A Performance Assessment of NASA's Heliophysics Program
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Committee on Heliophysics Performance Assessment
Space Studies Board
Division on Engineering and Physical Sciences

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In Section 301(a) of the NASA Authorization Act of 2005, the Congress directed the National Aeronautics and Space Administration to have “[t]he performance of each division in the Science directorate . . . reviewed and assessed by the National Academy of Sciences at 5-year intervals.” The first two of these assessments, for NASA’s Astrophysics Division and NASA’s Planetary Science Division, were started in 2006 and 2007, respectively. In late 2007, NASA asked the National Research Council (NRC) to conduct such an assessment for the agency’s Heliophysics Division (see Appendix A). The statement of task for the Committee on Heliophysics Performance Assessment was to study the alignment of NASA’s Heliophysics Division program with previous NRC advice—primarily the relevant decadal survey report, *The Sun to the Earth—and Beyond: A Decadal Research Strategy in Solar and Space Physics.* More specifically, the statement of task asked the committee to assess and comment on the following:

- How well NASA’s current program addresses the strategies, goals, and priorities outlined in the heliophysics decadal survey and other relevant Academy reports;
- Progress toward realizing these strategies, goals and priorities; and
- Any actions that could be taken to optimize the science value of the program in the context of current and forecasted resources available to it.

The letter of request from NASA also stated that

> [t]he review should not revisit or alter the scientific priorities or mission recommendations provided in the . . . [2003] decadal survey, but may provide guidance about implementing the recommended mission portfolio in preparation for the next decadal survey.

The committee held three meetings, in April, June, and August 2008. At the April and June meetings, the committee received presentations from members of the decadal survey, members of the astrophysics and planetary mid-decade assessments, the NRC’s Committee on Solar and Space Physics, NASA headquarters staff, NOAA staff, participants in the relevant NASA mission operating working groups, mission scientists, and other members

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of the research community. Because this was a congressionally directed study, the committee also asked relevant congressional staff for input on what kind of report would be most relevant to their work. In addition, committee representatives visited the NASA Goddard Space Flight Center and the Johns Hopkins University Applied Physics Laboratory to hear from their scientists and managers about the programs reviewed in this report.

The committee thanks those who made formal presentations at its meetings and expresses appreciation to the hosts of and presenters at the site visits. The conversations were sincere, informative, and invaluable to the assessment. The committee also thanks the NASA headquarters staff who provided the budget figures used in this report.
Acknowledgment of Reviewers

This report has been reviewed in draft form by individuals chosen for their diverse perspectives and technical expertise, in accordance with procedures approved by the National Research Council’s (NRC’s) Report Review Committee. The purpose of this independent review is to provide candid and critical comments that will assist the institution in making its published report 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. We wish to thank the following individuals for their participation in the review of this report:

Craig DeForest, Southwest Research Institute,
Janet Kozyra, University of Michigan,
Louis J. Lanzerotti, New Jersey Institute of Technology,
John Leibacher, National Solar Observatory,
Robert P. Lin, University of California, Berkeley,
William H. Matthaeus, University of Delaware, and
Mark Miesch, National Center for Atmospheric Research.

Although the reviewers listed above have provided many constructive 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 Peter M. Banks, Astrolabe Venture Partners. Appointed by the NRC, he 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.
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Since the 1990s, the pace of discovery in the field of solar and space physics has accelerated, largely owing to prior and continuing NASA investments in its Heliophysics Great Observatory fleet of spacecraft. These enable researchers to investigate connections between events on the Sun and in the space environment by combining multiple points of view. The field of solar and space physics comprises the phenomenology and physics of space plasmas and neutral gases, both individually and as coupled, nonlinear interacting systems driven from the Sun to Earth, to other members of the solar system, and out to the very edge of the heliosphere. Through NASA’s current Heliophysics Great Observatory, researchers use 12 spacecraft to address the basic science of variable solar outputs, their transmission to the geospace environment and beyond, and their impacts on technological systems.

Solar and space physics requires synergy between observational and theoretical initiatives, and between basic research and targeted research programs. Investments by NASA, the National Oceanic and Atmospheric Administration (NOAA), the National Science Foundation (NSF), and the Department of Defense (DOD) in space weather instruments, ground-based observatories, research, technology, and education have been important to sustaining progress. Collectively, they enable humanity’s deepest understanding of our nearest star and its interactions with all members of the heliosphere, including the technologies that sustain and nurture our presence in geospace and beyond.

Recognizing the importance of distributed observations of all elements of the Sun-to-Earth system and the synergies between observation and theory and between basic and targeted research, the National Research Council’s (NRC’s) 2003 solar and space physics decadal survey laid out an integrated research strategy that sought to extend and augment what has now become the Heliophysics Great Observatory as well as to enhance NASA, NOAA, NSF, and DOD’s other solar and space physics research activities. The Integrated Research Strategy provided a prioritized list of flight missions and theory and modeling programs that would advance the relevant physical theories, incorporate those theories in models that describe a system of interactions between the Sun and the space environment, obtain data on the system, and analyze and test the adequacy of the theories and models. As directed by Congress in the NASA Authorization Act of 2005, the purpose of this report is to assess the progress of NASA’s Heliophysics Division at the 5-year mark against the NASA goals and priorities laid out in the decadal survey.

1See Box 1.1 of this report for a detailed description of NASA’s Heliophysics Great Observatory.
In addition to the Integrated Research Strategy, the decadal survey also considered non-mission-specific initiatives to foster a robust solar and space physics program. The decadal survey set forth driving science challenges as well as recommendations devoted to the need for technology development, collaborations and cooperation with other disciplines, understanding the effects of the space environment on technology and society, education and public outreach, and steps that could strengthen and enhance the research enterprise.

Unfortunately, very little of the recommended NASA program priorities from the decadal survey’s Integrated Research Strategy will be realized during the period (2004-2013) covered by the survey. Mission cost growth, reordering of survey mission priorities, and unrealized budget assumptions have delayed or deferred nearly all of the NASA spacecraft missions recommended in the survey. As a result, the status of the Integrated Research Strategy going forward is in jeopardy, and the loss of synergistic capabilities in space will constitute a serious impediment to future progress.

Some of these factors were largely outside NASA’s control, but as the assessments in Chapter 2 of this report detail, many factors were driven by subsequent NASA decisions about mission science content, mission size, and mission sequence. Overcoming these challenges, as well as other key issues like launch vehicle availability, will be critical if NASA is to realize more of the decadal survey’s priorities over the next 5 years as well as priorities in solar and space physics research in the long term. Chapter 3 of this report provides recommendations about how NASA can better fulfill the 2003 decadal survey and improve future decadal surveys in solar and space physics.

**ASSESSMENT**

In Chapter 2 of this report the Committee on Heliophysics Performance Assessment evaluates NASA’s progress against the 2003 decadal survey recommendations. To make its assessment, the committee employed the following grading system:

- **A**—Achieved or exceeded the goal established in the decadal survey.
- **B**—Made significant progress toward the goal.
- **C**—Made some progress toward the goal.
- **D**—Made little progress toward meeting the decadal goal.
- **F**—Made no progress toward meeting the decadal goal or actually regressed from it.

The committee developed a summary finding to support each grade in this report. Chapter 2 provides additional information supporting each grade, including reprintings of the specific recommendations from the decadal survey and a more detailed assessment of the NASA program response to those recommendations.

Table S.1 summarizes the committee’s assessment, which consists of 21 grades, divided into 7 area assessments covering each chapter of the 2003 decadal survey and 14 program assessments covering the NASA program priorities recommended in the decadal survey.

**Area Assessments**

Seven of the committee’s grades correspond to the seven chapters in the decadal survey, which covered the following areas:

1. Milestones and Science Challenges
2. Integrated Research Strategy
3. Technology Development
4. Connections Between Solar and Space Physics and Other Disciplines,
5. Effects of the Solar and Space Environment on Technology and Society
6. Education and Public Outreach (E/PO)
7. Strengthening the Solar and Space Physics Research Enterprise.
TABLE S.1 Committee Assessment of NASA Progress Over 5 Years Against Recommendations Made in the 2003 Solar and Space Physics Decadal Survey

<table>
<thead>
<tr>
<th>Area or Program</th>
<th>Grade</th>
</tr>
</thead>
<tbody>
<tr>
<td>Area&lt;sup&gt;a&lt;/sup&gt;</td>
<td></td>
</tr>
<tr>
<td>Milestones and Science Challenges</td>
<td>B</td>
</tr>
<tr>
<td>Integrated Research Strategy</td>
<td>C</td>
</tr>
<tr>
<td>Technology Development</td>
<td>C</td>
</tr>
<tr>
<td>Connections Between Solar and Space Physics and Other Disciplines</td>
<td>F</td>
</tr>
<tr>
<td>Effects of the Solar and Space Environment on Technology and Society</td>
<td>C</td>
</tr>
<tr>
<td>Education and Public Outreach</td>
<td>C</td>
</tr>
<tr>
<td>Strengthening the Solar and Space Physics Research Enterprise</td>
<td>C</td>
</tr>
<tr>
<td>Program&lt;sup&gt;b&lt;/sup&gt;</td>
<td></td>
</tr>
<tr>
<td>Solar Probe</td>
<td>A</td>
</tr>
<tr>
<td>Magnetospheric Multiscale</td>
<td>B</td>
</tr>
<tr>
<td>Geospace Network</td>
<td>D</td>
</tr>
<tr>
<td>Jupiter Polar Mission</td>
<td>B</td>
</tr>
<tr>
<td>Suborbital Program</td>
<td>B</td>
</tr>
<tr>
<td>Explorer Program</td>
<td>C</td>
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<tr>
<td>Small Programs</td>
<td>A</td>
</tr>
<tr>
<td>Vitality Programs</td>
<td>B</td>
</tr>
<tr>
<td>Supporting Research and Technology</td>
<td>C</td>
</tr>
<tr>
<td>Coupling Complexity Initiative</td>
<td>C</td>
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<tr>
<td>Solar and Space Physics Information System</td>
<td>A</td>
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<tr>
<td>Guest Investigator Program</td>
<td>A</td>
</tr>
<tr>
<td>Theory and Data Analysis Program</td>
<td>B</td>
</tr>
<tr>
<td>Virtual Sun</td>
<td>B</td>
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<sup>a</sup> Decadal survey chapters and areas in which recommendations were made.


The committee provided a summary grade of NASA’s progress against the recommendations made in each chapter of the decadal survey. The grades and findings for each of these areas are as follows:

**Milestones and Science Challenges**

**Grade: B**

**Finding:** The highest-level objectives and research focus areas in the NASA Heliophysics Roadmap align with the decadal survey science challenges. However, there are several science questions in the decadal survey—most notably, coronal heating, magnetospheres and ionospheres of other planets, and interaction with the interstellar medium—that receive little or no attention in the roadmap.

**Integrated Research Strategy**

**Grade: C**

**Finding:** Progress in almost all the programs is seriously compromised by mission cost growth and rescoping and by reductions in funding for programs that provide regular mission opportunities. In addition, decisions to reorder the mission sequence recommended in the decadal survey undermined the Integrated Research Strategy set forth in the decadal survey, which was built around a set of spacecraft missions coordinated to afford opportunities to examine complex, interacting Sun-Earth subsystems from different regions simultaneously. The originally conceived program cannot be recovered before the next decadal survey. Thus, the status of the Integrated Research Strategy going forward is in jeopardy, with the potential for loss of synergistic space research capabilities.
Technology Development
Grade: C

**Finding:** NASA is planning to add new small and medium launch capabilities and has made some progress in developing advanced spacecraft systems and command-and-control and data acquisition technologies for spacecraft constellations. But NASA's progress in developing solar sails is limited, and NASA has only recently begun studying the feasibility of advanced space nuclear power systems and the availability of the necessary radioactive isotopes. These technologies have been identified as strategic needs for upcoming missions. It is also unclear if the rate of technological progress in spacecraft systems can be sustained in the absence of a replacement for NASA's canceled New Millennium Program, which provided a testbed for new technologies. NASA has also not followed up on decadal survey recommendations regarding advanced scientific instrumentation.

Connections Between Solar and Space Physics and Other Disciplines
Grade: F

**Finding:** NASA has taken no specific action on the connections recommendations, which remain valid. However, community interest in interdisciplinary interactions remains strong, and supporting research and technology programs continue to elicit interdisciplinary interest.

Effects of the Solar and Space Environment on Technology and Society
Grade: C

**Finding:** NASA/NOAA/NSF joint efforts on modeling and simulations are excellent examples of successful and close interagency coordination. However, the use of scientific spacecraft like NASA's Advanced Composition Explorer for operational purposes by other agencies at L1 is ill-advised and is a potential obstacle to an independent space weather monitoring program.

Education and Public Outreach
Grade: C

**Finding:** NASA's E/PO programs are regarded as generally successful, with several notable successes among the mission-associated programs. However, NASA programs have emphasized elementary-school and public education despite the decadal survey recommendation that educational efforts should focus on college and university-level training, a goal that remains poorly addressed.

Strengthening the Solar and Space Physics Research Enterprise
Grade: C

**Finding:** Some initiatives to strengthen the solar and space physics enterprise have made progress. NASA has processes in place to capitalize on existing research assets, has allocated funding to revitalize the Suborbital Program, includes space physics instruments in Planetary Division missions, and continues to have an open-door data policy. However, there has been limited or no progress on other initiatives. Launch capabilities continue to be inadequate, NASA has not undertaken an independent review of its relationship with academia, and some Announcements of Opportunity could better tailor mission rules to mission scope. Moreover, International Traffic in Arms Regulations (ITAR) continue to hamper international cooperation on missions.

Program Assessments

In its chapter on the Integrated Research Strategy, the decadal survey recommended a prioritized list of programs. The present committee graded NASA's progress on 14 of the recommended programs that have entered
formulation or implementation. For NASA programs that were recommended by the decadal survey but have not entered formulation, the committee provided no grade.

Solar Probe
Program Grade: A

Finding: NASA is to be commended for reconstituting the Solar Probe science definition team and producing a Solar Probe Plus mission implementation plan that could be conducted with a restricted cost profile. Although its mission design is promising, Solar Probe Plus sequencing is in conflict with the decadal survey, which conditioned Solar Probe implementation on the implementation of all the moderate missions recommended in the survey or on a budget augmentation to accelerate Solar Probe implementation. Neither condition has been met. Solar Probe received the highest possible grade due to efforts to control cost via intelligent mission redefinition. However, NASA has compromised the decadal survey’s mission sequence by advancing Solar Probe ahead of the fourth (Multi-Heliospheric Probes), fifth (Geospace Electrodynamic Connections), and seventh (Magnetospheric Constellation) moderate-mission priorities identified in the survey, an approach that has reduced the overall grade given to implementation of the Integrated Research Strategy.

Magnetospheric Multiscale
Program Grade: B

Finding: Magnetospheric Multiscale (MMS) is the number-one-priority moderate mission, with a science focus on reconnection as a fundamental plasma physical process. MMS is scheduled for launch in 2014 and has an estimated cost of $990 million. The launch date places it outside the time frame addressed by the decadal survey (2004-2013), and the cost places it well outside the moderate mission category of the decadal survey. Changes in payload capability, launch vehicles, and project requirements have all contributed to the increases in time and cost. Although it is encouraging to see MMS moving forward, its problems have necessitated the re-programming of subsequent moderate missions.

Geospace Network
Program Grade: D

Finding: As originally conceived, the Geospace Network mission aimed at exploring the synergy and coupling between the radiation environment in the inner magnetosphere and the underlying ionosphere and thermosphere, key regions for space weather effects. It has not been implemented, and the present plan essentially eliminates it from consideration.

Jupiter Polar Mission
Program Grade: B

Finding: Although there are some limitations due to mission design, instrumentation on the recently selected New Frontiers Juno mission will allow the main objectives of the decadal survey Jupiter Polar Mission to be accomplished.

Suborbital Program
Program Grade: B

Finding: NASA significantly increased its funding request for the Suborbital Program in FY 2009 in response to multiple findings over the years from the community. If passed, this increase appears to be sufficient to bring the support level back above the critical threshold for a viable program. This increased support for operational engineering, infrastructure, and inventory is in line with the relevant recommendation from the decadal survey.
Meeting the decadal survey recommendation for a revitalized Suborbital Program will also require an increase in science investigations to take advantage of the increased flight rate.

**Explorer Program**  
**Program Grade:** C

**Finding:** The Explorer Program is characterized by high science return and a minimum of cost overruns and mission expansion. However, reductions in Explorer Program funding have reduced the mission flight rate from one or more missions per year at the time of the decadal survey to one mission every 4 years, with serious implications for the vitality and balance of programs within the Heliophysics Division. The reinstatement of the Small Explorer and Mission of Opportunity competition in 2007 reversed a downward trend but has not restored funding to levels assumed by the decadal survey.

**Small Programs**  
**Program Grade:** A

**Finding:** Significant enhancements to scientific productivity in heliophysics are being achieved with relatively small resource commitments, including NASA cooperation on the European Space Agency’s Solar Orbiter mission.

**Vitality Programs**  
**Program Grade:** B

**Finding:** Although some of the specific initiatives recommended by the decadal survey were not undertaken, NASA’s Research and Analysis budget has effectively addressed the needs of present and future flight programs while continuing to foster new ideas and innovation.

**Supporting Research and Technology**  
**Program Grade:** C

**Finding:** The decadal survey recommended that funding for the Supporting Research and Technology (SR&T) program be increased to maximize the productivity of existing resources and ensure a sound foundation for the development of future programs. However, funding for this key activity was cut severely in FY 2006. In FY 2008, funding amounts have only recovered to their levels at the time of the decadal survey.

**Coupling Complexity Initiative**  
**Program Grade:** C

**Finding:** No federal agency has led the way in creating new, interagency theory and modeling programs, such as the Coupling Complexity Initiative recommended by the decadal survey. However, within constrained budgets, NASA has supported the development of some portion of these activities through existing programs, such as its Targeted Research and Technology (TR&T) and its Community Coordinated Modeling Center (CCMC).

**Solar and Space Physics Information System**  
**Program Grade:** A

**Finding:** The capabilities of a Solar and Space Physics Information System are being realized through the CCMC and the emerging capabilities of virtual observatories. However, these projects are in their infancy, and continuous careful examination should be undertaken to identify needed capabilities and specific weaknesses that could hamper their productivity.
Guest Investigator Program
Program Grade: A

Finding: The importance of the Guest Investigator Program in maximizing scientific returns from mission data sets and from the Heliophysics Great Observatory by broadening the types and range of scientific investigations is well recognized by NASA, and funding has been increased to maximize the program’s effectiveness.

Theory and Data Analysis Program
Program Grade: B

Finding: The heliophysics Theory and Data Analysis Program has labored under an inflationary funding profile. To fulfill the program’s mission of supporting groups of critical mass without increasing resources, the number of awards made every 3 years has been decreased. While such funding at least stems deterioration of capabilities in theory and modeling, it cannot foster the bold advances envisioned by the decadal survey.

Virtual Sun
Program Grade: B

Finding: While no new program element has been created in response to the Virtual Sun recommendation, which proposes an interagency program to develop the theoretical and modeling framework to represent the major elements of the Sun-Earth system, some of the recommendation’s objectives have been achieved through existing programs. Living With a Star (LWS) TR&T, for example, supports elements of Virtual Sun that will eventually lead to improvements in space weather applications.

RECOMMENDATIONS

In addition to assessing NASA’s progress against the decadal survey recommendations, the committee was charged with delivering guidance that could optimize the value of NASA’s heliophysics programs without altering the priorities and recommendations of the 2003 decadal survey and that could improve the next decadal survey. Based on the information and grades provided in Chapters 1 and 2 of this report, the committee makes nine recommendations and offers eight guidelines.

Recommendations to Fulfill the Integrated Research Strategy

The central recommendation of the decadal survey was the Integrated Research Strategy. Although it would be extremely difficult now to restore all of the content anticipated in the Integrated Research Strategy, the committee makes five recommendations that could help restore key features before the end of the decade.

Recommendation 1: (a) If no budget augmentation is forthcoming that is large enough to support the planned Solar Probe launch date of 2017 without impacting other Heliophysics Division missions, NASA should consult with the community through a formal review mechanism (such as committees of the NASA Advisory Council or other independent, external, community priority-setting bodies) to determine Solar Probe’s priority relative to that of other decadal survey recommendations and its launch date. (b) An implementation plan for the science objectives of the Geospace Network that includes both ionosphere-thermosphere and magnetosphere components should be developed as soon as possible in advance of lower-ranked moderate missions in the 2003 decadal survey’s recommended mission queue.

Recommendation 2: Funding for the Heliophysics Explorer Program should be restored to recommended levels as rapidly as possible. The ramp-up in the current 5-year-projection budget is encouraging and should be accelerated as soon as possible.