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Statement of
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Subcommittee on Space and Aeronautics
Committee on Science, Space and Technology
U.S. House of Representatives

Mr. Chairman and Members of the Subcommittee, thank you for the opportunity to discuss the accomplishments, status, and future direction of NASA's Heliophysics program and, in particular, NASA's response to the Heliophysics decadal survey, "*Solar and Space Physics: A Science for a Technological Society*," released in August 2012.

NASA's Heliophysics program studies the Sun, Earth's near-space environment, and the heliosphere (the magnetic bubble created from the Sun's energy output and inflated by the solar wind that contains our solar system) as an inter-connected system. By studying this system, NASA provides understanding of the fundamental space processes that occur throughout the universe and that drive our Sun-Earth connection.

Our ability to understand the Sun-Earth system is of growing importance to our Nation's economic well-being and security. The Sun is highly variable and produces geomagnetic storms and space weather (i.e., conditions on the Sun, the solar wind, and atmosphere that affect Earth's electromagnetic environment). Geomagnetic storms and the ensuing space weather effects are phenomena that can disrupt communications, navigation, satellite operations, and electric power distribution; a severe geomagnetic storm has the potential to cause significant socioeconomic loss as well as impacts to national security. Furthermore, space weather impacts can be seen throughout the solar system and the emerging science of interplanetary space weather forecasting is crucial to NASA's human and robotic exploration objectives beyond Earth's orbit.

Our program seeks answers to the following questions: What causes the Sun to vary? How do Earth and the heliosphere respond? What are the impacts on humanity?

The Role of Decadal Surveys

NASA uses the recommendations of the National Academy of Sciences' decadal surveys for guidance in planning the future of its science program. Decadal surveys have proven indispensable in establishing a broad national science community consensus on the state of the science, the highest priority science questions to be addressed, and actions that could be taken to address those priority science topics. NASA contracts with the Academy to prepare decadal surveys in all four science areas of NASA's Science Mission Directorate: Astrophysics, Earth Science, Heliophysics, and Planetary Science. NASA uses survey recommendations to set science priorities for its programs. These priorities are used not only for planning the flight program, but also for prioritizing technology development and evaluating proposals for theoretical and suborbital supporting research. The survey's science-based recommendations for flight missions are adapted to yearly budgets, technological capabilities, national policy, partnership opportunities, and other programmatic factors. Recently, the Academy has expanded its decadal survey portfolio to include its first decadal survey in the area of life and physical sciences investments.

The first Heliophysics decadal survey was published in 2003 and covered the period from 2003 to 2012. NASA's Heliophysics Division accomplished all of the NASA top-priority recommendations in the 2003 Decadal Survey of Solar and Space Physics in each of the four categories (Large/Moderate/Small Missions and Vitality of the Research Program). Implementation of the recommendations from that survey brought important changes to the field of solar and space physics. The field advanced from studying separate phenomena to an integrated research strategy whereby significant gains in understanding came through considering the investigations as interacting parts of a complex system. We are now able to track the evolution of solar events from the solar interior to the surface of Earth, connecting the magnetized structure in the Sun's corona to the detailed features of Earth-directed coronal mass ejections (CMEs), to the intricate anatomy of geomagnetic storms as they impact Earth two to three days later. Perhaps the most significant advance is what we have learned about the impact of these geomagnetic storms on society in terms of disrupting satellite operations and electric power grids. The 2003 survey made the study of space weather a high priority and forever changed our view of how interconnected our lives can be with our star, the Sun.

NASA found the recommendations of the previous decadal survey for this field to be invaluable. We anticipate even greater advances through this new decadal survey.

Recent Accomplishments and Current Missions

Today, NASA's Heliophysics flight missions are operated as a single observatory, the Heliophysics System Observatory (HSO).

Over the past year, the HSO produced a number of scientific discoveries.

- Using Solar Dynamics Observatory data, scientists shed new light on the question of how and when solar eruptions occur. They also discovered that the total energy from the extended phase of a solar flare event can supply more energy into the Earth system than the initial, highly visible phase of the flare.
- The Aeronomy of Ice in the Mesosphere (AIM) mission team has classified a wide range of ice structures in polar mesospheric clouds, some never seen before, to help us understand the complex structure of Earth's upper atmosphere and how it is affected by the Sun's processes and how it interacts with the lower atmosphere where we live. Some features show commonality with tropospheric clouds implying that similar processes are occurring.
- Voyager 1 has entered the previously unexplored region between our solar system and interstellar space where the wind of charged particles streaming out from our Sun has calmed and our solar system's magnetic field has piled up. The Voyagers are poised to provide the first ever measurements of the environment that envelop and govern our solar system.

- Thermosphere, Ionosphere, Mesosphere Energetics and Dynamics (TIMED) data collected over the last solar cycle (~11 years) has resulted in the creation of a new understanding of how the Earth's upper atmosphere, thermosphere, mesosphere, and ionosphere respond to changes in the Sun.
- Scientists studying Time History of Events and Macroscale Interactions during Substorms (THEMIS) mission data discovered that particles escape Earth's radiation belts by streaming out into space, in addition to raining down into Earth's atmosphere.
- STEREO has shown the value of using multiple vantage points to forecast the impact of solar storms and their impact on our Earth system. STEREO observations provide essential insights into the structure of coronal mass ejections (CMEs) and the distribution of the most hazardous solar particles as they traverse interplanetary space.
- Interstellar Boundary Explorer (IBEX) and Two Wide-angle Imaging Neutral-atom Spectrometers (TWINS) gave the best ever global picture of the evolution of near-Earth geomagnetic storms, especially of the processes by which the Sun injects energy into the magnetosphere to induce these storms, which will help us determine the path by which the extra energy is dissipated, including any effects on Earth.
- Hinode and the Solar and Heliospheric Observatory (SOHO) missions discovered that the evolution of the Sun's internal magnetic dynamo is not as uniform as has been assumed. That is, as the solar cycle unfolds every 11 years, the regular "flip" of the magnetic north and south poles of the Sun can be asymmetrical rather than simultaneous. Understanding the evolution of the Sun's intrinsic magnetic field is essential to the prediction of solar activity cycles and the ability to model and predict significant solar storms.

Collectively, these missions are an extremely valuable resource. We are able to observe the origins of solar flares and CMEs, we are able to study how these events evolve in transit through the solar system, and we are able to monitor the effects of the events as they engulf Earth and other key locations in the solar system. Several of these research satellites have become an essential part of our Nation's space weather prediction system. The capabilities are, in large part, what the previous solar and space physics decadal survey recommended and the accomplishments are points of pride for all involved. NASA undertook significant technical challenges to deploy this Sun to Earth observing system and accomplished a great deal toward what was once only aspiration. The benefit to the Nation has been significant.

NASA continues to develop new missions to support the heliophysics science program. Completion of the missions currently in development, cited as the top priority of this new Heliophysics decadal survey, will fill key gaps in the Heliophysics System Observatory and enable new scientific discovery in the field of Heliophysics.

- Launched in August 2012 and transitioned into routine operations in October, the Van Allen Probes mission, (formerly the Radiation Belt Storm Probe or RBSP mission), along with the related Balloon Array for RBSP Relativistic Electron Losses (BARREL) balloon flights will help us understand the Sun's influence on Earth and near-Earth space by studying the Earth's radiation belts. During periods of intense space weather, the density and energy of radiation belt particles can increase significantly posing a danger to astronauts and spacecraft that fly through these regions.
- Interface Region Imaging Spectrograph (IRIS), the next Explorer-class mission launching in early 2013, will increase our understanding of energy transport through the solar atmosphere into the corona and solar wind and provide an archetype for all stellar atmospheres.
- Magnetospheric Multiscale (MMS), which will launch in 2015, will use Earth's magnetosphere as a laboratory to study the microphysics of three fundamental plasma

processes: magnetic reconnection, energetic particle acceleration, and turbulence, all of which play key roles in space weather.

- Solar Orbiter Collaboration (SOC) is a European Space Agency-NASA partnership that will continue NASA's solar wind observations and that will address a central question of heliophysics: How does the Sun create and control the heliosphere? It is scheduled to launch in 2017.
- Solar Probe Plus (SPP) has been a top priority of the heliophysics science community for decades and will make the first visit to the solar corona about 3 months after launch to discover how the corona is heated, how the solar wind is accelerated, and how the Sun accelerates particles to high energy. Technically very challenging, this mission will be about eight times closer to the Sun than any spacecraft has come before (coming as close as 3.7 million miles) enduring 2600-degrees Fahrenheit, supersonic solar particles, and intense solar radiation. It is scheduled to launch in 2018.
- The next Explorer-class mission will be selected in spring 2013 from several concepts currently under study. At that time, NASA will choose one full mission for flight and potentially one mission of opportunity. The selected mission will continue the scientific discoveries that enable full understanding of our Sun and its interactions with the Earth and the solar system.

Planning the Future of Heliophysics –The 2012 Decadal Survey

Over a two-year period, several hundred people from the Heliophysics community worked to outline the highest priority science investigations for NASA to pursue over the next decade. NASA would like to express its appreciation to the survey Chairs, Dr. Daniel Baker and Dr. Thomas Zurbuchen, and to the many volunteers and staff who worked tirelessly to bring this effort to a successful conclusion.

The survey has been well received at NASA and has features that make it an effective guide for NASA's planning over the next decade.

- First, the scientific program recommended would significantly improve our understanding of the Sun-Earth-Heliosphere system; the survey specifically targets areas for which observations and understanding do not currently exist.
- Second, the survey recommended a realistic program for NASA's portion of the survey. The top priorities require only modest investments with the potential for immediate rewards. In addition, the survey includes Decision Rules that can be applied if resources are substantially different than projected. The Decision Rules preserve balanced progress across the sub-disciplines and minimize disruption of the highest-priority targets for advancement.
- Last, the program recommended can significantly advance our Nation's capability to provide space weather data and information for severe events and NASA appreciates the emphasis on inter-agency cooperation.

The decadal survey has five main recommendations that are listed below in priority order as designated in the decadal survey, and two applications-related recommendations. The survey's first recommendation is,

> **R0.0: Baseline Priority for NASA and NSF: Complete the 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 constitute the*

> *Heliophysics Systems Observatory (HSO) and successful implementation of programs in advanced stages of development."*

The decadal survey endorses NASA's current program of missions in development and formulation. At the time of the survey, the current program included the Van Allen Probes mission, that successfully launched on August 30, 2012, BARREL, IRIS, MMS, SOC, and SPP missions. Each of these missions is fully funded in the President's FY 2013 budget request to Congress.

The survey's second recommendation is,

> **R1.0 Implement the DRIVE Initiative:** *"The survey committee recommends implementation of a new, integrated, multiagency initiative (DRIVE—Diversify, Realize, Integrate, Venture, Educate) that will develop more fully and employ more effectively the many experimental and theoretical assets at NASA, NSF, and other agencies."*

The decadal survey made specific recommendations for augmenting NASA's Heliophysics operating missions, research grants programs, technology development, and low-cost access to space (LCAS) program. For the survey's DRIVE recommendations, NASA will complete the following studies, and, in consultation with its advisory groups, use the study findings to set program-level policies to best fulfill the survey's recommendations.

- NASA will conduct a study on the budget implications of setting aside competed research funding equal to 2% of each mission's life cycle costs for dedicated guest investigator programs.
- While continuing the current level of support for laboratory plasma astrophysics and spectroscopy investigations, NASA will open discussions with NSF and the Department of Energy (DOE) on the possibility of a jointly competed program in this area.
- NASA will open a joint study with NSF and other agencies to explore methods by which data from space- and ground-based observatories could be combined and utilized to maximize their potential to address larger-scale, Sun-Earth system scientific questions.
- NASA and NSF have recently demonstrated the value of jointly funded, larger-scale scientific investigations, commonly called "strategic capabilities", and NASA intends to continue supporting these partnerships when it is possible to do so. NASA believes it should be possible to extend this successful model to the solicitation and support of multidisciplinary teams that tackle high priority, grand scientific challenges as recommended in the survey.

The survey's third recommendation is,

> **R2.0 Accelerate and Expand the Heliophysics Explorer Program:** *"The survey committee recommends that NASA accelerate and expand the Heliophysics Explorer program, the most successful and impactful mission line in the Heliophysics program. The survey committee recommends that the current Heliophysics Explorer program budget be augmented by $70 million per year, in fiscal year 2012 dollars, restoring the option of Mid-size Explorer (MIDEX) missions and allowing them to be offered alternatively with Small Explorer (SMEX) missions every 2 to 3 years. The survey committee recommends that, as part of the augmented Explorer program, NASA should support regular selections of Missions of Opportunity, which will allow the research community to quickly respond to opportunities and leverage limited resources with interagency, international, and commercial partners."*

The Explorer program has a long history of returning cutting edge science and provides tremendous value to Heliophysics science. In fact, our Nation's first mission to space, Explorer 1, discovered the Earth's radiation belts and opened the field of space-based Heliophysics observations. The Explorer program continues today, providing frequent flight opportunities for world-class scientific investigations addressing heliophysics and astrophysics space science goals.

This recommendation is in-line with NASA's aspirations for the Explorer program. NASA will strive, budget allowing, to achieve the 24 to 36-month period between Explorer Announcements of Opportunity (AOs) although it will take a few years before this is established. Specifically, the next AO for a Heliophysics Explorer may not be feasible until 36 months after the current Explorer selections to be announced in spring 2013 (~52 months since the last AO came out) due to the Explorer budget. The only barrier to offering a MIDEX-size mission will be the availability of an appropriately priced launch vehicle.

The survey's next two recommendations are for the Solar Terrestrial Probes (STP) program and the Living with a Star (LWS) program,

> **R3.0: Solar Terrestrial Probes**: *"The survey committee recommends that NASA's Solar-Terrestrial Probes program be restructured as a moderate-scale, competed, principal-investigator-led (PI-led) mission line that is cost-capped at $520 million per mission in fiscal year 2012 dollars including full life-cycle costs."*
> and,
> **R4.0: Implement a large Living With a Star (LWS) mission to study the ionosphere-thermosphere-mesosphere system in an integrated fashion:** "*The survey committee recommends that, following the launch of RBSP and SPP, the next LWS science target focuses on how Earth's atmosphere absorbs solar wind energy."*

NASA concurs with the science priorities for the four recommended missions. Some of these missions will likely not launch in the decadal timeframe, however, NASA should be able to initiate formulation or pre-formulation activities for the majority of the missions within the decadal timeframe.

In addition, NASA appreciates the flexible nature of the survey's mission recommendations – by providing science targets and leaving the detailed implementation for the procurement phase, NASA can ensure that these missions are enabled by the latest technologies

For the three STP missions, SMD will endeavor to formulate them as moderate-scale, approximately $520M cost-capped missions with the mission requirements, capabilities, and designs consistent with this cost target. NASA intends to study further whether these missions should be "PI-led" in the same manner as for Explorer or Discovery Program missions.

Heliophysics and Space Weather

The Sun's influence is wielded through its gravity, radiation, solar wind, and magnetic fields, all of which interact with the gravity, magnetic field, and the extended atmosphere of the Earth and other solar system bodies to produce geomagnetic storms and space weather. Space weather refers to the conditions on the Sun and in the solar wind, magnetosphere, ionosphere, and thermosphere, which can cause disruption to satellite operations, communications, navigation, and electric power distribution grids; a severe geomagnetic storm has the potential to cause significant socioeconomic loss as well as impacts to national security.

Given the growing importance of space to our Nation's economic well-being and security, it is of increasing importance that NASA and its partner agencies continue to advance our Nation's capability to understand and predict space weather events. NASA, NSF, the National Oceanic and Atmospheric Administration (NOAA), the Department of the Interior, and the Department of Defense developed the satellites and models currently in use to predict space weather effects. Specifically, NASA and NOAA work together (with other government agencies) on satellite development, operations, data processing, and modeling that inform and improve space weather predictions. Together, much has been accomplished to advance understanding of the Sun-Earth system. However, much research and development remains to be done.

The decadal survey went beyond its Heliophysics science recommendations and also made recommendations related to space weather applications that are addressed collectively to the relevant government agencies. NASA recognizes the importance of the recommendations and will continue collaborating with other agencies to realize the decadal survey recommendations. However, as the survey acknowledges, these separate, space weather recommendations are above and beyond current funding resources for the foreseeable future and will most likely not be fulfilled in the decadal survey timeframe.

NASA intends to continue supporting solar, solar wind, and near-Earth environment observations that are essential for space weather prediction efforts and for the transition of NASA's research into NOAA's space weather operations. NASA and NOAA recently agreed to improve coordination, including expediting communications concerning space weather cooperation during major solar events and having periodic meetings with program managers and scientists to identify lessons learned and make adjustments as needed. NASA is committed to supporting its part of the National Space Weather Program (NSWP), a federal interagency initiative established to improve the Nation's capability to make timely and reliable predictions of significant disturbances in space weather, and to help protect critical societal infrastructure, including communication, navigation, and terrestrial meteorological spacecraft. NASA's responsibility is to understand the space environment and the causes of potential hazards for the benefit of society and for securing human and robotic space travel across the solar system.

Summary

NASA implements a research program to understand the Sun, its interactions with the Earth, and how these phenomena impact life and society. NASA researches and develops new mission and instrument capabilities in this area, providing new physics-based algorithms to advance the state of solar physics, space physics, and space weather modeling. This research program is conducted in partnership with other domestic and international research programs to maximize efficiencies and progress.

NASA is pleased with the results of the heliophysics decadal survey and plans to work towards accomplishing the priorities of the scientific community in a timely manner. In particular, the enhancement of the Explorers program is important to utilize the full potential of the heliophysics community toward meeting our national goal of understanding the space environment. The DRIVE program will optimize the scientific return of current and future missions by establishing a healthy research environment and will also enable future missions through its technology enhancements.

Although budget constraints present challenges to the implementation of the survey, the Decision Rules embedded with the survey provide valuable information to ensure the highest priority efforts are completed. NASA is in the process of utilizing the decadal survey recommendations to form the basis for a NASA Heliophysics science and technology strategic plan. This plan for addressing the Heliophysics decadal survey recommendations will be detailed as part of the President's FY 2015 budget request.

Mr. Chairman and Members of the Subcommittee, I appreciate your support of NASA's Heliophysics program. I would be pleased to respond to any questions you or the other Members of the Subcommittee may have.