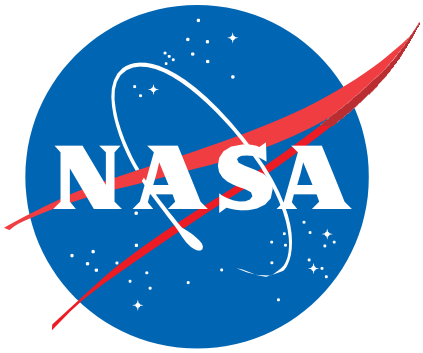

Agency Performance Report
Fiscal Year 2024

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

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1: Expand human knowledge though new scientific discoveries.

1.1: Understand the Earth system and its climate.

LEAD OFFICE
Science Mission Directorate (SMD)

GOAL LEADER
Karen Flynn, Deputy Associate Administrator for Management, SMD

As the world continues to grapple with the known and unknown risks of environmental change, NASA stands uniquely poised to lead humanity into the next wave of Earth system science and information. Understanding impacts to climate is vital for ensuring a sustainable and livable planet for current and future generations. Strategic Objective 1.1 directs NASA's capabilities in Earth observation, data analysis, research, and applications to support the effort to better understand and address the impacts of climate change.

Central to NASA's achievement of this objective is the publication of the *2024-2034 Earth Science to Action* strategy, which documents the strategic objectives and results of the Earth Science Division (ESD). The *Earth Science to Action* strategy aims to holistically observe, monitor, and understand the Earth system, as well as deliver trusted information to drive Earth resiliency activities. With the launch of the Plankton, Aerosol, Cloud, Ocean Ecosystem (PACE) mission in February 2024, NASA completed all planned elements of the agency priority goal related to using the local vantage point of space to advance the understanding of the earth system, its processes, and changing climate. PACE will provide a combination of atmosphere and ocean observations to benefit society in the areas of water quality, human health, fisheries management, ecological forecasting, disaster impacts, and air quality. NASA also advanced the Earth Systems Observatory (ESO), which will provide an unprecedented, holistic view of Earth – significantly advancing our ability to measure, predict, and respond to changes to our home planet. Formulation began for the Atmospheric Observing System (AOS) and Surface Biology and Geology (SBG) missions, and the GRACE-Continuity (GRACE-C, formerly Mass Change) mission moved into development.

Despite meeting all short-term goals and being on track to meet mid-term and long-term criteria, NASA is experiencing challenges in mission development due to lower-than-requested appropriations. To mitigate the impact of reduced funding on the Earth Science portfolio, NASA is pivoting to restructure large missions to reduce cost and scope, while also making greater use of international partnerships. NASA is also opening some missions up to competition, rather than implementing them as directed missions.

Based on SMD's strategy and accomplishments described in the above paragraphs, Strategic Objective 1.1 achieved a Green/Satisfactory rating during the 2024 Strategic Review Process.

1.1.1: Demonstrate progress in characterizing the behavior of the Earth system, including its various components and the naturally occurring and human-induced forcings that act upon it.

NASA achieved the fiscal year (FY) 2024 target, as determined by the Earth Science Advisory Committee in October 2024, leading to a Green rating for this multiyear Performance Goal. Below are examples of scientific progress reported in FY 2024.

A recent study advanced previous work by examining the impact of fires on the long-term public health burden in the United States. They first estimated daily gapless (i.e., spatially complete coverage) particulate matter 2.5 (PM2.5)[1] and black carbon (BC) concentrations at 1-kilometer resolutions and showed that their significant decreases alleviated the mortality burden from 2000 to 2020. However, the rates of decline have slowed down nationally, and have even reversed to increase in the western United States, due to increased fire emissions in the past decade. When the greater toxicity of black carbon is considered, PM2.5 led to an increase of around 930 deaths per year in the western United States, compared with an increase of 670 deaths per year when black carbon is not considered. This is much higher than the number of casualties directly caused by wildfires (around 89 deaths per year in the United States). The health benefits gained from air quality improvement measures are significantly offset by wildfires. Daily concentrations of PM2.5 and its highly toxic BC component at 1-kilometer resolution from 2000 to 2020 are derived using a deep learning approach that integrates satellite data from the Multi-angle Imaging SpectroRadiometer (MISR) and Moderate Resolution Imaging Spectroradiometer (MODIS) instruments, chemical transport models, and surface observations.

Using satellite observations of trends in solar absorption and emitted thermal radiation over the Arctic and Antarctic for the last two decades, scientists have shown that Arctic thermal emission is increasing at a rate that almost instantly compensates for changes in solar absorption due to reduced sea ice. This rapid adjustment means that the net Arctic energy imbalance has been invariant despite the rapidly warming Arctic climate. Conversely, Antarctic thermal emission is not responding to recent increases in solar absorption, demonstrating that Antarctic surface temperatures are not significantly influenced by the region's reflectivity. As a result, changes in energy input in the Antarctic are likely exerting a more substantial influence on poleward heat transport than those in the Arctic.

Researchers demonstrated that high-resolution satellite retrievals of land surface temperature can reveal ecosystem water use when coupled with soil moisture networks. They examined how soil moisture varied and affected ecosystem water use over the continental United States. Using data from NASA's Ecosystem Spaceborne Thermal Radiometer Experiment on Space Station (ECOSTRESS) mission, the researchers analyzed soil moisture profiles at different depths; ECOSTRESS provides high-resolution temperature and evapotranspiration data, allowing for detailed insights into how water availability influences plant water use strategies across various ecosystems. This study highlighted the critical role of soil moisture in maintaining ecosystem health, especially under changing climate conditions; understanding these

[1] PM2·5 is a term for tiny particles in the air that are 2.5 micrometers or less in diameter, about 30 times smaller than a human hair.

dynamics can help predict how ecosystems will respond to future droughts and improve water resource management strategies.

NASA scientists leveraged carbon and water cycle data from NASA's Orbital Carbon Observatory 2 (OCO-2) and Soil Moisture Active and Passive (SMAP) satellite missions to quantify flash drought impacts on U.S. carbon cycling, a critical indicator of ecosystem health. The authors found that, on average, carbon uptake and losses balance out over a ±3-month period surrounding flash drought onset, which contrasts with ecosystem models that currently underestimate pre-onset uptake and overestimate post-onset carbon losses. They further noted that spaceborne observations of solar induced fluorescence, a measurement of a plant's photosynthetic activity, provide a reliable indicator of flash droughts at lead times of two to three months, due to feedbacks between vegetation growth and soil water loss, facilitating flash drought early warning.

Arctic sea ice has undergone significant change in areal coverage, thickness, and ice type since the 1980s and more recently since the early 2000s, where a "New Arctic" regime now exists. Since the sea ice modulates exchanges of energy from the ocean to the atmosphere, this changing sea ice environment has profound effects on the local climate. The Atmospheric Infrared Sounder (AIRS) onboard NASA's Aqua satellite has been collecting twice daily, global data of the Earth's temperature and humidity for more than 20 years. Researchers used AIRS temperature and humidity data to investigate relationships between the sea ice and surface and atmospheric conditions between 2003 and 2022. Strongest correlations occur in the fall, when the surface and lower atmosphere are tightly coupled. When comparing the first (2003–2012) and last (2013–2022) decade of the New Arctic, results show that the warming and moistening is slowing as the sea ice regime and sea ice loss has stabilized in 2013–2022. Cooling and drying are occurring in winter in the Barents Sea, as well as other peripheral seas, in the last decade, possibly due to a negative feedback loop, where winter sea ice regrowth is occurring at a faster pace.

In a recent publication, NASA scientists demonstrated the potential of the Surface Water and Ocean Topography (SWOT) mission, launched in December 2022, using advanced radar technology to make headway in observing the variability of the elevation of water surfaces globally. The paper describes the first results from SWOT in mapping surface elevation of water over the ocean and land, including coastal regions. In a related study, scientists assess the accuracy of SWOT data in the retrieval of marine gravity and bathymetry (depth), reporting high fidelity and accuracy in SWOT bathymetry even after just ten repeat cycles of pre-validated SWOT sea surface height data.

On land, for the first time, the mission is making a global survey of volumetric changes in the world's rivers, lakes, and reservoirs. This new capability opens a new path to advancing the study of the small-scale ocean processes affecting climate change and the critical resources and hazards associated with rivers, lakes, and wetlands. Furthermore, the increased resolution will advance the study of near-shore processes to assess the coastal impact of sea level rise and severe weather, including in river deltas and estuaries.

1.1.2: Demonstrate progress in enhancing understanding of the interacting processes that control the behavior of Earth system, and in utilizing the enhanced knowledge to improve predictive capability.

NASA achieved the FY 2024 target, as determined by the Earth Science Advisory Committee in October 2024, leading to a Green rating for this multiyear Performance Goal. Below are examples of scientific progress reported in FY 2024.

NASA-funded scientists used a continuous time series of daily-repeat satellite synthetic-aperture radar interferometry data from the ICEYE constellation collected in March–June 2023 to document an ice grounding zone, or region of the transition boundary between grounded ice and ice afloat in the ocean, at the main trunk of Thwaites Glacier, West Antarctica. This area is a strong contributor to sea level rise with an ice volume equivalent to a 0.6-meter global sea level rise. They presented evidence for seawater intrusions occurring at tidal frequencies over many kilometers beneath the grounded ice of Thwaites Glacier, West Antarctica, a major contributor to sea level rise. The results call into question the traditional approach of modeling a fixed, abrupt transition from grounded ice to ice floating in the ocean with no ice melt at the transition boundary. The scientists delineated a tidally controlled grounding zone, two to six kilometers in length, and additionally irregular seawater intrusions extending another six kilometers inland at spring tide. The rushing of seawater beneath grounded ice over considerable distances makes the glacier more vulnerable to melting from a warmer ocean than anticipated, which in turn will increase projections of ice mass loss.

A study evaluated the representation of tropical cyclone precipitation (TCP) in reforecasts from the Subseasonal to Seasonal (S2S) Prediction Project, established by the World Climate Research Program (WCRP), and in which NASA is involved. The results suggest that the simulation of tropical cyclone (TC) occurrence and the storm-scale precipitation requires better representation in the models to reduce TCP biases and enhance the subseasonal prediction skill of mean and extreme total precipitation. The global distribution of precipitation in S2S models shows relevant biases in the multi-model mean ensemble that are characterized by wet biases in total precipitation and TCP, except for the Atlantic. The TCP biases can contribute more than 50% of the total precipitation biases in basins such as the southern Indian Ocean and South Pacific. The TCP biases result from biases in the frequency of TC occurrence—too few TCs in the Atlantic and western North Pacific and too many TCs in the Southern Hemisphere and eastern North Pacific. These findings suggest that the simulation of TC occurrence and the storm-scale precipitation require better representation to reduce TCP biases and improve predictions of mean and extreme total precipitation.

Scientists provided a statistical retrieval from two decades of Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) data to constrain volcanic activity patterns throughout pre- and post-eruption phases with a focus on subtle (1−2 Kelvin) thermal behavior, which is easily overlooked using lower spatial resolution data. The new statistical algorithm automatically detected the full range of thermal activity and applied it to more than 5,000 ASTER scenes at five volcanoes with well-documented eruptions. The innovative study found that smaller, subtle thermal detections served as precursory signals

in approximately 81% of eruptions. The algorithm's results have the potential to create a framework for classifying future eruptive styles, and implications for forecasting future activity.

Although landslides rarely claim lives, they can cause structural damage and can fail rapidly, transitioning into fast moving landslides. Several environmental factors, including precipitation, topography, and flow composition, can influence the stability of a landslide and can be used to forecast the location and likelihood of a landslide event. NASA-funded scientists used Interferometric Synthetic Aperture Radar (InSAR) and pixel tracking of PlanetScope optical data to characterize the precursory motion of a catastrophic landslide. They found that the slow, progressive, accelerating deformation that precedes catastrophic landslides differs from the persistent motion of slow-moving landslides, which can be distinguished by analyzing their time-dependent motion. This work highlights the importance of monitoring incipient slow motion of landslides, particularly where no discernible historical displacement has been observed, to better forecast larger landslides.

NASA-funded scientists demonstrated the utility of Gravity Recovery and Climate Experiment (GRACE) and its Follow-On (GRACE-FO) satellite data for flood forecasting applications. They calculated Antecedent Total Water Storage (ATWS) anomalies from the new 5-day solutions, a novel product vs the standard monthly solutions, to enhance the detection of pre-flood and active flood conditions and to map post-flood storage anomalies. The GRACE data were compared with approximately 3,300 flood events reported by the Dartmouth Flood Observatory (2002–2021), revealing distinct ATWS precursor signals in 5-day solutions, in contrast to the monthly solutions. Specifically, floods caused by saturation-excess runoff—triggered by persistent rainfall, monsoonal patterns, snowmelt, or rain-on-snow events—show detectable ATWS increases 15 to 50 days before and during floods, providing a valuable opportunity to improve flood monitoring. These 5-day solutions also facilitate a more rapid mapping of post-flood storage changes to assess flood recovery from tropical cyclones and sub-monthly weather extremes.

Scientists exploited the seven-hour revisit time over the tropics in Cyclone Global Navigation Satellite System (CYGNSS) observations of ocean surface winds in the environment and core region of hurricanes to advance weather research and prediction studies. They performed storm surge simulations with the Advanced Circulation (ADCIRC) model and validation studies against high water mark data provided by the U.S. Geological Survey. To provide context for the CYGNSS-based results, comparisons to storm surge predictions using NASA’s Modern-Era Retrospective analysis for Research and Applications, Version 2 (MERRA-2), wind fields are also analyzed using the example of hurricane Harvey. In this initial assessment, it is observed that augmenting existing wind estimates with information provided by Global Navigation Satellite Systems Reflectometry systems, such as CYGNSS, has the potential of improving surge predictions relative to existing sources of wind information.

1.1.3: Use the global vantage point of space along with the significant scientific knowledge acquired, to advance our understanding of the Earth system and to curate actionable information to help the Nation understand, mitigate, and adapt to climate change. (Agency Priority Goal)

NASA achieved the five FY 2024 milestones, resulting in a Green rating for this two-year Agency Priority Goal. NASA will continue to track progress toward the FY 2025 milestones through a Performance Goal in NASA's FY 2025 Agency Performance Plan:

- NASA launched the web-based portal and information system, U.S. Greenhouse Gas Center, in December 2023 by prototyping initial demonstration areas in collaboration with the Environmental Protection Agency (EPA), National Oceanic and Atmospheric Administration (NOAA), and National Institute of Standards and Technology (NIST). NASA is maturing the portal and information system and expects to establish a regular cadence of stakeholder engagement by the end of FY 2025.
- The Surface Biology and Geology (SBG) project completed the System Requirements Review development milestone in November 2023. SBG is part of NASA's Earth System Observatory (ESO), the next generation of flight missions that will help answer climate, ecosystems and natural resources, hydrology, solid Earth, and weather-related questions.
- NASA launched two new observing systems: Plankton, Aerosol, Cloud, ocean Ecosystem (PACE) mission on February 8, 2024, and Polar Radiant Energy in the Far InfraRed Experiment (PREFIRE) missions in May and June 2024. In May 2024, NASA announced the completion of step-1 for the Earth System Explorers new line of Earth Science missions by selecting four proposals for step-2 mission concept studies.

In pursuing these objectives, NASA will achieve significant benefits to society by establishing and maintaining a robust cadence of Earth Science missions, including new and innovative observing systems, which in turn will enable new and updated models, observations, research, and applications in various fields such as agriculture, air quality, and water resources.

1.2: Understand the Sun, solar system, and universe.

LEAD OFFICE
Science Mission Directorate (SMD)

GOAL LEADER
Karen Flynn, Deputy Associate Administrator for Management, SMD

Humanity has always been enthralled by the mysteries of our universe. Strategic Objective 1.2 seeks to expand our understanding of the universe, search for life elsewhere, and protect and improve life on Earth and in space. These efforts are guided by high-priority questions and recommendations from the National Academies' decadal surveys and are implemented by a balanced portfolio of programs.

Astrophysics aims to expand humanity's understanding of how the universe began and evolved, how it works, and whether there are places beyond Earth where life might thrive. Heliophysics studies the nature of the Sun, and how it influences the very nature of space – and, in turn, the atmospheres of planets and the technology that exists there. Planetary Science explores the objects in our solar system to better understand its history and the distribution of life within the solar system. Biological and Physical Sciences study phenomena in ways that cannot be done on Earth, to lead the world in fundamental space-based research, pioneer transformational discoveries, and enable sustained human presence.

In recent assessments, external expert review panels rated NASA's progress toward all nine of its Strategic Objective 1.2 science goals as having met expectations. The James Webb Space Telescope, the most powerful and complex space telescope ever built continues to study every phase in the history of our Universe. In October 2023, NASA launched Psyche, designed to visit a metal-rich asteroid that contains planetesimal, a building block of an early planet. The Mars Perseverance rover continues to seek signs of ancient life and has collected samples of rock and regolith for an eventual return to Earth. NASA continues development of Interstellar Mapping and Acceleration Probe (IMAP), Europa Clipper, the Nancy Grace Roman Space Telescope (Roman), and Near-Earth Object (NEO) Surveyor.

Despite NASA's excellent progress in the near-term to achieve performance goals related to understanding the universe, cost growth from missions in development and lower-than-requested appropriations have impacted NASA's science missions. Without additional funding or mitigation strategies, NASA will take longer than planned to achieve 25% of mid- and 33% of long-term success criteria.

These challenges are placing at risk NASA's ability to support new missions and activities recommended in new and upcoming decadal surveys and maintain the recommended cadence for the Explorer, Discovery, and New Frontiers competed mission lines. In addition, with decreased work at the centers, SMD will also have to address the resulting workforce challenges.

Based on the challenges described in the above paragraphs, Strategic Objective 1.2 achieved a Yellow/Focus Area for Improvement rating during the 2024 Strategic Review Process.

1.2.1: Demonstrate progress in exploring and advancing understanding of the physical processes and connections of the Sun, space, and planetary environments throughout the solar system.

NASA achieved the FY 2024 target, as determined by the Heliophysics Advisory Committee in September 2024, leading to a Green rating for this multiyear Performance Goal. Below are examples of the science progress made during FY 2024.

Our solar system is filled with magnetized charged particles continuously flowing supersonically away from the Sun. This so-called "solar wind" creates a bubble surrounding the solar system, the heliosphere, whose magnetic field helps to shield everything within it from galactic radiation, including

human explorers to the Moon and Mars. The solar wind also is a crucial part of the coupling between Earth's space environment (the magnetosphere) and energy coming from the Sun. NASA's Parker Solar Probe mission has made key discoveries that help us better understand the origin of the solar wind and its effects on the near-Earth space environment. How the solar wind is accelerated to extremely high speeds, about a million miles per hour, has been a decades-old question. A driver of the solar wind's fast speed has long been conjectured to be the large electric field that develops because electrons are two thousand times lighter than protons and can easily escape the Sun. This electric field accelerates the heavier protons that would otherwise be trapped by the Sun's gravity, allowing both electrons and protons to escape into the solar wind. Parker Solar Probe measured this electric field, and its strength is consistent with predictions first made in the 1960s. Parker Solar Probe's measurements have also revealed unexpected high-energy kinks in the magnetic field, called "switchbacks." These features permeate the solar wind near the Sun and act like whips that further heat and accelerate the solar wind out into interplanetary space. In addition, though the underlying magnetic field intensity in switchbacks is roughly constant, it was found that the distribution of magnetic field intensities over different intervals provides a means of differentiating the origin of individual solar wind streams directly from in-situ data, without relying on difficult and indirect procedures to map streams back to the Sun. These discoveries, and more, have shown that several mechanisms exist in the formation of the solar wind. Understanding these mechanisms is essential for space weather predictions and comprehending how the solar wind inflates and forms the heliosphere.

Magnetic reconnection is a physical process that leads to the explosive release of large amounts of energy stored in the magnetic fields that permeate space. One example occurs 50,000 miles away in the magnetic field on the side of Earth opposite to the Sun. There, magnetic reconnection accelerates and heats up the surrounding superheated plasma. This ultimately leads to the beautiful auroral light displays seen by people on Earth, but also drives many harmful effects of space weather. However, understanding the amount by which the plasma gets heated due to magnetic reconnection has been elusive. This year, measurements from NASA's Magnetospheric Multiscale (MMS) mission were used to determine the amount the electrons in the plasma get heated. The satellite observations were used to show that the heating of electrons follows a quantifiable relationship that is consistent with a theory suggested nearly a decade ago. Scientists can now predict the magnitude of electron heating using a single parameter. In addition to implications for the near-Earth space environment, this research can be applied to other settings where magnetic reconnection takes place, including solar flares in the Sun's atmosphere and in other planetary and astrophysical plasmas.

Earth's atmosphere is constantly evolving. While the lower atmosphere is mostly made of electrically neutral matter, the upper atmosphere called the ionosphere also contains electrons and positively charged ions. One way that the upper atmosphere evolves is by losing some of its ions to space. Over 60 years ago, researchers hypothesized that the electric force, along with gravity and Earth's magnetic field, controls the outward flow of ions. For the first time, NASA's Endurance suborbital rocket mission successfully confirmed the existence of the exceptionally weak "ambipolar" electric field driving the flow. The electric field, generated by the upward pressure of ionospheric electrons, tethers ions and electrons together and counteracts gravity acting on the ions. As a result, it effectively extends the

height of the polar ionosphere and lifts some ions high enough to escape to space, where they can be blown away by the solar wind. This planetary-sized electric field may have continuously shaped the evolution of Earth's atmosphere for billions of years. Similar electric fields may exist on other planets, including Venus and Mars, and may also impact the habitability of exoplanets.

While space in the inner region of the solar system is mostly permeated by tiny fundamental particles, the outer region of the solar system—called the Kuiper Belt—is made up of icy rocks. Billions of years ago, such rocks played a role in the formation of planets. When rocks in the Kuiper Belt collide, tiny remnants, referred to as "dust," are produced. There are models that predict how much dust is present in the Kuiper Belt, but it takes direct measurement to see which, if any, of these models are valid. NASA's New Horizons satellite has reached the outer edge of the Kuiper Belt, a distance five billion miles away—55 times the distance from the Sun to Earth. On New Horizons is a dust detector called the Venetia Burney Student Dust Counter, which was designed and built by students. New measurements reveal higher amounts of dust particles than expected from model predictions. One potential explanation for this unexpected observation is how much sunlight pushes dust particles farther away from the Sun. By understanding the dust population in the Kuiper Belt, scientists learn about the formation of the planets in our solar system and the formation of exoplanets throughout the universe. These measurements also help us understand the importance of solar radiation and its impact on neutral particles that inform us of the heliosphere's interaction with the interstellar medium.

1.2.2: Demonstrate progress in exploring and probing the origin, evolution, and destiny of the galaxies, stars, and planets that make up the universe.

NASA achieved the FY 2024 target, as determined by the Astrophysics Advisory Committee in November 2024, leading to a Green rating for this multiyear Performance Goal. Below are examples of scientific progress reported during FY 2024.

Astronomers with NASA's Fermi Gamma-ray Space Telescope searching for a gamma-ray feature related to the Cosmic Microwave Background (CMB) have found an unexpected and as-yet unexplained feature outside of our galaxy. The scientists combined 13 years of Fermi Large Area Telescope observations of gamma rays above about three billion electron volts (GeV). They discovered a much stronger (ten times larger than expected) gamma-ray signal in a different part of the sky than what was expected. Intriguingly, this gamma-ray signal is found in a similar direction and with a nearly identical magnitude as another unexplained feature, one produced by some of the most energetic cosmic particles ever detected. Scientists say the CMB originated when the hot, expanding universe had cooled enough to form the first atoms, an event that released a burst of light that, for the first time, could permeate the cosmos. In order to study the tiny temperature variations within the CMB, this dipole signal must be removed. Astronomers generally regard the pattern as a result of the motion of our own solar system relative to the CMB at about 230 miles (370 kilometers) per second. They removed all resolved and identified sources and stripped out the central plane of our Milky Way galaxy to analyze the extragalactic gamma-ray background.

Cosmic rays are accelerated charged particles – mostly protons and atomic nuclei. The rarest and most energetic particles, called UHECRs (ultrahigh-energy cosmic rays), carry more than a billion times the energy of three GeV gamma rays, and their origins remain one of the biggest mysteries in astrophysics. Since 2017, the Pierre Auger Observatory in Argentina has reported a dipole in the arrival direction of UHECRs. Being electrically charged, cosmic rays are diverted by the galaxy's magnetic field by different amounts depending on their energies, but the UHECR dipole peaks in a sky location similar to what another team finds in gamma rays. And both have strikingly similar magnitudes—about 7% more gamma rays or particles than average coming from one direction and correspondingly smaller amounts arriving from the opposite direction. The scientists think it is likely the two phenomena are linked—that as-yet unidentified sources are producing both the gamma rays and the ultrahigh-energy particles. To solve this cosmic conundrum, astronomers must either locate these mysterious sources or propose alternative explanations for both features.

NASA's Imaging X-ray Polarimetry Experiment (IXPE) mission is rewriting the textbooks on the shape and structure of the disk of hot gas that forms as matter falls into a black hole. Understanding that structure enables critical insights into the behavior and evolution of black holes. IXPE observed the "coronae" of a variety of these disks. The corona is a region associated with the disk that is full of electrons as hot as a billion degrees. Such intensely hot electrons emit enormous amounts of X-ray light. The observations clearly indicate that the coronae are distributed similarly to the other matter in these disks feeding black holes, spanning masses as small as a few times that of the Sun to billions of times a solar mass. These measurements are surprising given the differences in how these different mass black holes came into being.

NASA's James Webb Space Telescope is pushing the cosmic frontiers of space exploration, revealing a large abundance of "little red dots" in the early universe, when it was merely a few hundred million years old. These "little red dots" are compact and relatively high mass and appear red in multicolor images. While they were originally mistaken for massive, compact galaxies, more recent Webb observations reveal that their spectral properties are suggestive of an underlying intermediate mass black hole that may be 100 to 1000 times more massive than the black hole at the center of our own galaxy. If confirmed, this means that very massive black holes were formed when the universe was only 0.4 to 1 billion years old, which is currently believed to be too short of a timescale for forming such massive systems, challenging current models for black hole and galaxy formation.

Webb's Near-Infrared Camera (NIRCam) captured in the Serpens Nebula a long-awaited phenomenon. Astronomers found jets of gas spewing from newborn stars which have collided with nearby gas and dust at high speeds, seen in the northern area of this young, nearby star-forming region. Typically, these objects have varied orientations within one region. Here, however, they are all slanted in the same direction, to the same degree, like sleet pouring down during a storm. The discovery of these aligned objects, made possible due to Webb's exquisite spatial resolution and sensitivity in near-infrared wavelengths, is providing insight into the fundamentals of how stars are born. This region has been home to other coincidental discoveries, including the flapping "Bat Shadow," which earned its name when 2020 data from NASA's Hubble Space Telescope revealed a star's planet-forming disk to flap, or

shift. Next steps for the team are to use Webb's Near-Infrared Spectrograph (NIRSpec) to investigate the chemical makeup of the cloud, determining how volatile chemicals survive star and planet formation.

1.2.3: Demonstrate progress in exploring, observing, and understanding objects in the solar system in order to understand how they formed, operate, interact, and evolve.

NASA achieved the FY 2024 target, as determined by the Planetary Science Advisory Committee in September 2024, leading to a Green rating, for this multiyear Performance Goal. Below are examples of scientific progress reported in FY 2024.

One of NASA's asteroid-focused missions, Origins, Spectral Interpretation, Resource Identification, and Security–Regolith Explorer (OSIRIS-Rex), completed a key milestone in September 2023 when its capsule was dropped to Earth containing about 120 grams of pristine carbonaceous regolith from asteroid Bennu. The OSIRIS-REx science team undertook early analyses of this asteroid sample and described its delivery and initial allocation in a study that introduces its bulk physical, chemical, and mineralogical properties. Overall, the team found that the regolith is very dark but contains interspersed inclusions and particles that have higher reflectance. The particles range in size from submicron dust to a stone that is about 3.5 centimeters long. The sample confirms many of the remote sensing observations of Bennu made by OSIRIS-REx, including the detection of hydrated phyllosilicates, magnetite, organic compounds, carbonates, and anhydrous silicates. The sample's composition and mineralogy indicate that Bennu experienced substantial levels of aqueous alteration. The findings of this work highlight the value of sample return missions—especially for low-density material that may not survive atmospheric entry—and lay the groundwork for many more comprehensive analyses of the OSIRIS-REx samples.

Ocean worlds, or icy bodies in the outer solar system that have or once had subsurface liquid water oceans, are compelling targets for exploration, but confirming the existence of a subsurface ocean typically requires spacecraft observations taken from close proximity. In particular, Triton and Pluto are of interest because they are thought to have similar origins, but different evolutionary histories. In a new study, the team demonstrated a novel way to use remote observations to test whether Pluto and/or Triton may have, or once had, a subsurface ocean. They show that the current composition of volatiles on the surfaces and in the atmospheres of Pluto and Triton are deficient in carbon, which can only be explained by the loss of methane through a combination of aqueous chemistry and atmospheric processes. Further, they find that Triton's lower abundance of methane compared with Pluto—and the detection of carbon dioxide at Triton, but not Pluto—points to aqueous chemistry in a subsurface ocean that was more efficient and/or long lasting at Triton than Pluto. These results provide new insight into the role of volatiles in the outer solar system (i.e., in the formation of the giant planets and Kuiper Belt Objects, and in determining the conditions required to form subsurface liquid water oceans).

Despite broad similarities of Venus to Earth in terms of mass and size, there is no evidence of plate tectonics on its young surface, yet the question remains whether Venus ever experienced a plate tectonics regime. In new work, Venus's atmosphere, which is linked to its interior evolution, was used as a diagnostic to constrain the planet's evolution. The present-day Venus atmosphere was compared to modeled atmospheres generated by coupling long-term thermal-chemical-tectonic evolution models

with volcanic gas speciation models. The results indicate that a single-plate stagnant lid regime operating since the time of magma ocean solidification cannot explain the present-day atmospheric abundances of nitrogen, carbon dioxide, or Venus's surface pressure. Instead, the authors suggest that the atmosphere requires outgassing in an early phase of plate-tectonic activity. These findings imply that Venus's atmosphere results from a great climatic-tectonic transition—from an early phase of active lid tectonics that lasted for at least one billion years, followed by the current stagnant-lid-like mode of reduced outgassing rates. This work shows for the first time that a planet's atmosphere may be the best way to understand some of its ancient history that is not preserved on its surface and that both Earth and Venus may have had plate tectonic regimes operating at the same time in the past.

The global energy budget of a planet is pivotal for understanding planetary evolution and climate behaviors. Assessing the energy budget of giant planets, particularly those with large seasonal cycles, however, remains a challenge without long-term observations. In a new study, therefore, researchers used long-term observations of Saturn from NASA's Cassini mission to determine the planet's global energy budget. They systematically analyzed long-term (2004 to 2017) multi-instrument (Composite Infrared Spectrometer, Imaging Science Subsystem, and Visual and Infrared Mapping Spectrometer) observations. The results of the analyses suggest that Saturn's global energy budget is not in a steady state—exhibiting significant dynamical imbalances. They also found that there are seasonal energy imbalances at both the global and hemispheric scales that may contribute to the development of giant convective storms on Saturn. The authors suggest that similar global energy imbalances may exist on the other giant planets. This finding has strong implications for current models and theories of atmosphere, climate, and evolution of the gas giants that assume the global energy budgets are balanced.

1.2.4: Demonstrate progress in discovering and studying planets around other stars.

NASA achieved the FY 2024 target, as determined by the Astrophysics Advisory Committee in November 2024, leading to a Green rating for this multiyear Performance Goal. Below are examples of scientific progress reported during FY 2024.

Although the James Webb Space Telescope (Webb) provides the first opportunity to study the atmospheres of terrestrial exoplanets and to estimate their surface conditions, Earth-size planets around Sun-like stars are currently inaccessible with Webb. However, future direct imaging missions will be sensitive enough to characterize the atmospheres of these exoplanets. Being able to detect active volcanism on an Earth-like planet would be particularly valuable because it would provide insight into the planet's interior and provide important comparisons with Earth (and Venus). A team of researchers has therefore investigated the observational requirements that would be necessary for detection of volcanic activity on an Earth-like exoplanet from a future telescope. They used a 3D climate model to simulate several volcanic eruptions on Earth and then treated Earth as an exoplanet being observed from a hypothetic telescope with a coronagraph. Data from the model was used to simulate the planet's reflectance spectra and how it would change over time. The results showed that the most detectable and least ambiguous evidence of volcanism would be changes in ozone absorption and the slope of the reflectance spectrum—the size of ozone and water features would decrease while volcanic eruptions

were ongoing and would slowly return to their original size after the eruptions cease. It would, therefore, be difficult to identify ongoing volcanism from a single observation. Changes in such absorption features over the course of several observations, however, may provide the evidence required to identify volcanism on an Earth-like exoplanet.

Webb observations include atmospheric characterization of transiting exoplanets and some of the first exoplanets to be observed by Webb have equilibrium temperatures below 1,000 Kelvin—a regime where photochemical hazes are expected to form. The optical properties of these hazes (which control how they interact with light) are critical for interpreting exoplanet observations, but relevant experimental data have not previously been available. A team of scientists have measured the density and optical properties of organic haze analogues that were generated in water-rich exoplanet atmosphere experiments. They report optical constants for the organic haze analogues that are relevant to current and future observational and modeling efforts across the entire Webb instrumentation wavelength range (and a large part of the Hubble Space Telescope's). The team also used the new optical constants to generate hazy model atmospheric spectra. These synthetic spectra show that differences in haze optical constants have a detectable effect on the spectra and can thus impact how exoplanet observations are interpreted.

A previously uncharted asteroid inside the asteroid belt in our solar system was found by citizen scientists who searched through 37,000 Hubble images spanning 19 years. Easier to visually identify when they are illuminated by a distant galaxy and other astronomical objects, asteroids appear as curved trails in Hubble images because of the parallax induced by the fast orbital motion of the spacecraft. The parallax effect can be computed to obtain the distance to the asteroids. This technique resulted in the identification of 1,701 asteroid trails, with 1,031 of the asteroids previously uncatalogued. About 400 of these uncatalogued asteroids are below one kilometer in size. Professional scientists combined the volunteers' efforts with machine learning algorithms to identify the asteroids. This represents a new approach to finding asteroids in astronomical archives spanning decades, which may be effectively applied to other datasets. The large, random sample offers new insights into the formation and evolution of the asteroid belt.

1.2.5: Demonstrate progress in improving understanding of the origin and evolution of life on Earth to guide the search for life elsewhere, exploring and finding locations where life could have existed or could exist today, and exploring whether planets around other stars could harbor life.

NASA achieved the FY 2024 target, as determined by the Planetary Science Advisory Committee in September 2024, leading to a Green rating for this multiyear Performance Goal. Below are examples of scientific progress reported in FY 2024.

Identifying how common biological molecules, thought to have been present as life emerged, could have formed before life is a critical step in understanding the origin of life and the potential for life elsewhere in the solar system and beyond. For example, nucleic acids are biomolecules crucial to

modern life; they carry the genetic code and play a critical part in replication and function of cells. Although in modern biology, cellular machinery synthesizes these molecules, it possible that naturally occurring minerals played a role in their synthesis polymerization before life. In new work, the potential for a variety of minerals to promote elongation of ribonucleic acid (RNA) in water (as a model of condensation under plausible planetary conditions) was investigated. The results show that several of the newly tested minerals can promote synthesis, suggesting that a broader set of environments may have been able to host chemical reactions relevant to the origin of life than previously assumed.

Helping to guide the search for life elsewhere, a new study focused on water activity—a measure of the amount of free water molecules in an environment and a meaningful indicator of the habitability of an environment. Identifying the water activity limits for different types of biological activity is essential for predicting the habitability of Earth environments and other ocean worlds. Hypersaline brines provide excellent opportunities to study extreme microbial life, so in the study, the anabolic activity of nearly 6000 individual cells from sites with a range of water activities was investigated. The results indicate that, overall, average anabolic activity decreases exponentially with water activity. By extrapolating the obtained data, the authors suggest that anabolic activity likely continues beyond the previously established water activity limit for cell division and established a minimum detectable value for anabolic activity in seawater-sourced brines. These findings have important implications for life detection in areas of low water activity, such as putative liquid flows on Mars, as well as brines on Europa, Titan, and Enceladus.

Saturn's moon Enceladus is thought to be one of the most likely places in our solar system where life could exist or have existed in the past. Previous studies of in situ data collected by Cassini's Ion and Neutral Mass Spectrometer identified water, carbon dioxide, methane, ammonia, and hydrogen in the plume of ejected material emanating from Enceladus' south pole. Identification of additional, minor, species in the plume has been an ongoing challenge, however, because of the large number of possible combinations that can be used to fit these. In new work, the team therefore combined analyses of these Cassini data with a detailed statistical framework to enable discrimination between previously ambiguous molecules in the plume. The results indicate detection of several additional compounds that are important for understanding the habitability of Enceladus, including hydrogen cyanide, acetylene, propene, and ethane. These compounds—together with plausible mineralogical catalysts and redox gradients derived from surface radiolysis—could support extant microbial communities or drive complex organic synthesis leading to the origin of life.

A new study reports the discovery, by NASA's Transiting Exoplanet Survey Satellite (TESS), of a "super Earth exoplanet" (TOI-715b) that orbits an M-dwarf star only 137 light years from Earth. This planet's radius is about one and a half times that of Earth and orbits within the 'conservative' habitable zone of its parent star. The same system may also harbor a second, Earth-sized planet just inside the outer boundary of the habitable zone. The authors of this work demonstrate that TOI-715b is suitable for characterization using precise radial velocities and transmission spectroscopy and warrants further observations and investigations (e.g., to identify the composition of its atmosphere and its potential to harbor life).

1.2.6: Demonstrate progress in developing the capability to detect and knowledge to predict extreme conditions in space to protect life and society and to safeguard human and robotic explorers beyond Earth.

NASA achieved the FY 2024 target, as determined by the Heliophysics Advisory Committee in September 2024, leading to a Green rating for this multiyear Performance Goal. Below are examples of the progress made during FY 2024.

As described in the FY 2023 Annual Performance Report, SpaceX launched 49 Starlink satellites in February 2022, and within a couple of days, 38 of the satellites deorbited and were lost due to friction with the upper atmosphere, known as atmospheric drag. This loss of so many satellites was attributed to moderate space weather (i.e., the result of geomagnetic activity that was not particularly severe). This past year, significant progress was made to understand why moderate space weather had such a large impact on the satellite industry. Data from NASA's Heliophysics System Observatory, specifically the Solar and Heliospheric Observatory (SOHO), Solar Terrestrial Relations Observatory (STEREO), Solar Dynamics Observatory (SDO), Wind, and Advanced Composition Explorer (ACE) missions, combined with computer modeling of the upper atmosphere, were used to investigate the physical cause of the de-orbiting of the satellites. The comprehensive analysis performed this year revealed that the loss of the satellites was the result of several small coronal mass ejections, which increased the electrical currents in the upper atmosphere. These currents significantly heat the upper atmosphere through a process known as Joule heating, the same mechanism used to defrost rear windshields in automobiles. Several global computer models agreed on the amount by which frictional heating was increased due to the relatively small coronal mass ejections. Additionally, modeling of the satellites demonstrated that they deorbited in part due to orientation changes of the satellites resulting from the enhanced drag. The investigation established causality between the solar sources of space weather and their impact at low Earth orbit. It shows that even moderate space weather events can conspire to cause catastrophic losses for satellites launched into very low Earth orbit altitudes.

Solar energetic neutral atoms (ENAs) are high-energy particles that travel millions of miles through interplanetary space. They are formed near the Sun when a positively charged solar energetic particle (SEP) collides with a slow-moving neutral atom and steals an electron from it to become electrically neutral. Unlike charged particles in space, which are influenced by and also determine the structure of magnetic fields in the solar system, neutral atoms in space are unaffected by the magnetic fields of the Sun and Earth, so they travel unabated by the magnetic field through interplanetary space where they enter Earth's space environment. Consequently, they provide a unique probe of how SEPs are accelerated because they come directly from the site of their formation, rather than moving along interplanetary magnetic field lines. Up to now, solar ENAs have rarely been observed throughout interplanetary space. It is not yet clear whether they are common or rare, however, because current instrumentation on satellites is not designed to observe them. In the absence of a dedicated solar ENA instrument, instrumentation sensitive to SEPs have provided limited solar ENA detections under very particular conditions in which the solar ENAs can be distinguished from the more abundant SEPs. During the coronal mass ejection on February 15, 2022, the STEREO-A LET instrument observed a clear

signature of solar ENAs, verified by additional data from STEREO-A IMPACT and SECCHI instruments. Their arrival strongly peaked in the direction of the Sun, not the direction of the interplanetary magnetic field. Their range of velocities was consistent with them coming directly from a location near the Sun, rather than the longer path they would have taken if they traveled along the magnetic field. A comparison of the solar ENA energy distribution with model results and the timing of the solar ENA release indicates that they likely originated near a shock that formed as the result of a coronal mass ejection (CME) when the CME was still close to the Sun (at approximately 2-3 solar radii). Because solar ENAs carry the information of their parent SEP population, they can help us understand where and how those SEPs are produced and, thus, ultimately improve the prediction of SEPs, which are a danger to humans and technology in space.

During the geomagnetic storm of May 10-12, 2024, Northern Lights were seen across the United States. At the same time, NASA's Global-scale Observations of the Limb and Disk (GOLD) mission made unprecedented observations of changes in the upper levels of the atmosphere (the ionosphere and thermosphere), providing valuable insights into the effects of severe magnetic storms in near-Earth space. The GOLD mission captured the first images of Earth’s ionosphere and thermosphere from geostationary orbit during such a superstorm. These images showed unexpected and fundamental changes as Earth’s space environment was affected by the extreme geomagnetic storm. Within two hours, the Southern Lights in the southern hemisphere extended to mid-latitudes, reaching the southern tips of Africa and South America. This resulted in a complete absence of mid-latitude ionosphere in the affected region. About ten hours later, the superstorm produced remarkable changes in composition, temperature, and dynamics in Earth's thermosphere on the day side, attributed to variations of winds in the thermosphere. These observations, which also included comprehensive observations of composition, temperature, and neutral wind, provided valuable insights into the ionosphere's response to extreme geomagnetic disturbances that previously could not have been measured, emphasizing the intricate relationship between solar activity and Earth's upper atmosphere. These results provide critical data for improving space weather models and advance our capabilities for detecting, predicting, and mitigating disruptions during storm conditions in space. Such conditions negatively affect space-based operations and systems. For example, they can change satellite orbits, hamper satellite communication, or degrade a navigation system’s performance.

For more than 14 years, NASA’s SDO Extreme-ultraviolet Variability Experiment (EVE) has been making measurements of invisible, high-energy electromagnetic waves, called extreme ultraviolet (EUV) solar radiation. One of the early discoveries with SDO EVE was a class of solar flares during which the EUV radiation got brighter several minutes to even an hour after the flare reached its maximum brightness. It was previously postulated that these EUV-enhanced flares, called EUV Late Phase flares, could have additional impacts on the conductive upper atmosphere (the ionosphere) of Earth and other planets. Two recent studies investigated the ionosphere’s response to solar EUV Late Phase flares. The first study used data from multiple sources from the Sun (from SDO) and from Earth’s ionosphere (from the Global Navigation Satellite Systems (GNSS) and the Scripps Orbit and Permanent Array Center (SOPAC) ground stations). This study found that after a large flare on 2011 November 3, the EUV Late Phase emissions were energetic enough to significantly increase the plasma density of the ionosphere. The second study

used solar EUV data from the Sun, measured by SDO EVE, as input into an ionosphere-thermosphere model. This study found significant enhancements of the day side ionospheric plasma density in the 100 to 250-kilometer altitude range that correlated with both the main phase and EUV Late Phase of that flare. The detailed results highlight the importance of solar flares impacting Earth's upper atmospheric levels, because the ionospheric response can be about 30% larger for flares with EUV Late Phases. These insights are also directly applicable for research addressing the atmospheric and ionospheric variability on other planets, including exoplanets.

SEPs arise during solar storms both from the direct energization of protons during solar flares and in interplanetary space at the shock waves that form as a coronal mass ejection (CME) goes out into space. These particles have space weather implications because they can damage circuitry on satellites, interfere with radio communication, and are a radiation hazard for humans on airplanes, so it is important to understand the impact of SEPs on Earth. This year, a single large SEP event was studied with multiple spacecraft—Solar Orbiter, STEREO-A, Parker Solar Probe, BepiColombo, Mars Atmosphere and Volatile Evolution (MAVEN), ACE, SOHO, and Wind—at different distances from the Sun, from very close to the Sun all the way out to Mars. These observations showed that the resultant SEPs spread very far (more than 320 degrees) in longitude for this event. Moreover, it was found that there were significant differences in the observations of the CMEs that produced the SEPs even in nearby spacecraft, which implies that the three-dimensional CME structure is more complicated than previously thought. The study of widespread SEP events in the heliosphere is essential to advance our scientific understanding of CMEs and their impacts at Earth. This research was made possible because there is a fleet of heliophysics sensors now deployed, both in orbit around the Sun and in orbit around Earth, which is now able to provide an unprecedented combination of observations of the Sun itself and the inner heliosphere, where the solar wind, SEPs, and CMEs propagate toward the planets of our solar system. The combination of observations from the inner heliosphere together with observations from near Earth offers new opportunities for studying CME propagation from the corona to Earth, which is invaluable to increase the reliability of space weather forecasts.

1.2.7: Demonstrate progress in identifying, characterizing, and predicting objects in the solar system that pose threats to Earth or offer resources for human exploration.

NASA achieved the FY 2024 target, as determined by the Planetary Science Advisory Committee in September 2024, leading to a Green rating for this multiyear Performance Goal. Below are examples of scientific progress reported in FY 2024.

A small asteroid about one meter in size disintegrated harmlessly over Germany on January 21, 2024. At 95 minutes before it impacted Earth's atmosphere, NASA's Scout impact hazard assessment system, which monitors data on potential asteroid discoveries from the Minor Planet Center, gave advanced warning on the timing and location of the asteroid's impact. This is the eighth time in history that a small, Earth-bound asteroid has been detected while still in space, before entering and disintegrating in our atmosphere. The asteroid's impact produced a bright fireball (bolide) which was seen from as far away as the Czech Republic and may have scattered small meteorites on the ground at the impact site—

about 60 kilometers west of Berlin. The asteroid was later designated 2024 BX1. NASA was able to issue advance notification of this asteroid's impact on the agency's Asteroid Watch X account, and images of the asteroid safely disintegrating in the atmosphere were widely shared online, reinforcing NASA as a trusted source of information on asteroid close approaches.

Asteroid search teams, funded by NASA's Near-Earth Object Observations (NEOO) Program continue to make progress in discovering small bodies. As of July 30, 2024, 10,935 asteroids less than one kilometer in size had been discovered—bringing the total known population of near-Earth asteroids to 35,286 and of near-Earth comets to 123. High-precision orbit predictions computed by the Center for Near-Earth Object Studies (CNEOS) at NASA's Jet Propulsion Laboratory show that none of these objects is likely to strike Earth in the next century. However, 2,424 small bodies (of which 153 are larger than one kilometer in size) are in orbits that could become a hazard in the more-distant future and warrant continued monitoring.

In April 2024, NASA's Planetary Defense Coordination Office (PDCO), in partnership with Federal Emergency Management Agency (FEMA) and with the assistance of the U.S. Department of State Office of Space Affairs, convened the fifth biannual tabletop exercise to inform and assess our ability as a Nation to respond effectively to the threat of a potentially hazardous asteroid or comet. These hypothetical exercises provide valuable insights by exploring the risks, response options, and opportunities for collaboration posed by varying scenarios—from minor regional damage with little warning, to potential global catastrophes predicted years or decades in the future. Conducting exercises like these enables government stakeholders to identify and resolve potential issues as part of preparation for any real-world situation. This year's exercise brought together nearly 100 representatives from across U.S. government agencies and, for the first time, international collaborators on planetary defense. This exercise also directly responds to the National Preparedness Strategy and Action Plan for Near-Earth Object Hazards and Planetary Defense.[2].

NASA's Double Asteroid Redirection Test (DART) mission was another example of preparing to mitigate the effects of a potential asteroid threat. DART was the first mission to demonstrate asteroid deflection when the spacecraft impacted the asteroid Dimorphos on September 26, 2022. A new study provides a comprehensive summary of DART's achievements, particularly with regard to its planetary defense investigations. In particular, months of subsequent Earth-based observations of the binary system showed that Dimorphos' orbital period was changed by -33.24 minutes. In addition, dynamical models were used to determine that the momentum enhancement factor, resulting from the DART impact, is between 2.4 and 4.9 (depending on the mass of Dimorphos). More than 60 telescopes, as well as the Light Italian CubeSat for Imaging of Asteroids (LICIACube) spacecraft, contributed to the DART investigations, which addressed topics relating to ejecta and planetary defense requirements. Work to further understand DART's kinetic impact test and the Didymos system will continue (e.g., with the

[2] The National Preparedness Strategy and Action Plan for Near-Earth Object Hazards and Planetary Defense was released by the Planetary Defense Interagency Working Group of the National Science and Technology Council in April 2023.

European Space Agency's Hera mission that will build on DART and continue the ongoing international collaboration for planetary defense).

NASA continues to support significant studies focused on permanently shadowed regions at the Moon's polar regions that are thought to contain substantial potential resources (trapped water ice) and that are prime targets for upcoming robotic and crewed missions to the Moon. In a new study, the ages of these regions were investigated—to place new constraints on the amount of ice they may contain. The results show that, on average, the permanently shadowed regions are only 1.8 billion years old and that their cumulative area was half as large 2.2 billion years ago compared with today. Their area becomes negligible before 3.4 billion years ago. In addition, the NASA ShadowCam imaging experiment onboard the Korea Pathfinder Lunar Orbiter spacecraft is acquiring images of the lunar permanently shadowed regions. In one ShadowCam study, radiance-calibrated images, and modeling techniques, were used to characterize the secondary illumination of the permanently shadowed region of Shackleton crater at the lunar south pole. The results highlight the heterogeneous, dynamic, and complex nature of secondary lighting at permanently shadowed regions. In addition, the preliminary analysis of the floor of Shackleton crater from ShadowCam images acquired over multiple secondary illumination conditions does not indicate the presence of exposed surface ice even though temperatures are constantly below 110 kelvin in this region. Overall, both these studies indicate that the lunar permanently shadowed regions may contain less ice than previously thought.

1.2.8: Demonstrate progress in understanding the properties of physical and biological systems in spaceflight environments to advance scientific knowledge, enable space exploration, and benefit life on Earth.

The Biological and Physical Sciences Advisory Committee determined in November 2024 that NASA achieved the FY 2024 target, leading to a Green rating for this multiyear Performance Goal. Below are examples of science progress reported during FY 2024.

In the areas of fundamental physics, one notable advance was the first experimental demonstration of dual-species (potassium and rubidium) atom interferometry in space. This achievement was completed using the Cold Atom Lab (CAL) aboard the International Space Station (ISS). CAL enables innovative quantum physics experiments by cooling atoms to near-zero temperatures and studying them in microgravity for extended periods, free from the effects of gravity. Building on this demonstration of dual species atom interferometry in space, it was shown that the atom interferometer could be used as a quantum sensor using matter-wave interferometry in space to sense vibrations aboard the ISS. Furthermore, in the field of combustion research, the Saffire experiments were established to improve fire safety on spacecraft. These experiments study how fire spreads over solid materials in microgravity and evaluate how convection behavior in microgravity depends on pressure and oxygen levels.

NASA research also led to many significant discoveries in the biological sciences, funded by NASA. These include the identification of telomeric ribonucleic acid (RNA) responses in diverse organisms, such as humans and plants. The research has advanced our understanding of how deoxyribonucleic acid (DNA)

structure is influenced by stressful environments, such as spaceflight, climbing Mount Everest, and growing plants in simulated lunar regolith. Additional breakthroughs include insights into the impact of spaceflight on kidney function. Studies have shown that spaceflight can cause remodeling of kidney structure and function due to microgravity and galactic cosmic radiation, potentially leading to kidney stone formation and changes in urinary biochemistry in humans and animals. There has also been progress in developing peel-and-stick sensors that can be applied directly to plant leaves to monitor ethylene—a plant hormone that controls various physiological responses, including stress. These sensors could significantly improve the monitoring of plant health in enclosed environments, benefiting space crop production.

1.2.9: Achieve critical milestones of Science Mission Directorate's heliophysics, planetary science, and astrophysics major projects.

NASA achieved six of the nine FY 2024 milestones, resulting in a Yellow rating for this multiyear Performance Goal.

Several milestones reached full completion. The Europa Clipper mission moved closer to launch with the completion of its Pre-Ship Review in April 2024. The NEO Surveyor instrument passed its Critical Design Review in June, keeping this asteroid-hunting telescope on track. Also in June, the crucial Outer Barrel Assembly for the Roman Space Telescope was delivered. The Spectro-Photometer for the History of the Universe, Epoch of Reionization and Ices Explorer (SPHEREx) mission, designed to probe the universe's earliest moments, successfully completed its System Integration Review in November 2023. The Multi-Slit Solar Explorer (MUSE) completed its Preliminary Design Review in March, paving the way for deeper understanding of the Sun's dynamics. Finally, a Commercial Lunar Payload Services (CLPS) task order was awarded to Intuitive Machines on August 29 for delivery of research payloads to the lunar south pole.

Three milestones experienced delays. The first Dragonfly mission instrument Critical Design Review was rescheduled for early FY 2025 due to integration challenges with the new three-bladed rotor design. The Interstellar Mapping and Acceleration Probe (IMAP) instrument deliveries also experienced delays due to unexpected performance issues discovered during testing, pushing the completion date to December 2025. However, 60% of the IMAP instruments were completed by the end of FY 2024. Assembly and testing of the Payloads and Research Investigations on the Surface of the Moon 1b (PRISM-1b) payloads for lunar surface research encountered technical and programmatic challenges, delaying completion to mid-FY 2025. These delays contributed to the Performance Goal falling short of its target.

1.3: Ensure NASA's science data are accessible to all and produce practical benefits for society.

LEAD OFFICE
Science Mission Directorate (SMD)

GOAL LEADER
Karen Flynn, Deputy Associate Administrator for Management, SMD

Data accessibility is crucial for fostering innovation, enhancing decision-making, and driving efficiency across various sectors. When data is readily accessible, it allows researchers, businesses, and policymakers to identify trends, make informed choices, and develop solutions to complex problems more effectively. Furthermore, it democratizes information, enabling a wider range of individuals and organizations to participate in knowledge creation and problem-solving, ultimately leading to more equitable and inclusive advancements. Much of NASA's Earth, heliophysics, planetary, and astrophysics observations and data are freely accessible to all, including NASA's many partners in the United States, international organizations and governments, the scientific community, the private sector, and the public.

NASA has taken significant steps to ensure the accessibility and practical benefits of its scientific data. The agency has migrated the top 75 Earth Science datasets to the cloud through the Visualization, Exploration, and Data Analysis (VEDA) project, enabling researchers and commercial users to access them instantly, offering open-source tools for data processing, publishing, and visualization. The VEDA platform has been successfully deployed for the U.S. Greenhouse Gas Center, an interagency collaboration, and can be accessed online[3]. NASA's Science Mission Directorate has implemented Science Mission Directorate Policy SPD41a, a uniform data information policy that promotes open access to scientific publications, data, and software. Additionally, the agency has established the Science Discovery Engine to enhance the discoverability of over one million datasets and publications and has made over 50 awards to support open-source scientific software, data science at HBCUs, and open science projects.

Evolving and expanding cybersecurity demands and the need for increased data storage and processing continue to increase costs for NASA. Increased high-priority unplanned workloads are resulting in cost overruns and delays in implementations. NASA also faces risk related to staff retention and the potential for a skillset deficit. Given the transferability of skills that NASA personnel maintain, NASA is in close competition with private-sector technology firms to attract and retain talented and knowledgeable staff from a relatively limited talent pool.

Based on SMD's strategy and accomplishments described in the above paragraphs, Strategic Objective 1.3 achieved a Green/Satisfactory rating during the 2024 Strategic Review Process.

1.3.1: Accelerate the accessibility and use of NASA's science data and tools.

NASA achieved the two FY 2024 milestones, resulting in a Green rating for this multiyear Performance Goal. Below are examples of the progress made during the fiscal year.

NASA reached the target of making at least 95% of scientific data discoverable. The Science Discovery Engine (SDE) now incorporates data from across all Science Mission Directorates. In FY 2024, the SDE team integrated data from the NASA Science Explorer (SciX) and developed specialized search

[3] The VEDA dashboard can be accessed at https://www.earthdata.nasa.gov/dashboard/

interfaces, including one focused on environmental justice topics, providing access to curated datasets related to climate change, disasters, and other critical areas. A prototype search application for time-domain, multi-messenger astronomy was also developed. Further enhancements are planned, including the integration of INDUS, a suite of large language models, to improve the search experience.

NASA trained members of the over 2,200 individuals of the scientific community in Open Science principles, practices, and tools, exceeding the target. This included the release of the free Open Science 101 curriculum, offering online and instructor-led training, reaching over 1,900 participants. An additional three hundred individuals received training in introductory open science and data management plans. A new course on artificial intelligence and machine learning in Space Biology was also released, further equipping researchers with critical skills. These efforts directly contributed to this Performance Goal by ensuring that the expanded access to data is paired with the knowledge and skills needed to utilize it effectively.

1.3.2: Apply insights from Earth science to benefit the economy, health, quality of life, and environment around the globe.

NASA achieved the two FY 2024 milestones, resulting in a Green rating for this multiyear Performance Goal. Below are examples of the progress made during the fiscal year.

The target of advancing 40% of projects at least one Application Readiness Level (ARL) was surpassed by achieving 52% of projects (47 out of 90) advancing at least one ARL. Furthermore, six projects reached the crucial ARL 8 or 9 stages, indicating their integration into regular use and decision-making, surpassing the target of three projects. This achievement demonstrates the increasing maturity and practical applicability of NASA's Earth science research.

NASA engaged almost 18,000 people in capacity-building programs, significantly exceeding the target of 15,500 individuals. The Applied Remote Sensing Training Program (ARSET) alone reached over 16,870 individuals, while the SERVIR and DEVELOP programs also contributed substantially, engaging 827 and 201 individuals, respectively. These efforts underscore NASA's commitment to empowering communities with the knowledge and skills to utilize Earth science data for societal benefit.

NASA transitioned two projects to ARL 9. One project, focused on health and air quality, refined tools for predicting cholera transmission conditions and conducted a capacity-building workshop in Nairobi, Kenya. The other project, focused on water resources, developed a reservoir management tool tailored for the Indian state of Kerala, which is now being used to monitor hydropower dams and mitigate flood risks. These examples demonstrate the tangible impact of NASA's Earth science applications in addressing critical global challenges. These successes build upon previous efforts to make NASA data accessible and useful, aligning with the agency's commitment to expanding human knowledge and benefiting society.

2: Extend human presence to the Moon and onto Mars for sustainable long-term exploration, development, and utilization.

2.1: Explore the surface of the Moon and deep space.

LEAD OFFICE
Exploration Systems Development Mission Directorate (ESDMD)

GOAL LEADER
Ned Penley, Deputy Associate Administrator for Management, ESDMD

The Moon, our closest celestial neighbor, offers a unique testing ground for the technologies and innovations needed for future exploration of distant planets and exoplanets. The lunar surface offers us a valuable opportunity to uncover resources that could support long-term space travel and human settlements in the future. Strategic Objective 2.1 seeks to progress this goal by returning humanity to the surface of the Moon, including the first woman and first person of color.

The first crewed flight test launch for Artemis II, now slated for September 2025 after originally being scheduled for 2024, will send four astronauts on a journey around the Moon. The past year was pivotal, focused on developing mitigation strategies for remaining and emerging technical issues, delivering flight hardware and conducting testing, checkout, and preparations to support the Artemis II launch. The Orion spacecraft is progressing towards final assembly and testing, with ongoing hardware qualification and verification. Exploration Ground Systems will finalize Artemis II booster stacking, core stage mate, and integrated test and checkout operations in fall 2024. After the integration of Orion and SLS in the Vehicle Assembly Building (VAB) and final testing at Pad 39B, EGS will transport the integrated vehicle to the Pad for the crewed launch of Artemis II.

Artemis III's hardware development continues to achieve critical milestones. NASA continues to work with SpaceX to mature the Starship human landing system, with a focus on the Propellant Transfer Flight. Throughout FY 2024, NASA continued the assembly, integration, and testing of Artemis III's Command Module. By Spring 2025, installations of the secondary structure, as well as part one of the Environmental Control and Life Support System and propulsion components' proof and leak testing, will be completed. The Artemis III NASA Docking System, essential for Orion spacecraft's docking to a Gateway or Human Landing Systems element for Artemis III and future missions, will be delivered to Kennedy Space Center by the year’s end.

As a part of future developments, NASA is working with industry and international partners to establish infrastructure on the Moon to prepare for missions to Mars. NASA is working to advance capabilities for a lunar terrain vehicle that Artemis astronauts will use to travel around the lunar surface, conducting scientific research during the agency’s Artemis campaign at the Moon and preparing for future missions to Mars.

The preparation for later Artemis missions continues as well. The Mobile Launcher-2, the platform and structure from which the SLS Block 1B will be launched has entered the construction phase. Risks encountered in the engineering phase have largely been mitigated. The milestone, Jack and Set, for the ML2 demonstrates that procurement changes to add incentive fee payments to the contract and the new construction approaches have all been effective. The Jack and Set milestone was completed two weeks prior to the replan date.

Insufficient contractor performance threatens the cost and schedule of the Artemis missions. Given each mission is highly contingent upon the success of the prior missions, a slippage in cost and schedule in Artemis II and III could lead to delays in further Artemis missions. NASA has set Agency Baseline Commitments for the SLS Block 1B, Mobile Launcher 2, Gateway Initial Capability and HLS Initial Capability. ESDMD is also driving towards procurement strategies that enable cost savings and reductions.

NASA is currently working to mitigate the misalignment between the anticipated and required date of the initial delivery of the modules for the Gateway integrated mission spacecraft. The Gateway program is working closely with both its prime contractors for initial capability, Northrop Grumman and Maxar Space Systems (Maxar), to ensure the final mass of the Co-Manifested Vehicle aligns with the expected performance of the launch vehicle. The Gateway program is currently approaching the next major milestone in its life cycle, the Critical Design Review (CDR)-Informed Sync Review, where it will evaluate the integrity of the project design and its ability to meet mission requirements with appropriate margins and acceptable risk. The Gateway program continues to observe mass metrics and evaluate mass savings opportunities.

Based on ESDMD's strategy and accomplishments described in the above paragraphs, Strategic Objective 2.1 achieved a Green/Satisfactory rating during the 2024 Strategic Review Process.

2.1.1: Advance America's goal to land the first woman and first person of color on the Moon and pursue a sustainable program of exploration, support scientific discovery, and demonstrate capabilities that advance lunar exploration. By September 30, 2025, NASA will Launch Artemis II, the first crewed Artemis mission. Additionally, NASA will demonstrate a key enabling technology by completing an on-orbit propellant transfer test in preparation for Artemis III and it will deliver other key capabilities to enable deep space exploration. (Agency Priority Goal)

NASA has delayed the launch of Artemis II from September 2025 to April 2026 to address issues with Orion's heat shield and life-support systems. However, NASA completed two of four milestones and activities planned for FY 2024, resulting in a Yellow Performance Goal rating. The last remaining FY 2023 milestone was also completed. In Quarter One (Q1) the Artemis II SLS booster segments, aft skirts, nozzle extensions, and struts were delivered to the Kennedy Space Center (KSC), and initial offline processing was completed. This essential hardware directly supports the Artemis II launch.

Milestone 2.1.1.3, the Q3 completion of the Extravehicular Activity and Human Surface Mobility Program (EHP) Exploration Extravehicular Activity Services (xEVAS) Development Preliminary Design Review (PDR)-informed Sync Review, was achieved. The closure board for this review was held in August. This milestone contributes to the broader objective of developing capabilities for deep space exploration, as outlined in Performance Goal 2.1.1.

Originally planned in FY 2024, the kickoff of the Artemis III Integrated Sync Review #2, was rescheduled to FY 2025 Q1. Although related to lunar exploration, this milestone primarily supports Artemis III, not the Artemis II launch targeted by Performance Goal 2.1.1.

Milestone 2.1.1.4, the Q4 delivery of the Gateway Habitation and Logistics Outpost (HALO) Habitable Element, was below target. Delivery was delayed to January 2025. This milestone supports future deep space exploration goals but does not directly impact the Artemis II launch date.

2.1.2: Develop the capabilities and infrastructure necessary to transport human missions from Earth to cislunar space.

NASA completed four of five milestones and activities planned for FY 2024, resulting in a Green Performance Goal rating. The Artemis II Crew Module and Service Module completed vacuum performance testing in June 2024 (Milestone 2.1.2.1). The Mobile Launcher-1 was prepared for Artemis II crewed operations, returning to the Vehicle Assembly Building for final preparations (Milestone 2.1.2.2). Artemis III also saw advancements with the completion of Booster Aft Skirts, ready for Acceptance Checkout in July 2024 (Milestone 2.1.2.3). Looking ahead to Artemis IV, production began on the Exploration Upper Stage, and the RL10C-3 engines were completed (Milestone 2.1.2.5). While the Artemis III Crew Module initial power on was delayed until FY 2025 (Milestone 2.1.2.4), the overall progress on Performance Goal 2.1.2 remained on track.

2.1.3: Complete the exploration activities that will support missions with human crew members to the lunar surface.

NASA completed five of five milestones and activities planned for FY 2024, resulting in a Green Performance Goal rating. The Human Landing System (HLS) Option A (SpaceX) Starship Orbital Launch Architecture Assessment (Milestone 2.1.3.1) was completed in January 2024. The Gateway MAXAR Power and Propulsion (PPE) Critical Design Review (CDR), Milestone 2.1.3.2, was finalized in March 2024. Progress continued with the completion of the Exploration Extravehicular Activity Services (xEVAS) Artemis Suit Preliminary Design Review (PDR) (Milestone 2.1.3.3). The Axiom Artemis suit PDR and subsequent PDR-informed sync review were finished and prepared for presentation. Milestone 2.1.3.4, the HLS NextSTEP-2 Appendix P: Sustaining Lunar Development PDR, was also completed. Finally, the Lunar Terrain Vehicle (LTV) Phase 1 contracts (Milestone 2.1.3.5) were awarded in March 2024. These achievements build upon previous work, such as the Q2 selection of Intuitive Machines, Lunar Outpost, and Venturi Astrolab to advance LTV capabilities for Artemis astronauts.

2.2: Develop a human spaceflight economy enabled by a commercial market.

LEAD OFFICE
Space Operations Mission Directorate (SOMD)

GOAL LEADER
Tonya McNair, Deputy Associate Administrator for Management, SOMD

A human space flight economy is a catalyst for progress, driving advancements that extend beyond the boundaries of our planet and contributing to the collective growth and sustainability of human civilization. Expanding commercial activity is a critical aspect of pushing the frontiers of exploration and cultivating a sustained human presence in space, and commercial partners are important for quickly and cost-effectively advancing NASA's strategic objectives. Strategic Objective 2.2 directs NASA's commitment to foster a thriving space economy bolstered by a strong commercial market.

In the past year, NASA expanded the space economy by leveraging the International Space Station (ISS) to stimulate the growth of human spaceflight commercial activities and sustain the foundation of the Low Earth Orbit (LEO) ecosystem through commercial transportation systems and platforms via the Commercial Crew Program and Commercial LEO Development Program (CLDP). NASA continued to support the implementation of new technology demonstrations, enabling U.S. businesses and institutions of higher learning to raise the technological readiness level of their manufacturing technologies and products for In-Space Production Applications by sponsoring 15 investigations through NASA and the ISS National Laboratory and conducting at least 45 experiments using commercial facilities on the ISS.

To ensure NASA maintains the capability of applying these technology demonstrations in the future, the CLDP achieved key milestones, as they continue progress through their developmental phase. This includes essential reviews of functions of the new LEO destinations such as testing of Environmental Control and Life Support Systems and window material tests. Two partners under a funded Space Act Agreement (SAA) and one partner under a firm fixed price contract have successfully achieved their anticipated respective milestones for FY 2024. CLDP has also provided technical expertise, lessons learned, and data to several unfunded SAAs. Through all these industry partnerships, NASA continues to advance the development of commercial LEO destinations (CLDs).

NASA's continuing engagement with our commercial crew and cargo partners continue to demonstrate the United States leadership in commercial space efforts. The U.S. has regained global commercial launch market share and is currently the largest commercial launch service provider in the world with the U.S. being the only nation providing commercial human space access to customers across the globe.

The transition from ISS to CLDs will be complex and challenging to manage. NASA has taken actions to address this risk, particularly leveraging the CLDP to succeed the ISS and transition LEO capability to the private sector. The combination of a sustaining destination and research demands enable a private sector market to sustain the commercial transportation systems used on the ISS today. NASA also

released a study in FY 2024 reviewing potential models for a future National Laboratory in a post-ISS world, also known as a LEO National Lab.

Based on SOMD's strategy and accomplishments described in the above paragraphs, Strategic Objective 2.2 achieved a Green/Satisfactory rating during the 2024 Strategic Review Process.

2.2.1: Expand commercial activities in low Earth orbit (LEO) and stimulate the human spaceflight economy, with a focus on deploying commercial LEO destinations that can be used by NASA and other customers.

NASA completed three of three milestones and activities planned for FY 2024, resulting in a Green Performance Goal rating. The release of the initial set of Commercial LEO Development (CLD) Requirements was a key achievement. In October 2023, the Commercial LEO Program released a draft of the CLDP-REQ-1130 Requirements and Standards under the NASA Request for Information (RFI) process. This RFI yielded 627 comments from 13 companies, demonstrating strong industry engagement. These comments were reviewed and dispositioned, paving the way for baseline requirements for commercial destinations, transportation, and services. Further refinements to these requirements, including updates to the CLDP-STD-1101 Docking Standard, continued throughout the following quarters.

Progress also continued with the Commercial Destinations Free Flyers (CDFF) Space Act Agreements (SAAs) (Milestone 2.2.1.2). Two major milestones were completed, one on each of the CDFF SAAs. Starlab completed a Payload Research Facility Design and Groundbreaking, as well as a Starlab Station Design update. Blue Origin completed a Water Multifiltration System Design Review, ECLSS CO2 Reactor Testing, and a Payloads Interim Design Review. These milestones represent tangible advancements in the development of commercial LEO destinations. Amendments to the SAAs throughout the year further refined the scope of work and incorporated risk reduction activities.

2.2.2: Provide support for and utilization of commercial facilities onboard the International Space Station (ISS) for NASA, other Government agencies, and academic and industry users, including the ISS National Laboratory to expand the space economy.

NASA completed two of two milestones and activities planned for FY 2024, resulting in a Green Performance Goal rating.

Milestone 2.2.2.1, to conduct at least 45 experiments using commercial facilities on the ISS, was achieved as over 45 experiments were completed in FY 2024. Throughout the year, a diverse range of investigations leveraged the unique microgravity environment onboard the ISS. Earlier in the year, the Redwire BioFabrication Facility successfully three-dimensional (3D) bioprinted the first live human heart tissue sample. Microgravity allows for successful 3D printing of tissues with increased physical stability due to the reduction of gravity. This is the first step to move the field of tissue engineering closer to the promise of medical therapeutics using space-manufactured replacement organs and tissues, potentially

relieving some of the organ shortage on Earth. Another project, in partnership with the National Science Foundation and Bioserv Space Technologies, grew 3D cultures of heart cells that could provide a heart tissue model to mimic heart disease and assess potential drug therapies. Two dimensional cultures on Earth lack the appropriate environment for cell maturation and function. The cultures of the more mature cells grown on the ISS increase the safety of cell therapy for cardiac regeneration and the accuracy of disease modeling.

Milestone 2.2.2.2, to sponsor at least 15 investigations focused on in-space production, was also achieved, exceeding the target with 21 sponsored investigations. This milestone showcased the growing potential of space-based manufacturing to benefit Earth. A significant achievement was the production of more than seven miles of zirconium barium lanthanum aluminum sodium fluoride (ZBLAN) optical fiber by Flawless Photonics through the ISS National Laboratory. The investigation manufactured more than 3,700 feet in one day, surpassing the previous record of 82 feet. Fiber produced in space has a superior quality to those produced on the ground and can contribute to improved communication applications on Earth, highlighting the advantages of microgravity for advanced materials manufacturing. In February 2024, the University of California San Diego, Axiom Space, and Space Tango provided compelling evidence that cancer cells grow much faster in microgravity than on Earth, triggered by the activation of the gene that supports tumor growth, survival, and resistance to treatment. Investigators can target this gene to block its harmful effects, using it as a “kill switch” to stop cancer cells from replicating uncontrollably. The rapid growth also enables researchers to test anti-cancer drugs in a significantly shorter timeframe.

2.2.3: Provide operational resources to enable the closure of capability gaps in support of deep space exploration.

NASA completed three of five technology demonstrations targeted for initiation during FY 2024, resulting in a Yellow Performance Goal rating.

These technology demonstrations included the Saffire-VI experiment, delivered on Northrop Grumman's NG-19 mission; the Spacecraft Atmosphere Monitor Tech Demo Unit 2, delivered on SpaceX's SpX-29 mission; and the Upgraded Water Processor Assembly Catalytic Reactor, delivered in FY 2023 and initiated in Q3 of FY 2024. Of the remaining two, the Air Gas Analyzer was initiated just after the end of FY 2024, outside the goal window, and the Redesigned Universal Waste Management System Conductivity Monitor could not be initiated due to technical issues encountered with the main system it will be integrated into (the Universal Waste Management System).

2.2.4: Provide NASA crew transportation through commercial partners to the International Space Station (ISS) and low Earth orbit.

NASA successfully launched two of two Commercial Crew missions in FY 2024, resulting in a Green Performance Goal rating. Crew 8 launched in March 2024, and Crew 9 followed suit with a successful

launch to the ISS on September 28, 2024. These two launches fulfilled the metric for both the milestone and the performance goal. Also, a third crewed flight had significant activity as NASA elected to return Boeing's CFT test flight uncrewed, due to inflight technical issues experienced during the mission. This highlights the inherent benefits of multiple, dissimilar transportation systems. The CFT spacecraft landed successfully, and the data gathered is being used to assess spacecraft updates needed as we proceed toward Boeing's next flight.

2.3: Develop capabilities and perform research to safeguard explorers.

LEAD OFFICE
Space Operations Mission Directorate (SOMD)

GOAL LEADER
Tonya McNair, Deputy Associate Administrator for Management, SOMD

In space exploration, reducing risk is essential for ensuring the safety of astronauts, protecting immense financial investments, and increasing the likelihood of mission success. By prioritizing risk reduction, NASA safeguards human lives, promotes sustainable exploration, and upholds an ethical responsibility, ultimately ensuring the continued success of our exploration endeavors. Strategic Objective 2.3's focus is on NASA's Human Research Program (HRP) work that ensures astronauts are adequately protected from the hazards of spaceflight.

Under the Moon to Mars strategic framework, HRP aligned its resources to address the highest human health and performance risks identified in the NASA Human System Risk Board, Artemis Program, and Office of the Chief Health and Medical Officer exploration priorities. In addition to conducting ISS and ground-based analog studies on spaceflight biomedical risks and countermeasures to protect crewmembers in FY 2024, HRP released the Human Exploration Research Opportunities to nationally solicit applied flight and ground research in the following areas: Space Radiation, Human Health Countermeasures, Human Factors and Behavioral Performance, and Exploration Medical Capability.

To leverage its research funding and accelerate risk mitigation development, HRP fostered collaborations with universities, industry, the U.S. Government, and international partners in FY 2024 including the following: National Science Foundation on Antarctic station isolation studies; German Space Agency on Spaceflight-Associated Neuro-Ocular Syndrome and sensorimotor bedrest studies at the :envihab facility; Department of Energy on the NASA Space Radiation Laboratory and radiobiology studies; and European Space Agency on parabolic flight testing at lunar and Martian gravities. Looking forward, HRP is strategically aligning itself for working in a new era of commercial space exploration.

In support of the Moon to Mars strategy, HRP is working with the ESDMD Artemis Programs, including Orion, Gateway, and Human Landing System, and the Mars Capability Office to prioritize the highest engineering, health, and crew performance capability needs for Artemis missions. HRP is mitigating Artemis-relevant risks—including injury due to dynamic loads, impact to sensorimotor systems after gravity-transition, extravehicular activities, and exploration food systems.

HRP continued to fully utilize the ISS in FY 2024, to yield information on knowledge gaps and provide recommendations on Spaceflight-Associated Neuro-Ocular Syndrome (SANS) characterization, SANS countermeasures, nutrition, immune function, sleep, team dynamics, and pharmaceutical stability that will inform crew health and performance for future space exploration missions. HRP continued to implement the Complement of Integrated Protocols for Human Exploration Research (CIPHER) study, the most complex human life science experiment ever performed on the ISS. CIPHER integrates data across 14 different studies, which will be evaluated to identify patterns and gain a deeper understanding of how the human body reacts to long durations in space. Looking to the end of ISS operations in the 2030 timeframe, HRP has supported commercial programs to develop CLD utilization requirements to enable biomedical research on the new LEO commercial platforms.

In July 2024, NASA successfully completed the first year-long simulated Crew Health and Performance Exploration Analog (CHAPEA) mission. Four astronauts spent over one year confined to a simulated Mars environment, in an effort to study the impacts to human health and performance. SOMD is closely tracking the need for additional long-duration mission study subjects, but planning for future extended duration missions on ISS has become uncertain and dependent upon engaging opportunities as they arise.

Based on SOMD's strategy and accomplishments described in the above paragraphs, Strategic Objective 2.3 achieved a Blue/Noteworthy rating during the 2024 Strategic Review Process.

2.3.1: Identify activities that will mitigate the highest risks to crew health and performance.

NASA completed two of two milestones and activities planned for FY 2024, resulting in a Green Performance Goal rating. Milestone 2.3.1.1, focused on completing five new funded investigations, was not only achieved but surpassed. Six studies were completed, including two focusing on injury assessment reference values for the neck and lumbar spine, directly applicable to protecting crewmembers from injury during the dynamic phases of spaceflight. Additional studies evaluated include the efficacy of three sleep wake countermeasures designed to acutely promote sleep or waking at different circadian phases for Artemis, and changes in Staphylococcus strains in astronauts to ensure microbiological safety during spaceflight missions.

Milestone 2.3.1.2, targeting the publication of 150 peer-reviewed papers, significantly exceeded its target. A total of 221 papers were published throughout the year, showcasing a nearly 50% increase over the target. This robust output demonstrates NASA's commitment to disseminating valuable research findings to the broader scientific community. This substantial body of research directly supports Performance Goal 2.3.1 by providing the knowledge base necessary to identify and mitigate risks to crew health. The successful completion of these milestones underscores NASA's dedication to ensuring the safety and well-being of its explorers as it pushes the boundaries of human spaceflight.

2.4: Enhance space access and services.

LEAD OFFICE
Space Operations Mission Directorate (SOMD)

GOAL LEADER
Tonya McNair, Deputy Associate Administrator for Management, SOMD

Mission support capabilities are the foundational pillars of our cosmic ambition, enabling us not only to survive in the harshest conditions known to humanity, but to thrive and expand our footprint across the universe. Strategic Objective 2.4 represents NASA's commitment to affordable and reliable space launch capabilities for new missions and developing robust communications and navigation infrastructure to support ongoing missions.

As the launch agent for the U.S civil space sector, NASA relies on the Launch Services Program (LSP) to certify new commercial launch vehicles for readiness to fly high-value spacecrafts, and direct vital launch mission assurance efforts to ensure the greatest probability of launch mission success. LSP is the agency's recognized expert in all aspects of commercial launch services, including acquisition, certification, and mission management. Over the last year, LSP successfully managed and launched the Psyche payload, a science mission to explore a metal rich asteroid in our solar system; PACE, an Earth science satellite that will be used to better understand the exchange of carbon dioxide between our ocean and atmosphere; and the fourth and final Geostationary Operational Environmental Satellite-U (GOES-U) satellite to provide advanced imagery of weather observing data in the western hemisphere.

LSP continues to provide support to the development and integration of approximately 75 missions in flow in a variety of phases and life cycles, sustaining the dynamic cadence of managing numerous launches per fiscal year.

The Space Communications and Navigation (SCaN) program has demonstrated progress towards identifying solutions and preparing for implementation of those solutions based on the results of the Program Implementation Review of 2023. SCaN has maintained operational capabilities of NASA missions after the typhoon devastation of the Guam Remote Ground Terminal which could no longer enable services the Near Space Network and Tracking and Data Relay Satellite network. To make these missions possible, the SCaN program has overcome obstacles to maintain capability, focusing on priority investments needed to support and buy-down risks for future missions.

Given that the timelines and needs for the current Artemis mission portfolio have changed significantly since the 2019 Artemis plan was developed, and the communication and navigating requirements for Artemis flight elements are still not finalized, concurrent conflicting needs for mission support capabilities could result in SCaN experiencing cost and schedule impacts due to support requirements.

Based on SOMD's strategy and accomplishments described in the above paragraphs, Strategic Objective 2.4 achieved a Green/Satisfactory rating during the 2024 Strategic Review Process.

2.4.1: Complete Launch Services Program (LSP) commercial non-crewed launch services objectives for NASA-Managed science, exploration, U.S. Government, and Government-sponsored missions.

NASA completed three of three milestones and activities planned for FY 2024, resulting in a Green Performance Goal rating. First, the Psyche mission intended to explore a metal rich asteroid in our solar system, launched on October 13, 2023, accomplishing 100% of its launch services objectives and marking the first completed milestone (2.4.1.1) within this Performance Goal. Next, the Plankton, Aerosol, Cloud, ocean Ecosystem (PACE) mission, an Earth science satellite that will be used to better understand the exchange of carbon dioxide between our ocean and atmosphere, launched on February 8, 2024, also fulfilling 100% of its launch services objectives. This launch marked the completion of the second milestone (2.4.1.2), further contributing to the overall Performance Goal. Finally, the GOES-U mission, the fourth and final GOES satellite to provide advanced imagery of weather observing data in the western hemisphere, launched on June 25, 2024, fulfilling the final tracked milestone (2.4.1.3) for with 100% completion of launch services objectives.

2.4.2: Maintain the proficiency of Space Communications network services of at least 95% proficiency.

NASA completed one of one milestone for FY 2024, resulting in a Green Performance Goal rating. NASA's communications networks—the Deep Space Network (DSN) and the Near Space Network (NSN), which has relay and direct-to-Earth (DTE) components—achieved 99.4% service delivery, exceeding the FY 2024 target of a minimum 95% network proficiency, leading to a Green rating. NASA's communications networks serve more than 100 NASA and non-NASA missions. The DSN enables missions that explore the furthest points of our solar system, utilizing three ground stations located approximately 120 degrees apart on Earth. The NSN provides services for near-Earth missions, including DTE services and relay capabilities.

3: Catalyze economic growth and drive innovation to address national challenges.

3.1: Innovate and advance transformational space technologies.

LEAD OFFICE
Space Technology Mission Directorate (STMD)

GOAL LEADER
Mike Green, Deputy Associate Administrator for Management, STMD

Strategic Objective 3.1 reflects NASA's commitment to ambitious technology development to transform NASA missions and ensure American leadership in the space economy. To accomplish this, STMD continues to develop impactful partnerships, mature and demonstrate revolutionary high-payoff space technologies, and promote innovation.

Transformational technologies are critical to NASA's goal of exploring the unknown in space, benefitting life on Earth, and solving critical stakeholder needs. STMD partners with the American space industry on their most pressing shortfalls, specifically technology areas that require further development to meet future exploration and science mission needs. In April 2024, STMD identified and released 187 shortfalls and collected ranked feedback from within NASA and the greater space ecosystem. In July 2024, STMD released the ranked shortfalls to the public, allowing STMD and NASA to better make prioritization decisions across programs. As STMD reorganizes to a domain-based structure, new data from this survey will be used as an important tool to guide investment decisions across existing projects and new solicitations.

Since FY 2023, STMD has made significant progress to develop and deliver new technologies and additional capabilities, including NASA's sixth cycle of Tipping Point opportunity awards made to 11 U.S. companies which promise to develop technologies that will support long-term exploration on the moon and in space. In collaboration with the Defense Advanced Research Projects Agency, STMD will advance the goal of the world's first in-orbit demonstration of a nuclear thermal rocket engine, the Demonstration Rocket for Agile Cislunar Operations. In addition, the Solar Electric Propulsion project entered qualification testing, completed initial hot fire and vibration tests, and two of the three flight module thrusters are nearing assembly completion.

The Deep Space Optical Communications mission achieved "First Light" in November 2023, and has successfully sent and received optical data from 288 million miles away, demonstrating the farthest optical communication in human history. Finally, following an in-depth, independent project review, STMD has decided to discontinue the On-orbit Servicing, Assembly, and Manufacturing 1 (OSAM-1) project due to continued technical, cost, and schedule challenges, and lack of a definitive end user.

Based on STMD's strategy and accomplishments described in the above paragraphs, Strategic Objective 3.1 achieved a Green/Satisfactory rating during the 2024 Strategic Review Process.

3.1.1: Foster a diverse U.S engineering and technology talent base, expand commercial opportunities in the space industry, and advance innovative technology solutions. Target of 4-5 critical activities completed for Early Stage Innovation and Partnerships (ESIP) program supporting the Performance Goal.

NASA completed five of five milestones and activities planned for FY 2024, resulting in a Green Performance Goal rating.

Milestone 3.1.1.1, focused on knowledge transitions from four of NASA's early-stage programs, and was achieved with over 75% (173/230) of awarded projects demonstrating at least one transition. Specifically, 84% of Space Technology Research Grants (STRG) and 70% of NASA Innovative Advanced Concepts (NIAC), Center Innovation Fund (CIF), and Early Career Initiative (ECI) awards reported at least one knowledge transition.

Milestone 3.1.1.2, aiming for 90% of project owners reporting positive impacts from Prizes, Challenges, and Crowdsourcing (PCC) solutions, also exceeded expectations, reaching 96%. Out of 75 project managers surveyed, 72 confirmed that projects advanced their technologies.

For milestone 3.1.1.3, NASA targeted 100 external funding commitments from non- Small Business Innovation Research / Small Business Technology Transfer (SBIR/STTR) awards for small business technologies. It surpassed that target with 105 commitments secured across SBIR/STTR Phase II-E, Civilian Commercialization Readiness Pilot Program (CCRPP), Sequentials, and Phase III award mechanisms. This includes 56 Phase III awards, which all require non-SBIR/STTR funding on technologies that derive from, extend, or complete an effort previously funded through SBIR/STTR awards, and illustrates confidence in the small businesses and their technologies developed in previous phases.

Milestone 3.1.1.4, which aimed for 4,000 licenses and software usage agreements through NASA's Technology Transfer program, significantly exceeded its target, reaching 5,914 agreements. These technology transfers ensure that innovations developed for exploration and discovery are broadly available to the public, maximizing the benefit to the Nation.

Finally, milestone 3.1.1.5 focused on strategic engagement opportunities for diverse, first-time, and emerging research communities across the country, far surpassing its target of 15 opportunities, reaching 36. These activities included recruiting, awardee engagement, outreach, speaking engagements, and panels.

3.1.2: Mature technology projects that offer significant improvement to existing solutions or enable new capabilities.

NASA achieved 48% of planned key performance parameters (KPPs) when the target was set for 60% during FY 2024, resulting in a Yellow Performance Goal rating. While NASA did not achieve Green for this

Performance Goal target, technology development comes with inherent uncertainty. NASA's Game Changing Development (GCD) program faces this uncertainty head-on by taking informed risks and making data-driven decisions in order to stay innovative. Although these risks mean that we will not always achieve every planned milestone, the agency continues to make progress towards its goal of maturing technologies that will revolutionize space exploration and advance the most promising ideas in space technology.

Performance Goal 3.1.2 targeted 60% of KPP events. 55 out of 114 planned KPPs were achieved, representing approximately 48% completion. Flight integration, launch, and surface operation delays, projects specific schedule delays, and project de-scope/redirection led to the below-target status of Performance Goal 3.1.2. However, the KPPs' thresholds that NASA met or exceeded during FY 2024 each represent technology advancements that may lead to entirely new mission approaches and provide solutions to national needs.

NASA met KPPs in 19 of its GCD projects, including Deployable Lunar Hopper (Hopper-TP), High Performance Spaceflight Computer - Implementation (HPSC-I),Lunar DEM, Mapping, Modeling, and Validation (LuNaMaps), and Vertical Solar Array Technology (VSAT).

STMD has continued its partnership with Commercial Lunar Payload Services (CLPS) providers, and has multiple payloads planned to launch in FY 2025. Hopper-TP will develop and demonstrate a small robotic hopper that can provide access to extreme environments and locations of interest on the lunar surface and is planned to launch on IM-2 in early calendar year (CY) 2025. This demonstration drives a commercial venture and helps establish a space economy ecosystem.

The agency's HPSC project is developing a next-generation flight computing system that addresses computational performance, energy management and fault tolerance needs of NASA missions. HPSC was designed for autonomy and artificial intelligence (AI) at the edges of space and the demanding fault-tolerance needs of Human Exploration (HEO) missions. This improvement in space-based computing is expected to increase the computational capacity of current flight processors for the same amount of power by 100x.

While NASA's Technology Maturation Portfolio made significant advancements on a variety of technology projects, there were challenges in a number of projects that led to a Yellow rating for this Performance Goal. Nearly 31% of the KPPs that were unmet in FY 2024 were due to delays with CLPS lander integration activities, launch, and lunar operations. 39% of unmet KPPs were delayed due to project schedule adjustments, and the remaining unmet KPPs did not meet the minimum threshold due to technical challenges, project descope or redirection.

3.1.3: Rapidly develop and demonstrate technologies for exploration, discovery, and the expansion of space commerce through partnership with U.S. industry and academia.

NASA tested 62 technologies suborbitally or orbitally when the original FY 2024 target was 30 technologies, resulting in a Green Performance Goal rating. This achievement was driven by the Flight

Opportunities (FO) and Small Spacecraft Technology (SST) programs. These programs tested technologies on various platforms, including suborbital flights and orbital missions. For this annual target, technologies that were developed over multiple flights or transitioned from suborbital to orbital testing are counted more than once.

NASA's Small Spacecraft Technology program advanced critical space technologies with a wide variety of science, exploration, and commercial applications. Starling, the first demonstration of the capabilities for a fully autonomous distributed space mission, completed its primary mission objectives in 2024. Numerous 'firsts' were achieved, marking significant advancements in autonomous spacecraft and distributed systems, including autonomous distribution of information and data between spacecraft, relative navigation using star trackers, and foundation of an ad-hoc mesh network.

NASA's Advanced Composite Solar Sail System (ACS3) launched April 23, 2024. This demonstration was designed to mature a composite boom technology that is stiffer, lighter, and more stable in challenging thermal environments than previous designs. ACS3 completed its primary objective of deploying seven-meter booms, consequently unfurling a solar sail measuring approximately nine meters per side.

The agency's Flight Opportunities program utilized a variety of commercial platforms for testing, including reusable suborbital rockets and high-altitude balloons as noted in the two examples below.

August 29, 2024 marked the first time a NASA-funded university principal investigator (PI) conducted a hands-on experiment aboard a commercial suborbital rocket, representing a new era of flight testing. Not only did this flight test yield valuable scientific insights to support future missions to the Moon and Mars, but it also provided insights that will aid other researchers considering how to most impactfully leverage opportunities to fly with their payloads aboard suborbital flights.

Designed to address various communications challenges in wildland firefighting, Strategic Tactical Radio and Tactical Overwatch (STRATO) aims to enable real-time communication between firefighters and incident command posts, as well as valuable heat and spatial information to help them better understand the fire's characteristics. The 11-day flight test in August 2024 aboard a high-altitude balloon successfully provided a persistent, strong Long-Term Evolution (LTE) signal in areas with heavy tree canopy and canyonlike terrain. STRATO also provided useful imagery, including the first views of the Snag fire. The collaboration was led by NASA, the U.S. Forest Service, and the industry flight provider, and it involved numerous other federal, state, and local agencies and commercial companies.

3.1.4: Demonstrate new technologies and cross-cutting capabilities that are of direct interest and use to NASA missions and the commercial space sector. Major milestones (e.g., key decision points, major reviews, and technology demonstrations) completed.

NASA completed five of five milestones and activities planned for FY 2024, resulting in a Green Performance Goal rating. Through STMD's Technology Demonstration Missions (TDM) program, NASA

has made significant progress towards demonstrating technologies of interest to NASA and the commercial space sector.

The Solar White Project successfully closed out in December 2023, with the final report accepted in March 2024. The primary objective was to develop a novel, high reflectivity coating that could be applied to cryogenic systems as a passive thermal layer. Funding for this project started through the NASA Innovative Advanced Concepts (NIAC) program in 2015 at Technology Readiness Level (TRL) 2. Since then, the Solar White development work has been done under additional NIAC awards as well as funding from KSC Launch Services Program (LSP), Game Changing Development (GCD), and other sources, and is currently at TRL 4.

The Deep Space Optical Communications (DSOC) Post-Launch Assessment Review (PLAR) was completed on January 18, 2024, closing out the commissioning phase and then approving full operations and demonstrations. NASA's DSOC experiment is the agency's first demonstration of optical communications beyond the Earth-Moon system. The technology demonstration made headlines when it beamed the first ultra-high-definition video from space, featuring a cat named Taters, from the Psyche spacecraft to Earth on December 11, 2023, from 19 million miles away. DSOC concluded the first phase of its operations since launching aboard Psyche on October 13, 2023, by breaking the record for laser communications this summer, sending a laser signal from Earth to NASA's Psyche spacecraft about 290 million miles (460 million kilometers) away.

The agency's Tipping Point solicitations are designed to facilitate collaborations with the commercial space sector, leveraging emerging markets and capabilities to meet NASA's strategic goals and industry needs. NASA selected four Cryogenic Fluid Management (CFM) Tipping Points in FY 2020. In FY 2024, TDM targeted milestones in two of those TPs: the SpaceX CFM 2020 TP, and the United Launch Alliance (ULA) CFM 2020 TP. The SpaceX CFM 2020 TP successfully demonstrated cryogenic fluid transfer on the Starship OFT3 launch on March 14, 2024, and the ULA TP successfully completed its Critical Design Review (CDR) in late February 2024. Both of these milestones are necessary steps on the path to demonstrating advancements in fuel storage and transfer through CFM technologies.

In addition to making technical progress towards CFM technologies, NASA also successfully completed the annual review of its CFM portfolio. This review is used to evaluate the projects on technical, budget, and schedule performance measured against expected performance. The review uses an Independent Review Team (IRT) to advise on project performance and formulate any recommendations to TDM for consideration.

3.1.5: Ensure American global leadership in space technology innovations through increased partnering with industry, broadening the base of innovation, and demonstrating key lunar surface and deep space technologies. By September 30, 2025, NASA will demonstrate leadership in space technology by: enhancing partnerships with industry through delivery or completion of milestones for at least 3 Tipping Point opportunities, and at least 3 critical small business technology transitions to develop capabilities that support NASA and commercial needs; advancing at least 2 new technologies that will be demonstrated on the lunar surface or in lunar orbit; and completing at least 4 major milestones for projects that increase the Nation's capabilities in deep space. (Agency Priority Goal)

NASA completed four of four milestones and activities planned for FY 2024, resulting in a Green Performance Goal rating.

The launch of the Consortium for Space Mobility and ISAM Capabilities (COSMIC) in November 2023 (Milestone 3.1.5.1) brought together over 500 participants from industry, academia, and government to advance In-Space Servicing Assembly and Manufacturing (ISAM), a crucial element for deep space exploration. The executive steering committee began establishing priorities and developing products to address them.

Deep Space Optical Communications (DSOC) successfully launched on October 13, 2023, aboard the Psyche spacecraft and mission of the same name. DSOC achieved "First Light" on November 14, 2023, and First Operational Pass on January 1-2, 2024. The DSOC Post-Launch Assessment Review (PLAR) was completed on January 18, 2024, and the payload has been transmitting data including high-definition video beamed from 19 million miles away.

To advance technologies that will be demonstrated on the lunar surface, the three Cooperative Autonomous Distributed Robotic Explorers (CADRE) rovers were completed and put in storage on February 15, 2024, for delivery to the CLPS vendor for integration to their lander. This demonstration is planned for the IM-3 FY 2025 CLPS mission.

NASA has continued to mature, develop, and demonstrate technology through Tipping Point (TP) projects. In FY 2024, multiple TPs met design milestones, including:

- The Joining Demonstrations In-Space (JOINS) TP completed a company-internal System Requirements Review (SRR) and Initial Design Review
- The Mason TP SRR
- The SpaceX 2020 TP completed a successful cryogenic fluid transfer demonstration
- The Vulcan Engine Reuse Scale (VERS) 2022 TP completed its PDR
- The Blue Origin TP reached its KPP for 20K Cryocooler
- Completed the second Cryocooler Test Review

NASA is continuing to make progress towards all four of its FY 2025 milestones, though the completion of SEP Environmental Testing may slip into FY 2026.

Over the course of FY 2024, the Solar Electric Propulsion (SEP) project made significant progress in preparation for environmental testing. The Qualification Model (QM-1) successfully completed acceptance testing, and the overall project has continued to make strong progress towards the production of qualification and flight thrusters. Thermal vacuum chamber testing of QM-1 thruster at JPL will complete in FY 2025, and final environmental testing at GRC is currently scheduled to begin in late FY 2025 or early FY 2026.

Polar Resources Ice Mining Experiment (PRIME-1) was delivered to Intuitive Machines (IM) on July 19, 2024. The system is currently integrated to the spacecraft and awaiting final integration and test activities on the IM-2 NOVA-C lander. PRIME-1 is awaiting the IM-2 mission and is expected to launch aboard IM-2 in FY 2025 for demonstration operations on the Lunar Surface.

NASA's SBIR/STTR had four Sequential contracts complete in 2024. One of those projects has already received follow-on funding from NASA and an outside firm, plus orders for multiple flight units from U.S. and U.K. customers. One of the projects has generated significant follow-on interest, and another has promising leads.

The High Performance Spaceflight Computing (HPSC) project completed its Critical Design Review in July and August 2024, as well as a Technical Assessment Performance Review (TAPR) in August 2024. The project is on track to deliver its first processor evaluation boards in FY 2025.

The establishment of COSMIC enhanced partnerships with industry. The DSOC "first light" and the delivery of CADRE hardware advanced technologies for deep space and lunar surface operations. The completed tipping point project milestones further solidified industry partnerships and advanced critical technologies. These achievements clearly demonstrate progress towards ensuring American leadership in space technology and contribute to the broader Strategic Objective of innovating and advancing transformational space technologies.

3.2: Drive efficient and sustainable aviation.

LEAD OFFICE
Aeronautics Research Mission Directorate (ARMD)

GOAL LEADER
Barbara Esker, Deputy Associate Administrator for Program, ARMD

Sustainable and efficient aviation is a transformative force that propels humanity to a necessary coexistence with our planet while continuing to connect the world in unprecedented ways. Strategic Objective 3.2 envisions the long-term outcomes for aeronautics research and provides the basis for new

concepts leading to industry innovation and societal benefits. These include new options for air travel that are cleaner, faster, and safer.

Envisioning a more sustainable future for aeronautics poses challenges, including achieving continued growth that meets increasing global demand, safely integrating Unmanned Aircraft Systems and other innovative vehicle concepts with a myriad of applications, and proactively adapting to rapidly changing conditions. An overall key objective of this Administration is to solve these challenges in ways that minimize adverse impacts on the environment, with the goal of aviation achieving net-zero carbon emissions by 2050.

In FY 2024, ARMD demonstrated progress against its goals and continued to organize research efforts and partnerships around six Strategic Thrusts: 1) Safe, Efficient Growth in Global Operations, 2) Innovation in Commercial High-Speed Aircraft, 3) Ultra-Efficient Subsonic Airliners, 4) Safe, Quiet, and Affordable Vertical Lift Air Vehicles, 5) In-Time System-Wide Safety Assurance, and 6) Assured Autonomy for Aviation Transformation.

To support these thrusts, NASA continued programmatic progress on flight demos for green aviation and ultra-efficient flight with Electric Propulsion Flight Demonstrator's Key Decision Point (KDP)-C and Sustainable Flight Demonstrator's KDP-B. Additionally, NASA continued producing data and demonstrating tools that reduce the uncertainty in predicting landing and take-off noise levels of supersonic-relevant propulsion designs. Finally, ARMD's Strategic Leadership Team was convened three times to review the results of the latest strategic studies and future vector plans.

Despite ARMD's successes towards achieving Strategic Objective 3.2, uncertainty exists around the Low Boom Flight Demonstrator first flight date which may create insufficient time to complete the phase 3 test campaigns. It is still possible to achieve full success with changes in schedule and the mission, and projects are reconsidering mitigations that reduce the durations of phase 2 and 3 activities to regain some margins in the schedule.

Based on ARMD's strategy and accomplishments described in the above paragraphs, Strategic Objective 3.2 achieved a Green/Satisfactory rating during the 2024 Strategic Review Process.

3.2.1: Develop solutions that will enable the integration of a diverse range of non-traditional vehicles and operations into the National Airspace System by means of a scalable, service-oriented architecture.

NASA completed the three FY 2024 milestones, resulting in a Green rating for Performance Goal 3.2.1.

NASA completed an evaluation of cooperative operating practices for diverse aircraft in Upper Class E airspace. The first Collaborative Evaluation simulation (CE-1) was conducted with AeroStar International and AeroVironment. These partners connected to NASA's prototype upper Class E Traffic Management (or ETM) system, demonstrating the effectiveness of digital information sharing and Cooperative Operating Practices. The simulation focused on testing information exchange, refining operating

practices, and evaluating the prototype system's performance. A key achievement was the development of an Application Programming Interface to share telemetry and operational intent data. NASA and the Federal Aviation Administration (FAA) held meetings with industry partners to identify and evaluate candidate cooperative operating practices, which defined how different aircraft will interact safely and efficiently. CE-1 successfully showed the safe and cooperative operation of diverse aircraft, providing valuable data and insights for future ETM system development.

NASA assessed the feasibility and scalability of midterm Urban Air Mobility (UAM) operations in a cooperative traffic management environment through a series of simulations. NASA conducted a virtual workshop with industry partners in October 2023, which informed the definition of the reference system architecture. Subsequent simulations demonstrated increasing functionality, culminating in a successful two-stage simulation in August and September 2024. This simulation successfully tested various scenarios, including nominal and off-nominal operations in different airspace classes.

A first draft of the Wildland Fire Management Concept of Operations (ConOps) and use case roadmap were completed by September 2024. All six use cases, from "Prescribed Burns" to "Suppression", were documented and integrated into ConOps version 1.0. These use cases identified technological and organizational gaps in current wildland fire management and proposed solutions for improvement. The ConOps incorporated feedback from a March 2024 workshop and contributions from 36 government agencies and 181 subject matter experts.

3.2.2: Demonstrate the ability to reduce the perceived loudness of sonic booms and enable future industry innovation in commercial supersonic aircraft.

NASA achieved the FY 2024 milestone to complete the Flight Readiness Review (FRR) for the X-59 Low Boom Flight Demonstrator (LBFD) aircraft, resulting in a Green rating for this multiyear Performance Goal. This accomplishment signifies the successful completion of a critical step towards quieter supersonic flight.

An FRR board, composed of independent experts from across NASA, completed a study of the X-59 project team's approach to safety for the public and staff during ground and flight testing. The X-59 experimental research aircraft is at the center of NASA's Quesst mission, which will use it to gather data that could revolutionize air travel, potentially paving the way for a new generation of commercial aircraft that can travel faster than the speed of sound.

The FRR board looked in detail at the project team's analysis of potential hazards, focusing on safety and risk identification. The FRR is the first formal step in the flight approval process. The board's work will provide the X-59 team with insights and recommendations toward systems checkouts on the ground and first flight. With the FRR complete, the upcoming Airworthiness and Flight Safety Review will be the next safety milestone in the flight approval process.

3.2.3: Advance airframe and engine technologies to enable the development of future generations of ultra efficient air vehicles that minimize environmental impact and accelerate towards net-zero carbon emissions including opportunities to transition to alternative propulsion and energy.

NASA achieved two of the three FY 2024 milestones, resulting in a Yellow rating for this multiyear Performance Goal.

NASA developed a Model-Based Systems Analysis & Engineering (MBSA&E) framework, advancing multi-fidelity vehicle concept design and technology evaluations. This integral part of the Sustainable Flight National Partnership (SFNP) enables system-level digital integration for assessing and adopting sustainable technologies in potential future subsonic aircraft, currently projected for arrival the 2030s. The framework integrated multiple disciplines such as aerodynamics and propulsion using NASA's open-source OpenMDAO software framework, allowing comprehensive analysis of SFNP technologies. It was demonstrated through optimization studies of a truss-braced wing concept with electric propulsion and will support future technology assessments and sensitivity studies from FY 2025 to FY 2029.

NASA completed its targets for developing a new test article based on the SUGAR Transonic Truss-Braced Wing (TTBW) configuration for icing research. The wing-truss junction, critical for icing analysis, led to its creation for use in the NASA Icing Research Tunnel. Facing scaling challenges, a full-scale wing section was used for accurate flight-scale condition simulations at the leading edge, avoiding issues like boundary-layer separation. Crafted from machined aluminum for precision and quality, the article includes numerous pressure taps for alignment and testing against flight conditions. The icing test originally planned for FY 2024 has been rescheduled for early FY 2025, with results intended to enhance safety and certification through comparisons with simulation tools.

The Electrified Powertrain Flight Demonstration (EPFD) project completed the Integrated Baseline Review (IBR) in March 2024, resulting in a Yellow rating for this milestone. The project IBR included details from the EPFD contractors' (GE Aerospace and magniX) IBRs in preparation for the project Key Decision Point to enter the implementation phase of the project, which was completed in August 2024.

NASA's EPFD project is one of several NASA efforts under the Sustainable Flight National Partnership seeking to address the U.S. Aviation Climate Action Plan's goal of net-zero carbon emissions by 2050. The project team is working with GE Aerospace and magniX to conduct ground and flight tests of electrified aircraft propulsion (EAP) technologies to enable a new generation of more efficient aircraft with less emissions.

The Sustainable Flight Demonstrator (SFD) project completed its Systems Requirement Review. These efforts will lead to a firm X-66 configuration that will be assessed by Boeing and NASA at the Preliminary Design Review in 2025.

Under a Funded Space Act Agreement, Boeing leads the requirements definition, system design, and project execution to achieve key learnings needed to make decisions about the next generation of

commercial aircraft. NASA is supporting the effort with technical subject matter experts embedded on the integrated product teams to assess path to airworthiness and with NASA facilities and capabilities such as wind tunnel testing, computational fluid dynamics, structural testing, flight test facilities, and simulation.

3.2.4: Advance airframe and propulsion technologies to enable the development of future vertical take-off and landing (VTOL) vehicles that minimize noise and maximize safety including electric vehicle propulsion systems.

NASA completed the FY 2024 milestone, resulting in a Green rating for this multiyear Performance Goal. In collaboration with the University of Wisconsin, the project developed models and demonstrated a fault tolerant motor concept to improve the overall reliability of electric motors for Advanced Air Mobility (AAM) applications.

Two motor reliability models were developed, delivered, and thoroughly documented, including all theory, assumptions, references, step by step modeling procedures, example calculations, and verification against exact available solutions. The pair of models are complementary tools for the stakeholder and user community.

To illustrate the use of the models, a case study was completed. Six motor and drive concept designs were studied, and the relative reliabilities were compared using newly introduced fault-tolerant figures of merit. The models predict that a four-module, modular fault tolerant motor concept has more than 500 times greater reliability than a non-fault tolerant baseline motor while maintaining favorable over-rating factors and only a modest mass penalty.

To validate that fault tolerant features are feasible, a modular fault-tolerant electric motor concept was designed, built, and tested. The experiments successfully demonstrated four key fault-tolerant features: (1) terminal open circuit operation, (2) thermal isolation after fault, (3) terminal short-circuit operation, and (4) internal short-circuit operation.

The results of this work will benefit AAM vehicle developers, manufacturers and operators and the Federal Aviation Administration (FAA) and U.S. Department of Defense (DoD). Results will overcome key barriers for this emerging market by providing validated models for community use in propulsion system and thermal management design, and design and test guidelines for propulsion system components that will enable safe, reliable propulsion system designs. Data acquired will be available for use in standards development.

3.2.5: Define and demonstrate solutions that predict, identify, and mitigate emerging safety risks and address the national need to safely transform the National Airspace System.

NASA completed the FY 2024 milestone, resulting in a Green rating for this multiyear Performance Goal and implementing the In-Time System-Wide Safety Assurance data architecture. This Performance Goal is critical for ensuring the safe integration of diverse vehicles and missions into the future airspace.

This accomplishment involved extensive flight tests and simulations conducted by NASA, Ohio State University, and three partner university teams. The tests showcased a wide range of In-time Aviation Safety Management System (IASMS) capabilities, crucial for both small, unmanned aircraft systems (sUAS) and urban air taxis. These capabilities included an onboard inductive monitoring system, copilot-based run-time assurance monitors, an automated contingency function, and a supplementary data service provider-consolidated dashboard.

The partner teams, led by the University of Notre Dame, Virginia Commonwealth University, and George Washington University, contributed significantly, demonstrating capabilities such as machine learning-based trajectory risk prediction and high-resolution urban wind modeling. Findings from these efforts were disseminated through 21 technical research papers presented at major conferences and a comprehensive NASA Technical Report. The successful completion of this milestone underscores NASA's progress in transforming the national airspace.

3.2.6: Contribute toward the safe introduction of on-demand Urban Air Mobility (UAM) and other emerging operations by developing, applying, demonstrating, and validating advanced autonomy and automation technologies and providing methods or research results that support certification of autonomous systems.

NASA completed the three FY 2024 milestones, resulting in a Green rating for this multiyear Performance Goal. The focus on sustainability, certification, and flight test validation demonstrated tangible advancements in aviation autonomy and automation.

NASA's Collaborative Digital Departure Rerouting (CDDR) system, leveraging the Digital Information Platform (DIP), demonstrated substantial carbon dioxide (CO_2) reductions in the Dallas/Fort Worth, Texas area. A national assessment projected even greater potential benefits if implemented across the United States. The system was successfully scaled to airspace in Houston, Texas, with a Safety Risk Management Panel mitigating all identified risks. Software release version 1.9.2 met all requirements for the Sustainable Flight National Partnership operations use cases, and cloud deployment ensured remote accessibility. This milestone directly addressed the Performance Goal by demonstrating a tangible application of advanced automation for more sustainable aviation operations.

NASA delivered the technical memorandum "Recommendations on Evidence and Process for Certification of Learning-enabled Components in Aerospace Systems" (NASA Technical Memorandum 20240006865) to the Federal Aviation Administration (FAA), Department of Transportation, and industry

partners. Two supplementary reports further addressed system-level assurance and human-machine teaming. A collaboration with the FAA Chief Scientist for Artificial Intelligence commenced, focusing on applying FAA certification steps to case studies. This milestone provided critical research and recommendations directly supporting the certification of autonomous systems, a key aspect of the Performance Goal.

NASA demonstrated automated aircraft/airspace operations in the first Integration of Automated Systems flight test. Numerous flight tests using the Sikorsky Autonomy Research Aircraft validated hazard perception, avoidance, and flight path management technologies. This milestone provided practical flight test demonstrations of advanced automation, contributing to the validation of technologies crucial for the safe introduction of urban air mobility and other emerging operations.

4: Enhance capabilities and operations to catalyze current and future mission success.

4.1: Attract and develop a talented and diverse workforce.

LEAD OFFICE
Mission Support Directorate (MSD), Office of the Chief Human Capital Officer (OCHCO), and Office of Diversity and Equal Opportunity (ODEO)

GOAL LEADER
Bob Gibbs, Associate Administrator, MSD; Elaine Ho, Associate Administrator for Diversity and Equal Opportunity; Kelly Elliott, Chief Human Capital Officer

Diversity in the workforce enhances decision-making, fosters innovation and creativity, and improves access to a broader talent pool. Strategic Objective 4.1 articulates NASA's commitment to attracting and developing a talented and diverse workforce.

ODEO focuses on cultivating a diverse workforce and in FY 2024, developed Center, Mission Directorate, and Mission Support Enterprise Organizations-level DEIA implementation plans, which detail actions NASA will take to advance inclusive environments and equitable opportunities for all employees. NASA is also implementing a NASA Conflict Management initiative in the near term. This initiative is making progress to embed anti-harassment, safety, and other conflict management efforts at every level. ODEO continues to measure impacts based on the available indicators from sources such as the Federal Employee Viewpoint Survey (FEVS), NASA DEIA Organizational Climate Survey, Safety Culture Survey, Equal Employment Opportunity barrier analysis under Management Directive 715, and tracking diversity across the employee lifecycle. The Organizational Climate Survey measures work environment and employee experience as it relates to equity, inclusion, anti-harassment, accessibility, absence of discrimination, psychological safety, and comfort at NASA.

OCHCO continues to cultivate a diverse, talented, and agile workforce. OCHCO is using a multi-pronged approach to update the agency workforce strategy. In FY 2024, OCHCO updated the agency's strategic workforce planning process, establishing a formal process to identify and resolve gaps in workforce funding between the Mission Directorates and Centers/Mission Support Enterprise Organizations and has begun implementing the process for FY 2024 and FY 2025.

OCHCO used results from FEVS to inform updates to the NASA Employee Value Proposition (EVP), which articulates what NASA offers to its employees in exchange for their skills, capabilities, and experiences. OCHCO mapped FEVS questions to the EVP Pillars, of Mission, Person, Teams, and Grow to provide context to the overall work experience. Additionally, OCHCO improved FEVS reporting, analysis, and action planning through a statistically valid model and reporting tool that helps prioritize areas to focus on based on meaningful differences and potential impact to key outcomes. For the second year, FEVS data is available to all NASA supervisors to improve internal policy decisions and inform a better organizational culture.

OCHCO made significant reductions in the agency average time to hire. The FY 2023 agency overall average time to hire was 75 days, down from 99 days in FY 2022. As of July 2024, NASA's time to hire for FY 2024 remains stable at 75 days on average. Additionally, several new talent development programs were rolled out in FY 2024, including an agencywide mentoring program and the Summer of Artificial Intelligence learning campaign.

Based on MSD, ODEO, and OCHCO's strategies and accomplishments described in the above paragraphs, Strategic Objective 4.1 achieved a Green/Satisfactory rating during the 2024 Strategic Review Process.

4.1.1: Maintain Time to Hire.

NASA achieved the FY 2024 target (maintaining a time to hire less than or equal to 80 days), resulting in a Green rating for this multiyear Performance Goal. The average time to hire in FY 2024 was 76 days, successfully remaining below the 80-day target. This goal reflects the time elapsed between validating a hiring need and the new hire's entry on duty date, excluding Pathways interns and Senior Executive Service positions. NASA's Office of the Chief Human Capital Officer aims to maintain the time to hire at no more than 80 days.

4.1.2: Decrease percentage of negative rating on NASA Federal Employee Viewpoint Survey (FEVS) DEIA (Diversity, Equity, Inclusion, and Accessibility) index.

NASA did not achieve the FY 2024 target of 88%, resulting in a Red rating for this Performance Goal. NASA's FY 2024 actual result was 84.1%. Although NASA did not achieve the target, the agency is still ranked as #1 among the large Federal agencies scored for this index. While there are still improvements that can be made in this area, the agency believes those improvements can be better measured and evaluated through other means. NASA expects to retire this Performance Goal after FY 2024.

4.1.3: Conduct an Agency-wide Full Workforce Barrier Analysis via a multi-phase evaluation of barriers.

NASA made significant strides in understanding and addressing potential barriers faced by its workforce. Performance Goal 4.1.3 saw substantial progress, however NASA only completed two of the three planned phases in FY 2024, thereby achieving Yellow rating for this multiyear Performance Goal. This multiyear comprehensive analysis involves a multi-phase evaluation, examining barriers affecting race/ethnicity, gender, disability status, and LGBTQIA+ identities, including a focus on the leadership pipeline. Though the annual target was not achieved, there is no anticipated risk to overall Performance Goal achievement.

"Phase 1 - Personnel Data Analysis," was completed in the second quarter of FY 2024, which resulted identifying demographic differences across multiple personnel data points such as, workforce distribution, grades and positions, time in position, hiring and loss demographics, training participation, applicant data, and employee satisfaction surveys, resulting in the identification of systemic or

personnel management triggers related to diversity and inclusion. These triggers varied by demographic group, with some groups showing workforce participation discrepancies, grade discrepancies, and/or satisfaction discrepancies.

"Phase 2 - Shareholder Interviews," was completed in the third quarter of FY 2024. Interviews were completed with senior employees, key center leaders, and personnel from several mission support enterprise offices, which provided deeper understanding and insights into current personnel management practices. Insights obtained included recruitment, interviewing, and training communication challenges that may be contributing to some of the triggers identified in phase 1.

"Phase 3 - Quantitative Survey," is currently underway, albeit slightly behind schedule. This phase utilizes a two-pronged approach utilizing data from two DEIA surveys.

4.2: Transform mission support capabilities for the next era of aerospace.

LEAD OFFICE
Mission Support Directorate (MSD)

GOAL LEADER
Bob Gibbs, Associate Administrator, MSD; Joel Carney, Associate Administrator for OSI; Jeff Seaton, Chief Information Officer, OCIO

The landscape of the space economy and ecosystem is undergoing rapid change. Strategic Objective 4.2 supports NASA's ability to evolve their mission support services to meet the demands of a growing commercial space industry, increased technological needs, and an increasingly hybrid workforce.

PRIORITY AREA 1: Strengthen NASA's Agency Technical Authorities (ATA)

Through NASA's Technical Authorities, the agency ensures independent oversight of programs and projects in support of safety and mission success by providing independent engineering, health and medical, and safety insight, oversight, assessment of, and technical expertise to programs supporting successful launch and execution of the agency's missions and activities. The NASA Engineering and Safety Center (NESC) supports this authority and is currently working 165 active engineering and safety assessments, which includes 63 new activities to date in FY 2024.

The Academy of Program/Project and Engineering Leadership (APPEL) Knowledge Services delivered 180 courses in FY 2022, 143 courses in FY 2023, and 93 courses to 1957 practitioners to date in FY 2024. APPEL also delivered three Quick Webinars to 1,303 attendees. In addition, APPEL released nine new episodes of its Small Steps, Giant Leaps podcast, which received over 20,000 plays across all episodes.

The Office of the Chief Engineer (OCE) continued to advance Digital Engineering (DE) and gain efficiencies with consolidation of DE tools. Since the beginning of FY 2024, the team has taken initial steps to reduce the annual operational costs by $50,000. The team also developed a more sustainable chargeback model for one of the software packages used across the NASA Engineering domain and across all five Mission Directorates, which has been vetted and approved by senior leadership of OCE,

OCIO, Resource Management Office, MSD, and Mission Support Program Management Council for implementation in FY 2025.

OSMA's strategic focus is assuring safety and mission success across all NASA activities. OSMA has implemented a strategic plan focused on strengthening internal resource management decision-making, making policy and assessment processes risk-informed, objectives-driven & case-assured, and developing digital tools to transform SMA capabilities.

PRIORITY AREA 2: Modernize infrastructure and technical capabilities

The Aircraft Capability Management Office continues to make progress against internally set success strategies by establishing and executing agency-level aircraft capability management functions and duties. NASA will continue to develop and execute its aircraft capability management to enable the agency to optimally deploy aircraft capabilities and resources when and where needed, prioritize sustainment of current NASA aircraft capabilities, and support investment and divestment decisions.

In FY 2024, NASA's Office of Strategic Infrastructure (OSI) eliminated 39 facilities for a total of 530K square feet eliminated under the Construction of Facilities program. Eliminating the Armstrong Flight Research Center leased facility in Palmdale was a major accomplishment by NASA's OSI that contributed significantly to reaching the target. NASA's FY 2024 effort resulted in the elimination of $5.5 million in deferred maintenance. In addition, these actions ushered close to $3.3M in cost avoidance. Going forth, NASA will be able to redirect these funds to sustain its mission-critical real property. By continuing to eliminate inactive and obsolete facilities, NASA is advancing the Agency Master Plan (AMP) to maintain a mission-driven and cost-effective real property portfolio. These actions also help eliminate safety and environmental liabilities, while reducing energy consumption.

PRIORITY AREA 3: Support our workforce with secure, innovative technology

Advances in information technology (IT) generate value daily. IT contributes to all mission activities, including mission imagery support for SpaceX Crew-5, spacewalks at the International Space Station, and Artemis in FY 2024. OCIO supported ARMD's Test Data Portal to centralize flight test and research data for easy access by researchers across NASA, partners, and contractors. At NASA Headquarters, OCIO supported creation of the Earth Information Center, a dedicated space for people to understand NASA's research and reporting on Earth's climate change. SMD and OCIO partnered to empower open science via the beta Science Discovery Engine, which enables the public to explore the universe through discovery of NASA's science data, documentation, and code. Modernization of NASA's existing public data portals improved data sharing with updated data, better search capabilities, increased accessibility for visitors, and enhanced data security.

NASA's remains committed to exploring and advancing new technologies for its employees and partners. In FY 2024, over 150 automations of manual tasks and processes saved more than 42,000 hours, enabling users to focus on higher-value work while driving labor cost avoidance and savings. To help organizations achieve their transformation objectives, OCIO created a transformation fund with an initial $10 million investment for FY 2024. The Agency Roadmap Manager (ARM) provides the first

searchable inventory of agency-wide IT roadmap and portfolio content to expand awareness and insight into NASA's transformation portfolio. OCIO has been using initial insights from ARM and NASA's Application Portfolio Optimization effort to inform investment direction, such as reducing duplicate services, identifying divestment opportunities, and driving budget and transformation fund decisions.

Despite progress towards objectives in NASA's IT Strategic Plan, NASA continues to lag on implementation of the government-wide National Security Council (NSC) requirements to fortify specific cybersecurity capabilities.

NASA is working to mitigate impacts by transforming service delivery models and optimizing purchasing, but significant risks remain. Evolving enterprise architecture, strategic portfolio management, and targeted modernization and transformation investments are helping address risks by enabling and supporting risk-informed decisions. Additionally, expanded use of artificial intelligence can transform how NASA achieves its goals, but must be approached carefully to avoid amplifying risks.

Based on MSD's strategy, accomplishments, and challenges described in the above paragraphs, Strategic Objective 4.2 achieved Yellow/Focus Area for Improvement rating during the 2024 Strategic Review Process.

4.2.1: Minimize the number and severity of employee injuries and illnesses to support the next era of aerospace.

NASA achieved the FY 2024 target, resulting in a Green rating for this multiyear Performance Goal.

NASA tracks workplace injuries measured OSHA-defined Total Case Incident Rate (TCIR) and Days Away, Restricted, or Transferred (DART) rates against relevant industry averages generated by the North American Industry Classification System (NAICS). NASA maintained a TCIR of 0.33 per 100 employees (including both civil servants and contractors), remaining well below the NAICS code industry average rate of 0.9 (the FY 2024 target for this Performance Goal).

The DART rate also remained below the industry average rate of 0.3 (an FY 2024 target for this Performance Goal), recording 0.18 for all NASA employees and 0.05 for civil servants over the past 12 months.

No NASA centers exceeded their industry-specific TCIR or DART rates for the entire fiscal year, indicating a comprehensive agency-wide effort to maintain safe working environments. These combined achievements underscore NASA's dedication to fostering a healthy and secure work environment for all its employees, a critical element in enabling the agency to pursue its ambitious aerospace goals.

4.2.2: Reduce damage to NASA assets (excluding launched flight hardware).

NASA achieved the FY 2024 target, resulting in a Green rating for Performance Goal 4.2.2, which assesses the total damage cost from agency mishaps over a rolling 12-month period, as compared to the previous 5-year annual average.

Mishap damage costs to NASA assets over the past 12 months were $930,000, well below the 5-year annual average target of $3,520,000. The second and third quarter figures of $2.01 million and $1.95 million indicate that costs remained below the target threshold for the fiscal year.

4.2.3: Ensure the health and safety of NASA astronauts and pilots.

NASA maintained a steadfast focus on the health and safety of its astronauts and pilots, achieving the FY 2024 target and a Green rating for Performance Goal 4.2.3.

This achievement reflects safe implementation of health and medical policies and standards. In FY 2024, the Health and Medical Technical Authority (HMTA) did not issue any non-concurrences for major program milestones. HMTA did not issue any non-concurrences to proposed Program variances for Program requirements derived from HMTA technical standards. HMTA worked with Programs in the effective, safe implementation of requirements derived from health and medical standards and medical operations. This proactive coordination with programs contributed to the overall success of Performance Goal 4.2.3.

4.2.4: Safeguard NASA's information resources through critical enhancements to confidentiality, integrity, and availability.

NASA's overall score increased to 71.9%, below the FY 2024 target of 90% set for the internal NASA Cybersecurity Scorecard, resulting in a Red rating for this multiyear Performance Goal. Scoring was based on data collected from multiple agency sources which also feed the Federal Cybersecurity Dashboard. NASA's Cybersecurity Scorecard metric was taken from the average of the 20 individual overall scores and underlying metrics that span the missions, corporate organizations, and Centers/Federally Funded Research and Development Centers.

NASA continued strengthening internal safeguards for information resources in FY 2024, improving the agency's cybersecurity posture. Agency progress included achievement of the government-wide targets in the National Security Council's action to implement critical security measures, such as encryption and multi-factor authentication, across NASA's entire IT environment. This concerted effort significantly strengthened the agency's cybersecurity posture to protect NASA's data and safeguard missions more effectively.

These results highlight NASA's dedication to protecting agency missions and vital information resources.

4.2.5: Increase the cumulative annualized person hours saved through automation.

NASA significantly exceeded its FY 2024 target for increasing cumulative annualized person-hours saved through process automation to 45,000 hours or more, resulting in a Green rating for this Performance Goal.

Over 150 automations contributed to 52,000 cumulative hours saved in FY 2024. The automations primarily focused on streamlining processes within the NASA Shared Services Center, including help desk support, financial operations, and travel-related activities. The consistent annual growth in time savings demonstrates the effectiveness of NASA's ongoing automation initiatives.

The NASA Enterprise Automation Service's Community of Practice fostered agencywide collaboration and information sharing on automation solutions. This forum included monthly topics spanning training, an automation roadmap, vendor demos, and showcases of NASA's real world innovative success stories. Agencywide participants in NASA's first "Power Platform Palooza" event submitted automation solutions during a virtual internal competition to inspire creativity and information sharing. By working together to optimize internal processes and free up valuable time, NASA is better positioned to dedicate resources to its core mission and business objectives.

4.2.6: Demolish or eliminate obsolete/unneeded facilities to reduce the Agency's infrastructure footprint.

NASA achieved the FY 2024 target by 12%, resulting in a Green rating for this multiyear Performance Goal. NASA eliminated 39 facilities for a total of 530 thousand square feet, including the Armstrong Flight Research Center leased facility in Palmdale, California, which contributed significantly to reaching the target.

NASA's FY 2024 effort resulted in the elimination of $5.5 million in deferred maintenance. In addition, these actions ushered close to $3.3 million in cost avoidance. Going forward, NASA will be able to redirect these funds to sustain its mission-critical real property. By continuing to eliminate inactive and obsolete facilities, NASA is advancing the Agency Master Plan to maintain a mission-driven and cost-effective real property portfolio. These actions also help eliminate safety and environmental liabilities, while reducing energy consumption.

4.2.7: Improve NASA's ability to operate facilities sustainably and reduce overall resource demands.

NASA achieved the FY 2024 target for its sustainability efforts, resulting in a Green rating for this multiyear Performance Goal. This goal is measured by the extent to which sustainability goals are defined in the OMB Scorecard for Efficient Federal Operations/Management. NASA met or exceeded seven out of seven OMB Scorecard goals for FY 2023, the most recent Scorecard. The OMB Scorecard evaluates federal agencies' performance across seven key sustainability areas: net-zero emissions operations, carbon pollution-free electricity, zero-emission vehicle acquisition, net-zero buildings, federal facility energy use, federal facility water use, and federal facility efficiency investments. The scorecard is released about ten months after the end of each fiscal year.

NASA achieved an energy intensity reduction of 41% from 2003, exceeding the goal of 30%, and 0.5% reduction from FY 2022; reduction of energy use in goal subject facilities by 1.2%; and a water intensity reduction of 34% from 2007, exceeding the goal of 20%, and 0.8% reduction from FY 2022. NASA was

recognized as one of the top 25% of Federal agencies in completion of facility evaluations as required by EISA 2007. The OMB Scorecard evaluates federal agencies' performance across seven key sustainability areas: net-zero emissions operations, carbon pollution-free electricity, zero-emission vehicle acquisition, net-zero buildings, federal facility energy use, federal facility water use, and federal facility efficiency investments. The scorecard is released about ten months after the end of each fiscal year.

4.2.8: Demonstrate increased facility reliability for current and future mission needs through investments in preventative maintenance that reduce unscheduled maintenance.

NASA fell short of the FY 2024 target to limit the percentage of funds allocated to unscheduled maintenance to no more than 20%, resulting in a Yellow rating for this multiyear Performance Goal. The ratio grew 1.3% from FY 2023 levels to 21.7% in FY 2024.

The proportion of spending on unscheduled maintenance compared to total maintenance expenditures is an important indicator of the overall condition and reliability of the equipment. NASA faced continuing, unabated challenges related to its aging facilities in FY 2024. Financial constraints necessitate deferring critical infrastructure repairs and prioritizing risks more effectively. In 2025, NASA will fully implement Tiered Maintenance, which strategically allocates maintenance resources to the most mission-relevant facilities and infrastructure. The objective of this program is to maximize the use of available resources to ensure that the most vital equipment assets receive the necessary attention. This strategy, in conjunction with a robust Reliability Centered Maintenance approach, facility consolidation, renewal, and divestment initiatives and an agency infrastructure stewardship strategy, aims to mitigate the highest mission-relevant risks to the agency and support NASA in fulfilling its mission requirements.

4.3: Build the next generation of explorers.

LEAD OFFICE
Office of Science, Technology, Engineering, and Mathematics (STEM) Engagement (OSTEM)

GOAL LEADER
Kris Brown, Deputy Associate Administrator for Strategy and Integration, OSTEM

For decades, NASA has inspired generations of Americans to look towards the stars and beyond by building sustainable pathways to careers in STEM. Strategic Objective 4.3 comprises all endeavors to attract, engage, and educate students and to support educators and educational institutions. The objective also aims to build the next generation of technologists, innovators, and explorers. The Office of STEM Engagement (OSTEM) seeks to create unique opportunities for a diverse set of students, educators, and educational institutions to contribute to NASA's work in exploration and discovery. A diverse STEM workforce brings a variety of perspectives, experiences, and problem-solving approaches, which enhances the ability to tackle complex challenges and drive technological advancements.

Inclusion of underrepresented groups helps to ensure that scientific and technological developments are equitable and beneficial to all segments of society.

In FY 2024, NASA implemented key strategies and evaluation methods to enhance diversity, equity, inclusion, and accessibility (DEIA) in the STEM ecosystem. NASA supported 23 active national partnerships in student STEM engagement via Space Act Agreements or Memoranda of Understanding that resulted in over seven million digital engagements. Partnerships with entities such as Crayola, Minecraft, Google, U.S. Department of Education, and American Institute of Aeronautics and Astronautics Foundation (AIAA), enabled the dissemination of educational tools, games, and resources directed towards students and teachers, as wells as newsletters and information for grantees, sub-grantees, and stakeholders.

Space Grant, Minority University Research & Education Project (MUREP), Next Gen STEM (NGS), Established Program to Stimulate Competitive Research (EPSCoR), and Science Activation (SciAct) grantee and awardee institutions reported 3,577 verified and validated peer-review publications, technical papers and presentation in FY 2023 demonstrating STEM engagement investments' significant contributions to NASA's mission and work.

NASA provided nearly 10,000 internships, fellowships, research opportunities, educator professional development, engineering design challenges, and other college/pre-college STEM engagement opportunities to nearly 9,000 student and educator participants representing K-12 institutions and higher education institutions including 2-year, 4-year institutions and all Minority Serving Institution (MSI) classifications. These significant awards provided more than $44M in direct financial support to participants and engaged participants in over 2.4 million total contact hours. In these opportunities, 14.8% of participants identified as racially underrepresented[4], 17.4% identified as ethnically underrepresented[5], and 43.2% of the Agency's higher education internships and fellowship opportunities were filled by women. Two underrepresented statistics (i.e., race and ethnicity) exceeded the national averages for underrepresented students enrolled in STEM degree programs per the National Center for Educational Statistics[6] and participants were from all institutional categories and levels, as defined by the U.S. Department of Education, resulting in three out of four diversity categories being met.

OSTEM has clear strategies in place to continue achieving its articulated goals related to building diversity in the STEM ecosystem. To measure its success, OSTEM has implemented a Learning Agenda, aligned with the Evidence Act, to analyze student, educator, and educational institution outcomes for continuous programmatic improvement. Presently, no major strategic drawbacks or obstacles exist that would impede progress towards Strategic Objective 4.3.

[4] Underrepresented racial categories (American Indian or Alaskan Native; Black or African American; and/or Native Hawaiian or Pacific Islander).
[5] Underrepresented ethnicity (Hispanic or Latino).
[6] Reference location: https://nces.ed.gov

Based on OSTEM's strategy and accomplishments described in the above paragraphs, Strategic Objective 4.3 achieved Blue/Noteworthy rating during the 2024 Strategic Review Process.

4.3.1: Create unique opportunities for a diverse set of students to contribute to NASA's work in exploration and discovery.

NASA completed two of two milestones and activities planned for FY 2024, resulting in a Green Performance Goal rating. Milestone 4.3.1.1, aimed at measuring research output from students engaged in STEM investments, exceeded expectations. Programs like Space Grant, Minority University Research and Education Project (MUREP), Next Gen STEM, Established Program to Stimulate Competitive Research (EPSCoR), and Science Activation (SciAct) reported 3,577 verified peer-reviewed publications, technical papers, and presentations, surpassing the target of 2,200 and the FY 2022 level of 3,413. The second milestone, 4.3.1.2, involved completing the Space Grant Program-Level Evaluation. This evaluation, conducted by the Alaska Space Grant Consortium (University of Alaska Fairbanks) and their evaluator, the Goldstream Group, provided valuable insights into the program's effectiveness.

4.3.2: Build a diverse future STEM workforce by engaging students in authentic learning experiences with NASA's people, content, and facilities.

NASA achieved the target for Performance Goal 4.3.2 by exceeding national averages in three of four diversity categories in providing significant higher education awards, such as internships and fellowships, for the 2022-2023 academic year, resulting in a Green rating[7].
NASA provided almost 9,600 internships, fellowships, and other STEM opportunities to nearly 9,000 students and educators from K-12 through higher education institutions, including all Minority Serving Institution (MSI) classifications. These opportunities represented a significant investment of approximately $44.3 million and offered participants roughly 2.4 million contact hours. The results demonstrated a strong commitment to diversity: 14.8% of participants identified as racially underrepresented[8] and 17.4% as ethnically underrepresented[9], both exceeding national averages for STEM enrollment. Women filled 43.2% of higher education internships and fellowships, meeting the target for this category. Further demonstrating the breadth of reach, participants represented all institutional categories and levels, as defined by the U.S. Department of Education.

By offering a wide range of opportunities to a diverse group of students, NASA is actively cultivating the next generation of STEM professionals.

[7] NASA rates this Performance Goal using data reported on the academic calendar. The FY 2024 rating is based on verified and validated data from the 2022–2023 academic calendar.
[8] Underrepresented racial categories (American Indian or Alaskan Native; Black or African American; and/or Native Hawaiian or Pacific Islander)
[9] Underrepresented ethnicity (Hispanic or Latino)

4.3.3: Attract diverse groups of students to STEM through learning opportunities that spark interest and provide connections to NASA's mission and work.

NASA completed two of two milestones and activities planned for FY 2024, resulting in a Green rating for this Performance Goal. This accomplishment stemmed from the successful completion of Milestone 4.3.3.1, measuring the number and diversity of K-12 students exposed to these opportunities. In FY 2023, NASA engaged 725,051 K-12 students in STEM learning. This included 372,921 elementary students, 265,076 middle school students, and 87,054 high school students. Diversity data, collected from a subset of participants, indicated 40% identified as female, 10.2% as an underrepresented racial category, and 27.5% as Hispanic or Latino. This progress builds upon NASA's ongoing commitment to STEM education.

4.3.4: Promote equal opportunity compliance and encourage best practices among NASA grant recipient institutions to ensure that grantees are providing equal opportunity regardless of race, color, national origin, sex (including pregnancy, sexual orientation, gender identity), age, or disability.

NASA achieved 100% compliance with its Performance Goal 4.3.4, which promotes equal opportunity compliance and encourages best practices among NASA grant recipients, resulting in a Green rating. This goal ensures grantees provide equal opportunity regardless of race, color, national origin, sex (including pregnancy, sexual orientation, gender identity), age, or disability. NASA reviews two to three grant recipient institutions annually through on-site and desk audits, issuing recommendations and corrective actions where needed. This achievement demonstrates the effectiveness of these reviews in ensuring adherence to equal opportunity laws and mandates. This progress builds upon previous successes in fostering a diverse and inclusive environment within NASA's grant programs. NASA has reported on this goal for over ten years and has been 100% compliant every year. As NASA begins to establish the 2026 Strategic Plan, the Agency has determined that this goal should be retired to allow for additional focus in areas that offer greater insight into performance with grant recipients.