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NASA's Heliophysics Portfolio

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RESULTS IN BRIEF

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May 7, 2019 IG-19-018 (A-18-001-00)

WHY WE PERFORMED THIS AUDIT

NASA's space missions and much of the U.S. power grid, communications systems, and navigation infrastructure operate in an environment highly susceptible to the Sun. NASA's Heliophysics Division (HPD) and its portfolio of spacecraft, programs, and missions provide observations of solar and geophysical events—also known as "space weather" events—to advance our understanding of the Sun and its interaction with Earth's atmosphere. With a budget of $689 million for fiscal year (FY) 2018, HPD is currently managing 30 missions in various stages of operation and development. The majority of HPD's missions (17 of 30) are in extended operations—meaning they have been successfully launched and are beyond their prime (or initial) operating phase.

HPD's portfolio is heavily influenced by external stakeholders, including the National Research Council (NRC), the National Science and Technology Council (within the Executive Office of the President), and other federal agencies. The NRC has published two heliophysics decadal surveys—the first in 2003 and the second in 2013—identifying broad scientific challenges related to solar and space physics research and recommending a series of missions, facilities, and programs to address those challenges. Additionally, the National Science and Technology Council issued the National Space Weather Action Plan (NSWAP) that detailed tasks for federal agencies in HPD's governing documents to mitigate the adverse effects of space weather. Many of the recommendations and tasks outlined in these documents require NASA to partner with other federal agencies.

In this audit, we assessed NASA's management of its heliophysics portfolio, including to what extent the Agency (1) had an effective strategy for maintaining its heliophysics science capabilities; (2) was controlling costs for its current and planned missions; (3) had implemented appropriate recommendations and action plans; and (4) was effectively coordinating heliophysics activities across federal agencies and the private sector. In meeting these objectives, we interviewed HPD officials and external stakeholders, surveyed HPD project managers, and reviewed and analyzed relevant reports and NASA guidance.

WHAT WE FOUND

HPD has developed a comprehensive strategy that has enabled the Division to successfully manage NASA's heliophysics science capabilities and maintain a portfolio of spacecraft that increasingly includes missions in extended operations. Specifically, HPD developed a roadmap in 2014 to address the NRC's 2013 Heliophysics Decadal Survey (2013 Decadal) recommendations and leverage the Division's current assets in order to maximize the Agency's science return. However, this roadmap has not been updated to account for changes in HPD's portfolio and subsequent years' budgets. HPD has also implemented a Senior Review process that effectively evaluates HPD missions in extended operation and makes recommendations to maximize NASA's return on investment. Finally, HPD conducts weekly, monthly, and yearly assessments to evaluate the health and viability of the Division's spacecraft and instruments to ensure they meet science program goals.

In spite of the advanced age of its spacecraft fleet, NASA is generally controlling costs for all of its HPD missions in operation. Specifically, HPD's missions in extended operations expended more than $1 million less than budgeted in FYs 2016 and 2017, while both the Global-scale Observations of the Limb and Disk (GOLD) and Parker Solar Probe missions recently launched on schedule and within budget. However, HPD's remaining three missions in implementation—Ionospheric Connection Explorer (ICON), Solar Orbiter Collaboration (SOC), and Space Environment Testbeds (SET)—have missed their planned launch dates. Although ICON and SOC remain within their Agency Baseline Commitment costs, collectively, these three missions have incurred almost $41 million in cost growth. Further, the SOC mission did not conduct a Joint Cost and Schedule Confidence Level (JCL) analysis and ICON did not include its launch vehicle in its JCL analysis. A JCL analysis is required for all missions exceeding $250 million and is used to help predict the likelihood that a project will achieve its objectives within budget and on time. Performing a JCL analysis for the SOC mission and including ICON's launch vehicle in its JCL analysis could have provided decision makers better information upon which to base their schedule and budget estimates.

NASA has not completed 19 of its assigned NSWAP tasks, and through no fault of its own, 1 recommendation from the 2003 Heliophysics Decadal Survey (2003 Decadal) remains outstanding. NASA also has six open recommendations from the 2013 Decadal. With regard to NSWAP tasks, NASA officials stated that implementation delays for these 19 tasks occurred because of their complexity and a shortage of NASA and partner agency subject matter expertise. Additionally, the 2003 Decadal recommendation is not completed because of SOC launch delays and the 2013 Decadal recommendations remain open mainly due to budgetary concerns, technological availabilities, and complexity issues. Delays in implementing the NSWAP and decadal survey recommendations could hinder the federal government's efforts to predict and respond to space weather events and limit NASA's ability to develop future heliophysics missions.

Although NASA has established a successful working relationship with the National Oceanic and Atmospheric Administration, the Agency could more effectively collaborate with the Department of Defense (DOD) and the commercial space industry. Specifically, despite conducting similar space-weather-related work, the U.S. Air Force is not actively engaged in NASA's efforts to improve space weather forecasting and therefore is not currently pooling resources with NASA to improve these capabilities. Additionally, a commercial space industry representative noted a lack of established avenues for private industry to convey their heliophysics capabilities to NASA.

What We Recommended

To improve NASA's management of its heliophysics portfolio, we recommended the Associate Administrator for Science direct the HPD Director to (1) require that all JCL analyses include all discrete development risks including important risks managed outside of the project—such as a project's launch vehicle—with potential cost and/or schedule impacts; (2) complete implementation of NSWAP tasks; (3) reassess HPD's capabilities and resources and update its roadmap for implementing 2013 Decadal recommendations with expected completion dates based on the Division's updated budget and priorities over the next 5 years; and (4) establish a formal mechanism to increase collaboration with DOD and the commercial space industry regarding heliophysics research and space weather modeling and forecasting efforts.

We provided a draft of this report to NASA management who concurred or partially concurred with our recommendations and described planned actions to address them. We consider the proposed actions responsive to our recommendations and will close the recommendations upon verification and completion of the proposed actions.

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Acronyms

ABC	Agency Baseline Commitment
ACE	Advanced Composition Explorer
CCMC	Community Coordinated Modeling Center
DOC	Department of Commerce
DOD	Department of Defense
DSCOVR	Deep Space Climate Observatory
DYNAMIC	Dynamical Neutral Atmosphere-Ionosphere Coupling
ESA	European Space Agency
FY	fiscal year
GDC	Geospace Dynamics Constellation
GOES	Geostationary Operational Environmental Satellite
GOLD	Global-scale Observations of the Limb and Disk
HPD	Heliophysics Division
ICON	Ionospheric Connection Explorer
IMAP	Interstellar Mapping and Acceleration Probe
JCL	Joint Cost and Schedule Confidence Level
KDP	Key Decision Point
MEDICI	Magnetosphere Energetics, Dynamics, and Ionospheric Coupling Investigation
NOAA	National Oceanic and Atmospheric Administration
NPR	NASA Procedural Requirements
NRC	National Research Council
NSF	National Science Foundation
NSWAP	National Space Weather Action Plan
LWS	Living With a Star
OIG	Office of Inspector General
RHESSI	Reuven Ramaty High Energy Solar Spectroscopic Imager
SDO	Solar Dynamics Observatory
SET	Space Environment Testbeds
SMD	Science Mission Directorate
SOC	Solar Orbiter Collaboration
SOHO	Solar and Heliospheric Observatory
STP	Solar Terrestrial Probes
SWORM	Space Weather Operations, Research, and Mitigation
SWPC	Space Weather Prediction Center

INTRODUCTION

The Sun emits a continuous stream of plasma called solar wind in addition to sudden flashes of high-energy radiation called solar flares that release billions of tons of matter known as coronal mass ejections. When directed towards Earth, these "space weather" events can cause large magnetic storms potentially endangering human life, including astronauts working in space, and influencing the performance and reliability of spaceborne and ground-based communication systems and power grids. Heliophysics—the study of the Sun and its effects on Earth and space—enables us to predict space weather events, mitigate the hazards posed to spaceborne and ground-based assets, and understand how space weather impacts the solar system.

One of five major components of NASA's Science Mission Directorate (SMD), the Heliophysics Division (HPD) and its portfolio of spacecraft, programs, and missions provides observations of solar and geophysical events to the scientific community and other federal agencies that are used to advance our understanding of the Sun and its interaction with Earth's atmosphere.[1]

This audit assessed NASA's management of its heliophysics portfolio. Specifically, we evaluated whether NASA (1) had an effective strategy for maintaining its heliophysics science capabilities; (2) was controlling costs for its current and planned missions; (3) had implemented recommendations, decision rules, and action plans provided in HPD's governing documents; and (4) was effectively coordinating heliophysics activities across federal agencies and the private sector. See Appendix A for details on our scope and methodology.

Background

The term "heliophysics," meaning physics of the Sun, was widely adopted in the 1980s to encompass various disciplines that involve studying the Sun, including the immediate atmosphere around the Sun known as the heliosphere, the Sun's interactions with Earth's atmosphere, the magnetic field surrounding Earth known as magnetosphere, and Earth's upper atmosphere known as the ionosphere.

As society has become more reliant on computers and other electricity-based technologies, the need to study the Sun, space weather, and their potentially debilitating effects on such technology has increased. One of the most famous examples of the adverse effects of the Sun and space weather is known as the 1859 Carrington event. The event was caused by a solar storm that illuminated skies all over Earth in red, green, and purple auroras so bright that night became day and caused telegraph systems worldwide to malfunction, with electric spark discharges shocking telegraph operators and setting telegraph paper on fire. When telegraphers disconnected the batteries powering the telegraph lines, aurora-induced electric currents in the wires still enabled messages to be transmitted. In another example, which occurred on March 13, 1989, the entire province of Quebec, Canada, and parts of the United States suffered an electrical power blackout due to a powerful explosion on the Sun that

[1] SMD also includes the Astrophysics Division, Earth Science Division, Joint Agency Satellite Division, and Planetary Science Division.

released a billion-ton cloud of gas that caused electrical lines and power transformers to malfunction.[2] More recently, in September 2017 several powerful solar flares caused outages in high-frequency radio links used in federal disaster response and aviation tracking, impeding relief efforts in the Caribbean from hurricanes Harvey, Irma, Jose, and Maria.

The National Aeronautics and Space Act of 1958 directed NASA to conduct activities that contribute to "the expansion of human knowledge of phenomena in the atmosphere and space."[3] As the need to study the Sun became more apparent, NASA's Astrophysics Science Division established the Laboratory for Astronomy and Solar Physics in 1978. In 2004, as a result of a NASA reorganization, the Laboratory became HPD with a singular focus on studying the Sun.

HPD Strategic Objective and Science Goals

HPD's strategic objective is to understand the Sun and its interactions, including space weather, with Earth and the solar system. In support of this objective, HPD aims to achieve three overarching science goals:

- *Solve the fundamental mysteries of heliophysics.* Explore the physical processes in the space environment from the Sun to Earth and throughout the solar system.
- *Understand the nature of our home in space.* Advance understanding of the connections that link the Sun, Earth, planetary space environments, and outer reaches of the solar system.
- *Build the knowledge to forecast space weather throughout the heliosphere.*[4] Develop the knowledge and capability to detect and predict extreme conditions in space to protect life and society and safeguard human and robotic explorers beyond Earth.

Over the past 40 years, NASA has launched a fleet of spacecraft with missions that (1) provide observations of solar and geophysical events used in operational space weather forecasts and (2) assess satellite anomalies resulting from space weather events. The missions also provide information to enable safe and efficient operation of NASA's robotic and human missions, such as space weather forecasts for Agency assets located across the solar system. In addition, NASA's heliophysics activities include pioneering new missions and instrument capabilities and improving space weather prediction algorithms and models.

HPD Programs and Missions

HPD is comprised of 4 programs responsible for managing 30 missions.[5]

Living With a Star. The Living With a Star (LWS) Program focuses on the science necessary to understand those aspects of the Sun and space environment that most directly affect life on Earth. LWS missions target the links that connect the solar system with the ultimate goal of being able to predict the Sun's behavior and understand its influence. As of September 2018, the LWS Program included six missions in various stages of development and operation, including the $1.5 billion Parker

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[2] Several U.S. electrical utilities were affected due to interconnectivity between the Canadian and U.S. power grids.

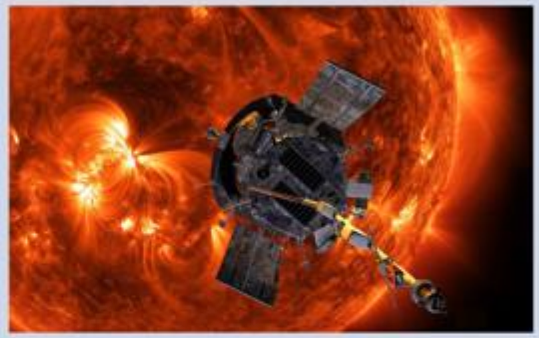
[3] National Aeronautics and Space Act of 1958, 42 U.S.C. § 2451 (2008).

[4] The heliosphere is the region of space in the solar system where solar wind has a significant influence.

[5] As of September 2018, HPD had eight projects that were either in preformulation or formulation phases, and in this report we classify them as "missions" for ease of readability.

Solar Probe that launched in August 2018. This mission will get closer to the surface of the Sun than any man-made object and is the most scientifically advance and costly mission in HPD's portfolio. The Solar Orbiter Collaboration (SOC), a joint project between NASA and the European Space Agency (ESA) where NASA is contributing about $436 million for two instruments and the launch vehicle, is scheduled to launch in February 2020.[6] Together these missions are designed to answer questions about the structure and dynamics of the Sun's corona.

Artist's Rendering of NASA's Parker Solar Probe approaching the Sun



Source: NASA.

Solar Terrestrial Probes. The Solar Terrestrial Probes (STP) Program focuses on specific scientific areas required to advance fundamental understanding of the connection between the Sun and the solar system. Targeting the "weakest links" in the scientific community's study of heliophysics, STP missions use a blend of in-situ and remote sensing observations, often from multiple points of observations, to understand the causes and effects of solar variability over vast spatial distances.[7] The STP Program features seven missions in various stages of development and operation, including the $1.2 billion Magnetospheric Multiscale Mission launched in March 2015 and the $492 million Interstellar Mapping and Acceleration Probe scheduled to launch in the mid-2020s.[8]

Explorers. The Explorers Program provides flights for scientific investigations utilizing small missions and so-called "missions of opportunity." These missions are offered to principal investigators from the scientific community who submit proposals and compete to investigate a wide array of science in the heliophysics field.[9] Categorized based on their estimated cost to NASA, the missions typically fall under one of the following three classes:

- *Small Explorers*—total cost to NASA not to exceed $115 million, excluding launch costs.
- *Medium-Class Explorers*—total cost to NASA between $200 million and $250 million, excluding launch costs.
- *Missions of Opportunity*—investigations characterized as being part of a non-NASA space mission, such as ride-sharing instruments on another federal agency's mission, of any size and having a total cost to NASA under $55 million.

The Explorers Program features eight missions, including the $73 million Global-scale Observations of the Limb and Disk (GOLD), the first mission to study the day-to-day weather of Earth's upper atmosphere. Launched in January 2018, GOLD is hosted on a commercial communications satellite and the first NASA science mission to fly as a commercially hosted payload.

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6 ESA is the European space organization comprised of 22 member countries. ESA is contributing more than $660 million for spacecraft and instrument development.

7 In-situ is something that is situated in an original, natural, or existing place or position.

8 Interstellar Mapping and Acceleration Probe's $492 million reflects the estimated principal investigator managed mission cost cap and does not include launch vehicle costs or NASA Headquarters held budget reserves, known as unallocated future expenses.

9 A principal investigator is responsible and accountable for the technical objectives and content of a project as well as for a project's planning and execution.

HPD Research. The HPD Research Program supports a wide array of research that studies the interconnected systems linking the Sun to Earth, the Sun to other planets in the solar system, and the particles and magnetic energy coursing through space itself. The Voyager 1 and 2 missions, which both launched in 1977, are now HPD Research Program missions after completing their primary planetary science objectives. Another major component of the HPD Research Program is the Sounding Rocket Program (see Appendix B for more information), which provides flight opportunities for small, typically sub-orbital science research experiments.

As of September 2018, HPD was managing 30 missions in various stages of operation and development: extended, implementation, and future. The majority of HPD's missions (17 of 30) are in extended operations—meaning they are beyond their prime (or initial) operating phase (see Table 1 for a list of extended HPD missions). Five HPD missions are in implementation—that is, NASA is designing, manufacturing, launching, or operating (prime phase) the mission. Of these implementation missions, two launched in 2018 (GOLD and Parker Solar Probe) and three are scheduled for launch over the next 2 years (Ionospheric Connection Explorer [ICON], SOC, and Space Environment Testbeds [SET]). HPD is currently developing technological and preliminary designs for the remaining eight future missions.

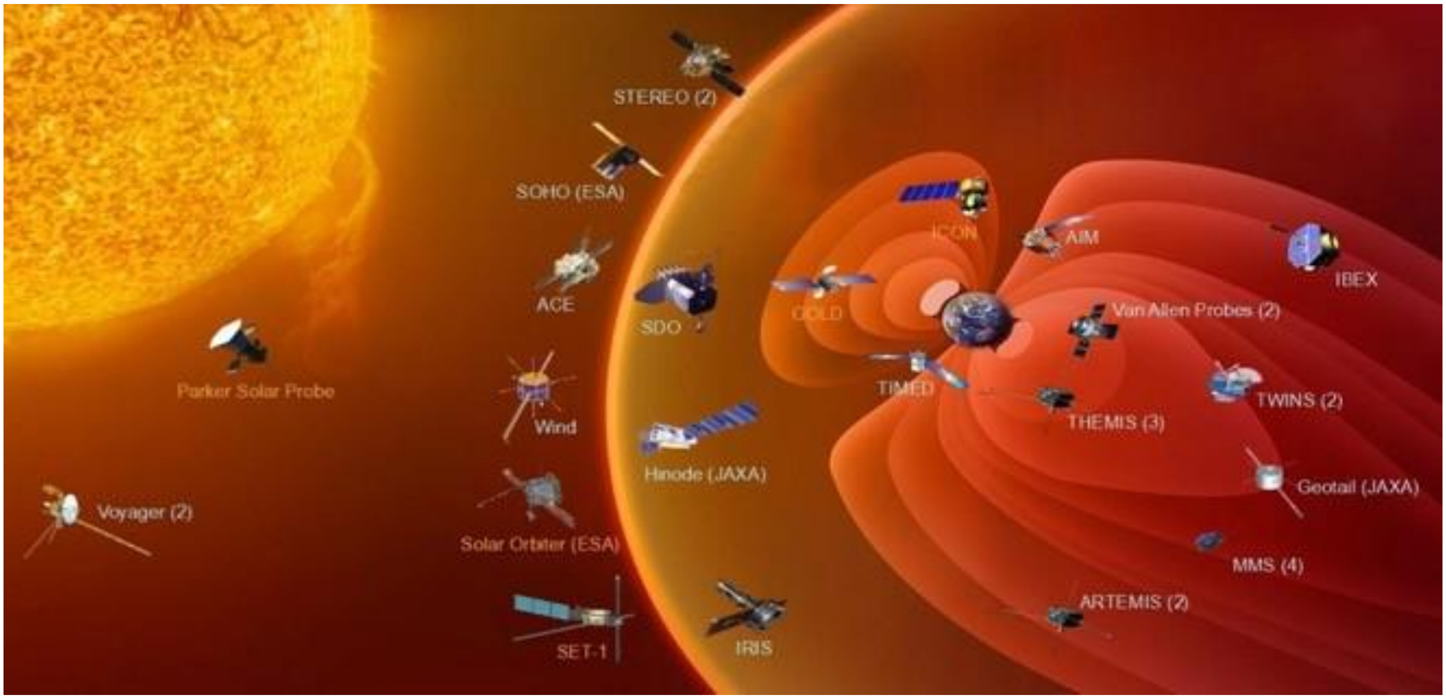
Table 1: HPD Missions in Extended Operation, as of September 2018

Mission	Program	Launch Date	Prime Mission Duration (in years)	Extended Mission Duration (in years)
Acceleration, Reconnection, Turbulence and Electrodynamics of Moon's Interaction with the Sun (ARTEMIS)	Explorers	February 17, 2007	2	9
Advanced Composition Explorer (ACE)	Explorers	August 25, 1997	2	19
Aeronomy of Ice in the Mesosphere (AIM)	Explorers	April 25, 2007	2	9
GEOTAIL	HPD Research	July 24, 1992	4	22
Hinode	STP	September 22, 2006	3	9
Interstellar Boundary Explorer (IBEX)	Explorers	October 19, 2008	2	8
Interference Region Imaging Spectrograph (IRIS)	Explorers	June 27, 2013	2	3
Magnetospheric Multiscale Mission (MMS)	STP	March 13, 2015	2	1
Solar Dynamics Observatory (SDO)	LWS	February 11, 2010	5	3
Solar and Heliospheric Observatory (SOHO)	HPD Research	December 2, 1995	2	21
Solar Terrestrial Relations Observatory (STEREO)	STP	October 25, 2006	2	10
Thermospheric Ionosphere Mesosphere Energetics and Dynamics (TIMED)	STP	December 7, 2001	2	15
Time History of Events and Macroscale Interactions During Substorms (THEMIS)	Explorers	February 17, 2007	2	9
Two Wide-angle Imaging Neutral-atom Spectrometers (TWINS A & B)	Explorers	June 28, 2006, and March 13, 2008	2	12 and 10
The Van Allen Probes	LWS	August 30, 2012	2	4
Voyager 1 & 2	HPD Research	September 5, 1977, and August 20, 1977	5	36
WIND	HPD Research	November 1, 1997	5	16

Source: NASA Office of Inspector General (OIG) analysis based on Agency information.

Figure 1 displays the HPD missions in extended or implementation phases and their general operating location in relation to the Sun and Earth. Appendix C contains detailed information regarding each HPD mission, including mission objectives and anticipated societal benefits.

Figure 1: HPD Mission Fleet Chart, as of September 2018



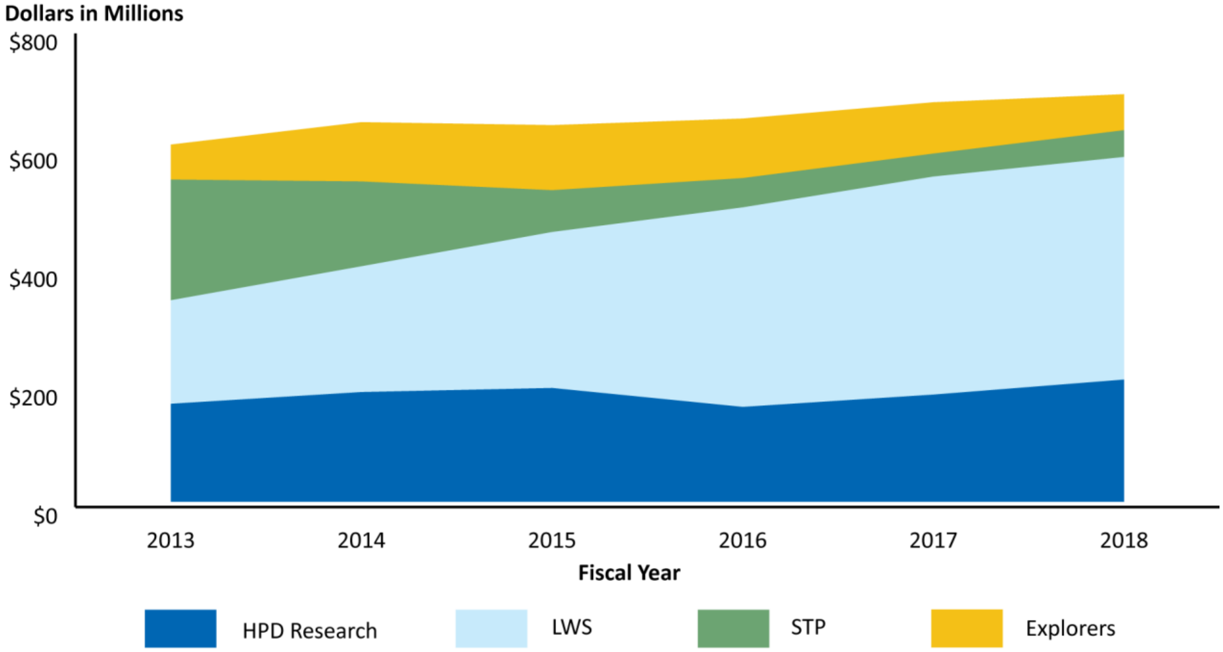
Source: NASA.

HPD Budget

From fiscal year (FY) 2013 through FY 2018, HPD's average annual budget was approximately $648 million. As shown in Figure 2, LWS has been HPD's most expensive program, followed by the HPD Research Program. While HPD's budget has increased from about $603 million to $689 million (or approximately 14 percent) over this time period, both NASA's and SMD's budgets, as a whole, have increased by 23 and 30 percent, respectively, for the same period.[10]

[10] NASA's budget increased from $16.86 billion in 2013 to $20.73 billion in 2018. SMD's budget increased from $4.78 billion to $6.22 billion over the same period.

Figure 2: HPD Budget by Program for FYs 2013 through 2018



Source: OIG analysis and presentation of NASA information.

NASA's Project Life Cycle

HPD missions follow NASA's project life cycle, which is divided into two phases—Formulation and Implementation—that are further divided into Phases A through F. The project life cycle also consists of numerous activities, including preformulation, evaluation, and Key Decision Points (KDP), that allow managers to plan, assess, and review a project's progress (see Figure 3).[11] Preformulation is where mission teams develop concept studies to provide information on mission costs, risks, and feasibility. The Formulation Phase is divided into Phases A and B during which mission teams identify how their mission supports NASA's strategic goals and develop technological and preliminary project designs. Once the process outlined in the Formulation Phase is confirmed, the project is approved for implementation at KDP-C, which occurs between Phases B and C, and transitions into the Implementation Phase. Divided into Phases C through F, the Implementation Phase is where mission development and operation project plans are executed and control systems are used to ensure they align with NASA's strategic goals. Once a project has been implemented, continuous evaluation of a project's status is conducted, including ongoing independent reviews and assessments.

[11] NASA Procedural Requirements (NPR) 7120.5E, *NASA Space Flight Program and Project Management Requirements* (August 14, 2012) and NASA/SP-2014-3705, *NASA Space Flight Program and Project Management Handbook* (September 2014).

Figure 3: NASA Project Life Cycle

PREFORMULATION	FORMULATION		APPROVAL/KPD-C	IMPLEMENTATION				EVALUATION
Pre-phase A Preformulation	**Phase A** Concept and technology development	**Phase B** Preliminary design and technology completion	Confirmation process for transitioning into implementation	**Phase C** Final design and fabrication	**Phase D** System assembly, integration, test, launch, and checkout	**Phase E** Operations and sustainment	**Phase F** Closeout	Ongoing independent review and assessment of a project's status

Source: OIG presentation of NASA information.

National Research Council Decadal Surveys

The National Research Council (NRC) conducts studies that present a consensus from the science community on key questions posed to NASA and other federal government agencies.[12] The broadest of these studies is known as a decadal survey in which NASA and its partners can ask the NRC to look 10 or more years into the future to prioritize research areas, observations, and missions. The NRC is congressionally mandated to review NASA's implementation of decadal survey priorities every 5 years.[13] Since HPD's creation, the NRC has published two heliophysics decadal surveys—the first in 2003 and the second in 2013.[14]

2003 Heliophysics Decadal Survey

The 2003 Heliophysics Decadal Survey (2003 Decadal) identified broad scientific challenges that defined the focus of solar and space physics research by describing a series of missions, facilities, and programs designed to address those challenges. The report also recommended revitalizing several existing NASA programs and advocated funding increases for others. In total, the 2003 Decadal contained 23 recommendations, 20 of which were directed to NASA, 2 to the National Science Foundation (NSF), and 1 to the National Oceanic and Atmospheric Administration (NOAA).

2013 Heliophysics Decadal Survey

The 2013 Heliophysics Decadal Survey (2013 Decadal) built on NASA's research accomplishments realized since the 2003 Decadal. The report recommendations, which were based on an assumed $800 million HPD annual budget, were primarily directed to HPD and the NSF Directorate for Geosciences, Division of Atmospheric and Geospace Sciences. The report also recommended actions by

[12] The NRC was the research arm of the National Academy of Sciences. In July 2015, the institution became the National Academies of Sciences, Engineering, and Medicine. For simplicity, we use the term NRC throughout the report to refer to both the NRC and National Academies of Sciences, Engineering, and Medicine.

[13] The NASA Authorization Act of 2005 requires that "the performance of each division in the Science directorate of NASA shall be reviewed and assessed by the National Academy of Sciences at 5-year intervals." NASA Authorization Act of 2005, Pub. L. No. 109-155 § 301 (2005).

[14] NRC, *The Sun to the Earth and Beyond: A Decadal Research Strategy in Solar and Space Physics* (2003) and *Solar and Space Physics: A Science for a Technological Society* (2013). As of February 2019, the NRC had begun its 5-year evaluation of NASA's implementation of the 2013 Heliophysics Decadal Survey.

other federal agencies, especially NOAA, that are charged with the day-to-day (operational) forecasting of space weather. The 2013 Decadal recommendations collectively informed four key science goals, each of which the NRC considered to be of equal priority:

1. Determine the origins of the Sun's activity and predict variations in the space environment.
2. Determine the dynamics and coupling of Earth's magnetosphere, ionosphere, and atmosphere and their response to solar and terrestrial inputs.
3. Determine the interaction of the Sun with the solar system and the interstellar medium.[15]
4. Discover and characterize the fundamental processes that occur both within the heliosphere and throughout the universe.

The 2013 Decadal prioritized 14 NASA specific recommendations comprised of 8 research and 6 survey application recommendations. For example, in response to these recommendations, NASA decreased funding beginning with its FY 2018 budget for programs with large strategic missions such as LWS and increased funding for programs with smaller, more frequent missions such as Explorers to develop a more flexible portfolio.

2015 National Space Weather Action Plan

In recognition of the importance of predicting and mitigating space weather effects, the National Science and Technology Council, an entity within the Executive Office of the President, concurrently issued in 2015 the National Space Weather Strategy (Strategy) and the National Space Weather Action Plan (NSWAP).[16] Together, the Strategy and NSWAP detail national goals for leveraging existing policies and ongoing research and development efforts, promoting enhanced domestic and international coordination and cooperation across public and private sectors, and establishing partnerships to mitigate the adverse effects of space weather. Additionally, NSWAP was designed to enhance observing networks, conduct research, develop prediction models, and supply the services necessary to protect life and property and to promote economic prosperity in the face of adverse space weather events.

NSWAP contains six goals, each of which is comprised of sub-tasks assigned to multiple agencies for implementation:

1. Establish benchmarks for space weather events.
2. Enhance response and recovery capabilities.
3. Improve protection and mitigation efforts.
4. Improve assessment, modeling, and prediction of impacts on critical infrastructure.
5. Improve space weather services through advancing understanding and forecasting.
6. Increase international cooperation.

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[15] Interstellar medium is the matter and radiation that exists in the space between star systems in a galaxy. This matter includes gas in ionic, atomic, and molecular form, as well as dust and cosmic rays.

[16] The Strategy established goals for a space weather strategy across the federal government while NSWAP defined specific tasks based on the Strategy's goals. National Science and Technology Council, *National Space Weather Strategy* (October 2015) and *National Space Weather Action Plan* (October 2015).

Each agency assigned a task is designated as a lead agency, co-lead agency, or supporting agency, and each task typically has a 1- to 3-year deadline for implementation. The majority of tasks assigned to NASA fall under goals 1, 5, and 6. Agencies working with NASA to complete these tasks include the Department of Defense (DOD), NOAA, and NSF. Specifically, out of a total of 97 tasks, NASA was assigned 41, of which it is the lead agency for 10, co-lead for 15, and supporting agency for 16. See Appendix D for a complete list of NSWAP tasks.

Overseeing and approving the implementation of NSWAP tasks is the Space Weather Operations, Research, and Mitigation (SWORM) Subcommittee, which was created as the federal interagency body of the U.S. National Science and Technology Council.

NASA IS EXECUTING AN EFFECTIVE STRATEGY FOR MAINTAINING HELIOPHYSICS SCIENCE CAPABILITIES

HPD developed a comprehensive strategy that has allowed the Division to successfully manage NASA's heliophysics science capabilities and maintain a portfolio of spacecraft that increasingly includes missions in extended operations. Specifically, HPD developed a roadmap to address the 2013 Decadal recommendations and leverage the Division's current assets in order to maximize the Agency's science return. HPD has also implemented a Senior Review process that effectively evaluates HPD missions in extended operation and makes recommendations to maximize NASA's return on investment.[17] Finally, HPD conducts weekly, monthly, and yearly assessments to evaluate the health and viability of the Division's spacecraft and instruments to ensure they meet science program goals.

HPD Roadmap Aligns with 2013 Decadal Recommendations

In response to the NRC's 2013 Decadal, HPD developed a roadmap to address the survey's science goals and challenges. Published in April 2014, *Our Dynamic Space Environment: Heliophysics Science and Technology Roadmap for 2014–2033* (Roadmap) leveraged HPD's fleet of spacecraft, the majority of which are operating well beyond their extended lifetime, to conduct a variety of scientific research missions.[18] Specifically, the Roadmap addressed the 2013 Decadal's highest priorities, including implementing NASA's portion of the Diversity, Realize, Integrate, Venture, and Educate Initiative; increasing NASA's use of the Explorers Program; and rebalancing the HPD Research Program and portfolio of spacecraft.[19]

The Roadmap recommended an integrated initiative encouraging extensive use of HPD's current assets to maximize the Agency's science return. For example, it explained the benefits of combining multiple missions to facilitate greater understanding of the fundamental physical processes that will improve space weather predictions. However, the Roadmap has not been updated since 2014 to account for changes in HPD's portfolio and subsequent years' budgets.

[17] NASA Transition and Authorization Act of 2017, Pub. L. No. 115-10 (2017), requires NASA to conduct a review of its extended phase operations missions every 3 years.

[18] NASA, *Our Dynamic Space Environment: Heliophysics Science and Technology Roadmap for 2014–2033* (April 2014). This report was developed by the NASA Advisory Council's Heliophysics Subcommittee with input from the heliophysics community.

[19] The Diversity, Realize, Integrate, Venture, and Educate Initiative represents an integrated approach among federal agencies, including NASA and the NSF, to manage crucial infrastructure investments and supporting program elements for space flight missions.

Senior Review Process Effectively Evaluates Missions in Extended Operation

In order to assess the continued relevance of its fleet and missions, in 1997 HPD established a Senior Review process to evaluate the ongoing need for previously approved HPD missions in extended operations, review new proposals for missions that have completed their prime mission phase, and assess the missions' return on investment.[20] Senior Reviews are conducted every 3 years by the Heliophysics Senior Review Panel, a subcommittee of the Heliophysics Advisory Committee comprised of officials from NASA, other federal agencies, academia, and the private sector.[21]

During each Senior Review, every HPD mission approaching the end of its prime mission or already in extended operations is evaluated as both a stand-alone mission and for its contribution to the HPD's fleet of spacecraft as a whole.[22] The Senior Review process relies on mission teams to report on the status of their mission, propose the science they hope to continue should the mission be extended, and explain the health and safety of their missions' instruments. Specifically, a mission's project scientist or principal investigator will report on the current health and operations of mission spacecraft in addition to forecasting future risks or issues and any operational changes that may be necessary. NASA uses the results of a Senior Review to develop an implementation strategy and give programmatic direction to HPD missions and projects for the next 5 years.

Since 2005, NASA has convened six Senior Reviews, with the most recent conducted in 2017. Overall, the 2017 Senior Review found that HPD had an "excellent" fleet of spacecraft and that the Division's missions in extended operations collectively contribute to HPD's strategic objectives. For example, the Review found that HPD's SDO mission, which is studying how and why the Sun's magnetic fields change, is a valuable asset that provides a breadth of observational information to enable cutting edge investigations, its data is used by many heliophysics missions, and provides for near-real-time space weather forecasting by other U.S. and international agencies. To address budget concerns, the Review recommended HPD assess SDO mission requirements, including operations and data timeliness, to help reduce overall mission costs.

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[20] The criteria for continuation include relevance to HPD goals; impact of scientific results as measured by publications, awards, and press releases; spacecraft and instrument health; science team productivity and vitality; promise of future impact and productivity; and broad accessibility and data usability.

[21] A stand-alone advisory committee established under the Federal Advisory Committee Act, the Heliophysics Advisory Committee provides advice to HPD, SMD, other Agency Mission Directorates, and the NASA Administrator regarding all aspects of heliophysics, including developments with the potential to provide long-term improvements to future space weather operational systems. Federal Advisory Committee Act, Pub. L. No. 92-463, 86 Stat. 770 (1972).

[22] The members of a Senior Review are experts in their fields of research who review each mission's proposal for extended operations.

HPD Has an Effective Process for Managing Heliophysics Science Capabilities

Given that 17 of HPD's 30 missions were operating beyond their prime mission as of September 2018—9 of which have been in extended operations for 10 or more years—it is critical that the Division maintain an adequate process to ensure it continues to receive vital science research data from these missions. We surveyed officials from all 17 missions in extended operations to understand how HPD is managing its science capabilities.[23] In accordance with NASA policy, we found these project-level officials routinely assess, evaluate, and document the health and viability of their mission spacecraft and instruments.[24]

HPD mission officials stated they regularly monitor instrument health and data quality for each of their missions by conducting weekly teleconferences on mission operations with HPD Headquarters officials and posting meeting minutes from these discussions to mission websites. In addition, missions produce a Space Science Mission Operations Weekly report that contains a short description of a mission's activities for that week, including any unusual instrument activity. For example, one of the SDO weekly reports we reviewed indicated that the mission experienced an issue with one of its computers but no science data was lost and the spacecraft was reconfigured back to its normal state the same day. According to an HPD Headquarters official, had the issue been more significant or prolonged they would have prepared an anomaly report.[25]

HPD mission officials also provided monthly and quarterly status reports to HPD Headquarters officials summarizing the issues, risks, and events for each HPD mission. The 10 status reports we reviewed showed that HPD consistently provided relevant information to effectively evaluate the missions. For example, the May 2018 report included an overall summary of HPD prime and extended missions and detailed top project concerns such as connectivity issues with the Reuven Ramaty High Energy Solar Spectroscopic Imager (RHESSI) mission, which was investigating particle acceleration and energy release in solar flares.[26] As a result of the issues and problems identified in these status reports and a recommendation from the Senior Review, the RHESSI mission was decommissioned in August 2018.

Finally, we found annual meetings held with HPD Headquarters officials to discuss mission budget renewal and report changes to spacecraft and instrument health are effective in evaluating the missions.

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[23] We also surveyed a Reuven Ramaty High Energy Solar Spectroscopic Imager (RHESSI) official before the mission was decommissioned in August 2018 and that response is a part of our survey results. Seventeen of 18 project officials surveyed responded.

[24] NPR 7120.5E.

[25] While their use is infrequent, anomaly reports document such things as hardware failures, unexpected mode changes (e.g., an instrument enters an anomalous state and cannot self-recover without external commanding), or loss of more than 24 hours of science data. In FYs 2017 and 2018, 6 HPD missions submitted 13 anomaly reports with issues ranging from an SDO ground antenna damaged by a lightning strike to two instruments on ACE unexpectedly powering off.

[26] RHESSI launched in February 2002 and for at least the past 16 years, had begun showing signs of declination. By July 2018 communication with the spacecraft was intermittent and as a result, the temperature of the sensor increased and what little science data captured was no longer useful. Mission officials sent the spacecraft a command to drain its batteries on July 19, 2018.

NASA IS EFFECTIVELY CONTROLLING COSTS FOR HPD MISSIONS IN OPERATION BUT FACES CHALLENGES IN MEETING COST AND SCHEDULE TARGETS FOR NEW MISSIONS

NASA is controlling costs for all of its HPD missions in extended operations and two of its five missions in implementation. Specifically, HPD's 18 missions in extended operations expended more than $1 million less than budgeted for FYs 2016 and 2017, while both the GOLD and Parker Solar Probe missions recently launched on schedule and within their Agency Baseline Commitment (ABC).[27] However, as of March 2019 HPD's three other missions in implementation—Ionospheric Connection Explorer (ICON), Solar Orbiter Collaboration (SOC), and Space Environment Testbeds (SET)—had missed their launch dates. In addition, ICON and SOC, while still within their ABC, have incurred almost $37 million in cost growth, while SET has exceeded its ABC by more than $4 million. Further, the SOC mission did not conduct a Joint Cost and Schedule Confidence Level (JCL) analysis required for all missions exceeding $250 million, and ICON did not include its launch vehicle in its JCL analysis. Performing these analyses for SOC and ICON could have provided decision makers better information upon which to base their schedule and budget estimates.[28]

HPD Missions in Extended Operation Stay within Budget Estimates

Once an HPD mission has completed its prime mission, NASA may choose to transition it into extended operations. If this happens, mission officials are responsible for monitoring mission costs through a variety of periodic reports and meetings, while HPD management relies on the Senior Review process to assess mission costs and operations.

In FYs 2016 and 2017, HPD expended more than $1 million less than budgeted for its 18 missions in extended operations, with missions operating under budget balancing out those few missions over budget (see Table 2). Because all extended missions are funded via the Mission Operations and Data Analysis budget for their respective programs, NASA is able to transfer funds from a mission under budget to a mission experiencing greater than expected costs within the same program.[29]

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[27] The ABC establishes and documents an integrated set of project requirements, cost, schedule, technical content, and agreed to Joint Cost and Schedule Confidence Levels that forms the basis for NASA's commitment to the Office of Management and Budget and Congress. The RHESSI mission was included in our review of mission costs for HPD's extended operations since it was not decommissioned until August 2018.

[28] A JCL analysis generates a representation of the likelihood a project will achieve its objectives within budget and on time.

[29] Consolidated Appropriations Act, 2018, Pub. L. No. 115-141 (2018).

Table 2: FYs 2016 and 2017 Budget and Actual Extended Missions Costs (dollars in millions)

Heliophysics Missions	Fiscal Year		Difference	Fiscal Year		Difference
	2016 Budget	2016 Actual		2017 Budget	2017 Actual	
ARTEMIS/THEMIS[a]	$4.6	$5.4	$(0.8)	$5.4	$5.4	$0.0
ACE	3.0	3.0	0.0	3.0	3.0	0.0
AIM	3.0	3.0	0.0	3.0	3.0	0.0
GEOTAIL	0.2	0.4	(0.2)	0.2	0.4	(0.2)
Hinode	7.3	7.3	0.0	7.0	7.0	0.0
IBEX	3.4	3.4	0.0	3.4	3.4	0.0
IRIS	7.7	7.6	0.1	7.7	7.7	0.0
MMS	30.1	30.1	0.0	17.4	19.9	(2.5)
RHESSI	1.9	1.9	0.0	1.9	1.9	0.0
SDO	9.5	12.0	(2.5)	12.0	12.1	(0.1)
SOHO	2.2	2.2	0.0	2.3	2.3	0.0
STEREO	9.5	8.3	1.2	9.5	6.5	3.0
TIMED	2.7	2.7	0.0	2.6	2.6	0.0
TWINS A & B	0.6	0.6	0.0	0.6	0.6	0.0
The Van Allen Probes	15.5	11.9	3.6	13.3	13.3	0.0
Voyager 1 & 2	5.7	5.7	0.0	5.6	5.6	0.0
WIND	2.2	2.2	0.0	2.2	2.2	0.0
Totals	**$109.1**	**$107.7**	**$1.4**	**$97.1**	**$96.9**	**$0.20**

Source: OIG analysis based on NASA information.

[a] ARTEMIS is an outgrowth of THEMIS and does not have an independent budget.

Three HPD Missions in Implementation Experienced Cost Growth

HPD has five missions currently in the Implementation Phase. We found that the GOLD and Parker Solar Probe missions launched in accordance with budget estimates and on schedule in January 2018 and August 2018, respectively. However, the ICON and SOC missions have experienced millions of dollars in cost growth due to missed launch dates and other launch-related delays, while the SET mission exceeded its budget by $4 million when it was brought out of storage in preparation for launch. Additionally, we found that project personnel did not consider the ICON launch vehicle as a risk factor in their JCL analysis and project personnel did not conduct a JCL analysis for the SOC mission, which could have helped these missions establish better cost and schedule estimates.[30]

[30] NPR 7120.5E requires missions that have an estimated life-cycle cost greater the $250 million to conduct a JCL analysis.

Two HPD Missions in Implementation Were Launched on Schedule and within Budget

Global-scale Observations of the Limb and Disk

NASA Lead Center: Goddard Space Flight Center

International Partner: None

Launch Date: January 25, 2018

Launch Location: Guiana Space Centre in Kourou, French Guiane

Launch Vehicle: Ariane 5

Mission Duration: 2 years

The GOLD mission is a part of HPD's Explorers Program and has an estimated life-cycle cost exceeding $73 million. Launched on schedule in January 2018, GOLD is designed to explore the nearest reaches of space and capture never-before-seen images of Earth's upper atmosphere. Gathering observations from geostationary orbit above the Western Hemisphere, GOLD measures the temperature and composition of gases in Earth's thermosphere, a portion of Earth's upper atmosphere that co-mingles with the ionosphere.[31] Activity in this region is responsible for a variety of key space weather events. Scientists are particularly interested in the cause of dense, unpredictable bubbles of charged gas that appear over the equator and tropics, sometimes causing communication problems. As NASA discovers the nature of the Earth-Sun interaction in this region, GOLD could help improve forecasts of space weather and mitigate its effects. This mission marks the first time NASA has flown a science mission as a hosted payload on a commercial satellite, which according to NASA, provides an opportunity for cost savings when compared to launching a mission on its own launch vehicle. With a life-cycle cost of more than $73 million, GOLD is within its ABC, having expended over $66 million as of January 2019 (see Table 3).

Table 3: GOLD Cost Performance (dollars in millions)

Mission Phase	FY 2015 ABC	January 2019 Estimate	Budget Remaining
Formulation	$12.9	$12.8	$0.1
Development	47.6	38.8	8.8
Operations	12.7	14.9	(2.2)
Total	**$73.2**	**$66.5**	**$6.7**

Source: OIG analysis based on NASA information.

[31] Geostationary orbit is located 22,236 miles above Earth's equator, which allows satellites to match Earth's rotation and is a position particularly well-suited for monitoring weather, communications, and surveillance.

Parker Solar Probe

NASA Lead Center: Goddard Space Flight Center

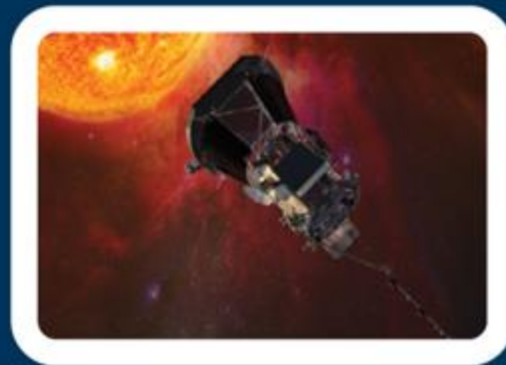
International Partner: None

Launch Date: August 12, 2018

Launch Location: Cape Canaveral Air Force Station, Florida

Launch Vehicle: Delta IV Heavy

Mission Duration: 7 years



Launched on schedule in August 2018, the Parker Solar Probe mission, with an estimated life-cycle cost approaching $1.6 billion, is part of HPD's LWS Program. The first-ever mission to "touch" the Sun, the spacecraft will fly into the outermost part of the Sun's corona, and at its closest approach, the spacecraft will be within 4 million miles of the Sun's surface. The mission will employ a combination of measurements and imaging designed to greatly improve understanding of the Sun's corona and expand knowledge of the origin and evolution of solar wind. The mission will also make critical contributions to scientists' ability to forecast changes in the space environment that affect life and technology on Earth. Previous development delays and testing failures with the instruments and spacecraft subsystems required the use of mission schedule reserves and $4.5 million from Headquarters SMD-held reserves. However, the mission is within its FY 2014 ABC life-cycle cost of approximately $1.6 billion, and as of December 2018, the mission expects to expend over $1.4 billion over its planned lifetime (see Table 4).

Table 4: Parker Solar Probe Cost Performance (dollars in millions)

Mission Phase	FY 2014 ABC	December 2018 Estimate	Budget Remaining
Formulation	$247.1	$247.1	$0.0
Development	1,055.7	979.9	75.8
Operations	250.6	197.6	53.0
Total	**$1,553.4**	**$1,424.6**	**$128.8**

Source: OIG analysis based on NASA information.

Three HPD Missions in Implementation Experienced Schedule Delays and Cost Growth

Ionospheric Connection Explorer

NASA Lead Center: Goddard Space Flight Center

International Partner: Belgium

Original Launch Date: February 2017

Launch Location: Cape Canaveral Air Force Station, Florida

Launch Vehicle: Pegasus

Mission Duration: 2 years

ICON is a nearly $253 million mission that is a part of HPD's Explorers Program. The mission will orbit Earth to explore its ionosphere—that is, the boundary region between Earth and space where ionized plasma and neutral gas collide and react. Because the ionosphere is the area through which GPS radio communications and signals travel, changes to this region of space can impact satellite communication and navigation systems on Earth. ICON will make direct measurements and use remote sensing to further researchers' understanding of Earth's upper atmosphere, the Earth-Sun connection, and the ways in which space weather drives Earth weather. The mission will also help determine the physics of Earth's space environment and pave the way for mitigating space weather effects on communications systems and technology.

Originally scheduled to launch in February 2017, ICON has missed several mission launch dates:

- In August 2014, NASA re-planned ICON to launch in June 2017 and align with the GOLD mission to achieve a more optimal overlap of the on-orbit science measurements of the two missions.
- In February 2017, the launch was delayed to no earlier than July 2017 when two rocket motors for its Pegasus launch vehicle fell off a truck during transit to the launch site.[32] The rocket motors were subsequently inspected and tested by the contractor with no damage found.
- In May 2017, the launch was further delayed to November 2017 due to ongoing engineering testing and analysis of two Pegasus launch vehicle rocket motors that fell off truck during transit to the launch site.
- In August 2017, the launch vehicle provider requested a December 2017 launch date.
- In November 2017, the launch was delayed to June 2018 when one of the nine bolt cutter assemblies on the Pegasus launch vehicle failed to fracture a bolt during testing.[33]

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[32] Pegasus is a three-stage rocket developed by Orbital Sciences Corporation (now part of the Northrop Grumman Corporation) used to deploy small satellites weighing up to 1,000 pounds into low Earth orbit. Pegasus is carried aloft by a Stargazer L-1011 aircraft to approximately 40,000 feet over open ocean, where it is released and free-falls for 5 seconds before igniting its first stage rocket motor. Pegasus typically delivers satellites into orbit in a little over 10 minutes.

[33] Vehicle bolt cutter assemblies hold the launch vehicle and payload together and are designed to separate during launch.

- In June 2018, the launch was postponed to October 2018 due to an anomalous telemetry reading from the Pegasus during a flight to Hawaii.
- In September 2018, the launch was delayed because of the possibility of cracked connectors in several of the launch vehicle's electronic boxes.
- In October 2018, the launch was further delayed to conduct more testing of Pegasus after observing a recurrence of the anomalous Pegasus telemetry during a ferry flight to Cape Canaveral Air Force Station.
- Following a November 2018 launch attempt, NASA made the decision to fly Pegasus and ICON back to its integration facility at Vandenberg Air Force Base in California to further investigate the recurrence of the anomalous Pegasus telemetry.

As of February 2019, NASA had not announced a new launch date for ICON and the mission is on hold until further testing is completed.

ICON is within its FY 2015 ABC of nearly $253 million, and as of November 2018, the mission expects to expend approximately $243 million (see Table 5). However, the multiple schedule delays have resulted in more than $16 million in unanticipated mission development costs and more than $4 million in launch vehicle costs. Mission development costs include launch operations testing, readiness tests, periodic battery checks, and launch preparations at the Vandenberg Air Force Base. According to ICON's Project Manager, NASA SMD management has allocated $7.5 million in Headquarters budget reserves for the mission. As of March 2019, these funds have not been used.

Table 5: ICON Cost Performance (dollars in millions)

Mission Phase	FY 2015 ABC	November 2018 Estimate	Budget Remaining
Formulation	$42.4	$38.7	$3.7
Development	196.0	189.2[a]	6.8
Operations	14.3	15.0	(0.7)
Total	**$252.7**	**$242.9**	**$9.8**

Source: OIG analysis based on NASA information.

[a] Project cost estimate may be updated based on the results of an ongoing anomaly investigation into the ICON launch delay.

A mission official stated that if ICON had launched in June 2017, the project would not have requested Headquarters budget reserves.[34] The official estimated that due to cancellation of the June 2018 launch, NASA is spending approximately $1 million a month to store and maintain the spacecraft and keep the mission's development team together until post-launch when the mission transitions to an operations team. However, this official stated that HPD management does not believe the mission will exceed its FY 2015 ABC if ICON is launched in the first half of 2019. One unknown factor is how much unallocated future expenses will be allotted for the launch vehicle during the launch delay. HPD management plans to review and reconcile ICON costs during the mission's Post-Launch Assessment Review, which occurs approximately 2 months after launch.[35]

[34] NASA refers to budget reserves as "unallocated future expenses." This is the portion of estimated costs required to meet the specified confidence level that cannot yet be allocated to the specific Work Breakdown Structure sub-elements because the estimate includes probabilistic risks and specific needs that are not known until these risks are realized.

[35] The Post-Launch Assessment Review evaluates the readiness of the spacecraft systems to proceed with full, routine operations after post-launch deployment. The review also evaluates the status of the project plans and the capability to conduct the mission with emphasis on near-term operations and mission-critical events.

Solar Orbiter Collaboration

NASA Lead Center: Goddard Space Flight Center

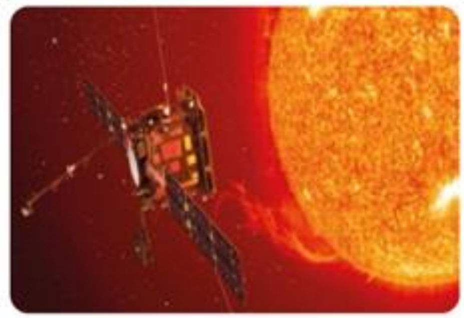
International Partner: European Space Agency

Original Launch Date: January 2017

Launch Location: Cape Canaveral Air Force Station, Florida

Launch Vehicle: Atlas V 411

Mission Duration: 7 years



NASA is contributing nearly $436 million to the SOC mission that is a part of HPD's LWS Program and a European Space Agency (ESA)-led collaboration that will provide insight into the evolution of sunspots, coronal holes, and other solar features and phenomena. After a 3-year journey from Earth, SOC will be placed into an elliptical orbit around the Sun, coming as close as 26 million miles from the star every 5 months. The inclined orbit will allow the mission to better image regions around the Sun's poles than ever before. Contributing more than $660 million to the joint effort, ESA is responsible for the mission's design, operations, and spacecraft, including 8 of the spacecraft's 10 science instruments. In return for providing the launch vehicle and the remaining 2 instruments—the Solar Orbiter Heliospheric Imager and the Heavy Ion Sensor—NASA will have access to the entire science mission data set.

SOC was originally scheduled to launch in January 2017. According to NASA, this launch date was moved to October 2018 because of a limited launch window and uncertainties in ESA's schedule regarding the amount of time it would need to develop its eight science instruments.[36] Subsequently, ESA requested a launch delay to February 2019 because of problems with integrating the science instruments onto the spacecraft. Further spacecraft design and observatory integration issues challenged ESA and forced it to request another delay to February 2020. According to NASA officials, the Agency has already delivered its two science instruments to Airbus, ESA's contractor responsible for designing and building the spacecraft, at its facility in the United Kingdom. NASA project officials stated that some of the mission delays are attributed to the contractor. In accordance with federal law, NASA reported SOC's schedule breach to Congress in May 2018.[37]

Despite these delays, SOC is within its FY 2013 ABC of nearly $436 million, and as of December 2018, the mission is expected to expend more than $373 million in life-cycle cost (see Table 6). The mission is still within its ABC primarily due to a more than $53 million decrease in launch vehicle costs. However, the multiple mission delays have cost NASA more than $17 million in unanticipated development costs and are expected to cost the Agency an additional $14 million by February 2020.

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[36] A mission's launch window is the time period during which a particular vehicle must be launched in order to reach its intended target.

[37] 51 U.S.C. § 30104 (2010).

Table 6: SOC Cost Performance (dollars in millions)

Mission Phase	FY 2013 ABC	December 2018 Estimate	Budget Remaining
Formulation	$41.5	$41.5	$0.0
Development	377.0	281.9	95.1
Operations	17.4	50.4	(33.0)
Total	**$435.9**	**$373.8**	**$62.1**

Source: OIG analysis based on NASA information.

Space Environment Testbeds

NASA Lead Center: Goddard Space Flight Center

International Partner: None

Original Launch Date: October 2009

Launch Location: Cape Canaveral Air Force Station, Florida

Launch Vehicle: SpaceX Falcon Heavy Rocket

Mission Duration: 1 year

The SET mission, with an initial estimated life-cycle cost of about $38 million, is part of HPD's LWS Program and anticipates to launch no earlier than March 2019. The mission will define the mechanisms for space environment effects, such as the impact the Sun has on spacecraft electronics and materials, spacecraft temperature, and radiation hazards to spacecraft instruments. The mission is also designed to reduce uncertainties in the space environment and its effects on spacecraft payloads. These include understanding solar variability and its effects on space and Earth environments with an ultimate goal of a reliable predictive capability of solar variability and developing strategies to mitigate the undesirable effects of solar variability on humans and human technology on the ground and in space. Furthermore, the mission seeks to improve design and operation guidelines and test protocols to reduce spacecraft anomalies and failures due to environmental effects.

In 2008, SET was completed and shipped to Cape Canaveral for integration and testing as a ride share on the U.S. Air Force's Deployable Structures Experiment spacecraft.[38] NASA has spent $3.7 million over the past 10 years in storage costs waiting to launch SET. Other missions having launch priority over SET, reassignments on the Kennedy Space Center launch manifest, and engineering challenges with developing the Space Exploration Technologies Corporation (SpaceX) Falcon Heavy rocket (e.g., SpaceX had to redesign the rocket's center core booster to accommodate heavier payloads) contributed to launch delays.[39]

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[38] The Air Force subsequently renamed the project "Demonstration and Space Experiments." Ride shares occur when multiple payloads launch into orbit on a single launch vehicle.

[39] The first Falcon Heavy was launched from Cape Canaveral in February 2018. As of February 2019, SET is planned to launch on the third Falcon Heavy no earlier than March 2019.

As of November 2018, SET anticipated exceeding its FY 2007 ABC of nearly $38 million by $4.2 million (see Table 7). A mission official stated this increase in cost can be attributed to storage costs and preparing the payload for launch. The official also stated that when SET's funding requirements exceeded its budget, additional money was allocated from other HPD program resources. Because SET is a rideshare payload, the mission has no control over the launch date, but HPD managers said the costs of purchasing a launch vehicle would far exceed the expense of storing the instrument.

Table 7: SET Cost Performance (dollars in millions)

Mission Phase	FY 2007 ABC	November 2018 Estimate	Budget Remaining
Formulation	$17.6	$17.6	$0.0
Development	19.5	23.7	(4.2)
Operations	0.6	0.6	0.0
Total	**$37.7**	**$41.9**	**($4.2)**

Source: OIG analysis based on NASA information.

Joint Cost and Schedule Confidence Level Analyses Did Not Account for All Project Risks

One of the key milestones during a project's life cycle is KDP-C—that is, the point at which NASA requires a project to conduct a JCL analysis for any space flight project with an estimated life-cycle cost that exceeds $250 million. NASA uses the JCL process to help predict the likelihood that a project will achieve its objectives within budget and on time.[40] The process relies on software tools and models that combine cost, schedule, risk, and uncertainty factors to evaluate how expected threats and unexpected events affect a project's cost and schedule. JCL policy also requires project managers to consider the risks associated with external contributions to the project that could affect cost and schedule, such as launch vehicles and the anticipated contributions of international partners, or that may have a detrimental impact on achieving mission goals and objectives.

Pegasus Launch Vehicle

Source: NASA.

We believe NASA could have identified and mitigated some of the issues and delays experienced by the ICON and SOC missions had it conducted a JCL for each mission element. According to NASA officials, a JCL analysis was not conducted for the ICON mission's launch vehicle because Agency practice has not required missions to include the launch vehicle as a risk factor. As discussed previously, the lack of readiness of ICON's Pegasus launch vehicle has contributed to multiple mission delays. During the mission's KDP-C, despite the fact that the Pegasus vehicle had only been used three times since 2012,

[40] NPR 7120.5E.

NASA included it as a fixed mission cost and therefore did not include it as a risk factor in the mission's JCL analysis. Accordingly, we believe NASA should have included the Pegasus launch vehicle in its JCL analysis to account for the added risks associated with an infrequently used launch vehicle—a risk that unfortunately has manifested itself in multiple launch delays leading to increased costs.

With regard to SOC, a NASA official said the Agency did not conduct a JCL for this mission because (1) similar to ICON, the launch vehicle is typically not included in a JCL analysis; (2) the two NASA-provided instruments are independent from each other; and (3) a contractor performed an independent cost and schedule estimate of these instruments. Although this situation is unique in that NASA is only providing the launch vehicle and 2 of the 10 mission instruments, NASA policy does not differentiate between stand-alone projects and projects that only provide instruments to a partner. With SOC's life-cycle cost approaching $436 million, well above the $250 million threshold for performing a JCL analysis, we believe a JCL could have provided NASA decision makers greater insight into the mission's cost and schedule risks.

NASA Had Difficulty Implementing Several National Space Weather Action Plan Tasks and Decadal Survey Recommendations

NASA has not completed 19 of its assigned NSWAP tasks, and through no fault of its own, 1 recommendation from the 2003 Decadal remains outstanding. NASA also has six open recommendations from the 2013 Decadal. With regard to the NSWAP tasks, NASA officials stated that implementation delays for these 19 tasks occurred because of task complexity and shortage of NASA and partner agency officials' subject matter expertise. Additionally, the 2003 Decadal recommendation is not completed because of SOC launch delays and the 2013 Decadal recommendations remain open mainly due to budgetary concerns, technological availabilities, and complexity issues. Delays in implementing the NSWAP and decadal survey recommendations could hinder the federal government's efforts to predict and respond to space weather events and limit NASA's ability develop future heliophysics missions.

Task Complexity and Personnel Issues have Delayed Implementation of Several NSWAP Tasks

NASA and other federal agencies, including the Department of Commerce (DOC) and DOD, have experienced difficulties meeting the initial NSWAP task deadlines. Of the 41 tasks assigned to NASA, the Agency still needs to implement 2 tasks as the prime lead agency, 5 tasks as the co-lead agency, and 13 tasks as the supporting agency. Table 8 lists the status of NASA tasks that remain unimplemented and its role as a prime lead, co-lead, or supporting agency. (See Appendix D for a full list of NSWAP tasks and descriptions.)

Table 8: NSWAP NASA's Outstanding Tasks as of October 2018

Task	Lead Agency	Co-lead Agency	Supporting Agency	Current Status	Current Due Date
NASA as the Primary Lead Agency					
1.2.3 Will develop enhanced benchmarks for ionizing radiation	NASA	DOC	DOD, DOT, FCC, and NSF	On track to meet deadline	October 2018
5.6.1 Will develop a formal process to enhance coordination between research modeling centers and forecasting centers[a]	NASA	NSF	DOC and DOD	Task completed as written in NSWAP February 2018, ongoing monitoring required	October 2016
NASA as the Co-lead Agency					
1.3.1 Will assess the feasibility and utility of establishing functional benchmarks	DOI	DOC, NASA, and NSF	DOE and DHS	On track to meet deadline	October 2018
1.4.3 Will develop enhanced benchmarks	DOC	DOD and NASA	DOI and FCC	On track to meet deadline	October 2018
1.5.3 Will develop enhanced benchmarks	DOC	DOD, NASA, and NSF	DOI and FCC	On track to meet deadline	October 2018
5.5.1 Will lead an annual effort to prioritize and identify opportunities for research and development to enhance the understanding of space weather and its sources	NSF	NASA	DOC and DOD	Ongoing Annual	April 2018
6.3.3 Will continue efforts within the Coordination Group for Meteorological Satellites to promote an ongoing agenda item on space-weather activities	DOC	NASA	–	Approved March 2017, ongoing annual	October 2016
NASA as the Supporting Agency					
1.3.3 Will develop enhanced benchmarks	DOC	DOD	DOI, FCC, NASA, and NSF	On track to meet deadline	October 2018
2.2.1 Will update next Strategic National Risk Assessment to include latest data on extreme space weather threats and vulnerabilities	DHS	–	DOC and NASA	On track to meet deadline	May 2018
2.6.1 Will develop training for scientific, national security, and emergency management professionals on the response protocols during extreme space weather events	DHS	–	DOC, DOD, DOT, and	Initial coordination started with FEMA, but no update since December 2017	October 2017
4.2.3 Will work with the commercial aviation industry, space operations and services, and international groups to define requirements for real-time monitoring of the charged particle radiation environment to protect the health and safety of crew and passengers during space weather events	DOC	–	DOD, DOT, and NASA	Making progress toward closing the action, last update April 2018	October 2016
4.2.4 Will define scope and requirements for a real-time reporting system that conveys situational awareness of the radiation environment to orbital, suborbital, and commercial aviation users during space weather events	DOT	–	DOC, Department of State, and NASA	Making progress toward closing the action, last update April 2018	October 2017
4.2.5 Will develop or improve models for the real-time assessment of radiation levels at commercial flight altitudes	DOC	DOT	NASA	The task is at an impasse, last update April 2018	October 2017
4.4.2 Will develop national capability for forecasting space weather impacts and develop relevant tools and products that ensure the operational execution and dissemination of forecasts	DHS	DOC	NASA and NSF	On track to meet deadline, last update April 2018	October 2018

Task	Lead Agency	Co-lead Agency	Supporting Agency	Current Status	Current Due Date
NASA as the Supporting Agency (cont.)					
5.3.2 Will develop options to deploy an operational satellite mission to replace the SOHO/Large Angle and Spectrometric Coronagraph capability	DOC	–	DOD and NASA	Development started, still pending, funding and technical issues	End of 2017
5.3.9 Will produce a plan for deployment of new operational space-weather-observing assets to provide the baseline measurements	DOC	–	DOD, DOI, NASA, and NSF	Technical issues	July 2018
5.6.2 Will develop a plan (which may include a center) that will ensure the improvement, testing, and maintenance of operational forecasting models	DOC	DOD	NASA and NSF	Submitted on May 2017, awaiting approval	May 2018
6.2.2 Will explore opportunities to leverage international partnerships to sustain baseline operational space-weather-observing capabilities	DOC	DOI	NASA and NSF	Approved March 2017, ongoing annually	October 2016
6.2.6 Will promote the improved exchange of data and information using the UN World Meteorological Organization Information System and other means, and organize international data comparison activities to promote the availability, intercalibration and interoperability of space-and ground base data	DOC	DOI	NASA and NSF	Submitted for approval on December 2017	October 2017
6.2.7 Will provide input to the UN World Meteorological Organization operational space-weather-observing requirements and Statement of Guidance and will report to relevant international organizations	DOC	DOI	NASA and NSF	Ongoing annual, initial action approved March 2017	October 2016

Source: OIG analysis of SWORM subcommittee documentation.

Note: Department of Interior (DOI), Department of Transportation (DOT), and Federal Communication Commission (FCC).

[a] NASA has completed Task 5.6.1; however, it is an ongoing NSWAP task and therefore remains outstanding.

With regard to the two tasks for which NASA serves as the primary implementation agency, the reasons for delays in implementing these tasks vary:

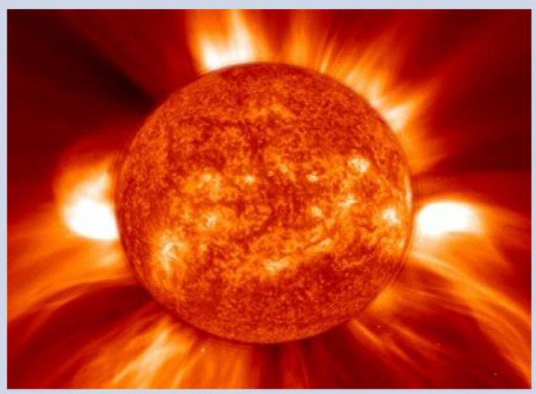
- According to NASA officials, tasks under NSWAP's Goal 1—*establish benchmarks for space weather events*—have been difficult to implement due to subject matter complexity and the fact that scientific research is in its infancy stage for this particular field, meaning that NASA had to start from scratch to establish something that has never been done before. Consequently, officials said the initial NSWAP deadline of 1 year for completing Task 1.2.3 was unrealistic. According to NASA officials, the SWORM subcommittee recognized this difficulty and granted several deadline extensions, pushing the original deadline from October 2017 to October 2018. Although NASA officials stated they are on track to meet the new deadline, as of December 2018, outstanding Goal 1 tasks have not been completed.

- Task 5.6.1. under Goal 5.6—*improve effectiveness and timeliness of the process that transitions research to operations*—directs NASA and NSF, in collaboration with DOC and DOD, to develop a formal process to enhance coordination between research modeling centers and forecasting centers.[41] Additionally, the task requires NASA to identify roles and responsibilities in testing, verification, and validation for transitioning space weather research models to space weather forecasting centers and for sustaining and improving models that transition into operations. The SWORM subcommittee considers the initial implementation of this task, as written in NSWAP, completed; however, subcommittee officials stated this is an ongoing directive and NASA needs to continue monitoring and implementing the task. According to NASA officials, the reasons for initial delays were mainly due to shortage of knowledgeable staff and competing priorities at other agencies. The latest efforts related to this task started in June 2018 and include actions taken by NASA to broaden its use of Memoranda of Agreements with federal agencies. As detailed later in this report, NASA is already using such an agreement with NOAA regarding space weather cooperation.

NASA is a co-lead or supporting agency on 10 tasks that remain to be implemented. For the most part, NASA has completed work on its portion of these tasks, but overall completion has been delayed due to lack of agency partner action, including a lack of space weather knowledgeable staff, competing priorities, and budgetary constraints.

Further delays in implementing NSWAP tasks could hinder the ability to predict, protect against, and mitigate adverse space weather incidents. For example, Task 5.3.2 directs NOAA, in coordination with NASA and DOD, to develop options to deploy an operational satellite mission to a position at least 1 million miles upstream on the Earth-Sun line.[42] The primary instrument on this mission will be a solar coronagraph that will replace NASA's SOHO mission, which is more than 22 years old and is projected to start failing in 2020 due to solar panel degradation. NOAA is developing two follow-on coronagraph instruments to be launched on the NOAA GOES-U and the Space Weather Follow On L1 satellites. Both launch dates are planned for the 2024 timeframe. If the replacement coronagraph is not operational by the time NASA's SOHO mission ends, global space weather forecasting capabilities will be significantly reduced given the one-of-a-kind nature of SOHO's coronagraph. As a supporting agency on this task, NASA is coordinating with NOAA to help with potential launch solutions such as ridesharing with another NASA mission once NOAA has completed instrument development.

Coronal Mass Ejection



SOHO's coronagraph provides observations of the Sun's coronal mass ejections (CME), which if directed at Earth, could adversely effect the health of astronauts aboard the International Space Station, as well as space and ground-based technologies. This image shows a widely spreading CME as it blasts more than a billion tons of matter out into space at millions of kilometers per hour.

Source: NASA.

[41] Research modeling centers develop forecasting models for space weather while forecasting centers use these models to predict space weather conditions.

[42] The Earth-Sun line refers to an imaginary straight line between Earth and the Sun on the same plane that allows the spacecraft to be located directly in the path of the Sun's Earth-bound rays.

One 2003 Decadal Recommendation Remains Outstanding due to Solar Orbiter Collaboration Launch Delays

As discussed previously, in May 2017 NASA contributed two instruments for the ESA-led SOC mission, fulfilling its part of a 2003 Decadal recommendation. However, although the mission was originally scheduled to launch in January 2017, it has been delayed several times due to instrument integration issues on ESA's part. The mission is currently scheduled to launch in February 2020, and NASA is awaiting delivery of the spacecraft from ESA before providing the launch vehicle. Because the overall intent of the recommendation has yet to be implemented and falls out of the previous decadal survey window (2003 to 2013), NASA must use resources that would otherwise be available to address 2013 Decadal recommendations. Even with these delays, NASA officials told us that the international partnership with ESA, shows a satisfactory return on investment given the Agency will have access to the mission's full data sets, which should offer valuable research information and improve knowledge related to the dynamics of the Sun.

NASA Has Yet to Implement Six Recommendations from the 2013 Decadal

NASA is at the halfway point of the 2013 Decadal and still has 6 of 15 recommendations that need to be implemented, including several related to larger strategic missions. For example, the report recommended that NASA implement missions similar to the Dynamical Neutral Atmosphere-Ionosphere Coupling (DYNAMIC) and Magnetosphere Energetics, Dynamics, and Ionospheric Coupling Investigation (MEDICI) missions.[43] Table 9 lists the six open recommendations and provides their status as of October 2018.

[43] DYNAMIC is designed to examine how lower-atmosphere variability affects geospace and drives neutral and plasma variability in the ionosphere-thermosphere system. A DYNAMIC-like mission will study how terrestrial weather on Earth affects the space weather condition in Earth's upper atmospheric layers. MEDICI is a new, strategic, notional mission concept that would study the complex magnetosphere-ionosphere-thermosphere relationship with solar forces.

Table 9: Open 2013 Decadal Recommendations

Recommendation	Status	Projected Closure Date	Funding Provided
Complete the current program, including launching GOLD, ICON, MMS, Parker Solar Probe, SET, and SOC	Launched GOLD, MMS, and Parker Solar Probe missions. ICON was expected to launch in November 2018; however, anomalies were identified and NASA is conducting further testing. Extended operations of several HPD missions as recommended by 2015 Senior Review. Instruments for two missions currently in development, SET and SOC, are complete. Waiting on Air Force Rideshare launch in 2019 for the SET mission. NASA SOC instruments were delivered in 2017 and are waiting on ESA spacecraft integration and tests. SOC is planned to launch in February 2020.	n/a	Yes
Continue solar wind observations from Lagrange point 1 (L1)	Established a partnership with NOAA relevant to science and operational efforts for solar and solar wind observations. These include support of continued solar irradiance observations and associated calibration, implementation of Interstellar Mapping and Acceleration Probe (IMAP), continued data provision from NASA missions at L1, support of NOAA's Space Weather Follow-On mission with a launch provision on the IMAP launch vehicle.	n/a	No
Implement an IMAP-like mission	The IMAP mission under development is a principal investigator-led mission with an anticipated launch in October 2024. A flat funding profile is the reason the launch readiness date moved from 2023 to 2024.	2024	Yes
Implement a DYNAMIC-like mission	Funding for a DYNAMIC mission was not provided. HPD budget remained flat at about $690 million instead of projected rise above $800 million.	n/a	No
Implement a MEDICI-like mission	Like DYNAMIC, MEDICI funding has not been provided.	n/a	No
Implement a large LWS Geospace Dynamics Constellation (GDC)-like mission	Funding not provided. Seed funds used to advance mission preformulation in 2019. GDC Science And Technology Definition Team began work in 2018.	2029	No

Source: NASA.

According to HPD officials, NASA chose to implement these strategic missions in the second half of the 2013 Decadal time period because the Agency was focusing on high-priority survey recommendations. These officials also said NASA has invested in technologies required to implement missions related to the remaining open 2013 Decadal recommendations such as starting preformulation of the GDC mission by establishing a Science and Technology Definition Team.[44]

An HPD official stated that several of the 2013 Decadal recommendations, including the GDC mission, were predicated on an increased budget that has not been realized. The 2013 Decadal acknowledged that an increased budget was needed to address some of its medium- and low-priority recommendations, projecting a funding increase to $800 million; however, the HPD budget remains flat at approximately $690 million resulting in a $110 million funding gap, which negatively impacts HPD's ability to implement all of 2013 Decadal recommendations.

[44] The Science and Technology Definition Team is a subcommittee of the Heliophysics Advisory Committee and supports the advisory needs of NASA, SMD, and HPD. Its specific goal is to define a compelling and executable mission concept for GDC.

Prior OIG reports have noted that past decadal surveys generally underestimated the cost of recommended missions and the time needed to implement recommendations.[45] For example, in the 2007 Earth Science Decadal Survey, NRC recommended four missions for launch by 2013.[46] However, NASA launched only two of these missions—the Soil Moisture Active-Passive mission and the Ice, Cloud, and Land Elevation Satellite-2 mission—in January 2015 and September 2018, respectively. Of the remaining two missions, NASA eliminated the Deformation, Ecosystem Structure and Dynamics of Ice mission in 2012 due to presidential budget priorities and the Climate Absolute Radiance and Refractivity Observatory mission is planned to launch no earlier than 2023.[47] Similarly, while the 2010 Astrophysics Decadal Survey recommended launch of the Wide Field Infrared Survey Telescope by 2020, NASA's FY 2017 budget request supports a launch no earlier than 2025.[48] Additionally, the SOC mission for HPD was recommended in the 2003 Decadal but is not scheduled to launch until February 2020.

[45] NASA OIG, *NASA's Earth Science Mission Portfolio* (IG-17-003, November 2, 2016).

[46] NRC, *Earth Science and Applications from Space: National Imperatives for the Next Decade and Beyond* (2007).

[47] The 2007 Earth Science Decadal Survey described the Deformation, Ecosystem Structure and Dynamics of Ice as a mission that would observe Earth surface deformation, terrestrial vegetation structure, and ice sheet dynamics to advance climate research. The Decadal Survey described Climate Absolute Radiance and Refractivity Observatory as a multi-spacecraft mission to improve climate predictions by measuring the solar irradiance absorbed by the Earth-ocean-atmosphere system and the radiation exchanged within that system and emitted to space. NASA subsequently scaled back the mission to a single instrument to be flown on the International Space Station.

[48] NRC, *New Worlds, New Horizons in Astronomy and Astrophysics* (2010). The Wide Field Infrared Survey Telescope is planned as the next large-scale orbiting telescope following the James Webb Space Telescope that is planned to launch in March 2021. It is designed to explore the nature of dark energy, complete the exoplanet census, and detect exoplanets.

NASA Could Benefit from Greater Collaboration with the Department of Defense and Commercial Space Industry

Although NASA has established a successful working relationship and framework with NOAA, the Agency could more effectively collaborate with DOD and the commercial space industry. Specifically, despite conducting similar space-weather-related work, the U.S. Air Force is not actively engaged in NASA's efforts to improve space weather forecasting and therefore is not currently pooling resources with NASA to develop applied sciences to improve these capabilities. Additionally, a commercial space industry representative noted a lack of established avenues for private industry to convey their heliophysics capabilities to NASA.

NASA Effectively Collaborates with the National Oceanic and Atmospheric Administration

Over the years, NASA has developed several collaboration efforts with NOAA that promote coordination and cooperation on space weather activities between the two agencies. In 2017, NASA established a Memorandum of Understanding with NOAA's Space Weather Prediction Center (SWPC). In addition to providing access to global environmental data and information from satellites and other sources, NOAA's National Environment Satellite, Data, and Information Service uses NASA as its acquisition agent to procure and launch weather satellites, including space weather instruments, for NOAA forecasters. Using NASA and NOAA satellites, SWPC monitors the Sun and space weather to provide forecasting for operational use by the public and commercial sectors, including electrical grid and satellite operators and the commercial airline industry. Additionally, an SWPC staff member was on a 1-year detail to HPD to facilitate ongoing cooperation between the two agencies and NOAA plans to provide another SWPC staff member in this capacity.

The deployment of space weather instruments on NOAA's Deep Space Climate Observatory (DSCOVR) mission and the Geostationary Operational Environmental Satellite (GOES) Series to replace capabilities on NASA's Advanced Composition Explorer (ACE) mission are examples of cooperation between the two agencies. Launched in 1997, ACE measures solar particles in space known as solar wind, data invaluable for predicting space weather incidents directed toward Earth. NOAA incorporates data from ACE into its operational space weather forecast. However, ACE's reliability has decreased as the mission continues to age well beyond its initially designed 5-year lifespan.[49] As a result, NOAA and NASA collaborated to replace ACE's capabilities by including comparable instruments on DSCOVR, and two GOES satellites: GOES-R and GOES-S. Built jointly by NASA and NOAA, DSCOVR, GOES-R, and GOES-S were launched by NASA in 2015, 2016, and 2018, respectively, and NOAA assumed responsibility for the missions once they became operational. NOAA relies on these three assets for space weather forecasting as does the heliophysics science community.

[49] Project managers estimate ACE has enough fuel to stay in orbit until 2024.

NASA Could Improve Collaboration with the Department of Defense and the Commercial Space Industry

Department of Defense

The U.S. Air Force's Policy, Resource, and Program Division is responsible for all military- and national-security-related space weather forecasting and mitigation for DOD. In particular, the 557th Weather Wing of the U.S. Air Force studies data about the Sun's emissions and provides mission-tailored analyses, forecasts, and warnings to military components. In addition to using space weather forecasts provided by NOAA that utilize NASA assets such as SOHO, the Air Force has its own ground-based assets for predicting space weather to help protect Air Force space assets and military communications. However, the Air Force relies on NASA's ability to transfer basic heliophysics research to applied science for space weather modeling and forecasting.

While the Air Force was initially involved with space weather efforts by investing in a joint project with NASA, coordination has been minimal during the last decade and currently no official framework or Memorandum of Agreement with the Air Force exists regarding space weather cooperation. Along with NASA, the Air Force was one of the original founding partners of the Community Coordinated Modeling Center (CCMC), a multi-agency partnership that provides the international research community with access to modern space science simulations and supports the transition of space research models to space weather operations. Creation of the CCMC was recommended in 1997 by a NASA-Air Force working group, and 2 years later the agencies signed an implementation plan. However, the agencies' cooperation failed to continue after establishment of the CCMC. An Air Force official stated that the Air Force planned to be part of the Memorandum of Understanding between NASA and NOAA, but no one officially asked them to be included in the agreement.[50]

Mindful of its lack of recent coordination with the Air Force, NASA officials have initiated efforts to reestablish cooperation between the two agencies leading to a potential Memorandum of Agreement. For example, NASA invited Air Force space weather officials to participate in the 2017 HPD Senior Review. For their part, an Air Force official said there is interest within the DOD to partner with NASA to develop space weather forecasting models. Furthermore, space-weather-related cooperation between NASA and DOD is one of the NSWAP tasks (Task 5.5.1) that remains to be implemented.

Commercial Space Industry

The private sector has been a vital part of the space weather community. For example, in 2011 a U.S. Air Force-contracted firm developed the first operational 6-day Disturbance Storm Time forecast.[51] In addition, in 2013 the commercial space industry started a program to measure radiation exposure from solar weather on frequent airplane flyers. Furthermore, given that adverse effects of space weather incidents directly impact large scale commercial infrastructure such as power grids, oil and gas pipelines, commercial airlines, and communication satellites, the private sector has a business interest in space weather prediction and mitigation efforts. However, a commercial space industry representative of a

[50] In June 2017, NASA and NOAA signed a Memorandum of Understanding for transitioning space weather research for operational use.

[51] The Disturbance Storm Time is an index of magnetic activity derived from a network of near-equatorial geomagnetic observatories.

trade group comprising 19 small- to mid-size space research companies stated that although NASA coordination with the commercial space industry regarding space weather has improved over the last 5 years, a need exists for an established framework where the private sector can participate in space-weather-related discussions among NASA, other federal agencies, and academia in order to present their capabilities related to advancing space weather science.

The lack of a framework for coordination with the commercial space industry has hindered NASA's ability to efficiently leverage existing private sector resources for forecasting space weather. For example, in 2012 NASA was interested in developing technology that could forecast space weather conditions in order to prevent astronauts from receiving electric shocks during maintenance and repair space walks on the International Space Station. Although NASA contacted NOAA to try to adopt its Vertical Total Electron Content forecast for this purpose, a better technology already existed in the private sector. Consequently, after reviewing the NOAA forecast, NASA decided it was unsuitable for the Agency's needs and contracted for the commercially available technology.

NASA officials cited ongoing efforts to reach out to the private sector regarding space weather. For example, HPD's 2018 Research Opportunities in Space and Earth Sciences announcement solicited basic and applied research from the private sector to support SMD, including heliophysics.[52] Although a step in the right direction, it is essential that NASA regularly include the commercial space industry in space-weather-related discussions to more effectively utilize their expertise and resources to further enhance the Agency's space weather forecasting and reaction capabilities.

[52] NASA periodically issues Research Opportunities in Space and Earth Sciences that solicit basic and applied research proposals from all entities—domestic and foreign, government and private, for profit and not-for-profit—supporting research and technology in SMD's space and Earth sciences.

CONCLUSION

NASA is effectively managing its heliophysics mission portfolio to continue collection of important data related to space weather. In spite of the advanced age of its spacecraft fleet, in FYs 2016 and 2017 HPD's 18 missions in extended operations were providing valuable science while operating under budget. However, several missions in development have experienced cost growth and schedule delays, and we remain concerned about SMD's application of JCL, particularly its reluctance to include launch vehicle risks in its analyses.

HPD has experienced challenges meeting implementation dates for recommendations established in the 2003 and 2013 decadal surveys while task complexity and a shortage of NASA and partner agency subject matter expertise has delayed completion of several NSWAP tasks. In addition, HPD would benefit from better coordination with the DOD and the commercial space industry to leverage resources and capabilities for improving space weather forecasting capabilities. Addressing these issues could improve the Agency's ability to address future heliophysics science goals and objectives and meet stakeholder space weather prediction needs.

Recommendations, Management's Response, and Our Evaluation

To improve NASA's management of its heliophysics portfolio, we recommended the Associate Administrator for Science Mission Directorate direct the HPD Director to

1. require that all JCL analyses include all discrete development risks managed outside of the project—such as a project's launch vehicle—with potential cost and/or schedule impacts;
2. complete implementation of 2015 NSWAP tasks in accordance with SWORM subcommittee deadlines;
3. reassess HPD's capabilities and resources and update the 2014 Roadmap for implementing 2013 Decadal recommendations with expected completion dates based on the Division's updated budget and priorities over the next 5 years; and
4. establish a formal mechanism to increase collaboration with DOD and the commercial space industry regarding heliophysics research and space weather modeling and forecasting efforts.

We provided a draft of this report to NASA management who concurred or partially concurred with our recommendations and described planned actions to address them. We consider the proposed actions responsive to our recommendations and will close the recommendations upon verification and completion of the proposed actions.

Management's full response to our report is reproduced in Appendix E. Their technical comments have been incorporated, as appropriate.

Major contributors to this report include Raymond Tolomeo, Science and Aeronautics Director; Adrian Dupree, Project Manager; Aleisha Fisher; Abtin Forghani; and Jobenia Parker. Sarah McGrath provided editorial and graphic support.

If you have questions about this report or wish to comment on the quality or usefulness of this report, contact Laurence Hawkins, Audit Operations and Quality Assurance Director, at 202-358-1543 or laurence.b.hawkins@nasa.gov.

Paul K. Martin
Inspector General

APPENDIX A: SCOPE AND METHODOLOGY

We performed this audit from January 2018 through March 2019 in accordance with generally accepted government auditing standards. Those standards require that we plan and perform the audit to obtain sufficient, appropriate evidence to provide a reasonable basis for our findings and conclusions based on our audit objectives. We believe that the evidence obtained provides a reasonable basis for our findings and conclusions based on our audit objectives.

Our overall objective was to assess NASA's management of its heliophysics portfolio and examine whether the Agency is achieving established goals and priorities. Specifically, we evaluated whether NASA (1) had an effective strategy for maintaining its heliophysics science capabilities; (2) was controlling costs for its current and planned missions; (3) had appropriately implemented recommendations, decisions rules, and action plans provided in HPD's governing documents; and (4) was effectively coordinating activities across multiple federal agencies and the private sector to manage its heliophysics portfolio.

To determine if NASA had a strategy for maintaining its science capabilities, we conducted interviews with HPD Headquarters officials to gain an understanding of their processes for managing science capabilities. We also reviewed and analyzed two HPD reports: *The Senior Reviews of Heliophysics Operating Missions* and *Our Dynamic Space Environment: Heliophysics Science and Technology Roadmap 2014-2033*. In addition, we conducted a short email survey (14 questions) to collect how HPD officials were maintaining their science capabilities. We received responses from 17 project scientists of missions in extended operations under HPD management.

To evaluate how NASA is controlling costs for HPD's extended operating missions, we reviewed FY 2016 and FY 2017 budget and actual data from the President's budget request reports for NASA as well as information provided by HPD officials. These officials also provided project ABC cost information and estimated current costs data for projects that have launched in the past year or plan to launch in the next 2 years.

To determine whether HPD appropriately implemented recommendations, decisions rules, and action plans provided in its governing documents, we gathered publicly available data on the status of each of HPD's missions. We also reviewed and analyzed recommendations made in the NRC's 2003 and 2013 decadal surveys and spoke with members of the 2013 Decadal committee and HPD staff. Additionally, we analyzed NSWAP tasks and interviewed NASA and SWORM subcommittee staff. We obtained documentation on NASA's response to and implementation of the 2003 and 2013 Decadal Survey recommendations and NSWAP tasks.

To evaluate whether HPD was effectively coordinating activities across multiple federal agencies and the private sector to manage its heliophysics portfolio, we identified and interviewed major external stakeholders, including officials from NOAA, the U.S. Air Force, and private space industry. We obtained memorandum of agreements between NOAA and NASA. We also attended a congressional hearing pertaining to federal agencies, academia, and private sector cooperation on space weather readiness, which can be accessed at https://science.house.gov/legislation/hearings/surveying-space-weather-landscape (last accessed, March 6, 2019).

To gain an understanding of NASA's heliophysics portfolio, we conducted our review at NASA Headquarters and Goddard Space Flight Center. We also obtained and examined internal and external applicable documents related to the heliophysics portfolio as well as NASA policy. The documents we examined included the following:

- NPR 7120.5E, *NASA Space Flight Program and Project Management Requirements* (August 14, 2012)
- NPR 7120.8, *NASA Research and Technology Program and Project Management Requirements* (September 14, 2018)
- *NASA Space Flight Program and Project Management Handbook* (September 2014)
- NRC, *Solar and Space Physics: A Science for a Technological Society* (2013)
- NRC, *The Sun to the Earth and Beyond: A Decadal Research Strategy in Solar and Space Physics* (2003)
- National Science and Technology Council, *National Space Weather Strategy* (October 2015)
- National Science and Technology Council, *National Space Weather Action Plan* (October 2015)
- *NASA Science Plan* (2014)
- *National Space Policy of the United States of America* (June 2010)

Use of Computer-Processed Data

We used computer-processed data to perform this audit. Specifically, heliophysics portfolio cost data was provided by respective NASA Headquarters officials. Generally, we concluded the data was valid and reliable for the purposes of the review.

Review of Internal Controls

We reviewed and evaluated internal controls related to NASA's heliophysics portfolio. This included assessing compliance with requirements such as applicable federal laws, regulations, directives, and NASA policies and procedures, and how the Division conducted its Senior Review, documented KDPs, and prepared operational reports. We concluded that the HPD's internal controls, except for those practices discussed in the report, complied with Agency requirements and best practices. The internal control recommendations discussed in the report, if implemented, should correct the weaknesses identified.

Prior Coverage

During the last 5 years, the NASA OIG and U.S. Government Accountability Office issued eight reports of significant relevance to the subject of this report. Unrestricted reports can be accessed at http://oig.nasa.gov/audits/reports and https://www.gao.gov, respectively.

NASA Office of Inspector General

NASA's 2017 Top Management and Performance Challenges (November 6, 2017)

NASA's 2016 Top Management and Performance Challenges (November 15, 2016)

NASA's Earth's Science Mission Portfolio (IG-17-003, November 2, 2016)

Audit of NASA's Joint Cost and Schedule Confidence Level Process (IG-15-024, September 29, 2015)

NASA's Efforts to Manage Its Space Technology Portfolio (IG-16-008, December 15, 2015)

NASA's The Science Mission Directorate's Mission Extension Process (IG-15-001, October 9, 2014)

U.S. Government Accountability Office

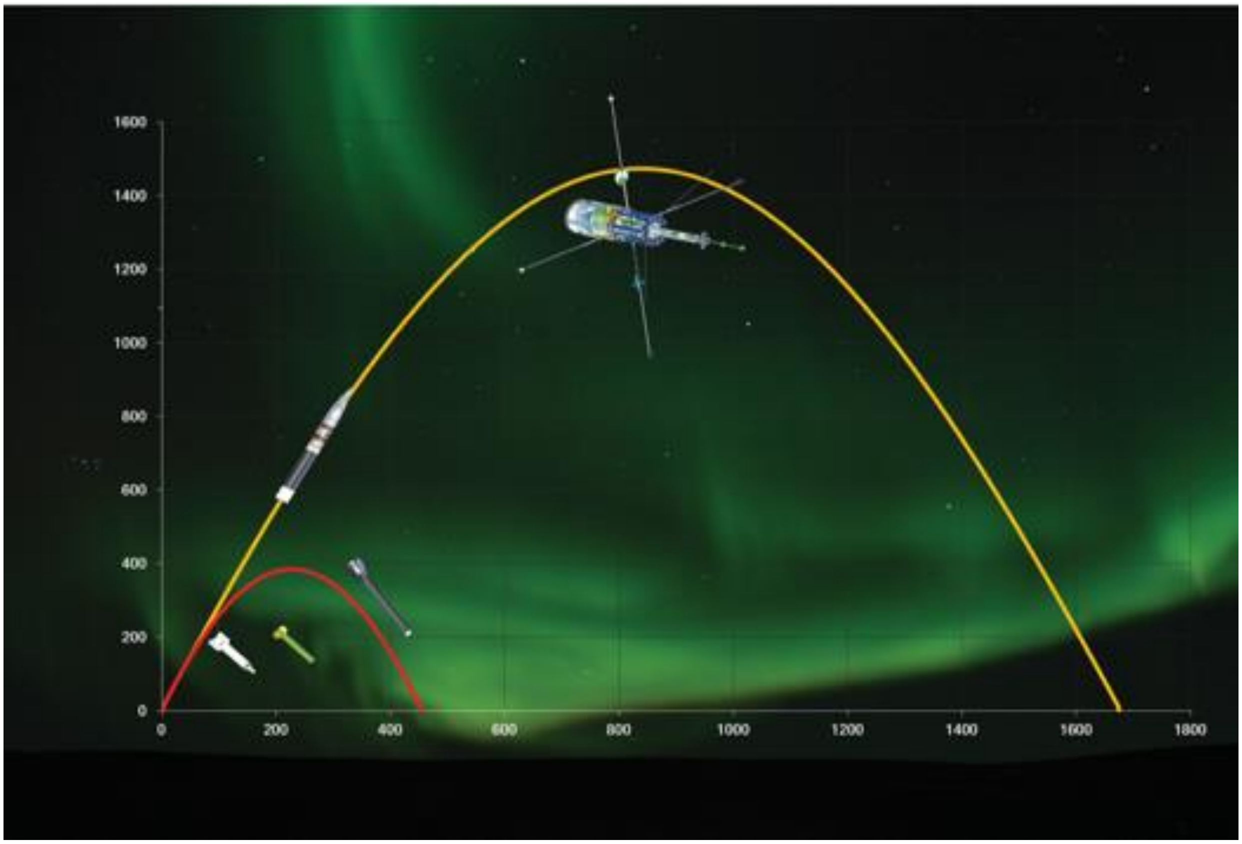
NASA: Assessments of Major Projects (GAO-18-280SP, May 2018)

NASA: Assessments of Major Projects (GAO-17-303SP, May 2017)

Appendix B: Sounding Rocket Program

Taking its name from the nautical term "to sound," which means to take measurements, NASA's Sounding Rocket Program is one of the components of the HPD Research Program. As shown in Figure 4, sounding rockets carry scientific instruments into sub-orbital space along a parabolic trajectory.

Figure 4: Sounding Rocket Flight Trajectory



Source: NASA.

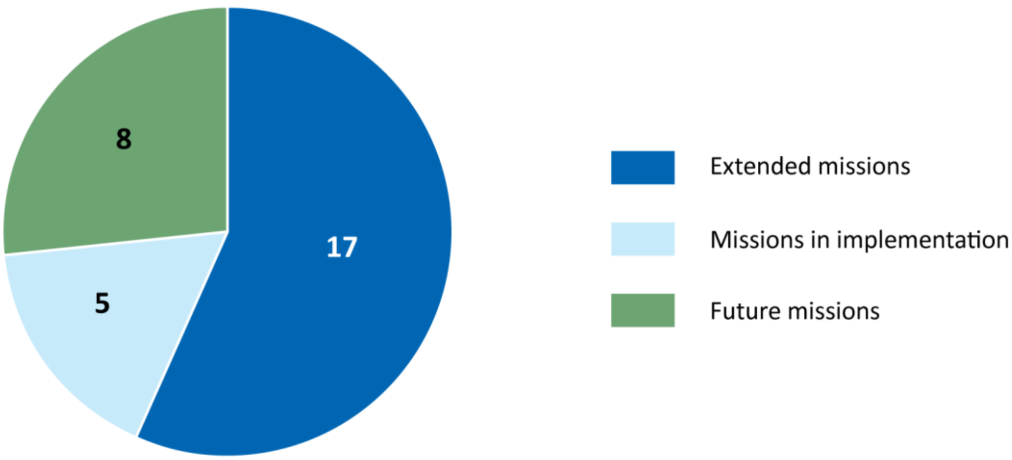
Launched from a variety of sites all over the world, a sounding rocket's overall time in space is brief, typically 5 to 20 minutes, and they travel at lower speeds compared to launch vehicles that carry satellites into orbit. The short time and lower vehicle speeds are sufficient to carry out successful scientific experiments. Furthermore, there are some important regions of space, just above Earth's upper atmosphere, that are too low for satellites to orbit, and thus, sounding rockets provide the only platforms that can carry research instruments to these regions. Specifically, sounding rocket missions investigate geospace science, high-energy astrophysics, ultraviolet astrophysics, solar physics, planetary atmospheres, plasma research, and technology maturation.

HPD is the main funding source of NASA's Sounding Rocket Program, at an average annual budget of $56 million over the last 5 years. This budget allows the Sounding Rocket Program to provide, on average, approximately 20 flight opportunities per year for scientific and technology demonstration investigations. As they do not require expensive boosters or extended telemetry and tracking coverage since they never go into orbit, launch costs associated with sounding rocket missions are substantially less than those required for orbital missions. At approximately $3 million to $5 million per launch, sounding rockets offer one of the most cost-effective options for conducting science experiments or technology demonstration missions. The Sounding Rocket Program provides low-cost launch options for all of SMD, but its main users are HPD and the Astrophysics Division. There are occasional users of the Sounding Rocket Program outside of NASA, including other federal agencies and universities. In these cases, the launch is funded through a reimbursable agreement with the external party.

APPENDIX C: HPD MISSION PORTFOLIO

As shown in Figure 5, HPD has a portfolio of 30 missions in various stages of operation. This appendix includes a brief overview of these missions, including launch dates, life-cycle cost estimates, and the focus areas for each mission when available. In addition, the summaries note the different science goals of each mission, as identified in Table 10.

Figure 5: HPD Mission Portfolio Breakdown



Source: OIG prepared based on NASA information.

Table 10: Science Goals Area and Icons

Science Goal Area	Description	Icon
Solve the fundamental mysteries of heliophysics	Explore the physical processes in the space environment from the Sun to the Earth and throughout the solar system	
Understand the nature of Earth's home in space	Advance scientific understanding of the connections that link the Sun, Earth, planetary space environments, and the outer reaches of the solar system	
Build the knowledge to forecast space weather throughout the heliosphere	Develop the knowledge and capability to detect and predict extreme conditions in space to protect life and society and to safeguard human and robotic explorers beyond Earth	

Source: OIG presentation of NASA information.

Extended Operating Missions

ARTEMIS

Status	Launch date	Life-cycle cost
Operating-extended	February 2007	Not Applicable (see THEMIS)

The Acceleration, Reconnection, Turbulence and Electrodynamics of Moon's Interaction with the Sun (ARTEMIS) mission allows scientists to learn more about the Earth-Moon Lagrange points, solar wind, the Moon's plasma wake, and how Earth's magnetotail and the Moon's own weak magnetism interact with solar wind. The mission uses two of the five in-orbit spacecraft from another HPD constellation of satellites (THEMIS) that were launched in 2007 and successfully completed their prime mission in 2010.

Operations platform	Satellite
Associated NASA program	Explorers
Partner	None
HPD focus areas	
Societal benefit	ARTEMIS's initial characterization of space weather on the Moon will support future studies on the protection needed for NASA or the commercial industry to perform science or work on the Moon.

ACE

Status	Launch date	Life-cycle cost
Operating-extended	August 1997	$225 million

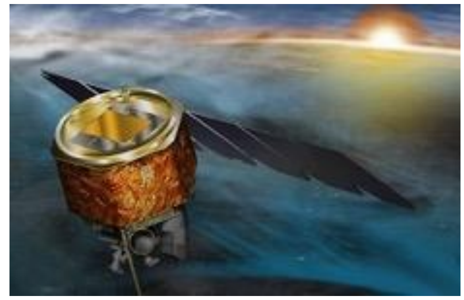
The Advanced Composition Explorer (ACE) mission aims to determine the composition of solar and interstellar matter, including solar wind, solar energetic particles, and galactic cosmic rays, in order to determine their origins.

Operations platform	Satellite
Associated NASA program	Explorers
Partner	NOAA
HPD focus areas	
Societal benefit	ACE delivers real time observations that support operational space weather services made available by NOAA.

AIM

Status	Launch date	Life-cycle cost
Operating-extended	April 2007	$155 million

The Aeronomy of Ice in the Mesosphere (AIM) mission is the first satellite mission dedicated to studying polar mesospheric clouds and the environment in which they form. These high-altitude clouds, which are visible over the summer polar regions, were nonexistent before 1885 but have systematically increased in frequency and brightness, raising concerns about the underlying cause.

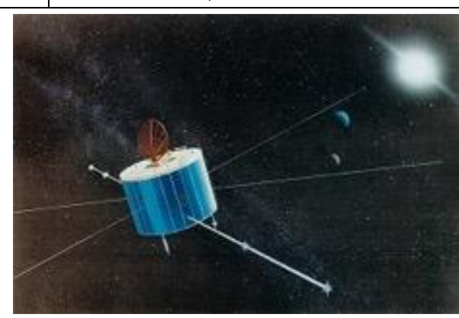


Operations platform	Satellite
Associated NASA program	Explorers
Partner	None
HPD focus areas	 
Societal benefit	AIM provides an understanding of potential precursor observations of climate change.

GEOTAIL

Status	Launch date	Life-cycle cost
Operating-extended	July 1992	$40 million

The Geotail mission measures global energy flow and transformation in the magnetotail to increase understanding of the fundamental magnetospheric processes, including the physics of the magnetopause, the plasma sheet, and reconnection and neutral line formation (i.e., the mechanisms of input, transport, storage, release, and conversion of energy in the magnetotail).



Operations platform	Satellite
Associated NASA program	HPD Research
Partners	Institute of Space and Astronautical Science and Japan Aerospace Exploration Agency
HPD focus areas	 
Societal benefit	Geotail advances scientific understanding of Earth and its fundamental physical processes.

Hinode

Status	Launch date	Life-cycle cost
Operating-extended	September 2006	$234 million

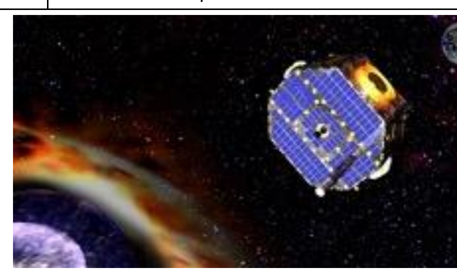
An international mission, Hinode includes a suite of three science instruments—the Solar Optical Telescope, X-ray Telescope, and Extreme Ultraviolet Imaging Spectrometer—that study the generation, transportation, and dissipation of magnetic energy from the photosphere to the Sun's corona. Hinode records how energy stored in the Sun's magnetic field is released, either gradually or violently, as the field rises into the Sun's outer atmosphere.

Operations platform	Satellite
Associated NASA program	STP
Partners	Japan Aerospace Exploration Agency and United Kingdom Space Agency
HPD focus areas	 
Societal benefit	By studying the active regions of highly energetic phenomena in the Sun that feed the development of solar flares and coronal mass ejections that could impact Earth, data gathered by Hinode could help in early detection of such events, thus enabling the safeguarding of electrical infrastructure.

IBEX

Status	Launch date	Life-cycle cost
Operating-extended	October 2008	$179 million

The Interstellar Boundary Explorer (IBEX) mission observes the faint signal of energetic neutral atoms that reach the inner solar system from interstellar space. Mapping these signals will allow scientists to infer processes at the boundary between the solar wind and the local interstellar medium.



Operations platform	Satellite
Associated NASA program	Explorers
Partner	University of Bern (Switzerland)
HPD focus area	
Societal benefit	IBEX advances scientific understanding of Earth and the fundamental physical processes.

IRIS

Status	Launch date	Life-cycle cost
Operating-extended	June 2013	$213 million

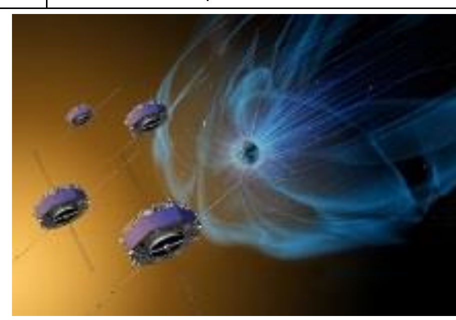
The Interface Region Imaging Spectrograph (IRIS) mission is observing how solar material moves, gathers energy, and heats up as it travels through a little-understood region in the Sun's lower atmosphere. Tracking how material and energy move through this region is a crucial part of understanding the dynamics of the Sun, including what causes the ejection of solar material that travel toward Earth and cause space weather.

Operations platform	Satellite
Associated NASA program	Explorers
Partner	Norwegian Space Agency
HPD focus areas	
Societal benefit	IRIS science information can help explain what causes the ejection of solar material. This includes the steady stream of the solar wind to larger, explosive eruptions such as coronal mass ejections that travel toward Earth and cause space weather that can disrupt human technology.

MMS

Status	Launch date	Life-cycle cost
Operating-extended	March 2015	$1.2 billion

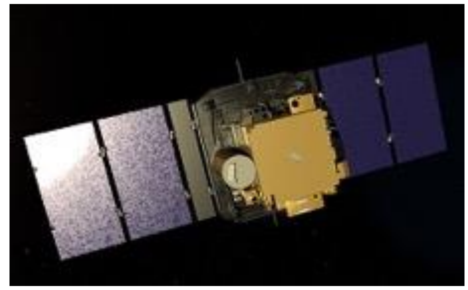
The Magnetospheric Multiscale (MMS) mission makes use of four identical spacecraft to measure the plasma and electric and magnetic fields inside the diffusion regions of Earth's magnetosphere in order to understand the components, interactions, and processes taking place in this area crucial to communication and navigation on Earth.



Operations platform	Satellite
Associated NASA program	STP
Partners	Swedish National Space Agency, Centre National d'Etudes Spatiales (France), Austrian Space Agency, and Japan Aerospace Exploration Agency
HPD focus areas	
Societal benefit	MMS analyzes the sudden release of large amounts of energy in the magnetosphere that feeds and directs energy to create the aurora which is very disruptive of communications and GPS signals.

SOHO		
Status	**Launch date**	**Life-cycle cost**
Operating-extended	December 1995	$516 million

The Solar and Heliospheric Observatory (SOHO) mission is an international collaboration between NASA and ESA. SOHO was designed to study the Sun, from its deep core to the outer corona, and solar wind. SOHO is a 3-axis stabilized spacecraft that constantly faces the Sun. It houses 12 instrument packages that have greatly improved scientists' ability to forecast space weather by giving up to 3-days' notice of Earth-directed disturbances and playing a lead role in the early warning system for space weather.



Operations platform	Satellite
Associated NASA program	HPD Research
Partners	ESA and NOAA
HPD focus areas	
Societal benefit	SOHO detects and tracks coronal mass ejections, which can assist in determining their space weather impact on Earth.

SDO		
Status	**Launch date**	**Life-cycle cost**
Operating-extended	February 2010	$862 million

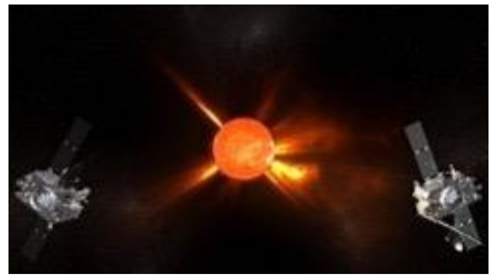
The Solar Dynamics Observatory (SDO) mission is helping to understand the how and why of the Sun's magnetic changes. The mission is determining how the Sun's magnetic field is generated and structured, and how stored magnetic energy is released into the heliosphere and geospace. SDO data and analysis is also helping to develop the ability to predict the solar variations that influence life on Earth and humanity's technological systems.

Operations platform	Satellite
Associated NASA program	LWS
Partner	None
HPD focus areas	
Societal benefit	SDO monitors the full Sun in high resolutions to feed multiple space weather models.

STEREO

Status	Launch date	Life-cycle cost
Operating-extended	October 2006	$549 million

The Solar Terrestrial Relations Observatory (STEREO) mission's two spacecraft (STEREO A and STEREO B) seek to understand the causes and mechanisms of coronal mass ejection initiation, characterize the propagation of coronal mass ejections through the heliosphere, discover the mechanisms and sites of energetic particle acceleration in the low corona and the interplanetary medium, and improve the determination of the structure of solar wind. The mission was designed to provide views of the Sun and its extended atmosphere from unique angles; however, contact with STEREO B was lost in October 2014, due to multiple hardware anomalies affecting control of the spacecraft. Communications with STEREO B were re-established briefly in August 2016 but no signal has been received since September 2016. STEREO A is still performing as expected.



Operations platform	Satellite
Associated NASA program	STP
Partners	Centre National d'Etudes Spatiales (France), University of Bern (Switzerland), Deutsches Zentrum für Luft und Raumfahrt (Germany), United Kingdom Space Agency, and NOAA
HPD focus areas	
Societal benefit	STEREO aids in characterizing potentially dangerous energetic events that can affect Earth.

TIMED

Status	Launch date	Life-cycle cost
Operating-extended	December 2001	$277 million

The Thermosphere Ionosphere Mesosphere Energetics and Dynamics (TIMED) mission measures upper atmospheric conditions in the region where the neutral atmosphere and Earth's weather give way to the space environment that dominates the rest of the universe. Some of this energy, from charged particles and complex distributions of electric and magnetic fields, creates aurora that can disrupt communications and increase satellite drag. TIMED increases the understanding on how solar wind affects changes in the chemical composition of Earth's atmosphere and its effects on Earth's weather.

Operations platform	Satellite
Associated NASA program	STP
Partner	None
HPD focus areas	
Societal benefit	TIMED increases our understanding of how solar wind reflects the changes in chemical composition of Earth's atmosphere and its effects on Earth's weather.

THEMIS

Status	Launch date	Life-cycle cost
Operating-extended	June 2007	$240 million

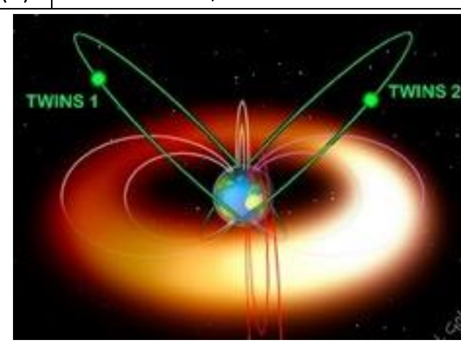
The Time History of Events and Macroscale Interactions during Substorms (THEMIS) mission aims to resolve one of the oldest mysteries in space physics, namely to determine what physical process in near-Earth space initiates the violent eruptions (substorms) in Earth's magnetosphere. Substorms occur when the magnetosphere suddenly releases vast amounts of stored solar wind energy. Different possible triggers have different locations, as such, the mission placed spacecraft in various locations in Earth's magnetic field to help determine the substorm point of origin.

Operations platform	Satellite
Associated NASA program	Explorers
Partners	Canadian Space Agency, Deutsches Zentrum für Luft und Raumfahrt (Germany), and Austrian Space Agency
HPD focus areas	 
Societal benefit	Advances scientific understanding of Earth and fundamental physical processes.

TWINS A and B

Status	Launch date	Life-cycle cost
Operating-extended	June 2006 (A) and March 2008 (B)	$33 million

The Two Wide-angle Imaging Neutral-atom Spectrometers (TWINS A and B) missions have a primary science objective of establishing the global connectivity and causal relationships between processes in different regions of Earth's magnetosphere. The missions will address this objective through stereoscopic neural atom imaging of the magnetosphere from two widely spaced, high-altitude, high-inclination spacecraft.



Operations platform	Satellite
Associated NASA program	Explorers
Partner	Deutsches Zentrum für Luft und Raumfahrt (Germany)
HPD focus area	
Societal benefit	Advances scientific understanding of Earth and the fundamental physical processes.

Van Allen Probes

Status	Launch date	Life-cycle cost
Operating-extended	August 2012	$679 million

The two Van Allen Probes spacecraft (formerly known as the Radiation Belt Storm Probes) study two extreme and dynamic regions of space known as the Van Allen Radiation Belts that surround Earth. Named for their discoverer, James Van Allen, these two concentric, donut-shaped rings are filled with high-energy particles that gyrate, bounce, and drift through the region, sometimes shooting down to Earth's atmosphere or sometimes escaping out into space.

Operations platform	Satellite
Associated NASA program	LWS
Partners	Czech Republic, Korea Astronomy and Space Science Institute, Comisión Nacional de Actividades Espaciales (Argentina), and Agência Espacial Brasileira (Brazil)
HPD focus areas	 
Societal benefit	Advances scientific understanding of Earth and its fundamental physical processes. This data is used to design radiation tolerant electronics for manned and unmanned spacecraft.

Voyager 1 and 2

Status	Launch date	Life-cycle cost
Operating-extended	August (2) and September 1977 (1)	$875 million

Voyager 1 is the fastest spacecraft on a trajectory leaving the solar system. Having crossed the heliopause into interstellar space in 2012, Voyager 1 is now the only spacecraft measuring the properties of the local interstellar medium in-situ. The spacecraft has shown that the interstellar boundary is critically important for shielding the interplanetary environment from galactic cosmic rays. Voyager 2 reached interstellar space in December 2018 and will for the first time measure helipause plasma properties, which was not possible with the Voyager 1 mission. The spacecraft will provide a second observational location for characterizing the interstellar medium, and the influence of short- and long-term changes of solar activity.

Operations platform	Satellite
Associated NASA program	HPD Research
Partner	None
HPD focus area	
Societal benefit	Advances scientific understanding of the fundamental physical processes of space.

WIND		
Status	**Launch date**	**Life-cycle cost**
Operating-extended	November 1994	$309 million

The Wind mission is a unique observatory for solar wind waves and the plasma processes that may be responsible for solar wind plasma bulk heating and acceleration. Moreover, the mission provides advanced suprathermal particle observations that can be used to infer particle acceleration. Many of the Wind instruments can be used to test and improve warning systems related to approaching shock waves and solar energetic particles.

Operations platform	Satellite
Associated NASA program	HPD Research
Partner	None
HPD focus areas	 
Societal benefit	WIND observations are used to compare with and readjust the real time observations of ACE and DSCOVR.

Missions in Implementation

GOLD		
Status	**Launch date**	**Planned life-cycle cost**
Implementation-operating	January 25, 2018	$73 million

The Global-scale Observations of the Limb and Disk (GOLD) mission measures densities and temperatures in Earth's thermosphere and ionosphere. GOLD makes these measurements by taking detailed full Earth-disk images with an ultraviolet imaging spectrograph on a geostationary satellite. These images will inform observations made by the TIMED, AIM, and ICON missions.

Operations platform	Satellite
Associated NASA program	Explorers
Partner	None
HPD focus areas	 
Societal benefit	Data from the GOLD mission will be used to refine space weather prediction models that help with communications and GPS signals.

ICON		
Status	**Planned Launch date**	**Planned life-cycle cost**
Implementation-development	TBD	$253 million

The Ionospheric Connection Explorer (ICON) mission is dedicated to understanding neutral-ion coupling in Earth's upper atmosphere, also known as the thermosphere. The mission is designed to resolve both long-standing and newly emerging questions about the mechanisms that control the daily development of plasma in Earth's space environment.

Operations platform	Satellite
Associated NASA program	Explorers
Partner	None
HPD focus areas	
Societal benefit	ICON will increase understanding of the boundary of terrestrial atmosphere and space, the region where space weather has its greatest impacts on society. The resulting improved modeling capability will be used to predict space weather in areas such as GPS and communications.

Parker Solar Probe		
Status	**Launch date**	**Planned life-cycle cost**
Implementation-operating	August 12, 2018	$1.6 billion

The Parker Solar Probe mission will determine the structure and dynamics of the magnetic fields at the sources of the fast and slow solar wind. The mission will trace the flow of energy that heats the solar corona and accelerates the solar wind and explore the mechanisms that accelerate and transport energetic particles.

Operations platform	Satellite
Associated NASA program	LWS
Partners	Belgium, Deutsches Zentrum für Luft und Raumfahrt (Germany), and Centre National d'Etudes Spatiales (France)
HPD focus areas	
Societal benefit	The Parker Solar Probe's ability to observe the solar wind, magnetic fields, and energetic particles within and just outside the corona could lead to better predictive modeling of geomagnetic storms and solar energetic particles at Earth.

SOC

Status	Planned Launch date	Planned life-cycle cost
Implementation-development	February 2020	$435 million

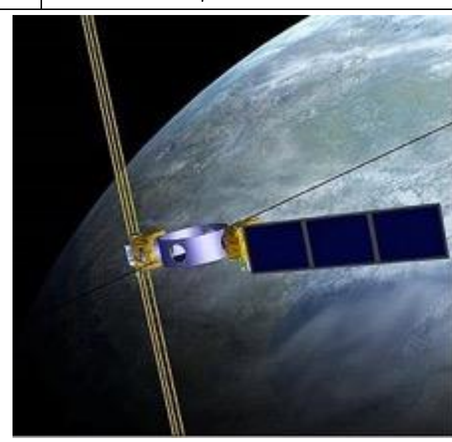
The Solar Orbiter Collaboration (SOC) mission is a joint effort between NASA and the European Space Agency to study how the Sun creates and controls the heliosphere. The mission will take in-situ measurements of solar wind plasma, fields, waves, and energetic particles.

Operations platform	Satellite
Associated NASA program	LWS
Partner	ESA
HPD focus areas	
Societal benefit	SOC will increase the understanding of the Sun's processes that feed the development of solar flares and coronal mass ejections that could affect space weather near Earth and potentially harm spacecraft in Earth orbit.

SET

Status	Launch date	Planned life-cycle cost
Implementation-development	TBD	$41 million

The Space Environment Testbeds (SET) mission will characterize the energetic space radiation environment and its interactions with spacecraft, and provide data to other SET-1 experiments.



Operations platform	Satellite
Associated NASA program	LWS
Partners	Centre National d'Etudes Spatiales (France) and United Kingdom Space Agency
HPD focus area	
Societal benefit	The SET mission will increase knowledge of the effects of radiation on electrical components on Earth, which will help improve the design of these electronics.

Future Missions

The following eight missions are future missions that either have not been selected yet or are in preformulation or early stages of the formulation and therefore do not yet have a launch date or estimated life-cycle cost.

Table 11: Heliophysics Missions in Preformulation or Early Stages of Formulation

Mission	Phase	Program
Heliophysics Mission Opportunity 2016	Formulation	Explorers
Heliophysics Small Explorers Missions 2016	Formulation	Explorers
Heliophysics Medium-Class Explorers	Preformulation	Explorers
Heliophysics Mission Opportunity	Preformulation	Explorers
Heliophysics Mission Opportunity 2018	Preformulation	STP
Interstellar Mapping and Acceleration Probe	Preformulation	STP
Technology Demonstration Program	Preformulation	STP
Geospace Dynamics Constellation	Preformulation	LWS

Source: OIG presentation of NASA information.

APPENDIX D: 2015 NATIONAL SPACE WEATHER ACTION PLAN TASKS

Goal	Task	Lead and Co-lead Agencies	Supporting Agencies	Original Deadline	Current Deadline
Goal 1: Establish benchmarks for space weather events					
1.1 Develop benchmarks for induced geo-electric fields	1.1.1 Assess feasibility of establishing functional benchmarks and produce Phase 1 benchmarks	DOI, DOC, and NASA	DHS, DOE, and NSF	April 2016	August 2017
	1.1.2 Assess the suitability of current data sets and methods to refine Phase 1 benchmarks, identify gaps in methods and available data, and project the cost of filling these gaps and potential improvements to the benchmarks	DOI, DOC, NASA, and NSF	DHS and DOE	October 2016	September 2017
	1.1.3 Improve on the induced geo-electric field benchmarks for the United States			October 2017	October 2018
1.2 Develop benchmarks for ionizing radiation	1.2.1 Assess the feasibility and utility of establishing functional benchmarks using the existing models and literature, and produce Phase 1 benchmarks	DOC and NASA	NSF, DOT, DOD, and FCC	April 2016	August 2017
	1.2.2 Assess the suitability of current data sets and methods to refine Phase 1 benchmarks, identify gaps in methods and available data, and project the cost of filling the gaps and improvements to the benchmarks			October 2016	September 2017
	1.2.3 Develop enhanced benchmarks			October 2017	October 2018
1.3 Develop benchmarks for ionospheric disturbances	1.3.1 Assess the feasibility and utility of establishing functional benchmarks and produce Phase 1 benchmarks	DOC and DOD	NASA, DOI, NSF, and FCC	April 2016	August 2017
	1.3.2 Assess the suitability of current data sets and methods to refine Phase 1 benchmarks, identify gaps in methods and available data, and project the cost of filling the gaps and improvements to the benchmarks			October 2016	September 2017
	1.3.3 Develop enhanced benchmarks			October 2017	October 2018
1.4 Develop benchmarks for solar radio bursts	1.4.1 Asses the feasibility and utility of establishing functional benchmarks and produce Phase 1 benchmarks	DOC, DOD, and NASA	DOI and FCC	April 2016	August 2017
	1.4.2 Assess the suitability of current data sets and methods to refine Phase 1 benchmarks, identify gaps in methods and available data, and project the cost of filling the gaps and improvements to the benchmarks			October 2016	September 2017
	1.4.3 Develop enhanced benchmarks			October 2017	October 2018
1.5 Develop benchmarks for upper atmospheric expansion	1.5.1 Asses the feasibility and utility of establishing functional benchmarks and produce Phase 1 benchmarks	DOC, DOD, NSF, and NASA	DOI and FCC	April 2016	August 2017
	1.5.2 Assess the suitability of current data sets and methods to refine Phase 1 benchmarks, identify gaps in methods and available data, and project the cost of filling the gaps and improvements to the benchmarks			October 2016	September 2017
	1.5.3 Develop enhanced benchmarks			October 2017	October 2018

Goal	Task	Lead and Co-lead Agency	Supporting Agency	Original Deadline	Current Deadline
Goal 2: Enhance response and recovery capabilities					
2.1 Complete an all-hazards power outage response and recovery plan	2.1.1 Develop annex to the Federal Interagency Operations Plans that includes the response to and recovery from extreme space weather events	DHS	DOE	February 2016	November 2016
2.2 Support government and private sector planning for and management of extreme space-weather events	2.2.1 Update next Strategic National Risk Assessment to include latest data on extreme space weather threats and vulnerabilities	DHS	NASA and DOC	October 2017, updating every 3 years	May 2018, updating every 3 years
	2.2.2 Ensure a consistent, joint government messaging on research, prediction, and preparedness for extreme space-weather events	DHS	DOC, DOD, and NASA	February 2016	September 2016
	2.2.3 Develop procedures for accessing and using available space weather forecast and impact assessment modeling tools to inform response and recovery decision-making	DHS	FEMA	May 2016	May 2018
	2.2.5 Incorporate space weather products, including a background on space weather phenomena, into national preparedness	DOC and DHS	–	Consistent with national frameworks and update cycle	Consistent with national frameworks and update cycle
	2.2.6 Develop templates for public information alerts and warning messaging for extreme space weather	DHS	DOC	October 2016	October 2016
2.3 Provide guidance on contingency planning for the effects of extreme space weather for essential government and industry services	2.3.1 Determine impacts of space weather events on essential government and industry services and provide guidelines on including these impacts for continuity and contingency for all-hazards planning and exercises	DHS	DOD, DOE, DOT, EPA, HHS, GSA, USDA, and USDT	October 2018	October 2018
2.4 Ensure capability and interoperability of communications systems during extreme space-weather events	2.4.1 Assess dependencies and vulnerabilities of various communications systems used by government and industry to support response and recovery operations in the wake of an extreme space weather event	DHS		February 2016	February 2019
	2.4.2 Develop guidance, including planning factors, on operating communications systems during and after a space-weather event			February 2016	June 2019

Goal	Task	Lead and Co-lead Agency	Supporting Agency	Original Deadline	Current Deadline
2.5 Encourage owners and operators of infrastructure and technology assets to coordinate development of realistic power-restoration priorities and expectations	2.5.1 Identify essential facilities that have sufficient back-up power capability to survive an extreme space weather event or have ability to quickly deploy or accept temporary power	DHS	DOD	Ongoing	Ongoing
2.6 Develop and conduct exercises to improve and test government- and industry-related space weather response and recovery plans	2.6.1 Develop training for scientific, national security, and emergency management professionals on the role and execution of emergency management protocols during response to extreme space weather events	DHS	DOC, DOD, DOT, and NASA	October 2016	October 2017
	2.6.2 Incorporate exercise objectives tailored to test and evaluate U.S. capabilities to respond to and recover from potential impacts of a benchmarked space weather event within relevant exercises	DHS	–	August 2016	February 2018
Goal 3: Improve protection and mitigation efforts					
3.1 Encourage development of space weather hazard-mitigation plans that reduce vulnerabilities, manage risks, and assist with response	3.1.1 Integrate space weather hazard information into existing mechanisms for information sharing and into national preparedness mechanisms that promote strategic alignment between public and private sectors	DHS	–	October 2016	October 2016
	3.1.2 Develop a guidance document for integrating space-weather mitigation into existing coordinating mechanisms for mitigation and protection, as outlined in the National Infrastructure Protection Plan		–	October 2016	October 2016
	3.1.3 Provide protection and mitigation guidance to enhance resilience across government and private sectors vulnerable to space weather events		Other agencies as appropriate	October 2018	October 2018
3.2 Work with industry to achieve long-term reduction of vulnerability to space weather events by implementing measures at locations most susceptible to space weather	3.2.1 Enhance strategic national risk assessments, analytic projects, national risk estimates, and other relevant activities that provide vulnerability assessments and prioritization guidance for infrastructure sectors at risk from space weather	DHS	Other relevant federal agencies	October 2016	October 2016
	3.2.2 Develop government resilience guidance for space weather, including tools for assessing the value of backup, redundant, and replacement systems, to identify which facilities and systems need protection			October 2018	October 2019
3.3 Strengthen public-private collaborations that support actions to reduce space weather vulnerabilities	3.3.1 Develop a cross-sector engagement strategy and assess the landscape and feasibility of incentives	DHS	–	October 2016	October 2018

Goal	Task	Lead and Co-lead Agency	Supporting Agency	Original Deadline	Current Deadline
Goal 4: Improve assessment, modeling, and prediction of impacts on critical infrastructure					
4.1 Assess the vulnerability of critical infrastructure systems to space weather	4.1.1 Assess vulnerability of critical infrastructure to space weather events based on Phase 1 benchmarks as an initial input and reevaluated upon the completion of Phase 2 benchmarks	DHS	DOD, DOE, DOT, EPA, HHS, GSA, USDA, and USDT	October 2017 (Phase 1); October 2018 (Phase 2)	October 2017 (Phase 1); October 2018 (Phase 2)
4.2 Develop a real-time infrastructure assessment and reporting capability	4.2.1 Develop plans to provide monitoring and data collection systems	DOE	DHS, DOC and energy sector	October 2016	September 2017
	4.2.2 Define data requirements to facilitate a centralized reporting system		Regulatory agencies and electric power industry		
	4.2.3 Work with the commercial aviation industry, space operations and services, and international groups to define requirements for real-time monitoring of the charged particle radiation environment to protect the health and safety of crew and passengers during space weather events	DOC	NASA, DOD, and DOT	October 2016	October 2016
	4.2.4 Define scope and requirements for a real-time reporting system that conveys situational awareness of the radiation environment to orbital, suborbital, and commercial aviation users during space weather events	DOT	DOC, State, and NASA	October 2017	October 2017
	4.2.5 Develop or improve models for the real-time assessment of radiation levels at commercial flight altitudes	DOC and DOT	NASA		
	4.2.6 Define requirements for real-time monitoring systems to assess atmospheric conditions that could affect these systems	DOC	NSF and DOI	October 2016	October 2016
	4.2.7 Define scope and observational requirements for a system that provides near-real-time situational awareness of the space environment for communication and Positioning, Navigation and Timing (PNT) systems	DHS, DOC, and DOD,	Government and commercial communica-tions PNT system users		
	4.2.8 Create and support a satellite-anomaly database to enable secure collection and analysis of satellite-anomaly data related to space weather	DOC and DOD	–		
4.3 Develop or refine operational models that forecast the effects of space weather on critical infrastructure	4.3.1 Work with forecasting centers, emergency managers, governments, and academic and commercial stakeholders to define and develop comprehensive requirements for operational models to forecast the effects of space weather on critical infrastructures	DHS	DOD, DOE, DOT, EPA, HHS, GSA, USDA, and USDT	October 2017	October 2017
	4.3.2 Identify gaps in current modeling capabilities and work with the research community to develop new and improved impact models and decision support tools	DHS and DOC	DOD, DOE, DOT, EPA, HHS, GSA, USDA, and USDT	October 2018	October 2018
	4.3.3 Test and validate the existing suite of infrastructure impact models to enable forecasting of a range of interconnected effects during an extreme space weather event			October 2019	October 2019

Goal	Task	Lead and Co-lead Agency	Supporting Agency	Original Deadline	Current Deadline
	4.3.4 Incorporate infrastructure impact models into existing and future exercises to develop realistic space weather scenarios for response and recovery	DHS	DOD, DOE, DOT, EPA, HHS, GSA, USDA, and USDT	October 2017	October 2017
	4.3.5 Recommend policy to standardize communication and data formatting from infrastructure monitoring systems and model outputs	DHS and DOC	Other entities	October 2016	March 2018
	4.3.6 Develop data stewardship, archiving, and access-provision capabilities for space weather infrastructure impact data and model output	DHS and DOC	–	October 2017	October 2017
4.4 Improve operational impact forecasting and communications	4.4.1 Conduct survey of commercial systems operators, government operators, and emergency managers to identify and assess the requirements for developing functional forecasting capabilities and alert products	DOC	Other relevant agencies	October 2016	September 2018
	4.4.2 Develop national capability for operational forecasting of space weather impacts that seeks to develop new or improved forecasting models and develop relevant tools and products that ensure the operational execution and dissemination of forecasts	DHS and DOC	NASA, NSF, and ether entities	October 2018	October 2018
4.5 Conduct research on the effects of space weather on industries, operational environments, and infrastructure sectors	4.5.1 Support scientific and engineering research by governments, academia, and private-sector stakeholders to increase understanding of space weather effects on critical infrastructure systems and to develop measurement systems and tools that enhance the forecasting and mitigation of effects	DHS	DOD, DOE, DOT, EPA, HHS, GSA, USDA, and USDT	October 2016	January 2018
	4.5.2 Support research into the social and economic impacts of space weather effects; federal agencies will develop quantitative estimates of the potential costs of a space weather event at the most severe level of estimated impact	DOC	DHS	October 2017	October 2017
Goal 5: Improve space weather services through advancing understanding and forecasting					
5.1 Improve understanding of user needs for space weather forecasting to establish lead-time and accuracy goals	5.1.1 Conduct comprehensive survey of space weather data and product requirements needed by user communities to help improve services	DOC	–	October 2016	September 2018
5.2 Ensure space weather products are intelligible and actionable to inform decision making	5.2.1 Assess best practices across federal government to identify and document most effective means to produce and deliver space weather alerts, warnings, and notifications	DOC and DOD	DHS	April 2016	October 2016
	5.2.2 Develop space weather event-specific protocols defining chain of command, control, and communication of space-weather-impact information during an extreme space-weather event	DHS	DOC	October 2016	May 2017
	5.3.1 Develop a strategy for (1) continuous operation of the SOHO/Large Angle and Spectrometric Coronagraph (LASCO) and (2) prioritize reception of LASCO data in anticipation of extreme space weather events	DOC, NASA, and NSF	–	October 2016	October 2016

Goal	Task	Lead and Co-lead Agency	Supporting Agency	Original Deadline	Current Deadline
5.3 Establish and sustain a baseline observational capability for space weather operations	5.3.2 Develop options to deploy an operational satellite mission to a position at least 1 million miles upstream on the Earth-Sunline to replace the SOHO/LASCO coronagraph capability	DOC	NASA and DOD	End of 2017	End of 2017
	5.3.3 Sustain or enhance solar imaging and measurements of solar X-ray irradiance, energetic particles, and on-site magnetic field vectors from geostationary orbit	DOC	–	Continuous	Continuous
	5.3.4 Sustain or enhance ground-based solar imaging	DOC and DOD	NSF		
	5.3.5 Sustain or enhance ground-based solar radio capabilities that provide continuous observations of solar radio emission to operational forecasting centers	DOD	DOC		
	5.3.6 Sustain existing ground-based geomagnetic monitoring network and enhance the network through installation of new observatories that will deliver data to operational centers in real time	DOI	DOC	October 2020, continuous thereafter	October 2020
	5.3.7 Enable and sustain acquisition and delivery of satellite-based Global Navigation Satellite System radio occultation data with sufficient geographical coverage, data-rate, and latency to satisfy operational ionospheric-forecasting requirements. DOC will also ensure that such data are assimilated into operational models of Earth's thermosphere and ionosphere.	DOC and DOD	–	2018	2018
	5.3.8 Develop options to sustain or enhance the worldwide ground-based neutron-monitoring network to include real-time reporting of ground-level events to operational space-weather-forecasting centers	DOC, DOD, and NSF	–	April 2016	November 2016
	5.3.9 Produce plan for deploying new operational space-weather-observing assets to provide the baseline measurements	DOC	DOD, NASA and NSF	October 2017	July 2018
	5.3.10 Develop plan to sustain availability of facilities for the calibration of space-weather-observing assets to ensure that measurements are accurate and comparable through traceability to international standards	DOC, DOD, DOI, NASA, and NSF	–	October 2016	August 2017
5.4 Improve forecasting lead-time and accuracy	5.4.1 Assess space-weather-observation platforms with deep-space orbital positions to allow for additional warning time of incoming space weather events	DOC and NASA	–	October 2016	October 2016
	5.4.2 Support development of novel sensor technologies and instrumentation to improve forecasting lead-time and accuracy	DOC, DOD, NASA, and NSF	–	October 2016	March 2017
	5.4.3 Prioritize and identify needs for improved coverage, timeliness, data rate, and data quality for space weather observations, and opportunities to address these needs through collaborations with academia, the private sector, and international community.	DOC, DOD, NASA, and NSF	–	October 2016, every year thereafter	May 2018
	5.5.1 Lead annual effort to prioritize and identify opportunities for research and development to enhance the understanding of space weather and its sources	NASA	DOC and DOD		April 2018

Goal	Task	Lead and Co-lead Agency	Supporting Agency	Original Deadline	Current Deadline
5.5 Enhance fundamental understanding of space weather and its drivers to develop and continually improve predictive models	5.5.2 Identify and support basic research opportunities that seek to advance understanding of solar processes and how the Sun's activity connects to and drives changes on Earth and its near-space environment	DOD, NASA, and NSF	–	October 2016, every year thereafter	October 2016
	5.5.3 Identify and support research opportunities that seek to address targeted operational space weather needs	DOC, DOD, and NASA	–		
	5.5.4 Assess and pilot a geo-electric monitoring capability through the installation of sensors at existing observatories to enhance the validation of electric field models	DOI	–	October 2016	October 2016
	5.5.5 Identify and fill gaps in magnetotelluric surveys, starting with the northeastern United States and concentrating on geographic regions judged to have the highest induction hazards.			October 2016	
	5.5.6 Map geomagnetic and geo-electric hazards using observatory and magnetotelluric data			Part 1 October 2016 Part 2 October 2017	Part1 October 2017 Part 2 May 2018
5.6 Improve effectiveness and timeliness of the process that transitions research to operations	5.6.1 Develop formal process to enhance coordination between research modeling centers and forecasting centers, including identifying roles and responsibilities in testing, verification, and validation for transitioning space weather research models to space-weather-forecasting centers and for sustaining and improving models that transition into operations	NASA and NSF	DOC and DOD	April 2016	October 2017
	5.6.2 Develop plan to leverage existing capabilities in academia and the private sector and enable feedback from operations to research to improve operational space weather forecasting	DOC and DOD	NASA and NSF		May 2018
Goal 6: Increase international cooperation					
6.1 Build international support and policies for acknowledging space weather as a global challenge	6.1.1 Ensure policy makers and leaders of partner nations are informed of need for a comprehensive and coordinated approach to preparing for an extreme space weather event	State	Coordination with other agencies	April 2017	August 2017
	6.1.2 Coordinate sustained U.S. participation in relevant international space weather initiatives	State	–	October 2016, every year thereafter	October 2016
6.2 Increase engagement with the international community on observation infrastructure, data sharing, numerical modeling, and scientific research	6.2.1 Lead development of a plan to expand real-time ground-based magnetometer network to improve global geophysical monitoring	DOI	–	October 2016	July 2017
	6.2.2 Explore opportunities to leverage international partnerships to sustain baseline operational space-weather-observing capabilities	DOC and DOI	NASA and NSF	October 2016, every year thereafter	October 2016
	6.2.3 Explore potential benefits and costs of space weather missions in orbits complementary to the sustained missions at the L1 Lagrangian point, which may include missions at the L5 Lagrangian point	DOC and NASA	–	October 2016	February 2017

Goal	Task	Lead and Co-lead Agencies	Supporting Agencies	Original Deadline	Current Deadline
	6.2.4 Sustain and enhance international partnerships for the acquisition of data from solar-imaging and solar-wind deep-space missions, building on the ongoing operational Real-Time Solar Wind network	DOC	State	October 2016	October 2016
	6.2.5 Maintain U.S. input to WMO Observing System Capability Analysis and Review database and encourage contributions of international partners to ensure comprehensive knowledge of international space weather observational systems and their data products currently in use and planned for operational forecasting	DOC	DOI	October 2016, with annual updates	October 2016
	6.2.6 Promote the improved exchange of data and information and organize international data comparison activities to promote the availability, intercalibration, and interoperability of space- and ground-based data	DOC and DOI	NSF and NASA	October 2017	October 2017
	6.2.7 Provide input to WMO operational space-weather-observing requirements and statement of guidance and report to relevant international organizations including the Coordination Group for Meteorological Satellites and the International Real-Time Magnetic Observatory Network	DOC and DOI	NSF and NASA	October 2016, every year thereafter	October 2016
	6.2.8 Promote and support continuation of space weather as a regular topic in the international efforts of the International Council for Science's Committee on Space Research and within the International Living with a Star program	NASA	–	October 2016, every year thereafter	October 2016
6.3 Strengthen international coordination and cooperation on space weather products and services	6.3.1 Lead U.S. efforts to engage international partners to ensure that communicated products and services are globally consistent during extreme events	DOC	–	October 2016, every year thereafter	November 2016
	6.3.2 Lead U.S. efforts to develop international standards for the provision of space weather information for international air navigation	DOT	DOC and DOD	October 2016	October 2016
	6.3.3 Continue efforts within Coordination Group for Meteorological Satellites to promote an ongoing agenda item on space weather activities	DOC and NASA	–	October 2016, every year thereafter	October 2016
	6.3.4 Sustain engagement with the International Space Environment Service and foster participation of additional nations in the network of space weather service providers.	DOC			
6.4 Promote a collaborative international approach to preparedness for extreme space weather events	6.4.1 Provide outreach and education to assist nations in understanding space weather effects and integrating space weather into national hazard and risk registries	DOC, DHS, and State	Other Federal Agencies	October 2016, every year thereafter	November 2016
	6.4.2 Work with relevant international organizations and key partners on assessing global economic impact of an extreme space weather event	DOC, DOE, DHS, NSF, and State	–	October 2016	
	6.4.3 Advise North Atlantic Treaty Organization (NATO) planners on possible implications of space weather on NATO operations; promote consistency in communications and operations among NATO members and partner nations; and assist in and, as appropriate, lead development of training and exercise events	DOT, DHS, and USPS	–	October 2016, every year thereafter	

Goal	Task	Lead and Co-lead Agencies	Supporting Agencies	Original Deadline	Current Deadline
	6.4.4 Develop space-weather event-specific protocols that define the communication of U.S. space-weather-impact information to other nations and international organizations during an extreme space weather event	State	DHS, DOD, and DOC	October 2017	February 2018
	6.4.5 Inform U.S. embassies and missions worldwide of the effects from an extreme space weather event	State	DHS, DOC, and DOT	April 2016	April 2016
	6.4.6 Support development and use of international standards for improved resilience of equipment to extreme space weather events by participating in the development of relevant open, consensus-based international standards	State	Coordination with relevant agencies	October 2016, every year thereafter	February 2018
	6.4.7 Address extreme space weather events in accordance with supply-chain issues and as part of the U.S. government's overall and ongoing efforts to implement the 2012 National Strategy for Global Supply Chain Security	State	DHS and DOC	October 2016, every year thereafter	November 2016

Source: OIG presentation of Office of Management and Budget information.

Note: Department of Commerce (DOC), Department of Defense (DOD), Department of Energy (DOE), Department of Health and Human Services (HHS), Department of Homeland Security (DHS), Department of Interior (DOI), Department of State (State), Department of Transportation (DOT), Environmental Protection Agency (EPA), Federal Communications Commission (FCC), Federal Emergency Management Agency (FEMA), General Services Administration (GSA), Nationals Science Foundation (NSF), U.S. Department of Agriculture (USDA), U.S. Department of Treasury (USDT), U.S. Postal Service (USPS), and World Meteorological Organization (WMO).

Appendix E: Agency Comments

National Aeronautics and Space Administration
Headquarters
Washington, DC 20546-0001

MAY - 2 2019

Reply to Attn of: Science Mission Directorate

TO: Assistant Inspector General for Audits

FROM: Associate Administrator for Science Mission Directorate

SUBJECT: Agency Response to OIG Draft Report, "NASA's Heliophysics Portfolio" (A-18-001-00)

NASA appreciates the opportunity to review and comment on the Office of Inspector General (OIG) draft report entitled, "NASA's Heliophysics Portfolio" (A-18-001-00) dated March 14, 2019.

In the report, the OIG found that NASA's Heliophysics Division (HPD) has developed a comprehensive strategy that has enabled the Division to successfully manage NASA's heliophysics science capabilities and maintain a portfolio of spacecraft that increasingly includes missions in extended operations. The Science Mission Directorate (SMD) is particularly pleased by the fact the OIG found that in spite of the advanced age of its spacecraft fleet, NASA is generally controlling costs for all of its HPD missions in operation. The report also highlights the successful working relationship NASA has established with the National Oceanic and Atmospheric Administration, while noting the Agency could more effectively collaborate with the Department of Defense (DOD) and the commercial space industry, to which HPD agrees.

The OIG makes four recommendations addressed to the Associate Administrator for Science Mission Directorate intended to improve NASA's management of its heliophysics portfolio. Specifically, to improve NASA's management of its heliophysics portfolio, the OIG recommends the Associate Administrator for Science Mission Directorate direct the HPD Director to:

Recommendation 1: Require all Joint Cost and Schedule Confidence Level (JCL) analyses to include all discrete development risks managed outside of the project—such as a project's launch vehicle—with potential cost and/or schedule impacts.

Management's Response: Partially Concur. SMD agrees that JCLs should include quantifiable discrete risks that could drive cost and schedule, including risks managed outside of the project (e.g. launch vehicles and partner contributions). SMD, in collaboration with the Office of the Chief Financial Officer (OCFO) and the Office of the Chief Engineer (OCE) and other stakeholders, will conduct a study to evaluate launch vehicle and partnership data to better inform our JCL analyses and, to the extent possible, quantify these risks. Based on the results of the assessment, SMD will evaluate in conjunction with OCFO and OCE, whether changes to JCL policy and guidance are necessary and incorporate the quantified risks into the existing process.

Estimated Completion Date: December 31, 2019

Recommendation 2: Complete implementation of 2015 the National Space Weather Action Plan (NSWAP) tasks in accordance with the Space Weather Operations, Research, and Mitigation (SWORM) subcommittee deadlines.

Management's Response: Concur. Noting that the 2019 NSWSAP will supersede the 2015 NSWAP, HPD will provide a plan to complete the 2019 National Space Weather Strategic and Action Plan (NSWSAP) tasks in accordance with the SWORM Working Group tasks, and satisfy the short-term actions for which NASA has the primary responsibility 24 months after it is released.

Estimated Completion Date: May 30, 2021

Recommendation 3: Reassess HPD's capabilities and resources and update the 2014 Roadmap for implementing 2013 Decadal recommendations with expected completion dates based on the Division's updated budget and priorities over the next 5 years.

Management's Response: Concur. Following the receipt of the 2013 decadal midterm assessment report, the HPD will updated the 2014 Roadmap plan to better align with the National Academy of Sciences' recommendations for completing the survey.

Estimated Completion Date: December 31, 2020

Recommendation 4: Establish a formal mechanism to increase collaboration with Department of Defense (DOD) and the commercial space industry regarding heliophysics research and space weather modeling and forecasting efforts.

Management's Response: Concur. HPD will establish a formal mechanism to increase space weather collaboration with DOD by establishing a Memorandum of Understanding (MOU) between NASA and with commercial space industry by competing and awarding Phase 1 and Phase 2 Small Business Innovation Research (SBIR) grants for potential commercialization.

Estimated Completion Date: May 30, 2021

We have reviewed the draft report for information that should not be publicly released. As a result of this review, we have not identified any information that should not be publicly released.

Once again, thank you for the opportunity to review and comment on the subject draft report. If you have any questions or require additional information regarding this response, please contact Peter Meister on (202) 358-1557.

Dr. Thomas H. Zurbuchen

cc:
Science Mission Directorate/Ms. Fox
Science Mission Directorate/Ms. Luce
Goddard Space Flight Center/Mr. Scolese

Appendix F: Report Distribution

National Aeronautics and Space Administration

Administrator
Deputy Administrator
Associate Administrator
Deputy Associate Administrator
Chief of Staff
Associate Administrator for Science Mission Directorate
Heliophysics Division Director

Non-NASA Organizations and Individuals

Office of Management and Budget
    Deputy Associate Director, Energy and Space Programs Division

Government Accountability Office
    Director, Office of Contracting and National Security Acquisitions

Congressional Committees and Subcommittees, Chairman and Ranking Member

Senate Committee on Appropriations
    Subcommittee on Commerce, Justice, Science, and Related Agencies

Senate Committee on Commerce, Science, and Transportation
    Subcommittee on Aviation and Space

Senate Committee on Homeland Security and Governmental Affairs

House Committee on Appropriations
    Subcommittee on Commerce, Justice, Science, and Related Agencies

House Committee on Oversight and Reform
    Subcommittee on Government Operations

House Committee on Science, Space, and Technology
    Subcommittee on Investigations and Oversight
    Subcommittee on Space and Aeronautics

(Assignment No. A-18-001-00)