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Statement of
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Committee on Commerce, Science, and Transportation,
United States Senate

Chairman Wicker, Ranking Member Cantwell, and members of the Committees, I am honored to appear before this committee to discuss Space Weather Protection, Planetary Defense and how we protect our home planet.

NASA's Science Mission Directorate (SMD) leverages space-, air-, and ground-based assets to answer fundamental questions about Earth, the solar system and the universe, and our place in the cosmos. Our scientists, engineers, and technologists work with a global community of researchers to provide the scientific discoveries that advance critical understanding and inform decision-making. Whether through disaster response, natural resource management, planetary defense, or space weather observations, NASA provides tangible benefits that help protect and improve life on Earth. At the same time, NASA is leading the quest to answer some of the most pressing human questions, among them how Earth and the universe evolved, how life emerged, and whether we are alone in the universe.

Space Weather

Space weather is the result of complex interactions between the Sun, solar wind, Earth's magnetic field, and Earth's atmosphere. Our ability to understand and predict space weather is of growing importance to our nation's economy, national security, and even NASA Astronauts. NASA's role in space weather is threefold: we enable new understanding of how space weather works, we develop new technologies and instruments, and we transition understanding, models and technology for use by the operational space weather agencies (NOAA and DOD).

NASA's Heliophysics Division is a crucial research arm of the nation's space weather effort, coordinating its efforts with NOAA, the National Science Foundation (NSF), the U.S. Geological Survey (USGS), and Department of Defense (DoD). This division continues to study the Sun, how it influences the very nature of space, the atmospheres of planets and in the case of Earth, the technology that exists in low earth orbit and on the surface. The extensive, dynamic solar atmosphere surrounds the Sun, Earth, and planets and extends far out into the solar system. Mapping out this interconnected system requires a holistic study of the Sun's influence. NASA has a fleet of spacecraft strategically placed throughout our heliosphere -- from Parker Solar Probe nearest the Sun, observing the very start of the solar wind, to satellites around Earth, to the farthest human-made object, Voyager, which is sending back observations on interstellar space. Each mission is positioned at a critical, well-thought out vantage point to observe and understand the flow of energy and particles throughout the solar system.

Several key missions are particularly focused on improving our understanding of space weather. The Parker Solar Probe traveling through the Sun's atmosphere, or corona, is now joined by the ESA/NASA Solar Orbiter mission, providing information about coronal heating and the source of the solar wind. The Advanced Composition Explorer along with NOAA's Deep Space Climate Observatory observe the solar wind as it travels away from the Sun toward Earth and the other planets. The Solar Dynamics Observatory, the Solar and Terrestrial Relations Observatory, and the joint ESA/NASA Solar and Heliospheric Observatory all observe solar eruptions on the Sun. The Global-scale Observations of the Limb and Disk (GOLD) mission and the Ionospheric Connection (ICON) mission, launched last year, are improving our understanding of what is happening in the ionosphere. Each of these missions provide a different view of the complex system that leads to the space weather we experience. Looking to the future, the Heliophysics Division is beginning to implement the Geospace Dynamics Constellation (GDC) which will study the top-most region of the atmosphere that shields Earth's surface from solar radiation. In this region, there are >20,000 objects orbiting, including the International Space Station, weather, communications, and other operational Government assets. These assets may be adversely impacted when exposed to solar and geomagnetic activity. For example, solar and geomagnetic activity in the past have resulted in degraded communications, GPS positioning errors due to the ionospheric disturbances, increased space-to-surface transmission noise affecting military monitoring of the north pole region, satellite drag, and rerouting of flights due to potential impacts to airplane flight crew and passenger health.

In preparation for these missions, NASA develops new technologies and instruments for measuring the effects and processes associated with space weather. For example, NASA's historic Parker Solar Probe mission, which has already completed four close approaches to our Sun, will swoop closer to the Sun's surface than any spacecraft before it, facing brutal heat and radiation conditions. The spacecraft will come as close as 3.83 million miles (6.16 million kilometers) to the Sun, well within the orbit of Mercury and more than seven times closer than any spacecraft has come before. To perform these unprecedented investigations, the spacecraft and instruments are protected from the Sun's heat by a 4.5-inch-thick (11.43 cm) carbon-composite shield, which needs to withstand temperatures outside the spacecraft that reach nearly 2,500 degrees Fahrenheit (1,377 degrees Celsius). The compact, solar-powered probe houses solar arrays that retract and extend as the spacecraft swings toward or away from the Sun during several loops around the inner solar system, making sure the panels stay at proper temperatures and power levels. At its closest passes the spacecraft must survive solar intensity of about 475 times what spacecraft experience while orbiting Earth.

Through its Artemis program, NASA is accelerating its exploration plans and working to land the first woman and next man on the Moon by 2024. To meet these objectives, we continue to accelerate development of the systems required to ensure success. The Artemis missions will send humans beyond the protection of Earth's magnetic field for the first time since Apollo, and expose our astronauts and the systems upon which they will depend to a potentially hazardous space weather environment. NASA's Heliophysics division is working closely with the Artemis Program to support the human exploration of deep space, and on potential approaches to measure the radiation environment on and around the Moon. These measurements would aid in the prediction and validation of the radiation environment to which our astronauts will be subjected. Looking further in the future to journeys to Mars, NASA astronauts will need the capability to autonomously generate their own space weather data and predictions. To this end, the Heliophysics Division is working with the Space Radiation Analysis Group (SRAG) at the Johnson Space

Center on possible experiments in cislunar space to develop the science and technology needed for such predictions.

NASA will conduct many more science investigations and technology demonstrations on the Moon ahead of a human return through its Commercial Lunar Payload Services (CLPS) initiative. Several payloads among those already selected through this program earlier this year will provide data of interest to solar and space physicists, and future payloads could include dedicated space weather instruments. The Artemis Program seeks to establish a sustainable architecture with our commercial and international partners on the Moon and this architecture will support a future of scientific research.

NASA already addresses space weather impacts on astronauts and spacecraft while maintaining the International Space Station (ISS) and protecting the astronauts living there. The Community Coordinated Modeling Center team at the Goddard Space Flight Center works with NOAA's Space Weather Prediction Center to provide data and forecasts to the SRAG, who can then assess risks to the ISS. This experience will help NASA as it considers how best to protect Artemis astronauts from space weather impacts. Space weather events are not only a concern for our astronauts and spacecraft; airline travel, communications and precision navigation and timing systems like the global positioning system (GPS), and the electrical power grid, on which we depend each day, can all be impacted by space weather.

In addition to research missions discussed already, NASA supports improvements in space weather prediction models, such as those used by NOAA Space Weather Prediction Center, the U.S. government's official source for space weather forecasts. The multi-agency Community Coordinated Modeling Center plays a key role in supporting our sister agencies by transitioning space research models to space weather operations. NASA is also a member of the Space Weather Operations, Research, and Mitigation (SWORM) Interagency Working Group run by the National Science and Technology Council, which coordinates interagency efforts to carry out the actions and meet the objectives identified in the National Space Weather Strategy and Action Plan.

NASA's Space Weather Science and Applications (SWxSA) program works to effectively support the transition of heliophysics science results to applications that enhance the user communities' ability to address impacts caused by the dynamic space environment. This activity supports interagency space weather efforts and is consistent with the recommendations of the 2013 Decadal Survey for Solar and Space Physics. Under SWxSA, NASA competitively funds ideas and products, leverages existing agency capabilities, collaborates with other agencies, and partners with user communities. NASA established SWxSA in collaboration with sister federal agencies, academia and industry. Recent achievements include the award of grants that target research efforts to advance science priorities identified by our operational agency partner, investments in high end computing and the community coordinated modeling center.

Furthermore, in coordination with NOAA, we have initiated a pilot program to expand the interagency capability and improve space weather products and services for Research to Operations and Operations to Research (R2O2R). Together with NOAA, we are developing a shared framework for research to operations, and once we have established an effective and efficient process, we will explore the possibility to further integrate NSF, DoD, academia and private industry into the framework.

Planetary Defense

NASA's Planetary Defense Coordination Office (PDCO) is the primary group responsible for the coordination of U.S. Government efforts to find hazardous near-Earth objects (NEOs) and guide planning for the response to an actual impact threat. PDCO accomplishes this important task by supporting ground- and space-based assets in detecting, tracking, and characterizing NEOs, as well as by coordinating U.S. efforts for cooperating with multiple international organizations. The PDCO funds NASA's NEO Observations Program, the activities of the Minor Planet Center (MPC), and the JPL Center for NEO Studies (CNEOS). Operating under the auspices of the International Astronomical Union, the MPC is the central node for receiving observations from observatories worldwide and distributing the most up-to-date database of minor planets, comets, asteroids, and other small bodies in the solar system.[1] The MPC operates from the Smithsonian Astrophysical Observatory at Harvard University. When any observatory around the world detects a NEO, it voluntarily reports the detection to the MPC for additional verification and follow-up observations, and makes all data publicly available for study. The CNEOS computes high-precision orbits for NEOs in support of the PDCO. These orbit solutions are used to predict NEO close approaches to Earth, and produce comprehensive assessments of impact probabilities of any NEO for at least the next century.

These activities led to the accomplishment of the Spaceguard Survey goal of discovering and cataloguing 90 percent of the predicted NEO population greater than 1 kilometer in size, which was completed in 2011. The Spaceguard Survey results determined that there is very little probability of a cataclysmic event in the next 100 years from NEOs greater than 1 kilometer in size, but discovery of new NEOs in this size range continue at the rate of about three to five per year. However, risks remain from smaller, undiscovered NEOs that could cause regional or localized destruction.

In 2005, Congress tasked NASA with the George E. Brown (GEB) Survey of NEOs greater than 140 meters in size, with a goal of 90 percent completion by 2020. Discovery of NEOs greater than 140 meters in size is steadily progressing with current ground-, and space-based capabilities. Over the past 20 years, NASA, with assistance from partners, has discovered, tracked, and catalogued approximately one-third of the predicted population of asteroids greater than 140 meters in size. There are several survey programs supporting this effort, including the Catalina Sky Survey, Pan-STARRS, and the NEOWISE project. Of the roughly 21,665 Near Earth Asteroids found to date, almost 8,915 are larger than 140 meters in size, which translates to approximately 36 percent of the estimated total population of NEOs of this size. A 2017 updated report from the NEO Science Definition Team (SDT) has validated the population estimate with more complete statistical analysis and characterized the impact risk from NEOs larger than 140 meters in size more accurately.[2]

There also has been increasing awareness that objects on the order of 30-140 meters in size pose a significant enough impact hazard that they ought not to be ignored. For example, the Tunguska event in 1908, which leveled trees over an area of about 2,000 square kilometers, is estimated to have been caused by an airburst of an object roughly only 40-60 meters in size. The airburst over Chelyabinsk, Russia on February 15, 2013, was caused by a 20-meter sized object exploding in the atmosphere. This well-documented airburst is estimated to have caused more than $30 million in

[1] http://www.minorplanetcenter.net/

[2] https://cneos.jpl.nasa.gov/doc/2017_neo_sdt_final_e-version.pdf

damages, mostly due to broken windows. Over 1,600 people reported to hospitals with injuries ranging from lacerations from broken glass to concussions and mild burns.

In June 2018, the National Science and Technology Council Committee on Homeland and National Security published the National Near-Earth Object Preparedness Strategy and Action Plan (referred herein as “the Action Plan”).[3] The Action Plan is a whole-of-government approach to managing the NEO threat through all phases of a NEO impact timeline. Underpinning the national efforts are five strategic goals:

- Enhance NEO Detection, Tracking, and Characterization Capabilities
- Improve NEO Modeling, Prediction, and Information Integration
- Develop Technologies for NEO Deflection and Disruption Missions
- Increase International Cooperation on NEO Preparation
- Strengthen and Routinely Exercise NEO Impact Emergency Procedures and Action Protocols

The development of the Action Plan included representatives from the Department of Homeland Security (including the Federal Emergency Management Agency), Department of Defense, Department of State, NASA, Department of the Interior, Department of Energy, National Science Foundation, Department of Commerce, National Nuclear Security Administration, and Executive Office of the President. The Action Plan lays out a framework for addressing the variety of NEO impact hazards through coordination of U.S. Federal Departments and Agencies that are implementing the above goals.

The National Academies of Sciences, Engineering, and Medicine (NASEM), at NASA’s request, produced the June 2019 report “Finding Hazardous Asteroids Using Infrared and Visible Wavelength Telescopes”[4] that notes the importance of ground- and space-based survey assets.

To date, a space-based infrared (IR) mission has been considered by recent studies to be the most effective method to discover and initially characterize relevant NEOs and increase the NEO detection rate. IR CCD cameras would be capable of finding and characterizing NEOs that are darker and fainter than those observable with any telescope on the ground and would be more effective than a visible space telescope. A survey spacecraft at the L1 or L2 Lagrange point would allow for observation of asteroids both well ahead and behind Earth along its orbital path while maintaining constant communication range with Earth, allowing for the best and latest techniques in dark object detection and characterization processing to be used. Currently, NASA is continuing to mature concepts for a space-based NEO survey capability aimed at significantly increasing the NEO detection rate. This includes instrument and sensor development for a future infrared space-based asset. The 2019 NASEM study concluded none of the considered alternatives is competitive with a thermal-infrared space telescope in terms of detection capabilities or cost. NASA’s current planning is consistent with the goal of implementing a NEO surveillance capability similar to that described in the report.

Current research has identified three possible options that could be employed to divert an object on

[3] https://www.whitehouse.gov/wp-content/uploads/2018/06/National-Near-Earth-Object-Preparedness-Strategy-and-Action-Plan-23-pages-1MB.pdf
[4] https://www.nap.edu/catalog/25476/finding-hazardous-asteroids-using-infrared-and-visible-wavelength-telescopes

a likely collision course with Earth. The size of an asteroid and length of warning time influences the most practical methods for deflecting an asteroid. With a sufficiently long warning time, a gravity tractor could be used. A gravity tractor is a spacecraft that would rendezvous with an asteroid (but not land on its surface) and maintain a relative, optimal position to use the mutual gravity attraction between the spacecraft and the asteroid to slowly tug on it to alter the course of the asteroid. A kinetic impactor is currently the simplest and most technologically mature method available to defend against asteroids. In this technique, a spacecraft is launched that simply slams itself into the asteroid at a relative speed of several kilometers per second. For a complete overview of possible mitigation techniques, please refer to the 2010 National Research Council report "Defending Planet Earth: Near-Earth-Object Surveys and Hazard Mitigation Strategies".[5] The limited discussion here is about the three most viable techniques at this time, due to their current technology readiness level. For large asteroids that are identified with relatively short warning time, high-energy release approaches, such as detonating a nuclear explosive device, may be the most effective or even the only feasible way of preventing a cataclysmic event.

NASA's Double Asteroid Redirection Test (DART) mission is a planetary defense-driven test of the kinetic impactor technique. DART is in Phase C of development and is led by the Johns Hopkins University Applied Physics Laboratory with support from other NASA centers. DART's primary objective is to demonstrate the effects of a kinetic impact on the small moon of the asteroid Didymos. NASA is developing the DART kinetic impactor demonstration for launch in summer 2021 and encounter with Didymos by October 2022.

Bolstered by international communication and cooperation, the United States also has an accurate and up-to-date picture of global efforts in NEO activities. The International Asteroid Warning Network (IAWN), of which NASA is a leading member, is an operational network that links together the observatories and data processing and analysis of institutions in many nations that are discovering, monitoring, and characterizing the hazardous NEO population. The Space Mission Planning Advisory Group (SMPAG) is a forum of the space capable nations' space agencies and offices whose primary purpose is to prepare for an international response to discovered NEO impact threats. There are several nations (e.g., Europe, Russia, Japan, and China) leading efforts that incorporate varying degrees of coordination and cooperation with the United States, and provide opportunities to collaborate or include data from observations to discover, track, and characterize NEOs.

Protecting our home planet

No discussion of space missions to protect our planet would be complete without touching on how NASA's missions help us understand changing conditions here on Earth. NASA's Earth Science Division (ESD) plays a unique and essential role in today's rapidly changing world. ESD develops new observational capabilities and new technologies and uses them to advance our fundamental understanding of how the Earth works and improve the lives of citizens in the United States and in the world. The agency fosters global observations of our Earth system from the unique vantage point of space, the ISS, aircraft and in situ data, and regional to global Earth system models. These observations allow ESD to explore spatially, unearthing new discoveries in Earth's forests, ice, oceans, and solid Earth, but also temporally, unlocking secrets and patterns in our changing climate by looking at long-term trends in Earth properties.

[5] https://www.nap.edu/catalog/12842/defending-planet-earth-near-earth-object-surveys-and-hazard-mitigation

Two years ago, the National Academy of Sciences released the 2017-2027 Decadal Survey for Earth Science and Applications from Space. The Decadal Survey gives us the compass for the future of Earth science, as well as a challenge. The reliance on Earth information in the daily lives of people and businesses has been built on sustained efforts to conduct exploratory and applied Earth science. Sustaining and improving our ability to understand the Earth system is challenging when it changes (through both natural- and human-caused means) nearly as fast as we characterize it. A robust, resilient, and appropriately balanced Earth observation program will be necessary to meet the nation's needs for the coming decades.

The FY 2021 budget provides continued support for the Earth Science Division's important work to ensure the vast scientific information produced by NASA instruments can be used by decision-makers across the private sector and the U.S. government.

Thank you for the invitation to be here with you today, and I am happy to answer any questions you may have.