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REPORT IN BRIEF

Solar and Space Physics: A Science for a Technological Society

The 2013-2022 Decadal Survey in Solar and Space Physics

Space Studies Board · Division on Engineering & Physical Sciences · August 2012

From the interior of the Sun, to the upper atmosphere and near-space environment of Earth, and outwards to a region far beyond Pluto where the Sun's influence wanes, advances during the past decade in space physics and solar physics have yielded spectacular insights into the phenomena that affect our home in space. This report, the final product of a study requested by NASA and the National Science Foundation, presents a prioritized program of basic and applied research for 2013-2022 that will advance scientific understanding of the Sun, Sun-Earth connections and the origins of "space weather," and the Sun's interactions with other bodies in the solar system. The report includes recommendations directed for action by the study sponsors and by other federal agencies—especially NOAA, which is responsible for the day-to-day ("operational") forecast of space weather.

Recent Progress: Significant Advances from the Past Decade

The disciplines of solar and space physics have made remarkable advances over the last decade—many of which have come from the implementation of the program recommended in 2003 Solar and Space Physics Decadal Survey. For example, enabled by advances in scientific understanding as well as fruitful interagency partnerships, the capabilities of models that predict space weather impacts on Earth have made rapid gains over the past decade. Reflecting these advances and a society increasingly vulnerable to the adverse effects of space weather, the number of users of space weather services has grown rapidly. Indeed, a growing community has come to depend on constant and immediate access to space weather information.

Some of the highlights from an exciting decade of discovery include new insights into the variability of the mechanisms that generate the Sun's magnetic field; a new understanding of the unexpectedly deep minimum in solar activity; significant progress in understanding the origin and evolution of the solar wind; striking advances in understanding of both explosive solar flares and the coronal mass ejections that drive space weather; new imaging methods that permit direct observations of the space weather-driven changes in the particles and magnetic fields surrounding Earth; new understanding of the ways that space storms are fueled by oxygen originating from Earth's own atmosphere; and the surprising discovery that conditions in near-Earth space are linked strongly to the terrestrial weather and climate below.

Scientific Goals and Guiding Principles for the Next Decade

The decadal survey committee—the authors of the survey report—built their recommended program around 4 overarching scientific goals, each of which is considered of equal priority, and several "guiding principles;" they are listed here.

Scientific Goals

Determine the origins of the Sun's activity and predict the variations of the space environment.

Determine the dynamics and coupling of Earth's magnetosphere, ionosphere, and atmosphere and their response to solar and terrestrial inputs.

Determine the interaction of the Sun with the solar system and the interstellar medium.

Discover and characterize fundamental processes that occur both within the heliosphere and throughout the universe.

Guiding Principles

To make transformational scientific progress, the Sun, Earth, and heliosphere must be studied as a coupled system;

To understand the coupled system requires that each sub-discipline be able to make measurable advances in achieving its key scientific goals; and

Success across the entire field requires that the various elements of solar and space physics research programs—the enabling foundation comprising theory, modeling, data analysis, innovation, and education, as well as ground-based facilities and small-, medium-, and large-class space missions—be deployed with careful attention to both the mix of assets and to the schedule (cadence) that optimizes their utility over time.

Top-Level Decadal Survey Research and Application Recommendations

The decadal survey committee's recommendations were fit to anticipated budgets, which appear likely to be highly constrained for the foreseeable future. However, recognizing the importance of crafting a resilient program, the survey report includes "decision rules" to guide programmatic changes, should they become necessary. The committee found a number of challenges that could impede implementation of its recommendations: the assumed budget may not be realized or missions could experience cost growth; the necessity to coordinate activities across multiple agencies; and the limited availability of appropriately-sized and affordable space launch vehicles, which is a particular problem for medium-class launch vehicles.

Implementation of the survey committee's recommended programs will ensure the United States maintains its leadership in solar and space physics and, the committee believes, lead to significant—even transformative—advances in scientific understanding and observational capabilities. In turn, these advances will support critical national needs for information that can be used to anticipate, recognize, and mitigate space weather effects that are adverse to human life and the technological systems society depends upon.

While a few of the research recommendations are presented in the below table, a more complete discussion, along with potential applications, is detailed in the full NRC report.

Baseline Priority for NASA and NSF: Complete and Current Program

The survey committee's recommended program for NSF and NASA assumes continued support in the near-term for the key existing program elements that comprise the "Heliophysics Systems Observatory" (HSO) and successful implementation of programs in advanced stages of development (RBSP, MMS, IRIS, SPP, and Solar Orbiter). NASA's existing heliophysics flight missions and NSF's ground-based facilities form a network of observing platforms that operate simultaneously to investigate the solar system. This array can be thought of as a single observatory—the Heliophysics System Observatory (HSO). The evolving HSO lies at the heart of the field of solar and space physics and is a rich source of observations that can be used to address increasingly interdisciplinary and longterm scientific questions. Missions under development will expand the HSO and drive discovery.

For NSF, the previous decade witnessed the initial deployment in Alaska of the Advanced Modular Incoherent Scatter Radar (AMISR), a mobile facility used to study the upper atmosphere and to observe space weather events, and the initial development of the Advanced Technology Solar Telescope (ATST), a 4-meter aperture optical solar telescope—by far the largest in the world—that will provide the most highly resolved measurements of the Sun's plasma and magnetic field ever obtained. These new NSF facilities join a broad range of existing ground-based assets that provide an essential global synoptic perspective and complement space-based measurements of the solar and space physics system. With adequate science and operations support, they will enable frontier research even as they add to the long-term record necessary for analyzing space climate over solar cycles.

Other Recommendations

Implement the DRIVE Initiative

The survey committee's first priority after completion of the ongoing program is to implement a new, integrated, multiagency initiative, DRIVE, which encompasses specific, cost-effective augmentations to NASA and NSF heliophysics programs. DRIVE will bring existing "enabling programs" to full fruition and support larger-scale activities recommended for later in the decade. Its components are: Diversify observing platforms with microsatellites and mid-scale ground-based assets; Realize scientific potential by sufficiently funding operations and data analysis; Integrate observing platforms and strengthen ties between agency disciplines; Venture forward with science centers and instrument and technology development; and Educate, empower, and inspire the next generation of space researchers.

The specific DRIVE augmentations recommended for NASA are detailed in the report. For NSF, the survey committee recommends that funding be sufficient for essential synoptic observations and efficient and scientifically productive operation of the Advanced Technology Solar Telescope (ATST)—a revolutionary new window on the solar magnetic atmosphere—and that a new competitively selected mid-scale project funding line be created in order to enable projects and instrumentation for projects such as the Coronal Solar Magnetism Observatory (COSMO) and the Frequency-Agile Solar Radio-telescope (FASR).

Accelerate and Expand the Heliophysics Explorer Program

The Explorer program's strength lies in its ability to respond rapidly to new concepts and developments in science as well as in the program's synergistic relationship with larger-class "strategic" missions. Explorer-class missions have an outstanding record of delivering—cost-effectively—scientific results of great consequence. The survey committee recommends that NASA accelerate and expand the Heliophysics Explorer program with an augmentation of the current program by $70 million per year, in fiscal year 2012 dollars. This will enable restoration of the mid-size Explorers (MIDEX) and allow them to be offered in alternation with Small Explorers (SMEX) every 2 to 3 years. Historically, MIDEX missions offered an opportunity to resolve many of the highest-level science questions, but they have not been feasible with the current Explorer budget. As part of the augmented Explorer program, NASA should also support regular selections of Missions of Opportunity. Regular selections of Missions of Opportunity (MOOs) will also allow the research community to respond quickly and to leverage limited resources with interagency, international, and commercial flight partnerships. For relatively modest investments, such opportunities can potentially address the high-priority science aims identified in the decadal survey.

Restructure Solar Terrestrial Probes as a Moderate-scale, PI-Led Line

The survey committee recommends that NASA's Solar Terrestrial Probes program be restructured as a moderate-sized, competed, principal investigator-led (PI-led) mission line that is cost-capped at approximately $520 million per mission in fiscal year 2012 dollars including full lifecycle costs. NASA's Planetary Science Division has demonstrated success in implementing mid-sized missions as competed, cost-capped, PI-led investigations via the Discovery and New Frontiers programs. These are managed in a manner similar to Explorers and have superior cost performance history relative to larger flagship missions. The committee concludes that STP missions should be managed likewise, with the PI empowered to make scientific and mission design trade-offs necessary to remain within the cost cap. With larger-class LWS missions and smaller-class Explorers and MOOs, this new approach will lead to a more balanced and effective overall NASA HPD mission portfolio that is implemented at a higher cadence and provides the vitality needed to accomplish the breadth of our science goals. The eventual recommended minimum cadence of STP missions is one every four years.

Although the new STP program would involve moderate missions being chosen competitively, the survey committee recommends that their science targets be ordered as follows so as to systematically advance understanding of the full coupled solar-terrestrial system:

The first new STP science target is to understand the outer heliosphere and its interaction with the interstellar medium, as illustrated by the reference mission Interstellar Mapping and Acceleration Probe. Implementing IMAP as the first of the STP investigations will ensure coordination with NASA Voyager missions. The mission implementation also requires measurements of the critical solar wind inputs to the terrestrial system.

The second STP science target is to provide a comprehensive understanding of the variability in space weather driven by lower atmosphere weather on Earth. This target is illustrated by the Dynamical Neutral Atmosphere-Ionosphere Coupling reference mission.

The third STP science target is to determine how the magnetosphere-ionosphere-thermosphere system is coupled and how it responds to solar and magnetospheric forcing. This target is illustrated by the Magnetosphere Energetics, Dynamics, and Ionospheric Coupling Investigation reference mission.

Implement a Living With a Star (LWS) mission to study the Ionosphere-Thermosphere-Mesosphere System in an integrated fashion

Certain landmark scientific problems are of such scope and complexity that they can only be addressed with major missions. In the survey committee's plan, major heliophysics missions would be implemented within NASA's LWS Program; the survey committee recommends that they continue to be managed and executed by NASA Centers.

Other integral thematic elements are essential to the LWS science and technology program besides the flight program. The unique LWS research, technology, strategic capabilities, and education programs remain of great value. It is recommended that the next LWS science target focus on how Earth's atmosphere absorbs solar wind energy; the recommended reference mission is Geospace Dynamics Constellation (GDC).

Enable Effective Space Weather and Climatology (SWaC) Capabilities

Multiple agencies of the federal government have vital interests related to space weather and efforts to coordinate these agencies' activities are seen in the National Space Weather Program (NSWP). Nonetheless, additional approaches are needed to develop the capabilities outlined in the 2010 National Space Policy document and envisioned in the 2010 NSWP plan. Enabling an effective SWaC capability will require action across multiple agencies and an integrated program that builds on the strengths of individual agencies.

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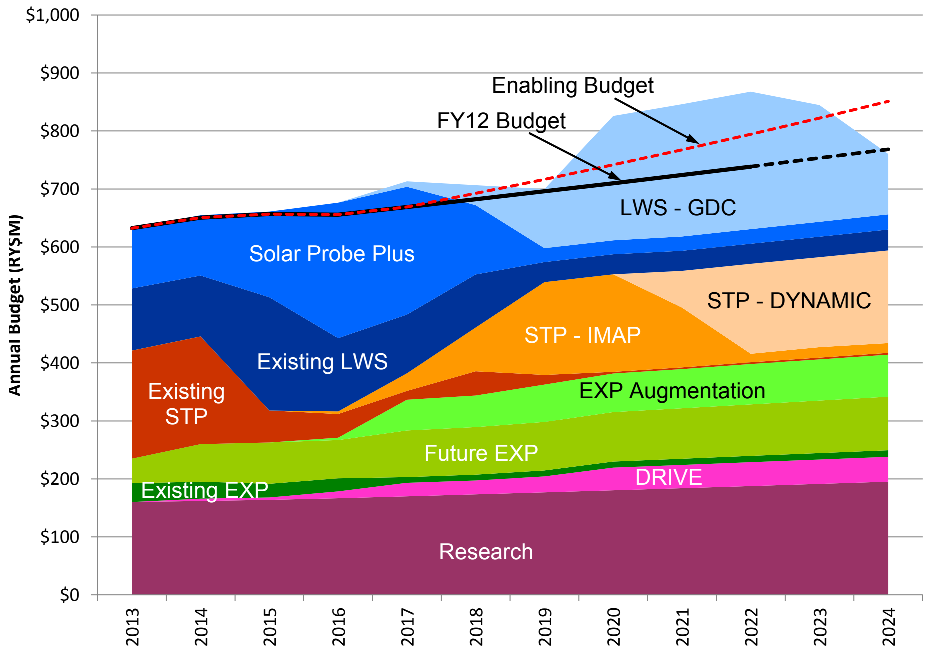

The committee's recommended program for NASA Heliophysics Division is shown in the figure above. The plan restores the medium-class Explorers and, together with small-class Explorer missions and Missions of Opportunity, achieves the recommended minimum mission cadence. The committee's recommended new starts in the restructured Solar-Terrestrial Probes (STP) mission line and the Living With a Star Program (LWS) also begin in the latter part of the decadal survey interval. The solid black line in the figure indicates the funding level from 2013 to 2022 provided to the committee by NASA as the baseline for budget planning, and the dashed black line extrapolates the budget forward to 2024. After 2017, the amount increases with a nominal 2% inflationary factor. The red dashed "Enabling Budget" line includes a modest increase from the baseline budget starting in 2017, allowing implementation of the survey-recommended program at a more efficient cadence that better meets scientific and societal needs and improves optimization of the mix of small and large missions. From 2017 to 2024 the Enabling Budget grows at 1.5% above inflation. If necessary, GDC implementation could be stretched (at some cost) to conform to the projected funding profile.

TABLE S-1. Top-Level Decadal Survey Research Recommendations

Priority	Recommendation	NASA	NSF	Other
0.0	**Complete the Current Program**	X	X	
1.0	**Implement the DRIVE Initiative** Small satellites; mid-scale NSF projects; vigorous ATST and synoptic program support; science centers and grant programs; instrument development	X	X	X
2.0	**Accelerate and Expand the Heliophysics Explorer Program** Enable MIDEX line and Missions of Opportunity	X		
3.0	**Restructure STP as a Moderate, PI-Led Program**	X		
3.1	Implement an IMAP-Like Mission	X		
3.2	Implement a DYNAMIC-Like Mission	X		
3.3	Implement a MEDICI-Like Mission	X		
4.0	**Implement a Large LWS GDC-Like Mission**	X		

TABLE S-2. Top Level Decadal Survey Applications Recommendations

Priority	Recommendation	NASA	NSF	Other
1.0	**Re-charter the National Space Weather Program**	X	X	X
2.0	**Multi-Agency Partnership for Solar/Solar Wind Observations**	X	X	X
2.1	L1 Solar Wind (DSCOVR, IMAP)	X		X
2.2	Coronagraph and Magnetograph	X		X
2.3	Evaluate New Observations, Platforms	X	X	X
2.4	Establish a SWx Research Program for Effective Research-to-Operations Transition at NOAA			X
2.5	Establish Distinct Programs for Space Physics Research and Space Weather Forecasting and Specification	X	X	X

These tables summarize some of the committee's recommendations. They are discussed in greater detail in the full NRC report.

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