Near Earth Asteroid Rendezvous - Shoemaker (NEAR)

http://science.nasa.gov/missions/near

Overview

This is the first NASA mission to travel to and orbit an asteroid (433 Eros). NEAR Shoemaker studied the asteroid for approximately 1 year, then landed on the surface and transmitted the first images from an asteroid.

Launch

February 17, 1996

Arrival

(orbit) February 14, 2000; (touchdown) February 12, 2001

End of Mission

(last communication) February 28, 2001

Goals

Collect data on the properties, composition, surface features, interior, and magnetic field of Eros. Study surface properties, interactions with solar wind, possible currents of dust or gas, and asteroid spin. Look for clues about the formation of Earth and other planets.

Findings

This was the first-ever mission to orbit an asteroid and the first to touch down on the surface of an asteroid. It took 160,000 images of Eros revealing more than 100,000 craters and about 1 million house-sized (or bigger) boulders. The photos showed a layer of debris resulting from a long history of impacts. Eros is not a “rubble pile” of loosely bound pieces, but rather a solid object. Asteroids like Eros are linked to meteorite samples found on Earth. At mission’s end, scientists attempted to land NEAR Shoemaker on the asteroid, something the spacecraft had not been designed to do. On descent, it took dozens of detailed pictures. These photos were the highest resolution images ever of an asteroid. Some of the photos were from as close as 120 meters (394 feet) showing features as small as a golf ball. The spacecraft touched down at a gentle 4 mph. For two weeks it continued operating and communicating gamma-ray spectrometer data about the composition on and just below the asteroid’s surface.
Hayabusa


Overview

The Japan Aerospace Exploration Agency sent this unmanned spacecraft to near-Earth asteroid, 25143 Itokawa. Hayabusa succeeded in collecting a sample of material and bringing it back to Earth for further study.

Launch
May 9, 2003

Arrival
September 12, 2005

End of Mission
June 13, 2010

Goals

Collect a surface sample of material from the small (550 × 180 meter) asteroid, 25143 Itokawa, and return the sample to Earth. Record detailed studies of the asteroid’s shape, spin, topography, color, composition, density, brightness, interior, and history.

Findings

Hayabusa initially surveyed the asteroid’s surface and mapped it from a distance of about 20 km. The craft made two landings in November 2005. This marked the first controlled landing on an asteroid and the first ascent from any other solar system body except the Moon. On April 25, 2007, Hayabusa started its return to Earth.

Hayabusa returned to Earth on June 13, 2010, and the capsule was recovered. Scientists have confirmed that minute particles are in the sample container. Scientists will study these samples for many years to determine the processes of asteroid formation.
**Dawn**

http://dawn.jpl.nasa.gov/

**Overview**

Dawn is traveling to the asteroid belt (between Mars and Jupiter) to investigate two objects and learn more about the earliest history of the solar system.

**Launch**

September 27, 2007

**Arrival**

(orbit Vesta) 2011–2012; (orbit Ceres) 2015

**End of Mission**

Still operating as of 2018

**Goals**

Learn the conditions and processes of the early solar system by detailed investigation of asteroids Vesta and Ceres, two of the largest protoplanets not broken up since their formation. Determine how protoplanet size and water content are involved in the evolution of planets.

**Findings**

Vesta is rocky and dense with two enormous craters, 500 km (310 mi) and 400 km (250 mi) wide. The larger crater is younger, 95% of the entire diameter of Vesta, 12 mi deep, and overlies the other crater. Its central peak is 12–16 mi high and 100 miles wide, making it compete with Mars’ Olympus Mons as the largest mountain the in solar system. During the impacts that formed these craters, debris was ejected into space. About 5 percent of all meteorites we find on Earth may be a result of debris from these ancient impacts on Vesta. Since March 2015, Dawn has been orbiting Ceres, which is a world of both rock and ice. Ceres’ low density indicates ices are a major part of its composition. There is evidence for water vapor and an atmosphere. If Ceres were composed of 25 percent water, it may have more water than all the fresh water on Earth, though it would be in the form of water ice.

As of November 2017, NASA plans to allow the spacecraft to descend to lower altitudes and make observations that may reveal more about Ceres’ composition and how much ice it contains. Dawn will still be in orbit when the dwarf planet goes through its closest approach to the Sun, called perihelion, in April 2018. Then more ice on Ceres’ surface may turn to water vapor, which may in turn become part of its weak transient atmosphere.
Stardust
http://stardust.jpl.nasa.gov

Overview
Stardust went on a mission to collect interstellar dust and samples from Comet Wild 2. The craft returned to Earth’s orbit to drop off the samples—by parachuting the canister containing the samples to a site in Utah. The same spacecraft then flew on another mission, Stardust NExT, to travel to Comet Tempel 1 (arrival in 2011) and inspect the crater made by Deep Impact in 2005.

Launch
February 7, 1999

Arrival
January 2, 2004

End of Mission
January 15, 2006

Goals
Collect comet dust during a close encounter with Comet Wild 2 (pronounced “Vilt 2”). Collect interstellar dust.

Findings
Comet dust particles were returned to Earth when Stardust parachuted its samples to the Utah Test Range. The canister with comet particles and interstellar dust particles was taken to NASA’s Johnson Space Center. Samples were distributed to an international team of 200 scientists for study. Many of the organic compounds appear to be more “primitive” than those seen in meteorites. Comet particles have a wide range of compositions, indicating that there must have been a lot of mixing of material in the white-hot regions of the inner Solar System and also in the extremely cold (near 0 Kelvin) regions at the edge of the Solar System. Comets are truly a mixture of fire and ice. Continued analysis may yield important insights into the evolution of the Sun, its planets, and possibly even the origin of life.
Deep Space I

http://nmp.jpl.nasa.gov/ds1/

Overview

Deep Space 1 was able to accomplish more than anticipated. First, it tested new scientific instruments and software that will help in future space missions, and then it was able to capture images and gather scientific data about asteroid Braille and comet Borrelly.

Launch

October 24, 1998

Arrival

September 22, 2001

End of Mission

December 18, 2001

Goals

Test 12 new, high-risk technologies. These include ion propulsion (rocket engine using ionized xenon gas), Autonav (automatic navigation system), Remote Agent (remote intelligent self-repair software), Small Deep-Space Transponder (miniaturized radio system and instruments), Solar Concentrator Array, Beacon Monitor experiment, and others.

Findings

The twelve technologies all tested successfully. The craft did a flyby of asteroid Braille and Asteroid 1992 KD in July 1999 at 27 km altitude. After finishing its primary mission, Deep Space 1 embarked on an ambitious extended mission that ended in an encounter with Comet Borrelly. The craft returned the best pictures and other scientific data ever collected from a comet.
Rosetta Orbiter

http://rosetta.jpl.nasa.gov/

Overview

Rosetta was sent by the European Space Agency and a combined international team on a 10-year mission to Comet 67P Churyumov-Gerasimenko where it plans to land a robot in the year 2014. On its way, Rosetta will make observations of other comets, planets and asteroids.

Launch

March 2, 2004

Arrival

May 2014

End of Mission

September 30, 2016

Goals

Study the origin of comets. Study the relationship between comets and other interstellar material and what this tells us about the origin of the solar system. Describe the comet nucleus, surface features, and composition. Study the nucleus of comets and the interaction of dust and gas in the comet’s inner head.

Findings

During its journey to Comet C-G, Rosetta performed two gravity-assist flybys of Earth and Mars. En route to Mars, Rosetta’s instruments provided before and after images of the collision between Deep Impact’s impactor and Comet Tempel 1. Rosetta also returned extraordinary images in July 2010 of the large asteroid, 21-Lutetia.
Voyager 1 and 2

http://voyager.jpl.nasa.gov/

Overview

Voyager 1 and Voyager 2 are twin spacecraft, both launched in 1977 on flyby missions to gather data about planets in the outer solar system. Voyager 2 was launched before Voyager 1, but Voyager 1 arrived at Jupiter ahead of Voyager 2. More than 30 years later, these spacecraft continue to transmit data and are the farthest man-made objects from Earth. They are now at the edge of the solar system and will be the first probes to leave the solar system and enter interstellar space.

 Originally planned as five-year missions, but on January 1, 1990, Voyager 2 and its twin, Voyager 1, began an extended mission. It took 12 years to reach the last planet, Neptune, traveling at an average speed of 19 km/second (42,000 mph). Following Voyager's success in observing Neptune for 4 months in 1989, Voyager 2 and its twin, Voyager 1, began an extended mission to explore the boundaries of our solar system and travel into interstellar space.

It is expected that there is enough fuel to last into 2020 and perhaps more. Both spacecraft are still active more than 30 years later, exceeding expectations and adding significantly to our knowledge of the solar system and beyond.

Launch

(Voyager 1) September 5, 1977; (Voyager 2) August 20, 1977

Arrival

Jupiter
(Voyager 1) March 5, 1979; (Voyager 2) July 9, 1979

Saturn
(Voyager 1) November 12, 1980; (Voyager 2) August 25, 1981

Uranus
(Voyager 2) January 24, 1986

Neptune
(Voyager 2) August 25, 1989

Outer solar system
(Voyager 1) 2004; (Voyager 2) 2007

Interstellar space
(Voyager 1) 2012
Voyager 1 and 2 (continued)

End of Mission

Still operating as of 2018; expected to operate until 2025

Goals

Conduct close-up studies of Jupiter and Saturn, Saturn’s rings, and the larger moons of the two planets.

Findings

At Jupiter

Voyager 1 identified nine active volcanoes on Io. Voyager 2 also observed eight of the nine volcanoes. Plumes from the volcanoes reach more than 300 kilometers (190 miles) above the surface. The material was being ejected at velocities up to 1.05 kilometers per second (2300 mph). Compare that to the ejecta velocities of one of Earth’s most explosive volcanoes, Mt. Etna, which are 50 meters per second (112 mph). Volcanism on Io is related to tidal action from its interactions with Jupiter and with Europa and Ganymede (two large satellites nearby). Io is constantly being pulled back and forth. This causes tidal bulges of 100 meters (330 feet) on Io’s surface. Typical tidal bulges on Earth resulting from our interactions with the Moon are about one meter (three feet).

Voyager 1 photos of Europa showed a large number of crossing linear features. Scientists at first believed the features might be deep cracks, caused by rifts in the crust or tectonic processes.

Although astronomers had studied Jupiter from Earth for several centuries, they were surprised by many Voyager mission findings. They now understand that important physical, geological, and atmospheric processes go on in the planet, its satellites, and magnetosphere.

At Saturn

Measured winds at high speeds in Saturn—500 meters a second (1,100 miles an hour) near the equator. Detected auroras.

Both Voyagers found that Saturn’s atmosphere is almost entirely hydrogen and helium—about 7% of the volume of Saturn’s upper atmosphere is helium (compared with 11% of Jupiter’s atmosphere), while almost all the rest is hydrogen. It was expected that Saturn’s helium content would be the same as Jupiter’s and the Sun’s. The lower abundance of helium in the upper atmosphere of Saturn may imply that the heavier helium is slowly sinking through Saturn’s hydrogen. That might also explain the excess heat that Saturn radiates, more than the energy it receives from the Sun. Saturn is the only planet less dense than water. In the unlikely event that a large enough lake could be found, Saturn would float in it.
Voyager 1 and 2 (continued)

At Uranus
Voyager 2 sent thousands of images and data on Uranus, its moons, rings, atmosphere, interior, and the magnetic environment. Images of the five largest moons showed complex surfaces due to geological events in the past. The spacecraft also detected 10 previously unseen moons. It studied Uranus’ previously known rings in fine detail and two newly detected rings. Miranda, innermost of the five large moons, is one of the strangest bodies yet observed in the solar system. Its surface is heavily cratered with regions of ridges and valleys.

At Neptune
Voyager 2 passed about 4950 km (3000 miles) above Neptune’s north pole. Five hours later, it passed 40,000 km (25,000 miles) from Neptune’s largest moon, Triton. It captured images of several geyser-like volcanic vents. These vents were spewing nitrogen gas containing extremely fine, dark particles. The particles were carried to altitudes of 2 to 8 km and then blown downwind before being deposited on Triton’s surface. Most of the winds on Neptune blow in a westward direction, which is opposite (retrograde) to the rotation of the planet.

Beyond Neptune
Both Voyagers 1 and 2 continue to send back data, providing scientists with valuable observations of the solar system’s edge and interstellar space. Voyager 1 is now the furthest human-made object from the Sun, having surpassed Pioneer 10 on February 17, 1998. On June 28, 2010, Voyager 2 completed 12,000 days of continuous operation.

The Voyagers are expanding our knowledge of where the “edge” of the solar system is by their measurements of energized particles from the Sun that create what is known as solar wind. Both spacecraft have reported entering a region where the solar wind slows down suddenly to subsonic speed (less than 100 km/sec). That region is known as the termination shock, because of the abrupt decrease in speed of the solar wind. Voyager 1 reached the termination shock in December of 2004, with Voyager 2 following in 2007. While the solar wind is slow and turbulent past the termination shock, the magnetic influence of the Sun is still measured. The entire region around the Sun where its magnetic field has influence is called the heliosphere. The extreme edge of the heliosphere is called the heliopause, and beyond that is interstellar space, where the Sun’s influence is no longer measurable. The region between the termination shock and the heliopause is known as the heliosheath.

Interstellar Space
In 2012, Voyager 1 crossed the heliopause and is the first spacecraft to enter and send back data from interstellar space, where the solar wind is overpowered by forces from beyond the solar system, including other magnetic fields and galactic cosmic rays. Voyager 1 continues to return new data to Earth and is estimated to have enough battery power to last until 2025. As of November 2017, Voyager 2 is still within the heliosheath and is expected to cross the heliopause into interstellar space in late 2019 or 2020.
Deep Impact

http://science.nasa.gov/missions/deep-impact/

Overview

Deep Impact was a flyby and landing mission to gather data about comet Tempel 1—one part of the spacecraft separated from the main craft and purposely crashed into the comet to create a crater. The other part of the spacecraft photographed the impact and gathered information about the comet’s composition.

Launch

January 12, 2005

Arrival

July 4, 2005

End of Mission

This mission ended and the spacecraft was put to sleep in July, 2005. In 2007, the spacecraft was awakened and used in additional missions.

Goals

Find answers to these questions:
Where is the original material in comets?
Do comets lose their ice or seal it in?
What do we know about crater formation?

Use a spacecraft built in two parts, (1) an impactor to land on the comet and (2) a flyby section that will photograph the comet from a safe distance during the encounter.

Findings

The comet nucleus, about 5 km (3.1 mi) across and 7 (4.3 mi) km tall, was found to be extremely porous with up to 80% empty space. Material from the impact contained more dust and less ice than expected. Analysis of spectra indicated clays, carbonates, sodium, crystalline silicates, and a surprisingly high number of organic molecules. The spacecraft passed just 500 km (300 mi) from the comet, taking pictures of the crater position, the ejecta plume, and the entire cometary nucleus. Professional and amateur astronomers at both large and small telescopes on Earth and
Deep Impact (continued)

in orbit observed the impact and its aftermath. Europe’s Rosetta spacecraft, which was about 80 million km from the comet at the time of impact, observed the impact blast a crater about 100 meters wide and up to 30 meters deep. Material ejected from the impact obscured the view so that the spacecraft was unable to image the final crater. Stardust NExT did a flyby on February 14, 2011, to observe the new crater on Tempel 1.
Pioneer 10

http://science.nasa.gov/missions/pioneer-10-11/

Overview

Pioneer was a series of unmanned space probes launched over a period of 20 years. Pioneers 10 and 11 are most famous because they were sent to explore the outer solar system, and then eventually go beyond our solar system into interstellar space.

Launch

March 2, 1972

Arrival

(closest approach to Jupiter) December 3, 1973

End of Mission

The mission officially ended on March 31, 1997. Pioneer 10 continues to coast through deep space with the last data communication detected in 2002. It will take 2 million years to reach Aldebaran, the red star in the constellation Taurus.

Goals

Investigate the Jupiter system, the constellation Taurus, and beyond.

Findings

Pioneer 10 was the first spacecraft to travel through the asteroid belt on its way to Jupiter. It passed Jupiter within 1.3 million km (81,000 miles). It was the first spacecraft to make direct observations and obtain close-up images of Jupiter. Pioneer 10 imaged the planet and its moons, and took measurements of Jupiter’s radiation belts, magnetic field, atmosphere, and interior. The radiation measurements of the environment near Jupiter were crucial in designing the spacecraft Voyager and Galileo. Pioneer 10 is now headed toward the constellation Taurus. Pioneer 10 will make valuable scientific investigations in the outer regions of our solar system until the end of its mission when it will be over 10 billion km (6.3 billion miles) away.
Pioneer 11

Overview

Pioneer was a series of unmanned space probes launched over a period of 20 years. Pioneers 10 and 11 are most famous because they were sent to explore the outer solar system, and then eventually go beyond our solar system into interstellar space.

Launch

April 5, 1973

Arrival

Jupiter in 1974 and Saturn in 1979

End of Mission

The mission officially ended on September 30, 1995 when the last data transmission was received. Pioneer 11 continues to coast through deep space and will take 4 million years to reach a star in the constellation Aquila.

Goals

Investigate Jupiter, Saturn, and the outer solar system. Study energetic particles in the outer solar system (heliosphere).

Findings

Pioneer 11 was the first craft to explore the planet Saturn and its main rings. Pioneer 11, like Pioneer 10, used Jupiter’s gravitational field to change its trajectory. It passed close to Saturn and then it followed an escape trajectory from the solar system. Pioneer 11 ended its transmissions when its power source was exhausted. It is now headed toward the constellation Aquila.
Space Missions—Printable Format
Outer Solar System Missions

Juno


Overview

Juno is a solar-powered spacecraft that is on a 5-year journey to Jupiter to gather data about the formation of that planet and to help us learn more about the origin of the solar system.

Launch

August 5, 2011

Arrival

July, 2016

End of Mission

Still operating as of 2018, planned to end in 2018-19

Goals

Build on the results of previous missions and provide new information to help determine how, when, and where this giant planet formed. Collect data from highly elliptical polar orbits (traveling over the north pole to the south pole and back to the north pole) that skim only 5,000 km above the planet’s atmosphere. Improve our understanding of the origin of the solar system.

Findings

Early results are that Jupiter is a complex, gigantic, turbulent world, with Earth-sized polar cyclones, plunging storm systems that travel deep into the heart of the gas giant. When Juno beamed microwaves into the deep atmosphere, the data showed signs of ammonia plumes welling up from the equator, forming giant weather systems that extend well beneath the cloud tops. Mammoth cyclones reach up to 1,400 km (900 mi) wide – 10 times larger than Earth’s biggest cyclones. The storms also reached close to 100 km high - up out of Jupiter’s atmosphere. Contrary to previous predictions, Jupiter’s internal layers are not uniform at all, but instead regularly mix together. Jupiter’s mammoth magnetic field is twice as strong as previously thought, and lumpy, indicating it may be generated closer to the planet’s surface than previously thought. That is very different to Earth’s magnetic field, which originates in movements in the hot liquid iron core deep below the crust. Violet-blue aurorae were detected when Juno passed over the poles. On Earth, the Northern and Southern lights occur when charged particles from the solar wind are funnelled down through the magnetosphere into the polar regions. But Juno’s instruments show that Jupiter’s aurorae are powered by the electrons being sucked out of the planet’s polar region, which means Jupiter powers the aurora all on its own.
**Space Missions—Printable Format**

**Outer Solar System Missions**

**Galileo**

http://solarsystem.nasa.gov/galileo

**Overview**

Galileo was launched from the space shuttle Atlantis and sent on a 2-year mission to study Jupiter and its moons. The spacecraft had two parts—an orbiter and a probe. The probe parachuted down to Jupiter’s surface to study the atmosphere and returned data until it melted in the heat, about 1 hour later. The orbiter extended its mission and gathered data for almost 8 years, before it was purposely crashed into Jupiter’s surface in 2003.

**Launch**

October 18, 1989

**Arrival**

December 7, 1995

**End of Mission**

September 21, 2003

**Goals**

Collect data on the magnetosphere and study Jupiter and its moons. Study Venus, Earth, the Moon, and two asteroids, Gaspra and Ida, during flybys.

**Findings**

Galileo discovered a tiny moon, Dactyl, orbiting the asteroid Ida. When Comet Shoemaker-Levy 9 crashed into Jupiter, Galileo was in position to directly observe the collision.

Galileo’s probe detected an atmosphere that was drier than expected and measured winds of 724 kilometers per hour (450 mph) before melting and vaporizing 58 minutes later.

Galileo’s orbiter found evidence of subsurface saltwater on Europa, Ganymede, and Callisto, and revealed the intensity of volcanic activity on Io. The spacecraft was purposely put on a collision course with Jupiter to eliminate any chance of an unwanted impact between the spacecraft and Jupiter’s moon Europa. Galileo found that Jupiter’s moon Amalthea is a pile of icy rubble less dense than water, instead of denser rocky material. This finding shakes up long-held theories of how moons form around giant planets.
Cassini-Huygens

http://saturn.jpl.nasa.gov/

Overview

Cassini is a joint project of NASA, the European Space Agency and the Italian Space Agency. Cassini was launched and sent on an initial mission to study Saturn and its moons. The spacecraft had two parts—the orbiter Cassini and the probe Huygens. Huygens parachuted down to Titan’s surface (one of Saturn’s moons) in 2005 to study the atmosphere and returned data for 2 1/2 hours. The Cassini orbiter has extended its mission several times and continued to operate on the Solstice Mission, which was not scheduled to end until 2017.

Launch

October 15, 1997

Arrival

June 30, 2004; (Huygens on Titan) January 14, 2005

End of Mission

On September 15, 2017, Cassini spacecraft was programmed to plunge into the atmosphere of Saturn, ending its 13-year tour of Saturn.

Goals

Conduct a detailed study of Saturn and its moons, including temperature and composition of Saturn’s atmosphere, cloud properties, winds, internal structure, its rings, icy moons, and deploy Huygens probe to plunge through the atmosphere of Titan. The mission was extended to study Saturn’s northern hemisphere and the rings’ northern face and further study Titan and Enceladus.

Findings

Cassini recorded powerful lightning storms; 10,000 times stronger than those on Earth. These storms occurred in huge, deep thunderstorm columns nearly as large as the entire Earth. Auroras on Saturn continue for days rather than minutes or hours like on Earth. The wind speeds recorded by Cassini are different from those found by Voyager—Saturn may lose its place as the windiest planet in the solar system.

Rings: Cassini found several times the amount of matter in the densest rings than previously measured. It discovered entirely new kinds of channel-like structures within the rings. It found small moonlets within strands of ring material producing complicated, shifting patterns. It
Cassini-Huygens (continued)

discovered that the stranded F-ring has changed since Voyager studied it. The craft discovered a new moonlet clearing its own empty gap in the A-ring. It found objects no larger than a football field buried deeply in the A-ring. The most common materials within the rings are meter-sized.

**Enceladus:** Liquid water may be just beneath the surface. The craft discovered geysers of water-ice jetting a distance three times the diameter of Enceladus. Particles from these geysers are becoming part of Saturn’s rings.

**Titan:** Images of Titan show what Earth might have been like before life evolved. Like Earth, Titan has lakes, rivers, channels, dunes, rain, snow, clouds, mountains, and possibly volcanoes. But unlike Earth, Titan’s lakes, rivers and rain are made of methane and ethane, at ~179°C.

New Horizons

http://pluto.jhuapl.edu/

Overview

New Horizons will be the first to explore Pluto and its moon Charon, located at the edge of the solar system in extreme, icy conditions. This will be a flyby mission so the spacecraft can continue on (maybe until 2020) to explore another object in the Kuiper Belt. At the time the mission was planned, Pluto was still considered to be our ninth planet.

Launch

January 19, 2006

Arrival

July 2015

End of Mission

Still operating as of 2018. Flyby of Kuiper Belt Object 2014 MU69 is planned for January 1, 2019.

Goals

Map surface composition of Pluto and Charon.
Characterize geology and morphology (how they look) of Pluto and Charon.
Characterize the neutral atmosphere of Pluto and its escape rate.
Search for an atmosphere around Charon.
Map surface temperatures on Pluto and Charon.
Search for rings and additional satellites around Pluto.
Conduct similar investigations of one or more Kuiper Belt objects.

Findings

Some of Pluto’s surface features seem surprisingly young. Pluto has much more atmosphere than predicted. Pluto’s largest moon, Charon, has an equatorial tectonic belt that hints Charon may have had a water-ice ocean in the distant past, now frozen inside the moon. Pluto could well have an internal water-ice ocean today. Scientists dated the age of the craters on the surface of Pluto’s moons, and the data supports the idea that they were formed together in a single collision
New Horizons (continued)

between Pluto and another planet in the Kuiper Belt long ago. Charon’s dark, red polar cap is unprecedented in the solar system, and may be the result of atmospheric gases that escaped Pluto and then accreted on Charon’s surface. Pluto’s vast 1,000-kilometer-wide heart-shaped nitrogen glacier (informally called Sputnik Planum) is the largest known glacier in the solar system.
Space Missions—Printable Format
Mars Missions

Phoenix Mars Lander

http://phoenix.lpl.arizona.edu

Overview

Phoenix was a spacecraft that landed in a northern polar region on Mars to study water and climate, and to search for evidence of life and the conditions for potential habitation. The spacecraft had a science laboratory in the center with a long robotic arm for digging and two large solar panels on either side to power its batteries. The spacecraft lasted longer than the expected three months, but the solar cells did not survive the extreme cold and ice of a Martian winter.

Launch

August 4, 2007

Arrival

May 25, 2008

End of Mission

(last communication) November 2, 2008; May 24, 2010

Goals

Study the history of water in the Martian arctic region. Search for evidence of past life in the ice-soil boundary. Analyze the water and soil for evidence of climate cycles and whether the environment could have supported microbial life. Take panoramic, stereoscopic images and close-up images of the soil and water ice from the Martian surface. Describe the geology of Mars, monitor the weather, and investigate properties of the atmosphere and clouds.

Findings

On June 2, 2008, one week after landing, Phoenix lifted its first scoop of Martian soil to test the lander’s robotic arm. Phoenix sprinkled a spoonful of Martian soil onto the sample wheel of the spacecraft’s robotic microscope station on June 12. This soil appeared to be very similar to surface soils found in the upper dry valleys in Antarctica. One inch into the surface layer, the soil is very basic, with a pH between 8 and 9. The instruments also found the chemicals needed for life as we know it. On July 31, 2008, Phoenix Mars Lander identified water in a soil sample.
Space Missions—Printable Format
Mars Missions

Mariner 4

http://nssdc.gsfc.nasa.gov/nmc/spacecraftDisplay.do?id=1964-077A

Overview

The Mariner program consisted of a series of 10 unmanned flyby missions launched by NASA between 1962 and 1973. These missions were designed to be the first to travel to other planets, specifically Venus, Mars, and Mercury. Seven were successful; three were lost. In summary:

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<th>Destination</th>
<th>Launch year</th>
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After an 8-month voyage, Mariner 4 performed a flyby of Mars and was the first spacecraft to send back close-up photographs of another planet. There were 22 images. Mariner 4 stayed in space and transmitted other data for about 3 years.

Launch

November 28, 1964

Arrival

July 14, 1965

End of Mission

December 21, 1967

Goals

Fly as close as 9,846 km (6,118 mi) from Mars and make measurements with various field and particle sensors and detectors, get images.
Mariner 4 (continued)

Findings

Mariner 4 was the first spacecraft to get a close look at Mars. Revealed Mars to have a cratered, rust-colored surface, with signs on some parts of the planet that liquid water had once etched its way into the soil. Television camera took 22 pictures covering about 1% of the planet.
Mars Pathfinder

http://mpfwww.jpl.nasa.gov/MPF/

Overview

Mars Pathfinder landed in a rocky area of Mars. Contained inside the spacecraft was a robotic rover vehicle, Sojourner, which rolled down a ramp and out onto the Martian surface to travel around and explore. Both lander and rover carried out scientific experiments and returned more data than expected.

Launch

December 4, 1996

Arrival

July 4, 1997

End of Mission

(last communication) September 27, 1997; March 10, 1998

Goals

Demonstrate key engineering technologies and concepts for use in future missions to Mars. Deliver science instruments to the surface of Mars to investigate the structure of the atmosphere, surface meteorology, surface geology, as well as the form, structure, and elemental composition of rocks and soil.

Findings

Pathfinder used the first rover to explore the Martian surface. It returned more than 16,000 images from the lander and 550 images from the rover and extensive data on winds and other weather factors. Images revealed a rocky plain, about 20% of which was covered by rocks, that appears to have been deposited and shaped by catastrophic floods. The AXPS (Alpha Proton X-ray Spectrometer) instrument performed chemical analyses of several rocks and soils that showed a diversity of rock types at the landing site and a higher silica content than Martian meteorites. The soil chemistry of the landing site was similar to that found at the Viking 1 and 2 sites. Martian dust was discovered to be very fine, about one micron, and include magnetic particles. Evidence of wind abrasion of rocks and dune-shaped deposits was also found, indicating the presence of sand-sized particles.
Mars Global Surveyor

http://marsprogram.jpl.nasa.gov/mgs/

Overview

Mars Global Surveyor orbited above Mars for nearly 9 years, methodically collecting images and data to make a complete map of the Martian surface. Due to a computer software error, MGS was given incorrect information that likely resulted in melted batteries, loss of power, and ultimate loss of the spacecraft.

Launch

November 7, 1996

Arrival

September 11, 1997

End of Mission

(last communication and loss of spacecraft) November 2, 2006; January 28, 2007

Goals

• Collect global snapshots from 400 km (249 miles) above the Martian surface by circling in a polar orbit (traveling over the north pole to the south pole and back to the north pole) once every 2 hours, 12 times a day.

• Contribute to the four main science goals of the Mars Exploration Program:
  1. determine whether life ever arose on Mars,
  2. characterize the climate of Mars,
  3. characterize the geology of Mars, and
  4. prepare for human exploration.

Findings

Mars Global Surveyor found signs of past water, such as an ancient delta, as well as currently active water features in the gullies of canyon walls. A delta-like fan on Mars suggests ancient rivers were there for long periods of time and other images suggest water still flows in brief spurts on Mars.
**Mars Odyssey**

http://mars.jpl.nasa.gov/odyssey/

**Overview**

Mars Odyssey orbits Mars to map the distribution of elements and detect radiation on the Martian surface. At the end of a long boom arm extending out from the spacecraft is a gamma ray spectrometer, one of the instruments used to collect scientific data.

**Launch**

April 7, 2001

**Arrival**

October 24, 2001

**End of Mission**

Still operating as of 2018, expected to operate until 2025

**Goals**

Map the amount and distribution of elements and minerals that make up the Martian surface. Record the radiation environment in low-Mars orbit to determine the radiation-related risk to humans who might explore in the future.

**Findings**

Measurements by Odyssey have enabled scientists to create maps of minerals and chemical elements and identify regions with buried water ice. Images that measure the surface temperature have provided spectacular views of Martian topography. Radiation in low-Mars orbit is twice that in low-Earth orbit. This is an essential piece of information for eventual human exploration because of its potential health effects. Maps of hydrogen distribution led scientists to discover vast amounts of water ice in the polar regions buried just beneath the surface. Data shows evidence of salt deposits where water once was abundant and where evidence might exist of possible Martian life. This mission also discovered entrances to seven possible caves on the slopes of a Martian volcano. These are of interest as potential underground habitat for microbial life.
Mars Reconnaissance Orbiter

http://marsprogram.jpl.nasa.gov/mro/

Overview

One question that Mars Reconnaissance Orbiter will try to answer is whether the water that flows on Mars has ever stayed long enough to support life. MRO will explore science and communication/navigation goals from orbit. While orbiting, its navigation equipment will assist other missions that plan to land on the Martian surface and its onboard scientific instruments will study Mars’ geologic history, landforms, minerals, and ice. When MRO’s main mission is over at the end of 2010, it will have enough fuel to continue on for another 5 years.

Launch

August 12, 2005

Arrival

March 10, 2006

End of Mission

Scheduled for December 31, 2010, but still operating as of 2018

Goals

Investigate the history of water on Mars, using equipment that allows closer views than previous missions; establish a communications and navigation relay point for future space missions.

Findings

Despite some technology glitches with software and cameras, Mars Reconnaissance Orbiter has returned more data than all other interplanetary missions combined. This data reveals information about the diverse and changing Martian atmosphere, surface, and subsurface. Scientists have learned that Mars’ atmosphere changes seasonally, that the surface has deep canyons, and that they can see possible evidence of salty water flowing in craters during spring and summer. They have found that chloride minerals are present, which result from the evaporation of mineral-enriched water. MRO has helped monitor dust storms that would affect the rovers, Spirit and Opportunity, photographed Phoenix as it parachuted to the surface, and helped select landing sites for Mars Science Laboratory.
Mariner 9

http://solarsystem.nasa.gov/missions/profile.cfm?MCode=Mariner_09

Overview

Mariner 9 was the first spacecraft to orbit another planet. Because of a large dust storm on Mars, Mariner 9 had to wait several months for the dust to settle before it could begin sending clear images. Although its mission ended in 1972 and communication stopped, Mariner 9 continues to orbit Mars. It is expected to burn up or crash into the Martian surface sometime around 2022.

Launch

May 30, 1971

Arrival

November 14, 1971

End of Mission

October 27, 1972

Goals

Transmit images and measure UV and IR emissions.

Findings

After 349 days in orbit, Mariner 9 had transmitted 7,329 images, covering over 80% of Mars’ surface. The images revealed river beds, craters, massive extinct volcanoes, canyons. One of the canyons discovered was Valles Marineris, a massive system of canyons over 4,000 km (2,500 miles) named in honor of the spacecraft. Mariner 9 found evidence of wind and water erosion, weather fronts, and fog. It photographed Mars’ tiny moons, Phobos and Deimos. One of the largest global storms ever observed on Mars obscured all details except the summits of Olympus Mons and the three Tharsis volcanoes.
Mars Express

http://sci.esa.int/science-e/www/area/index.cfm?fareaid=9

Overview

Mars Express was launched by the European Space Agency. The spacecraft had two parts, an orbiter and a lander called Beagle 2, which was supposed to take samples and collect data from the Martian surface. When the lander was jettisoned to make its landing, communication was lost and never regained so that part of the mission failed. Fortunately, the orbiter is successful and continues to collect data.

Launch

June 2, 2003

Arrival

December 26, 2003

End of Mission

Still operating as of 2018

Goals

Search for subsurface water from orbit. Study the interaction between the solar wind and the atmosphere of Mars. Find out what happened to the large amount of water that was once on Mars.

Findings

Mars Express found evidence of recent glacial activity, explosive volcanism, and methane gas; those findings are still being debated by scientists. Seven instruments conducted investigations to help answer questions about the geology, atmosphere, surface environment, history of water, and potential for life on Mars. A radar instrument MARSIS (Mars Advanced Radar for Subsurface and Ionospheric Sounding) provided information about features beneath the Martian surface, including buried impact craters and hints of deep underground water ice.
Space Missions—Printable Format
Mars Missions

Viking 1

http://nssdc.gsfc.nasa.gov/planetary/viking.html

Overview

Viking 1 and Viking 2 were identical two-part spacecrafts launched about 3 weeks apart. Each orbiter—lander flew together as a unit until it reached orbit with Mars. An onboard camera helped select a suitable landing site. The landers then detached from the orbiters and each landed in a different area of the Martian surface. Because of a fuel leak in Viking 2’s orbiter and battery failure in Viking 2’s lander, Viking 1 outlasted Viking 2, but both missions far exceeded their planned 90-day time period for gathering data.

Launch

August 20, 1975

Arrival

(orbiter) June 19, 1976; (lander) July 20, 1976

End of Mission

(orbiter) August 17, 1980; (lander) November 13, 1982

Goals

Obtain high resolution images of the Martian surface, characterize the structure and composition of the atmosphere and surface, and search for evidence of life.

Findings

Both Viking 1 and Viking 2 took images of the entire surface of Mars. Analysis of the landing-site soils showed these areas to be rich in iron, but found no signs of life. Volcanoes, lava plains, huge canyons, craters, wind-formed features, and evidence of surface water were seen in the Viking orbiter images. The planet was found to have two main regions, low plains in the north and cratered highlands in the south. The craft measured temperatures from -123°C to -23°C (-189°F to -1ºF). The Vikings also observed seasonal dust storms, pressure changes, and movement of atmospheric gases between the polar caps.
**Mars Missions**

**Viking 2**

http://nasascience.nasa.gov/missions/viking

**Overview**

Viking 1 and Viking 2 were identical two-part spacecrafts launched about 3 weeks apart. Each orbiter—lander flew together as a unit until it reached orbit with Mars. An onboard camera helped select a suitable landing site. The landers then detached from the orbiters and each landed in a different area of the Martian surface. Because of a fuel leak in Viking 2’s orbiter and battery failure in Viking 2’s lander, Viking 1 outlasted Viking 2, but both missions far exceeded their planned 90-day time period for gathering data.

**Launch**

September 9, 1975

**Arrival**

(orbiter) August 7, 1976; (lander) September 3, 1976

**End of Mission**

(orbiter) June 25, 1978; (lander) April 11, 1980

**Goals**

Obtain high resolution images of the Martian surface, characterize the structure and composition of the atmosphere and surface, and search for evidence of life.

**Findings**

Viking 1 and 2 took images of the entire surface of Mars. Analysis of the landing-site soils showed these areas to be rich in iron, but found no signs of life. Volcanoes, lava plains, huge canyons, craters, wind-formed features, and evidence of surface water were seen in the Viking orbiter images. The planet was found to have two main regions, low plains in the north and cratered highlands in the south. The craft measured temperatures from -123°C to -23°C (-189°F to -1°F). Viking also observed seasonal dust storms, pressure changes, and movement of atmospheric gases between the polar caps.
Mars Missions

Mars Exploration Rover—Spirit

http://marsrovers.nasa.gov/home

Overview

Spirit was the first of two robotic, solar-powered, six-wheel exploration rovers to arrive on Mars. Its twin, Opportunity, arrived about three weeks later and landed on the opposite side of Mars. NASA hoped that each rover would explore for about 90 days and drive over about 1 kilometer of the Martian surface. The rovers traveled separately to Mars, each inside a protective landing shell, but once the antennas deployed, cameras and scientific instruments calibrated, the rovers went on independent of their protective shells. Through several cameras “eyes” that send images back to engineers on Earth, scientists are able to command the rovers to navigate and perform science investigations, using the onboard instruments, which include a panoramic camera (Pancam), navigational camera, microscopic imager to obtain close-up images of rocks and soils, and instruments to analyze the minerals. A diamond-coated Rock Abrasion Tool exposed fresh material in Martian rocks.

To test the rover idea prior to sending them to Mars, a prototype rover called FIDO was sent to several desert areas in the United States where scientists practiced navigating and performing experiments.

Spirit outlasted longevity expectations by more than twenty times and traveled almost ten times farther than originally planned. Unfortunately, Spirit got stuck in 2009 in soft soil and engineers were unable to get it unstuck. It continued to return scientific data from its stuck spot, but finally became unresponsive in 2010.

Launch

June 10, 2003

Arrival

January 4, 2004

End of Mission

(last communication) March 22, 2010; May 24, 2011

Goals

Study rocks and soils that may hold clues to past water activity on Mars, study geologic processes near the landing site, verify the accuracy of data obtained by Mars Reconnaissance Orbiter, and determine if environmental conditions were ever conducive to life on Mars.
Mars Exploration Rover—Spirit (continued)

Findings

Spirit endured far beyond its original expectation of 90 days to last 2,269 days in the Martian environment. It survived dust storms that blocked sunlight needed to maintain a power supply, wheels that stopped working, and stresses far beyond anything that was expected. Spirit landed in Gusev Crater, a 170 km diameter crater that formed three to four billion years ago. A channel system drains into the crater that likely, at some point in Mar’s history, carried liquid water or a combination of water and ice. The crater appears to be an old lake bed filled with sediments. It was hoped that sedimentary material from this early era could be studied. At first the region proved disappointing because there was no exposed bedrock on the flat lava plains of the crater. Spirit eventually made its way to the Columbia Hills, a small group of low-lying hills about 3 km from the landing site. Rocks examined there do show evidence of interaction with small amounts of briny (salty) water.
Mars Exploration Rover—Opportunity

Overview

Opportunity was the second of two robotic, solar-powered, six-wheel exploration rovers to arrive on Mars. Its twin, Spirit, arrived about three weeks earlier and landed on the opposite side of Mars. NASA hoped that each rover would explore for about 90 days and drive across 1 kilometer of the Martian surface. The rovers traveled separately to Mars, each inside a protective landing shell, but once the antennas deployed, cameras and scientific instruments calibrated, the rovers went on, independent of their protective shells. Through several cameras “eyes” that send images back to engineers on Earth, scientists are able to command the rovers to navigate and perform science investigations, using the onboard instruments, which include a panoramic camera (Pancam), navigational camera, microscopic imager to obtain close-up images of rocks and soils, and instruments to analyze the minerals. A diamond-coated Rock Abrasion Tool exposes fresh material in Martian rocks.

To test the rover idea prior to sending the vehicles to Mars, a prototype rover called FIDO was sent to several desert areas in the United States where scientists practiced navigating and performing experiments.

Opportunity has far outlasted longevity expectations—by more than thirty times—and has also traveled many times farther than originally planned.

Launch

July 7, 2003

Arrival

January 25, 2004

End of Mission

Still operating as of 2018

Goals

Study rocks and soils that may hold clues to past water activity on Mars, study geologic processes near the landing site, verify the accuracy of data obtained by Mars Reconnaissance Orbiter, and determine if environmental conditions were ever favorable to life on Mars.
Mars Exploration Rover—Opportunity (continued)

Findings

Opportunity endured far beyond its original expectation of 90 days, surpassing 13 years in the Martian environment (and it's still going!), as it continues to make new and profound discoveries. It has survived dust storms that blocked sunlight needed to maintain a power supply, getting stuck and then released from a sand dune, and stresses far beyond anything that was expected. Opportunity originally landed inside a small impact crater, Eagle Crater. The craft found iron mineral hematite in the form of small spherical pebbles nicknamed “blueberries.” Opportunity traveled 7 km (4.3 miles) from the landing site to several other craters (Endurance, Erebus, and Victoria Craters). In its travels, Opportunity found layers of sedimentary rock exposed in the walls of craters containing sulfites and jarosite, chlorine, and bromine, all minerals that require interaction with water to form. These findings provided evidence that suggests the landing site was once the shoreline of a salty sea. Opportunity also discovered an intact meteorite.
Lunar Prospector

http://lunar.arc.nasa.gov/

Overview

The mission for Lunar Prospector focused on mapping the Moon’s surface and looking for evidence of water ice. The spacecraft orbited the Moon for several months, and then it deliberately crash landed into the lunar south pole to see if it could detect any evidence of ice. The probe carried a small amount of the remains of lunar geologist, Eugene Shoemaker. This was a low-cost program as the small craft (weighed only 295 kg) was built from “off-the-shelf,” flight-proven hardware. The program came together quickly, being developed in only 22 months.

Launch

January 7, 1998

Arrival

January 11, 1998

End of Mission

July 31, 1999

Goals

Use a gamma-ray spectrometer to detect suspected water ice buried inside the lunar crust. Detect other natural resources, minerals, and gases that could be used to build and sustain a human lunar base or in manufacturing fuel for launching spacecraft from the Moon to the rest of the solar system.

Findings


As scheduled, on July 31, 1999, the probe crashed into the Moon to gather evidence for the presence of water ice in the impact area. None was found.
Surveyor

http://nasascience.nasa.gov/missions/surveyor-1-7

Overview

There were seven Surveyor missions sent to the Moon between 1966 and 1968. Surveyor 1 was the first successful moon landing for the United States. Surveyor 2 and Surveyor 4 crash-landed. Surveyor 3 made three bounces before it finally landed—engine trouble, but useful data was still sent back to Earth. The unmanned Surveyor missions tested soft landings and looked for appropriate landing sites on the Moon before the Apollo manned missions were sent. The spacecraft were equipped with television cameras for close-up photos and digging equipment to sample the soil.

Launch

Seven missions between May 30, 1966 and January 7, 1968

Arrival

Seven missions between June 2, 1966 and January 10, 1968

End of Mission

Seven missions between September 22, 1966 and February 20, 1968

Goals

Surveyor was designed to find a way to safely land on the Moon. Take close-up images of the lunar surface and make other observations that would help pinpoint locations for safe Apollo landings.

Findings

After three practice missions, five of the seven Surveyor spacecraft made it to the Moon. Those five successful landings electrified the scientific community and sparked worldwide acclaim.
Space Missions—Printable Format

Moon Missions

Ranger 7, 8, and 9

http://science.nasa.gov/missions/ranger/

Overview

There were nine Ranger missions between 1961 and 1964, the first U.S. attempt to get close-up images of the Moon’s surface. The Ranger spacecraft were designed to fly straight toward the Moon and send back images from their six onboard cameras until the moment of impact. For various reasons, the first six missions failed, but Ranger 7, 8, and 9 were successful.

Launch

(Ranger 7) July 28, 1964; (Ranger 8) February 17, 1965; (Ranger 9) March 21, 1965

Arrival and End of Mission

(Ranger 7) July 31, 1964; (Ranger 8) February 20, 1965; (Ranger 9) March 24, 1965

Goals

Take close-up images of the Moon’s surface to scout possible landing sites for manned missions.

Findings

Images from Ranger 7, 8 and 9 provided 1000 times better resolution than Earth-based views. These highly detailed images showed Apollo planners that a smooth landing site was not going to be easy to find. Ranger 7 struck mare terrain modified by crater rays. Ranger 8 also struck mare terrain, but in an area with a complex system of ridges. Ranger 9 hit a large crater in the lunar highlands. The Ranger images showed one important thing: the Moon’s surface was littered with impact craters down to the smallest size measurable.

The success of Ranger 7, 8, and 9 had more profound implications—it gave the United States space program the sound footing needed to move forward to the Moon and the planets beyond.
Clementine

http://www.cmf.nrl.navy.mil/clementine/

Overview

Clementine, officially known as Deep Space Probe Science Experiment, was a low-cost cooperative mission to test new space technology. The spacecraft had five different types of camera systems onboard and planned to make detailed maps of the Moon’s surface, then fly on to near-Earth asteroid 1620 Geographos. A malfunction in one of the onboard computers on May 7, 1994, caused a thruster to fire, which used up all of the spacecraft’s fuel and sent it into a spin. Since no useful data could be gathered at the asteroid, the spacecraft went to the Van Allen radiation belt and tested the onboard equipment under those conditions. The mission ended when there was no more power for sending data back to Earth.

Launch
January 25, 1994

Arrival
(Moon) February 19, 1994

End of Mission
June, 1994

Goals

Map the lunar surface. Test lightweight imaging sensors and component technologies for the next generation of Department of Defense spacecraft. Fly by asteroid Geographos, approaching within 100 km.

Findings

During two months of lunar orbit, Clementine provided over 1.6 million images of the Moon’s surface with spectacular results. Its cameras mapped the surface of the Moon at 125–250 megapixel resolution. Clementine also used a laser to gather altitude data, making it possible to generate the first lunar topographic map. When scientists reviewed the data from Clementine, they found the possible existence of ice within some of the Moon’s craters.
Lunar Crater Observation and Sensing Satellite (LCROSS)

http://lcross.arc.nasa.gov/mission.htm

Overview

LCROSS was a robotic mission to the Moon trying to detect the presence of water ice. The spacecraft had two parts: the LCROSS shepherding spacecraft and the probe, Centaur. The spacecraft got positioned in orbit, and then on October 9, the probe deployed and purposely crash-landed into the Cabeus crater area of the lunar south pole, where it was suspected there might be water ice. It was hoped that Centaur’s crash would create a plume of debris, then LCROSS itself would descend a few minutes after Centaur’s crash and use the scientific instruments onboard to analyze the materials in the debris plume, before it too crash-landed.

Launch

June 18, 2009

Arrival

June 23, 2009

End of Mission

October 9, 2009

Goals

Search for water in the form of ice in a crater that is always in shadow at the Moon’s south pole. Deploy a device to crash into the crater, creating a plume of potentially icy debris to be measured, then crash itself into the crater, creating a second plume.

Findings

The LCROSS probe, Centaur, crashed into the surface at Cabeus crater and created a debris plume. The main spacecraft flew through the plume, collecting data, and relaying it back to Earth before crashing into the lunar surface. NASA confirmed that emissions in the ultraviolet spectra indicated the presence of water in the crater.
Space Missions—Printable Format
Moon Missions

Apollo


Overview

On May 25, 1961, President John F. Kennedy set an ambitious goal for the United States—send a man to the Moon and return him safely to Earth before the end of the decade (by 1969). New kinds of spacecraft and equipment needed to be developed and tested, which meant some early missions were unmanned. NASA needed a spacecraft that could reenter Earth’s atmosphere without burning up, carry three astronauts rather than one, and have two independent parts: a command module (CM) that would remain in orbit around the Moon and a lunar module (LM) that could land on the Moon, take off, and rejoin/dock with the orbiting command module. Altogether there were nearly 20 Apollo missions, some ending in catastrophe and others triumphant. Apollo 11 achieved President Kennedy’s goal when the lunar module Eagle landed on the Moon with astronauts Neil Armstrong and Buzz Aldrin on July 20, 1969, and then returned safely to Earth on July 24, 1969.

Launch

February 26, 1966 through December 7, 1972

Arrival

(the Moon and other locations) February 26, 1966 through December 11, 1972

End of Mission

February 26, 1966 through December 19, 1972

Goals

Send a man to the Moon and return him safely to Earth before the end of the decade (1969).

Findings

(manned missions)

Apollo 7: October 11–22, 1968—Earth Orbit and Return

• 10 days, 20 hours; 163 Earth orbits
• First manned command space module, first live television from manned spacecraft
• Astronauts: Walter M. Schirra, Jr., Donn F. Eisele, and R. Walter Cunningham
Apollo 8: December 21–27, 1968—Lunar Orbit and Return
- 6 days, 3 hours; lunar orbit 20 hours, with 10 orbits
- First manned lunar-orbital mission, support facilities tested, photographs taken of Earth and Moon, live television broadcasts
- Astronauts: Frank Borman, James A. Lovell, Jr., and William A. Anders

Apollo 9: March 3–13, 1969—Earth Orbit and Return
- 10 days, 1 hour; 152 orbits
- First manned flight of all lunar hardware but in an Earth orbit, 37 minutes of extravehicular activities (EVA or space walking), human reactions to space and weightlessness tested in 152 orbits, first manned flight of lunar module
- Astronauts: James A. McDivitt, David R. Scott, and Russell L. Schweickart
- Command Module: Gumdrop; Lunar Module: Spider

Apollo 10: May 18–26, 1969—Lunar Orbit and Return
- 8 days, 3 minutes; lunar orbit 61.6 hours, with 31 orbits
- Dress rehearsal for Moon landing, first manned CM/LM operations in lunar environment; simulation of first lunar-landing profile, LM taken to within 15,243 m of lunar surface, first live color television from space.
- Astronauts: Eugene A. Cernan, John W. Young, and Thomas P. Stafford
- Command Module: Charlie Brown; Lunar Module: Snoopy

Apollo 11: July 16–24, 1969—Moon Landing in Sea of Tranquility and Return
- 8 days, 3 hours, 18 minutes; EVA of 2 hours, 31 minutes; lunar surface 21.6 hours; lunar orbit 59.5 hours, with 30 orbits
- First manned lunar-landing mission (“Houston, Tranquility Base here. The Eagle has landed.”) and lunar-surface EVA; flag and instruments deployed; gathered 20 kg of material; unveiled plaque on the LM descent stage with inscription, “Here Men From Planet Earth First Set Foot Upon the Moon. July 1969 A.D. We Came In Peace For All Mankind.”
- Command Module: Columbia; Lunar Module: Eagle

Apollo 12: November 14–24, 1969—Moon Landing in Ocean of Storms and Return
- 10 days, 4 hours, 36 minutes; lunar surface 31.5 hours; lunar orbit 89 hours, with 45 orbits.
- Retrieved parts of Surveyor 3, which landed on the Moon two years earlier, Apollo lunar-surface experiments package (ALSEP) deployed, gathered 34 kg of material.
Apollo (continued)

- Astronauts: Charles “Pete” Conrad, Jr., Richard F. Gordon, Jr., and Alan L. Bean
- Command Module: Yankee Clipper; Lunar Module: Intrepid

Apollo 13: April 11–17, 1970—Lunar Flyby and Return (Moon Landing Aborted)
- 5 days, 22.9 hours
- Moon landing not possible after rupture of an oxygen tank, classed as “successful failure” because of experience in rescuing crew
- Astronauts: James A. Lovell, Jr., John L. Swigert, Jr., and Fred W. Haise, Jr.
- Command Module: Odyssey; Lunar Module: Aquarius

Apollo 14: January 31–February 09, 1971—Moon Landing in Fra Mauro and Return
- 9 days; lunar surface 33.5 hours; 67 hours in lunar orbit, with 34 orbits; EVA 9 hours, 25 minutes
- ALSEP and other instruments deployed; gathered 42.9 kg of materials; used handcart for first time to transport rocks
- Astronauts: Alan B. Shepard, Jr., Stuart A. Roosa, and Edgar D. Mitchell
- Command Module: Kitty Hawk; Lunar Module: Antares

Apollo 15: July 26–August 7, 1971—Moon Landing in Hadley-Apennine Region and Return
- 12 days, 17 hours, 12 minutes; EVA 10 hours, 36 minutes; lunar surface 66.9 hours; lunar orbit 145 hours, with 74 orbits
- First use of Lunar roving vehicle (LRV), electric-powered, four-wheel-drive car, traverse total 27.9 km; improved spacesuits gave increased mobility and stay-time; ALSEP deployed; scientific payload landed on Moon doubled; gathered 6.6 kg of material
- Astronauts: David R. Scott, James B. Irwin, and Alfred M. Worden
- Command Module: Endeavor; Lunar Module: Falcon

Apollo 16: April 16–27, 1972—Moon Landing in Descartes Highlands and Return
- 11 days, 1 hour, 51 minutes; lunar surface 71 hours; lunar orbit 126 hours, with 64 orbits
- First study of highlands area, selected surface experiments deployed, ultraviolet camera/spectrograph used for first time on Moon, LRV used for second time, gathered 94.7 kg of lunar samples
- Command Module: Casper; Lunar Module: Orion

Apollo 17: December 7–19, 1972—Moon Landing in Taurus-Littrow Area and Return
Apollo (continued)

- 12 days, 13 hours, 52 minutes; EVAs of 22 hours, 4 minutes; lunar surface 75 hours; lunar orbit 17 hours
- Last Apollo mission to land on Moon, Schmitt is first scientist-astronaut to land on Moon, sixth automated research station set up, LRV travels 30.5 km, gathered 110.5 kg of material
- Astronauts: Eugene A. Cernan, Ronald B. Evans, and Harrison H. “Jack” Schmitt
- Command Module: America; Lunar Module: Challenger
Pioneer Venus

http://heasarc.nasa.gov/docs/heasarc/missions/pvo.html

Overview

The Pioneer Venus mission consisted of two spacecraft, launched separately: an orbiter and a five-part multiprobe (one part to transport the other four parts). The orbiter orbited Venus much longer than planned, finally crashing into Venus in August, 1992. The multiprobes were released and sent down to the Venusian surface, sending back data about the atmosphere as they descended.

Launch

May 20, 1978 (orbiter); August 8, 1978 (multiprobe)

Arrival

December 4, 1978 (orbiter); November 16 and 20, 1978 (multiprobe parts)

End of Mission

October 8, 1992 (orbiter); December 9, 1978 (multiprobe parts)

Goals

Mission goals were to study the composition of the atmosphere, to investigate the solar wind near Venus, to map Venus’ surface through a radar imaging system, and to study the characteristics of Venus’ upper atmosphere and ionosphere.

Findings

The highly elliptical orbit of Pioneer Venus around the planet allowed the craft to use radar to map the clouds, atmosphere, ionosphere, and Venus’ surface. During the flight, the craft was able to make observations of several comets. Even with no heat shield or parachute, the craft was able to make measurements to about 110 km altitude before burning up. The multiprobe separated into five separate probes. All the probes entered the atmosphere of Venus within 11 minutes of each other. The probes descended toward the surface over approximately an hour long period sending back data to Earth. Gamma Ray detector detected 217 new cosmic gamma ray bursts and 126 solar flares.
Space Missions—Printable Format

Mercury and Venus Missions

Mariner 2

http://nssdc.gsfc.nasa.gov/nmc/spacecraftDisplay.do?id=1962-041A

Overview

The Mariner program consisted of a series of 10 unmanned flyby missions launched by NASA between 1962 and 1973. These missions were designed to be the first to travel to other planets, specifically Venus, Mars, and Mercury. Seven were successful; three were lost. In summary:

<table>
<thead>
<tr>
<th>Spacecraft</th>
<th>Destination</th>
<th>Launch year</th>
<th>Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mariner 1</td>
<td>Venus</td>
<td>1962</td>
<td>destroyed</td>
</tr>
<tr>
<td>Mariner 2</td>
<td>Venus</td>
<td>1962</td>
<td>flyby</td>
</tr>
<tr>
<td>Mariner 3</td>
<td>Mars</td>
<td>1964</td>
<td>lost</td>
</tr>
<tr>
<td>Mariner 4</td>
<td>Mars</td>
<td>1964</td>
<td>flyby</td>
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<tr>
<td>Mariner 5</td>
<td>Venus</td>
<td>1967</td>
<td>flyby</td>
</tr>
<tr>
<td>Mariner 6</td>
<td>Mars</td>
<td>1969</td>
<td>flyby</td>
</tr>
<tr>
<td>Mariner 7</td>
<td>Mars</td>
<td>1969</td>
<td>flyby</td>
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<tr>
<td>Mariner 8</td>
<td>Mars</td>
<td>1971</td>
<td>lost</td>
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<tr>
<td>Mariner 9</td>
<td>Mars</td>
<td>1971</td>
<td>flyby</td>
</tr>
<tr>
<td>Mariner 10</td>
<td>Venus, Mercury</td>
<td>1973</td>
<td>flyby</td>
</tr>
</tbody>
</table>

Goals

Fly by Venus and return data on the planet’s atmosphere, magnetic field, charged particle environment, and mass. Make measurements of the interplanetary medium during the cruise to Venus and after the flyby.

Launch

August 27, 1962

Arrival

December 14, 1962 (closest approach)

End of Mission

January 3, 1963 (last communication)
Mariner 2 (continued)

Findings

Mariner 2 was the first spacecraft to successfully encounter another planet. Found Venus has a slow retrograde rotation rate, hot surface temperatures and high surface pressures, a predominantly carbon dioxide atmosphere, continuous cloud cover with a top altitude of about 60 km, and no detectable magnetic field. It was also shown that in interplanetary space the solar wind streams continuously and the cosmic dust density is much lower than the near-Earth region. Mariner 2 made improved estimates of Venus’ mass and the value of the astronomical unit.
Space Missions—Printable Format
Mercury and Venus Missions

Mariner 5

http://nssdc.gsfc.nasa.gov/ncm/spacecraftDisplay.do?id=1967-060A

Overview

The Mariner program consisted of a series of 10 unmanned flyby missions launched by NASA between 1962 and 1973. These missions were designed to be the first to travel to other planets, specifically Venus, Mars, and Mercury. Seven were successful; three were lost. In summary:

Launch

June 14, 1967

Arrival

October 19, 1967 (closest approach)

End of Mission

November, 1967 (Mariner 5 mission officially ended.) Six months later NASA tried to re-establish contact with the spacecraft. At first there was no signal, then on October 14, 1968, a weak signal, but the spacecraft was not able to respond to commands, so further attempts were abandoned on November 5, 1968.

Goals

Fly by Venus at a distance of 3,990 kilometers (2,480 miles). Originally built to be backup for Mariner 4 to Mars, but was refurbished and modified to go to Venus instead. Measure interplanetary and Venusian magnetic fields, charged particles, and plasmas, radio refractivity, and UV emissions of the Venusian atmosphere.

Findings

With more sensitive instruments than Mariner 2, revealed new information about Venus’ atmosphere, including its composition of 85-99% carbon dioxide. The spacecraft passed 4,000 km from Venus. The spacecraft instruments successfully measured all objectives.
Mariner 10


Overview

Mariner 10 was the first spacecraft to use the gravitational pull of one planet (Venus) to reach another (Mercury), and the first spacecraft mission to visit two planets. The Mariner program consisted of a series of 10 unmanned flyby missions launched by NASA between 1962 and 1973. These missions were designed to be the first to travel to other planets, specifically Venus, Mars, and Mercury. Seven were successful; three were lost. In summary:

Launch

November 3, 1973

Arrival

February 5, 1974 (Venus flyby); March 29, 1974 (first Mercury flyby), September 21, 1974 (second Mercury flyby), March 16, 1975 (third Mercury flyby)

End of Mission

March 24, 1975

Goals

Fly by Venus and Mercury. At Mercury, measure the environment, atmosphere, surface, and body characteristics. Make similar investigations of Venus. Perform experiments in the interplanetary medium and obtain experience with a dual-planet, gravity-assist mission.

Findings

On its flyby of Venus, Mariner 10 discovered rotating clouds and a very weak magnetic field, and sent back the first ever close-up images of Venus. The three flybys of Mercury revealed a moon-like surface, which scientists had not been able to detect previously with telescopes. About 40% of Mercury’s surface was mapped in detail using close-up images. Mariner 10 found that Mercury has an atmosphere consisting primarily of helium, as well as a magnetic field and a large iron-rich core. Radiometer readings suggested that Mercury has a nighttime minimum temperature of −183°C (−297°F) and maximum daytime temperature of 187°C (369°F). Mariner 10 also made ultraviolet observations of Comet Kohoutek in January 1974.
Venus Radar Mapper—Magellan

http://www2.jpl.nasa.gov/magellan/

Overview

Because this mission would make the first detailed maps of the entire surface of Venus, it was named after the 16th century Portuguese explorer, Ferdinand Magellan, who circumnavigated and mapped Earth. Venus’ dense and opaque atmosphere meant that normal optical cameras wouldn’t work for imaging—instead, Magellan used bursts of microwave energy that passed through the clouds and illuminated the planet’s surface. The radar system measured the brightness of each pulse as it reflected back, and then that data was used to map the planet, strip by strip as it rotated. Magellan was the first spacecraft to be launched from a space shuttle.

Launch

May 4, 1989

Arrival

August 10, 1990

End of Mission

October 13, 1994

Goals

Make the most detailed radar images of Venus, map the surface topography, and the electrical characteristics. Use precision radio tracking to measure Venus’ gravitational field and show the planet’s internal mass distribution.

Findings

Magellan collected radar images of 98% of the planet’s surface and measured the surface topography and electrical characteristics. It provided evidence to understand the role of impacts, volcanism, and tectonics in the formation of surface structures on Venus. Magellan helped us see that Venus’ surface is covered by volcanic materials and features (lava plains, small lava domes, and large-shield volcanoes). There are few impact craters, suggesting that the surface is geologically young, less than 800 million years old. Magellan found lava channels over 6000 km long providing evidence for river-like flows of lava that probably erupted at a high rate. What Magellan did not find were typical signs of terrestrial plate tectonics, continental drift, and basin floor spreading. Instead, the tectonics features found were global rift zones and numerous broad,
Venus Radar Mapper-Magellan (continued)

low dome structures called coronae. Coronae are formed by the upwelling and settling of magma from the mantle. Although Venus has a dense atmosphere, there is no data to support wind erosion. This is different from Mars, where there is a thin atmosphere, but good evidence for wind erosion of dust and sand.
MErcury Surface, Space ENvironment, GEOchemistry and Ranging (MESSENGER)

http://messenger.jhuapl.edu/

Overview
The first spacecraft to visit Mercury was Mariner 10 (1975). Nearly 40 years later, MESSENGER is the second spacecraft to visit Mercury. MESSENGER spent 4 years getting to Mercury, performed several flyby missions where it mapped the planet and gathered data, and finally entered into orbit in 2011. MESSENGER will spend at least 1 year gathering data while it orbits.

Launch
August 3, 2004

Arrival
March 18, 2011

End of Mission
April 13, 2015

Goals
Understand the history, origin, and evolution of Mercury and the other terrestrial planets. Map the planet in color, image the surface in high resolution. Measure the composition of the surface, atmosphere, and magnetic field. MESSENGER seeks answers to these questions:
1. Why is Mercury so dense?
2. What is the geologic history of Mercury?
3. What is the structure of Mercury’s core?
4. What is the nature of Mercury’s magnetic field?
5. What are the unusual materials at Mercury’s poles?
6. What volatiles (gases involved in volcanic eruptions) are important at Mercury?

Findings
New data from the 2008 flyby shows that unlike the moon, Mercury has huge cliffs with structures snaking hundreds of miles across the planet’s surface. These cliffs preserve a record of fault activity from early in the planet’s history. Images revealed impact craters that appear very
MErcury Surface, Space ENvironment, GEochemistry and Ranging (MESSENGER) (continued)

different from lunar craters. A unique feature was discovered, the Spider. The Spider consists of more than a hundred narrow, flat-floored troughs radiating from a central region. Similar to Earth, Mercury has magnetic fields caused by a liquid metallic outer core deep in the planet’s center.
**Hinode (Solar-B)**

http://msslxr.mssl.ucl.ac.uk:8080/SolarB/Solar-B.jsp

**Overview**

Hinode began as a 3-year international mission with Japan, the United States, and the United Kingdom to study our star, the Sun. It has gone beyond the initial timeframe and continues to observe the Sun using three advanced solar telescopes: (1) solar optical to observe solar magnetic fields, (2) X-ray telescope, and (3) extreme ultraviolet imaging spectrometer. In Japanese, Hinode means “sunrise.”

**Launch**

September 22, 2006

**Arrival**

(Sun orbit) November, 2006

**End of Mission**

Still operating as of 2018

**Goals**

Understand why and how the Sun’s magnetic field varies and how this affects total solar output and solar weather.

Answer the following questions:

1. Why does a hot corona exist above the cool atmosphere? What drives explosive events such as solar flares?
2. What creates the Sun’s magnetic fields?

**Findings**

The polar regions of the Sun were thought to be inactive in X-rays and weak in magnetic field strength before Hinode, but Hinode has discovered surprisingly frequent occurrence of X-ray jets in the Sun’s polar regions. Magnetic activity creates the jets. The chromosphere, that portion of the solar atmosphere between the photosphere and the corona, is rich in jet activity, which was not known before. The jets throughout the chromosphere occur at a much smaller scale (smaller than several hundred km) as compared to coronal X-ray jets. Larger chromospheric jets that reach heights of 2,000-5,000 km cannot be accounted for by simple jet motion models. Scientists believe that magnetism may form the main body of the jets, and waves may transfer the X-rays along magnetic field lines.
Reuven Ramaty High Energy Solar Spectroscopic Imager (RHESSI)

http://science.nasa.gov/missions/rhessi/

Overview

Solar flares happen on an 11-year cycle. They are giant explosions that take place on the Sun and have disruptive consequences on Earth and for vehicles traveling in space. Solar flares can release as much energy as a billion one-megaton nuclear bombs. Solar flares cannot be predicted and are not well understood because emissions happen at wavelengths that human eyes cannot detect. The equipment onboard RHESSI, a small explorer spacecraft orbiting above Earth’s atmosphere, is designed to make X-ray and spectroscopic images that humans can see. An additional benefit of studying solar flares is that they model high-energy explosions and particle acceleration happening at more distant places in the universe, which are not accessible.

Launch

February 2, 2002

Arrival

February 2, 2002 (Earth orbit)

End of Mission

Still operating as of 2018

Goals

RHESSI’s primary goal is to investigate the physics of particle acceleration and energy release in solar flares. To do this it will observe the processes that take place in the magnetized plasmas of the solar atmosphere during a flare: impulsive energy release, particle acceleration, and particle and energy transport.

Findings

RHESSI performed hard X-ray imaging spectroscopy and high-resolution spectroscopy of gamma-ray lines in solar flares. It obtained observations of at least a hundred X-ray flares and ten gamma-ray flares. However, it appears that some of these flares might have shuffled antimatter around, producing it in one location and destroying it in another. These observations provided insights into solar flares, which are the most powerful explosions in the solar system. RHESSI
Reuven Ramaty High Energy Solar Spectroscopic Imager (RHESSI) (continued)

made the most detailed analysis to date of the gamma rays emitted when antimatter destroys ordinary matter in the solar atmosphere.

RHESSI was the first satellite to image solar gamma rays from a solar flare. RHESSI was the first satellite to accurately measure terrestrial gamma-ray flashes that come from thunder storms, and RHESSI found that such flashes occur more often than thought and the gamma rays have a higher frequency on average than the average for cosmic sources.
Genesis (Solar Wind Sample Return)

http://science.nasa.gov/missions/genesis/

Overview

Genesis was designed to collect uncontaminated samples of solar wind and return canisters containing those samples to Earth for analysis. Based on the idea that solar wind is a time capsule of particles containing dust and gases ejected from the outer surface of the Sun, and that those particles have not changed in the more than 4 billion years since the solar system originated, it was hoped that the collected solar wind samples would help answer the question, how did the Sun’s family of planets (our solar system) originate? In addition, getting information about the original state of the solar system would help scientists uncover the processes that have changed our solar system to its present state.

The Genesis mission was designed to ensure uncontaminated samples of concentrated particles. After recovering the capsules containing the samples at a site in the Utah desert, the canisters would be opened in a clean room before careful analysis. Unfortunately, the parachutes failed and the capsules crash–landed, while traveling more than 200 miles per hour. Some samples were contaminated, but some were still usable.

Launch

August 8, 2001

Arrival

November 16, 2001 (halo orbit at L1, a place where Sun and Earth gravities are balanced, and a pristine sample of solar wind could be collected)

End of Mission

September 8, 2004 (sample capsule returned to Earth; spacecraft is still in orbit around Sun)

Goals

Collect samples of solar wind particles and return them to Earth for detailed analysis. Precisely measure the abundance of solar isotopes and elements, and provide a source of solar matter for future scientific analysis. Precisely measure ratios of oxygen, nitrogen, and noble gases in the different phases of solar activity.
Genesis (Solar Wind Sample Return)

Findings

Despite the canisters’ crash-landing, the team has identified ions of solar origin. Genesis was the first sample return mission since the Apollo program and the first to return samples from beyond the Moon. Comparisons were made between solar wind samples from Genesis and solar wind studies based on Moon rock samples. Despite contamination from the crash, scientists hope to obtain useful data.
Solar and Heliospheric Observatory (SoHO)

http://sohowww.nascom.nasa.gov

Overview

The spacecraft, a joint effort by the European Space Agency and NASA, is orbiting the Sun near the L1 equilibrium point. Although it was originally planned as a two-year mission, it continues to operate more than 15 years later. Besides its mission goals to study the sun, it also reports on space weather.

Launch

December 2, 1995

Arrival

May, 1996 (began operating)

End of Mission

Still operating as of 2018

Goals

SOHO was designed to answer the following three fundamental scientific questions about the Sun:

1. What is the structure and dynamics of the solar interior?
2. Why does the solar corona exist and how is it heated to such an extremely high temperature?
3. Where is the solar wind produced and how is it accelerated?

Findings

SoHO has observed the changing Sun during its 11-year solar cycle, from quiet to stormy, and back again. On January 4, 2008, a reversed-polarity sunspot appeared, signaling the start of Solar Cycle 24. SoHO data are being used to try to predict, in real-time, the approach and intensity of solar particles that would threaten astronauts and technology in space. SoHO data shows that solar flares drive global oscillations (starquakes) in the Sun, confirming a prediction made more than 30 years ago. A similar phenomenon is known on Earth after large earthquakes. SoHO also discovered more than 2,100 comets that flew close to the Sun.
Transition Region and Coronal Explorer (TRACE)

http://sunland.gsfc.nasa.gov/smex/trace/

Overview

TRACE was a small explorer project sent to observe the Sun and study the connection between its magnetic fields and the heating of the Sun’s corona. It worked in conjunction with SoHO. It is hoped that this investigation will deepen our understanding of the effects of the Sun’s magnetic field on its own atmosphere and to help us understand the changes that this causes in the heliosphere between the Sun and Earth, and in the space around Earth, including our own atmosphere.

Launch

April 1, 1998

Arrival

April 7, 1998 (first transmission)

End of Mission

June 21, 2010 (last image)

Goals

Explore the three-dimensional magnetic structures which emerge through the visible surface of the Sun—the photosphere—and define both the geometry and dynamics of the upper-solar atmosphere, the transition region and corona.

Findings

TRACE collected movies and images of the Sun’s surface from 1998 through 2010. In a movie example of the solar limb (edge), one-million-degree plasma flows in loops long enough to wrap around the Earth four times. The loops extend several thousand kilometers deeper through the Sun’s chromosphere before they reach the surface where they are anchored to regions of strong magnetic field called sunspots.
Solar Terrestrial Relations Observatory (STEREO)

http://stereo.gsfc.nasa.gov

Overview

For stereophonic sound recordings, there are multiple microphones and two transmission channels to simulate hearing something live. The STEREO mission consists of two space-based observatories—one ahead of Earth in its orbit, the other trailing behind. Using this pair of viewpoints, scientists will have stereoscopic images that show the structure and evolution of solar storms as they blast from the Sun and move out through space. On February 6, 2011, the two spacecraft were exactly 180 degrees apart from each other, allowing the entire Sun to be seen at once for the first time.

Launch

October 26, 2006

Arrival

December 15, 2006 and January 21, 2007 (heliocentric orbit)

End of Mission

Still operating as of 2018

Goals

STEREO will trace the flow of energy and matter from the Sun to Earth as well as reveal the 3-D structure of coronal mass ejections and help us understand why they happen. Provide alerts for Earth-directed solar ejections, from its unique side-viewing perspective adding it to the fleet of Space Weather detection satellites. Coronal mass ejections directed toward Earth can damage and even destroy satellites, are extremely hazardous to Astronauts when outside of the protection of the Space Shuttle or the International Space Station performing Extra Vehicular Activities (EVAs), and they have been known to cause electrical power outages.

Findings

STEREO discovered powerful radio waves in the radiation belts around Earth that are capable of pushing electrons to near the speed of light. This speed gives the electrons enough energy to quickly knock out computers, pierce spacesuits, and damage the tissues of astronauts. It had been thought that this increase in speed happens over a span of minutes or even tens of hours, but in fact electrons can be energized in a tenth of a second. Solar “tsunamis” have been observed in
Solar Terrestrial Relations Observatory (STEREO) (continued)

four different wavelengths corresponding to four different temperatures, enabling the team to see how the wave moves through the different layers of the solar atmosphere. STEREO observed loops in the Sun’s corona (atmosphere) in 3-D, revealing structure as never before.
Solar Dynamics Observatory (SDO)

http://sdo.gsfc.nasa.gov/

Overview

Solar Dynamics Observatory is the first mission of NASA’s Living With a Star Program, designed to understand the causes of solar variability and its impacts on Earth.

Launch

February 11, 2010

Arrival

May 14, 2010 (began collecting data)

End of Mission

Still operating as of 2018

Goals

1. Study the Sun’s influence on Earth and near-Earth space by observing the solar atmosphere at a small scale in many wavelengths at the same time.
2. Determine how the Sun’s magnetic field is generated, structured, and released in the form of energy.
3. Predict solar variations that can affect life on Earth, such as solar flares that can affect cell phone and other technology.

Findings

SDO produced spectacular views of the sun’s corona (atmosphere) that otherwise is best visible during eclipses. With high-resolution images, SDO has monitored the Sun, detecting many solar flares that are powerful bursts of radiation. It provides information on predicted magnetic activity. When a solar flare is intense enough, its radiation can disturb Earth’s atmosphere in the layer where GPS and communications signals travel. See NOAA’s Space Weather Prediction Center (http://spaceweather.gov), the U.S. government’s official source for space weather forecasts, alerts, watches and warnings. SDO captured images and video of a solar “tornado” that was five times wider than Earth, moving across the sun’s surface, the first time a video had been caught of the activity.
Space Missions—Printable Format

Space Telescopes

Kepler

http://nasa.gov/kepler

Overview

Kepler is a planet hunter. Its mission is to search for earth-like planets outside our solar system that are capable of supporting life. Using a 95-megapixel camera, it watches for regular patterns of dimming light. There is a lot of excitement as potential planets are watched, data is analyzed, and planets are confirmed. Once every quarter, the spacecraft is rolled to keep its solar panels facing the Sun and twice a month, data is downloaded and analyzed at the NASA Ames Research Center.

Launch

March 7, 2009

Orbit

Earth-trailing heliocentric with a period of 372.5 days

End of Mission

The prime mission ended May 11, 2013 after failure of two of its four reaction wheels. Three were needed for accurate pointing of the instrument. However, a new K2 mission uses the still-functional optical system (photometer) that is aimed with a clever use of the two remaining working reaction wheels. K2 is still operating as of 2017 and expected to last through sometime in 2018.

Goals

Survey 100,000 stars in our region of the Milky Way Galaxy to detect hundreds of Earth-size and smaller planets in or nearby the stars’ habitable zones. A habitable zone is a region near a star where liquid water can exist on a planet’s surface. Determine sizes and shapes of the orbits of the planets detected. Determine properties of those stars that harbor planetary systems.

Findings

The Kepler and K2 missions have detected about 4,500 planet candidates of which 2,340 planets are confirmed as of October 2017.
**Hubble Space Telescope**

http://hubble.nasa.gov/

**Overview**

The Hubble Space Telescope, named after astronomer Edwin Hubble, was put into orbit by the Space Shuttle Discovery in 1990. It is still functioning more than 20 years later, thanks to it being designed so astronauts can service it and make repairs, similar to what auto mechanics do for cars. Its extremely detailed images of the farthest places in the universe have been responsible for many scientific discoveries. The aperture (2.4 meters) is very large, but the Hubble isn’t just a telescope—it’s a combination of cameras, spectrographs, photometers, mirrors, gyroscopes, and electronics.

**Launch**

April 24, 1990

**Orbit**

Low earth

**End of Mission**

Still operating as of 2018

**Goals**

Use a large, space-based observatory to provide unprecedented deep and clear views of the universe, ranging from our own solar system to extremely remote fledgling galaxies.

**Findings**

One of NASA’s most successful and long-lasting science missions, Hubble has beamed hundreds of thousands of images back to Earth, shedding light on many of the great mysteries of astronomy.

- Helped determine the age of the universe, the identity of quasars, and the existence of dark energy.
- Revealed the age of the universe to be about 13 to 14 billion years, much more accurate than the old range of anywhere from 10 to 20 billion years.
- Played a key role in the discovery of dark energy, a mysterious force that causes the expansion of the universe to accelerate.
- Shown galaxies in all stages of evolution, including toddler galaxies that were around when the universe was still young, helping understand how galaxies form.
Hubble Space Telescope (continued)

- Found protoplanetary disks, clumps of gas and dust around young stars that likely function as birthing grounds for new planets.
- Discovered that gamma-ray bursts—strange, incredibly powerful explosions of energy—occur in far-distant galaxies when massive stars collapse.

More than 7,000 scientific articles have been published based on Hubble data.
Spitzer Space Telescope

http://www.spitzer.caltech.edu/

Overview

Spitzer is the fourth and final mission in NASA’s Great Observatories Program where each uses a different kind of light (Hubble—optical, Compton—gamma rays, Chandra—X-Rays, and Spitzer—infrared). Infrared imaging will provide a direct way of separating the stars from the warm dust, thereby dissecting a galaxy. Colorful images from Spitzer are beautiful to see.

Launch

August 25, 2003

Orbit

Heliocentric with a 2-year orbit period

End of Mission

May 15, 2009 (liquid helium supply that cools most of the onboard instruments was exhausted)

One camera operates without coolant so the spacecraft continues to collect data, but is now called the Spitzer Warm Mission. Still operating as of 2018.

Goals

Use infrared to peer into regions of space which are hidden from optical telescopes. Since many areas of space are filled with vast, dense clouds of gas and dust which block our view, infrared light can penetrate these clouds, allowing a glimpse into regions of star formation, the centers of galaxies, and into newly forming planetary systems. Infrared also brings us information about the cooler objects in space, such as smaller stars which are too dim to be detected by their visible light, extrasolar planets, and giant molecular clouds. Also, many molecules in space, including organic molecules, have their unique signatures in the infrared.

Findings

- Verified that at least one of 17 invisible objects observed years ago lies within the body of our Milky Way galaxy, thereby supporting a hypothesis the puzzle of dark matter in the universe.
- Discovered seven objects that may be supermassive black holes that powered the bright cores of the earliest active galaxies.
- Discovered dusty disk swirling around the nearby star Vega, probably caused by collisions of objects, perhaps as big as Pluto.
Spitzer Space Telescope (continued)

- Obtained the deepest and sharpest view yet of the core region of the Milky Way galaxy where stars are packed together densely as they race around the supermassive black hole that lies at the very center.
- Discovered cataclysmic variable stars (two-star systems with a low mass, cool “brown dwarf” star orbiting a highly magnetic white dwarf star) with excess amounts of infrared radiation, suggesting that these odd objects are surrounded by large disks of cool dust.
- Discovered an object that looks like a giant tornado in space in a region where new stars are forming.
Chandra X-Ray Observatory

http://chandra.harvard.edu/

Overview

Chandra was launched by the space shuttle Columbia in 1999. Rather than being an optical telescope, Chandra uses special nested mirrors to precisely focus X-rays. No earth-bound telescope could do this because most X-rays are absorbed by Earth’s atmosphere. Chandra’s orbit takes it beyond the Van Allen radiation belt and it has been instrumental in gathering information about supernovas, black holes, and dark matter.

Launch

July 23, 1999

Orbit

Elliptical with orbit period of 65 hours (Chandra can observe for 55 of 65 hours.)

End of Mission

Still operating as of 2018

Goals

Observe X-rays from high-energy regions of the universe, such as the remnants of exploded stars, and active galaxies. Increase our understanding of the origin, evolution, and destiny of the universe.

Findings

Began exploration of the hot turbulent regions in space with images 25 times sharper than previous X-ray pictures. Studied the process of jets of matter being ejected from supermassive black holes in the dense central regions of galaxies. Observed X-rays from particles up to the last second before they fall into a black hole. Observed quasars ten billion ly away. New images of the Crab Nebula supernova remnant and its pulsar in X-rays. Studies of black holes, supernovas, dark matter. Obtained accurate determination of the amount of dark matter in galaxy clusters with implications for the total matter density of the universe—stars in the galaxies and hot gas together contribute only about 13 percent of the mass—the rest must be in the form of dark matter. Discovered that Saturn may act as a mirror, reflecting explosive activity from the Sun.