Statement of

Dr. Thomas Zurbuchen
Associate Administrator for the Science Mission Directorate
National Aeronautics and Space Administration

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Chairman Cruz, Ranking Member Markey, and members of the Subcommittee, I am excited to be here today to tell you about NASA's science program.

The work of NASA Science is at the forefront of scientific discovery and innovation. The questions we seek to answer affect humanity on a global scale and focus on our place in the universe – Where did we come from? Are we alone? Questions that are well-aligned with the topic of this hearing. Tackling such difficult questions requires courage and a dedication to excellence. It requires a culture where there is a willingness to learn and change and to take risks in the interest of science. Our commitment to challenge ourselves means that we learn from our successes, and, more importantly, even when we do not succeed, we still dig deep for lessons, make adjustments, and continue to expand our knowledge.

Later this month, NASA will launch our next daring satellite mission of exploration and science, harnessing cutting-edge technology to advance humanity's knowledge of our star's secrets by "touching the sun", by actually flying deep through its atmosphere. The Parker Solar Probe is the first spacecraft designed to do so, providing us with the closest-ever observations of a star. Parker Solar Probe's measurements will revolutionize our understanding of the Sun's corona and expand our knowledge of the origin and evolution of the solar wind. The mission will also make critical contributions to our ability to forecast changes in space weather that affect life and society's essential technological infrastructure on Earth. It will also help us better understand how stars like ours affect the potential habitability of planets around other stars.

NASA uses the unique vantage points of space, airborne, and ground-based assets, as well as teams of scientists, engineers, and technologists to expand our knowledge of the Earth, our Sun and solar system, and the universe. NASA measurements and research advance critical understanding, inform decision making, and improve the quality of life for citizens in the United States and humankind around the globe. NASA integrates science within overall agency goals, including human space exploration. Executing a balanced portfolio, NASA illuminates the secrets of the universe, searches for life elsewhere, and ensures that we continue to play an important role in protecting and improving life on Earth.

When the Parker Solar Probe launches, it will join numerous other exciting missions launched in the last few months. The Transiting Exoplanet Survey Satellite (TESS), launched on April 18, 2018, is NASA's next planet-hunting mission, searching for planets orbiting nearby stars. On July 25, it began conducting the first-ever spaceborne all-sky transit survey and is expected to catalog more than 1,500 exoplanet candidates, including 500 Earth-size and super-Earth-size planets. TESS will identify prime targets for further, more detailed characterization with the James Webb Space Telescope and other missions.

The twin GRACE Follow-On satellites (a partnership with German research and space agencies), were launched on May 22, 2018, and are undergoing on-orbit checkout. The mission is already providing new information on Earth's gravity field, which is affected by ice sheet and oceanic mass balances, underground water storage changes in aquifers, and regional drought conditions. While carrying on the extremely successful work of its predecessor, GRACE Follow-On mission is also successfully testing a new spaceborne laser ranging technology designed to dramatically improve the already remarkable precision of its measurements.

Also launched in May, NASA's newest Mars lander - the Interior Exploration using Seismic Investigations, Geodesy and Heat Transport or InSight lander is now en route for a November touchdown. It will join a complement of NASA rovers, landers, and orbiters at the Red Planet. InSight's advanced payload will provide unique information on the interior structure of Mars, providing glimpses into the processes that shaped the four rocky planets of the inner solar system. Insight is accompanied on its trip by an exciting technology experiment: twin briefcase-sized CubeSats called Mars Cube One, or MarCO – the first CubeSats to travel to deep space.

Collaborating closely with the Human Exploration and Operations Mission Directorate, SMD continues to use the International Space Station as a valuable platform for great science. For Earth observation, the ISS hosts the Lightning Imaging Sensor (LIS) to detect lightning both day and night, the Stratospheric Aerosol and Gas Experiment-III (SAGE-III) to measure atmospheric ozone and aerosol profiles, and the Total and Spectral Solar Irradiance Sensor-1 (TSIS-1) to precisely monitor solar radiation reaching the Earth. On June 29, the low-cost, competitively-selected ECOsystem Spaceborne Thermal Radiometer Experiment on Space Station (ECOSTRESS) instrument was carried to the space station in the Dragon trunk of a SpaceX commercial resupply mission. ECOSTRESS measures agricultural water use in the United States and vegetation stress around the globe and will identify drought warning conditions. Looking outward into the universe, the Neutron Star Interior Composition Explorer (NICER) and the Cosmic Ray Energetics and Mass (CREAM) experiments were installed on the ISS in 2017. Scientists analyzing NICER data have discovered an x-ray pulsar in a record-fast orbit of only 38 minutes. CREAM is monitoring the cosmic rays that constantly shower the Earth.

NASA also integrates science and future human exploration goals with regard to the eventual return of humans to the Moon. Establishing a new Agency-wide Lunar Discovery and Exploration program and leveraging NASA's extensive lunar science experience and data, NASA is jump-starting commercial partnerships, innovative approaches for building and launching next-generation sophisticated science instruments, and the development of small rovers that will reach the Moon's surface via commercial landers. We also will put our Lunar Reconnaissance Orbiter to new use supporting both science and human exploration goals.

NASA issued a draft request for proposals (RFP) for Commercial Lunar Payload Services (CLPS) on April 27, encouraging the U.S. commercial space industry to introduce new technologies to deliver payloads to the Moon; we anticipate releasing the final RFP in August. NASA intends to award multiple contracts for these services through the next decade, with contract missions to the lunar surface expected to begin as early as 2019, and with a company's first delivery no later than Dec. 31, 2021.

These types of innovative partnerships with commercial and international organizations, as well as the use of small and less expensive satellites, enable us to maintain a balanced science program, achieve high-priority science and applications objectives in a cost-effective manner, and develop enduring and mutually beneficial new partnerships with the private sector. NASA's Earth Science program is pioneering many of these partnerships and mission strategies. It is undertaking pilot data buys and evaluations of data products from commercial, on-orbit small-satellite constellations; NASA will have Blanket Purchase Agreements with at least three private-sector small-satellite data providers in place by Fall 2018. Two major competitively selected payloads – the Tropospheric Emissions: Monitoring of Pollution (TEMPO) instrument to measure North American air quality, and the Geostationary Carbon Cycle Observatory (GeoCarb) instrument to measure natural carbon flux processes in the western hemisphere – are being developed for flight as hosted payloads on commercial geostationary communications satellites. Similarly, the competitively selected Multi-Angle Imager for Aerosols (MAIA) instrument will fly as the first NASA hosted science payload on a commercial low-Earth orbiting satellite; MAIA will make detailed measurements of dust and other particles in the atmosphere, enabling researchers and medical professionals to gain insight into the connections between particulate pollution and health problems such as respiratory diseases.

There is no program in NASA Science that has more impact on our everyday life than our Earth Science program. Whether it is developing the tools to predict severe weather or droughts, or whether it is to understand the complex interactions of the Earth system, what we learn here affects our lives.

The Earth Science Division is working with the Earth science and applications communities to implement the findings of the 2017-2027 Earth Science Decadal Survey, "Thriving on Our Changing Planet," released by the National Academies in January 2018. The decadal survey recognized the value of NASA's Earth Science Program and identified a suite of high-priority science and observation objectives for NASA's Earth Science Division.

However, we already have an impactful fleet on orbit. For example, in the midst of the 2017 hurricane season, data products from NASA Earth-observing research satellites were used to support real-time decision-making and response efforts by the Federal Emergency Management Agency, other operational agencies, and first responders on the ground in the affected areas during the catastrophic landfalls of hurricanes Harvey, Irma, and Maria. Precise, broad-coverage observations from NASA's Global Precipitation Measurement (GPM) Core Observatory enabled forecasters to understand and track the storms, and to generate accurate flood predictions. A suite of NASA satellite missions, including the Soil Moisture Active Passive (SMAP) satellite, assisted with flood mapping and recovery planning. NASA's assets stand at the ready to contribute critical information to help prepare for, and recover from, disasters around the world.

Also, in December 2016 we launched the Cyclone Global Navigation Satellite System (CYGNSS) is a constellation of eight small satellites to measure rapidly evolving tropical storms and hurricanes using reflected Global Positioning System (GPS) signals from the ocean. CYGNSS measurements of surface wind speeds in the tropics are the equivalent of a fleet of 32 hurricane hunter airplanes flying 24-7. As we move into the 2018 hurricane season, CYGNSS will be collecting unprecedented data to help the weather forecasting community improve existing storm prediction models.

Looking to the future, the Ice, Cloud and land Elevation Satellite-2 (ICESat-2), the follow-on to NASA's ICESat and IceBridge missions, will launch in Fall 2018 to map and monitor land ice topography and glacier flow, sea ice thickness, and the heights of the vegetation canopy at low- and mid-latitudes across the globe. The competitively selected Global Ecosystem Dynamics Investigation (GEDI) will launch to the space station in November, to make global observations of vegetation canopy height. NASA remains on track to launch Landsat-9 in December, 2020 to continue the critical land imaging series begun with our United States Geological Survey (USGS) partners in 1972.

NASA-developed satellites and technologies are helping other federal agencies carry out their missions. NASA's Joint Agency Satellite Program brings NASA's best practices to bear to support our largest interagency customer, the National Oceanic and Atmospheric Administration (NOAA), in the development of critical weather satellites for the Nation. The Joint Polar Satellite System-1 (JPSS-1, now NOAA-20) successfully launched in November 2017, and the Geostationary Operational Environment Satellite-S (GOES-S, now GOES-17) launched in March 2018. NASA and NOAA are exploring a potential partnership to use a single launch vehicle for the Interstellar MApping Probe (IMAP) and a NOAA space weather monitoring payload. The partnership would provide NOAA access to the L1 Lagrange point for future space weather monitoring.

Space weather also affects our lives even in less visible ways. The source of beautiful aurora, space weather affects us as a technological society each and every day and is a significant threat to space and ground-based infrastructure like power grids and GPS satellites. NASA's objective is to explore the underlying science of space weather so we can support other agencies that are tasked with operational predictions of these events.

For example, NASA continues operation and analysis of data from the Solar Dynamics Observatory (SDO), the Solar and Terrestrial Relations Observatory (STEREO), and other missions which constantly monitor the Sun, revealing coronal mass ejections and releases of solar energetic particles, while also advancing scientific understanding of our star's fundamental dynamics. Focusing closer to Earth, the Magnetospheric Multiscale (MMS) mission uses four small spacecraft flying in precision formation to gather information on Earth's magnetic environment, changing our understanding of how that environment protects our planet.

Heliophysics is preparing the launch of several innovative missions, as well. The Global-scale Observations of the Limb and Disk (GOLD) instrument was launched aboard a commercial communications satellite in January 2018, and the Ionospheric Connection Explorer (ICON) spacecraft will launch later in 2018. Together, they will provide the most comprehensive

observations of the ionosphere – a region of charged particles in Earth's upper atmosphere – ever achieved.

The Space Environment Testbed 1 mission, a technology demonstration mission developed in partnership with the United States Air Force, is scheduled for launch in 2018, and three Heliophysics CubeSats are being prepared for launch as part of NASA's CubeSat Launch Initiative.

Planetary science provides some of the most exciting views of the unexplored worlds in our solar system and has potential answers to tantalizing questions such as "is there life out there"? Small planetary bodies hurling through space have scarred the Earth and planets around us and are a threat to humanity. Protecting the Earth from asteroid or comet impacts is a key focus for us.

NASA maintains a vigorous Planetary Defense Program. The Near-Earth Object Observations project will continue to fund ground-based NEO discovery, tracking, and characterization efforts, while laying the foundation for future space-based NEO detection missions. The Double Asteroid Redirection Test (DART) will demonstrate asteroid deflection technology. DART will use the kinetic impactor technique to change the orbit of a small moon circling the asteroid Didymos, which will be about seven million miles from Earth at its closest approach in 2022.

It is great to see how fundamental research is delivering societal value. This research remains strong at NASA. Exciting things are happening and there is much to look forward to in the next year in NASA's Planetary Science program. NASA's Origins, Spectral Interpretation, Resource Identification, Security-Regolith Explorer (OSIRIS-REx) mission will arrive at the asteroid Bennu later this year, providing unique data that will shed light on the early history of the solar system. OSIRIS-REx measurements of the composition of the potentially hazardous Bennu will also inform NASA as we design future missions to mitigate asteroid impacts on Earth, an effort within NASA's new Planetary Defense program. And then the New Horizons mission flyby of MU69 will happen on New Year's Day 2019 – this will be the first close-approach of a Kuiper Belt object beyond Pluto, providing unprecedented view of these little understood objects at the far reaches of our solar system.

Progress continues on the Mars 2020 rover, which will carry a small, autonomous rotorcraft or drone, demonstrating the viability heavier-than-air vehicles at the Red Planet. NASA is also planning for a potential Mars Sample Return mission – a top priority identified by the scientific community in the most recent planetary decadal survey – incorporating commercial and international partnerships. During 2019, NASA will continue development of the cutting-edge Europa Clipper mission to fly by Jupiter's ocean moon and will announce the next scientifically and technologically innovative New Frontiers mission: either a comet sample return or a drone to explore Saturn's largest moon, Titan.

In many ways, NASA's Astrophysics and planetary science programs are working more closely together. Astrophysics investigates the universe and our place in it. It works to understand how the universe works and how we got here, including searching for and studying planets around other stars. It examines how habitable environments develop and contributes to the search for the signature of life on other worlds – thanks to key NASA missions like Kepler and to

collaborations with ground-based observatories around the globe, we now know there are thousands of planets around other stars (exoplanets). At times, these worlds appear to be analogous to the planets in our solar system, but sometimes they are totally different. There is much we still have to learn about exoplanets, and we are excited to be part of that endeavor.

Our Astrophysics program operates the Hubble, Chandra, Spitzer, Fermi, Kepler, and Swift space telescopes, flies the airborne Stratospheric Observatory for Infrared Astronomy (SOFIA), and conducts balloon and suborbital rocket campaigns. Collectively, this balanced portfolio is focused on unlocking the secrets of the Universe and teaching us how to ask new and different questions that do not only change what we know, but sometimes change how we think about the universe and ourselves.

NASA is committed to answering the big questions, and this requires a commitment to new and challenging missions. In 2021, NASA's impressive observatories will be joined by the James Webb Space Telescope. Webb will be larger and more powerful than any previous space telescope. It will be capable of examining the first stars and galaxies that formed, viewing the atmospheres of nearby planets outside our solar system, and informing our understanding of the evolution of our own solar system. Webb is currently undergoing integration and testing (I&T). Webb's telescope and instruments are fully integrated and performed superbly during testing, and the Spacecraft Element, comprised of the spacecraft bus and a tennis-court sized sunshield, is completely assembled and undergoing testing.

In March 2018, NASA recognized that Webb would take longer and cost more to develop than previously estimated due to issues involved with I&T of the Spacecraft Element. I established an Independent Review Board to provide an independent assessment of the time and cost necessary to complete development. The IRB provided valuable recommendations and emphasized that mission success should be the highest priority in completing Webb's development. In response to their recommendations, we are taking steps including working with the prime contractor to prevent schedule and cost impacts due to human errors during I&T and identifying and correcting any embedded problems that may exist that could pose a risk to schedule, cost, or mission success.

Based on the IRB's schedule analysis as well as other input, NASA established March 30, 2021, as Webb's new launch date. This launch date includes time to accommodate I&T technical issues, addresses schedule over-optimism identified by the IRB, and reestablishes appropriate schedule reserves. To support the March 30, 2021, launch date and five years of science operations, we estimate that Webb's new life-cycle cost will be $9.663 billion. The estimated development cost to support the new launch date, including launch and commissioning, is $8.803 billion, up from the $7.998 billion development-cost estimate established in 2011. Over Webb's lifetime, about $837 million in new funding will be necessary beyond previous requests. Along with the scientific community and the public, we are disappointed that completing Webb is taking longer and costing more than expected, but NASA is absolutely committed to successfully completing, launching, and commissioning Webb, and to carrying out its important scientific mission.

In August 2017, NASA selected six astrophysics Explorer Program proposals for concept studies. The proposed missions would collect unprecedented measurements of gamma-ray and X-ray emissions from galaxy clusters and neutron star systems, infrared emissions from galaxies in the early universe, and atmospheres of exoplanets. In January 2019, NASA will select at least two of these proposals for flight.

In conclusion, as we look forward to the rest of this year and into 2019, NASA's science program will continue to contribute to the scientific and technological advancement of the United States. We cannot fully predict what wonderful science discoveries lie ahead, but our science program is fully integrated into NASA's broader goals, especially working in close partnership with the Agency's human space exploration and technology activities to advance both science and exploration in the coming years. As recommended by the National Academies, we will maintain program balance through a combination of large, challenging missions that push the boundaries of fundamental knowledge, and innovative commercial and international partnerships that enable high-priority science and applications objectives in a cost-effective manner. Teams of scientists, engineers, and technologists at NASA continue the important work of safeguarding and improving life on Earth, while inspiring the next generation of scientists and engineers to reach for the stars. I would be happy to answer any questions you may have.