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SPACE MISSIONS OF GLOBAL IMPORTANCE: PLANETARY DEFENSE, SPACE WEATHER PROTECTION, AND SPACE SITUATIONAL AWARENESS

HEARING

BEFORE THE

COMMITTEE ON COMMERCE, SCIENCE, AND TRANSPORTATION UNITED STATES SENATE

ONE HUNDRED SIXTEENTH CONGRESS

SECOND SESSION

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SENATE COMMITTEE ON COMMERCE, SCIENCE, AND TRANSPORTATION

ONE HUNDRED SIXTEENTH CONGRESS

SECOND SESSION

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SPACE MISSIONS OF GLOBAL IMPORTANCE: PLANETARY DEFENSE, SPACE WEATHER PROTECTION, AND SPACE SITUATIONAL AWARENESS

WEDNESDAY, FEBRUARY 12, 2020

U.S. SENATE,
COMMITTEE ON COMMERCE, SCIENCE, AND TRANSPORTATION,
Washington, DC.

The Committee met, pursuant to notice, at 10:02 a.m., in room SD–216, Dirksen Senate Office Building, Hon. Roger F. Wicker, Chairman of the Committee, presiding.

Present: Senators Wicker [presiding], Gardner, Blackburn, Scott, and Cantwell.

OPENING STATEMENT OF HON. ROGER WICKER, U.S. SENATOR FROM MISSISSIPPI

The CHAIRMAN. This hearing will come to order. Welcome.

This morning's hearing on Space Missions of Global Importance will focus on three missions that often do not receive the level of attention they deserve: planetary defense, space weather protection, and space situational awareness. Our ability to prepare for and mitigate asteroid impacts, solar storms, and space debris is an important part of preserving global commerce, and even human life. Sounds like a movie script, but it is reality.

And here we are, welcoming our panel, today, who will help the Committee and the public understand these issues. This morning we are joined by: Dr. Thomas Zurbuchen, Associate Administrator, Science Mission Directorate, National Aeronautics and Space Administration; Mr. Kevin M. O'Connell, Director, Office of Space Commerce, Department of Commerce; Mr. William Murtagh, Director, Space Weather Prediction Center, National Oceanic and Atmospheric Administration; and Dr. Moriba Jah, Professor at the University of Texas.

NASA is the lead agency tasked with detecting and monitoring celestial projectiles that could impact Earth. Avoiding a devastating asteroid or comet strike requires the cataloging of those objects, monitoring them, and developing capabilities to prevent an impact. This has been an education to me as Chairman of this Committee.

Thanks to Earth's atmosphere, we rarely notice the impacts from thousands of objects hitting our planet every day. Fortunately, incidents such as the 1908 Tunguska event, which flattened 80 million trees over 2,000 square kilometers of land in Siberia, are exceed-

ingly rare. Conservative estimates of that kind of event put the explosive force at 185 times stronger than the energy unleashed at Hiroshima. And sometimes, as our colleagues from Arizona know, the craters left behind from these events can become tourist destinations.

NASA has identified many of the largest near-Earth objects, but more work is needed and we have given direction in this regard. Congress has previously directed the agency to conduct a survey of all near-Earth objects greater than 140 meters in diameter. The NASA Authorization Act, reported favorably by this committee, would require NASA to launch a space-based telescope to facilitate detection. We look forward to hearing about the future of NASA's planetary defense mission. The Committee's NASA authorization bill also supports efforts to study the physics of our Sun and its effects on Earth's magnetic field. NASA missions such as the Parker Solar Probe contribute to our understanding of the solar phenomena behind space weather. NASA's work is complemented by NOAA's Space Weather Prediction Center in Colorado.

Last year, this Committee marked up the Space Weather Research and Forecasting Act sponsored by Senators Peters and Gardner. This legislation would clarify responsibilities for Federal agencies and establish an interagency working group to coordinate these efforts. I look forward to working toward passage of space weather legislation during this Congress.

High-energy space weather events can significantly disrupt air travel, radio communications, and the electronic devices that underpin our digital economy. The committee would benefit from the witnesses' testimony on how the United States is preparing for these events.

At the same time, hundreds of thousands of objects in orbit are increasingly making space more unforgiving. Over 2,000 active satellites and over 500,000 pieces of debris larger than a marble are currently orbiting Earth. Space situational awareness programs and technology to track objects and avoid collisions are increasingly important as the private sector begins to populate space with so-called mega-constellations of hundreds or thousands of satellites to provide connectivity around the globe. In response to this challenge, the National Space Council, chaired by Vice President Pence, has issued the National Space Traffic Management Policy, which directs the Secretary of Commerce to take the lead role in providing basic space situational awareness data and space traffic management services to the public.

Senator Cruz's Space Frontier Act would help the Department of Commerce implement its assigned role by elevating the current Office of Space Commerce to the Bureau of Space Commerce and designate its leader as an Assistant Secretary. This organization change—organizational change would give space situational awareness the higher profile it deserves.

And one more paragraph. The United States has an indispensable role in addressing the challenges of planetary defense, space weather protection, and space situational awareness. We are the world's preeminent spacefaring nation. I look forward to hearing from our witnesses as to how we construct a policy framework to meet these challenges.

And I now turn to our Ranking Member, my friend Senator Cantwell, for her opening comments.

STATEMENT OF HON. MARIA CANTWELL,
U.S. SENATOR FROM WASHINGTON

Senator CANTWELL. Thank you, Mr. Chairman for holding this hearing.

And welcome to the witnesses.

I so appreciate having a hearing about the space mission of global importance. The space economy, to the State of Washington, is tremendously important. It's a $1.8 billion economy, and with companies like Blue Origin, SpaceX, and Aerojet Rocketdyne, thousands of jobs are dependent on how the country continues to move forward in this area.

The U.S. Government, industry, and citizens are increasingly dependent on satellites for a number of critical activities, including financial transactions, national security, intelligence operations, forecasting of natural disasters, and the services provided by in-space assets are nearly ubiquitous in our daily lives, from everything from Google Maps to weather apps to data from NOAA's satellite fleet.

Satellites are also critically important for improving our understanding of climate and how to help monitor our natural resources. Many of these satellites aren't owned by a country, but, instead, privately operated. The global commercial space industry is already worth $385 billion. As I mentioned, in the State of Washington it's a big economic impact, and we are certainly proud of the long history that we have had with the space industry.

It is critical that we manage space in a way that allows that economy to continue to grow. Threats like orbital debris, a congested space environment, space and weather, and near-Earth asteroids all pose a threat to the satellites. Despite the potential devastation of satellite collisions, a massive space or weather event, or other impact of large asteroids impacting Earth, we still don't know enough about these incidents and possibilities. So, it is long past time for the Federal Government to try to tackle these issues. For too long, our science and observations have needed improvements,which is why the Committee included a provision in our NASA Authorization Act requesting that the administration study new funding mechanisms to address missions of national importance.

Take planetary defense, for example. While cataloging near-Earth asteroids is critical to safety and even survival, the science of detecting these objects isn't at the cutting edge of where we need to be. For a long time, the only way a mission to detect these asteroids could be funded was by competing with other missions in NASA. And we certainly don't want to continue to see that happen. Consequently, an asteroid detection mission was not approved, because it was not considered high enough on the value chain for science. And the government needs to change that.

Our understanding of space weather is still at its infancy, and forecasters cannot currently predict with confidence how a space weather event will impact life on Earth. And emissions from the Sun can disrupt electrical power grids, communication networks,

and aircraft systems. In 1989, a geomagnetic solar storm caused a 12-hour blackout in the entire providence of Quebec, Canada. In 2005, solar activity severely degraded airline pilot communications over the United States. So, infrastructure in the high-altitude regions and such, as in Washington State, where we're very vulnerable to space weather, NOAA provides space weather warnings for the Nation. Unfortunately, some of the satellites NOAA uses for space weather forecasts are over 20 years old.

So, finally, we must tackle the challenge of orbital debris and the congested space environment. There are currently more than 2,200 active satellites in orbit, and several companies have proposed launching new mega-constellations that could push that number to the tens of thousands. In addition, there are over a half a million pieces of orbital debris, much of which is not tracked, and a collision between these could also be very problematic. Near-collisions are happening with increasing frequency. The United States and other spacefaring nations need to improve our tracking of these objects. And today, the Air Force provides thousands of notifications of those potential collisions, most of which are ignored by the satellite operators because they cannot rely on an unpredictable system.

We need to explore this and think about guidelines that we should have for this kind of orbital debris and making sure we don't have these collisions.

We need to dramatically increase our research dollars in all of these areas. We need to ensure that agencies like NASA can fund missions and operations to improve our understandings of these threats and continue to give assessments to—here in Washington, to policymakers so we can move forward.

My constituency is very excited about the future of space. I guarantee it. That's why we call it the Space Needle. And we will continue to want to push forward on this agenda. There are many pioneers there, but we also have to do our job here in making sure that we continue to fund the level of research and development necessary for us to continue to be leaders in this sector.

Thank you, Mr. Chairman.

The CHAIRMAN. Senator Cantwell, how long has the Space Needle been around?

Senator CANTWELL. 1963 World's Fair.

The CHAIRMAN. You know, it's still pretty special.

Senator CANTWELL. Very special. Very special.

The CHAIRMAN. Impressive to a small-town Mississippi boy.

So, who wants to go first? Shall we start with NASA?

Dr. Zurbuchen, you're recognized for 5 minutes. And your entire statement—all of your entire statements will be submitted to the record. You're welcome——

STATEMENT OF THOMAS ZURBUCHEN, PH.D., ASSOCIATE ADMINISTRATOR, SCIENCE MISSION DIRECTORATE, NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Dr. ZURBUCHEN. Thank you so much, sir. Usually, with my last name, I'm last, you know? So, Chairman——

The CHAIRMAN. I know the feeling.

Dr. ZURBUCHEN. I know.

Chairman Wicker, Ranking Member Cantwell, and members of the Committee, I am honored to appear before you today. Whether through space weather observations, planetary defense, or studying the Earth, NASA science provides tangible benefits that help protect and improve life on Earth.

Our ability to understand and predict space weather is of growing importance to our Nation's economy, national security, and the safety of our astronauts, too. NASA's role is threefold. We enable new understanding of how space weather works. We develop new technologies and instruments, and transition understanding models and technology for use by the operational space weather agencies, NOAA, and the Department of Defense.

NASA is a critical research arm of the Nation's space weather effort. We study the Sun, how it influences the solar system and affects technology on Earth. NASA has a fleet of spacecraft strategically placed throughout our heliosphere, from Parker Solar Probe and the recently launched—this week, in fact—Solar Orbiter, nearest the Sun to the farthest human-made objects, Voyager 1 and 2, now in interstellar space to provide research data on space weather.

In preparation for future missions, NASA develops new technologies and instruments. For example, NOAA Space Weather Follow-on Mission relies, in part, on technologies developed in NASA's Research Program.

NASA's scientists working closely with the Artemis Program in Johnson Space Center to support the human exploration of deep space. The multi-agency Community Coordinated Modeling Center team at NASA Goddard works with NOAA's Space Weather Prediction Center to provide data and forecasts to NASA Johnson, who can then assess space weather risks to the ISS. This experience will help NASA to protect Artemis astronauts from space weather impacts at the Moon and eventually on their way to Mars.

NASA also supports improvements in space weather prediction models used by NOAA's Space Weather Prediction Center, the U.S. Government official resource for space weather forecasts.

Finally, in coordination with NOAA, we have initiated a pilot program to expand the interagency capability to improve space weather products and services for research to operations, and operations to research.

The next risk I will talk about is planetary defense. NASA's Planetary Defense Coordination Office is the primary group responsible for the coordination of U.S. Government efforts to find hazardous near-Earth objects and guide planning for the response of any impact threat. This office detects, tracks, and characterize NEOs, and coordinates U.S. efforts within the national organizations. We fund the NEO Observation Programs, the activities of the Minor Planet Center, and the JPL Center for NEO Studies. When anyone around the world detects a NEO, they voluntarily report the detection to that office, which verifies the finding and coordinates follow up observations, and makes the data publicly available for study. JPL computes high-precision orbits for NEOs that are used to predict if a NEO will approach Earth anytime in the next century.

NASA met the congressional goal of discovering 90 percent of the NEOs over 1 kilometer in 2011. Now we are focusing on NEOs greater 140 meters in size, using ground- and space-based capabilities. NASA and our partners have already discovered about one-third of the predicted population of these asteroids.

The 2019 National Academy 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 the one described in that report. In addition, NASA's DART mission is scheduled to launch in 2021, will be the first planetary defense-driven test of a kinetic impactor technique.

The United States lead the world in planetary defense, but we are not alone. The International Asteroid Warning Network, of which NASA is the leading member, is an operational network that links together worldwide data processing and analysis efforts.

No discussion of space missions to protect our planet would be complete without touching on how we understand changing conditions here on Earth. NASA's Earth Science develops new observational capabilities and technologies to advance our fundamental understanding of how the Earth works and improves the lives of citizens in the United States and abroad. NASA fosters global observations of our Earth system from a unique vantage point of space, unlocking secrets and patterns in our changing climate by looking for long-term trends in Earth properties by following the National Academy's Decadal Survey. NASA plans to provide continued support for the Earth Science Division's important work to ensure the vast scientific information produced by NASA's instruments can be used by decisionmakers across the private sector and the U.S. Government.

Thank you again for the invitation to be here with you today. And I'm happy to answer any questions you might have.

[The prepared statement of Dr. Zurbuchen follows:]

PREPARED STATEMENT OF THOMAS ZURBUCHEN, PH.D.,
ASSOCIATE ADMINISTRATOR, SCIENCE MISSION DIRECTORATE,
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

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 com-

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

putes 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 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

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

[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*

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 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.

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[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.

The CHAIRMAN. Thank you very much, Doctor.

Mr. Murtagh.

STATEMENT OF WILLIAM MURTAGH, PROGRAM COORDINATOR, NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION SPACE WEATHER PREDICTION CENTER, U.S. DEPARTMENT OF COMMERCE

Mr. MURTAGH. Good morning, Chairman Wicker, Ranking Member Cantwell, and members of the Committee. I am Bill Murtagh, the Program Coordinator for NOAA's Space Weather Prediction Center, or SWPC, in Boulder, Colorado.

NOAA is the official U.S. Government source for civilian space weather forecasts, warnings, and alerts to the public, industry, and to government agencies. We do work very closely with the U.S. Air Force, who is responsible for all DOD and related national security needs for space weather information. We work with NASA and other Federal agencies, as well as private industry, academia, and international partners, to ensure access to data and analysis that support our 24/7 mission to deliver products and services that protect our society and economy from space weather events. These events could drastically affect our electric power grid, telecommunications, GPS-dependent technologies, astronauts and space exploration, and, of course, aviation.

Critical to our mission operations are four things: observations, forecasts and warnings, science, and partnerships. And I'll briefly highlight each one of these.

For observations, NOAA uses an array of space- and ground-based observations employing specialized instruments to support our space weather forecast operations and related research. NOAA operates at three viewpoints to acquire the space-based observations necessary to meet SWPC's operational requirements. Those three, in deep space, at the Lagrange point, located 1 million miles from Earth, to observe the solar wind; a geostationary orbit for key observations of solar flares, of X-rays, and energetic particle radiation; and lower-Earth orbit, for measurements of the ionosphere.

NOAA leverages additional data from NASA and European satellites. NOAA is in the process of developing the Space Weather Follow-on Program, which will provide mission continuity and augment capabilities at the L1 point and in geostationary orbit.

Ground-based data are also important to the SWPC operations; in particular, magnetic field observations provided by the USGS

which are critical in our geomagnetic storm warning processes, also radio and solar observations provided by the U.S. Air Force and solar magnetic field maps from the NSF.

In forecasts and warnings, once an eruption occurs, the forecasters feed these observations into computer models to determine the likely effects of solar events on Earth. These models help forecasters estimate when the effects will begin, how long they will last, and how severe the event will be.

Similar to the categories we use to classify hurricanes or tornados, the space weather scales are used for communicating the severity of space weather storms. These scales address radio blackouts, solar flares, solar radiation storms due to the sun-emitted energetic particles, and geomagnetic storms from corona mass, ejected plasma, and magnetic fields. These—the scales list possible impacts for each level of storming, and indicate how often such events happen. NOAA's space weather alerts and warnings are employed by Federal agencies and users across many sectors to aid in national preparedness and response to space weather.

That category of science, NOAA is also advancing a Research-to-Operations process. This includes a new program, the Earth Prediction Innovation Center, or EPIC. EPIC will use the partnership with academic, the private sector, and relevant agencies to test and validate new capabilities, and transition those capabilities from research to operations, thereby improving our existing forecast and warning capabilities. NOAA is also exploring with NASA the potential for a space weather testbed to further accelerate the transfer of research to operations, and operations to research.

And finally, in partnerships, strong public, private, academic partnerships are essential to maintain and improve the observing networks, conduct the research, create the forecast models, and supply the services necessary to support our national security and economic prosperity. NOAA is committed to working toward the growth of the private sector as our national infrastructure and technological base becomes more sensitive to the impacts of space weather, thus demanding more and improved space weather services. NOAA will continue to explore partnerships with commercial and academic community as we work to maintain and improve our operational capabilities.

In closing, NOAA appreciates the ongoing support we have received from Congress for our critically important space weather programs. We will continue to work with other Federal agencies and the private sector in this effort to enhance American preparedness for, and resilience to, the effects of space weather. And I look forward to answering your questions.

[The prepared statement of Mr. Murtagh follows:]

PREPARED STATEMENT OF WILLIAM MURTAGH, PROGRAM COORDINATOR, NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION SPACE WEATHER PREDICTION CENTER, U.S. DEPARTMENT OF COMMERCE

Introduction & NOAA's Role

Good morning Chairman Wicker, Ranking Member Cantwell, and members of the Committee. My name is Bill Murtagh and I am the Program Coordinator for the National Oceanic and Atmospheric Administration (NOAA) Space Weather Prediction Center (SWPC) in the Department of Commerce. Thank you for the opportunity to testify at this hearing about space weather. NOAA is the U.S. Govern-

ment's official source of civilian space weather forecasts, warnings, and alerts to the general public, industry, and government agencies. NOAA works closely with our partners in the U.S. Air Force (USAF) 557th Weather Wing, who are responsible for all Department of Defense (DOD) and related national security needs for space weather information.

Through the SWPC, NOAA's mission is to deliver space weather products and services that protect our society and economy from space weather events that could wreak havoc on our Nation's electrical grid, telecommunications, GPS-dependent technologies, astronauts and space exploration, and aviation.

SWPC operates 24 hours a day providing observations/situational awareness, forecasts, and warnings of space weather storms with advance notice ranging from hours to days. In addition to the DOD, SWPC efforts are closely integrated with other agencies, including the Department of Homeland Security, National Aeronautics and Space Administration (NASA), National Science Foundation (NSF), and the U.S. Geological Survey (USGS), as well as commercial service providers, private industry, and academia. SWPC also works with international partners to ensure access to essential data and analyses that support our mission, and to ensure consistency in forecasts. It is SWPC's goal to produce accurate and timely space weather products and decision-support tools that protect national critical infrastructure.

Observation Platforms

NOAA's space weather products and services start with observations. NOAA uses an array of space-and ground-based observatories that use specialized instruments that support our space weather forecast operations and related research.

NOAA, through its National Environmental Satellite, Data, and Information Service, operates space-based observatories at three viewpoints to meet SWPC's operational requirements: deep space Lagrange point 1 (L1), the point located one million miles above the surface of the Earth for solar wind measurements; in geostationary orbit at 22,240 miles for key observations of solar flares, x-rays, and energetic particle radiation enhancements; and in low Earth orbit polar-orbit at 310 miles for measurements of the ionosphere. NOAA also ingests supplemental information by leveraging additional data from NASA research, and European research and operational satellites. NOAA is currently in the process of developing the Space Weather Follow-On (SWFO) program, which will provide mission continuity and augment capabilities at the L1 point and geostationary orbit.

Ground-based data are also important in SWPC operations. The underpinning data used by NOAA to supply geomagnetic storm warnings and alerts are the ground-based magnetic field observations provided by the USGS Geomagnetism Program. These observations describe the local intensity of the changes in magnetic fields and allow NOAA to characterize the intensity of geomagnetic storms. NOAA also relies on the USAF Solar Electro-Optical Network (SEON) and NSF's Global Oscillations Network Group (GONG). SEON provides continuous solar optical observations and solar radio emissions from ground stations around the world. GONG consists of a network of six stations that provide continuous solar imaging and magnetograms.

Modeling and Product Dissemination

Using these observations, forecasters predict the probability of eruptions on the Sun. When an eruption occurs, forecasters feed the data from the data collection platforms into computer models to determine the likely effects of solar events on Earth. The models help forecasters estimate when the effects will begin, how long they will last, and how severe the event will be. The model output will also provide critical infrastructure owners and operators with key decision points and thresholds for action, enabling more effective mitigation procedures and practices. NOAA is actively working with NASA and NSF to tap into their support of research and space weather modeling developed in the academic community to increase forecast skill.

NOAA is also pursuing a more effective Research-to-Operations-to-Research process through its new program, the Earth Prediction Innovation Center (EPIC). EPIC will utilize partnerships with academia, the private sector, and relevant agencies to validate and test new capabilities (*e.g.,* products, models, observations, applications, and techniques), transition those capabilities from research to operations, and establish a process to evaluate and improve existing operational capabilities. As part of EPIC, space weather prediction models will benefit from the increased focus on enterprise collaboration.

NOAA forecasters communicate current and forecasted space weather conditions using a variety of products. Similar to the categories we use to classify hurricanes, there are also Space Weather Scales for communicating the relative severity of space weather storms. Space weather scales communicate potential impacts such as

Radio Blackouts (from solar flares), Solar Radiation Storms (due to solar energetic particles), and Geomagnetic Storms (from coronal mass ejections). The scales list possible impacts for each level and indicate how often such events happen. Watches, warnings, and alerts are issued by e-mail via a product subscription service and by telephone notification to critical customers such as power grid operators, FEMA, and Mission Control at NASA. NOAA's space weather alerts and warnings are essential for enhancing national preparedness for space weather.

In September 2019, NOAA and USGS announced the release of the new Geoelectric Field model. This model indicates the level of space weather impact affecting the U.S. electrical power grid and helps operators mitigate effects on critical infrastructure. The model relies on USGS magnetometers (described above), and work has already begun on improving the product to include Canada and to add a prediction capability that will rely on L1 measurements.

Commercial Sector Engagement

Additionally, NOAA continues to actively engage the commercial sector on opportunities to meet U.S. government requirements for weather and space weather information. NOAA ensures all space weather data, real-time and retrospective, and services are made available to the growing private sector service providers. The NOAA-private sector partnership plays a vital role in meeting the Nation's needs for space weather services. NOAA recognizes that a strong public-private partnership is essential to establish the observing networks, conduct research, create forecast models, and supply the services necessary to support national security and economic prosperity. NOAA is committed to working toward the growth of the private sector as the national infrastructure demands more space weather services. These activities are governed by the NOAA Policy on Partnerships in the Provision of Environmental Information, NOAA Commercial Space Policy, and the NESDIS Commercial Space Activities Assessment Process. NOAA will continue to explore partnerships with the commercial sector as it maintains its operational capabilities to provide space weather awareness.

NOAA's Interagency Coordination with SWORM

On March 26, 2019, the National Science and Technology Council released the National Space Weather Strategy and Action Plan. This is an update to the original Strategy and Action Plan published in October 2015. The Strategy and Action Plan unites the U.S. national-and homeland-security enterprise with the science and technology enterprise to formulate a cohesive approach to enhance national preparedness for space weather. Key to the success of this update was input from the public on ways to leverage private capital and expertise on space weather research, observations, forecasts, and mitigation of effects on critical infrastructure. The National Science and Technology Council, Space Weather Operations, Research, and Mitigation (SWORM) Interagency Working Group, comprised of over 20 Federal Departments and Agencies, is the interagency body that defines, coordinates, and oversees implementation of the objectives in the Strategy and Action Plan. This important update seeks to improve the government's coordination on long-term guidance for Federal programs and activities to enhance national preparedness to space weather events. The new strategy aligns with priorities identified by the Administration in the 2017 National Security Strategy and the Space Policy Directives.

Conclusion

NOAA appreciates the on-going support we have received from Congress for our critically-important space weather program. We will continue to collaborate with other Federal agencies and the private sector to develop and strengthen our activities in space weather research and forecasting. Thank you for the opportunity to testify today. I look forward to answering any questions you may have.

The CHAIRMAN. Thank you very much, Mr. Murtagh.
Mr. O'Connell.

STATEMENT OF KEVIN M. O'CONNELL, DIRECTOR, OFFICE OF SPACE COMMERCE, NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION, U.S. DEPARTMENT OF COMMERCE

Mr. O'CONNELL. Good morning, everyone. Thank you, Chairman Wicker, Ranking Member Cantwell, and members of the Committee, for inviting me to testify today about the urgent need to improve the Nation's space situational awareness capabilities. It is es-

sential that we deal with this problem now as a key enabler of our ambitious plans for space exploration and space commerce.

Two weeks ago, on January 29th, two U.S. space objects, a decommissioned space telescope and an experimental payload, came into close approach in low-Earth orbit. Throughout the day, the probability of conjunction dramatically increased from 1 in 1,000 to 1 in 20, signaling an extremely close approach. To place this in context, satellite operators begin collision planning avoidance maneuvers when the probability of collision reaches 1 in 10,000. Neither object had any ability to maneuver. Thankfully, the two objects narrowly passed, by some calculations at a distance of only 18 meters. Experts predict that if the two relatively large objects had collided, they would have created a cloud of new debris of up to 15,000 new debris objects.

Because the Department of Defense's Space Domain Awareness Mission prioritizes threats to active satellites and the International Space Station, it did not initially assign space surveillance assets to this event. This is technically a debris-on-debris event. Second, LEO labs, one of a number of innovative U.S. companies already providing SSA services, provided the initial, and then subsequent, warnings of the possible conjunction. Third, this close approach between two objects was only one of five similar events during that day.

Why does it matter? As challenging as the space debris problem is today, it is bound to grow more complex. Space debris creates risks to the International Space Station and the billions of dollars of U.S. investment in space, including the services they enable here on Earth. This year alone, if SpaceX and OneWeb plans are successful, they will launch over 1,000 new satellites into low-Earth orbit, thereby increasing the number of active satellites by almost 50 percent. The United States and many other countries have very ambitious space plans over the next decade.

Finally, as we consider the next wave of space commerce in areas like satellite servicing, space manufacturing, and tourism, and even early plans to remove space debris, those will require much more timely, accurate, and continuous monitoring of the space environment. Analysts are projecting significantly higher probabilities of collision, which could impact our ability to bring benefits to Earth from areas of space for an entire generation.

Space Policy Directive 3 directed the Department of Commerce to assume on-orbit collision avoidance notifications for private sector and international users, a mission traditionally held by the Department of Defense. Drawing upon a range of national security sensors, DOD maintains a catalog of roughly 26,000 space objects larger than the size of a softball. DOD shares SSA-related data through agreements with foreign military and other organizations, and it provides information for space operator use through the Space-track.org website.

The focal point for these activities in the Department of Commerce is my office, the Office of Space Commerce. We developed a strong partnership with DOD and the Space Force officials to ensure a seamless transfer of these responsibilities. Last year, the Department detailed the senior commerce liaison to the 18th Space Control Squadron at Vandenberg Air Force Base, California, where

DOD provides us access to their data, their systems, and their processes. We've also participated in exercises designed to explore effective integration of government and commerce SSA capabilities, including those of our allies. Our partnership with NASA is strong, and growing.

Our work on SSA internal to the office is focused in key areas: industry engagement, improving international standards and best practices, and the development of a modern system, known as an Open Architecture Data Repository, or OADR. In order to achieve these, we must have the right mix of mission-critical staff.

In sum, the OADR is being designed to bring modern commercial technologies and business concepts to the U.S. space situational awareness enterprise. This will allow us to provide collision-avoidance notices to a growing number of private-sector and international operators. Ultimately, the OADR will provide conjunction notice services that exceed current Federal support and encourage the continued growth of a commercial space safety industry.

Improving SSA is also an imperative of sustaining American leadership in space. We've had extensive conversations with our allies about the OADR and how they can bring civil and commercial capabilities to bear as part of their responsibilities in space safety and sustainability.

To summarize, the essential first step in creating a highly effective civil space traffic management system, as directed by SPD–3, is to improve space situational awareness. That system would start with the data from DOD's authoritative catalog, bolster it with commercial sensor capabilities, apply state-of-the-art analytic and visualization tools, some from the space industry but also from others from the much broader analytics market, and use them in a modern operational concept in order to warn satellite operators in a trusted, timely, and highly accurate fashion.

From our vantage point at the Commerce Department, Mr. Chairman, we see the elements necessary for a trillion-dollar space economy over the next two decades, if not sooner. Enabling an incredibly innovative U.S. ecosystem of entrepreneurs as one of them, avoiding the very bad day and decades-long consequences that space debris can cause is another.

Thank you, and I'll look forward to your questions.

[The prepared statement of Mr. O'Connell follows:]

PREPARED STATEMENT OF KEVIN M. O'CONNELL, DIRECTOR, OFFICE OF SPACE COMMERCE, NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION, U.S. DEPARTMENT OF COMMERCE

Thank you, Chairman Wicker, Ranking Member Cantwell, and members of the Committee. I am pleased to testify before the Committee to talk about the urgent need to improve space situational awareness (SSA). My testimony will cover the work the Administration is doing to address this urgent need, and the responsibilities that have been given to the Department of Commerce by the President and the National Space Council in Space Policy Directive 3 on Space Traffic Management. I will also discuss how the space environment is changing, the tremendous opportunities to leverage commercial capabilities to enhance space safety and sustainability, and why it is essential to do so in order to achieve our ambitious pursuits from space exploration to space commerce.

This hearing represents an important opportunity to discuss how our collective efforts will promote responsible U.S. innovation, investment, and space operations, and how commercial efforts can support our Federal missions and the U.S. economy.

The United States currently has an opportunity to capture the lion's share of an expected trillion-dollar space economy by 2040.

The Department's Direction to Establish an Open Architecture Data Repository (OADR)

Space Policy Directive 3 (SPD–3) directs the Department of Commerce to develop a modern, open data repository as the place from which to ultimately provide conjunction notifications. This state-of-the-art open architecture data repository (OADR) will apply modern technology and business approaches to space situational awareness, providing conjunction analysis to private sector and international users.

The OADR will provide conjunction notification services for participating commercial and international space operators that exceed current Federal models. Participating members will serve as contributors to the augmented space situational awareness repository as well as reap the benefits of protecting their assets in space through better understanding of the space traffic environment.

We believe that innovations can be applied across the board, from sensors and analytic tools to new concepts of operations and warning systems.

The OADR will also be designed to include a platform where companies can interact with one another to create new commercial service offerings around space safety and sustainability.

This is also an imperative of sustaining American leadership in space. We have had extensive conversations with a number of U.S. allies about the OADR and their interest in participation; our allies have offered to consider bringing civil and commercial capabilities into the OADR as part of their contribution.

The OADR will leverage commercial innovation to protect and enhance civil and commercial space activities in real-time.

A Very Near Miss in Space—One of Many

Our work on the OADR cannot be timelier, as space traffic expands and near misses are common news. On January 29, 2020, expert and even public attention was captured by the close approach between two space objects—a decommissioned U.S. space telescope (Infrared Astronomical Satellite or IRAS) launched in 1983 and a U.S. experimental payload (Gravity Gradient Stabilization Experiment or GGSE–4) launched in 1967. Throughout the day, probability of a collision dramatically increased from 1 in 1000 to 1 in 20, in other words an extremely close approach. To place this in context, satellite operators begin planning collision avoidance maneuvers for active space objects when the probability of collision reaches 1 in 10,000.

Neither object had any ability to maneuver. Thankfully, the two objects narrowly passed, by some calculations at only a distance of 18 meters. Some experts predict that if the two relatively large objects had collided, at a relative speed of almost 33,000 miles per hour, they could have created a debris cloud of up to 15,000 debris objects, one of the largest such events in the history of spaceflight.

Even if you followed the news reporting on that close approach, there are some things that you might not know. First, because the Department of Defense (DoD) national security mission of Space Domain Awareness prioritizes allocation of space surveillance and analysis assets at monitoring threats to active satellites and the International Space Station, DoD did not initially assign assets to this event (This was technically a "debris on debris" event). DoD did ultimately raise the priority for U.S. sensors as news of the possible conjunction broke. Second, LeoLabs, one of a number of innovative U.S. companies already providing space situational awareness services, provided the initial and subsequent warnings of the possible conjunction. Third, this close approach between two objects was only one of five similar events during that day.

Why Does it Matter?

This recent event, and many like it, demonstrates the risk that space debris creates for the astronauts on board the International Space Station and the billions of dollars of U.S. government and commercial investment, both in terms of spacecraft and in products and services delivered on Earth. It also creates risks for the space investments of many other countries, including our allies. As challenging as the current space debris problem is, however, Space Traffic Management is bound to become far more complex, given current and planned future space operations.

Let me elaborate. In 2020 alone, Space X and Europe's Arianespace have planned over twenty launches each. China is also planning over forty launches this year. Many of these launches are designed to release over twenty satellites. If the launch plans for Space X and OneWeb in 2020 go as planned, the two companies alone will launch over 1,000 satellites, all to low earth orbit. Looking ahead, three American companies have applied for licenses to launch a combined 57,000+ satellites over the next decade.

The problem is not confined to the launches of large satellite constellations: modern design practices for smaller commercial satellites may create vulnerability from smaller pieces of space debris. As Secretary Ross likes to say, even a paint chip travelling at thousands of miles per hour can do serious damage to a solar panel, fuel tank, or other critical part of a satellite.

As new missions like satellite servicing, space tourism, and commercial space stations emerge, they will critically depend on an increased ability to understand the space environment in order to ensure space safety and sustainability.

Analysts are projecting significantly higher probabilities of collision which, if they occur, will create space debris in and near operational orbits, potentially impacting the ability of commercial and government satellites to bring national and economic benefit to this Nation for a generation.

One visceral response to this increased threat to space operations could be to limit launches or otherwise create a regulatory framework that might inhibit use of space in the hope of mitigating a crisis. This would be reactionary. In the Department's view, the best possible approach right now to ensuring that space is used in a safe and sustainable way is to better understand what goes on there. Only then can the best possible regulatory instruments be crafted to ensure space safety.

Unless we carefully consider the impact of regulation, space operators will simply take their investment capital, ingenuity, and potential space risk and launch from another country. Such an approach will allow us to ultimately drive right-sized regulatory requirements at Federal and international levels.

Let's look at this problem in another way. Today's growth in space commerce is partly based on the application of commercial efficiencies to what was a traditionally government-focused business model. The commercial launch industry has transformed the industry by implementing techniques such as launch vehicle reusability, miniaturization, efficient production, and continuous learning, which are resulting in the substantial lowering of costs associated with space access and operations. A failure to improve our understanding of the space environment and mitigate creation of additional space debris threatens adding costs and complexity once again. Space debris is the "speed bump" on the path to the trillion-dollar space economy.

Updating the Nation's SSA System—The Role of the Department of Commerce

SPD–3 directed the Department of Commerce, in partnership with DoD, to assume responsibility for private sector and international notifications worldwide. Two key rationales exist for this transition. First, DoD, through the Space Force, has been directed to provide freedom of operation for the United States in, from, and to space, and to protect the interests of the United States in the space domain in the face of rapidly changing threats. Second, as already mentioned, our current SSA system needs to be modernized in order to effectively coordinate activities in the rapidly changing space environment.

The focal point for all of these activities is the Office of Space Commerce (OSC). At the Secretary's direction, OSC has moved quickly to implement the Department's SPD–3 responsibilities. OSC's efforts begin with leveraging the many different capabilities within the Department.

OSC's work on improving SSA is focused in three key areas: improving standards and best practices, industry engagement, and the development of the OADR. In order to achieve these goals OSC first needs to have the right mix of critical mission staff.

Commerce has developed a strong and continuing partnership with DoD and U.S. Air Force officials, at both senior leadership and staff levels, to ensure a seamless transfer of these responsibilities. Last year, the Department detailed a senior Commerce liaison to the 18th Space Control Squadron at Vandenberg Air Force Base (AFB), California, where DoD is providing access to their current data, systems, and processes for Commerce's awareness. Commerce is also participating, sometimes as co-lead, in exercises, experiments, and war games designed to help understand how to integrate government and commercial capabilities. Secretary Ross visited Vandenberg AFB in late 2018 for a first-hand view of the current SSA system and has spoken on numerous occasions about the importance of improving space safety.

The Need to Incorporate New Technologies and Processes

For the past five decades, the operational support mission to satellite owners has been a mission of the Department of Defense. Drawing upon a range of radar and optical sensors designed for missile warning and other national security purposes, the Department of Defense maintains a catalogue of roughly 26,000 space objects larger than the size of a softball. The Combined Forces Space Component Command, an element of the United States Space Command, shares SSA-related data through

a series of agreements with foreign military and domestic and international civil and commercial space organizations. It also provides information for space operator and public use through the Space-track.org website. While this approach served us well for the space environment of the past, it will not serve us adequately for the future.

Why not? Our national SSA system has not kept up with modern technologies and organizational approaches characteristic of civil and commercial space operations, mostly because of the press of national security business. An improved understanding of the space environment will benefit from the application of new sensors, analytic and visualization tools, as well as a modern alerting and warning system. While these capabilities were initially developed via traditional government acquisition processes, today many of them are available in the commercial market. Some of these come directly from space-focused companies. Others come from the convergence of other technologies like machine learning and cloud computing. The Department and the Office of Space Commerce routinely engage with companies that have SSA-related sensor and analytic capabilities, as well as other companies that have ideas about innovative new services to help with space safety and sustainability.

The Department of Commerce's SSA-related relationships are especially strong with DoD and with the National Aeronautics and Space Administration (NASA). Commerce is currently evaluating the United States Air Force's Unified Data Library as an initial input to the future OADR, and we are working with the NASA Ames and Goddard Centers on their conjunction analysis tools and models of the space environment. Simultaneously, we are evaluating other technical and system architectural concepts.

We cannot neglect attention to the downstream analytics and notification parts of the enterprise. As national sensor capabilities expand with the activation of the Space Fence, satellite operators are concerned that they will receive an overwhelming number of conjunction warnings per day if analysis and reporting tools are not upgraded as well. This is likely to result in inaction. One overarching goal of all of our efforts under SPD–3 is to produce actionable warnings that are more precise, accurate, and timely in order to optimize satellite operator actions.

Looking forward: FY 20, FY 21, and Beyond—

FY 2021 is a critically important building block year as we move toward achieving the goals of SPD–3. In FY 2020, we have reprioritized our activities to ensure that significant strides can be made in our SSA-related activities.

With these core foundations set, FY 2021 is an important year to continue our work on planning for the transition of SSA responsibility for on-orbit collision avoidance support from the DOD to a civilian agency. In FY 2021, the Department is aiming to achieve some key milestones on our critical path for standing up the OADR on schedule:

I. Further developing the OADR design and our acquisition strategy approaches;

II. Engaging with Federal agencies and the private sector on standards and best practices related to space safety and sustainability;

III. Conducting SSA development activities with industry; and

IV. Continuing to expand international partnerships for enhancing global cooperation on sharing SSA data.

However, to ensure that the OADR can provide these critical functions, even more needs to be done, as our mission and the need for the OADR is essential.

Conclusion

Mr. Chairman and members of the Committee, thank you for inviting me to discuss the Department of Commerce's vision for the OADR and the Office of Space Commerce. It is absolutely the right time to elevate our focus on how commercial innovation can enhance Federal space missions and protect the billions of dollars that U.S. companies are investing in both traditional and paradigm-shifting space operations.

The Department appreciates Congress' ongoing support for these efforts, which have continued to ensure that the United States remains the flag of choice for space innovators and operators, and the ability for U.S. technology to drive dramatically improved protection of U.S. government missions and commercial assets. Thank you again for the opportunity to testify before the Committee today. I look forward to answering any questions you may have.

The CHAIRMAN. Thank you very much.

Dr. Jah.

STATEMENT OF MORIBA K. JAH, PH.D., ASSOCIATE PROFESSOR, AEROSPACE ENGINEERING AND ENGINEERING MECHANICS DEPARTMENT, COCKRELL SCHOOL OF ENGINEERING, THE UNIVERSITY OF TEXAS AT AUSTIN

Dr. JAH. Yes. Good morning. Thank you very much, Chairman Wicker, Ranking Member Cantwell, other members of this committee.

I come to you today from the University of Texas at Austin, where I'm an Associate Professor of Aerospace Engineering and Engineering Mechanics.

So, near-Earth space is geopolitically contested, it's commercially contested, and it's in dire need of environmental protection, because it is a finite resource. All of outer space might be infinite, but near-Earth space, where we place our satellites, is a finite resource.

We see lots of stuff in the news these days. We just heard a few members here talk about this near collision. If that would have happened, many thousands of objects would have been created, adding more and more to this population of rampant debris. We even hear things like Russian satellites that might be behaving in some way to generate extra interest in what they might be up to. And we also heard, from Ms. Cantwell; she described how ubiquitous space services and capabilities are to people's lives. And nothing is guaranteeing the protection of these things. There's no Space Vice, as it were.

We launch satellites into common neighborhoods. OK? We don't just launch them anywhere in space. Common neighborhoods, think of these as shipping lanes. And these lanes are very dynamic. When most of the stuff in space kind of dies off, they tend to stay there well beyond our lifetimes and that of our children and children's children. That's something to really think about.

We even have these things that are called "graveyard orbits." So, you know, we're good at having landfills here on Earth, so we have an equivalent landfill in space. You know, what could go wrong with that idea?

So, near-Earth space highways are becoming more crowded, but we still lack this global set of norms of behavior on how to manage that finite resource. Very recently, the European Space Agency had the satellite Aeolus. There was this predicted possible collision between Aeolus and one of SpaceX's Starlink satellites. Apparently, the European Space Agency tried to get a hold of SpaceX, wasn't able to, they decided to do an evasive maneuver. At the end of the day, SpaceX said, "Well, based on the information that we had, it really didn't meet our threshold for making some sort of decision to get out of the way." All right. So, that means that not everybody has the same idea of what risk on orbit means, not everybody computes it the same way. Do we really want to get into this game of chicken on orbit? And I would say, not so much.

We worry a lot about these collisions, but I'll say that our problems don't end there, they just begin with the whole collision stuff. Every domain of human activity suffers from malicious behavior. And space is no different. OK? We speak about space traffic man-

agement, except that we can't manage what we don't know, and we don't know what we don't measure. And so, fundamentally, one of the biggest hurdles in really being able to make space transparent and predictable is sharing of observational data. And we don't do that very well these days.

We don't fully understand the effects and impacts of the space environment on how space objects behave. And I think one of the Achilles tendons of space situational awareness is that, oftentimes, many different hypotheses explain the same evidence, so there's a lot of ambiguity.

"Oh, my satellite stopped working. Why was it? Was it because the Sun hiccupped? Was it because somebody did something to me?" It's very questionable. All this is happening right before our eyes.

Space Policy Directive Number 3, signed June 18, 2018, laid out a nice path on how to move forward on space situational awareness, space traffic management. Goal number one, advance the research behind the science and technology that underpins that. And I can testify before you today that that has been significantly underfunded. We, in academia, are very much ready to do this research, but, overwhelmingly, you know, we have not seen that funding. I don't know where the National Academies stand on this issue. Where is the National Science Foundation? It doesn't really fund research in this area. And I can tell you, as an academic: all the time, I get people wanting to get students to fill this growing space commerce work force, and the guff is empty. We can't keep up with the demands to supply competent people to work in all these endeavors.

So, I'll just say that Apollo did not happen without academia. GPS did not happen without academia. SSA and space traffic management can't really happen without academia.

Thank you for your time, and I'm looking forward to answering your questions.

[The prepared statement of Dr. Jah follows:]

PREPARED STATEMENT OF MORIBA K. JAH, PH.D., ASSOCIATE PROFESSOR, AEROSPACE ENGINEERING AND ENGINEERING MECHANICS DEPARTMENT, COCKRELL SCHOOL OF ENGINEERING, THE UNIVERSITY OF TEXAS AT AUSTIN

Mr. Committee Chairman Wicker, Ms. Ranking Member Cantwell, and other members of this committee, thank you for the invitation to appear before you today to share my perspectives regarding salient issues on space safety, security, and sustainability. It is an honor to be seated at this table with these great witnesses. It has been two years since I last testified to this great body's subcommittee on Space, Science, and Competitiveness. My name is Moriba Jah. I'm an astrodynamicist and space environmentalist. My perspectives have been shaped through a 20-year aerospace engineering career in government, industry and academia. I started my career as a member of the technical staff of the NASA Jet Propulsion Laboratory. Whilst there, I contributed to the navigation of a variety of spacecraft to Mars and Asteroid Itokawa, and also developed advanced spacecraft navigation algorithms toward autonomy and improved orbital knowledge, beginning with Mars Global Surveyor and ending with the Mars Reconnaissance Orbiter mission. After JPL, I worked as a Civil Servant in the Air Force Research Laboratory (AFRL), where I led the design, development, and implementation of algorithms that have successfully and autonomously detected, tracked, identified, and characterized human-made objects in space, so called "Resident Space Objects," to include orbital debris. My last position within AFRL was as the Mission Lead for Space Situational Awareness. Amongst my achievements, I was given the highest award that can be earned as an AFRL employee, that of AFRL Fellow. I currently serve on the faculty of the Aerospace

Engineering and Engineering Mechanics Department, in the Cockrell School of Engineering at The University of Texas at Austin. At UT Austin, I lead a transdisciplinary research program focused on delivering pragmatic solutions to problems regarding space safety, security, and sustainability. I am a Fellow of several organizations and professional societies and serve as a chair and member of several major space-related national and international technical committees. However, I am here today as an individual citizen and the views I express are mine alone. I'd like to also thank my wife Cassaundra, and children Denali, Ari, and Satyana for lending me to you, today.

Executive Summary

Near Earth Space is (a) geopolitically contested (b) commercially contested and (c) a finite resource in need of environmental protection.

The entire set of space events and processes that occur and can happen, as a whole, is unknowable for a myriad of reasons, not the least of which that we still do not widely share our observations of the space domain. If we wish to know something, we must measure it and if we want to understand something, we must predict it! What do we call this knowledge regarding causal relationships for things in space? We call it Space Situational Awareness.

If we wish to protect ourselves from extraterrestrial hazards in the form of near-Earth asteroids, space environment effects and impacts on satellites and Earth-based infrastructure, as well as space activities and services from loss, disruption, or degradation, we must have timely and actionable Space Situational Awareness. Just a couple of weeks ago, two dead satellites in Low Earth Orbit were predicted to have an alarmingly high probability of collision [1] but these probabilities were quite varied: one entity said 1 in 10, another 1 in 100, another 1 in 1000. The decisions anyone might make given each of those might be extremely different. Is there consensus in the combined Space Situational Awareness? No! Case in point? Recently, there was a predicted conjunction between Aeolus, a European Space Agency satellite and a Starlink satellite belonging to the SpaceX Internet constellation [2]. The European Space Agency attempted to contact SpaceX to coordinate an evasive maneuver but antiquated methods (relying on e-mail) of communication conjured a systemic obstacle in meaningful space debris mitigation. The European Space Agency maneuvered Aeolus to prevent the predicted collision. SpaceX stated in hindsight, obviating the communication snafu, that they would not have maneuvered anyway because their Space Situational Awareness and decision threshold indicated it not sufficiently risky to them. Do we want to be "playing chicken" in our orbital commons? We have no "rules of the road" for space. The world's space debris experts agree that there is a very high rate of non-compliance with space debris mitigation guidelines. It's common practice to operate satellites long past their intended safe and useful lifespan. Last but not least, the global Astronomy community has taken issue with the exponential growth of resident space objects as these "corrupt" their astronomical images and negatively impact the science [3]. Humanity as a whole is left to suffer the consequences of these behaviors.

A safe, secure, and sustainable space domain requires improved transparency, predictability and for us to develop an *independently corroborated* body of evidence of space activities, events, and actor behaviors that can be used to hold people accountable and can inform meaningful space policies, rules, regulations, and norms of behavior.

U.S. National Space Policy Directive #3, signed by President Trump on June 18th of 2018, laid out very succinct goals to address these issues. Its first goal is to advance Space Situational Awareness and Space Traffic Management Science and Technology. It further states that the United States should continue to engage in and enable Science and Technology research and development to support the practical applications of Space Situational Awareness and Space Traffic Management. These activities include (a) improving fundamental knowledge of the space environment, such as the characterization of Resident Space Objects, (b) advancing the Science and Technology of critical Space Situational Awareness inputs such as an openly accessible and curated set of multi-source observational data, algorithms, and physics-based models necessary to improve Space Situational Awareness capabilities, and (c) developing open-source software to support big-data science and analytics. In summary, we must develop the required science and technology to reliably deter, predict, operate through, recover from, or attribute cause to the loss, disrup-

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[1] *https://spacenews.com/potential-satellite-collision-shows-need-for-active-debris-removal/*

[2] *https://spacenews.com/esa-spacecraft-dodges-potential-collision-with-starlink-satellite/*

[3] *https://www.forbes.com/sites/startswithabang/2020/01/30/dangers-to-astronomy-intensify-with-spacexs-latest-starlink-launch/#337a38a56a57*

tion, or degradation of any given space service, activity, or capability. This means making space transparent and predictable, and having the evidence to hold entities accountable.

Beyond examples I previously listed, I can personally attest to the fact that we are significantly behind in this endeavor as evidenced by our inability to accurately and precisely infer unique or unambiguous causal relationships between space domain events and observed satellite anomalies. You can read about these in the news frequently these days. Satellites are experiencing malfunctions where the evidence could have more than one explanation: was it the environment? was it caused by another entity? If so, was it intentional? The information collection, curation, analysis, and dissemination requirements for Space Situational Awareness does not end with collision risk assessments or re-entry predictions; they only begin there! The much more difficult and critical requirement is to assemble the evidence of events, processes, and activities in space that would need to be used to assign culpability of negligent behavior, for instance, or assessing compliance or the lack thereof with space policies. Nobody is quantifying these needs. Every domain of human activity has experienced malicious behavior and to think otherwise is naïve at best. In the face of a next "space race" or "gold rush" equivalent, driven by global space commerce, it's not a matter of if, but when! The space domain is holistically poorly monitored. We are unprepared and ill-equipped to deal with disputes resulting from space activities and events.

The U.S. is home to some of the world's top-ranked research institutions; these should be brought to bear to, once and for all, bring us out of the dark ages in terms of space domain decision-making knowledge and actualize us in order to meet the great demands of space commerce, exploration, and other activities. A well-funded and dedicated Space Situational Awareness Institute could undertake the Science and Technology research and development we desperately require. Europe and other countries are becoming leaders in these endeavors. Academia, the source of the purported workforce to meet the demands of operating so-called mega-constellations, has been mostly neglected in this area. As a professor at a top-tiered research university, I alone find myself turning away over a dozen qualified U.S. citizens every year, from joining my research program due to an absence of resources and financial support to perform clearly needed research.

The National Science Foundation does not fund Space Situational Awareness research although there are many basic research problems still salient in this mission area. The Air Force Research Laboratory and Air Force Office of Scientific Research have been the only real, and overwhelmingly underfunded, organizations making any semblance of investments in Space Situational Awareness research. I know this because I was the Mission Lead for Space Situational Awareness at the Air Force Research Laboratory for several years. The National Academies has several relevant boards that should be invoked to engage in studies that inform a nationally committed roadmap of Space Situational Awareness Science and Technology Research. Moreover, these research outputs must be committed to being transitioned into operationally relevant environments that could directly support the U.S. Department of Commerce's stewardship of providing Basic Space Situational Awareness and Space Traffic Management services and products to the global community.

What are the next steps required to put this into effect?

- Per National Space Policy Directive #3, provide the Department of Commerce with an adequately funded and resourced mandate to: 1) have a Space Traffic Management Pilot Program to work with USSPACECOM and the community to provide the first instance of a Civil Space Traffic Management system and 2) begin collecting, curating, and exploiting multi-sourced resident space object (*e.g.,* non-Space Surveillance Network tracking) data for orbital safety and sustainability purposes that is open and widely accessible, with multi-tiered access and dissemination (*e.g.,* ASTRIAGraph [4]).
- Create or expand the existing role of NASA to: 1) uniquely focus upon leading the *scientific and technical* requirements for a robust, effective, and meaningful Civil Space Traffic Management System, and 2) to work closely with other government agencies, industry, and academia.
  - Conjunction Analysis concerns itself with predicting so-called "close approaches" between any two Resident Space Objects [5]; it is a growing and changing field, and research into new methods is critical to keep up with the rapidly changing and marginally predictable space environment. NASA al-

[4] *http://bit.ly/astriagraph*
[5] *http://astriacss03.tacc.utexas.edu/ui/min.html*

ready has an effort in this area (the CARA Program at Goddard Space Flight Center) that can be leveraged along with 30+ years of developing and executing this capability for use by civil space operators. It is government's role to retire risk, invest in Science and Technology (S&T) Research and Development (R&D), and share the results with the community to encourage growth.

- Invest in and expand the role of University Affiliated Research Centers (UARCs) as foundational, dedicated, and focused government-academic partnerships to solidify science and technology (S&T) research and development for critical space-related core technical competencies and technology risk-retirement needed by the U.S. Space Exploration program and Commercial Space Industry[6].
- Engage and craft mechanisms for Industry to get their investment and participation in a Civil Space Traffic Management System:
  - Satellite manufacturers
  - Satellite launch providers
  - Space Insurance Brokers and Providers
  - Commercial Space Situational Awareness Providers
  - Space Angel Investors and Venture Capitalists
  - Space Service Users

At The University of Texas at Austin, we are taking our own steps in a meaningful direction by (a) becoming the first academic partner to the USSPACECOM in Space Situational Awareness Data Sharing, (b) collaborating with the NASA CARA program, hosting their tools at the Texas Advanced Computing Center (TACC) and leveraging our large scale computing platforms to improve current state-of-practice regarding collision risk assessments, (c) finalizing a fully executed set of Cooperative Research and Development Agreements (CRADAs) with the Department of Commerce's space weather prediction center and NOAA satellite operations facility in Suitland MD, (d) advancing the state-of-the-art in developing the world's first crowdsourced space traffic monitoring system, ASTRIAGraph, initially funded by the Federal Aviation Administration, (e) leading a dedicated transdisciplinary academic programs in space safety, security, and sustainability.

Mr. Chairman, we have some wicked problems to solve in near earth space and we need Congress to act now. Perfect is the enemy of good enough! We know that we won't have a perfect system at the start but let's create a system that is agile and adaptive to meet the growing demands and as a community, we will iteratively refine our tradecraft and collaboration and get better. This committee should provide the required leadership; the opportunity to act is before you.

Narrative

In my vast travels around the globe, speaking to and collaborating with space scientists, engineers, and policymakers, it is evident that "American Exceptionalism" is still invoked and desperately yearned for, by many. America's leadership in the space domain, underscored by taking on and delivering upon what seemed to be an impossible feat, to send humans to another celestial body and return them safely, has inspired not only our great nation, but an entire planet, and seeded some of the world's most creative and innovative ideas.

Exploration is critical to who we are as a species; it drives our growth and evolution. When our minds and bodies are idle, we tend to self-defeating behaviors. What brings out the best in us? Rising to great challenges, and working as a nation to overcome them. What got us to the Moon and back, safely and repeatedly? Government, Industry and Academia working seamlessly, together. No one sector could do it by themselves.

The U.S. Space Command (USSPACECOM) currently has over 26,000 records active in its space situational awareness database, commonly referred to as the Department of Defense "catalog." Of these, well over 18,000 records correspond to well-tracked, well-understood Resident Space Objects in Earth-centric orbit, roughly 3,000 of which are operational satellites; the rest are so-called "space junk." The remaining records in USSPACECOM's active space situational awareness database are not as well-tracked or understood, which creates increased uncertainty when operational satellites are screened against them to identify possible orbital safety hazards, or conjunctions. The number of Resident Space Objects is increasing given an increase in launches, and on-orbit breakup events (*i.e.,* when one Resident Space Object collides with another, a satellite explodes, or breaks on its own due to space

[6] *https://www.arlut.utexas.edu*

aging and material fatigue and stresses). If we could track every detected object, we could wrap a sensible Space Traffic Management system around that and even develop empirically-based policies and regulations. Unfortunately, it is hypothesized that we can only track a few percent of the total number of Resident Space Objects that can cause loss, disruption, or degradation to critical space services, capabilities, and activities. In other words, we have an orbital iceberg equivalent of sorts. The ability to track a Resident Space Object depends on two main factors: our ability to detect the object AND our ability to uniquely identify the object. This is to underscore that *an object that is detectable does not imply it is trackable,* and this is a critical distinction to make moving forward.

Tracking an object means that we know where it was, a notion of where it is, and have some idea of what it is and where it will be. Think of how we track air traffic, where the aircraft is in the "custody" of someone who monitors its motion and relationship to other aircraft. The following Figure (1) puts into perspective the problem we face in our inability to track more of the objects we can detect. It was generated from real data collected by the U.S. Space Surveillance Telescope, currently in Exmouth, Australia. It is worth mentioning that we have the long-awaited Space Fence on Kwajalein, and I've been told that the initial results are much like with the Space Surveillance Telescope, as seen in Figure 1. When one has an exquisite sensor and it's unique, you'll get very accurate observations during a very small part of the total orbit and you'll be observing things that other sensors will not or cannot. Think of a hula-hoop. An exquisite sensor is having one hand on this hoop. Think about the variety of ways in which the hula-hoop can rotate if you only grab it with one hand. This is like the ambiguity you will have with a unique and exquisite sensor. It will help but you'll have a large number of objects that you can detect but will be unable to track.

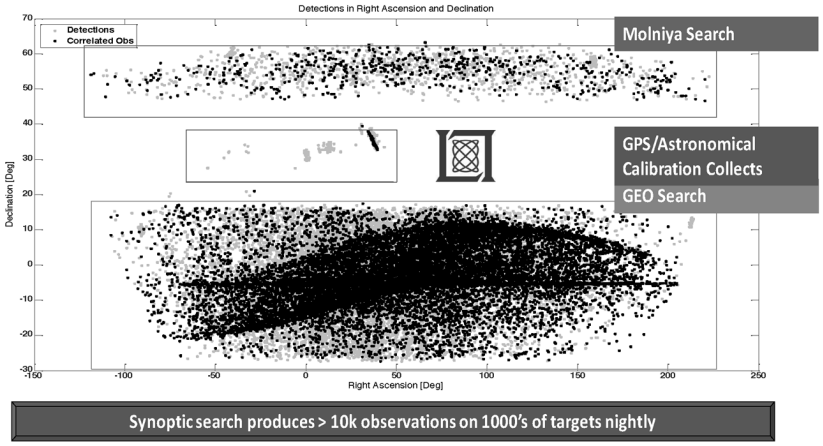

Figure 1. A Single Night's Worth of Resident Space Object (RSO Detections (for various orbital regions) from the U.S. Space Surveillance Telescope (SST) in New Mexico. Detections (dots) that are Black are those believed to be from known (cataloged) RSOs. All else (Cyan) are Detectable but Untrackable RSOs.

So, what prevents us from doing better at tracking objects in space? First, we don't have ubiquitous observations, meaning we don't persistently detect all objects all of the time. In fact, we generally have very sparse observations on any given object in space. Globally, we do not share observational data as a community. This lack of data sharing is perhaps the single biggest problem in us having a more robust space traffic monitoring and management capability. Secondly, every single object in the world's largest space object catalog (that of our DoD) is represented and modeled as a sphere, a cannonball in space! Needless to say, there aren't many human-made cannonball-shaped objects in space. Only those Resident Space Objects whose motion is not significantly different from that of a sphere in between observations, are ones we can "track." Gravity is what I call an equal opportunity accelerator: just tell me where you are and I will tell you your acceleration due to gravity, regardless of your size, shape, material constitution, orientation, etc. However, there are non-gravitational forces experienced by every single Resident Space Object

and all of these depend on the object's physical characteristics. Thus, *the lack of a rigorous Resident Space Object characterization and classification scheme is a strong contributor to our inability to track more objects in space.* When we wish to understand any population of things, we first "tag" individuals in that population and then "track" these individuals through time, space, frequencies, and evaluate their interaction with other individuals and their environment. We formulate hypotheses, test them, and draw conclusions based upon evidence. We do not do this, rigorously and scientifically, for Resident Space Objects, in great part because we cannot physically go to them and tag them. If we wish to someday have Norms of Behavior for Near Earth Space that led to safety, security, and sustainability, we will need to know how many classes or species of Resident Space Objects there are, and how each class or specie moves, behaves, is influenced by the local space environment, etc. Trucks carrying hazardous fuel are regulated differently than Vespa scooters, Oil Tankers on our seas are regulated differently than kayaks and canoes. So, why would we treat all Resident Space Objects as the same thing . . . cannonballs? The following figure (2) is a cartoon to show the difference between the limitations imposed by assuming space objects to be cannonball-like versus what they actually are like.

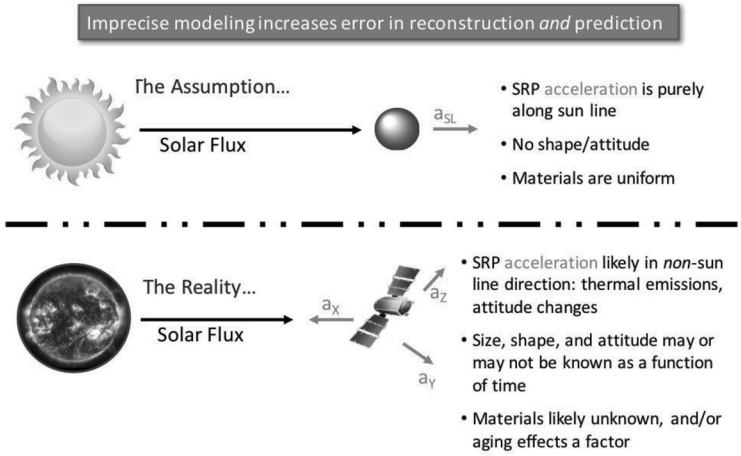

Figure 2. Difference between the motion experienced by a spherical (cannonball-like) space object and a satellite with realistic size, shape, orientation, and material properties. For the sphere, the acceleration due to the sun's effects are unidirectional. In reality, our tracking data informs us that objects experience accelerations due to the Sun's effects in 3-dimensional space (multi-directional).

Lastly, *regarding our inability to track more objects in space, are the mathematics and physics we use to process the observed data and infer physical quantities regarding these objects. It really matters . . . call these our algorithms.* Our representation of uncertainty is demonstrably and inarguably oftentimes flawed, unrealistic, and inconsistent amongst our software and tools. The following figure (3) shows a picture our current problem with having multiple detections at multiple times and having to find clever methods of uniquely identifying objects in order to make them go from detectable to trackable. Most Resident Space Objects are defunct and therefore do not self-report their identities.

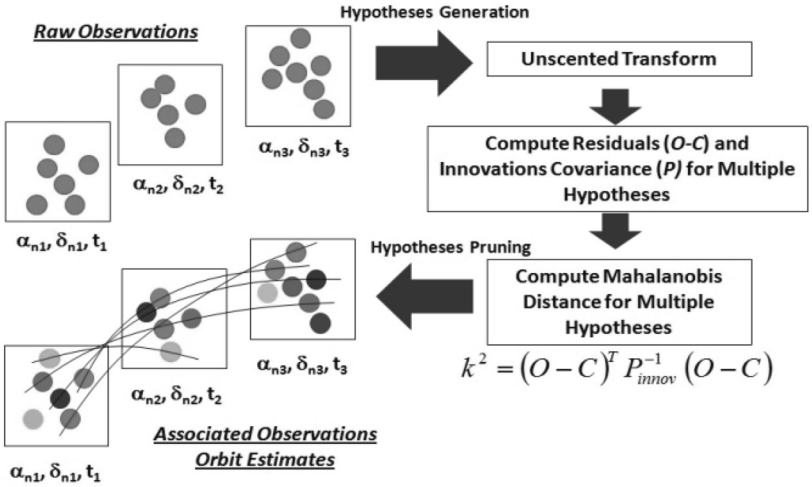

Figure 3. How to Uniquely Identify Space Objects from a Set of Unidentified Detected Objects in Order to Make Detectable Objects, Trackable. The method shown here is one of Multiple Hypothesis Testing as a mechanism to decide which detections should be paired to which objects.

If the Resident Space Object population was held constant, I'd say we'd might have more time on our hands to figure this all out. However, our global space environment is finite, getting increased traffic, and all in the absence of global governance related to safety and sustainability.

We don't even agree on what is on orbit or where it is. I know this because I have developed the world's first crowdsourced space traffic monitoring system, called ASTRIAGraph[7] at The University of Texas at Austin, initially funded by the FAA. Here, we combine multiple independent sources of information and can visualize these all in a common frame of reference.

Figure (4) shows an example of what this combined database of Resident Space Objects looks like.

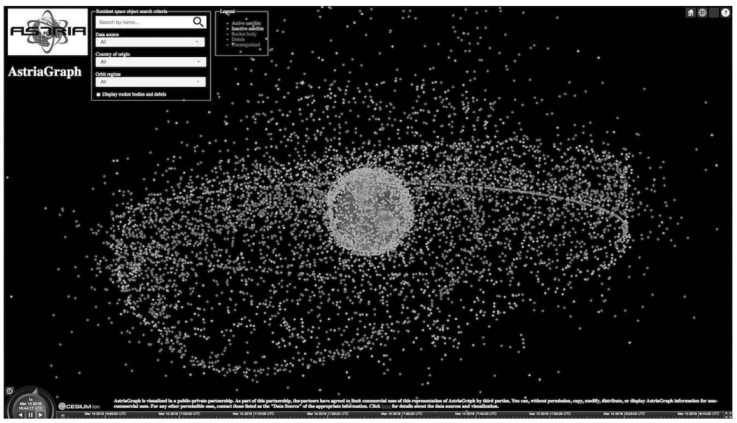

Figure 4. ASTRIAGraph: World's First Crowdsourced Space Traffic Monitoring System.

Our eventual goal is to make this like a "Waze" for space. To wit, we seek to create a so-called participatory sensing capability that openly allows and encourages

[7] *http://bit.ly/astriagraph*

those with sources of information about anything in space, to make contributions and benefit from the information that can only be inferred from the aggregated big-data science and analytics.

To my earlier point, if one only had the USSPACECOM public catalog, Figure (5) shows you what your space traffic map might look like.

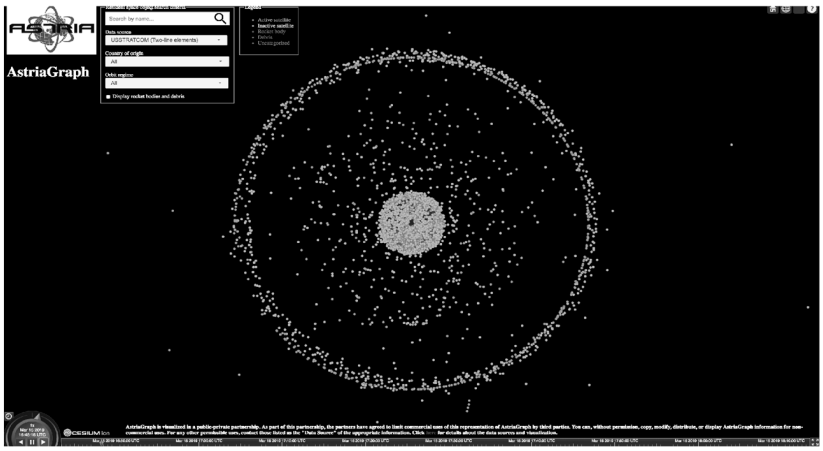

Figure 5. ASTRIAGraph: USSPACECOM Information Only.

Alternatively, if one only had the Russian JSC Vimpel catalog, Figure (6) shows you what your space traffic map might look like.

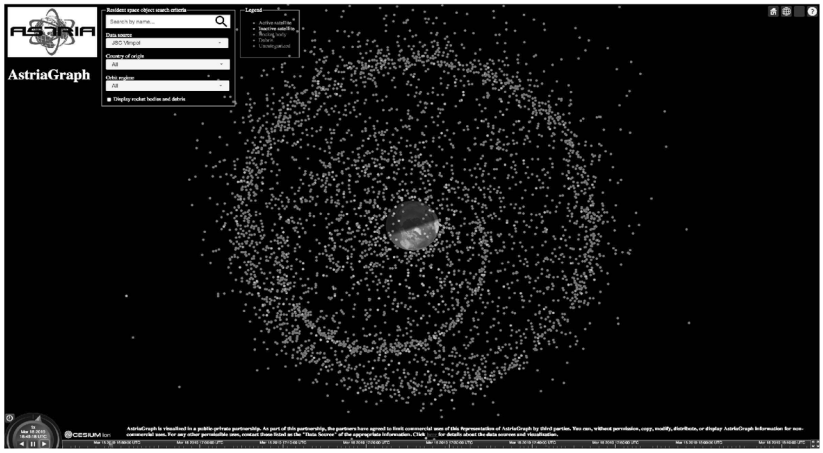

Figure 6. ASTRIAGraph: JSC Vimpel Information Only.

Which source does one believe as accurate? These sets of information reflect a very different space traffic picture. This is a major source of ambiguity. Moreover, the problem gets a bit worse. Figure (7) shows you an example of multiple opinions on a single common Resident Space Object (FLOCK 1C 10 in this case).

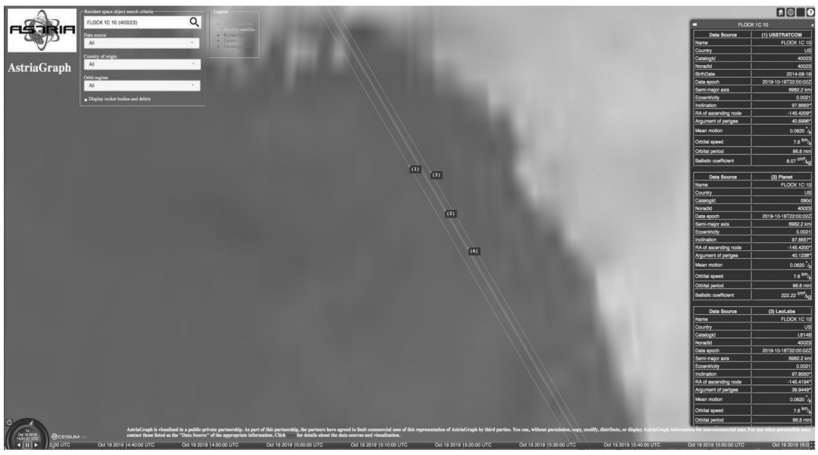

Figure 6. ASTRIAGraph: Multiple Opinions for One Resident Space Object.

The difference in positions between these is on the order of a few hundred meters. However, when it comes to predicting a collision, this variance alone could be the difference between a high or really low collision probability and hence could lead to flawed decisions that could have dire consequences.

As the cost of access to space is decreasing, the number of space actors is increasing. It's like what the Transcontinental Railroad did for helping businesses explode, connecting the East Coast and Western Frontier. In the past 3 years, we saw a record-braking 104 satellites being deployed by India's PSLV space capabilities. Unfortunately, while they did assess potential collisions amongst these 104 satellites, no one performed analyses of potential collisions between those 104 newly deployed satellites and the remainder of the current Resident Space Object population. OneWeb just recently launched their first batch of a few dozen satellites with the aim of deploying over 1000 satellites that will aim to provide global internet. SpaceX is well on its way toward the same goal, having several hundred satellites already on orbit and will surely aim to launch a planned ~4000+ satellites.

As was experienced in the Western Frontier of old, the environmental impact of runaway mining and prospecting was harsh and detrimental in many instances. Examples are mercury poisoning, silt in our water sources, etc. Our space environment is becoming much more commercially driven and populated. Many "New Space" companies or start-ups are getting significant investment from Angel Investors and Venture Capitalists who are focused on getting a Return On Investment (ROI) within a few years, believing Space Traffic and Orbital Safety to be someone else's problem. I have personally found an absence of space operations expertise amongst the workforce driving some of these "New Space" ventures, causing me further concern regarding orbital safety and long-term sustainability of space activities. There is a mentality of "take risks and fail often." While this worked well for software companies in Silicon Valley, we can't afford to have this mentality in space.

We should look to so-called tenets of Traditional Ecological Knowledge (TEK) as a model for achieving space sustainability. Some of our indigenous peoples have learned how to become sustainable over many millennia. One tenet underscores the need to quantify the carrying capacity of the environment before making decisions on how to interact with it. My personal experiences have shown me that "Mother Nature" tends to seek states of equilibrium. Do we know what the carrying capacity is for different orbits? If we launch 60+ satellites every several weeks, to we know what the equilibrium state of the environment will be? We are operating in the space domain well beyond our ability to make sound and sustainable decisions, and this will be to our eventual detriment.

I propose that Congress move to create a Civil Space Traffic Management (CSTM) system led by the Department of Commerce (as directed by national space policy) that will:

- Accelerate the pace and reduce the costs of Civil Space Traffic Management development by modernizing approaches to Space Situational Awareness and Space Traffic Management, with focus on long-term sustainability of space ac-

tivities, through the creation of new federated data standards, measurement standards, models and ontologies, open source software, and big-data management and analysis techniques that aid in the scientific evaluation of the efficacy and safety of space operations, and attendant policies.

- Act as an entity that could create consortia of industry, academia, and government for collaboration and sharing of databases, computational techniques, and standards.
- Operate a Civil Space Traffic Management system that provides the accuracies and products necessary to safely enable innovative and non-traditional commercial uses of space.

The Civil Space Traffic Management Mission should be to:

- Assure the safety of operations in space.
- Maximize, encourage, and incentivize the use of commercial capabilities and data sources.
- Provide transparency, advocacy of informed guidelines, and safety services as a public good to preserve the space environment.

The Civil Space Traffic Management Primary Functions would be to:

- *Observe and Monitor:* Space Domain and Traffic Observations, Space Situational Awareness (SSA)
- *Track and Catalog:* Identify, Characterize, and Catalog Objects; Relational Statistics, Catalog Updates, Traffic Attribution, Achieve Track "Custody"
- *Analyze and Inform:* Information Dissemination, Safety Products, Conjunction Data Messages

The Tenets of a Civil Space Traffic Management system would be to provide and incentivize:

- *Open observational data*—All collected or acquired data will be made open and available for 3rd party analysis to improve learning and enable high Quality of Service domain analysis.
- *Open catalog of space objects and events*—All derived conclusions from Civil Space Traffic Management data will be made open and available for 3rd party verification and peer-review of results and conclusions.
- *Open Safety Advisory Services*—As these services are intended to be a global public good, they will be made available to the world.
- *Open and objective verification of data and analyses*—As the Civil Space Traffic Management capabilities and processes improve, impartial feedback will be made available to all service providers in the spirit of achieving increasingly effective Quality of Service.
- *Open Market*—It is not the role of the Department of Commerce to define the economics of the data and/or analysis marketplace. The intent of the Civil Space Traffic Management is to empower industry to stay involved in the provision of service to all space domain actors.
- *Open Workforce Development*—It is to the benefit of all for the specialized skills required of effective space traffic managers to proliferate globally. To this end this Civil Space Traffic Management will support mechanisms which result in the education of additional skilled space traffic managers and analysts.

The Benefits of a Civil Space Traffic Management system are that it would:

- Provide standard and benchmark data sets that enable quantifiably consistent comparative analyses between competing tools, techniques, and algorithms.
- Provide the government with a transparent mechanism to guide and exploit Civil Space Traffic Management activities and capabilities AND a sustained/focused investment in STEM education.
- Provide industry with a free foundational Civil Space Traffic Management service and a marketplace of focused, cost-shared and openly available sciences and technologies that it can "pick up" and operationalize/commercialize for its own profit.
- Provide academia with a sustained scientific and technological Civil Space Traffic Management research and educational investment, to ensure that the U.S. is stocked with capable and skilled workforce to handle the scientific and technological problems of tomorrow.

How does industry profit from such an activity, financially? It can easily wrap profit-making services around the foundational "for public good" layer of basic space situational awareness and space traffic management services and products. It lowers the bar for entry for new space initiatives as they don't need to shoulder the burden of self-providing of these basic space situational awareness and space traffic management services. It's like the benefit of the U.S. developed, owned, and operated Global Positioning System (GPS)! Think of not only the paradigm-changing science but explosion of commerce that has resulted from this U.S. Government investment and service. Many companies have developed profit-making applications which exploit the layer of foundational service provided by GPS.

I also propose that the U.S Government create the NASA Space Situational Awareness Institute using Cooperative Agreements (like the NASA Astrobiology Institute) as a mechanism under which an academic consortium could be assembled, invested in, and properly leveraged to deliver on goal #1 of Space Policy Directive #3. The funding would need to be appropriated and delivered to NASA with a strategic roadmap on how the S&T is developed and transitioned to both government and industry. Several University Affiliated Research Centers (UARCs) should also be invoked, invested in, and leveraged, to be foundational partners in this NASA Space Situational Awareness Institute. The UARCs could provide foundational capabilities and sciences to NASA and those Space Situational Awareness Institute academic members could then focus uniquely on SSA needs and requirements, working closely with the government and commercial communities.

The motto of my research program at UT Austin is:

> Ex Coelestis, Scientia . . . Nihil Arcanum Est! This loosely translates to, "from the heavens, knowledge . . . nothing hides!"

As Ever,

MORIBA K. JAH, PH.D.

The CHAIRMAN. Wow. Well, thank you very much.

Who—among the three of our first witnesses, who wants to, sort of, summarize the division of authority and responsibilities?

Mr. O'Connell, can you help us differentiate what you do and what Mr. Murtagh does and what Dr. Zurbuchen does?

Mr. O'CONNELL. So, I would summarize it this way, Senator. What Mr. Murtagh and I do are actually highly complementary. We're both within NOAA right now.

The CHAIRMAN. Right.

Mr. O'CONNELL. We actually strive to work much closer together. What he's doing in the space weather arena is very much complementary to what we're trying to do in the SSA arena, on the one hand.

I think a commonality—I wouldn't speak to the authorities, per se, but I'd say there's a strong commonality across all three mission areas, in terms of the need to do better modeling of objects in space, better analytics and prediction of how things move, where they move, et cetera. And I think all of us would agree that that kind of work needs to be done across all three of these areas.

The CHAIRMAN. But, there's a reason to have two separate offices in NOAA.

Mr. O'CONNELL. So, my office is in the Office of Space—is the Office of Space Commerce.

The CHAIRMAN. Right.

Mr. O'CONNELL. Bill Murtagh is in the Space Weather Prediction Center. We're just in different pieces of NOAA right now.

The CHAIRMAN. And, Dr. Zurbuchen, do you want to add anything to that?

Dr. ZURBUCHEN. I mean, generally speaking, I think, in all of these domains—and I agree with the professor over there that, in space situational awareness piece, perhaps at lesser levels at this

moment in time as we're reacting to a—the Space Policy Directive—but, in all these domains, NASA provides research and support from that, and seeks to transition that research to operational capabilities in other agencies. The one exception, I would say that is there is that, in a case of, you know, planetary defense, we do have an operational role, as well; namely, the monitoring of the objects out there. There's not another agency to transition that to. The response to it, of course, is a multi-agency response.

The CHAIRMAN. OK. Now, I don't know if all four of you can deal with this in the 3 minutes that I have left, but we've got the Tunguska event in 1908, hundreds of times stronger than the bomb at Hiroshima. You've got this air burst over Russia in 2013 caused by a 20-meter-sized object exploding. And then, Mr. O'Connell, you mentioned in your testimony this near miss that could have resulted in thousands of debris objects.

Ideally, how serious would these have been to folks living on the Earth? And if we had the resources, how would you stop these? What would you have done, back in 1908 or 2013, if you had the resources?

Dr. ZURBUCHEN. On the impactor, the 1908 one, with the tools that we currently have, our hope would be that we would see it coming. So, we actually saw it on an early orbit, and we should see them coming. Now, the reason I'm saying it, our hope will be——

The CHAIRMAN. See it coming and you run?

Dr. ZURBUCHEN. No. Well—so, the first—see it coming. In many cases, the right answer to, "How do we react to that?" is, in fact, running, because it—depending on which angle we're at, you know, that—the idea is to get out of the way of harm. Just like we evacuate our population with a hurricane, we would, in this case, evacuate people from that. In some future, we currently don't have, but we're working on, what we'd actually like to see is the option of deflecting it. That's why we do the collision experiment with DART, to learn that technology, how to deflect an object out of its path, away—either in the ocean or away from Earth entirely. That takes energy, but that's a future that we want to build. At this moment in time, the answer, mostly, is to know exactly where it's coming, and protect life and property, wherever possible.

Mr. MURTAGH. Senator——

The CHAIRMAN. I'd like to comment briefly. The——

Mr. MURTAGH.—one thing to add to the list, you didn't mention—so, there was an event, a space weather event in 2012 that was a near miss. We often categorize it as a century-class event. It was—the eruption occurred on the other side of the Sun. It wasn't facing the Earth. But, we believe that that particular event was similar to a big event that occurred in 1859, and it would have a significant impact on Earth, and especially the electric power grid. So, everything we're talking about with the observations, the research, and getting the research into operations, is all about better predicting those kind of big events.

The CHAIRMAN. If you know it's coming, what do you do?

Mr. MURTAGH. We alert the power grid, in particular, as much notice as possible, and they take the action necessary to mitigate from the induced current that's going to occur once that eruption

hits us here at Earth. It's all about timely and accurate notification, and they must do the right thing.

The CHAIRMAN. Why don't the other two of you take half a minute each.

Mr. O'CONNELL. Thanks, Senator.

By coincidence, the event that I discussed took place in low-Earth orbit over Pittsburgh, Pennsylvania. But, in fact, people on Earth were not really expected to be impacted, had there been a collision. And, in fact, many of the objects might have burned up coming through the atmosphere. Almost all of them would have burned up.

The threat we're really concerned about is the——

The CHAIRMAN. Almost all of them.

Mr. O'CONNELL.—the threat to investment, to all of the—threat to investment of all the billions of dollars that we have invested in space, and those of our allies, et cetera, for the services that we expect on Earth. And that's what we're really worried about. Less, the debris coming down. There are rare occurrences of debris falling around the world. Very, very small numbers of examples. But, the impact we're really worried about is the effect on space commerce and our national security satellites and the Space Station, and things like that.

The CHAIRMAN. Dr. Jah.

Dr. JAH. I don't have too much to add to what has previously been said, except for the fact that—what I tell my students is, in order to know something, you have to measure it. And if you want to understand it, you have to predict it. And we can't predict very well. And so, we—that really hinders our decisionmaking process.

The CHAIRMAN. Senator Cantwell.

Senator CANTWELL. Thank you, Mr. Chairman.

Mr. Murtagh, following up, writ large, on space weather forecasting, why not launch a satellite sooner than 2024?

Mr. MURTAGH. So, we—the satellites we have in place right now, the DSCOVR spacecraft, we had an issue with it, but, fortunately, it'll be back in operations by the beginning of next month. And that's our solar wind satellite. And we've also still have the NASA ACE spacecraft. So, we've got two spacecraft up there now providing us this key information. So, the planned launch in 2024, we believe, and Dr. Zurbuchen can correct me if I'm wrong here, but I think ACE should be good, fuel-wise. True——

Dr. ZURBUCHEN. Absolutely.

Mr. MURTAGH. —2025.

Dr. ZURBUCHEN. Absolutely.

Mr. MURTAGH. So, we have two spacecraft up there right now that will provide those critical solar wind measurements. So, the timing should be just right to get that into orbit, the new space weather follow-on, by——

Senator CANTWELL. So, there's no additional information or support that you would like to see?

Mr. MURTAGH. So, the—we have—currently, our biggest concern is the SOHO spacecraft. The SOHO was launched December 1995. You mentioned earlier that—how old some of these spacecraft are.

Senator CANTWELL. Right.

Mr. MURTAGH. There's a coronagraph onboard that spacecraft. It is a single-point failure, to some degree. But, NASA—again, thank you—have a STEREO mission, and the STEREO spacecraft that's going around the Sun in the next 4 or 5 years will be in a location that it will—and it has a coronagraph—will help us. So, we won't be blind. We'll be hurting a little bit if we lose that spacecraft, but we won't be blind. But, we have to get the coronagraph and the solar wind measurements in space by 2024.

Senator CANTWELL. Yes. Well, mark me down as somebody who wants to be more aggressive in this space. So, I think this is critical data and information and we should be as aggressive as we can possibly be.

I feel the same way about satellites for our information as it relates to weather. We're seeing dramatic shifts in weather events. And having data, since you can measure every algorithm in a storm now, means you have greater predictability. I feel the same way about space.

Mr. MURTAGH. Yes. I——

Senator CANTWELL. We're not staying ahead. I'm—you know, we're not—I don't know that we're hearing about European space forecasts, but we're definitely hearing about European weather forecasts that have become the standard above ours. So, look, if we want to be the leaders here in space, then we need to have the information.

Dr. Jah, we haven't gotten enough to you today on the other aspect. You know, it's so interesting. There are so many bills in Congress, saying, "Let's map the oceans. Let's get the information out there." And yet, here we are, with all this debris in space. And it could be very easy to map it and do something to better measure that. And yet, we're not doing that. You mentioned that this, you know, space situational awareness, the—you know, the data and algorithms that could be developed and that it could be open source, which is also interesting, so then we can pair this big data and analytics with it. I mean, that's, like, "Well, let's go." When you say things like that, I'm, like, "Let's go. What's holding us back from doing that?" Because that's just really basic, you know, almost, like, software and information application to a problem that we know we have that's probably a pretty low-cost development. It's, like, that doesn't cost us a lot of money to get that done, particularly if you're adding in open source.

Dr. JAH. Yes. So, thank you very much for that.

One of the things that I'll say is, everybody thinks it's a good idea, but who's going to go first? And I think that's been part of this issue, is that, by and large, there has been no dedicated funding to actually make this happen. And so, it's all best-efforts basis. What—you know, it's the "stone soup" sort of model. The "stone soup" model is slow. It's a bit lethargic. I feel that if there were some dedicated resources to making this happen, you're going to find no shortage of people, not just in the United States, but even abroad, who would be willing to contribute to this, and really build it up.

Senator CANTWELL. Not to put you on the spot, but maybe your Senator will show up here, at some point in time, and say, "Yes, let's give it to the"—you're at University of Austin? Where are you?

Texas. University of Texas. So, with a small amount of money, you could start that project.

Dr. JAH. Yes, absolutely. I would say that we have started already, actually. We've started, initially funded by the FAA, to build this sort of crowd-source space-traffic monitoring system. We're partnering with Department of Commerce, with CRADAs, with NASA, with Space Act Agreements to get their information. Also, we're the first academic partner to U.S. Space Command for SSA data-sharing. So, we're piecing these things together. But, it's not—it could be accelerated if there was dedicated funding.

Senator CANTWELL. Yes.

Yes, Mr. O'Connell.

Mr. O'CONNELL. Thank you, Senator.

This is exactly the idea of this open architecture data repository that we're talking about. Again, we're working with Dr. Jah and a number of other people to do this. What we really want to do—by definition, the data that Defense provides is limited because of classification and sensitivity and things. So, the data that they send out on Space Safety, by definition, control. We're going to take that as the basis for what we do in the architecture, add commercial data, and allow for a truly open exchange between commercial vendors, allies, and others, and apply this heavy analytics that you're—you've spoken about previously. This is a problem that is ripe for a big-data analytics problem. When Defense got into this originally, those capabilities did not exist. Increasingly, they are coming forward in the market at rapid speed, both in the space business, but also from a much larger——

Senator CANTWELL. Right. From the larger——

Mr. O'CONNELL.—commercial base.

Senator CANTWELL. Right. That's why I'm saying this isn't really that hard. It's just, like, "Let's give some money to a university, or whoever, to get the project going."

Mr. O'CONNELL. And this is exactly our plan at Commerce, as well.

Senator CANTWELL. You have a budget request? Is that what——

Mr. O'CONNELL. Yes, we——

Senator CANTWELL.—you're saying?

Mr. O'CONNELL. Yes, ma'am, we absolutely do.

Senator CANTWELL. What is it?

Mr. O'CONNELL. The President's budget request is $15 million for the Office of Space Commerce for 2021.

Senator CANTWELL. OK. But, that includes this——

Mr. O'CONNELL. Oh, absolutely, the——

Senator CANTWELL.—development of a software open-architecture system.

Mr. O'CONNELL. Yes, ma'am, absolutely.

Senator CANTWELL. OK.

Mr. O'CONNELL. The bulk of our resource request in 2021 is for the Space Situational Awareness Mission that I've described here today.

Senator CANTWELL. Is that enough, Dr. Jah, to do the kind of mapping that we're talking about?

Dr. JAH. Yes. So—you know, I've been looking at this for quite some time, and I would say that if we had something on the order

of $15 million a year to bring just—not just University of Texas, but other research institutions to work as a consortium toward this, I think we'd start seeing very quick results, and you'd start seeing things turn around in a positive direction rather quickly.

Senator CANTWELL. Great.

Thank you very much.

Senator CANTWELL [presiding]. I think—Senator Gardner.

STATEMENT OF HON. CORY GARDNER,
U.S. SENATOR FROM COLORADO

Senator GARDNER. Thank you, Ranking Member Cantwell.

And, to the panelists today, thank you very much for being here today to help educate us on needs, but also your service to our country. Thank you very much.

Dr. Murtagh, welcome from Boulder, Colorado. We're proud of the work that you do, grateful for it. So, thank you very much.

In preparation for today's hearing, I checked out SpaceWeather.com and was looking—learned a couple of things there. Number one, the satellite, SOHO, that we've talked about is flaking insulation and makes the coronagraphs a little—look a little streaky. I've learned about that. And I also learned that cosmic rays are surging, which sounds a little too hip for Congress right now, so I don't know if you could talk, in SpaceWeather, in terms of what that means, and then get into a little bit about the Space Weather bill that we have.

Mr. MURTAGH. Well, the cosmic-rays-are-surging piece, first of all, it's—the sun goes through an 11-year cycle—solar maximum, solar minimum. And when it's solar maximum, the—we see a lot of sunspots. And, essentially, the Sun, during its maximum, it prohibits the influx of cosmic radiation from deep space, from outside the sphere of influence from the Sun. But, during solar minimum, when things quieten down, it allows for more enhanced cosmic radiation. So, it comes into play for NASA, for the astronauts. It even comes into play for aviation interests at high latitudes. So, really, it's just an inverse cycle. Right now, in solar minimum, the Sun is quiet, we're not seeing big eruptions, but we are seeing the highest levels of background cosmic radiation. So, that's what that's about. It's easily predictable. It's just up and down with the—an inverse with the solar cycle.

Senator GARDNER. Very good. Thank you.

And, you know, Senator Peters and I have been working on, as you know the Space Weather Research and Forecasting Act since 2016. The bill is aimed—as we've talked about here today, the bill is aimed at ensuring that we have a clear, unified Federal approach on space weather. We're continuing to work with our colleagues in the House on this measure. And in your witness—in your written testimony today, you described NOAA's work with its Federal partners. And so, if you could just, to the Committee, why, from your perspective, it's important to have a clear, unified, long-term strategy to space weather at the Federal level.

Mr. MURTAGH. The space weather impacts so many different technologies, so many different critical infrastructures. It was—we recognized, a decade ago, we needed to—all the Federal departments and agencies needed to work together to—we needed some

kind of cohesive approach to address this threat. So, at the White House, in the last administration, continuing through this administration, the Space Weather Operations and Research and Mitigation Committee, or Task Force, was formed with 20 different Federal departments and agencies to define the actions necessary to mitigate this threat of space weather. What we're very excited about with the action in Congress is, this will codify many of the actions that we have defined in that action plan. An action plan—as you know, an action plan or strategy, in itself, sure, it's good, but it doesn't have the force of law, if you will. We either need executive order or we need something from Congress to really move this thing along, especially when you've got so many different agencies, so many different departments involved in it. That's what the legislation is doing. I commend you for your leadership on that. It identifies lots of the things that we've identified in the strategy and action plan that must happen if we are going to make this Nation more resilient to space weather.

Senator GARDNER. Very good. And you mentioned NSF, as well. This Committee has done a lot of work on the National Science Foundation, and increased funding along the way. Could you talk about which NSF directorates the administration is working with and consulting to bolster its space weather efforts?

Mr. MURTAGH. Sure. So, we work with different groups in the NSF. For different—for instance, we get the GONG information, which is a ground network, where we work with the National Solar Observatory. That information is critical for our prediction. We work with the NSF headquarters, the GEO group on the information that they provide. They do a lot of funding for some of the critical research needs, so we work closely with them. They're part of that White House group I was mentioning. So, they're in lockstep with us every step of the way and with, also, NASA. We actually have an MOU, a memorandum of agreement, between the three different agencies, identifying roles and responsibilities and how we can work best together.

Senator GARDNER. Very good. Thank you.

And I'm going to cut it short, because I've got to go vote, as has everybody on the Committee. So, I'm going to put the Committee in a brief recess for a few minutes. Senator Wicker—Chairman Wicker will be right back to resume the hearing immediately. So, we'll have a few minutes of a break, and then we will get back to business.

So, with that, I will put the Committee into recess.

The Chairman has just taken the Committee out of recess, so——

[Laughter.]

The CHAIRMAN [presiding]. Well, hello. So, what did I miss?

[Laughter.]

The CHAIRMAN. I don't—you know, I don't know why the leadership does this to us. It's—we're in the middle of four votes. And normally, we wouldn't have these until, say, noon or maybe early afternoon. But, for some reason, it was deemed proper to have them at 10:30 today. And so, here we are.

I'll tell you that Mr. Thune, our Whip, denies any responsibility for causing this.

[Laughter.]

The CHAIRMAN. So, what have we missed? Let's summarize. Who would like to—let's pretend I'm the last questioner, which I will not be. What would you like to follow up on that other Senators have asked about?

Mr. O'Connell.

Mr. O'CONNELL. Thank you, Senator.

I wanted to go back to your question a few minutes ago on authorities, and I'd like to frame it in a slightly different way.

The CHAIRMAN. OK.

Mr. O'CONNELL. Because people sometimes ask me, Why would the Commerce Department be involved in this mission area? And I'd like to say that we are already tapping into a wide range of skills and expertise within the Department. On the one hand, with NOAA, my colleague Bill Murtagh here, the Space Weather Prediction Center—and again, there's a nice technical affinity between space weather and what we have to do on space situational awareness. But, obviously, as we sit here, NOAA's protecting satellites from space debris 24/7 at a facility not too far from here. And so, we're drawing upon that expertise. But, that's only one part of what we're doing in pursuit of our SSA mission. We're drawing on the National Institutes for Standards and technology and their role in both evaluating and organizing standards development. Dr. Jah talked about the need for rules of the road, which is different from the technology architecture that I mentioned as well. We have NTIA, other parts of the Department. And so, what we're trying to do from the office in pursuit of this specific mission is leverage the entire Department to help out as we try to improve the Nation's space situational awareness capabilities. And, as well, we're working very closely with NASA—in particular, up to at Goddard and out at Ames, the two centers there, because they have activities underway which are centrally related to what we're doing on SSA.

The CHAIRMAN. OK. Anybody want to follow up on that?

OK, there—we had testimony, before I left the room about a near miss, where, basically it was described as a "game of chicken." And—was that your testimony, Dr. Jah? And, basically, those were two objects that are operational and could have been moved. And I think one eventually was. How—what percent of the Defense and space-related potential accidents would be described in that category, as opposed to the ones where—that you can't move them at all, it's just a matter of hoping they don't hit and dealing with that if it happens?

Dr. JAH. Yes. So, I can't give you actual percentages, but I can tell you this. We've created a conjunction streaming service—it's a website that anybody in the public can access—where you can actually see, over a continuous 20-minute window, how many things come within, say, 10 kilometers of each other. And it happens a lot.

The CHAIRMAN. Who has access to that?

Dr. JAH. Yes, you do right now on your cellphone.

The CHAIRMAN. OK.

Dr. JAH. Yes. I—I'll give you the website here in——

The CHAIRMAN. Well, come up here and help me. No, no, I'm just kidding.

[Laughter.]

Dr. JAH. OK. Yes, but these things happen very frequently all the time between debris-on-debris, one thing works and the other thing's dead, two things are working. I would say one of the major issues that we have is ignorance. We're very ignorant of what's happening in space. The domain, as a whole, is poorly monitored——

The CHAIRMAN. I mean, even people at the scientific knowledge level of you four gentlemen, there's a lot you don't know——

Dr. JAH. Oh, yes.

The CHAIRMAN. that you're ignorant about.

Dr. JAH. Oh, yes. Oh, yes. The thing is—look, let me put it this way. The world's largest, most awesome catalog of objects orbiting the Earth, maintained by the Department of Defense, are all modeled as spheres, they're all assumed to be cannonballs. You know how many of those things look like cannonballs? Not much. So, the thing is, we don't have a taxonomy, a classification scheme, for these human-made objects in space. You know, we treat Vespa scooters and semis differently, and we regulate them differently. We treat kayaks and oil tankers differently on the oceans. But, in space, everything's, like, the same thing. And it's not. So, there's a lot that we don't know, actually.

The CHAIRMAN. In a situation that you've described, the parties were SpaceX, on the one hand, and what was the other——

Dr. JAH. The European Space Agency.

The CHAIRMAN. OK. And in the end, the European Space Agency——

Dr. JAH. Made the maneuver.

The CHAIRMAN.—out of an abundance of caution, made the maneuver.

Dr. JAH. Yes.

The CHAIRMAN. I take it there's not an international protocol about how that should be resolved.

Dr. JAH. Correct.

The CHAIRMAN. OK. And is that something we need on a global basis, some——

Dr. JAH. Absolutely.

The CHAIRMAN.—International——

Dr. JAH. Yes, that is critical, that we get something like that in place. And I would say, even more so, the body of evidence that people have to make those decisions are all different. And so, based on my information, looks like it's not a hazard. Oh, but based on my information, it looks like—there's no common pot of shareable knowledge to where everybody can infer stuff from that same body of evidence so that they can reach some sort of standard or some consensus.

The CHAIRMAN. OK. Are we anywhere down the road in approaching some sort of international protocol?

Yes, Mr. O'Connell.

Mr. O'CONNELL. Senator, if I may.

As we speak, there's an interagency group in Vienna, at the United Nations, the Science and Technical Working Group in Vienna, which is actually working to promote space safety standards. OK? It's been a long history there. And, in fact, the Russians actually stalled the most basic of principles—they're known as the 21

Long-Term Sustainability Guidelines—for the better part of a decade. Our diplomats, NASA, even Commerce are in Vienna right now arguing for reasonable approaches to international cooperation on this.

One of the aspects that they have explicitly included in their efforts is the role of the private sector in space, and how it's growing, and the extent to which we have to accommodate a growing commercial space world into those rules and standards. But, that part of the discussion, as well as industry-based standards and best practices, have to be part of this rules-of-the-road discussion that is—needs to happen in parallel, some of the technical developments.

The CHAIRMAN. The OSCE Parliamentary Assembly is meeting in Vienna next week. Do you think I should take time out to run over to that office and chat with them?

Mr. O'CONNELL. Sir, you're certainly more than welcome to. I think the discussions are underway right now and this week, so I don't think they'll still be in play. There is a—the U.N. Space—Office of Outer Space Affairs that you could certainly visit.

The CHAIRMAN. And that is a U.N. office——

Mr. O'CONNELL. That is a U.N. office.

The CHAIRMAN.—that is——

Mr. O'CONNELL. Absolutely.

The CHAIRMAN.—located——

Mr. O'CONNELL. And, of course, the U.S. mission in Vienna is actively involved in this, as well, and they could probably give you a readout of the developments that are taking place this week.

The CHAIRMAN. OK.

Responses by Mr. Murtagh or Dr. Zurbuchen?

Mr. MURTAGH. From the space weather perspective, it's interesting that—just—you know, you're looking at this panel here, Senator, and we are actually going to take one of Dr. Jah's students in, in our center, this summer to work with us. And we just sent one of our people into Kevin's office to work with him, because the space environment—they—the density of where these spacecraft are orbiting in low-Earth orbit can change during space weather. And we get these big eruptions, all of a sudden the spacecraft is traveling at this speed. It's here now, it's supposed to be here in an hour from now, but it's not. Why? Because one of these big eruptions. Obviously, that plays into calculations of—for debris and collision avoidance. So, that element of space weather is key. Dr. Jah talked to me before this meeting just about how we're going to work this together. But, it's a key piece. We've got to be able to predict that better so they have the information, so that we have the information necessary to protect these critical assets in lower-Earth orbit.

The CHAIRMAN. OK. Just one moment. Let me check on—let me try to be situationally aware of my colleagues.

We're—this first 15-minute vote is taking longer than 15 minutes.

So, let's do this. If we leave this hearing with one or two takeaways, and if the listening public needs to know the basic bottom line, who will help us with those goals? You want to start, Dr. Zurbuchen?

Dr. ZURBUCHEN. I would say that the first bullet in a summary like that would be that all of these elements that we've talked about are absolutely important, and they're increasingly important as we advance as a technological society. Some of them have been with us for—well, all of them have been with us for millennia. But, the impact of these issues is increasingly important.

The second element is that the—there are multiple roles to play. All of them need to be done in a coherent and a deliberate fashion. The roles include research. There's much of what we're looking at, in any one of those domains, that we don't currently understand. We need to advance our understanding to that. The second element is, there are government regulatory functions that are in other agencies and operational functions that need to be stood up. But, in all cases, I think it's critical to understand that the regulations, as well as the research, need to involve a broad community of stakeholders outside of the government, such as academia, and, increasingly, I believe, the commercial sector, at the level that has been stated.

So, that's how I would summarize it.

The CHAIRMAN. All right.

Dr. Murtagh—Mr. Murtagh.

Mr. MURTAGH. The—Senator, the observations that we rely on to provide the alerts and warnings are critical. So, my message would be that we have to support and recognize the value of that information to our operations. Should we lose some of those key spacecraft that we talk about, I won't say we're blind, but we're darn close. It will impact our ability to support this Nation's need for space weather services. And I don't want to see that happen. So, observations are critical.

And one other piece I'd like to touch on—and Dr. Zurbuchen just kind of teed it up for me—he talked about the research, recognizing there's so—we have so much we need to do to better understand and predict space weather. But, the next piece on that is getting that research into operations, the—to have a formal process to transition research to operations. Much like the National Weather Service had for the—has for meteorology, we need that in space weather. There's an awful lot of money been pumped into the research, into the science community, some great work being done, but there's this funnel. We need to get that information into our operations center to improve our predictions for the Nation.

The CHAIRMAN. Good.

Let's do this. We'll recognize Senator Scott at this point, and then we do want to give our other two witnesses an opportunity to summarize and follow up on what has been said by the others, later on.

So, at this point, Senator Scott.

STATEMENT OF HON. RICK SCOTT, U.S. SENATOR FROM FLORIDA

Senator SCOTT. First, I want to thank Chairman Wicker for holding this important hearing.

For Chairman Wicker's State and my State, the space industry is a pretty big deal. And we're—it's very—you know, we've got Kennedy Space Center. I just—I've only been here a year. I finished 8

years as Governor, and we put a lot of money into trying to—we—trying to make sure the Kennedy Space Center and our entire Space Coast thrived. Right before I became Governor is when the Obama administration stopped manned flight, and it had a pretty big impact. But, now we can't find enough people to work in our space industry, which is really nice.

So, what do you think that we can do at the Federal level, what can Congress do, to more effectively promote, you know, at—both at the Federal level, at the State level, and at the private level, growth and innovation in our space industry? What do you think there are things we should be doing that we're not doing? Or we should be doing better, or more of?

Mr. O'CONNELL. If I may. Thank you, Senator. Nice to see you again.

Senator SCOTT. Nice seeing you.

Mr. O'CONNELL. There are a wide range of things that are already underway. The first is to encourage the entrepreneurship we see in this country. One of the best things that I see in my job at the Office of Space Commerce is the wide range of entrepreneurs that knock on our door every day. The state of space entrepreneurship in this country is absolutely incredible. It's backed by an ecosystem of finance and insurance that actually helps enable it.

I think what we're trying to do is do a couple of things. We're trying to streamline regulations related to that. And we need your assistance in helping with that, modernizing some of the legal basis for regulations that we have today. And then, to the point of this hearing, we think the space situational awareness mission is critically important.

Let me come at it from a slightly different perspective. The growth that we're seeing in space commerce is really based on the fact that we're applying business efficiencies to a traditional government business model, if you will. And this is why we see concepts of reusability and lean manufacturing, and things like that. And the result of that has been that that has lowered the cost of access to and operations in space.

The—one of the risks of space debris is that it will raise those costs and complexities once again. And that's why, in the plan that we have in Space Policy Directive 3, the initial emphasis is on improving space situational awareness so people understand where they are, where there's risk, and it's done in a highly timely and accurate fashion for the kinds of space missions that we see coming into space today.

Mr. MURTAGH. I'll just piggyback a little bit on that. And the proposed legislation from Senators Peter and Senator Gardner on space weather kind of covers this. And it is bringing in the private sector more into our community. We're a little bit different, because we're the space weather. We've got a budding kind of space weather services community out there doing some really good work, really interesting work. One company is—centers on the NOAA buoys. We arrange that through the U.S. Air Force so that we're getting sensing the ionosphere out in that remote area of the ocean, which will be very useful to us. Another company is working with the Texas power grid on assessing how vulnerable the grid is in Texas to geomagnetic storms.

So, the private-sector growth, I think, is something we should be supporting the legislators' language in the legislation that helps do that. So, that's something I'm—I feel very positive about that's coming out of Congress.

Dr. ZURBUCHEN. I spent the weekend at Kennedy, and we had one of the most beautiful launches I've ever seen. It's really great to launch in a full-moon night.

I believe one of the things that we're already doing—and I'm excited to be doing with the kind of regulations that are being set up, which is to take advantage of the industry that's out there, in the sense that we actually can do things in a different fashion. For example, as we go to the Moon, we do so with commercial lunar payload services as the fastest element of it, in which we—instead of building our own landers, we actually go out there and say, "Can we buy services from companies that say that they can do so?" And there are companies all over the country that have built and are actually in that segment now. The same is true with Earth observation data. We have companies, for their own motivation, commercial motivation, which is how a company should work, have built satellites that are looking at the Earth in novel fashion, and in a way we wouldn't have done with NASA. We now try to become customers of those data by taking the data and actually finding out what the right value is to make that data available to the scientific community at large; and therefore, both helping the companies, because there's an additional customer, but, at the same time, also enhance the scientific community by making that data available. So, it's elements like that, I think, will be an important part of that answer.

Dr. JAH. I think, you know, for me, I remember the days of, you know, at least studying, not personally, the renaissance and how scientists used to have a lot of knowledge in different parts of physics and mathematics. And these days, we've become so specialized and problems have become so difficult that we have these stovepipes of excellence. And I think we need a better renaissance. We need to have a new renaissance for space that recognizes that space weather, you know, planetary defense, space situational awareness, all these things have interdependencies and play with each other. So, there needs to be a more holistic view in how to approach the problem. And I think we could achieve great things if we did that.

Senator SCOTT. I have another question. Do you—are we out of time?

The CHAIRMAN. You know, in light of the attendance, take as much time as you'd like.

[Laughter.]

Senator SCOTT. So, in many areas, China has become our adversary. And, I think, in space it's an area where China has become an adversary. How, from a national security standpoint, are we able to make sure that our advances, our innovation is not being stolen and used by the Chinese government?

Dr. JAH. I'll put it this way. In my own research program, one of my postdocs is from China. And when you go to a lot of U.S. universities, you see a lot of people that are from China and go back. Last year, I was invited to go there to give some short courses on

methods of orbit determination, and I will say that they have very, very smart people over there.

One of the things that I've always done to try to make sure that I'm at the leading edge is just to make sure that I'm out in front of everybody else. We're not going to be able to occult or become so insular that we can make sure or prevent China from doing this, that, or the other. We just need to be better. And to do that, we actually need to provide resources to, again, get great U.S. citizens through that process of STEM. And I think we're failing when it comes to that.

There are so many students, so many, they e-mail me all the time, "Dr. Jah, can I be part of your research program?" "I don't have the resources to bring you on." And so, I'm turning U.S. citizens away because—not because we don't have room. We just don't have the support.

Senator SCOTT. Yes, sir.

Mr. O'CONNELL. Senator, we know that China has very ambitious space plans. One of the things we're doing in the Office of Space Commerce is, we're hearing routinely from industry about the kinds of behaviors that they are experiencing in the market from Chinese competitors. And so, many people in the U.S. Government are focused on the totality of the China Space Program. We're focused on things like unfair pricing, economic espionage, anti-competitive practices, things like that. And we're going to increasingly call attention to those kinds of behaviors as we see it in the market. Very important problem to pay attention to.

Dr. ZURBUCHEN. Within NASA, of course, we have a series of regulations that limit us from interaction with China at a certain level, and we follow those rules. I would like to say that, for us, relative to out-innovating everybody, whether it's the Chinese, the Europeans, or anybody, is certainly a goal that I see. I think we should always, every time, even in a place where we're in a leadership position, we should be nervous about that leadership position, because leaders who are nervous remain leaders. And so, for me, I'm nervous, and I make everybody nervous around me about that. And I will continue to do so as I'm working in this agency.

I do believe that the second way of really leading in this is to establish the standards of behavior, and internationally enforce them. That is—and some of the—how science is done—largely speaking, if you want to be a scientists of any international stature, you have to follow the rules that, largely, were developed in our society, were developed in our agencies, and so forth. I want to be in the business to, kind of, be first in places so we can actually establish the rules. And I believe some of the discussions that we have on space situational awareness, some of the other discussions, follow that paradigm, as well. I think it's important that we set the rules and we also, frankly, enforce them, whether it's in the civil space or elsewhere.

Senator SCOTT. The Chinese government is clearly sending people over here to steal our—steal—I mean, they're sending them to our universities, they're doing a—they're participating in research projects, basically, to steal things. I mean, they—I mean, they are—they're clearly an adversary. They don't want to play by the rules. They're never going to—I don't care what they agree to,

they're not going to do it. I don't believe, in the new trade deal, they're comply with it. So, I'm glad the Trump administration is trying things like that. I just don't believe the Chinese government's ever going to comply with anything. They never have in—they never have, this Chinese government hasn't. So, I think we all have to be very vigilant to stop the espionage and really understand they are an adversary, they're not a friend.

Thank you, Mr. Chairman.

The CHAIRMAN. Thank you very much.

Dr. Jah, I've got, here, on the smartphone, astriacss03.tacc .utexas.edu——

Dr. JAH.—Ui/min.html. You got it.

The CHAIRMAN. There we go. OK.

Now—so, I press "Go." How does the uninitiated, typical Senate Committee Chairman——

[Laughter.]

The CHAIRMAN.—understand this graph that's got dots going up and out? Is there a part of that website that gives us, as laymen, some idea about actually what we're seeing?

Dr. JAH. Well, as you say exactly what you're saying, I'm secretly e-mailing my grad students to create such a mechanism to better inform you about what you're seeing. But, I can give you a quick soundtrack. OK?

The CHAIRMAN. OK.

Dr. JAH. Basically, what we're doing is, we're taking all the information that we believe we know about stuff in space, and we're predicting, over a continuous 20-minute window, how many of those objects, two at a time, might come within 10 kilometers of each other. And if there are any predicted conjunctions, as we call them, any predicted two objects that are going to come within, say, 10 kilometers of each other, it plots that. And so, what you see is this sliding window. You see these dots. The red dots are: both objects are debris, they can't move, just like the stuff that happened over Pittsburgh, recently. You will see some yellow dots: one of the things could move, the other one, presumably, is defunct. And then the green dots are: both could actually do something about it.

Twenty minutes is not long enough for it to be actionable. Consider it a crawl-walk-run capability. But, it shows you that there are many predicted conjunctions that are happening right now, and continuously. So, even though conjunctions doesn't equal collisions, thank goodness, because then, you know—yes, we'd have a bigger problem on our hands. But, it tells you there are many things crisscrossing each other constantly.

Now, one of the other things that you're going to see on the top, you're going to see some histograms. The top-right histogram is relative speed. And you're going to see a spike somewhere around 15 kilometers per second. Yikes.

The CHAIRMAN. It's right there, yes.

Dr. JAH. Yes. So, 1 kilometer per second is the speed of a bullet, 15 kilometers per second, you know, is quite fast. And so, the damage that a very small thing could do at that speed is considerable. And so, this is part of what we need to be concerned about, is that, you know, we're sitting here in this room, talking about these

things, but things in space are happening, regardless of what we discuss. So.

The CHAIRMAN. Good.

Well, I'm going to run, vote, and leave the gavel with Senator Blackburn. I will be back.

Thank you so much.

STATEMENT OF HON. MARSHA BLACKBURN, U.S. SENATOR FROM TENNESSEE

Senator BLACKBURN [presiding]. Thank you, Mr. Chairman.

And thank you all for being here. I have to tell you, it's a fascinating hearing.

And, Dr. Jah, it must be fascinating to be in your class. I am sure that your University of Texas students enjoy taking your class and learning from you.

Mr. O'Connell, I want to come to you first. Space Policy Directive 3—and, of course, we apologize for being in and out—in transferring from DOD to Commerce, if you would comment—I don't know if anyone's asked you, but we would like an update on how that transition is going, what you see as problems, or has there been anything identified as needing extra attention.

Mr. O'CONNELL. So, Senator, thank you very much for the question.

We have moved out, from day one of Space Policy Directive 3 at the Commerce Department, to actually implement that. And I'm not sure if you were here during part of my testimony. One of the first things we did was establish a very close partnership with the Department of Defense, and now the Space Force officials who are going to actually help that. We actually assigned a senior Commerce liaison at Vandenberg Air Force Base, California. So, he is literally sitting there, watching how the system currently exists, how it operates today.

And, for those that don't know, Space Policy Directive 3 mandates this transition, for two important reasons. One, because the Department of Defense has other missions it needs to tend to in space. But, second, because the system that we have in place today is in need of modernization. In particular, it would not scale to the kind of commercial space world that we're heading into at lightning speed.

And so, the partnership has been absolutely outstanding, so far. Having somebody on the ground there at Vandenberg is very important.

Another thing that we've done is that the Air Force shared with us something called the Unified Data Library, which is a tool that they have of sensor data as kind of a first step for us to look on what we would put into our open architecture as we develop it. And so, we've been evaluating that tool, what's useful about it, you know, where are the places that we won't be able to use it, even as we think about how to create this architecture. We're thinking, partly, of leveraging some of NOAA's cloud computing resources.

You know, some of this is really about applying modern technology—a lot of this is about applying modern technology and business concepts to the space situational awareness enterprise. And I'll give you one simple example. If you were to go to Vandenberg,

you have an extensive operations floor for the many different missions the Department of Defense operates there. And sometimes people will say to me, "Hey, Kevin, are you trying to create another Vandenberg?" Absolutely not. The piece of this that we're going to transition is the on-orbit collision notifications piece for the private sector and for international actors. And so, in my mind, I have a modern version of an operations center, a small activity. In fact, Bill Murtagh, in the Space Weather Prediction Center, has a modern government version of that kind of an operations center—small number of people, lots of data, globally, that they can leverage. We've also seen many commercial examples of that.

And so, the partnership, again, is—been very strong. It's continuing. It starts at the Secretary Ross and General Raymond level, but it goes all the way down throughout the organization and the different things that we have to do to move this along.

Senator BLACKBURN. Well, some of us that are working from the Defense end on great-power competition——

Mr. O'CONNELL. Yes, ma'am.

Senator BLACKBURN.—and are needing those bright young minds to come in, we realize, fully, that we need to think differently about how we look at 21st-century warfare, how we look at the utilization of everything that is going to be done with spectrum that we're going to do with satellites, that we're going to—how we're going to utilize these technologies, and that, many times, we don't need to in-house something that we need to do more to engage the commercial sector. So, we have been interested in following this and looking at what you all are going to do, and then rebooting the potential between NASA and NOAA, and bringing Commerce to bear in this.

You all have been patient with us. I do have a couple of other questions.

Dr. Murtagh, let me come to you. When we talk about hazardous space weather, what are the limitations that are—that you deal with when you are looking at the predictability of space weather? Where are your limitations?

Mr. MURTAGH. They are many.

Senator BLACKBURN. I know there are many——

Mr. MURTAGH. Yes.

Senator BLACKBURN.—but——

Mr. MURTAGH. And it'll——

Senator BLACKBURN.—build out a little bit of a framework.

Mr. MURTAGH. Sure. It's—I'll start right at the Sun. We—what we're looking for in the Space Weather Prediction Center is the development of sunspots. That's kind of the——

Senator BLACKBURN. OK.

Mr. MURTAGH.—localized magnetic stressed areas in the Sun that will produce the eruptions. We have no real capability to predict when those sunspots are going to——

Senator BLACKBURN. OK.

Mr. MURTAGH.—occur. So, we could be sitting, today, very quiet, and, 2 days from now, have a major sunspot cluster evolve.

Senator BLACKBURN. OK.

Mr. MURTAGH. So, that's a big drawback in our ability to predict this stuff. And when they do occur, and the eruption occurs, this

coronal mass ejection is shot out into space, sometimes right toward Earth. It's like a magnet just got shot out into space. We don't know the magnetic structure within that coronal mass ejection, we call it, so it takes, maybe, 20 or 30 hours to get from the Sun to the Earth, but, until it hits that spacecraft, our buoy in space, that it's DSCOVR or ACE spacecraft, we don't know what the magnetic structure is like. And that is everything to us, because that'll tell us how these two magnets, Earth's magnetic field and this Sun magnet that just got shot out, how are they going to couple together.

Senator BLACKBURN. And so, this is——

Mr. MURTAGH. But, that's a great——

Senator BLACKBURN.—what causes the national security and the grid security risk.

Mr. MURTAGH. That's correct. That last piece is the big piece. We've got to get that information out to the grid. We have a process where we notify the North American Electrical Liability Corporation Reliability Centers, 20 of them around the entire United States and Canada. As soon as we detect these things and we recognize that they—the magnetic response will be big, we get that information out to them immediately so that they can redistribute that information to all their power-generation and transmission entities in their areas of responsibility to take the appropriate action to keep the lights on.

Senator BLACKBURN. We thank you for that.

With that, no one else is here. Let me close our hearing.

The hearing record will remain open for two weeks. During this time, Senators are asked to submit any questions for the record. Upon receipt, the witnesses are requested to submit their written answers to the Committee as soon as possible.

At this, I want to thank the witnesses for being here today.

And the Committee is adjourned.

[Whereupon, at 11:27 a.m., the hearing was adjourned.]

A P P E N D I X

RESPONSE TO WRITTEN QUESTIONS SUBMITTED BY HON. MIKE LEE TO
THOMAS ZURBUCHEN, PH.D.

Question 1. The Utah State University Space Dynamics Lab has long partnered with the University of Arizona and NASA's Jet Propulsion Laboratory on the Near-Earth Object (NEO) Surveillance Mission. The main purpose of the NEO Surveillance Mission is to help discover and characterize potentially hazardous asteroids, which enables us to take preventative action should we find an asteroid that is on a life-threatening path towards Earth.

Could you provide a status update on the NEO Surveillance Mission?

Answer, The NASA Near-Earth Object Surveillance Mission (NEOSM) Science Mission Directorate (SMD) flight project now in formulation would accelerate the discovery of undetected NEOs (and therefore, the completion of the George E. Brown (GEB) survey) by positioning a spacecraft operating in the infrared part of the spectrum at the Sun-Earth L1 gravity Lagrange point. A space-based, infrared capability was recommended by the June 2019 National Academies of Sciences, Engineering, and Medicine (NASEM) report "Finding Hazardous Asteroids Using Infrared and Visible Wavelength Telescopes." In addition to development and delivery to orbit, NASA capabilities include the necessary analysis of data for detection, tracking and characterization of potentially hazardous objects. NASA estimates that the GEB survey goal would be achieved approximately 10 years after the mission begins on-orbit operations.

FY 2020 funding for the mission is $35.6 million, consistent with FY 2020 appropriations report language which allowed entry into the formulation phase. As such, a mission management structure has been established with all key stakeholders. The mission recently completed its System Requirements Review (SRR)/mission definition review (MDR) life-cycle review. It is anticipated that NEOSM will be ready to complete the Key Decision Point-B (KDP–B) milestone by the end of calendar year 2020.

Question 2. Is there a target launch date for the NEO Surveillance Mission? And are there any current barriers that are delaying the launch date?

Answer. The current budget projection for the Planetary Defense Program supports a LRD of no earlier than 2029.There are currently no technical barriers influencing the launch date.

RESPONSE TO WRITTEN QUESTION SUBMITTED BY HON. DEB FISCHER TO
THOMAS ZURBUCHEN, PH.D

Question. The Planetary Protection Independent Review Board issued several recommendations in October 2019 regarding NASA's policy on planetary protection. Given those recommendations, what will be NASA's next steps to update the planetary protection standards, and will NASA ensure those standards are not so burdensome that they stifle commercial space activities?

Answer. NASA has already begun updates to its internal policies, releasing two NASA Interim Directives on July 9, 2020—one for missions to the Moon and one for future human missions to Mars. An update of the NASA Procedural Requirements (NPR) for Planetary Protections is underway and currently going through the formal Agency review process. In addition, the Office of Planetary Protection is writing a NASA Technical Standard that will provide clear guidance on the technical processes and details missions can use to comply with the NPR. The draft Standard reduces the burden of reporting and encourages missions to incorporate technical innovations based on industry standards from healthcare, biosafety, and other relevant sectors.

NASA continuously seeks the input of stakeholders on issues of planetary protection, including the private sector. The Planetary Protection Independent Review Board (PPIRB) chartered by NASA consisted of members from multiple aerospace

companies, research institutes, academia, and a commercial trade organization. As NASA began the process of implementing the recommendations of the PPIRB, it requested that the Space Studies Board of the National Academies of Science, Engineering, and Medicine create a Committee on Planetary Protection (CoPP) to provide advice on planetary protection policy. CoPP would also provide advice on the knowledge and capability gaps NASA will need to address in order to set planetary protection requirements for future missions. NASA explicitly required that the CoPP members come from a broad range of backgrounds and sectors, including commercial entities.

RESPONSE TO WRITTEN QUESTIONS SUBMITTED BY HON. AMY KLOBUCHAR TO THOMAS ZURBUCHEN, PH.D.

Question 1. In your testimony, you note that several agencies—including NASA, the Department of Defense, and the Department of Commerce—share responsibility for planetary defense from near-earth objects such as the asteroid that exploded over Russia in 2013, injuring over a thousand people. What steps is NASA taking to carry out these defense efforts, and would additional resources enable NASA to improve the effectiveness of these efforts?

Answer. In 2016, NASA established the Planetary Defense Coordination Office (PDCO) to manage the ongoing mission of its planetary defense program. The PDCO carries out a variety of planetary defense efforts and works with several departments and agencies, including the Departments of Homeland Security (DHS), Defense (DoD) and Energy (DOE). Specifically, PDCO's responsibilities include:

- Managing NASA's Planetary Defense Program;
- Ensuring the early detection of potentially hazardous objects (PHOs)—the subset of NEOs whose orbits predict they will come within 5 million miles of Earth's orbit, and of a size large enough (at least 30 to 50 meters) to reach Earth's surface;
- Tracking and characterizing PHOs and issuing warnings about potential impacts;
- Providing timely and accurate communications about PHOs;
- Studying strategies and technologies for mitigating PHO impacts; and,
- Performing a lead role in coordinating U.S. Government planning for response to an actual impact threat.

The highest priority for Planetary Defense is to find any potential impacting object as early as possible to enable more options to mitigate it. The President's FY 2021 budget request includes $150 million for planetary defense efforts, as NASA plans to continue support for current NEO survey projects, enhance NEO detection and tracking analysis capabilities, and continue instrument formulation for a potential space-based infrared capability, the NEO Surveillance Mission, that would support NEO survey objectives as identified in the 2019 National Academies study.

Question 2. NASA's missions are critical to efforts to address the growing skills gap in our economy and inspire the next generation of scientists and engineers. My bipartisan legislation with Senator Rubio, the Supporting Veterans in STEM Careers Act, encourages veterans and military spouses to pursue study in STEM fields and was signed into law last week. What actions does NASA plan to take to continue its outreach to encourage students and veterans to pursue careers in STEM fields?

Answer. NASA can only reach a sustained presence at the Moon beginning in 2024, if we make a concerted effort to broaden participation across all groups, but especially non-traditional students and veterans who served our Nation. NASA funds over 8,000 interns each summer, many from minority-serving institutions. Veteran preference regulations already assist our efforts to help veterans in science, technology, engineering, and mathematics (STEM) careers. For outreach, NASA participates at air shows, Walter Reed Medical Center, U.S. Science and Engineering Festival and other large-scale public events to inspire students and veterans to pursue STEM fields.

RESPONSE TO WRITTEN QUESTIONS SUBMITTED BY HON. TOM UDALL TO THOMAS ZURBUCHEN, PH.D.

Near Earth Orbit Tracking

Question 1. Do you think we are overly reliant on medium and large space monitoring telescopes and satellites for Near Earth Orbit tracking?

Answer. No, there are currently no medium or large space-based telescopes that perform NASA's Near-Earth Object (NEO) tracking efforts. One small space telescope being used by NASA, NEOWISE, is nearing its end of life. NASA's Planetary Defense Program sponsors projects through its NEO Observations Program that employ a variety of ground and space-based telescopes to search for NEOs, determine their orbits, and measure their physical characteristics.

Question 2. Is there a role for small satellites fulfill that mission or, at the least, be used to fill the gaps in current data sets for Near Earth Orbit object tracking and warning?

Answer. Numerous methods for increasing the NEO detection rate, including use of small satellites, have been assessed over the years by multiple organizations, including the National Academies. These studies concluded that small satellites could indeed increase the NEO detection rate, but that a space-based telescope with at least a 0.5-meter aperture looking in the mid-infrared part of the spectrum would accelerate the discovery of undetected NEOs more quickly than any other alternative. This size telescope is currently beyond small satellite capabilities.

DoD and NASA Cooperation

Question 1. How can DoD and NASA better share data to further planetary defense from impacts from outer space?

Question 2. Should DoD take a more pro-active role in this effort?

Answer. Currently, NASA and DoD share data related to planetary defense, and both have an active role in implementing the National NEO Preparedness Strategy and Action Plan—the goal of which is to help organize and coordinate NEO-related efforts within Federal Departments and Agencies, with a particular focus on efforts that are already existing and resourced. The NASA NEO Observations program receives data from DoD assets capable of detecting and tracking asteroids, such as the new Space Surveillance Telescope about to begin operations in Australia, and on bolides—large, naturally occurring meteors—as they impact Earth's atmosphere. NASA, DoD, and others also routinely exercise NEO impact emergency procedures and action protocols, thereby improving emergency preparedness and response/recovery timelines. These activities allow for satisfactory communication and data sharing across not only NASA and DoD, but all Federal and international entities involved.

Small Satellite Deployment

Question. How should we employ small satellites for research and development of systems that are able to resist space weather effects on our satellites?

Answer. Small satellites (SmallSats) have opened the window of space research and technology development in many ways. Heliophysics, and space weather in particular, can benefit greatly from multi-point observations that are made possible by SmallSats and SmallSat constellations. Due to SmallSats' size and their ability to make coordinated measurements across vast regions in space, Heliophysics is able to leverage them to make in-situ observations that help inform our understanding of space weather effects. This improved understanding helps enable the development of future systems that can resist space weather effects on our satellites. Three examples relevant to space weather research and development of resistance systems are:

1. *Investigations of the variability of the ionosphere, which is key to understanding the impact of space weather on global navigation, communications, and positioning systems:* Over the last year and in the next 24 months, no fewer than 12 SmallSats have been or will be launched to conduct research relevant to characterizing space weather effects on spacecraft and their instruments. Each investigation has a particular stand-alone focus on research or technology development that together, will act as pathfinders for future constellation missions of SmallSats. These investigations will provide information that can be used to improve spacecraft design, engineering, and operations in order to protect spacecraft and instrumentation from harmful radiation. The missions are: Auroral Emission Radio Observer (AERO), Daily Atmospheric Ionospheric Limb Imager Mission (DAILI), Electron Losses and Fields Investigation (ELFIN), Enhanced Tandem Beacon Experiment (E–TBEx), International Sat-

ellite Program in Research and Education (INSPIRESat1), Lower Atmosphere/Ionosphere Coupling Experiment (LAICE), Low-Latitude Ionosphere/Thermosphere Enhancements in Density (LLITED), Oxygen Photometry of the Atmospheric Limb (OPAL), Plasma Enhancements in the Ionosphere-Thermosphere Satellite (PetitSat), Scintillation Observations and Response of the Ionosphere to Electrodynamics (SORTIE), Scintillation Prediction Observations Research Task (SPORT), and Vector Interferometry Space Technology using AERO (VISTA). Additionally, NASA takes advantage of rideshare opportunities to advance space weather research. Space Environment Testbeds (SET–1) is a rideshare with the U.S. Air Force Demonstration and Science Experiments (DSX) mission. SET–1 studies how to protect satellites in space by characterizing the harsh space environment near Earth and how it affects spacecraft and their instruments.

2. *PUNCH and SunRISE selections:* SmallSat constellations are being developed to image the solar wind (PUNCH) and to study the Sun in radio waves (SunRISE). The Polarimeter to Unify the Corona and Heliosphere (PUNCH) mission will be a group of four small satellites that will provide real-time images of the solar atmosphere, studying the Sun's corona and monitoring for coronal mass ejections (CMEs). The Sun Radio Interferometer Space Experiment (SunRISE) mission will be an array of six CubeSats operating like one large radio telescope and will investigate how giant space weather storms from the Sun are accelerated and released into planetary space.
3. *Access to inter-planetary space:* Increased and enhanced access to inter-planetary space is enabling research with SmallSats directly related to space weather around the Moon, at the Sun-Earth Lagrange 1 point, and closer to the Sun with one particular mission using solar sails.

Space Weather Mitigation Technology

There are several NASA programs that leverage suborbital flight for research and tech development.

Question. Is there a role for these in developing space weather mitigation technologies or practices?

Answer. Yes, suborbital flight programs for research and tech development play a significant role in developing space weather mitigation technologies and practices. The NASA suborbital sounding rocket program has for over 40 years advanced technology and science, much of which is relevant for developing technologies that help advance our understanding of space weather. Compact in-situ measurement techniques, sensors, and mirror technologies have been developed through the sounding rocket program that are appropriate for SmallSats, as well as large missions. Additionally, the Heliophysics Flight Opportunities for Research and Technology (H–FORT) program element supports Low-Cost Access to Space (LCAS) initiatives including investigations conducted using suborbital vehicles (*e.g.,* sounding rockets, balloons, commercial reusable suborbital launch vehicles), as well as CubeSats and the International Space Station (ISS).

Technologies utilized in H–FORT feed future dedicated Heliophysics missions. Space weather research and technology development has been and continues to be a beneficiary of these important programs; key space missions directly relevant to space weather are enabled by technologies and measurement techniques developed and matured through these programs. Some examples of missions are: Advanced Composition Explorer (ACE), Fast Auroral Snapshot Explorer (FAS), Solar and Heliophysics Observatory (SOHO), Time History of Events and Macroscale Interactions during Substorms (THEMIS), and Transition Region and Coronal Explorer (TRACE). Recent technology advancements in detectors and measurement techniques on sounding rockets such as the High Resolution Coronal Imager (Hi-C) and Chromospheric Layer Spectropolarimeter (CLASP) show great promise for advancement and improvement of future missions for space weather. Hi-C is a sub-orbital telescope designed to take high-resolution images of the Sun's corona and CLASP is an ultraviolet sun-gazing instrument used to study the solar atmosphere. Both Hi-C and CLASP are launched from the White Sands Missile Range in New Mexico.

RESPONSE TO WRITTEN QUESTIONS SUBMITTED BY HON. KYRSTEN SINEMA TO THOMAS ZURBUCHEN, PH.D.

Detecting Near-Earth Objects

Thank you, Chairman Wicker and Ranking Member Cantwell, for holding this hearing and to our witnesses, for holding today's hearing.

As Ranking Member on the Aviation and Space Subcommittee, I'm proud to have joined Subcommittee Chairman Cruz, Chairman Wicker, and Ranking Member Cantwell in introducing legislation to address a number of space missions of global importance.

Late last year, this committee passed our NASA Authorization Act of 2019, which includes language directing NASA to ensure that missions of national importance do not have to compete for funding with high-priority science missions.

In the Space Frontier Act, which passed the Senate unanimously last Congress and passed out of this committee last year, clearer rules of the road for orbital debris mitigation and space weather forecasting are established.

This is a pivotal time for our national security and space leadership. Decisions we make and legislation we pass now will determine if we are prepared for the future development of space.

We must address these challenges head-on with strong bipartisan solutions.

Our leadership on planetary defense, space weather, and space situational awareness will set global standards and ensure America's national security remains strong.

As you know, in 2005 Congress passed the George E. Brown Jr. Near-Earth Object Survey Act, which requires NASA to plan, develop, and implement a program to survey threats posed by near-Earth objects, or asteroids, which could collide with Earth. Congress required NASA to catalog at least 90 percent of near-Earth objects by December 30, 2020. With the deadline now less than a year away, NASA is not on track to meet this goal.

Last summer, the National Academies of Science found that in order to meet its congressionally mandated goal, NASA should fund a dedicated space-based infrared telescope.

Fortunately, researchers from the University of Arizona and NASA's Jet Propulsion Laboratory have spent the past decade developing the type of telescope recommended by the National Academies. I am pleased that NASA finally announced last fall that it would fund this project but I am concerned that the administration has waited this long to fulfill a Congressional mandate. Additionally, just this week, the administration failed to dedicate funding for this mission in their budget proposal.

Question 1. Now that you have committed to the mission, how do you plan on funding it and how long does NASA expect it will take to launch the mission and complete the George E. Brown Jr. Survey?

Question 2. And how can this committee help to ensure that the survey is completed as quickly as possible?

Answer. The President's FY 2021 budget requests $150 million for NASA's Planetary Defense Program, including funding for an infrared instrument project for detection and tracking of NEOs. The current mission concept, the Near-Earth object (NEO) Surveillance Mission, would accelerate the discovery of undetected NEOs (and therefore, the completion of the George E. Brown survey) by positioning a spacecraft operating in the infrared part of the spectrum at the Sun-Earth L1 gravity Lagrange point. We estimate the George E. Brown survey would be completed approximately 10 years after the launch of a space-based infrared mission. Ultimately, an important step Congress could take is to fully fund the Administration's budget request for Planetary Defense.

Question 3. Given that NASA has failed to prioritize the completion of the George E. Brown Jr. survey and the development of a space-based infrared telescope mission until now, do you believe that NASA is the appropriate agency to handle planetary defense missions?

Question 4. Why should this committee not assign that responsibility to another Federal agency that will be able to act more quickly?

Answer. NASA leads the world in the detection and characterization of NEOs, and NASA-sponsored NEO search projects are responsible for the discovery of over 96 percent of all NEOs found since our program began in 1998. NASA leads a wide array of activities related to NEOs, including a long-standing, ground-based observing campaign, focused flight missions to study both asteroids and comets, as well as conceptual studies and technology development to improve our ability to find NEOs. NASA uses radar techniques to better characterize the orbits, shapes, and

sizes of observable NEOs, and funds research activities to better understand their composition and nature. NASA also funds the key reporting and dissemination infrastructure that allows for world-wide follow-up observations of NEOs as well as research-related activities, including computer modeling, sample analysis, and workshops to disseminate information about NEOs to the larger scientific and engineering community.

Because of this history and expertise, NASA's Planetary Defense Coordination Office (PDCO) is uniquely suited to handle planetary defense missions and is considered the primary Government group responsible for the coordination of U.S. Government efforts to find hazardous NEOs and guide planning for the response to an actual impact threat. In this role, NASA coordinates with other Government agencies, such as the Department of Homeland Security and the Department of Defense, on planetary defense activities and to implement the National NEO Preparedness Strategy and Action Plan—which seeks to leverage and enhance existing assets and capabilities to effectively manage the risks associated with NEOs.

RESPONSE TO WRITTEN QUESTIONS SUBMITTED BY HON. KYRSTEN SINEMA TO WILLIAM MURTAGH

Space Weather Prediction

While NOAA's Space Weather Prediction Center is a model for coordinating and disseminating information related to space weather events, I am concerned that the satellite infrastructure NOAA uses to make space weather predictions is rapidly aging. Currently, NOAA's solar-monitoring satellites do not have total coverage of the sun, meaning it is possible to fail to immediately detect a coronal mass-ejection.

Fortunately, researchers at Arizona State University have developed a proposal for a cube-satellite, called the Space Weather and Impact Monitoring Satellite. If a network of these cube-satellites were funded, NOAA could be guaranteed to have 360-degree coverage of the sun, to ensure that any coronal event was detected as early as possible.

Question 1. Do you believe there could be value in a cube-sat constellation being deployed to better predict space weather?

Answer. Cube satellites (cubesats) have the potential to lower costs and provide greater diversity of coverage relative to our current generation of observational satellites. However, the sensors that provide our solar observations are currently too large to be flown on cubesats. NOAA is continually monitoring the evolution of satellite and sensor technologies to determine how smaller satellites (smallsats), including cubesats, could provide greater utility for NOAA's space missions in the future; particularly the NASA and NSF-funded technology development, demonstrations and science missions that enable heliophysics smallsat constellations. NOAA also sees future possibilities for *in situ* measurements from cubesats in low earth orbit and geostationary orbit, as well as possibilities for complementing the solar imaging provided on NOAA geostationary platforms and the hemispheric imaging coverage provided by geostationary payloads like the recently launched NASA Global-scale Observations of the Limb and Disk mission manifested on a commercial satellite.

Technology demonstration missions, such as those proposed by research institutions like Arizona State University, are important early incubation steps necessary to advance miniaturization, artificial intelligence, and constellation operation concepts. The recently completed multi-year NOAA Satellite Observing Systems Architecture (NSOSA) study considered the use of smallsats to meet future space-weather *in situ* and solar imagery needs. The findings and conclusions of the study can be found in the response to Question 2 below.

Question 2. What would the advantages or disadvantages of a space weather cubesat constellation be to the work currently done at the Space Weather Prediction Center?

Answer. The observing requirements for the National Weather Service's Space Weather Prediction Center (SWPC) are independent of the particular type of satellite that is taking the measurement(s). With respect to coronal imaging, SWPC requires a robust continuous view of the Sun with high dynamic range and low data latency.

NOAA currently collects observations from several highly capable smallsats, including NOAA's DSCOVR mission and NASA's Advanced Composite Explorer mission. NOAA's Space Weather Follow-On represents a new smallsat mission that will be continuing these observations starting in 2024. The NSOSA study considered the use of smallsats to meet future space-weather *in situ* and solar imagery needs. The

study found that the expected size, weight, and power requirements of the current instruments indicated a need for spacecraft larger than cubesats to meet NOAA's current space weather mission. To provide future solar observations NOAA will embrace a hybrid constellation with many sizes of satellites matched to mission need. NOAA recognizes the need to incorporate critical new technology development and demonstration; will continue to study cubesat and related emerging technologies; and will evaluate their applicability to our mission.

RESPONSE TO WRITTEN QUESTIONS SUBMITTED BY HON. MARIA CANTWELL TO KEVIN M. O'CONNELL

Civilian Space Situational Awareness Funding

This Administration has proposed shifting the responsibility for alerting commercial satellite operators about potential in-space collisions from the Department of Defense to your office at the Department of Commerce. In order to consider such a shift, Congress needs to know what resources are needed and how exactly the Department of Commerce will use those resources.

Question 1. If Congress approves giving the Department of Commerce civilian space situational awareness responsibilities, how much funding will the department need to perform these operations?

Answer. The President's FY 2021 Budget includes $15 million for a consolidated Office of Space Commerce (OSC) and Commercial Remote Sensing Regulatory Affairs (CRSRA) in the Office of the Secretary. Current spend plans anticipate over $10 million to be devoted to establishing the Department's commercial space situational awareness (SSA) services and information responsibilities in FY21. This includes an increase (of 13 FTE) in space-qualified staff and will allow OSC to further leverage commercial capabilities that are already in the market through new SSA-related sensors, analytic tools, visualization capabilities, and more.

Question 2. Is this a shift of funding from the Department of Defense or new resources?

Answer. Currently, the 18th Space Control Squadron (18 SPCS) at Vandenberg Air Force Base provides the space traffic management (STM) function for military, commercial, and civilian satellite operators. The Department of Defense (DOD) systems primarily support the larger space domain awareness (SDA) mission and contribute to performing the STM function for military, civil, and commercial satellite operators as a subset of the SDA mission. These resources cannot be transferred to the Department of Commerce (DOC) as DOD requires use of these systems for the broader SDA mission including continued STM for military satellite operators. DOC's implementation will allow DOD to devote its full attention to the increasingly complex national security defense needs in space, and DOC to build a modern infrastructure that builds upon DOD SDA data and capitalizes on commercial SSA data and other capabilities.

Orbital Debris Regulations

Current Federal guidelines require that satellites deorbit within 25 years after the end of operations.

Question. Given the congestion of space, should that requirement be revisited?

Answer. Last year, the U.S. Government revised its U.S. Government Orbital Debris Mitigation Standard Practices (ODMSP). As part of that update, the 25-year rule was reaffirmed as a minimum requirement for the government's space assets. However, the revised ODMSP also identified disposal options that involve immediate removal of the space object from Earth orbit as preferred disposal options, and specified for the first time that objects disposed of via passive atmospheric re-entry should be left in orbits that will limit orbital lifetime to a period that is "as short as practicable." In April, and as part of a rulemaking proceeding occurring in parallel with the ODMSP revisions, the Federal Communications Commission (FCC) released a Further Notice of Proposed Rulemaking that sought comments on possible requirements to facilitate the "as short as practicable" approach. These requirements include a possible requirement for spacecraft maneuverability or shorter timeframes for post-mission orbital lifetimes such as five years. Further, there are many older space debris objects left on-orbit. This has adversely impacted specific orbital debris regimes. DOC led a Commercial Orbital Debris Interagency Working Group to inform the FCC rulemaking process.

RESPONSE TO WRITTEN QUESTIONS SUBMITTED BY HON. TOM UDALL TO
KEVIN M. O'CONNELL

Department of Commerce Involvement in Space

Question 1. How does the Department of Commerce fit into space operations?

Answer. Space Policy Directive-3 (SPD–3) directs the Department of Commerce (DOC) to provide on-orbit collision avoidance support services. The Department of Defense (DOD) currently provides these services to commercial, civilian, and military operators; however, DOD will only be required by law to provide these services in the interest of national security beginning in 2024. Two key rationales exist for this transition: first, DOD has been directed to further focus on its mission to protect and defend the space domain against current and emerging hostile threats. As commercial space activities expand and grow more complex, DOD plans to exit the commercial notifications part of the business to focus on national security. Second, there are opportunities to modernize the SSA system that we use today with a wide range of new sensors, analytics, and visualization to enhance SSA and enable a modern alerting and warning system. Commercial companies are the source of much of this innovation and modernization. DOC has ongoing and substantive interaction with the U.S. commercial space community and is aware of these developments, and is able to leverage these capabilities in the implementation of SPD–3.

Question 2. Why should the Department of Commerce be involved in Space Traffic Management over any other civil agency?

Answer. DOC has a wide range of resources, skills, capabilities, and experience in the many areas necessary to successfully complete the transition of space situational awareness services from DOD. Key Commerce organizations include the National Oceanic and Atmospheric Administration (NOAA), which has deep experience in space situational awareness (SSA) and space traffic management (STM), most importantly protecting 16 essential satellites from space debris in four space orbits, as well as in the related field of space weather prediction. The National Institute of Standards and Technology (NIST) has experience in promoting standards—essential to the "rules of the road" needed for space safety—as well as cybersecurity and repository expertise. The National Telecommunications and Information Administration (NTIA) promotes rules related to the prevention of radiofrequency interference, including for space, as well as important relations with the Federal Communications Commission (FCC). The Department's National Technical Information Service (NTIS) works with academia, industry and non-profits on approaches to data science and improved decision-making: these computational methods will continue to be essential for improving the accuracy of conjunction assessments. Externally, we have also been working closely with the National Aeronautics and Space Administration (NASA) on their collision avoidance efforts for NOAA and U.S. Geological Survey (USGS) satellites, space science collaboration, and established relationships with international partners.

Further, the Department is one of the Nation's lead "data agencies" with a wide range of experience using complex data sets, including those related to public safety. It works with large volumes of data, giving it considerable experience with cloud-based data management, analytics, and dissemination approaches for public consumption. As the number of government and commercial satellites grows, and our understanding of the space environment improves, improved management of and access to space debris data will be key to space safety. The DOC's experience and relationship with industry can be further leveraged to create a cost effective, efficient and scalable solution to enhance SSA and improve orbital safety while helping to grow and expand the overall space economy.

DoD and Space Traffic Management

Major General Stephen Whiting, who oversees space traffic management for the Department of Defense, recently said that the Department of Defense is "eager" to transfer space traffic management responsibilities to the Department of Commerce.

Question 1. What is the current collaboration between the Department of Commerce and the DOD on space traffic management?

Answer. Since the announcement of Space Policy Directive-3 (SPD–3), which directs the Department of Commerce (DOC) to provide on-orbit collision avoidance support services, DOC has developed a strong and continuing partnership with the Department of Defense (DOD), U.S. Air Force, and U.S. Space Force officials, at senior and at working levels, to ensure a seamless transfer of these responsibilities. Last summer, DOC detailed a senior Commerce liaison to the 18th Space Control Squadron at Vandenberg Air Force Base (AFB), where the U.S. Air Force presently conducts the space situational awareness (SSA) mission. DOD is providing access to their current data, systems, and processes for DOC awareness, and ongoing bi-

weekly discussions cover issues such as data validation, data architectures, and synergies across the two Departments. These discussions also include the ultimate drive for efficiency in data buys and other commercial interactions. DOC has participated, sometimes as co-lead, in exercises, experiments, and war games designed to help understand how to transition and integrate national and commercial capabilities. Secretary Ross visited Vandenberg AFB in November of 2018 for a first-hand view of the current SSA system.

In addition to the new SSA functions directed to DOC in SPD–3, the Office of Space Commerce performs a vital advocacy mission on behalf of the U.S. Commercial Space Industry. Title 51 U.S.C. has long provided authorities to the Office of Space Commerce in DOC to foster conditions for economic growth and technological advancement of U.S. space commerce industry, streamline and anticipate licensing/regulatory/export reforms, and promote international norms, standards, sustainable practices. As recent examples, the Office of Space Commerce has worked on streamlining the regulatory environment for commercial space operators through changes in the Commercial Remote Sensing Regulatory Affairs rules.

Question 2. Would the space traffic management system be able to utilize the investments of the Department of Defense, such as Space Fence, to execute the civil and commercial mission?

Answer. DOC's space situational awareness-related relationships are especially strong with DOD and with the National Aeronautics and Space Administration (NASA). DOC has spent significant amount of time evaluating the United States Air Force's Unified Data Library as an initial input to the future Open Architecture Data Repository, and we are working with NASA on their conjunction analysis tools and models of the space environment. DOC will continue to leverage DOD systems and products as we migrate to a commercial based service that will support our basic operation requirements and facilitate commercial market development to include advanced products for various stakeholders. DOC will also continue to be integrated with DOD to ensure the safety of our space environment.

Question 3. What, if anything, needs to happen from a policy and funding standpoint so that the Department of Defense can focus more on its priority mission areas instead of space traffic control?

Answer. SPD–3 tasked DOC with providing on-orbit collision avoidance support services, a role which DOD currently supports. DOC has moved aggressively to implement the SPD–3 responsibilities for space traffic coordination and management within current resources. The President's FY 2021 Budget includes additional resources to ramp up these support services at DOC.

RESPONSE TO WRITTEN QUESTION SUBMITTED BY HON. MARIA CANTWELL TO MORIBA K. JAH, PH.D.

Question. Current Federal guidelines require that satellites deorbit within 25 years after the end of operations. Given the congestion of space, should that requirement be revisited?

Answer. I have yet to see how sensitive the answer is to the underlying modeling and data assumptions. To wit, I've never seen a 25-year rule study that I would consider to be either rigorous or subject to wide peer-review and scrutiny. For instance, there are half a dozen or so scientific models for the Earth's atmosphere. How do the results from the 25-year rule studies vary if each one is used independently? What about the assumptions regarding how actively controlled satellites will behave? Currently, SpaceX has automated much of the Starlink Satellite maneuvers. No one knows what is the onboard logic making maneuver decisions. So, there is no way that any U.S. Government study can say it has rigorously or comprehensively assessed the impacts and effects on space traffic and space debris for this 25-year rule. Yes, this should not only be revisited but a group of experts should be brought to bear to jointly perform this study and assessment, leveraging high performance computing capabilities and physics-based models, as well as gathering operationally relevant inputs from the actual satellite operators, with an agreement to properly protect their intellectual property. In fact, the National Academies via one or multiple boards, should be brought to bear on this subject. I'm currently not a member but would gladly volunteer to be directly engaged in this if it came to be.

RESPONSE TO WRITTEN QUESTIONS SUBMITTED BY HON. TOM UDALL TO MORIBA K. JAH, PH.D.

International Cooperation on Space Issues

Last year I introduced Senate Resolution 386, which supports international cooperation and continued U.S. leadership to maintain access to space while achieving advances in space technology. I have heard from stakeholders in the space industry in New Mexico that it is important that the United States work with other countries to address concerns that a growing level of space traffic is posing.

Question 1. What is your perspective on the United States working with the UN Committee on the Peaceful Use of Outer Space to advance the 21 guidelines to promote sustainable and safe operations in space?

Answer. I strongly believe that one of the best things the United States could do to both demonstrate leadership and aid in the long-term sustainability of space is to make as many of the 21 UN COPUOS LTS Guidelines into U.S. Space Law. In fact, I formally briefed at the 2019 UN COPUOS STSC in February in Vienna on this topic[1]. The actual slides I used are in the footnotes of this page. One caveat with making one or more of these guidelines into law is how to enforce? Moreover, I argue that one cannot enforce what is unknown, and one cannot know what is not measured. Therefore, the basis of making these guidelines into successful space law is to first focus on comprehensive space activity monitoring and assessment, and identifying the required body of evidence required to enforce any given space law.

Another issue to consider is that there is no open and transparent global Space Traffic Monitoring system. The closest thing to that is perhaps ASTRIAGraph[2] and this is not an operational platform. The Keldysh Institute of Applied Mathematics (KIAM), in Moscow, Russia, has signed an agreement with the UN Office of Outer Space Activities (UN OOSA) to deploy low-cost telescopes to developing space nations for educational purposes[3]. We all know that these sensor observations will also be feeding Russia's Space Surveillance and Tracking (SST) capabilities. The U.S. is being left behind in these endeavors and other nations are filling up the apparent leadership vacuums. We in the U.S. could establish a U.S. led academic consortium for Space Situational Awareness and Space Traffic Management that could then incorporate international academic partners, strategically. We would need the support and financial resources to make this become manifest, but I am fully confident that we at UT Austin could organize and lead such an effort.

To be sure, an academic consortium does not provide the complete and consistent operational capability required to address the precise real-time needs of the planet's space traffic. Among other concerns, academia is unlikely to ever have the exquisite sensing capabilities that governments and industry possess. This is what industry must work with the Department of Commerce to deliver.

Nevertheless, an academic consortium serves several valuable roles: (a) pragmatically demonstrates what a meaningful partnership looks like, (b) explores the art of the possible, and (c) delivers this tradecraft into the current state of practice. We are continuing to expand our partnerships with academic institutions worldwide in this shared computational and research environment we've begun to develop at UT Austin.

Question 2. Do you see a value in Congress expressing its support for this effort?

Answer. Indeed, and in fact I do not see this being successful or meaningful in the absence of *significant* congressional involvement and shepherding.

Autonomous Satellites

Companies like SpaceX and others are trying to develop satellites that can autonomously maneuver in space when there is a danger of a close approach or collision.

Question. Do you think there is promise in the near term for satellites that can autonomously avoid debris?

Answer. I believe that ultimately, space operations autonomy is the only long-term solution to collision avoidance. However, what SpaceX has done is to prematurely deploy this capability based upon flawed information. Yes, we should automate maneuvers but not do so in the absence of quantifying the effects and impacts (to included possible unintended consequences) in the presence of flawed and incomplete information because we actually risk making matters worse than before.

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[1] *https://www.dropbox.com/s/tip2dod3wpqab6u/AIAA%20Presentation%20-%20M%20Jah%20-%20COPUOS%20STSC%20-%20Vienna%20-%20Feb2019.pdf?dl=0*

[2] *http://bit.ly/astriagraph*

[3] *http://www.spaceref.com/news/viewpr.html?pid=55062*

Independent Space Situational Awareness Institute

In the opening remarks that you provided to the Committee, you state that the U.S. should consider creating a, "well-funded and dedicated Space Situational Awareness Institute [that could] undertake the Science and Technology research and development we desperately require."

Question 1. In your opinion, should this organization have a degree of independence to carry out its work?

Answer. Indeed, this organization should be comprised of research institutions that could be funded in part by Cooperative Agreements with the U.S. Government. A great example is the NASA Astrobiology Institute. This proposed SSA Institute should also have an advisory board comprised of interagency government staff and should be given a mandate to host an annual workshop where the National Space Council is directly briefed on research results and how these are being successfully transitioned into operationally relevant environments. The National Academies should be invoked to help the SSA Institute in making it successful. The National Science Foundation should have a portion of its budget dedicated to supporting the fundamental research of the SSA Institute.

Question 2. And would the Federally Funded Research and Development Center model be a good fit for such an institute?

Answer. I believe that a more effective model is having a consortium of research institutions, FFRDCs and University Affiliated Research Centers included, via Cooperative Agreements; 5-year terms can be put in place and those that are thriving and relevant can re-compete. The NASA Astrobiology Institute is an example as a potential model.

RESPONSE TO WRITTEN QUESTIONS SUBMITTED BY HON. KYRSTEN SINEMA TO MORIBA K. JAH, PH.D.

University Collaborations on Space Situational Awareness

As the number of satellites in-orbit increases, the risk of a collision in-orbit increases. We can all agree that a more comprehensive system of space traffic management is needed as low-earth orbit becomes increasingly commercially viable.

There are not yet sufficient resources available at the Department of Defense, Department of Commerce, or NASA to develop a modern-day space traffic management system, universities have been stepping up.

For example, at the University of Arizona, Dr. Vishnu Reddy and a team of five undergraduate students build the RAPTORS telescope, which can track satellites and debris in low-earth orbit. The students were able to build two 24-inch telescopes in seven months for about $30,000. The RAPTORS telescopes have been used in NASA-led international exercises, and the University is now exploring opportunities to use the telescopes to support work being done at the Air Force Research Laboratory.

This is one example of how universities are able to make critical contributions to space missions of national importance. More often than not, universities complete their missions on-time, and under-budget.

Question 1. As we consider how to best mitigate orbital collisions, what roles can universities play?

Answer. First, thanks for this question. I was actually a member of the faculty recruitment committee that hired Vishnu Reddy and I consider him to be both a colleague and friend. He's awesome. In fact, my ASTRIANet telescopes were initially designed by him!

In terms of orbital collision mitigation, we at UT Asutin have developed and deployed the world's first Conjunction Streaming Service (CSS) that can be viewed here: *http://astriacss03.tacc.utexas.edu/ui/min.html*

What you'll see are some dotted lines streaming continuously, over the next 20 minutes. What we have done is take the currently available public space object catalog and computed which pair of objects are predicted to come closer than 10 kilometers from each other, and those that meet that criterion are plotted. Green dots are a pair of working satellites, yellow dots are when one is working and the other is not, and red dots re two dead objects or debris.

I feel confident that universities could collaborate on scaling this to a week-long predictive window and on top of that, compute collision risks and deliver an automated service to the community for those objects with high likelihood of collision. This would require so-called Conjunction Data Messages (CDMs) as inputs, and in turn these CDMs are a result of statistically comparing predicted space object trajectories. These space object trajectories are informed by sensor observations. Ulti-

mately, we universities require sensor observations to then level-up the information to eventually yield these collision alerts. The problem is in hand if we can receive the sensor data.

Universities tend to be funding sinks not sources, so we would need funding to either have our own sensors and/or purchase senor data (or receive these from the U.S. government as Government Purpose Rights data).

Question 2. Are their programs at the Department of Defense, Department of Commerce, or NASA to support university collaborations?

Answer. The answer to this is quite varied. For the DoD, there is some S&T research funding via the Air Force Research laboratory (AFRL) and the Air Force Office of Scientific Research (AFOSR). The funding from AFRL is disparate, inconsistent, and oftentimes funding redundant things. In other words, it is not coordinated across the enterprise. There is no AFRL-strategic funding for SSA/STM research. There was a Senior Scientist for Space Situational Awareness, but that position disappeared when Dr Tom Cooley accepted the position as Chief Scientist for the AFRL Space Vehicles Directorate. I'd highly suggest creating this Senior Scientist for SSA position again.

Regarding AFOSR, there was a Program Office for SSA there, but that position has gone away since Dr Stacie Williams accepted a position with DARPA. IT is unlikely that AFOSR will fill that with another SSA person unless they are encouraged to do so. Moreover, anything less than say $6–10M per annum for this SSA portfolio would not do the area any justice so to speak. I would say that having a AFOSR Multidisciplinary University Research Initiative (MURI) on SSA would make a lot of sense and really start to tackle the foundational scientific roadblocks that currently exist.

Regarding Dept of Commerce, no, there is no funding for SSA/STM there. There should be, given Space Policy Directive #3.

Regarding NASA, there is also no funding for SSA/STM. My recommendation has (and is) to have a NASA SSA Institute (set up like the NASA Astrobiology Institute) whereby research institutions are enlisted via Cooperative Agreements (5-year terms) and NASA Goddard could administer it under the leadership of Lauri Kraft Newman who currently leads the NASA CARA project which is the most relevant to this mission area.

Question 3. What further steps can this committee take to promote further collaboration?

Answer. I would recommend the following:

1. Enable the development and sustainability of a core academic consortium within the U.S. to focus uniquely on the scientific and technological (S&T) hurdles regarding space safety, security, and sustainability relevant to Space Situational Awareness and Space Traffic Management needs, per national Space Policy Directive #3. This can be done via:
   a. AFOSR/AFRL MURI on SSA
   b. NASA SSA Institute via Cooperative Agreements
2. Have this consortium become indispensable partners to the Department of Commerce and focus the relationship on successful Tech. Transfer into their Open Architecture Data Repository (OADR) and operationally relevant frameworks.
3. Incentivize Industry partnership by requiring companies to take the S&T developed by the academic consortium and finish maturing/operationalizing these for the Department of Commerce. Have industry contribute some of their own resources/funding to be a part of this endeavor, like a membership fee that goes to helping develop and mature the S&T.
4. Enlist the National Academies to also work with this academic consortium on exploring the solution space to meet national and international SSA/STM needs.
5. Require the academic consortium to host an annual symposium to report out on S&T research results, with at least some aspect of this open to the public. Have it in DC!
6. Resurrect the Intergovernmental Personnel Act (IPA) and use it as a sort of sabbatical for academics to allow them to work directly with government staff on these SSA/STM problems.

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