## OUTCOME 2.3: ASCERTAIN THE CONTENT, ORIGIN, AND EVOLUTION OF THE SOLAR SYSTEM AND THE POTENTIAL FOR LIFE ELSEWHERE.

Planetary Science's missions have revolutionized understanding of the origin and history of the solar system. NASA has missions circling the innermost planet, Mercury, and heading for the outer reaches of the solar system, where Pluto orbits among other Kuiper Belt objects. Its missions have orbited and roved the surface of Mars, finding evidence of liquid water. Closer to home, Planetary Science uses ground-based sensors in coordination with the National Science Foundation and the U.S. Air Force to survey the volume of near-Earth space to detect, track, catalog, and characterize near-Earth objects that may either pose hazards to Earth or provide destinations and resources for future exploration.

NASA's robotic science missions are paving the way for understanding the origin and evolution of the solar system and identifying past and present habitable locations. With this knowledge, NASA is enabling human space exploration by studying and characterizing planetary environments beyond Earth and identifying possible resources that will enable safe and effective human missions to destinations beyond low Earth orbit.

Robotic explorers gather data to help scientists understand how the planets formed, what triggered different evolutionary paths among planets, what processes are active, and how Earth formed, evolved, and became habitable. To search for evidence of life beyond Earth, scientists use this data to map zones of habitability, study the chemistry of unfamiliar worlds, and unveil the processes that lead to conditions necessary for life.

**Providing National Scientific Capabilities in Planetary Sciences**

NASA continues to develop the Nation's capabilities in support of NASA's science objectives by funding research and mission development performed by scientists and engineers at universities, research centers, private sector organizations, and NASA Centers. The majority of research awards also include funding for postdoctoral fellows, graduate students, and undergraduate students, thereby supporting the education and training of future scientists and engineers.

Programs and activities serving this goal in FY 2012 include:

- The Research Opportunities in Space and Earth Science annual solicitation;
- Basic technology development in instrumentation and power systems;
- Graduate student, postdoctoral and early career Earth and space science fellowships;
- Presidential Early Career Award for Scientists and Engineers;
- Hands-on Project Experience; and
- Venus Transit public educational and viewing event.

The establishment, operation, and maintenance of necessary facilities is critical to the Nation's scientific capabilities. In FY 2012, NASA provided:

- Operations, basic data analysis, and resources for operation centers for the MSL *Curiosity*, Cassini, Dawn (now ended), LRO, New Horizons, the Mars Exploration Rover *Opportunity*, MRO, Juno, MESSENGER, Mars Odyssey, and GRAIL (now ended) missions;

# PERFORMANCE REPORTING AND PLANNING

- The Planetary Data System (PDS), which archives all NASA planetary science mission data and provides open access to the science community and the public through the PDS discipline nodes, including Atmospheres, Geosciences, Imaging, Navigational and Ancillary Information, Planetary Plasma Interactions, Planetary Rings, and Small Bodies;
- Facilities operation of ground-based Infrared Telescope Facility and Keck Observatories and Astromaterials Curation, including lunar and extraterrestrial specimens; and
- Support for the NASA Astrobiology Institute, the NASA Lunar Science Institute, and analysis working groups providing cross-disciplinary community engagement and research collaborations.

NASA requires that all funded research investigations publish their results in open, peer reviewed science literature, ensuring that data and knowledge are captured. Each year, the Planetary Science Subcommittee of NASA's external advisory Science Committee evaluates the progress made by NASA toward each science objective. In FY 2012, the subcommittee found that expectations had been fully met by research results that included those discussed below.

## Reported Multi-Year Performance

**Multi-Year Performance Goal 2.3.1.1: Provide national scientific capabilities through necessary skilled researchers and supporting knowledge base. (In support of objective 2.3.1: "Inventory solar system objects and identify the processes active in and among them.")**

| | |
|---|---|
| **FY11** | NASA provides the skilled researchers and supporting planetary science knowledge base necessary for the Nation's scientific capabilities as detailed. |
| **Green** | |
| **FY12** | **Dawn at Vesta** |
| **Green** | The Dawn spacecraft completed its observations at the giant asteroid Vesta. The results from Dawn warranted an entire issue of *Science* (May 11, 2012) dedicated to the new findings. Results show asteroid Vesta has geomorphological features such as varied topography and depositional and erosional environments indicating active surface processes. Data from the Dawn spacecraft reveal Vesta to be a dwarf planet with an inner iron core like the Moon and rocky planets. |
| | **Satellite of Pluto Discovered** |
| | Researchers from NASA's New Horizons mission to Pluto used the Hubble Space Telescope to discover a fifth moon orbiting Pluto in images taken during June–July 2012. The moon, tentatively called "P5," has a diameter of about 15 kilometers, making it the smallest and faintest of Pluto's moons yet discovered. The image of the new moon and other images will enable the mission team to assess the safety of several candidate trajectories for New Horizons as it passes near Pluto in July 2015. |
| | **Can a Moon Have a Moon? Saturn's Mysterious Iapetus May Have Had One** |
| | Two NASA-funded research groups proposed that Iapetus, Saturn's outermost major moon, once had its own satellite. Both groups propose that this "subsatellite" was formed by collision with another moon during Iapetus' formation. The research groups are investigating the fate of the lost moon. One team suggests that the subsatellite spiraled out |

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| | from Iapetus and was responsible for Iapetus' very slow spin before ultimately being lost. The other research team proposes that the subsatellite ultimately spiraled back toward Iapetus, breaking up into a debris ring, and forming the equatorial accretion ridge. |

| **Update to Multi-Year Performance Goal** | |
|---|---|
| **FY13 Update** | This performance goal remains the same in FY13. |
| **FY14** | This performance goal remains the same in FY14. |

| **Reported Annual Performance** | | | | | |
|---|---|---|---|---|---|
| **PS-12-1: Demonstrate planned progress in inventorying solar system objects and identifying the processes active in and among them. Progress relative to the objectives in NASA's 2010 Science Plan will be evaluated by external expert review.** | | | | | |
| **Contributing Theme:** | | Planetary Science | | | |
| **Contributing Program(s):** | | Multiple Programs | | | |
| **FY07** | **FY08** | **FY09** | **FY10** | **FY11** | **FY12** |
| **None** | **None** | **None** | **None** | **PS-11-1 Green** | **PS-12-1 Green** |

| **Planned Annual Performance** | |
|---|---|
| **FY13 Update** | PS-13-1: Demonstrate planned progress in inventorying solar system objects and identifying the processes active in and among them. Progress relative to the objectives in NASA's 2010 Science Plan will be evaluated by external expert review. |
| **FY14** | PS-14-1: Demonstrate planned progress in inventorying solar system objects and identifying the processes active in and among them. Progress relative to the objectives in NASA's 2010 Science Plan will be evaluated by external expert review. |

## Reported Multi-Year Performance

**Multi-Year Performance Goal 2.3.1.2: By 2017, launch at least two missions in support of objective 2.3.1.**

| **FY11** |
|---|
| **Green** |
| **FY12** |
| **Green** |
| |

The purpose of this performance goal is to design, develop, and launch satellites in support of objective 2.3.1, as outlined in the NASA Science Mission Directorate's 2010 Science Plan. NASA selected the Origins-Spectral Interpretation-Resource Identification-Security-Regolith Explorer, or OSIRIS-REx, project in FY 2011 through a NASA Announcement of Opportunity. Planned for launch in 2016, it will be the first U.S. mission to bring samples from an asteroid back to Earth. The project team chose to extend the formulation phase, which will help reduce mission risk. OSIRIS-REx successfully conducted a Mission Design Review on May 8-10, 2012. The Preliminary Design Review initially planned for FY 2012 will be held in March 2013.

NASA selected the second mission serving this performance goal in August 2012 from three Discovery 12 concept studies. Also planned for launch in 2016, InSight will take the first look into the deep interior of Mars to see why it evolved differently as a terrestrial planet from Earth.

# PERFORMANCE REPORTING AND PLANNING

| Update to Multi-Year Performance Goal | |
|---|---|
| **FY13 Update** | This performance goal remains the same in FY13. |
| **FY14** | This performance goal remains the same in FY14. |

| Reported Annual Performance | | | | | |
|---|---|---|---|---|---|
| **PS-12-2: Complete New Frontiers 3 Preliminary Design Review.** | | | | | |
| **Contributing Theme:** | | Planetary Science | | | |
| **Contributing Program(s):** | | New Frontiers | | | |
| **FY07** | **FY08** | **FY09** | **FY10** | **FY11** | **FY12** |
| **None** | **None** | **None** | **10PS04 Green** | **PS-11-3 Green** | **PS-12-2 Yellow** |
| **Why this APG was not achieved:** At the time of the performance plan update, NASA had not completed the final negotiation on the procurement the Origins Spectral Interpretation Resource Identification Security Regolith Explorer (OSIRIS-REx) mission. The final agreement resulted in a proposed extended Phase B for the OSIRIS-REx project, which moved the Preliminary Design Review (the APG milestone) beyond fiscal year 2012, with the planned completion of the Mission Definition Review in FY 2012 instead. NASA made this change to reduce risk to cost and schedule performance for the project. | | | | | |
| | | | | | |
| **Planned Annual Performance** | | | | | |
| **FY13 Update** | PS-13-5: Complete the OSIRIS-REx Preliminary Design Review (PDR). | | | | |
| **FY14** | PS-14-2: Complete the OSIRIS-REx Critical Design Review (CDR). | | | | |

| Reported Annual Performance | | | | | |
|---|---|---|---|---|---|
| **PS-12-3: Complete the Discovery 12 mission concept studies.** | | | | | |
| **Contributing Theme:** | | Planetary Science | | | |
| **Contributing Program(s):** | | Discovery | | | |
| **FY07** | **FY08** | **FY09** | **FY10** | **FY11** | **FY12** |
| **None** | **None** | **None** | **None** | **None** | **PS-12-3 Green** |
| | | | | | |
| **Planned Annual Performance** | | | | | |
| **FY13 Update** | PS-13-2: Initiate the preliminary design for the Discovery 12 mission. | | | | |
| **FY14** | PS-14-3: Complete InSight Mission (Discovery 12) Critical Design Review. | | | | |

# PERFORMANCE REPORTING AND PLANNING

## Reported Multi-Year Performance

**Multi-Year Performance Goal 2.3.2.1: Provide national scientific capabilities through necessary skilled researchers and supporting knowledge base. (In support of objective 2.3.2: "Improve understanding of how the Sun's family of planets, satellites, and minor bodies originated and evolved.")**

| | |
|---|---|
| **FY11**<br>**Green**<br>**FY12**<br>**Green** | NASA provides the skilled researchers and supporting planetary science knowledge base necessary for the Nation's scientific capabilities.<br><br>**LRO Reveals Scars of Lunar Tectonics**<br><br>Scars observed on the Moon by NASA's Lunar Reconnaissance Orbiter (LRO) suggest that the Moon was not fully molten when it first formed. Cooling of a fully melted moon would have erased any localized stretching that formed the features seen today. With the recent imaging capability of the high-resolution camera onboard LRO, new discoveries about the formation of the Moon are coming into focus. High-resolution images show a recent graben, or depression, bordered by parallel faults formed by tectonics, leaving a scar on the lunar surface. The graben is less than 50 million years old based on its lack of craters and micrometeorite infill.<br><br>**GRAIL Redefines The Lunar Gravity Field**<br><br>The most accurate global gravity model of the Moon to date has been developed from the first three months of Gravity Recovery and Interior Laboratory (GRAIL) data, with surface resolution as small as 23 kilometers. The new model reveals a much more detailed lunar landscape, particularly over the lunar far side, showing the gravity signals of craters and basins not seen before and with an accuracy at least an order of magnitude more precise than any previous model. This data also reveal lunar surface features and provide measurements of the interior composition, subsurface structure, and the lunar thermal history.<br><br>**Volatile-rich Terrains on Mercury**<br><br>The MESSENGER spacecraft has sent back a wealth of data from the innermost planet. One of the major discoveries from orbit is of "hollows," shallow, rimless, irregularly shaped depressions found in impact craters all over Mercury. The strange landforms can be tens of meters to a few kilometers wide. The origin of the hollows is not yet known, but one of the most likely formation mechanisms involves recent loss of volatiles through some combination of sublimation, space weathering, outgassing, or pyroclastic volcanism. These features support the inference that Mercury's interior contains higher abundances of volatile materials than predicted by most scenarios for the formation of the solar system's innermost planet. Although Mercury was thought to be relatively old and dead, MESSENGER images of the hollows show that parts of it may be active today. |

| **Update to Multi-Year Performance Goal** | |
|---|---|
| **FY13 Update** | This performance goal remains the same in FY13. |
| **FY14** | This performance goal remains the same in FY14. |

# PERFORMANCE REPORTING AND PLANNING

| Reported Annual Performance | | | | | |
|---|---|---|---|---|---|
| **PS-12-4: Demonstrate planned progress in understanding how the Sun's family of planets, satellites, and minor bodies originated and evolved. Progress relative to the objectives in NASA's 2010 Science Plan will be evaluated by external expert review.** | | | | | |
| **Contributing Theme:** | Planetary Science | | | | |
| **Contributing Program(s):** | Multiple Programs | | | | |
| **FY07** | **FY08** | **FY09** | **FY10** | **FY11** | **FY12** |
| **7SSE1 Green** | **8PS01 Green** | **9PS1 Green** | **10PS01 Green** | **PS-11-4 Green** | **PS-12-4 Green** |
| | | | | | |
| **Planned Annual Performance** | | | | | |
| **FY13 Update** | PS-13-3: Demonstrate planned progress in understanding how the Sun's family of planets, satellites, and minor bodies originated and evolved. Progress relative to the objectives in NASA's 2010 Science Plan will be evaluated by external expert review. | | | | |
| **FY14** | PS-14-4: Demonstrate planned progress in understanding how the Sun's family of planets, satellites, and minor bodies originated and evolved. Progress relative to the objectives in NASA's 2010 Science Plan will be evaluated by external expert review. | | | | |

| Reported Annual Performance | | | | | |
|---|---|---|---|---|---|
| **PS-12-5: Complete MESSENGER mission success criteria.** | | | | | |
| **Contributing Theme:** | Planetary Science | | | | |
| **Contributing Program(s):** | Discovery | | | | |
| **FY07** | **FY08** | **FY09** | **FY10** | **FY11** | **FY12** |
| **7SSE2 Green** | **8PS02 Green** | **None** | **None** | **PS-11-5 Green** | **PS-12-5 Green** |
| | | | | | |
| **Planned Annual Performance** | | | | | |
| **FY13 Update** | No annual performance goal in FY13. | | | | |
| **FY14** | No annual performance goal in FY14. | | | | |

## Reported Multi-Year Performance

**Multi-Year Performance Goal 2.3.2.2: By 2015, launch at least three missions in support of objective 2.3.2.**

| FY11 |
|---|
| Green |
| FY12 |
| Green |

The purpose of this performance goal is to design, develop, and launch satellites in support of objective 2.3.2, as outlined in the NASA Science Mission Directorate's 2010 Science Plan. On August 5, 2011, NASA launched the first mission, Juno, supporting this performance goal. It is on its way to the largest planet in the solar system, Jupiter, to collect data that will help scientists better understand how this gas giant planet formed and evolved. Shortly into FY 2013, Juno headed back toward the inner solar system to fly past Earth, gaining a gravity boost that sped it toward Jupiter.

NASA also is researching solar system bodies closer to home in support of its science objectives. On September 10, 2011, NASA launched the twin GRAIL spacecraft into orbit around the Moon to map lunar gravity and use that information to increase understanding of the Moon's interior and thermal history. By May 2012, GRAIL had accomplished its mission success criteria.

# PERFORMANCE REPORTING AND PLANNING

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| | The third mission also will be focused on lunar research. NASA completed the Delta-Systems Integration Review for the Lunar Atmosphere and Dust Environment Explorer (LADEE) on August 9, 2012, giving the project the go-ahead to integrate the systems into the spacecraft bus and begin testing. LADEE is planned for launch in late 2013, within the completion timeframe for this performance goal. LADEE will orbit the Moon to gather detailed information about the lunar atmosphere, conditions near the surface, and environmental influences on lunar dust. |

| **Update to Multi-Year Performance Goal** | |
|---|---|
| **FY13 Update** | This performance goal remains the same in FY13. |
| **FY14** | This performance goal remains the same in FY14. |

| **Reported Annual Performance** | | | | | |
|---|---|---|---|---|---|
| **PS-12-2: Complete New Frontiers 3 Preliminary Design Review.** | | | | | |
| **Contributing Theme:** | | Planetary Science | | | |
| **Contributing Program(s):** | | New Frontiers | | | |
| **FY07** | **FY08** | **FY09** | **FY10** | **FY11** | **FY12** |
| **None** | **None** | **None** | **10PS04 Green** | **PS-11-3 Green** | **PS-12-2 Yellow** |
| **Why this APG was not achieved:** At the time of the performance plan update, NASA had not completed the final negotiation on the procurement the Origins Spectral Interpretation Resource Identification Security Regolith Explorer (OSIRIS-REx) mission. The final agreement resulted in a proposed extended Phase B for the OSIRIS-REx project, which moved the Preliminary Design Review (the APG milestone) beyond fiscal year 2012, with the planned completion of the Mission Definition Review in FY 2012 instead. NASA made this change to reduce risk to cost and schedule performance for the project. | | | | | |
| | | | | | |
| **Planned Annual Performance** | | | | | |
| **FY13 Update** | PS-13-5: Complete the OSIRIS-REx Preliminary Design Review (PDR). | | | | |
| **FY14** | PS-14-2: Complete the OSIRIS-REx Critical Design Review (CDR). | | | | |

| **Reported Annual Performance** | | | | | |
|---|---|---|---|---|---|
| **PS-12-3: Complete the Discovery 12 mission concept studies.** | | | | | |
| **Contributing Theme:** | | Planetary Science | | | |
| **Contributing Program(s):** | | Discovery | | | |
| **FY07** | **FY08** | **FY09** | **FY10** | **FY11** | **FY12** |
| **None** | **None** | **None** | **None** | **None** | **PS-12-3 Green** |
| | | | | | |
| **Planned Annual Performance** | | | | | |
| **FY13 Update** | PS-13-2: Initiate the preliminary design for the Discovery 12 mission. | | | | |
| **FY14** | PS-14-3: Complete InSight Mission (Discovery 12) Critical Design Review. | | | | |

# PERFORMANCE REPORTING AND PLANNING

| Reported Annual Performance | | | | | |
|---|---|---|---|---|---|
| **PS-12-6: Complete the Lunar Atmosphere and Dust Environment Explorer (LADEE) Systems Integration Review.** | | | | | |
| **Contributing Theme:** | Planetary Science | | | | |
| **Contributing Program(s):** | Lunar Quest | | | | |
| **FY07** | **FY08** | **FY09** | **FY10** | **FY11** | **FY12** |
| **None** | **None** | **None** | **None** | **None** | **PS-12-6 Green** |
| | | | | | |
| **Planned Annual Performance** | | | | | |
| **FY13 Update** | PS-13-4: Launch the Lunar Atmosphere and Dust Environment Explorer (LADEE). | | | | |
| **FY14** | No annual performance goal in FY14. | | | | |

| Reported Annual Performance | | | | | |
|---|---|---|---|---|---|
| **PS-12-18: Complete GRAIL mission success criteria.** | | | | | |
| **Contributing Theme:** | Planetary Science | | | | |
| **Contributing Program(s):** | Discovery | | | | |
| **FY07** | **FY08** | **FY09** | **FY10** | **FY11** | **FY12** |
| **None** | **None** | **9PS3 Green** | **10PS03 Green** | **PS-11-7 Green** | **PS-12-18 Green** |
| | | | | | |
| **Planned Annual Performance** | | | | | |
| **FY13 Update** | No annual performance goal in FY13. | | | | |
| **FY14** | No annual performance goal in FY14. | | | | |

## Reported Multi-Year Performance

**Multi-Year Performance Goal 2.3.3.1: Provide national scientific capabilities through necessary skilled researchers and supporting knowledge base. (In support of objective 2.3.3: "Improve understanding of the processes that determine the history and future of habitability of environments on Mars and other solar system bodies.")**

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|---|
| **FY11** |
| **Green** |
| **FY12** |
| **Green** |

NASA provides the skilled researchers and supporting planetary science knowledge base necessary for the Nation's scientific capabilities.

**Mars Science Laboratory Curiosity's Roving Laboratory**

On November 26, 2011, the Mars Science Laboratory (MSL) Curiosity rover launched from Cape Canaveral. During the eight-month journey to Mars, the Radiation Assessment Detector (RAD), an instrument designed to measure the radiation levels on Mars, measured the radiation dose and detected a solar flare during the transport to Mars. On August 6, 2012, the Mars Reconnaissance Orbiter (MRO) imaged MSL's Curiosity rover as it successfully descended and landed via the skycrane landing system.

All of the science instruments on-board Curiosity are operating as expected. One of the earliest science highlights is from the Chemistry & Camera (ChemCam) instrument. ChemCam returned spectra from a basalt rock, demonstrating the first use of laser-based, active spectroscopy measurement for mineralogy identification on another planetary body. ChemCam imaged the ablated surface, providing magnified images of the fresh and

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| | weathered surfaces. On the drive from the Bradbury landing site toward Mt. Sharp, Curiosity investigated several rock outcrops, indicative of a streambed. For more information on MSL science results, join Curiosity on the traverse to Glenelg.<br><br>**Martian Meteorites Show Macromolecular Carbon of Non-Biological Origin**<br><br>The source and nature of carbon on Mars have been a subject of intense speculation. Recent results of spectroscopy on Martian meteorites, spanning about 4.2 billion years of Martian history, show that they contain a type of carbon that formed at high-temperature (i.e. in molten rock or magma). The association of organic carbon within magmatic minerals indicates that Martian magmas favored precipitation of reduced carbon species during crystallization. The ubiquitous distribution of this form of organic carbon in Martian rocks is important for understanding the Martian carbon cycle and has implications for future missions to detect possible past Martian life.<br><br>**Mars' Interior as Wet as Earth's**<br><br>Scientists have determined that the amount of water in the interior of Mars is comparable to the amount of water in the interior of Earth. The researchers study OH, a proxy for water, in apatite. Apatite is a mineral formed at high temperature in a hydrated magma (magma and water), and found in Martian meteorites. Those meteorites containing apatite represent a range of both depleted (crustal) and enriched (mantle) material on Mars. Laboratory investigations of the water abundance needed to form apatite in synthetic rocks were compared with the two Martian meteorites. The water content needed to form apatite in these meteorites is similar to the amount of water found in Earth mantle rocks like basalts. |

| **Update to Multi-Year Performance Goal** | |
|---|---|
| **FY13 Update** | This performance goal remains the same in FY13. |
| **FY14** | This performance goal remains the same in FY14. |

| **Reported Annual Performance** | | | | | |
|---|---|---|---|---|---|
| **PS-12-7: Demonstrate planned progress in understanding the processes that determine the history and future of habitability of environments on Mars and other solar system bodies. Progress relative to the objectives in NASA's 2010 Science Plan will be evaluated by external expert review.** | | | | | |
| **Contributing Theme:** | Planetary Science | | | | |
| **Contributing Program(s):** | Multiple Programs | | | | |
| **FY07** | **FY08** | **FY09** | **FY10** | **FY11** | **FY12** |
| **7SSE6 Green** | **8PS06 Green** | **9PS8 Green** | **10PS09 Green** | **PS-11-8 Green** | **PS-12-7 Green** |

# PERFORMANCE REPORTING AND PLANNING

| Planned Annual Performance | |
|---|---|
| **FY13 Update** | PS-13-6: Demonstrate planned progress in understanding the processes that determine the history and future of habitability of environments on Mars and other solar system bodies. Progress relative to the objectives in NASA's 2010 Science Plan will be evaluated by external expert review. |
| **FY14** | PS-14-5: Demonstrate planned progress in understanding the processes that determine the history and future of habitability of environments on Mars and other solar system bodies. Progress relative to the objectives in NASA's 2010 Science Plan will be evaluated by external expert review. |

| Reported Annual Performance | | | | | |
|---|---|---|---|---|---|
| **PS-12-8: Complete the Mars Science Laboratory (MSL) Launch Readiness Review.** | | | | | |
| **Contributing Theme:** | | Planetary Science | | | |
| **Contributing Program(s):** | | Mars Exploration | | | |
| **FY07** | **FY08** | **FY09** | **FY10** | **FY11** | **FY12** |
| **7SSE5 Green** | **8PS05 Green** | **9PS4 Red** | **10PS06 Yellow** | **PS-11-9 Green** | **PS-12-8 Green** |
| | | | | | |
| **Planned Annual Performance** | | | | | |
| **FY13 Update** | No annual performance goal in FY13. | | | | |
| **FY14** | PS-14-6: Achieve mission success criteria for Mars Science Laboratory (MSL). | | | | |

## Reported Multi-Year Performance

**Multi-Year Performance Goal 2.3.3.2: By 2015, launch at least two missions in support of objective 2.3.3.**

| FY11 |
|---|
| Green |
| FY12 |
| Green |

The purpose of this performance goal is to design, develop, and launch satellites in support of objective 2.3.3, as outlined in the NASA Science Mission Directorate's 2010 Science Plan. On November 26, 2011, NASA launched the biggest, most ambitious Mars science mission ever, MSL, which carried the Curiosity rover to the surface of Mars. Enabled by numerous new technologies and advanced capabilities (including an entirely new Sky Crane landing system, a radioisotope-based power system, an advanced communications capability, autonomous robotic navigation technologies, and compact science instrumentation), MSL successfully landed on Mars on August 6. Shortly after landing, Curiosity was taking panoramic photos of its surroundings. Since then, it has been on its mission to determine if the planet has ever had an environment capable of supporting life.

The second mission that will support this performance goal is the Mars Atmosphere and Volatile Evolution (MAVEN), planned for launch in late 2013. NASA completed the Systems Integration Review on June 28, 2012, giving the project the go-ahead to integrate the systems into the spacecraft bus and to start testing. MAVEN will orbit Mars to help determine how much of the Martian atmosphere has been lost over time. It will measure the current rate of atmospheric escape to space and gather enough information about the relevant processes to allow scientists to extrapolate backward in time.

| Update to Multi-Year Performance Goal | |
|---|---|
| **FY13 Update** | This performance goal remains the same in FY13. |
| **FY14** | This performance goal remains the same in FY14. |

# PERFORMANCE REPORTING AND PLANNING

| Reported Annual Performance | | | | | |
|---|---|---|---|---|---|
| **PS-12-8: Complete the Mars Science Laboratory (MSL) Launch Readiness Review.** | | | | | |
| **Contributing Theme:** | | Planetary Science | | | |
| **Contributing Program(s):** | | Mars Exploration | | | |
| **FY07** | **FY08** | **FY09** | **FY10** | **FY11** | **FY12** |
| **7SSE5 Green** | **8PS05 Green** | **9PS4 Red** | **10PS06 Yellow** | **PS-11-9 Green** | **PS-12-8 Green** |
| | | | | | |
| **Planned Annual Performance** | | | | | |
| **FY13 Update** | No annual performance goal in FY13. | | | | |
| **FY14** | No annual performance goal in FY14. | | | | |
| **Comments** | The Mars Science Laboratory spacecraft successfully launched on November 26, 2011. MSL's rover, Curiosity, is in operation on Mars, where it is collecting data in support of performance goal 2.3.3.1 through FY 2014, when it will conclude its prime mission. At that time, NASA will evaluate whether the Mars Science Laboratory achieved its mission success criteria. | | | | |

| Reported Annual Performance | | | | | |
|---|---|---|---|---|---|
| **PS-12-9: Complete the Mars Atmosphere and Volatile Evolution Mission (MAVEN) Systems Integration Review.** | | | | | |
| **Contributing Theme:** | | Planetary Science | | | |
| **Contributing Program(s):** | | Mars Exploration | | | |
| **FY07** | **FY08** | **FY09** | **FY10** | **FY11** | **FY12** |
| **None** | **None** | **None** | **10PS08 Green** | **PS-11-10 Green** | **PS-12-9 Green** |
| | | | | | |
| **Planned Annual Performance** | | | | | |
| **FY13 Update** | PS-13-7: Complete the Mars Atmosphere and Volatile EvolutioN Mission (MAVEN) Pre-Ship Review (PSR). | | | | |
| **FY14** | PS-14-7: Launch the MAVEN mission. | | | | |

## Reported Multi-Year Performance

**Multi-Year Performance Goal 2.3.4.1: Provide national scientific capabilities through necessary skilled researchers and supporting knowledge base. (In support of objective 2.3.4: "Improve understanding of the origin and evolution of Earth's life and biosphere to determine if there is or ever has been life elsewhere in the universe.")**

| | |
|---|---|
| **FY11** **Green** | NASA provides the skilled researchers and supporting planetary science knowledge base necessary for the Nation's scientific capabilities. |
| **FY12** **Green** | **New Equatorial Lakes Appear on Titan**<br><br>Observations from Cassini infrared spectra suggest a hydrocarbon lake (probably methane) and a few small ponds present in the equatorial region of Titan. With the exception of Earth, Titan is the only solid object in the solar system to circulate liquids in a cycle of rain and evaporation. On Titan, the process is driven by methane rather than water. This cycle is expected to form lakes near the moon's poles, but not at its dune-covered equator, where Cassini measurements show that humidity levels are low and little rain falls to the surface. |

# PERFORMANCE REPORTING AND PLANNING

Any surface liquid there should evaporate and be transported to the cooler poles, where it should condense as rain. The lake is approximately 60 kilometers long and 40 kilometers wide, and at least one meter deep. The shallower ponds resemble marshes on Earth, with knee- to ankle-level depths. Because equatorial lakes on Titan should evaporate over a period of just a few thousand years, the researchers argue that these ponds and lakes are being replenished by subsurface oases of liquid methane.

**Earth's History in Fossil Raindrops**

For the first time, studies define a constraint on total atmospheric pressure for early Earth, and could dramatically improve climate models for this timeframe, changing researchers' understanding of the planet at a time when life first arose. Researchers supported by the Exobiology element of the NASA Astrobiology Program have shown that fossil raindrop imprints constrained surface air density 2.7 billion years ago to less than twice modern levels. By studying the signatures of raindrops falling into volcanic ash, the researchers determined a relationship between the imprint size and raindrop impact momentum. Raindrop terminal velocity is dependent on air density, meaning that fossil raindrop imprints can provide direct information about the density of Earth's early atmosphere.

**DNA Building Blocks Made in Space**

NASA researchers found evidence that nucleobases, DNA components essential to life, were likely created in space. The findings support the theory that meteorite and comet impacts may have delivered a "kit" of ready-made materials from space to the early Earth, assisting the origins of life on this planet. Researchers also found abiotically produced "nucleobase-analogs" in the meteorites; these are extremely rare on Earth. The precursor nucleobases are present in space and demonstrate a possible mechanism for nucleobase generation in space.

| **Update to Multi-Year Performance Goal** | |
|---|---|
| **FY13 Update** | This performance goal remains the same in FY13. |
| **FY14** | This performance goal remains the same in FY14. |

| **Reported Annual Performance** | | | | | |
|---|---|---|---|---|---|
| **PS-12-11: Demonstrate planned progress in understanding the origin and evolution of life on Earth and throughout the biosphere to determine if there is or ever has been life elsewhere in the universe. Progress relative to the objectives in NASA's 2010 Science Plan will be evaluated by external expert review.** | | | | | |
| **Contributing Theme:** | Planetary Science | | | | |
| **Contributing Program(s):** | Multiple Programs | | | | |
| **FY07** | **FY08** | **FY09** | **FY10** | **FY11** | **FY12** |
| **7SSE4 Green** | **8PS04 Green** | **9PS5 Green** | **10PS07 Green** | **PS-11-11 Green** | **PS-12-11 Green** |

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| Planned Annual Performance | |
|---|---|
| **FY13 Update** | PS-13-8: Demonstrate planned progress in understanding the origin and evolution of life on Earth and throughout the biosphere to determine if there is or ever has been life elsewhere in the universe. Progress relative to the objectives in NASA's 2010 Science Plan will be evaluated by external expert review. |
| **FY14** | PS-14-8: Demonstrate planned progress in understanding the origin and evolution of life on Earth and throughout the biosphere to determine if there is or ever has been life elsewhere in the universe. Progress relative to the objectives in NASA's 2010 Science Plan will be evaluated by external expert review. |

## Reported Multi-Year Performance

**Multi-Year Performance Goal 2.3.5.1: Provide national scientific capabilities through necessary skilled researchers and supporting knowledge base. (In support of objective 2.3.5: "Identify and characterize small bodies and the properties of planetary environments that pose a threat to terrestrial life or exploration or provide potentially exploitable resources.")**

| | |
|---|---|
| **FY11** | NASA provides the skilled researchers and supporting planetary science knowledge base necessary for the Nation's scientific capabilities. |
| **Green** | |
| **FY12** | **NASA Near Earth Asteroid Survey** |
| **Green** | |
| | NASA and its partners maintain a watch for near-Earth objects, asteroids, and comets that pass close to Earth as part of an on-going effort to discover, catalog, and characterize these potentially hazardous objects. This fiscal year, asteroid search teams funded by NASA's Near Earth Object Observation (NEOO) Program found another 21 asteroids larger than one kilometer in size with orbits coming within Earth's vicinity. Asteroid search teams also found one more near-Earth comet and 896 smaller asteroids of less than one kilometer in average diameter, bringing the total number known of all sizes to 9,118. The high precision orbit predictions computed by NASA's Jet Propulsion Laboratory show that none of these objects is likely to hit Earth in the next century. An object designated 2011 AG5 currently has the highest chance of Earth impact, currently computed at one in 500 on February 5, 2040. However, 1,330 (of which 154 are larger than 1 kilometer in diameter) are in orbits that could become a hazard in the more distant future and warrant continued monitoring. |
| | **Detailed Characterization of Potentially Hazardous Asteroid** |
| | During its November 2011 passage, researchers obtained physical properties of potentially hazardous asteroid 2005 YU55 from multiple observations made by Goldstone, Arecibo, the Very Long Baseline Array, and the Green Bank Telescope. Radar analysis led to accurate measurement of the asteroid's albedo and spin period, and revealed a number of structures on the surface of the asteroid. High-resolution images showed concavities, a ridge near the asteroid's equator, and numerous features interpreted as decameter-scale boulders. The number of boulders on the surface is comparable to that seen on the asteroid 25143 Itokawa by the Hayabusa spacecraft. |
| | **Automated Potential NEA Destinations Assessment** |
| | In a cooperative effort between the Goddard Space Flight Center's Navigation and Mission Design Branch and the Jet Propulsion Laboratory's NEO Program Office, a new capability was added to routine near-Earth asteroid (NEA) processing in March 2012 that assesses the accessibility for human and robotic spaceflight destinations for all NEAs as they are |

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|---|---|
| | discovered. The assessment data is continuously updated automatically and made available to researchers and mission designers via a new section on NASA's NEOO Program Web page "Accessible NEAs." The goal is to identify NEAs that may be good targets for both human and robotic exploration missions. Any interested party also may go online to subscribe to a mailing list to receive a daily email notification of updated results.<br><br>The automated NEA accessibility assessment system monitors the space flight accessibility of the latest discoveries from the NEO search teams with up to date orbits and daily email notifications. The system continuously updates a comprehensive publically available database of potential human and robotic space flight targets and their round-trip mission opportunities. The Web site also displays upcoming opportunities to observe those NEAs using ground-based telescopes and radar. The database of NEAs potentially suitable for human space exploration will naturally continue to grow in the months and years to come as more and more NEAs are discovered and observed. |

| **Update to Multi-Year Performance Goal** | |
|---|---|
| **FY13 Update** | This performance goal remains the same in FY13. |
| **FY14** | This performance goal remains the same in FY14. |

| **Reported Annual Performance** | | | | | |
|---|---|---|---|---|---|
| **PS-12-12: Demonstrate planned progress in identifying and characterizing small bodies and the properties of planetary environments that pose a threat to terrestrial life or exploration or provide potentially exploitable resources. Progress relative to the objectives in NASA's 2010 Science Plan will be evaluated by external expert review.** | | | | | |
| **Contributing Theme:** | Planetary Science | | | | |
| **Contributing Program(s):** | Multiple Programs | | | | |
| **FY07** | **FY08** | **FY09** | **FY10** | **FY11** | **FY12** |
| **7SSE8 Green** | **8PS08 Green** | **9PS9 Green** | **10PS10 Green** | **PS-11-12 Green** | **PS-12-12 Green** |

| **Planned Annual Performance** | |
|---|---|
| **FY13 Update** | PS-13-9: Demonstrate planned progress in identifying and characterizing small bodies and the properties of planetary environments that pose a threat to terrestrial life or exploration or provide potentially exploitable resources. Progress relative to the objectives in NASA's 2010 Science Plan will be evaluated by external expert review. |
| **FY14** | PS-14-9: Demonstrate planned progress in identifying and characterizing small bodies and the properties of planetary environments that pose a threat to terrestrial life or exploration or provide potentially exploitable resources. Progress relative to the objectives in NASA's 2010 Science Plan will be evaluated by external expert review. |

| **Reported Annual Performance** | |
|---|---|
| **No annual performance goal in FY12 or trended performance.** | |
| **Contributing Theme:** | Planetary Science |
| **Contributing Program(s):** | Multiple Programs |

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| Planned Annual Performance | |
|---|---|
| **FY13 Update** | No annual performance goal in FY13. |
| **FY14** | PS-14-10: Conduct research into mitigation strategies utilizing observed characteristics and properties of those small bodies that pose a threat to terrestrial life. |

## Reported Multi-Year Performance

**Multi-Year Performance Goal 2.3.5.2: Return data for selection of destinations in order to lower risk for human space exploration beyond low Earth orbit.**

| FY11 |
|---|
| Green |
| FY12 |
| Green |

The routine processing and listing of accessible NEAs on the NASA NEOO Program Web site identifies and lists future observing opportunities for ground-based assets. These observing opportunities are used to obtain physical characterization information that could determine whether or not a particular NEA is suitable as a potential human destination. Ground-based sensors can provide details concerning the size, configuration, rotation rate, and composition of the NEA to help NASA mission planners and planetary scientists select the best targets for future human spaceflight missions. These opportunities are listed for optical and radar assets, which are used by the worldwide planetary astronomy community to perform physical characterization observations of these potentially accessible NEAs.

Several steps have been taken to aid the collection of physical characterization data on these potentially human accessible NEAs. Two presentations were held in 2012 to brief the international NEA observing community at the Lunar and Planetary Science Conference and the Division for Planetary Sciences Meeting about the new listing of accessible targets and their associated observing opportunities. Both of these meetings generated significant interest in these targets, and several observers expressed a desire to help NASA obtain physical characterization data on these potentially NEA destinations. Awareness of this new capability has led many observers to check routinely the list of accessible NEAs to plan and schedule telescope time for upcoming observation periods. In addition, daily emails of accessible NEAs are distributed and scanned for new discoveries, and if a promising target is immediately or soon-to-be observable, a request is sent out to the international observing community for physical characterization observations.

The NEOO Program pursued additional risk reduction efforts in coordination with the Human Exploration and Operation Mission Directorate's Joint Robotic Precursor Activity:

• Increased resources for time on ground-based planetary radars at Goldstone, CA, and Arecibo, PR, which enables a five-fold increase in the number of NEAs observed and characterized for precise orbit, size, and rotation information. An upgrade to the Goldstone radar has increased the resolution that can be imaged down to four meters.
• Performed extensive analyses to develop several design reference missions for NEA human exploration including identification of additional investments required (i.e., concepts of operations, vehicle sizing, advanced propulsion) to expand number of viable NEAs to explore.
• Supported multiple analog field tests, such as Desert Research and Technology Studies (RATS) and NASA Extreme Environment Mission Operations (NEEMO), for NEA mission system and operational concept validation and began planning for near-term asteroid analog mission at the International Space Station.
• Released a Request for Information from industry for design of an NEA detection instrument to be flown as a hosted secondary payload on geosynchronous satellites.

# PERFORMANCE REPORTING AND PLANNING

| Update to Multi-Year Performance Goal | |
|---|---|
| **FY13 Update** | This performance goal remains the same in FY13. |
| **FY14** | This performance goal remains the same in FY14. |

| Reported Annual Performance | | | | | |
|---|---|---|---|---|---|
| **PS-12-13: Demonstrate planned progress in characterizing potentially hazardous objects that are possible destinations for future human space exploration.** | | | | | |
| **Contributing Theme:** | | Planetary Science | | | |
| **Contributing Program(s):** | | Multiple Programs | | | |
| **FY07** | **FY08** | **FY09** | **FY10** | **FY11** | **FY12** |
| **None** | **None** | **9AC16 Green** | **10AC17 Green** | **PS-11-13 Green** | **PS-12-13 Green** |
| | | | | | |
| **Planned Annual Performance** | | | | | |
| **FY13 Update** | PS-13-10: Demonstrate planned progress in characterizing potentially hazardous objects that are possible destinations for future human space exploration. | | | | |
| **FY14** | PS-14-11: Demonstrate planned progress in characterizing potentially hazardous objects that are possible destinations for future human space exploration. | | | | |