ANNEXES 2014

CHAPTER 1

LEFT:
On October 31, 2012, NASA’s Curiosity rover used the Mars Hand Lens Imager to capture this set of 55 high-resolution images, which were stitched together to create this full-color self-portrait.
Image Credit: NASA

The NASA science program seeks to unravel the mysteries of our Sun, Earth,

solar system, and the universe—out to its farthest reaches and back to its earliest moments of existence.
Image Credit: NASA/Jenny Mottar

CHAPTER 2

LEFT:
A ‘Blue Marble’ image of the Earth taken from the Visible Infrared Imaging Radiometer Suite instrument aboard Suomi NPP (Suomi National Polar-Orbiting Partnership).
Image Credit: NASA

NASA launched the Balloon Array for Radiation-belt Relativistic Electron Losses (BARREL) over Halley Research Station in February 2014 to float above Antarctica and observe magnetic fields to augment measurements from the Van Allen Probes spacecraft.
Image Credit: NASA

Developed in conjunction with Homeland Security’s Science and Technology Directorate, the prototype technology called Finding Individuals for Disaster and Emergency Response (FINDER) is based on remote sensing radar tech nology developed by the NASA Jet Propulsion Laboratory. FINDER can locate individuals buried as deep as 30 feet (9 meters) in crushed materials or hid den behind 20 feet (6 meters) of solid concrete.
Image Credit: NASA/Bill Ingalls

National Policy Direction on Earth and Space Science Recommendations from the U.S. Scientific Community

CHAPTER 3

LEFT:
On August 31, 2012 a long filament coronal mass ejection (CME) erupted from the Sun traveling at over 900 miles per second. The CME did not travel directly toward Earth, but did connect with Earth’s magnetic en-vironment, or magnetosphere, causing aurora to appear.
Image Credit: NASA

NASA’s 2014 strategic plan outlines the following science goals for the Agency:

Principles

competition. Appendix C identifies the categories for each SMD program/strategic mission line. Suborbital programs, comprising sounding rockets, balloons, and aircraft, provide complementary observations, opportunities for innovative instrument demonstration, and a means for workforce development, as highlighted by the NRC in its report

Strategies

Design and successfully implement programs that accomplish breakthrough science and applications.

Challenges

Figure 3.1 SMD missions that excelled in managing cost and schedule
*Formerly RBSP
Figure 3.1 (Continued) SMD missions that excelled in managing cost and schedule
*Formerly RBSP

Satellite data in this visualization are from the Advanced Very High Resolution Radiometer (AVHRR) and Moderate Resolution Imaging Spectroradiometer (MODIS) instruments, which contribute to a vegetation index that allows re searchers to track changes in plant growth over large areas. Of the 10 million square miles (26 million square kilometers) of northern vegetated lands de picted, 34 to 41 percent showed increases in plant growth (green and blue), 3 to 5 percent showed decreases in plant growth (orange and red), and 51 to 62 percent showed no changes (yellow) over the past 30 years.
Image Credit: NASA's Goddard Space Flight Center Scientific Visualization Studio

Flying at an altitude of approximately 204 miles above Earth, the expedition 32 crew onboard the International Space Station (ISS) recorded a series of images of Aurora Australis on July 15, 2012. The Canadarm2 robot arm is in the foreground.
Image Credit: NASA

This artist's concept shows the Wide-field Infrared Survey Explorer, or WISE spacecraft, in Earth orbit. WISE was decommissioned after it successfully completed its original astrophysics mission in 2011. In September 2013, engineers reactivated the mission to hunt for more asteroids and comets in a project called Near Earth Objects WISE, or NEOWISE.
Image Credit: NASA

CHAPTER 4

LEFT:
This image of the Horsehead Nebula was taken in infrared light by the Hubble Space Telescope in honor of the 23rd anniversary of Hubble's launch. The rich tapestry of the Horsehead Nebula pops out against the backdrop of Milky Way stars and distant galaxies that are easily seen in infrared light.
Image Credit: NASA/STScI

Heliophysics
Image Credit: NASA

Solar-Terrestrial Probes Program
Figure 4.1 NASA Heliophysics Missions

Living With a Star Program

STEREO (2)
SOHO-ESA
RHESSI
Cluster–ESA (4)
Formulation
Implementation
Primary Ops
Extended Ops
ACE
SDO
GOLD
ICON
AIM
IBEX

CINDI

Solar Probe Plus

TIMED

TWINS (2)

THEMIS (3)

Hinode–JAXA

Van Allen Probes (2)
Voyager (2)
Solar Orbiter–ESA
WIND
Geotail–JAXA
SET-1
IRIS
ARTEMIS (2)
MMS (4)

Heliophysics Explorer Program

Heliophysics Research Program

Table 4.1 Current Heliophysics Missions

Mission—Launch Year (Extended or Prime), Partners	Objective
Solar-Terrestrial Physics Program	
Thermosphere, Ionosphere, Mesosphere, Energetics, and Dynamics (TIMED)—2001 (Extended)	SExplores the Earth's Mesosphere and Lower Thermosphere (60–180 kilometers up), to understand the transfer of energy into and out of these regions and the basic structure that results from the energy transfer into the region.
Hinode (Solar B)—2006 (Extended) in partnership with Japan and the United Kingdom	Studies the generation, transport, and dissipation of magnetic energy from the photosphere to the corona to record how energy stored in the Sun's magnetic field is released, either gradually or violently, as the field rises into the Sun's outer atmosphere.

Solar Terrestrial Relations Observatory (STEREO)—2006 (Extended) in partnership with France, Switzerland, United Kingdom, Germany, Belgium, DOD	Traces the flow of energy and matter from the Sun to Earth with two space-based observatories. Reveals the 3D structure of coronal mass ejections and the reasons why they happen. STEREO observations are used for space weather forecasting by NOAA.
Living With a Star Program	
Solar Dynamics Observatory (SDO)—2010 (Prime)	Studies the creation of solar activity and how space weather results from that activity by measuring the Sun's interior, magnetic field, the hot plasma of the solar corona, and solar spectral irradiance.
Van Allen Probes (Radiation Belt Storm Probes)—2012 (Prime) in partnership with Czech Republic	Use two identical spacecraft in elliptical orbits to provide an understanding, ideally to the point of predictability, of how populations of relativistic electrons and penetrating ions in space form or change in response to variable inputs of energy from the Sun. It is anticipated that Van Allen Probes observations will be used for space weather "nowcasting" by NOAA.
Heliophysics Explorer Program	
Advanced Composition Explorer (ACE)—1997 (Extended)	Observes particles of solar, interplanetary, interstellar and galactic origins. Solar wind observations are used on an operational basis for space weather forecasting by both NOAA and USAF.

Reuven Ramaty High Energy Solar Spectroscope Imager (RHESSI)—2002 (Extended)	Advances our understanding of the fundamental high-energy processes at the core of the solar flare problem by imaging flares in x and gamma rays and obtaining a detailed energy spectrum at each point of the image.
Two Wide-Angle Imaging Neutral-Atom Spectrometers (TWINS)—2006 and 2008 (Extended) in partnership with National Reconnaissance Office (NRO), Germany	Enables the 3-D visualization and the resolution of large scale structures and dynamics within the magnetosphere by imaging the charge exchange of neutral atoms over a broad energy range, using two identical instruments on two widely spaced high-altitude, high-inclination spacecraft
Time History of Events and Macroscale Interactions during Substorms (THEMIS)—2007 (Extended) in partnership with Germany, France, and Austria	Originally used five identically instrumented spacecraft to answer questions concerning the nature of the sub-storm instabilities that abruptly and explosively release solar wind energy stored within the Earth's magnetotail. Two of the five spacecraft have been re-purposed as the ARTEMIS mission to study the space weather environment around the Moon.
Aeronomy of Ice in the Mesosphere (AIM)—2007 (Extended)	Explores Polar Mesospheric Clouds, which form an icy membrane at the edge of Earth's atmosphere, to find out why they form and why they are changing

Table 4.1 (Continued) Current Heliophysics Missions

Mission—Launch Year (Extended or Prime), Partners	Objective
Heliophysics Explorer Program (Continued)	
Aeronomy of Ice in the Mesosphere (AIM)—2007 (Extended)	Explores Polar Mesospheric Clouds, which form an icy membrane at the edge of Earth's atmosphere, to find out why they form and why they are changing
Coupled Ion-Neutral Dynamics Investigation (CINDI)—2008 (Extended) in partnership with USAF	Uncovers the role of ion-neutral interactions in the generation of small and large-scale electric fields in the Earth's upper atmosphere.
Interstellar Boundary Explorer (IBEX)—2008 (Extended) in partnership with Switzerland	Measures energetic neutral atoms created at the boundary that separates our heliosphere from the local interstellar medium, giving us the first evolving images of the heliosphere's outer edge and surroundings.
Interface Region Imaging Spectrograph (IRIS)— 2013 (Prime) in partnership with Norway	Increases our understanding of energy transport into the corona and solar wind and provides an archetype for all stellar atmospheres by tracing the flow of energy and plasma through the chromosphere and transition region into the corona using spectrometry and imaging.
Heliophysics Research Program*	
Voyager—1977 (Extended)	The Voyager Interstellar Mission explores the outer heliosphere, heliosheath and now the interstellar medium with plasma, energetic particle, magnetic field and plasma wave instrumentation. Among them, the two Voyagers hold the records of the longest- operating and the most distant spacecraft.

Geotail—1992 (Extended) in partnership with Japan	Studies the dynamics of the Earth's magnetotail over a wide range of distances and measures global energy flow and transformation in the magnetotail.
Wind—1994 (Extended) in partnership with France	Measures solar radio bursts, solar wind and energetic particle properties, and complements ACE near the Lagrange 1 (L1) point. It also supports investigations of Gamma ray bursts in tandem with the Astrophysics SWIFT Gamma-ray Explorer mission.
Solar and Heliospheric Observatory (SOHO)—1995 (Extended) in partnership with ESA	Studies the internal structure of the Sun, its extensive outer atmosphere and the origin of the solar wind and solar energetic particles. SOHO observations are used for space weather forecasting by NOAA.
Cluster-II—2000 (Extended) in partnership with ESA	The four identical Cluster II satellites study the impact of the Sun's activity on the Earth's space environment by flying in formation around Earth. For the first time in space history, this mission is able to collect three-dimensional information on how the solar wind interacts with the magnetosphere and affects near-Earth space and its atmosphere, including aurorae.

Missions listed either existed before or were part of an international partnership outside the current Heliophysics Division's implementation structure.
TOP: Voyager 1's plasma wave instrument detected vibrations of dense in terstellar plasma, or ionized gas, from October to November 2012 and April to May 2013. The graphic shows the frequency of the waves, which indicates the density of the plasma. Image Credit: NASA/JPL-Caltech/University of Iowa
BOTTOM: This artist's concept depicts NASA's Voyager 1 spacecraft entering interstellar space, or the space between stars. Image Credit: NASA/JPL-Caltech
TOP: NASA's Interstellar Boundary Explorer (IBEX) recently mapped the boundaries of the solar system's tail (the heliotail). This data from IBEX shows what it observed looking down the heliotail. The yellow and red colors represent areas of slow-moving particles, and the blue represents the fast-moving particles. Image Credit: NASA/IBEX
BOTTOM: A new radiation belt has been discovered above Earth; it is shown here using actual data as the middle arc of

orange and red of the three arcs seen on each side of the Earth. The new belt was observed for the first time by Relativistic Electron Proton Telescopes (REPT) flying on NASA's twin Van Allen Probes. Image Credit: NASA

Table 4.2 Heliophysics Missions in Formulation or Development

Mission—Launch Year (Extended or Prime), Partners	Objective
Solar-Terrestrial Physics Program	
Magnetospheric Multiscale (MMS)—2015 in partnership with Austria, France, Japan and Sweden	Consists of four identically instrumented spacecraft that will use Earth's magnetosphere as a laboratory to study the microphysics of three fundamental plasma processes: magnetic reconnection, energetic particle acceleration, and turbulence.
Living With a Star Program	
Space Environment Testbeds (SET-1)—2016 in partnership with United Kingdom, France, and the U.S. Air Force	Improve the engineering approach to accommodate and / or mitigate the effects of solar variability on spacecraft design and operations, specifically demonstrate improved hardware performance in the space radiation environment.

Solar Orbiter Collaboration (SOC)—NLT 2018* in partnership with ESA	Study the Sun from a distance closer than any spacecraft previously has. This mission will explore the inner solar system from high latitudes to improve the understanding of how the Sun determines the environment of the inner solar system and how fundamental plasma physical processes operate near the Sun. To answer these questions, it is essential to make in-situ measurements of the solar wind plasma, fields, waves, and energetic particles close enough to the Sun that they are still relatively unprocessed, and to connect the in situ measurements with remote sensing of the near-Sun atmosphere.
Solar Probe Plus (SPP)—2018 in partnership with France, Germany, and Belgium	The SPP will fly into the Sun's atmosphere (or corona) and employ a combination of in-situ measurements and imaging to achieve the mission's primary scientific goal: to understand how the Sun's corona is heated and how the solar wind is accelerated. SPP will revolutionize our knowledge of the physics of the origin and evolution of the solar wind.

Reflects the Agency baseline commitment to launch no later than (NLT) the year identified.

Table 4.2 (Continued) Heliophysics Missions in Formulation or Development

Mission—Launch Year (Extended or Prime), Partners	Objective
Heliophysics Explorer Program	

Ionospheric Connection (ICON)—2017 in partnership with Belgium	ICON will explore the boundary between Earth and space to understand the physical connection between our world and our space environment. ICON will employ a revolutionary concept of combining remote optical imaging and in situ measurements of the plasma at points where these are tied together by Earth's magnetic field. With these measurements, ICON will simultaneously retrieve all of the properties of the system that both influence and result from the dynamical and chemical coupling of the atmosphere and ionosphere.
Global-scale Observations of the Limb and Disk (GOLD)—2017	The GOLD mission of opportunity will fly an ultraviolet imaging spectrograph on a geostationary satellite to measure densities and temperatures in Earth's thermosphere and ionosphere. GOLD will perform unprecedented imaging of the weather of the upper atmosphere and examine the response of the upper atmosphere to forcing from the Sun, the magnetosphere and the lower atmosphere.

Artist's impression of SPP, its solar panels folded into the shadows of its protective shield, gathering data on its approach to the Sun. As SPP approaches the Sun, its revolutionary carbon-composite heat shield must withstand temperatures exceeding 2,550 degrees Fahrenheit and blasts of intense radiation. Image Credit: NASA/John Hopkins University/Applied Physics Laboratory

TOP: The four MMS spacecraft are stacked in preparation for vibration test ing. Image Credit: NASA/GSFC

BOTTOM: This artist's concept depicts three of the four identical MMS mission spacecraft. Image Credit: NASA/JPL-Caltech

Table 4.3 Heliophysics Future Missions

Mission—Launch Year (Extended or Prime), Partners	Objective

Solar-Terrestrial Physics Program	
Heliospheric Boundary and Solar Wind Plasma Mission—2022	Advance our understanding of the interstellar boundary and its interaction with the interstellar medium through remote sensing observation and unravel the mechanisms by which particles are energized.
Lower Atmosphere Driving Mission—2025	Understand how lower atmospheric wave energy drives the variability and structure of the near-Earth plasma.
Magnetosphere-Ionosphere-Thermosphere Coupling Mission—2033	Determine how the magnetosphere-ionosphere-thermosphere system is coupled and responds to solar and magnetospheric forcing.
Living With a Star Program	
Geospace Dynamics Coupling Mission—2030	To characterize and understand the tightly coupled ionosphere-atmosphere as a regulator of nonlinear dynamics in the geospace system.
Heliophysics Explorer Program	
Explorers and Missions of Opportunity—2020, 2023, 2026, 2029	High priority science investigations, filling focused, but critical gaps in our knowledge

Figure 4.2 Summary of Heliophysics Science Missions

Heliophysics Timeline

STP-5 Prime Mission

SMEX/MO Extended Mission

SPP SOC
ICON
GOLD
SET-1
MMS
IRIS
Van Allen
SDO
IBEX
CINDI
TWINS
AIM
THEMIS/Artemis

STEREO
Hinode
RHESSI
TIMED
Cluster
ACE SOHO
WIND
Geotail
Voyager

TIMELINE 2000 2003 2006 2009 2012

The extended missions depicted in Figure 4.2 are approved for continued operations based on a senior peer review conducted by scientists every two years to determine the scientific value and priority of further mission extensions.

An aurora on March 8, 2012, shimmering over snow-covered mountains in Faskrudsfjordur, Iceland.

Image Credit: Jónína Óskarsdóttir

The term “space weather” refers to variable conditions on the Sun, in the solar wind, and in the near-space environment that can create risks for humans in space and cause disruption to electric power distribution on Earth and satellite operations, communications, and navigation. Modern society depends on a variety of tech-nologies susceptible to the extremes of space weather. Strong electrical currents driven along the Earth’s surface during geomagnetic events disrupt electric power grids and contribute to the corrosion of oil and gas pipelines. Changes in the ionosphere during geomagnetic storms interfere with high-frequency radio communications and GPS navigation. Exposure of spacecraft to energetic so- lar particles can cause temporary operational anomalies, damage critical electronics, degrade solar arrays, and blind systems such as imagers, star trackers, and sci-entific instrumentation. Given the growing importance of space to our nation’s economic well-being and security, it is of increasing importance that NASA and its partner agencies continue to advance our nation’s capability to understand and predict space weather events.

Space weather forecasting in interplanetary space is crucial to NASA’s human and robotic exploration ob- jectives beyond Earth’s orbit. Eventually, astronauts will travel to distant places where natural shielding like Earth’s magnetic field is absent. NASA’s plans to send astronauts to asteroids and Mars safely rely on our ability to successfully understand and predict space weather. Protection of humans in space is an operational activity within NASA’s HEOMD. SMD collaborates with HEOMD’s Space Radiation Analysis Group at NASA’s Johnson Space Center, which is directly responsible for ensuring that the radiation exposure of astronauts remains below established safety limits.

In support of NOAA satellites and to enable NOAA to fulfill its responsibility for delivering operational space weather forecasts and products to the nation, NASA research spacecraft (e.g., ACE, STEREO, SOHO, SDO, and Van Allen Probes missions) supply real-time space weather data. Other partnerships include the CINDI in- strument NASA supplied for an Air Force satellite, and TWINS-A B the Agency provided for two National

Reconnaissance Office satellites. NASA will continue to cooperate with other agencies to enable new knowledge in this area and to measure conditions in space critical to both operational and scientific research.

Interagency coordination of space weather activities has been formalized through the National Space Weather Program Council, which is hosted by the Office of the Federal Coordinator for Meteorology. This multiagency organization comprised of representatives from ten federal agencies functions as a steering group responsible for tracking the progress of the National Space Weather Program. External constituencies requesting and making use of new knowledge and data from NASA's efforts in heliophysics include NOAA, the Department of Defense, and the Federal Aviation Administration.

Space weather is of international importance and NASA is the U.S. representative at the United Nations (UN) Committee on the Peaceful Uses of Outer Space (UNCOPUOS) for space weather matters. This responsibility includes leadership of the International Space Weather Initiative (ISWI), a UN initiative to advance space weather science by establishing a global space weather data and modeling network. NASA also serves on the Steering Committee of the International Living with a Star (ILWS), which includes 31 space agencies worldwide. ILWS provides world leadership for the coordination of solar and space physics missions, observations, and understanding.

Earth Science

Image Credit: NASA

Earth Systematic Missions Program
Earth System Science Pathfinder Program

Figure 4.3 NASA Earth Science Missions
CYGNSS
ICESat-2
TEMPO
GRACE-FO (2)
SWOT
PACE
NI-SAR
Formulation Implementation Primary Ops Extended Ops
SAGE III (on ISS)
SMAP
SORCE
OCO-2
TRMM
QuikSCAT
Aquarius Suomi NPP
Terra
ACRIMSAT
Landsat-7
(USGS)
EO-1
(NOAA)
Landsat-8
(USGS)
GPM
Aqua
CloudSat
CALIPSO
Aura
GRACE (2)
OSTM/Jason 2
(NOAA)

Earth Science Research Program

Know as Operation IceBridge, NASA's annual airborne missions to the Arctic and Antarctica bridge the data gap between the Ice, Cloud, and land Elevation Satellite (ICESat—which ceased operating in 2009) and ICESat-2. Seen from the NASA P-3B on the Apr. 5, 2013 IceBridge survey flight, Helheim Glacier, one of the largest glaciers in Greenland, drains into the ocean through this fjord.

Image Credit: NASA

Applied Sciences Program

SERVIR-Africa installed wireless sensor networks in Kenya to support the automated frost mapping system they designed and implemented. The near real-time frost mapping system identifies and displays frost-impacted areas by analyzing night time land surface temperature data from NASA's Moder ate Resolution Imaging Spectrometers aboard the Terra and Aqua spacecraft, identifying areas with high potential for frost to the Kenya Meteorological Ser vice and agriculture insurance companies.

Image Credit: NASA/SERVIR-Africa

Earth Science Technology Program

Table 4.4 Current Earth Science Missions

Mission—Launch Year (Extended or Prime), Partners	Objective
Earth Systematic Missions (ESM) Program	
Tropical Rainfall Measuring Mission (TRMM)—1997 (Extended) in partnership with Japan	First-time use of both active and passive microwave instruments has made TRMM the world's foremost satellite for the study of precipitation and associated storms and climate processes in the tropics.
Landsat-7—1999 (Extended) in partnership with USGS	Spanning 40 years of multispectral imaging of the Earth's surface, Landsat 7 is part of the long history of land remote sensing spacecraft.
Quick Scatterometer (QuikSCAT)—1999 (Extended)	QuikSCAT's SeaWinds instrument is a specialized microwave radar that measures near- surface wind speed and direction under all weather and cloud conditions over Earth's oceans. Having exceeded its design life by 8 years, QuikSCAT now serves as a transfer standard to calibrate other satellites.

Terra—1999 (Extended) in partnership with Japan and Canada	Studies clouds, water vapor, aerosol particles, trace gases, terrestrial and oceanic surface properties, biological productivity of the land and oceans, Earth’s radiant energy balance, the interaction among them, and their effects on climate.
Earth Observing-1 (EO-1)—2000 (Extended)	Advanced land-imaging mission that demonstrates new instruments and spacecraft systems. The hyperspectral instrument (Hyperion) is the first of its kind to provide images of land-surface in more than 220 spectral colors.
Aqua—2002 (Extended) in partnership with Japan and Brazil	Observes the Earth’s oceans, atmosphere, land, ice and snow covers, and vegetation, providing high measurement accuracy, spatial detail, and temporal frequency.
Solar Radiation and Climate Experiment (SORCE)—2003 (Extended)	Provides state-of-the-art measurements of incoming X-ray, ultraviolet, visible, near- infrared, and total solar radiation. The measurements specifically address long-term climate change, natural variability and enhanced climate prediction, and atmospheric ozone and UV-B radiation.
Aura—2004 (Extended) in partnership with The Netherlands and the United Kingdom	Studies the chemistry and dynamics of the atmosphere with emphasis on the upper troposphere and lower stratosphere. Provides daily global observations of atmospheric ozone, air quality, and climate parameters.

Ocean Surface Topography Mission/Jason 2 (OSTM/Jason 2)—2008 (Extended) in partnership with EUMETSAT, France, and NOAA	Measures sea surface height by using a radar altimeter mounted on a low-Earth orbiting satellite. Measurements of sea-surface height, or ocean surface topography, reveal the speed and direction of ocean currents and tell scientists how much of the Sun's energy is stored by the ocean.
Suomi National Polar-Orbiting Partnership (NPP)—2011 (Prime) in partnership with NOAA	Serves as the bridge between the EOS satellites and the forthcoming series of Joint Polar Satellite System (JPSS) satellites. Suomi NPP data are being used for climate research and operational weather prediction.

Table 4.4 (Continued) Current Earth Science Missions

Mission—Launch Year (Extended or Prime), Partners	Objective
Earth Systematic Missions (ESM) Program (Continued)	
Landsat Data Continuity Mission (LDCM)/ Landsat 8—2013 (Prime) in partnership with USGS	Provides moderate-resolution measurements of the Earth's terrestrial and polar regions. Provides continuity with the Landsat land imaging data set. Provides data for land use planning and monitoring on regional to local scales, and supports disaster response and evaluations, and water use monitoring.
Global Precipitation Measurement (GPM)—2014 (Prime) in partnership with Japan	Next-generation observations of precipitation (rain and snow) worldwide every three hours, to advance understanding of the water and energy cycles and extend the use of precipitation data to directly benefit society.

Earth System Science Pathfinder (ESSP) Program	
Gravity Recovery and Climate Experiment (GRACE)—2002 (Extended) in partnership with Germany	Accurately maps variations in the Earth's gravity field. GRACE data is used to estimate global models for the variable Earth gravity field approximately every 30 days, and reveals changes in levels of large underground aquifers.
Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observations (CALIPSO)—2006 (Extended) in partnership with France	Combines an active lidar with passive infrared and visible imagers to study the role clouds and aerosols (airborne particles) play in weather, climate and air quality.
CloudSat—2006 (Extended) in partnership with Canada	Provides a comprehensive characterization of the structure and composition of clouds and their effects on climate under all weather conditions using an advanced cloud profiling radar.
Earth Venture Sub-orbital-1 (EVS-1):	Five investigations selected through the first Earth Venture Suborbital opportunity are being conducted from 2010 through 2015.
Aquarius—2011 (Prime) in partnership with Argentina	Measures global sea surface salinity with unprecedented precision. Monthly sea surface salinity maps give clues about changes in freshwater input and output to the ocean associ¬ated with precipitation, evaporation, ice melting, and river runoff.

Airborne Microwave Observatory of Subcanopy and Subsurface (AirMOSS)
Airborne Tropical Tropopause Experiment (ATTREX)
Carbon in Arctic Reservoirs Vulnerability Experiment (CARVE)
Deriving Information on Surface Conditions from Column and Vertically Resolved Observations Relevant to Air Quality (DISCOVER-AQ)
Hurricane and Severe Storm Sentinel (HS3)
The Earth Systematic Missions (ESM) Program encompasses the division's strategic and directed missions. Table 4.4 includes missions that were selected prior to the creation of the ESM Program Office, such as missions under the previously existing Earth Observing System (EOS)

Program. The missions within the Earth System Science Pathfinder (ESSP) Program are competitively selected under the program itself or as Earth Venture missions.

The midnight sun casts a golden glow on an iceberg and its reflection in Dis ko Bay, Greenland. Much of Greenland's annual ice mass loss occurs through calving of such icebergs. Image Credit: University of Washington/Ian Joughin

The ravages of deforestation, wildfires, windstorms and insects on global forests during this century are revealed in unprecedented detail in a new study based on data from Landsat-7. The maps from the study are the first to document forest loss and gain using a consistent method around the globe, at high resolution. The forest cover maps also capture natural disturbances such as this 2011 tornado path in Alabama. Image Credit: NASA/GSFC

Table 4.5 Earth Science Strategic Research Missions in Formulation and Development

Mission—Expected Launch Year, Partners	Objective
Earth Systematic Missions (ESM) Program	
Soil Moisture Active/Passive (SMAP)—NLT 2015*	Soil moisture and freeze-thaw for weather and hydrological cycle processes.
Stratospheric Aerosol and Gas Experiment III (SAGE III-ISS)—NLT 2016*	Global stratospheric aerosols measurements, and measurements of ozone, water vapor and nitrogen dioxide, to understand their significant roles in atmospheric radiative and chemical processes and monitor climate change. SAGE III is scheduled to fly to ISS aboard one of NASA's commercial Space X flights.
Ice Cloud and land Elevation Satellite-2 (ICESat-2)—LRD under review	Ice sheet height changes for climate change diagnosis and assessment of land carbon standing stock.
Gravity Recovery and Climate Experiment Follow-on (GRACE FO)—NLT 2018* in partnership with Germany	Continue high-resolution gravity field measurements; determine time variable gravity and mass re-distribution involved in Earth system component interactions.

Surface Water and Ocean Topography (SWOT)—2020 in partnership with France and Canada	Oceanography and hydrology through broad swath altimetry. First global determination of the ocean circulation at high resolution and first global inventory of fresh water storage and its change.
Earth System Science Pathfinder (ESSP) Program	
Orbiting Carbon Observatory-2 (OCO-2)—NLT 2015*	Global atmospheric column CO_2 measurement from space to help quantify CO_2 fluxes.
Cyclone Global Navigation Satellite System (CYGNSS) Earth Venture Mission-1 (EVM-1)—NLT 2017*	Frequent and accurate measurements of ocean surface winds throughout the life cycle of tropical storms and hurricanes to enable improvement in hurricane forecasting.
Tropospheric Emissions: Monitoring of Pollution (TEMPO) Earth Venture Instrument-1 (EVI-1)—available in 2018 for flight as a hosted payload	TEMPO's measurements from geostationary orbit (GEO) of tropospheric ozone, ozone precursors, aerosols, and clouds will create a revolutionary dataset (hourly and at high spatial resolution) that provides understanding and improves prediction of air quality and climate forcing.

Reflects the Agency baseline commitment to launch NLT the year identified.

TOP LEFT:

This artist's concept depicts NASA's OCO-2 spacecraft.
Image Credit: NASA/JPL

BOTTOM LEFT

: NASA's OCO-2 spacecraft is moved into a thermal vacuum chamber at Orbital Sciences Corporation's Satellite Manufacturing Facility in Gilbert, Ariz., for a series of environmental tests. The tests confirmed the integrity of the observatory's electrical connections and subjected the OCO-2 instrument and spacecraft to the extreme hot, cold and airless environment they will encounter once in orbit.
Image Credit: NASA/JPL

TOP RIGHT:

The SMAP spacecraft and instrument, having just been put together into what is called the “Observatory” in January 2014. The spinning portion of SMAP’s instrument system is seen mounted on top of the rectangular, box-like structure of the spacecraft. Prominently featured in the upper portion of the instrument and on its right-hand side are the deployable reflector antenna, which looks like a bundle of black-colored tubular elements, and the deployable boom above (also black in color), which will eventually support the antenna while spinning in space.
Image Credit: NASA/JPL

SMAP: Understanding the Earth System through Interdisciplinary Synergies

NASA’s SMAP mission will provide global measurements of soil moisture and the soil freeze/thaw state. The NRC Earth science decadal survey explains how SMAP will enable interdisciplinary studies of the Earth system:

Soil moisture serves as the memory at the land surface in the same way as sea-surface temperature does at the ocean surface. The use of sea-surface temperature observations to initialize and constrain coupled ocean-atmosphere models has led to important advances in long-range weather and seasonal prediction. In the same way, high-resolution soil-moisture mapping will have transformative effects on Earth system science and applications (Entekhabi et al., 1999; Leese et al., 2001). As the ocean and atmosphere community synergies have led to substantial advances in Earth system understanding and improved prediction services, the availability of high-resolution mapping of surface soil moisture will be the link between the hydrology and atmospheric communities that share interest in the land interface. The availability of

Artist’s concept of SMAP.
Image Credit NASA/JPL

such observations will enable the emergence of a new generation of hydrologic models for applications in Earth system understanding and operational severe-weather and flood forecasting.

Table 4.6 Future Earth Science Strategic Research Missions

Mission—Expected Launch Year, Partners	Objective
Earth Systematic Missions (ESM) Program	

Sustained Solar irradiance measurements—Instrument of opportunity —No earlier than (NET) 2020	Responsibility transferred from NOAA to NASA in the FY2014 President's budget request to provide sustained solar irradiance measurements beginning in the 2020 timeframe. Will continue the 34 year measurement record that includes SORCE and the Total solar irradiance Calibration Transfer Experiment (TCTE).
Pre-Aerosol, Cloud, ocean Ecosystem (PACE)—NET 2020	Provide aerosol, cloud, and ocean color measurements until availability of decadal survey Tier 2 Aerosol-Clouds-Ecosystems mission.
NASA-India Space Research Organization Synthetic Aperture Radar (NI-SAR)—NET 2021 in partnership with India	NI-SAR (a.k.a. DESDynI Radar) mission to study solid Earth deformation (earthquakes, volcanoes, landslides), changes in ice (glaciers, sea ice) and changes in vegetation.

Table 4.6 (Continued) Future Earth Science Strategic Research Missions

Mission—Expected Launch Year, Partners	Objective
Earth Systematic Missions (ESM) Program (Continued)	

Earth's Radiation Budget—on JPSS-2—NET 2021	Responsibility transferred from NOAA to NASA in the FY2014 President's Budget Request to provide sustained measurements of the Earth's radiation budget that have been made by the Clouds and the Earth's Radiant System (CERES) instruments on TRMM, Terra, Aqua and Suomi NPP and are planned for the JPSS-1 in 2016. The Radiation Budget Instrument (RBI) to be provided by NASA for flight on JPSS-2 in 2021 will be a follow-on to the CERES instruments.
Future Land Imaging—Under study	To extend global Landsat-quality multispectral and thermal infrared measurements beyond the expected operation of Landsat-8, NASA initiated, in FY 2014, the Sustainable Land Imaging Architecture Study, with support from USGS. The study will define the scope, measurement approaches, cost, and risk of a viable long-term land imaging system that will achieve national objectives. Evaluations and design activities will include consideration of a range of solutions including large and small dedicated spacecraft, formation flying, hosted instruments, integration of other compatible land imaging data sets, and international and private sector collaborations.

Climate Absolute Radiance and Refractivity Observatory (CLARREO)—NET 2023	CLARREO will make highly accurate spectrally resolved measurements of reflected solar and thermally emitted radiation that are directly traceable to International System of Units (SI) standards to achieve the required levels of accuracy for quantification and characterization of the Earth's energy balance as an indicator of climate change on decadal scales.
Tier 2 and 3 Missions—TBD	
Earth System Science Pathfinder (ESSP) Program	
Future Earth Venture Solicitations	

- Active Sensing of CO2 Emissions Over Nights, Days, and Seasons (ASCENDS)
- Geostationary Coastal and Air Pollution Events (GEO-CAPE)
- Hyperspectral Infrared Imager (HyspIRI)
- Aerosol-Clouds-Ecosystems
- Precipitation and All-weather Temperature and Humidity (PATH)
- Snow and Cold Land Processes (SCLP)
- Global Atmospheric Composition Mission (GACM)
- Three-Dimensional Tropospheric Winds (3D-Winds) (demo)
- Lidar Surface Topography (LIST)
- Gravity Recovery and Climate Experiment-II (GRACE-II)

- Earth Venture Suborbital (EVS)—2 in 2013 and at 4-year intervals
- Earth Venture Instrument (EVI)—2 in 2013 and at 18-month intervals
- Earth Venture Full Orbital Missions(EVM)—2 in 2015 and at 4-year intervals

Figure 4.4 Summary of Earth Science Missions
Earth Science Timeline
TIMELINE
Prime Mission Extended Mission
2000 2003 2006 2009 2012 2015 2018 2021 2024
The extended missions depicted in Figure 4.4 are approved for continued operations based on a senior peer review conducted by scientists every two years to determine the scientific value and priority of further mission extensions.
Funded by the Earth Science and Technology Office and Goddard Internal Research and Development Program, the

airborne Lidar Surface Topography (LIST) Simulator is proving the technology needed to measure the height of Earth's surface to within 10 centimeters and at 5 meter resolution.
Image Credit: NASA/GSFC
Artist's rendering of ISS-RapidScat instrument (inset), which will measure ocean surface wind speed and direction and help improve weather forecasts, including hurricane monitoring. RapidScat will be installed on the end of the station's Columbus laboratory.
Image Credit: NASA/JPL

SMD works in close partnership with the ISS Program to enable science observations from the ISS. The ISS provides the access to space and most on-orbit resources (power, data and communications, instrument operations, and post-flight disposal). In some cases, ISS provides some or all of the initial hardware, while for others, SMD develops and delivers the hardware. In all cases SMD defines the science observations and funds the processing of the data into scientific observations and research results.

For Earth observations, the ISS provides a specific and unique perspective. Its mid-inclination orbit at +/- 51 degrees enables visibility of most of the population centers on the Earth, of all the tropical regions, and of many critical dynamic phenomena. The low altitude enables high-resolution observations, while the precessing orbit allows the ISS-mounted instruments to cross orbits with the extensive fleet of polar and geosynchronous Earth observing satellites, allowing ISS instruments to be cross checked and cross calibrated with those other observations. This capability is particularly important to develop and improve long-term data records that require consistency across generations of observing instruments in highly varying orbits.

The ISS is useful for astrophysics research because it offers a large, stable platform that can support experiments with large mass, large power requirements, high data rates, and modest pointing requirements, which would be difficult or impossible to support on a satellite bus. The ISS platform is most useful for particle astrophysics and high energy astrophysics.

NASA will be making use of these capabilities for a number of Earth and space observations. The Hyperspectral Imager for the Coastal Ocean (HICO) is operating now on ISS, making measurements of coastal and ocean color. The ISS SERVIR Environmental Research and
Visualization System (ISERV) is providing useful images for use in disaster monitoring and assessment and environmental decision making. Future instruments on ISS include the Rapid Scatterometer (RapidScat) instrument to continue ocean winds measurements, the Cloud- Aerosol Transport System (CATS) to make lidar aerosol measurements, the Lightning Imaging Sensor (LIS) that will measure global lightning (amount, rate, radiant energy) during both day and night, and the Stratospheric Aerosol and Gas Experiment III (SAGE III) instrument to measure atmospheric ozone profiles, extending a 20+ year data record for NASA. In particular, the inclined orbit of ISS is well suited for obtaining latitudinal distributions of ozone-destroying gases using SAGE III's primary solar occultation viewing mode.

For astrophysicists, the Cosmic Ray Energetics and Mass (CREAM) experiment will extend direct measurements of cosmic rays to energies capable of generating gigantic air showers, which have mainly been observed with ground-based experiments with no elemental identification. The Neutron star Interior Composition ExploreR (NICER) mission will explore the exotic states of matter inside neutron stars, where density and pressure are higher than in atomic nuclei, confronting theory with unique observational constraints.

Looking to the future, NASA plans welcome proposals for instruments or even small missions that are best adapted to the ISS. The Earth Venture Mission (EVM) and Earth Venture Instrument (EVI) solicitations are released regularly and are open to all platforms, including the ISS. Similarly, the Astrophysics and Heliophysics Explorer AOs allow for ISS-based Mission of Opportunity proposals. The ISS Program has been working with the SMD to improve the utility and usability of the ISS as a science observation platform, which should support more substantial Earth and space observations from the ISS.

Planetary Science

Image Credit: NASA/JPL

Discovery Program
New Frontiers Program
Mars Exploration Program

Figure 4.5 NASA Planetary Science Missions

Juno
Lunar Reconnaissance Orbiter
MESSENGER
Formulation Implementation Primary Ops Extended Ops

BepiColumbo (ESA)
Ro (E
Cassini (NASA/ESA)
Mars Odyssey
MF Ma Ex (E
JUICE (ESA)
OSIRIS-REx
Opportunity Rover
Cu Ro

2020
NEO-WISE
LADEE

Planetary Science Research and Analysis Program

Near-Earth Objects Program

MARS EARTH

This set of images compares the Link

outcrop of rocks on Mars with similar rocks seen on Earth. The image of Link, obtained by NASA's Curiosity rover, shows rounded gravel fragments, or clasts, up to a couple inches (few centimeters) in size, within the rock outcrop. Erosion of the outcrop results in gravel clasts that fall onto the ground, creating the gravel pile at left. The Link outcrop's characteristics are consistent with a sedimentary conglomerate, or a rock that was formed by the deposition of water and is composed of many smaller rounded rocks cemented together. A typical Earth example of sedimentary conglomerate formed of gravel fragments in a stream is shown on the right.
Image Credit: NASA/JPL

Table 4.7 Current Planetary Science Missions

Mission—Expected Launch Year, Partners	Objective
Discovery Program	
Mercury Surface, Space Environment, Geochemistry and Ranging (MESSENGER)—2004 (Extended)	Image all of Mercury for the first time, as well as gather data on the composition and structure of Mercury's crust, its geologic history, the nature of its active magnetosphere and thin atmosphere, and the makeup of its core and the materials near its poles.
Venus Express—2005 (Extended) ESA mission with U.S. participation	Investigating the noxious atmosphere and clouds in detail and making global maps of the planet's surface temperatures..
Dawn—2007 (Prime)	Characterizing the conditions and processes of the solar system's earliest epoch by investigating in detail the dwarf-planets (Ceres and Vesta), which have remained intact since their formation.

Lunar Reconnaissance Orbiter (LRO)—2009 (Extended) in partnership with HEOMD	Identify lunar sites that are close to potential resources and have high scientific value, favorable terrain, and the environment necessary for safe future robotic and human lunar missions.
Venus Climate Orbiter—2010 (Prime) JAXA mission with U.S. participation	Study the dynamics of the atmosphere of Venus from orbit, particularly the upper atmosphere super-rotation and the three-dimensional motion in the lower part of the atmosphere, using multi-wavelength imaging. Measure atmospheric temperatures and look for evidence of volcanic activity and lightning.

Table 4.7 (Continued) Current Planetary Science Missions

Mission—Expected Launch Year, Partners	Objective
New Frontiers Program	
New Horizons—2006 (Prime)	Make the first reconnaissance of Pluto, Charon, and one or more Kuiper Belt objectives to reveal the origin and evolution of our planetary neighbors.
Juno—2011 (Prime)	Improve our understanding of our solar system's beginnings by revealing the origin and evolution of Jupiter. Will also look deep into Jupiter's atmosphere to measure composition, temperature, cloud motions and other properties.
Mars Exploration Program	

Mars Odyssey—2001 (Extended)	Globally map the amount and distribution of many chemical elements and minerals that make up the Martian surface. Maps of hydrogen distribution led scientists to discover vast amounts of water ice in the polar regions buried just beneath the surface.
Mars Express—2003 (Extended) ESA mission with U.S. participation	Answer fundamental questions about the geology, atmosphere, surface environment, history of water and potential for life on Mars.
Opportunity (Mars Exploration Rover)—2003 (Extended) in partnership with Germany	Perform on-site geological investigations on Mars to search for and characterize a wide range of rocks and soils that hold clues to past water activity on Mars. Now in the seventh year of a 90-day mission, Opportunity is poised to explore the giant crater Endeavor.
Mars Reconnaissance Orbiter (MRO)—2005 (Extended) in partnership with Italy	Provide information about the surface, subsurface, and atmosphere of Mars. Characterizes potential landing sites for other missions including MSL. Detected evidence that water persisted on the surface of Mars for a long period of time, and is examining underground Martian ice.
Mars Science Laboratory (MSL)/Curiosity rover—2011 (Prime) in partnership with Canada, France, Germany, Spain and Russia	Assess whether Mars ever was, or is still today, an environment able to support microbial life. MSL's mission is to determine the planet's "habitability."

Mars Atmosphere and Volatile Evolution (MAVEN) —2013 (Prime) in partnership with France	Explore Mars's upper atmosphere, ionosphere and interactions with the Sun and solar wind.
Strategic and Other Missions	
Cassini—1997 (Extended) in partnership with ESA and Italy	Completed its first extended mission at Saturn in 2010; its second mission extension will allow for the first study of a complete seasonal period. (A Saturn year is 30 Earth years).
Rosetta—2004 (Prime) ESA mission with U.S. participation	An orbiter and lander that will investigate the origin of comets. Will rendezvous with Comet 67P/Churyumov-Gerasimenko and remain in close proximity to the icy nucleus as it plunges toward the Sun. A small lander will be released onto the surface of the comet for in situ investigations of the chemistry and formation of volatiles.
Near Earth Object Wide-field Infrared Survey Explorer (NEOWISE)—2009 (Extended)	Search for potentially hazardous NEOs. Although the solid hydrogen is gone, NEOWISE can still operate at its two shortest infrared wavelengths, returning valuable data on the numbers, orbits, sizes, and compositions of asteroids and comets.
Lunar Atmosphere and Dust Environment Explorer (LADEE)—2013 (Prime)	Orbit the Moon to characterize the atmosphere and lunar dust environment. LADEE aims to determine the global density, composition, and time variability of the fragile lunar atmosphere before it is perturbed by further surface exploration activity.

TOP LEFT:

The underlaying pixels in this image indicate plumes of water vapor detected over Europa’s south pole in observations taken by the Hubble Space Telescope in December 2012. The superimposed image of Europa was take by the Galileo spacecraft.
Image Credit: NASA/ESA/JPL/STScI

BOTTOM LEFT:

Comet ISON, named after the International Scientific Optical Network (the Russian instrument array that first observed the comet) comes in from the bottom right and moves out toward the upper right, getting fainter and fainter, in this time-lapse image from the ESA/NASA Solar and Heliospheric Observatory. The image of the Sun at the center is from NASA’s SDO satellite.
Image Credit: ESA/NASA/SOHO/SDO/GSFC

TOP RIGHT:

Using a precision formation-flying technique, the twin GRAIL spacecraft mapped the moon’s gravity field, as depicted in this artist’s rendering.
Image Credit: NASA/JPL

Table 4.8 Planetary Science Missions in Formulation and Development

Mission—Expected Launch Year, Partners	Objective
Discovery Program	
Hayabusa 2—2014 JAXA mission with U.S. participation	Hayabusa 2 will collect surface and possible subsurface materials from asteroid 1999 JU3 and return the samples to Earth in a capsule for analysis in 2020.
BepiColumbo—2015 ESA mission with U.S. participation	Study and understand the composition, geophysics, atmosphere, magnetosphere and history of Mercury
Interior Exploration using Seismic Investigations, Geodesy and Heat Transport (InSight)—NLT 2016*, in partnership with France and Germany	Study the deep interior of Mars to address fundamental issues of planet formation and evolution. Investigate the dynamics of Martian tectonic activity and meteorite impacts and compare to like phenomena on Earth.
New Frontiers Program	

Origins Spectral Interpretation, Resource Identification and Security Regolith Explorer (OSIRIS-REx)—NLT 2016*, in partnership with Canada	Study near-Earth asteroid Bennu (101955), in detail, and bring back a sample to Earth in 2023. This sample will help with investigating planet formation and the origin of life, and aid in understanding asteroids that can impact Earth.
Jupiter Icy Moons Explorer (JUICE)—2022 ESA mission with U.S. participation	ESA-led joint mission with NASA to Ganymede and Jupiter system. NASA will supply one U.S.-led science instrument and hardware for two European instruments.
Mars Exploration Program	
ExoMars Trace Gas Orbiter—2016 ESA mission with U.S. participation	ESA-led joint mission with Russia; Mars orbiter with entry, descent, landing system (EDLS) tech demo; and telecom package. NASA providing Electra telecom package.
ExoMars Rover—2018 ESA mission with U.S. participation	ESA-led joint mission with Russia. NASA to provide a critical science instrument, the Mars Organic Molecule Analyzer (MOMA) mass spectrometer to the rover payload.
Mars Rover—2020 NASA mission with possible international contribution	Re-fly MSL rover and sky-crane EDLS. Rover will have different instrument suite including a caching system for future potential sample return.

Reflects the Agency baseline commitment to launch NLT the year identified.

With the Mars Curiosity rover, NASA demonstrated a specialized landing system that delivered a ready-to-operate rover. NASA's new Mars rover, scheduled for 2020, will be much more capable than Curiosity, and will in clude a caching system for future potential sample return. Image Credit: NASA

Table 4.9 Future Planetary Science Missions

Mission—Expected Launch Year, Partners	Objective

Discovery Program	
Discovery—2020	Small to medium sized competed mission open to all relevant mission concepts. AO planned for FY14.
Discovery—2022	Small to medium sized competed mission open to all relevant mission concepts. AO planned for FY17.
New Frontiers Program	
New Frontiers 4—TBD	Medium sized competed missions. Candidates for concept studies will be selected from recommendations in the NRC decadal survey; Comet Surface Sample Return, Lunar South Pole-Aitken Basin Sample Return, Saturn Probe, Trojan Tour and Rendezvous, and Venus In Situ Explorer. AO not currently planned.

Figure 4.6 Summary of Planetary Science Missions

Planetary Science Timeline
TIMELINE
Prime Mission Extended Mission Arrival at Target
2000 2003 2006 2009 2012 2015 2018 2021 2024

Excluding MRO, MER/Opportunity, and Mars Odyssey, which are critical to current and future Mars exploration activities, the extended missions depicted in Figure 4.6 are approved for continued operations based on a senior peer review conducted by scientists every two years to determine the scientific value and priority of further mission extensions.

Artist's concept of a Mars sample return mission. Image Credit: Wickman Spacecraft & Propulsion.

On June 10, 2011, NASA's LRO spacecraft pointed its Narrow Angle Cameras to capture a dramatic sunrise view of Tycho crater on the Moon. Image Credit: NASA/GSFC

These superimposed photos of the Moon and a near-Earth asteroid depict the concept behind NASA's Asteroid Redirect Mission. Image Credit: guardianlv.com

In addition to advancing NASA's scientific goals, SMD missions and research also generate data and knowl⊠ edge important to advance NASA's human exploration goals. Since Explorer I discovered the Van Allen radia⊠ tion belts while orbiting the Earth, robotic missions have tested the waters for human exploration, providing useful data as either the product or byproduct of their scien⊠ tific investigations. SMD partnered with the HEOMD to map the Moon's surface in unprecedented detail with LRO, and to measure the radiation environment during the cruise trip to Mars from inside the MSL spacecraft. More recently, SMD and HEOMD established SSERVI to conduct basic and applied research fundamental to un derstanding the Moon, Mars and its moons, near-Earth asteroids, and the near-space environments of these target bodies, while advancing human exploration of the solar system. The ISS best embodies the knowledge

NASA is currently developing the first-ever mission to redirect a near-Earth asteroid safely into the Earth-Moon system, and send astronauts to explore it. This mission will bring together the best of NASA's science, technology, and human exploration efforts to achieve the President's goal of sending humans to an asteroid by 2025. SMD's Planetary Science Research and Analysis Program will contribute to this effort by helping to identify a potential asteroid target, using ground- and space-based assets to characterize and select a candidate asteroid. NASA's existing NEO Program is exploring ways to improve de tection and characterization techniques.

Furthermore, SMD's Heliophysics Division elements provide predictive capabilities essential to the protec tion of human and robotic explorers. The LWS and STP Programs explore the interactions between solar phenomena and planetary environments, which pro duce what is known as space weather. Space weather forecasting in interplanetary space is crucial to NASA's human and robotic exploration objectives beyond LEO.

Astrophysics

Image Credit: NASA, ESA, and E. Sabbi/STScI

Physics of the Cosmos Program

Cosmic Origins Program

Figure 4.7 NASA Astrophysics Missions

Swift Suzaku (JAXA) F ermi

Formulation Implementation Primary Ops Extended Ops

XMM-Newton (ESA)

Euclid (ESA)

Spitzer Hubble Kepler

JWST

Astro-H (JAXA)

NICER (on ISS)

Chandra

NuSTAR TESS

LISA Pathfinder (ESA)

SOFIA

Exoplanet Exploration Program

Astrophysics Explorer Program

Astrophysics Research Program

On April 27, 2013, NASA satellites, working in concert with ground-based telescopes, captured never-before-seen details of gamma-ray bursts (GRB) that challenge current theories of how gamma-ray bursts work. These maps show the sky at energies above 100 MeV as seen by NASA Fermi's Large Area Telescope. Left: The sky during a 3-hour interval before GRB 130427A. Right: A 3-hour map ending 30 minutes after the burst. Image Credit: NASA

Table 4.10 Current Astrophysics Missions

Mission—Expected Launch Year, Partners	Objective
Physics of the Cosmos Program	
Chandra X-ray Observatory—1999 (Extended) in partnership with the Netherlands	X-ray observatory that detects X-ray emission from very hot regions of the Universe such as exploded stars, clusters of galaxies, and matter around black holes.
X-ray Multi-Mirror Mission (XMM-Newton)—1999 (Extended), ESA mission with U.S. participation	X-ray observatory that detects and studies celestial X-ray sources. NASA provided elements of XMM-Newton's instrument package.
Fermi Gamma-ray Space Telescope (Fermi)—2008 (Extended) in partnership with DOE, France, Germany, Italy, Japan, and Sweden	Gamma-ray observatory that detects gamma-rays from the most energetic regions of the universe including particle jets accelerated from black holes, powerful magnetic fields of neutron stars, and antimatter bubbles at the center of the Milky Way galaxy.
Cosmic Origins Program	
Hubble Space Telescope (HST)—1990 (Prime) in partnership with ESA	Ultraviolet/visible/near-infrared observatory that provides astronomers with the capability of measuring the acceleration of the universe, observing the formation of planetary systems, and detecting the atmospheric signatures of planets orbiting other stars.
Spitzer Space Telescope—2003 (Extended)	Infrared observatory that obtains images and spectra to provide scientists a unique view of the universe and to look into regions of space that are hidden from visible telescopes.
Stratospheric Observatory for Infrared Astronomy (SOFIA)—2010 (Prime) in partnership with Germany	Largest airborne observatory in the world, it makes mid and far infrared observations that are impossible for ground-based telescopes. SOFIA is used to study astronomical phenomena such as star birth and death.
Exoplanet Exploration Program	

Kepler Space Telescope—2009 (TBD)	High precision optical photometer capable of continuously measuring the brightness of 150,000 stars in order to detect the tiny dimming caused when a planet transits in front of its parent star.
Astrophysics Explorer Program	
Swift—2004 (Extended) in partnership with Italy and the United Kingdom	A multi-wavelength observatory dedicated to the study of Gamma-ray burst (GRB) science. Swift's three instruments have worked together to observe GRBs and afterglows in the gamma ray, X-ray, ultraviolet, and optical wavebands.
Suzaku—2005 (Extended) in partnership with Japan	Japanese satellite providing scientists with information to study events in the X-ray energy range. NASA provided one of Suzaku's three instruments.
Nuclear Spectroscopic Telescope Array (NuSTAR)—2012 (Prime) in partnership with Denmark and Italy	High-energy X-ray telescope that is the first focusing high-energy X-ray telescope to orbit Earth and is capable of, among other things, measuring the spin of supermassive black holes and mapping the heavy elements created in a supernova explosion.

TOP LEFT:

In 2013, using the NASA Hubble Space Telescope Wide Field Camera 3, two teams of scientists found faint signatures of water in the atmospheres of five distant planets. This is the first study to conclusively measure and compare the profiles and intensities of these signatures on multiple worlds. To determine what is in the atmosphere of an exoplanet, astronomers watch the planet pass in front of its host star and look at which wavelengths of light are transmitted and which are partially absorbed. This illustration shows a star's light illuminating the atmosphere of a planet. Im⊠ age Credit: NASA/GSFC

TOP RIGHT:

One of the biggest mysteries in astronomy, how stars blow up in supernova explosions, is finally being unraveled with the help of NASA's
NuSTAR spacecraft. The high-energy X-ray observatory has created the first map of radioactive material in a supernova remnant. The results, from a rem⊠ nant named Cassiopeia A, reveal how shock waves likely rip apart massive dying stars. Image Credit: NASA/Caltech

BOTTOM:

Astronomers using the NASA/ESA Hubble Space Telescope have solved the 40-year-

old mystery of the origin of the Magellanic Stream, a long ribbon of gas (the pink stream in this image) stretching nearly halfway around the Milky Way. New Hubble observations reveal that most of this stream was stripped from the Small Magellanic Cloud some two billion years ago, with a smaller portion originating more recently from its larger neighbour.
Image Credit: NASA/StSci

Table 4.11 Astrophysics Missions in Development or Formulation

Mission—Expected Launch Year, Partners	Objective
Cosmic Origins Program	
James Webb Space Telescope (JWST)—NLT 2018* in partnership with ESA and Canada	Infrared successor to Hubble to image first light after the Big Bang and the first galaxies to form in the early universe. Top-ranked space-based "Major Initiative" in the 2001 decadal survey.
Physics of the Cosmos Program	
Laser Interferometer Space Antenna (LISA) Pathfinder—2015 ESA mission with U.S. participation	Flight demonstration of key technologies for future space-based gravitational wave observatories. NASA provides colloidal micronewton thrusters and a drag-free dynamic controller.
Euclid—2020 ESA mission with U.S. participation	Visible/near infrared observatory to study dark energy. NASA provides detector subsystems for the Near Infrared Spectrophotometer instrument.
Astrophysics Explorer Program	
ASTRO-H—NLT 2016* JAXA mission with U.S. participation	X-ray observatory to study material in extreme gravitational fields. NASA provides X-ray optics and a Soft X-ray Spectrometer, the primary instrument for JAXA's ASTRO-H observatory.

Neutron Star Interior Composition Explorer (NICER)—NLT 2017*	High precision array of X-ray photometers mounted on the International Space Station to explore the exotic states of matter within neutron stars and reveal their interior and surface compositions. Data will also be used to demonstrate pulsar navigation techniques for STMD.
Transiting Exoplanet Survey Satellite (TESS)—2018	Array of cameras to discover transiting exoplanets ranging from Earth-sized to gas giants, in orbit around the nearest and brightest stars in the sky. Will find exoplanets as targets for JWST follow-up observations.

Reflects the Agency baseline commitment to launch NLT the year identified.

TOP LEFT:
A full-scale JWST sunshield membrane deployed on the membrane test fixture at ManTech International Corporation's facilities in Huntsville, Alabama, ready for a precise measurement of its three dimensional shape. The JWST sunshield comprises five of these layers, each of which has to be precisely spaced with respect to the next.
Image Credit: Northrop Grumman Aerospace Systems

TOP RIGHT:
TESS is an Explorer-class planet finder. In the first-ever spaceborne all-sky transit survey, TESS will identify planets ranging from Earth-sized to gas giants, orbiting a wide range of stellar types and orbital distances.
Image Credit: NASA/GSFC

BOTTOM LEFT:
The first six flight-ready JWST primary mirror segments are prepped to begin final cryogenic testing at NASA's Marshall Space Flight Center in Huntsville, Alabama.
Image Credit: NASA/Chris Gunn

Table 4.12 Future Astrophysics Missions

Mission—Expected Launch Year, Partners	Objective
Physics of the Cosmos Program	
L2—2028 ESA mission with possible U.S. participation	An ESA advanced X-ray observatory to study the hot and energetic universe. NASA will participate in concept studies with ESA and discuss contributing to the mission.

Exoplanet Exploration Program	
Wide Field Infrared Survey Telescope (WFIRST)/ Astrophysics Focused Telescope Assets (AFTA) — TBD NASA mission with possible international contribution	A widefield visible/near infrared observatory to study dark energy, exoplanets, and galactic structure. Several concepts are being studied, including a 2.4m version using existing telescope assets and an optional coronagraph.
Astrophysics Explorer	
Astrophysics Explorer— ~2020	Small to medium sized competed mission or MoO. AO planned for FY14.
Astrophysics Explorer— early/mid 2020s	Small to medium sized competed mission or MoO. AO ~2016-17.
Astrophysics Explorer— mid 2020s	Small to medium sized competed mission or MoO. AO ~2019-20.

Figure 4.8 Summary of Astrophysics Science Missions
Astrophysics Timeline
TIMELINE
Prime Mission Extended Mission
2000 2003 2006 2009 2012 2015 2018 2021 2024
Excluding the Great Observatories HST and Chandra, the extended missions depicted in Figure 4.8 are approved for continued operations based on a senior peer review conducted by scientists every two years to determine the scientific value and priority of further mission extensions.
Image of the newly discovered planet, HD 95086 b. The star, which the planet orbits, has been blocked out by a coronagraph and the diffraction patterns removed during data reduction. Image Credit: ESO/VLT and Rameau et al
The artist's concept depicts Kepler-186f, the first validated Earth-size planet to orbit a distant star in the habitable zone. Image Credit: NASA Ames/SETI Institute/JPL-Caltech
Exoplanets are currently a topic studied in both SMD's Planetary Science and Astrophysics Divisions at NASA, and are a priority according to the decadal surveys of both disciplines. The Planetary Science Division's Research and Analysis Program and the Astrophysics Division's Exoplanet Exploration Program coordinate their studies of exoplanets to determine the origins of stellar systems that are similar to our own.
The specific goals of the Astrophysics Division include searching for planets and planetary systems around stars in our galaxy, determining the percentage of planets that are in or near the habitable zone of a wide variety of stars, and characterizing planets around other stars for their habitability and other physical character istics. The Planetary Science Division's specific goals include understanding the origin and evolution of the atmospheres of planets and their satellites, under standing the formation and early evolution of planetary systems, and providing the fundamental research and

analysis necessary to characterize those planetary sys tems, including their habitability. While the Astrophysics Division emphasizes observational detection and study of exoplanets, the Planetary Science Division primarily focuses on the knowledge necessary for understanding exoplanets through modeling, data analysis, theoretical studies, and ground-based observations.
The Kepler mission was developed as a Discovery Program Mission in the Planetary Science Division and is now run by the Astrophysics Division as part of the NASA Exoplanet Exploration Program.
Launched in 2009, Kepler is a spaceborne photom eter designed to survey distant stars to determine the prevalence of Earth-like planets. Utilizing data
Candidate exoplanets discovered by the Kepler Space Telescope sorted by exoplanet size. Includes all Kepler-discovered exoplanets as of November 2013.
from the Kepler mission, scientists are approach ing confirmation of the existence of almost 2000 planets that orbit stars other than our Sun.
The Planetary Science Division provides the baseline parameters that the Astrophysics Division looks for with its Exoplanet Exploration Program missions.
The NASA Astrobiology Institute, a virtual institute jointly funded by the Planetary Science Division and the Astrophysics Division, currently includes the Virtual Planetary Laboratory that is exclusively focused on exoplanets.
Working together, the Planetary Science and Astrophys ics Divisions hope to lead humankind on a voyage of unprecedented scope and ambition, promising insight into two of our most timeless questions: Where did we come from? Are we alone?
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CHAPTER 5

LEFT:
The Suomi NPP satellite acquired this natural-color image of Hurricane Sandy on October 28, 2012.
Image Credit: NASA/GSFC/CIMSS and J. Allen
Image Credit: NASA/GSFC

JPSS Program
GOES-R Series Program
Reimbursable Projects Program

Table 5.1 NOAA Missions in Development or Formulation

Mission—Expected Launch Year, Partners	Objective
JPSS Program	
Joint Polar Satellite System (JPSS)-1 2—2017 2021	U.S. civilian operational polar satellite system providing environmental observational data to accurately predict weather three to ten days in the future

GOES-R Series Program	
Geostationary Operational Environmental Satellite-R, S, T U (GOES-R, S, T, U)—2016, 2017, 2019, 2024	Next generation of U.S. operational geostationary weather satellites for meteorological and space weather monitoring
Reimbursable Projects Program	
Deep Space Climate Observatory (DSCOVR)—2015	Primary mission is to monitor space weather, with secondary mission of Earth observation.
Joint Altimetry Satellite Oceanography Network-3 (JASON-3)—2015	Will extend the next decade of continuous climate record of ocean surface topography.
Meteorological Operational (MetOp) C—2017	European contribution for the collaborative Initial Joint Polar Orbiting Operational Satellite System
Total Solar Irradiance Sensor-1 (TSIS-1) Instrument (acquisition strategy for hosting TSIS-1 is being evaluated)	Continues the 34-year record of total solar irradiance, enabling scientists to understand the causes of climate change on our planet

TOP:
Jason-3 is an operational ocean altimetry mission designed to precisely measure sea surface height to monitor ocean circulation and sea level. Jason-3 will follow in the tradition of previous NASA-JPL missions such as Topex/Poseidon, Jason-1 and the Ocean Surface Topography Mission/ Jason-2.
Image Credit: CNES, CLS

MIDDLE:
Building on the success of the Suomi NPP polar-orbiting satellite, JPSS-1 will feature advanced technologies and instruments to ensure a continuous flow of Earth observations.
Image Credit: Ball Aerospace Technologies Corp.

BOTTOM:
The advanced spacecraft and instrument technology employed by the GOES-R series will provide significant improvements in the detection and observations of environmental phenomena that directly affect public safety, protection of property, and our nation’s economic health and prosperity.
Image Credit: NOAA/GOES-R.

CHAPTER 6

LEFT:
The heat shield for NASA's Mars Science Laboratory is the largest ever built for a planetary mission. Technicians in the photo are installing the electronics for the Mars Science Laboratory Entry, Descent and Landing Instrument (MEDLI)—an instrument that collected data about temperature and pressure during descent through the Mars atmosphere.
Image Credit: NASA/JPL

Table 6.1 STMD Programs Supporting NASA Science Technology Development

STMD Technology Program	TRL Range	Examples Relevant to SMD	Future Opportu
NASA Innovative Advanced Concepts (NIAC)	1-3	Advanced concepts such as printable spacecraft, cave-hopping robots, ultra- lightweight optics, ghost imaging	Compet solicitati through umbrella NRA (REDDI
Space Technology Research Grants (STRG)	1-3	Early Career Faculty/Early Stage Innovations	Compet solicitati through umbrella NRA (REDDI
Center Innovation Fund (CIF)	1-3	Lightweight telescope systems using novel nano-layered synthesized materials, nanosat mobility and autonomy for small bodies exploration, ultra-high-resolution X-ray optics	Selecte NASA Centers
Small Business Innovative Research (SBIR)/ Small Business Technology Transfer (STTR)	1-6	Current solicitation has thirty-one subtopics covering instrument and platform technologies relevant to SMD	Compet solicitati
Game Changing Development	3-5	SEXTANT, WFIRST-AFTA coronagraph, advanced entry technologies	New sta selecte STMD
Centennial Challenges	3-5	Sample return robot to locate and retrieve geologic samples from a wide and varied terrain without human control	Various challeng
Small Spacecraft Technology	3-7	Propulsion, communication and other platform technologies for CubeSats and smallsats	Compet solicitati (REDDI
Flight Opportunities	5-7	Technology demonstration on emerging suborbital launch vehicles	Compet solicitati (REDDI

Technology Demonstration 5-7 Missions	Laser Communications Relay Demonstration, Deep Space Atomic Clock, Green Propulsion Infusion Mission, Solar Sail Demonstration	Compet solicitati (REDDI

TOP:
Artist's concept of the Lunar Laser Communications Demonstration (LLCD) aboard the LADEE spacecraft.
Image Credit: NASA

BOTTOM LEFT:
Artist's concept of the Intelligent Payload Experiment (IPEX) and M-Cubed/COVE-2 (CubeSat Onboard processing Validation Experiment-2), two NASA Earth-orbiting cube satellites ("CubeSats") that were launched as part of the NRO Launch-39 GEMSat (Government Experimental Multi-Satellite) mission from California's Vandenberg Air Force Base on Dec. 5, 2013. CubeSats typically have a volume of exactly one liter.
Image Credit: NASA/JPL

BOTTOM RIGHT:
Currently, space clocks utilize Cesium ions to keep their time synchronous with Earth. Drift is a phenomenon that occurs over time where two clocks will no longer display the same time as one another. To avoid drift and to increase the stability of the ion clock, a new atomic element is needed for use in new space clocks. NASA engineers have been studying use of Mercury ions in satellite space clocks to allow engineers on the ground to more precisely navigate spacecraft and control their onboard instruments.
Image Credit: NASA

CHAPTER 7

LEFT:
Life-size model of JWST on display at the 2013 South by Southwest (SXSW) conference in Austin, Texas.
Image Credit: NASA/Jenny Mottar

Students attending Space Camp at the Space and Rocket Center in Huntsville, AL eagerly ask questions of the deep space exploration panel during the public viewing of the flawless launch of the MAVEN mission to Mars on November 18, 2013.
Image Credit: NASA/MSFC/Emmett Given

The Global Learning and Observation to Benefit the Environment (GLOBE) program is a worldwide community of students, teachers, scientists and citizens working together to promote the teaching and learning of science, enhance environmental literacy and stewardship, and promote scientific discovery.
Image Credit: NASA/GLOBE

Available on iTunes®, YouTube®, and Vimeo®, ScienceCasts are short videos about fun, interesting, and unusual NASA science topics.

Image Credit: NASA

Science Education
Workforce Development

Science On a Sphere® is a room-sized, global display system that uses computers and video projectors to display planetary data onto a six foot diameter sphere, analogous to a giant animated globe.
Image credit: NASA

Appendices

LEFT:
This long-exposure Hubble Space Telescope image of massive galaxy cluster Abell 2744 is the deepest ever made of any cluster of galaxies. It shows some of the faintest and youngest galaxies ever detected in space. The immense gravity in Abell 2744 acts as a gravitational lens to warp space and brighten and magnify images of nearly 3,000 distant background galaxies—some that formed more than 12 billion years ago, not long after the big bang.
Image Credit: NASA/STScI

Appendix A: Status of NRC Decadal Survey Recommendations and/or National Priorities

HELIOPHYSICS

Program/Mission Concept Class* Recommendation Status
Heliophysics Explorer Program Accelerate and expand program Next AO NET 2016
Ionospheric Connection (ICON) Small Complete missions in development In formulation. Launch Readiness Date (LRD): 2017
Global-scale Observations of the Small Complete missions in development In formulation. LRD: 2017 Limb and Disk (GOLD)
Solar Terrestrial Probes Program Restructure as higher cadence medium STP-5 LRD: NET 2023 PI-led program

Magnetospheric Multiscale (MMS) Large Complete missions in development In development. LRD: 2015			
Living With a Star Program Start next LWS mission by end of the decade Next LWS AO post 2020			
Space Environment Testbeds (SET-1) Small Complete missions in development In development. LRD: 2016			
Solar Orbiter Collaboration (SOC) Medium Complete missions in development In development. LRD: NLT 2018^			
Solar Probe Plus (SPP)	Large	Complete missions in development	In developm LRD: 201

- As determined by the 2013 Heliophysics decadal survey, which defines mission class as follows: Small (Explorer Class) - $50M-$300M; Medium - $300M-$600M; and Large - $600M
  ^ Reflects the Agency baseline commitment to launch NLT the year identified.

EARTH SCIENCE

Program/Mission Concept	Class	Recommendat
Earth Systematic Missions Program		
Global Precipitation Measurement (GPM)	FM (DS-2007)	Launch GPM b 2012 (DS-200
Soil Moisture Active-Passive (SMAP)	Tier 1 Mission	Complete missions in development
	CCAP	LRD: 2014
Stratospheric Aerosol and Gas Experiment III (SAGE III)	CCAP	LRD: 2013
Ice, Cloud and land Elevation Satellite – 2	Tier 1 Mission (DS-2007)	Launch: 2010-
Gravity Recovery and Climate Experiment Follow-on (GRACE FO)	CCAP	LRD: 2016
Surface Water and Ocean Topography (SWOT)	Tier 2 Mission (DS-2007)	Launch: 2013-

EARTH SCIENCE

(Continued)

Program/Mission Concept	Class	Recommenda
Earth Systematic Missions Program (Continued)		
Sustained Solar Irradiance Measurements	National Priority	Responsibility transferred fro NOAA to NAS
Pre-Aerosol, Cloud, ocean Ecosystem (PACE)	CCAP	LRD: 2018
L-Band Synthetic Aperture Radar	Tier 1 Mission	Launch: 2010
	CCAP	LRD: 2017
Vertical Ozone Profiles	National Priority	Responsibility transferred fro NOAA to NAS
Earth's Radiation Budget	National Priority	Responsibility transferred fro NOAA to NAS
Climate Absolute Radiance and Refractivity Observatory (CLARREO)	Tier 1 Mission (DS-2007)	Launch: 2010
	CCAP	LRD: 2017
Active Sensing of CO2 Emissions Over Nights, Days, and Seasons (ASCENDS)	Tier 2 Mission (DS-2007)	Launch: 2013
	CCAP	LRD: 2019
Geostationary Coastal and Air Pollution Events (GEO-CAPE)	Tier 2 Mission (DS-2007)	Launch: 2013
Hyperspectral Infrared Imager (HyspIRI)	Tier 2 Mission (DS-2007)	Launch: 2013
Aerosol-Clouds-Ecosystems	Tier 2 Mission (DS-2007)	Launch: 2013
Precipitation and All-weather Temperature and Humidity (PATH)	Tier 3 Mission (DS-2007)	Launch: 2016
Snow and Cold Land Processes (SCLP)	Tier 3 Mission (DS-2007)	Launch: 2016
Global Atmospheric Composition Mission (GACM)	Tier 3 Mission (DS-2007)	Launch: 2016
Three-Dimensional Tropospheric Winds (3D-Winds) (demo)	Tier 3 Mission (DS-2007)	Launch: 2016
Lidar Surface Topography (LIST)	Tier 3 Mission (DS-2007)	Launch: 2016

Gravity Recovery and Climate Experiment-II (GRACE-II)	Tier 3 Mission (DS-2007)	Launch: 2016
Future Land Imaging	National Priority	Establish a sustained land imaging capability for t nation

EARTH SCIENCE (Continued)

Program/Mission Concept	Class	Recommenda
Earth System Science Pathfinder Program		
Orbiting Carbon Observatory-2 (OCO-2)	CCAP	
Earth Venture Mission (EVM)	Earth Venture (DS-2007)	Initiate frequen low-cost, innovative research and application missions
	CCAP	EVM-2 LRD: 2017
Earth Venture Instrument (EVI)	Earth Venture (DS-2007)	Initiate frequen low-cost, innovative research and application missions
Earth Venture Suborbital (EVS)	Earth Venture (DS-2007)	Initiate frequen low-cost, innovative research and application missions
Earth Science Research Program		
Suborbital Program	Program Element (DS-2007)	Augment fund for suborbital program

FM: Foundation Mission DS:

Decadal Survey
CCAP: NASA's 2010 Climate-centric Architecture Plan ^ Reflects the Agency baseline commitment to launch NLT the year identified.

PLANETARY SCIENCE

Program/Mission Concept	Class*	Recommend
The Discovery Program	Continue program with 2yr cadence on mission AOs	Next Discove AO in FY14; planning a 3 cadence for future calls
InSight	Small	
New Frontiers Program	7 candidate missions with 2 selected before 2022	Next AO TBD
Origins Spectral Interpretation, Resource Identification and Security Regolith Explorer (OSIRIS-REx)	Medium	
Mars Exploration Program		
ExoMars Trace Gas Orbiter (ESA)	N/A	

PLANETARY SCIENCE (Continued)

Program/Mission Concept	Class*	Recommendatio
Mars Exploration Program (Continued)		
ExoMars Rover (ESA)	N/A	
Mars Astrobiology Explorer-Cacher (MAX-C)	Large	1st priority flagship mission launched before 2022 @ $2B in FY15 dollars
Strategic Missions		
Jupiter Icy Moons Explorer (JUICE) (ESA)	N/A	
Jupiter Europa Orbiter	Large	2nd priority flagship mission to be launched before 2022
Uranus Orbiter and Probe	Large	3rd priority flagship mission to be launched before 2022

Enceladus Orbiter	Large	4th priority flagship mission to be launched before 2022
Venus Climate Orbiter	Large	5th priority flagship mission to be launched before 2022

- As determined by the 2011 Planetary Science decadal survey, which defines mission class as follows: Small - $450M; Medium - $450M-$900M; and Large - $900M.
^ Reflects the Agency baseline commitment to launch NLT the year identified.

ASTROPHYSICS

Program/Mission Concept	Class*	Recomme
Physics of the C	osmos Program er Space Antenna Medium ESA-led mission with NASA participation. LRD: 2015	
Laser Interferomet (LISA) Pathfinder Euclid		Medium
Laser Interferometer Space Antenna (LISA)	Large	Also recomme 2001 dec survey
International X-ray Observatory (IXO)	Large	4th priorit mission c
Cosmic Origins Program James Webb Space Telescope (JWST)	Large	Top priori 2001 dec survey

ASTROPHYSICS (Continued)

Program/Mission Concept	Class*	Recommend
Exoplanet Exploration Program		
Wide Field Infrared Survey Telescope (WFIRST)	Large	Top priority f large scale mission in 20 decadal surv
Astrophysics Explorers Program	Augment current plans to two medium explorers, two small explorers and four MoOs.	Planned cad supports NR recommenda

ASTRO-H	Small	
Neutron star Interior Composition Explorer (NICER) – 2016	Medium	-
Transiting Exoplanet Survey Satellite (TESS)	Medium	-
Space Infrared Telescope for Cosmology and Astrophysics (SPICA) Mission (Japan)	Small	Contribution Japanese mission
Astrophysics Research Program		
Suborbital Program	Small	Augmentatio
New Worlds Technology Development Program	N/A	New progran support post 2020 planet imaging miss
Inflation Probe Technology Development Program	N/A	New progran support post- 2020 cosmic microwave background inflation miss

- As determined by the 2010 Astrophysics decadal survey, which defines mission class as follows: Small - $300M; Medium - $300M-$1B; and Large - $1B.
^ Reflects the Agency baseline commitment to launch NLT the year identified.

Appendix B: NASA Strategic Goals and Objectives, SMD Division Science Goals, Decadal Survey Priorities, and SMD Missions

NASA Strategic Objective	SMD Division Science Goals	Decadal Survey Priority (Associated SMD Division Science Goals in parentheses)	S M (A D S F p
NASA Strategic Goal: Expand the frontiers of knowledge, capability, and opportunity in space.			
HELIOPHYSICS Understand the Sun and its interactions with Earth and the solar system, including space weather.			A A A C C (c J (l H E d II IC (a M F
PLANETARY SCIENCE Ascertain the content, origin, and evolution of the solar system and the potential for life elsewhere.	and evolve.		M (a E (a E (a V C C c c H (a (a F C c c

1. Explore the physical processes in the space environment from the Sun to the Earth and throughout the solar system.
2. Advance our understanding of the connections that link the Sun, the Earth, planetary space environments, and the outer reaches of our solar system.
3. Develop the knowledge and capability to detect and predict extreme conditions in space to protect life and society and to safeguard human and robotic explorers beyond Earth.

1. Determine the origins of the Sun's activity and predict the variations of the space environment. (1, 3)
2. Determine the dynamics and coupling of Earth's magnetosphere, ionosphere, and atmosphere and their response to solar and

terrestrial inputs. (2, 3)

3. Determine the interaction of the Sun with the solar system and the interstellar medium. (1, 2)
4. Discover and characterize fundamen tal processes that occur both within the heliosphere and throughout the universe. (1, 2)

1. Explore and observe the objects in the solar system to understand how they formed and evolve.
2. Advance the understanding of how the chemical and physical processes in our solar system operate, interact
3. Explore and find locations where life could have existed or could exist today.
4. Improve our understanding of the origin and evolution of life on Earth to guide our search for life elsewhere.
5. Identify and characterize objects in the solar system that pose threats to Earth, or offer resources for human exploration.

1. Building New Worlds—advance the understanding of solar system beginnings (1, 2)
2. Planetary Habitats—search for the requirements for life (3, 4)
3. Workings of Solar Systems—reveal planetary processes through time (1, 2, 5)

Appendix B (Continued): NASA Strategic Goals and Objectives, SMD Division Science Goals, Decadal Survey Priorities, and SMD Missions

NASA Strategic Objective	SMD Division Science Goals	Decadal Survey Priority (Associated SMD Division Science Goals in parentheses)
NASA Strategic Goal (Continued): Expand the frontiers of knowledge, capability, and opportunity in space.		

ASTROPHYSICS Discover how the universe works, explore how it began and evolved, and search for life on planets around other stars.		
NASA Strategic Goal: Advance understanding of Earth and develop technologies to improve the quality of life on our home planet		
EARTH SCIENCE Advance knowledge of Earth as a system to meet the challenges of environmental change, and to improve life on our planet.	water cycle evolves in response to climate change.	* NASA's 2010 climate-centric architecture plan

1. Probe the origin and destiny of our uni verse, including the nature of black holes, dark energy, dark matter and gravity.
2. Explore the origin and evolution of the galaxies,

stars and planets that make up our universe.

3. Discover and study planets around other stars, and explore whether they could harbor life.

1. Search for the first stars, galaxies, and black holes (1, 2)
2. Seek nearby habitable planets (3)
3. Advance understanding of the fundamen tal physics of the universe (1, 2)

1. Advance the understanding of changes in the Earth's radiation balance, air quality, and the ozone layer that result from changes in atmospheric composition.
2. Improve the capability to predict weather and extreme weather events.
3. Detect and predict changes in Earth's ecological and chemical cycles, including land cover, biodiversity, and the global carbon cycle.
4. Enable better assessment and manage ment of water quality and quantity to accurately predict how the global
5. Improve the ability to predict climate changes by better understanding the roles and interactions of the ocean, atmosphere, land and ice in the climate system.
6. Characterize the dynamics of Earth's sur face and interior, improving the capability to assess and respond to natural hazards and extreme events.
7. Further the use of Earth system science research to inform decisions and provide benefits to society.

1. Understand the complex, changing planet on which we live, how it supports life, and how human activities affect its ability to do so in the future. (3, 5, 6, 7)
2. Revitalize the nation's research satellite system, providing near-term measure- ments to advance science, underpin policy, and expand applications and societal benefits* (5)
3. Advance climate research, multiply applications using the full set of available (NASA and non-NASA) satellite measure ments for direct societal benefit, and develop/mature technologies required for the next generations of Earth observing missions* (1, 2, 4)

^ The FY15 Budget greatly reduces funding for SOFIA

Appendix C: Program/Strategic Mission Lines

Program/Strategic Mission Lines	Category*	Objectives Features
Earth Systematic	Strategic missions	Make new measurem to address unanswere questions
Missions	(Category 1, 2, 3)	and reduce remaining uncertainti maintain continuity
		measurem awaiting transition t operationa systems managed
		by other agencies.
Earth System Science	Competed,	Address fo Earth scien objectives provide opportuniti
Pathfinder (ESSP)	PI-led missions	for new sci investigatio Includes th Venture cla suborbital
	(Category 3)	campaigns small satel and instrum of opportun
Discovery	Competed,	Regular, lo cost, highly focused planetary science investigatio
	PI-led missions	any solar s bodies oth than the Ea and Sun.
	(Category 2, 3)	
New Frontiers	Competed,	Focused scientific investigatio designed t enhance o understand
	PI-led missions	of the sola system; competitive selected fr among a specified li
	(Category 1, 2)	candidate missions/s targets.
Mars Exploration	Strategic missions	Maximize t scientific re technology infusion, a public
	(Category 1, 2)	engageme the robotic exploration the Red Pl Each strate
		mission ha linkages to previous missions, a orbiters an landers

		support ea other's operations
Solar Terrestrial Probes	Strategic missions	Strategic sequence missions to provide understand the
(STP)	(Category 1,2)	fundament plasma processes inherent in astrophysi systems.
Living With a Star	Strategic missions	Strategic missions targeted to those aspe the Sun ar space
(LWS)	(Category 1, 2)	environme most direc affect life a society.
Heliophysics Explorers	Competed,	Provide flig opportuniti focused sc investigatio from
	PI-led missions	space in Heliophysi
	(Category 2, 3)	
Cosmic Origins	Strategic missions	Strategic missions to understand the familia universe o
	(Category 1, 2, 3)	galaxies, a planets are formed ove
Physics of the Cosmos	Strategic missions	Strategic missions to explore fundament questions regarding
	(Category 1, 2, 3)	physical fo and laws o universe including t nature of
		spacetime behavior o matter and energy in extreme environme
		the cosmo parameter governing inflation ar evolution o
		universe, a the nature dark matte dark energ
Exoplanet Exploration	Strategic missions	Strategic missions to explore an characteriz worlds, en

	(Category 1, 2, 3)	advanced telescope searches f Earth-like planets, ar discover
		habitable environme around neighborin stars
Astrophysics Explorers	Competed,	Provide flig opportuniti focused sc investigatio
	PI-led missions	from space Astrophysi
	(Category 2, 3)	

- Category 1: > $1B; Category 2: $250M - $1B; Category 3: < $250M
^ The FY15 Budget greatly reduces funding for SOFIA

Appendix D: Science Directorate Decision-Making Process for Missions ⊠

Mission Lifecycle	

Phase Description
Spaceflight Mission SMD spaceflight missions are initiated by one of two processes:
Initiation 1. Strategic missions for SMD are initially developed as candidates from multiple mission investigation concepts that derive from various surveys and studies performed by science advisory boards and panels, or that meet specific Agency Science goals.
2. Competed missions are those selected through open AOs, which solicit a scientific investigation that includes development of a flight mission or instruments to fly on currently planned flight missions or platforms such as the ISS.
All proposed missions must fit within a Science Mission Directorate goal or specific objective. Division Directors then package related missions into appropriate programs for further management consideration.
Pre-formulation* The NASA Headquarters Science Management Council (SMaC) reviews candidate science programs and makes appropriate recommendations to the SMD AA who approves new initiatives for further study. Approved mission initiatives must clear Key Decision Points (KDPs) to determine readiness before they are allowed to proceed to the next mission lifecycle phase. Missions that do not clear a KDP are either given more

time to achieve readiness or considered for termination.

Phase-A Phase A of Formulation defines mission and system concepts, parameters, constraints, and requirements that will allow the project (Formulation) to be developed on a schedule that meets established goals and can be achieved for a realistic cost. This is done by conducting
studies that examine the mission characteristics permitted within identified constraints, and through continued development of enabling technology toward achieving an acceptable TRL. A prime focus is to identify the top-level requirements that the mission must satisfy in order to meet science objectives. The transition to Phase B involves independent review and approvals at multiple levels, culminating in the KDP-B meeting to ensure that the project is ready to proceed from Phase A to Phase B.

Phase-B Phase B of Formulation concentrates on applying results of mission studies and trades completed in Phase A to generate (Formulation) preliminary mission, instrument, and spacecraft designs that satisfy the identified constraints and requirements, and that will allow the project to be developed on a schedule to meet established goals within budget. A descope plan must be prepared to pursue scope reduction and risk management to control cost. It is a time to finalize the requirements and establish the cost caps that will become firm requirements in the Decision Memoranda signed at KDP-C.

Phase-C Phase C comprises final mission design and fabrication. While there are no strategic decisions during this stage, the SMD AA

(Final Design and has a vested interest in ensuring that mission implementing organizations carry out assigned tasks effectively, tracking the Fabrication) performance of a project against the program-level requirements and against the schedule and cost cap.
Phase-D Phase D includes integration, test and launch. Phase D begins after final assembly of the deliverable system (whether a (Integration, Test, spacecraft or an instrument) commences. It also includes system-level environmental testing, delivery to the launch site for launch Launch) processing, launch operations, and on-orbit checkout. The transition of a flight project from Phase D to Phase E occurs only after on-orbit checkout has been completed, typically 30 to 90 days after launch.
Phase-E Phase E comprises operation of the prime or planned mission. At the end of the prime mission, an End of Prime Mission (EOPM) (Operations) review is held to (1) evaluate and document how the mission achieved its Level 1 science requirements and mission success
criteria, and (2) identify lessons learned based on the actual operations that can be used to improve future missions. It is not considered a gate review, but the EOPM results are considered when inviting the mission to propose for an extended mission.
Mission Cancellation The project will implement a mission within the established cost and schedule baseline. If a mission is expected to exceed its (Pre-Launch) baseline cost and schedule commitments, it can be considered for cancellation by NASA.
Mission Termination Missions that continue functioning near the end of their prime operational mission, and any previously extended mission are subject to a Senior Review, which is a science peer review process conducted every two years to determine the scientific value

	and priority of further mission extensions. Those that do not receive a positive outcome for continuation are subject to termination.

- Strategic missions require approval from the NASA Administrator, the Office of Management and Budget, and Congress. Approval by the SMD AA of missions originating from a Program line like Explorers or Discovery is subject to the availability of funds.

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Resources for Earth and Space Science Education: www .nasawavelength.org
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Service and Advice for Research and Analysis (SARA): http://science.nasa.gov/researchers/sara

Appendix F: Acronyms and Abbreviations

of Meteorological Satellites
COVE-2

Abbreviations and Acronyms	Abbreviations Definition and Acronyms	Definition
AA	Associate Administrator CRaTER	LRO Cosmic Ray Telescope for the Effects
AAAC	Astronomy and Astrophysics Advisory Committee	of Radiation instrument
ACE	CREAM Advanced Composition Explorer	Cosmic Ray Energetics and Mass
ACT	Advanced Component Technology CSA	Canadian Space Agency
AFTA	Astrophysics Focused Telescope Assets CSLI	CubeSat Launch Initiative
AIM	Aeronomy of Ice in the Mesosphere CYGNSS	Cyclone Global Navigation Satellite System
AIST	Advanced Information Systems Technologies DAAC	Distributed Active Archive Centers
AMSU-A	Advanced Microwave Sounding Unit-A DISCOVER-AQ	Deriving Information on Surface Conditions from Column and Vertically Resolved Observations
AO	Announcement of Opportunity	Relevant to Air Quality
APRA	Astrophysics Research and Analysis DLR	Deutsches Zentrum für Luft- und Raumfahrt (national
ARSET	Applied Remote SEnsing Training	aeronautics and space research center of the Federal Republic of Germany)

ARTEMIS	Acceleration, Reconnection, Turbulence and DOD Electrodynamics of the Moon's Interaction with the Sun probes DOE	Department of Defense Department of Energy
ASAG	Applied Sciences Advisory Group DRIVE	Diversify, Realize, Integrate, Venture, Educate
ASCENDS	Active Sensing of CO over Nights, Days and Seasons DS 2	Decadal Survey
ATI	Advanced Technology Initiatives DSCOVR	Deep Space Climate Observatory
ATTREX	Airborne Tropical Tropopause Experiment DWSS	Defense Weather Satellite System
AU	Astronomical Unit E/PO	Education and Public Outreach
AVHRR	Advanced Very High Resolution Radiometer EAR	Export Administration Regulations
CALIPSO	Cloud-Aerosol Lidar and Infrared Pathfinder EDLS Satellite Observations	Entry, Descent, Landing System
CARVE	Carbon in Arctic Reservoirs Vulnerability Experiment E LV	Expendable Launch Vehicle
CASI	Climate Adaptation Science Investigators EM	Exploration Mission
CATS	Cloud-Aerosol Transport System EO-1	Earth Observing–1
CBP	Capacity Building Program EOPM	End of Prime Mission
CCAP	NASA's 2010 Climate-Centric Architecture Plan EOS	Earth Observing System
CCMC	Community Coordinated Modeling Center EOSDIS	EOS Data and Information System
CENRS	Committee on Environment, Natural Resources, and Sustainability E PA	Environmental Protection Agency
CERES	Cloud and the Earth's Radiant Energy System ESA	European Space Agency

CIF	Center Innovation Fund ESD	Earth Science Division
CINDI	Coupled Ion-Neutral Dynamics Investigations ESM	Earth Systematic Missions
CLARREO	Climate Absolute Radiance and Refractivity Observatory ESSP	Earth System Science Pathfinder
CNES	Centre National d’Etudes Spatiale ESTO (French Space Agency)	Earth Science Technology Office
CO_2	Carbon dioxide EUMETS AT	European Organization for the Exploitation
CoSTEM	Committee on Science Technology, Engineering and Math Education EVI	Earth Venture —Instrument
CubeSat Onboard processing Validation Experiment-2 EVM	Earth Venture – Mission	

Abbreviations and Acronyms Definition

EVS Earth Venture – Suborbital
FAA Federal Aviation Administration
FY Fiscal Year
GACM Global Atmospheric Composition Mission
GAO Government Accountability Office
GCIS Global Change Information System
GCOM-W1 Global Change Observation Mission—Water satellite (JAXA)
GEMS Gravity and Extreme Magnetism Small Explorer
GEO Geostationary Orbit
GEO-CAPE Geostationary Coastal and Air Pollution Events
GEOS Goddard Earth Observing System
GLOBE Global Learning and Observation to Benefit the Environment
GOES Geostationary Operational Environmental Satellite
GOLD Global-scale Observations of the Limb and Disk
GOMI Gulf of Mexico Initiative
GEMSat Government Experimental Multi-Satellite
GPM Global Precipitation Measurement
GPS Global Positioning System
GRACE Gravity Recovery and Climate Experiment
GRACE FO Gravity Recovery and Climate Experiment Follow-on
GRAIL Gravity Recovery and Interior Laboratory
GRB Gamma-ray burst
HEOMD Human Exploration and Operations Mission Directorate (NASA)
H-GCR Heliophysics-Grand Challenges Research
H-GI Heliophysics-Guest Investigator
HICO Hyperspectral Imager for the Coastal Ocean
HS3 Hurricane and Severe Storm Sentinel
HSO Heliophysics System Observatory
HST Hubble Space Telescope

H-TIDeS Heliophysics Technology and Instrument Development for Science
IBEX Interstellar Boundary Explorer
ICEsat-2 Ice, Clouds and land Elevation Satellite-2
ICON Ionospheric Connection
IIP Instrument Incubator Program
IPEX Intelligent Payload Experiment
IR Infrared

Abbreviations and Acronyms Definition

IRIS Interface Region Imaging Spectrograph
ISERV ISS SERVIR Environmental Research and Visualization System
ISON International Scientific Optical Network
ISS International Space Station
ITAR International Traffic in Arms Regulations
IXO International X-ray Observation
JASD Joint Agency Satellite Division
JASON Joint Altimetry Satellite Oceanography Network
JAXA Japanese Space Agency (Japan Aerospace Exploration Agency)
JPSS Joint Polar Satellite System
JUICE Jupiter Icy Moons Explorer (ESA)
JWST James Webb Space Telescope
KDP Key Decision Point
L1 Lagrange point 1
LADEE Lunar Atmosphere and Dust Environment Explorer
LCAS Low-Cost Access to Space
LCC life cycle cost
LDCM Landsat Data Continuity Mission
O Low Earth Orbit
LIS Lightning Imaging Sensor
LISA Laser Interferometer Space Antenna
LIST Lidar Surface Topography
LLCD Lunar Laser Communications Demonstration
LMSSC Lockheed Martin Space Systems Company
LRD Launch Readiness Date
LRO Lunar Reconnaissance Orbiter
LWS Living With a Star
MatISSE Maturation of Instruments for Solar System Exploration
MAVEN Mars Atmosphere and Volatile Evolution
MAX-C Mars Astrobiology Explorer-Cacher
MEP Mars Exploration Program
MESSENGER Mercury Surface, Space Environ ment, Geochemistry and Ranging
MetOp Meteorological Operational
MMS Magnetospheric Multiscale
MOMA Mars Organic Molecule Analyzer
MOMA-MS Mars Organic Molecule Analyzer Mass Spectrometer
MRO Mars Reconnaissance Orbiter

Abbreviations and Acronyms Definition

MSL Mars Science Laboratory
N/A Not applicable
NAC NASA Advisory Council
NAI NASA Astrobiology Institute
NASA National Aeronautics and Space Administration
NEO Near Earth Object
NEOWISE Near-Earth Object Wide-field Infrared Survey Explorer
NESSF NASA Earth and Space Science Fellowship
NET No earlier than
NEX NASA Earth Exchange
NIAC NASA Innovative Advanced Concepts
NI-SAR NASA-India Space Research Organization Synthetic Aperture Radar
NLT No later than
NOAA National Oceanic and Atmospheric Administration
NPOESS National Polar-orbiting Operational Environmental Satellite System

NPP National Polar-Orbiting Partnership
NRA NASA Research Announcement
NRC National Research Council
NRO National Reconnaissance Office
NSF National Science Foundation
NSTC National Science and Technology Council
NuSTAR Nuclear Spectroscopic Telescope Array
OCE Office of the Chief Engineer
OCO Orbiting Carbon Observatory
OCT Office of the Chief Technologist
OMPS Ozone Mapper and Profiler Suite
ORS-3 Operationally Responsive Space-3
OSC Orbital Sciences Corporation
OSIRIS-REx Origins, Spectral Interpretation, Resource Identification, Security Regolith Explorer
OSTM Ocean Surface Topography Mission
PACE Pre-Aerosol, Clouds, and Ecosystems
PATH Precipitation and All-weather Temperature and Humidity
PDS Planetary Data System
PI Principal Investigator
PICASSO Planetary Instrument Concepts for the Advancements of Solar System Observations
POES Polar-orbiting Operational Environmental Satellites
R&A Research and analysis

Abbreviations and Acronyms Definition

RapidScat Rapid Scatterometer
RBI Radiation Budget Investment
RBSP Radiation Belt Storm Probes
REDDI Research, Development, Demonstration, and Infusion
RHESSI Reuven Ramaty High Energy Solar Spectroscope Imager
ROSES Research Opportunities in the Space and Earth Sciences
RPP Reimbursable Projects Program
RPS Radioisotope Power System
SAGE Stratospheric Aerosol and Gas Experiment
SAR Synthetic Aperture Radar
SARA Service and Advice for Research and Analyses
SAT Strategic Astrophysics Technology
SBIR Small Business Innovative Research
SCLP Snow and Cold Land Processes
SDO Solar Dynamics Observatory
SDT Science Definition Team
SEM Space Environment Monitor
SEPOF Science Education and Public Outreach Forum
SET Space Environment Testbed
SEXTANT Station Explorer for X-ray Timing and Navigation
SI International System of Units
SLS Space Launch System
SMAP Soil Moisture Active/Passive
SMD Science Mission Directorate (NASA)
SOC Solar Orbiter Collaboration
SOFIA Stratospheric Observatory For Infrared Astronomy
SOHO Solar and Heliospheric Observatory
SORCE Solar Radiation and Climate Experiment
SpaceX Space Explorations Technology Corporation
SPICA Space Infrared Telescope for Cosmology and Astrophysics
SPP Solar Probe Plus
SSERVI Solar System Exploration Research Virtual Institute
STEM Science, Technology, Engineering and Mathematics
STEREO Solar Terrestrial Relations Observatory
STMD Space Technology Mission Directorate (NASA)
STP Solar Terrestrial Probes

STRG Space Technology Research Grants

Abbreviations and Acronyms Definition

STTR Small Business Technology Transfer
Suomi NPP Suomi-National Polar-orbiting Partnership
SWOT Surface Water and Ocean Topography
SXSW South by Southwest
TBD To be determined
TCTE TSI (Total Solar Irradiance) Calibration Transfer Experiment
TEMPO Tropospheric Emissions: Monitoring of Pollution
TESS Transiting Exoplanet Survey Satellite
THEMIS Time History of Events and Macroscale Interactions during Substorms
TIMED Thermosphere, Ionosphere, Mesosphere, Energetics, and Dynamics
TIROS Television Infrared Observation Satellite
TRL Technology Readiness Level
TRMM Tropical Rainfall Measuring Mission
TSI Total Solar Irradiance
TSIS Total Solar Irradiance Sensor
TWINS Two Wide-angle Imaging Neutral Atom Spectrometers
U.S. United States
UHF Ultra-High Frequency
ULA United Launch Alliance
ULDB Ultra Long Duration Balloon
UN United Nations
UNCOPUOS United Nations Committee on the Peaceful Uses of Outer Space
USAF United States Air Force
USAID United States Agency for International Development
USDA United States Department of Agriculture
USGCRP United States Global Change Research Program
USGS United States Geological survey
UV ultraviolet
VIIRS Visible Infrared Imager Radiometer Suite
WFIRST Wide-Field Infrared survey Telescope
WISE Wide-field Infrared survey Explorer
XMM X-ray Multi-Mirror Mission