Current and Future Studies: Preparing for the Next Planetary Science Decadal Survey

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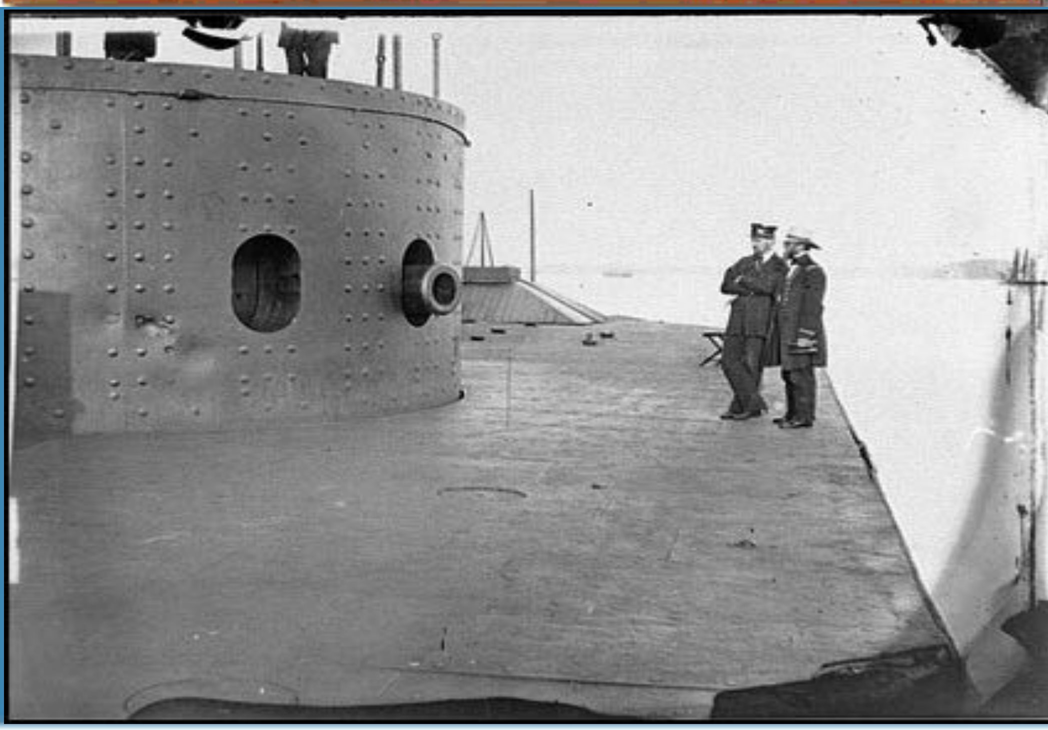
Space Studies Board

Outer Planets Assessment Group
La Jolla, 7 September 2017

National Academies: Who We Are?



Schedule of the Next Decadal Survey I

3-2011 *Vision and Voyages* delivered to NASA

9-2016 NASA requests *Vision and Voyages* midterm assessment

9-2017 Fourth meeting of *V&V* midterm assessment committee

1-2017 Release of AO for New Frontiers 4
12/2017 New Frontiers 4 Downselect?

5-2018 *V&V* midterm assessment delivered to NASA?

10/2018 New Frontiers 4 Phase A study report due???
3/2019 Discovery AO Released ???
5/2019 New Frontiers 4 Selected???

9/2019 Organizing meeting for 3rd planetary decadal survey

Schedule of the Next Decadal Survey II

9/2019	Organizing meeting for 3rd planetary decadal survey
1/2020	Statement of task finalized and survey formally initiated?
3/2020	Chair selected and announced?
7/2020	Survey committee and panel meetings begin?
9/2021	First complete draft of survey report assembled?
3/2022	Survey report released?

Recently Completed Studies

- Decadal Surveys: Lessons Learned and Best Practices (completed 2015)
- Achieving Science Goals with CubeSats (completed 2016)
- NASA Science Mission Extensions: (completed 2016)
- Review of SMD/PSD Reorganized R&A Programs (completed 2017)
- Large Strategic NASA Science Missions (completed 2017)
- Getting Ready for the Next Planetary Decadal (completed 2017)

Ongoing and Future Studies

- Review of the Planetary Protection Policy Development Process (underway)
- Planetary Science Decadal Midterm Review (underway)
- Review of Extraterrestrial Sample Analysis Facilities (committee appointed)
- Exoplanet Exploration Strategy (committee recruiting)
- Astrobiology Strategy for Search for Life (committee recruiting)
- Martian Moons Planetary Protection Characterization (committee recruiting)

Review of the Planetary Protection Policy Development Process

- Requested by Office of the NASA Chief Scientist
- Committee is looking at the processes by which planetary protection policies are determined nationally and internationally, who are the key players, what are their respective roles and responsibilities. Not setting new requirements
- Study motivated by new challenges to current planetary protection policy development processes and, in particular: new space agencies sending missions to bodies of concern, commercial entities currently do not have a seat at the table, what to do about planetary protection in an era of human exploration and interplay between Articles VI and IX of OST
- Committee met for the first time in March 2018 and drafted an interim report on the goals, rationales and definitions of planetary protection (requested by Thomas Zurbuchen). Final report due to NASA by end of 2018 Q1

Planetary Science Decadal Midterm Review

- Requested by NASA/SMD (mandated by NASA Authorization of 2005)

- It will describe the most significant scientific discoveries, technical advances, and relevant programmatic changes in planetary sciences over the years since the publication of *Vision & Voyages*

- Assess the degree to which NASA's current planetary science program addresses the strategies, goals, and priorities outlined in the V&V and other relevant NRC and Academies reports

- Will conduct a detailed review of NASA Mars exploration architecture (as mandated by the NASA Transition Authorization Act of 2017)

- Will NOT reprioritize science or mission goals of *V&V*

- Committee just held its fourth meeting and will deliver report in 2018 Q2

Review of Extraterrestrial Sample Analysis Facilities

•Requested by Jim Green

•Will review the current capabilities of the U.S. and international planetary science community's analytical laboratory facilities, their future requirements, and any associated challenges

•Committee just appointed

•Will hold first meeting in November

•Site visits to facilities in US, Europe and Japan are included in the scope of the study

•Will report to NASA in the latter part of 2018

•Report will be of direct relevance to the next planetary science decadal survey committee

Exoplanet Exploration Strategy

- Requested by U.S. Congress (via NASA Transition Authorization Act of 2017)
- Survey the status of the field of exoplanet science, including the use of current and planned facilities such as TESS, JWST, WFIRS, and recommend an Exoplanet Science Strategy that outlines the key scientific questions for exoplanet science and research and related near/medium/far-term measurement and technology goals
- Committee recruitment now underway
- Scheduled to hold three meetings in period 2017 Q4 to 2018 Q2
- Deliver report to NASA and Congress by August 2018
- Specifically designed to provide input to the next astronomy and planetary decadals
- Will coordinate closely with Astrobiology strategy study

Astrobiology Strategy for the Search for Life in the Universe

- Requested by U.S. Congress (via NASA Transition Authorization Act of 2017)
- Will examine the state of the science of astrobiology as it relates to the search for life in the solar system and extrasolar planetary systems and define key science questions
- Committee recruitment now underway
- Scheduled to hold three meetings in period 2017 Q4 to 2018 Q2
- Deliver report to NASA and Congress by August 2018
- Study will consider solar system bodies and extrasolar planetary systems
- A follow-on activity to the SSB's December 2016 Workshop on Searching for Life Across Space and Time
- Specifically designed to provide input to the next astronomy and planetary decadals

Planetary Protection Characterization of Samples Returned from Martian Moons

- Requested by NASA and ESA Planetary Protection Offices
- Motivated by NASA and ESA participation in JAXA's MMX mission
- To be conducted by a joint committee of the National Academies and the European Science Foundation, with some participation by Japanese scientists
- Committee of 10-12 (4-5 from US, 4-5 from Europe and 2 from Japan)
- Scheduled to hold a single meeting in the UK in 2017 (Q4) and report to NASA, ESA (and JAXA) in 2018 (Q1-2)
- Tasked to assess research sponsored by NASA and ESA PPOs on survival of organisms subject to radiation, exposure to space and hypervelocity impacts
- Goal is to determine if sample-return missions from Phobos and/or Deimos should be classified as "restricted" or "unrestricted" Earth return.

EXTRA

Statement of Task:
Decadal Midterm Review I

The National Academies of Sciences, Engineering, and Medicine shall convene an ad hoc committee to review the response of NASA's Planetary Science program to the 2011 decadal survey, *Vision and Voyages for Planetary Sciences in the Decade 2013-2022* (V&V). The committee's review will include the following tasks:

- Describe the most significant scientific discoveries, technical advances, and relevant programmatic changes in planetary sciences over the years since the publication of the planetary decadal survey (Vision & Voyages or V&V);

- Assess the degree to which NASA's current planetary science program addresses the strategies, goals, and priorities outlined in the V&V and other relevant NRC and Academies reports and assess NASA progress toward realizing these strategies, goals, and priorities, and effectiveness in maintaining programmatic balance;

Statement of Task: Decadal Midterm Review II

- With respect to the Mars program within the planetary science program, the committee's assessment will include:

– the Planetary Science Division's Mars exploration architecture and its responsiveness to the strategies, priorities, and guidelines put forward by the National Academies' V&V and other relevant National Academies Mars-related reports;

– the long-term goals of the Planetary Science Division's Mars Exploration Program and the program's ability to optimize the science return, given the current fiscal posture of the program;

– the Mars exploration architecture's relationship to Mars-related activities to be undertaken by foreign agencies and organizations; and

– the extent to which the Mars exploration architecture represents a reasonably balanced mission portfolio.

Statement of Task: Decadal Midterm Review III

- Recommend any actions that could be taken to optimize the science value of the planetary science program including how to take into account emergent discoveries since the decadal in the context of current and forecasted resources available to it;

- Provide guidance about implementation of the decadal's recommended mission portfolio and decision rules for the remaining years of the current decadal survey, but do not revisit or redefine the scientific priorities or mission recommendations from the V&V and;

- Recommend any actions that should be undertaken to prepare for the next decadal survey, such as community discussion of science goals, potential missions, and programmatic balance, and NASA support of potential mission concept studies.

Decadal Midterm Review Committee

- **Louise M. Prockter**, *Co-Chair*
Lunar and Planetary Institute
- **Joseph H. Rothenberg**, *Co-Chair*
Consultant
- **David A. Bearden**
The Aerospace Corporation
- **Scott Bolton**
Southwest Research Institute
- **Barbara H. Cohen**
NASA Goddard Space Flight Center
- **Andrew M. Davis**
University of Chicago
- **Melinda Darby Dyar**
Mount Holyoke College
- **Alan W. Harris**
MoreData! Inc.
- **Amanda R. Hendrix**
Planetary Science Institute
- **Bruce M. Jakosky**
University of Colorado, Boulder
- **Margaret G. Kivelson**
University of California, Los Angeles
- **Juan Perez-Mercader**
Harvard University
- **Scott L. Murchie**
Applied Physics Laboratory
- **Mark P. Saunders**
Consultant
- **Suzanne Smrekar**
Jet Propulsion Laboratory
- **David J. Stevenson**
California Institute of Technology

Statement of Task: Review of Extraterrestrial Sample Analysis Facilities

To prepare for the analysis of diverse extraterrestrial samples in the coming decade, NASA requires information on the current capabilities of the planetary science community's analytical laboratory facilities, their future requirements, and any associated challenges. Therefore, the National Academies of Sciences, Engineering, and Medicine will assemble a committee to perform a study addressing the following questions:

- What laboratory analytical capabilities are required to support the NASA Planetary Science Division's (and partners') analysis and curation of existing and future extraterrestrial samples?

- Which of these capabilities currently exist, and where are they located (including international partner facilities)?

- What existing capabilities are not currently accessible that are/will be needed?

- Whether the current sample laboratory support infrastructure and NASA's investment strategy meets the analytical requirements in support of current and future decadal planetary missions.

- How can NASA ensure that the science community can stay abreast of evolving techniques and be at the forefront of extraterrestrial sample analysis?

The National Academies of SCIENCES ENGINEERING MEDICINE

Sample Science Facilities Committee

- **Roberta L. Rudnick**, *Chair*
U. of California, Santa Barbara

- **James H. Crocker**
Lockheed Martin Corporation (Retired)

- **Vinayak P. Dravid**
Northwestern University

- **John M. Eiler**
California Institute of Technology

- ~~**Katherine H. Freeman**~~
Pennsylvania State University

- **Abby Kavner**
University of California, Los Angeles

- **Timothy J. McCoy**
Smithsonian Institution

- **Clive R. Neal**
University of Notre Dame

- **Frank M. Richter**
University of Chicago

- **Hanika Rizo**
University of Quebec, Montreal

- **Kimberly T. Tait**
Royal Ontario Museum

Statement of Task: Review of the Planetary Protection Policy Development Process 1

The National Academies of Sciences, Engineering, and Medicine will appoint an ad hoc committee to carry out a study that will describe how international and national planetary protection policy has been formulated and adopted and identify associated lessons to inform future policy development. Specifically, the committee will assess the current state of planetary protection policy development, and the extent to which the current policy-making process is responsive to the present state of science, technology, and engineering, including biological science, as well as the exploration interests of state and non-state actors. The committee's review will lead to recommendations on how to assure the planetary protection policy process is supportive of future scientific and societal interests, as well as spaceflight missions.

It is suggested that the committee organize its review around three themes:

- Historical context and the current policy development process--including a working definition of planetary protection and its goals;
- Key factors in the current policy development process; and
- The future of the policy development process.

Statement of Task: Review of the Planetary Protection Policy Development Process 2

Historical Context and the Current Policy Development Process--including a working definition of planetary protection and its goals:
In addressing this theme, the committee should consider the following questions and formulate lessons learned where appropriate:

- How has the planetary protection policy development process evolved over the course of lunar and planetary exploration? What approaches to planetary protection policy development were used in the Apollo and Viking eras of solar system exploration, and subsequent Mars exploration? What factors informed and drove those choices?

- What worthwhile lessons can policymakers take from the history of planetary protection policy development in looking toward future exploration and sample return missions?

- Who are the actors involved in the present-day planetary protection policy development process? What are the respective roles and responsibilities of international organizations, national organizations and national space agencies (including agencies' planetary protection officers), advisory committees, and others in the process?

Statement of Task: Review of the Planetary Protection Policy Development Process 3

- Who are the actors involved in the present-day planetary protection policy development process? What are the respective roles and responsibilities of international organizations, national organizations and national space agencies (including agencies' planetary protection officers), advisory committees, and others in the process?

- What scientific, technical, philosophical, and/or ethical assumptions and values about the importance of avoiding forward contamination of extraterrestrial planetary environments are prioritized in the current planetary protection policy development process?

- What scientific, technical, philosophical, and ethical assumptions and values about the importance of protecting Earth and its environment ("backward contamination") are prioritized in the current planetary protection policy development process?

- How does the current process take into account new scientific and technical knowledge?

- How does the state of scientific understanding of planetary environments and their ability to harbor life inform the current planetary protection policy development process? What scientific knowledge or exploration interests are not taken into account?

The National Academies of SCIENCES ENGINEERING MEDICINE

Statement of Task: Review of the Planetary Protection Policy Development Process 4

- How does the current planetary protection policy development process balance interest in acquiring scientific knowledge of planetary environments to inform future scientific studies, exploration, and planetary protection policy choices with the interest in protecting those environments in the here-and-now?

Key Factors in the Current Policy Development Process

In addressing this theme, the committee should consider the following questions and formulate recommendations as appropriate:

- To what extent does the current process consider the interests of state and non-state actors in exploring planetary environments, including obligations under Article VI of the Outer Space Treaty?

- How does the current process reconcile uncertainties in knowledge, differences between scientific and other exploration interests, as well as potentially competing interests?

- What are the barriers, or challenges, that inhibit the process of effective planetary protection policy development?

Statement of Task: Review of the Planetary Protection Policy Development Process 5

The Future of the Policy Development Process

Looking at both historical and contemporary approaches to planetary protection policy development, the committee should make recommendations about the future of planetary protection policy process development in relation to these questions:

- How could the planetary protection policy development process be made more adaptable to the evolving landscape of knowledge about and myriad interests in planetary environments?

- How can a planetary protection regulatory environment in the U.S. government be established and evolve to keep pace with non-governmental spacefaring entities?

- How does a future process evaluate the state of the art and what technologies are required to ensure compliance with planetary protection policy for future missions?

- What risk assessment and/or quality control principles should be applied to ensure that a future process takes into account our understanding of the capabilities of Earth organisms and the potential for extraterrestrial life to be encountered by planetary missions?

Planetary Protection Policy… Committee

- **Joseph K. Alexander**, *Chair*

Alexander Space Policy Consultants

- **John Casani**

Jet Propulsion Laboratory (Retired)

- **Leroy Chiao**

NASA (Retired)

- **David P. Fidler**

Indiana University

- **Joanne I. Gabrynowicz**

University of Mississippi

- **G. Scott Hubbard**

Stanford University

- **Eugene H. Levy**

Rice University

- **Norine Noonan**

U. of South Florida, St. Petersburg

- **Kenneth Olden**

EPA (Retired)

- **Francois Raulin**

University of Paris Est Créteil

- **Gary Ruvkun**

Harvard Medical School

- **Mark P. Saunders**

Consultant

- **Beth A. Simmons**

University of Pennsylvania

- **Pericles D. Stabekis**

Independent Consultant

- **Andrew Steele**

Carnegie Institution of Washington

Statement of Task: Exoplanet Exploration Strategy

In preparation for and as an input to the upcoming decadal surveys in astronomy and astrophysics and planetary science, the National Academies of Sciences, Engineering and Medicine will appoint an ad hoc committee to perform a study with the following objectives:

- Survey the status of the field of exoplanet science, including the use of current and planned facilities such as Transiting Exoplanet Survey Satellite, the James Webb Space Telescope, the Wide Field Infrared Survey Telescope, and any other telescope, spacecraft, or instrument, as appropriate;
- Recommend an Exoplanet Science Strategy that outlines the key scientific questions for exoplanet science and research and related near-, medium-, and far-term measurement and technology goals. The Strategy will include the search for life in the universe as well as cross-discipline opportunities in Earth science, astrophysics, heliophysics, and planetary science.
- Discuss which of the key goals of the committee's Strategy could be addressed via current decadal survey recommended priority activities and also identify opportunities for coordination with international partners, commercial partners, and not-for-profit partners;
- In the course of conducting this study, the committee will consider and regularly consult with the concurrent study "Astrobiology Strategy for the Search for Life in the Universe," in the area of assessing habitability, searching for signs of life, and other relevant areas of scientific overlap . Also the committee will not revisit or redefine the scientific priorities or mission recommendations from previous decadal surveys.

The National Academies of SCIENCES ENGINEERING MEDICINE

Statement of Task: Astrobiology Strategy for the Search for Life in the Universe

In preparation for and as an input to the upcoming decadal surveys in astronomy and astrophysics and planetary science, the National Academies of Sciences, Engineering and Medicine will appoint an ad hoc committee to carry out a study of the state of the science of astrobiology as it relates to the search for life in the solar system and extrasolar planetary systems. The study will have the following objectives:

- Take account of and build on NASA's current Astrobiology Strategy 2015;
- Outline key scientific questions and technology challenges in astrobiology, particularly as they pertain to the search for life in the solar system and extrasolar planetary systems;
- Identify the most promising key research goals in the field of the search for signs of life in which progress is likely in the next 20 years;
- Discuss which of the key goals could be addressed by U.S. and international space missions and ground telescopes in operation or in development;
- Discuss how to expand partnerships (interagency, international and public/private) in furthering the study of life's origin, evolution, distribution, and future in the universe;
- Make recommendations for advancing the research, obtaining the measurements, and realizing the NASA's goal to search for signs of life in the universe
- In the course of conducting this study, the committee will consider and regularly consult with the concurrent study “Exoplanet Science Strategy,” in the area of assessing habitability, searching for signs of life, and other relevant areas of scientific overlap. Also the committee will not revisit or redefine the scientific priorities or mission recommendations from previous decadal surveys.

Statement of Task: Planetary Protection Characterization of the Martian Moons

The National Academies will establish an ad hoc committee to review and assess recent research sponsored by NASA and the European Space Agency (ESA) relating to the planetary protection concern that hypothetical martian life might exist on the surfaces of the martian moons, Phobos and Deimos, consequent to their ejection from the surface of Mars following a major impact event. In particular, the committee will address the following tasks:

1. Review, in the context of current understanding of conditions relevant to inactivation of carbon-based life, recent theoretical, experimental, and modelling research on the environments and physical conditions encountered by Mars ejecta during the following processes:

    a) excavation from the martian surface via crater-forming events;
    b) while in transit through cismartian space;
    c) during deposition on Phobos or Deimos; and
    d) after deposition on Phobos or Deimos;

2. Recommend whether missions returning samples from Phobos and/or Deimos should be classified as "restricted" or "unrestricted" Earth return in the framework of the planetary protection policy maintained by the ICSU Committee on Space Research (COSPAR); and

3. Suggest any other refinements in planetary protection requirements that that might be required to accommodate spacecraft missions to and sample returned from Phobos and/or Deimos

Extending Science – NASA's Space Science Mission Extensions and the Senior Review Process

Committee on NASA Science Mission Extensions

September 12, 2016

Victoria E. Hamilton, Co-chair
Harvey D. Tananbaum, Co-chair

Opportunity Sol 4228
42.65 km driven

Statement of Task

The NRC will appoint an ad hoc committee to conduct an assessment of the scientific value of extended missions in the overall program of NASA's Science Mission Directorate (SMD). The committee's report will provide recommended guidelines for future NASA decision-making about such mission extensions. In conducting this study, the committee could address the following questions:

1. Historically, what have been the scientific benefits of mission extensions? How important are these benefits (for example, benefits that might only accrue during the extended mission phase but not earlier)?

2. What is the current SMD Senior Review process for extending missions--for example, how are reviews chartered and conducted, by whom, and using what criteria? What should be division dependent and what should be uniform across the Directorate?

3. The NASA Authorization Act of 2005 requires biennial Senior Reviews for each mission extension. Is this biennial time period optimal for all divisions? Would a longer or shorter time period between reviews be advantageous in some cases?

4. Does the balance currently struck between starting new missions and extending operating missions provide the best science return within NASA's budget? That is, how much of an acceleration of new mission initiation could realistically be achieved by reallocating resources from mission extensions to new programs, compared to the corresponding scientific loss from terminated or diminished mission extensions?

5. Are there innovative cost reduction approaches that could increase the science cost-effectiveness of extended missions? Are there any general principles that might be applied across the board or to all of the missions for an individual science theme or a particular class? Are there alternative mission management approaches (e.g., transfer to an outside technical or educational institution for training or other purposes) that could reduce mission costs during extended operations and continue to serve SMD's science objectives?

Extended Mission Science is Productive and Valuable

- Voyagers in operation nearly 40 years, over three decades beyond prime missions, now at edge of the heliosphere

- Together with Hubble, the Spitzer Space Telescope identified very distant galaxy GNz-11, finding that star formation proceeds much more rapidly than previously known in early universe

- The Aqua Earth-observing spacecraft showed that the melting of the Greenland ice sheet in 2012 was the most extensive surface melting measured to date

- The STEREO spacecraft obtained the first 360 degree images of the sun

- The Mars Exploration Rovers Spirit and Opportunity identified habitable hydrothermal environments on Mars

- The Lunar Reconnaissance Orbiter identified thin layers of water ice in the permanently shadowed polar regions

Committee Roster

VICTORIA E. HAMILTON, Southwest Research Institute, *Co-Chair*

HARVEY D. TANANBAUM, Smithsonian Astrophysical Observatory, *Co-Chair*

ALICE BOWMAN, Johns Hopkins University, Applied Physics Laboratory

JOHN R. CASANI, Jet Propulsion Laboratory (Retired)

JAMES H. CLEMMONS, The Aerospace Corporation

NEIL GEHRELS, NASA Goddard Space Flight Center

FIONA A. HARRISON, California Institute of Technology

MICHAEL D. KING, University of Colorado Boulder

MARGARET G. KIVELSON, University of California, Los Angeles

RAMON E. LOPEZ, The University of Texas at Arlington

AMY MAINZER, Jet Propulsion Laboratory

ALFRED S. MCEWEN, University of Arizona

DEBORAH VANE, Jet Propulsion Laboratory

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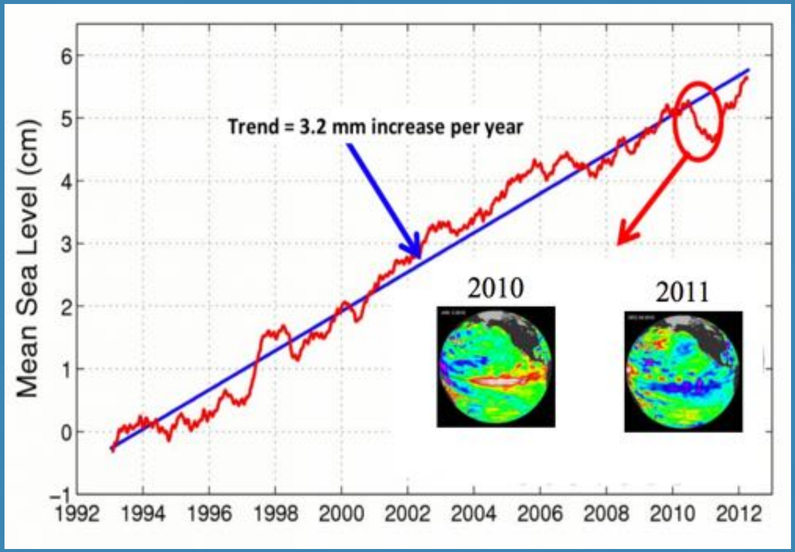
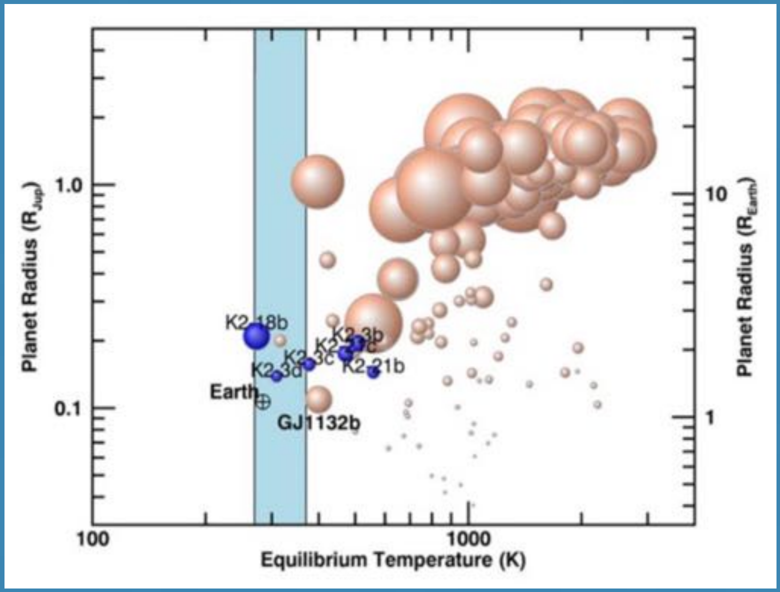
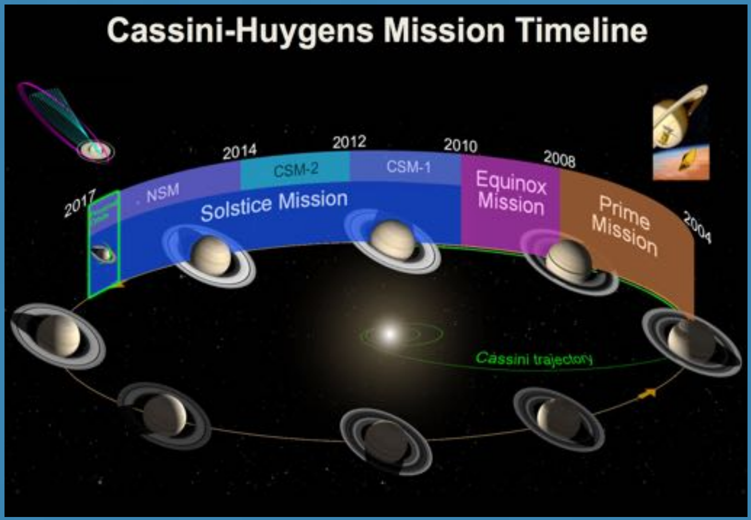


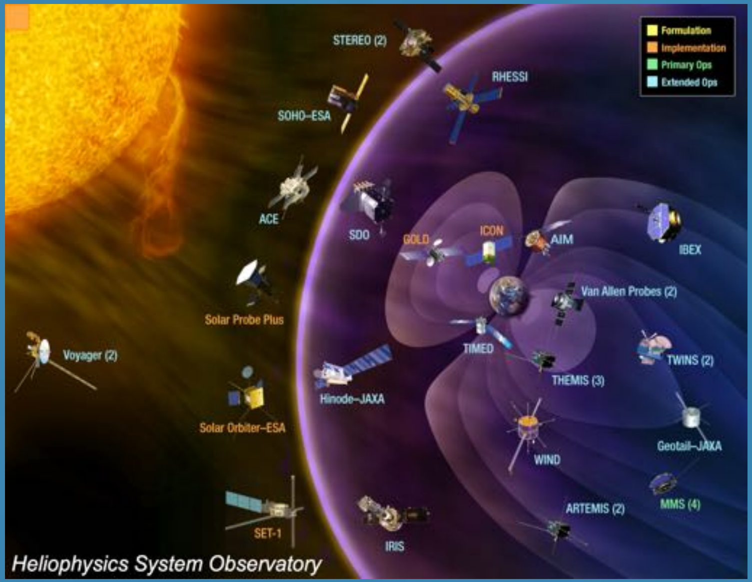
A half-dozen Earth Science missions contribute to documenting sea level rise and ocean mass changes



Kepler/K2 added many potentially rocky planets to set of known transiting planets



Significantly more of the Saturnian year observed since prime mission

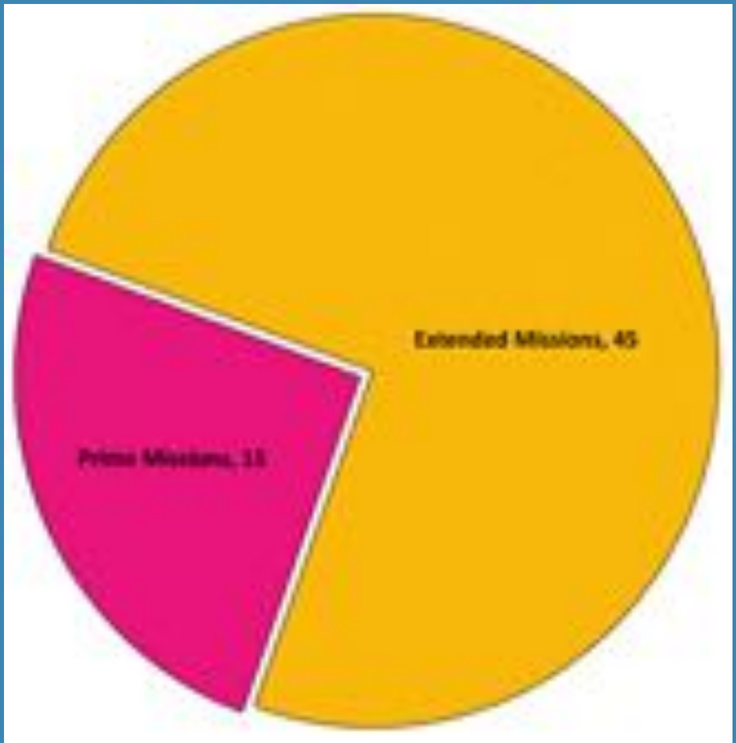


Heliophysics System Observatory depends on extended missions for synoptic view of heliosphere

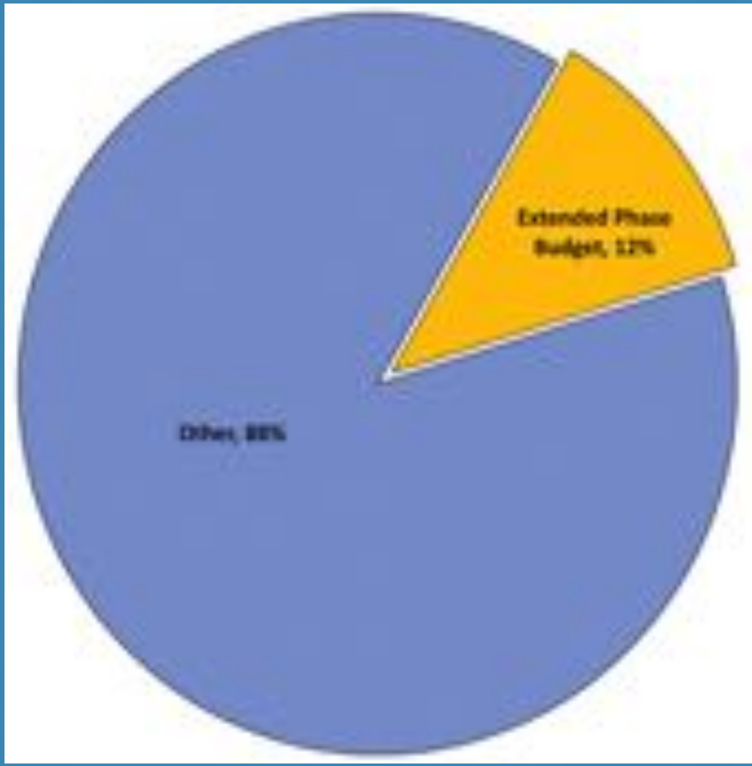
Extended Mission Science is a Bargain

Approximately three quarters of the NASA science missions currently flying are in extended phase, but represent only ~12% of the Science Mission Directorate's FY16 budget

Active space science missions



SMD budget, including extended phase missions



Bottom Line

- **Many extended science missions have made important discoveries via new destinations, observation types or targets, and/or data analysis methods**

- **Continuous coverage, long-baseline data sets, and statistically significant observations of infrequent events require continuity of measurement over years or decades and are best provided through missions in extended phase**

- **NASA's extended missions commonly achieve science objectives identified by the decadal surveys while providing unique insights for determining priorities and approaches for future exploration**

Based upon its assessment, the committee concluded that extended phase science missions are a vital part of NASA's overall science effort.

Recommendations
Cadence

Recommendation: NASA should conduct full Senior Reviews of science missions in extended operations on a 3-year cadence. This will require a change in authorizing language, and NASA should request such a change from Congress.

The Earth Science Division conducts annual technical reviews. The other divisions should assess their current technical evaluation processes, which may already be sufficient, in order to ensure that the divisions are fully aware of the projected health of their spacecraft, while keeping these technical reviews moderate in scope and focused on changes since the preceding review. (Chapter 3)

Why a Three-Year Cadence Instead of Two?

- Currently, proposal teams spend up to six months preparing for a 24-month mission extension. This creates an excessive burden on proposers and impacts ongoing planning and analyzing scientific data.
- Volunteer review teams should be easier to recruit over three-year periods as opposed to two.
- NASA currently spends considerable time, effort, and money conducting Senior Reviews every two years and will spend less with a three-year cadence.
- Spacecraft reliability and science observations can be easily predicted three years out (provided that NASA regularly assesses spacecraft and instrument health, as called for in the recommendation).

A three-year cadence would ease these burdens, while enabling timely assessment of the quality of the data returned from these missions and their potential for continued productivity.

NASA will get more science, and more value, with a three-year review cadence.

Recommendations
Cadence Flexibility

Recommendation: NASA science divisions should be allowed to conduct reviews out of phase to allow for special circumstances and should have the added flexibility in organizing their reviews to take advantage of unique attributes of each division's approach to science. (Chapter 3)

Recommendations
The Importance of Extended Missions

Recommendation: NASA's Science Mission Directorate (SMD) policy documents should formally articulate the intent to maximize science return by operating spacecraft beyond their prime mission, provided that the spacecraft are capable of producing valuable science data and funding can be identified within the SMD budget. (Chapter 5)

Recommendation: NASA should strongly support a robust portfolio of extended-phase science missions. This support should include advance planning and sufficient funding to optimize the scientific return from continued operation of the missions. (Chapter 2)

Recommendation: If a Senior Review recommends termination of a mission due to funding limitations rather than limited science return, NASA should allow the team to re-propose with an innovative, possibly less scientifically ambitious, approach at reduced operational cost and increased risk. (Chapter 3)

Recommendations: *Range of Objectives for Senior Review Proposals*

Recommendation: In order to obtain best value for money, NASA should encourage extended mission proposals to propose any combination of new, ground-breaking, and/or continuity science objectives. (Chapter 3)

Recommendation: NASA should continue to encourage and support extended missions that target new approaches for science and/or for national needs, as well as extended missions that expand their original science objectives and build on discoveries from the prime phase mission. (Chapter 5)

Recommendations
Senior Review Panels (1)

Recommendation: Each of the divisions should ensure that their timelines allocate sufficient time for each stage of the Senior Review process, including a minimum of 6 to 8 weeks from distribution of proposals to the panels until the panel meets with the mission teams. The panels should have at least 4 weeks to review the proposals and to formulate questions for the mission teams, and the mission teams should be allocated at least 2 weeks to generate their responses to the panel questions. (Chapter 3)

Adequate time for the reviews is vital for a thorough review. Expensive and irreplaceable spacecraft are being assessed and the job cannot be rushed or it may be done badly. Review teams are volunteers, not contractors.

Recommendations
Senior Review Panels (2)

Recommendation: NASA's Science Mission Directorate should assemble Senior Review panels that:

- **Are comprised primarily of senior scientists knowledgeable about and experienced in mission operations so as to ensure that the operational context of the science being proposed and evaluated is considered in the review (individuals with operations and/or programmatic expertise may also be included as needed);**
- **Are assembled early to avoid or accommodate conflicts of interest, and ensure availability of appropriate expertise;**
- **Include some continuity of membership from the preceding Senior Review to reap advantage of corporate memory;**
- **Include some early-career members to introduce new and important perspectives and enable them to gain experience for future Senior Reviews.**

(Chapter 3)

Recommendations
Senior Review Panels (3)

Recommendation: NASA's Science Mission Directorate division directors should continue to communicate among themselves to identify and incorporate best practices across the divisions into the Senior Review proposal requirements and review processes and procedures. (Chapter 3)

Recommendation: In its guidelines to the proposal teams and the Senior Review panels, NASA should state its intention to solicit feedback from its proposal teams and review panels about the suitability of the proposal content and review process. After obtaining such feedback, NASA should respond and iterate as needed with stakeholders to improve the review process, where possible. (Chapter 3)

Recommendations: *Effective Practices, Risk Posture, and Communication*

Recommendation: NASA should provide open communications and dissemination of information based on actual experience with extended missions so that all missions are aware of and able to draw on prior effective practices and procedures, applying them during development of ground systems and flight procedures, as well as when formulating staffing and budgetary plans for the prime and extended-mission phases. (Chapter 5)

Recommendation: NASA should continue to assess and accept increased risk for extended missions on a case-by-case basis. The headquarters division, center management, and the extended-mission project should discuss risk posture during technical reviews and as part of the extended mission and subsequent Senior Review proposal preparation process and should make all parties fully aware of all cost, risk, and science trade-offs. (Chapter 5)

Recommendations: *Funding for Extended Missions (1)*

Recommendation: NASA should continue anticipating that missions are likely to be extended and identify funding for extended missions in the longer-term budget projections. (Chapter 5)

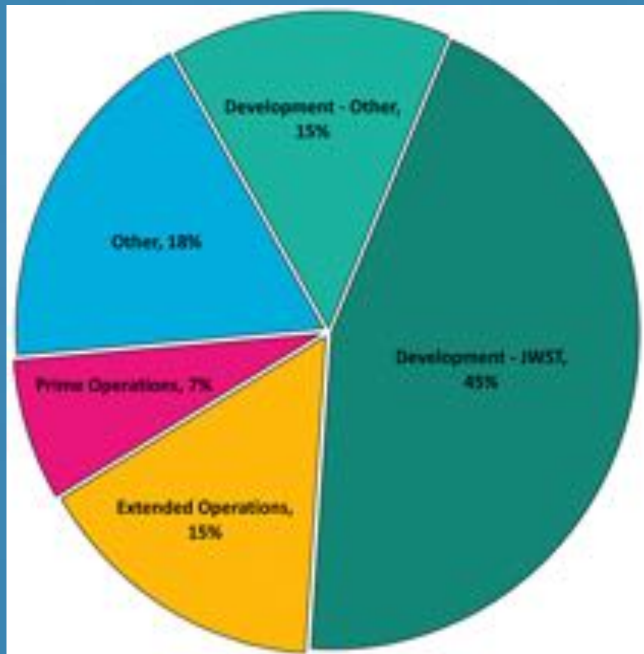
Recommendation: NASA should continue to provide resources required to promote a balanced portfolio, including a vibrant program of extended missions. (Chapter 4)

Recommendations: *Funding for Extended Missions (2)*

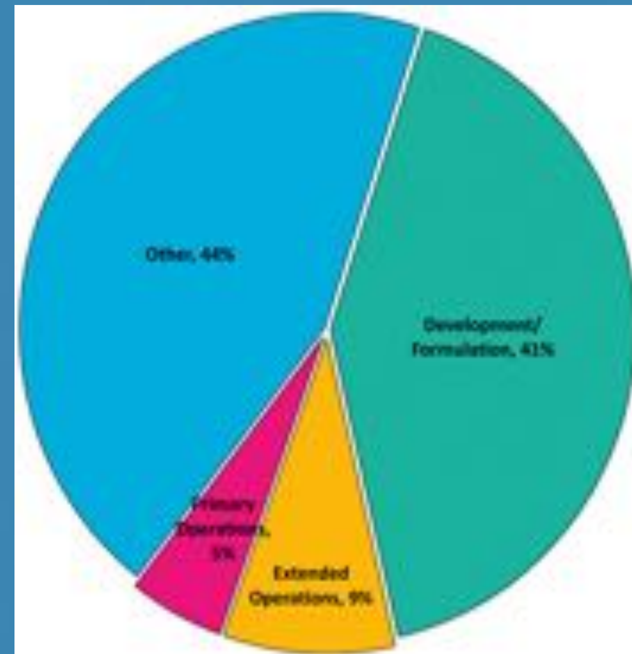
Recommendation: Given the demonstrated science return from extended missions, NASA should continue to recognize their scientific importance and, subject to assessments and recommendations from the Senior Reviews, ensure that after the first two Senior Reviews, both operations and science for high-performing missions are funded at roughly constant levels, including adjustments for inflation. (Chapter 5)

Most cost savings are made during the transition from prime to extended phase and during the early extended phase. After that, most efficiencies have been achieved, and costs may even increase due to issues pertaining to an aging spacecraft. Stable funding (including inflation) after the first two Senior Reviews is vital. Further cuts at this point often disproportionately affect science return.

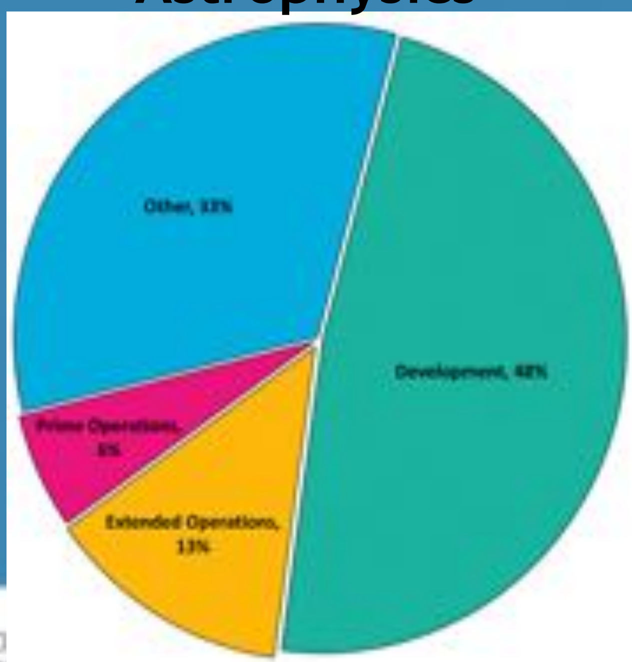
NASA Science Division Budgets FY 2016



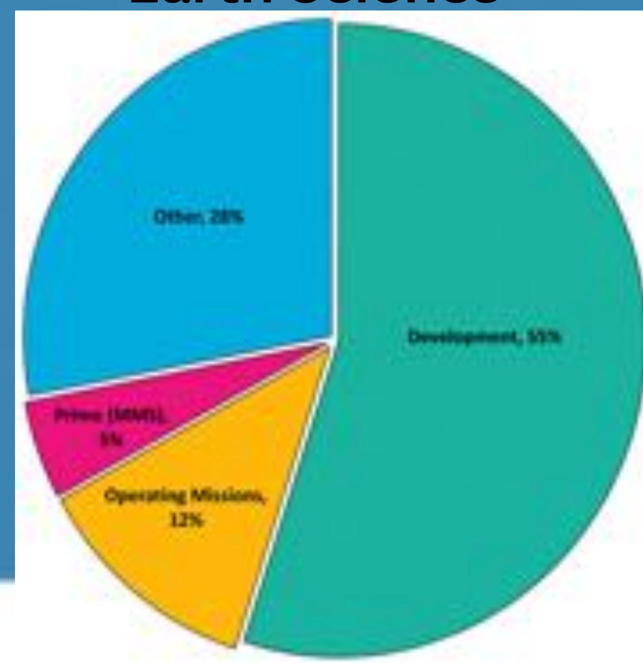
Astrophysics



Earth Science



Planetary



Heliophysics

Powering Science—NASA's Large Strategic Science Missions

Committee on Large Strategic NASA Science Missions

August 17, 2017

Ralph L. Mcnutt, Co-Chair
Karthryn C. Thornton, Co-Chair

Statement of Task

This study will examine the role of large, strategic missions within a balanced program across NASA Science Mission Directorate (SMD) space and Earth sciences programs. The study will consider the role and scientific productivity of such missions in advancing science, technology and the long-term health of the field, and provide guidance that NASA can use to help set the priority of larger missions within a properly balanced program containing a range of mission classes.

The National Academies will appoint an ad-hoc committee that will:

1. Provide recommendations to help guide future prioritization by NASA of large strategic space and Earth science missions within a balanced program containing a range of mission classes. That is, what are general principles that SMD could use (e.g., a figure of merit approach) to trade off within a limited budget between development and operation of large, strategic missions and the cadence and/or cost caps of medium size and small PI-led mission lines?

The committee will not offer prioritized recommendations on any specific current or future missions, which is a function of each science theme's decadal survey process.

2. In this framework, assess the impact of current and recent SMD missions with a range of life cycle costs. A representative subset of missions within each of SMD's four science theme areas may be selected for analysis. The committee's analysis of each representative mission will include a discussion of the relation between mission scientific impact and mission life cycle cost (or cost to date) in order to understand the return on expenditures for various mission classes. In describing the impact of the chosen missions the committee should consider dimensions such as:

- Scientific productivity;
- Impact on the current and future health of the relevant scientific community; and
- Contribution to development and demonstration of technology applicable to future missions.

The National Academies of SCIENCES ENGINEERING MEDICINE

Committee On Large Strategic NASA Science Missions

- RALPH L. MCNUTT, Jr., Applied Physics Laboratory, Co-Chair
- KARTHRYN C. THORNTON, University of Virginia, Co-Chair
- DAVID A. BEARDEN, The Aerospace Corporation
- JOEL N. BREGMAN, University of Michigan
- ANNY CAZENAVE, International Space Sciences Institute
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- MARC L. IMHOFF, University of Maryland
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- CAROL S. PATY, Georgia Institute of Technology
- MARC D. RAYMAN, Jet Propulsion Laboratory
- WILLIAM S. SMITH, ScienceWorks International
- EDWARD L. WRIGHT, University of California, Los Angeles
- GARY P. ZANK, University of Alabama in Huntsville

Important First Question

What is meant by “large, strategic mission”? NASA tries to not use the term “flagship” any more. But “large, strategic missions” refers to “flagship” missions.

It is possible to have smaller strategic missions, and also possible to have missions (e.g. LRO) that are strategic to other parts of NASA.

However, not all strategic missions are large, but all large missions are strategic.

Meetings

First meeting: Oct 5-6, 2016. Washington

Heard from new associate administrator for science, plus all four division directors, as well as former AA for SMD, current and former congressional staff.

Second meeting: Dec 5-7, 2016. Irvine

Heard from former chairs of decadal surveys as well as PIs for large and smaller missions, as well as experts on cost estimation.

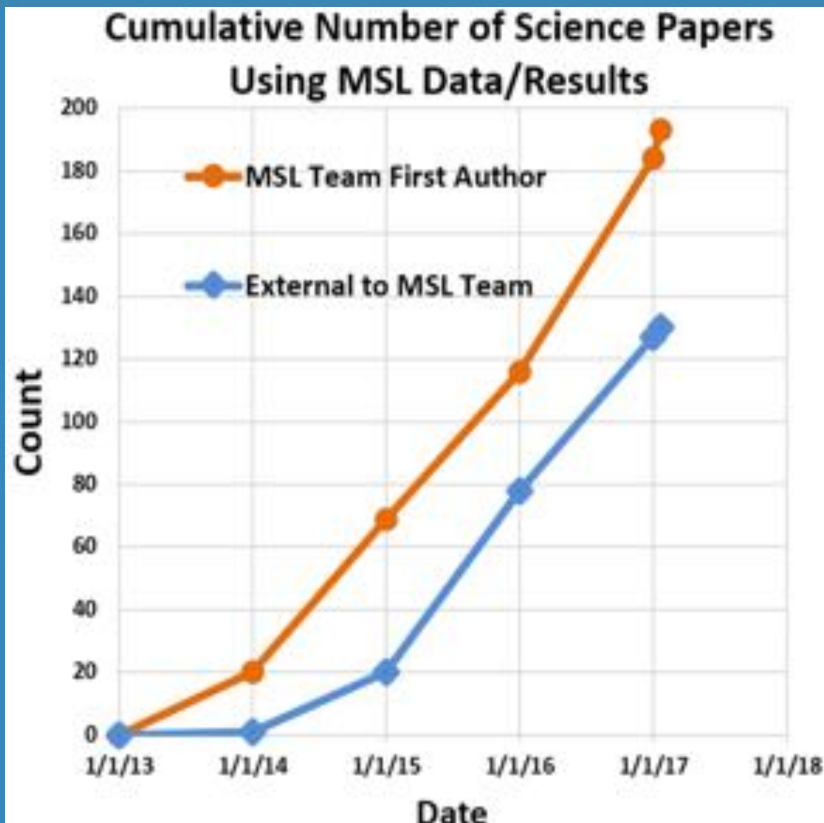
Third meeting: Feb 15-17, 2017. Washington

Mostly writing meeting. Follow-up with NASA sponsors for any revised input.

Large Strategic Missions Have Many Benefits

- Capture science data that cannot be obtained in any other way, owing usually to the physics of the data capture driving the scale and complexity of the mission.
- Answer many of the most compelling scientific questions facing the scientific fields supported by NASA's Science Mission Directorate, and most importantly develop and deepen humanity's understanding of the Earth, our Solar System, and the universe.
- Open new windows of scientific inquiry, expanding the discovery space of humanity's exploration of our own planet and the universe, and providing new technology and engineering approaches that can benefit future small, medium-size, and large missions.
- Provide high quality (precise and with stable absolute calibration) observations sustained over an extended period of time.
- Receive a high degree of external visibility, often symbolically representing NASA's science program as a whole.
- Support the workforce, the industrial base, and technology development
- Provide greater opportunities for international collaboration as well as opportunities for deeper interdisciplinary investigations across NASA science areas.
- Maintain U.S. leadership in space

Scientific Productivity and Supporting the Workforce



The diversity of science enabled by the MSL instrument suite has led to the involvement of a large segment of the Mars science community in the analysis of MSL data—the entire science team consists of 485 people.

Since landing, the number of peer-reviewed science papers first-authored by members of the MSL team has increased steadily. Additional papers using MSL data or results have been published by members of the scientific community who are not MSL team members.

Large Strategic Missions are Essential

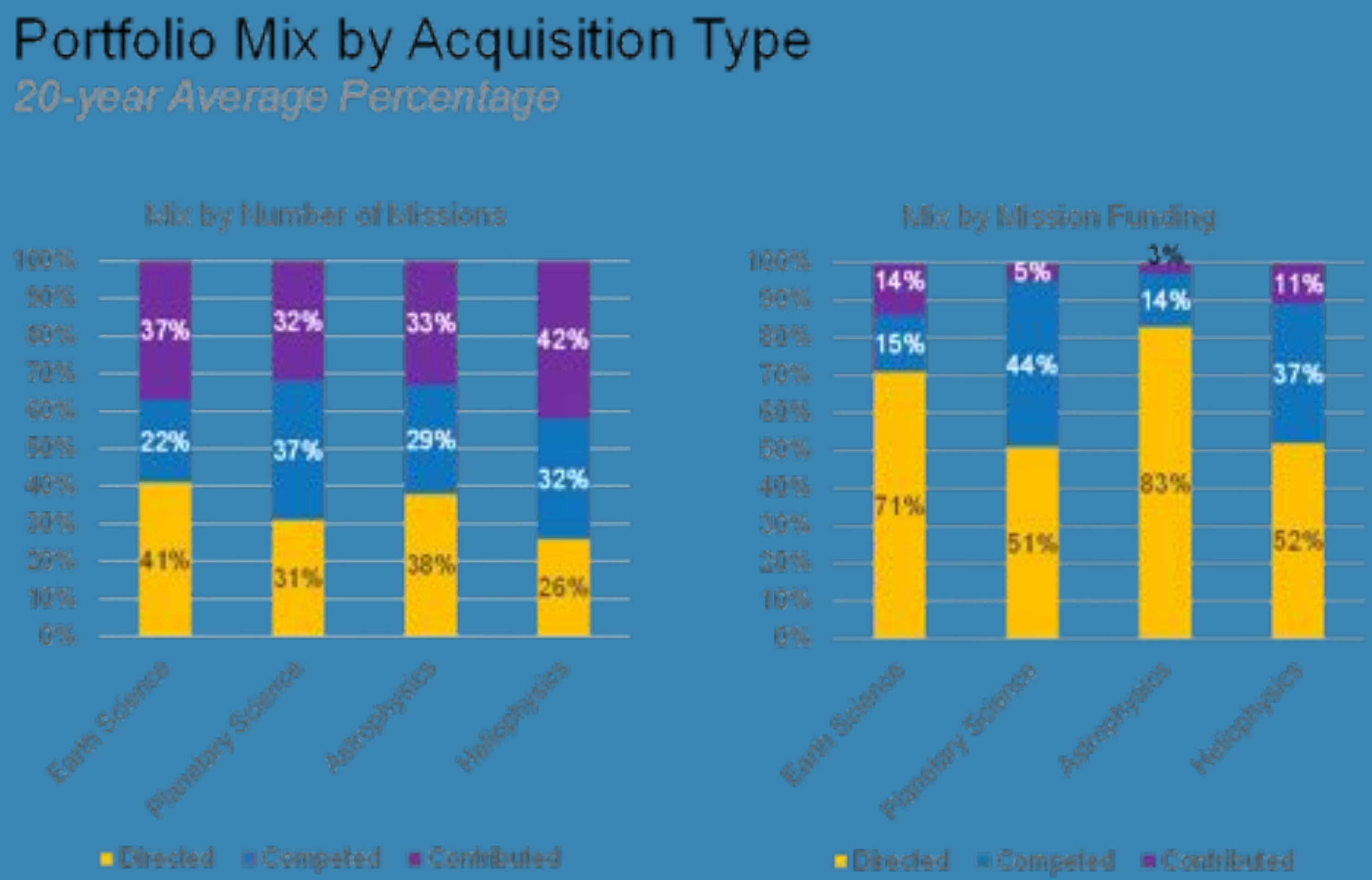
- Large strategic missions are critical for the conduct of space science in each of NASA's four divisions and are required for the pursuit of compelling scientific questions.

- Large strategic missions are essential to maintaining the global leadership of the United States in space exploration and in science.

- Large strategic science missions support large teams of scientists and graduate students and therefore support the development and the health of their respective scientific communities in ways that smaller missions cannot.

- Balance across the entire NASA science program includes an appropriate mix of small, medium-size, and large missions.

Part of a Balanced Program

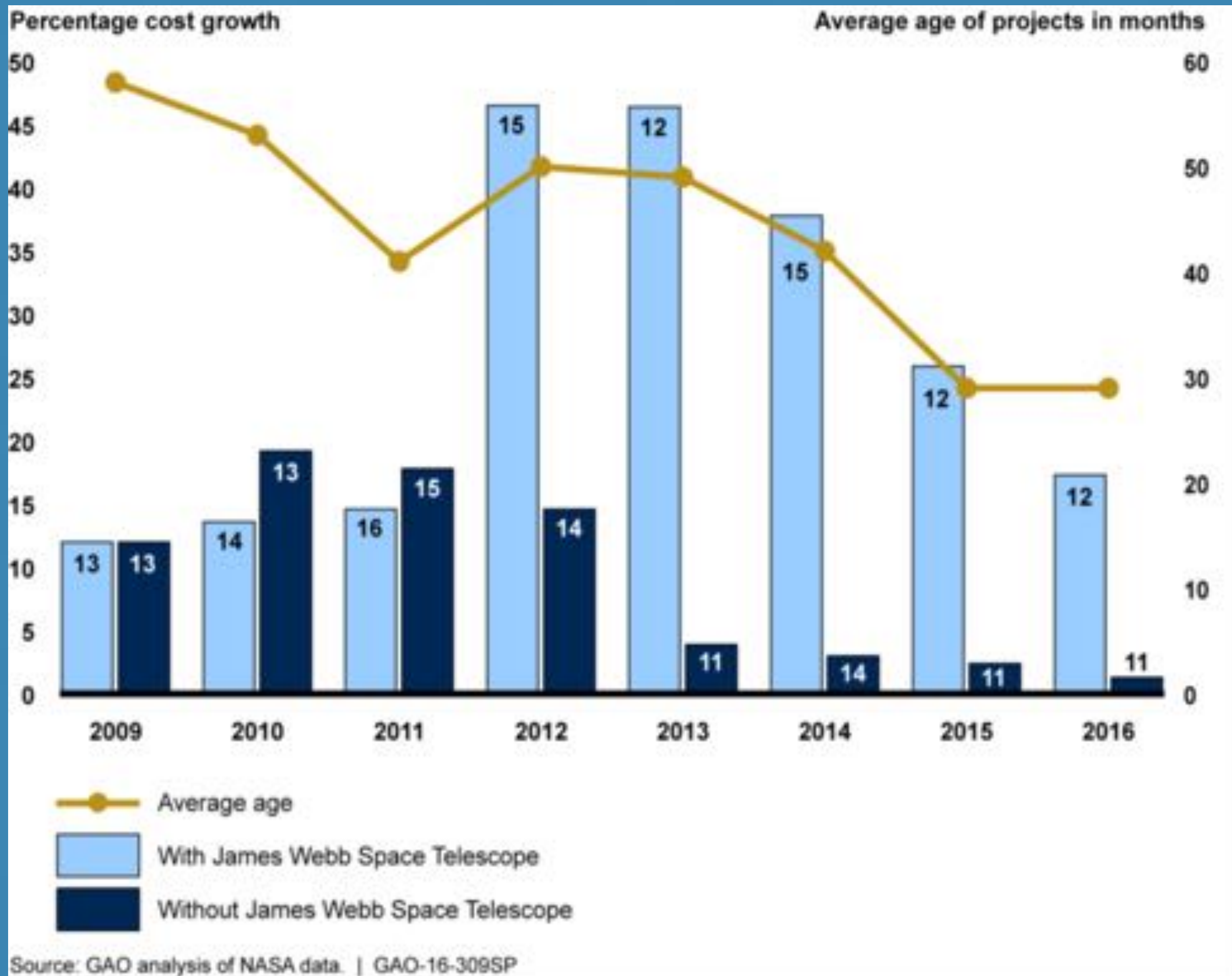


When the portfolio mix is evaluated by number of missions, the mix is much more evenly distributed than when it is evaluated by funding, both within each division and when the divisions are compared to each other. The difference between evaluating the portfolio mix by budget amounts vs. numbers of missions highlights one of the difficulties of trying to assess "balance," especially across divisions.
SOURCE: Aerospace Corp

Cost Control Mechanisms Work, And are Vital for Maintaining Balance

- In the last decade, NASA has introduced numerous cost control and cost evaluation mechanisms. These mechanisms have been effective at limiting unexpected overruns and impacts on programmatic balance. The committee concluded that this has been an important NASA accomplishment in the past decade that has led to greater programmatic stability and allowed the divisions to better achieve their goals for balance.

- Cost control of large strategic missions remains vital in order to preserve overall programmatic balance



Percentage of cost growth for a range of NASA missions from 2009 to 2016. The data, when the James Webb Space Telescope is excluded, show a steady decrease in cost growth since 2010. This is consistent with other analyses such as that conducted by The Aerospace Corporation.

SOURCE: Government Accountability Office.

Recommendations
Prioritization

- RECOMMENDATION: NASA should continue to plan for large strategic missions as a primary component for all science disciplines as part of a balanced program that also includes smaller missions.

- RECOMMENDATION: When faced with the requirement to trade off between development and operation of large strategic missions and the smaller missions within their portfolios, NASA's Science Mission Directorate divisions should look first to their relevant decadal surveys and their midterm reviews for guidance. If these are insufficient, the SMD divisions should seek the advice of their relevant advisory groups.

Recommendations
Prioritization 2

RECOMMENDATION: NASA should ensure that robust mission studies that allow for trade-offs (including science, risk, cost, performance, and schedule) on potential large strategic missions are conducted prior to the start of a decadal survey. These trade-offs should inform, but not limit, what the decadal surveys can address.

Recommendations
Flexibility

- RECOMMENDATION: In preparation for the decadal surveys, large strategic mission proposal teams should consider describing ranges of scientific scope for their recommended large strategic missions, such as minimum science goals and maximum budgets, as well as identifying what science goals are most desirable at different budget levels. This approach may allow the scientific community and NASA to develop less expensive implementation strategies for mission concepts that do not exceed current budget limitations.

- RECOMMENDATION: The decadal surveys should formulate mission concept variants or other means to assess the boundaries of cost and technical risk and recommend the application of decision rules to provide flexibility to the NASA science divisions and most importantly the scientific community. This will enable further refinement of mission concepts when pursuing the scientific priorities identified by the decadal surveys.

Recommendations
Budget Estimation 1

- RECOMMENDATION: Budget constraints should be included in the development of a decadal scientific program. Flexibility in the “decision rules” that decadal surveys produce should allow for both the de-scoping of large strategic missions in the face of cost overruns or insurmountable technical barriers as well as the “up-scoping” of missions as new technological or other opportunities arise.

- RECOMMENDATION: Decadal surveys should be informed by, but not narrowly restricted to, future projections of available budgets. Such flexibility may enable new and potentially revolutionary large strategic missions.

Recommendations
Budget Estimation 2

- RECOMMENDATION: NASA should continue to use its various cost estimation and cost management tools to assess and control the costs and risks of large strategic missions to ensure that they remain a viable option. As new technologies and new missions arise, new cost estimation tools will be required to enable NASA to determine their likely costs. NASA should support the development of new tools to perform robust cost estimates and risk assessment. These new cost estimation tools will also be helpful in support of the National Academies' decadal surveys.

Recommendations: *NASA Can Publicly Make a Better Case*

- RECOMMENDATION: In order to demonstrate the role and scientific productivity of large strategic missions in advancing science, technology, and the long-term health of the field, NASA's Science Mission Directorate should develop a publicly accessible database, updated at least annually, that tracks basic data related to all confirmed missions in development as well as operational and past missions from each of the SMD divisions. These data should include development costs; publication numbers and other bibliographic data; outreach data (number of press releases and so on should be tracked); science, engineering, and other full-time equivalents (FTEs); and other routine data typically sought in senior review proposal submittals once prime missions have been completed. These data should be of sufficient detail and quality to enable basic analyses related to scientific productivity and contributions to the health of the respective fields.