The Present and Future of Space Science at NASA[1]

PAUL HERTZ
Chief Scientist
NASA Science Mission Directorate

Author's note: This paper was delivered to the American Philosophical Society on 24 April 2010. It captures a snapshot of NASA's Earth and space science program. Time has marched on: many of the events that were forecast have occurred, and some of the plans that were contemplated have been changed. Nevertheless, the science is still correct, and the breadth of the program described remains a valid indication of today's Earth and space science programs at NASA.

NASA conducts an extensive robotic science and exploration program, as well as extensive human-enabled science and exploration programs onboard the Space Shuttle and the International Space Station. The current overview summarizes the agency's robotic science program in Earth and space science.

NASA uses the vantage point of space to enable science that is from space, in space, and about space. It operates outward-looking satellites that study the universe, has the world's largest fleet of Earth-studying satellites, and is the largest contributor of climate monitoring and Earth systems science data.

NASA's science program focuses on answering several of the following profound questions that touch us all:

- How and why are Earth's climate and the environment changing?
- How and why does the Sun vary and affect Earth and the rest of the solar system?
- How do planets and life originate?
- How does the universe work, and what are its origin and destiny?
- Are we alone?

1 Read 24 April 2010, as part of the symposium *Space Science and Engineering: Present and Future*.

NASA is one of several federal government agencies dedicated to science. Its responsibilities include providing leadership in fundamental research, enhancing environmental stewardship, educating the next generation to create a world-class workforce, driving technological innovation, and extending partnerships domestically and internationally.

A number of strategic goals guide NASA's science program, and these goals are to:

- Advance scientific understanding of the changing Earth system to meet societal needs;
- Understand the Sun and its interactions with Earth and the solar system;
- Advance scientific knowledge of the origin and history of the solar system and the potential for life elsewhere; and
- Discover how the universe works, explore how the universe began and developed into its present form, and search for life elsewhere.

NASA's science practices conform to the highest standards of scientific integrity. NASA fully supports and implements the 4 August 2009 memorandum from the Directors of the President's Office of Management and Budget (OMB) and the Office of Science and Technology Policy (OSTP) to "conduct programs in accordance with the highest standards of ethical and scientific integrity and to have clear principles, guidelines, and policies on issues such as scientific openness, scientific misconduct, conflicts of interest, protection of privacy, and the appropriate treatment of human subjects."

NASA prioritizes its Earth and space science program based on input from the National Academy of Sciences (hereafter referred to as "the National Academy"). It has divided the science program into four general disciplines in science, and in each of those areas, the National Academy provides a decadal survey laying out the highest priority science to be accomplished in the upcoming decade. At the time this overview was delivered in 2010, the four most recent decadal surveys were *Astronomy and Astrophysics in the New Millennium* (2001); *New Frontiers in the Solar System: An Integrated Exploration Strategy* (2002); *The Sun to the Earth—and Beyond: A Decadal Research Strategy in Solar and Space Physics* (2003); and *Earth Science and Applications from Space: National Imperatives for the Next Decade and Beyond* (2007). As of April 2010, the three new decadal surveys in preparation are *New Worlds, New Horizons in Astronomy and Astrophysics* (2010); *Visions and Voyages for Planetary Science in the Decade 2013–2022* (2011); and *Solar and Space Physics: A Science for a Technological Society* (2012).

When NASA receives a new decadal survey, the science program of future exploration and missions is adjusted to be responsive to the priorities in science that are identified by the science community through the National Academy's decadal surveys. Because there is always too much science to do and not enough funding, one of the ways that NASA can ensure that its program advances the highest priorities in Earth and space sciences is to be responsive to the advisory reports received from the community and the National Academy.

The year 2009–10 was busy for NASA (Figure 1).[2] Some of the milestones from that period include: (1) the launch of two weather satellites that were built by NASA for the National Oceanic and Atmospheric Administration (NOAA); (2) the final servicing mission to the Hubble Space Telescope; (3) the launch of two European Space Agency (ESA) space telescopes that include major NASA contributions (i.e., Herschel, an infrared telescope, and Planck, a telescope to study the remnants of the Big Bang); (4) the launch of NASA's own infrared survey telescope, WISE; (5) the launch of the Solar Dynamics Observatory; and (6) a number of significant accomplishments in NASA's planetary science program.

In planetary science, the highlights include: (1) the launch of the Lunar Reconnaissance Observatory and that of the LCROSS Lunar Impactor, which impacted the Moon in October 2009 and revealed the presence of water ice in one of the permanently shadowed craters near the south pole of the Moon; (2) a flyby of Mercury by the MESSENGER spacecraft; and (3) several flybys of Saturn's moons by the Cassini spacecraft, which has been orbiting Saturn since 2004.

Earth Science

NASA has the largest fleet of Earth-observing satellites in the world. These satellites are continuing to provide data on a daily basis to observe our changing planet and help us understand how the Earth science systems interact with each other. NASA's Earth science program addresses the following questions:

- How is the global Earth system changing?
- What are the sources of change in the Earth system and their magnitude and trends?
- How will the Earth system change in the future?
- How can Earth system science improve mitigation of and adaptation to global change?

2 All Figures appear in the Appendix at the end of this paper.

Figure 2 is an image taken on 15 April 2010 of the Eyjafjallajökull volcano in Iceland using the Moderate Resolution Imaging Spectroradiometer onboard NASA's Aqua satellite. Eyjafjallajökull is the volcano whose eruption interrupted air travel throughout Europe and the north Atlantic. This image is the type of real-time data that NASA can provide not only to the science community but also to the operational community that responds to natural disasters like the Eyjafjallajökull eruption.

By observing the sea surface and atmospheric temperatures, long-duration oscillations in the ocean atmospheric system can be identified, including the Arctic Oscillation (Figure 3). The Arctic Oscillation is a seesawing strengthening and weakening of semi-permanent areas of low and high atmospheric pressure in the Arctic and mid-latitudes. One consequence of the oscillation's negative phase is cold, snowy weather in Eurasia and North America during the winter months. For example, the atmosphere was in an extreme negative phase of the Arctic Oscillation in December 2009 and January 2010, which contributed to the persistent cold and snow across much of the Northern Hemisphere's mid-latitudes during that time. The extreme negative dip of the Arctic Oscillation Index in December 2009 was the lowest monthly value observed for the past six decades.

The GRACE satellite is a gravity mapper in orbit around the Earth. By mapping the Earth's gravitational field, it is possible to map the motion of the continental plates. However, GRACE is so sensitive that it is actually possible to map the changing amount of groundwater in different parts of the Earth. Two examples shown in Figure 4 are in California. A long-term decline can be seen in the amount of water in the aquifers in central California; these aquifers provide the water for agriculture there. Additionally, in India, a declining amount of groundwater can be seen in the areas of the country where a significant number of people live; this depletion is occurring because the water is being used faster than it is being replenished by the melting glaciers from the Himalayas.

Heliophysics

A fleet of satellites throughout the solar system is dedicated to *heliophysics*, or the study of the Sun and its influence on the Earth and the solar system. NASA has satellites in orbit around the Earth to observe the Earth's magnetic field and upper atmosphere, and there are satellites through the Earth's greater magnetosphere to monitor the energy input that comes in from the Sun. NASA also has satellites throughout

the solar system, such as Voyager and SOHO. SOHO is a million miles closer to the Sun than Earth and is constantly observing the Sun from that upstream location, whereas Voyager is on its way out to the outer edges of the solar system and is sampling the boundary between our heliosphere and the galaxy itself. NASA's heliophysics program addresses the following questions:

- What causes the Sun to vary?
- How do the Earth and heliosphere respond?
- What are the impacts of space weather on humanity?

Figure 5 is a picture of the Sun taken on 30 March 2010 using NASA's Solar Dynamics Observatory. The Solar Dynamics Observatory is sending down 1.5 terabytes of data per day; it takes full-disk images of the Sun in multiple spectral bands with 0.5 arcsecond spatial resolution every 10 seconds. The high-definition images contain beautiful detail at several times the resolution of the printed image shown here. A large solar prominence is visible on the upper left-hand side.

One of the missions in place for monitoring the Sun is STEREO. STEREO is a pair of satellites, one of which (STEREO A) is in orbit ahead of the Earth and one of which (STEREO B) is in orbit behind the Earth. They are looking at two different views of the Sun, whereas missions such as SOHO and the Solar Dynamics Observatory are near the Earth and are looking at the Sun only from the Earth's viewpoint. This means that solar activity such as that shown in Figure 6, which formerly could be seen only by SOHO on the limb of the Sun, can now be seen by STEREO B on the face of the Sun. These multiple viewpoints enable the creation of three-dimensional (3-D) models of dynamic structures on the Sun so they can be studied in their full 3-D glory.

Another mission in space right now is the Interstellar Boundary Explorer, which for the first time is making an image of the boundary between our solar system and the rest of the galaxy. It does this by detecting the neutral atoms that are scattered off the shock wave that is formed as our Sun and its planets move through the interstellar medium. In this first image (Figure 7), the expectation was to see the boundary of the solar system looking like a traditional dipole, where it would be brighter in the direction the Sun is moving and fainter in the opposite direction. However, the structure looks like a ribbon, and none of the theorists predicted that—but all of the theorists can explain it after the fact. The current explanation is that this finding is an indicator of strong galactic magnetic fields that are concentrating the ions along the particular great circle projected on the bow wave that the solar system is making as it moves in the galaxy.

Planetary Science

Planetary science is a very exciting area of NASA's program. NASA has a fleet of missions throughout the solar system, with particular attention given to the planet Mars because it is extremely interesting and quite accessible. That combination makes it a great place to go exploring. NASA has two rovers, Spirit and Opportunity, on Mars. The Phoenix Lander completed its mission in 2009; NASA will be launching a new rover in November 2011.[3] NASA's planetary science program addresses the following questions:

- How did the Sun's family of planets, satellites, and minor bodies originate and evolve?
- What are the characteristics of the solar system that lead to habitable environments?
- How and where could life begin and evolve in the solar system?
- What are the characteristics of small bodies and planetary environments that pose hazards or provide resources?

The MESSENGER spacecraft will be the first spacecraft to go into orbit around Mercury in 2011.[4] It is very hard to get into orbit around Mercury because once a spacecraft is flying toward Mercury, it is then also falling into the Sun. This accelerates the spacecraft, and by the time it gets to Mercury, it is going too fast to enter into orbit around the planet. What MESSENGER has to do is make several retrograde flybys of Mercury and lose a little speed each time. It is on the fourth flyby that it will actually go into orbit around Mercury. Some pictures from the first two flybys are shown in Figure 8, and parts of Mercury that have never been seen before, including extremely large impact basins with newer craters on top of them, are also shown. Several scarps and other very sharp features, which are probably due to gravitational stressing of the planet from being close to the Sun, are visible. Mercury is in a resonant orbit so that every second time around the Sun, the same side of the planet will come back around to face the Sun.

With the ESA's Venus Express mission, evidence of recent volcanism on Venus has been seen. This result is obtained by comparing the Magellan images from several decades ago with the new images from the current mission (Figure 9).[5] So once again, revisiting a planet allows short-term changes (short on geological timescales) to be seen that are

3 The Mars Science Laboratory, carrying the Curiosity rover, successfully landed on Mars on 6 August 2012.

4 The MESSENGER spacecraft successfully entered orbit around Mercury on 18 March 2011; the MESSENGER mission ended when the spacecraft impacted the Mercury surface on 30 April 2015.

5 NASA's Magellan spacecraft entered Venus orbit on 10 August 1990; radio contact with Magellan was lost on 12 October 1994.

happening on the planet. Venus is a dynamically alive planet, as well as Mars.

Moving out into the solar system, Figure 10 is a picture of Mars showing an avalanche that took place on the planet. One of the great things about having long-lived observatories around other planets is that they are actually operating long enough to see secular changes take place. Here, an avalanche, which occurred because of some small meteorite that probably hit there and caused this very loosely bound dust on the edge of the mountain to flow down under the influence of gravity, is visible.

When imaging is repeated at certain places on Mars, changes can be seen. As seen in Figure 11, a fresh meteorite crater apparently revealed ice at the bottom, and then 90 days later, that ice has sublimated and disappeared from the surface of Mars. Such changes have to be caught by accident, of course: they cannot be predicted. However, several have been observed by now. This ice is only about a meter below the surface. If the Viking Landers of the 1970s had dug just a little bit deeper, they may have actually reached ice under the surface of Mars. The Phoenix Lander that went to the polar region of Mars recently did touch the ice at that northern latitude, but even near the Equator, it is possible that ice is not too far below the surface over much of the planet. This ice could be a great resource for sending humans to Mars some day in the future.

Titan, the largest moon of Saturn, has been imaged dozens of times by the Cassini spacecraft as it flies by. Titan has a complete hydrological methane cycle, or rather an atmosphere so full of methane that it is very near the point at which methane can rain out of the atmosphere. When it rains out, it forms rivers, which form lakes, and then the methane evaporates back up to complete a weather cycle on the surface of Titan. Figure 12 provides several images of Titan. The lower image is one of the lakes on Titan; Titan is covered with opaque clouds, so these pictures are taken with a radar that can see through the clouds, which is why it does not quite look like an optical image. The upper image was taken by the Cassini spacecraft when Titan was between it and the Sun, and a specular reflection of the Sun off of one of the lakes on Titan is visible. This evidence strongly suggests that the lakes on Titan are actually filled with liquids as opposed to something frozen: the methane lakes on Titan really are filled with liquid methane.

Figure 13 shows an image of the limb of the moon Enceladus, which is another one of Saturn's moons. Enceladus has geysers erupting near its south pole, and this is a false color image of them. The upper left image is a thermal image of the part of Enceladus from where the geysers erupt; it shows the geysers erupting at warm areas. These

geysers are being heated from below; the energy to heat them comes from the tidal stressing of Enceladus, which is a result of the moon's orbit around Saturn, and the material that erupts from the geysers is water. The water then freezes into ice, which is known because Cassini was flown at a height of 50 kilometers through the plume so that the composition could be determined to be water ice. Enceladus is another place in the solar system where water exists beneath the surface.

NASA's next large planetary mission is the Mars Science Laboratory; it will be launching in October 2011 (Figure 14). Late in 2011 is the next time when the planets align so it is energetically efficient to send something to Mars. The Mars Science Laboratory is now in the assembly and test phase, which leads up to launch operations, and all major components are waiting to be assembled.[6]

Astrophysics

NASA has a suite of satellites in orbit to study the universe. Space science is very much a global enterprise, and more than 70% of NASA's missions are partnerships with other space agencies. These space telescopes study the universe at different wavelengths and with different capabilities. NASA's astrophysics program addresses the following questions:

- How do matter, energy, space, and time behave under the extraordinary diverse conditions of the cosmos?
- How did the universe originate and evolve to produce the galaxies, stars, and planets we see today?
- What are the characteristics of planetary systems orbiting other stars, and do they harbor life?

Figure 15 is a picture released on 24 April 24 2010, the Hubble Space Telescope's 20th anniversary. It is a star-forming region in the Carina Nebula. Originally, there was a large cloud of gas and dust; now, there are bright stars outside the area of the image, which are radiating strongly and burning away the dust, except where there is a new star forming. The new star forms a shadow, and behind that star, in the shadow of the radiation, a column or pillar of gas and dust remains. These are the types of images that scientists have been using the Hubble Space Telescope to obtain to allow an understanding of the process of star formation in our own galaxy.

NASA's Fermi telescope is a gamma ray telescope. It is the first telescope that can image with gamma rays and to such an extent that, in

6 The Mars Science laboratory, carrying the Curiosity rover, successfully landed on Mars on 6 August 2012.

fact, the Centaurus A Radio galaxy is visible on the all-sky map (Figure 16). The background star field is from a visible light image, but the purple is the gamma rays. The galaxy is clearly resolved in gamma rays. This galaxy has radio jets that come out in the vertical direction, and the energetic particles forming the radio jets will interact with the surrounding magnetic fields to generate the gamma ray radiation that is imaged by Fermi. This is the first extra galactic source to be resolved in gamma rays, and there will be more coming from the Fermi telescope.

Figure 17 shows two images from the Hubble Space Telescope. The left image is a *brown dwarf*, a small star that is one-fifth the mass of the Sun, and this brown dwarf has a companion. Through the magic of computer imaging, the light from the brown dwarf star is subtracted out to reveal just the companion in the right image. This companion's mass is five times that of Jupiter's. One might say that the companion is a planet around the brown dwarf; however, the current International Astronomical Society definition of a planet says a planet has to be orbiting a star. Because there is some discussion about whether brown dwarfs qualify as stars, there is also discussion about whether the companion qualifies as a planet. So, the companion is carefully labeled as a *planetary mass companion* rather than a planet.

The WISE mission was launched in December 2009. A launch picture is shown in Figure 18. WISE is conducting an all-sky survey in the near- and mid-infrared. It is going to find things that are cold and best detected by their thermal radiation rather than by visible light radiation. It will find some of the brightest galaxies in the universe, where their brightness is obscured by significant dust surrounding them. WISE will also find local objects, such as asteroids, in our solar system that are relatively dark but can be seen through their thermal radiation. Finally, it may find the star that is closest to the Sun, if there is a star closer than Proxima Centauri and if that star is a brown dwarf or some other cool star that is too faint in visible light to have been previously discovered.

Coming online in 2010 is the SOFIA airborne observatory (Figure 19). It has a 100-inch-diameter (2.5-meter-diameter) telescope that is optimized for the far infrared. SOFIA will be flying at a 40,000-ft. altitude, which is above 99.9% of the water in the Earth's atmosphere, so it can get a clear view of the far infrared sky without the expense of sending a cryogenic instrument into space. SOFIA will be carrying cryogenically-cooled instruments in the cabin with the scientists. Although SOFIA has the capabilities of a space telescope, every night it will come home. It will be serviced; it will have its cryogens refilled; the instruments will be changed out; and it will fly again the next night. In

2010, SOFIA is undergoing its flight tests and will have its first light in May 2010 and its first science later in 2010.[7]

The next great observatory that NASA is building is the James Webb Space Telescope (JWST; Figure 20). JWST has a 6.5-meter segmented primary telescope. All the hardware for JWST is coming together. The middle right image is a model of the tennis-court-sized sunshields, which will open up and protect the telescope from the Sun so that it can remain passively cooled to an operating temperature of about 40° K. The upper right image shows three of the flight mirror segments being tested at cryogenic temperatures in our cryogenic test facility in Huntsville, Alabama. The lower right image shows the support mechanism that will hold the mirror panels in the proper position for imaging. The upper center image is the support mechanism that will hold the three primary scientific instruments, which will sit right behind the sunshield. JWST will be launching in 2018. As of 2015, JWST is entering the assembly and test phase, and it is on track for launch in October 2018.

The president's fiscal year 2011 (FY2011) budget request for NASA science (Figure 21) provides the funding required for NASA to continue executing a space and Earth science program that addresses national needs and priorities. The NASA science budget planning strategy is:

- Be responsive to the science community by supporting the priorities established in the National Academy of Sciences decadal surveys;
- All missions should be chosen through decadal surveys or competitive peer review; and
- Be responsive to national priorities.

The highlights of the president's plan for NASA include[8]:

- Earth Science
  - All Foundational missions launched by mid-calendar-year (CY) 2013 (Glory, Aquarius, NPP, LDCM, GPM).
  - OCO-2 development and launch by February 2013.
  - Accelerate selected decadal survey systematic missions; launch all four Tier-1 missions between 2014 and 2017.
    - ◊ SMAP (November 2014); ICESAT-2 (October 2015); DESDynI (2017); CLARREO-1 (2017).
  - Expand and accelerate Venture-class competitive, PI-led program.

7 SOFIA completed development and entered full science operations in May 2014.

8 As of 2015, not all of the projects and missions that were included in the FY2011 budget request are still planned for implementation.

  - Develop selected climate continuity missions.
    - ◊ SAGE-III refurbishment ready for flight to ISS late CY2013
    - ◊ Launch GRACE follow-on (GRACE-FO) in late CY2015 (joint with DLR).
- Heliophysics
  - Develop and launch SDO and RBSP, the first 2 missions in the Living with a Star program.
  - Continue MMS and Solar Probe Plus.
- Planetary Science
  - Pursue partnership with ESA for Mars Program & Outer Planet Flagship.
  - Prepare Juno, MSL, and GRAIL for launch in 2011 and MAVEN for launch in 2013.
  - Begin production of Pu-238 for future missions
- Astrophysics
  - Develop JWST, SOFIA, NuSTAR, Astro-H, and GEMS.
  - Respond to the decadal survey.

Figures 22 and 23 show the milestones coming up for NASA science missions over 2010–12. In 2010 and early 2011, SOFIA will begin conducting science flights; NASA will be launching two climate-monitoring satellites (Aquarius measures the salinity of the oceans, and Glory measures aerosols and particulates in the Earth's atmosphere); Cassini will be continuing its flybys of the moons of Saturn; Rosetta will be flying by an asteroid; EPOXI will be flying by a comet; MESSENGER will be entering orbit around Mercury; and the NExT spacecraft will also be flying by a comet. In 2011 and early 2012, the NuSTAR hard X-ray telescope will be launched; the GRAIL gravity mapper will be launched to measure the interior of the Moon and determine the structure of the lunar core; Dawn will be going into orbit around the asteroid Vesta and, after 6 months there, will move on to Ceres; Juno will be launching to Jupiter; and the Mars Science Laboratory will be launching to Mars.

Figures 24, 25, and 26 show NASA's mission plans in Earth and space science for the next few years.

In closing, consider the beautiful image of Saturn in Figure 27. This picture of Saturn was taken from a unique vantage point. The Cassini spacecraft is on the far side of Saturn, looking back toward the inner solar system. The Sun is behind Saturn, providing a view of Saturn's night side, which can never be seen from the Earth because the Earth is always on the same side of Saturn as the Sun. Additionally, the Earth itself is visible behind Saturn's rings, providing a unique vista of humanity's place in the universe. One of the unique roles of NASA is to provide such valuable new vantage points from which to conduct compelling science investigations.

Appendix

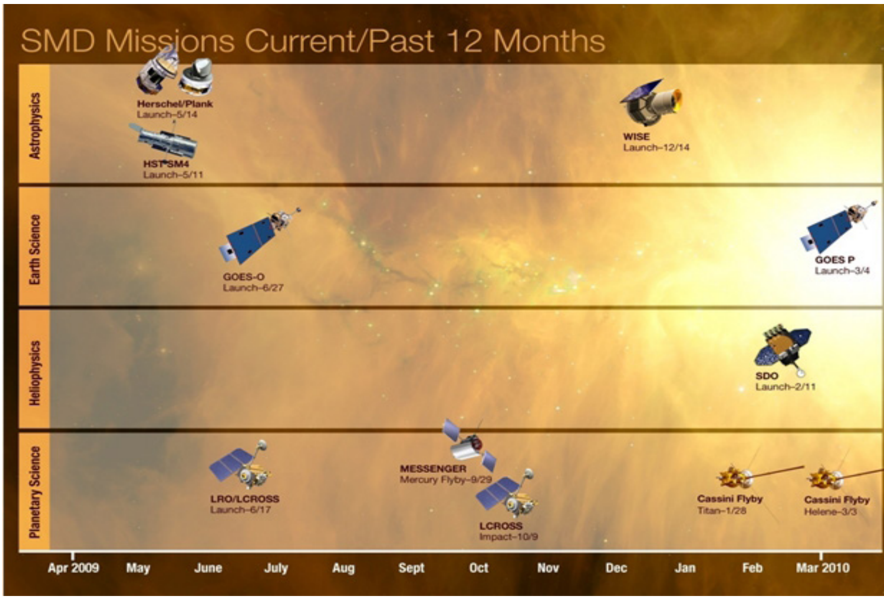

FIGURE 1. Milestones for NASA's science missions in 2009–10.

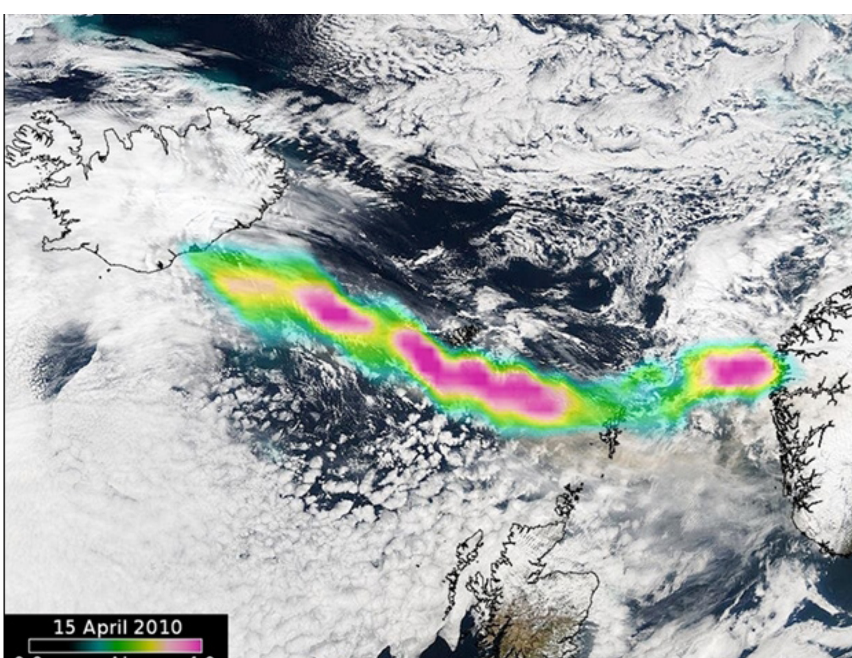

FIGURE 2. Images of the Eyjafjallajökull ash cloud obtained with the Aqua satellite.

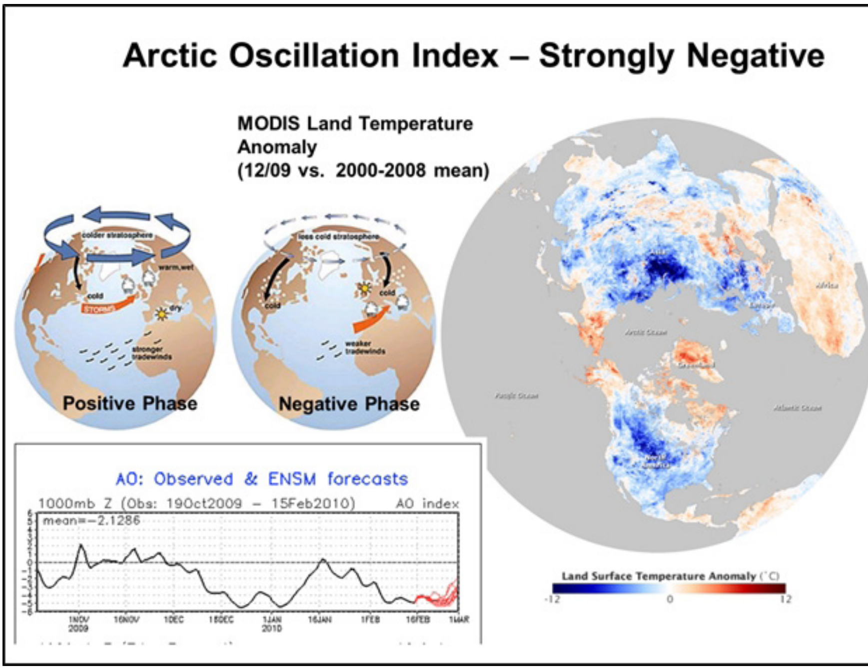

FIGURE 3. The Arctic Oscillation Index.

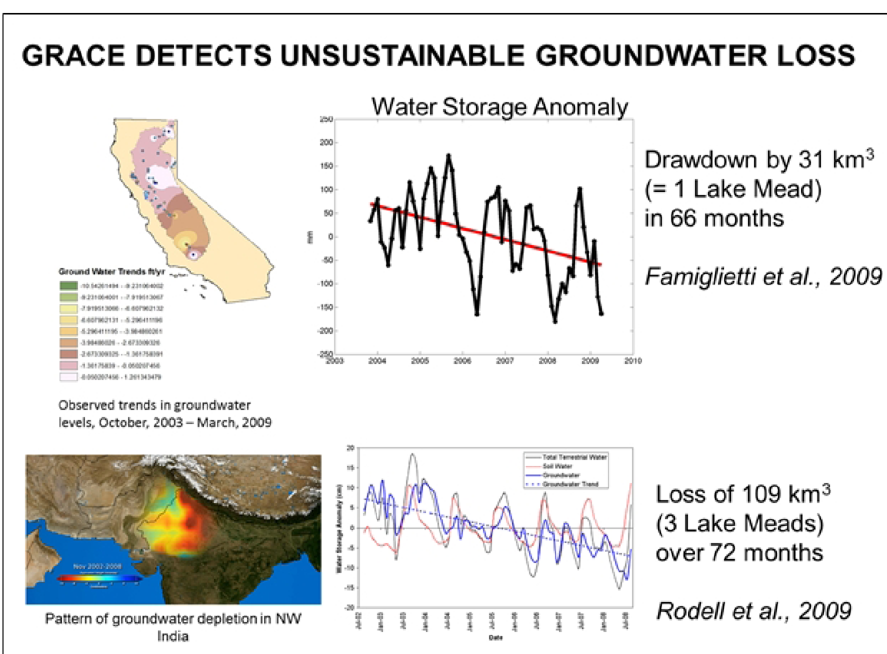

FIGURE 4. GRACE detects unsustainable groundwater loss.

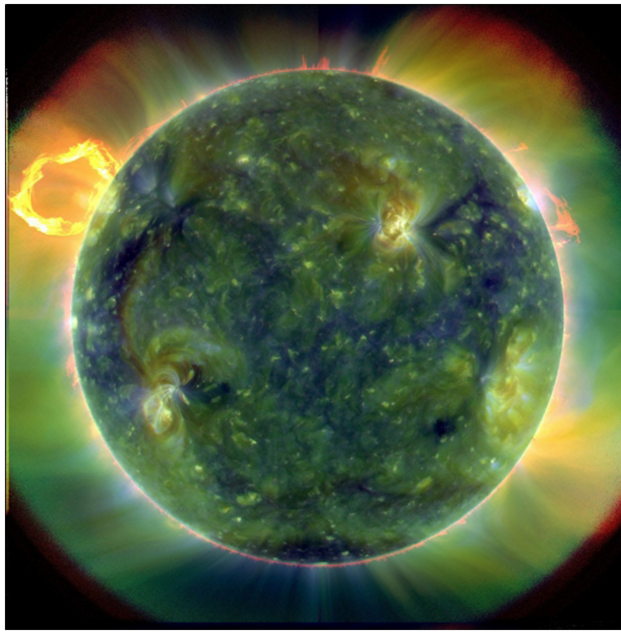

FIGURE 5. Image of the Sun obtained on 30 March 2010 with the Solar Dynamics Observatory.

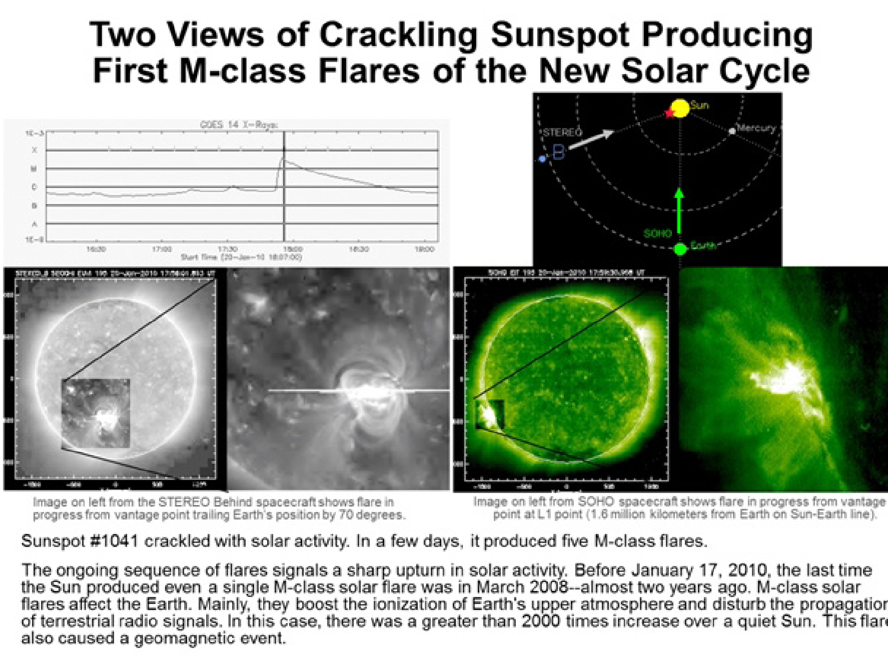

FIGURE 6. Two views of a crackling sunspot producing the first M-class flares of the new solar cycle.

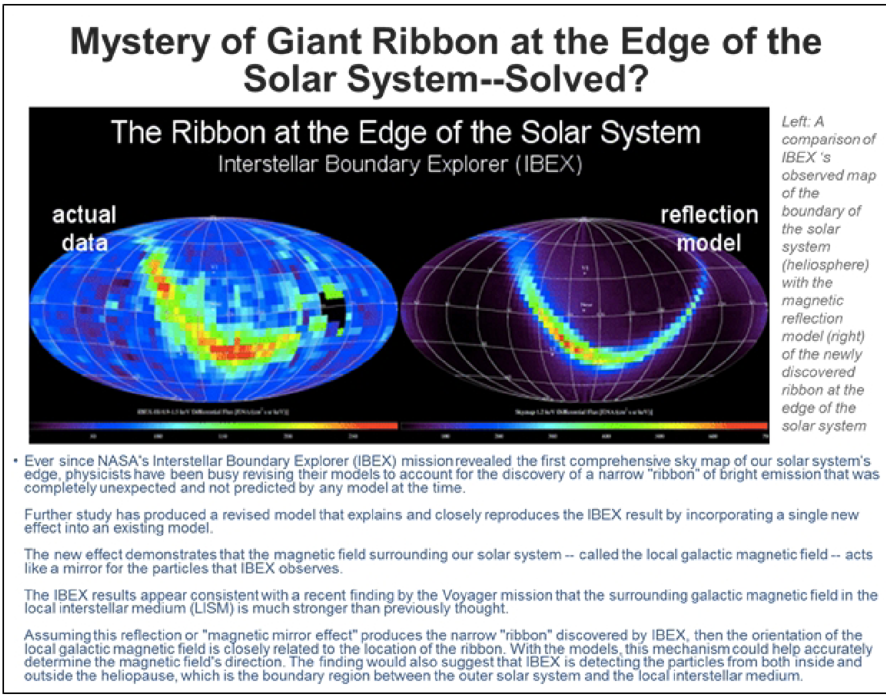

FIGURE 7. Mystery of giant ribbon at the edge of the solar system solved by the IBEX mission?

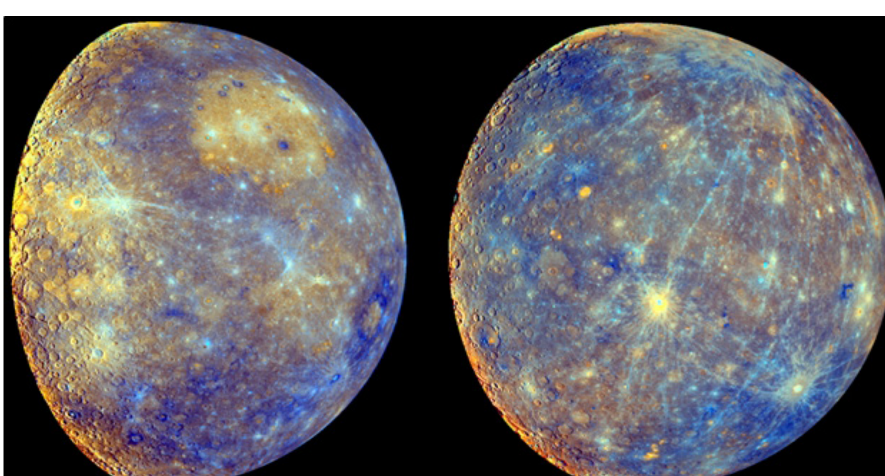

FIGURE 8. Images from MESSENGER flybys of Mercury in January and October 2008.

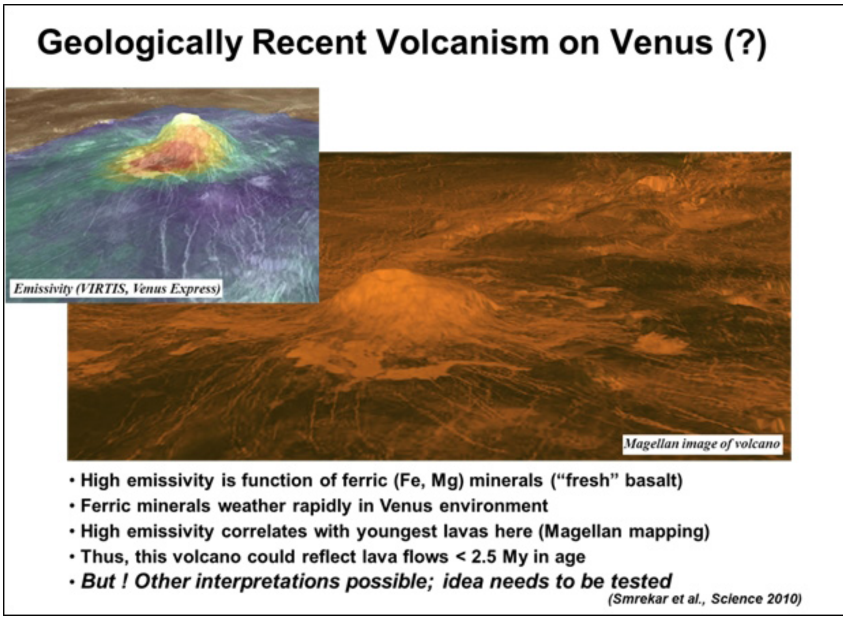

FIGURE 9. Geologically recent volcanism on Venus.

FIGURE 10. Images of an avalanche on Mars obtained with the Mars Reconnaissance Observatory.

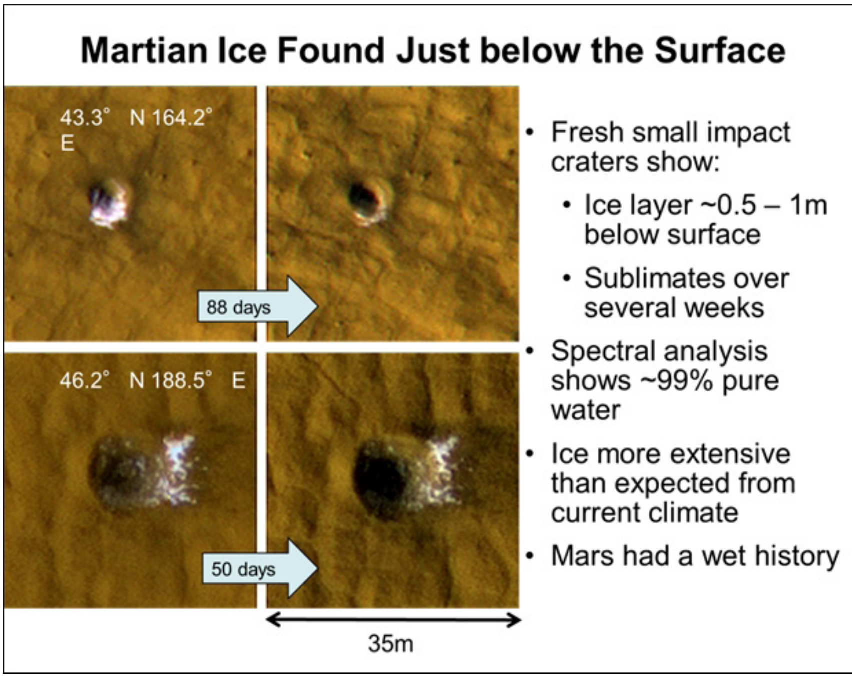

FIGURE 11. Martian ice found just below the surface.

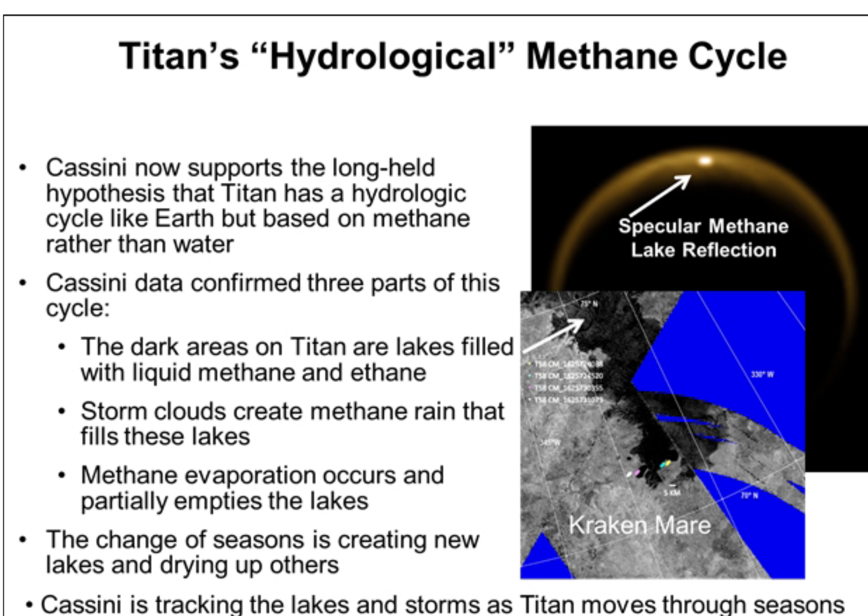

FIGURE 12. Titan's "hydrological" methane cycle.

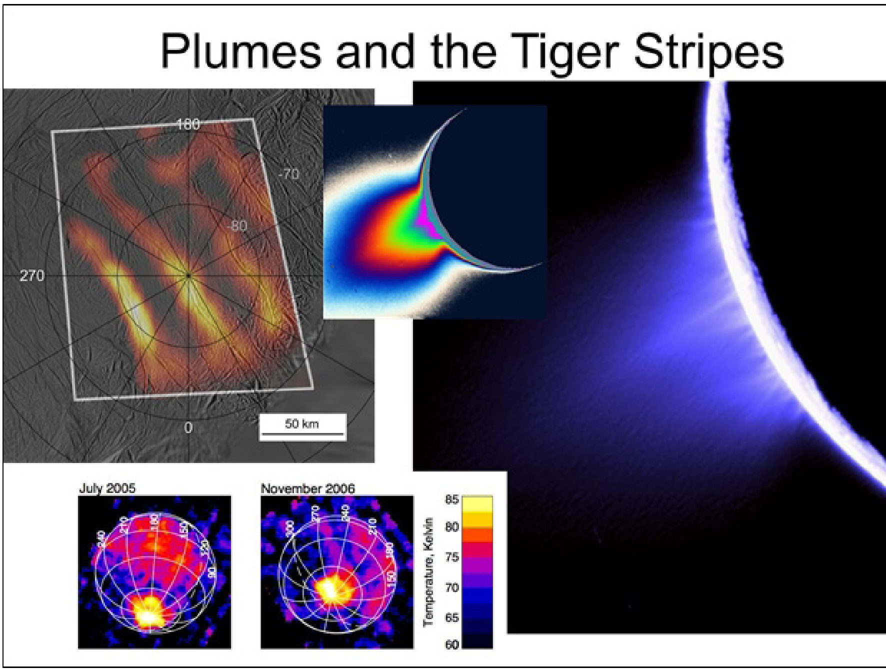

FIGURE 13. Plumes from Saturn's moon Enceladus.

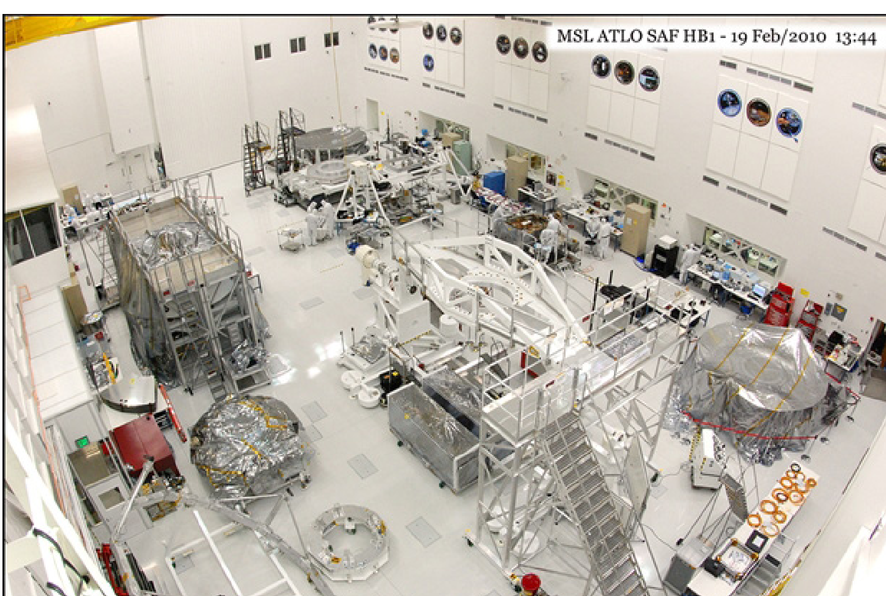

FIGURE 14. Mars Science Laboratory at the Jet Propulsion Laboratory during the integration and test phase of development.

Figure 15. Hubble Space Telescope image of HH 901 and HH 902 in the Carina Nebula.

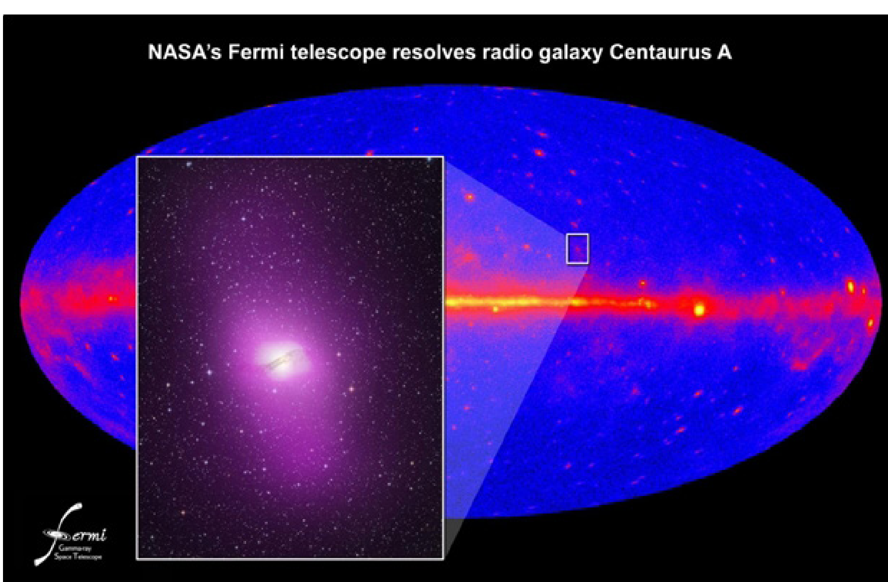

Figure 16. Fermi telescope resolves radio galaxy Centaurus A.

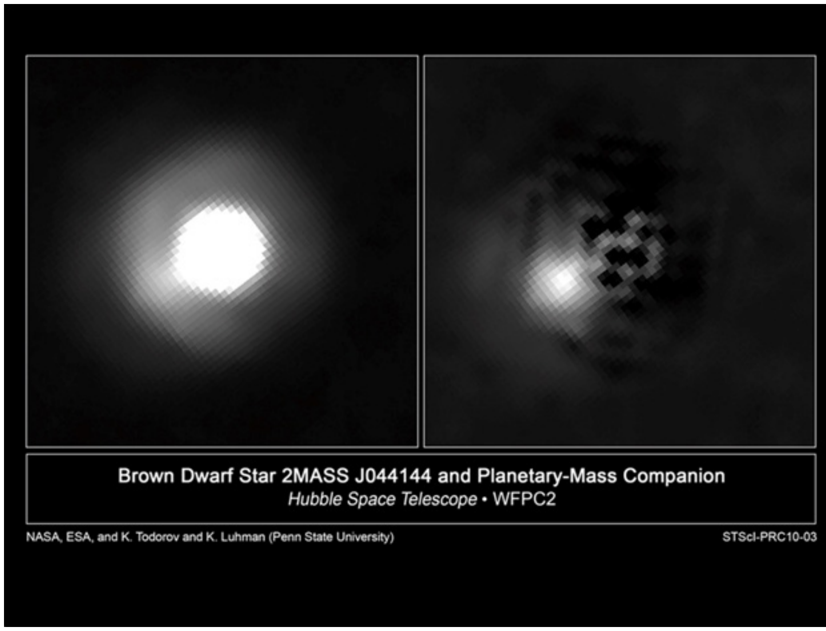

FIGURE 17. Hubble Space Telescope image of a brown dwarf star and its planetary mass companion.

FIGURE 18. The WISE all-sky infrared survey is underway.

FIGURE 19. The SOFIA airborne observatory.

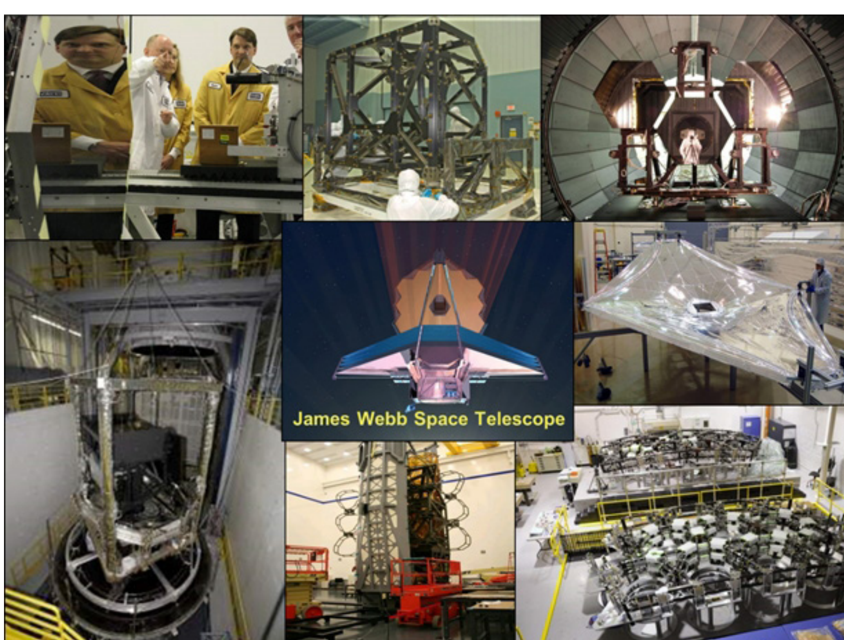

FIGURE 20. The James Webb Space Telescope under development.

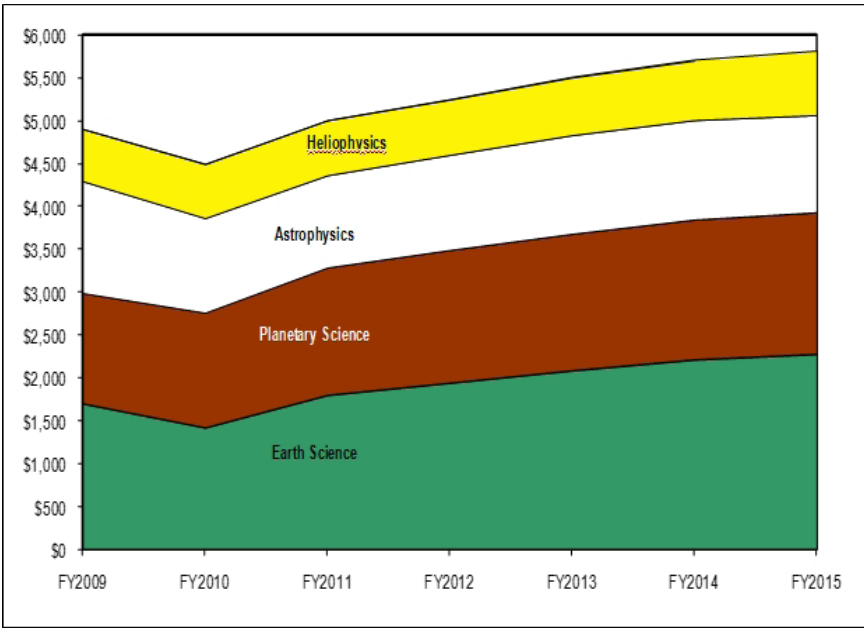

Figure 21. The president's FY2011 budget request for NASA science, including the notional 5-year run out for planning purposes.

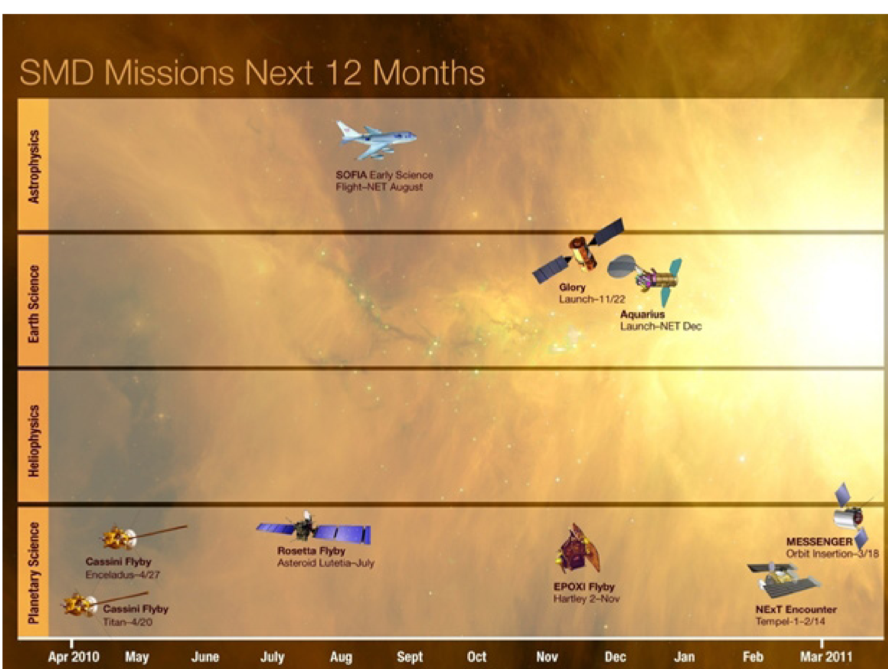

Figure 22. Milestones for NASA's science missions 2010–11.

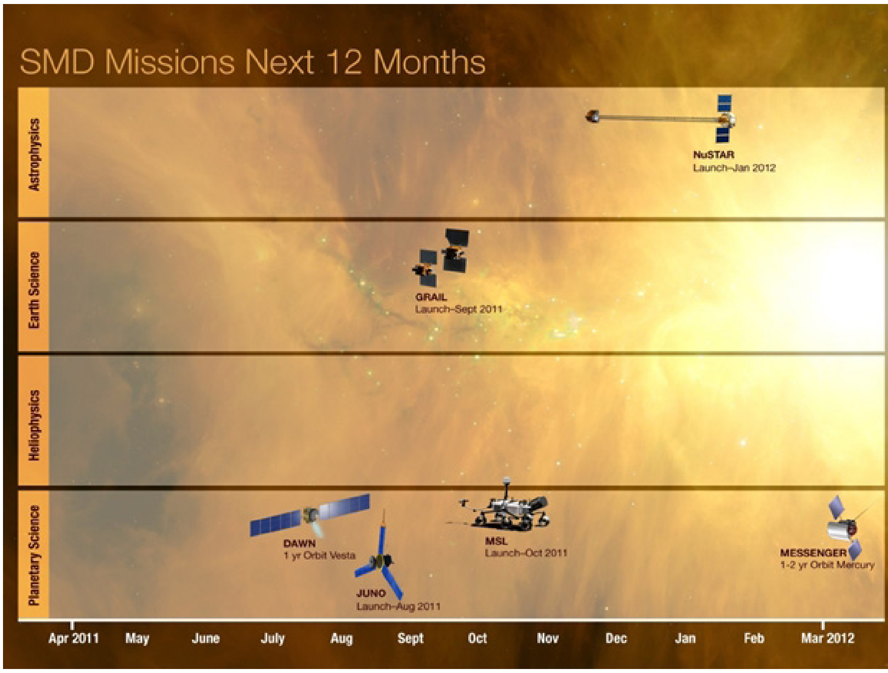

FIGURE 23. Milestones for NASA's science missions 2011–12.

Upcoming Planetary Mission Events

2010

June 13 - Hayabusa (JAXA) asteroid sample return
July 10 – Rosetta (ESA) closest approach for Lutetia
August 28 – Launch of O/OREOS
November 4 - EPOXI encounters comet Hartley 2
Late '10 Venus Climate Orbiter (JAXA) arrives at Venus
Late '10- Early '11 – Opportunity gets to Endeavour

2011

February 14 - Stardust NExT encounters comet Tempel-1
March 18 - MESSENGER orbit insertion at Mercury
July - Dawn orbit insertion at asteroid Vesta
August - Juno launch to Jupiter
September - GRAIL launch to the Moon
October - MSL launch to Mars

2012

Mid-year – Dawn leaves Vesta starts on its journey to Ceres
August - MSL lands on Mars
Late '12 to early '13 - LADEE launch to the Moon

FIGURE 24. Upcoming events in planetary science.

Future Earth Science Missions

Mission	LRD	Description
Glory	11/2010	Aerosol properties & total solar irradiance
Aquarius	NET 12/2010	Sea surface salinity
NPP	NET 9/2011	Continue key measurements from Terra & Aqua
LDCM	12/2012	Land cover / land use change
GPM Core	7/2013	Global precipitation
OCO-2	2/2013	Global measurement of atmospheric CO_2
SAGE-III on ISS	11/2013	Atmospheric composition
SMAP	11/2014	Soil Moisture
ICESAT-2	10/2015	Ice sheet topography (successor for ICESAT)
GRACE-FO	12/2015	Earth's gravity field (successor for GRACE)
CLARREO	10/2017	Solar and Earth radiation
DESDynI	10/2017	Land surface and ice sheet deformation
Venture Class		Annual Instrument Solicitation Beginning FY12; First small-sat Venture mission call in FY12

FIGURE 25. Upcoming events in Earth science.

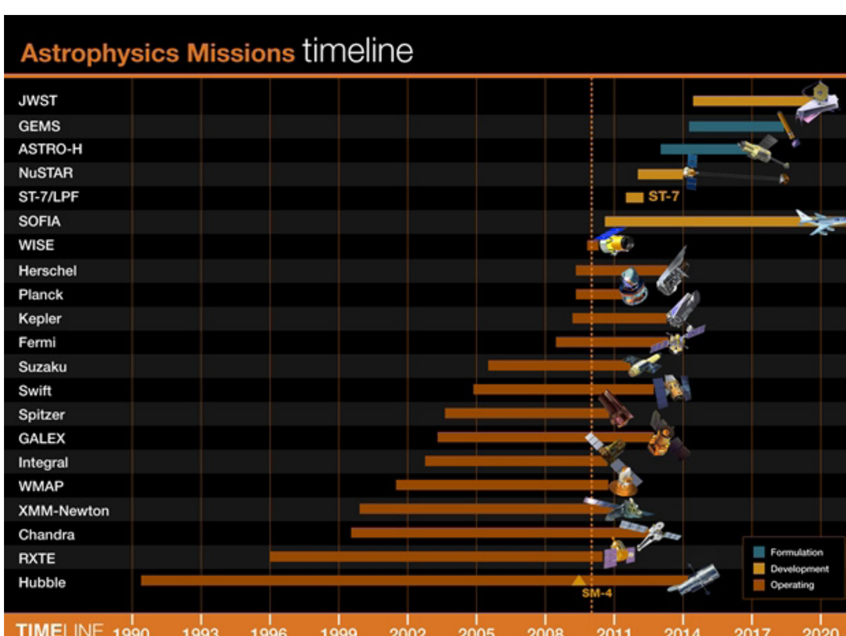

FIGURE 26. Upcoming events in astrophysics.

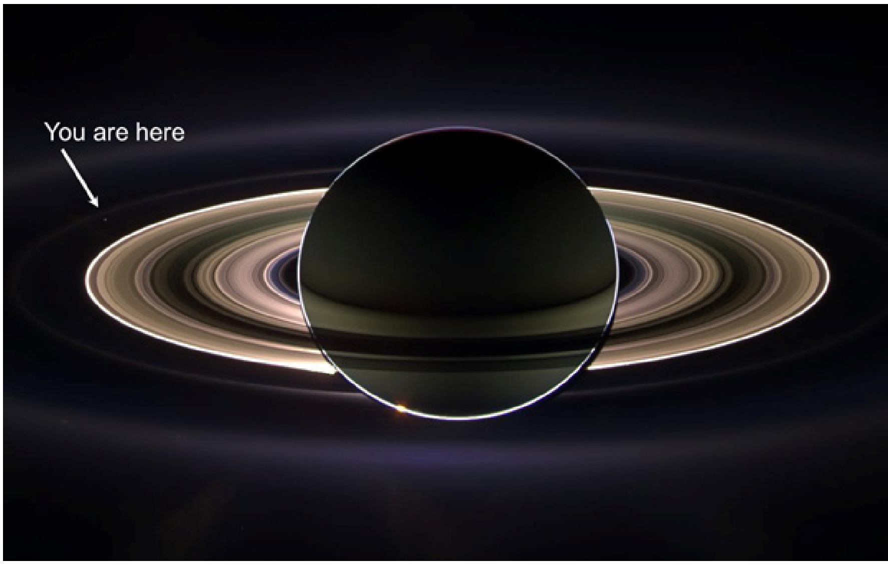

FIGURE 27. A view of Saturn and Earth from the Cassini spacecraft.