Spacecraft Missions and Programs to Moon

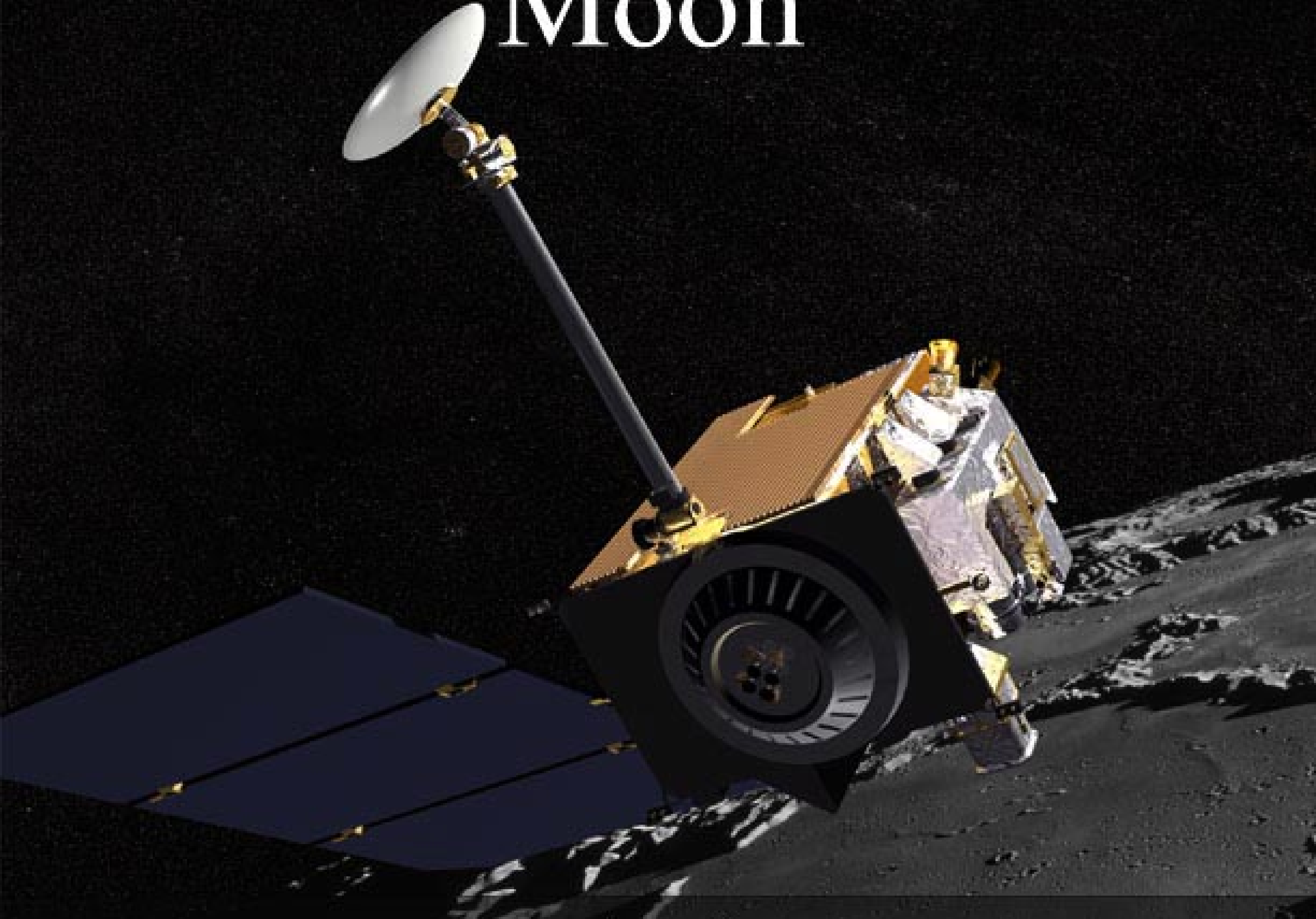

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Table of Contents

Chapter- 1

Ranger Program

First image of the moon returned by a Ranger mission (Ranger 7 in 1964)

The **Ranger program** was a series of unmanned space missions by the United States in the 1960s whose objective was to obtain the first close-up images of the surface of the Moon. The Ranger spacecraft were designed to impact the lunar surface, returning imagery until they were destroyed upon impact. A series of mishaps, however, led to the failure of the first six flights beginning in 1961 until Ranger 7 successfully returned images in July 1964, followed by two more successful missions.

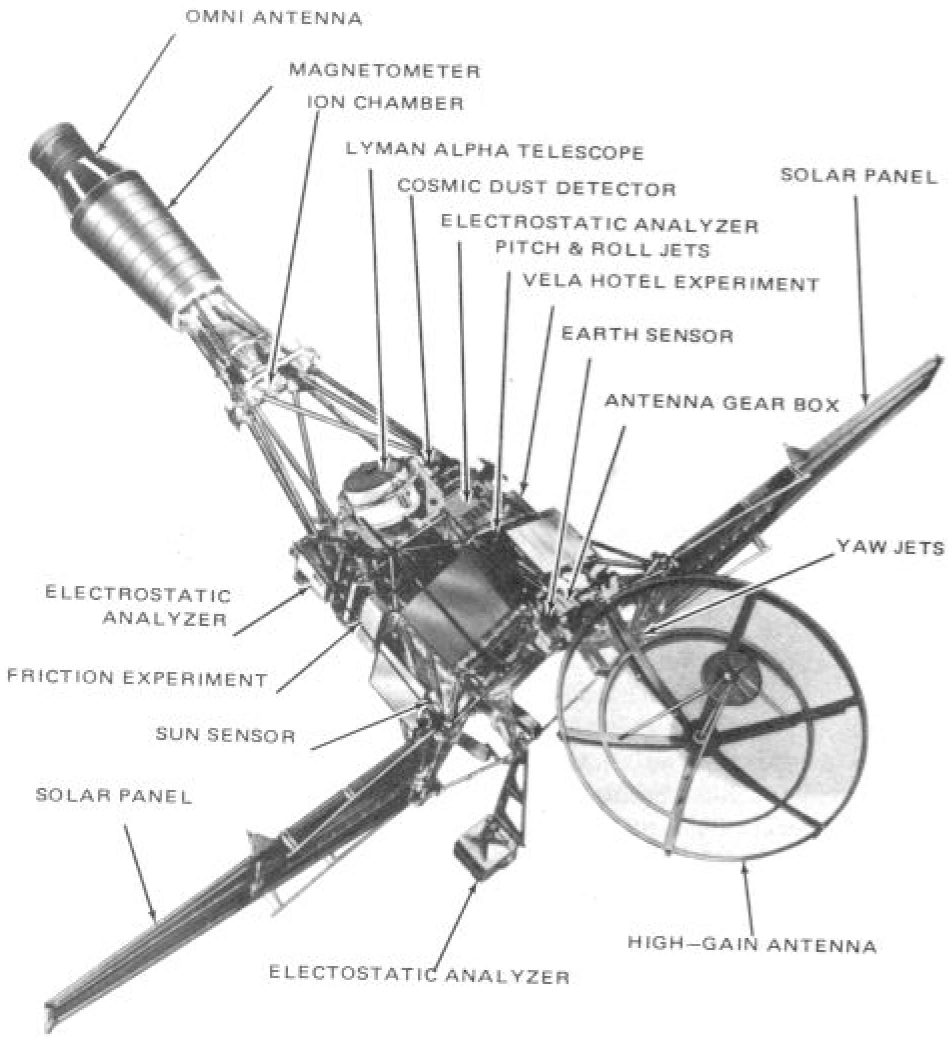
Ranger was originally designed, beginning in 1959, in three distinct phases, called "blocks". Each block had different mission objectives and progressively more advanced system design. The JPL mission designers planned multiple launches in each block, to maximize the engineering experience and scientific value of the mission and to assure at least one successful flight. Total research, development, launch, and support costs for the Ranger series of spacecraft (Rangers 1 through 9) was approximately $170 million.

The Ranger spacecraft

Each Ranger spacecraft had six cameras on board. The cameras were fundamentally the same with differences in exposure times, fields of view, lenses, and scan rates. The camera system was divided into two channels, P (partial) and F (full). Each channel was self-contained with separate power supplies, timers, and transmitters. The F-channel had two cameras: the wide-angle A-camera and the narrow angle B-camera. The P-channel had four cameras: P1 and P2 (narrow angle) and P3 and P4 (wide angle). The final F-channel image was taken between 2.5 and 5 seconds before impact (altitude about 5 km) and the last P-channel image 0.2 to 0.4 seconds before impact (altitude about 600 m). The images provided better resolution than was available from Earth based views by a factor of 1000.

Mission list

Block 1 missions



Ranger block I spacecraft diagram. (NASA)

- Ranger 1, launched 23 August 1961, lunar prototype, launch failure
- Ranger 2, launched 18 November 1961, lunar prototype, launch failure

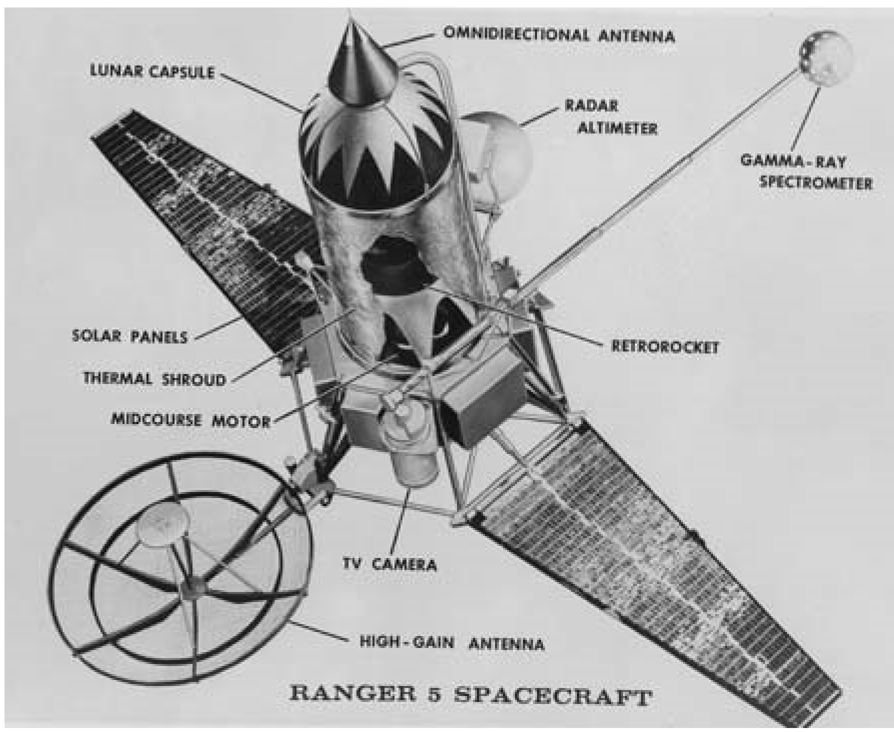
Block 1, consisting of two spacecraft launched into Earth orbit in 1961, was intended to test the Atlas-Agena launch vehicle and spacecraft equipment without attempting to reach the Moon.

Most elements of spacecraft technology taken for granted today were untested before Ranger. Perhaps the most important of these was three-axis attitude stabilization, meaning that the spacecraft is fixed in relation to space instead of being stabilized by spinning. This would permit pointing large solar panels at the Sun, a large antenna at

Earth, and cameras and other directional scientific sensors at their appropriate targets. Rocket propulsion carried aboard the spacecraft was another critically important new technology, needed for accurate targeting at the Moon or distant planets.

In addition, two-way communication and closed-loop tracking, requiring spacecraft and ground system development, and the use of on-board computing and sequencing combined with commands from the ground, all had to be developed and tried out in flight. Unfortunately, problems with the early version of the launch vehicle left Ranger 1 and Ranger 2 in short-lived, low-Earth orbits in which the spacecraft could not stabilize themselves, collect solar power, or survive for long. In 1962, JPL utilized the Ranger 1 and Ranger 2 design for the failed Mariner 1 and successful Mariner 2 deep-space probes to Venus.

Block 2 missions



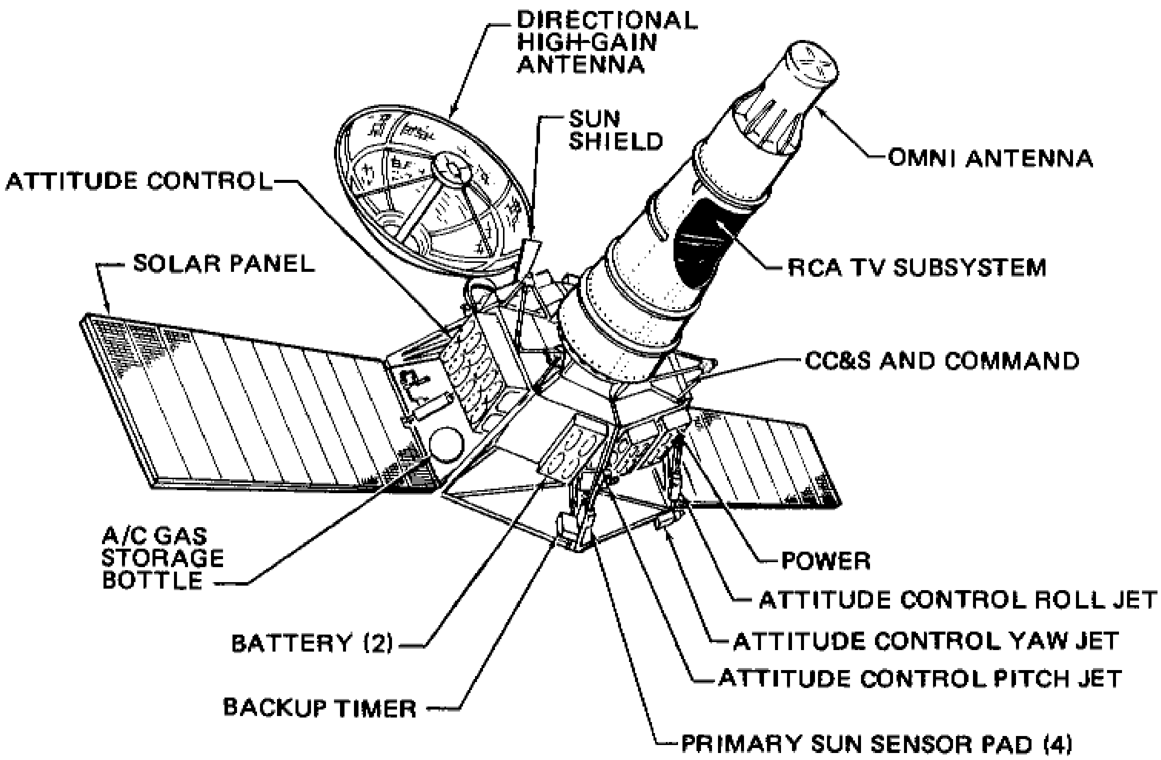
Ranger block II spacecraft diagram. (NASA)

- Ranger 3, launched 26 January 1962, lunar probe, spacecraft failed, missed moon
- Ranger 4, launched 23 April 1962, lunar probe, spacecraft failed, impact
- Ranger 5, launched 18 October 1962, lunar probe, spacecraft failed, missed

Block 2 of the Ranger project launched three spacecraft to the Moon in 1962, carrying a TV camera, a radiation detector, and a seismometer in a separate capsule slowed by a rocket motor and packaged to survive its low-speed impact on the Moon’s surface. The three missions together demonstrated good performance of the Atlas/Agena B launch vehicle and the adequacy of the spacecraft design, but unfortunately not all on the same attempt. Ranger 3 was launched into deep space, but an inaccuracy put it off course and it missed the Moon entirely. Ranger 4 had a perfect launch, but the spacecraft was completely disabled. The project team tracked the seismometer capsule to impact just out of sight on the lunar far side, validating the communications and navigation system. Ranger 5 missed the Moon and was disabled. No significant science information was gleaned from these missions. The craft weighed 331 kg.

Around the end of Block 2, it was discovered that a type of diode used in previous missions produced problematic gold-plate flaking in the conditions of space. This may have been responsible for some of the failures.

Block 3 missions



Ranger block III spacecraft diagram. (NASA)

- Ranger 6, launched 30 January 1964, lunar probe, impact, cameras failed
- Ranger 7
  - Launched 28 July 1964
  - Impacted Moon 31 July 1964 at 13:25:49 UT
  - 10°21′S 339°25′E / 10.35°S 339.42°E - Mare Cognitum
- Ranger 8
  - Launched 17 February 1965
  - Impacted Moon 20 February 1965 at 09:57:37 UT
  - 2°40′N 24°39′E / 2.67°N 24.65°E - Mare Tranquillitatis (Sea of Tranquility)
- Ranger 9

- Launched 21 March 1965
- Impacted Moon 24 March 1965 at 14:08:20 UT
- 12°50′S 357°38′E / 12.83°S 357.63°E - Alphonsus crater

Ranger's Block 3 embodied four launches in 1964-65. These spacecraft boasted a television instrument designed to observe the lunar surface during the approach; as the spacecraft neared the Moon, they would reveal detail smaller than the best Earth telescopes could show, and finally details down to dishpan size. The first of the new series, Ranger 6, had a flawless flight, except that the television system was disabled by an in-flight accident and could take no pictures.

The next three Rangers, with a redesigned television, were completely successful. Ranger 7 photographed its way down to target in a lunar plain, soon named Mare Cognitum, south of the crater Copernicus. It sent more than 4,300 pictures from six cameras to waiting scientists and engineers. The new images revealed that craters caused by impact were the dominant features of the Moon's surface, even in the seemingly smooth and empty plains. Great craters were marked by small ones, and the small with tiny impact pockmarks, as far down in size as could be discerned—about 50 centimeters (16 inches). The light-colored streaks radiating from Copernicus and a few other large craters turned out to be chains and nets of small craters and debris blasted out in the primary impacts.

In February 1965, Ranger 8 swept an oblique course over the south of Oceanus Procellarum and Mare Nubium, to crash in Mare Tranquillitatis where Apollo 11 would land 4½ years later. It garnered more than 7,000 images, covering a wider area and reinforcing the conclusions from Ranger 7. About a month later, Ranger 9 came down in the 90 km diameter (55 mile) crater Alphonsus. Its 5,800 images, nested concentrically and taking advantage of very low-level sunlight, provided strong confirmation of the crater-on-crater, gently rolling contours of the lunar surface.

Thus, after a long trouble-plagued start that taught the system engineers a great deal and the scientists very little, Project Ranger finished with three flights that greatly advanced the lunar scientists' knowledge of the surface and whetted their appetites for a closer look.

Chapter- 2

Chinese Lunar Exploration Program

Insignia of the program

Chinese Lunar Exploration Program (**CLEP**) (simplified Chinese: 中国探月; traditional Chinese: 中國探月; pinyin: *Zhōngguó Tànyuè*) also known as **Chang'e program** is a program of robotic explorations and human missions to the Moon undertaken by China National Space Administration (CNSA), People's Republic of China's space agency. It uses Chang'e lunar orbiters, rovers and soil return spacecraft and adapted Long March 3A, Long March 5/E and Long March 7 launch vehicles. The launch and the flight are monitored constantly by a TT&C System (Deep Space Tracking Network, with radio antennas of 50 m in Beijing, 40 m in Kunming, Shanghai and Ürümqi, forming a 3000 km VLBI antenna.) and the Ground Application System, responsible for downlink data reception.

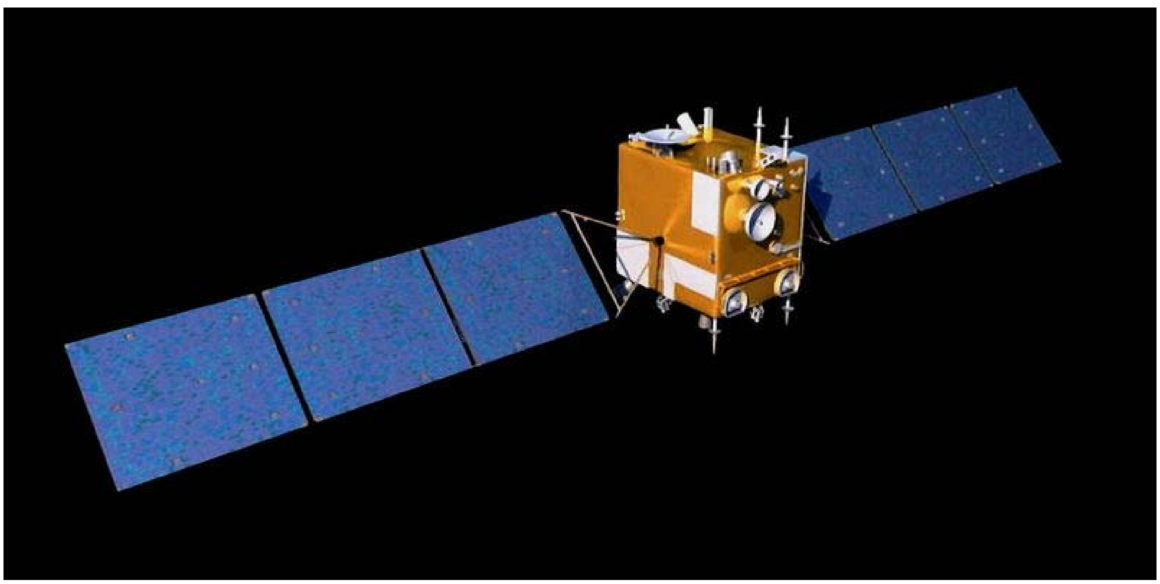
The first spacecraft of the program, Chang'e 1, an un-manned lunar orbiter was successfully launched at Xichang Satellite Launch Center on October 24, 2007 (delayed from 17–19 April 2007).

Ouyang Ziyuan, one of the most prominent Chinese experts in geological research on underground nuclear testing and extraterrestrial materials, was the first to advocate not only the exploitation of the known huge lunar reserves of metals such as iron, but also the mining of lunar helium-3 as an ideal fuel for nuclear fusion power plants. He is now in charge of the Chang'e program. He is known to be one of the strongest supporters of the Chinese human lunar exploration program, and is currently serving as the chief scientist of the program. Another prominent Chinese scientist, Sun Jiadong, was assigned as the general designer, while a younger scientist Sun Zezhou (孙泽州, unrelated to Sun Jiadong) was assigned as the deputy general designer. The program manager was Luan Enjie (栾恩杰).

Program structure

According to CNSA, the program will go through three phases :

Phase I : Orbital mission (Chang'e 1 & 2)



Chang'e 2 spacecraft.

The first phase of the exploration program starts with the launch of two lunar orbiters.

- Chang'e 1 was the first to be successfully launched as scheduled on October 24, 2007.
- Chang'e 2 was launched on October 1, 2010.

Phase II : Soft lander (Chang'e 3)

In the second phase of the lunar exploration program, two lunar landers will be launched to deploy moon rovers for surface exploration in a limited area. These missions were originally planned for 2012 requiring the use of the CZ-5/E heavy launch vehicle.

Currently, the second and third phases of the program will both require the availability of the heavy-lift Long March 5 (CZ-5) booster. Huang Chunping, the former head of rocket science at China's manned space program, told Xinhua news agency in March 2007 that the Long March 5 (CZ-5) rocket would be ready for launch 'in seven or eight years', which implied that CZ-5 would not be used in the second phase of the Chang'e program. The Hainan Spaceport, fourth and southernmost space center, will be upgraded to suit the new CZ-5 Heavy ELV. It has also been reported that the second phase might use a CZ-3B rocket instead.

It is said that the second phase of the program would include the launch of at least two landers, that will carry small remote-controlled Moon rovers to conduct an inspection of the moon's surface and probe the moon's resources. It would also provide data to determine the selection of a moon base.

On December 14, 2005, many aspects of the above information were confirmed, when it was reported "an effort to launch lunar orbiting satellites will be supplanted in 2007 by a program aimed at accomplishing an unmanned lunar landing. A program to return unmanned space vehicles from the moon will begin in 2012 and last for five years, until the manned program gets underway" in 2017.

A six-wheeled lunar vehicle has been under development since 2002 at the Shanghai Aerospace System Engineering Institute where a specialized testing laboratory has been outfitted to replicate the lunar surface. The 1.5-meter high, 200-kilogram rover is designed to transmit video in real time, dig and analyze soil samples. With an average speed of 100 meters/hour, it can negotiate inclines and has automatic sensors to prevent it from crashing into other objects.

In late 2008, Chen Qiufa (deputy Minister of MIIT and head of SASTIND) indicated that Chang’e 3 Lunar Rover would launch in late 2011 on a Long March 3B rocket. The rover will conduct studies of the Moon’s geology, topography, and mineral and chemical composition.

In 2009, the 2013 launch date was confirmed, for a landing craft and rover called Chang'e-3. It will use variable thrusters to make a vertical landing on the surface near the moon's equator area. The lunar rover will leave Chang'e-3 and work on the surface for three months. Energy will be provided by radioisotope thermoelectric generator so that the rover survives lunar nights.

Phase III : Automated sample return (Chang'e 4)

The third phase of the lunar exploration program is planned for 2017 with the use of the CZ-5/E heavy launch vehicle. On the basis of the lander mission, a lunar sample return mission will be undertaken, with up to two kilograms of lunar samples returned to Earth.

After that a manned lunar landing might be possible in 2025–2030.

Key technologies (phase I)

Orbit design and flight sequence control

Under the condition of three-body movement of the earth, the moon and its satellite, the orbit design of lunar exploration satellite is more complicated than that of the previous earth satellite. The lunar satellite will be sent into the highly elliptical earth orbit atop a launch vehicle first. After separating from the launch vehicle it will enter into the earth-moon transfer orbit through three accelerations in the phase-modulated orbit (16h, 24h, 48h) by its own propulsion system, during which it needs to carry out several orbit adjustments and attitude maneuvers so as to ensure to be captured by lunar gravity. After operating in the earth-moon orbit for 4–5 days, it will enter into the lunar acquisition orbit. Then, it will enter into the target lunar orbit and carry out pre-designed missions after three brakings and experiencing three different orbit phases.

The three-vector control problem of the lunar satellite's attitude control

During the flight orbiting the moon the satellite should be always oriented to the earth, the moon and the sun: all the onboard detectors should be kept facing the lunar surface to complete the scientific exploration missions; the transmitting/receiving antennas should be maintained facing the earth to receive the commands from the earth and transfer scientific data to the earth for the ground application research; the solar panels should be oriented to the sun to acquire the power for normal operation. During the flight orbiting the moon, the three bodies of the earth, the moon and the sun rotate relatively, so the attitude control is a three-vector control process.

The satellite environment adaptability design

The complexity of the space environment during the satellite operation has higher requirements of the environment adaptability and reliability for the satellite and its instruments. For instance, the strong radiation environment in the earth-moon space will exert great effect on the electronics; the temperature change ranges greatly from 130℃ of the side facing the sun to -170℃ of the side back to the sun, so it has stricter requirements of temperature control for the detectors.

Long-range TT&C and communication

The biggest challenge in the Phase I of the Lunar Exploration Program is TT&C system (Telemetry, Tracking and Command), because its transmission capability must have such a long range. China's previous satellite telemetry has a range of as much as 80,000 km, but the distance between the moon and the earth is about 400,000 km, which brings up new challenge to the TT&C system. In addition, the lunar satellite must carry out many attitude maneuvers during its flight to the moon and during operations orbiting the moon. The distance from east to west in China is only 5,000 km, which is also a challenge to TT&C continuity. China hasn't set up a deep space TT&C network. At present, the combination of space TT&C network and astronomical observation network can meet the basic needs of TT&C, but with a small margin.

Russian cooperation

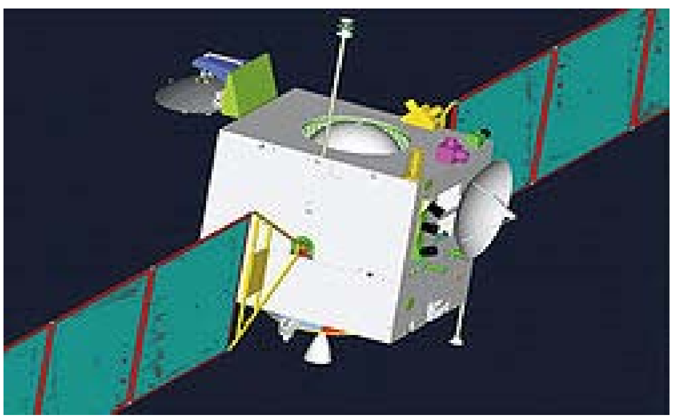
Anatoly Perminov, head of the Russian Federal Space Agency revealed in September 2006 in RIA Novosti that the two countries were indeed working on the Moon as partners, and that the Russian-Chinese space sub-commission's priority was to conclude a joint Moon exploration agreement by the end of that year.

Chapter- 3

Chang'e (1-3)

Chang'e 1

Chang'e 1



Operator	China National Space Administration (CNSA)
Mission type	Orbiter / impactor
Satellite of	The moon
Launch date	2007-10-24, 10:05:04.602 UTC
Carrier rocket	Long March 3A
Launch site	Xichang Satellite Launch Center, Launch Pad 3 Xichang, The People's Republic of China
Mission	2009-03-01, 08:13:10 UTC

duration	1 year, 4 months, 4 days, 22 hours and 7 minutes
COSPAR ID	2007-051A
Homepage	CLEP
Mass	2,350 kg
	Orbital elements
Inclination	~64°
Apoapsis	~200 km
Periapsis	~200 km
Orbital period	~127 minutes

Chang'e 1 (pronounced *chang-uh*; simplified Chinese: 嫦娥一号; traditional Chinese: 嫦娥一號; pinyin: *Cháng'é yī hào*) was an unmanned Chinese lunar-orbiting spacecraft, part of the first phase of the Chinese Lunar Exploration Program. The spacecraft was named after the Chinese moon goddess, Chang'e.

Chang'e 1 was launched on 24 October 2007 at 10:05:04 UTC from Xichang Satellite Launch Center. It left lunar transfer orbit on 31 October and entered lunar orbit on 5 November. The first picture of the Moon was relayed on 26 November 2007. On 12 November 2008, a map of the entire lunar surface was released, produced from data collected by Chang'e 1 between November 2007 and July 2008.

The mission was scheduled to continue for a year, but was later extended and the spacecraft operated until 1 March 2009, when it was taken out of orbit. It impacted the surface of the Moon at 08:13 UTC. Data gathered by Chang'e 1 was able to create the most accurate and highest resolution 3-D map ever created of the lunar surface. Its sister orbital probe Chang'e 2 was launched on the first of October 2010.

Objectives

The Chang'e 1 mission had four major goals:

1. Obtaining three-dimensional images of the landforms and geological structures of the lunar surface, so as to provide a reference for planned future soft landings. The orbit of Chang'e 1 around the Moon was designed to provide complete coverage, including areas near the north and south poles not covered by previous missions.

2. Analysing and mapping the abundance and distribution of various chemical elements on the lunar surface as part of an evaluation of potentially useful resources on the Moon. China hopes to extend the number of elements studied to 14 (potassium (K), thorium (Th), uranium (U), oxygen (O), silicon (Si), magnesium (Mg), aluminium (Al), calcium (Ca), tellurium (Te), titanium (Ti), sodium (Na), manganese (Mn), chromium (Cr), and lanthanum (La)), compared with the 10 elements (K, U, Th, Fe (iron), Ti, O, Si, Al, Mg, and Ca) previously probed by NASA's Lunar Prospector.
3. Probing the features of the lunar soil and assessing its depth, as well as the amount of helium-3 (^3He) present.
4. Probing the space environment between 40,000 km and 400,000 km from the Earth, recording data on the solar wind and studying the impact of solar activity on the Earth and the Moon.

In addition, the lunar probe engineering system, composed of five major systems – the satellite system, the launch vehicle system, the launch site system, the monitoring and control system and the ground application system – accomplished five goals:

- Researching, developing and launching China's first lunar probe
- Mastering the basic technology of placing satellites in lunar orbit
- Conducting China's first scientific exploration of the Moon
- Initially forming a lunar probe space engineering system
- Accumulating experience for the later phases of China's lunar exploration program

Mission

The launch of Chang'e 1 at Xichang Satellite Launch Center

According to the schedule, detailed design of the first program milestone was completed by September 2004. Research and development of a prototype probe and relevant testing of the probe were finished before the end of 2005. Design, manufacture, general assembly, test and ground experiments of the lunar orbiter were finished before December 2006.

Originally scheduled for April 2007, the launch was postponed until October as this was "a better time for sending a satellite into the moon's orbit". Chang'e 1 was launched by a Long March 3A rocket at 10:05 GMT on October 24, 2007 from Xichang Satellite Launch Center in Sichuan Province.

After liftoff, Chang'e 1 made three orbits around the Earth, a burn at perigee extending the orbit's apogee further each time, until a final translunar injection burn placed it on course for the Moon on October 31, 2007. Another burn placed it in a polar orbit around the Moon, with burns at the perilune of the first three orbits decreasing the apolune until it entered a final circular orbit. Lunar orbit insertion was achieved on the November 5, 2007. To mark this occasion, the probe transmitted 30 classical Chinese songs and musical pieces, including "My Motherland", "The Song of the Yangtze River", and "High Mountains and Flowing Water".

The probe was remotely controlled from stations at Qingdao and Kashgar. As well as Chinese facilities, the ESA Maspalomas Tracking Station was used to transmit signals to and from the probe.

The first pictures of the Moon were relayed on November 26, 2007. The probe was designed to orbit the Moon for one year, but operations were later extended, and it remained in lunar orbit until March 1, 2009.

End of mission

On 1 March 2009, at 08:13:10 UTC, Chang'e 1 crashed onto the surface of the Moon, ending its mission. According to the State Administration of Science, Technology and Industry for National Defense (China), this was a planned and controlled impact. Impact point was 1°30′S 52°22′E / 1.50°S 52.36°E . During its orbital mission the probe transmitted 1,400 gigabits or 175 gigabytes (GB) of data.

Design and instrumentation

The Chang'e 1 spacecraft had a mass of 2,350 kg, with a 130 kg payload, carrying 24 instruments including a Charge-coupled device (CCD) stereo camera, microprobe instruments, and a high-energy solar particle detector.

- Stereo camera with an optical resolution of 120 m and spectrometer imager operating at wavelengths of 0.48 μm to 0.96 μm.
- Laser altimeter with 1064 nm, 150 mJ laser, a range resolution of 1 m and a spot size of 300 m.
- Imaging spectrometer
- Gamma and X-ray spectrometer working in an energy range of 0.5 to 50 keV for X-rays and 300 keV to 9 MeV for gamma rays.
- Microwave radiometer detecting 3, 7.8, 19.35 and 37 GHz with a maximal penetration depth of 30, 20, 10, 1 m and a thermal resolution of 0.5 K.
- High energy particle detector and two solar wind detectors capable of the detection of electrons and heavy ions up to 730 MeV.

Chang'e 2

Chang'e 2

Operator	CNSA
Mission type	Orbiter / impactor
Satellite of	The Moon
Launch date	2010-10-01, 10:59:57 UTC
Carrier rocket	Long March 3C
Launch site	Xichang Satellite Launch Center Xichang, Sichuan, China
Mission duration	> 6 months elapsed: 4 months, and 18 days
COSPAR ID	2010-050A
Mass	2,500 to 2,600 kg (5,500 to 5,700 lb)
Orbital elements	
Apoapsis	100 km (62 mi)
Periapsis	15 km (9.3 mi)
Instruments	
Main instruments	Charge-Coupled Device (CCD) improved stereo camera Laser altimeter Gamma/X-ray Spectrometers Microwave Detector
Spatial	10 meter at 100 km altitude and 1.5 meter

resolution	at 15 km altitude

Chang'e 2 simplified Chinese: 嫦娥二号; traditional Chinese: 嫦娥二號; pinyin: *Cháng'é èr hào*), is a Chinese un-manned lunar probe that was launched on 1 October 2010. It is a follow-on to the Chang'e 1 lunar probe launched in 2007 and is part of the first phase of the Chinese Lunar Exploration Program. The probe will conduct research at a 100-kilometer-high lunar orbit as a preparation for a soft landing by Chang'e 3. Chang'e 2 is similar to Chang'e 1 with some improvements, including a better camera with a resolution of one meter. It is named after a legendary Chinese goddess of the moon. The total expenditure for the Chang'e 2 mission is approximately CN¥900 million, or US$134 million.

Description

Chang'e 2 is similar to the Chang'e 1 mission, but has important differences. While Chang'e 1 operated in a 200-kilometer orbit, Chang'e 2 is flying at only 100 kilometers, leading to better quality and resolution of the science data. Chang'e 2 also has a higher resolution camera.

Some other key differences between Chang'e 1 and Chang'e 2, as summarized by Qian Huang of the Shanghai Astronomical Observatory and Yong-Chun Zheng of the NAOC:

- Chang'e 2 will have a shorter Earth to Moon cruise of 5 days rather than 12 days. The launch rocket has two more boosters to accomplish this more direct route to the Moon.
- The laser altimeter's footprint will be smaller, and will achieve 5-meter vertical accuracy in estimate of the Moon's radius. It will also pulse more frequently, five times per second rather than just 1 time per second.
- The main camera's spatial resolution will be 10 meters rather than 120 meters.
- Late in the mission, the orbit will be lowered to an elliptical one with the same apolune (100 kilometers) but a perilune of only 15 kilometers
- Tracking will be performed with new X-band radio capability.

Zheng also remarked that "The mission goals of CE-2 will be focused into the high resolution image for the future landing site of CE-3 lunar lander and rover. The key technology about soft landing on the Moon will be tested in the CE-2 mission. The success of CE-2 will provide important technical basis for the successful implementation of China's future lunar exploration."

Launch

Chang'e 2 spacecraft was launched on 1 October 2010 at 10:59:57 UTC, aboard a Long March 3C rocket from Xichang Satellite Launch Center in Xichang, Sichuan. The spacecraft entered an orbit with a perigee of 200 kilometers and apogee of 380,000 kilometers and separated from the carrier rocket as planned. It was the first time that a Chinese lunar probe directly entered the earth-moon transfer orbit without orbiting the earth first. After the launch, Chang'e 2 was expected to arrive at its lunar orbit in about 112 hours (about 4 days and 16 hours), much faster than the 12 days taken by Chang'e 1. Later, the probe was to lower its orbit to 100 km (62 mi) and have a lower point of only 15 km (9.3 mi). Chang'e 2 entered its 100 km working orbit on 9 October 2010 after three successful brakings. On 8 November 2010, China announced the success of all missions of Chang'e 2 and published moon surface images with resolution up to 1.3 metres.

Significance

The launch of the probe coincided with the National Day of the People's Republic of China, on October 1, in a symbolic celebration of the country's 61st anniversary.

Chang'e 3

Chang'e 3

Operator	CNSA
Mission type	Orbiter, lander and one rover
Satellite of	The Moon
Launch date	2013
Mass	3,750-kg. (8,250-lb.)

Chang'e 3 is a Chinese lunar-lander and rover scheduled for launch in 2013. It will be China's first lunar rover, part of the second phase of the Chinese lunar exploration program undertaken by the China National Space Administration (CNSA).

In 2009, the 2013 launch date was confirmed for a landing craft and rover. It will use variable thrusters to make a vertical landing on the surface. At that time, the stated target for the lander was near the moon's equator. The rover will leave Chang'e 3 and work on the surface for three months. Energy will be provided by radioisotope thermoelectric generator so that the rover can operate through lunar nights.

A six-wheeled lunar vehicle has been under development since 2002 at the Shanghai Aerospace System Engineering Institute, where a specialized testing laboratory has been outfitted to replicate the lunar surface. The 1.5 meter high, 120 kg (with 20 kg payload) rover has completed assembly by May 2010, and is designed to transmit video in real time, and dig and analyze soil samples. With an average speed of 100 meters/hour, it can negotiate inclines and has automatic sensors to prevent it from crashing into other objects.

Chang'e 3 is scheduled to land at Sinus Iridum, a plain of basaltic lava that forms a northwestern extension to the Mare Imbrium. Since Sinus Iridum has a latitude of 44 degrees north it contradicts the previously stated equatorial site.

Chapter- 4

Lunar Precursor Robotic Program

The LRO and LCROSS leave the launch pad.

The **Lunar Precursor Robotic Program** (**LPRP**) is a program of robotic spacecraft missions which NASA will use to prepare for future human spaceflight missions to the Moon. Two LPRP missions, the Lunar Reconnaissance Orbiter (LRO) and the Lunar Crater Observation and Sensing Satellite (LCROSS), were launched in June 2009. The lift off above Cape Canaveral Air Force Station in Florida was successful on June 18, 2009. The unmanned Atlas V rocket launched the two space probes towards the moon, where they will provide a 3-D map and search for water in conjunction with the Hubble Space Telescope. The launch date, originally planned for October 2008, was shifted to Thursday from Wednesday (June 17) due to a postponement of the Saturday (June 13) launch of the Space Shuttle Endeavour, resulting from a hydrogen fuel leak. This lunar program marks the first United States mission to the moon in over ten years. Neil Armstrong's first step on the moon occurred July 20, 1969, and this launch was just 32 days shy of the 40th anniversary. The actual journey to the moon will take about four days, at which time the LRO will enter a low orbit around the moon, while the LCROSS mission will perform a "swing-by" to enter a much different orbit to set up for a collision with the moon's surface several months later. Projected lunar impact of the Centaur and LCROSS spacecraft is on October 9, 2009 at 11:30 UT (7:30 a.m. EDT, 4:30 a.m. PDT), ± 30 minutes. The plume from the Centaur impact may be visible through telescopes with apertures as small as 10 to 12 inches.

Program history

The Atlas V-Centaur rocket carrying the LRO and LCROSS just after take off.

Initially, the LPRP program was a part of the Science Mission Directorate of NASA (SMD) and was called the Robotic Lunar Exploration Program (RLEP). Management of the RLEP program was assigned to Goddard Space Flight Center (GSFC) in February, 2004. At that time, the Program's goal was to "...initiate a series of robotic missions to the Moon to prepare for and support future human exploration activities." In 2005, responsibility for RLEP was moved to NASA's Exploration Systems Mission Directorate (ESMD) and management assigned to the Ames Research Center (ARC). In 2006, the program was renamed to the Lunar Precursor Robotic Program and management responsibility re-assigned to the Marshall Space Flight Center (MSFC). The US$583 million space mission comes equipped with a $504 million state of the art 4,200 pounds (1,905 kg) LRO space probe and a $79 million LCROSS satellite.

LRO

The Lunar Reconnaissance Orbiter (LRO) is the first mission of the LPRP program. Management of LRO was assigned to Goddard Space Flight Center (GSFC) in 2004. LRO launched on an Atlas V 401 rocket from Cape Canaveral Air Force Station on June 18, 2009 at 5:32 p.m. EDT (2132 GMT). The planned lift off for 5:12 p.m. EDT (2112 GMT) was slightly delayed by 20 minutes due to thunderstorms. It will orbit the Moon for one year, gathering high resolution images of the lunar surface that will allow the creation of detailed maps. LRO's goals include finding safe landing sites for human visits to the Moon, identifying lunar resources, and studying the lunar radiation environment. The LRO will provide a 3-D map of the moon's surface to allow astronauts to return to the moon in 2020. On board the LRO are seven instruments, the Cosmic Ray Telescope for the Effects of Radiation (CRaTER), Diviner Lunar Radiometer Experiment (DLRE), Lyman-Alpha Mapping Project (LAMP), Lunar Exploration Neutron Detector (LEND), Lunar Orbiter Laser Altimeter (LOLA), Lunar Reconnaissance Orbiter Camera (LROC), and Miniature Radio Frequency radar (Mini-RF).

LCROSS

The Lunar Crater Observation and Sensing Satellite (LCROSS) mission is co-manifested with LRO. It was selected as a secondary payload in 2006, and management of the program was assigned to Ames Research Center (ARC). The mission will explore a permanently shadowed region of a lunar pole by crashing the 2,300 pounds (1,043 kg) spent Centaur rocket upper stage of the Atlas V launch vehicle into a dark crater. The composition of the ejecta plume will be observed by a shepherding spacecraft, which will itself crash-land 4 minutes later, creating a second plume. NASA expects the impact velocity will be over 9,000 km/h (5,600 mph). The ejecta plume will be in the order of 350 tons (317 metric tons) and rise 6 miles (10 km) from the surface.

Future projects

As LRO and LCROSS send back high-resolution data, the Lunar Mapping and Modeling project will use those data to develop detailed topographic maps of the lunar surface. In addition, solar radiation levels will be mapped and modeled. These integrated data will be used to make decisions about, for example, lunar outpost designs.

A mission planned for 2012, LADEE will measure dust particulates before any human presence disturbs it.

For the proposed International Lunar Network, LPRP would land two stations on the lunar surface.

Chapter- 5

Lunar Reconnaissance Orbiter

Lunar Reconnaissance Orbiter

LRO spacecraft, artist's rendering

Operator	NASA/Goddard Space Flight Center
Mission type	Orbiter
Satellite of	Earth's Moon
Orbits	30–70 km polar orbit, extended mission 30–216 km
Launch date	18 June 2009 21:32:00 UTC
Launch vehicle	Atlas V 401
Launch site	Space Launch Complex 41 Cape Canaveral Air Force Station
Mission duration	one year, extended mission of up to five years

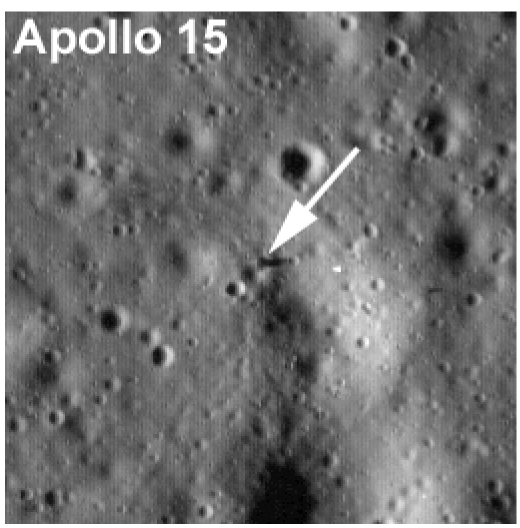
	elapsed: 1 year, 8 months, and 4 days
COSPAR ID	2009-031A
Homepage	http://lunar.gsfc.nasa.gov/
Mass	1,846 kg
Power	1,850 W

The **Lunar Reconnaissance Orbiter** (**LRO**) is a NASA robotic spacecraft currently (as of April 2010) orbiting the Moon on a low 50 km polar mapping orbit. The LRO mission is a precursor to future manned missions to the moon by NASA. To this end a detailed mapping program will identify safe landing sites, locate potential resources on the moon, characterize the radiation environment, and demonstrate new technology.

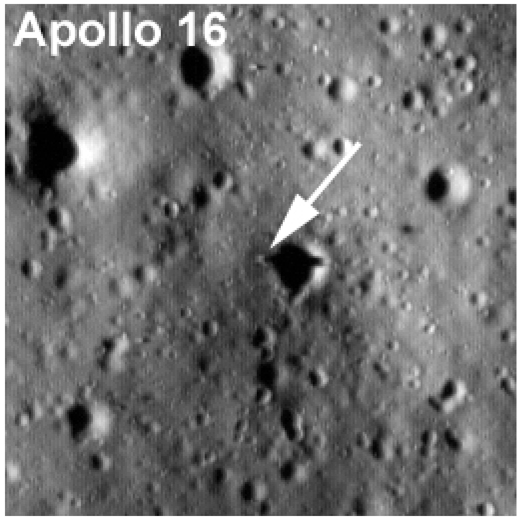
The probe will make a 3-D map of the Moon's surface and has provided some of the first images of Apollo equipment left on the Moon. The first images from LRO were published on 2 July 2009, showing a region in the lunar highlands south of Mare Nubium (*Sea of Clouds*).

Launched on 18 June 2009, in conjunction with the Lunar Crater Observation and Sensing Satellite (LCROSS), as the vanguard of NASA's Lunar Precursor Robotic Program, this is the first United States mission to the Moon in over ten years. LRO and LCROSS are the first missions launched as part of the United States's Vision for Space Exploration program.

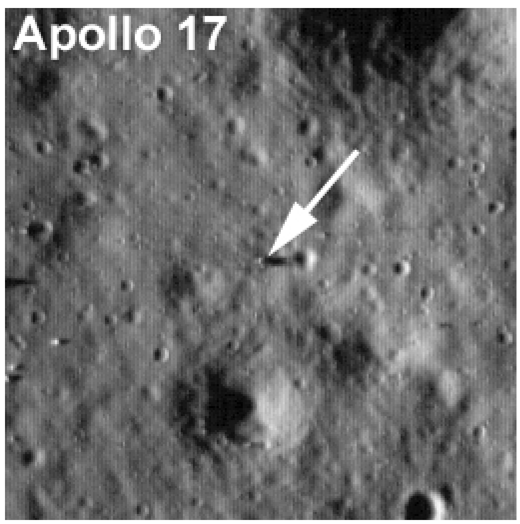
The total cost of the mission is reported as US$583 million, of which $504 million pertains to the main LRO probe and $79 million to the LCROSS satellite.



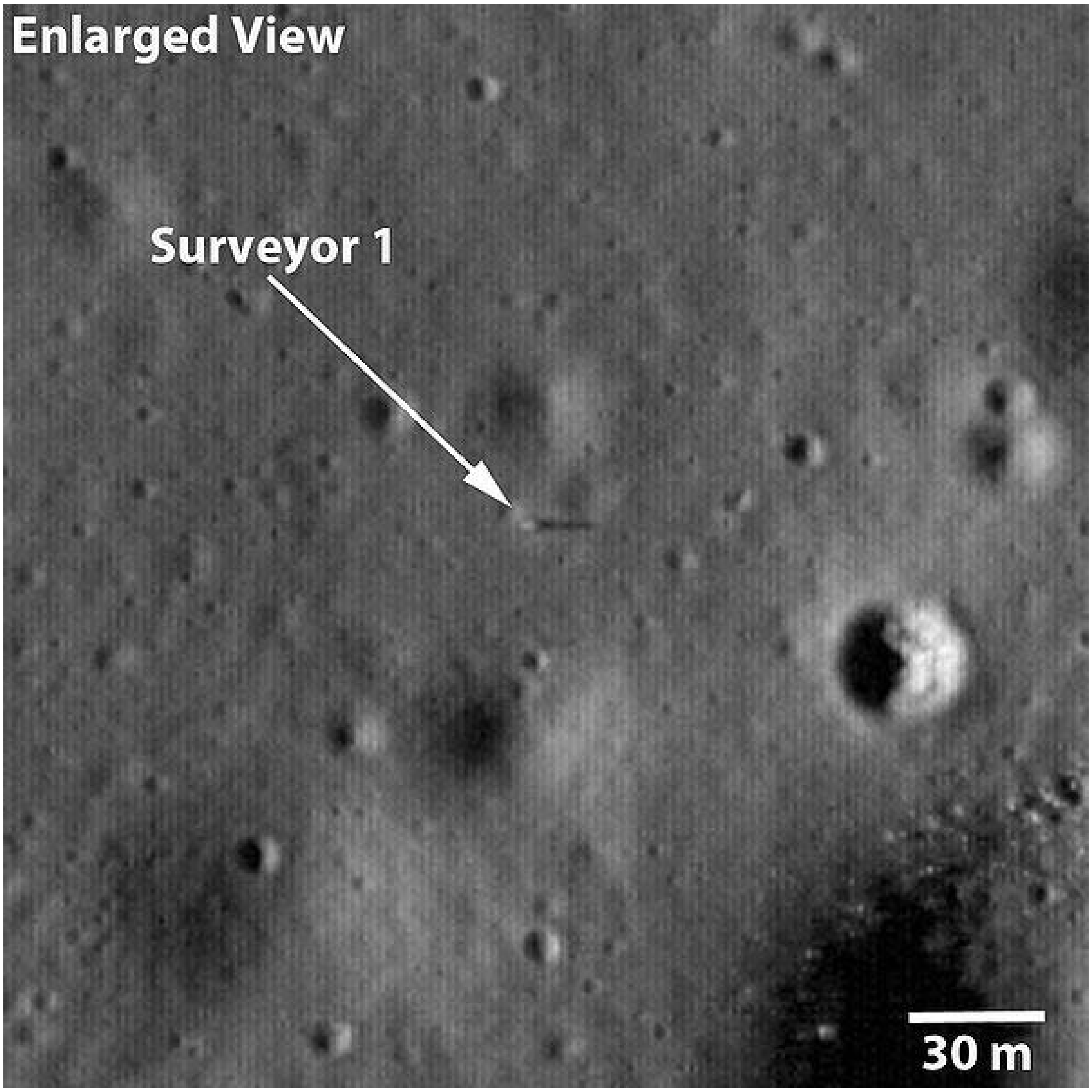
LRO sees Apollo 15 landing site.



LRO sees Apollo 16 landing site.



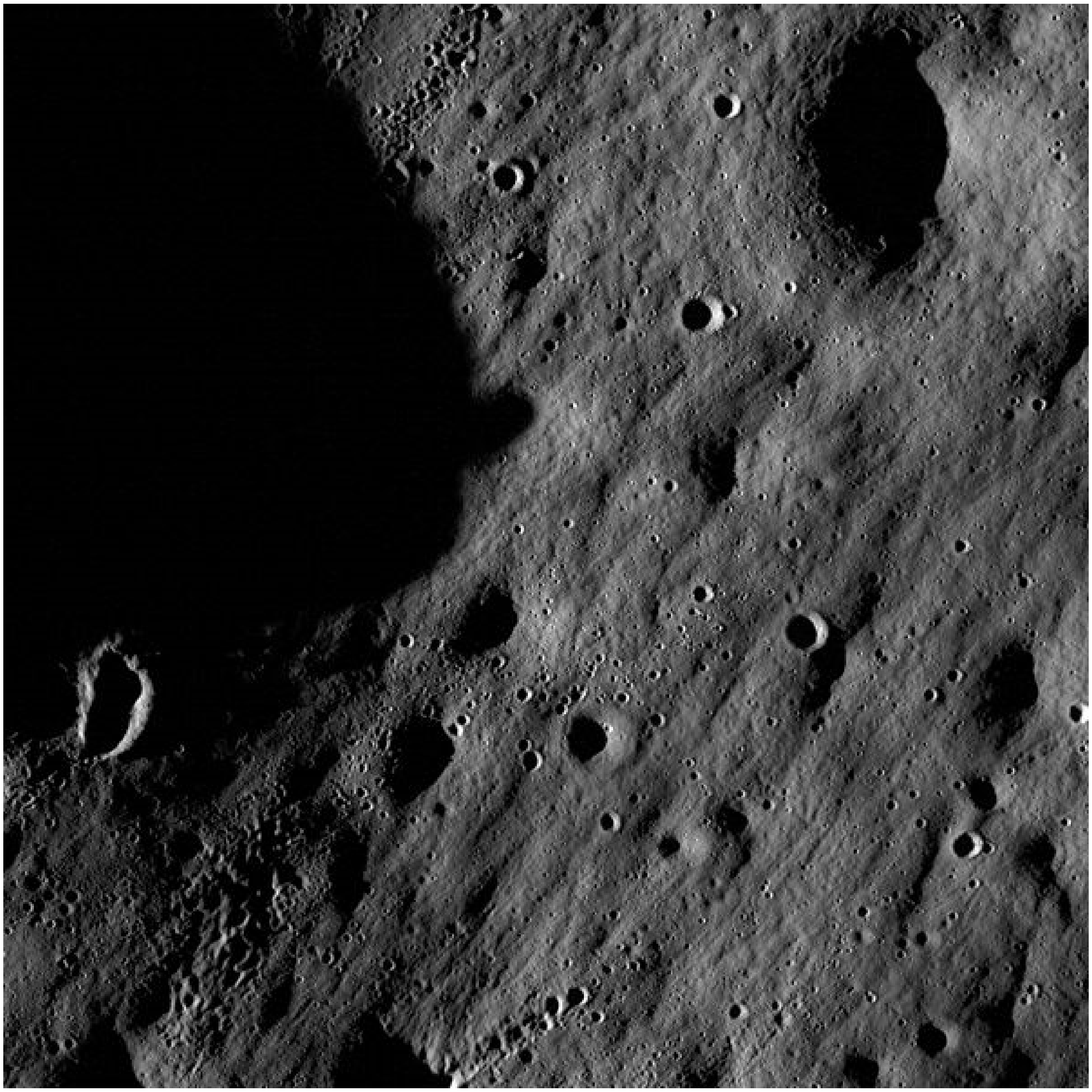
LRO sees Apollo 17 landing site.



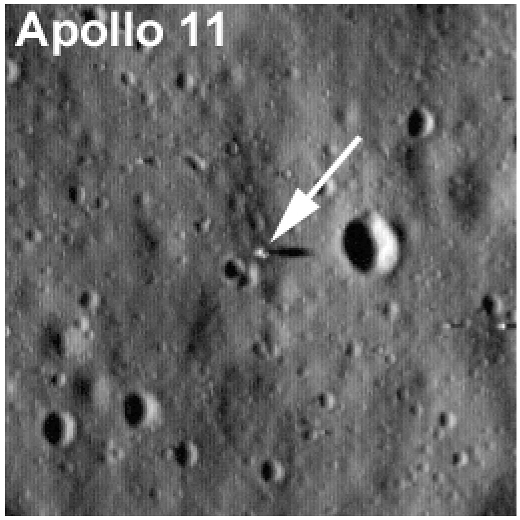
LRO sees Surveyor 1 landing site.

Mission

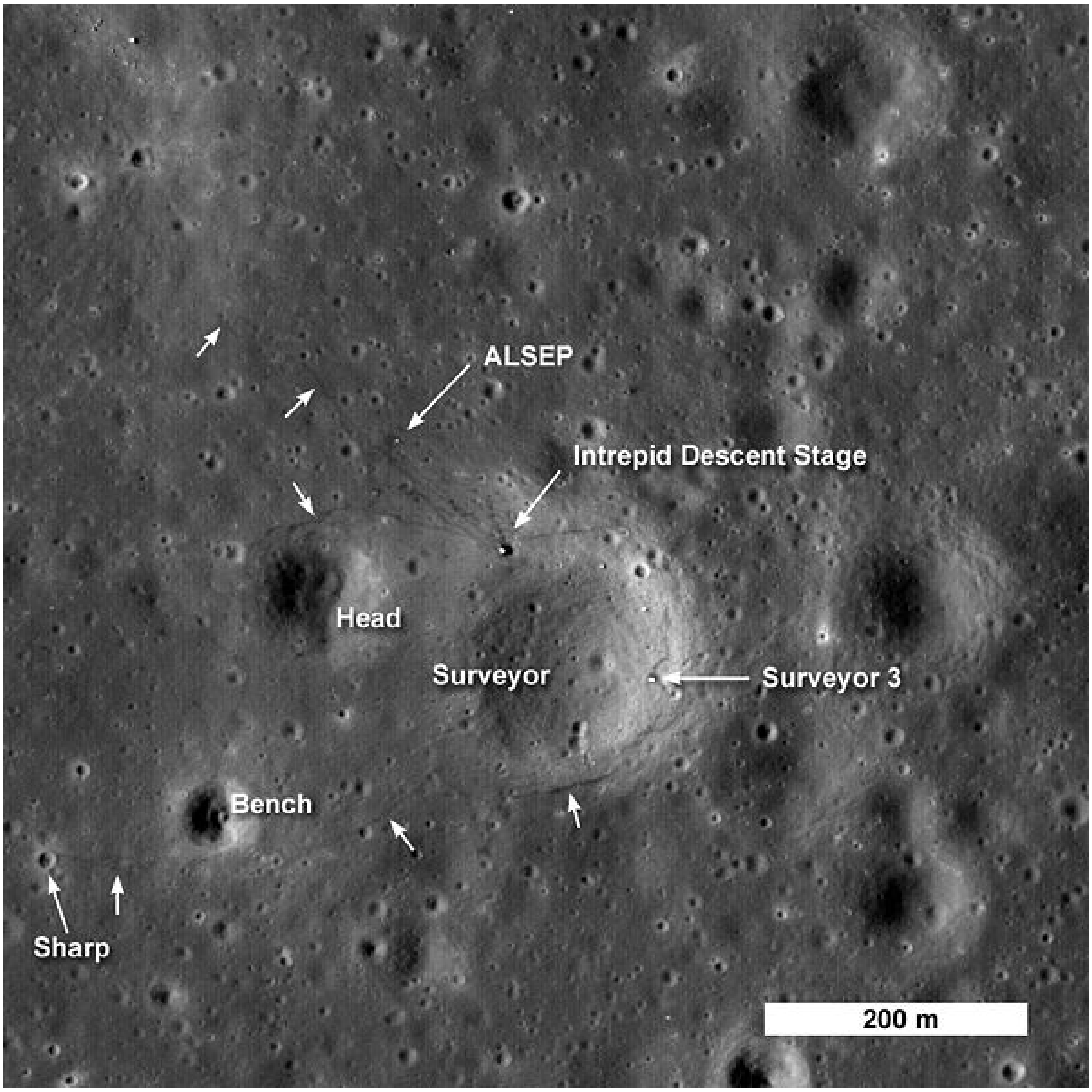
Developed at NASA's Goddard Space Flight Center, LRO is a large (1,900 kg) and sophisticated spacecraft planned to fly in a lunar polar orbit for a mission of one Earth year. An optional extended phase of the mission (up to five years) could provide a communications relay for future lunar ground missions, such as a Moon lander or rover.



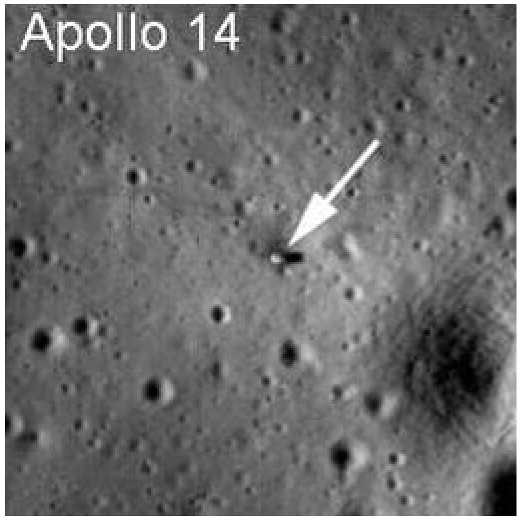
The spacecraft transmitted its first images of the lunar surface captured with the LROC that were activated on 2009-06-30.



LRO sees Apollo 11 landing site.



LRO sees Apollo 12 and Surveyor 3 landing site.



LRO sees Apollo 14 landing site.

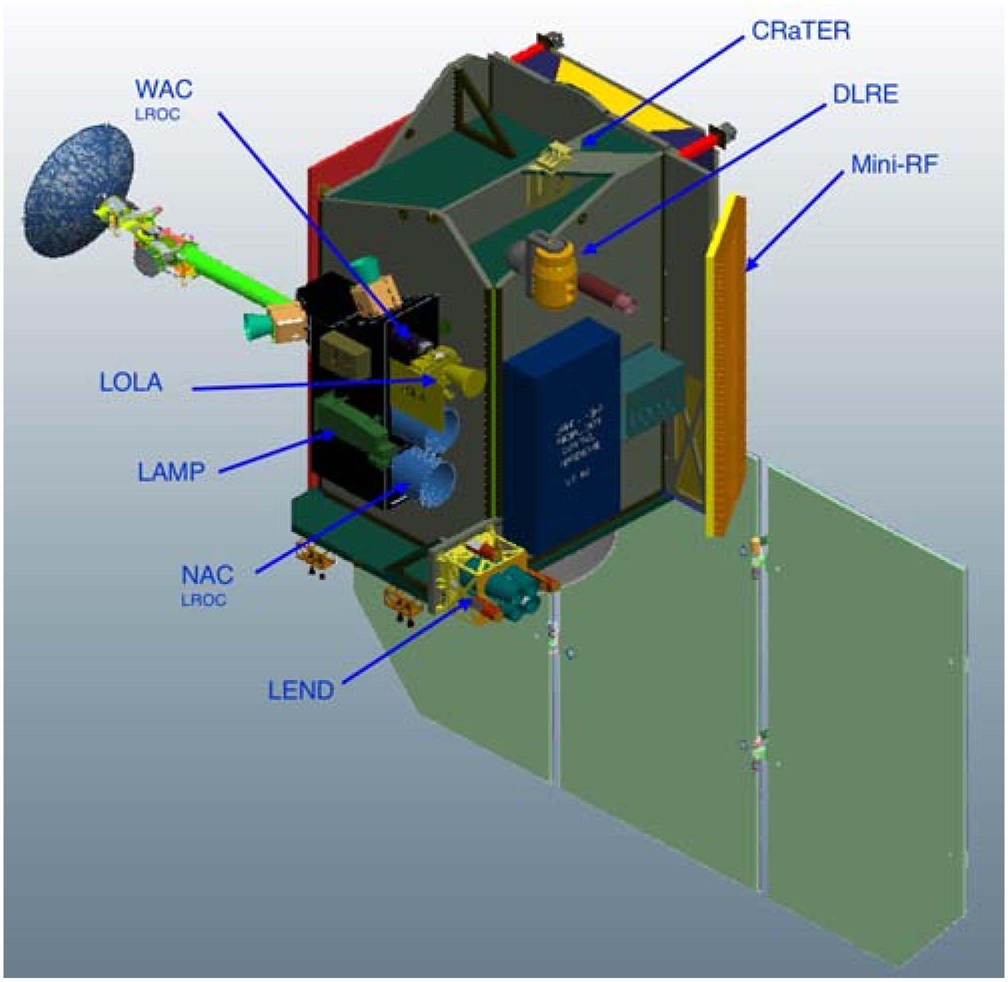
After completing a preliminary design review in February 2006 and a critical design review in November 2006, the LRO was shipped from Goddard Space Flight Center to Cape Canaveral Air Force Station on 11 February 2009. Launch was planned for October 2008, but this slid to April as the spacecraft underwent testing in a thermal vacuum chamber. Launch was rescheduled for June 17, 2009 because of the delay in a priority military launch, and happened one day later, on June 18. The one-day delay was to allow the Space Shuttle Endeavour a chance to lift off for mission STS-127 following a hydrogen fuel leak that canceled an earlier planned launch.

Areas of investigation will include:

- Selenodetic global topography.
- Characterization of deep space radiation in lunar orbit.
- The lunar polar regions, including possible water ice deposits and the lighting environment. The lunar polar regions experience temperatures of −223 °C (−369.4 °F) and may be able to hold water ice.
- High-resolution mapping (max 0.5 metres (1.6 ft)) to assist in the selection and characterization of future landing sites.

In addition, LRO has provided some of the first images of leftover Apollo equipment on the Moon.

Payload



Onboard instruments.

The orbiter carries a complement of six instruments and one technology demonstration:

- **CRaTER**—The primary goal of the **C**osmic **Ra**y **T**elescope for the **E**ffects of **R**adiation is to characterize the global lunar radiation environment and its biological impacts.
- **DLRE**—The **D**iviner **L**unar **R**adiometer **E**xperiment will measure lunar surface thermal emission to provide information for future surface operations and exploration.
- **LAMP**—The **L**yman-**A**lpha **M**apping **P**roject will peer into permanently shadowed craters in search of water ice, seeing by the ultraviolet light from stars and the interplanetary medium.
- **LEND**—The **L**unar **E**xploration **N**eutron **D**etector will provide measurements, create maps, and detect possible near-surface water ice deposits.
- **LOLA**—The **L**unar **O**rbiter **L**aser **A**ltimeter investigation will provide a precise global lunar topographic model and geodetic grid.

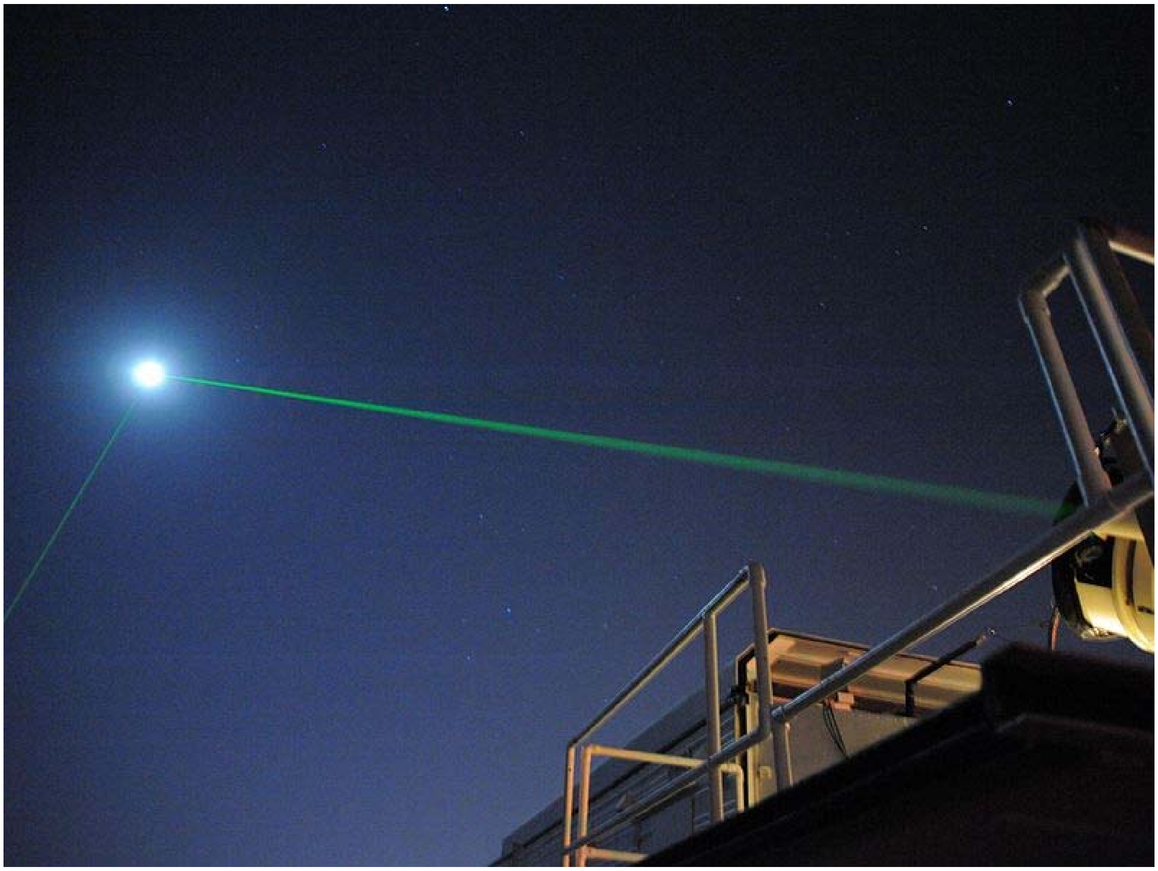
- **LROC**—The **L**unar **R**econnaissance **O**rbiter **C**amera has been designed to address the measurement requirements of landing site certification and polar illumination. LROC comprises a pair of narrow-angle cameras (NAC) and a single wide-angle camera (WAC). LROC will fly several times over the historic Apollo lunar landing sites at 31 miles (50 km) altitude; with the camera's high resolution, the lunar rovers and Lunar Module descent stages and their respective shadows will be clearly visible, along with other equipment previously left on the Moon. The mission will return approximately 70–100 Terabytes of image data. It is expected that this photography will boost public acknowledgement of the validity of the landings, and further discredit Apollo conspiracy theories.
- **Mini-RF**—The **Mini**ature **R**adio **F**requency radar will demonstrate new lightweight SAR and communications technologies and locate potential water-ice.

Names to the Moon

The microchip panel containing 1.6 million names.

Prior to the LRO's launch, NASA gave members of the public the opportunity to have their names placed in a microchip on the LRO. The deadline for this opportunity was 31 July 2008. About 1.6 million names were submitted.

Mission progress



In this image, the lower of the two green beams is from the Lunar Reconnaissance Orbiter's dedicated tracker.

On June 23, 2009, the Lunar Reconnaissance Orbiter entered into orbit around the Moon after a four and a half day journey from the Earth. When launched, the spacecraft was aimed at a point ahead of the Moon's position. A mid-course correction was required during the trip in order for the spacecraft to correctly enter Lunar orbit. Once the spacecraft reached the far side of the Moon, its rocket motor was fired in order for it to be captured by the Moon's gravity into an elliptical lunar orbit. A series of four rocket burns over the next four days put the satellite into its commissioning phase orbit where each instrument was brought online and tested. On September 15, 2009, the spacecraft started its primary mission by orbiting the Moon at about 50 kilometers (31 mi) for one year.

On August 21, 2009, the spacecraft, along with the Chandrayaan-1, was used to perform a Bistatic radar experiment to detect the presence of water ice on the lunar surface. In this experiment, Chandrayaan transmitted radar pulses which, after reflection from the surface, were picked up by the receivers of LRO and in a different angle by the Chandrayaan. Both receivers, Mini-RF in LRO and Mini-SAR in Chandrayaan, are similar in nature. They were pointed at the Erlanger crater for four minutes during which the observations were made.

NASA's LCROSS mission culminated with two lunar impacts at approximately 4:30 a.m. PDT on October 9. The goal of the impact was the search for water in the Cabeus crater near the Moon's south pole, and preliminary results indicated the presence of both water and hydroxyl, an ion related to water.

On December 17, 2010, the topographic map of the Moon based on data gathered by the LOLA instrument was released to the public. This is the most accurate topographic map of the Moon to date.

Chapter- 6

LCROSS

LCROSS

LCROSS spacecraft, artist's rendering

Operator	NASA/Ames Research Center
Mission type	Impactor
Launch date	2009-06-18 21:32:00 UTC
Launch vehicle	Atlas V 401
Launch site	Cape Canaveral SLC-41
Mission duration	June 18, 2009 – October 9, 2009 Elapsed: 1 year, 8 months, and 1 day
COSPAR	2009-031B

ID	
Homepage	http://www.nasa.gov/LCROSS
Mass	LCROSS Shepherding Spacecraft: 621 kg (1,369 lb) (min.); Centaur at impact: 2,249 kg (4,958 lb) (min.)
	Orbital elements
Regime	Highly elliptical
Orbital period	37 days

The **Lunar Crater Observation and Sensing Satellite** (**LCROSS**) was a robotic spacecraft operated by NASA. The main LCROSS mission objective was to explore the presence of water ice in a permanently shadowed crater near a lunar polar region. It was successful in discovering water in the southern lunar crater Cabeus.

It was launched together with the Lunar Reconnaissance Orbiter (LRO) on June 18, 2009, as part of the shared Lunar Precursor Robotic Program, the first American mission to the Moon in over ten years. Together, LCROSS and LRO form the vanguard of NASA's return to the Moon, and are expected to influence United States government decisions on whether or not to colonize the Moon.

LCROSS was designed to collect and relay data from the impact and debris plume resulting from the launch vehicle's spent Centaur upper stage (and data collecting Shepherding Spacecraft) striking the crater Cabeus near the south pole of the Moon.

Centaur had nominal impact mass of 2,305 kg (5,081 lb), and an impact velocity of about 10,000 km/h (6,200 mph).

LCROSS suffered a malfunction on August 22, depleting half of its fuel and leaving very little fuel margin in the spacecraft.

Centaur impacted successfully on October 9, 2009, at 11:31 UTC. The Shepherding Spacecraft descended through Centaur's ejectate plume, collected and relayed data, impacting six minutes later at 11:37 UTC.

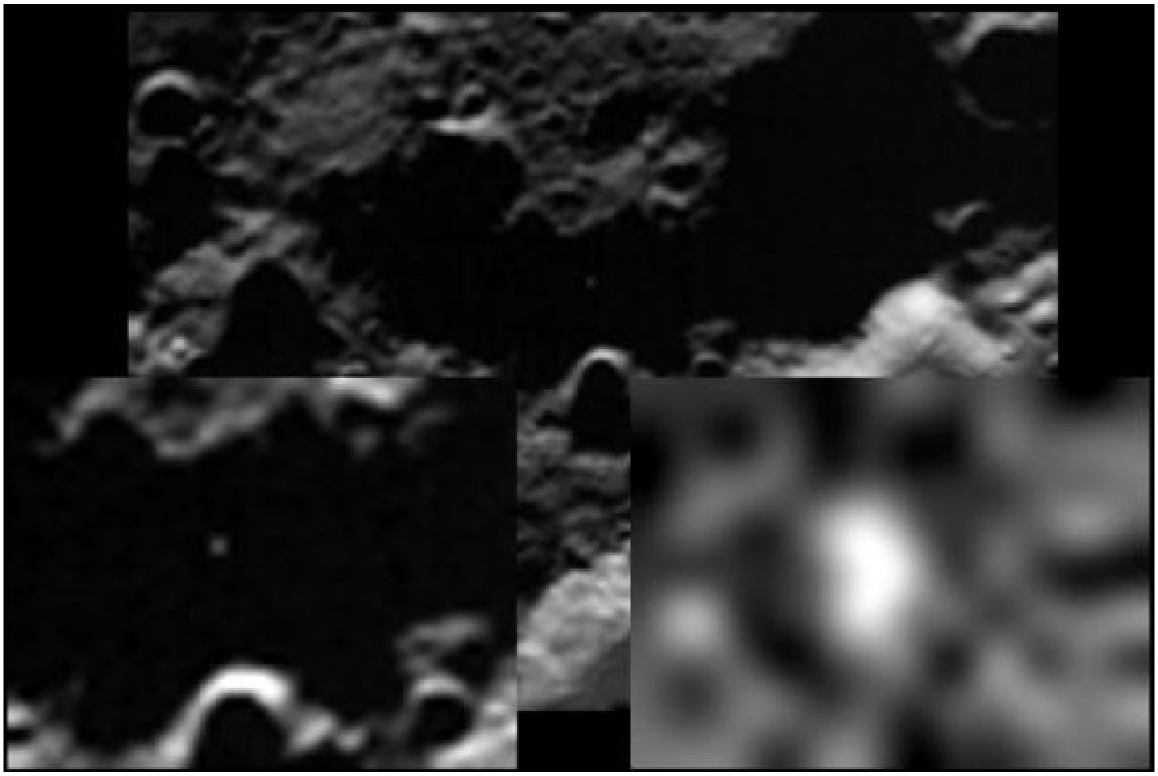
Mission

LCROSS was a fast-track, low-cost companion mission to the LRO. The LCROSS payload was added after NASA moved the LRO from the Delta II to a larger launch vehicle. It was chosen from 19 other proposals. LCROSS's mission was dedicated to late American broadcaster Walter Cronkite.

LCROSS launched with the LRO aboard an Atlas V rocket from Cape Canaveral, Florida, on June 18, 2009, at 21:32 UTC (17:32 EDT). On June 23, four and a half days after launch, LCROSS and its attached Centaur booster rocket successfully completed a lunar swingby and entered into polar Earth orbit with a period of 37 days, positioning LCROSS for impact on a lunar pole.

Early in the morning on August 22, 2009, LCROSS ground controllers discovered an anomaly caused by a sensor problem, which had resulted in the spacecraft burning through 140 kilograms (309 pounds) of fuel, more than half of the fuel remaining at the time. According to Dan Andrews, the LCROSS project manager, "Our estimates now are if we pretty much baseline the mission, meaning just accomplish the things that we have to [do] to get the job done with full mission success, we're still in the black on propellant, but not by a lot."

The Atlas V rocket carrying LRO and LCROSS.

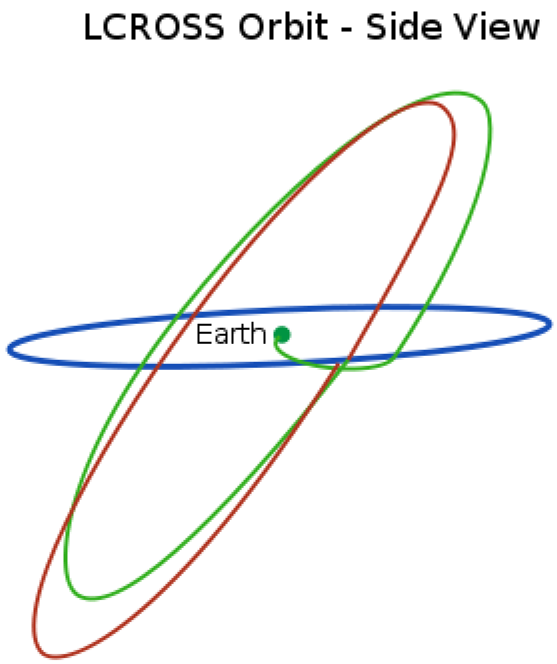


The flash from the LCROSS Centaur impact.

Lunar impacts, after approximately three orbits, occurred on October 9, 2009, with the Centaur crashing into the Moon at 11:31 UTC and the Shepherding Spacecraft following a few minutes later. The mission team initially announced that Cabeus A would be the target crater for the LCROSS dual impacts, but later refined the target to be the larger, main Cabeus crater.

On its final approach to the Moon, the Shepherding Spacecraft and Centaur separated October 9, 2009, at 01:50 UTC. The Centaur upper stage acted as a heavy impactor to create a debris plume that rose above the lunar surface. Following four minutes after impact of the Centaur upper stage, the Shepherding Spacecraft flew through this debris plume, collecting and relaying data back to Earth before it struck the lunar surface to produce a second debris plume. The impact velocity was projected to be 9,000 km/h (5,600 mph). The actual impact was later calculated to have been over 10,000 km/h (6,200 mph).

The Centaur impact was expected to excavate more than 350 metric tons (390 short tons) of lunar material and create a crater about 20 m (65 ft) in diameter to a depth of about 4 m (13 ft). The Shepherding Spacecraft impact was projected to excavate an estimated 150 metric tons (170 short tons) and create a crater 14 m (46 ft) in diameter to a depth of about 2 m (6 ft). Most of the material in the Centaur debris plume was expected to remain at (lunar) altitudes below 10 km (6 mi).



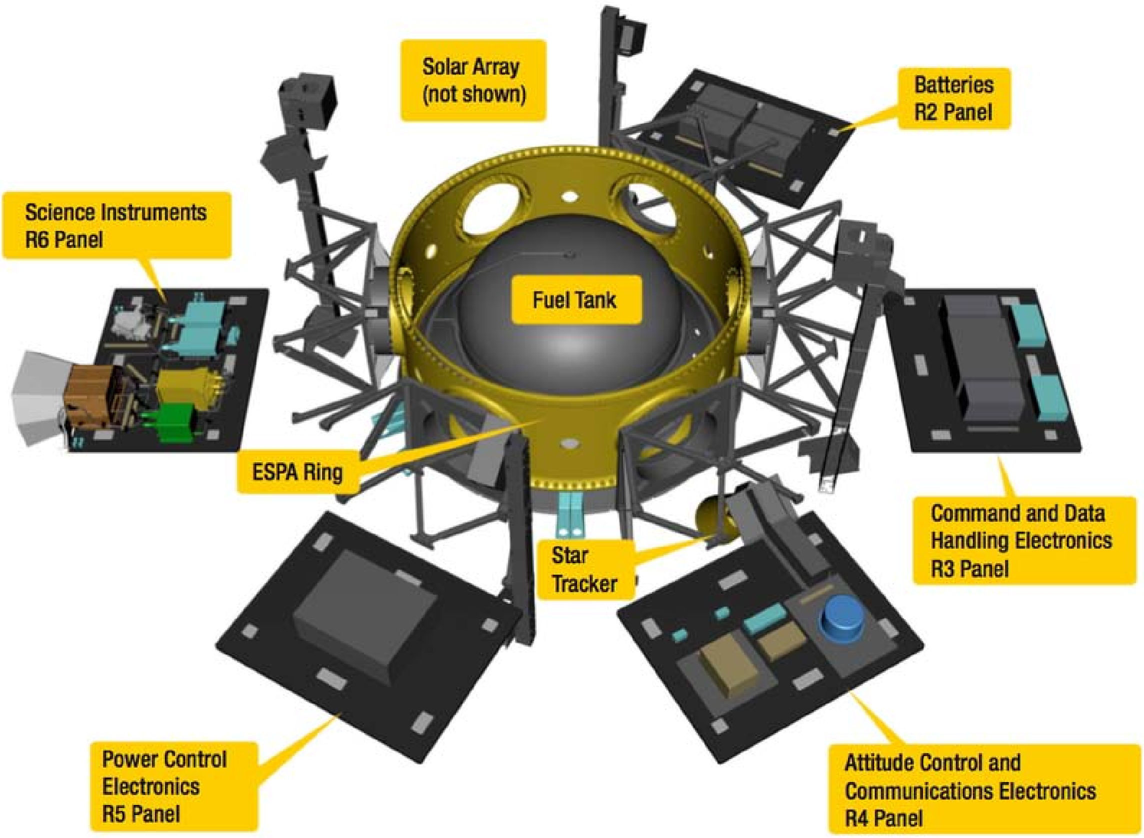
The LCROSS trajectory


An illustration of the LCROSS Centaur rocket stage and shepherding spacecraft as they approach impact with the lunar south pole on October 9, 2009.

It was hoped that spectral analysis of the resulting impact plume would help to confirm preliminary findings by the Clementine and Lunar Prospector missions which hinted that there may be water ice in the permanently shadowed regions. Mission scientists expected that the Centaur impact plume would be visible through amateur-class telescopes with apertures as small as 25 to 30 cm (10 to 12 inches). But no plume was observed by such amateur telescopes. Even world class telescopes such as the Hale telescope, equipped with adaptive optics, did not detect the plume. The plume may have still occurred but at a small scale not detectable from earth. Both impacts were also monitored by Earth-based observatories and by orbital assets, such as the Hubble Space Telescope.

Whether or not LCROSS would find water had been stated to be influential in whether or not the United States government pursues creating a Moon base. On November 13, 2009, NASA confirmed that water was detected after the Centaur impacted the crater.

Spacecraft



LCROSS spacecraft (exploded view)

The LCROSS mission took advantage of the structural capabilities of the Evolved Expendable Launch Vehicle (EELV) Secondary Payload Adapter (ESPA) ring used to attach LRO to the Centaur upper stage rocket. Mounted on the outside of the ESPA were six panels that hold the spacecraft's science payload, command and control systems, communications equipment, batteries, and solar panels. A small monopropellant propulsion system was mounted inside of the ring. Also attached were two S Band omnidirectional antennas and two medium-gain antennas. The mission's strict schedule, mass, and budget constraints posed difficult challenges to engineering teams from NASA Ames Research Center (ARC) and Northrop Grumman. Their creative thinking led to a unique use of the ESPA ring and innovative sourcing of other spacecraft components. Usually, the ESPA ring is used as a platform to hold six small deployable satellites; for LCROSS, it became the backbone of the satellite, a first for the ring. LCROSS also took advantage of commercially available instruments and used many of the already-flight-verified components used on LRO.


LRO (top, silver) and LCROSS (bottom, gold) prepared for fairing

LCROSS is managed by NASA's ARC and was built by Northrop Grumman. The LCROSS preliminary design review was completed on September 8, 2006. The LCROSS mission passed its Mission Confirmation Review on February 2, 2007, and its Critical Design Review on February 22, 2007. After assembly and testing at Ames, the instrument payload, provided by Ecliptic Enterprises Corporation, was shipped to Northrop Grumman on January 14, 2008, for integration with the spacecraft. LCROSS passed its review on February 12, 2009.

Instruments

The LCROSS science instrument payload, provided by NASA's ARC, consisted of a total of nine instruments: one visible, two near infrared, and two mid-infrared cameras; one visible and two near-infrared spectrometers; and a photometer. A data handling unit (DHU) collected the information from each instrument for transmission back to LCROSS Mission Control. Because of the schedule and budget constraints, LCROSS took advantage of rugged, commercially available components. The individual instruments went through a rigorous testing cycle that simulated launch and flight conditions, identifying design weaknesses and necessary modifications for use in space, at which point the manufacturers were allowed to modify their designs.

Results

The impact was not as visually prominent as had been anticipated. Project manager Dan Andrews believed that this was due to pre-crash simulations that exaggerated the plume's prominence. Because of data bandwidth issues, the exposures were kept short, which made the plume difficult to see in the images in the visible spectra. This resulted in the need for image processing to increase clarity. The infrared camera also captured a thermal signature of the booster's impact.

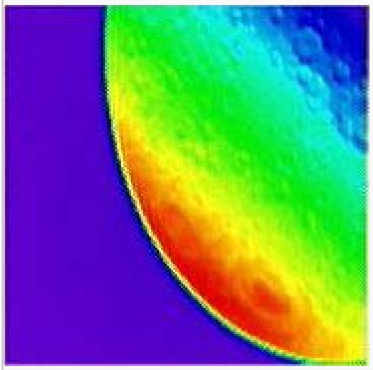
Presence of water

On 13 November 2009, NASA reported that multiple lines of evidence show water was present in both the high-angle vapor plume and the ejecta curtain created by the LCROSS Centaur impact. As of November 2009, the concentration and distribution of water and other substances required more analysis. Additional confirmation came from an emission in the ultraviolet spectrum that was attributed to hydroxyl fragments, a product from the break-up of water by sunlight. Analysis of the spectra indicate that a reasonable estimate of the concentration of water in the frozen regolith is on the order of one percent. Evidence from other missions suggests that this may have been a relatively dry spot, as thick deposits of relatively pure ice appear to present themselves in other craters. A later, more definitive, analysis found the concentration of water to be "5.6 ± 2.9% by mass."

Imagery

LCROSS lunar swingby photos (June 23, 2009)

One of the first images from the Lunar Crater Observation and Sensing Satellite (LCROSS) using the visible light camera during the swingby of the Moon. LCROSS has nine science instruments that collect different types of data which are complementary to each other.

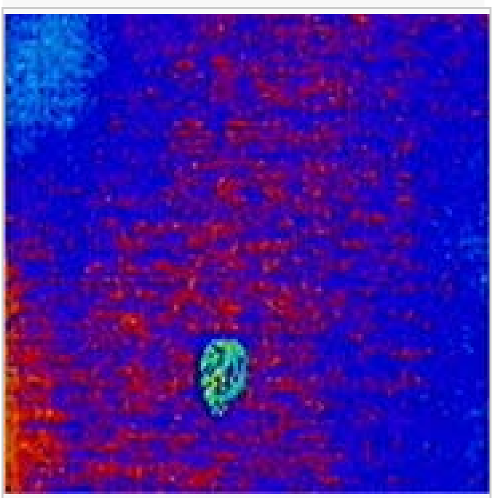


An infrared camera image of the Moon taken with the Lunar Crater Observation and Sensing Satellite (LCROSS) mid-infrared camera. This is the first infrared image ever taken of the far side of the Moon.

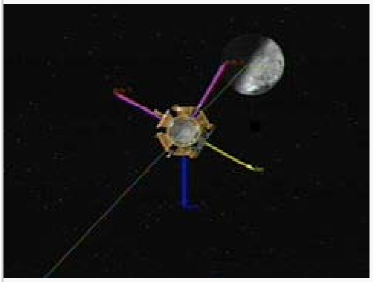
Another visible light camera image of the Moon taken by the LCROSS spacecraft during lunar swingby

LCROSS Centaur separation photos (Impact - 9hrs 40min, October 9, 2009)

Near infrared image of the LCROSS Centaur separation as seen from the LCROSS Shepherding Spacecraft



Mid infrared (false color) image of the LCROSS Centaur separation (red->hot, blue->cold)



STK (Satellite Tool Kit) image of the LCROSS spacecraft after Centaur separation

Centaur/LCROSS impact photos (11:31 UTC October 9, 2009)

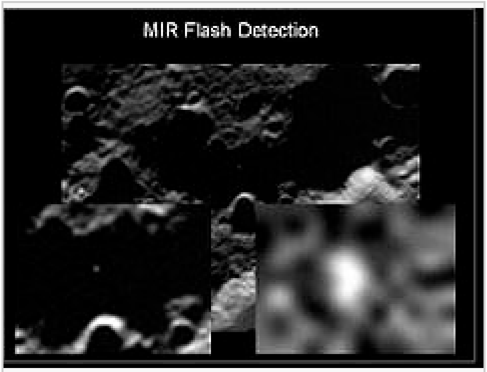
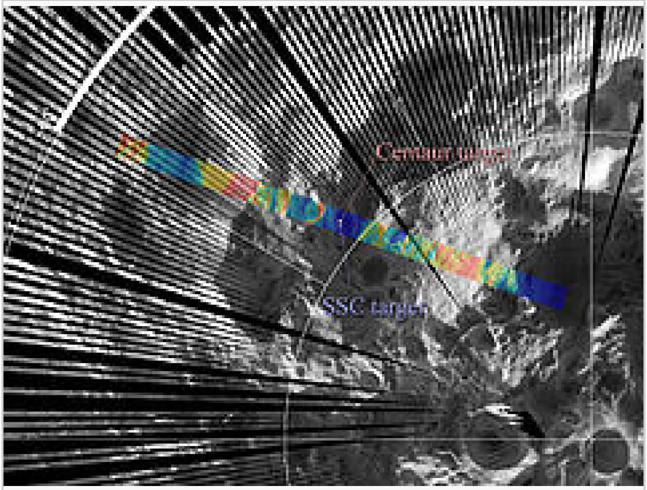
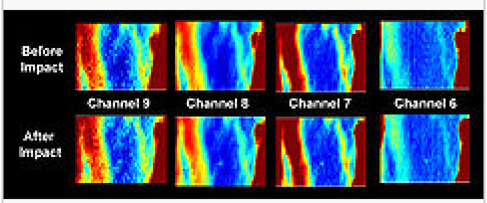


Image taken of the Centaur upper stage impact in the Cabeus crater near the south pole of the moon. The images were taken by the LCROSS shepherding spacecraft.



Locations of the Diviner LCROSS impact swaths overlain on a grayscale daytime thermal map of the Moon’s south polar region. Diviner data were used to help select the final LCROSS impact site inside Cabeus Crater, which sampled an extremely cold region in permanent shadow that can serve as an effective cold trap for water ice and other frozen volatiles.



Preliminary, uncalibrated LRO/Diviner thermal maps of the Centaur/LCROSS impact site acquired two hours before the impact, and 90 seconds after the impact. The thermal signature of the impact was clearly detected in all four Diviner thermal mapping channels.

Awards

LCROSS has received numerous awards for its technical, managerial, and scientific accomplishments.

- 2010: Northrop Grumman Northrop Grumman Corporate 2010 Award for Excellence (Northrop Grumman team)
- 2010: Popular Mechanics magazine's 2010 Breakthrough Award for innovation in science and technology.
- 2010: NASA Honor Award – Group Achievement, (LCROSS Science Team)
- 2010: NASA Honor Award – Group Achievement, (LCROSS Mission Operations Team)
- 2010: NASA Honor Award – Group Achievement, for “outstanding professionalism, innovation in outreach and education, and for integrating outreach for two missions into one launch.” (LRO/LCROSS/LPRP EPO teams)
- 2010: NASA Honor Award - Outstanding Leadership Medal, (Dan Andrews & Tony Colaprete)
- 2010: NASA Honor Award - Group Achievement, LCROSS Science and Payload Team
- 2010: NASA Ames Honor Award, category “Exceptional Achievement” (Rusty Hunt & Ken Galal)
- 2010: Northrop Grumman AS Sector President’s Award, category “Operational Excellence” (Northrop Grumman team)
- 2010: Aviation Week Laureate Award Nominee, Category “Space”
- 2010: Space Foundation “John L. 'Jack' Swigert Jr., Award for Space Exploration”
- 2010: National Space Society “Space Pioneer Award” 2009, Category “Science and Engineering”
- 2010: Northrop Grumman “Distinguished Engineering Project Achievement Award”, 55th Annual Engineering Council
- 2010: NASA OCE Systems Engineering Award, NASA Office of Chief Engineer
- 2010: Aviation Week 2009 Program Excellence Award, Category “System Level Production & Sustainment”
- 2009: Northrop Grumman Technical Services’ “Award for Excellence”: 2009, (LCROSS team)
- 2009: NASA Ames Honor Award, category “team” (LCROSS Team)
- 2009: NASA Ames Honor Award, category “Engineering” (Tom Luzod)
- 2009: NASA Honor Award - Exceptional Achievement Medal, (Dan Andrews)
- 2009: NASA Honor Award - Group Achievement, LCROSS Project Team
- 2008: ILEWG International Lunar Exploration “Technology Award”, for the development of advanced technologies within hard constraints of short time and cost
- 2008: NASA Ames Honor Award, category “Engineering” (Bob Barber)
- 2008: Northrop Grumman “Mission Excellence” Award, LCROSS Spacecraft Team

- 2007: NASA Ames Honor Award - Group Achievement, Successful completion of CDR
- 2006: NASA Ames Honor Award, category “Project Management” (Dan Andrews)

Chapter- 7

Lunar Prospector

Lunar Prospector

Operator	NASA
Major contractors	Discovery Program
Mission type	Planetary Science
Satellite of	The Moon
Orbits	~7060
Launch date	1998-01-07, 02:28:44 UTC
Launch vehicle	Athena II
Mission duration	570 days
Mission highlight	Entered lunar orbit 1998-01-11, 10:28 UTC
COSPAR ID	1998-001A

Homepage	NASA NSSDC Master Catalog
Mass	158 kilograms (350 lb)
Orbital elements	
Semimajor axis	6,478.2 km (4,025.4 mi)
Eccentricity	0.00046
Inclination	90.55°
Apoapsis	101.2 km (62.9 mi)
Periapsis	99.45 km (61.80 mi)
Orbital period	117.9 minutes
Lunar landing	
Date	1999-07-31, 9:52:02 UTC
Coordinates	87°42′S 42°06′E / 87.7°S 42.1°E
Instruments	
Gamma ray spectrometer (GRS)	
Lunar prospector neutron spectrometer (NS)	
Alpha particle spectrometer (APS)	
Doppler gravity experiment (DGE)	
Magnetometer (MAG)	
Electron reflectometer (ER)	

The **Lunar Prospector** mission was the third selected by NASA for full development and construction as part of the Discovery Program. At a cost of $62.8 million, the 19-month mission was designed for a low polar orbit investigation of the Moon, including mapping of surface composition and possible polar ice deposits, measurements of magnetic and gravity fields, and study of lunar outgassing events. The mission ended July 31, 1999, when the orbiter was deliberately crashed into a crater near the lunar south pole in an unsuccessful attempt to detect the presence of water.

Data from the mission allowed the construction of a detailed map of the surface composition of the Moon, and helped to improve understanding of the origin, evolution, current state, and resources of the Moon. Several articles on the scientific results were published in the journal *Science*.

Lunar Prospector was managed out of NASA Ames Research Center with the prime contractor Lockheed Martin. The Principal Investigator for the mission was Dr. Alan

Binder. His personal account of the mission *Against all Odds* is highly critical of the bureaucracy of NASA overall, and of its contractors.

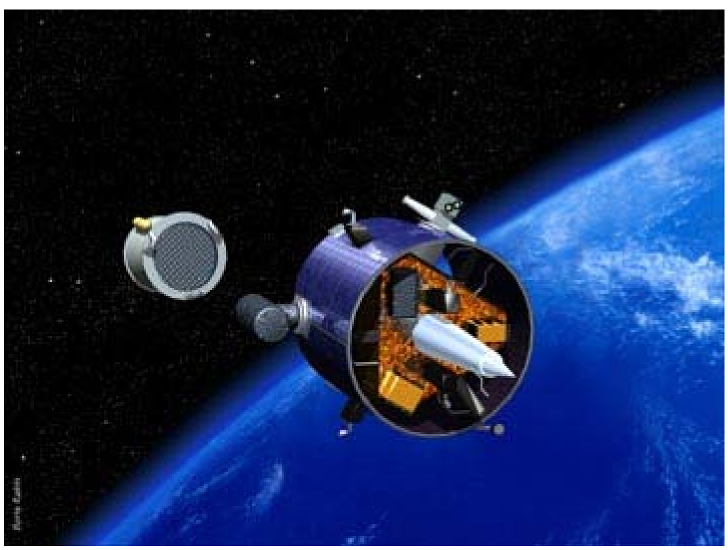
Spacecraft and subsystems

The fully assembled Lunar Prospector spacecraft is shown mated atop the Star 37 Trans Lunar Injection module

The spacecraft was a graphite-epoxy drum, 1.36 m (4.5 ft) in diameter and 1.28 m (4.2 ft) high with three radial 2.5 m (8.2 ft) instrument booms. A 1.1 m (3.6 ft) extension boom at the end of one of the 2.5 m booms held the magnetometer. Total initial mass (fully fueled) was 296 kg (650 lb). It was spin-stabilized (nominal spin rate 12 rpm) with its spin axis normal to the ecliptic plane. The spacecraft was controlled by six hydrazine monopropellant 22-newton thrusters (two aft, two forward, and two tangential). Three fuel tanks mounted inside the drum held 138 kg (300 lb) of hydrazine pressurized by helium. The power system consisted of body-mounted solar cells which produced an average of 186 W and a 4.8 A•h rechargeable NiCd battery. Communications were through two S-band transponders, a slotted, phased-array medium-gain antenna for downlink, and an omnidirectional low-gain antenna for downlink and uplink. The on-board computer was a Harris 80C86 with 64 kilobytes of EEPROM and 64 kilobytes of static RAM. All control was from the ground, the computer echoing each command to the ground for verification there. Once the command was ground-verified, an "execute" command from the ground told the computer to proceed with execution of the command. The computer built telemetry data as a combination of immediate data and also read from a circular queue buffer which allowed the computer to repeat data it had read 53 minutes earlier. This simple solid-state recorder ensured that all data collected during communications blackout periods would be received, providing the blackout was not longer than 53 minutes.

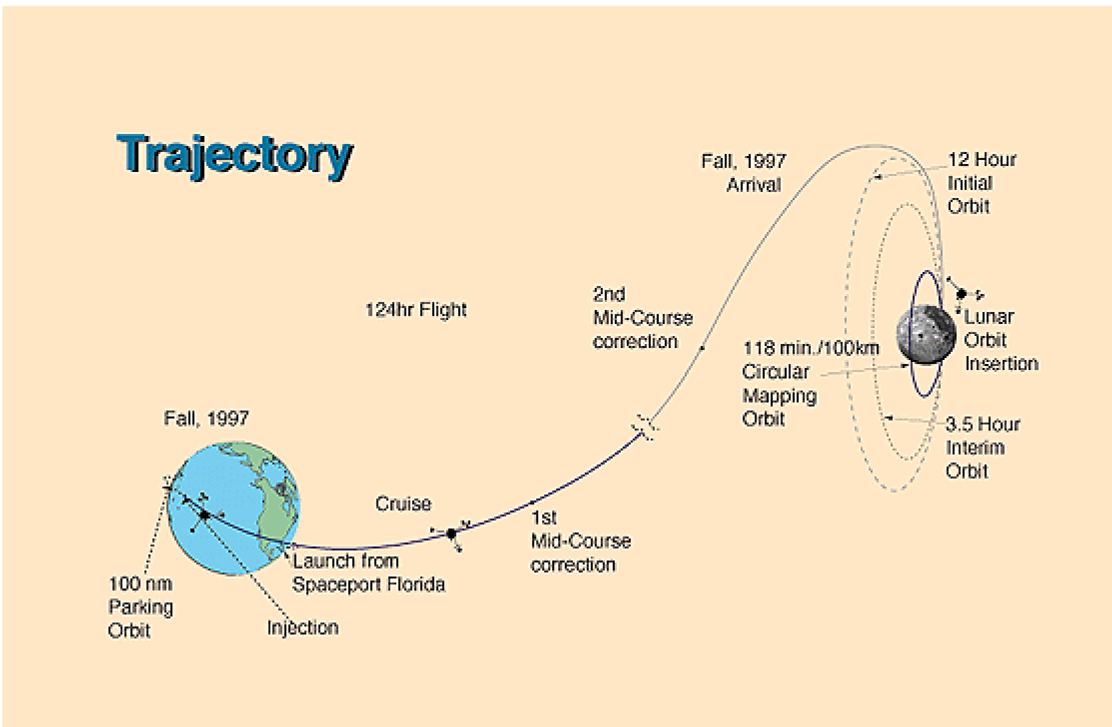
The probe also carried a small amount of the remains of Dr. Eugene Shoemaker (April 28, 1928 – July 18, 1997), astronomer and co-discoverer of Comet Shoemaker-Levy 9, to the moon for a space burial.

Mission profile



Artist's impression of NASA's Lunar Prospector probe leaving Earth orbit after separating from the booster fourth stage.

Following launch on January 7, 1998 UT (6 January EST) aboard a four-stage Athena II rocket, the Lunar Prospector had a 105 hour cruise to the Moon. During the cruise, the three instrument booms were deployed. The MAG and APS collected calibration data, while the GRS, NS, and ER outgassed for one day, after which they also collected calibration data in cis-lunar space. The craft was inserted into an 11.6-hour period capture orbit about the Moon at the end of the cruise phase. After 24 hours Lunar Prospector was inserted into a 3.5-hour period intermediate orbit, followed 24 hours later (on January 13, 1998) by transfer into a 92 km (57 mi) x 153 km (95 mi) preliminary mapping orbit, and then on 16 January by insertion into the near-circular 100 km (62 mi) altitude nominal lunar polar mapping orbit with an inclination of 90 degrees and a period of 118 minutes. Lunar calibration data was collected during the 11.6- and 3.5-hour orbits. Lunar mapping data collection started shortly after the 118 minute orbit was achieved. The data collection was periodically interrupted during the mission as planned for orbital maintenance burns, which took place to recircularize the orbit whenever the periselene or aposelene was more than 20 km (12 mi) to 25 km (16 mi) from the 100 km nominal orbit; this occurred about once a month. On December 19, 1998, a maneuver lowered the orbit to 40 km (25 mi) to perform higher resolution studies. The orbit was altered again on 28 January to a 15 km (9.3 mi) x 45 km (28 mi) orbit, ending the one year primary mission and beginning the extended mission.



Path of the Lunar Prospector space probe

The mission ended on July 31, 1999 at 9:52:02 UT (5:52:02 EDT) when Lunar Prospector was deliberately targeted to impact in a permanently shadowed area of the Shoemaker crater near the lunar south pole. It was hoped that the impact would liberate water vapor from the suspected ice deposits in the crater and that the plume would be detectable from Earth; however, no such plume was observed.

The Lunar Prospector mission was the third mission selected by NASA for full development and construction as part of NASA's Discovery Program. Total cost for the mission was $62.8 million including development ($34 million), launch vehicle (~$25 million) and operations (~$4 million).

Scientific experiments

The spacecraft carried six instruments: a Gamma Ray Spectrometer, a Neutron Spectrometer, a Magnetometer, an Electron Reflectometer, an Alpha Particle Spectrometer, and a Doppler Gravity Experiment. The instruments were omnidirectional and required no sequencing. The normal observation sequence was to record and downlink data continuously.

Gamma Ray Spectrometer (GRS)

The Lunar Prospector GRS produced the first global measurements of gamma-ray spectra from the lunar surface, from which are derived the first "direct" measurements of the chemical composition for the entire lunar surface. This data effectively maps the distribution of various important elements across the Moon. For example, the Lunar Prospector GRS has identified several regions with high iron concentrations.

The fundamental purpose of the GRS experiment was to provide global maps of elemental abundances on the lunar surface. The GRS was designed to record the spectrum of gamma rays emitted by:

1. the radioactive decay of elements contained in the Moon's crust; and
2. elements in the crust bombarded by cosmic rays and solar wind particles.

The most important elements detectable by the GRS were uranium (U), thorium (Th), and potassium (K), radioactive elements which generate gamma rays spontaneously, and iron (Fe), titanium (Ti), oxygen (O), silicon (Si), aluminum (Al), magnesium (Mg), and calcium (Ca), elements which emit gamma rays when hit by cosmic rays or solar wind particles. The uranium, thorium, and potassium in particular were used to map the location of KREEP (potassium, rare-earth element, and phosphorus containing material, which is believed to have developed late in the formation of the crust and upper mantle, and is therefore important to understanding lunar evolution). The GRS was also capable of detecting fast (epithermal) neutrons, which complemented the neutron spectrometer in the search for water on the Moon.

The Gamma Ray Spectrometer was a small cylinder which was mounted on the end of one of the three 2.5 m (8.2 ft) radial booms extending from the Lunar Prospector. It consisted of a bismuth germanate crystal surrounded by a shield of borated plastic. Gamma rays striking the bismuth atoms produced a flash of light with an intensity proportional to the energy of the gamma ray which was recorded by detectors. The energy of the gamma ray is associated with the element responsible for its emission. Due to a low signal-to-noise ratio, multiple passes were required to generate statistically significant results. At nine passes per month, it was expected to take about three months to confidently estimate abundances of thorium, potassium, and uranium, and 12 months for the other elements. The precision varies according to element measured. For U, Th, and K, the precision is 7% to 15%, for Fe 45%, for Ti 20%, and for the overall distribution of KREEP 15% to 30%. The borated plastic shield was used in the detection of fast neutrons. The GRS was designed to achieve global coverage from an altitude of approximately 100 km (62 mi) and with a surface resolution of 150 km (93 mi).

Neutron Spectrometer (NS)

Based on Lunar Prospector Neutron Spectrometer (NS) data, mission scientists have determined that there is indeed water ice in the polar craters of the Moon, an estimated 3 billion metric tons (260 billion US gallons).

The NS was designed to detect minute amounts of water ice which were believed to exist on the Moon. It was capable of detecting water ice at a level of less than 0.01%. The Moon has a number of permanently shadowed craters near the poles with continuous temperatures of −190 °C (−310.0 °F). These craters may act as cold-traps of water from incoming comets and meteoroids. Any water from these bodies which found its way into these craters could become permanently frozen. The NS was also used to measure the abundance of hydrogen implanted by solar wind.

The neutron spectrometer was a thin cylinder colocated with the Alpha Particle Spectrometer at the end of one of the three radial Lunar Prospector science booms. The instrument had a surface resolution of 150 km (93 mi). For the polar ice studies, the NS was slated to examine the poles to 80 degrees latitude, with a sensitivity of at least 10 ppm by volume of hydrogen. For the implanted hydrogen studies, the NS was intended to examine the entire globe with a sensitivity of 50 ppmv. The neutron spectrometer consisted of two canisters each containing helium-3 and an energy counter. Any neutrons colliding with the helium atoms give an energy signature which can be detected and counted. One of the canisters was wrapped in cadmium, and one in tin. The cadmium screens out thermal (low energy or slow-moving) neutrons, while the tin does not. Thermal neutrons are cosmic-ray-generated neutrons which have lost much of their energy in collisions with hydrogen atoms. Differences in the counts between the two canisters indicate the number of thermal neutrons detected, which in turn indicates the amount of hydrogen on the Moon's crust at a given location. Large quantities of hydrogen would likely be due to the presence of water.

The Alpha Particle Spectrometer (APS)

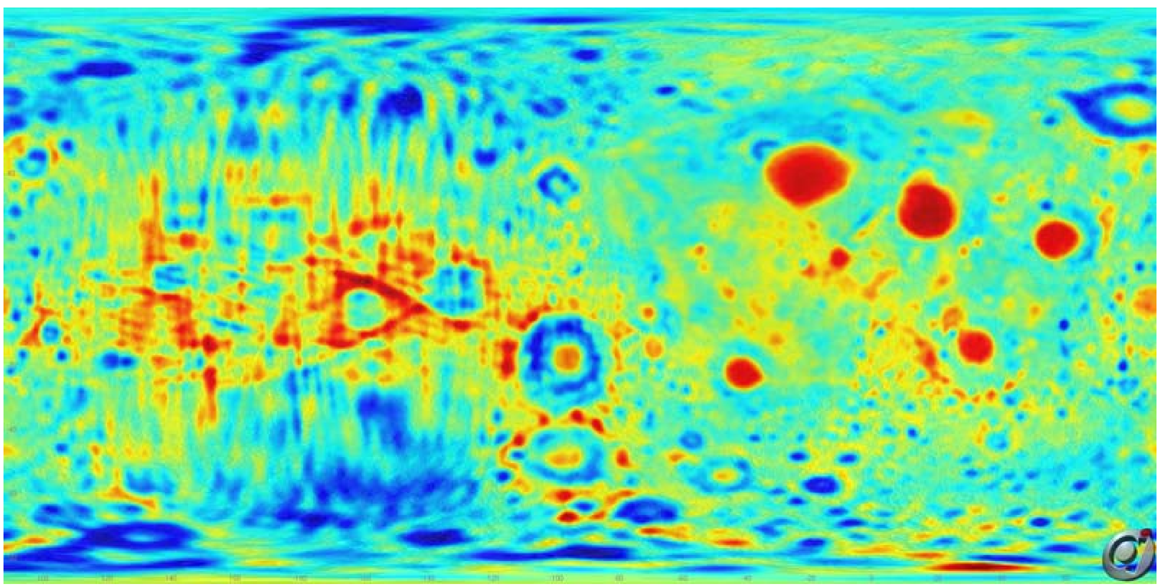
The Alpha Particle Spectrometer (APS) was damaged during launch, ruining one of the five detecting faces. Additionally, due to sunspot activity peaking during the mission, the lunar data is obscured by solar interference. NASA has stated that the information can eventually be recovered by subtracting out the effects of the solar activity. In the meantime, however, the APS has not yielded any useful results.

The APS was designed to detect radon outgassing events on the surface of the Moon. The APS recorded alpha particle signatures of radioactive decay of radon gas and its daughter product, polonium. These putative outgassing events, in which radon, nitrogen, and carbon dioxide are vented, are hypothesized to be the source of the tenuous lunar atmosphere, and may be the result of the low-level volcanic/tectonic activity on the

Moon. Information on the existence, timing, and sources of these events may help in a determination of the style and rate of lunar tectonics.

The APS was a cube approximately 18 cm (7.1 in) on a side colocated with the neutron spectrometer on the end of one of the three radial 2.5 m (8.2 ft) Lunar Prospector science booms. It contained ten silicon detectors sandwiched between gold and aluminum disks arranged on five of six sides of the cube. Alpha particles, produced by the decay of radon and polonium, leave tracks of charge on the silicon wafers when they impact the silicon. A high voltage is applied to the silicon, and the current is amplified by being funneled along the tracks to the aluminum disk and is recorded for identification. The APS was designed to make a global examination of gas release events and polonium distribution with a surface resolution of 150 km (93 mi) and a precision of 10%.

Doppler Gravity Experiment (DGE)



A visualization of the lunar gravity field based on spherical harmonic coefficients determined from Lunar Prospector data. The left side of the image shows the far of the moon where the increased uncertainty in the gravity field can be seen.

The Doppler Gravity Experiment (DGE) was the first polar, low-altitude mapping of the lunar gravity field. The Clementine mission had previously produced a relatively low-resolution map, but the Prospector DGE obtained data approximately five times as detailed: the "first truly operational gravity map of the Moon". The practical benefits of this are more stable long-term orbits and better fuel efficiency. Additionally, the DGE data is hoped to help researchers learn more about lunar origins and the nature of the lunar core. The DGE has identified three new near-side mascons (mass concentrations).

The purpose of the Lunar Prospector DGE was to learn about the surface and internal mass distribution of the Moon. This is accomplished by measuring the Doppler shift in the S-band tracking signal as it reaches Earth, which can be converted to spacecraft accelerations. The accelerations can be processed to provide estimates of the lunar gravity field, from which the location and size of mass anomalies affecting the spacecraft orbit can be modeled. Estimates of the surface and internal mass distribution give information on the crust, lithosphere, and internal structure of the Moon.

This experiment provided the first lunar gravity data from a low polar orbit. Because line-of-sight tracking is required for this experiment, only the near-side gravity field could be estimated using this Doppler method. The experiment is a byproduct of the spacecraft S-band tracking, and so has no listed weight or power requirements. The experiment was designed to give the near-side gravity field with a surface resolution of 200 km (120 mi) and precision of 5 mGal (0.05 mm/s^2) in the form of spherical harmonic coefficients to degree and order 60. In the extended mission, in which the spacecraft descended to an orbit with an altitude of 50 km (31 mi) and then to 10 km (6.2 mi), this resolution was expected to improve by a factor of 100 or more.

The downlink telemetry signal was transmitted at 2273 MHz, over a ±1 MHz bandwidth as a right-hand circularly polarized signal at a nominal power of 5 W and peak power of 7 W. Command uplinks were sent at 2093.0542 MHz over a ±1 MHz bandwidth. The transponder was a standard Loral/Conic S-Band transponder. An omnidirectional antenna can be used for uplink and downlink, or a medium gain helix antenna can be used (downlink only). Since the spacecraft was spin-stabilized, the spin resulted in a bias in the Doppler signal due to the spacecraft antenna pattern spinning with respect to the Earth station of 0.417 Hz (27.3 mm/s) for the omnidirectional antenna, and −0.0172 Hz (−1.12 mm/s) for the medium gain antenna. LOS data was sampled at 5 seconds to account for the approximately 5 second spin rate of the spacecraft, leaving a residual of less than 0.1 mm/s.

Electron Reflectometer and Magnetometer (MAG/ER)

The Magnetometer and Electron Reflectometer (collectively, MAG/ER) detected anomalous surface magnetic fields on the Moon, which are in stark contrast to a global magnetosphere (which the Moon lacks). The Moon's overall magnetic field is too weak to deflect the solar wind, but MAG/ER discovered a small surface anomaly that can do so. This anomaly, about 100 km (62 mi) in diameter, has therefore been referred to as "the smallest known magnetosphere, magnetosheath and bow shock system in the Solar System". Due to this and other magnetic features of the Moon's surface, hydrogen deposited by solar wind is non-uniformly distributed, being denser at the periphery of the magnetic features. Since hydrogen density is a desirable characteristic for hypothetical lunar bases, this information may be useful in choosing optimal sites for possible long-term Moon missions.

The electron reflectometer (ER) and magnetometer (MAG) were designed to collect information on the lunar magnetic fields. The Moon has no global magnetic field, but it does have weak localized magnetic fields at its surface. These may be paleomagnetic remnants of a former global magnetic field, or may be due to meteor impacts or other local phenomena. This experiment was to help map these fields and provide information on their origins, allow possible examination of distribution of minerals on the lunar surface, aid in a determination of the size and composition of the lunar core, and provide information on the lunar induced magnetic dipole.

The ER determined the location and strength of magnetic fields from the energy spectrum and direction of electrons. The instrument measured the pitch angles of solar wind electrons reflected from the Moon by lunar magnetic fields. Stronger local magnetic fields can reflect electrons with larger pitch angles. Field strengths as small as 0.01 nT could be measured with a spatial accuracy of about 3 km (1.9 mi) at the lunar surface. The MAG was a triaxial fluxgate magnetometer similar in design to the instrument used on Mars Global Surveyor. It could measure the magnetic field amplitude and direction at spacecraft altitude with a spatial resolution of about 100 km (62 mi) when ambient plasma disturbances are minimal.

The ER and the electronics package were located at the end of one of the three radial science booms on Lunar Prospector. The MAG was in turn extended further on a 0.8 m (2.6 ft) boom—a combined 2.6 m (8.5 ft) from the Lunar Prospector in order to isolate it from spacecraft generated magnetic fields. The ER and MAG instruments had a combined mass of 5 kg (11 lb) and used 4.5 watts of power.

Chapter- 8

SMART-1

SMART-1	
Operator	ESA
Mission type	Orbiter
Satellite of	Moon
Launch date	September 27, 2003
Launch vehicle	Ariane 5
Mission duration	3 years
COSPAR ID	2003-043C
Homepage	SMART-1
Mass	367 kg (809 lb)

SMART-1 was a Swedish-designed European Space Agency satellite that orbited around the Moon. It was launched on September 27, 2003 at 23:14 UTC from the Guiana Space Centre in Kourou, French Guiana. "SMART" stands for **Small Missions for Advanced Research in Technology**. On September 3, 2006 (05:42 UTC), SMART-1 was deliberately crashed into the Moon's surface, ending its mission.

Spacecraft design

SMART-1 was about one metre across, and lightweight in comparison to other probes. Its launch mass was 367 kg or 809 pounds, of which 287 kg (633 lb) was non-propellant.

It was propelled by a solar-powered Hall effect thruster (Snecma PPS-1350-G) using xenon propellant, of which there was 82 kg (50 litres by volume at a pressure of 150 bar) at launch. The thrusters used an electrostatic field to ionize the xenon and accelerate the ions to a high speed. This ion engine setup achieved a specific impulse of 16.1 kN·s/kg

(1,640 seconds), more than three times the maximum for chemical rockets. Therefore 1 kg of propellant (1/350 to 1/300 of the total mass of the spacecraft) produced a delta-v of about 45 m/s. The electric propulsion subsystem had a weight of 29 kg with a peak power consumption of 1,200 watts.

The solar arrays made 1,190 W available for powering the thruster, giving a nominal thrust of 68 mN, hence an acceleration of 0.2 mm/s² or 0.7 m/s per hour (i.e., just under 0.00002 *g* of acceleration). As for all ion-engine powered craft, orbital maneuvers were not carried out in short bursts but very gradually. The particular trajectory taken by SMART-1 to the Moon required thrusting for about one third to one half of every orbit. When spiralling away from the Earth thrusting was done on the perigee part of the orbit. At the end of the mission, the thruster had demonstrated the following capability :

- Thruster operating time: 5000 h
- Xenon throughput: 82 kg
- Total Impulse: 1.1 MN-s
- Total ΔV: 3.9 km/s

As part of the European Space Agency's strategy to build very inexpensive and relatively small spaceships, the total cost of SMART-1 was a relatively small 110 million euros (about 170 million U.S. dollars). SMART-1 was designed and developed by the Swedish Space Corporation on behalf of ESA. Assembly of the spacecraft was carried out by Saab Space in Linköping. Tests of the spacecraft were directed by Swedish Space Corporation and executed by Saab Space. The project manager at ESA was Giuseppe Racca and the project manager at the Swedish Space Corporation was Peter Rathsman; the Principal Project Scientist was Bernard Foing.

Instruments

AMIE

The Advanced Moon micro-Imager Experiment was a miniature colour camera for lunar imaging. The CCD camera with three filters of 750, 900 and 950 nm was able to take images with an average pixel resolution of 80 m (about 260 ft). The camera weighed 2.1 kg (about 4.5 lb) and had a power consumption of 9 watts.

D-CIXS

The Demonstration of a Compact X-ray Spectrometer was an X-ray telescope for the identification of chemical elements on the lunar surface. It detected the x-ray fluorescence (XRF) of crystal compounds created through the interaction of the electron shell with the solar wind particles to measure the abundance of the three main components: magnesium, silicon and aluminium. The detection of iron, calcium and titanium depended on the solar activity. The detection range for x-rays was 0.5 to 10 keV. The spectrometer and XSM (described below) together weighed 5.2 kg and had a power consumption of 18 watts.

XSM

The X-ray solar monitor studied the solar variability to complement D-CIXS measurements.

SIR

The Smart-1 Infrared Spectrometer was an infrared spectrometer for the identification of mineral spectra of olivine and pyroxene. It detected wave lengths from 0.93 to 2.4 µm with 256 channels. The package weighed 2.3 kg and had a power consumption of 4.1 watts.

EPDP

The Electric Propulsion Diagnostic Package was to acquire data on the new propulsion system on SMART-1. The package weighed 0.8 kg and had a power consumption of 1.8 watts.

SPEDE

The Spacecraft Potential, Electron and Dust Experiment. The experiment weighed 0.8 kg and had a power consumption of 1.8 watts. Its name was intentionally chosen so that its acronym is the same as the nickname of Spede Pasanen, famous Finnish movie actor, movie producer, inventor etc.

KATE

K_a band TT&C (telemetry, tracking and control) Experiment. The experiment weighed 6.2 kg and had a power consumption of 26 watts.

Flight

SMART-1 was launched September 27, 2003 together with Insat 3E and eBird 1, by an Ariane 5 rocket from the Guiana Space Centre in French Guiana. After 42 minutes it was released into a geostationary transfer orbit of 7,035 × 42,223 km. From there it used its Solar Electric Primary Propulsion (SEPP) to gradually spiral out during thirteen months.

The orbit can be seen up to October 26, 2004 at moontoday.net, when the orbit was 179,718 × 305,214 km. On that date, after the 289th engine pulse, the SEPP had accumulated a total on-time of nearly 3,648 hours out of a total flight time of 8,000 hours, hence a little less than half of its total mission. It consumed about 58.8 kg of xenon and produced a delta-v of 2,737 m/s (46.5 m/s per kg xenon, 0.75 m/s per hour on-time). It was powered on again on November 15 for a planned burn of 4.5 days to enter fully into lunar orbit. It took until February 2005 using the electric thruster to decelerate into the final orbit 300-3,000 km above the Moon's surface. The end of mission performance demonstrated by the propulsion system is stated above.

Summary of osculating geocentric orbital elements

Epoch (UTC)	Perigee (km)	Apogee (km)	Eccentricity	Inclination (deg) (to Earth equator)	Period (h)
September 27, 2003	~7,035	~42,223	~0.714	~6.9	~10.6833
October 26, 2003, 21:20:00.0	8,687.994	44,178.401	0.671323	6.914596	11.880450
November 19, 2003, 04:29:48.4	10,843.910	46,582.165	0.622335	6.861354	13.450152
December 19, 2003, 06:41:47.6	13,390.351	49,369.049	0.573280	6.825455	15.366738
December 29, 2003, 05:21:47.8	17,235.509	54,102.642	0.516794	6.847919	18.622855
February 19, 2004, 22:46:08.6	20,690.564	65,869.222	0.521936	6.906311	24.890737
March 19, 2004, 00:40:52.7	20,683.545	66,915.919	0.527770	6.979793	25.340528
August 25, 2004, 00:00:00	37,791.261	240,824.363	0.728721	6.939815	143.738051
October 19, 2004, 21:30:45.9	69,959.278	292,632.424	0.614115	12.477919	213.397970
October 26, 2004, 06:12:40.9	179,717.894	305,214.126	0.258791	20.591807	330.053834

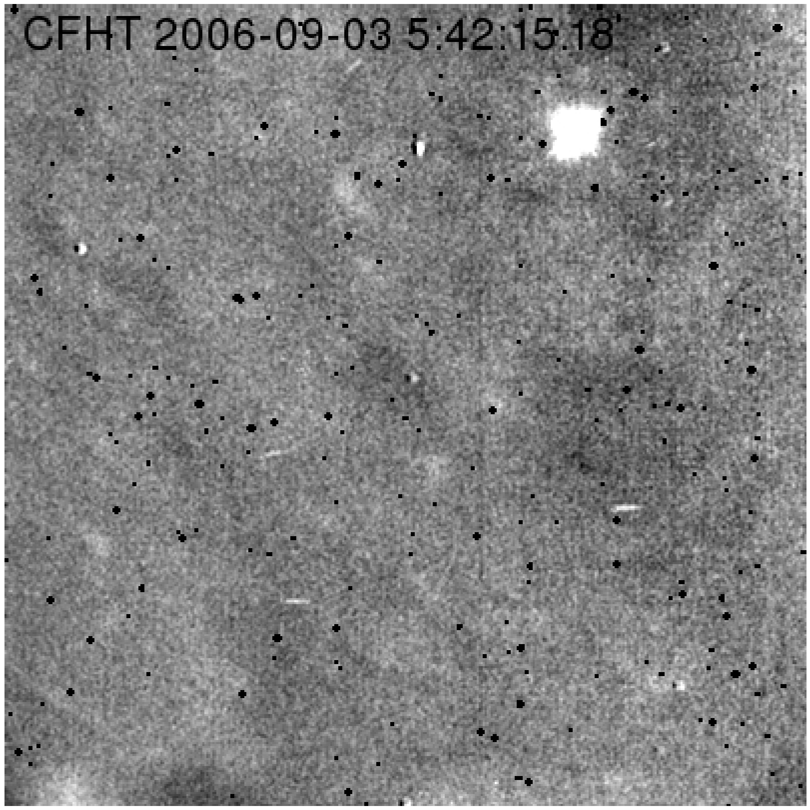
After its last perigee on November 2, on November 11, 2004 it passed through the L_1 Lagrangian Point and into the area dominated by the Moon's gravitational influence, and at 1748 UT on November 15 passed the first periselene of its lunar orbit. The osculating orbit on that date was 6,704 × 53,208 km, with an orbital period of 129 hours, although the actual orbit was accomplished in only 89 hours. This illustrates the significant impact that the engine burns have on the orbit and marks the meaning of the osculating orbit, which is the orbit that would be travelled by the spacecraft if at that instant all perturbations, including thrust, would cease.

Summary of osculating selenocentric orbital elements

Epoch (UTC)	Periselene (km)	Aposelene (km)	Eccentricity	Inclination (deg) (to Moon equator)	Period (h)
November 15, 2004, 17:47:12.1	6,700.720	53,215.151	0.776329	81.085	129.247777
December 4, 2004 10:37:47.3	5,454.925	20,713.095	0.583085	83.035	37.304959
January 9, 2005, 15:24:55.0	2,751.511	6,941.359	0.432261	87.892	8.409861
February 28, 2005, 05:18:39.9	2,208.659	4,618.220	0.352952	90.063603	4.970998
April 25, 2005, 08:19:05.4	2,283.738	4,523.111	0.328988	90.141407	4.949137
May 16, 2005, 09:08:52.9	2,291.250	4,515.857	0.326807	89.734929	4.949919
June 20, 2005, 10:21:37.1	2,256.090	4,549.196	0.336960	90.232619	4.947432
July 18, 2005, 11:14:28.0	2,204.645	4,600.376	0.352054	90.263741	4.947143

ESA announced on February 15, 2005, the endorsement of a proposal to extend the mission of *SMART-1* by one year until August 2006. This date was later shifted to September 3, 2006, to enable scientific observations from Earth.

Lunar impact



SMART-1 impact flash

SMART-1 impacted the Moon's surface as planned, on September 3, 2006 at 05:42:22 UTC, ending its mission. Moving at approximately 2,000 m/s (4,500 mph), SMART-1 created an impact visible with ground telescopes from Earth. It is hoped that not only will this provide some data simulating a meteor impact, but also that it might expose materials in the ground, like water ice, to spectroscopic analysis.

ESA estimated that impact occurred at 34°24′S 46°12′W / 34.4°S 46.2°W. These numbers can be entered into NASA's World Wind, to see where on the Moon it crashed. At the time of impact, the Moon was visible in North and South America, and places in the Pacific Ocean, but not Europe, Africa, or western Asia.

This project has generated data and know-how that will be used for other missions, such as the ESA's BepiColombo mission to Mercury.

The Committee on Space Research has established rules to protect planets and moons from possible contamination by spacecraft. In response to concerns of SMART-1 contaminating the Moon, ESA claims that "every chemical element present on SMART-1 and in its instruments exists naturally on the Moon".

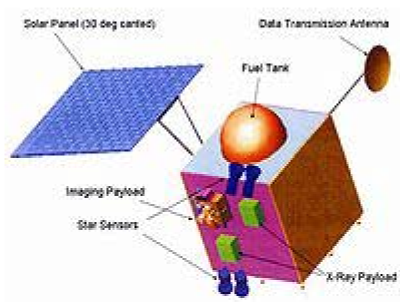
Important events and discoveries

- September 27, 2003: SMART-1 launched from the European Spaceport in Kourou by an Ariane 5 launcher.
- June 17, 2004: SMART-1 took a test image of Earth with the camera that would later be used for Moon closeup pictures. It shows parts of Europe and Africa. It was taken on May 21 with the AMIE camera.
- November 2, 2004: Last perigee of Earth orbit.
- November 15, 2004: First perilune of lunar orbit.
- January 15, 2005: Calcium detected in Mare Crisium.
- January 26, 2005: First close up pictures of the lunar surface sent back.
- February 27, 2005: Reached final orbit around the Moon with an orbital period of about 5 hours.
- April 15, 2005: The search for PELs begins.
- September 3, 2006: Mission ends with a planned crash into the Moon during orbit number 2,890.

Chapter- 9

Chandrayaan-1

Chandrayaan-1



Configuration of Chandrayaan-1 that lift off on the PSLV-C11

Operator	Indian Space Research Organisation
Mission type	Orbiter
Satellite of	Moon
Orbital insertion date	12 November 2008
Orbits	3400 orbits around the Moon.
Launch date	22 October 2008 00:52 UTC
Launch vehicle	PSLV-C11
Launch site	SDSC, Sriharikota
Mission duration	Intended: 2 years Achieved: 312 days

COSPAR ID	2008-052A
Homepage	Chandrayaan-1
Mass	1,380 kg (3,042 lb)
	Orbital elements
Eccentricity	near circular
Inclination	polar
Apoapsis	initial 7,500 km (4,660 mi), final 100 km (62 mi), final (wef 19 May 2009) 200 km (124 mi)
Periapsis	initial 500 km (311 mi), final 100 km (62 mi), final (wef 19 May 2009) 200 km (124 mi)

Chandrayaan-1 (Sanskrit: चंद्रयान-१, lit: moon vehicle) was India's first unmanned lunar probe. It was launched by the Indian Space Research Organisation in October 2008, and operated until August 2009. The mission included a lunar orbiter and an impactor. India launched the spacecraft with a modified version of the PSLV, PSLV C11 on 22 October 2008 from Satish Dhawan Space Centre, Sriharikota, Nellore District, Andhra Pradesh, about 80 km north of Chennai, at 06:22 IST (00:52 UTC). Former prime minister Atal Bihari Vajpayee announced the project on course in his Independence Day speech on 15 August 2003. The mission was a major boost to India's space program, as India researched and developed its own technology in order to explore the Moon. The vehicle was successfully inserted into lunar orbit on 8 November 2008.

On 14 November 2008, the Moon Impact Probe separated from the Chandrayaan orbiter at 20:06 and struck the south pole in a controlled manner, making India the fourth country to place its flag on the Moon. The probe impacted near Shackleton Crater at 20:31 ejecting underground soil that could be analysed for the presence of lunar water ice.

The estimated cost for the project was ₹386 crore (US$80 million).

The remote sensing lunar satellite had a mass of 1,380 kilograms (3,042 lb) at launch and 675 kilograms (1,488 lb) in lunar orbit. It carried high resolution remote sensing equipment for visible, near infrared, and soft and hard X-ray frequencies. Over a two-year period, it was intended to survey the lunar surface to produce a complete map of its chemical characteristics and three-dimensional topography. The polar regions are of special interest as they might contain ice. The lunar mission carries five ISRO payloads and six payloads from other space agencies including NASA, ESA, and the Bulgarian Aerospace Agency, which were carried free of cost.

After suffering from several technical issues including failure of the star sensors and poor thermal shielding, Chandrayaan stopped sending radio signals at 1:30 AM IST on 29 August 2009 shortly after which, the ISRO officially declared the mission over. Chandrayaan operated for 312 days as opposed to the intended two years but the mission achieved 95 percent of its planned objectives. Among its many achievements was the discovery of the widespread presence of water molecules in lunar soil.

Objectives

The stated scientific objectives of the mission were:

- to design, develop, launch and orbit a spacecraft around the Moon using an Indian-made launch vehicle
- to conduct scientific experiments using instruments on the spacecraft which would yield data:
    - for the preparation of a three-dimensional atlas (with high spatial and altitude resolution of 5–10 m) of both the near and far side of the Moon
    - for chemical and mineralogical mapping of the entire lunar surface at high spatial resolution, mapping particularly the chemical elements magnesium, aluminium, silicon, calcium, iron, titanium, radon, uranium, and thorium
    - to increase the scientific knowledge
    - to test the impact of a sub-satellite (Moon Impact Probe — MIP) on the surface on the Moon as a fore-runner to future soft-landing missions

Specifications

Mass
: 1,380 kg at launch, 675 kg at lunar orbit, and 523 kg after releasing the impactor.

Dimensions
: Cuboid in shape of approximately 1.5 m

Communications
: X band, 0.7 m diameter dual gimballed parabolic antenna for payload data transmission. The Telemetry, Tracking & Command (TTC) communication operates in S band frequency.

Power
: The spacecraft is mainly powered by its solar array, which includes one solar panel covering a total area of 2.15 x 1.8 m generating 750 W of peak power, which is stored in a 36 A·h lithium-ion battery for use during eclipses.

Propulsion
: The spacecraft uses a bipropellant integrated propulsion system to reach lunar orbit as well as orbit and altitude maintenance while orbiting the Moon. The

power plant consists of one 440 N engine and eight 22 N thrusters. Fuel and oxidizer are stored in two tanks of 390 litres each.

Navigation and control

The craft is 3-axis stabilized with two star sensors, gyros and four reaction wheels. The craft carries dual redundant bus management units for attitude control, sensor processing, antenna orientation, etc.

Specific areas of study

- High-resolution mineralogical and chemical imaging of the permanently shadowed north- and south-polar regions
- Searching for surface or sub-surface lunar water-ice, especially at the lunar poles
- Identification of chemicals in lunar highland rocks
- Chemical stratigraphy of the lunar crust by remote sensing of the central uplands of large lunar craters, and of the South Pole Aitken Region (SPAR), an expected site of interior material
- Mapping the height variation of features of the lunar surface
- Observation of X-ray spectrum greater than 10 keV and stereographic coverage of most of the Moon's surface with 5 m resolution
- Providing new insights in understanding the Moon's origin and evolution

Payloads

The scientific payload had a total mass of 90 kg and contained five Indian instruments and six foreign instruments.

Indian Payloads

- **TMC** or the **Terrain Mapping Camera** is a CCD camera with 5 m resolution and a 40 km swath in the panchromatic band and was used to produce a high-resolution map of the Moon. The aim of this instrument was to completely map the topography of the Moon. The camera works in the visible region of the electromagnetic spectrum and captures black and white stereo images. When used in conjunction with data from Lunar Laser Ranging Instrument (LLRI), it can help in better understanding of the lunar gravitational field as well. TMC was built by the ISRO's Space Applications Centre (SAC) at Ahmedabad. The TMC was successfully tested on 29 October 2008 through a set of commands issued from ISTRAC.

- **HySI** or **Hyper Spectral Imager** performed mineralogical mapping in the 400-900 nm band with a spectral resolution of 15 nm and a spatial resolution of 80 m.

- **LLRI** or **Lunar Laser Ranging Instrument** determines the height of the surface topography by sending pulses of infrared laser light towards the lunar surface and detecting the reflected portion of that light. It operated continuously and collected

10 measurements per second on both the day and night sides of the Moon. It was successfully tested on 16 November 2008.

- **HEX** is a **High Energy aj/gamma x-ray spectrometer** for 30 – 200 keV measurements with ground resolution of 40 km, the HEX measured U, Th, ^{210}Pb, ^{222}Rn degassing, and other radioactive elements.

- **MIP** or the **Moon Impact Probe** developed by the ISRO, is an impact probe which consisted of a C-band Radar altimeter for measurement of altitude of the probe, a video imaging system for acquiring images of the lunar surface and a mass spectrometer for measuring the constituents of the lunar atmosphere. It was ejected at 20:00 hours IST on 14 November 2008. The Moon Impact Probe successfully crash landed at the lunar south pole at 20:31 hours IST on 14 November 2008. It carried with it a picture of the Indian flag. India is now the fourth nation to place a flag on the Moon after the Soviet Union, United States and Japan.

Payload from other countries

- **C1XS** or **X-ray fluorescence spectrometer** covering 1- 10 keV, mapped the abundance of Mg, Al, Si, Ca, Ti, and Fe at the surface with a ground resolution of 25 km, and monitored solar flux. This payload results from collaboration between Rutherford Appleton laboratory, U.K, ESA and ISRO. It was activated on 23 November 2008.

- **SARA**, **The Sub-keV Atom Reflecting Analyser** from the ESA mapped mineral composition using low energy neutral atoms emitted from the surface.

- **M^3**, the **Moon Mineralogy Mapper** from Brown University and JPL (funded by NASA) is an imaging spectrometer designed to map the surface mineral composition. It was activated on 17 December 2008.

- **SIR-2**, A near infrared spectrometer from ESA, built at the Max Planck Institute for Solar System Research, Polish Academy of Science and University of Bergen, also maped the mineral composition using an infrared grating spectrometer. The instrument is similar to that of the Smart-1 SIR. It was activated on 19 November 2008 and scientific observations were successfully started on 20 November 2008.

- **miniSAR**, designed, built and tested for NASA by a large team that includes the Naval Air Warfare Center, Johns Hopkins University Applied Physics Laboratory, Sandia National Laboratories, Raytheon and Northrop Grumman; it is the active Synthetic Aperture Radar system to search for lunar polar ice. The instrument transmitted right polarised radiation with a frequency of 2.5 GHz and monitored scattered left and right polarised radiation. The Fresnel reflectivity and the circular polarisation ratio (CPR) are the key parameters deduced from these measurements. Ice shows the Coherent Backscatter Opposition Effect which results in an enhancement of reflections and CPR, so that water content of the Moon's polar regions can be estimated.

- **RADOM-7**, **Radiation Dose Monitor Experiment** from the Bulgarian Academy of Sciences maps the radiation environment around the Moon. It was successfully tested on 16 November 2008.

Space flight

Chandrayaan-1 was launched on 22 October 2008 at 6.22 am IST from Satish Dhawan Space Centre using the ISRO's 44.4 metre tall four-stage PSLV launch rocket. Chandrayaan-1 was sent to the Moon in a series of orbit-increasing manoeuvres around the Earth over a period of 21 days as opposed to launching the craft on a direct trajectory to the Moon. At launch the spacecraft was inserted into geostationary transfer orbit (GTO) with an apogee of 22,860 km and a perigee of 255 km. The apogee was increased with a series of five orbit burns conducted over a period of 13 days after launch.

For the duration of the mission, ISRO's telemetry, tracking and command network (ISTRAC) at Peenya in Bangalore, tracked and controlled Chandrayaan-1. Scientists from India, Europe, and the U.S. conducted a high-level review of Chandrayaan-1 on 29 January 2009 after the spacecraft completed its first 100 days in space.

Earth orbit burns

First orbit burn

The first orbit-raising manoeuvre of Chandrayaan-1 spacecraft was performed at 09:00 hrs IST on 23 October 2008 when the spacecraft's 440 Newton Liquid Engine was fired for about 18 minutes by commanding the spacecraft from Spacecraft Control Centre (SCC) at ISRO Telemetry, Tracking and Command Network (ISTRAC) at Peenya, Bangalore. With this Chandrayaan-1's apogee was raised to 37,900 km, and its perigee to 305 km. In this orbit, Chandrayaan-1 spacecraft took about 11 hours to go around the Earth once.

Second orbit burn

The second orbit-raising manoeuvre of Chandrayaan-1 spacecraft was carried out on 25 October 2008 at 05:48 IST when the spacecraft's engine was fired for about 16 minutes, raising its apogee to 74,715 km, and its perigee to 336 km, thus completing 20 percent of its journey. In this orbit, Chandrayaan-1 spacecraft took about twenty-five and a half hours to go round the Earth once. This is the first time an Indian spacecraft has gone beyond the 36,000 km high geostationary orbit and reached an altitude more than twice that height.

Third orbit burn

The third orbit raising manoeuvre was initiated on 26 October 2008 at 07:08 IST when the spacecraft's engine was fired for about nine and a half minutes. With this its apogee was raised to 164,600 km, and the perigee to 348 km. In this orbit, Chandrayaan-1 took about 73 hours to go around the Earth once.

Fourth orbit burn

The fourth orbit-raising maneuver took place on 29 October 2008 at 07:38 IST when the spacecraft's engine was fired for about three minutes, raising its apogee to 267,000 km and the perigee to 465 km. This extended its orbit to a distance more than half the way to the Moon. In this orbit, the spacecraft took about six days to go around the Earth once.

Final orbit burn

The fifth and final orbit raising manoeuvre was carried out on 4 November 2008 04:56 am IST when the spacecraft's engine was fired for about two and a half minutes resulting in Chandrayaan-1 entering the Lunar Transfer Trajectory with an apogee of about 380,000 km.

Lunar orbit insertion

Chandrayaan-1 successfully completed the lunar orbit insertion operation on 8 Nov 2008 at 16:51 IST. This manoeuvre involved firing of the liquid engine for 817 seconds (about thirteen and half minutes) when the spacecraft passed within 500 km from the Moon. The satellite was placed in an elliptical orbit that passed over the polar regions of the Moon, with 7502 km aposelene (point farthest away from the Moon) and 504 km periselene (nearest to the Moon). The orbital period was estimated to be around 11 hours. With the successful completion of this operation, India became the fifth nation to put a vehicle in lunar orbit.

First orbit reduction

First Lunar Orbit Reduction Manoeuvre of Chandrayaan-1 was carried out successfully on 9 November 2008 at 20:03 IST. During this, the engine of the spacecraft was fired for about 57 seconds. This reduced the periselene from 504 km to 200 km while aposelene remained unchanged at 7,502 km. In this elliptical orbit, Chandrayaan-1 took about ten and a half hours to circle the Moon once.

Second orbit reduction

This manoeuvre, which resulted in steep decrease in Chandrayaan-1's aposelene from 7,502 km to 255 km and its periselene from 200 km to 187 km, was carried out on 10 November 2008 at 21:58 IST. During this manoeuvre, the engine was fired for about

866 seconds (about fourteen and half minutes). Chandrayaan-1 took two hours and 16 minutes to go around the Moon once in this orbit.

Third orbit reduction

Third Lunar Orbit Reduction was carried out by firing the on board engine for 31 seconds on 11 November 2008 at 18:30 IST. This reduced the periselene from 187 km to 101 km, while the aposelene remained constant at 255 km. In this orbit Chandrayaan-1 took two hours and 9 minutes to go around the Moon once.

Final orbit

Chandrayaan-1 spacecraft was successfully placed into a mission-specific lunar polar orbit of 100 km above the lunar surface on 12 November 2008. In the final orbit reduction manoeuvre, Chandrayaan-1's aposelene was reduced from 255 km to 100 km while the periselene was reduced from 101 km to 100 km. In this orbit, Chandrayaan-1 takes about two hours to go around the Moon once. Two of the 11 payloads – the Terrain Mapping Camera (TMC) and the Radiation Dose Monitor (RADOM) – have already been successfully switched on. The TMC successfully acquired images of both the Earth and the Moon.

Impact of the MIP on the lunar surface

The Moon Impact Probe (MIP) crash-landed on the lunar surface on 14 November 2008, 15:01 UTC (20:31 Indian Standard Time (IST)) near the crater Shackleton at the south pole. The MIP was one of eleven scientific instruments (payloads) on board Chandrayaan-1.

The MIP separated from Chandrayaan at 100 km from lunar surface and began its nosedive at 14:36 UTC (20:06 IST). going into free fall for thirty minutes. As it fell, it kept sending information back to the mother satellite which, in turn, beamed the information back to Earth. The altimeter then also began recording measurements to prepare for a rover to land on the lunar surface during a second Moon mission - planned for 2012.

Following the successful deployment of the MIP, the other scientific instruments were turned on, starting the next phase of the mission.

After scientific analyses of the received data from the MIP, the Indian Space Research Organisation confirmed the presence of water in the lunar soil and published the finding in a press conference addressed by its then Chairman Sri. G. Madhavan Nair.

Rise of spacecraft's temperature

ISRO had reported on 25 November 2008 that Chandrayaan-1's temperature had risen above normal to 50 °C, scientists said that it was caused by higher than normal temperatures in lunar orbit. The temperature was brought down by about 10 °C by rotating the spacecraft about 20 degrees and switching off some of the instruments. Subsequently ISRO reported on 27 November 2008 that the spacecraft was operating under normal temperature conditions. In subsequent reports ISRO says, since the spacecraft was still recording higher than normal temperatures, it would be running only one instrument at a time until January 2009 when lunar orbital temperature conditions are said to stabilise. The spacecraft was experiencing high temperature because of radiation from the Sun and infrared radiation reflected by the Moon.

Mapping of minerals

The mineral content on the lunar surface was mapped with the Moon Mineralogy Mapper (M^3), a NASA instrument on board the orbiter. The presence of iron was reiterated and changes in rock and mineral composition have been identified. The Oriental Basin region of the Moon was mapped, and it indicates abundance of iron-bearing minerals such as pyroxene.

Mapping of Apollo landing sites

ISRO claims that the landing sites of the Apollo Moon missions have been mapped by the orbiter using multiple payloads. Six of the sites have been mapped including that of Apollo 11, the first mission that brought humans on the Moon.

Images acquisition

The craft completed 3000 orbits acquiring 70000 images of the lunar surface, which many in ISRO believe is quite a record compared to the lunar flights of other nations. ISRO officials estimated that if more than 40,000 images have been transmitted by Chandrayaan's cameras in 75 days, it worked out to nearly 535 images being sent daily. They were first transmitted to Indian Deep Space Network at Byalalu near Bangalore, from where they were flashed to ISRO's Telemetry Tracking And Command Network (ISTRAC) at Bangalore.

Some of these images have a resolution of up to 5 metres, providing a sharp and clear picture of the Moon's surface, while many images sent by some of the other missions had a 100-metre resolution.

On 26 November, the indigenous Terrain Mapping Camera, which was first activated on 29 October 2008, acquired images of peaks and craters. This came as a surprise to ISRO officials because the Moon consists mostly of craters.

Detection of X-Ray signals

The X-ray signatures of aluminium, magnesium and silicon were picked up by the C1XS X-ray camera. The signals were picked up during a solar flare that caused an X-ray fluorescence phenomenon. The flare that caused the fluorescence was within the lowest C1XS sensitivity range.

Full Earth image

On 25 March 2009 Chandrayaan beamed back its first images of the Earth in its entirety. These images were taken with the TMC. Previous imaging was done on only one part of the Earth. The new images show Asia, parts of Africa and Australia with India being in the center.

Orbit raised to 200 km due to malfunctions

After the completion of all the major mission objectives, the orbit of Chandrayaan-1 spacecraft, which was at a height of 100 km from the lunar surface since November 2008, had to be raised to 200 km due to malfunctions. The orbit raising manoeuvres were carried out between 09:00 and 10:00 IST on 19 May 2009. The spacecraft in this higher altitude enabled further studies on orbit perturbations, gravitational field variation of the Moon and also enabled imaging lunar surface with a wider swath. However, it was later revealed that the true reason for the orbit change was that it was an attempt to keep the temperature of the probe down. It was "...assumed that the temperature [of the spacecraft subsystems] at 100km above the Moon's surface would be around 75 degrees Celsius. However, it was more than 75 degrees and problems started to surface. We had to raise the orbit to 200km."

Altitude sensing due to Star Sensor failure

The star sensor, a device used for direction finding of which the mission carried two, failed in orbit after nine months of operation. Afterward, the direction of Chandrayaan was determined using a back-up procedure using a two axis Sun sensor and taking a bearing from a ground station. This was used to update three axis gyroscopes which enabled spacecraft operations, although some failures may have reduced the craft's lifetime. The first of the sensors failed on 26 April. The second failure, detected on 16 May, was attributed to excessive radiation from the Sun.

Bistatic RADAR experiment with LRO

On 21 August 2009 Chandrayaan-1 along with the Lunar Reconnaissance Orbiter was used to perform a bistatic radar experiment to detect the presence of water ice on the lunar surface. In this experiment, Chandrayaan emanated RADAR pulses which, after reflection from the surface, were picked up by the receivers of both the Chandrayaan and the LRO. Both receivers, Mini-SAR in Chandrayaan and Mini-RF in LRO, were pointed at the Erlanger crater for four minutes during which the observations were made. In March 2010, it was reported that the Mini-Sar experiment onboard the Chandrayaan-1 had discovered cold dark spots which are hypothesized to contain an estimated "at least 600 million metric tonnes" of water-ice held within northern polar craters.

End of the mission

The mission was launched in 22 October 2008 and expected to operate for 2 years. However, at 09.02 (UTC) on 29 August 2009 communication with the spacecraft was suddenly lost. The probe had operated for 312 days. The craft will remain in orbit for approximately another 1000 days, eventually crashing into the lunar surface.

A member of the science advisory board of Chandrayaan-1 said that it is difficult to ascertain reasons for the loss of contact. ISRO Chairman -Madhavan Nair- said that due to very high radiation, power-supply units controlling both the computer systems on board failed, snapping the communication connectivity. However, information released later showed that the power supply failed due to overheating.

Completion of primary objectives

Although the mission was less than 10 months in duration, and less than half the intended 2 years in length, a review by scientists termed the mission successful, as it had completed 95% of its primary objectives, consisting of:

- To construct the complex spacecraft with 11 scientific instruments.
- To place the spacecraft in a circular orbit around the Moon by orbit raising manoeuvres from a near Earth orbit.
- To place the Flag of India on the Moon.
- To carry out imaging operations and to collect data on the mineral content of the lunar soil.
- To set up a deep space tracking network and implement the operational procedures for travel into deep space.

The data collected from the mission have been disseminated to Indian scientists and also the partners from Europe and U.S.A. for analysis.

Data collected analysis result

Chandrayaan's Moon Mineralogy Mapper has confirmed the magma ocean hypothesis, meaning that the moon was once completely molten. "It proves beyond doubt the magma ocean hypothesis. There is no other way this massive rock type could be formed," said Carle Pieters, science manager at the NASA-supported spectroscopy facility at Brown University in the US.

The Terrain mapping camera Camera on board Chandrayaan-1 , besides producing more than 70,000 three dimensional images, has recorded images of the landing site of US spacecraft Apollo 15, rubbishing conspiracy theories that the US mission to land on the moon four decades back was a hoax.

"TMC and HySI payloads of ISRO have covered about 70 per cent of the lunar surface, while M^3 covered more than 95 per cent of the same and SIR-2 has provided high-resolution spectral data on the mineralogy of the moon", ISRO said.

Indian Space Research Organisation said interesting data on lunar polar areas was provided by Lunar Laser Ranging Instrument (LLRI) and High Energy X-ray Spectrometer (HEX) of ISRO as well as Miniature Synthetic Aperture Radar (Mini-SAR) of the USA.

LLRI covered both the lunar poles and additional lunar regions of interest, HEX made about 200 orbits over the lunar poles and Mini-SAR provided complete coverage of both North and South Polar Regions of the moon.

Another ESA payload - Chandrayaan-1 imaging X-ray Spectrometer (C1XS) - detected more than two dozen weak solar flares during the mission duration. The Bulgarian payload called Radiation Dose Monitor (RADOM) was activated on the day of the launch itself and worked until the mission's end.

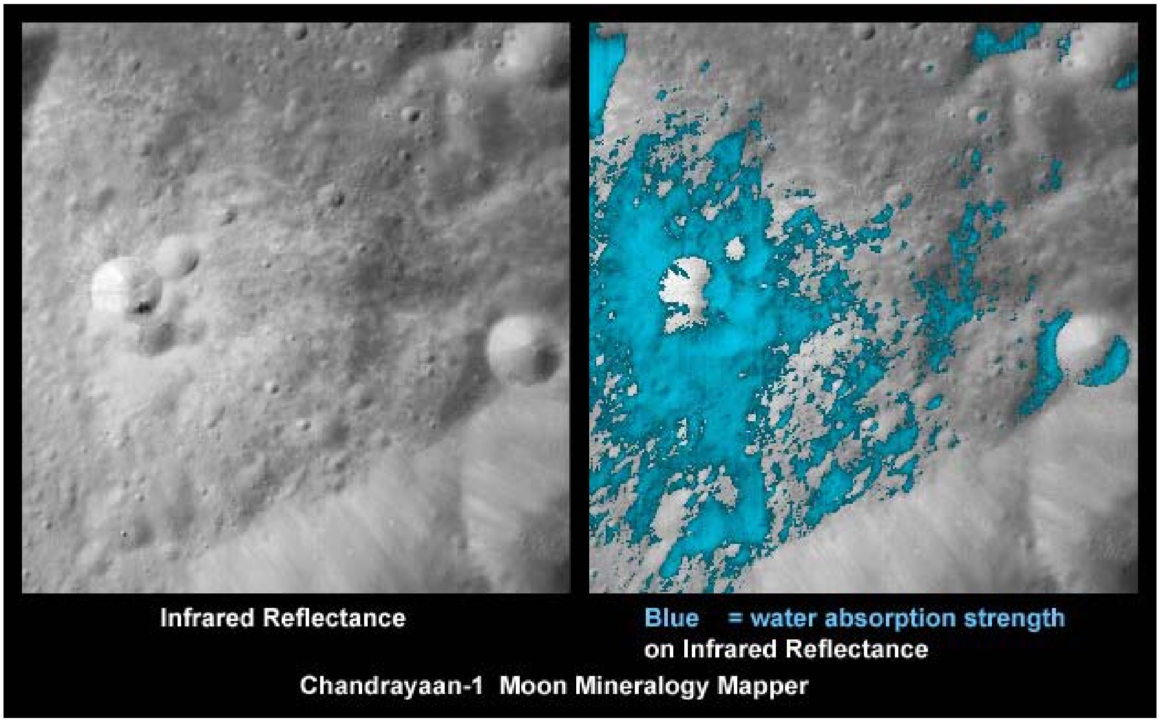
ISRO said scientists from India and participating agencies expressed satisfaction on the excellent performance of Chandrayaan-1 mission as well as the high quality of data sent by the spacecraft.

They have started formulating science plans based on the data sets obtained from the mission. It is expected that in the next few months, interesting results about lunar topography, mineral and chemical contents of the moon and related aspects are expected to be published,ISRO said.

A Chandrayaan-1 moon mission payload has enabled scientists to study the interaction between the solar wind and a planetary body like moon without a magnetic field, a meeting convened by ISRO was told.

In its 10-month orbit around the moon, Chandrayaan-1's X-ray Spectrometer (C1XS) has detected titanium, confirmed the presence of calcium, and gathered the most accurate measurements yet of magnesium, aluminium and iron on the lunar surface.

Water discovered on moon



These images show a very young lunar crater on the side of the moon that faces away from Earth, as viewed by NASA's Moon Mineralogy Mappicleshow/5057854.cms ISRO found water on the moon 10 months ago

This was confirmed on 24 September 2009, when Science Magazine reported that NASA's Moon Mineralogy Mapper (M^3) on Chandrayaan-1 has detected water on the moon. M^3 detected absorption features near 2.8-3.0 µm on the surface of the Moon. For silicate bodies, such features are typically attributed to hydroxyl- and/or water-bearing materials. On the Moon, the feature is seen as a widely distributed absorption that appears strongest at cooler high latitudes and at several fresh feldspathic craters. The general lack of correlation of this feature in sunlit M^3 data with neutron spectrometer H abundance data suggests that the formation and retention of OH and H_2O is an ongoing surficial process. OH/H_2O production processes may feed polar cold traps and make the lunar regolith a candidate source of volatiles for human exploration.

The Moon Mineralogy Mapper (M^3), an imaging spectrometer, was one of the 11 instruments on board Chandrayaan-I that came to a premature end on 29 August 2009. M^3 was aimed at providing the first mineral map of the entire lunar surface.

Lunar scientists have for decades contended with the possibility of water repositories. They are now increasingly “confident that the decades-long debate is over,” a report says. “The moon, in fact, has water in all sorts of places; not just locked up in minerals, but scattered throughout the broken-up surface, and, potentially, in blocks or sheets of ice at depth." The results from the NASA's Lunar Reconnaissance Orbiter are also "offering a wide array of watery signals."

How The Moon Produces Its Own Water

A scientific instrument on Chandrayaan-1 — the Sub keV Atom Reflecting Analyser or SARA — made this discovery that was published in the latest edition of the Planetary and Space Science journal.

According to European Space Agency (ESA) scientists, hydrogen nuclei from solar winds are absorbed by the lunar regolith (a loose collection of irregular dust grains making up the moon's surface). An interaction between the hydrogen nuclei and oxygen present in the dust grains are expected to produce hydroxyls and water.

SARA, developed by the ESA and the Indian Space Research Organisation, was designed to study the moon's surface composition and solar wind-surface interactions. Recently, another instrument on the Indian spacecraft, the Moon Mineralogy Mapper — an imaging spectrometer developed by the U.S. National Aeronautics and Space Administration — first found water molecules on the lunar surface.

SARA's results also highlight a mystery: not every hydrogen nucleus is absorbed. One out of every five rebounds into space, combining to form an atom of hydrogen. "We didn't expect to see this at all," said Stas Barabash of the Swedish Institute of Space Physics, who is the European Principal Investigator for SARA.

Hydrogen shoots off at speeds of around 200 km per second and escapes without being deflected by the moon's weak gravity, the team found.

This knowledge provides timely advice for scientists who are readying ESA's BepiColombo mission to mercury. The spacecraft will carry two instruments similar to SARA and may find that the innermost planet is reflecting more hydrogen than the moon because the solar wind is more concentrated closer to the sun.

Discovery of Caves on Moon

Chandrayaan-1 has discovered large caves on the lunar surface that can act as human shelter on moon. The tunnel, which has been discovered near the lunar equator, is an empty volcanic tube, measuring about two km in length and 360 metres in width. According to AS Arya, scientist SF of Ahmedabad-based Space Application Centre (SAC), this could be a potential site for human settlement on moon. Earlier, Japanese Lunar orbiter Kaguya (SELENE) had also discovered a cave on moon.

Award for Chandrayaan-1

The American Institute of Aeronautics and Astronautics (AIAA) has selected ISRO's Chandrayaan-1 mission as one of the recipients of its annual AIAA SPACE 2009 awards, which recognizes key contributions to space science and technology.

The International Lunar Exploration Working Group (ILEWG) chose the Chandrayaan-1 team for giving the International Cooperation award, M, Annadurai, project director, Chandrayaan-1.The Chandrayaan team of the Indian Space Research Organisation (ISRO) was chosen for the award for accommodation and tests of the most international lunar payload ever (from 20 countries consisting of India, the European Space Agency representing 17 European countries, NASA and Bulgaria) and the successful launch of the probe on PSLV rocket on 22 October and the lunar insertion of the spacecraft carried out subsequently.

Team

The scientists considered instrumental to the success of the Chandrayaan-1 project are:

- G. Madhavan Nair – Chairman, Indian Space Research Organization
- Dr. T. K. Alex – Director, ISAC (ISRO Satellite Centre)
- Mylswamy Annadurai – Project Director, Chandrayan-1
- S. K. Shivkumar – Director - Telemetry, Tracking and Command Network
- Mr. M.Pitchaimani – Operations Director, Chandrayan-1
- Mr. Leo Jackson John – Spacecraft Operations Manager, Chandrayan-1
- Dr. K. Radhakrishnan (scientist) – Director, VSSC
- George Koshy – Mission Director, PSLV-C11
- Srinivasa Hegde – Mission Director, Chandrayaan-1
- M C Dattan – Director of the Satish Dhawan Space Centre, Sriharikota
- Prof. J N Goswami – Director of Physical Research Laboratory and Principal Scientific Investigator of Chandrayaan-1
- Rajendra Masanta - Server Operation Lead Specialist - Pool - 19 Space Satellite
- Anil Prasad - Server Operation Specialist - Pool - 19 Space Satellite

Public release of Data

ISRO has stated recently, that the voluminous data gathered by Chandrayaan-I would be made available to the public by the end of the year 2010. The data would be eventually split into two seasons with the first season going public by the end of 2010 and the second going public by the mid of 2011. The data would contain rare pictures of the moon and also data from the chemical and mineral mapping of the lunar surface.

Chandrayaan-2

ISRO is also planning a second version of Chandrayaan named Chandrayaan II. According to former ISRO Chairman G. Madhavan Nair, "The Indian Space Research Organisation (ISRO) hopes to land two motorised rovers- one Russian and another Indian - on the Moon in 2013, as a part of its second Chandrayaan mission. The rover will be designed to move on wheels on the lunar surface, pick up samples of soil or rocks, do on-site chemical analysis and send the data to the mother-spacecraft Chandrayaan II, which will be orbiting above. Chandrayaan II will transmit the data to Earth."

Lunar outpost

Chandrayaan's imagery will be used to identify regions of interest that will be explored in detail by the NASA Lunar Reconnaissance Orbiter. The interest lies in identifying lunar water on the surface that can be exploited in setting up a future lunar outpost. The Mini-SAR, one of the U.S payloads on Chandrayaan, was used to determine the presence of water ice.