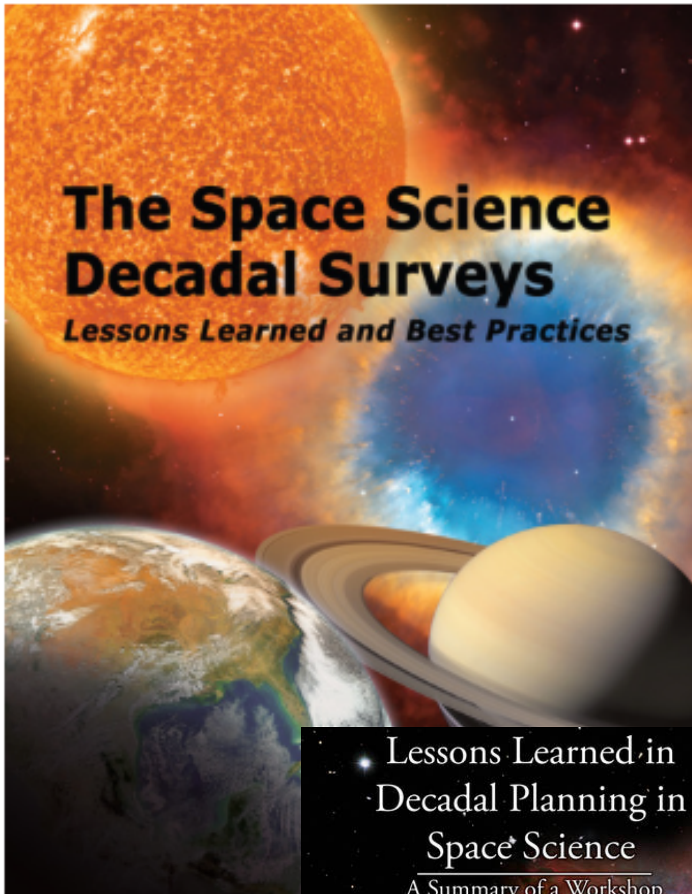

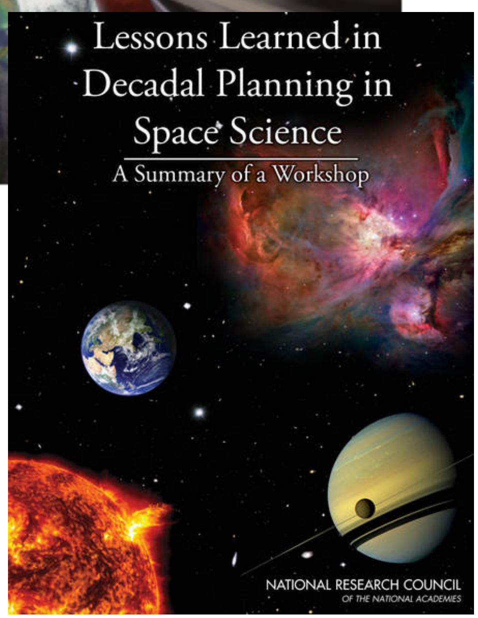

2012 Workshop Report

COMMITTEE ON SURVEY OF SURVEYS: LESSONS LEARNED FROM THE DECADAL SURVEY PROCESS

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Strategic missions played a prominent role in the committee's report.

from the Report Summary – "Challenges for Future Surveys"

The biggest missions and facilities*. The difficulty, complexity, and cost of "flagship" (or "strategic," or "high-profile") missions and facilities have grown, creating substantial challenges for decadal surveys.*

How can robust evaluations of the costs of such missions be made, and cost growth be contained, to protect other missions and activities?

How can multi-decade programs be managed successfully?

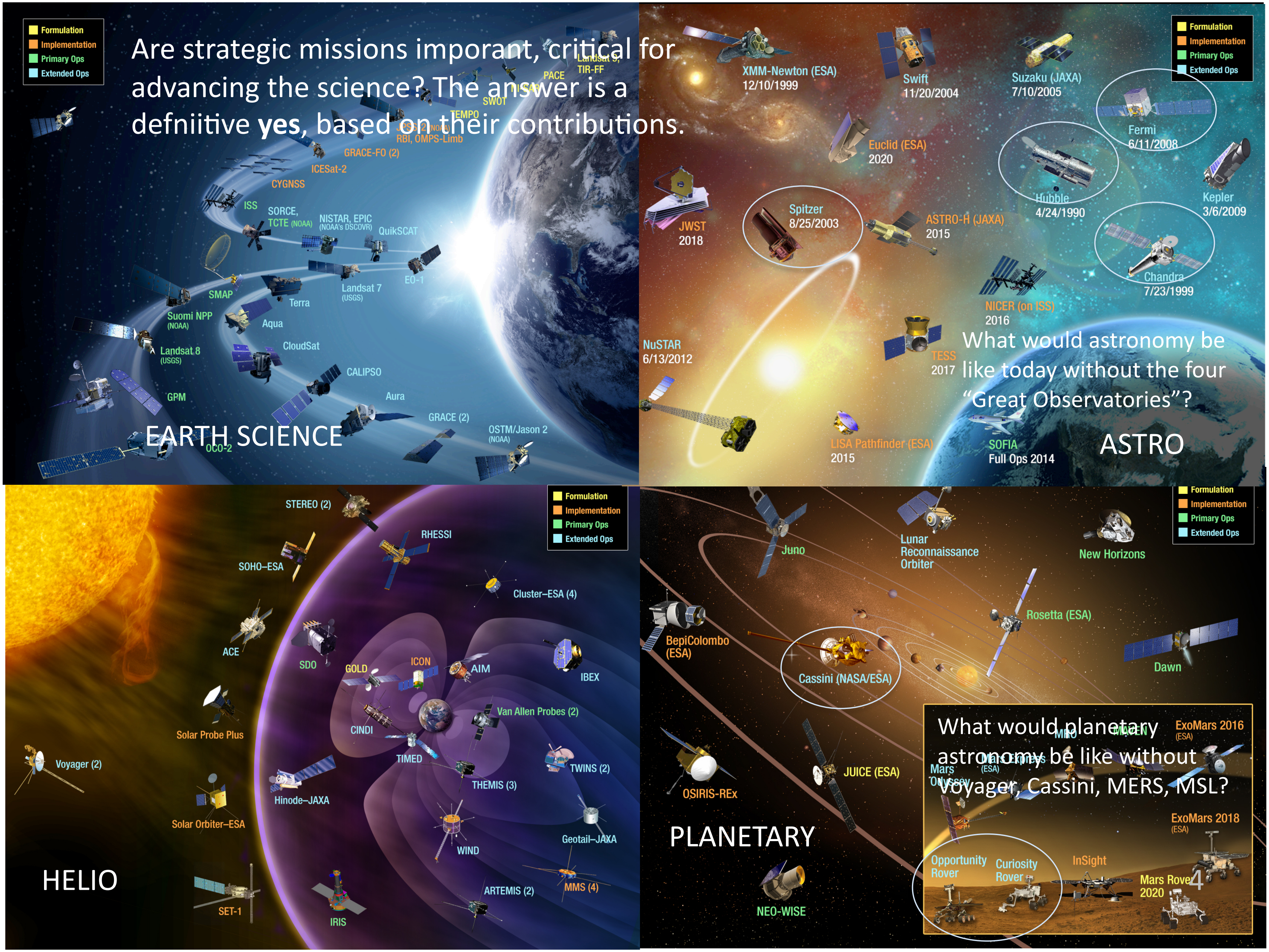
How might we protect important human resources, for example, the education and research support of the next generation of scientists, especially those with skills in technology development?

High-Profile (Strategic, Flagship) Missions – the good

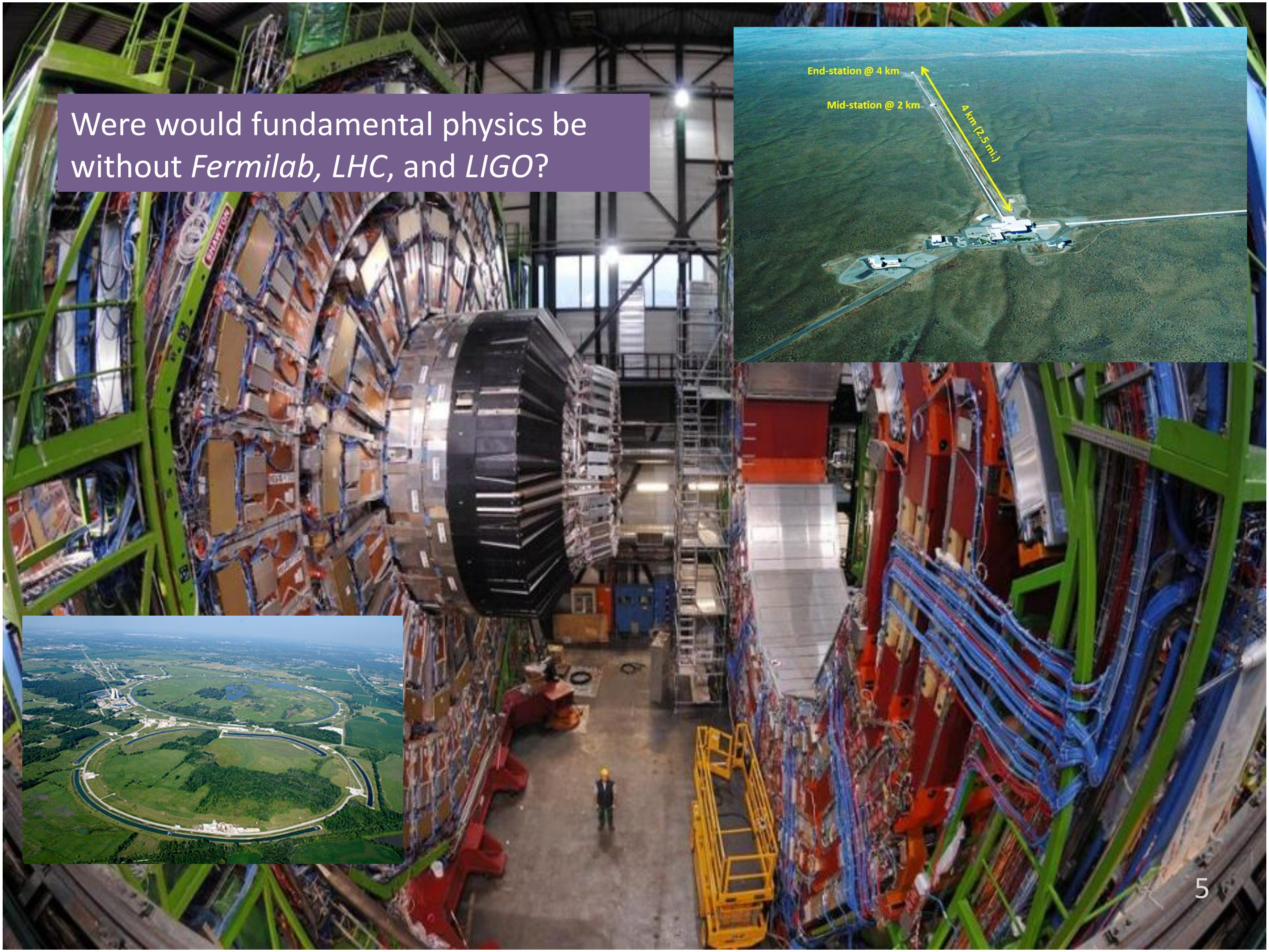
Within each division of NASA SMD, there are facilities and missions with the potential to have large-scale impacts on the program due to their strategic importance, scope, and/or size. These so-called high-profile missions address critical science goals or questions for the decade.

*High-profile missions are uniquely characterized by an implementation strategy that is performance-driven rather than cost-constrained. Performance-driven missions are driven by specific measurement or other requirements rather than cost constraints. This is contrasted with (typically) PI-led cost-capped missions where **descope**s are required if a performance requirement cannot be met within pre-established cost constraints.*

*Because a substantial part of the science accomplished in a decade comes from smaller missions, it is important for surveys to strike a **balanc**e between larger, non-competed, high-profile missions and the competed line of smaller missions.*


Are strategic missions imporant, critical for advancing the science? The answer is a defniitive **yes**, based on their contributions.
Formulation
Implementation
Primary Ops
Extended Ops
EARTH SCIENCE
Landsat 9, TIR-FF
PACE
NISAR
SWOT
TEMPO
JPSS-2 (NOAA)
RBI, OMPS-Limb
GRACE-FO (2)
ICESat-2
CYGNSS
ISS
SORCE, TCTE (NOAA)
NISTAR, EPIC (NOAA'S DSCOVR)
QuikSCAT
EO-1
Landsat 7 (USGS)
Terra
SMAP
Suomi NPP (NOAA)
Aqua
CloudSat
Landsat 8 (USGS)
CALIPSO
GPM
Aura
GRACE (2)
OSTM/Jason 2 (NOAA)
OCO-2
ASTRO
XMM-Newton (ESA) 12/10/1999
Swift 11/20/2004
Suzaku (JAXA) 7/10/2005
Fermi 6/11/2008
Euclid (ESA) 2020
Hubble 4/24/1990
Kepler 3/6/2009
JWST 2018
Spitzer 8/25/2003
ASTRO-H (JAXA) 2015
Chandra 7/23/1999
NICER (on ISS) 2016
NuSTAR 6/13/2012
TESS 2017
What would astronomy be like today without the four “Great Observatories”?
LISA Pathfinder (ESA) 2015
SOFIA Full Ops 2014
HELIO
STEREO (2)
RHESSI
SOHO–ESA
Cluster–ESA (4)
ACE
SDO
GOLD
ICON
AIM
IBEX
Van Allen Probes (2)
CINDI
TIMED
Solar Probe Plus
Voyager (2)
TWINS (2)
THEMIS (3)
Hinode–JAXA
Solar Orbiter–ESA
WIND
Geotail–JAXA
ARTEMIS (2)
MMS (4)
SET-1
IRIS
PLANETARY
Juno
Lunar Reconnaissance Orbiter
New Horizons
Rosetta (ESA)
BepiColombo (ESA)
Cassini (NASA/ESA)
Dawn
What would planetary astronomy be like without Voyager, Cassini, MERS, MSL?
MRO
MAVEN
ExoMars 2016 (ESA)
Mars Express (ESA)
Mars Odyssey
OSIRIS-REx
JUICE (ESA)
ExoMars 2018 (ESA)
Opportunity Rover
Curiosity Rover
InSight
Mars Rover 2020
NEO-WISE

Were would fundamental physics be without *Fermilab, LHC*, and *LIGO*?



High-Profile Missions – the challenges

Hish-profile missions usually probe the limits of our scientific knowledge and technical capabilities, with attendant difficulties in the organization, management, building, and operation of a unprecedentedly complex machine. They are some of the most complicated things ever built.

*High-profile missions, as the term is used here, refer to missions of significant importance to a program that are able to have substantial **negative impact** on program health if not implemented successfully or within fiscal constraints.*

Within each division of NASA SMD, there are facilities and missions with the potential to have large-scale impacts on the program due to their strategic importance, scope, and/or size… High-profile missions continue to be critical parts of the program because certain missions cannot simply be broken down in an efficient or effective manner into smaller components and still accomplish the science goal.

*Because of their importance to the community's science ambitions, high-profile missions have the potential for a significant (negative) impact on performance across all activities within a division, and possibly across NASA SMD, for the coming decade **if there is a mission failure or significant unanticipated cost growth.***

"…most serious case of a high-profile mission that exceeded its division resources…Early estimates of technical difficulty were substantially underestimated and the project was critically under-funded throughout its development phase to 2011."

Mission creep: "…pressures from a disciplinary community…for a more advanced and capable mission than envisioned by the survey…Changes in mission science emphasis led to technology development challenges, significant cost growth, and launch delay."

JWST

BOX 3.1
James Webb Space Telescope

The recent, most serious case of a high-profile mission that exceeded its division resources is the James Webb Space Telescope (JWST). Early estimates of technical difficulty were substantially understated, and the project was critically underfunded throughout its development phase to 2011. This resulted in significant increases in cost and major launch delays, whi … y JWST was determined to be an agency-wide priority missio … s-trophysics Division into its own funding line within the Scienc …

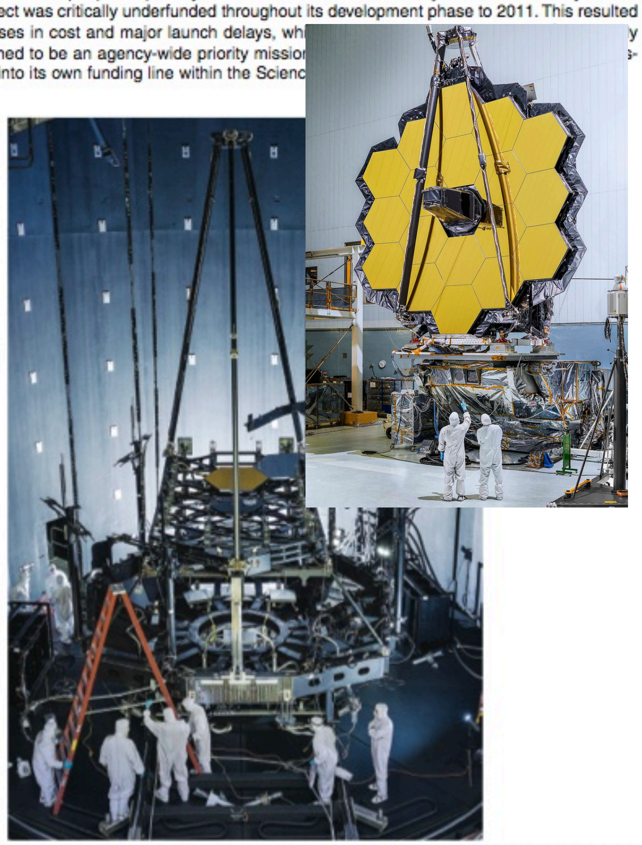


FIGURE 3.1.1 Major structural components of the James Webb Space Telescope being prepared for a cryogenic test. SOURCE: Courtesy of NASA/Chris Gunn.

[1]See JWST Independent Comprehensive Review Panel, *Final Report*, October 29, 2010, http://www.nasa.gov/pdf/499224main_JWST-ICRP_Report-FINAL.pdf.

ICESat-2

BOX 3.2
Requirements Creep

Mission creep can occur in missions of any size. The 2007 Earth science and applications from space decadal survey warned that "NASA and the scientific community must avoid 'requirements creep' and the consequent damaging cost growth."[1] Yet, as noted in that survey's midterm assessment, "absent a countervailing mechanism, there is a natural tendency for individual missions to become more responsive to single communities or disciplines rather than to the overall Earth system science community. For example, changes to the survey-recommended ICESat-2 mission were, in part, the result of pressures from a disciplinary community whose desires for a more advanced and capable mission than envisioned by the survey were not restrained by consideration of the budgetary impact on development of future missions serving different communities."[2] Changes in mission science emphasis led to technology development challenges, significant mission cost growth, and launch delay.[3]

FIGURE 3.2.1 The Ice, Cloud, and land Elevation Satellite-2 (ICESat-2) is the second generation of the laser altimeter ICESat mission and is scheduled for launch in July 2016. SOURCE: Courtesy of Orbital ATK.

[1] National Research Council (NRC), *Earth Science and Applications from Space: National Imperatives for the Next Decade and Beyond*, The National Academies Press, Washington, D.C., 2007, p. 43.
[2] NRC, *Earth Science and Applications from Space: A Midterm Assessment of NASA's Implementation of the Decadal Survey*, The National Academies Press, Washington, D.C., 2012, p. 29.
[3] See Dan Leone, "NASA's IceSat-2 Busts Budget, Report Headed to Congress," *Space News*, December 3, 2013, http://spacenews.com/38475nasas-icesat-2-busts-budget-report-headed-to-congress/.

Recommended program from Planetary 2013: two high-profile “budget busters”

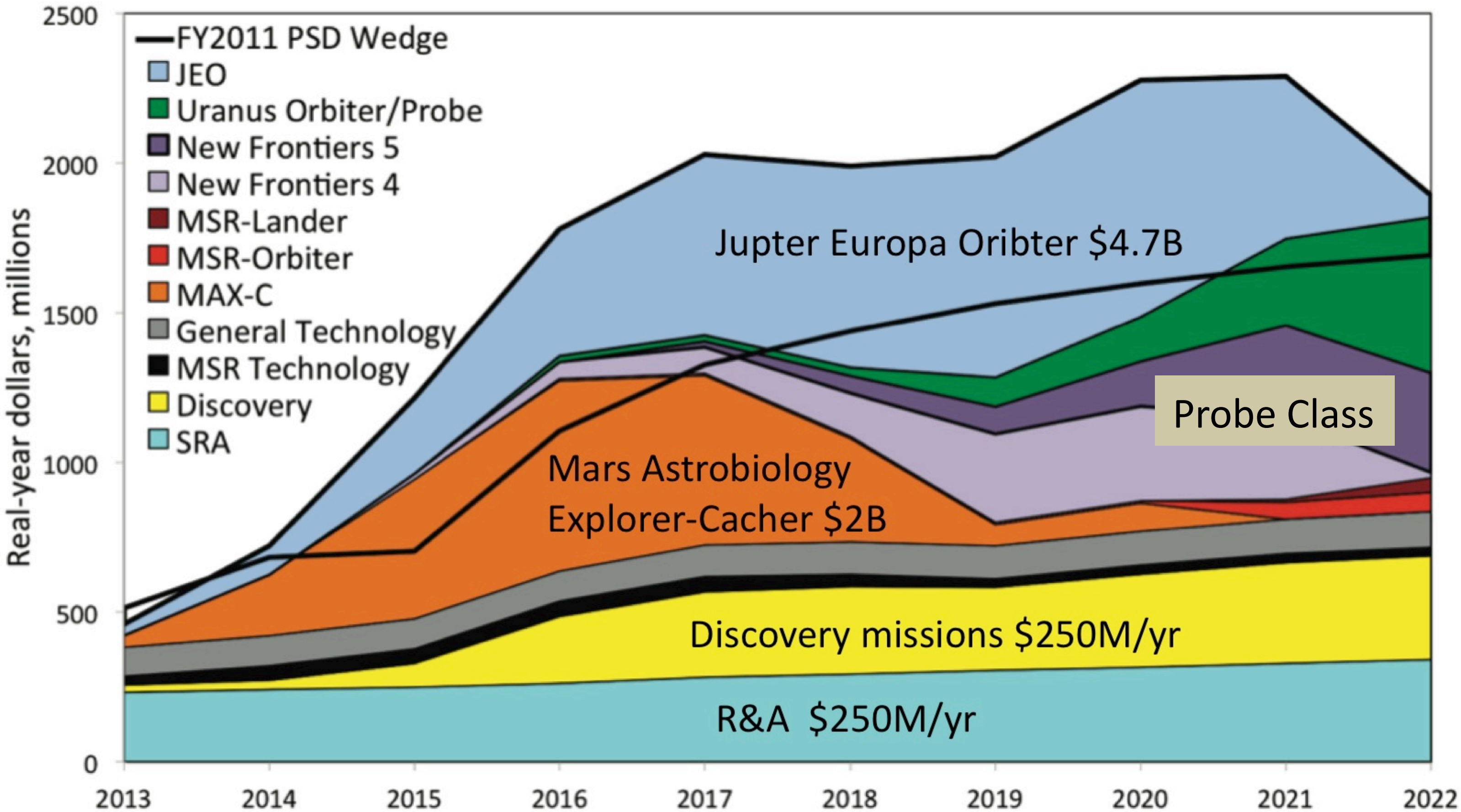


FIGURE 3.1 Notional funding profiles for the planetary science decadal survey with recommended programs, in real-year dollars, for fiscal years 2013-2022. The heavy black line shows the projected (at the time of the decadal survey) available funding for the NASA Planetary Science Division (PSD), accounting for all commitments at the time (including the Mars Trace Gas Orbiter). The available funding grows sharply in the first few years of the decade as some current programs come to an end. The cost assumed for the Jupiter Europa Orbiter (JEO) is $4.7 billion, illustrating clearly why a reduction in the scope and cost of this mission was necessary. NOTE: Acronyms are defined in Appendix F.

Contrary to lore, the fraction of NASA budget in high-profile missions is about constant.

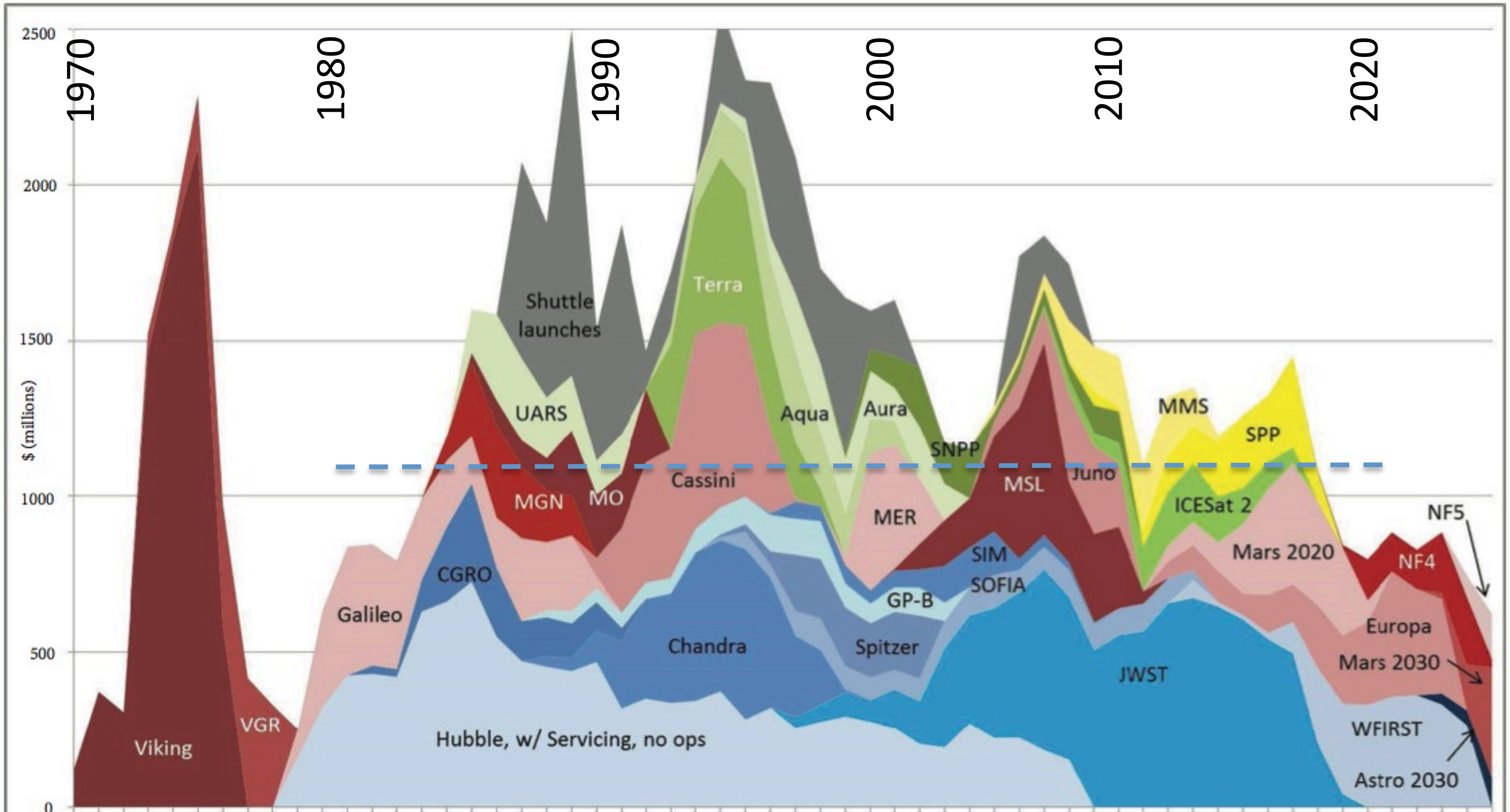


FIGURE 3.2 Annual expenditures in millions of dollars (normalized to fiscal year [FY] 2015) for the development and operation of high-profile science missions for all of the divisions within NASA's Science Missions Directorate from 1969 to 2026. Also shown are the estimated costs associated with science-focused space shuttle launches, such as Magellan, Galileo, Compton Gamma Ray Observatory (CGRO), Upper Atmosphere Research Satellite (UARS), Chandra X Ray Observatory, and Hubble Space Telescope and its five servicing missions. Decadal surveys pay attention to both the peak expenditures during development and the integrated cost (including operations) of recommended missions in order to ensure the maintenance of programmatic balance. The figures quoted for FY 2015 and beyond, and all missions after Solar Probe Plus, are notional. Following official NASA practice, the cost of each space shuttle launch was assumed to be $400 million and allocated over 3 fiscal years. NOTE: Acronyms are defined in Appendix F. SOURCE: NASA Science Mission Directorate.

This issue is not exclusive to NASA. For example, NSF's participation in the Atacama Large Millimeter/submillimeter Array (ALMA), an international endeavor, was a high priority for Astro2000. This facility is the premier facility of submillimeter radio astronomy in the world. However, cost growth in ALMA construction and operations has been substantial, resulting in an erosion in NSF's support for ground-based optical telescopes, particularly those "open-access" facilities run by the National Optical Astronomy Observatories, and also for the program of research grants run by NSF AST.

Although there are parallels to some large facilities in the NSF AST, [the Decadal Survey report] focuses on NASA missions because the level of cost growth and its negative consequences has been a bigger problem…

ALMA's construction and operations costs were substantially underestimated.

"It can be challenging, if not impossible, for a single NASA division to maintain a balanced portfolio of activities while supporting the development of a multibillion dollar mission in the face of significant cost growth."

Because NASA's high-profile missions often start with cost estimates of more than $1 billion, cost growth can pose a significant threat to programmatic balance, given individual division budgets of ≤$1.8 billion per year. It can be challenging, if not impossible, for a single NASA division to maintain a balanced portfolio of activities while supporting the development of a multibillion dollar mission in the face of significant cost growth. Thus, it is imperative that survey committees make clear which parts of a performance-driven mission are truly required, and where any compromises or de-scopes might be acceptable. Furthermore, these compromises must be sufficient to execute the high-profile mission within the discipline's own budget. Both can be accomplished through ***clearly stated decision rules*** *that set forth the criteria by which the high-profile mission retains or loses its priority under various circumstances.*

Lesson Learned: High-profile missions are special cases within each of the disciplinary areas, presenting great opportunities for major advances in understanding, but also carrying significant risk for maintaining a balanced portfolio of activities—should unanticipated cost growth occur.

Examples of Decision Rules: MAX-C and JEO

Decision rules in Planetary 2013 *"required both missions to trim their budgets significantly to retain their priority rating…further required that high-profile missions be descoped or delayed rather than impact the other aspects of the planetary science portfolio."*

"Following these rules—despite much lower-than-anticipated funding levels… the Mars community was able to develop a credible Mars 2020 mission that addressed most of the key goals of the decadal survey…A rescoped Europa mission was granted a new start in administrations budget request for FY16."

BOX 3.3
Decision Rules

Five large high-profile missions were identified and prioritized by 2011 planetary science decadal survey.[1] The highest ranked of these missions were a Mars rover with sample-caching capability—as the first step toward Mars sample return—and a Europa orbiter mission (Jupiter-Europa Orbiter). The decision rules developed by the survey committee required both missions to trim their budgets significantly to retain their priority ranking. The decision rules further required that high-profile missions be de-scoped or delayed rather than negatively impact the other aspects of the planetary science portfolio. Following these rules—despite much lower-than-anticipated funding levels for the Planetary Science Division, the Mars community was able to develop a credible Mars 2020 mission that addressed most of the key goals of the decadal survey, while minimizing impact on the rest of the program. A re-scoped Europa mission was granted a new start in the administration's budget request for fiscal year 2016.

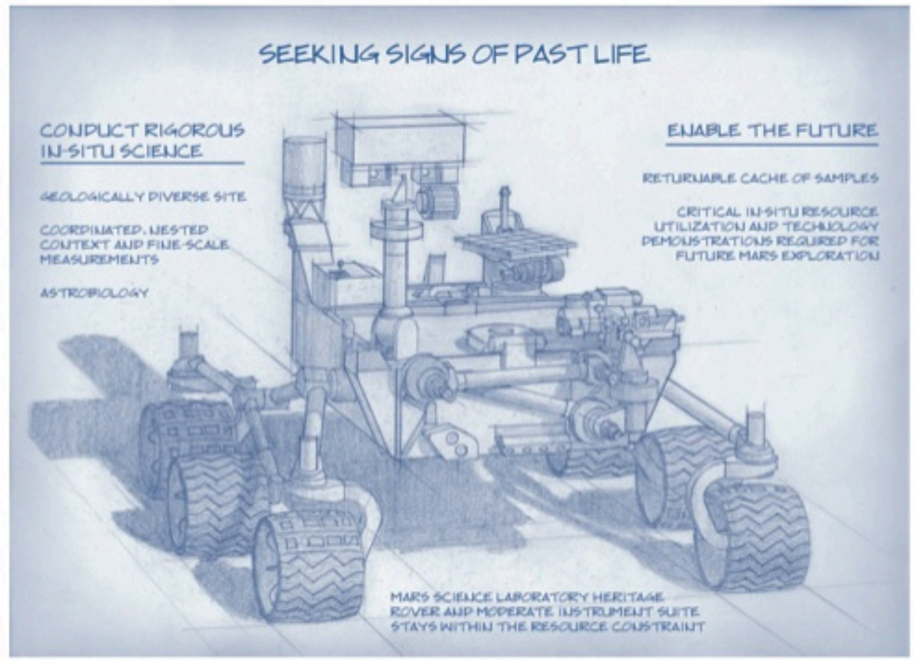


FIGURE 3.3.1 An artist's sketch of the Mars 2020 rover, NASA's implementation of the 2011 planetary science decadal survey's sample-caching rover. SOURCE: Courtesy of NASA/JPL-Caltech.

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

The long timescales of high-profile missions engender special challenges.

Consequences of the Long Timescales of High-Profile Missions

High-profile space missions are often multi-decadal in nature…significant evolution can occur in its science goals and objectives and its instrument and mission capabilities. While this evolution almost always results in cost escalation, it can also result in a mission or observing system that is significantly different from that originally conceived in a decadal survey. As an example, the high-profile Mars Science Laboratory mission (Curiosity) within NASA PSD evolved significantly in both architecture and cost from the original concept [in Planetary 2003] before the mission was launched in 2011. Despite such evolution, there is a tendency to keep the original mission as the highest priority for the program due to the large amount of resources already committed.

Best Practice: *While high-profile missions are likely to retain their high ranking from one decadal survey to the next, evolution in mission concepts and changing science priorities may occur over time. As such, it is desirable that the survey committee and panels carefully evaluate all candidate mission concepts on their merits, rather than be unduly influenced by advocacy and inertia.* [An illustrative example of this was the Space Interferometry Mission – SIM.]

Once a NASA high-profile mission is launched, the mission lifetime often greatly exceeds the prime mission timescale, resulting in one or many proposals for extended mission…Given the high development cost…there is a sensible desire to exploit them fully by gleaning as much science as possible…[but] the cost of maintaining existing capability can preclude the initiation of new missions that could make quantum advances in the field.

Bottom line: High-profile missions are essential, but they must carried out out within practices and constraints that minimize unintended consequences.

In summary, high-profile missions remain a vital part of most decadal programs, but their execution within a containable budget remains a challenge…High-profile missions should be reserved for the highest-priority science goals, those that cannot be accomplished in any other way. When a high-profile mission is recommended, it should be accompanied by clearly stated expectations regarding its implementation, denoting which aspects of the mission are essential to retaining the mission's consensus priority and which can be further considered during design development to enable cost control.

Lesson Learned: Mission creep within high-profile missions and large facilities and a general unwillingness to de-scope or cancel large missions or facilities during development can result in large, negative impacts on other programs at the division and directorate level.

Best Practice: When recommending high-profile missions, survey committees are advised to explicitly state which aspects of the project are essential to retaining the mission's consensus priority and which can be further considered during design development to enable cost control.

Best Practice: Clear decision rules for high-profile missions and large facilities that include both de-scope and cancellation options can provide some level of protection against unconstrained cost growth and possible collateral damage to other programs

Encouraging decadal surveys to develop "reference missions" for new high-profile mission concepts

Planning within tight budgets has led to increased specificity in the recommended programs of decadal surveys. Implementation plans, in particular, have included detailed descriptions of the facilities, missions, and observing system concepts that have been motivated by the desire to accomplish as much of the science program as possible. However, over-specified programs are a problem for program managers at the agencies for several reasons. One is that implementation of a particular mission architecture is often much more costly than the estimate derived from studying an immature concept, as was the case for the James Webb Space Telescope (JWST) and the Mars Science Laboratory (Curiosity rover). The full cost of ambitious, high-profile missions may not be knowable at the time, he survey is conducted.

[Role of *CATE* -- Cost Assessment and Technical Evaluation in future surveys]

A best practice going forward is that missions described in the survey's recommendations might best be considered as "reference missions"… A reference mission is intended to serve as a proof of concept that there is a way to do the science within a certain cost bin, rather than as a detailed recommendation for implementation….The most important thing is for the decadal survey to state clearly the minimum set of requirements underlying a mission's recommendation and the rationale for its prioritization, including any necessary decision rules to be considered by implementers. After all, it is first and foremost the science that is being prioritized in a decadal survey, not any particular design for a mission or facility.

Increasing Interagency and International Collaboration

High-profile NASA missions often fall in the upper range of cost envelopes that are possible within a division budget without adversely affecting the balance of programs within the division. NSF has faced similar challenges. Consequently, it is highly desirable to offset some costs through participation of other domestic agencies, foreign space agencies, or foreign governmental science agencies.

Participation of organizations outside NASA can result in a far more capable mission than would be possible with division funding alone. The Cassini-Huygens mission to Saturn, a joint mission between NASA and the European Space Agency (ESA), is an excellent example. In particular, the Huygens probe developed by ESA provided significant complementary science capability in understanding the unique environment on Titan.

Our report emphasizes the crucial importance of expanding such collaborative activities and offers ideas to exploit activities associated with international meetings and program planning, for example, decadal surveys and ESA's selection process for 'Large' and 'Medium' class missions.

International collaboration is crucial for future strategic missions.

Despite the clear advantages of such collaborative missions, the challenges to successful implementation can be large, with differing planning cycles, funding systems, and priorities. Such issues present major challenges for decadal surveys, particularly for high-profile missions, where joint participation is often required to meet decadal budget requirements. As such, sponsoring agencies may wish to provide specific instructions to survey committees on how they deal with such missions.

Best Practice: Strong preferences by the agencies on how to deal with high-profile missions and interagency and/or international participation in missions and facilities need to be spelled out in the statement of task.

From Chapter 4 "Implementing the Decadal Survey: "Impediments to International Collaboration"

• Mission selection processes that may be asynchronous and have substantial differences.
• Difficulty in securing commitment to a joint project—Who will commit first to a program that one nation cannot accomplish on its own?
• Technologies are often proprietary and not easily shared (e.g., issues associated with the International Trafficking in Arms Regulations); citing D. Southwood, ESA's former director of science and robotic exploration, "European scientists are very reluctant to become involved in hardware exchange because of the economic and political sensitivities of Earth remote-sensing technologies."
• Differences in data policy.
• Community building and mission-concept development processes that may vary greatly over the world's space agencies.
• Varying planning processes.
• Different relationships between agencies and their governments, in particular in terms of commitments to funding or the cancellation of existing commitments.
• Concerns about security and sharing of resources—for instance, the security requirements for launching missions using nuclear power sources from Europe on a European launcher, and vice-versa (now that Europe is developing its own radioisotope power systems based on americium-243).
• Organizational communication and managerial issues.
• International politics.• Cost evaluation of foreign contribution.
• Impediments to U.S. participation in and reign meetings, given current federal restrictions on travel and conference attendance.

Interagency and international collaboration is key to many future high-profile missions

Despite the challenges, the success of international collaborations on strategic missions has been remarkable. The figure at left is an artist conception the Global Precipitation Measurement mission, a NASA-JAXA collaboration. The figure caption lists 16 other important missions where collaboration among NASA, ESA, JAXA, CNES, ASI, CSA, and other space agencies have been crucial to realizing the mission and bringing it to successful operation, for example, the five-nation collaboration on the Earth Observing Systems *Aqua, Aura, and Terra*.

BOX 3.4
Collaborative Missions

Joint international missions are common in all the NASA Science Mission Directorate (SMD) disciplines. In heliophysics, Solar Heliospheric Observatory (SOHO, 1995 launch) and Cluster (relaunched in 2000 after a 1996 launch failure) are two shining examples with extensive European Space Agency (ESA) partnership. Yohkoh (1991 launch, a.k.a. Solar-A) and Hinode (2006, a.k.a. Solar-B) are examples NASA-Japan Aerospace Exploration Agency (JAXA) partnership on smaller-scale missions. International cooperation between NASA and ESA has been critical to the success of large Earth science system missions Aqua, Aura, and Terra (the Earth Observing System (EOS) platforms, a collaboration between NASA, ESA, Canada, Japan, and Brazil) and smaller-scale missions such as Global Precipitation Measurement (GPM, a collaboration between NASA and JAXA). NASA-ESA collaborations on astrophysics missions include the Hubble Space Telescope, Spitzer Space Telescope, Chandra X-ray Observatory, Herschel, Planck, and the James Webb Space Telescope (JWST, also with Canadian Space Agency [CSA]). NASA has collaborated on numerous satellites built by JAXA missions, most recently Astro-H (JAXA) and Astro-E2 (Susaku).

FIGURE 3.4.1 An artist's conception of the core observatory spacecraft of the Global Precipitation Measurement mission, a joint activity with NASA and the Japan Aerospace Exploration Agency. SOURCE: Courtesy of NASA.

For higher-cost missions…more detailed studies are generally required to ensure a viable decadal science strategy based on a full understanding of the costs and risks… for Astro2010 the agencies sponsored detailed mission-concept studies that were fed directly into the decadal survey process for evaluation and prioritization.

In January, 2016 Paul Hertz, Director of NASA Astrophysics, announced the Division's plans to study four large mission concept studies in preparation for Astro2020, following the Astrophysics Roadmap: ***Enduring Quests-Daring Visions***

LUVOIR – a Large-Aperture UV-Op-IR telescope (a Hubble successor)
"…map the distribution of nearby dark matter, detect water worlds and biomarkers on distant Earth-like planets"

Origins Space Telescope (a Far-IR Surveyor, a Spitzer successor)
"might find bio-signatures in the atmosphere of exoplanets…map the beginnings of chemistry"

Habitable Exoplanet Imaging Mission (HabEx) **--"**could search for signs of habitability in the atmospheres of exoplanets"

X-ray Surveyor ***"might discover the first generation of supermassive black holes,*** unravel the structure of the cosmic web…*and its influence on galaxy evolution"*

High-Profile Missions – a summary in Lessons Learned, Best Practices

Lesson Learned: *High-profile missions are special cases within each of the disciplinary areas, presenting great opportunities for major advances in understanding, but also carrying significant risk for maintaining a balanced portfolio of activities—should unanticipated cost growth occur.*

Lesson Learned: *Mission creep within high-profile missions and large facilities and a general unwillingness to de-scope or cancel large missions or facilities during development can result in large, negative impacts on other programs at the division and directorate level.*

Best Practice: *When recommending high-profile missions, survey committees are advised to explicitly state which aspects of the project are essential to retaining the mission's consensus priority and which can be further considered during design development to enable cost control.*

Best Practice: *Clear decision rules for high-profile missions and large facilities that include both de-scope and cancellation options can provide some level of protection against unconstrained cost growth and possible collateral damage to other programs.*

Best Practice: ***Strong preferences by the agencies*** *on how to deal with high-profile missions and interagency and/or international participation in missions and facilities* ***need to be spelled out in the statement of task.***