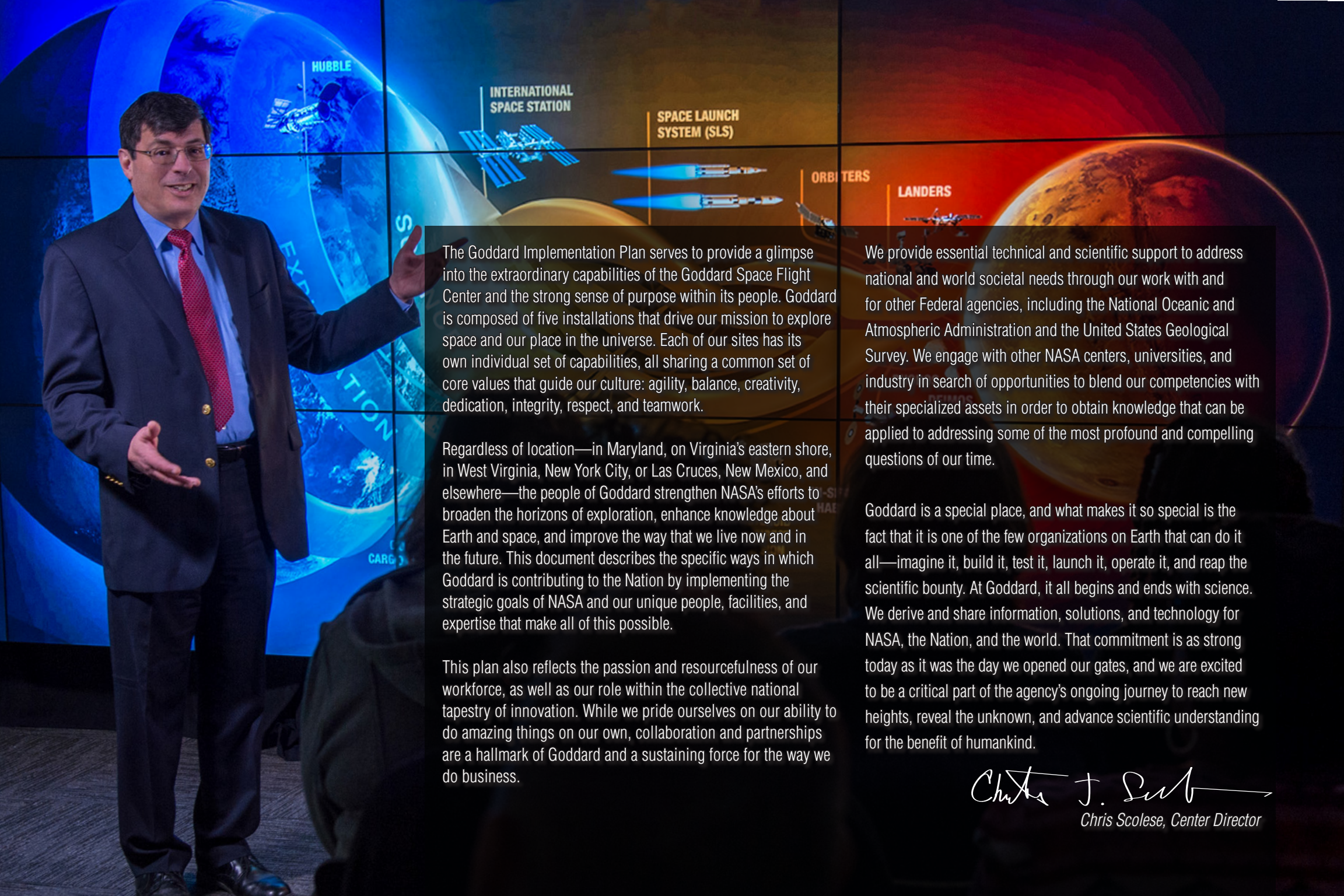
TITLE from dreams, through concepts and builds, to reality and implementation
NAME Goddard DATE 1959–2014 ... AND BEYOND!
National Aeronautics and Space Administration
NASA
SOLAR FLARE
SOLAR ACTIVE REGIONS
I have watched you fly
... & I have shared your freedom
F19
GPM CORE
GCOM-W1
NPP
JPSS-1
NOAA-19
igniter
needle valves
rocket motor
liquid oxygen line
gasoline line
exhaust shield
hinged rod
pull cord
pressure relief vent
liquid oxygen tank
cork float valves
alcohol burner
oxygen gas pressure line
gasoline tank
check valve
pull cord
detachable starting hose
oxygen cylinder
pipe
Goddard: We Begin And End With Science
Center Implementation Plan



The Goddard Implementation Plan serves to provide a glimpse into the extraordinary capabilities of the Goddard Space Flight Center and the strong sense of purpose within its people. Goddard is composed of five installations that drive our mission to explore space and our place in the universe. Each of our sites has its own individual set of capabilities, all sharing a common set of core values that guide our culture: agility, balance, creativity, dedication, integrity, respect, and teamwork.

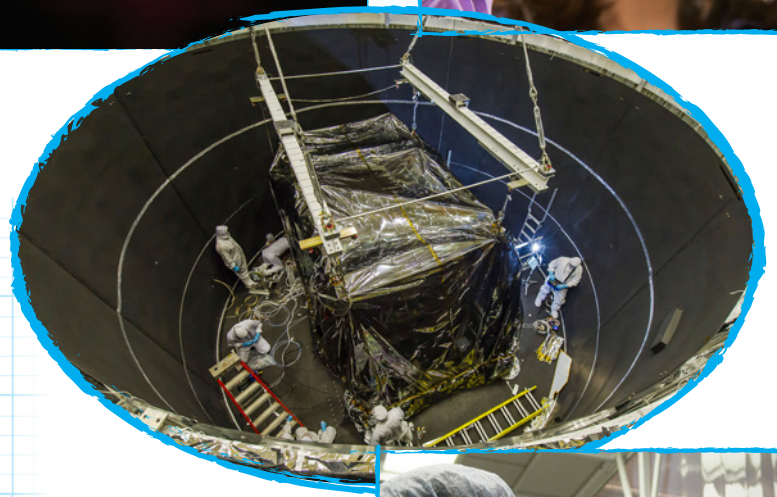
Regardless of location—in Maryland, on Virginia's eastern shore, in West Virginia, New York City, or Las Cruces, New Mexico, and elsewhere—the people of Goddard strengthen NASA's efforts to broaden the horizons of exploration, enhance knowledge about Earth and space, and improve the way that we live now and in the future. This document describes the specific ways in which Goddard is contributing to the Nation by implementing the strategic goals of NASA and our unique people, facilities, and expertise that make all of this possible.

This plan also reflects the passion and resourcefulness of our workforce, as well as our role within the collective national tapestry of innovation. While we pride ourselves on our ability to do amazing things on our own, collaboration and partnerships are a hallmark of Goddard and a sustaining force for the way we do business.

We provide essential technical and scientific support to address national and world societal needs through our work with and for other Federal agencies, including the National Oceanic and Atmospheric Administration and the United States Geological Survey. We engage with other NASA centers, universities, and industry in search of opportunities to blend our competencies with their specialized assets in order to obtain knowledge that can be applied to addressing some of the most profound and compelling questions of our time.

Goddard is a special place, and what makes it so special is the fact that it is one of the few organizations on Earth that can do it all—imagine it, build it, test it, launch it, operate it, and reap the scientific bounty. At Goddard, it all begins and ends with science. We derive and share information, solutions, and technology for NASA, the Nation, and the world. That commitment is as strong today as it was the day we opened our gates, and we are excited to be a critical part of the agency's ongoing journey to reach new heights, reveal the unknown, and advance scientific understanding for the benefit of humankind.

Chris Scolese, Center Director



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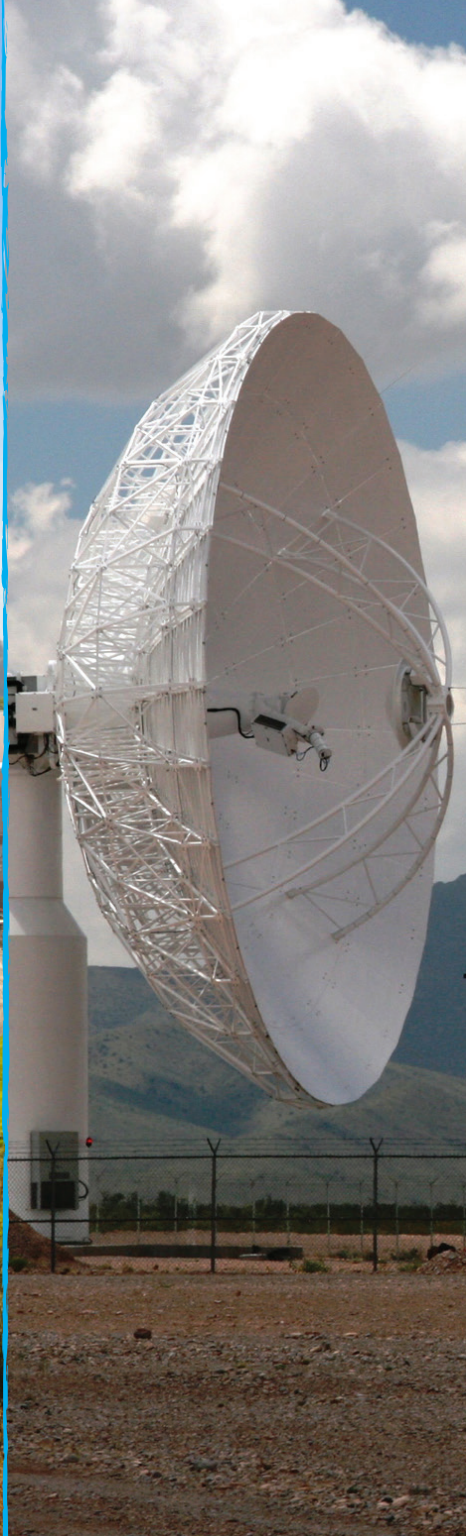
ud of the Past, Prepared for the Future. 58

(Top to bottom) Goddard at work: Preparing for launch at Wallops. Validating sample preparation for the Sample Analysis at Mars instrument. Lowering the Integrated Science Instrument Module into the Space Environment Simulator. Working on a microsatellite in a cleanroom. Retrieving mid-mission supplies for an arctic mission.

NASA

ANTARES

RESTAURANT



In support of the National Aeronautics and Space Administration's (NASA) overarching mission to extend the bounds of humankind's scientific knowledge, Goddard Space Flight Center has emerged as a definitive national and global resource for Earth and space science. At Goddard, we provide end-to-end mission capability; teams conceive, design, build, test, launch, track, and operate science exploration missions; as well as interpret, model, archive, and share data from those missions. We do all of this within one organization, which allows us to drive science discovery and technology innovation for the benefit of NASA, the Nation, and the world.

Goddard plays a pivotal role in the quest to:

- Understand our Earth as a system.
- Discover the origins and structure of the universe.
- Search for life-harboring planets around other stars.
- Study the closest star, our Sun.
- Investigate the interaction of the Sun with the Earth.
- Explore our solar system and look for signs of life.
- Enable scientific and human exploration through satellite servicing, communications, and launch services.

Goddard makes these contributions with the Nation's largest community of scientists, engineers, and technologists; world-class instrument and spacecraft engineering; preeminent project management expertise; and the only NASA-owned launch range. Goddard also provides services globally, including spaceflight communications and oversight of two of NASA's three space communications networks.

Meeting our commitments is critical to the success of our missions, our center, and NASA. Goddard has a proven record of building distinguished teams of civil servants, contractors, and partners tailored to the evolving requirements of our customers. Our diligence combined with our expertise in scientific research, cutting-edge technology, and complex technical management empowers ongoing and future missions.

Consistently recognized as one of the best places to work in the Federal Government, Goddard seeks to fully engage our entire workforce, from Nobel-prize-winning teams to early career professionals. Goddard Space Flight Center comprises five locations that each possess unique capabilities: the Goddard Greenbelt campus, Greenbelt, Maryland; Wallops Flight Facility, Wallops Island, Virginia; Independent Verification and Validation (IV&V) Facility, Fairmont, West Virginia; Goddard Institute for Space Studies (GISS), New York City; and White Sands Complex, Las Cruces, New Mexico. Goddard's strength is anchored in our dedicated workforce, proven capabilities, and one-of-a kind facilities throughout all locations, which together provide unprecedented science, flight, and technology capacity for the achievement of NASA's vision.

(Previous page) A slice of life—the five sites that make up One Goddard: the Greenbelt campus, Wallops Flight Facility, GISS, IV&V, and White Sands Complex. (Right) We drive science discovery and technology innovation for the benefit of NASA, the Nation, and the world.

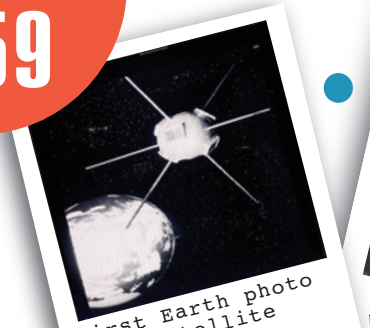
Goddard AT A GLANCE

ROBERT H. GODDARD
THE FATHER OF MODERN ROCKETRY

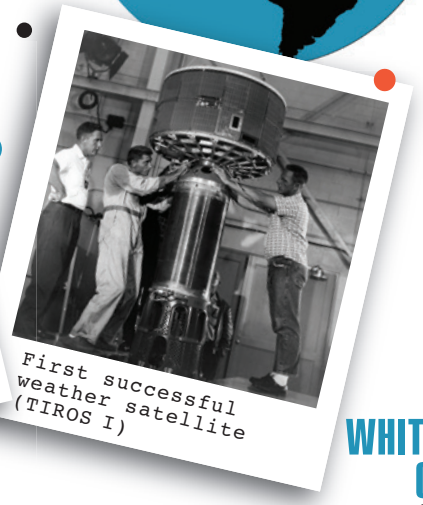
(1882–1945) The American engineer, professor, physicist, and inventor who is credited with creating and building the world's first liquid-fueled rocket.

GODDARD: NASA'S **FIRST** SPACEFLIGHT CENTER

EST. **MAY 1959**



First Earth photo from satellite (Vanguard II)



First successful weather satellite (TIROS I)

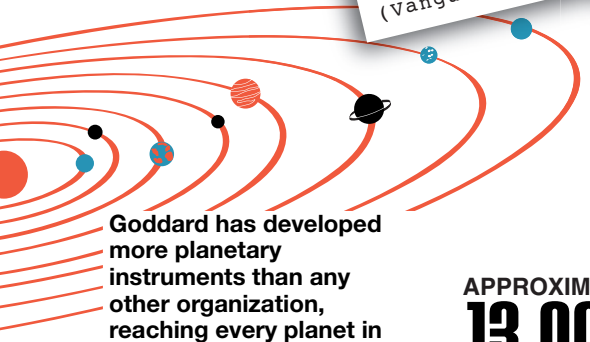
GODDARD
GREENBELT CAMPUS
MARYLAND

WALLOPS FLIGHT FACILITY
WALLOPS ISLAND
VIRGINIA

INDEPENDENT VERIFICATION & VALIDATION FACILITY
FAIRMONT
WEST VIRGINIA

WHITE SANDS COMPLEX
LAS CRUCES
NEW MEXICO

GODDARD INSTITUTE FOR SPACE STUDIES
NEW YORK CITY
NEW YORK



Goddard has developed more planetary instruments than any other organization, reaching every planet in the solar system.

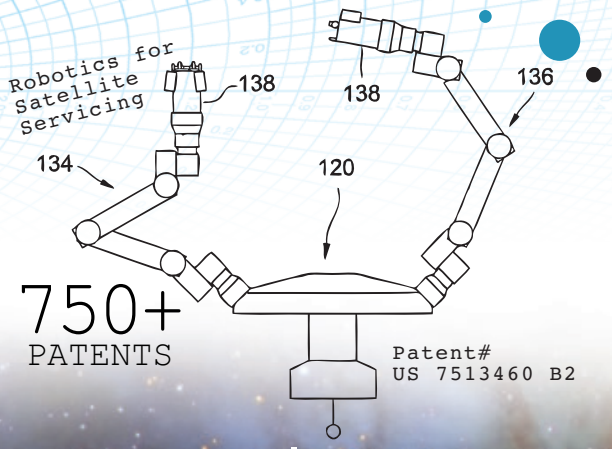
APPROXIMATELY **13,000+** CIVIL SERVANTS, ONSITE CONTRACTORS, AND OTHERS

one Goddard
We are Stronger Together

Goddard invests more than **80%** of its funding in businesses, academia, and nonprofit organizations.

100%
OF U.S. WEATHER SATELLITES FOR NOAA

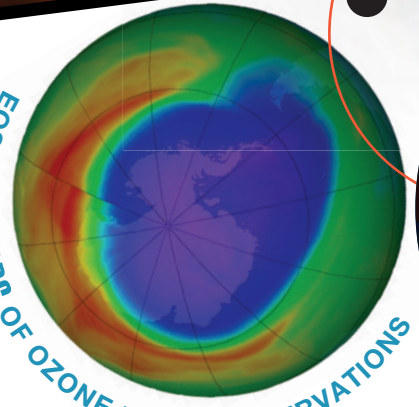
Hurricane Gonzalo
GOES-East Satellite

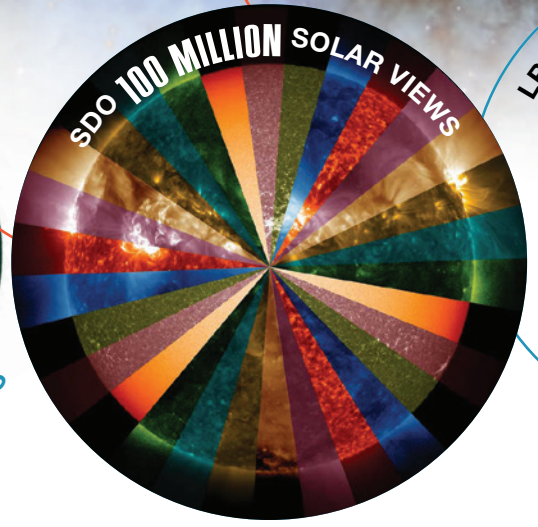


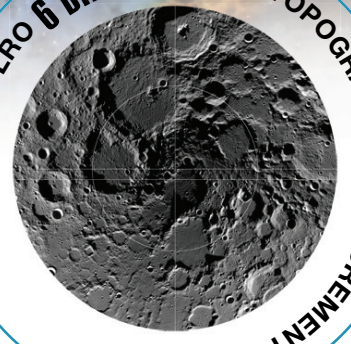
750+
PATENTS

25 YEARS | HUBBLE SPACE TELESCOPE

1 MILLION OBSERVATIONS
and 11,000+ scientific papers



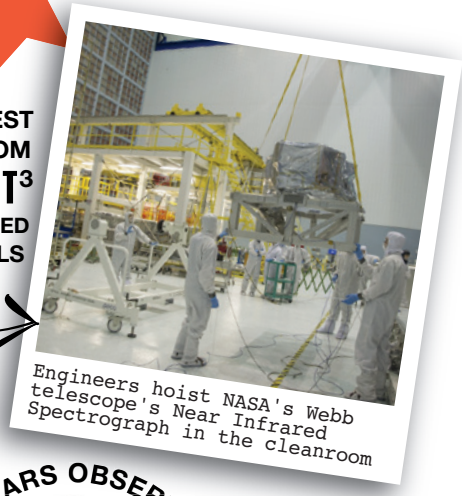




NOBEL PRIZE WINNER

Dr. John Mather and the COBE team confirmed the Big Bang theory to extraordinary accuracy. Goddard has also contributed to 3 additional Nobel Prizes.

WORLD'S LARGEST ISO 7 CLEANROOM
1.3 MILLION FT³
≈15 OLYMPIC-SIZED SWIMMING POOLS


Engineers hoist NASA's Webb telescope's Near Infrared Spectrograph in the cleanroom

300+
MISSIONS

LANDSAT 5 set a
GUINNESS WORLD RECORD
"Longest-Operating Earth Observation Satellite"

TITLE
Goddard NAME 5 PAGE

The Goddard Life Cycle

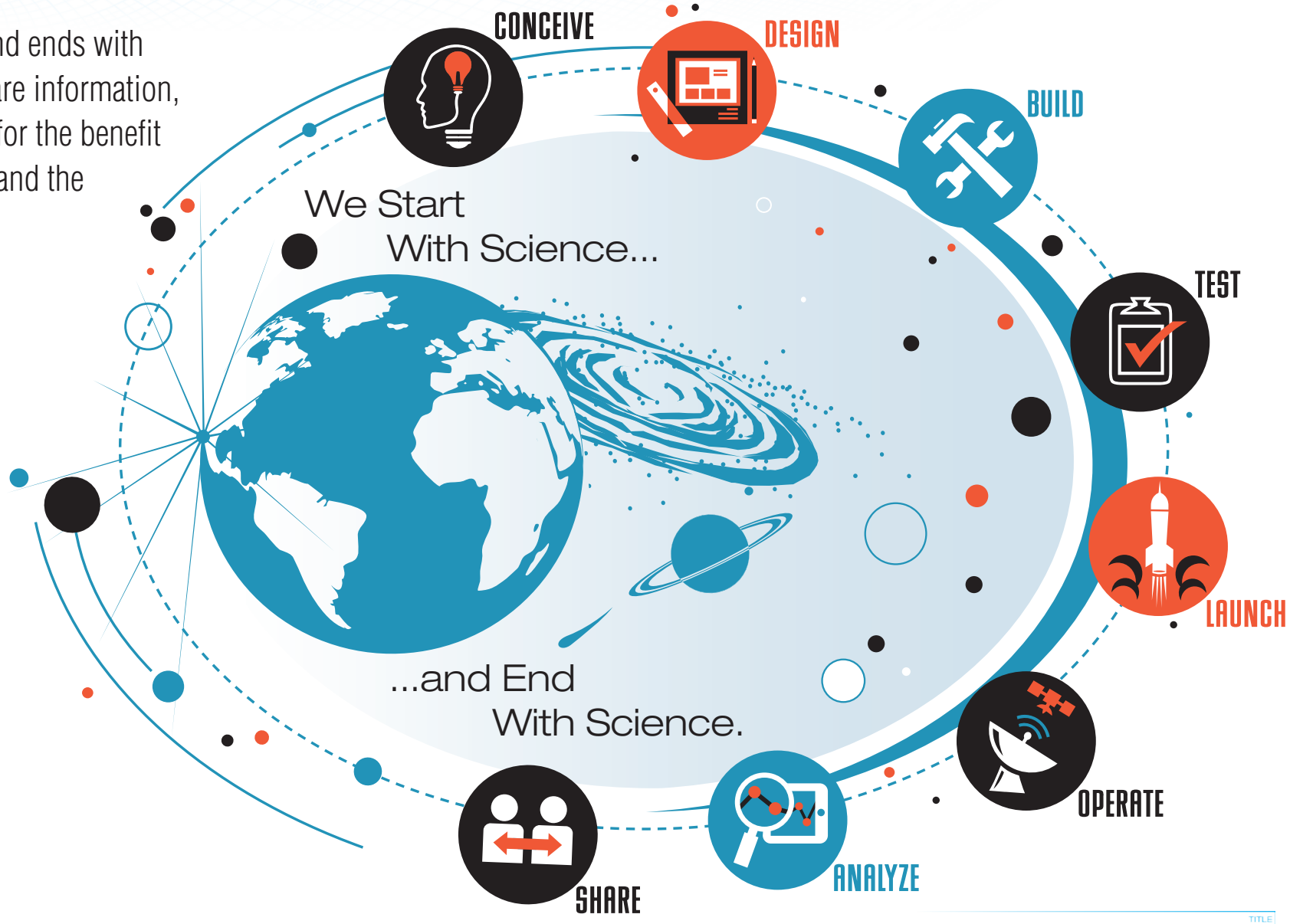
At Goddard, we launch science. We help answer crucial science questions through complex missions that depend on dedicated, innovative teams to develop pioneering technologies. Goddard is one of the few organizations worldwide to manage a mission from concept through operations—utilizing internal, partner, and industry expertise and resources—covering suborbital through planetary missions.

The depth and expertise of our scientists, engineers, technologists, project managers, support personnel, and facilities form the foundation of our unique strength. With our leadership in scientific research and instruments and spacecraft development, the center has a notable capability to conceive and manage advanced science, technology, and space systems through the entire life cycle of a mission.

- Science teams develop concepts and potential solutions based on stakeholder needs.
- Project management teams ensure mission success by following stringent methodologies from formulation through launch and beyond.
- Engineering teams and technologists design, build, and test solutions including spacecraft, instruments, ground systems, software, and supporting technologies.
- Launch support teams prepare and execute mission launches and monitor ascents, orbits and descents.
- Mission operations teams control and maintain spacecraft and instruments from Goddard's mission operations centers.
- Mission support personnel provide a myriad of services to ensure that infrastructure and facilities are optimized; information technologies are secure and effective; the right team members are hired, trained, and retained; quality and safety are inherent in all products; and resources are appropriately utilized and managed throughout the mission life cycle.
- Education, communications, science, and engineering teams package and disseminate information and data sets to stakeholders, including science communities, international partners, academia, students, and the general public.
- Science teams analyze satellite and instrument data; build models using large-scale, supercomputing applications; and apply the results.
- Research results guide teams as they develop new concepts and work with stakeholders to identify future challenges that will further human knowledge and understanding.

The Antares rocket, with the Cygnus cargo spacecraft aboard, is seen in this false color infrared image, as it launches from Pad-0A of the Mid-Atlantic Regional Spaceport (MARS), Wednesday, Sept. 18, 2013, at Wallops Flight Facility in Virginia.

At Goddard, it all begins and ends with science. We derive and share information, solutions, and technology for the benefit of all—NASA, the Nation, and the world.



Goddard: Past and Present

Goddard Dedication Ceremony (1961)

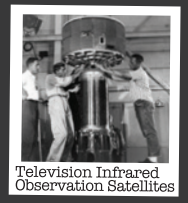
MAY 1959
Goddard designated as NASA's first spaceflight center.

OCTOBER 1958
NASA began operation after the signing of the National Aeronautics and Space Act of 1958.

AUGUST 1959
Explorer VI: First successful launch of a Goddard-managed science satellite.

Goddard's Early Communications Networks

1959–1975
Communications for the first satellites and manned missions (Mercury, Gemini, and Apollo).


Television Infrared Observation Satellites

1960–PRESENT
TIROS-1 ('60) was the first of many successful weather satellites Goddard has provided through its history.

FEBRUARY 1961
Explorer IX: First orbital mission launched from Wallops.

MAY 1961
GISS established.

Telstar I

JULY 1962
Telstar I launched, providing the first satellite telephone and television signals.

DECEMBER 1962
Relay 1 launched, providing the first TV transmissions across the Pacific in 1963.

APRIL 1966
The first of four Orbiting Astronomical Observatories launched, setting the stage for Hubble.

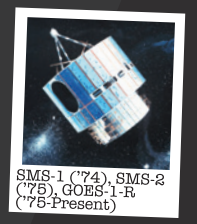
"One Small Step..."

JULY 1969
Apollo 11: Famous first words transmitted from the moon.

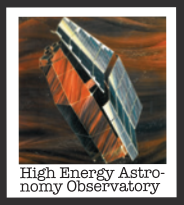
Landsat Earth-Observing Satellites

1972–PRESENT
Landsat began 40+ years of documenting the surface of planet Earth.

1975–1989
The Spaceflight Tracking and Data Network began communications for low Earth-orbiting missions, including the space shuttle.


SMS-1 ('74), SMS-2 ('75), GOES-1-R ('75-Present)

1975–PRESENT
GOES formed the basis of U.S. weather monitoring and forecasting for 40+ years, after the launch of two Synchronous Meteorological Satellites (SMS).


High Energy Astronomy Observatory

AUGUST 1977
HEAO program began surveying the X-ray sky.

FEBRUARY 1978
Goddard-managed ground communications stations established at White Sands.

NIMBUS 7

OCTOBER 1978
Nimbus 7 launched with Goddard's TOMS which discovered ozone hole and long-term damage to the ozone layer.

FEBRUARY 1980
Solar Maximum Mission (SMM) launched to study the Sun in detail.

OCTOBER 1981
Wallops Flight Facility became part of Goddard.

TDRS-A ('83) – TDRS-L ('14)

1983–PRESENT
Tracking and Data Relay Satellites (TDRS) deployed. Space communication networks expand to global coverage.

APRIL 1984
First-ever in-orbit satellite repair mission, for SMM.

OCTOBER 1984
Earth Radiation Budget Satellite launched. Provided data on the ozone layer that was key to the Montreal Protocol.

1960 1965 1970 1975 1980 1985

Goddard is a unique national resource with a rich history and promising future. Named for American rocketry pioneer, Dr. Robert H. Goddard, the center was established in 1959 as NASA's first spaceflight complex. Goddard's Wallops Flight Facility was established in 1945 to support the National Advisory Committee for Aeronautics (NACA), NASA's predecessor, and joined Goddard in 1981.

Goddard's heritage as an "all-purpose" space center with end-to-end capabilities has resulted in a broad, robust program of scientific research and space systems development. Goddard's missions—which study and explore the Earth, our Sun and solar system, planets orbiting distant stars, and the cosmos—are key to NASA's aim to expand horizons, increase knowledge, and improve lives. Together with our partners in other NASA centers, government agencies, academic institutions, and industry, we continue to unlock the mysteries of our world and reap scientific breakthroughs.

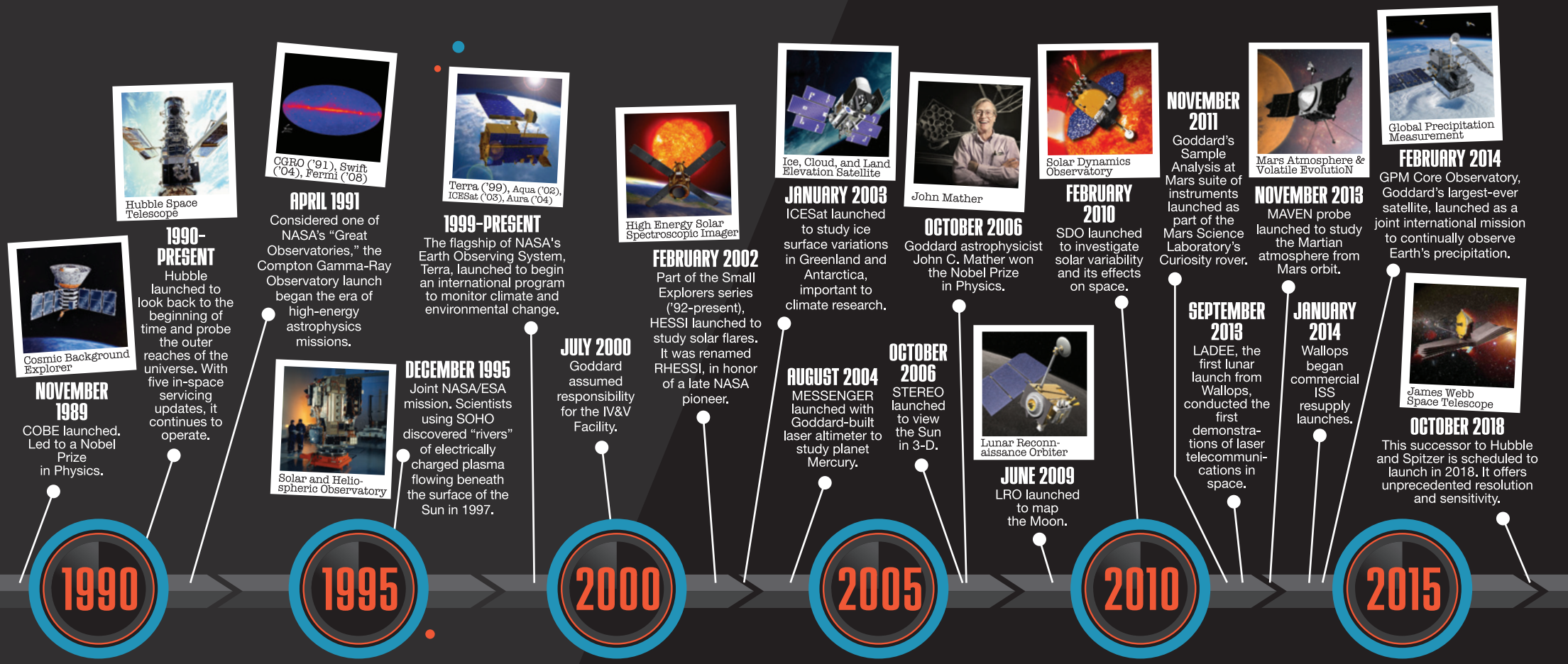
Today, Goddard continues to advance space exploration and scientific discovery, pushing the frontiers of science and engineering to address three fundamental questions:

Why are we here?

We seek to understand of the origins of life itself. Through planetary science missions such as the Mars Atmosphere and Volatile EvolutioN mission (MAVEN) and (the Origins Spectral Interpretation Resource Identification Security–Regolith Explorer (OSIRIS–REx), we gain insight into how planets formed and life began by studying asteroids and other solar system bodies as well as the atmosphere, climate, liquid water, and habitability of Mars.

How do we survive and thrive?

We strive to further our understanding of the changing Earth system and how our lives are influenced by the Sun. This is accomplished through Earth science missions such as the Global Precipitation Measurement



(GPM) mission; the Ice, Cloud, and land Elevation Satellite (ICE-Sat) series; the Geostationary Operational Environmental Satellite (GOES) series, the Landsat Data Continuity Mission (Landsat-8); the Suomi National Polar-orbiting Partnership (Suomi NPP) mission; and the Joint Polar Satellite System (JPSS). Goddard's work in Earth science provides global precipitation maps to study global climate and improve the forecasting of extreme events, improves observations of Earth's environment that directly affect public safety, and extends long-term climate and short-term weather observations.

We study how to live with a star, our Sun, by conducting space weather research and learning how our closest star affects our near-space environment. Goddard is involved in multiple heliophysics missions including the Solar Dynamics Observatory (SDO), the Magnetospheric Multiscale (MMS) mission, and Solar Probe Plus. Understanding and predicting space weather effects, which can impact space-based assets and ground-based technology, benefits the Nation and the world.

What is out there?

We seek to better understand the greater cosmos and our place within through numerous astrophysics missions, including the Hubble Space Telescope, the James Webb Space Telescope, the ASTRO-H X-ray observation satellite, the Transiting Exoplanet Survey Satellite (TESS), and the Swift Gamma-ray Burst Explorer. These missions are transforming our knowledge of the universe by observing the most distant stars and galaxies, studying formation of solar systems, examining high-energy phenomena in the universe, and surveying the entire sky for planets orbiting other stars. Goddard's work in astrophysics science probes the origin and evolution of cosmic objects and the universe; examines distant planets for life; and explores the mysterious nature of black holes, dark matter, and dark energy.

REACH NEW HEIGHTS

REVEAL THE UNKNOWN

BENEFIT ALL HUMANKIND

Goddard's Role in Fulfilling NASA's Vision

NASA Vision

We reach for new heights and reveal the unknown for the benefit of humankind.

Goddard's Role in Fulfilling the NASA Vision

For the good of our Nation and the world, we lead scientific research and exploration that transforms our understanding of Earth and space. Applying our breakthroughs to the economy and community enhances the lives of people on our home planet.

(Left) This high-altitude balloon mission launched successfully from Fort Sumner, New Mexico, to study the composition of objects in our solar system. (Above) This Hubble image is of a small portion of the Carina Nebula, one of the largest-seen star-birth regions in the galaxy.

Goddard's Role in Fulfilling NASA's Mission

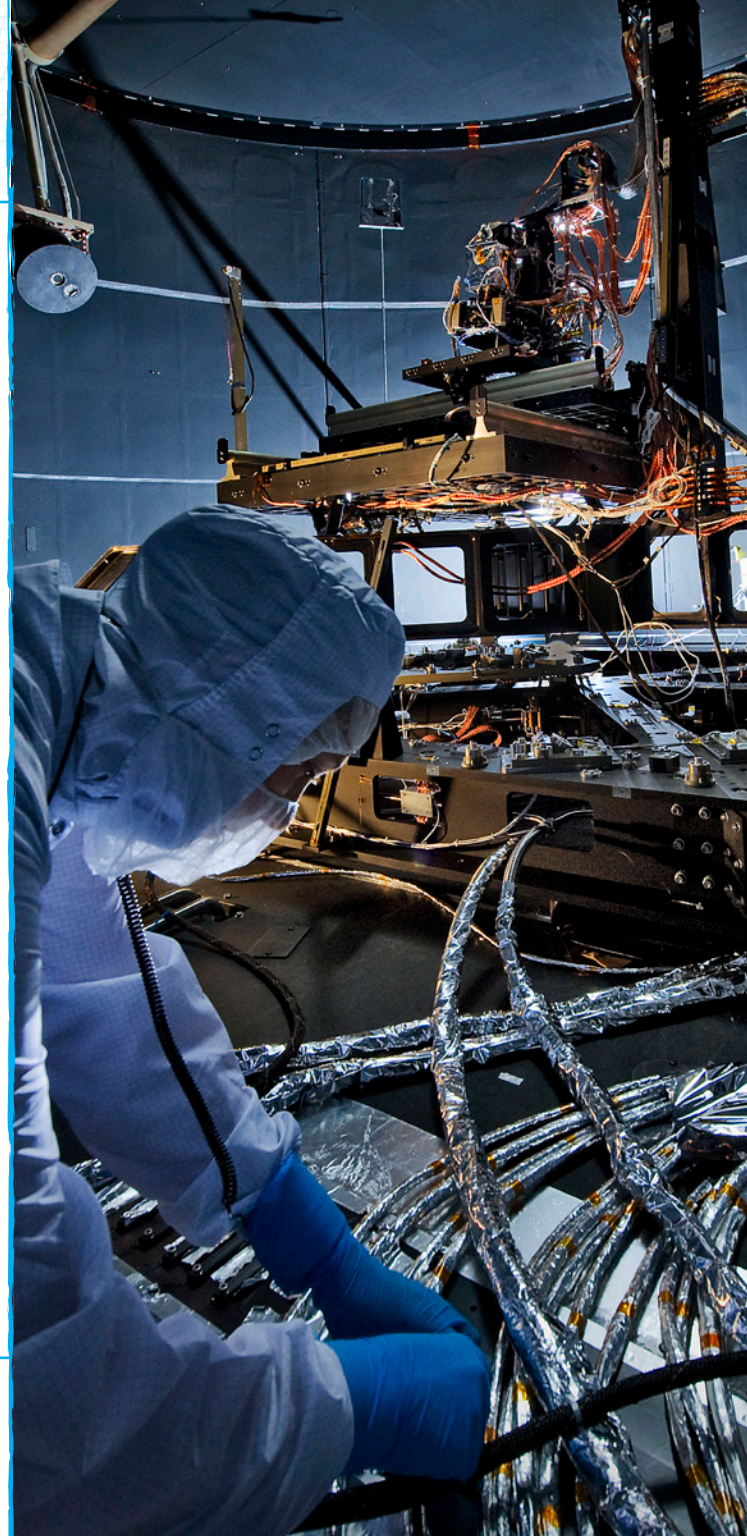
NASA Mission

Drive advances in science, technology, aeronautics, and space exploration to enhance knowledge, education, innovation, economic vitality, and stewardship of Earth.

Goddard's Role in Fulfilling the NASA Mission

Goddard advances NASA's mission by leading scientific research, and by building, launching, and operating instruments and spacecraft. As a science center, Goddard seeks to understand the Earth and to explore the universe through a robust program of scientific research in Earth science, astrophysics, heliophysics, and planetary science. As a spaceflight center, Goddard utilizes its core technical and programmatic expertise and facility capabilities to execute a broad range of flight missions and field campaigns. We are engaged in developing the advanced technologies that allow the agency to continuously expand the capabilities of its scientific spacecraft, instruments, and information systems.

Goddard expands knowledge to stimulate economic growth, foster education, and inspire the Nation, particularly the next generation of builders and explorers. Goddard is committed to enabling innovation and the creation of new technologies to advance the agency's capabilities and achieve its mission.



(Above) A Goddard technologist and team have developed a low-cost, low-mass technique for protecting spacecraft components from outgassed contaminants, such as from this paint sample. (Right) Equipment is prepared for testing in a large thermal vacuum chamber.

Goddard's Role in Fulfilling NASA's Values

NASA's core values and key priorities are inherent in and embodied by the people who are leading the effort to achieve its mission.

At Goddard, we recognize that our workforce is our greatest asset. Together, all facets of the diverse Goddard community are dedicated to these objectives for the benefit of the agency and the public:

- Conduct NASA's missions while fully minimizing risk to life, property, communities, and the environment. Safety and environmental stewardship are vital to NASA's continued success.
- Meet our commitments to the agency and its customers by delivering high-quality products on time and on schedule. It is our highest priority to uphold the agency's reputation of scientific distinction and reliability.
- Foster effective collaboration among individuals, teams, and management within the center, across NASA, and externally. Goddard's accomplishments result from these successful relationships as well as numerous strategic partnerships.
- Protect, support, and encourage employees by engaging, enabling, and empowering them in all of their efforts to safeguard the public trust. We maintain a world-class workforce dedicated to the execution of NASA's mission by:
  - Demonstrating confidence, fairness, honesty, and balance.
  - Providing opportunities for development and mobility.
  - Promoting diversity and inclusion.
- Ensure the success of our missions by supporting and sustaining employee dedication, agility, creativity, and commitment to excellence at all levels in the organization.
- Promote transparency and accountability by actively sharing our results and activities with customers, stakeholders, and the public, as well as engaging communities who are the ultimate beneficiaries of our work.
- Goddard is also committed to focusing on NASA's other overarching approaches to finding new ways of doing business and investing in new technology.

Astrobiologists work in the lab on developing methods of extracting organic compounds from Titan-like gas samples.

PARTNERSHIPS:
THE KEY TO ACHIEVING GODDARD'S MISSION

Goddard's partners are also important to mission success and the implementation of NASA's core values and strategic goals. Goddard's strategic partnerships with academia, industry, and other government agencies are integral to the Goddard community. These diverse partnerships include many long-term relationships. Our activities include:

- *Working with the National Oceanic and Atmospheric Administration (NOAA) to build flagship spacecraft constellations such as the Geostationary Operational Environmental Satellite (GOES) and the Joint Polar Satellite System (JPSS).*
- *Providing space operations services for all NASA spaceflight programs, other government agencies, and the commercial space sector with the Tracking and Data Relay Satellite System (TDRSS) and participation in NASA's Space Communications and Navigation (SCaN) program.*
- *Collaborating with worldwide scientific organizations including other Federal agencies, academia, private industry, and international space organizations, including Canada, Japan, the participating countries of the European Space Agency, and other nations.*
- *Deploying suborbital and small- to medium-class orbital missions at the Wallops Flight Facility along with all branches of the Department of Defense, and the Mid-Atlantic Regional Spaceport (MARS) for government–commercial space-launch operations.*

Goddard's Alignment with NASA's Strategic Plan

Goddard and NASA's Strategic Plan

NASA outlined the following goals in its 2014 Strategic Plan:

1. Expand the frontiers of knowledge, capability, and opportunity in space
2. Advance understanding of Earth and develop technologies to improve the quality of life on our home planet
3. Serve the American public and accomplish our mission by effectively managing our people, technical capabilities, and infrastructure

Goddard plays a critical and unique role in implementing these strategic goals and objectives as summarized here:

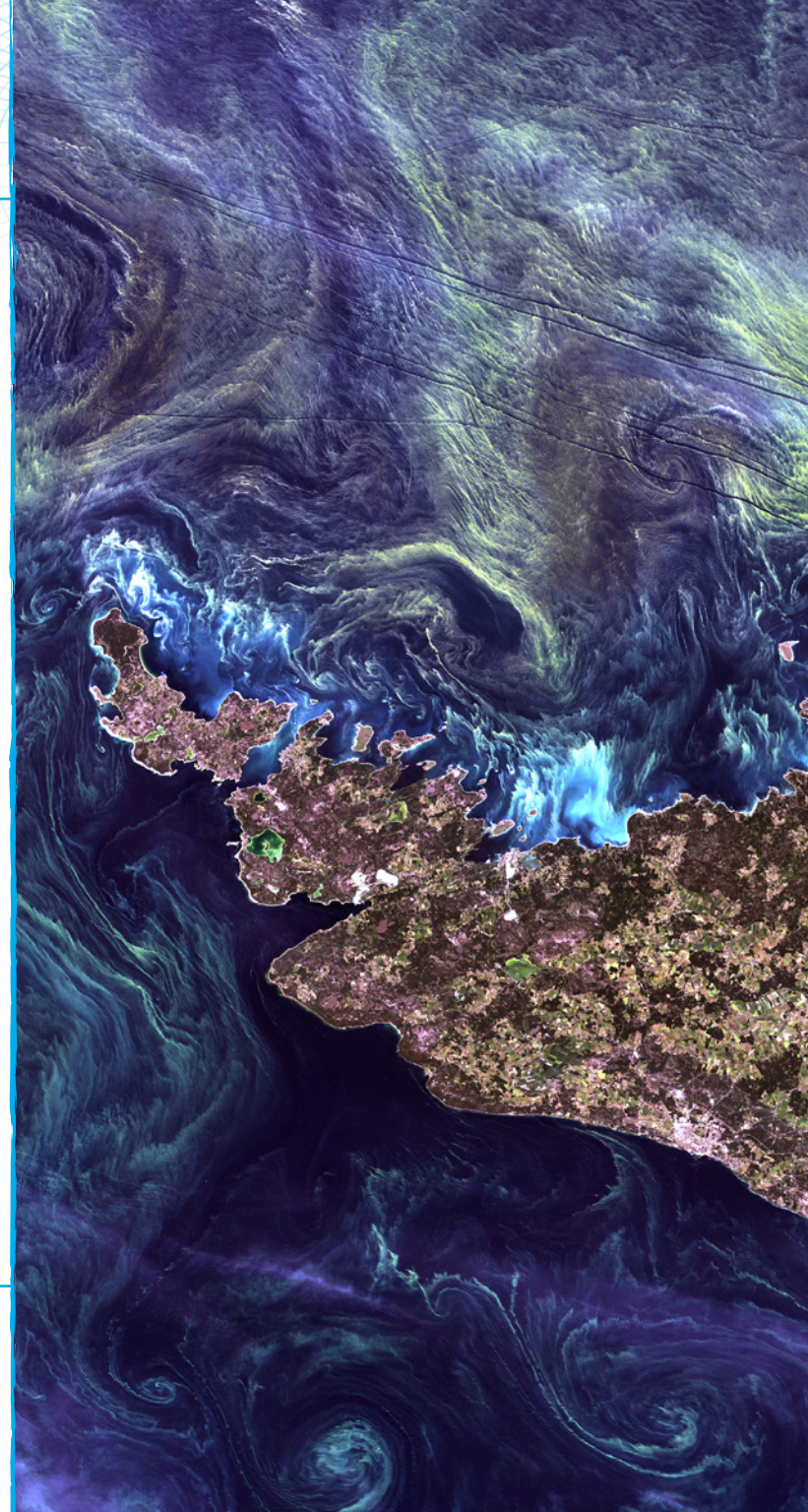
Goddard's Contribution to NASA Strategic Goal 1

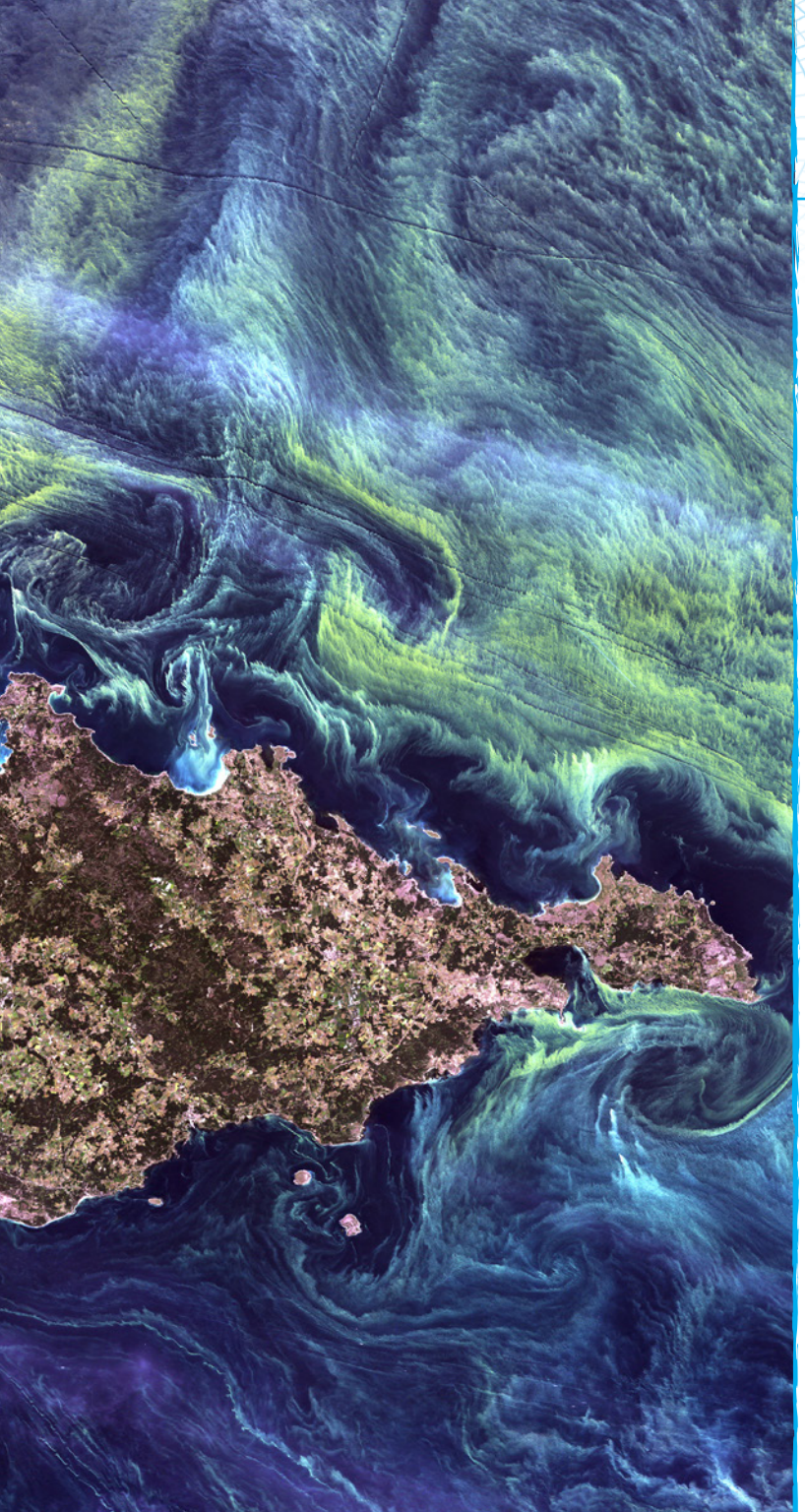
As both an enabler and implementer of science research conducted from the vantage point of space, Goddard contributes significantly to NASA's efforts to expand the frontiers of knowledge, capability, and opportunity in space. The center accomplishes this through the execution of a preeminent science program in the areas of Earth science, astrophysics, heliophysics, and planetary science. Goddard uses measurements from space complemented by suborbital, ground-based, and laboratory measurements; numerical modeling; and theoretical investigations. We also provide suborbital platforms and launch range services as well as software verification and validation for Goddard, the agency, and others.

Goddard's Contribution to NASA Strategic Goal 2

To support NASA's advancement of our understanding of Earth and technologies that improve our lives, Goddard provides a unique combination of science and engineering. We conduct a comprehensive scientific program that researches Earth's natural systems and processes as well as the Sun's effects on them. We also maintain a cutting-edge engineering staff that develops and demonstrates new technologies that drive advances in scientific understanding and meet societal needs.

(Left) Goddard technologists examine a test board for a prototype Ka-band space communications system. (Right) This Landsat 7 image shows phytoplankton swirling in the water around Gotland in the Baltic Sea.





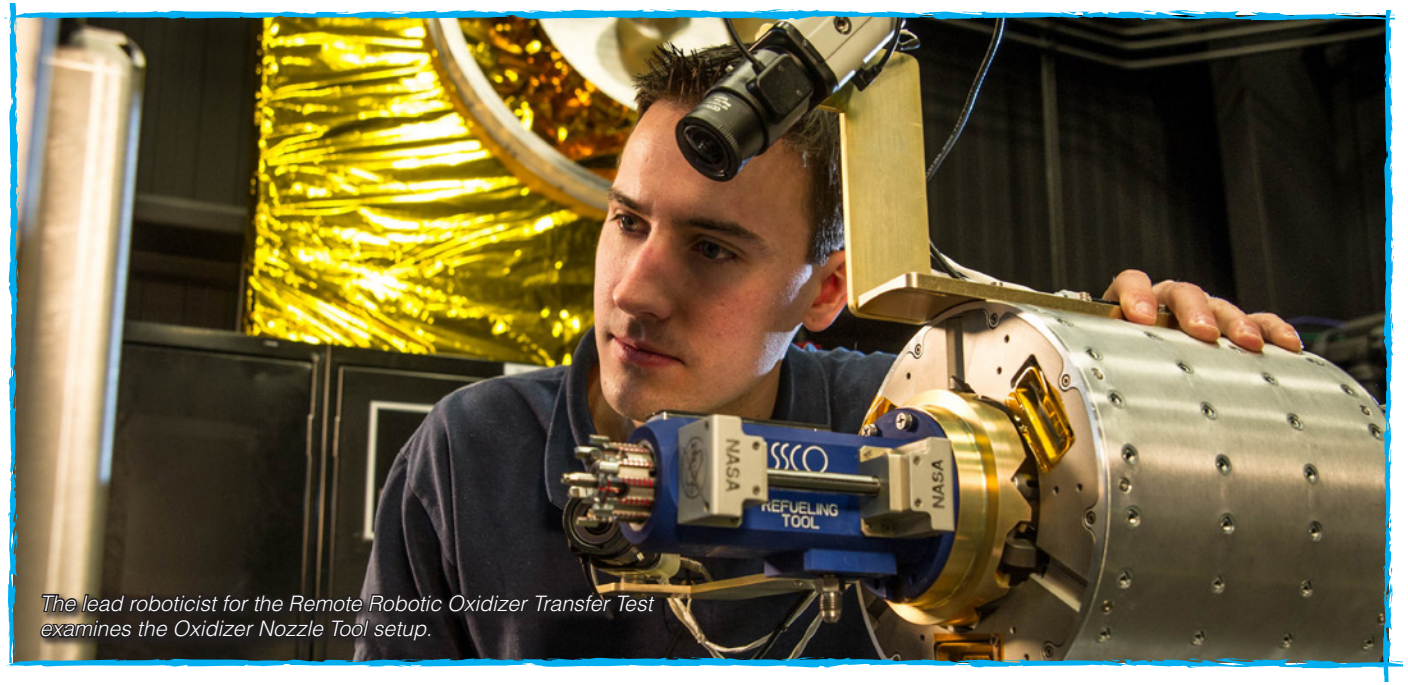
Goddard's Alignment with NASA's Strategic Plan

Goddard's Contribution to NASA Strategic Goal 3

Goddard provides key personnel, services, facilities, and mission-enabling activities critical to NASA's mandate to serve the American public. Our teams develop and operate the space and ground network systems that enable communication for NASA's scientific and exploration missions, in addition to spaceflight-tracking and data acquisition networks. We develop, verify, validate, and maintain advanced information systems for the collection, display, analysis, storage, and distribution of Earth and space science data. We also establish and maintain satellite servicing capabilities essential for extending the operational life and improving the functionality of valuable observatories in orbit.

Our Wallops Flight Facility provides operational capabilities that enable launch, aircraft, and suborbital operations worldwide. We also are greatly committed to many other activities that engage the public, educators, students, and other stakeholders with the excitement, results, and value of our important mission.

Details on Goddard's efforts in support of NASA's strategic goals and their objectives are provided in the following sections. The strategic objectives are presented in three groups that reflect Goddard's integrated approach: science, crosscutting capabilities, and mission support.



The lead roboticist for the Remote Robotic Oxidizer Transfer Test examines the Oxidizer Nozzle Tool setup.

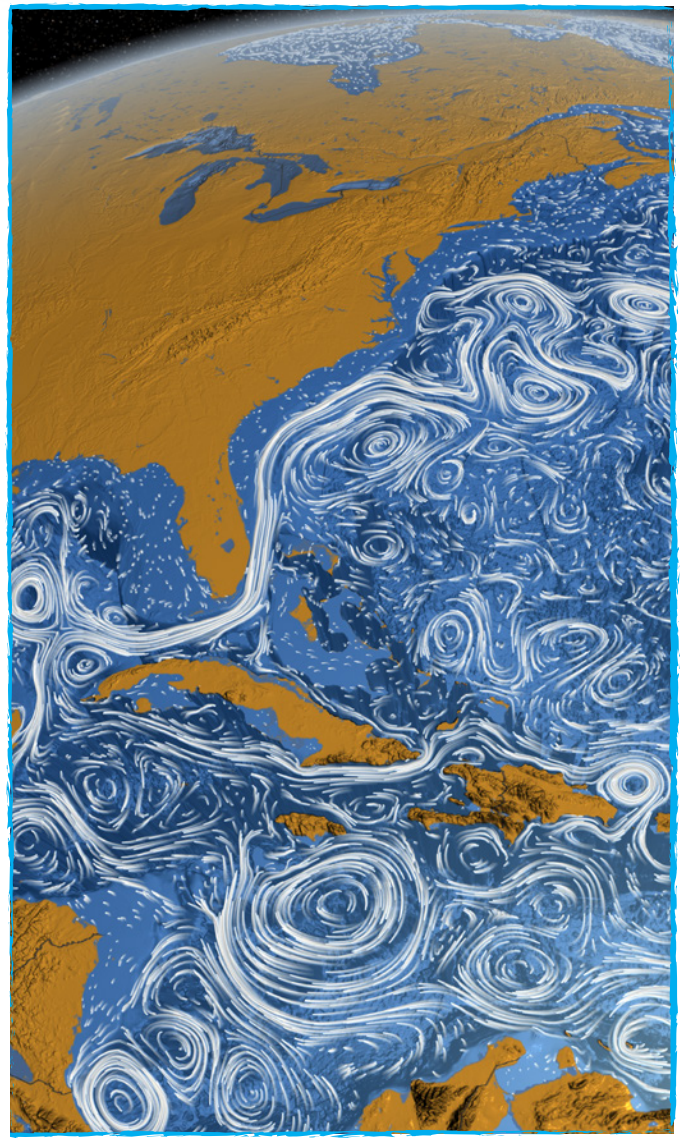
Scientists at Goddard are involved in every aspect of advancing NASA's science objectives. Our scientists actively participate in the broader science community; develop crucial science questions to pursue in consideration of NASA Headquarters direction, community and decadal inputs; identify the methodology to answer those questions; develop the theory behind an experiment; build specialized instrumentation and carry out an experiment from ground-based, to airborne and suborbital, to orbital and interplanetary; collect and analyze the data and create sophisticated models; and share newfound results and knowledge with the community.

Goddard scientists advance NASA's science objectives to further our understanding of the Earth and its environment, the Sun, the solar system, and the universe beyond. This research process involves cyclic and interdependent methods of observation, data analysis, modeling, prediction, and dissemination of findings. Science teams lead the definition and development of instruments to provide new observations and measurements, analyze the resulting data with models, use these models to predict scientific phenomena, then further validate and improve them using new observations. Goddard's researchers then share their results and data with the scientific community, while education and public outreach programs help explain the science and its impact to students and the general public.

Goddard partners with NASA Headquarters, the broader national and international scientific communities, and others to define complex science questions and to develop new technologies designed to explore and understand these science objectives.

Goddard is a world leader in instrumentation development (detectors, optics, and instruments) for ground-, aircraft-, balloon-, and space-based instrument payloads. Goddard relies upon both internal capabilities and partnerships with external groups and institutions to develop these instruments in direct support of the needs of the scientific community. We collaboratively develop and operate a broad spectrum of flight missions and field campaigns, from ground-based and suborbital experiments to observations from the International Space Station, Earth-orbiting, and interplanetary missions.

In order to process and share the results of these missions, Goddard also designs and implements large-scale data systems that manage a wide range of science data. Goddard's high-performance computing and data archives enable rapid-access scientific modeling and analysis across missions and disciplines.



(Left) The Solar Dynamics Observatory is lowered to a horizontal position for testing. (Right) This Scientific Visualization Studio image shows ocean surface currents around the world for two and half years.

NASA Strategic Objective 2.2: Advance knowledge of Earth as a system to meet the challenges of environmental change, and to improve life on our planet.

Overview: Goddard's Earth science teams research our planet's natural systems and processes, encompassing four strategic science goals that drive our work in Earth science:

1. Improve our understanding of Earth's processes and their interactions, on timescales that span days to decades, using NASA's observations and Goddard-developed computer models
2. Study key aspects of the energy, carbon, and water cycles and how they interact to support life on Earth
3. Provide information and insight to develop and implement new observations that will significantly affect our ability to monitor the environment and to improve the models used to predict the future state of the Earth system
4. Communicate our results to the scientific community, the public, and policy makers

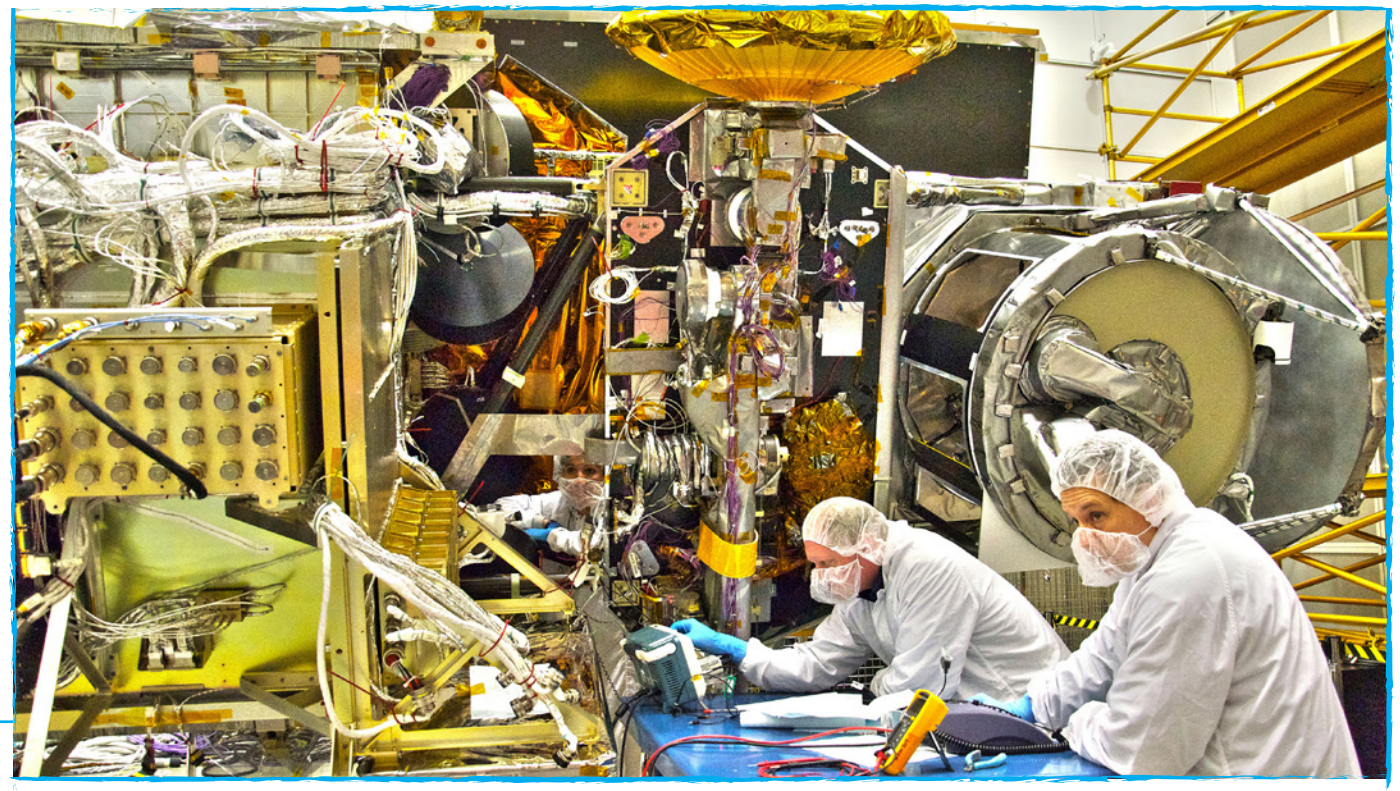
Goddard's research into the Earth system focuses on: atmospheric composition, hydrospheric processes, carbon cycle and ecosystems, climate and weather, and Earth's surface and interior. Goddard Earth science also supports a broad range of science application activities by engaging user communities who benefit from our data and products.

Atmospheric Composition

This research area includes studying the composition of and changes in atmospheric chemistry and atmospheric aerosols, developing chemical and climate-prediction models, and projecting future changes in trace gases and aerosols.

Atmospheric Composition Questions

- How is climate change impacting emissions and morphology of natural and anthropogenic substances?
- How will climate change affect the stratosphere and the ozone layer? How does ozone modify climate?



Goddard engineers at work building the Global Precipitation Measurement (GPM) Core Observatory in the cleanroom.

Atmospheric Aerosols Questions

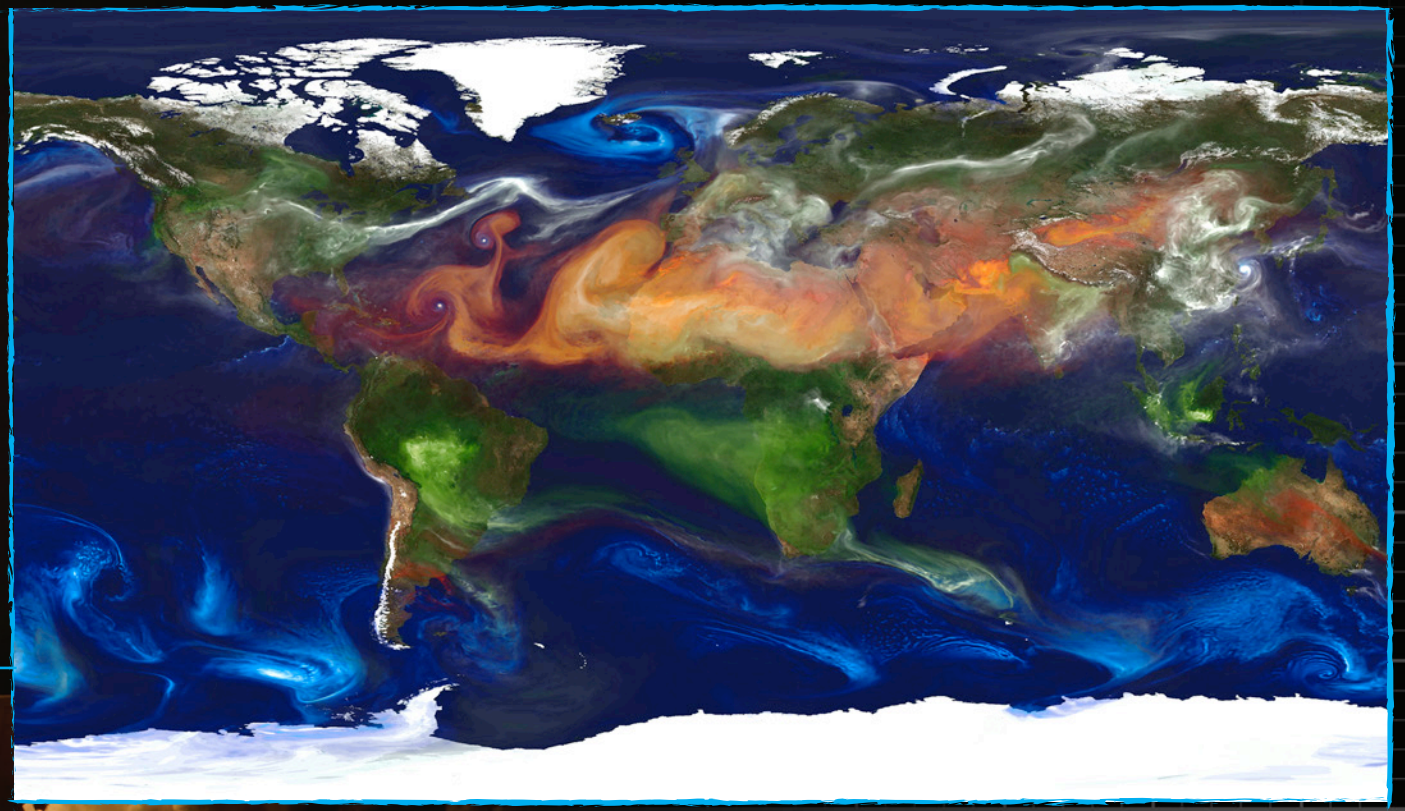
- What are the properties of aerosols in the atmospheric system?
- How are the properties of aerosols related to their sources, sinks, and evolution over their lifetime?

Hydrospheric Processes

Goddard scientists explore and understand the linkages among water in all of its forms, the land, and life on Earth. This work involves the study of the water cycle (atmospheric and terrestrial), polar climate change, and oceanography.

Water Cycle Questions

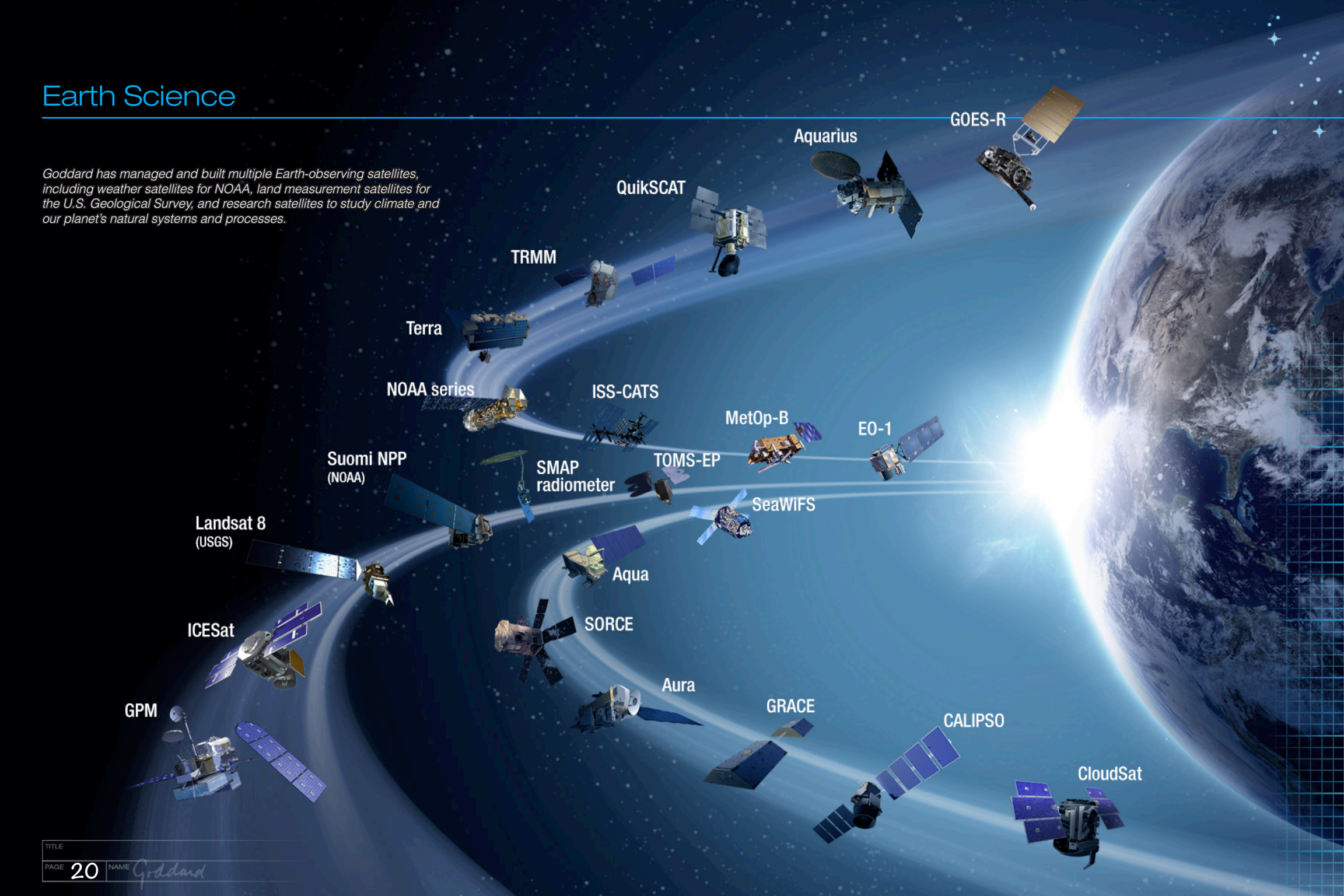
- What are the causes of water cycle variations?
- How do clouds, water vapor, and precipitation processes (rain, snow, sleet, or hail) affect regional-to-global weather and climate?
- Are variations in the global and regional water cycle predictable?



(Above) The GPM Core Observatory thundered into space at 1:37 p.m. eastern time Thursday, Feb. 27 from Japan. (Right) This nine-month visualization shows aerosols over the world including dust and sea salt swirling inside cyclones, carbon bursts from fires, and sulfate streams from volcanoes.

Earth Science

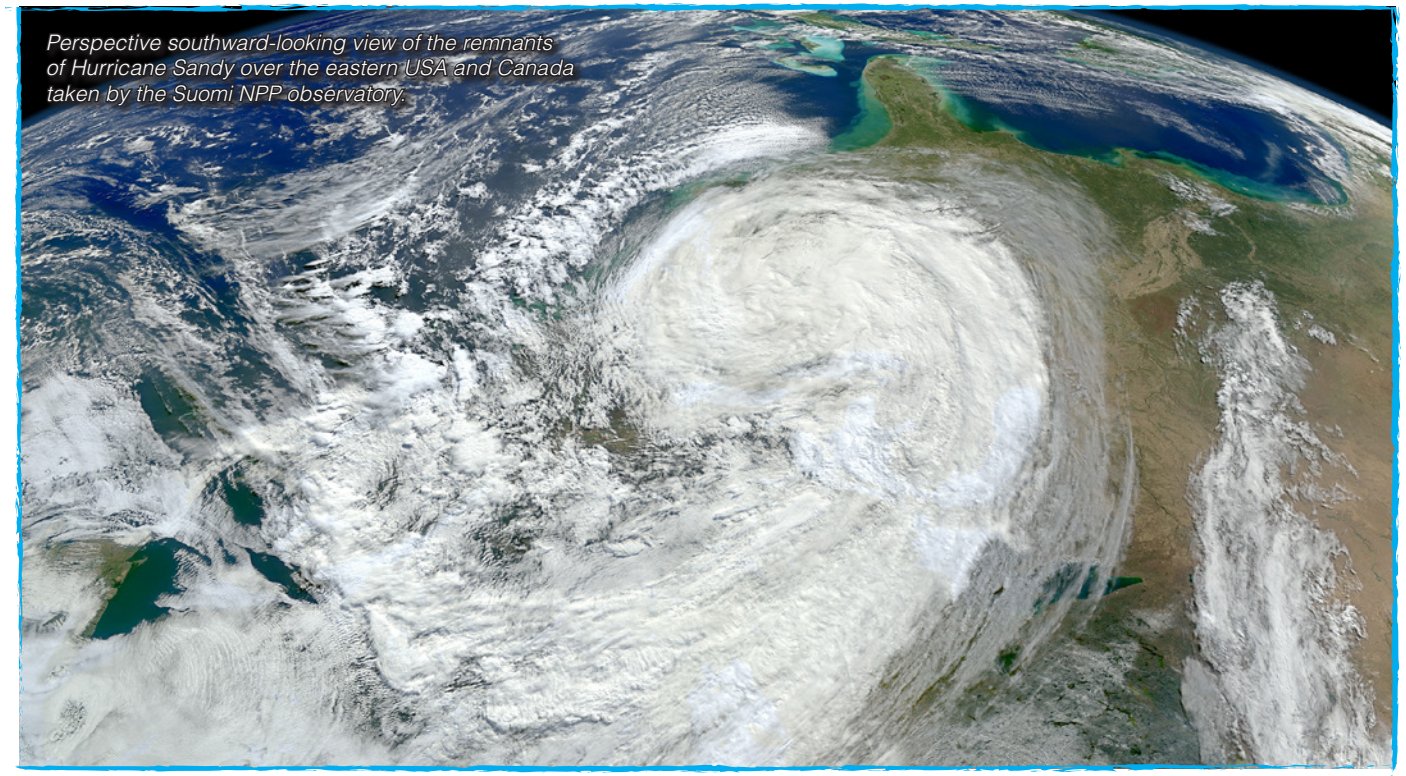
Goddard has managed and built multiple Earth-observing satellites, including weather satellites for NOAA, land measurement satellites for the U.S. Geological Survey, and research satellites to study climate and our planet's natural systems and processes.



Carbon Cycle and Ecosystems

The carbon cycle is the global process by which carbon is stored and exchanged between the air, oceans, Earth, and living things. NASA's Carbon Cycle and Ecosystems focus area addresses the distribution and cycling of carbon among the land, ocean, atmospheric reservoirs, and ecosystems as they are affected by humans; the chemical, physical, geological, and biological processes of each; and climate variations.

Global climate modeling of the relationship between climate and carbon over decades and centuries is the central focus of work at GISS. Goals in this area are to measure global productivity, biomass, carbon fluxes, and changes in land cover; document and understand changes in all components of the global carbon cycle including land cover and use; and provide useful projections of future changes in global carbon cycling and ecosystems on land and in oceans. A key objective is to fully understand the carbon cycle, including its atmospheric, land, and oceanic components.



Perspective southward-looking view of the remnants of Hurricane Sandy over the eastern USA and Canada taken by the Suomi NPP observatory.

Climate and Weather: Analysis, Modeling, Assimilation, and Prediction

Goddard develops models in support of NASA's mission to analyze and predict weather and climate and to understand the linkages between the chemistry of Earth's atmosphere; the movement, distribution, and quality of water on Earth, and; the interactions of Earth's ecosystems and atmosphere. Ultimately, this work aims to present a consistent representation of the Earth as an integrated system, utilizing models of the land, the oceans, and the atmosphere and cryosphere (including biological components). Meteorological analyses support NASA's satellite observations and field missions, including studies of long-range pollution transport. Emerging efforts are extending these models from the "weather" context to other aspects of Earth science, including air pollution, carbon cycle, and decadal-scale climate change.

Earth's Surface and Interior

Goddard's Earth and planetary scientists collaborate on research of the structure, dynamics, and evolution of the Earth, the Moon, and the planets. This research uses *in situ* and remote-sensing data, including imagery, geodetic information (derived from spacecraft tracking and space geodetic networks), gravity, topography, and magnetic field information. The study of Earth's surface and interior includes the following processes: impact cratering, volcanism, seismicity, mass redistribution (including ice mass change), sea-level change, rotational variations, spin-orbit coupling, and core dynamo generation of magnetic fields.

Astrophysics

NASA Strategic Objective 1.6: Discover how the universe works, explore how it began and evolved, and search for life on planets around other stars.

Goddard's astrophysics science teams research astronomy and fundamental physics, organized around three strategic science goals:

1. Physics of the cosmos: Probe the origin and destiny of our universe including the nature of black holes, dark energy, dark matter, and gravity
2. Cosmic origins: Explore the origin and evolution of the galaxies, stars and planets that make up our universe
3. Exoplanet exploration: Discover and study planets around other stars and explore whether they could harbor life

Physics of the Cosmos

Goddard scientists study the electromagnetic spectrum from the far-infrared to gamma rays, cosmic rays, and the new frontier of gravitational radiation.

Physics of the Cosmos Priorities

- Lead the development of precision cosmology detectors and polarization technologies for the far-infrared, sub-millimeter and millimeter wave bands
- Remain the preeminent developer of X-ray astronomy instrumentation in the United States and the world
- Lead studies to define future NASA strategic X-ray missions through participation in ESA's Athena mission, and in studies of large and medium X-ray missions to be proposed to the 2020 Astrophysics Decadal Survey
- Continue to be the leader U.S. space-based gravitational wave astronomy
- Provide leadership in the emerging field of time-domain astronomy using the existing Swift Explorer and the Fermi Gamma-ray Space Telescope, and in the development of new instruments for future flight opportunities
- Lead studies using future gamma-ray space telescopes

In celebration of its 25th anniversary, Hubble revisited the famous "Pillars of Creation," providing a sharper and larger view of the pillars, which are part of a small region of the Eagle Nebula, a vast star-forming region 6,500 light-years from Earth.

Cosmic Origins

Goddard scientists perform research on the evolution of the cosmos, including the earliest moments of the universe; the origin and evolution of planets, stars, and galaxies; and extreme astrophysical environments where strong gravity dominates. The James Webb Space Telescope, which is being managed and integrated at Goddard, will observe the first generation of galaxies that formed after the Big Bang and follow their evolution over 13 billion years to today. Future gravitational wave detectors will map the merging of massive black holes, mapping the growth of structure throughout cosmic time.

Cosmic Origins Priorities

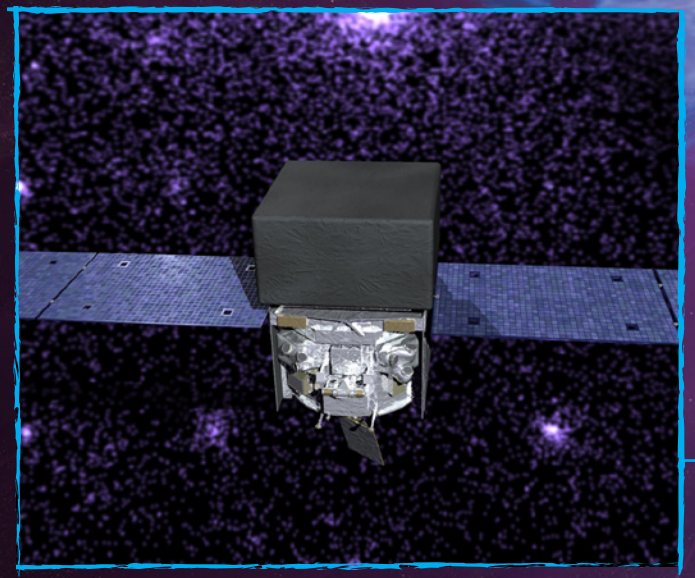
- Support the development of the James Webb Space Telescope
- Develop sensitive, large-format submillimeter detectors for ground-based telescopes and suborbital missions
- Lead studies using the next generation of large space telescopes spanning from optical to far-infrared wavelengths

Exoplanet Exploration

Goddard scientists study the formation and evolution of stars, exoplanets, planetary systems, and protoplanetary disks, driven by the fundamental question, “Are we alone?” Their research also contributes to the search for Earth-like planets and habitable environments around other stars.

Exoplanet Exploration Priorities

- Lead technology development for direct imaging of exoplanets
- Collaborate with other Goddard science divisions to study exoplanetary atmospheres
- Carry out computational modeling of astrophysical systems, including protoplanetary disks
- Lead studies on future space observatories such as the Wide-Field Infrared Survey Telescope, exoplanet probe missions, and a future flagship mission to study Earth-like exoplanets.

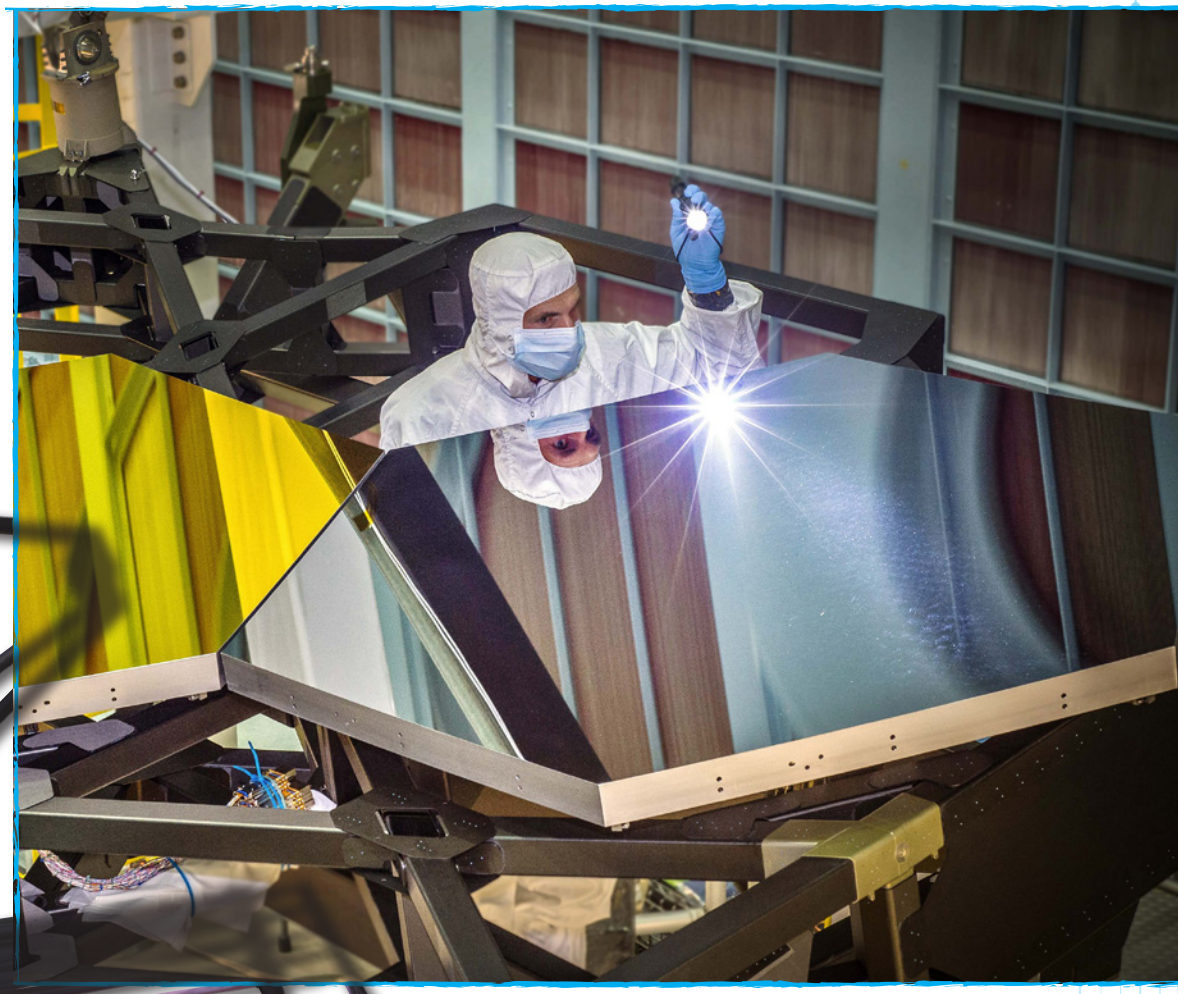


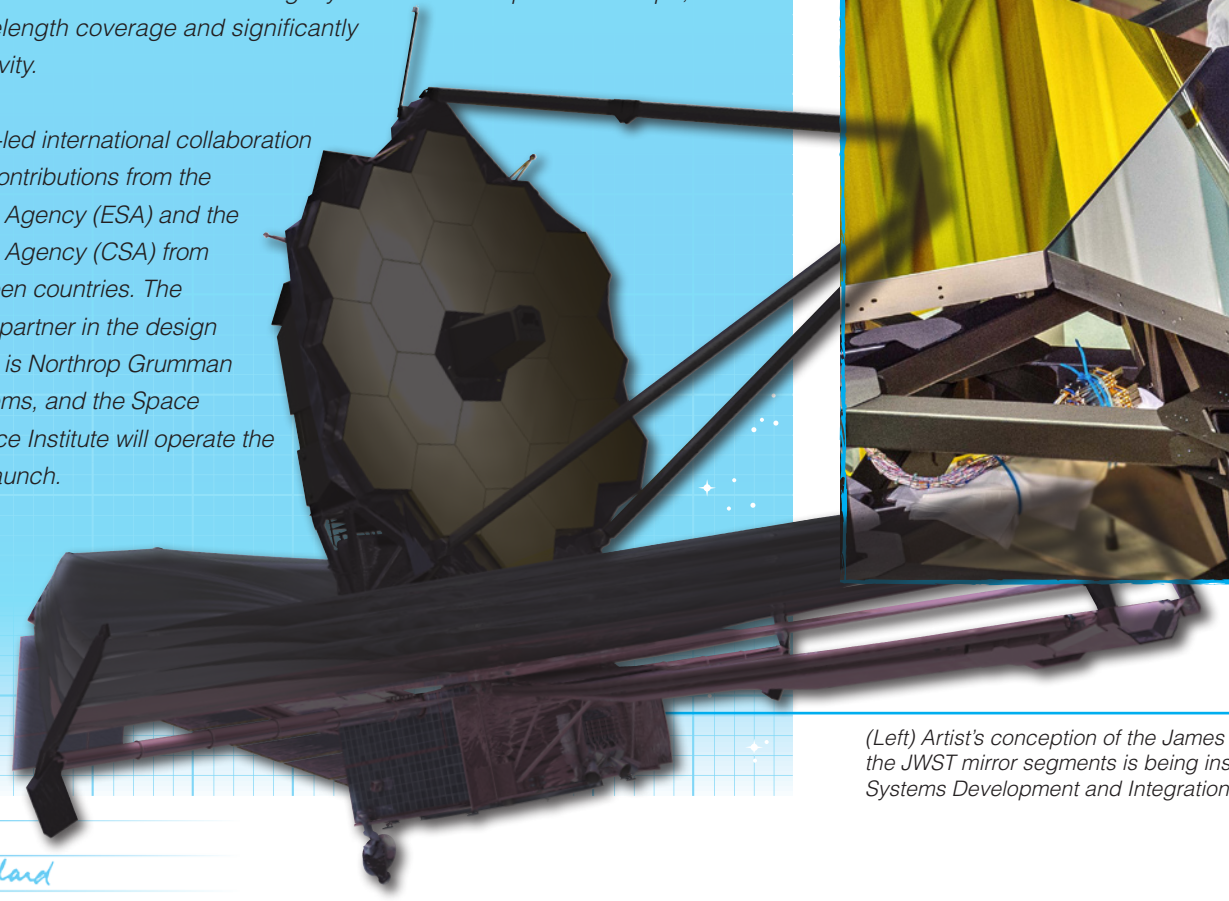
The Fermi spacecraft (left) observes high-energy eruptions in neutron stars which can trigger ruptures in a highly magnetized star's crust, as shown in this artist's rendering (above).

Astrophysics

The James Webb Space Telescope (JWST) is NASA's flagship astrophysics program that has galvanized the work of Goddard and its partners for many years, and will serve as the driver of space science research for the foreseeable future. JWST is our premier and pioneering observatory and is targeted to launch in 2018. Serving thousands of astronomers worldwide, it will study every phase in the history of our Universe, ranging from the first luminous glows after the Big Bang, to the formation of solar systems capable of supporting life on planets like Earth, to the evolution of our own solar system. The telescope consists of a 6.5-meter aperture deployable telescope (18 primary mirror segments) and four science instruments designed to work in the near-to-mid infrared range of the electromagnetic spectrum. The mission will complement and further the research legacy of the Hubble Space Telescope, with longer wavelength coverage and significantly improved sensitivity.

JWST is a NASA-led international collaboration with significant contributions from the European Space Agency (ESA) and the Canadian Space Agency (CSA) from a total of seventeen countries. The primary industry partner in the design and construction is Northrop Grumman Aerospace Systems, and the Space Telescope Science Institute will operate the telescope after launch.





(Left) Artist's conception of the James Webb Space Telescope (JWST) spacecraft. (Above) One of the JWST mirror segments is being inspected in Goddard's giant High Bay Clean Room in the Space Systems Development and Integration Facility.

NASA Strategic Objective 1.4: Understand the Sun and its interactions with Earth and the solar system, including space weather.

Goddard's heliophysics science teams conduct research on the Sun, its extended solar system environment (the heliosphere), and its interactions with Earth, other planets, small bodies, and interstellar gas with the heliosphere.

Goddard scientists study the complex interactions between electromagnetic radiation, thermal plasmas, energetic particles, and magnetic fields with three principle objectives:

1. Understand the changing flow of energy and matter throughout the Sun, solar atmosphere, heliosphere, and planetary environments
2. Explore the fundamental physical processes that characterize space plasmas
3. Define the origins and the societal impacts of variability in the Sun-Earth system

Goddard provides scientific leadership and expertise to achieve NASA's strategic science goals in solar physics, heliospheric physics, geospace physics, and space weather.

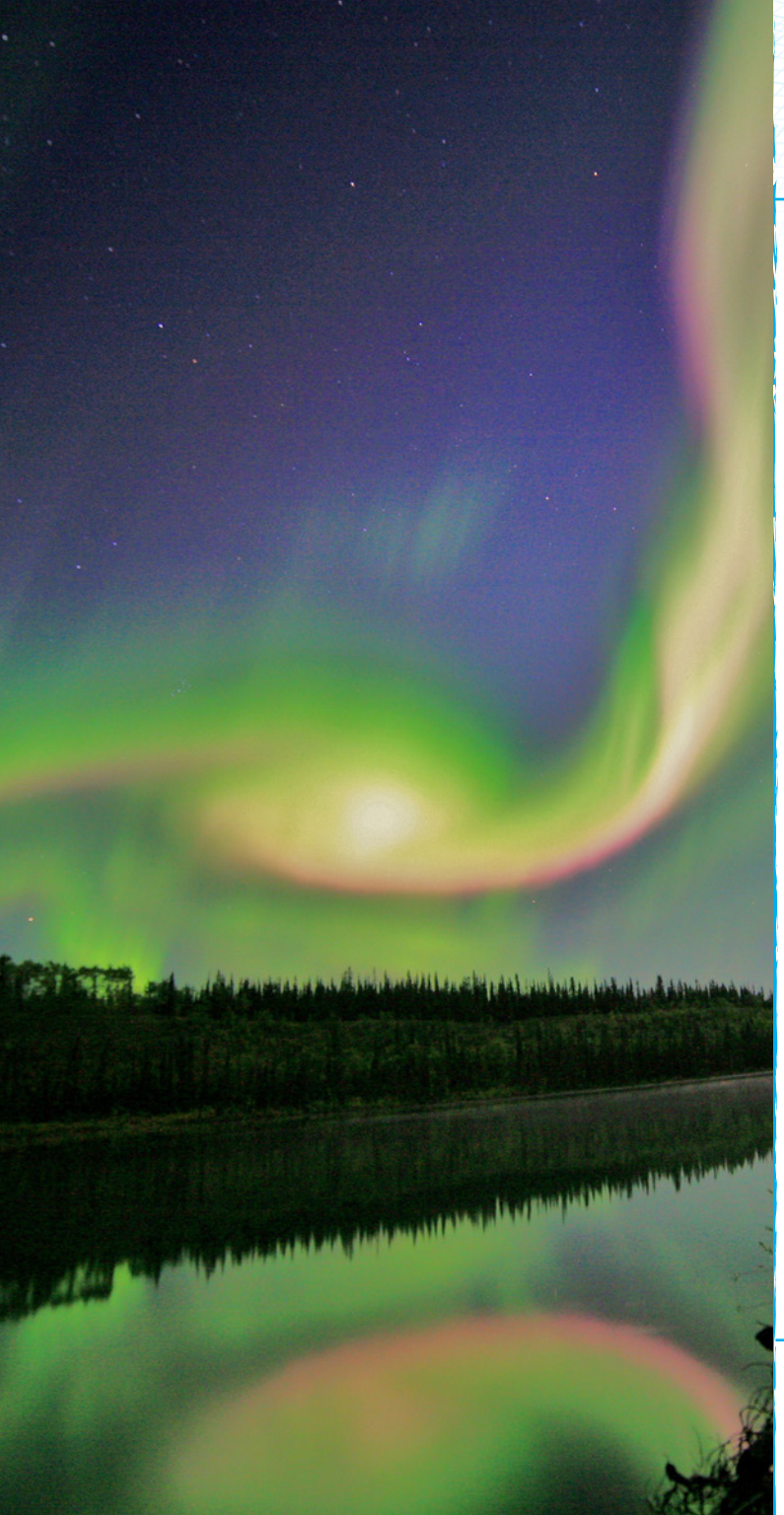
Solar Physics

Research in solar physics aims to understand the Sun as both a star and the primary driver of activity throughout the solar system, including solar structure and magnetic activity.

Solar Physics Priorities:

- Coronal physics, imaging, and spectroscopy: Understanding the Sun's outer atmosphere
- High-energy solar physics: Understanding flare energy release, particle acceleration, and thermal response
- Solar activity: Understanding and forecasting space weather throughout the heliosphere and the solar cycle connection
- Chromosphere-corona system: Understanding dynamic and energetic coupling
- Heliophysics data access and virtual observatories
- Development of new mission concepts for solar physics applications

Sun image taken by the Solar Dynamics Observatory (sketched).



Heliophysics

Heliospheric Physics

Research into heliospheric physics investigates the origins and acceleration of the solar wind and the effects of solar outbursts on the heliosphere.

Heliospheric Physics Priorities

- Solar wind acceleration and heating
- Wave-particle interactions and turbulence in the solar wind
- Solar energetic particle acceleration and diffusion
- Coronal mass ejection propagation and evolution
- Interplanetary shock and discontinuity physics
- Heliospheric models of global magnetohydrodynamics (MHD), the study of the dynamics of electrically conducting fluids
- Interactions between the heliosphere and the interstellar medium
- Miniaturization of energetic particle instruments for CubeSat missions
- Development of new mission concepts for heliospheric applications

Geospace Physics

Research into geospace physics focuses on processes occurring in the magnetospheres of magnetized planets and the interaction of the solar wind with planetary magnetospheres.

Geospace Physics Priorities

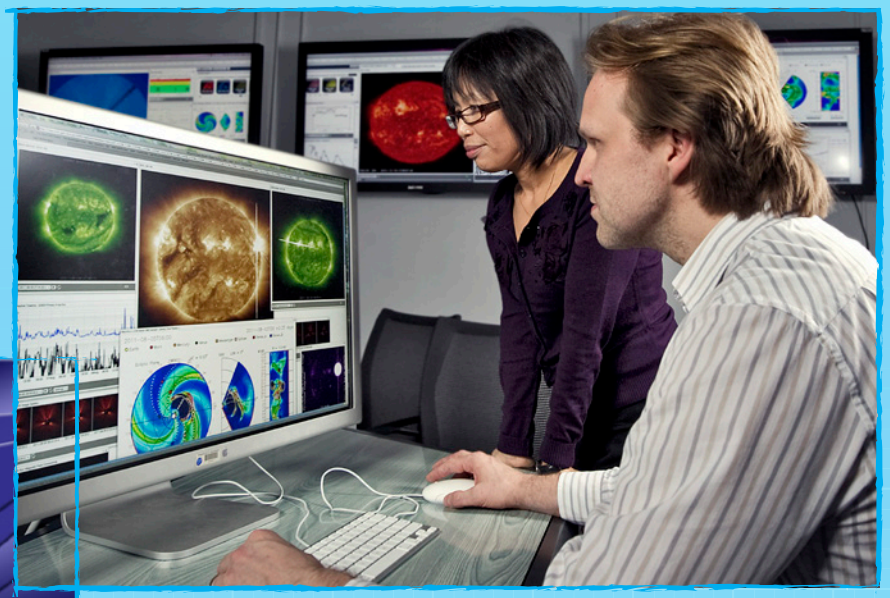
- Fundamental plasma processes in geospace and planetary atmospheres
- Understanding of the reconnection process
- Radiation-belt modeling, and evaluating the acceleration and loss of energetic particles in Earth's magnetosphere
- Wave-particle interactions and their contribution to particle energization and loss
- Magnetosphere-ionosphere-thermosphere coupling
- Global Hall-magnetohydrodynamics (Hall-MHD) of planetary magnetospheres
- Miniaturization of plasma instruments and magnetometers
- Development of new mission concepts for the geospace environment

Swirls of green and red appear in an aurora over Whitehorse, Yukon. Goddard launches sounding rocket missions to study the aurorae, auroral winds, and atmospheric and magnetospheric effects of the solar wind.

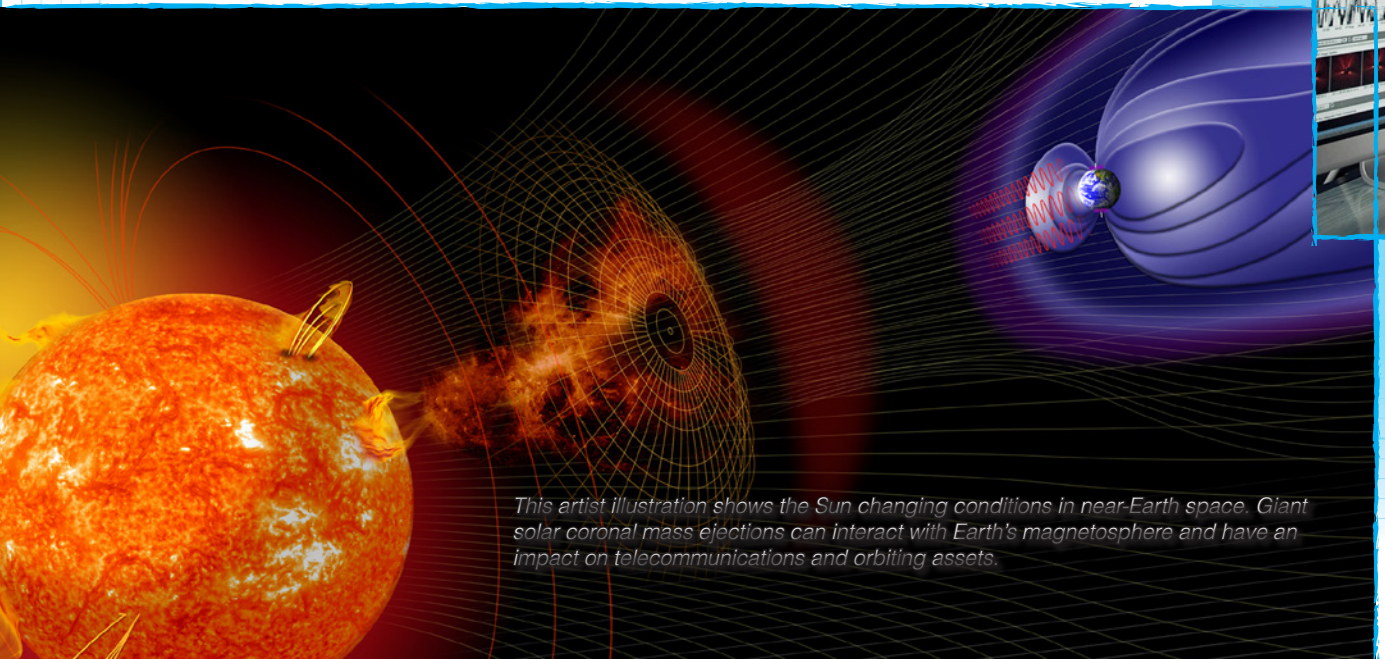
Space Weather

Another major topic of heliospheric research is space weather. Space weather results from the constantly changing environment of our solar system, driven by the amount and type of energy and particles being released by the Sun. Studying space weather is important to our national economy because what happens on the Sun can affect advanced technology like cell phones and global positioning systems that we depend upon in our lives. Goddard scientists research space weather, including fundamental processes like plasma physics, magnetohydrodynamics, and particle acceleration. Goddard space weather research supports all of NASA's science, exploration, operations, and technology goals, particularly in its role supporting all of NASA's robotic missions, space-based assets, human spaceflight, and radiation experiments. Goddard research, data, and modeling are also critical for the heliophysics community including local and Federal agencies such as NOAA and the Department of Defense, as well as domestic and foreign private industries and universities. Goddard's space weather team relies upon both internal capabilities and key partnerships with external groups and institutions.

The Community-Coordinated Modeling Center (CCMC) is a multi-agency partnership to advance research and development for the next generation of space science models and space weather analysis and forecasting capabilities. The CCMC serves an expanding collection of modern space research models to the international research community through the one-of-a-kind Runs-on-Request service. The CCMC tests and evaluates models, addresses space weather needs of NASA's missions, and provides opportunities for hands-on space weather education.



Goddard space weather forecasters help implement ensemble forecasting, a computer technique that will improve NASA's ability to predict the path and impact of severe solar storms.



This artist illustration shows the Sun changing conditions in near-Earth space. Giant solar coronal mass ejections can interact with Earth's magnetosphere and have an impact on telecommunications and orbiting assets.

Planetary Science

NASA Strategic Objective 1.5: Ascertain the content, origin, and evolution of the solar system and the potential for life elsewhere.

Goddard planetary scientists investigate the structure, dynamics, and evolution of the inner and outer solar system's rocky planets, as well as their atmospheres and satellites. The team conducts theoretical and experimental research to explore the solar system and understand the formation and evolution of planetary systems. Goddard researchers investigate areas as diverse as astrochemistry, astrobiology, planetary atmospheres, extrasolar planetary systems, Earth science, planetary geodynamics, space geodesy, and comparative planetary studies.

Goddard specialties include in-depth laboratory and *in situ* analyses to identify and quantify water, organic compounds, and other chemicals that are fundamental to life on Earth. Goddard also serves as NASA's and the Nation's main depository and service center for space science data, supporting the National Space Science Data Center, the Planetary Data System, and the Crustal Dynamics Data Information System.

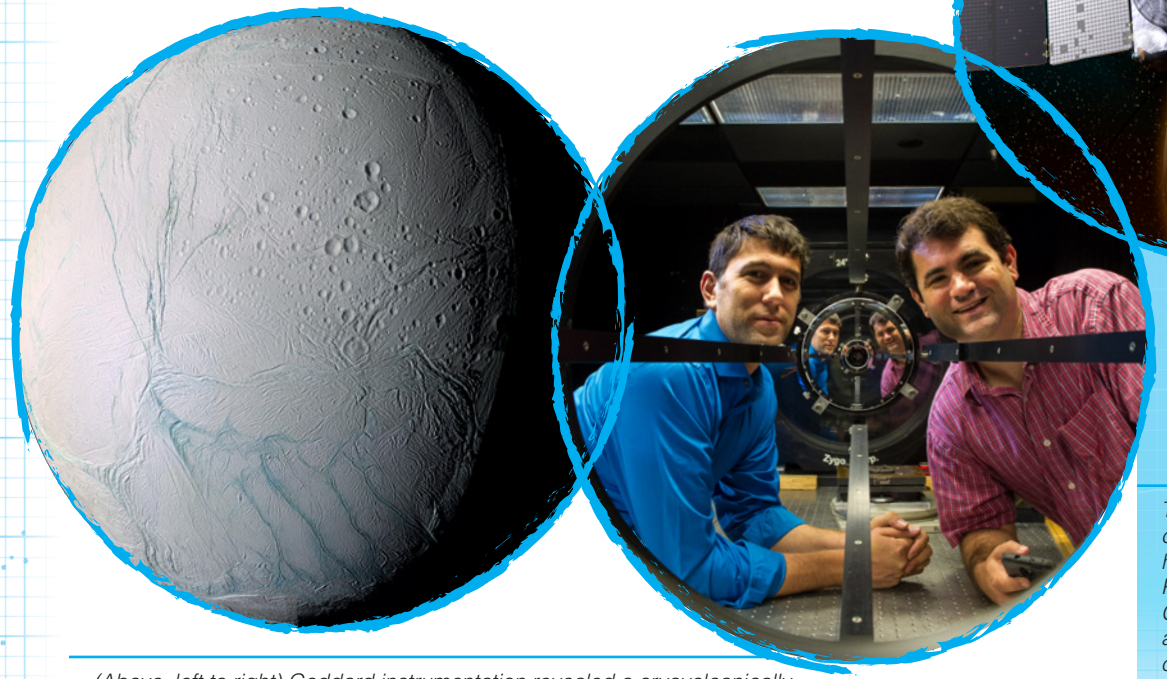
Planetary Science Priorities

- Solar system formation and evolution, including theoretical studies and modeling to explain how these planets arrived at their present state
- Planets of the outer solar system, including the structure, dynamics, and evolution of the solar system giant planets and their ring systems and moons
- Small bodies of the solar system, including their formation and the solar system dynamics that affect them
- Icy satellites such as those of Jupiter and Saturn, including processes that shape these icy bodies
- Lunar science, including studies of the Moon for new insights into the evolution of the solar system and the history of Earth, and research efforts using data from the Goddard-built and -managed Lunar Reconnaissance Orbiter (LRO)
- The Goddard Center for Astrobiology, including the study of the emergence and evolution of life
- The Solar System Exploration Research Institute, including activities to better understand the harsh space environment on airless bodies including the Moon, moons of Mars, and near-Earth asteroids
- The Planetary Data System and other space science data systems and services

(Left) Goddard's Laser Ranging Facility directs a laser toward the LRO spacecraft in orbit around the Moon. (Right) Goddard-built instrumentation on the Cassini mission studies Saturn's system.

Habitable Environments and Mars Exploration

Goddard performs research and analysis to understand how prebiotic organic compounds are created, destroyed, and altered during stellar evolution and subsequently delivered to planets and their moons by comets and asteroids. Goddard's planetary science group continues its exploration of Mars with a focus on the planet's earliest environments and evolution, including the potential for habitability. Goddard scientists play leadership roles in Mars missions, including as the principal investigator for the Sample Analysis at Mars (SAM) instrument suite on the Mars Science Laboratory's Curiosity rover and as the project scientist for the MAVEN mission.



(Above, left to right) Goddard instrumentation revealed a cryovolcanically active region in the "Tiger Stripes" at the bottom of Saturn's moon, Enceladus. Goddard has developed more instruments for planetary exploration than any other organization, sent to every planet in the solar system. An artist's depiction of the MAVEN spacecraft, which was inserted into Martian orbit in September 2014.

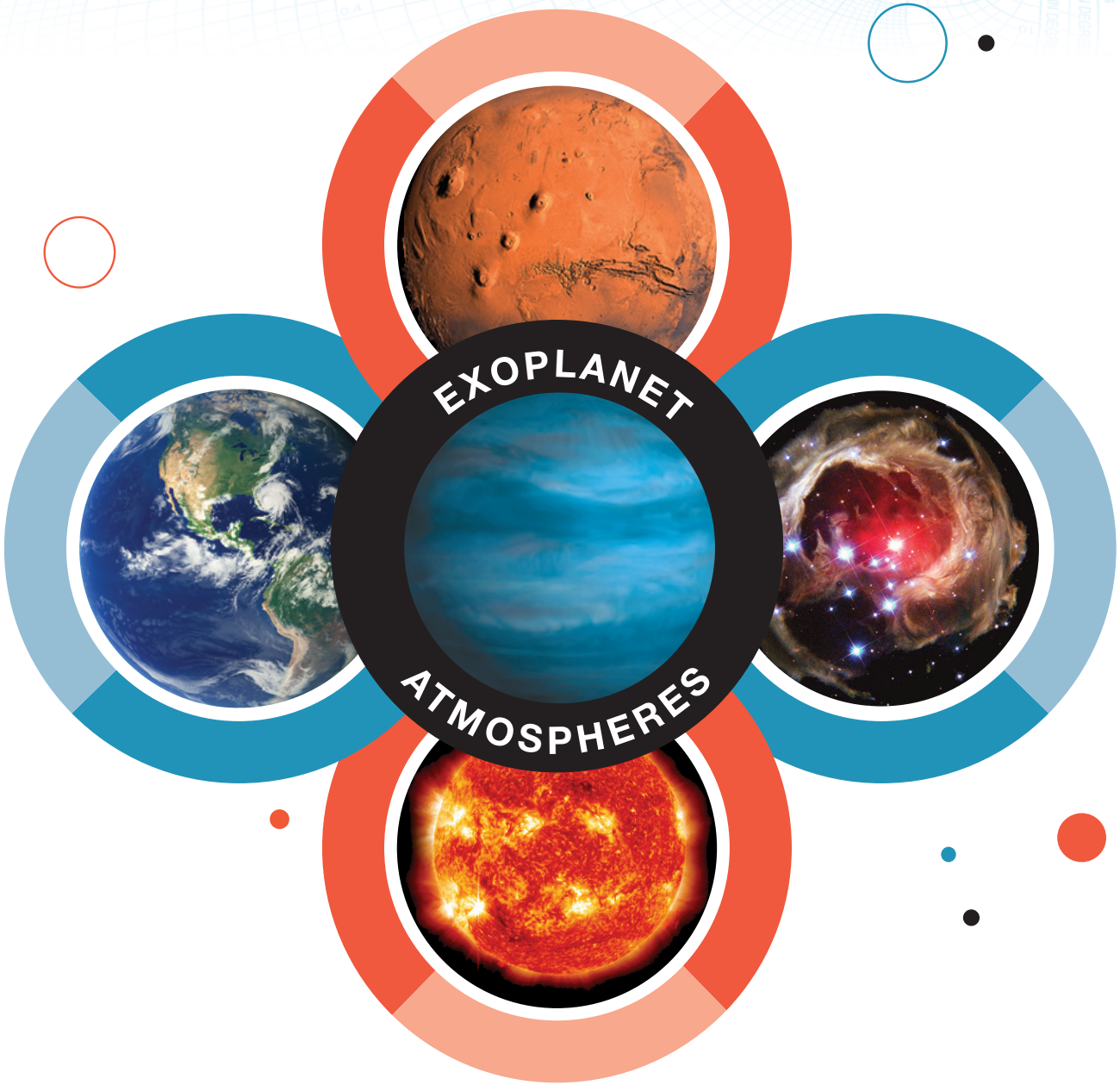
Among Goddard's specialties are the innovative quadrupole mass spectrometers designed and built in the Planetary Environments Laboratory—a storied program that dates back to the Pioneer Venus Orbiter. Goddard's mass spectrometers are carried on Mars by the Curiosity rover and MAVEN. The analyses conducted by the SAM instrument suite on Curiosity have contributed important chemical evidence of a wet and possibly habitable ancient lakebed environment, as well as results that suggest that the top region of Mars' atmosphere may have been lost to interplanetary space. The mass spectrometer on MAVEN will determine the basic structure and formation of Mars' upper atmosphere, and help us understand Martian atmospheric loss processes.

The Curiosity rover after completing the first drill holes on Mars at John Klein in Gale Crater. Goddard scientists played a key role in the analysis of volatiles released from the mudstone with the SAM instrument that provided the first detection of organic matter on Mars.

Multidisciplinary Science: Exoplanet Atmospheres

Goddard's Exoplanet Climate Group is an interdisciplinary, crosscutting collaboration between scientists from all four science divisions at the Goddard Greenbelt campus and GISS. The driving objective of this team is to apply Goddard's significant expertise in Earth and planetary climate modeling and data retrieval to the rapidly expanding study of extrasolar planets.

- Existing space telescope missions such as Kepler have discovered thousands of new exoplanet systems with a frequency and diversity unheard of as little as a decade prior, including the most Earth-like planets outside of our solar system to date.
- The James Webb Space Telescope will dedicate significant effort to the study of transiting exoplanets using infrared spectroscopy.
- Ongoing studies to determine any history of habitability of Mars, Venus, and Saturn's moon Titan, will provide insights into the range of conditions that might be suitable for life in systems around other stars and inform future studies and potential missions.
- With sophisticated models of atmospheric chemistry and climate, the team intends to simulate a broad range of planets within and beyond our solar system.
- Applying Earth science's general circulation models to exoplanets will provide a new context for understanding Earth's past and future.



Goddard engineers and scientists work to advance NASA's mission in areas that complement and enable science research, including support for human exploration, commercial crew and cargo, technology innovation, and aeronautics research.

Support for Human Exploration

NASA Strategic Objective 1.1: Expand human presence into the solar system and to the surface of Mars to advance exploration, science, innovation, benefits to humanity, and international collaboration.

NASA Strategic Objective 1.2: Conduct research on the International Space Station (ISS) to enable future space exploration, facilitate a commercial space economy, and advance the fundamental biological and physical sciences for the benefit of humanity.

NASA Strategic Objective 3.2: Ensure the availability and continued advancement of strategic, technical, and programmatic capabilities to sustain NASA's mission

Goddard provides both direct and indirect critical services to support NASA's Human Exploration and Operations (HEO) efforts.

Direct support includes:

1. Space communications for all HEO programs as well as other agency programs
2. Range services that support the resupply of the International Space Station

Indirect support includes Goddard's science missions that inform human exploration by characterizing the unknown, identifying threats and opportunities, and framing questions for human explorers.

(Above) Astronaut Mike Fossum transfers the Robotics Refueling Mission payload during a spacewalk. (Right) Technicians prepare the Robotic Refueling Mission module for flight.

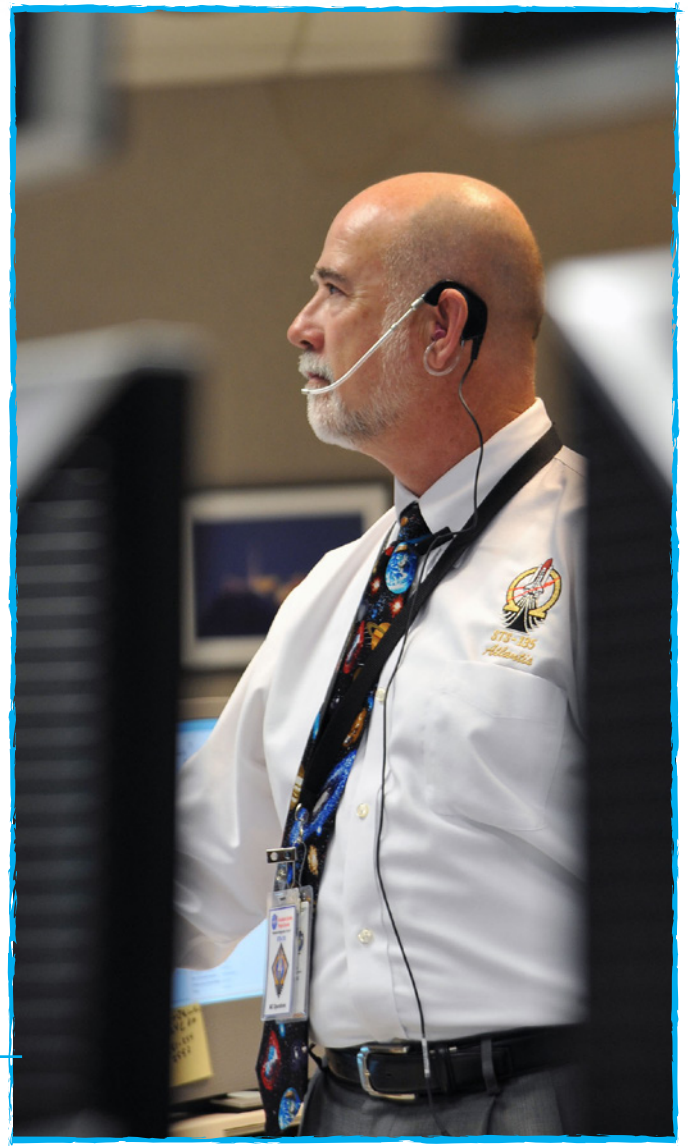
Space Communications

Goddard's Space Communications programs provide end-to-end Earth to space communications to satisfy NASA's requirement to connect with in-space assets. Goddard-developed and -managed networks and systems serve as the vital communication link between Earth and NASA's critical mission spacecraft in orbit up to two million kilometers, including the ISS and LRO.

The primary Goddard-led elements of the NASA space communications system are the Space Network and the Near Earth Network.

Space Network

The Space Network is a data communication system consisting of a geosynchronous constellation of Tracking and Data Relay Satellites (TDRS) connected with various ground terminals employing high-gain microwave antennas. The combination of elements composing the Space Network allows Goddard to offer continuous telemetry, tracking, and command services between low-Earth-orbit spacecraft and customer control and data processing facilities.



Goddard manages networks and systems that provide vital communication links between Earth and NASA's critical missions that support human exploration.

Near Earth Network

The Near Earth Network is a network of NASA and commercial ground stations in locations including Wallops in Virginia, Florida, New Mexico, Alaska, Hawaii, Germany, Norway, Sweden, Chile, South Africa, Australia, and Antarctica. The Near Earth Network provides telemetry, tracking, and commanding services to approximately 35 spacecraft for an average of 140 passes per day. Each of the daily data acquisition interactions is scheduled from the Data Services Management Center, located at Goddard's White Sands Complex.

Range Services for Resupply of the International Space Station

Beginning in 2013, Goddard's Wallops Flight Facility began providing regular launch services to provide supplies and scientific instruments to the International Space Station. Goddard, in partnership with the Mid Atlantic Regional Spaceport, has established a ground infrastructure capable of supporting medium-class launch vehicle operations at Wallops. Major systems deployed include:

- Wallops Launch Range: Launch towers and rocket launch pad complex
- Wallops Payload and Vehicle Integration Facilities: Horizontal Integration Facility, spacecraft fueling facility, and cargo integration facility
- Wallops Launch Control Centers: Downrange instrumentation systems

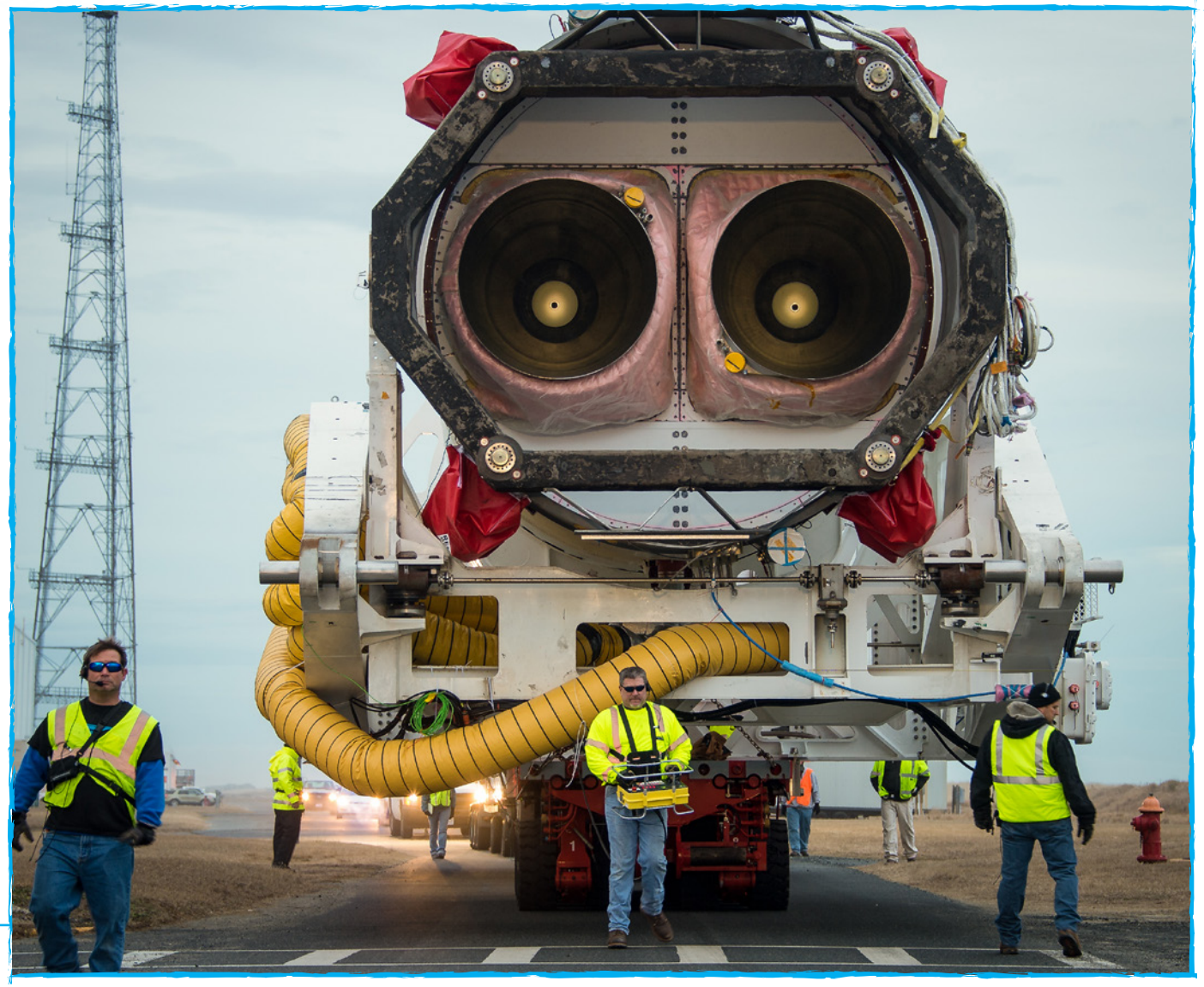
With these new assets and its long-standing launch range capability, Goddard provides key support to the International Space Station program (including up to four commercial cargo launches per year) and for other NASA, Department of Defense, and commercial launches.

Commercial Capabilities

NASA Strategic Objective 1.3: Facilitate and utilize U.S. commercial capabilities to deliver cargo and crew to space.

Wallops Launch Range, part of Goddard's Wallops Flight Facility, has played an important part in NASA's objective to transition the role of access provider to low-Earth orbit from NASA to the commercial space industry. Working with industry and state partners, Goddard has created a successful spaceport at Wallops that advances commercial and NASA capabilities to resupply the ISS. The Antares rocket, along with its Cygnus resupply spacecraft, is contracted for up to four launches per year for this program.

At the IV&V Facility, Goddard engineers provide expertise in software and software assurance to industry partners and the agency for the Commercial Cargo and Crew programs, in collaboration with NASA's Kennedy Space Center and NASA's Johnson Space Center.



The back of an Antares rocket is seen as the vehicle is transported to the launch pad at Wallops Island, VA.

Technology transfer and shared use of the Goddard's exceptional capabilities in instruments, spacecraft, communications, test beds, and computational technologies are helping the space industry to forge its own groundbreaking innovations for NASA and the Nation. Enabled by hundreds of agreements with commercial partners, Goddard's facilities and personnel routinely support projects and activities that combine the best of government and industry innovation to develop new space technologies and foster the commercial use of space.

Technology Innovation

NASA Strategic Objective 1.7: Transform NASA missions and advance the Nation's capabilities by maturing crosscutting and innovative space technologies.

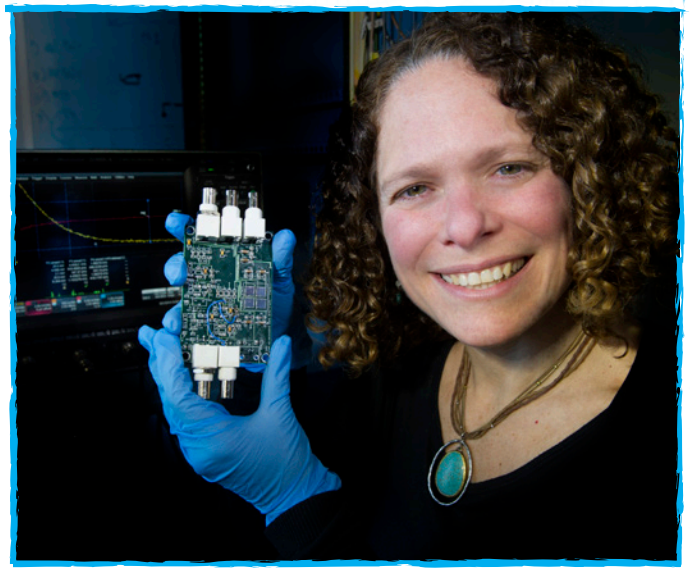
NASA Strategic Objective 2.3: Optimize agency technology investments, foster open innovation, and facilitate technology infusion, ensuring the greatest national benefit.

Goddard is a leader in technology development, which is a NASA priority for supporting the agency's ongoing and anticipated missions. Goddard supports the Nation's science and technology goals by focusing on roles which the center is well-suited to perform.

Achieving scientific discoveries requires innovation to develop advanced technology, complex instruments and spacecraft, and mission support capabilities. Goddard invests in next generation technologies and methodologies to spur innovation through its:

- Business development process to identify needed technologies.
- Internal Research and Development program as well as open innovation.
- Small Business Innovation Research and Small Business Technology Transfer programs.
- Flight projects under development.
- Innovative technology partnerships with other NASA centers, universities, government organizations, and industry.

Supported by unique world-class facilities, Goddard's talented and diverse engineering workforce applies emerging technologies to develop high-performance, cost-effective solutions to the most challenging problems in science and exploration. The center provides a myriad of research platforms that scientists and engineers can use to acquire new scientific measurements and develop new instruments, sensors, and data systems. Goddard is a leading organization known for demonstrating critical NASA technologies. Wallops platforms



Goddard develops advanced technologies for future missions. (Top) This scientist holds a component for her miniature neutron spectrometer, designed for a CubeSat. (Bottom) A Goddard scientist seals a test tube with a sample of Allnede meteorite dust that is 4.567 billion years old.

and launch vehicle accommodations are a key capability for such demonstrations, with examples including NASA's Langley Research Center's Inflatable Re-entry Vehicle Experiment mission, and NASA's Jet Propulsion Laboratory's Low Density Supersonic Decelerator mission.

Support for Aeronautics Research

NASA Strategic Objective 2.1: Enable a revolutionary transformation for safe and sustainable U.S. and global aviation by advancing aeronautics research.

Goddard engineers and operations personnel provide comprehensive flight test environments, operations management, safety planning, and data acquisition in support of realistic flight testing of NASA aeronautics systems and technologies. Goddard leverages the NASA-controlled airspace, airfield, air traffic control, and data acquisition capabilities of the Wallops Research Airfield to meet agency goals. Goddard's efforts directly support the exploration and flight of two agency initiatives: the Aviation Safety Program and the Unmanned Aerial Systems Integration in the National Airspace System program. Contributions by Goddard have included automated aircraft recovery-in-flight systems, advancement of noise reduction technologies, and wake vortex modeling. To support efforts in this area, Goddard partners with other NASA centers including Langley Research Center and Armstrong Flight Research Center.

Goddard's safety and mission assurance experts contribute to system-wide safety assurance and autonomy for aviation transformation. Goddard's assurance efforts on Automatic Dependent Surveillance-Broadcast and the Automated Collision Avoidance System are improving the safety and quality of deployed systems and associated products.

(Left) Wallops Research Airfield supports science flight operations as well as aeronautical research, development, test, and evaluation activities.

(Below) A look inside the Aircraft Operations Center at Wallops.

All of Goddard's activities are made possible by dedicated and talented personnel who provide critical infrastructure and support efforts to effectively manage and secure center resources, while ensuring transparency and accountability.

To implement NASA's goals, Goddard depends on the work of teams in education, mission and institutional support, information technology, and safety and mission success.

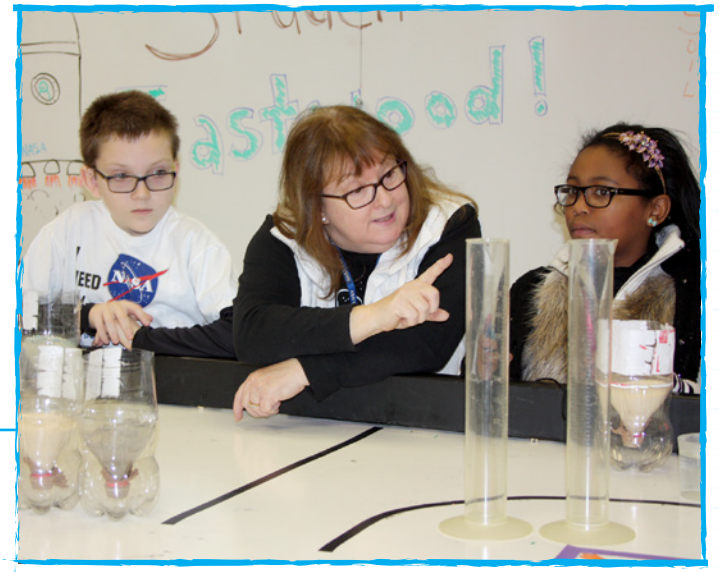
Education

NASA Strategic Objective 2.4: Advance the Nation's STEM education and workforce pipeline by working collaboratively with other agencies to engage students, teachers, and faculty in NASA's missions and unique assets.

Goddard serves a pivotal role in NASA's Science, Technology, Engineering, and Mathematics (STEM) education programs for the Nation. Through STEM experimental learning activities, internships, fellowships, post-doctoral opportunities, and professional development for educators, Goddard translates its core missions into learning experiences that motivate and inspire students and excite educators at all levels. We directly involve universities, faculty, students, and researchers in performing the center's programs and projects. Scientists and engineers at universities are principal partners in all phases of our work.

Within the following four focus areas, Goddard implements education initiatives in support of the agency's priorities.

1. Goddard's Educator Professional Development program partners with state and local education institutions to increase their in-service, pre-service, and informal educators' ability to deliver NASA's STEM content. Goddard supports a vast array of professional development opportunities for informal educators, as well as STEM faculty serving underrepresented populations.
2. Our STEM Engagement program connects learners of all ages using resources unique to NASA that spark their interest in STEM. Events are held for school districts, scouts, museums, and science centers. Examples include family science nights at Goddard's Visitor Center, camps, formal research programs for high school and college students, and onsite special events.
3. The Institutional Engagement program fosters capacity-building and institutional support for formal and informal education at the elementary, secondary, and higher



Goddard strives to inspire future researchers by making space science accessible. (Left) The Robert Goddard French Immersion School's students joined scientists from the Aura mission at the Goddard Visitor Center in Greenbelt, MD. (Right) Students from Eastwood Elementary School participate in IV&V's Education Program activities.

education levels. Goddard participates in collaborative partnerships to strengthen STEM education at all levels.

4. The NASA Internships, Fellowships, and Scholarships program provides competitive awards for students in high school through graduate school. The science and technical communities at Goddard's Greenbelt campus, Wallops Flight Facility, IV&V, and GISS offer research-based opportunities aligned with current scientific and engineering missions. Recipients are select from numerous applications received. This program serves an integral role in developing the future STEM workforce.

Together, we are creating opportunities, deriving new knowledge, strengthening the national education landscape, equipping today's educators, and engaging tomorrow's scientists, engineers, innovators, and leaders.

Goddard hosts over 450 high school and college student interns every summer. Interns participate in every aspect of Goddard's work, gaining hands-on experience in scientific research, engineering, technology development, and mission support.

Workforce and Institutional Support

NASA Strategic Objective 3.1: Attract and advance a highly skilled, competent, and diverse workforce, cultivate an innovative work environment, and provide the facilities, tools, and services needed to conduct NASA's missions.

Goddard's people are the center's greatest strength and asset. The Goddard workforce is composed of civil servants and contractors. Scientists, engineers, project managers, safety and mission assurance personnel, technicians, and other specialists directly support the sciences as well as the design and delivery of spacecraft, instruments, and data. Institutional support staff undergird mission activities and serve a key role in accomplishing the center's goals.

Goddard's contractor workforce is an integral part of mission success. Goddard attracts and maintains exemplary contract employees to meet the demands of implementing the agency's mission. A variety of opportunities, from interdependent civil-servant–contractor teams to the Goddard Contractors Association all combine to create a high-performing and inclusive contractor workforce.

Recruitment and Retention

Goddard is an attractive employer offering compelling, meaningful work and a chance to make a difference. Goddard's civil servant recruitment strategy targets a highly talented and diverse pool of permanent employees, interns, and Pathways Program participants. The internship and Pathways programs serve as pipelines to the permanent workforce by providing opportunities for students and recent graduates to experience short-term mentored work at Goddard and to be considered for full-time, Federal employment.

Goddard invests in our most important asset through training opportunities such as the:

- Leadership Development and Excellence in Management Program and other leadership training
- Technical Managers Training
- Systems Engineering Education Development Program
- Product Development Lead Training Program
- Flight Projects Development Program
- Research Engineering Program
- Science and Engineering Collaboration Program

The nature of Goddard's matrixed organizational structure also contributes to employees' ability to grow in their careers. At any time, Goddard manages multiple missions at various stages of the development life cycle, which provides a variety of opportunities for employees. As projects end, employees are rotated from one mission to another, which allows them to work with new people, learn new skills, and apply their knowledge to new challenges. Goddard makes internal project and development opportunities open and available, and fosters an environment of organizational mobility that allows for position changes, varied responsibilities, and advancement. Goddard's Quality of Worklife Program also helps retain a vibrant workforce by advancing programs and policies designed to encourage balance between work and home commitments. In addition, Goddard promotes a robust employee awards and recognition program.

GODDARD EMPLOYS APPROXIMATELY **13,000+** CIVIL SERVANTS AND CONTRACTORS

WITH A WIDE ARRAY OF **OCCUPATIONS** AND SKILL SETS

Organizational Culture

Goddard maintains an organizational culture that values each individual; respects the diversity of viewpoints, experience, talents, and ideas; and fosters inclusion. This environment promotes a shared cultural commitment to these values, driven by both employees and management across all locations. Employee engagement manifests itself in continuous learning events held throughout the year: poster sessions, "lunch and learn" activities, and numerous employee-driven colloquia series, which feature subject matter experts in engineering, science, information science and technology, systems engineering, and leadership. A strong sense of community is also evident through the more than 40 active employee clubs at Goddard that cover a wide range of social, athletic, and cultural interests.

Commitment to Equal Employment Opportunity and Diversity and Inclusion

Goddard is committed to cultivating a workforce that represents the Nation's diversity and engages employees in the creation of a positive work environment that is conducive to their best performance. At Goddard, diversity and inclusion is a business

imperative that drives innovation and creativity, and serves a critical role in team effectiveness and mission success. Our definition of diversity includes important characteristics that affect an individual's values, opportunities, and perceptions of self and others at work. These characteristics include, but are not limited to, age, ethnicity, gender, ability, race, sexual orientation, religion, and family status. We continually strive to exceed the requirements set forth by the Federal Equal Employment Opportunity (EEO) regulations and foster an organizational climate of inclusion and mutual respect.

The focus on EEO and diversity and inclusion makes Goddard a better organization, partner, and place to work. This outcome was evidenced by the 2014 Office of Personnel Management Employee Viewpoint Survey, where Goddard placed second out of over 300 Federal organizations regarding employee perception of support for diversity and inclusion.

Employees gain new perspectives through the Diversity Dialogue Program and the Power and Privilege education series, as well as outreach events, collaborations, and other educational and cultural competency activities. Goddard Advisory Committees play a vital role in promoting these programs and values across the workforce and help us to address issues. They include:

- African American Advisory Committee
- Asian Pacific American Advisory Committee
- Equal Accessibility Advisory Committee
- Hispanic Advisory Committee for Employees
- Lesbian, Gay, Bisexual, and Transgender Advisory Committee
- Native American Advisory Committee
- New and Developing Professionals Advisory Committee
- Veterans Advisory Committee
- Women's Advisory Committee

(Left) Employees visit an advisory committee booth during a Celebrate Goddard Day event. (Right) Goddard's Assistive Technology Lab provides support to people with disabilities.

Institutional Support

Goddard's institutional planning and execution is based on meeting the demands of our mission while ensuring a safe, secure, reliable, accessible, and sustainable workplace. Goddard's institutional workforce provides a broad spectrum of services to support the mission of the center, including

- Legal
- Procurement
- Information technology
- Financial management
- Human capital management
- Equal opportunity programs
- Diversity and inclusion
- Conflict management (alternative dispute resolution, anti-harassment)
- Protective services
- Environmental and medical management
- Facilities management and transportation
- Logistics
- Knowledge and information management
- Government and community relations
- Proposal development
- Education and public outreach
- Public communications

These services help us meet our mission commitments in an effective, transparent, and compliant manner that safeguards the public trust. Goddard also maintains the largest acquisition workforce in the agency, supporting procurements for both the center and NASA Headquarters.

Sustainability and environmental stewardship is a central part of Goddard's institutional planning and execution, which is consistent with our Earth science perspective. The Goddard Master Plan, which includes all five Goddard locations, is a living document with forward-looking, mission-driven planning principles and goals as its foundation. A fundamental facility planning goal is to provide flexible facilities of the appropriate quality, reliability, and efficiency to meet the technical demands of each mission.

Information Technology

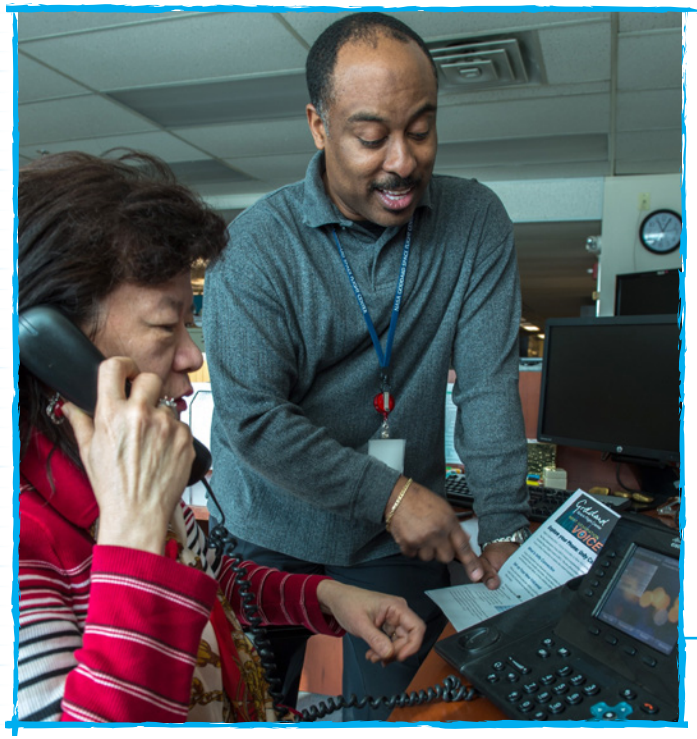
NASA Strategic Objective 3.3: Provide secure, effective, and affordable information technologies and services that enable NASA's mission.

Goddard's scientists, engineers, and professionals require information technology (IT) in order to conduct the center's efforts to transform human understanding of Earth and space. Goddard IT engineers and specialists support the center in achieving its science and technology mission through the efficient and secure application of IT by:

- Providing the Goddard workforce the information infrastructure and tools that adapt and evolve to effectively and securely support management, science, research, and technology programs.
- Developing, implementing, and operating specialized IT systems to support mission and project implementation.
- Providing systems that disseminate information to the public and protect NASA's information assets.

Performing routine datacenter maintenance is essential to keeping Goddard applications and services running smoothly.

In order to meet these needs, Goddard's IT personnel provide a full range of IT services and capabilities for the center, including desktop support, application development, collaboration tools, network engineering, and cybersecurity. The team brokers enterprise services from the agency to provide efficient and cost-effective solutions, and extends those services with local solutions to meet the unique requirements of the center's science missions. The priorities of Goddard IT can be divided into three major areas: capability, cybersecurity, and sustainability.



IT Capability: Enabling Goddard Science and Technology

Goddard manages and operates the IT services that the center's workforce relies on every day —networks, telephones, video communications, custom software applications, and desktop and computing services. As part of NASA's Communications Services Office, Goddard also plays a lead role in the agency's mission network infrastructure. Goddard's IT service delivery priorities are to ensure that the center's IT infrastructure and application capabilities and services continue to meet evolving stakeholder needs and enable mission success.

Cybersecurity: Securing Goddard Science Data and Assets

Information security is fundamental to ensuring the confidentiality, integrity, and availability of Goddard's critical scientific and institutional data and IT assets. Goddard's cybersecurity priority is to enhance and integrate information security throughout the system life cycle, ensuring that Goddard's data and information are protected from cyber-attack. Goddard uses a risk-based approach to information security management, which balances the appropriate level of security with the need to integrate emerging technologies to allow scientific collaboration and achieve mission success.

Goddard manages IT services needed for every day operations—networks, telephones, video communications, custom software applications, and desktop and computing services.

IT Sustainability: Optimizing Support for Goddard Science

The last major priority for IT at Goddard is to enable Goddard missions and science through:

- Innovative, sustainable, and transparent support.
- Effective IT planning, enterprise architecture, and IT governance.

Goddard's unique and effective IT governance model employs representative center participation to coordinate IT strategy and oversee the center's IT investment portfolio. Enterprise architecture creates a blueprint for the center to translate these strategies and plans into core capabilities.

Safety and Mission Success

NASA Strategic Objective 3.4: Ensure effective management of NASA programs and operations to complete the mission safely and successfully.

Goddard ensures successful and safe missions through a multidisciplinary approach that includes engineering, Safety and Mission Assurance, IV&V, and project management. Our Safety and Mission Assurance organization offers an independent voice and perspective. Goddard maintains a strong culture rooted in safety and prevention along with robust safety processes to protect civil servant and contractor personnel; ground, space, and launch systems; and the public.

Goddard performs external and internal compliance monitoring with emphasis applied where risk is the highest, which results in exemplary project management, excellent technical performance, and cost-effective, on-time mission completion.

As part of the agency's Safety and Mission Success Program, Goddard personnel within the IV&V Program are contributing to informed decision-making that reduces risk associated with the safety and mission critical software on NASA missions, and improves the likelihood that NASA programs, projects, and operations will be completed safely and successfully. Specifically, the IV&V Program provides system and software assurance to NASA missions across the entire agency.

(Left) A balloon payload is readied for electronics and communications testing in preparation for launch in Fort Sumner, NM. (Below) Goddard safety and mission assurance personnel conduct software simulations and testing in IV&V's Jon McBride Software Testing Research (JSTAR) laboratory.

one Goddard: We are Stronger Together

For more than fifty years, the achievement of NASA's science goals has required the combined resources of an extraordinarily diverse and broad organization. Goddard is composed of five main sites with unique contributions and a unified purpose: the Goddard Greenbelt campus, the Wallops Flight Facility, the Independent Verification and Validation Facility, the Goddard Institute for Space Studies, and the White Sands Complex. Each installation plays a specific, complementary role in the center's implementation of NASA's science and exploration objectives.

Goddard Greenbelt campus is located in Greenbelt, Maryland, and home to the largest portion of Goddard's workforce. As part of the Federal science and technology sector in metropolitan Washington, D.C., this campus is a major U.S. laboratory for developing and operating unmanned scientific spacecraft. A multidisciplinary team at the Greenbelt campus manages many of NASA's Earth observation, astronomy, and space physics missions. Encompassing 1,270 acres, its grounds include more than 30 buildings that provide over three million square feet of research, development, and office space.

one Goddard: We are Stronger Together

Wallops Flight Facility is located on Wallops Island, Virginia, encompassing 6000 acres of the Eastern Shore. Missions and activities for Earth science, astrophysics, and other disciplines conducted by Wallops involve the development and deployment of low-cost, highly capable suborbital and orbital research carrier vehicles. These efforts are accomplished around the world using sounding rockets, scientific balloons, expendable launch vehicles (ELVs), unmanned aerial vehicles (UAVs) and student experiment carriers. Wallops includes:

- Wallops Research Airfield (with three major runways), including an Aircraft Control Center
- Wallops Launch Range, including Launch Control Centers
- Wallops Payload and Vehicle Integration Facilities (including services for aircraft, balloon, and sounding rocket missions)
- Wallops Antenna Stations (supporting the Near Earth Network)
- Other Wallops Facilities (including administrative offices and science and mission planning labs)

Independent Verification and Validation Facility is located in Fairmont, West Virginia. The facility was established as part of a NASA-wide strategy to provide high levels of safety and cost-effectiveness for the agency's mission-critical software. IV&V services include software safety, verification and validation, quality assurance, cybersecurity and information assurance, simulation and modeling, and independent testing, which support Goddard's science missions as well as other programs across the agency. The IV&V Program, an agency-level service, was founded under the NASA Office of Safety and Mission Assurance as a result of recommendations made by the National Research Council and the Report of the Presidential Commission on the Space Shuttle Challenger Accident.

Goddard Institute for Space Studies is located on Columbia University's campus in New York City. Much of the institute's early work in Earth science involved examination of planetary atmospheres using data collected by telescopes and space probes. This led to GISS becoming a leading facility for atmospheric modeling and climate change study. Current Earth science research at GISS emphasizes a broad study of global change across various time scales, addressing natural and man-made changes in our environment that affect the habitability of our planet.

GISS Director Gavin Schmidt

The White Sands Complex is located outside Las Cruces, New Mexico, on the grounds of NASA's Johnson Space Center's White Sands Test Facility. It enables the operation of the Space Network, the agency's extensive and complete global telecommunications system. The White Sands Complex ground terminals provide the hardware, software, and personnel necessary for continuous communications with orbiting spacecraft for operations and collection of data for low-Earth orbiting assets, including the International Space Station, expendable launch vehicles, and scientific missions.

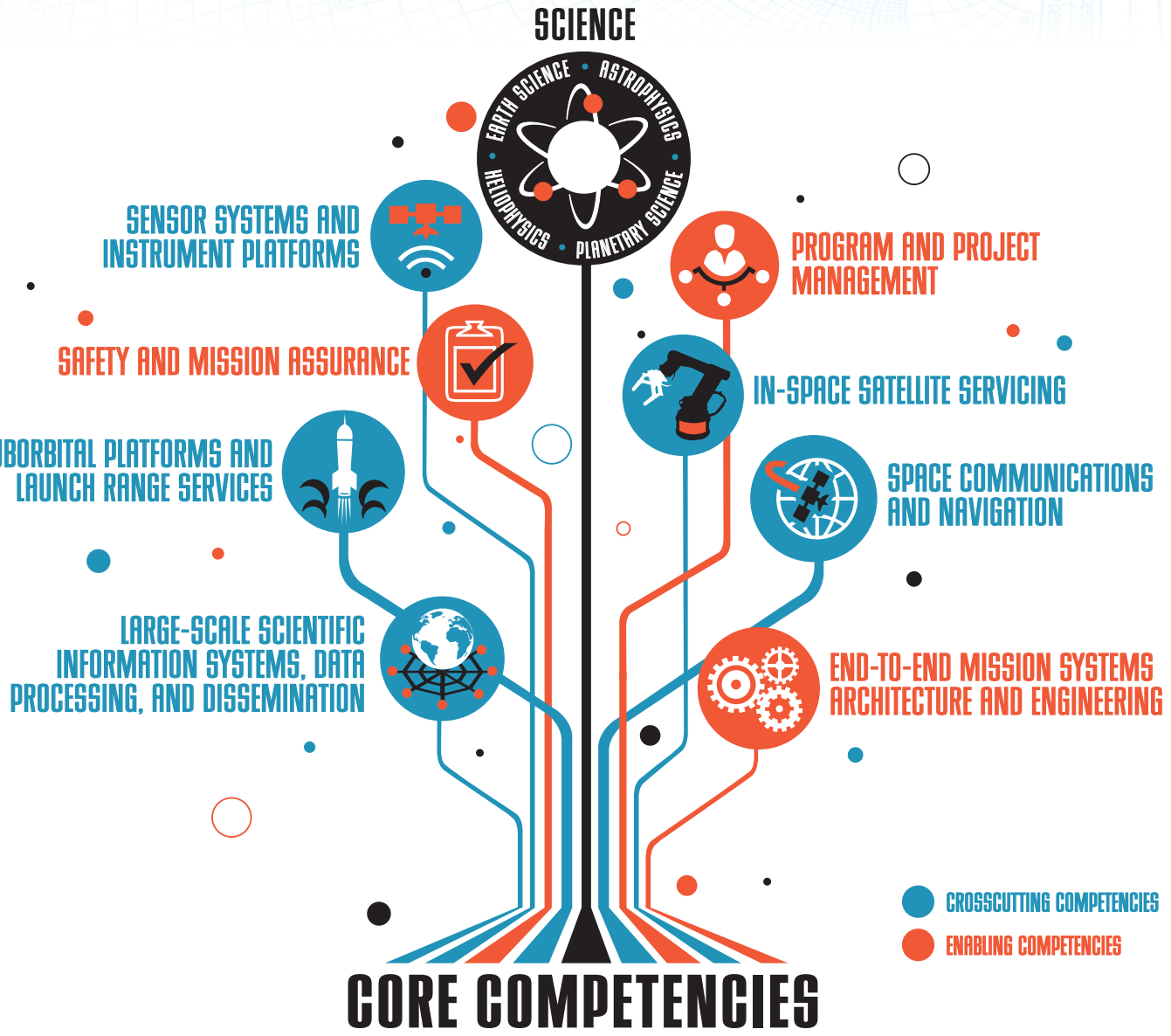
Goddard's Strategic Core Competencies

The identification and cultivation of strategic core competencies is essential to Goddard's current and future ability to successfully deliver outstanding science products and services to NASA and the Nation. We define a Goddard core competency as an area of expertise that is:

- Necessary to support NASA's science and exploration mission and that Goddard is uniquely suited to provide,
- Required to fulfill Goddard's implementation of NASA's strategic plan and that does not readily exist elsewhere,
- Essential to Goddard's ability to conduct scientific missions and provide technological expertise and services that meet customer requirements.

Goddard's strategic core competencies, as defined by these criteria, are divided into three categories:

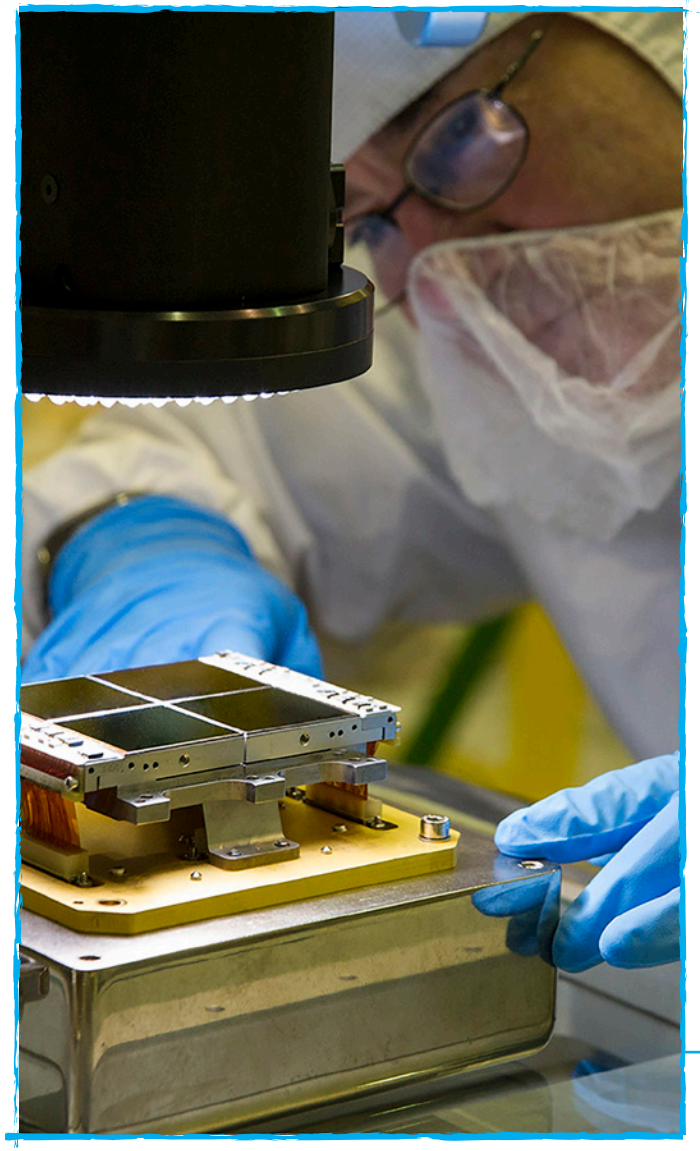
1. Technical competencies consisting of science research
2. Crosscutting engineering and technology competencies that support science research
3. Enabling competencies that are the foundation of all of the center's work in science, spaceflight, and technology



Core Technical Competencies

Goddard's research activities primarily focus on Earth and space science, both theoretical and experimental.

- **Earth science:** Goddard conducts research on Earth's natural systems and processes. Major focus areas include climate change, severe weather, the atmosphere, the oceans, sea ice glaciers, and the land surface.
- **Astrophysics:** Goddard conducts research in astronomy, astrophysics, and fundamental physics. Major focus areas include the nature of dark matter and dark energy, the search for habitable planets around other stars, the origin and evolution of the universe, and the nature of space, time, and matter at the edges of black holes.
- **Heliophysics:** Goddard conducts research on the Sun, its extended solar system environment (the heliosphere), and interactions of Earth, other planets, small bodies, and interstellar gas with the heliosphere. Research also encompasses geospace (Earth's uppermost atmosphere, the ionosphere, and the magnetosphere) and solar system weather.
- **Planetary science:** Goddard conducts research to explore the solar system and understand the formation and evolution of planetary systems. Areas of investigation include astrochemistry, astrobiology, planetary atmospheres, extrasolar planetary systems, Earth science, planetary geodynamics, space geodesy, and comparative planetary studies.



Using a powerful three-dimensional microscope, an optics technician aligns a replacement focal plane assembly for the Near-Infrared Camera instrument.

Core Crosscutting Competencies

Goddard's crosscutting competencies, which support our scientific technical competencies, include:

- Sensor systems and instrument platforms
- Suborbital platforms and launch range services
- Space communications and navigation
- Large-scale scientific information systems, data processing, and dissemination
- In-space satellite servicing

Sensor Systems and Instrument Platforms

Goddard develops and builds state-of-the-art Earth science, astrophysics, heliophysics, planetary science, and exploration instruments and missions. Scientists and engineers from all of Goddard's engineering disciplines develop instruments—from subsystems, such as detectors and optical elements, to complete instruments to instrument suites. Instrument capabilities operate across the entire electromagnetic spectrum, and the full range of sensing techniques including: imagers, LIDARs, radiometers, synthetic aperture radars, spectrometers and spectrographs, magnetometers, and polarimeters, emphasizing high sensitivity, improved performance, and miniaturization.

The Lunar Atmospheric Dust Environment Explorer (LADEE) mission highlighted the breadth of Goddard capabilities with the center playing leadership roles across the entire mission. Goddard employees delivered key instruments, developed ground-breaking laser communications technology through the Lunar Laser Communications Demonstration, provided launch vehicle support as well as range and safety services, and utilized its worldwide data collection networks to create and enable mission success for NASA's return to the Moon.

An artist's concept shows the LADEE spacecraft and the onboard Lunar Laser Communications Demonstration—NASA's first high-rate, two-way space laser communication prototype that sends signals to and from orbit around the Moon.

Goddard's Strategic Core Competencies

Goddard supports the simultaneous development of multiple missions, instruments, and payloads internally. Goddard also oversees and provides technical expertise for external missions, simultaneously assisting in the development of approximately 20 or more projects.

Suborbital Platforms and Launch Range Services

Goddard manages and implements suborbital programs (sounding rockets, balloons, and aircraft) and owns and operates Wallops Launch Range, which is NASA's only launch range and one of four space-lift capable ranges in the Nation. Goddard aircraft routinely fly airborne science missions in support of Earth science, accounting for nearly half of all flight hours conducted for the agency. Unique crosscutting competencies for suborbital mission execution include sounding rocket trajectory and stability analyses, communications during highly dynamic and spinning trajectories, recovery systems, fine-pointing and inertial reference systems, thin-film balloon material and design, and multi-platform aircraft modification and operation. Suborbital mission platforms provide worldwide reach for science missions on short timescales.

Range competencies for orbital and suborbital launches include flight and ground range safety, radar, telemetry, command destruct, communications, surveillance, clearance, recovery, meteorology, and offline and real-time safety analysis tools. The Wallops Launch Range is recognized for its innovations in autonomous flight safety, mobile capability, space-based communications, low cost, and flexible approach to requirements and schedule. Range services are routinely provided worldwide through mobile assets.

Space Communications and Navigation

Goddard is a leader in analyzing and modeling spacecraft mission communications and navigation needs and matching them with the appropriate network. Goddard is managing the Space Network and Near Earth Network for the Space Communications and Navigation Program and is enhancing the networks with optical communications capabilities. Goddard integrates and tests the networks, providing seamless coverage to missions through its Network Integration Center. In addition, Goddard manages the Satellite Laser Ranging network on behalf of the science community as well as leads the search and rescue network's research and development for other U.S. Government

agencies and international partners. All of these efforts provide a foundation for NASA's scientific observations and human exploration conducted on the ground and in space.

Space Communications Assets

The network assets and customer focus areas include:

- **Space Network**
  Includes the TDRS fleet of eleven communications relay spacecraft in geosynchronous orbit and primary ground terminals in New Mexico, Guam, and Blossom Point, MD. The Space Network provides communications services to missions below geosynchronous orbit at S-, Ku-, and Ka-band frequencies.
- **Near Earth Network**
  Provides communications services to satellites in low Earth orbit, geosynchronous orbit, highly elliptical orbit, lunar orbit, and missions with S, X, Ka, and VHF frequency bands.
- **Satellite Laser-Ranging Network and International Laser-Ranging Services**
  Goddard's satellite laser ranging measurement network supports national and international scientific programs in Earth dynamics, ocean and ice surface altimetry, navigation, and positioning.

(Left) NASA antenna AS-3 at the Alaska Satellite Facility is an asset of the Goddard-managed Near Earth Network (NEN).

The Space Network's constellation of nine Tracking and Data Relay Satellites, located in geosynchronous orbit, provides two-way communications services to users in low-Earth orbit.

Goddard's Strategic Core Competencies

- **Optical Communications**
  Leveraging the Lunar Laser Communications Demonstration (LLCD) managed by Goddard, further technology initiatives and demonstrations are underway to extend Goddard's communications and navigation services to include optical communications, with efforts such as the Laser Communications Relay Demonstration (LCRD) mission being developed in partnership with MIT Lincoln Laboratory.

- **Search and Rescue**
  Goddard leads search and rescue efforts, supports the National Search and Rescue Plan, and serves as the designated agency to perform search and rescue research and development to meet current and future needs. In the 30 years since the system began operations, these efforts directly saved more than 30,000 lives worldwide.

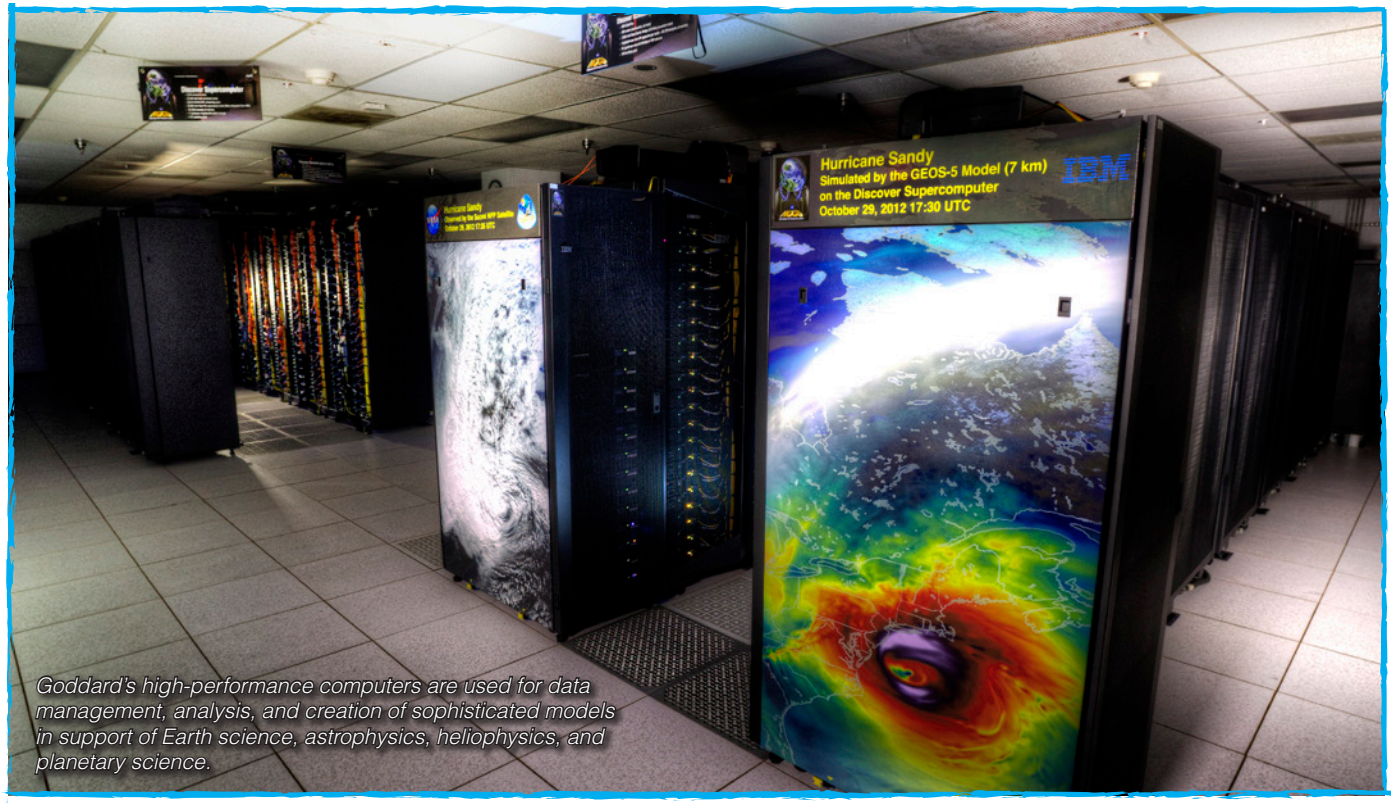
Navigation and Trajectory Design

Goddard provides navigation and trajectory design expertise to flight projects and technology development efforts, including:

- Orbit design studies for mission concept development
- Analysis of orbit determination and control requirements
- Development of ground systems for flight dynamics product generation
- In-flight orbit determination and orbit control
- Analysis of autonomous systems for navigation (flight and ground systems)
- New trajectory optimization techniques
- Advanced modeling of orbit errors

Large-Scale Scientific Information Systems, Data Processing, and Dissemination

Goddard is a world-class provider of data management and high-performance computing and networking, providing quality software products, services, and data management expertise to enable the success of NASA missions. These products and services include flight, ground, and science data systems and technologies; mission environments; software systems engineering; and software and data systems project management. Goddard's data are utilized globally for long-term science data systems development and management in support of Earth science, astrophysics, heliophysics, and planetary science.



Goddard's high-performance computers are used for data management, analysis, and creation of sophisticated models in support of Earth science, astrophysics, heliophysics, and planetary science.

This capability includes long-term management of current and historic mission data as well as information and knowledge obtained from a variety of sources, including satellite, aircraft, ground *in situ* measurements, and science models.

In-Space Satellite Servicing

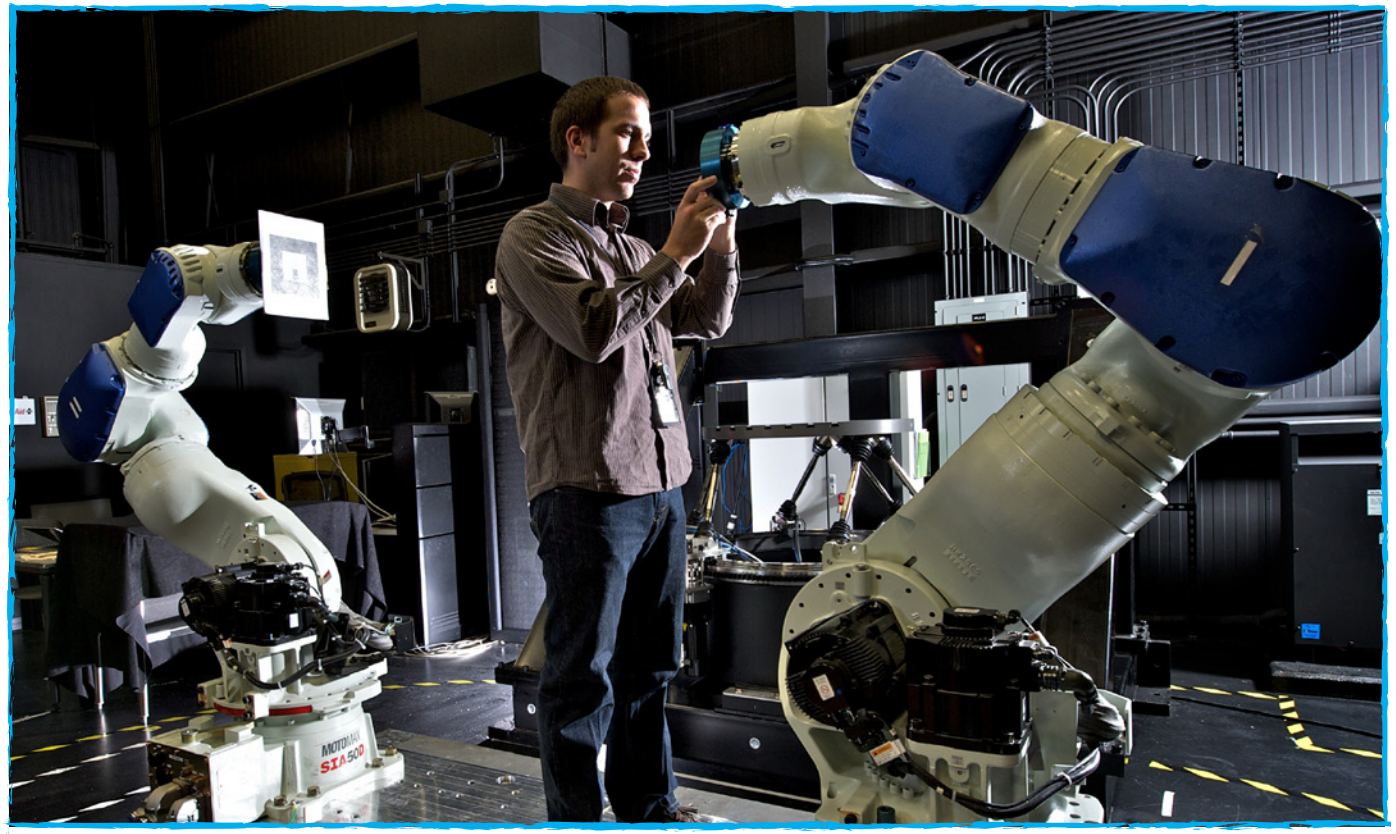
In-space satellite servicing bridges NASA's science and exploration efforts. It is vital to the agency's ability to conduct long-term human exploration and Earth and space science missions. Goddard satellite servicing capabilities include in-orbit spacecraft refueling and repair, assembly of large structures in orbit, and modular designs that allow for spacecraft upgradability. These capabilities offer options for extended mission operations, upgradability, reconfiguration, and recovery. With a 30-year history of satellite servicing and repair—including the legacy of conducting five successful missions to upgrade the Hubble Space Telescope—Goddard's satellite servicing team is working to:

- Advance the state of robotic servicing technology to enable the routine servicing of satellites that were not designed with servicing in mind.
- Sustain and strengthen U.S. global leadership in the in-space repair, maintenance, and disposal of satellites.
- Help to build a sustainable future U.S. industry for the servicing of satellites.

Goddard is developing, maturing, and testing a suite of integrated technologies that enable servicing capabilities in low- and geosynchronous-Earth-orbit including:

- Autonomous rendezvous and proximity operations system
- Dexterous robotics
- High-speed, fault-tolerant computing
- Advanced robotic tools
- Non-cooperative propellant transfer

Two Motoman robot arms are readied for rendezvous simulation; the right arm's sensor is ready to track the motion of the left arm's target.



Goddard's Strategic Core Competencies

Core Enabling Competencies

Goddard's enabling competencies, which are integral to all of Goddard's work in science and exploration, are the following:

- End-to-end mission systems architecture and engineering
- Program and project management
- Safety and mission assurance

End-to-End Mission Systems Architecture and Engineering

During mission development, every effort is made to understand and model all the parameters that could impact the mission's ultimate success. End-to-end systems engineering addresses the full life cycle of science missions, spacecraft, *in situ* and remote-sensing instruments, and payload development, from advanced concepts through implementation.

Goddard has implemented systems architecture assembly and "system-of-systems" analysis, which includes research and application for complex systems involving multi-faceted sensors and related electronics, digital signal processing, guidance navigation and control-sensing algorithms, and software. Tools developed internally at Goddard provide high-fidelity mission simulations, from concept to deployment to decommissioning,

NASA Administrator Charlie Bolden visits the Magnetospheric Multiscale (MMS) mission with Goddard Center Director Chris Scolese and MMS personnel, seen here in front of the four spacecraft stacked in a cleanroom.

Goddard's Strategic Core Competencies

as well as immersive software and flight hardware-in-the-loop simulations. Flight project responsibilities include orbit design studies for mission concept development, analysis of orbit determination and control requirements, development of ground systems for generating flight dynamics products, and in-orbit determination and orbit control.

Program and Project Management

NASA's compelling mission is driven by ideation and initiative. Program and project management transforms a research goal into an executable science mission in collaboration with teams of scientists, engineers, technicians, and business and management practitioners. NASA's 2014 Strategic Plan has identified a number of common issues and challenges often observed in the pursuit of agency-wide goals. Goddard actively addresses these issues as part of our program and project management process, including: monitoring mission and cost estimates, maintaining key schedules, developing technology, managing risk, and ensuring results.

In support of NASA's science strategy, Goddard manages the formulation, design, integration, test and operations of spacecraft, instruments and ground control and data processing systems, and tailors its management and implementation approach for each mission. Using our expertise in program and project management and our proficiency in systems engineering, we actively manage the technical and programmatic aspects of our mission and instrument development activities, including cost, schedule, technical excellence, and risk.

The Mars Atmosphere and Volatile EvolutioN (MAVEN) spacecraft launches aboard an Atlas V rocket from the Cape Canaveral Air Force Station Space Launch Complex 41 in Florida.

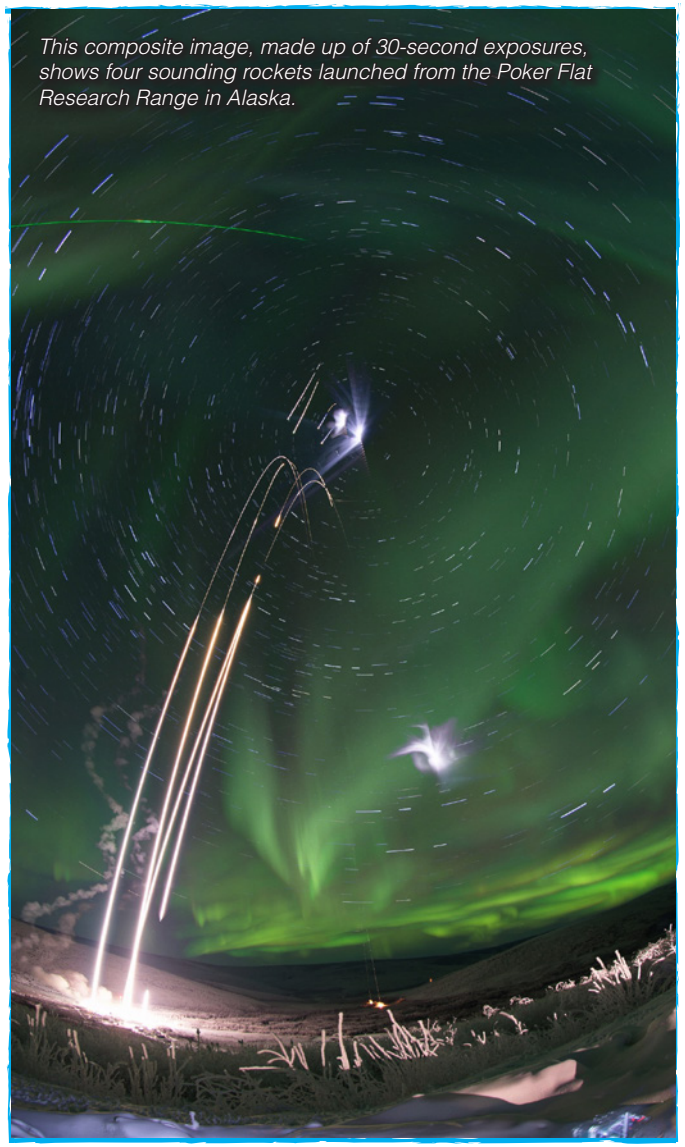
In September 2014, MAVEN flawlessly accomplished a thirty-four minute engine burn that successfully inserted the spacecraft into its required Mars orbit. Ten months earlier, MAVEN had launched on schedule, meeting all technical requirements and expecting budget savings of ten percent. Today, spacecraft, science instruments and payloads work together seamlessly. MAVEN's success is attributed to the project's highly collaborative management, science, and engineering team.

Key drivers of MAVEN's success include:

- *Focused science mission consistent with anticipated funding*
- *Vigilant monitoring and adherence to technical requirements and schedule*
- *Continuity of project leadership with clear roles and accountability for meeting technical, schedule and cost objectives*
- *Effective communication within the project team and among partner institutions, the program office, NASA Headquarters and other stakeholders*
- *Robust risk management allowing early identification and risk mitigation*
- *Incorporation of heritage spacecraft and instrument technologies including past lessons learned*
- *Commitment to meeting NASA program requirements throughout the agency*

"MAVEN wasn't magic. It required tons of collaboration, communication, and hard work to ensure mission success." —MAVEN Project Manager

Goddard's Strategic Core Competencies



This composite image, made up of 30-second exposures, shows four sounding rockets launched from the Poker Flat Research Range in Alaska.

As a matrixed organization, Goddard's functional units closely interact to develop multiple simultaneous flight and technology projects. Program managers, project managers, and their teams are responsible for satisfying the technical requirements necessary to meet the scientific research objectives, and for meeting cost and schedule commitments. Each must ensure that project resources—including staff, tools, technologies, facilities and finances—are aligned, organized, and optimally utilized. For example, we perform rigorous cost estimates, which are consistently monitored from concept through implementation, for the smallest instruments to the largest flagship projects.

Skilled project and program management is reflected in Goddard's history of achievement. To date, we have:

- Successfully delivered major Goddard-managed science and technology missions that launched on schedule with significant cost savings, including Landsat 8, MAVEN, GPM, and TDRS-K.
- Successfully delivered over 300 satellites and instruments that have reliably produced science and technology advancements and continue to generate science data beyond their planned life cycles.
- Launched over 16,000 missions through Wallops Launch Range.
- Employed more than half of the NASA-certified project and program managers working at the agency.

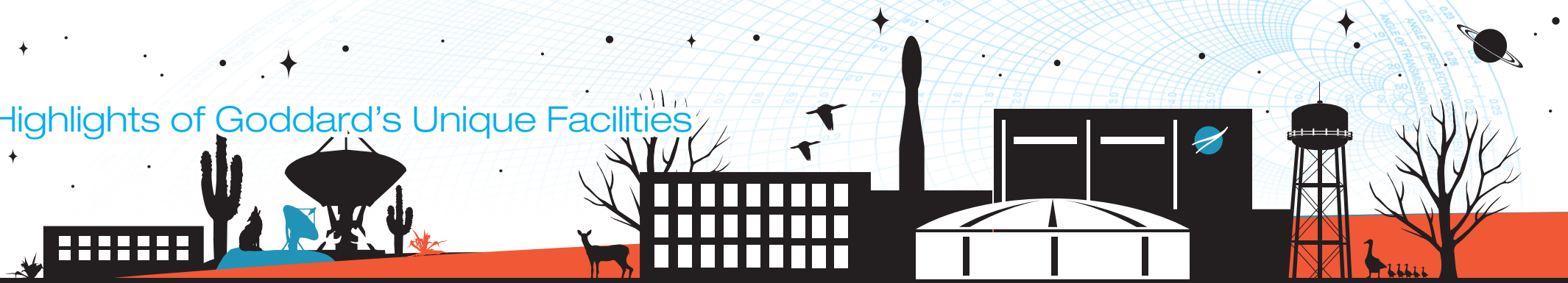
Safety and Mission Assurance

Goddard is a leader in safety and mission assurance, with a lengthy history of implementing effective, innovative, and cost-effective approaches designed to reduce risks, and protect and preserve our critical mission assets and personnel. Safety and mission assurance personnel and processes are integrated throughout Goddard. They ensure the safety and mission success of all of the center's operations and flight projects. Technical experts from all safety and mission assurance disciplines are integral members of flight project teams from concept through post-launch operations, resulting in risk-informed decision-making and safe work environments.

(Right) Engineers use this small chamber to test space hardware at very cold temperatures that would be experienced in space.

(Background) Sharing science results. (Clockwise from top) Building the Solar Aspect System, a sophisticated targeting technology for precise observations. Sewing thermal blankets for hardware protection and thermal control. Testing remote operations for in-space satellite servicing from Goddard Greenbelt campus with an industrial robot at NASA's Kennedy Space Center, over 800 miles away.

Highlights of Goddard's Unique Facilities



GODDARD MISSION SERVICES EVOLUTION CENTER

The Goddard Mission Services Evolution Center (GMSEC) is a software framework that allows existing satellite control software products to be easily integrated to create sophisticated mission control centers. The GMSEC approach includes the use of middleware, standardized message formats, and cross-platform plug and play mission support applications.

WHITE SANDS COMPLEX GROUND TERMINALS

The Space Network ground segment at the White Sands Complex consists of satellite ground terminals: the Second TDRSS Ground Terminal and White Sands Ground Terminal, plus the remotely operated Guam Remote Ground Terminal and Blossom Point Ground Terminal. These terminals enable nonstop, real-time satellite communications, data relay, and tracking services for spacecraft, launch vehicles, and science missions.

SPACE TELESCOPE OPERATIONS CONTROL CENTER

The Space Telescope Operations Control Center (STOCC) manages the control, flight, and health of the Hubble Space Telescope. Hubble has made more than a million observations since its launch in 1990, and its record-breaking orbit encompassing millions of miles is made possible by the efforts of engineers, technicians, and controllers at this focal point of all Hubble operations.

WALLOPS LAUNCH RANGE

This only NASA-owned launch range consists of a control center, multiple orbital and suborbital launch pads, processing and assembly facilities, and numerous tracking assets. Mobile assets are often deployed at downrange sites and around the world to support science missions wherever required.

SPACE SYSTEMS DEVELOPMENT AND INTEGRATION FACILITY

The Space Systems Development and Integration Facility (SSDIF) is an 86,000-square-foot building used to integrate and test space hardware. It houses the 1.3 million-cubic-foot High Bay Clean Room, the largest of its kind in the world. The SSDIF currently supports James Webb Space Telescope integration and test activities.

INTEGRATED DESIGN CENTER & MISSION PLANNING LAB

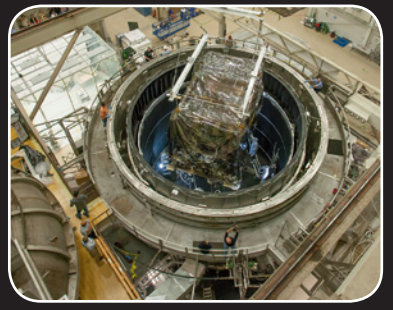
These facilities are unique resources for concurrent engineering where engineers and scientists use a collaborative process and sophisticated tools to rapidly produce mission, science instrument, and mission-enabling technology concepts. Services provided include end-to-end design and analysis, visualization, realistic mission simulation, evaluation of platform selection, and flight profiles, among others. The Integrated Design Center includes Architecture, Mission, and Instrument Design Labs. The Mission Planning Lab also provides launch-range specific analysis.

DETECTOR DEVELOPMENT AND CHARACTERIZATION LABORATORIES

Built within a 4,800-square-foot Class 10/100 cleanroom, the Detector Development Laboratory (DDL) is a microelectronics fabrication facility dedicated to the development of advanced detectors, micro-electrical-mechanical-systems, nanotechnology, circuits, and components for NASA missions with the capability of full-scale custom wafer fabrication. The Detector Characterization Laboratory (DCL) is an advanced facility for complete optical and electrical characterization of custom detectors.

INTEGRATION AND TEST COMPLEX

This suite of Integration and Test facilities provides the capability to simulate the critical environmental conditions generated by ground handling, launch, and orbital flight for science missions. It supports testing of acoustic and vibration spectrum and intensity, rotational acceleration, electromagnetic environment simulation and determination, temperature extremes, atmospheric pressure deprivation, and varying magnetic field levels. Key facilities include the Space Environment Simulator, a 40-foot by 27-foot thermal vacuum chamber which exposes spacecraft components and payloads to the environmental conditions experienced in space; the Acoustic Test Chamber, a 42-foot tall chamber which exposes payloads to the noise of a launch with the help of 6-foot tall speakers; and the High-Capacity Centrifuge, a 120-foot diameter centrifuge which simulates the increased feeling of gravity's pull during launch.



FLIGHT DYNAMICS FACILITY

The Flight Dynamics Facility (FDF) assists satellites, expendable launch vehicles, and crewed spacecraft to ensure that the craft is travelling in the correct direction. The FDF calculates the trajectory based on measurements from space- or ground-based antennas and provides information to redirect these antennas to establish the link for tracking and communications. During a mission, FDF engineers ensure that the vehicle can communicate with the mission control centers.

NASA CENTER FOR CLIMATE SIMULATION

This facility provides state-of-the-art supercomputing and data services for weather and climate research with worldwide access. It also provides data analysis and visualization tools to interpret modeling data, including the Data Exploration Theater. This theater features a 20-foot by 6-foot 10-inch multi-screen visualization "hyperwall," a joint effort of the center and the Scientific Visualization Studio.

SCIENTIFIC VISUALIZATION STUDIO

The Scientific Visualization Studio (SVS) fosters scientific inquiry and outreach within NASA programs through animations and artistic concepts based on science data. The studio works closely with scientists to promote a greater understanding of Earth and space science and provides these visualizations for free to the general public via the Goddard web site.

WALLOPS PAYLOAD AND VEHICLE INTEGRATION FACILITIES

The Suborbital Programs (sounding rockets, balloons, and aircraft) organization manages unique facilities that enable worldwide science. They include vehicle and payload processing facilities as well as specialized launch systems.

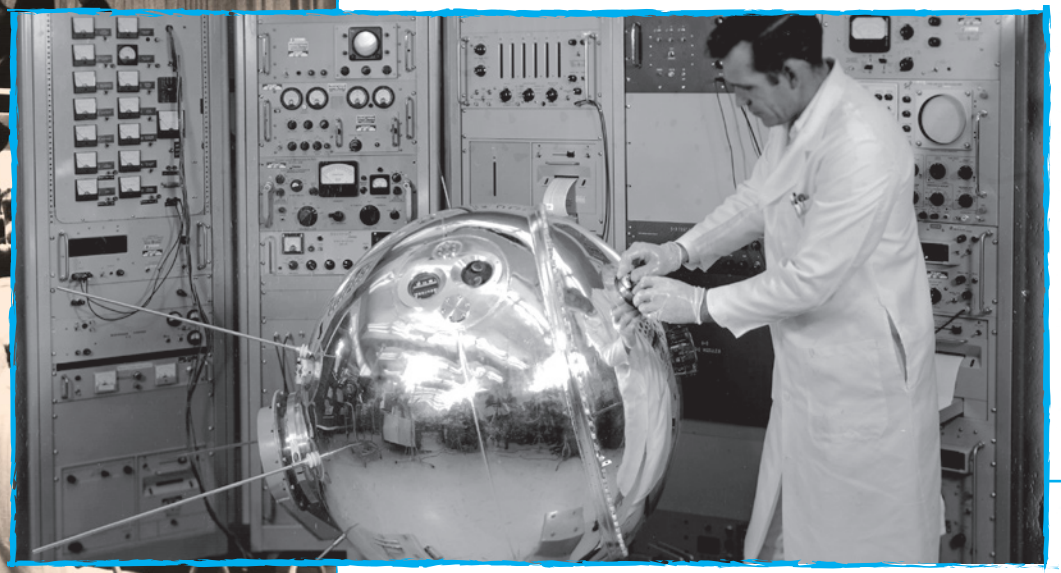
WALLOPS RESEARCH AIRFIELD

This airfield provides immediate access to restricted airspace, consists of three runways providing support to NASA's Earth science missions and Wallops Launch Range, and serves as a test site for aircraft research.

Proud of the Past, Prepared for the Future

Goddard's success in enabling NASA discovery and applying these scientific achievements to society is evident. Goddard supports NASA's strategic goals by leveraging its people, technical capabilities and infrastructure to conceive, launch, and operate new missions, acquire data through its network systems, and disseminate the results. In the process, each of Goddard's five locations supports the center's ability to stimulate and strengthen economic activity by:

- Expending goods and services to perform its mission.
- Generating technology transfer and spinoff activities.
- Broadening small business opportunities through its robust contracting program.



Proud of the Past, Prepared for the Future

Goddard invests more than 80 percent of its funding into businesses, academia, and nonprofit organizations. Goddard's collective efforts provide benefits beyond the local communities of its five locations, extending across the Nation and the globe.

Through scientific innovation and technology transfer, we are continuously applying research to help solve real-world challenges and support human needs in such areas as medicine (insulin delivery and medical imaging technology), emergency management (radio communication, satellite imaging), and commercial design and engineering (planes, trains, automobiles, and skyscrapers). Goddard's public outreach efforts provide a window into research outcomes for individuals nationwide and around the world, and our education activities inspire and engage the next generation of scientists, explorers, and leaders.

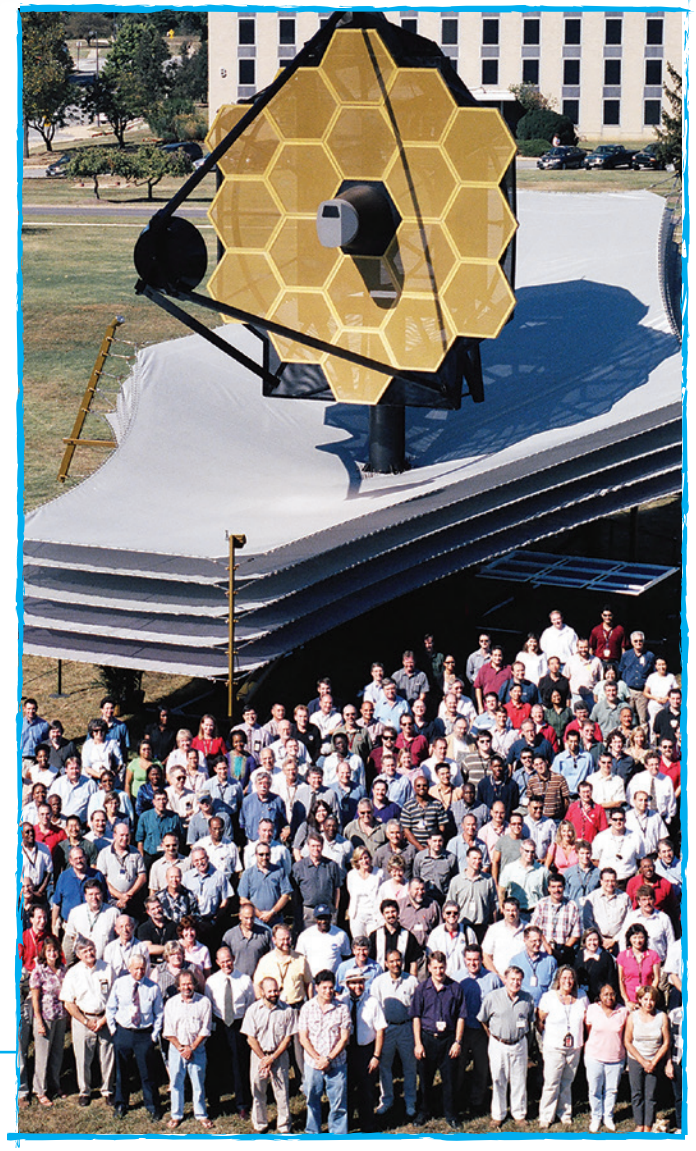
The positive impact of these actions can be observed every day by: televised weather reports made possible with images from Goddard-developed satellites; people in distress whose lives have been saved by Goddard-enabled search and rescue capabilities; and generations of students inspired to become scientists, engineers, and professionals after participating in NASA projects or programs.

All that we do today improves lives now and in the future.

And with much reason to celebrate a long history of world-class mission accomplishments, technological innovation, and scientific leadership, Goddard is now sharply focused on a promising future that shares roots with our successful past.

Goddard will bring new tools to bear as it adapts to an even more challenging competitive landscape of the future. An energized new collaborative spirit flows through Goddard's forward-looking approaches to scientific missions and strategically acquiring new business opportunities. Aligning center strengths with those of other organizations to achieve beneficial collaborations will be a chief thrust for the future, and Goddard will continue to aggressively establish new short- and long-term external relationships.

As technological progress and budgetary realities combine to reduce mission size and cost, the center is embracing the challenge of implementing "right-sized" innovative missions and their supporting technologies. By combining its project experience from flagship missions such as the Hubble and James Webb Space Telescopes with flexible, tailored processes used routinely on suborbital and other small missions, Goddard will chart new pathways in this arena of smaller missions, while embracing effective management and mission assurance approaches to meeting NASA and national objectives.



(Previous page, left) Goddard Space Flight Center dedication ceremony March 16, 1961. (Previous page, right) A Goddard researcher works on the Explorer XVII satellite, used to study the Earth's atmosphere, which launched on April 3, 1963. (Right) Goddard's dedicated workforce is represented by the JWST team, seen here in front of a life-sized model of the James Webb Space Telescope.

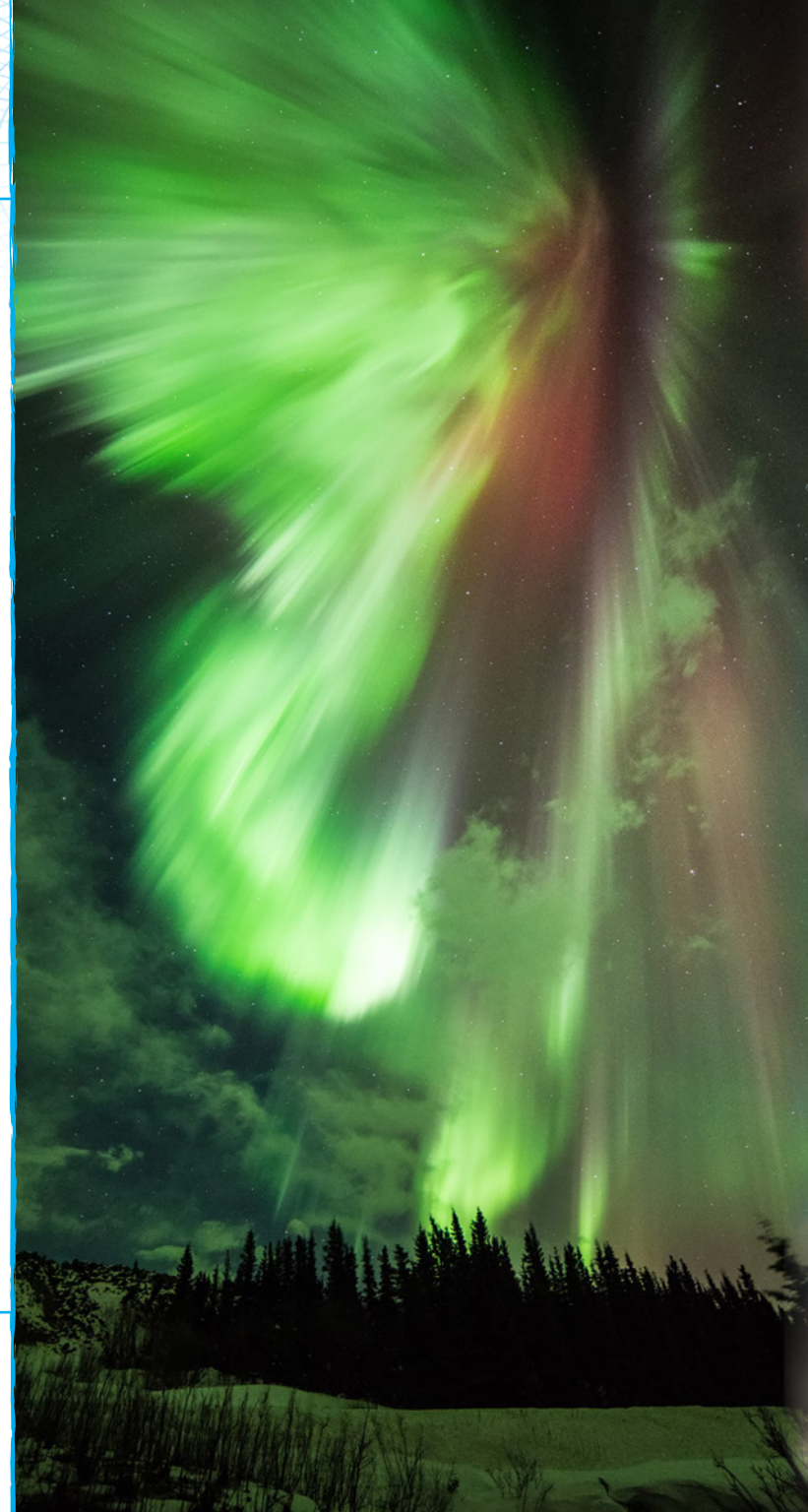
Proud of the Past, Prepared for the Future

A number of major activities that will benefit from these approaches are:

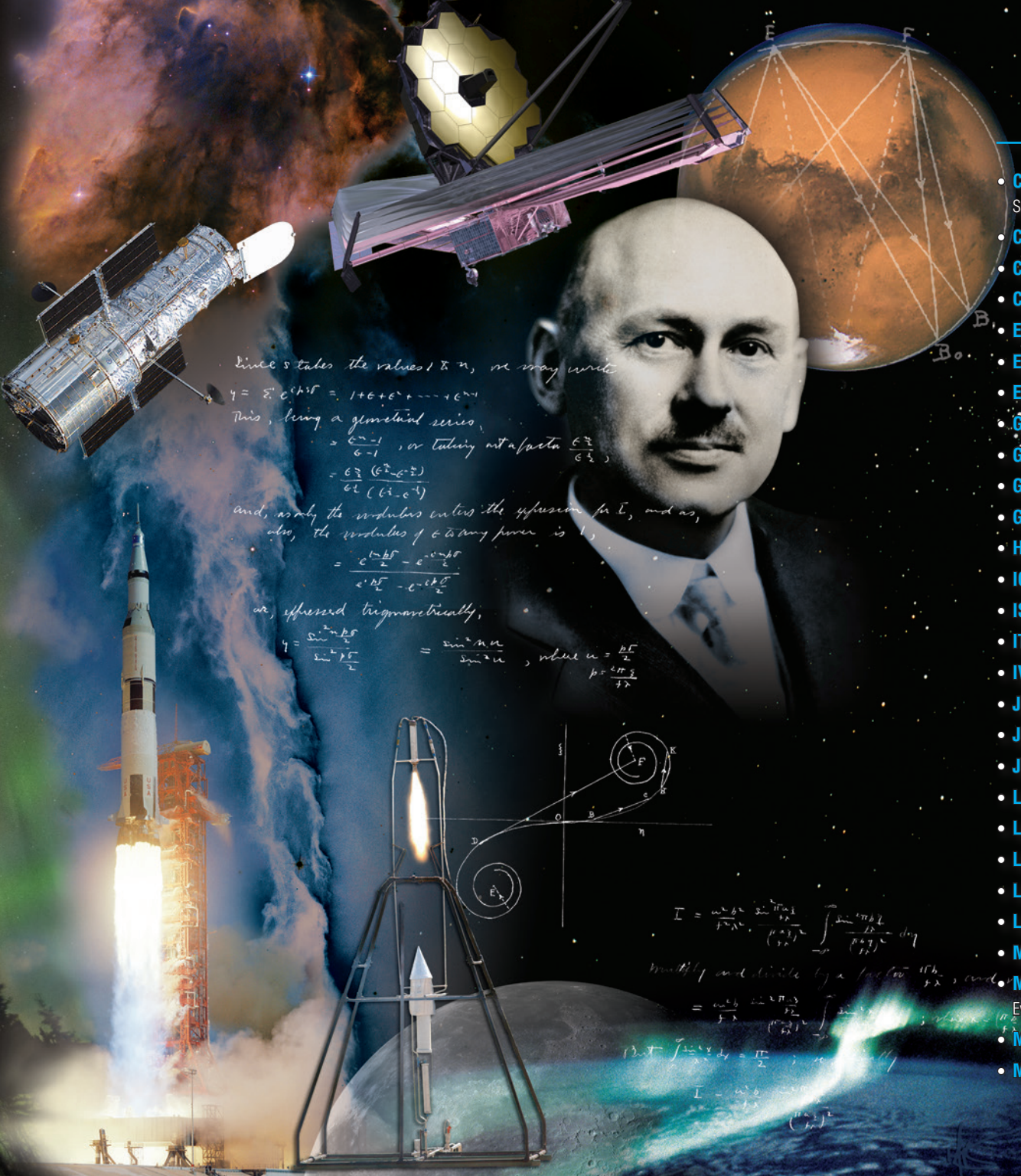
- Science. Goddard anticipates continued opportunities to apply science and technology solutions to the biggest challenges facing our society, such as: providing reliable, worldwide climate predictions on seasonal and decadal scales; characterizing exoplanets; analyzing materials returned from Mars for prior biological activity; predicting space weather to ensure the safety of astronauts and assets in space and on Earth; and providing routine robotic servicing of spacecraft to extend the life and value of science missions.
- Sensors. Capitalizing on its existing world-class capabilities, Goddard will continue to lead the agency and the world in developing future sensors both internally and collaboratively within synergistic teams. We will remain a highly sought-after sensor systems provider and partner for space systems and missions worldwide.
- End-to-End Missions. Informed flexibilities in our technical approaches combined with harmonious partnerships will allow Goddard to remain NASA's trusted and intelligent "buyer" and implementer of science missions.
- Advanced Flight and Ground Systems. Revolutionary yet reliable mission-enabling capabilities such as fine pointing systems, suborbital and orbital launch services, in-space servicing capabilities, and space- and ground- networks providing worldwide connectivity remain an area of excellence for Goddard in the future.
- Large-Scale Scientific Information Systems. Remaining informed by the dramatic advances of industry and government in large-scale computing and cognizant of the importance of scientific data as the end product of our missions, Goddard will focus on developing accurate, innovative processing and modeling advances, and work with partners to manage, store, and disseminate mission results.

Together, this strategic implementation combined with bold approaches to leverage our internal strengths and our external partnering opportunities make Goddard a vibrant and essential element of NASA's future. We are on a path of continuous organizational improvement--by adapting to challenges and applying lessons learned to future approaches. As *One Goddard*, we conceive, design, and launch spacecraft, provide supplies to and return new scientific findings from the International Space Station, deploy humanity's next great observatories, and pursue enduring questions about our Earth and our universe while pondering what is yet to come. This is a journey full of untold possibilities, and we look forward to sharing both the experience and the results with all of our colleagues, partners, customers, stakeholders, and the public.

Leading the way into this bright tomorrow, the Goddard community of employees known for excellence, accomplishment, and innovation, remains a key component of the foundation through which NASA and the Nation will meet the challenges ahead.



Goddard's future scientific discoveries will continue to inspire the public, as evidenced by this spectacular image of an aurora over Donnelly Creek, Alaska, contributed by Sebastian Saarloos.



Acronyms

- **CALIPSO:** Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observation
- **CATS:** Cloud-Aerosol Transport System
- **CGRO:** Compton Gamma-Ray Observatory
- **COBE:** Cosmic Background Explorer
- **EO/EOS:** Earth Observing System
- **ERBS:** Earth Radiation Budget Satellite
- **ESA:** European Space Agency
- **GISS:** Goddard Institute for Space Studies
- **GOES:** Geostationary Operational Environmental Satellite
- **GPM:** Global Precipitation Measurement
- **GRACE:** Gravity Recovery And Climate Experiment
- **HEAO:** High Energy Astronomy Observatory
- **ICESat:** Ice, Cloud, and land Elevation Satellite
- **ISS:** International Space Station
- **IT:** Information Technology
- **IV&V:** Independent Verification and Validation
- **JPSS:** Joint Polar Satellite System
- **JSTAR:** Jon McBride Software Testing and Research
- **JWST:** James Webb Space Telescope
- **LADEE:** Lunar Atmospheric Dust Environment Explorer
- **LCRD:** Laser Communications Relay Demonstration
- **LIDAR:** Light Detection and Ranging
- **LLCD:** Lunar Laser Communications Demonstration
- **LRO:** Lunar Reconnaissance Orbiter
- **MARS:** Mid-Atlantic Regional Spaceport
- **MAVEN:** Mars Atmosphere and Volatile EvolutioN mission
- **MetOp:** Meteorological Operational
- **MMS:** Magnetospheric Multiscale
- **NASA:** National Aeronautics and Space Administration
- **NOAA:** National Oceanic and Atmospheric Administration
- **OAO:** Orbiting Astronomical Observatories
- **OSIRIS–REx:** Origins Spectral Interpretation Resource Identification Security–Regolith Explorer
- **QuikSCAT:** Quick Scatterometer
- **RHESSI/HESSI:** Reuven Ramaty High Energy Solar Spectroscopic Imager
- **SAM:** Sample Analysis at Mars
- **SeaWiFS:** Sea-viewing Wide Field-of-view Sensor
- **SDO:** Solar Dynamics Observatory
- **SMAP:** Soil Moisture Active Passive
- **SMM:** Solar Maximum Mission
- **SMS:** Synchronous Meteorological Satellites
- **SOHO:** Solar and Heliospheric Observatory
- **SORCE:** Solar Radiation and Climate Experiment
- **STDN:** Spaceflight Tracking and Data Network
- **STEM:** Science, Technology, Engineering, and Mathematics
- **STEREO:** Solar TErrestrial RElations Observatory
- **Suomi NPP:** Suomi National Polar-orbiting Partnership
- **TDRS/TDRSS:** Tracking and Data Relay Satellite System
- **TESS:** Transiting Exoplanet Survey Satellite
- **TIROS:** Television Infrared Observation Satellites
- **TOMS/TOMS-EP:** Total Ozone Mapping Spectrometer – Earth Probe
- **TRMM:** Tropical Rainfall Measuring Mission
- **VHF:** Very High Frequency

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