

Spacecraft Missions to Mars

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Table of Contents

Chapter 1 - Mars Program

Chapter 2 - Dawn (Spacecraft)

Chapter 3 - Mariner 4

Chapter 4 - Mariner 6 and 7

Chapter 5 - Mars 2 & Mars 3

Chapter 6 - Mars Global Surveyor

Chapter 7 - Mars Express

Chapter 8 - Phobos Program

Chapter- 1

Mars Program

The **Mars program** was a series of unmanned spacecraft launched by the Soviet Union between 1960 and 1973. The spacecraft were intended to explore Mars, and included flyby probes, landers and orbiters.

Early Mars spacecraft were small, and launched by Molniya rockets. Starting with two failures in 1969, the heavier Proton-K rocket was used to launch larger 5 tonne spacecraft, consisting of an orbiter and a lander to Mars. The orbiter bus design was likely somewhat rushed into service and immature, considering that it performed very reliably in the Venera variant after 1975. This reliability problem was common to much Soviet space hardware from the late 1960s and early 1970s and was largely corrected with a deliberate policy, implemented in the mid-1970s, of consolidating (or "debugging") existing designs rather than introducing new ones.

In addition to the Mars program, the Soviet Union also sent a probe to Mars as part of the Zond program; Zond 2, however it failed en route. Two more spacecraft were sent during the Fobos program. In 1996, Russia launched Mars 96, its first interplanetary mission since the dissolution of the Soviet Union, however it failed to depart Earth orbit.

Spacecraft

Mars 1M



Mars 1 stamp

The first Soviet attempts to send a probe to Mars were the two Mars 1M spacecraft, which each had a mass of about 650 kg. Both were launched in 1960 and failed to achieve orbit. The spacecraft were dubbed *Marsnik* by the Western media.

Mars 3MV

Mars 1 was launched in 1962 but failed en route to Mars. Two other Soviet launches at around the same time, Mars 2MV-4 No.1 and Mars 2MV-3 No.1 were 900-kilogram (2,000 lb) spacecraft, however both failed to leave Earth orbit due to problems with the upper stages of their carrier rockets.

Mars 2M

Mars 2M No.521 and Mars 2M No.522, known in the West as Mars 1969A and B, were heavier spacecraft with masses of 5 tonnes (4.9 LT; 5.5 ST). They were launched by Proton-K rockets, and consisted of orbiters and landers similar to late Venera, and Vega spacecraft.

Mars 4M

The Mars 4M spacecraft; Mars 2 and Mars 3 missions consisted of identical spacecraft, each with an orbiter and an attached lander, which became the first spacecraft to reach the surface of Mars.

The orbiters' primary scientific objectives were to image the Martian surface and clouds, determine the temperature on Mars, study the topography, composition and physical properties of the surface, measure properties of the atmosphere, monitor the solar wind and the interplanetary and Martian magnetic fields, and act as communications relays to send signals from the landers to Earth.

Mars 2



Mars 2 stamp

- Launch date/time:
 - Mars 2: May 19, 1971 at 16:22:44 UTC
- Launch mass (including fuel):
 - Combined: 4650 kg
 - Orbiter: 3440 kg
 - Lander: 1210 kg
- On-orbit dry mass: 2265 kg

- Dimensions: 4.1 meters tall, 2 meters across (5.9 meters across with solar panels deployed)

Mars 2 released the descent module 4.5 hours before reaching Mars on November 27, 1971. The descent module entered the Martian atmosphere at roughly 6.0 km/s at a steeper angle than planned. The descent system malfunctioned and the lander crashed at 45°S 30°W / 45°S 30°W, delivering the Soviet Union coat of arms to the surface. Meanwhile, the orbiter engine performed a burn to put the spacecraft into a 1380 x 24,940 km, 18 hour orbit about Mars with an inclination of 48.9 degrees. Scientific instruments were generally turned on for about 30 minutes near periapsis.

Mars 3

- Launch date/time:
 - Mars 3: May 28, 1971 at 15:26:30 UTC
- Launch mass (including fuel):
 - Combined: 4650 kg
 - Orbiter: 3440 kg
 - Lander: 1210 kg
- On-orbit dry mass: 2265 kg
- Dimensions: 4.1 meters tall, 2 meters across (5.9 meters across with solar panels deployed)

Mars 3's descent module was released at 09:14 UT on December 2, 1971, 4 hours 35 minutes before reaching Mars. The descent module entered the Martian atmosphere at roughly 5.7 km/s. Through aerodynamic braking, parachutes, and retrorockets, the lander achieved a soft landing at 45°S 158°W / 45°S 158°W and began operations. However, after 20 seconds the instruments stopped working for unknown reasons, perhaps as a result of the massive surface dust storms raging at the time of landing. Mars 3 lander still managed to transmit a portion of the first picture of Martian surface. Meanwhile, the orbiter had suffered from a partial loss of fuel and did not have enough to put itself into a planned 25 hour orbit. The engine instead performed a truncated burn to put the spacecraft into a long 12 day, 19 hour period orbit about Mars with an inclination thought to be similar to that of Mars 2 (48.9 degrees).

Both landers had a small Mars 'rover' on board, which would move across the surface on skis while connected to the lander with a 15-meter umbilical. Two small metal rods were used for autonomous obstacle avoidance, as radio signals from Earth would take too long to drive the rovers using remote control. Each rover had both a densitometer and a dynamic penetrometer, to test the density and the bearing strength of the soil. Because of the demise of the landers, neither rover saw action.

The Mars 2 and 3 orbiters sent back a large volume of data covering the period from December 1971 to March 1972, although transmissions continued through August. It was announced that Mars 2 and 3 had completed their missions by August 22, 1972, after 362 orbits completed by Mars 2 and 20 orbits by Mars 3. The probes sent back a total of 60

pictures. The images and data enabled creation of surface relief maps, and gave information on the Martian gravity and magnetic fields.

Mars 3MS

Kosmos 419 was launched on May 5, 1971. It consisted of only an orbiter, and was intended to become the first spacecraft to enter areocentric orbit, thereby beating the American Mariner 8 and Mariner 9 spacecraft.

The Mars 4 and Mars 5 orbiters, launched in 1973, were designed to orbit Mars and return information on the composition, structure, and properties of the Martian atmosphere and surface. The spacecraft were also designed to act as communications links to the Mars 6 and 7 landers. Like earlier heavy spacecraft, they were launched by Proton-K rockets.

Mars 4

- Launch date/time:
 - Mars 4: July 21, 1973 at 19:30:59 UTC
- On-orbit mass:
 - Dry: 2270 kg
 - Fully-fuelled: 3440 kg

The Mars 4 orbiter reached Mars on February 10, 1974. Due to a flaw in the computer chip which resulted in degradation of the chip during the voyage to Mars, the retro-rockets designed to slow the craft into Mars orbit did not fire, and Mars 4 flew by the planet at a range of 2200 km. It returned one swath of pictures and some radio occultation data which constituted the first detection of the nightside ionosphere on Mars. It continued to return interplanetary data from solar orbit after the flyby.

Mars 5

- Launch date/time:
 - Mars 5: July 25, 1973 at 18:55:48 UTC
- On-orbit mass:
 - Dry: 2270 kg
 - Fully-fuelled: 3440 kg

Mars 5 reached Mars on February 12, 1974 at 15:45 UT and was inserted into an elliptical 1755 by 32,555 km, 24 h 53 min orbit with an inclination of 35.3 degrees. Nearly synchronized with the rotation of the planet, its two phototelevision cameras could be commanded to take 12 pictures during each close approach. The Vega camera used a wide area 52mm lens with color filters, the Zulfar camera used a telescopic 350mm lens and long-pass orange filter. Images were transmitted in a rapid 220-line mode, and then selected pictures were retransmitted at 880 or 1760 line resolution. Mars 5 collected data for 22 orbits until a loss of pressurization in the transmitter housing

ended the mission. About 60 images were returned over a nine day period showing swaths of the area south of Valles Marineris, from 5°N 330°W / 5°N 330°W to 20°S 130°W / 20°S 130°W.

Mars 3MP

The 1973 Mars launch window was inefficient and thus the Proton could not deliver sufficient mass to the necessary trajectory to reach Mars, as had been possible in 1971. To resolve this problem, two landers were launched with orbiter type buses, but without fuel to enter orbit. The Mars 4 and 5 orbiters, which had been launched separately, were used to relay communications, and to complete mission objectives which would have been completed by orbiters launched with the Mars 6 and 7 spacecraft had they been flown.

Mars 6

Mars 6 successfully lifted off on August 5, 1973, into an intermediate Earth orbit on a Proton SL-12/D-1-e booster and then launched into a Mars transfer trajectory. Total fueled launch mass of the lander and bus was 3260 kg. It reached Mars on March 12, 1974. The descent module separated from the bus at a distance of 48,000 km from Mars. The bus continued on into a heliocentric orbit after passing within 1600 km of Mars. The descent module entered the atmosphere at 09:05:53 UT at a speed of 5.6 km/s. The parachute opened at 09:08:32 UT after the module had slowed its speed to 600 m/s by aerobraking. During this time the craft was collecting data and transmitting it directly to the bus for immediate relay to Earth. Contact with the descent module was lost at 09:11:05 UT in "direct proximity to the surface", probably either when the retrorockets fired or when it hit the surface at an estimated 61 m/s. Mars 6 landed at 23°54'S 19°25'W / 23.90°S 19.42°W in the Margaritifer Terra region of Mars. The landed mass was 635 kg. The descent module transmitted 224 seconds of data before transmissions ceased, the first data returned from the atmosphere of Mars. Much of the data was unreadable due to a flaw in a computer chip which led to degradation of the system during its journey to Mars.

Mars 7

Mars 7 successfully lifted off on August 9, 1973, into an intermediate Earth orbit on a Proton SL-12/D-1-e booster and then launched into a Mars transfer trajectory. Total fueled launch mass of the lander and bus was 3260 kg. It reached Mars on March 9, 1974. Due to a problem in the operation of one of the on-board systems (attitude control or retro-rockets) the landing probe separated prematurely (4 hours before encounter) and missed the planet by 1300 km. The early separation was probably due to a computer chip error which resulted from degradation of the systems during the trip to Mars. The intended landing site was 50°S 28°W / 50°S 28°W. The lander and bus continued on into heliocentric orbits.

Mars 4NM and 5NM

The Mars 4NM and Mars 5NM projects would have seen heavier spacecraft launched by N1 rockets. They would have deployed Marsokhod rovers onto the surface, and conducted sample return missions. The N1 failed on all four of its test flights, and was never used to launch any Mars spacecraft.

Chapter- 2

Dawn (Spacecraft)

Dawn



Artist's concept of *Dawn* with Vesta (left) & Ceres (right)
(the proximity of Vesta to Ceres is not to scale.)

Operator	NASA
Major contractors	Orbital Sciences, JPL, UCLA
Mission type	Flyby / Orbiter
Flyby of	Mars
Satellite of	Vesta, Ceres
Orbital insertion date	Vesta: July 2011 (projected) Ceres: February 2015 (projected)
Launch date	2007-09-27 11:34:00 UTC (3 years, 179 days ago)
Launch vehicle	Delta II 7925H

Launch site	Space Launch Complex 17B Cape Canaveral Air Force Station
Mission duration	In Transit Mars flyby <i>(completed 2009-02-04)</i>
COSPAR ID	2007-043A
Homepage	dawn.jpl.nasa.gov
Mass	1,250 kg (2,800 lb)
Power	1000 W (Solar array)

Orbital elements

Eccentricity	~ circular
Inclination	Polar

Dawn is a robotic spacecraft sent by NASA on a space exploration mission to the two most massive members of the asteroid belt: Vesta and the dwarf planet Ceres. Launched on September 27, 2007, *Dawn* is scheduled to explore Vesta between 2011 and 2012, and Ceres in 2015. It will be the first spacecraft to visit either body.

Dawn is innovative in that it will be the first spacecraft to enter into orbit around a celestial body, study it, and then re-embark under powered flight to proceed to a second target. All previous multi-target study missions—such as the Voyager program—have involved rapid planetary flybys.

The Dawn mission to Vesta and Ceres is managed by NASA's Jet Propulsion Laboratory, a division of the California Institute of Technology in Pasadena, for NASA's Science Mission Directorate, Washington.

Launch

Dawn was scheduled to launch from pad 17-B at the Cape Canaveral Air Force Station on a Delta 7925-H rocket. On April 10, 2007, *Dawn* arrived at the Astrotech Space Operations subsidiary of SPACEHAB, Inc. in Titusville, Florida, where it was prepared for launch. Launch was originally scheduled for June 20, but was delayed until June 30 due to delays with part deliveries. A broken crane at the launch pad, used to raise the solid rocket boosters, delayed the launch for a week, until July 7, but on June 15 the second stage was successfully hoisted into position. A mishap at the Astrotech Space Operations facility, involving slight damage to one of the solar arrays, did not have an effect on the launch date; however, bad weather caused the launch to slip to July 8. Range tracking problems then delayed the launch to July 9, and then July 15, before the launch

was delayed further to avoid knock-on delays with the Phoenix mission to Mars, which was successfully launched on August 4.



A Delta II launching *Dawn* from CCAFS SLC-17

Launch of *Dawn* was then rescheduled for September 26, 2007, then September 27, due to bad weather delaying fueling of the second stage, the same problem which had earlier delayed the July 7 launch attempt. The launch window extended from 07:20 – 07:49 EDT (11:20 – 11:49 GMT). During the final built-in hold at T-4 minutes, a ship entered the exclusion area offshore, the sea strip where the rocket boosters were likely to fall after separation. The ship was commanded to leave the area, then the launch had to wait for the end of a collision avoidance window with the International Space Station. The spacecraft launched at 07:34 EDT from pad 17-B on a Delta II launch vehicle.

The launch rocket propelled *Dawn* to 11.46 kilometers per second (25,600 miles per hour) relative to earth. Thereafter *Dawn's* ion thrusters took over.

Status

After initial checkout, during which the ion thrusters accumulated more than 11 days of thrust, *Dawn* began long-term cruise propulsion on December 17, 2007. On October 31, 2008, *Dawn* completed its first thrusting phase to send it on to Mars for a gravity assist flyby in February 2009. During this first interplanetary cruise phase *Dawn* spent 270 days, or 85% of this phase using its thrusters. It expended less than 72 kilograms (158 pounds) of xenon propellant for a total change in velocity of 1.81 kilometers per second (4050 miles per hour). On November 20, 2008, *Dawn* performed its first trajectory correction maneuver (TCM1), firing its number 1 thruster for 2 hours, 11 minutes. Following *Dawn's* solar conjunction, an originally scheduled course correction maneuver in January 2009 was determined not necessary.

Dawn made its closest approach (549 km) to Mars on February 17, 2009 during a successful gravity assist. On this day the spacecraft placed itself in safe mode resulting in some data acquisition loss. The spacecraft was reported to be back in full operation two days later with no impact to the subsequent mission. The root cause of the event was reported to be a software programming error.

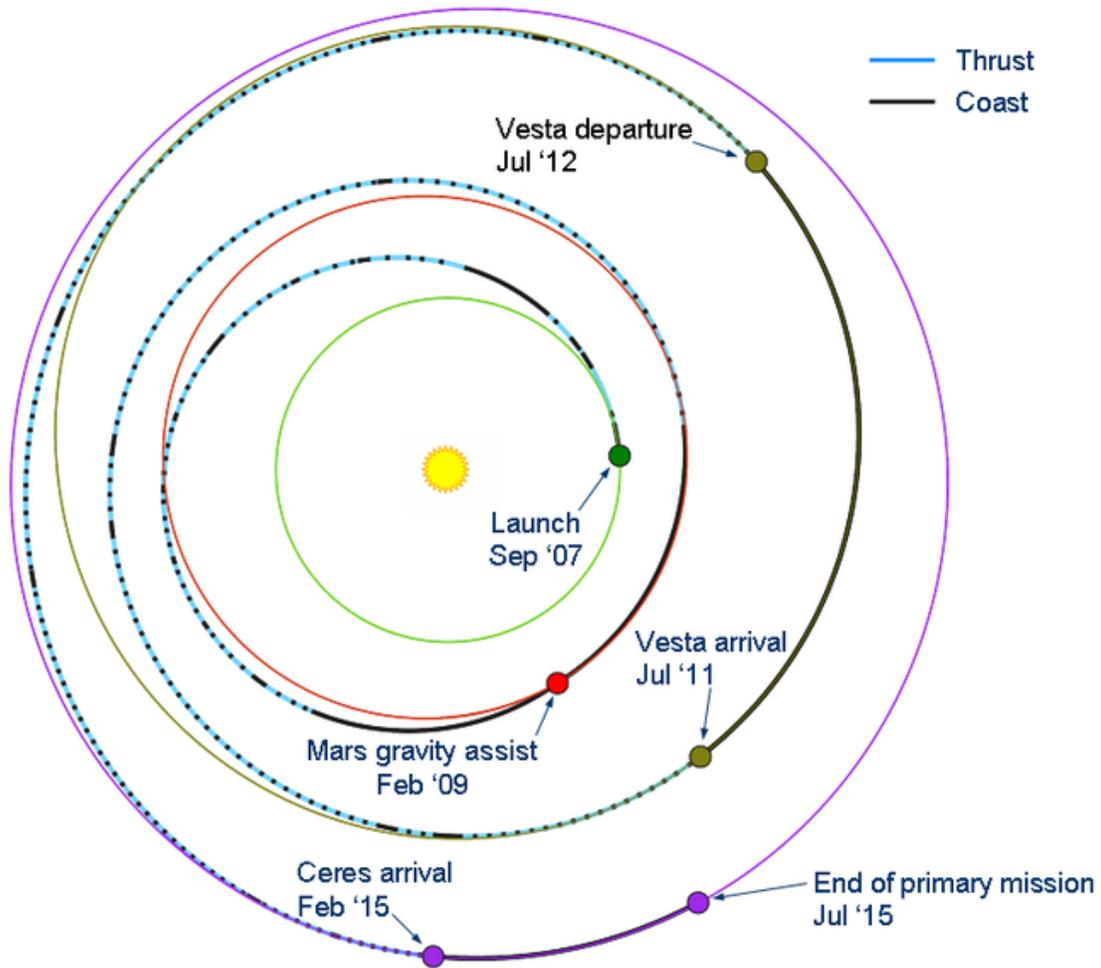
Mission



Dawn mission patch

The mission's goal is to characterize the conditions and processes of the solar system's earliest epoch by investigating in detail two of the largest protoplanets remaining intact since their formation. Ceres and Vesta have many contrasting characteristics that are thought to have resulted from them forming in two different regions of the early solar system; Peter Thomas of Cornell University has proposed that Ceres has a differentiated interior; its oblateness appears too small for an undifferentiated body, which indicates that it consists of a rocky core overlain with an icy mantle. There is a large collection of potential samples from Vesta accessible to scientists, in the form of over 200 HED meteorites, giving insight into Vestian geologic history and structure. Vesta is thought to consist of a metallic iron–nickel core, an overlying rocky olivine mantle, with a surface crust.

Using two redundant framing cameras, a visual and infrared spectrometer, and a Gamma Ray and Neutron Spectrometer, *Dawn* will take pictures and measure the chemical composition of Ceres and Vesta.



Planned flight trajectory

To cruise from Earth to its targets it will travel in a long outward spiral. The estimated chronology is as follows:

- September 27, 2007: launch
- February 17, 2009: Mars gravity assist
- July 2011: Vesta arrival
- July 2012: Vesta departure
- February 2015: Ceres arrival
- July 2015: End of primary operations

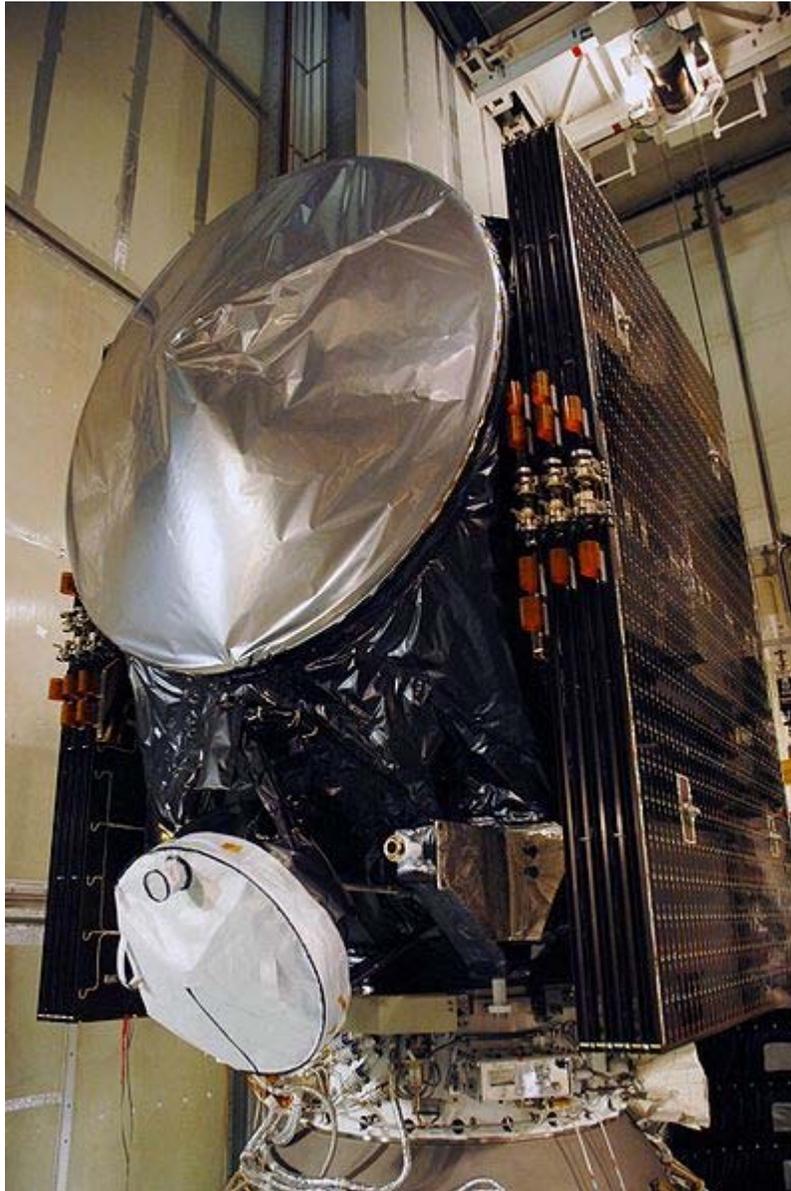
NASA posts the current location of *Dawn* on the web.

An extended mission following the completion of the Ceres study is also possible, although unlikely, as greater return is expected by spending the available time at Vesta and Ceres. Although 2 Pallas would have been a feasible extended target for the originally scheduled launch date, launch delays have meant that this may no longer be the case. Fuel was also not specifically allocated to break orbit from Ceres, and will depend upon the details of the flight reaching Ceres.

Mission team

The *Dawn* mission team is led by UCLA space scientist and *Dawn* Principal Investigator Christopher T. Russell. NASA's Jet Propulsion Laboratory provided overall planning and management of the mission, the flight system and scientific payload development, and provided the Ion Propulsion System. Orbital Sciences Corporation provided the spacecraft, which constituted the company's first interplanetary mission. The Max Planck Institute for Solar System Research and the German Aerospace Center (DLR) provided the framing cameras, the Italian Space Agency provided the mapping spectrometer, and the DOE Los Alamos National Laboratory provided the gamma ray and neutron spectrometer.

Motivation



Dawn waits for encapsulation at its launch pad on July 1, 2007

Dawn is intended to study two large bodies in the asteroid belt in order to answer questions about the formation of the solar system.

Ceres and Vesta were chosen as two contrasting protoplanets, the first one apparently "wet" (that is, icy) and the other "dry" (or rocky), whose accretion was terminated by the formation of Jupiter. They provide a bridge in our understanding between the formation of rocky planets and the icy bodies of our solar system, and under what conditions a rocky planet can hold water.

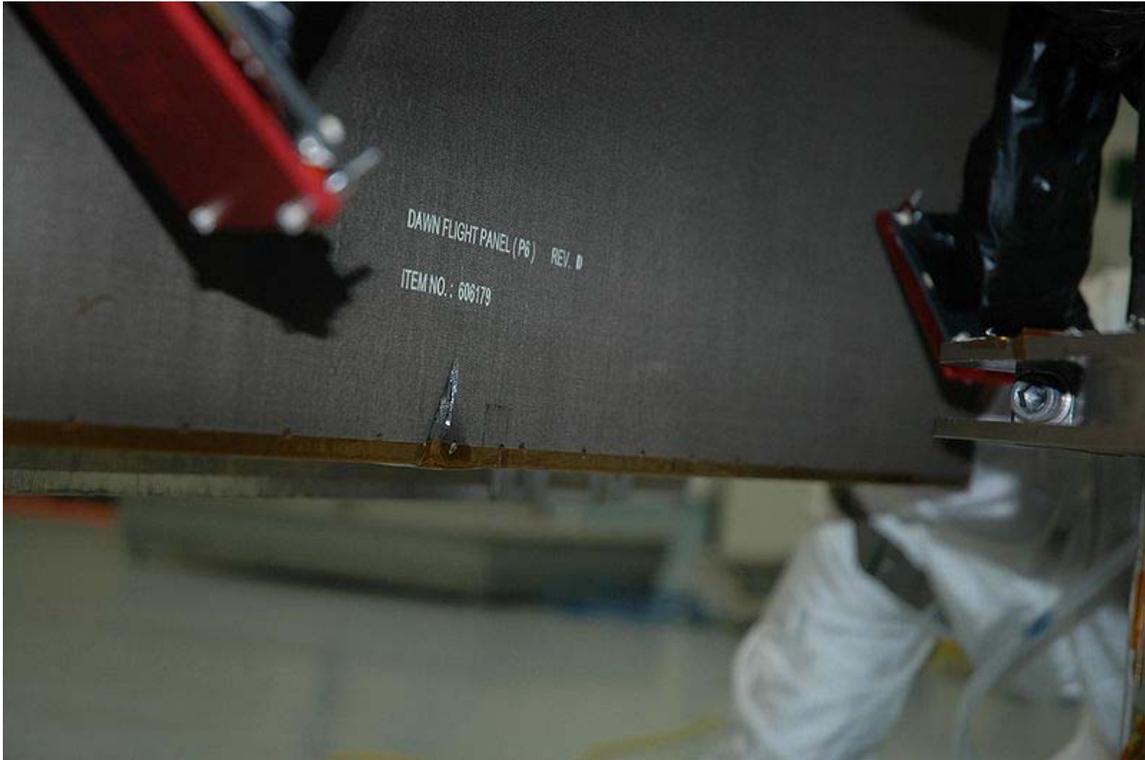
The IAU adopted a new definition of planet on August 24, 2006, and thus, if the IAU's definition stands and the spacecraft experiences no delays, *Dawn* will become the first mission to study a dwarf planet, arriving at Ceres five months prior to the arrival of *New Horizons* at Pluto.

Ceres is a dwarf planet whose mass comprises about one-third of the total mass of the bodies in the asteroid belt and whose spectral characteristics suggest a composition similar to that of a water-rich carbonaceous chondrite. Smaller Vesta, a water-poor achondritic asteroid, has experienced significant heating and differentiation. It shows signs of a metallic core, a Mars-like density and lunar-like basaltic flows.

Both bodies formed very early in the history of the solar system, thereby retaining a record of events and processes from the time of the formation of the terrestrial planets. Radionuclide dating of pieces of meteorites thought to come from Vesta suggests that Vesta differentiated quickly, in only three million years. Thermal evolution studies suggest that Ceres must have formed a little later, more than three million years after the formation of CAIs (the oldest known objects of Solar System origin).

Moreover, Vesta is the source of many smaller objects in the solar system. Most (but not all) V-type near-Earth asteroids, and some outer main-belt asteroids have spectra similar to Vesta and are known as *vestoids*. Five percent of the found meteoritic samples on Earth, the Howardite Eucrite Diogenite ("HED") meteorites, are thought to be the result of a collision or collisions with Vesta.

Mission cancellations and reinstatements



The slightly damaged solar array (NASA)

The status of the *Dawn* mission has changed several times. In December 2003, the project was first cancelled, and then reinstated in February 2004. In October 2005, work on *Dawn* was placed in "stand down" mode. In January 2006, *Dawn's* "stand down" was discussed in the press as "indefinitely postponed", even though NASA had announced no new decisions regarding the mission's status. On March 2, 2006, *Dawn* was publicly, but not formally canceled by NASA headquarters.

The spacecraft's manufacturer Orbital Sciences Corporation appealed the decision and offered to build the spacecraft at cost, forgoing any profit in order to gain experience in a new market field. NASA then put the cancellation under review, and on March 27, 2006, it was announced that the mission would not be canceled after all. In the last week of September 2006, the *Dawn* mission instrument payload integration reached a full functional status.

Propulsion system

The *Dawn* spacecraft is propelled by three DS1 heritage xenon ion thrusters (firing only one at a time). They have a specific impulse of 3,100 s and produce a thrust of 90 mN. The whole spacecraft, including the ion propulsion thrusters, is powered by a 10 kW triple-junction photovoltaic solar array. To get to Vesta, *Dawn* is allocated 275 kg (606 lb) Xe, with another 110 kg (243 lb) to reach Ceres, out of a total capacity of 425 kg

(937 pounds) of on-board propellant. All in all, it will perform a velocity change of over 10 km/s, far more than any other spacecraft has done after being propelled by its launch rocket. *Dawn* is NASA's first purely exploratory mission to use ion propulsion engines.

The *Dawn* microchip

Onboard *Dawn* is a small computer microchip bearing the names of more than 360,000 space enthusiasts. The names were submitted online as part of a public outreach effort between September 2005 and November 4, 2006. The microchip (about the size of a nickel) was installed above the forward ion thruster, underneath the spacecraft's High Gain Antenna, on May 17, 2007. More than one microchip was made, with a back-up copy on display at the *2007 Open House* at the Jet Propulsion Laboratory in Pasadena, California.

Chapter- 3

Mariner 4

Mariner 4



Operator	NASA
Mission type	Flyby
Flyby of	Mars
Launch date	November 28, 1964 at 14:22:01 UTC
Launch vehicle	Atlas-Agena D launch vehicle
Mission duration	November 28, 1964 to December 21, 1967
COSPAR ID	1964-077A
Mass	260.68 kg
Power	170 W

Orbital elements

Semimajor axis	199,591,220 km
Eccentricity	0.17024754

Inclination	2.51
Apoapsis	233,571,130 km
Periapsis	165,611,300 km
Orbital period	562.888

Mariner 4 (together with Mariner 3 known as **Mariner-Mars 1964**) was the fourth in a series of spacecraft, launched on November 28, 1964, intended for planetary exploration in a flyby mode and performed the first successful flyby of the planet Mars, returning the first pictures of the Martian surface. It captured the first images of another planet ever returned from deep space; their depiction of a cratered, seemingly dead world largely changed the view of the scientific community on life on Mars. Mariner 4 was designed to conduct closeup scientific observations of Mars and to transmit these observations to Earth. Other mission objectives were to perform field and particle measurements in interplanetary space in the vicinity of Mars and to provide experience in and knowledge of the engineering capabilities for interplanetary flights of long duration. On December 21, 1967 communications with Mariner 4 were terminated.

Spacecraft and subsystems

The Mariner 4 spacecraft consisted of an octagonal magnesium frame, 1270 mm across a diagonal and 457 mm high. Four solar panels were attached to the top of the frame with an end-to-end span of 6.88 meters, including solar pressure vanes which extended from the ends. A 1,168 mm diameter high-gain parabolic antenna was mounted at the top of the frame as well. An omnidirectional low-gain antenna was mounted on a seven foot, four inch (2235 mm) tall mast next to the high-gain antenna. The overall height of the spacecraft was 2.89 meters. The octagonal frame housed the electronic equipment, cabling, midcourse propulsion system, and attitude control gas supplies and regulators.

Scientific instruments included:

- A helium magnetometer, mounted on the waveguide leading to the omnidirectional antenna, to measure the magnitude and other characteristics of the interplanetary and planetary magnetic fields.
- An ionization chamber/Geiger counter, mounted on the waveguide leading to the omnidirectional antenna nearer the body of the spacecraft, to measure the charged-particle intensity and distribution in interplanetary space and in the vicinity of Mars.
- A trapped radiation detector, mounted on the body with counter-axes pointing 70° and 135° from the solar direction, to measure the intensity and direction of low-energy particles.
- A cosmic ray telescope, mounted inside the body pointing in anti-solar direction, to measure the direction and energy spectrum of protons and alpha particles.

- A solar plasma probe, mounted on the body pointing 10° from the solar direction, to measure the very low energy charged particle flux from the Sun.
- A cosmic dust detector, mounted on the body with microphone plate approximately perpendicular to the plane of orbit, to measure the momentum, distribution, density, and direction of cosmic dust.
- A television camera, mounted on a scan platform at the bottom center of the spacecraft, to obtain closeup pictures of the surface of Mars.

The electrical power for the instruments and the radio transmitter of Mariner 4 was supplied by 28,224 solar cells contained in the four 176 x 90 cm solar panels, which could provide 310 watts at the distance of Mars. A rechargeable 1200 W·h silver-zinc battery was also used for maneuvers and backup. Monopropellant hydrazine was used for propulsion, via a four-jet vane vector control motor, with 222-newton (50 lbf) thrust, installed on one of the sides of the octagonal structure. The space probe's attitude control was provided by 12 cold nitrogen gas jets mounted on the ends of the solar panels and three gyros. Solar pressure vanes, each with an area of 0.65 square meter (seven ft²), were attached to the tips of the solar panels. Positional information was provided by four Sun sensors, and a sensor for either the Earth, Mars, or the star Canopus, depending on the time in its spaceflight. Mariner 4 was the first space probe that needed a star for a navigational reference object, since earlier missions, which remained near either the Earth, the Moon, or the planet Venus, had sighted onto either the bright face of the home planet or the brightly lit target. During this flight, both the Earth and Mars would be too dim to lock onto. Another bright source at a wide angle away from the Sun was needed and Canopus filled this requirement. Subsequently, Canopus was used as a reference point in many following missions.

The telecommunications equipment on Mariner 4 consisted of dual S-band transmitters (with either a seven-watt triode cavity amplifier or a ten watt traveling-wave tube amplifier) and a single radio receiver which together could send and receive data via the low- and high-gain antennas at 8¹/₃ or 33¹/₃ bits per second. Data could also be stored onto a magnetic tape recorder with a capacity of 5.24 million bits for later transmission. All electronic operations were controlled by a command subsystem which could process any of 29 direct command words or three quantitative word commands for mid-course maneuvers. The central computer and sequencer operated stored time-sequence commands using a 38.4 kHz synchronization frequency as a time reference. Temperature control was achieved through the use of adjustable louvers mounted on six of the electronics assemblies, plus multilayer insulating blankets, polished aluminum shields, and surface treatments. Other measurements that could be made included:

- Radio signal occultation
- Celestial mechanics based on precision tracking

Mission profile



Launch of Mariner 4

Launch

After launch from Cape Canaveral Air Force Station Launch Complex 12 the protective shroud covering Mariner 4 was jettisoned and the Agena D/Mariner 4 combination separated from the Atlas D booster at 14:27:23 UTC on November 28, 1964. The Agena D's first burn took place from 14:28:14 to 14:30:38. The initial burn put the spacecraft into an Earth parking orbit and the second burn from 15:02:53 to 15:04:28 injected the craft into a Mars transfer orbit. Mariner 4 separated from the Agena D at 15:07:09 and began cruise mode operations. The solar panels deployed and the scan platform was unlatched at 15:15:00 and Sun acquisition occurred 16 minutes later.

Lock on Canopus

After Sun acquisition, the Canopus star tracker went searching for Canopus. The star tracker was set to respond to any object more than one-eighth as, and less than eight times as bright as Canopus. Including Canopus, there were seven such objects visible to the sensor. It took more than a day of "star-hopping" to find Canopus, as the sensor

locked on to other stars instead: a stray light pattern from the near Earth, Alderamin, Regulus, Naos, and Gamma Velorum were acquired before Canopus.

During the early part of the mission, roll error signal transients occurred frequently, making the spacecraft lose its lock on Canopus. The lock was lost six times in less than three weeks, each time requiring radio commands to reacquire the lock. Analysis concluded that it was probably due to small dust particles that scattered sunlight at the same brightness as Canopus. If the brightness of the object exceeded the maximum limit of eight times the brightness of Canopus, the spacecraft would search for a new star. A radio command was sent on December 17, 1964 to remove this limit; the limit was initially implemented to prevent a lock on Earth, but no longer necessary. No further loss of the Canopus lock was experienced, although roll transients occurred 38 more times before the encounter with Mars.

Midcourse maneuver

The 7½ months of flight of Mariner 4 involved one midcourse maneuver on December 5, 1964. The maneuver was initially scheduled for December 4, but due to a loss of lock with Canopus, it was postponed. The maneuver was successfully completed on December 5; it consisted of a negative pitch turn of 39.16 degrees, a positive roll turn of 156.08 degrees, and a thrusting time of 20.07 seconds. The turns aimed the motor of the spacecraft back in the general direction of Earth, as the motor was initially pointed along the direction of flight. Both the pitch and roll changes were completed with better than 1% accuracy, the velocity change with about 2½% accuracy. After the maneuver, Mariner 4 was on course for Mars as planned.

Mars flyby

The spacecraft flew by Mars on July 14 and July 15, 1965. Planetary science mode was turned on at 15:41:49 UT on July 14. The camera sequence started at 00:18:36 UT on July 15 (7:18:49 p.m. EST on July 14) and 21 pictures using alternate red and green filters, plus 21 lines of a 22nd picture were taken. The images covered a discontinuous swath of Mars starting near 40° N, 170° E, down to about 35° S, 200° E, and then across to the terminator at 50° S, 255° E, representing about 1% of the planet's surface. The closest approach was 9,846 km from the Martian surface at 01:00:57 UT July 15, 1965 (8:00:57 p.m. EST July 14). The images taken during the flyby were stored in the on-board tape recorder. At 02:19:11 UT Mariner 4 passed behind Mars as seen from Earth and the radio signal ceased. The signal was reacquired at 03:13:04 UT when the spacecraft reappeared. Cruise mode was then re-established. Transmission of the taped images to Earth began about 8.5 hours after signal reacquisition and continued until August 3. All images were transmitted twice to ensure no data was missing or corrupt.

The spacecraft performed all programmed activities successfully and returned useful data from launch until 22:05:07 UT on October 1, 1965, when the distance from Earth (309.2 million km) and the antenna orientation temporarily halted signal acquisition.

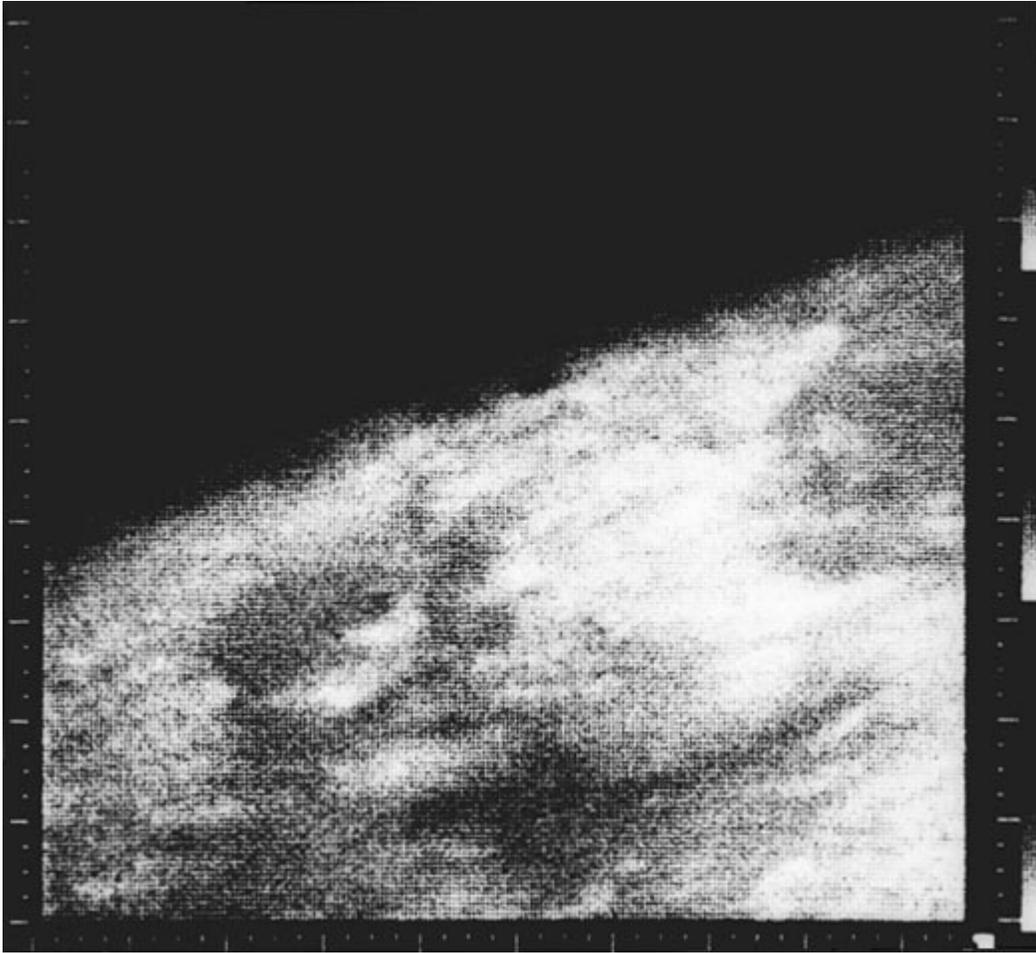
Micrometeoroid hits and end of communications

Data acquisition resumed in late 1967. The cosmic dust detector registered 17 hits in a 15 minute span on September 15, part of an apparent micrometeoroid shower which temporarily changed the spacecraft attitude and probably slightly damaged the thermal shield. Later it was speculated that the probe passed through the debris of Comet D/Swift, and even made a close flyby of that comet's possibly shattered nucleus at only 20 million kilometers.

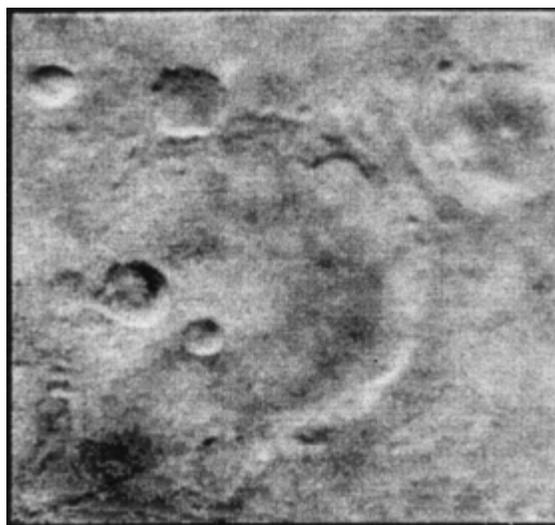
On December 7 the gas supply in the attitude control system was exhausted, and on December 10 and 11 a total of 83 micrometeoroid hits were recorded which caused perturbation of the attitude and degradation of the signal strength. On December 21, 1967 communications with Mariner 4 were terminated. The spacecraft is currently in an exterior heliocentric orbit.

Results

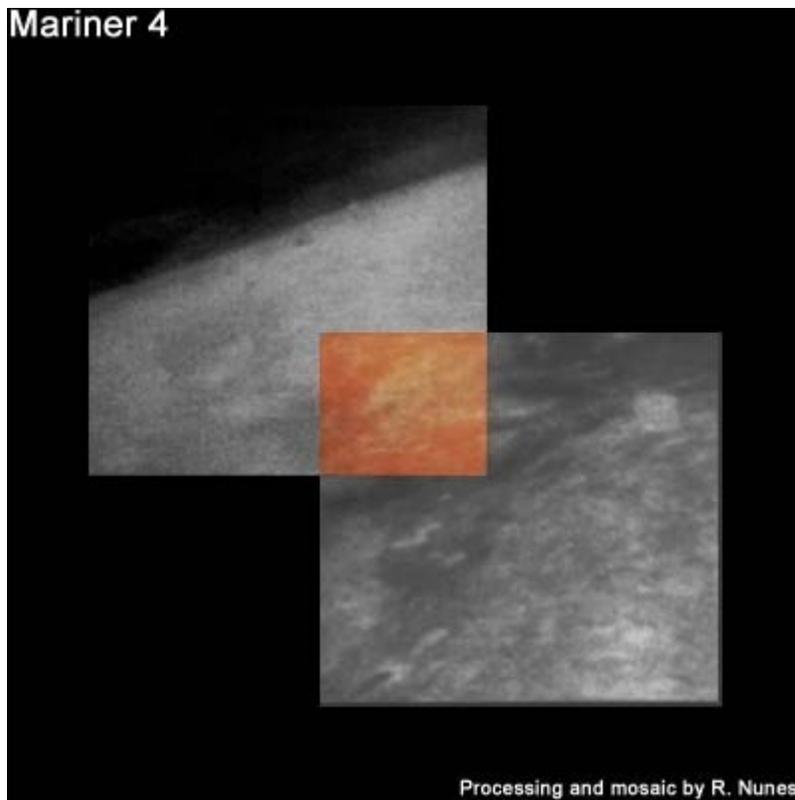
The total data returned by the mission was 5.2 million bits (about 634 kB). All instruments operated successfully with the exception of a part of the ionization chamber, namely the Geiger-Müller tube, which failed in February 1965. Also, the plasma probe had its performance degraded by a resistor failure on December 8, 1964, but by taking this failure into account, experimenters were able to recalibrate the instrument and still interpret the data. The images returned showed a Moon-like cratered terrain, which later missions showed was not typical for Mars, but only for the more ancient region imaged by Mariner 4. A surface atmospheric pressure of 4.1 to 7.0 millibars (410 to 700 pascals) and daytime temperatures of -100 degrees Celsius were estimated. No magnetic field or Martian radiation belts were detected.



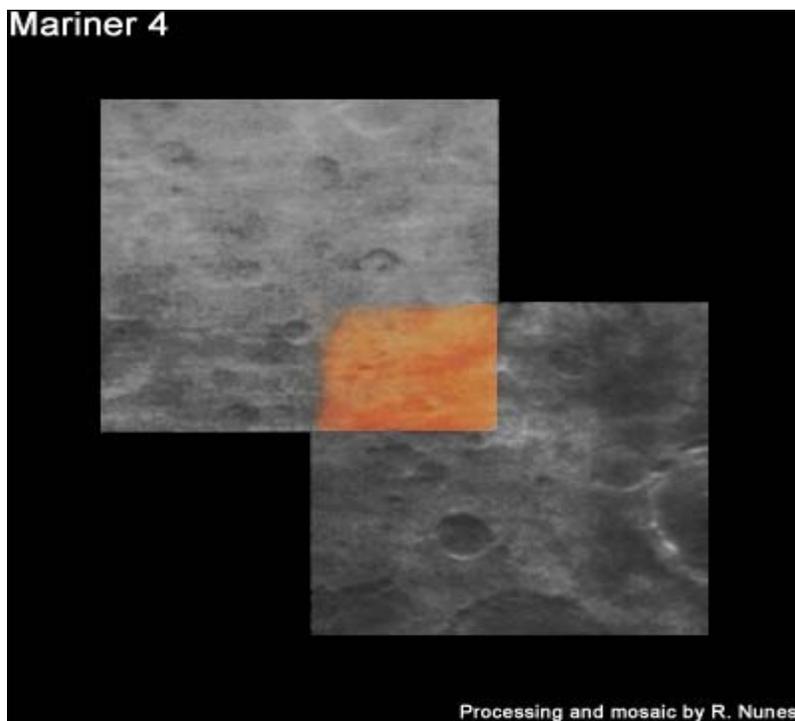
The first close-up image ever taken of Mars, this photo shows an area about 330 km across by 1200 km from limb to bottom of frame.



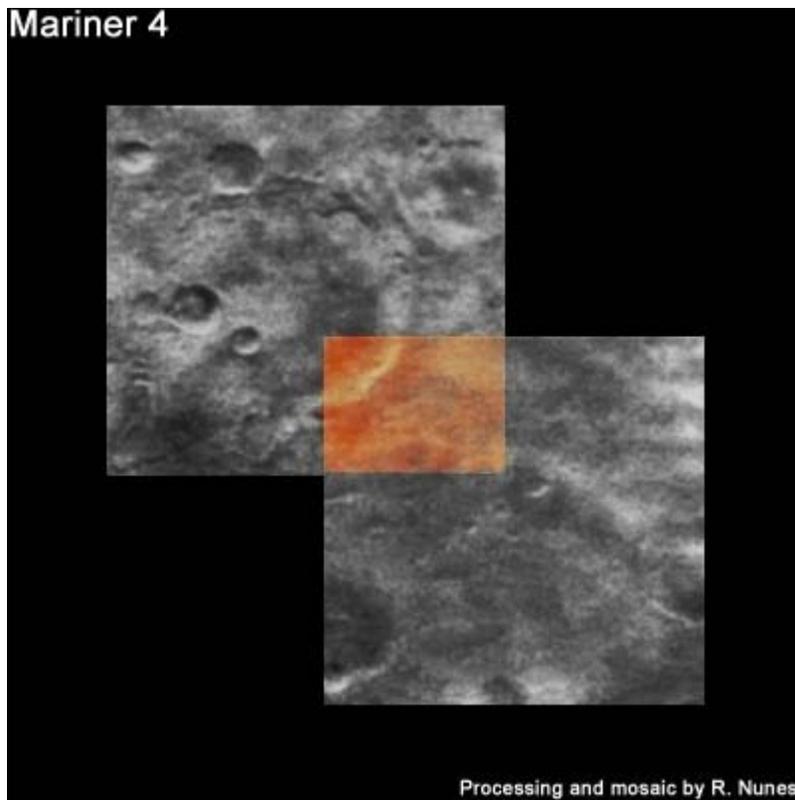
The clearest Mariner 4 image, showing craters.



Mosaic of frame 1&2. The Martian atmosphere is visible over the planet's limb.



Mosaic of frame 9&10.



Mosaic of frame 11&12.

Images of craters and measurements of a thin atmosphere, indicating a relatively inactive planet exposed to the harshness of space, generally dissipated hopes of finding intelligent life on Mars. Life on Mars had been the subject of speculation and science fiction for centuries. If there was life on Mars, after Mariner 4 most concluded it would probably be smaller, simpler forms. Others concluded that a search for life on Earth at kilometer resolution, using several thousand photographs, did not reveal a sign of life on the vast majority of these photographs; thus, based on the 22 photographs taken by Mariner 4, one could not conclude there was no intelligent life on Mars.

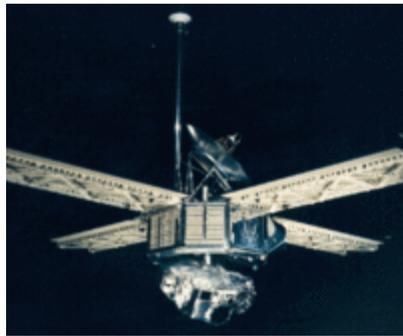
Mariner 4 may have concluded the gradual change, in science fiction, from describing intelligent aliens as dwellers on other planets in our Solar System, to describing them as living on planets circling distant stars.

The total cost of the Mariner 4 mission is estimated at \$83.2 million. Total research, development, launch, and support costs for the Mariner series of spacecraft (Mariners 1 through 10) was approximately \$554 million.

Chapter- 4

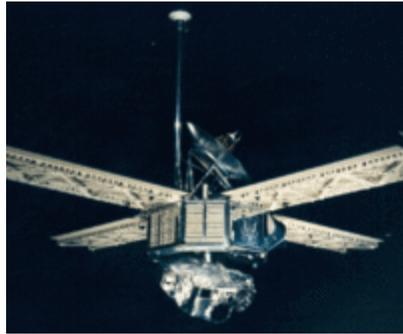
Mariner 6 and 7

Mariner 6



Operator	NASA
Mission type	Flyby
Flyby of	Mars
Launch date	February 24, 1969 at 01:29:02 UTC
Launch vehicle	Atlas-Centaur SLV-3C launch vehicle
COSPAR ID	1969-014A
Mass	411.8 kg
Power	449 W

Mariner 7



Operator	NASA
Mission type	Flyby
Flyby of	Mars
Launch date	March 27, 1969 at 22:22:01 UTC
Launch vehicle	Atlas-Centaur SLV-3C launch vehicle
COSPAR ID	1969-030A
Mass	411.8 kg
Power	449 W

As part of NASA's wider Mariner program, **Mariner 6 and Mariner 7** (Mariner Mars 69A / 69B) completed the first dual mission to Mars in 1969. Mariner 6 was launched from Launch Complex 36B at Cape Kennedy and Mariner 7 from Launch Complex 36A at Cape Kennedy. The craft flew over the equator and south polar regions, analyzing the atmosphere and the surface with remote sensors, and recording and relaying hundreds of pictures. The mission's goals were to study the surface and atmosphere of Mars during close flybys, in order to establish the basis for future investigations, particularly those relevant to the search for extraterrestrial life, and to demonstrate and develop technologies required for future Mars missions. Mariner 6 also had the objective of providing experience and data which would be useful in programming the Mariner 7 encounter 5 days later.

On July 29, 1969, less than a week before closest approach, NASA Jet Propulsion Laboratory lost contact with Mariner 7. The center regained the signal via the backup low-gain antenna and were able to start using the high gain antenna again shortly after Mariner 6's close encounter. It was later determined a battery onboard Mariner 7 had exploded. Based on the observations made by Mariner 6, Mariner 7 was reprogrammed in flight to take further observations of areas of interest and actually returned more pictures than Mariner 6, despite the explosion.

By chance, both flew over cratered regions and missed both the giant northern volcanoes and the equatorial grand canyon discovered later. Their approach pictures did, however, photograph about 20 percent of the planet's surface, showing the dark features long seen from Earth, but none of the canals mistakenly observed by ground-based astronomers. In total 198 photos were taken and transmitted back to Earth, adding more detail than the earlier mission, Mariner 4. Both craft also studied the atmosphere of Mars.

Closest approach for Mariner 6 occurred July 31, 1969, at 05:19:07 UT at a distance of 3,431 kilometres (2,132 mi) above the martian surface. Closest approach for Mariner 7 occurred August 5, 1969 at 05:00:49 UT at a distance of 3,430 kilometres (2,130 mi) above the martian surface.

The ultraviolet spectrometer onboard Mariners 6 and 7 was constructed by the Laboratory for Atmospheric and Space Physics.

The engineering model of Mariners 6 and 7 still exists, and is owned by the Jet Propulsion Laboratory. It is currently on loan to the Laboratory for Atmospheric and Space Physics, and is on display in the lab's lobby.

The craft are now defunct in heliocentric orbits.

Spacecraft and subsystems

The Mariner 6 and 7 spacecraft were identical, consisting of an octagonal magnesium frame base, 138.4 cm (54.5 in) diagonally and 45.7 cm (18.0 in) deep. A conical superstructure mounted on top of the frame held the high-gain 1 meter diameter parabolic antenna and four solar panels, each measuring 215 x 90 cm (35 in), were affixed to the top corners of the frame. The tip-to-tip span of the deployed solar panels was 5.79 m. A low-gain omnidirectional antenna was mounted on a 2.23 m high mast next to the high-gain antenna. Underneath the octagonal frame was a two-axis scan platform which held scientific instruments. Overall science instrument mass was 57.6 kg (127 lb). The total height of the spacecraft was 3.35 m.

The spacecraft was attitude stabilized in three axes, referenced to the sun and the star Canopus. It utilized 3 gyros, 2 sets of 6 nitrogen jets, which were mounted on the ends of the solar panels, a Canopus tracker, and two primary and four secondary sun sensors. Propulsion was provided by a 223-newton rocket motor, mounted within the frame, which used the mono-propellant hydrazine. The nozzle, with 4-jet vane vector control, protruded from one wall of the octagonal structure. Power was supplied by 17,472 photovoltaic cells, covering an area of 7.7 square meters (83 sq ft) on the four solar panels. These could provide 800 watts of power near Earth, and 449 watts while orbiting Mars. The maximum power requirement was 380 watts, once Mars was reached. A 1200 watt-hour, rechargeable, silver-zinc battery was used to provide backup power. Thermal control was achieved through the use of adjustable louvers on the sides of the main compartment.

Three telemetry channels were available for telecommunications. Channel A carried engineering data at $8\frac{1}{3}$ or $33\frac{1}{3}$ bit/s, channel B carried scientific data at $66\frac{2}{3}$ or 270 bit/s and channel C carried science data at 16,200 bit/s. Communications were accomplished through the high- and low-gain antennas, via dual S-band traveling wave tube amplifiers, operating at 10 or 20 watts, for transmission. The design also included a single receiver. An analog tape recorder, with a capacity of 195 million bits, could store television images for subsequent transmission. Other science data was stored on a digital recorder. The command system, consisting of a central computer and sequencer (CC&S), was designed to actuate specific events at precise times. The CC&S was programmed with both a standard mission and a conservative backup mission before launch, but could be commanded and reprogrammed in flight. It could perform 53 direct commands, 5 control commands, and 4 quantitative commands.

Instrumentation:

1. IR Spectrometer
2. Two-Channel IR Radiometer Mars Surface Temperature
3. UV Spectrometer
4. S-Band Occultation
5. Thermal Control Flux Monitor (Conical Radiometer)
6. Mars TV Camera
7. Celestial Mechanics
8. General Relativity

Chapter- 5

Mars 2 & Mars 3

Mars 2

Mars 2

Operator	USSR
Mission type	Orbiter and lander
Orbital insertion date	November 27, 1971
Orbits	362
Launch date	1971-05-19 at 16:22:44 UTC
Launch vehicle	Proton K with Blok D
Mission duration	22 August 1972
COSPAR ID	1971-045A
Mass	4650 kg

Orbital elements

Eccentricity	.71178
Inclination	48.9°
Apoapsis	24940 km
Periapsis	1380 km
Orbital period	17.96 h

The **Mars program** was a series of Mars unmanned landers and orbiters launched by the Soviet Union in the early 1970s.

The Mars 2 and Mars 3 missions consisted of identical spacecraft, each with an orbiter and an attached lander; they were the first human artifacts to impact the surface of Mars. They were launched by Proton K heavy launch vehicle with a Block D upper stage.

- Launch Date/Time:
 - Mars 2: 1971-05-19 at 16:22:44 UTC
- Launch mass (including fuel):
 - Combined: 4650 kg
 - Orbiter: 3440 kg
 - Lander: 1210 kg
- On-orbit dry mass: 2265 kg
- Dimensions: 4.1 meters tall, 2 meters across (5.9 meters across with solar panels deployed)

Orbiter

The orbiter engine performed a burn to put the spacecraft into a 1380 x 24,940 km, 18 hour orbit about Mars with an inclination of 48.9 degrees. Scientific instruments were generally turned on for about 30 minutes near periapsis

The orbiter primary scientific objectives were to image the Martian surface and clouds, determine the temperature on Mars, study the topography, composition and physical properties of the surface, measure properties of the atmosphere, monitor the solar wind and the interplanetary and Martian magnetic fields, and act as communications relays to send signals from the landers to Earth.

The Mars 2 orbiter sent back a large volume of data covering the period from December 1971 to March 1972, although transmissions continued through August. It was announced that Mars 2 had completed their mission by 22 August 1972, after 362 orbits. The probe, combined with Mars 3, sent back a total of 60 pictures. The images and data revealed mountains as high as 22 km, atomic hydrogen and oxygen in the upper atmosphere, surface temperatures ranging from -110 °C to +13 °C, surface pressures of 5.5 to 6 mbar (0.55 to 0.6 kPa), water vapor concentrations 5000 times less than in Earth's atmosphere, the base of the ionosphere starting at 80 to 110 km altitude, and grains from dust storms as high as 7 km in the atmosphere. The images and data enabled creation of surface relief maps, and gave information on Martian gravity and magnetic fields.

Lander

The lander crashed on the Martian surface and was lost.

The Mars 2 descent module was mounted on the bus/orbiter opposite the propulsion system. It consisted of a spherical 1.2 m diameter landing capsule, a 2.9 m diameter conical aerodynamic braking shield, a parachute system and retro-rockets.

The entire descent module had a fueled mass of 1210 kg, the spherical landing capsule accounting for 358 kg of this. An automatic control system consisting of gas micro-engines and pressurized nitrogen containers provided attitude control. Four "gunpowder" engines were mounted to the outer edge of the cone to control pitch and yaw.

The main and auxiliary parachutes, the engine to initiate the landing, and the radar altimeter were mounted on the top section of the lander. Foam was used to absorb shock within the descent module. The landing capsule had four triangular petals which would open after landing, righting the spacecraft and exposing the instrumentation.

The lander was equipped with two television cameras with a 360 degree view of the surface as well as a mass spectrometer to study atmospheric composition; temperature, pressure, and wind sensors; and devices to measure mechanical and chemical properties of the surface, including a mechanical scoop to search for organic materials and signs of life. It also contained a pennant with the Soviet coat of arms.

Four aerials protruded from the top of the sphere to provide communications with the orbiter via an onboard radio system. The equipment was powered by batteries which were charged by the orbiter prior to separation. Temperature control was maintained through thermal insulation and a system of radiators. The landing capsule was sterilized before launch to prevent contamination of the martian environment.

The descent module separated from the orbiter on 27 November 1971 about 4.5 hours before reaching Mars. After entering the atmosphere at approximately 6 km/s, the descent system on the module malfunctioned, possibly because the angle of entry was too steep. The descent sequence did not operate as planned and the parachute did not deploy. Mars 2 was the first manmade object to reach the surface of Mars. The landing site is unknown.

Prop-M Rover

Mars 2 lander had a small 4.5 kg Mars 'rover' on board, which would move across the surface on skis while connected to the lander with a 15-meter umbilical. Two small metal rods were used for autonomous obstacle avoidance, as radio signals from Earth would take too long to drive the rovers using remote control. The rover carried a dynamic penetrometer and a radiation densitometer.

The main PROP-M frame was a squat box with a small protrusion at the center. The frame was supported on two wide flat skis, one extending down from each side elevating the frame slightly above the surface. At the front of the box were obstacle detection bars.

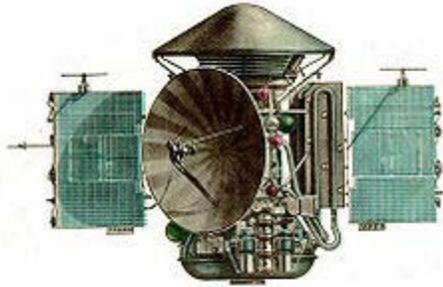
The rover was planned to be placed on the surface after landing by a manipulator arm and to move in the field of view of the television cameras and stop to make measurements

every 1.5 meters. The traces of movement in the martian soil would also be recorded to determine material properties.

Because of the demise of the lander, the rover never saw action.

Mars 3

Mars 3 Orbiter



Mars 3 Orbiter

Operator	USSR
Mission type	Orbiter
Satellite of	Mars
Orbital insertion date	December 2, 1971
Launch date	May 28, 1971 at 15:26:30 UTC
Launch vehicle	Proton-K with Blok D
Mission duration	May 28, 1971 to August 22, 1972
COSPAR ID	1971-049A
Mass	2265 kg

Orbital elements

Eccentricity	.95548
Inclination	60°
Apoapsis	211400 km
Periapsis	1500 km
Orbital period	12.79 d

Mars 3 Lander

Operator	USSR
Mission type	Lander
Launch date	May 28, 1971 at 15:26:30 UTC
Launch vehicle	Proton-K with Blok D
Mission duration	December 2, 1971
COSPAR ID	1971-049F
Mass	358 kg

The **Mars program** was a series of Mars unmanned landers and orbiters launched by the Soviet Union in the early 1970s.

The Mars 2 and Mars 3 missions consisted of identical spacecraft, each with an orbiter and an attached lander. Although Mars 2 crashed, the Mars 3 mission was the first spacecraft to touch down on Mars. They were launched by Proton-K rockets with Blok D upper stages.

- Launch Date/Time:
 - Mars 3: May 28, 1971 at 15:26:30 UTC
- Launch mass (including fuel):
 - Combined: 4650 kg
 - Orbiter: 3440 kg
 - Lander: 1210 kg
- On-orbit dry mass: 2265 kg
- Dimensions: 4.1 meters tall, 2 meters across (5.9 meters across with solar panels deployed)

Orbiter

The orbiter suffered from a partial loss of fuel and did not have enough to put itself into a planned 25 hour orbit. The engine instead performed a truncated burn to put the spacecraft into a long 12 day, 19 hour period orbit about Mars.

The orbiter primary scientific objectives were to image the Martian surface and clouds, determine the temperature on Mars, study the topography, composition and physical properties of the surface, measure properties of the atmosphere, monitor the solar wind and the interplanetary and Martian magnetic fields, and act as communications relays to send signals from the landers to Earth.

The Mars 3 orbiter sent back a large volume of data covering the period from December 1971 to March 1972, although transmissions continued through August. It was announced that Mars 3 had completed their mission by 22 August 1972, after 20 orbits. The probe, combined with Mars 2, sent back a total of 60 pictures. The images and data revealed mountains as high as 22 km, atomic hydrogen and oxygen in the upper atmosphere, surface temperatures ranging from -110 C to +13 C, surface pressures of 5.5 to 6 mb, water vapor concentrations 5000 times less than in Earth's atmosphere, the base of the ionosphere starting at 80 to 110 km altitude, and grains from dust storms as high as 7 km in the atmosphere. The images and data enabled creation of surface relief maps, and gave information on the Martian gravity and magnetic fields.

Lander

The Mars 3 descent module was mounted on the bus/orbiter opposite the propulsion system. It consisted of a spherical 1.2 m diameter landing capsule, a 2.9 m diameter conical aerodynamic braking shield, a parachute system and retro-rockets.

The entire descent module had a fueled mass of 1210 kg, the spherical landing capsule accounted for 358 kg of this. An automatic control system consisting of gas micro-engines and pressurized nitrogen containers provided attitude control. Four "gunpowder" engines were mounted to the outer edge of the cone to control pitch and yaw.

The main and auxiliary parachutes, the engine to initiate the landing, and the radar altimeter were mounted on the top section of the lander. Foam was used to absorb shock within the descent module. The landing capsule had four triangular petals which would open after landing, righting the spacecraft and exposing the instrumentation.

The lander was equipped with two television cameras with a 360 degree view of the surface as well as a mass spectrometer to study atmospheric composition; temperature, pressure, and wind sensors; and devices to measure mechanical and chemical properties of the surface, including a mechanical scoop to search for organic materials and signs of life. It also contained a pennant with the Soviet coat of arms.

Four aerials protruded from the top of the sphere to provide communications with the orbiter via an onboard radio system. The equipment was powered by batteries which were charged by the orbiter prior to separation. Temperature control was maintained through thermal insulation and a system of radiators. The landing capsule was sterilized before launch to prevent contamination of the martian environment.

Mars 3's descent module was released at 09:14 UT on December 2, 1971, 4 hours 35 minutes before reaching Mars. The descent module entered the Martian atmosphere at roughly 5.7 km/s.

Through aerodynamic braking, parachutes, and retrorockets, the lander achieved a soft landing at 45° S, 158° W and began operations.

After 14.5 seconds, at 13:52:25, transmission on both data channels stopped for unknown reasons and no further signals were received at Earth from the martian surface. It is not known whether the fault originated with the lander or the communications relay on the orbiter. A partial panoramic image returned showed no detail and a very low illumination of 50 lux. The cause of the failure may have been related to the extremely powerful martian dust storm taking place at the time which may have induced a coronal discharge, damaging the communications system. The dust storm would also explain the poor image lighting.

Prop-M Rover

Mars 3 lander had a small 4.5 kg Mars 'rover' on board, which was planned to move across the surface on skis while connected to the lander with a 15-meter umbilical. Two small metal rods were used for autonomous obstacle avoidance, as radio signals from Earth would take too long to drive the rovers using remote control. The rover carried a dynamic penetrometer and a radiation densitometer.

The main PROP-M frame was a squat box with a small protrusion at the center. The frame was supported on two wide flat skis, one extending down from each side elevating the frame slightly above the surface. At the front of the box were obstacle detection bars.

The rover was planned to be placed on the surface after landing by a manipulator arm and to move in the field of view of the television cameras and stop to make measurements every 1.5 meters. The traces of movement in the Martian soil would also be recorded to determine material properties.

Because of the demise of the lander, the rover was not deployed.

Chapter- 6

Mars Global Surveyor

Mars Global Surveyor



Artist's conception of Mars Global Surveyor

Operator NASA

Major contractors Orbiter

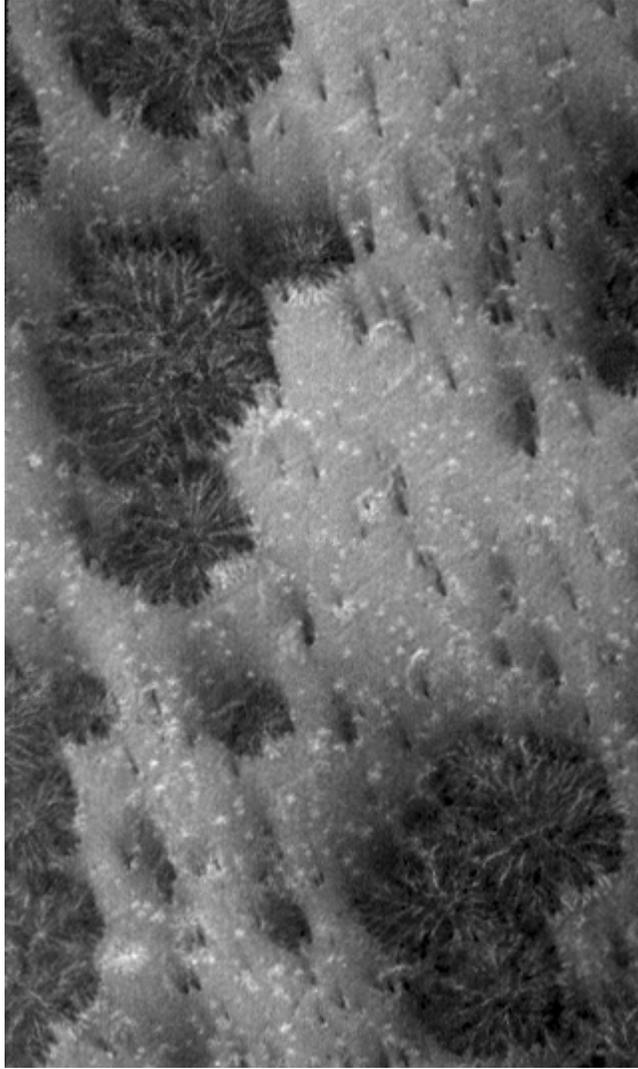
Satellite of	Mars
Orbital insertion date	1997-09-12 01:17:00 UTC
Launch date	1996-11-07 17:00:50 UTC (14 years, 3 months, and 14 days ago)
Launch vehicle	Delta 7925
Mission duration	April 1, 1999 - November 2, 2006 (lost communication) Primary mission <i>(completed 2001-01-31)</i> First extended mission <i>(completed 2002-01-31)</i> Second extended mission <i>(completed 2002-12-31)</i> Comm Relay mission <i>(completed 2006-09-30)</i> Relay extended mission <i>(completed 2006-11-02)</i>
COSPAR ID	1996-062A
Homepage	Mars Global Surveyor
Mass	1,030.5 kg (2,272 lb)
Power	980 W (Solar array / 2 NiH ₂ batteries)

Orbital elements

Eccentricity	.7126
Inclination	93°
Apoapsis	17,836 km (11,083 mi)
Periapsis	171.4 km (107 mi)
Orbital period	11.64 h



The *Mars Global Surveyor (MGS)* was a US spacecraft developed by NASA's Jet Propulsion Laboratory and launched November 1996. It began the United States's return to Mars after a 10-year absence. It completed its primary mission in January 2001 and was in its third extended mission phase when, on 2 November 2006, the spacecraft failed to respond to messages and commands. A faint signal was detected three days later which indicated that the craft had gone into safe mode. All attempts to recontact the Mars Global Surveyor and resolve the problem failed. In January 2007 NASA officially ended the mission.



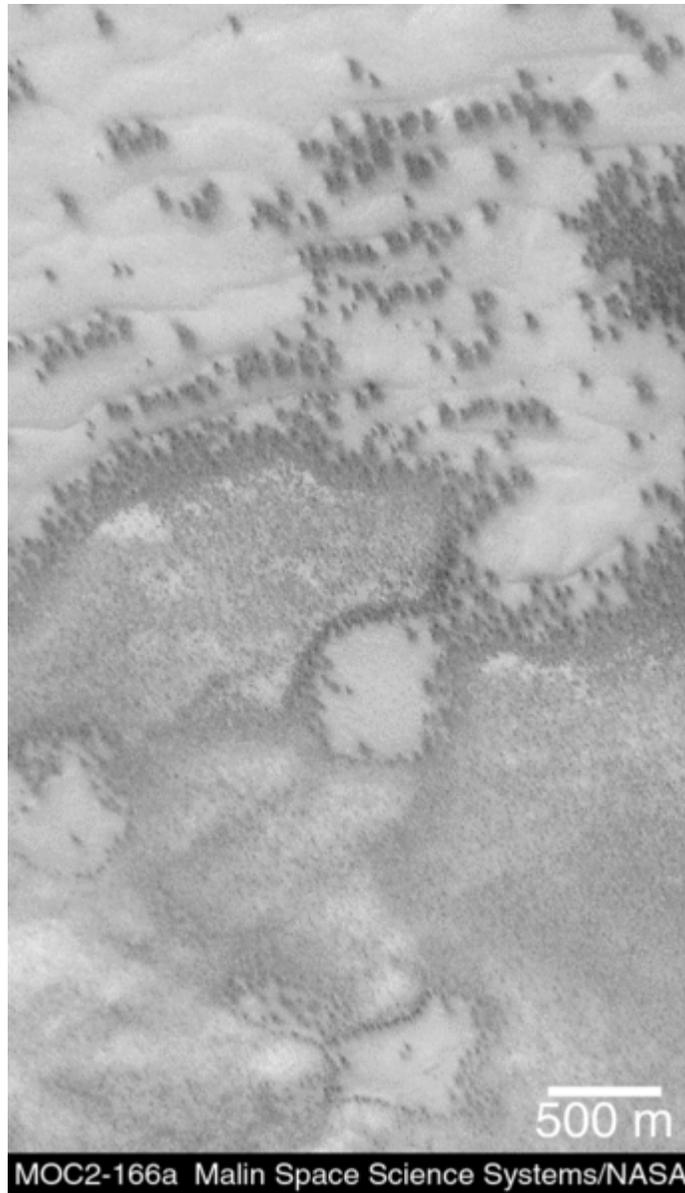
Surface of Mars taken by the Mars Global Surveyor and released on 16 October 2000.



Surface of Mars taken by the Mars Global Surveyor.



Surface of Mars taken by the Mars Global Surveyor.



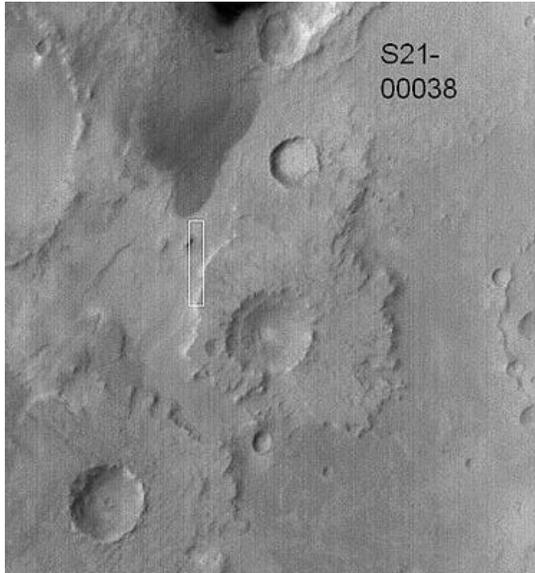
Surface of Mars taken by the Mars Global Surveyor on 10 August 1999.

Specifications

The *Surveyor* spacecraft, fabricated at the Lockheed Martin Astronautics plant in Denver, is a rectangular-shaped box with wing-like projections (solar panels) extending from opposite sides. When fully loaded with propellant at the time of launch, the spacecraft weighed 1,060 kg (2,337 lb). Most of *Surveyor's* mass lies in the box-shaped module occupying the center portion of the spacecraft. This center module is made of two smaller rectangular modules stacked on top of each other, one of which is called the equipment module and holds the spacecraft's electronics, science instruments, and the 1750A

mission computer. The other module, called the propulsion module, houses *Surveyor's* rocket engines and propellant tanks.

The planet was found to have a layered crust to depths of 10 km or more. To produce the layers, large amounts of material had to be weathered, transported and deposited.



This set of images from the public target request program shows many layers on a butte near the top of the image rectangle. These craters are within the much larger crater called Tikhonravov.

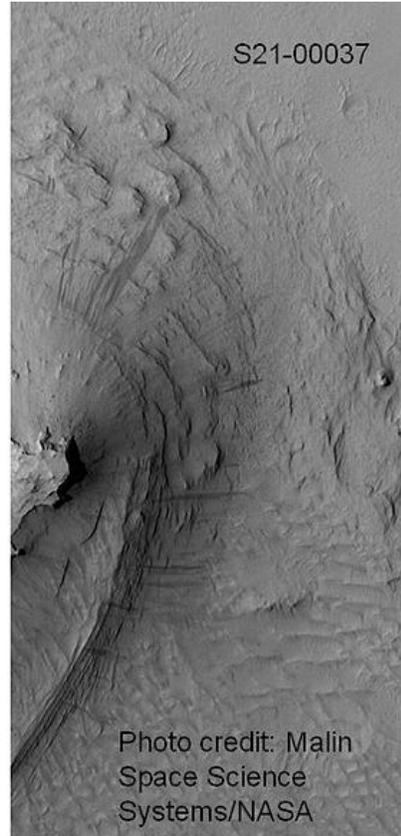
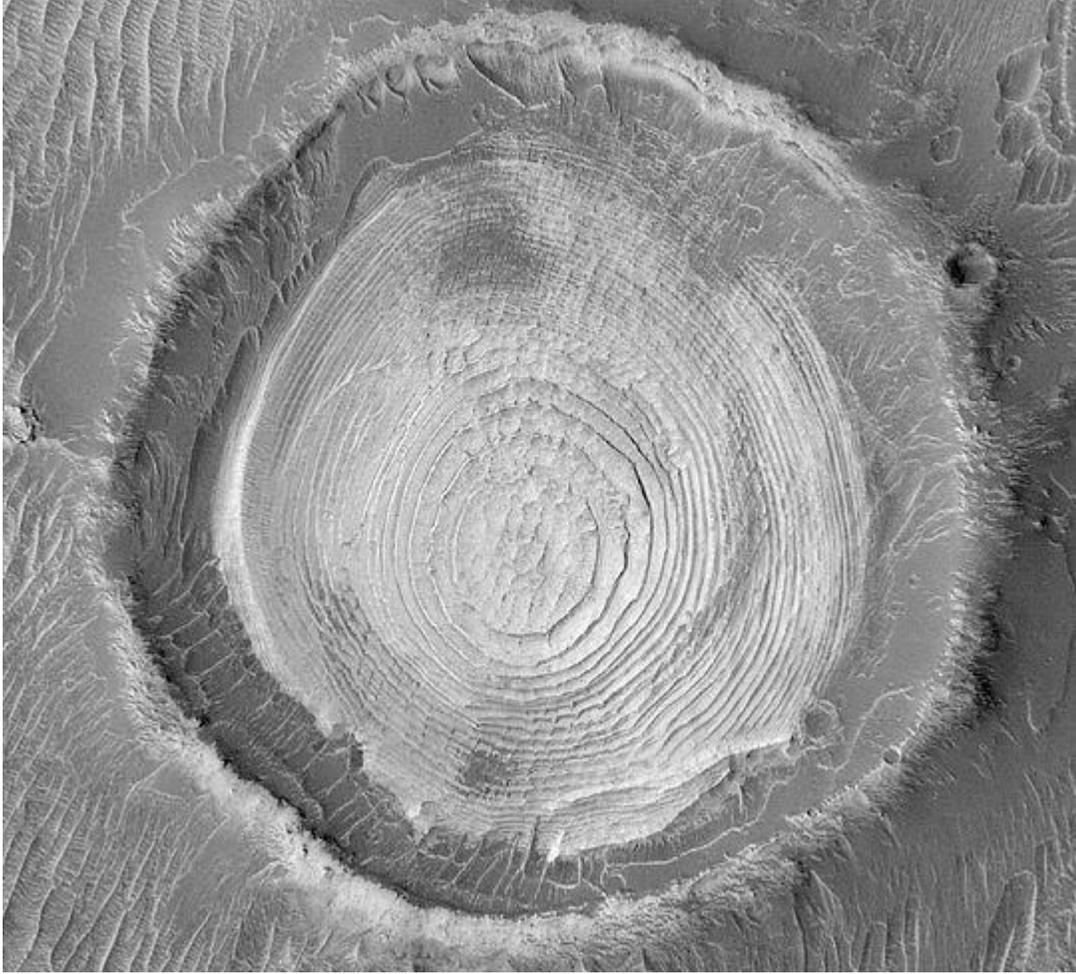


Photo credit: Malin Space Science Systems/NASA

Layers in an old crater in Arabia, as seen by Mars Global Surveyor (MGS). Layers may form from volcanoes, the wind, or by deposition under water. The craters on the left are pedestal craters.



Layers in crater found within the Schiaparelli crater basin as seen by Mars Global Surveyor. Image from the Sinus Sabaeus quadrangle.



Layers in Monument Valley. These are accepted as being formed, at least in part, by water deposition. Since Mars contains similar layers, water remains as a major cause of layering on Mars.



Buttes and layers in Aeolis quadrangle, as seen by Mars Global Surveyor.

Scientific instruments

Five scientific instruments fly onboard *Mars Global Surveyor*:

- **MOC** - the Mars Orbiter Camera, operated by Malin Space Science Systems
- **MOLA** - the Mars Orbiter Laser Altimeter
- **TES** - the Thermal Emission Spectrometer
- **MAG/ER** - a Magnetometer and electron reflectometer
- **USO/RS** Ultrastable Oscillator for Doppler measurements
- **MR** Mars Relay - Signal receiver

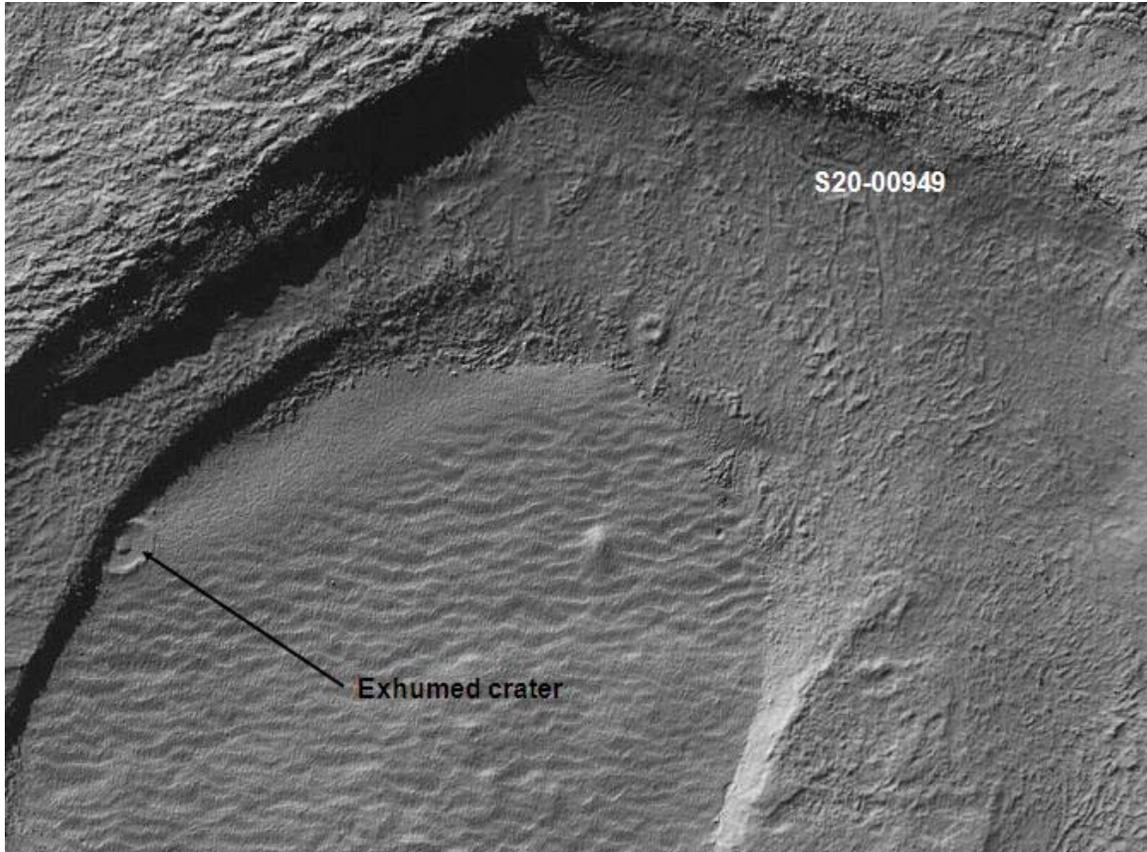
The Mars Orbiter Camera (MOC) science investigation used 3 instruments: a narrow angle camera that took (black-and-white) high resolution images (usually 1.5 to 12 m per

pixel) and red and blue wide angle pictures for context (240 m per pixel) and daily global imaging (7.5 km per pixel). MOC returned more than 240,000 images spanning portions of 4.8 Martian years, from September 1997 and November 2006. A high resolution image from MOC is either 1.5 or 3.1 km wide. So any image from this camera is at most 3.1 km wide. Often, a picture will be smaller than this because it has been cut to just show a certain feature. These high resolution images may be 3 to 10 km long. When a high resolution image is taken, a context image is taken as well. The context image shows the image footprint of the high resolution picture. Context images are typically 115.2 km square with 240 m/pixel resolution.

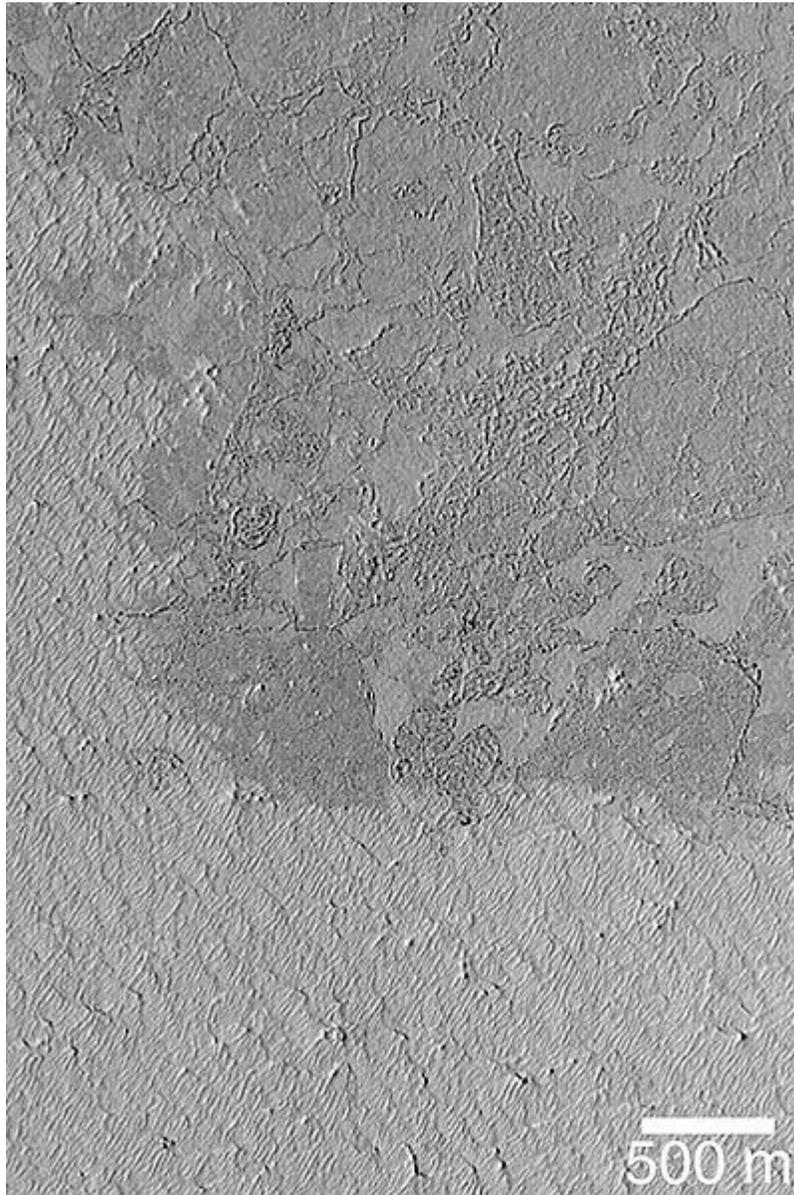
Launch and orbit insertion

The *Surveyor* spacecraft was launched from the Cape Canaveral Air Station in Florida on 7 November 1996 aboard a Delta II rocket. The spacecraft traveled nearly 750 million kilometers (466 million miles) over the course of a 300-day cruise to reach Mars on 11 September 1997.

Upon reaching Mars, *Surveyor* fired its main rocket engine for the 22-minute Mars orbit insertion (MOI) burn. This maneuver slowed the spacecraft and allowed the planet's gravity to capture it into orbit. Initially, *Surveyor* entered a highly elliptical orbit that took 45 hours to complete. The orbit had a periapsis of 262 km (163 mi) above the northern hemisphere, and an apoapsis of 54,026 km (33,570 mi) above the southern hemisphere.



Crater that was buried in another age and is now being exposed by erosion, as seen by the Mars Global Surveyor. Image is located in the Noachis quadrangle.



Lava flows were once covered over, now these platy flows are being exposed.

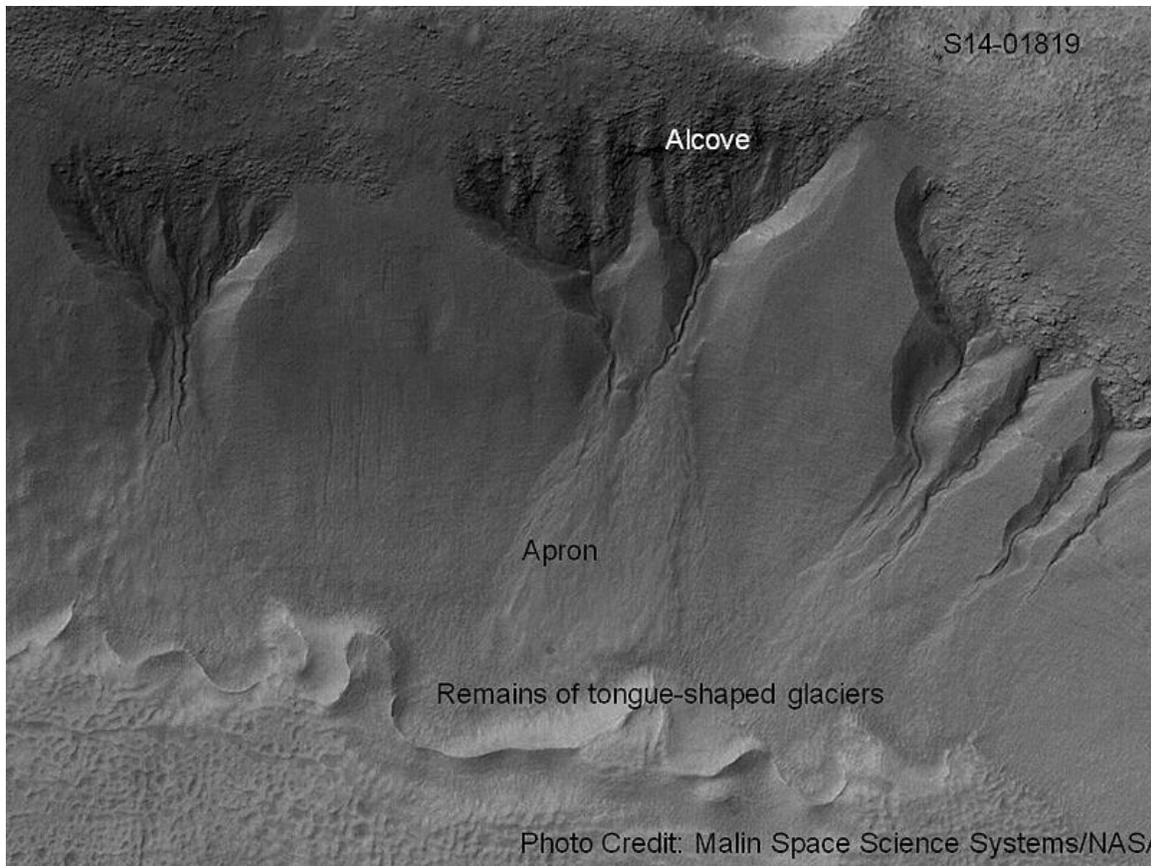


Crater was buried, now it is being exhumed by erosion. Image located in Ismenius Lacus quadrangle.



The northern hemisphere appears smooth, but the craters are covered over. Here, a group of craters are partially exposed. Image located in Cebrenia quadrangle.

Hundreds of gullies were discovered that were formed from liquid water, possible in recent times.



Group of gullies on north wall of crater that lies west of the crater Newton (41.3047 degrees south latitude, 192.89 east longitude). Image taken with Mars Global Surveyor. Image is located in the Phaethontis quadrangle.

Aerobraking

After orbit insertion, *Surveyor* performed a series of orbit changes to lower the periapsis of its orbit into the upper fringes of the Martian atmosphere at an altitude of about 110 km (68 mi). During every atmospheric pass, the spacecraft slowed down by a slight amount because of atmospheric resistance. The density of the Martian atmosphere at such altitudes is comparatively low, allowing this procedure to be performed without damage to the spacecraft. This slowing caused the spacecraft to lose altitude on its next pass through the orbit's apoapsis. *Surveyor* used this aerobraking technique over a period of four months to lower the high point of its orbit from 54,000 km (33,554 mi) to altitudes near 450 km (280 mi).

On 11 October, the flight team performed a maneuver to raise the periapsis out of the atmosphere. This suspension of aerobraking was performed because air pressure from the atmosphere caused one of *Surveyor's* two solar panels to bend backward by a slight amount. The panel in question was slightly damaged shortly after launch in November 1996. Aerobraking was resumed on 7 November after flight team members concluded

that aerobraking was safe, provided that it occurs at a more gentle pace than proposed by the original mission plan.



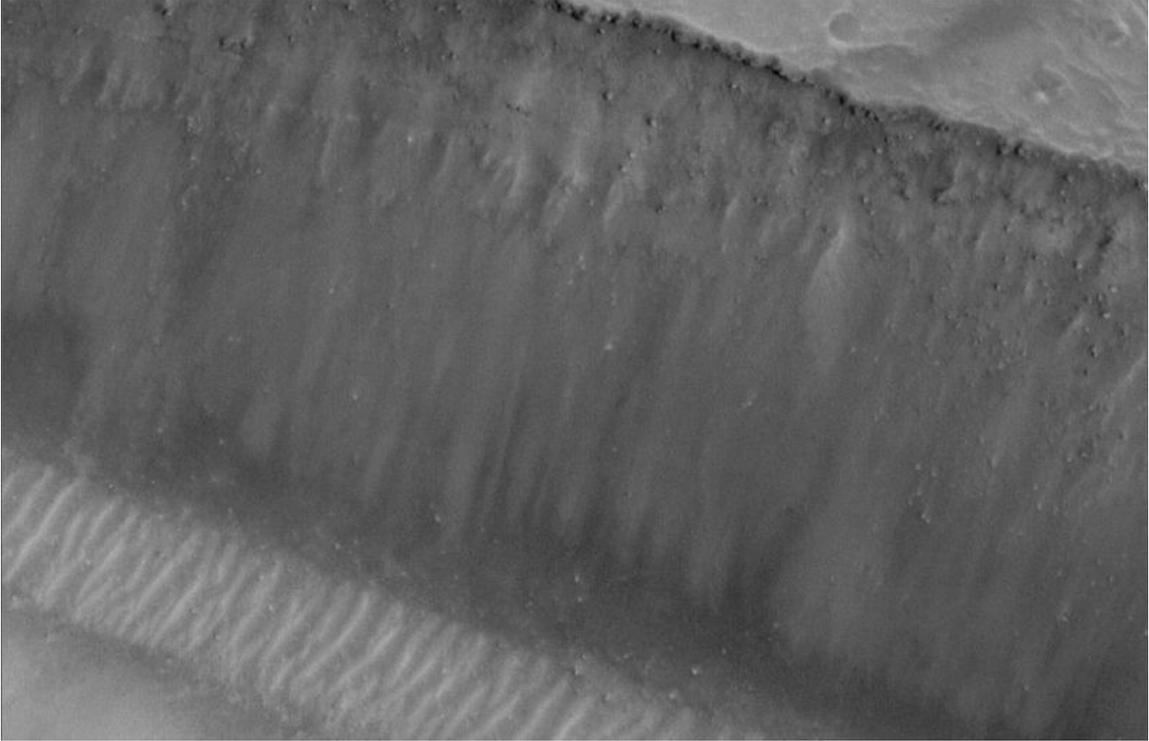
This image taken by *Mars Global Surveyor* spans a region about 1,500 m (4,921 ft) across, showing gullies on the walls of Newton Basin in Sirenum Terra. Similar channels on Earth are formed by flowing water, but on Mars the temperature is normally too cold and the atmosphere too thin to sustain liquid water. Nevertheless, many scientists hypothesize that liquid groundwater can sometimes surface on Mars, erode gullies and channels, and pool at the bottom before freezing and evaporating.

Under the new mission plan, aerobraking occurred with the low point of the orbit at an average altitude of 120 km (75 mi), as opposed to the original altitude of 110 km (68 mi). This slightly higher altitude resulted in a decrease of 66 percent in terms of air resistance pressure experienced by the spacecraft. During these six months, aerobraking reduced the orbit period to between 12 and 6 hours.

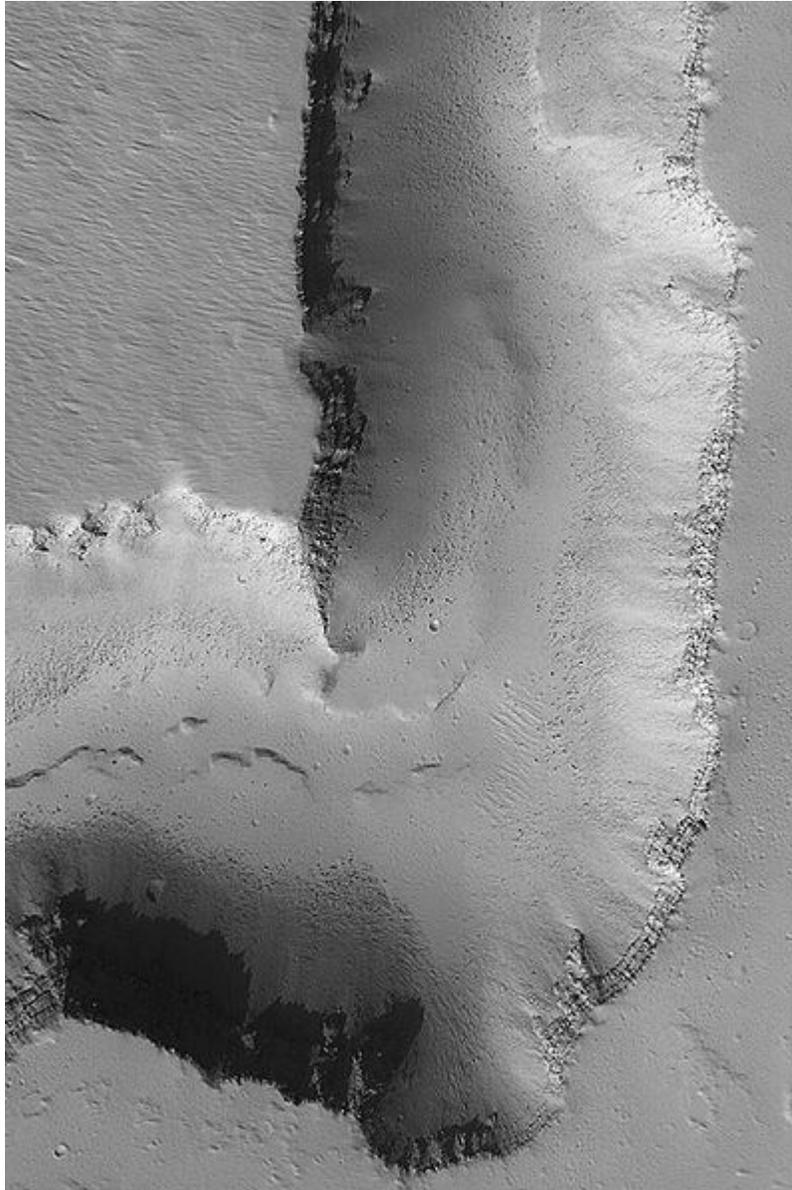


Small Volcano in Phoenicis Lacus quadrangle. Image is 1.9 miles wide.

Hundreds of house-sized boulders were found in some areas. This indicates that some materials are strong enough to hold together, even when moving downslope. Most of the boulders appeared in volcanic regions so they were probably from weathered lava flows.

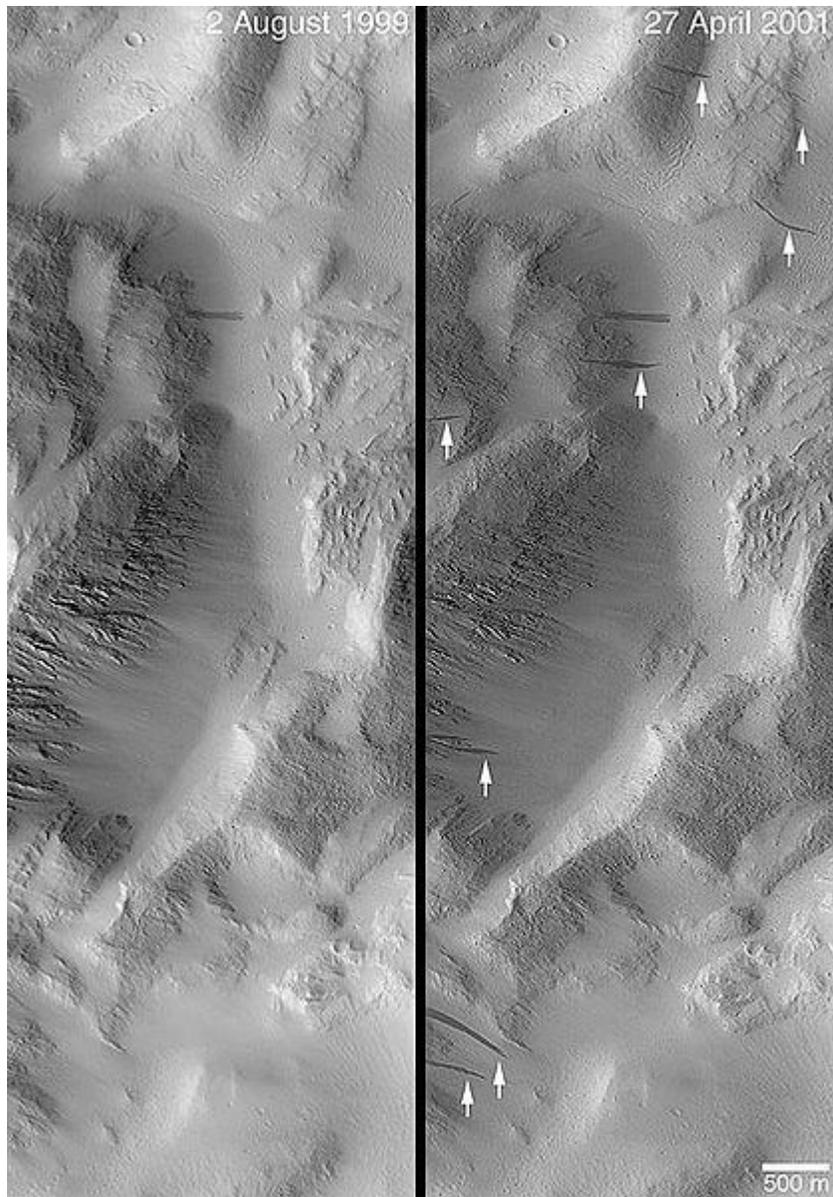


House-sized boulders are scattered throughout this image.

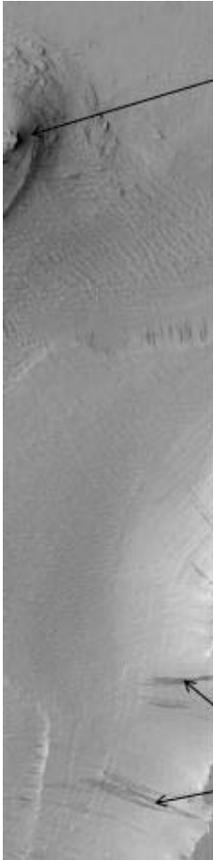


These boulders are near Ascraeus Mons, a Martian volcano. Volcanoes on Mars probably form hard boulders made up of basalt that is resistant to erosion in the current environment of Mars.

Thousands of Dark Slope Streaks were observed. Most scientists believe they result from the avalanching of dust. However, some researchers think that water may be involved.

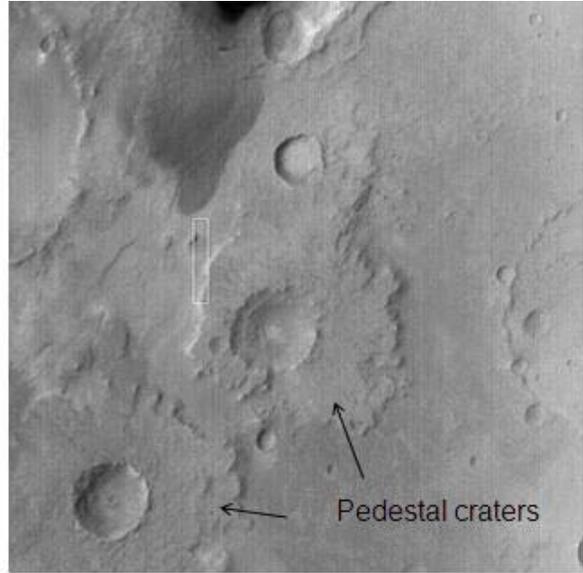


Many streaks underwent changes during the many years that MGS functioned.



Butte with layers on side

Dark slope streaks



Pedestal craters

Image on left is inside white box.

Tikonravev Crater Floor, as seen by Mars Global Surveyor.



Dark streaks in Diacria quadrangle, as seen by Mars Global Surveyor.

From May to November 1998, aerobraking was temporarily suspended to allow the orbit to drift into the proper position with respect to the Sun. Without this hiatus, 'Surveyor' would complete aerobraking with its orbit in the wrong solar orientation. In order to maximize the efficiency of the mission, these six months were devoted to collecting as much science data as possible. Data was collected between two to four times per day, at the low point of each orbit.

Finally, from November 1998 to March 1999, aerobraking continued and shrank the high point of the orbit down to 450 km (280 mi). At this altitude, *Surveyor* circled Mars once every two hours. Aerobraking was scheduled to terminate at the same time the orbit drifted into its proper position with respect to the Sun. In the desired orientation for mapping operations, the spacecraft always crossed the day-side equator at 14:00 (local Mars time) moving from south to north. This geometry was selected to enhance the total quality of the science return.

Mapping

The spacecraft circled Mars once every 117.65 minutes at an average altitude of 378 kilometers (235 miles). It is in a near polar orbit (inclination = 93°) which is almost perfectly circular, moving from being over the south pole to being over the north pole in just under an hour. The altitude was chosen to make the orbit sun-synchronous, so that all images that were taken by the spacecraft of the same surface features on different dates were taken under identical lighting conditions. After each orbit, the spacecraft viewed the planet 28.62° to the west because Mars had rotated underneath it. In effect, it was always 14:00 for *Mars Global Surveyor* as it moved from one time zone to the next exactly as fast as the Sun. After seven sols and 88 orbits, the spacecraft would approximately retrace its previous path, with an offset of 59 km to the east. This ensured eventual full coverage of the entire surface.

In its extended mission, MGS did much more than study the planet directly beneath it. It commonly performed rolls and pitches to acquire images off its nadir track. The roll maneuvers, called ROTOs (Roll Only Targeting Opportunities), rolled the spacecraft left or right from its ground track to shoot images as much as 30° from nadir. It was possible for a pitch maneuver to be added to compensate for the relative motion between the spacecraft and the planet. This was called a CPROTO (Compensation Pitch Roll Targeting Opportunity), and allowed for some very high resolution imaging by the onboard MOC (Mars Orbiting Camera).



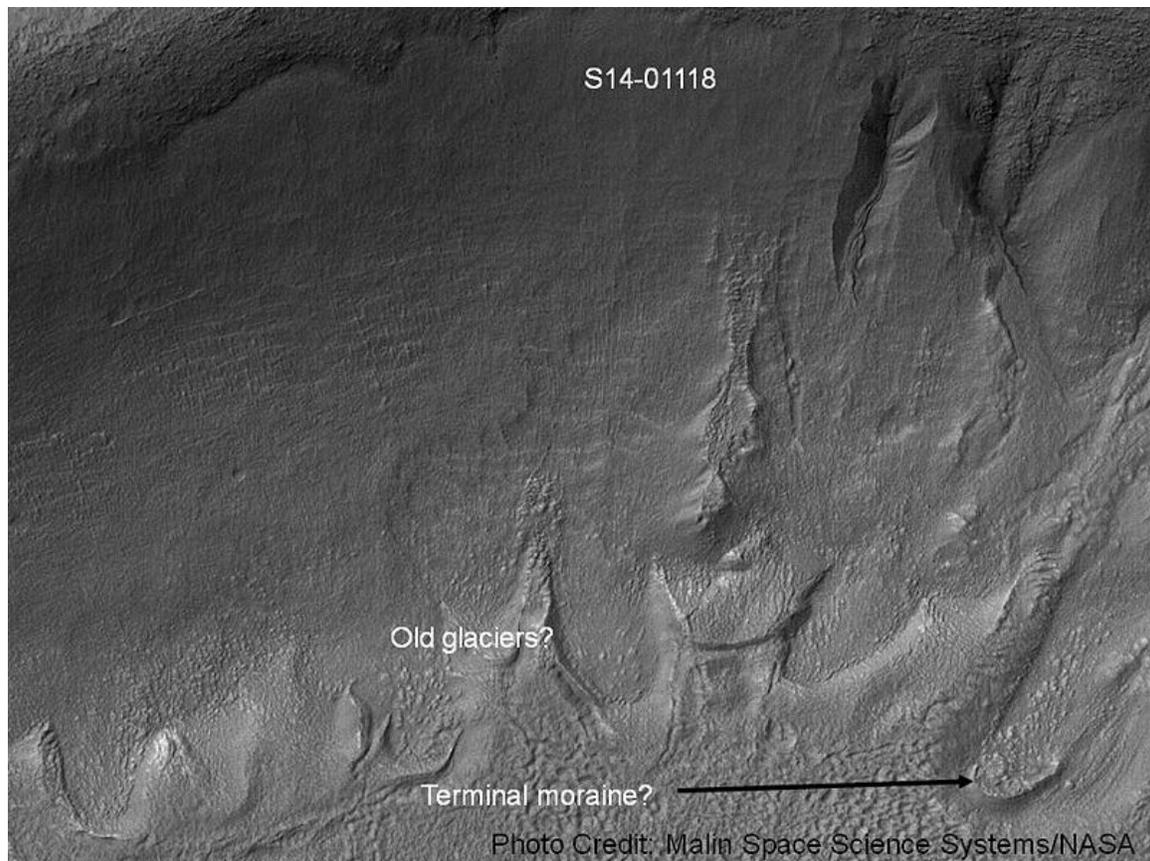
The Phobos monolith (right of center) as taken by the Mars Global Surveyor (MOC Image 55103) in 1998.

In addition to this, MGS could shoot pictures of other orbiting bodies, such as other spacecraft and the moons of Mars. In 1998 it imaged what was later called the Phobos monolith, found in MOC Image 55103.

Primary Mission Results

After analyzing hundreds of high-resolution pictures of the Martian surface taken by the orbiting Mars Surveyor spacecraft, a team of researchers found that weathering and winds on the planet create landforms, especially sand dunes, remarkably similar to those in some deserts on Earth.

Results from the Mars Global Surveyor primary mission (1996–2001) were published in the *Journal of Geophysical Research* by M. Malin and K. Edgett. Some of these discoveries are:



Gullies in a crater in Eridania quadrangle, north of the large crater Kepler. Also, features that may be remains of old glaciers are present. One, to the right, has the shape of a tongue.



Gullies on one wall of Kaiser Crater. Gullies usually are found in only one wall of a crater.

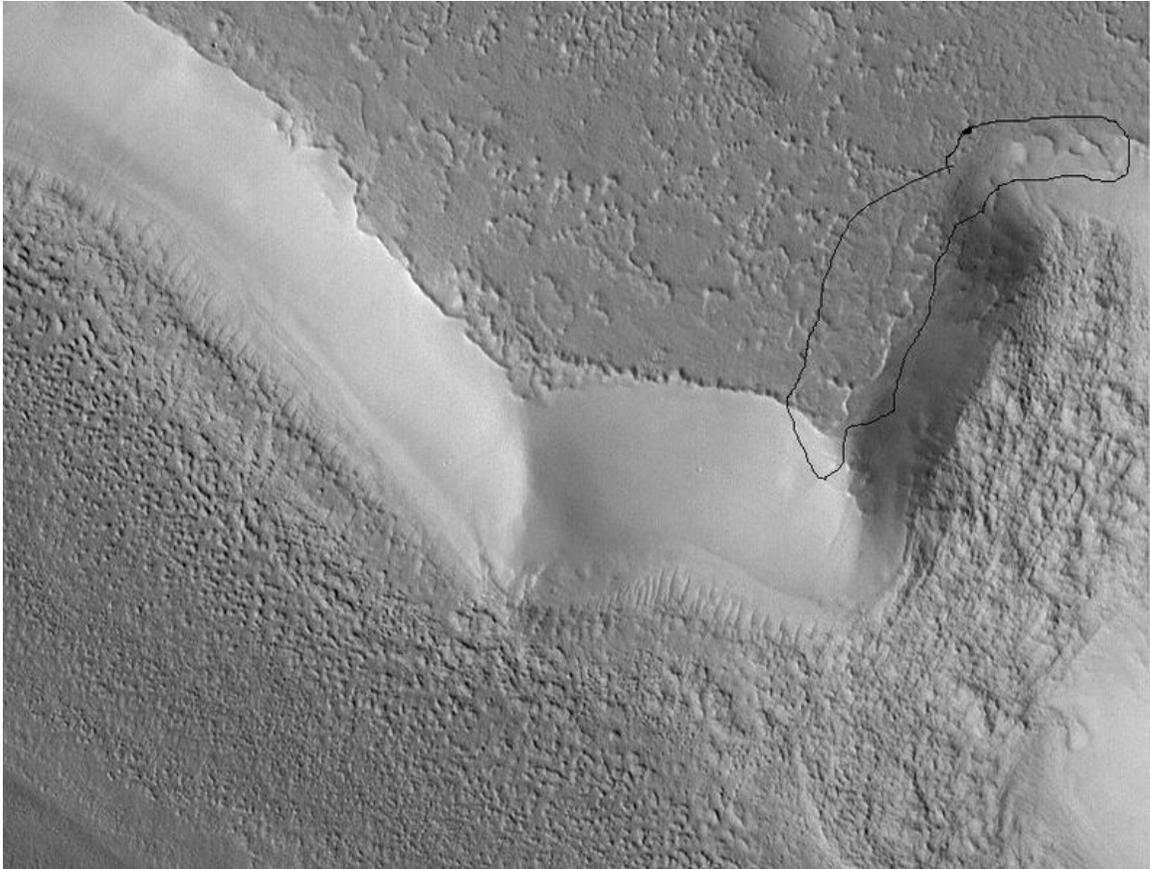


Full color image of gullies on wall of Gorgonum Chaos. Image is located in the Phaethontis quadrangle.

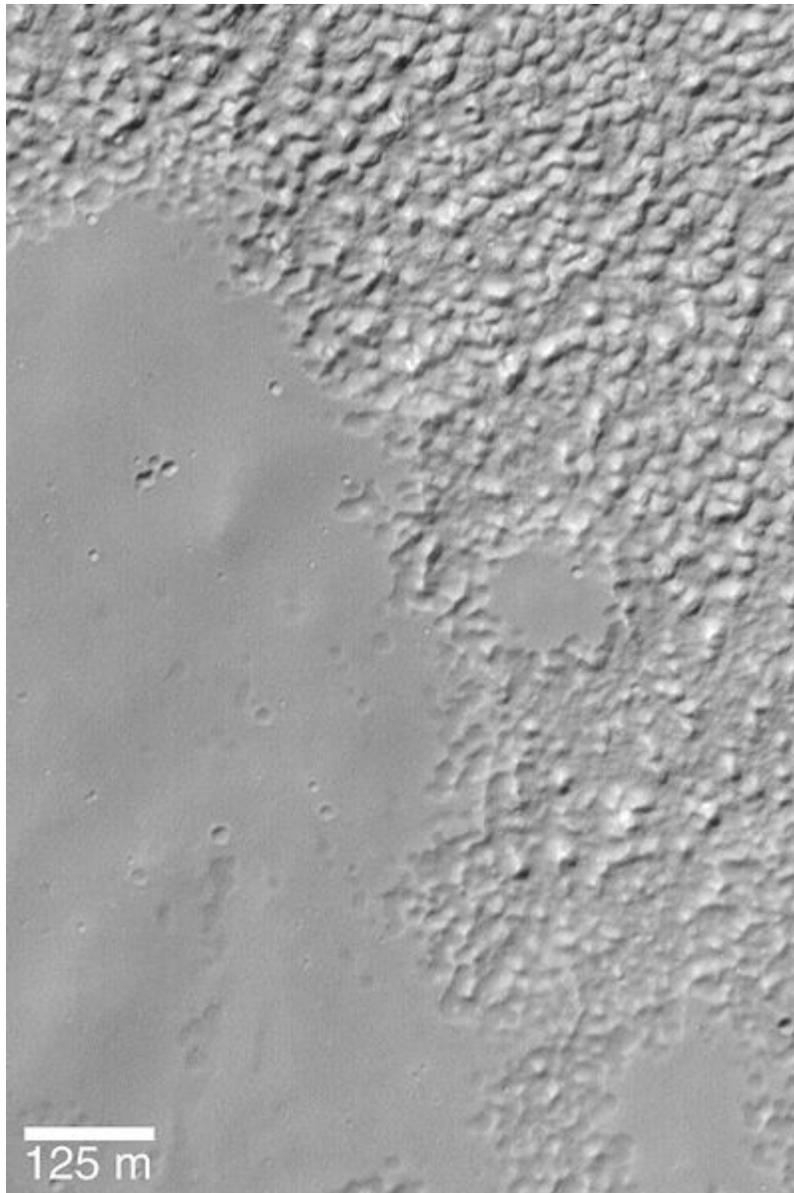
Large areas of Mars are covered by a mantle that coats all, but the very steepest slopes. The mantle is sometimes smooth, sometimes pitted. Some believe the pits are due to the escape of water through sublimation (ice changing directly to a vapor) of buried ice.



Close up image of Phaethontis surface taken with Mars Global Surveyor. Pits are thought to be caused by buried ice turning into a gas.



The mantle drapes most of the area. Note the absence of boulders on the cliff face. An area that shows the edges of the mantle is circled. Image located in Ismenius Lacus quadrangle.



Mantle material, as seen by MGS.

Cliff from bottom of S02-00191. This cliff is over a half mile high. Some cliffs in this region are over a mile high. The wrinkles may be evidence of movement. Such cliffs or scarps are common in fretted terrain on Mars.

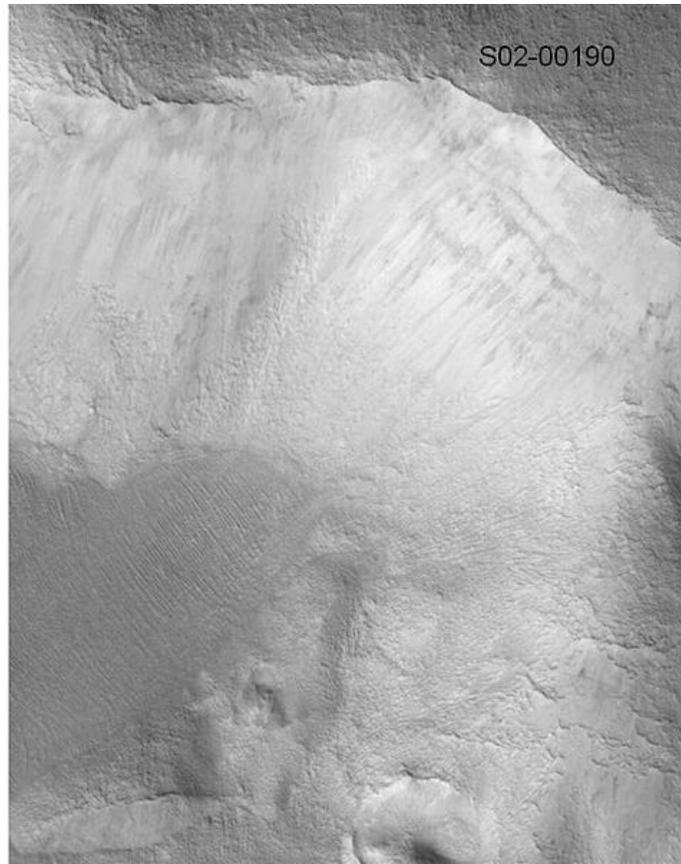


Photo credit: Malin
Space Science
Systems/NASA

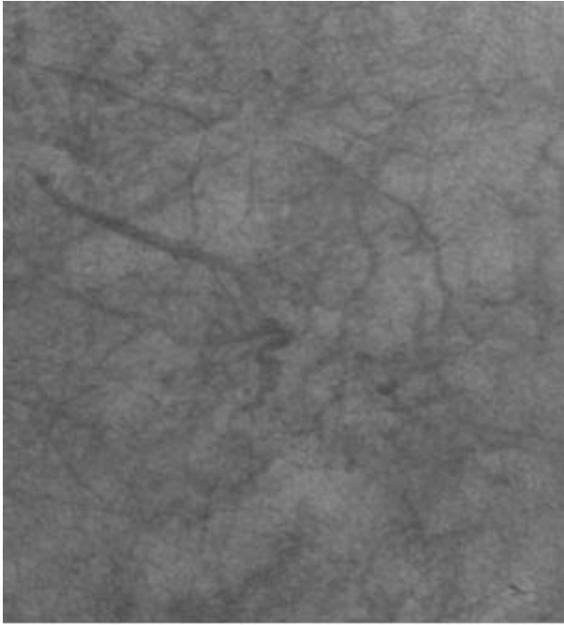
Steep Cliff in Ismenius Lacus quadrangle with smooth mantle covering its face.

Some areas are covered by hematite-rich material. The hematite could have been put in place by liquid water in the past.

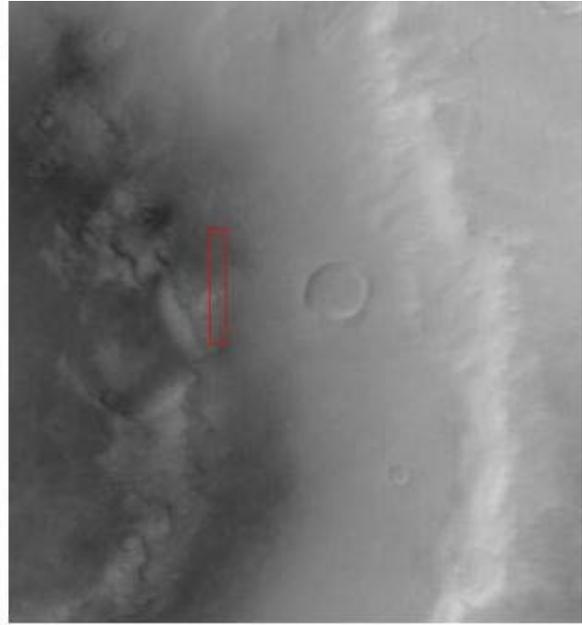
Dark streaks were found to be caused by giant dust devils. Dust Devil Tracks were observed to frequently change; some changed in just one month.



Pattern of large and small tracks made by giant dust devils as seen by Mars Global Surveyor. Image is located in Eridania quadrangle.

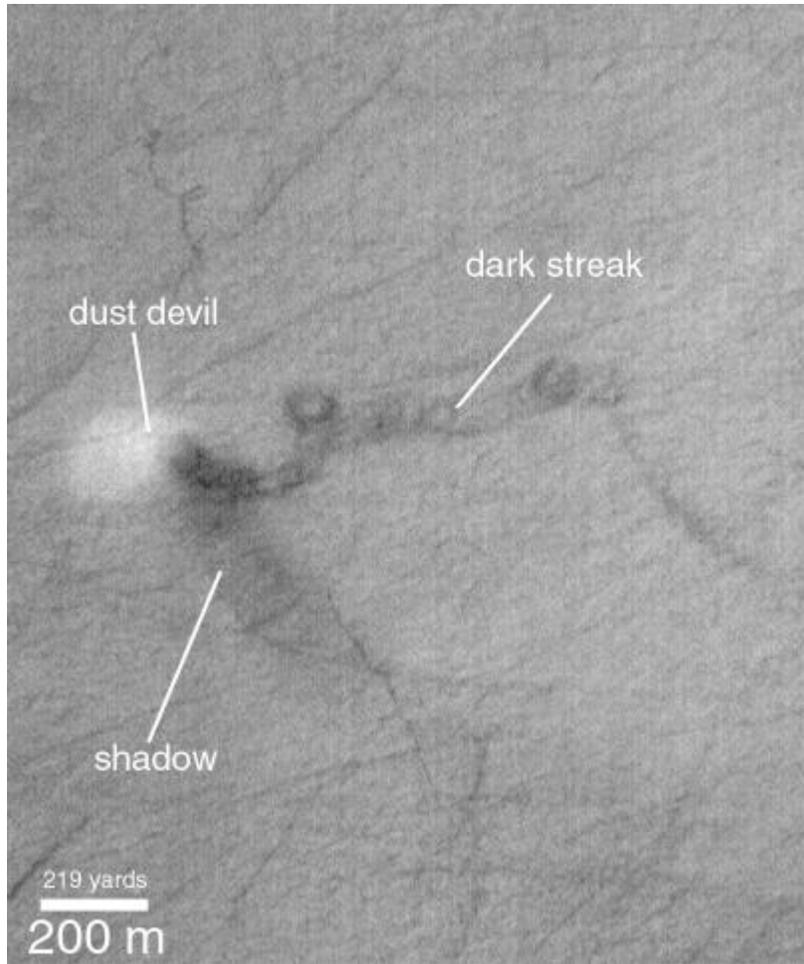


Dark curvy lines are dust devil tracks.

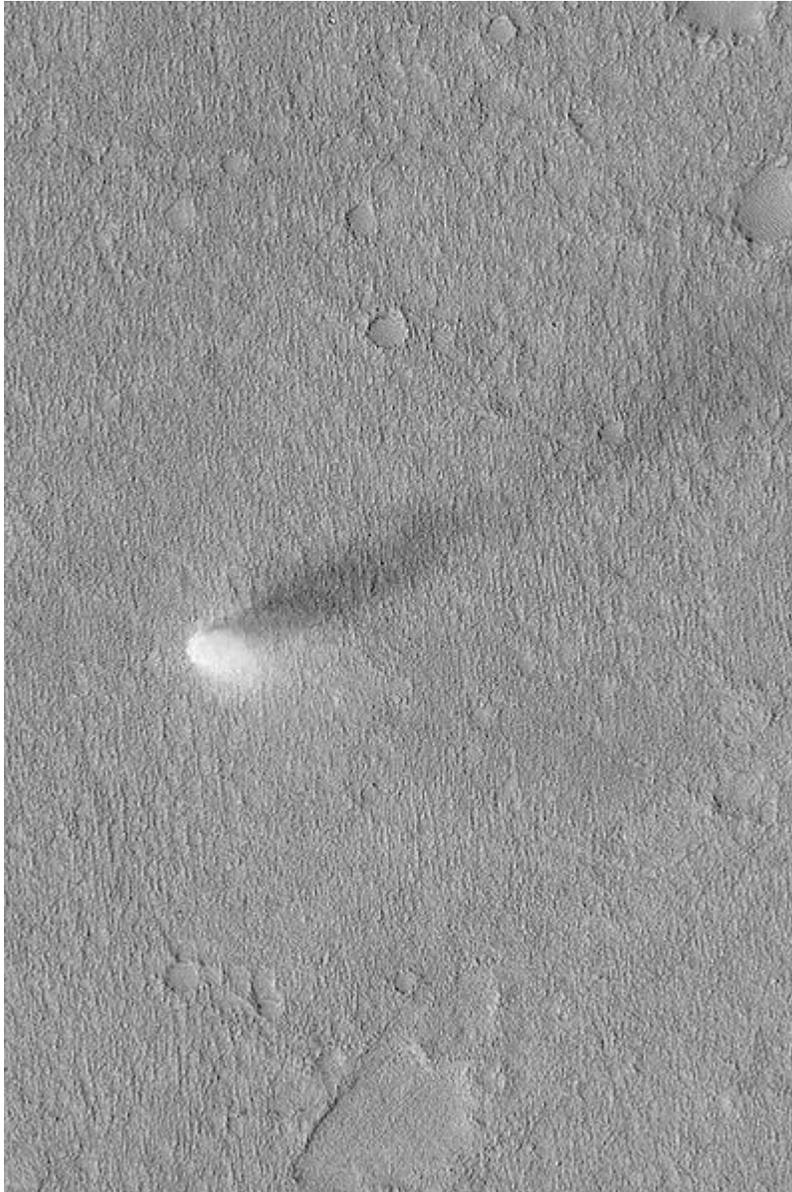


Context for image on left

Kepler (Martian crater) showing dust devil tracks, as seen by Mars Global Surveyor. Kepler is a large crater in the Eridania quadrangle.

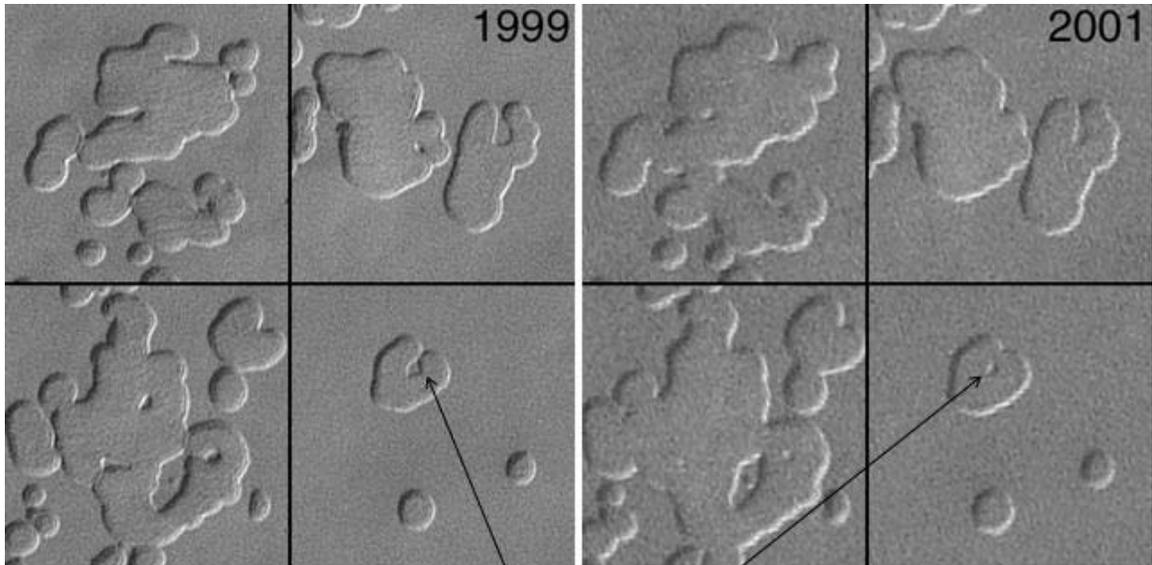


Dust Devil, as seen by MGS.



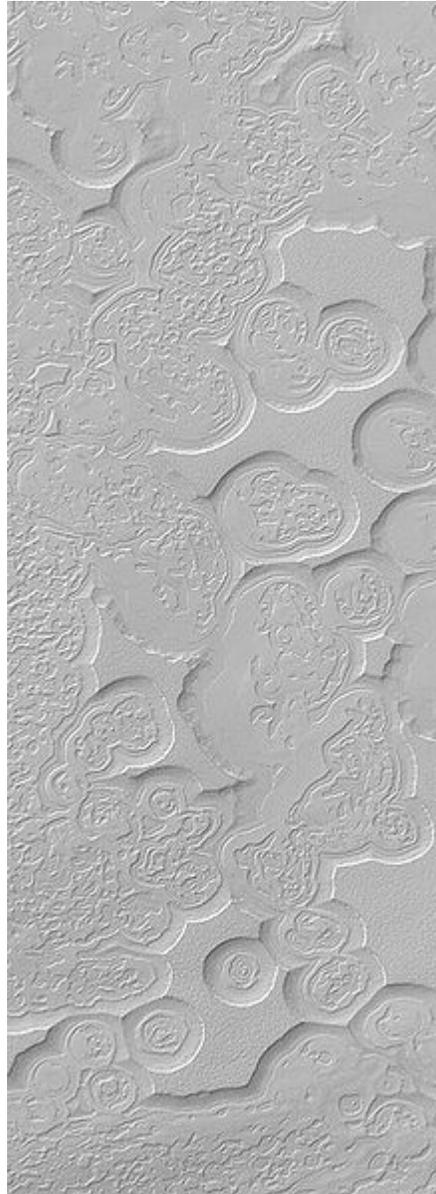
Dust Devil in action showing shadow to the right. Image located in Cebrenia quadrangle.

The south pole's residual cap was observed to look like Swiss cheese. The holes are generally a few meters deep. The holes get bigger each year, so Mars may be warming.

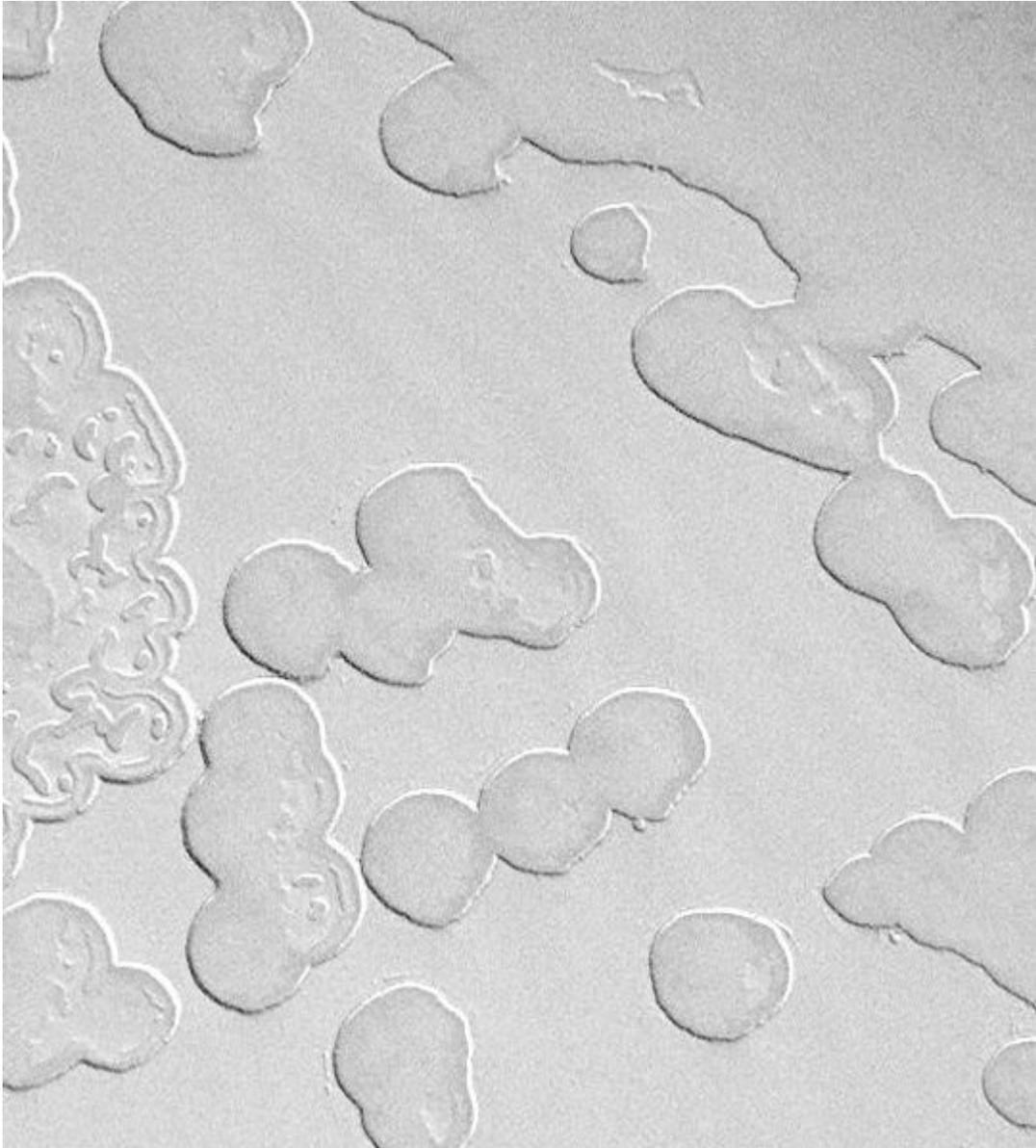


Notice many changes in two years time.

Changes in South Pole from 1999 to 2001, as seen by Mars Global Surveyor. Notice how swiss-cheese type holes have grown in the two years.



Swiss Cheese Terrain, as seen by MGS. Largest mesa in image is 4 meters high.



Layers in Swiss Cheese Terrain. There is a bright upper layer and a darker lower layer.

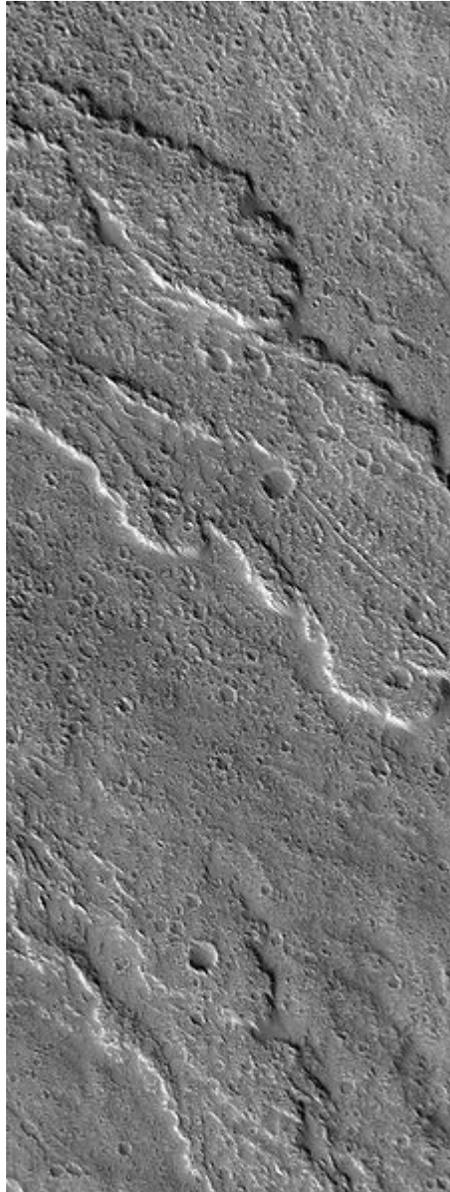


Close-up view of Swiss Cheese Terrain. Polygonal pattern was probably formed by shallow troughs.

The Thermal Emission Spectrometer found that just about all of the surface of Mars is covered with volcanic rock.



Ceraunius Tholus, one of many volcanoes found on Mars.



Lava flows in the Tharsis quadrangle.

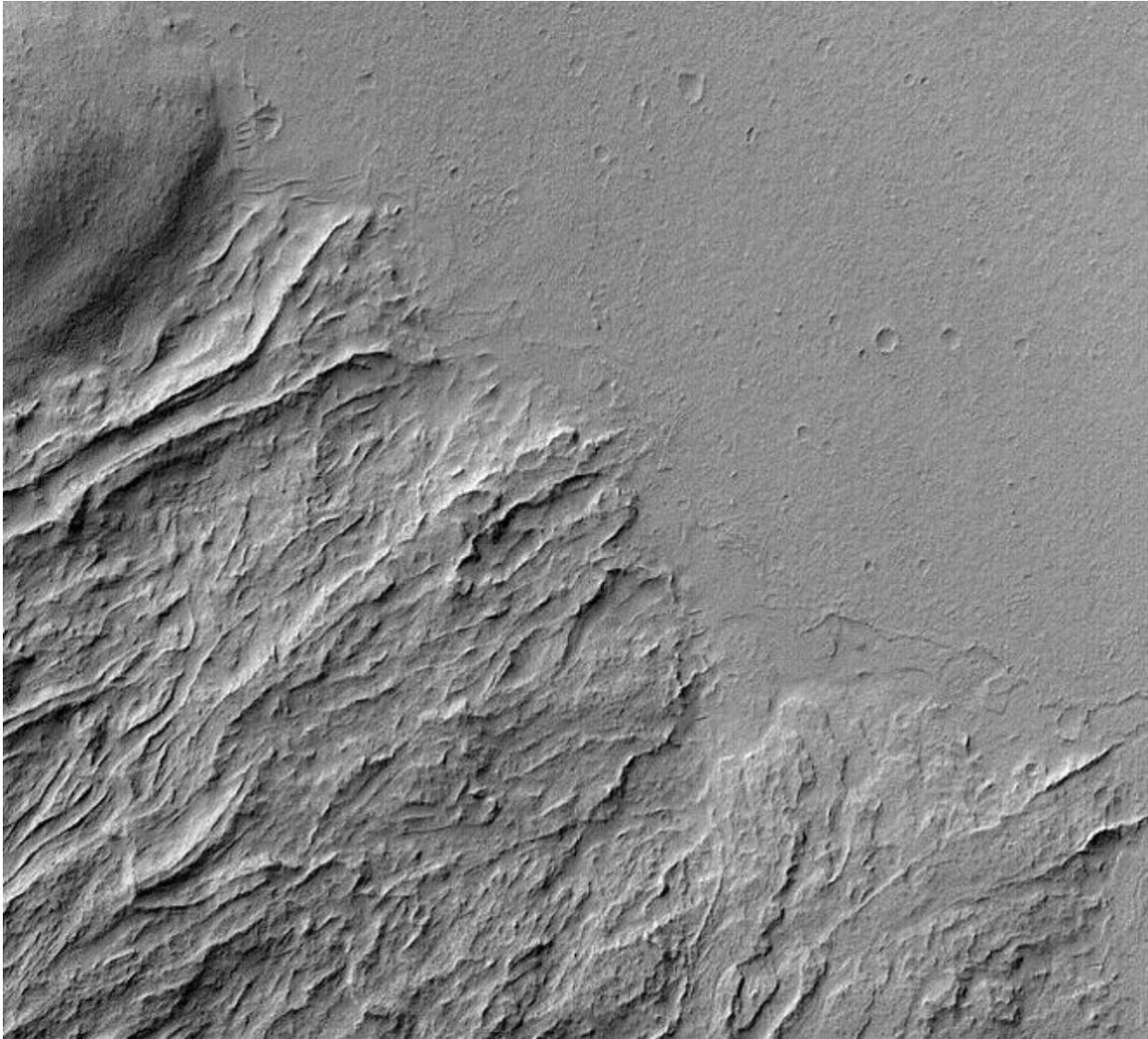


Image shows both young and old lava flows from the base of Olympus Mons. The flat plain is the younger flow. The older flow has channels with levees along their edges. The presence of levees is quite common in many lava flows.

MER communications subsystem

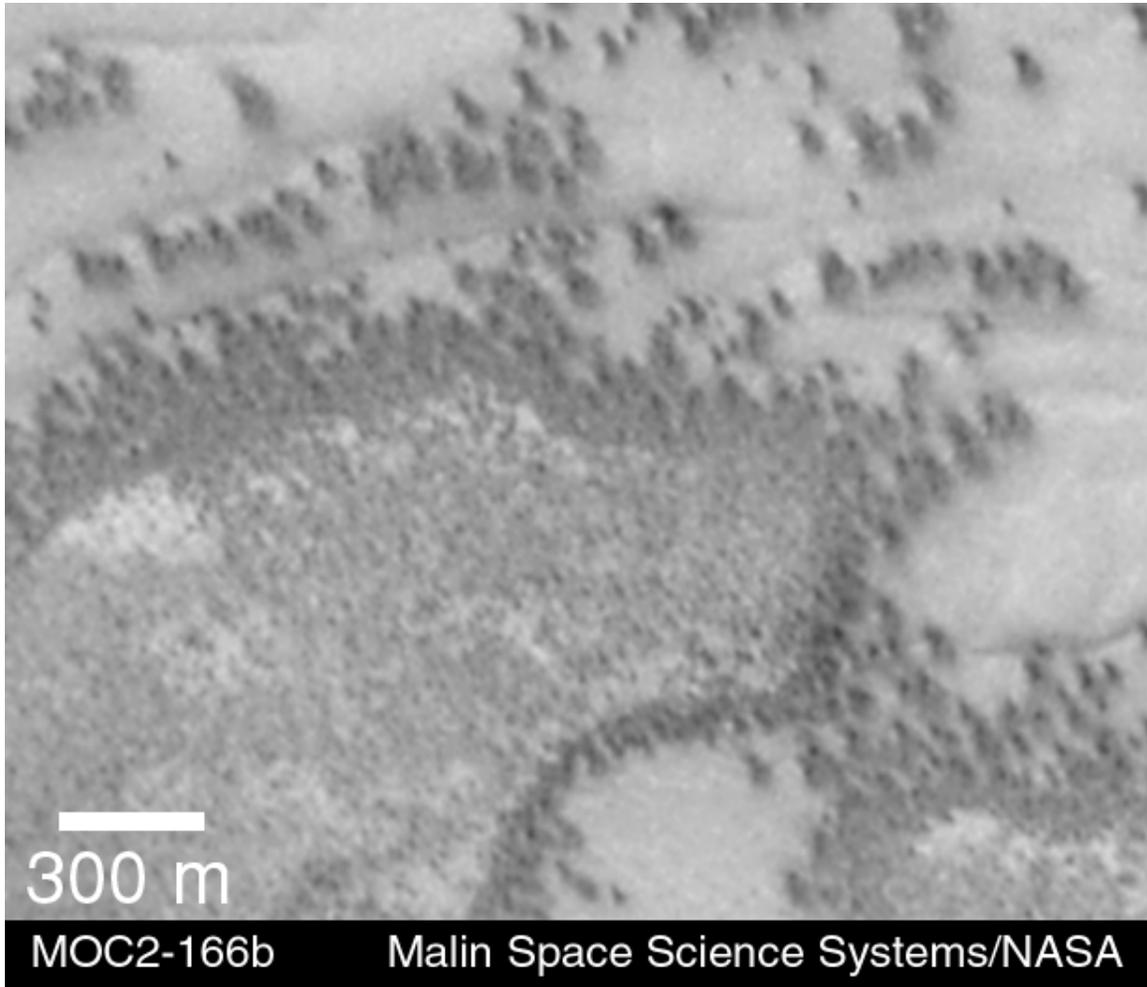
Mars Global Surveyor functioned as a communications satellite relaying data back to Earth from the MER surface landers. Portions of MGS had been scheduled to remain active until at least September 2008 to support MER.

Loss of contact

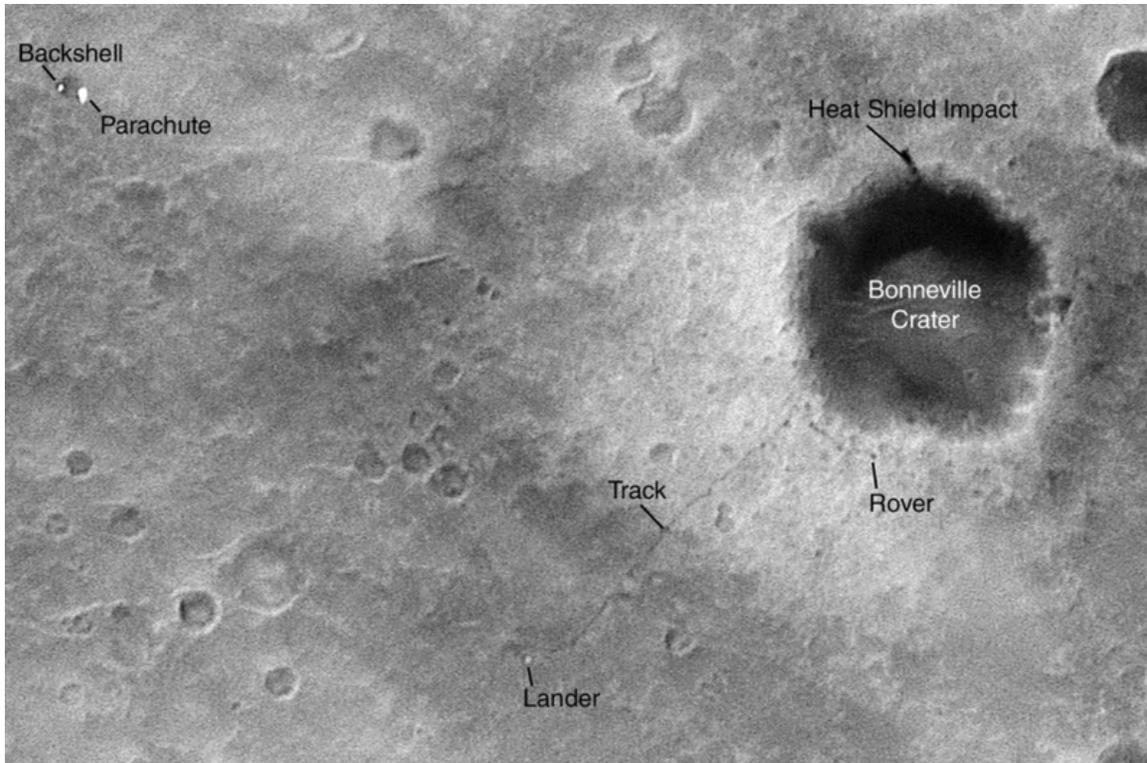
On **November 2, 2006**, NASA lost contact with the spacecraft after commanding it to adjust its solar panels. Several days passed before a faint signal was received indicating that the spacecraft had entered safe mode and was awaiting further instructions.

On **November 20, 2006**, the Mars Reconnaissance Orbiter spacecraft attempted to image *Mars Global Surveyor* to verify the orientation of the spacecraft. The effort was unsuccessful.

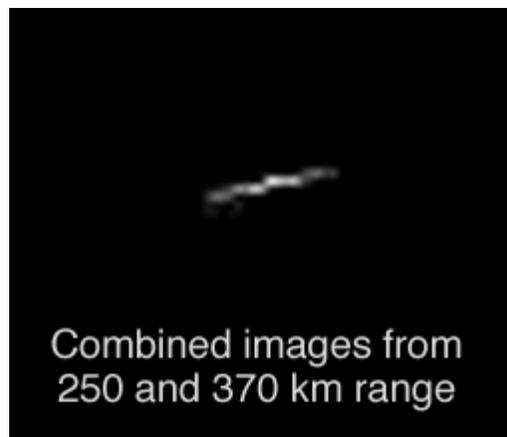
On **November 21 and 22, 2006**, *Mars Global Surveyor* failed to relay communications to the Opportunity rover on the surface of Mars. In response to this complication, Mars Exploration Program manager Fuk Li stated, "Realistically, we have run through the most likely possibilities for re-establishing communication, and we are facing the likelihood that the amazing flow of scientific observations from Mars Global Surveyor is over."



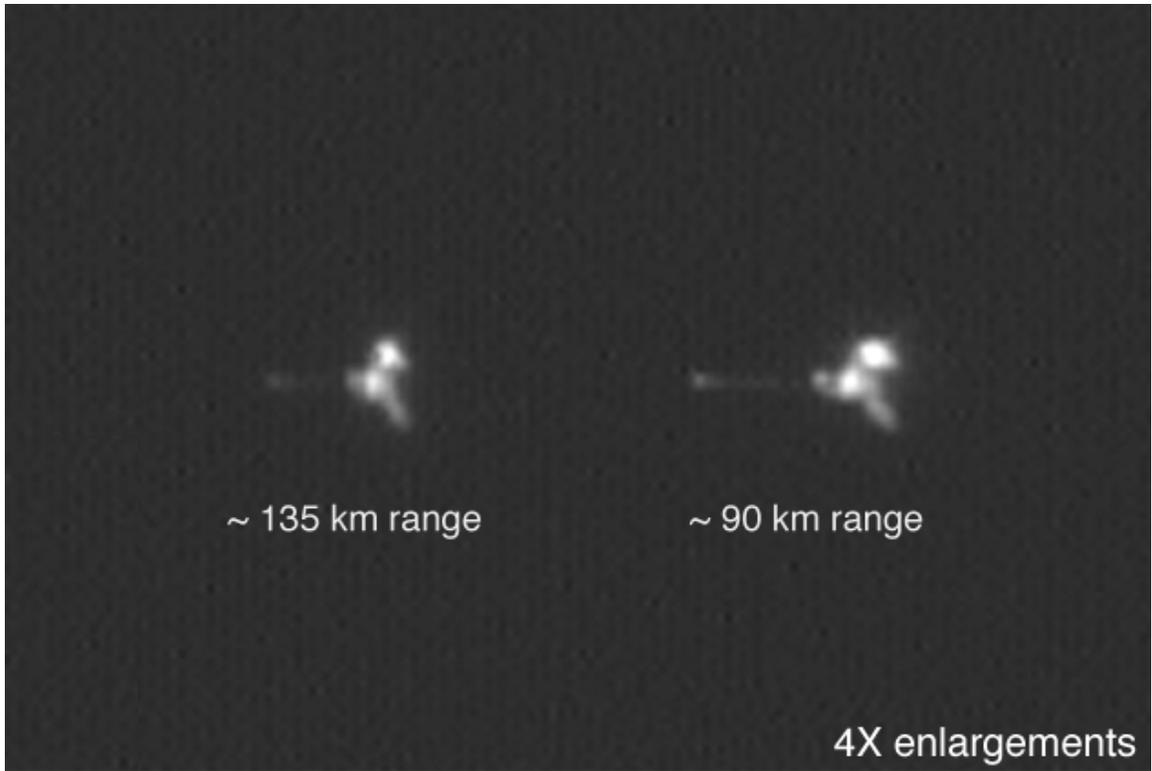
Surface of Mars taken by the Mars Global Surveyor on 10 August 1999.



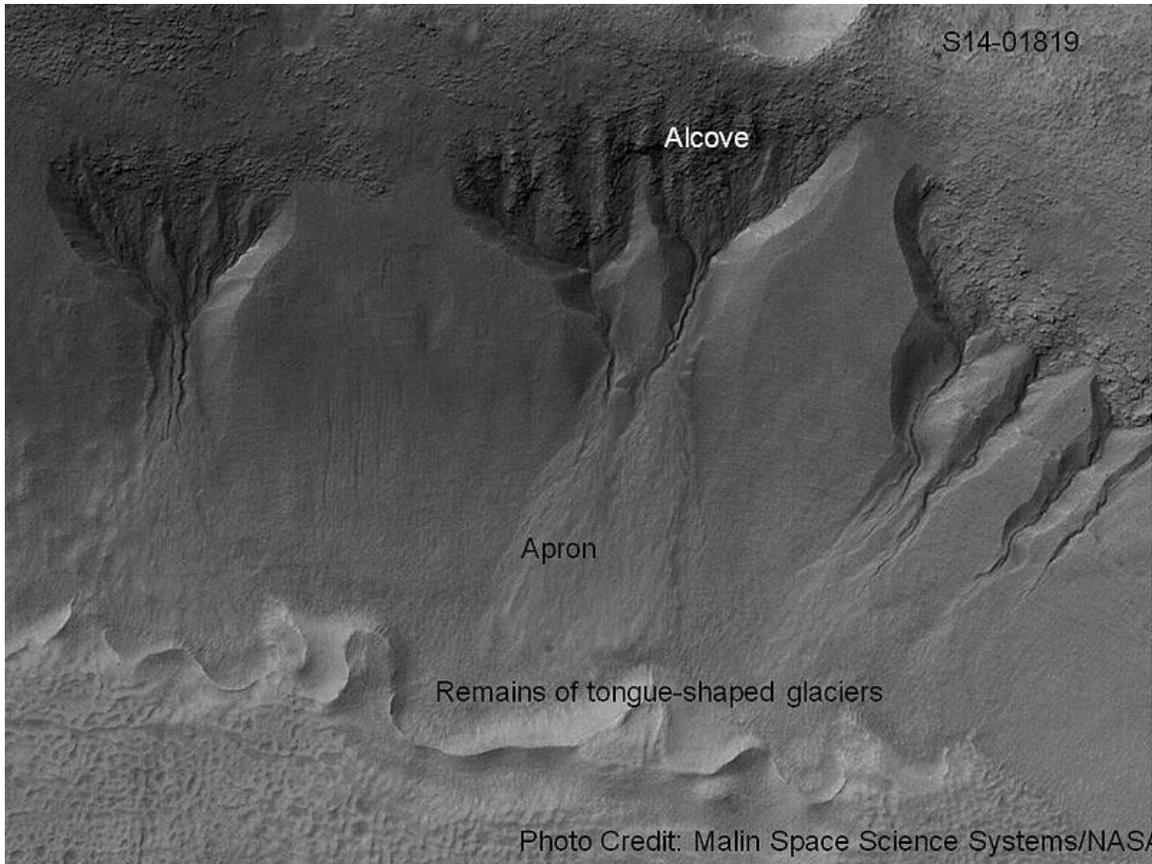
The Mars Rover Spirit's landing site and tracks taken by *Mars Global Surveyor*.



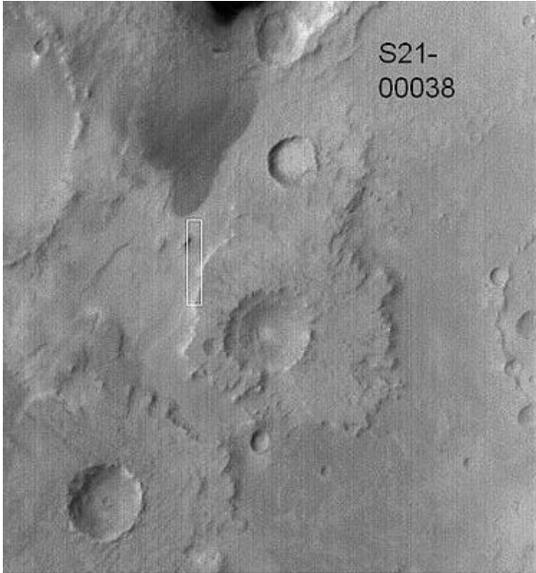
The Mars Express spacecraft image taken by *Mars Global Surveyor*.



The Mars Odyssey spacecraft image taken by *Mars Global Surveyor*.



Group of gullies on north wall of crater that lies west of the crater Newton (41.3047 degrees south latitude, 192.89 east longitude). Image taken with Mars Global Surveyor.



This set of images from the public target request program shows many layers on a butte near the top of the image rectangle. These craters are within the much larger crater called Tikhonravov.

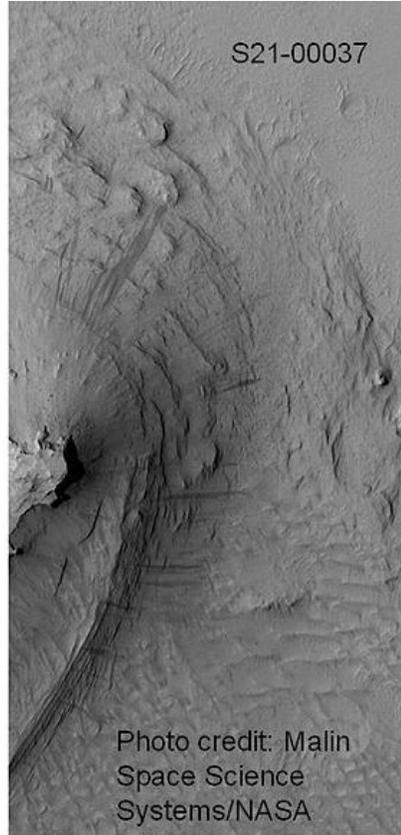
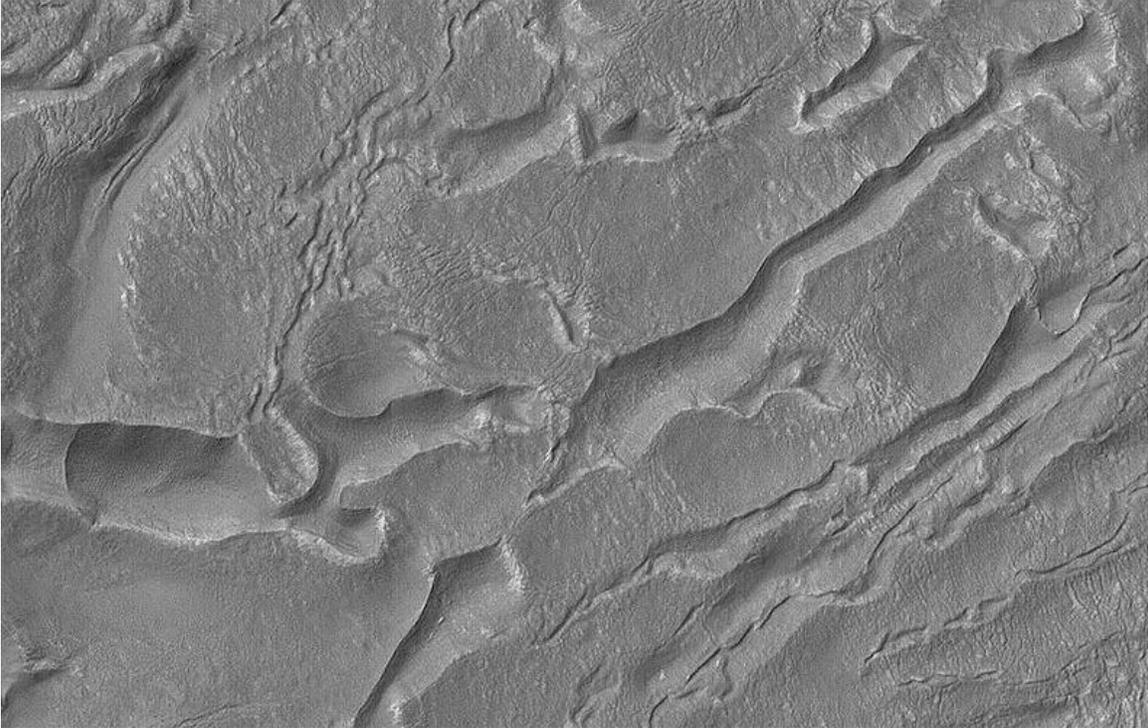


Photo credit: Malin Space Science Systems/NASA

Layers in an old crater in Arabia, as seen by Mars Global Surveyor (MGS) Mars Global Surveyor Layers may form from volcanoes, the wind, or by deposition under water. The craters on the left are pedestal craters.



Layers in the canyon wall in Coprates quadrangle, as seen by Mars Global Surveyor.



Banded or taffy-pull terrain in Hellas, as seen by Mars Global Surveyor. Origin is unknown at present.

On **April 13, 2007**, NASA announced the loss of the spacecraft was caused by a flaw in a parameter update to the spacecraft's system software. The spacecraft was designed to hold two identical copies of the system software for redundancy and error checking. Subsequent updating to the software encountered human error when two independent operators updated separate copies with differing parameters followed by a corrective update that unknowingly included a memory fault which resulted in the loss of the spacecraft.

Previously, in November of 2005, two operators had changed unknowingly, the same parameter on separate copies of the system software. Each operator had used a slightly different precision when inputting a parameter, which resulted in a small but significant difference in the two copies. A subsequent memory readout revealed this inconsistency to the mission's team.

In order to correct the error, an update was drafted in June of 2006. However, two memory addresses were incorrectly handled in the update, which could allow values to be written into the wrong memory addresses and further complications with the mission. Five months later, the problematic memory addresses were called, resulting in the solar arrays being driven until they hit a hard stop and became unmovable. The complication lead the spacecraft to incorrectly diagnose

a failure of a gimbal motor causing the spacecraft to rotate to allow the unmovable solar array to point toward the Sun. However, in this position the remaining usable battery was also directed toward the Sun, resulting in the battery overheating and eventually failing. The spacecraft subsequently went into safe mode and contact with the spacecraft was lost.

Originally, the spacecraft was intended to observe Mars for 1 Martian year (approximately 2 Earth years). However, based on the vast amount of valuable science data returned, NASA had previously extended the mission three times.

MGS and general relativity: the Lense-Thirring test

Data from MGS have also been used to perform a test of the general relativistic Lense-Thirring effect which consists of a small precession of the orbital plane of a test particle moving around a central, rotating mass such as a planet. The interpretation of the out-of-plane Root-Mean-Square (RMS) time series of MGS in terms of such a relativistic feature of motion by L. Iorio was criticized by K. Krogh; however, L. Iorio supported his thesis with new arguments.

Discovery of water on Mars



Inner channel on floor of Nanedi Valles that suggests that water flowed for a fairly long period. Image from Lunae Palus quadrangle.

On 6 December 2006 NASA released photos of two craters called Terra Sirenum and Centauri Montes which appear to show the presence of water on Mars at some point between 1999 and 2001. The pictures were produced by the Mars Global Surveyor and are quite possibly the spacecraft's final contribution to our knowledge of Mars and the question of whether life or water exists on the planet.

Hundreds of gullies were discovered that were formed from liquid water, possible in recent times. These gullies occur on steep slopes and mostly in certain bands of latitude.

A few channels on Mars displayed inner channels that suggest sustained fluid flows. The most well-known is the one in Nanedi Valles. Another was found in Nirgal Vallis.

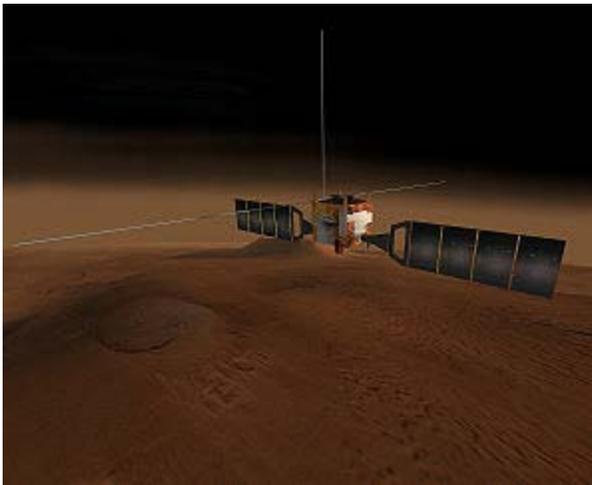
Mission timeline

- 7 November 1996: Launch from Cape Canaveral.
- 11 September 1997: Arrival at Mars, began orbit insertion.
- 1 April 1999: Primary mapping phase began.
- 1 February 2001: First extended mission phase began.
- 1 February 2002: Second extended mission phase began.
- 1 January 2003: Relay mission began.
- 30 March 2004: *Surveyor* photographed the Mars Exploration Rover *Spirit* along with its wheel tracks showing its first 85 sols of travel.
- 1 December 2004: Science and Support mission began.
- April 2005: MGS became the first spacecraft to photograph another spacecraft in orbit around a planet other than Earth when it captured two images of the Mars Odyssey spacecraft and one image of the Mars Express spacecraft.
- 1 October 2006: Extended mission phase began for another two years.
- 2 November 2006: Spacecraft suffers an error while attempting to reorient a solar panel and communication was lost.
- 5 November 2006: Weak signals were detected, indicating the spacecraft was awaiting instructions. The signal cut out later that day.
- 21 November 2006: NASA announces the spacecraft has likely finished its operating career.
- 6 December 2006: NASA releases imagery taken by MGS of a newly found gully deposit, suggesting that water still flows on Mars.
- 13 April 2007: NASA releases its Preliminary Report on the cause(s) of MGS' loss of contact.

Chapter- 7

Mars Express

Mars Express



CG image of Mars Express

Operator	ESA
Mission type	Orbiter + Lander
Satellite of	Mars
Orbital insertion date	December 25, 2003
Launch date	June 2, 2003
Launch vehicle	Soyuz-FG/Fregat
COSPAR ID	2003-022A
Homepage	<i>ESA Mars Express</i> project (official site)

Mass 1123 (666 + 457 fuel) kg

Power 460 W (Mars)

Orbital elements

Eccentricity 0.943

Inclination 86.3°

Apoapsis 10,107 km

Periapsis 298 km

Orbital period 7.5 hr

Mars Express is a space exploration mission being conducted by the European Space Agency (ESA). The Mars Express mission is exploring the planet Mars, and is the first planetary mission attempted by the agency. "Express" originally referred to the speed and efficiency with which the spacecraft was designed and built. However "Express" also describes the spacecraft's relatively short interplanetary voyage, a result of being launched when the orbits of Earth and Mars brought them closer than they had been in about 60,000 years.

Mars Express consists of two parts, the *Mars Express Orbiter* and the *Beagle 2*, a lander designed to perform exobiology and geochemistry research. Although the lander failed to land safely on the Martian surface, the Orbiter has been successfully performing scientific measurements since early 2004, namely, high-resolution imaging and mineralogical mapping of the surface, radar sounding of the subsurface structure down to the permafrost, precise determination of the atmospheric circulation and composition, and study of the interaction of the atmosphere with the interplanetary medium.

Due to the valuable science return and the highly flexible mission profile, *Mars Express* has been granted four mission extensions, the latest until December 31, 2012.

Some of the instruments on the orbiter, including the camera systems and some spectrometers, reuse designs from the failed launch of the Russian Mars 96 mission in 1996 (European countries had provided much of the instrumentation and financing for that unsuccessful mission). The basic design of Mars Express is based on ESA's Rosetta mission, on which a considerable sum was spent on development. The same design was also used for the *Venus Express* mission in order to increase reliability and reduce development cost and time.

Mission profile and timeline overview

Mission overview

The Mars Express mission is dedicated to the orbital (and originally in-situ) study of the interior, subsurface, surface and atmosphere, and environment of the planet Mars. The scientific objectives of the Mars Express mission represent an attempt to fulfil in part the lost scientific goals of the Russian Mars-96 mission, complemented by exobiology research with Beagle-2. Mars exploration is crucial for a better understanding of the Earth from the perspective of comparative planetology.

The spacecraft originally carried seven scientific instruments, a small lander, a lander relay and a Visual Monitoring Camera, all designed to contribute to solving the mystery of Mars' missing water. All of the instruments take measurements of the surface, atmosphere and interplanetary media, from the main spacecraft in polar orbit, which will allow it to gradually cover the whole planet.

The overall Mars Express budget excluding the lander is €150 million (roughly US\$185 million).

Spacecraft construction

The prime contractor for the construction of Mars Express Orbiter was EADS Astrium Satellites.

Mission preparation

In the years preceding the launch of a spacecraft numerous teams of experts distributed over the contributing companies and organisations prepared the space and ground segments. Each of these teams focussed on the area of its responsibility and interfacing as required. A major additional requirement raised for the Launch and Early Orbit Phase (LEOP) and all critical operational phases was that it was not enough merely to interface; the teams had to be integrated into one Mission Control Team. All the different experts had to work together in an operational environment and the interaction and interfaces between all elements of the system (software, hardware and human) had to run smoothly for this to happen:

- the flight operations procedures had to be written and validated down to the smallest detail;
- the control system had to be validated;
- system Validation Tests (SVTs) with the satellite had to be performed to demonstrate the correct interfacing of the ground and space segments;
- mission Readiness Test with the Ground Stations had to be performed;
- a Simulations Campaign was run.

Launch

The spacecraft was launched on June 2, 2003 at 23:45 local time (17:45 UT, 1:45 p.m. EDT) from Baikonur Cosmodrome in Kazakhstan, using a Soyuz-FG/Fregat rocket. The Mars Express and Fregat booster were initially put into a 200 km Earth parking orbit, then the Fregat was fired again at 19:14 UT to put the spacecraft into a Mars transfer orbit. The Fregat and Mars Express separated at approximately 19:17 UT. The solar panels were then deployed and a trajectory correction maneuver was performed on June 4 to aim Mars Express towards Mars and allow the Fregat booster to coast into interplanetary space.

Near earth commissioning phase

The Near Earth Commissioning phase extended from the separation of the spacecraft from the launcher upper stage until the completion of the initial check out of the orbiter and payload. It included the solar array deployment, the initial attitude acquisition, the declamping of the Beagle-2 spin-up mechanism, the injection error correction manoeuvre and the first commissioning of the spacecraft and payload (final commissioning of payload took place after Mars Orbit Insertion). The payload was checked out one instrument at a time. This phase lasted about one month.

The interplanetary cruise phase

This five month phase lasted from the end of the Near Earth Commissioning phase until one month prior to the Mars capture manoeuvre and included trajectory correction manoeuvres and payloads calibration. The payload was mostly switched off during the cruise phase, with the exception of some intermediate check-outs. Although it was originally meant to be a "quiet cruise" phase, It soon became obvious that this "cruise" would be indeed very busy. There were star Tracker problems, a power wiring problem, extra manoeuvres, and on the 28th of October, the spacecraft was hit by one of the largest solar flares ever recorded.

Lander jettison

The Beagle 2 lander was released on December 19 at 8:31 UTC (9:31 CET) on a ballistic cruise towards the surface. It entered Mars' atmosphere on the morning of December 25. Landing was expected to occur at about 02:45 UT on December 25 (9:45 p.m. EST December 24). However, after repeated attempts to contact the lander failed using the Mars Express craft and the NASA Mars Odyssey orbiter, it was declared lost on February 6, 2004, by the Beagle 2 Management Board. On February 11, ESA announced an inquiry would be held into the failure of *Beagle 2*.

Orbit insertion

Mars Express arrived at Mars after a 400 million km journey and course corrections in September and in December 2003.

On December 20 Mars Express fired a short thruster burst to put it into position to orbit the planet. The Mars Express Orbiter then fired its main engine and went into a highly elliptical initial-capture orbit of 250 km × 150,000 km with an inclination of 25 degrees on December 25 at 03:00 UT (10:00 p.m., December 24 EST).

First evaluation of the orbital insertion showed that the orbiter had reached its first milestone at Mars. The orbit was later adjusted by four more main engine firings to the desired 259 km × 11,560 km near-polar (86 degree inclination) orbit with a period of 7.5 hours. Near periapsis the top deck is pointed down towards the Martian surface and near apoapsis the high gain antenna will be pointed towards Earth for uplink and downlink.

After 100 days the apoapsis was lowered to 10,107 km and periapsis raised to 298 km to give an orbital period of 6.7 hours.

MARSIS deployment

On May 4, 2005, *Mars Express* deployed the first of its two 20-metre-long radar booms for its MARSIS (Mars Advanced Radar for Subsurface and Ionosphere Sounding) experiment. At first the boom did not lock fully into place; however, exposing it to sunlight for a few minutes on May 10 fixed the glitch. The second 20 m boom was successfully deployed on June 14. Both 20 m booms were needed to create a 40 m dipole antenna for MARSIS to work; a less crucial 7-meter-long monopole antenna was deployed on June 17. The radar booms were originally scheduled to be deployed in April 2004, but this was delayed out of fear that the deployment could damage the spacecraft through a whiplash effect. Due to the delay it was decided to split the four week commissioning phase in two parts, with two weeks running up to July 4 and another two weeks in December 2005.

The deployment of the booms was a critical and highly complex task requiring effective inter-agency cooperation ESA, NASA, Industry and public Universities.

Nominal science observations began during July 2005.

Operations of the spacecraft

Operations for Mars Express are carried out by a multinational team of engineers from ESA's Operation Centre (ESOC) in Darmstadt. The team began preparations for the mission about 3 to 4 years prior to the actual launch. This involved preparing the ground segment and the operational procedures for the whole mission.

The Mission Control Team is composed of the Flight Control Team, Flight Dynamics Team, Ground Operations Managers, Software Support and Ground Facilities Engineers. All of these are located at ESOC but there are additionally external teams, such as the Project and Industry Support teams, who designed and built the spacecraft. The Flight Control Team consists of:

- The Spacecraft Operations Manager
- Eight Operations Engineers
- Three Mission Planners
- One Spacecraft Analyst
- Five Spacecraft controllers

The team build-up, headed by the Spacecraft Operations Manager, started about 4 years before launch . He was required to recruit a suitable team of engineers that could handle the varying tasks involved in the mission. For Mars Express the engineers came from various other missions. Most of them had been involved with Earth orbiting satellites.

Routine phase: Science return

Since orbit insertion Mars Express has been progressively fulfilling its original scientific goals. Nominally the spacecraft points to Mars while acquiring science and then slews to earth-pointing to downlink the data, although some instruments like Marsis or Radio Science might be operated while spacecraft is earth-pointing.

Mars Express Spacecraft Orbiter and subsystems

Structure

The Mars Express Orbiter is a cube-shaped spacecraft with two solar panel wings extending from opposite sides. The launch mass of 1123 kg includes a main bus with 113 kg of payload, the 60 kg lander, and 457 kg of propellant. The main body is 1.5 m × 1.8 m × 1.4 m in size, with an aluminium honeycomb structure covered by an aluminum skin. The solar panels measure about 12 m tip-to-tip. Two 20 m long wire dipole antennas extend from opposite side faces perpendicular to the solar panels as part of the radar sounder.

Propulsion

The Soyuz/Fregat launcher provided most of the thrust Mars Express needed to reach Mars. The final stage of the Fregat was jettisoned once the probe was safely on a course for Mars. The spacecraft's on-board means of propulsion was used to slow the probe for Mars orbit insertion and subsequently for orbit corrections.

The body is built around the main propulsion system, which consists of a bipropellant 400 N main engine. The two 267-liter propellant tanks have a total capacity of 595 kg. Approximately 370 kg are needed for the nominal mission. Pressurized helium from a 35 liter tank is used to force fuel into the engine. Trajectory corrections will be made using a set of eight 10 N thrusters, one attached to each corner of the spacecraft bus. The spacecraft configuration is optimized for a Soyuz/Fregat, and was fully compatible with a Delta II launch vehicle.

Power

Spacecraft power is provided by the solar panels which contain 11.42 square meters of silicon cells. The originally planned power was to be 660 W at 1.5 AU but a faulty connection has reduced the amount of power available by 30%, to about 460 W. This loss of power is not expected to significantly impact the science return of the mission. Power is stored in three lithium-ion batteries with a total capacity of 64.8 Ah for use during eclipses. The power is fully regulated at 28 V. During routine phase, the spacecraft's power consumption is in the interval 450 W - 550 W.

Avionics

Attitude control (3-axis stabilization) is achieved using two 3-axis inertial measurement units, a set of two star cameras and two Sun sensors, gyroscopes, accelerometers, and four 12 N·m·s reaction wheels. Pointing accuracy is 0.04 degree with respect to the inertial reference frame and 0.8 degree with respect to the Mars orbital frame. Three on-board systems help Mars Express maintain a very precise pointing accuracy, which is essential to allow the spacecraft to communicate with a 35-metre and 70-metre dish on Earth up to 400 million kilometres away.

Communications

The communications subsystem is composed of 3 antennas: A 1.7 m diameter parabolic dish high-gain antenna and two omnidirectional antennas. The first one provide links (Telecommands uplink and Telemetry downlink) in both X-band (7.1 GHz) and S-band (2.1 GHz) and is used during nominal science phase around Mars. The low gain antennas are used during Launch and early operations to Mars and for eventual contingencies once in orbit. Two Mars lander relay UHF antennas are mounted on the top face for communication with the Beagle 2.

Earth Stations

Although communications with Earth were originally scheduled to take place with the ESA 35-meter wide Ground Station in New Norcia (Australia) New Norcia Station, the mission profile of progressive enhancement and science return flexibility have triggered the use of the newest ESA ESTRACK Ground Station in Cebreros Station, Madrid, Spain.

In addition, further agreements with NASA Deep Space Network have made possible the use of American stations for nominal mission planning, thus increasing complexity but with a clear positive impact in scientific returns.

This inter-agency cooperation has proven effective, flexible and enriching for both sides. On the technical side, it has been made possible (among other reasons) thanks to the adoption of both Agencies of the Standards for Space Communications defined in CCSDS

Thermal

Thermal control is maintained through the use of radiators, multi-layer insulation, and actively controlled heaters. The spacecraft must provide a benign environment for the instruments and on-board equipment. Two instruments, PFS and OMEGA, have infrared detectors that need to be kept at very low temperatures (about -180 °C). The sensors on the camera (HRSC) also need to be kept cool. But the rest of the instruments and on-board equipment function best at room temperatures (10-20 °C).

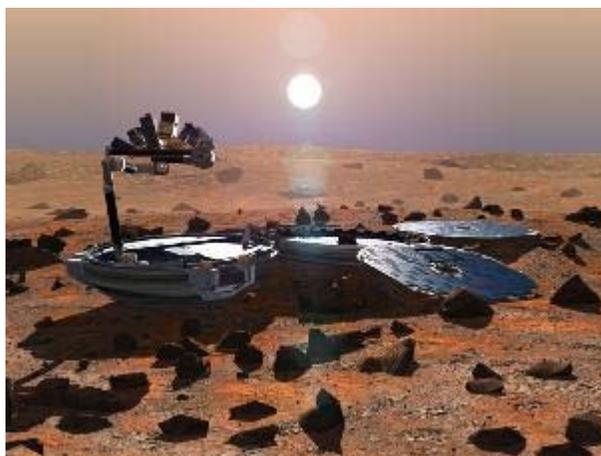
The spacecraft is covered in gold-plated aluminium-tin alloy thermal blankets to maintain a temperature of 10-20 °C inside the spacecraft. The instruments that operate at low temperatures to be kept cold are thermally insulated from this relatively high internal temperature, and emit excess heat into space using attached radiators.

Control Unit and Data storage

The spacecraft is run by two Control and Data management Units with 12 gigabits of solid state mass memory for storage of data and housekeeping information for transmission. The on-board computers control all aspects of the spacecraft functioning including switching instruments on and off, assessing the spacecraft orientation in space and issuing commands to change it.

Another key aspect of the Mars Express mission is the Mars Express AI Tool (MEXAR2). The primary purpose of the AI tool is the scheduling of when to download various parts of the collected scientific data back to Earth, a process which used to take ground controllers a significant amount of time. The new AI tool saves operator time, optimizes bandwidth use on the DSN, prevents data loss, and allows better use of the DSN for other space operations as well. The AI decides how to manage the spacecraft's 12 gigabits of storage memory, when the DSN will be available and not be in use by another mission, how to make the best use of the DSN bandwidth allocated to it, and when the spacecraft will be oriented properly to transmit back to Earth.

Lander



The *Beagle 2* lander component of Mars Express, as it would have appeared on the Martian surface.

The *Beagle 2* lander objectives were to characterize the landing site geology, mineralogy, and geochemistry, the physical properties of the atmosphere and surface layers, collect data on Martian meteorology and climatology, and search for possible signatures of life. However, the landing attempt was unsuccessful and the lander was declared lost. A Commission of Inquiry on *Beagle 2* identified four possible causes, including insufficiently strong airbags and problems with parts of the landing system colliding, but was unable to reach any firm conclusions.

Mars Express instruments

The scientific objectives of the Mars Express Payload are to obtain global high-resolution photo-geology (10 m resolution), mineralogical mapping (100 m resolution) and mapping of the atmospheric composition, study the subsurface structure, the global atmospheric circulation, and the interaction between the atmosphere and the subsurface, and the atmosphere and the interplanetary medium. The total mass budgeted for the science payload is 116 kg.

- **Visible and Infrared Mineralogical Mapping Spectrometer (OMEGA)**(Observatoire pour la Minéralogie, l'Eau, les Glaces et l'Activité) - France - Determines mineral composition of the surface up to 100 m resolution. Is mounted inside pointing out the top face. Instrument mass: 28.6 kg
- **Ultraviolet and Infrared Atmospheric Spectrometer (SPICAM)** - France - Assesses elemental composition of the atmosphere. Is mounted inside pointing out the top face. Instrument mass: 4.7 kg
- **Sub-Surface Sounding Radar Altimeter (MARSIS)** - Italy - A radar altimeter used to assess composition of sub-surface aimed at search for frozen water. Is mounted in the body and is nadir pointing, and also incorporates the two 20 m antennas. Instrument mass: 13.7 kg
- **Planetary Fourier Spectrometer (PFS)** - Italy - Makes observations of atmospheric temperature and pressure (observations suspended in September 2005). Is mounted inside pointing out the top face. , currently working. Instrument mass: 30.8 kg
- **Analyzer of Space Plasmas and Energetic Atoms (ASPERA)** - Sweden - Investigates interactions between upper atmosphere and solar wind. Is mounted on the top face. Instrument mass: 7.9 kg
- **High Resolution Stereo Camera (HRSC)**- Germany - Produces color images with up to 2 m resolution. Is mounted inside the spacecraft body, aimed through the top face of the spacecraft, which is nadir pointing during Mars operations. Instrument mass: 20.4 kg
- **Mars Express Lander Communications (MELACOM)** - UK - Allows Mars Express to act as a communication relay for landers on the Martian surface. (Has

been tested with Mars Exploration Rovers, and was used to support the landing of NASA's Phoenix mission)

- **Mars Radio Science Experiment (MaRS)** - Uses radio signals to investigate atmosphere, surface, subsurface, gravity and solar corona density during solar conjunctions. It uses the communications subsystem itself.
- A small camera to monitor the lander ejection, VMC.
- More on Payload

Scientific discoveries and important events

For more than 5000 orbits, Mars Express Payload instruments have been nominally and regularly operated. HRSC camera has been consistently mapping the Martian surface with unprecedented resolution and has taken dozens of breath-taking pictures.

2004

- January 23

ESA announced the discovery of water ice in the South Polar ice cap, using data taken on January 18 with the OMEGA instrument.

- January 28

Mars Express Orbiter reaches final science orbit around Mars.

- March 17

Orbiter detects polar ice caps that contain 85% highly carbon dioxide (CO₂) ice and 15% water ice.

- March 30

A press release announces that the orbiter has detected methane in the Martian atmosphere. Although the amount is small, about 10 parts in a thousand million, it has excited scientists ask about its source. Since methane is removed from the Martian "air" very fast, there needs to be a current source that releases fresh methane still today. Because one of the possible sources could be microbial life, it is planned to verify the reliability of this data and especially watch for difference in the concentration in various places on Mars. It is hoped that the source of this gas can be discovered by finding its location of release.

- April 28

ESA announced that the deployment of the boom carrying the radar based MARSIS antenna was delayed. It described concerns with the motion of the boom

during deployment, which can cause the spacecraft to be struck by elements of it. Further investigations are planned to make sure that this will not happen.

- July 15

Scientists working with the PFS instrument announced that they tentatively discovered the spectral features of the compound ammonia in the Martian atmosphere. Just like methane discovered earlier (see above), ammonia breaks down rapidly in Mars' atmosphere and needs to be constantly replenished. This points towards the existence of active life or geological activity; two contending phenomena whose presence so far have remained undetected.

2005

- In 2005, ESA scientists reported that the OMEGA (Visible and Infrared Mineralogical Mapping Spectrometer)(Observatoire pour la Minéralogie, l'Eau, les Glaces et l'Activité) instrument data indicates the presence of hydrated sulphates, silicates and various rock-forming minerals.

- February 8

The delayed deployment of the MARSIS antenna has been given a green light by ESA . It is planned to take place in early May 2005.

- May 5

The first boom of the MARSIS antenna was successfully deployed . At first, there was no indication of any problems, but later it was discovered that one segment of the boom did not lock . The deployment of the second boom was delayed to allow for further analysis of the problem.

- May 11

Using the Sun's heat to expand the segments of the MARSIS antenna, the last segment locked in successfully.

- June 14

The second boom was deployed, and on June 16 ESA announced it was a success

- June 22

ESA announces that MARSIS is fully operational and will soon begin acquiring data. This comes after the deployment of the third boom on June 17, and a successful transmission test on June 19.

2006

- September 21

ESA's Mars Express High Resolution Stereo Camera (HRSC) has obtained images of the Cydonia region, the location of the famous "Face on Mars". The massif became famous in a photo taken in 1976 by the American Viking 1 Orbiter. The image recorded with a ground resolution of approximately 13.7 metres per pixel.

- September 26

The Mars Express spacecraft has emerged from an unusually demanding eclipse season introducing a special, ultra-low-power mode nicknamed 'Sumo' - an innovative configuration aimed at saving the power necessary to ensure spacecraft survival.

This mode was developed through tight teamwork between ESOC mission controllers, principal investigators, industry and mission management.

- October

In October 2006 the Mars Express spacecraft has encountered a superior solar conjunction (alignment of Earth-Sun-Mars Express). The angle Sun-Earth-MEX reached a minimum on 23-Oct at 0.39 deg. at a distance of 2.66 AU. Operational measures were undertaken to minimize the impact of the link degradation, since the higher density of electrons in the solar plasma heavily impacts the radio frequency signal. More on

- December

Following the loss of NASA JPL Mars spacecraft Mars Global Surveyor (MGS), Mars Express team was requested to perform actions in the hopes of visually identifying the American spacecraft. Based on last ephemeris of MGS provided by JPL, the on-board high definition HRSC camera swept a region of the MGS orbit. Two attempts were made to find the craft, both unsuccessful.

2007

- January

First agreements with NASA-SPL undertaken for the support of Mars Express on the landing of the American lander Phoenix in May 2008

- February

The small camera VMC (used only once to monitor the lander ejection) has been recommissioned and first steps had been taken to offer students the possibility to participate in a campaign "Command Mars Express Spacecraft and take your own picture of Mars". Details to come.

- February 23

As result of the important science return, the Science Program Committee (SPC) has granted a mission extension until May 2009 to Mars Express.

- June 28

The High Resolution Stereo Camera (HRSC) has produced dramatic images of key tectonic features in Aeolis Mensae.

2008

The Mars Express Team was the winner of the Sir Arthur Clarke Award for Best Team Achievement.

2009

- February 4

The ESA's Science Programme Committee has extended the operations of Mars Express until December 31, 2009.

- October 7

ESA's Science Programme Committee has approved the extension of mission operations for Mars Express until 31 December 2012.

2010

- March 5

Flyby of Phobos to try to measure Phobos' gravity

Chapter- 8

Phobos Program

Phobos 2



Illustration of the Phobos spacecraft

Operator	IKI
Mission type	Orbiter
Satellite of	Mars
Orbital insertion date	January 29, 1989
Launch date	July 12, 1988
Launch vehicle	Proton-K rocket

COSPAR ID 1988-059A

Mass 2600 kg (6220 kg with orbital insertion hardware attached)

The **Phobos** (Russian: Фобос, Fobos) **program** was an unmanned space mission consisting of two probes launched by the Soviet Union to study Mars and its moons Phobos and Deimos. Phobos 2 became a Mars orbiter and returned 38 images with a resolution of up to 40 meters. Both probes suffered from critical failures.

Phobos 1 and 2 were of a new spacecraft design, succeeding the type used in the Venera planetary missions of 1975-1985, last used during the Vega 1 and Vega 2 missions to comet Halley.

Phobos 1 was launched on July 7, 1988 and Phobos 2 on July 12, 1988, each aboard a Proton-K rocket. They each had a mass of 2600 kg (6220 kg with orbital insertion hardware attached).

The program featured co-operation from 14 other nations including Sweden, Switzerland, Austria, France, West Germany, and the United States (who contributed the use of its Deep Space Network for tracking the twin spacecraft).

Objectives

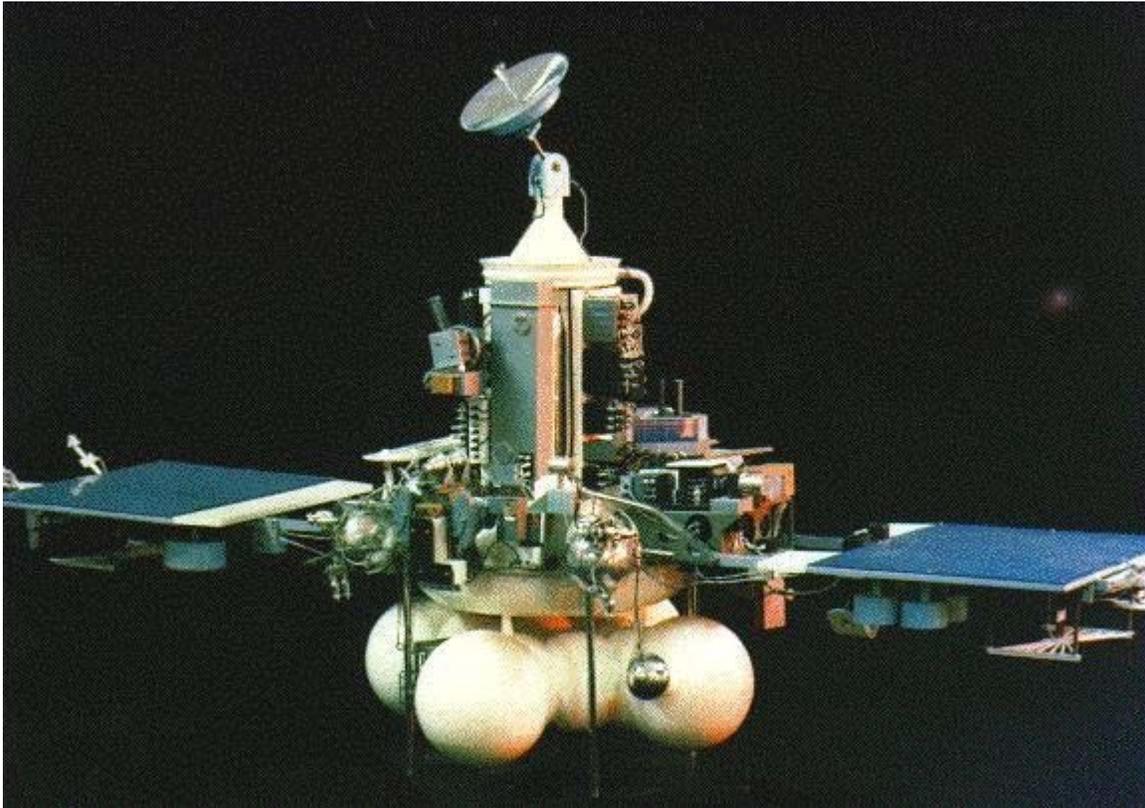
The objectives of the Phobos missions were to:

- conduct studies of the interplanetary environment;
- perform observations of the Sun;
- characterize the plasma environment in the Martian vicinity;
- conduct surface and atmospheric studies of Mars; and,
- study the surface composition of the Martian satellite Phobos.

Spacecraft design

The main section of the spacecraft consisted of a pressurized toroidal electronics section, surrounding a modular cylindrical experiment section. Below these were mounted four spherical tanks (the Fregat vehicle) containing hydrazine for attitude control and, after the main propulsion module was to be jettisoned, orbit adjustment. A total of 28 thrusters (twenty-four 50 N thrusters and four 10 N thrusters) were mounted on the spherical tanks, with additional thrusters mounted on the spacecraft body and solar panels. Attitude was maintained through the use of a three-axis control system, with pointing maintained with Sun and star sensors.

Phobos 1



Phobos spacecraft

Phobos 1 operated nominally until an expected communications session on September 2, 1988 failed to occur. The failure of controllers to regain contact with the spacecraft was traced to an error in the software uploaded on August 29/August 30, which had deactivated the attitude thrusters. By losing its lock on the Sun, the spacecraft could no longer properly orient its solar arrays, thus depleting its batteries.

A natural question is "Why would a spacecraft have instructions that turn off the attitude control, normally a fatal operation?" In this case, these instructions were part of a routine used when testing the spacecraft on the ground. Normally this routine would be removed before launch. However, the software was coded in PROMs, and so removing the test code would have required removing and replacing the entire computer. Because of time pressure from the impending launch, engineers decided to leave the command sequence in, though it should never be used. However, a single character error in constructing an upload sequence resulted in the command executing, with subsequent loss of the spacecraft.

Phobos 2

Phobos 2 operated nominally throughout its cruise and Mars orbital insertion phases on January 29, 1989, gathering data on the Sun, interplanetary medium, Mars, and Phobos. Shortly before the final phase of the mission, during which the spacecraft was to approach within 50 m of Phobos' surface and release two landers, one a mobile "hopper", the other a stationary platform, contact with Phobos 2 was lost. The mission ended when the spacecraft signal failed to be successfully reacquired on March 27, 1989. The cause of the failure was determined to be a malfunction of the on-board computer.

The Phobos design was used again for the long delayed Mars 96 mission which ended in failure when the launch vehicle's fourth stage misfired.

Controversial "last photo"

In 1989 several photographs were published, which were made shortly before *Phobos 2* failure. They lead to speculations of large UFO with 20-25km size which supposedly prevented *Phobos 2* from completing its mission. Shortly, these speculations were publicly dismissed by Glavcosmos expert M.Naraeva, who attributed artifacts on images to a distorted image of the shadow of Phobos on the surface of Mars.

Systems and sensors

Phobos probes carried several instruments: solar x-ray and ultraviolet telescopes, a neutron spectrometer and the Grunt radar experiment designed to study the surface relief of Phobos. The lander had an x-ray/alpha spectrometer to provide information on the chemical element composition of the surface of Phobos, a seismometer to determine the internal structure of Phobos, and the "Razrez" penetrator with temperature sensors and an accelerometer for testing the physical and mechanical properties of the surface.

The Phobos 2 infrared spectrometer (ISM) obtained 30 000 spectra in the near infrared (from 0.75 to 3.2 μm) in the equatorial areas of Mars, with a spatial resolution ranging from 7 to 25 km, and 400 spectra of Phobos at 700 m resolution. These observations made it possible to retrieve the first mineralogical maps of the planet and its satellite, and to study the atmosphere of Mars. ISM was developed at IAS and DESPA (Paris Observatory) with support from CNES.

List of instruments:

- "VSK" TV imaging system
- PROP-F "hopping" lander. Only carried by Phobos 2.
 - ARS-FP automatic X-ray fluorescence spectrometer
 - ferroprobe magnetometer
 - Kappameter magnetic permeability / susceptibility sensor
 - gravimeter

- temperature sensors
 - BISIN conductometer / tiltmeter
 - mechanical sensors (penetrometer, UIU accelerometer, sensors on hopping mechanism)
- "DAS" (long-lived autonomous station) lander
 - TV camera
 - ALPHA-X Alpha-Proton-X-Ray Spectrometer
 - LIBRATION sun sensor (also known as STENOPEE)
 - Seismometer
 - RAZREZ anchor penetrometer
 - Celestial mechanics experiment
- "ISM" thermal infrared spectrometer/radiometer - 1–2 km resolution
- near-infrared imaging spectrometer
- thermal imaging camera; magnetometers
- gamma-ray spectrometers
- X-ray telescope
- radiation detectors
- radar and laser altimeters
- Lima-D laser experiment - designed to vaporise material from the Phobos surface for chemical analysis by a mass spectrometer
- "Grunt" imaging radar - Only carried by Phobos 1