surface materials, specifically the crystalline and amorphous phases comprising rocks and sediments analyzed by the Mars Science Laboratory (MSL) rover. Prior to entering graduate school, Ms. Achilles received her Bachelor of Science degree in Molecular and Cellular Biology and in Microbiology from The University of Arizona in 2008. From 2005 -2008, she was a member of the engineering and operations team for the Surface Stereo Imager on the Phoenix Mars Lander. Following the Phoenix mission, Ms. Achilles joined the Astromaterials and Research Exploration Science group at NASA Johnson Space Center (JSC). While at JSC she was involved in several Mars-related research projects and became a member the MSL Science Team working with the CheMin instrument. In addition to her involvement with the Mars research group, she contributed to the analysis of interplanetary dust particles as well as the sampling and analysis of hypervelocity impact structures from space hardware (e.g., Space Shuttle, ISS). Ms. Achilles left JSC in 2013 to pursue her Ph.D. but continues her involvement in CheMin operations and research while at Arizona.

SARAH PEACOCK was a Lloyd V. Berkner Space Policy Intern with the SSB. She is a fourth year doctoral candidate at the University of Arizona's Lunar and Planetary Laboratory. Her research interests include exoplanet atmospheres and habitability. Her dissertation work involves modeling the high-energy radiation environment around M dwarf stars and applying that radiation to planetary atmospheres. Ms. Peacock is the recipient of a NASA Earth and Space Science Fellowship and a Galileo Circle Scholarship. She received her M.S. in planetary sciences from the University of Arizona in 2016 and her B.A. in astronomy-physics from the University of Virginia in 2013.

MICHAEL MOLONEY is the director for space and aeronautics at the SSB and the Aeronautics and Space Engineering Board (ASEB) of the National Academies. Since joining the ASEB/SSB, Dr. Moloney has overseen the production of more than 40 reports, including four decadal surveys—in astronomy and astrophysics, planetary science, life and microgravity science, and solar and space physics—a review of the goals and direction of the U.S. human exploration program, a prioritization of NASA space technology roadmaps, as well as reports on issues such as NASA's Strategic Direction, orbital debris, the future of NASA's astronaut corps, and NASA's flight research program. Before joining the SSB and ASEB in 2010, Dr. Moloney was associate director of the BPA and study director for the decadal survey for astronomy and astrophysics (Astro2010). Since joining the Academies in 2001, Dr. Moloney has served as a study director at the National Materials Advisory Board, the Board on Physics and Astronomy, the Board on Manufacturing and Engineering Design, and the Center for Economic, Governance, and International Studies. Dr. Moloney has served as study director or senior staff for a series of reports on subject matters as varied as quantum physics, nanotechnology, cosmology, the operation of the nation's helium reserve, new anti-counterfeiting technologies for currency, corrosion science, and nuclear fusion. In addition to his professional experience at the National Academies, Dr. Moloney has more than 7 years' experience as a foreign-service officer for the Irish government—including serving at the Irish Embassy in Washington and the Irish Mission to the United Nations in New York. A physicist, Dr. Moloney did his Ph.D. work at Trinity College Dublin in Ireland. He received his undergraduate degree in experimental physics at University College Dublin, where he was awarded the Nevin Medal for Physics.

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Glossary and Acronyms

GLOSSARY

astrobiology	Studies of the origin, evolution, distribution, and future of life on Earth and the potential for life elsewhere. This includes the habitability of the early Earth as well as the potential for habitable environments to arise and be sustained elsewhere in the universe.
astronomy	Acquisition of Earth-based observations of non-Earth bodies, structures, or systems.
atmospheres	Studies of the chemistry, structure, and dynamics of the gases surrounding a planet or other material body that are held in place by the gravity of that body.
cosmochemistry	Analytical, experimental and theoretical studies of chemical processes in the universe. Includes: studies of the chemistry and mineralogy of astromaterials (meteorites, dust, returned samples); nucleosyntheis; galactic chemical evolution; chemical modeling of solar system and planetary formation; experimental petrology.
exosphere	Studies of the thin, atmosphere-like volume surrounding a planet or natural satellite where molecules are gravitationally bound to that body, but where the density is too low for them to behave as a gas by colliding with each other. Includes escaping gasses (e.g. Enceladus plumes).
geochemistry	Studies of the chemistry of planetary processes and systems. The term is usually applied to studies of larger bodies such as planets and moons. However, studies of martian meteorites and samples from the Moon may be coded as either cosmochemistry or geochemistry. Usually excludes studies of atmospheric and exospheric chemistry, which are coded under those separate headings.
geology	Studies of planetary surface features and the surface expressions of internal processes.
geophysics	Studies of the physical processes and physical properties of planetary bodies, and their surrounding space environment (excluding magnetospheres).
magnetospheres	Studies of the space environment surrounding planetary bodies in which electromagnetic fields are important. Magnetospheres and Atmospheres may be used together to designate auroral zone, ionosphere, and thermosphere studies.
planetary dynamics	Studies of orbital configuration and dynamic events contributing to the evolution of a single planetary object or planet-moon or planet-ring or moon-ring system.

planetary protection	Studies and other activities related to processes to detect and mitigate biological and organic contamination of spacecraft systems (regardless of their origin).
solar system dynamics	Studies of the evolution of star systems, including the structure, and dynamics of proto-planetary disks.
spectroscopy	The acquisition and/or study of laboratory and/or remote-sensing measurements of spectroscopic properties or characteristics, without further scientific conclusions.

ACRONYMS

AO	announcement of opportunity
AOR	Authorized Organizational Representative
CDAP	Cassini Data Analysis Program (focused program element)
COLDTech	Concepts for Ocean Worlds Life Detection Technology
COMPLEX	Committee on Lunar and Planetary Exploration
DAP	data analysis program
DAPS	Data Analysis and Participating Scientists Program
DDAP	Discovery Data Analysis Program (strategic program element)
ELV	Expendable Launch Vehicle
EW	Emerging Worlds (core research program element)
EXO	Exobiology (core research program element)
FY	fiscal year
GPRAMA	Government Performance and Results Modernization Act
HEO	Human Exploration and Operations
HOTTech	Hot Operating Temperature Technology
HW	Habitable Worlds (core research program element)
KBO	Kuiper belt object
LARS	Laboratory Analysis of Returned Samples (strategic program element)
LDAP	Lunar Data Analysis Program (focused program element)
MatISSE	Maturation of Instruments for Solar System Exploration (core technology program element)
MDAP	Mars Data Analysis Program (strategic program element)

NAC	NASA Advisory Council
NASA	National Aeronautics and Space Administration
NEO	near Earth object
NEOO	Near Earth Object Observations
NFDAP	New Frontiers Data Analysis Program (strategic program element)
NRA	NASA Research Announcement
NRC	National Research Council
NSPIRES	NASA Solicitation and Proposal Integrated Review and Evaluation System
PAST	Planetary Astronomy
PDART	Planetary Data Archiving, Restoration, and Tools (strategic program element)
PI	principal investigator
PICASSO	Planetary Instrument Concepts for the Advancement of Solar System Observations (core technology program element)
PME	Planetary Major Equipment (core technology program element)
PPR	Planetary Protection Research (strategic program element)
PSD	Planetary Science Division
PSTAR	Planetary Science and Technology from Analogue Research (strategic program element)
R&A	research and analysis
R&DA	research and data analysis
ROSES	Research Opportunities in Earth and Space Sciences
SIMPlEx	Small, Innovative Missions for Planetary Exploration
SDD	Selection Decision Document
SMD	Science Mission Directorate
SO	selection official
SPD	SMD Policy Document
SRP	Selection Requirements Package
SSB	Space Studies Board
SSO	Solar System Observations (core research program element)
SSW	Solar System Workings (core research program element)
TNO	trans-neptunian object
TRL	technology readiness level
XRP	Exoplanets Research (strategic program element)