

Handbook of Space Probes



Verdell Jefferson

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Chapter- 1

Clementine (Spacecraft)

Clementine



Organization	BMDO / NASA
Major contractors	Naval Research Laboratory
Mission type	Lunar science
Satellite of	Moon
Launch	January 25, 1994 at 16:34:00 UTC
Launch vehicle	Titan 23G
End of mission	Signal too weak to receive: June 1994
Mission duration	115 days

Mass	227 kg
NSSDC ID	1994-004A
Webpage	NASA NSSDC Master Catalog
Orbital elements	
Semimajor axis	5,116.0 km
Eccentricity	0.36
Inclination	90°
Orbital period	300 minutes
Apoapsis	4,594 km
Periapsis	2,162 km
Orbits	360
Instruments	
Charged particle telescope	Measure the flux and spectra of energetic protons and electrons
Ultraviolet/Visible camera	Study the Moon and 1620 Geographos at five different wavelengths in the ultraviolet spectrum
Near-Infrared CCD camera (NIR)	Study the Moon and 1620 Geographos at six different wavelengths in the near-

	infrared spectrum
Laser Image Detection and Ranging (LIDAR) system	Measure the distance from the spacecraft to a point on the surface of the Moon
High-resolution camera (HIRES)	Study selected portions of the Moon and asteroid

Clementine (officially called the **Deep Space Program Science Experiment (DSPSE)**) was a joint space project between the Ballistic Missile Defense Organization (BMDO, previously the Strategic Defense Initiative Organization, or SDIO) and NASA. Launched on January 25, 1994, the objective of the mission was to test sensors and spacecraft components under extended exposure to the space environment and to make scientific observations of the Moon and the near-Earth asteroid 1620 Geographos. The Geographos observations were not made due to a malfunction in the spacecraft.

The lunar observations made included imaging at various wavelengths in the visible as well as in ultraviolet and infrared, laser ranging altimetry, gravimetry, and charged particle measurements. These observations were for the purposes of obtaining multi-spectral imaging of the entire lunar surface, assessing the surface mineralogy of the Moon, obtaining altimetry from 60N to 60S latitude, and obtaining gravity data for the near side. There were also plans to image and determine the size, shape, rotational characteristics, surface properties, and cratering statistics of Geographos.

Clementine carried seven distinct experiments on-board: a UV/Visible Camera, a Near Infrared Camera, a Long Wavelength Infrared Camera, a High Resolution Camera, two Star Tracker Cameras, a Laser Altimeter, and a Charged Particle Telescope. The S-band transponder was used for communications, tracking, and the gravimetry experiment. The project was named Clementine after the song "Oh My Darling, Clementine" as the spacecraft would be "lost and gone forever" following its mission.

Spacecraft design

The spacecraft was an octagonal prism 1.88 m high and 1.14 m across with two solar panels protruding on opposite sides parallel to the axis of the prism. A 42-inch-diameter (1,100 mm) high-gain fixed dish antenna was at one end of the prism, and the 489 N thruster at the other end. The sensor openings were all located together on one of the eight panels, 90 degrees from the solar panels, and protected in flight by a single sensor cover.

The spacecraft propulsion system consisted of a monopropellant hydrazine system for attitude control and a bipropellant nitrogen tetroxide and monomethyl hydrazine system

for the maneuvers in space. The bipropellant system had a total capability of about 1,900 m/s with about 550 m/s required for lunar insertion and 540 m/s for lunar departure.

Attitude control was achieved with 12 small attitude control jets, two star tracker cameras, and two inertial measurement units. The spacecraft was three-axis stabilized in lunar orbit via reaction wheels with a precision of 0.05 deg in control and 0.03 deg in knowledge. Power was provided by gimbaled, single axis, GaAs/Ge solar panels which charged a 15 A·h, 47 W·h/kg Nihau (Ni-H) common pressure vessel battery.

Spacecraft data processing was performed using a MIL-STD-1750A computer (1.7 MIPS) for savemode, attitude control, and housekeeping operations, a RISC 32-bit processor (18 MIPS) for image processing and autonomous operations, and an image compression system provided by the French Space Agency CNES. A data handling unit sequenced the cameras, operated the image compression system, and directed the data flow. Data was stored in a 2 Gbit dynamic solid state data recorder.

Mission



Clementine launch

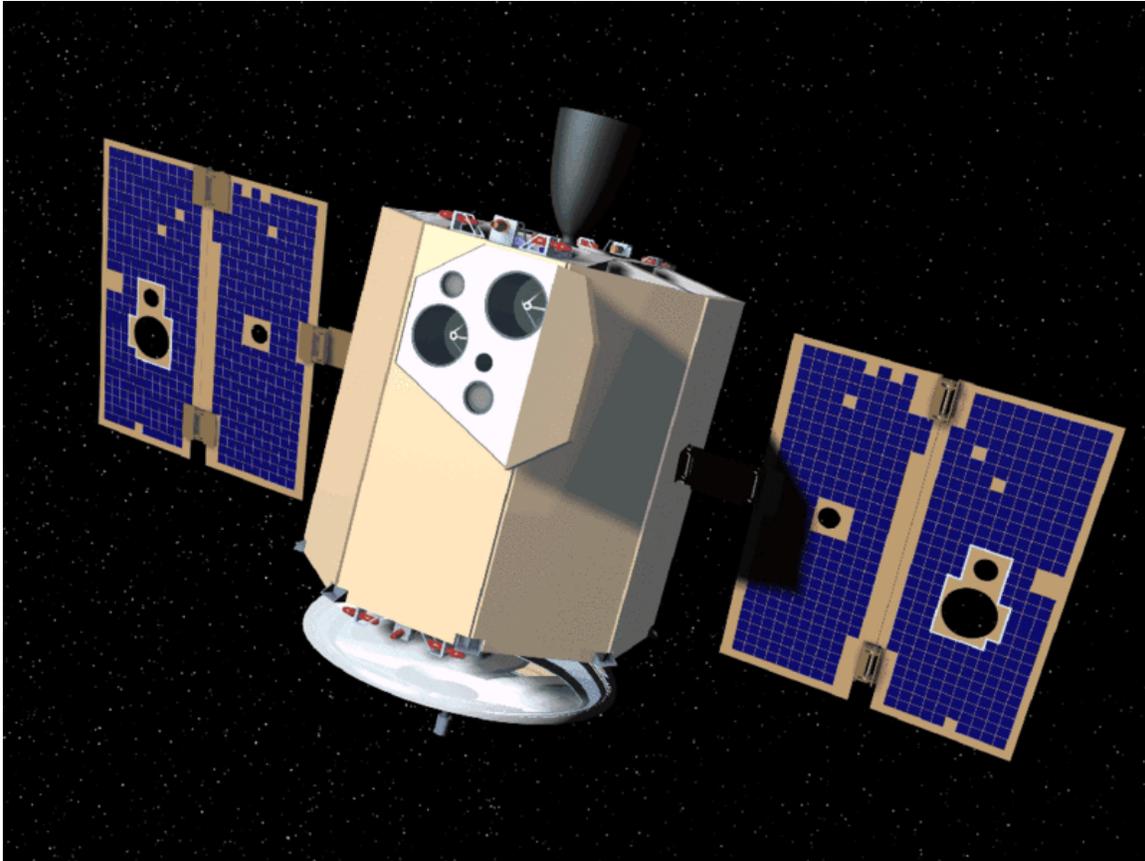
On January 25, 1994, Clementine was launched from Space Launch Complex 4 West at Vandenberg Air Force Base, California using a Titan II launch vehicle. The mission had two phases. After two Earth flybys, lunar insertion was achieved approximately one month after launch. Lunar mapping took place over approximately two months, in two parts. The first part consisted of a five hour elliptical polar orbit with a periapsis of about 400 km at 30 degrees south latitude and an apoapsis of 8300 km. Each orbit consisted of an 80 minute lunar mapping phase near periapsis and 139 minutes of downlink at apoapsis.

After one month of mapping the orbit was rotated to a periapsis at 30 degrees north latitude, where it remained for one more month. This allowed global imaging and altimetry coverage from 60° south to 60° north, over a total of 300 orbits.

After an Earth to moon transfer and two more Earth flybys, the spacecraft was to head for Geographos, arriving three months later for a flyby, with a nominal approach closer than 100 km. Unfortunately, on May 7, 1994, after the first Earth transfer orbit, a malfunction aboard the craft caused one of the attitude control thrusters to fire for 11 minutes, using up its fuel supply and causing Clementine to spin at 80 rpm. Under these conditions, the asteroid flyby could not yield useful results, so the spacecraft was put into a geocentric orbit passing through the Van Allen radiation belts to test the various components on board.

The mission ended in June 1994 when the power level onboard dropped to a point where the telemetry from the spacecraft was no longer intelligible.

NASA announced on March 5, 1998 that data obtained from Clementine indicated that there is enough water in polar craters of the moon to support a human colony and a rocket fueling station. Doubt has since been cast on this interpretation, however.



Artist's conception of Clementine fully deployed

Science instruments

Charged Particle Telescope (CPT)

The Charged Particle Telescope (CPT) on Clementine was designed to measure the flux and spectra of energetic protons (3–80 MeV) and electrons (25–500 KeV). The primary goals of the investigation were to: (1) study the interaction of the Earth's magnetotail and interplanetary shocks with the Moon; (2) monitor the solar wind in regions far removed from other spacecraft as part of a multimission coordinated study; and, (3) measure the effects of incident particles on the operating ability of the spacecraft solar cells and other sensors.

In order to meet the stringent limit on the mass of the instrument (<1 kg), it was implemented as a single element telescope. The telescope had a 10 degree half-angle field of view. The detector, a silicon surface-barrier type with an area of 100 mm² and a thickness of 3 mm, was shielded so as to prevent protons below 30 MeV from reaching it from directions other than via the aperture. The aperture was covered by a very thin foil to prevent light impinging on the detector and generating noise. The signal from the detector was broken up into nine channels, the lowest six dedicated to electron detection and the highest three to protons and heavier ions.

Ultraviolet/Visible camera

The Ultraviolet/Visible camera (UV/Vis) was designed to study the surfaces of the Moon and the asteroid Geographos at five different wavelengths in the ultraviolet and visible spectrum. The Geographos rendezvous was canceled due to equipment malfunction. This experiment yielded information on the petrologic properties of the surface material on the Moon, as well as giving images useful for morphologic studies and cratering statistics. Most images were taken at low Sun angles, which is useful for petrologic studies but not for observing morphology.

The sensor consisted of a catadioptric telescope with an aperture of 46 mm and fused silica lenses focused onto a coated Thompson CCD camera with a bandpass of 250–1000 nm and a six-position filter wheel. The wavelength response was limited on the short wavelength end by the transmission and optical blur of the lens, and on the long end by the CCD response. The CCD was a frame transfer device which allowed three gain states (150, 350, and 1000 electrons/bit). Integration times varied from 1–40 ms depending on gain state, solar illumination angle, and filter. The filter center wavelengths (and bandpass widths (FWHM)) were 415 nm (40 nm), 750 nm (10 nm), 900 nm (30 nm), 950 nm (30 nm), 1000 nm (30 nm), and a broad-band filter covering 400–950 nm. The field of view was 4.2×5.6 degrees, translating to a cross-track width of about 40 km at a nominal 400 km lunar altitude. The image array was 288×384 pixels. Pixel resolution varied from 100–325 m during a single orbit mapping run at the Moon. At Geographos the pixel resolution would have been 25 m at the 100 km closest approach, giving an image size about 7×10 km. The camera took twelve images in each 1.3 s image burst, which occurred 125 times over the 80-minute mapping span during each five-hour lunar orbit. The Moon's surface was covered completely during the two month lunar mapping phase of the mission. The dynamic range was 15,000. The signal-to-noise ratio varied from 25–87 depending on the surface albedo and phase angle, with a relative calibration of 1% and an absolute calibration of 15%.

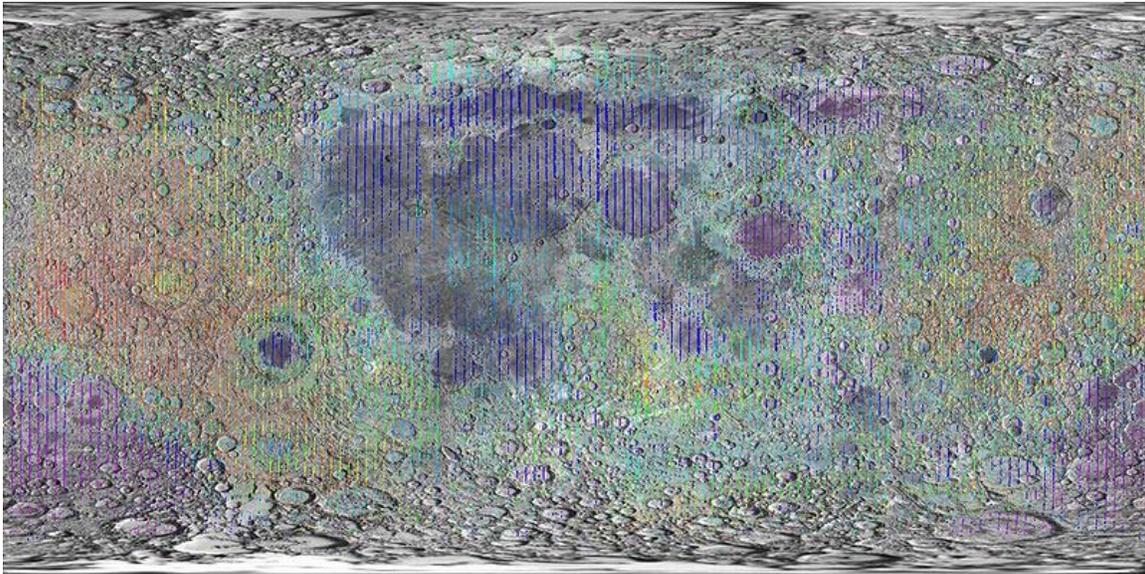
Near-Infrared CCD Camera (NIR)

The Clementine Near-Infrared camera (NIR) was designed to study the surfaces of the Moon and the near-Earth asteroid 1620 Geographos at six different wavelengths in the near-infrared spectrum. This experiment yielded information on the petrology of the surface material on the Moon. The rendezvous with Geographos was canceled due to equipment malfunction.

The camera consisted of a catadioptric lens which focused on a mechanically cooled (to a temperature of 70 K) Amber InSb CCD focal-plane array with a bandpass of 1100–2800 nm and a six-position filter wheel. The filter center wavelengths (and bandpass widths (FWHM)) were: 1100 nm (60 nm), 1250 nm (60 nm), 1500 nm (60 nm), 2000 nm (60 nm), 2600 nm (60 nm), and 2780 nm (120 nm). The aperture was 29 mm with a focal length of 96 mm. The field of view was 5.6×5.6 degrees, giving a cross-track width of about 40 km at a nominal 400 km lunar altitude. The Moon had complete mapping coverage during the two month lunar phase of the mission. The image array is 256×256

pixels, and pixel resolution varied from 150–500 m during a single orbit mapping run at the Moon. (At Geographos the pixel resolution would have been 40 m at closest approach, giving an image size about 10×10 km.) The camera took twelve images in each 1.3 s image burst, which occurred 75 times over the 80 minute mapping span during each five hour lunar orbit. The dynamic range was 15,000. The signal-to-noise ratio varied from 11–97 depending on the surface albedo and phase angle, with a relative calibration of 1% and an absolute calibration of 30%. The gain varied from 0.5X to 36X.

Laser Image Detection and Ranging (LIDAR) System



Relief measurements made by LIDAR

The Clementine Laser Image Detection And Ranging (LIDAR) experiment was designed to measure the distance from the spacecraft to a point on the surface of the Moon. This will allow an altimetric map to be made, which can be used to constrain the morphology of large basins and other lunar features, study stress and strain and flexural properties of the lithosphere, and can be combined with gravity to study the density distribution in the crust. The experiment was also designed to measure distances to the surface of Geographos, but this phase of the mission was canceled due to a malfunction.

The LIDAR system consisted of a 180 mJ, 1064 nm wavelength Nd-YAG (Yttrium-Aluminum-Garnet) laser transmitter which transmitted pulses to the lunar surface. The laser produced a pulse with a width less than 10 ns. At 1064 nm wavelength, the pulse had an energy of 171 mJ with a divergence less than 500 microrad. At 532 nm, it had a 9 mJ pulse with a 4 millirad divergence. The reflected pulse travelled through the High-Resolution Camera telescope, where it was split off by a dichroic filter to a silicon avalanche photodiode detector. The detector was a single 0.5×0.5 mm cell SiAPD receiver with a field of view of 0.057 square degrees. The laser had a mass of 1250 g, the receiver was housed in the 1120 g HIRES camera. The travel time of a pulse gave the range to the surface. The LIDAR memory could save up to six return detections per laser

firing, with a threshold set for the best compromise between missed detections and false alarms. The returns were stored in 39.972 m range bins, equal to the resolution of the 14-bit clock counter. The LIDAR has a nominal range of 500 km, but altimetric data was gathered for altitudes up to 640 km, which allowed coverage from 60 degrees south to 60 degrees north by the end of the lunar phase of the mission. The vertical resolution is 40 m, and the horizontal spot resolution is about 100 m. The across track spacing of the measurements at the equator was about 40 km. One measurement was made each second over a 45 minute period during each orbit, giving an along track spacing of 1–2 km.

High-Resolution Camera (HIRES)

The Clementine High-Resolution Camera consisted of a telescope with an image intensifier and a frame-transfer CCD imager. The imaging system was designed to study selected portions of the surfaces of the Moon and the near-Earth asteroid 1620 Geographos, although the asteroid rendezvous was canceled due to a malfunction. This experiment allowed the detailed study of surface processes on the Moon and, combined with spectral data, allowed high-resolution compositional and geologic studies.

The imager was an intensified Thompson CCD camera with a six position filter wheel. The set of filters consisted of a broad-band filter with a bandpass of 400 to 800 nm, four narrow-band filters with center wavelengths (and bandpass width (FWHM)) of 415 nm (40 nm), 560 nm (10 nm), 650 nm (10 nm), and 750 nm (20 nm), and 1 opaque cover to protect the image intensifier. The field of view was 0.3 x 0.4 degrees, translating to a width of about 2 km at a nominal lunar altitude of 400 km. The image array is 288 x 384 pixels, (pixel size of 23 x 23 micrometers) so the pixel resolution at the Moon was 7–20 m depending on the spacecraft altitude. (At Geographos the resolution would have been <5 m at closest approach.) The clear aperture was 131 mm and the focal length was 1250 mm. The nominal imaging rate was about 10 frames per second in individual image bursts covering all filters at the Moon. The high resolution and small field of view only allowed coverage of selected areas of the Moon, in the form of either long, narrow strips of a single color or shorter strips of up to four colors. The instrument has a signal to noise ratio of 13 to 41 depending on the albedo and phase angle, with a 1% relative calibration and a 20% absolute calibration, and a dynamic range of 2000.

The telescope of the High-Resolution Camera was shared by the LIDAR instrument. The 1064 nm laser return was split to the LIDAR receiver (an avalanche photodiode detector) using a dichroic filter.

Bistatic Radar Experiment

The "Bistatic Radar Experiment", improvised during the mission, was designed to look for evidence of Lunar water at the Moon's poles. Radio signals from the Clementine probe's transmitter were directed towards the Moon's north and south polar regions and their reflections detected by Deep Space Network receivers on Earth. Analysis of the magnitude and polarisation of the reflected signals suggested the presence of volatile ices, interpreted as including water ice, in the Moon's surface soils. A possible ice deposit

equivalent to a sizeable lake was announced. However, later studies made using the Arecibo radio telescope showed similar reflection patterns even from areas not in permanent shadow (and in which such volatiles cannot persist), leading to suggestions that Clementine's results had been misinterpreted and may have been due to other factors such as surface roughness.

Chapter- 2

Mars Climate Orbiter

Mars Climate Orbiter



Artist's conception of the Mars Climate Orbiter.



Operator	NASA / JPL
Major contractors	Lockheed Martin Astronautics
Mission type	Orbiter
Satellite of	Mars
Launch date	1998-12-11 18:45:51 UTC (12 years, 2 months, and 13 days ago)
Launch vehicle	Delta II 7425 / Star 48

Launch site Space Launch Complex 17A
Cape Canaveral Air Force Station

Failure in transit

Mission duration (Last contact on day 286)
(1999-9-23 09:06:00 UTC)

COSPAR ID 1998-073A

Homepage Mars Climate Orbiter Website

Mass 338 kg (745 lb)

Power 500 W
(Solar array / NiH₂ batteries)

The *Mars Climate Orbiter* (formerly the Mars Surveyor '98 Orbiter) was a 338-kilogram (750 lb) robotic space probe launched by NASA on December 11, 1998 to study the Martian climate, atmosphere, surface changes and to act as the communications relay in the Mars Surveyor '98 program, for Mars Polar Lander. However, on September 23, 1999, communication with the spacecraft was lost as the spacecraft went into orbital insertion, due to a navigational error. The spacecraft encountered Mars at an improperly low altitude, causing it to incorrectly enter the upper atmosphere and disintegrate.

Mission background

History

After the loss of Mars Observer and the onset of the rising costs associated with the future International Space Station, NASA began seeking cheaper, smaller solutions to scientific interplanetary missions. In 1994, the Panel on Small Spacecraft Technology was established to set guidelines for future miniature spacecraft. The panel determined that the new line of miniature spacecraft should be under 1000-kilograms with highly focused instrumentation. In 1995, a new Mars Surveyor program began as a set of missions designed with limited objectives, low costs, and frequent launches. The first mission in the new program was Mars Global Surveyor, launched in 1996 to map Mars and provide geologic data using instruments intended for Mars Observer. Following Mars Global Surveyor, *Mars Climate Orbiter* carried two instruments, one originally intended for Mars Observer, to study the climate and weather of Mars.

The primary science objectives of the mission included:

- determine the distribution of water on Mars
- monitor the daily weather and atmospheric conditions
- record changes on the martian surface due to wind and other atmospheric effects

- determine temperature profiles of the atmosphere
- monitor the water vapor and dust content of the atmosphere
- look for evidence of past climate change.

Spacecraft design

The *Mars Climate Orbiter* bus measured 2.1-meters tall, 1.6-meters wide and 2-meters deep. The internal structure is largely constructed with with graphite composite/aluminum honeycomb supports, a design found in many commercial airplanes. With exception to the scientific instruments, battery and main engine, the spacecraft includes dual redundancy on the most important systems.

Attitude control and propulsion

The spacecraft was 3-axis stabilized and included eight, hydrazine monopropellant thrusters (*four 22N thrusters to perform trajectory corrections; four 0.9N thrusters to control attitude*). Orientation of the spacecraft was determined with a star tracker, two Sun sensors and two inertial measurement units. Orientation was controlled by firing the thrusters or using three reaction wheels. To perform the Mars orbital insertion maneuver, the spacecraft also included a LEROS 1B main engine rocket , providing 640N of thrust by burning hydrazine fuel with nitrogen tetroxide (NTO) oxidizer.

Communications

The spacecraft included a 1.3-meter high-gain antenna to transceive data with the Deep Space Network over the x-band. The radio transponder designed for the Cassini–Huygens mission was utilized as a cost saving measure. The orbiter also included a two-way UHF radio frequency system to relay communications with Mars Polar Lander upon an expected landing on December 3, 1999.

Power

The space probe was powered with a 3-panel solar array, providing an average of 500 W at Mars. Deployed, the solar array measures 5.5-meters in length. Power is stored in 12-cell, 16-amp-hour Nickel hydrogen batteries. The batteries were intended to be recharged when the solar array received sunlight and power the spacecraft as it passed into the shadow of Mars. When entering into orbit around Mars, the solar array was to be utilized in the aerobraking maneuver, to slow the spacecraft until a circular orbit was achieved. The design is largely adapted from guidelines from the Small Spacecraft Technology Initiative outlined in the book, *Technology for Small Spacecraft*.

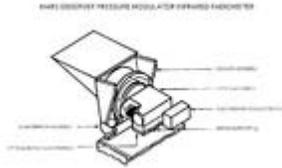
Computer

In an effort to simplify previous implementations of computers on spacecraft, *Mars Climate Orbiter* featured a single computer using an IBM RAD6000 processor capable of 5MHz, 10MHz and 20MHz operations. Data storage is maintained on 128MB of random-access memory (RAM) and 18MB of flash

memory. The flash memory was intended to be used for highly important data, including triplicate copies of the flight system software.

Scientific instruments

Pressure Modulated Infrared Radiometer (PMIRR)



Utilizes narrow-band radiometric channels and two pressure modulation cells to measure atmospheric and surface emissions in the thermal infrared and a visible channel to measure dust particles and condensates in the atmosphere and on the surface at varying longitudes and seasons.

- **Principal investigator:** Daniel McCleese / JPL/CALTECH
- similar objectives achieved with *Mars Climate Sounder* on board Mars Reconnaissance Orbiter

Mars Color Imager (MARCI)

The Mars Color Imager is a two-camera (medium-angle/wide-angle) imaging system designed to obtain pictures of the martian surface and atmosphere. Under proper conditions, resolutions up to 1-kilometer (0.5-miles) are possible.

Filters



Medium Angle Camera Filters			Wide Angle Camera Filters		
Filter Name	Wavelength	Sensitivity	Filter Name	Wavelength	Sensitivity
			UV1	280nm	N/A
			UV2	315nm	N/A
MA1	445nm		WA1	453nm	
MA2	501nm				
MA3	562nm		WA2	561nm	
			WA3	614nm	
MA4	639nm		WA4	636nm	
MA5	767nm		WA5	765nm	
MA6	829nm	N/A			
MA7	903nm	N/A			
MA8	1002nm	N/A			

- **Principal investigator:** Michael Malin / Malin Space Science Systems (website)
- relocated to **Mars Reconnaissance Orbiter**

Images of the spacecraft

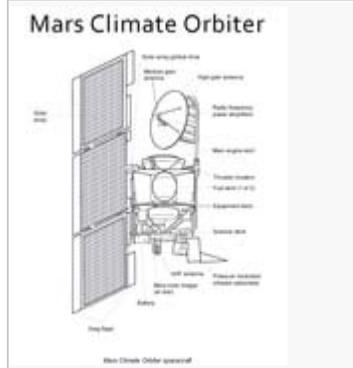
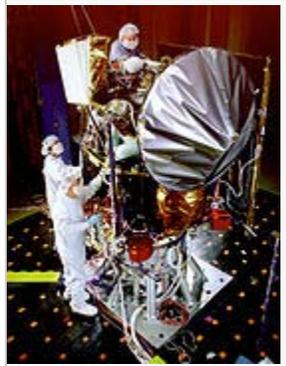


Diagram of *Mars Climate Orbiter*.



Mars Climate Orbiter during assembly.



Mars Climate Orbiter undergoing acoustic testing.



Mars Climate Orbiter awaiting a spin test in November 1998.

Mission profile

Timeline of travel

Date	Event
1998-12-11	Spacecraft launched at 18:45:51 UTC Mars orbital insertion maneuver.
1999-9-23	Time Event
	• = Events that are unaccounted for but planned for the mission.
1999-09-23	Communication with spacecraft lost at 09:04:52 UTC.
1999-09-25	Mission declared a loss. No further attempts to contact.

Launch and trajectory

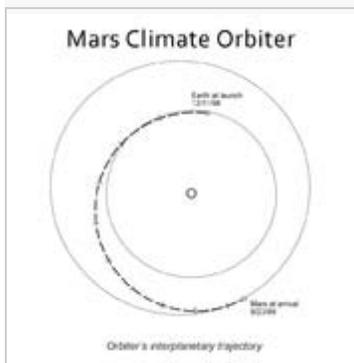
The *Mars Climate Orbiter* probe was launched on December 11, 1998 at 18:45:51 UTC by the National Aeronautics and Space Administration from Space Launch Complex 17A at the Cape Canaveral Air Force Station in Florida, aboard a Delta II 7425 launch vehicle. The complete burn sequence lasted 42 minutes bringing the spacecraft into a Hohmann transfer orbit, with a final velocity of 5.5km/s relative to Mars, and sending the probe into a 669 million-kilometer trajectory. At launch, *Mars Climate Orbiter* weighed 638-kilograms (1,418-pounds) including propellant.



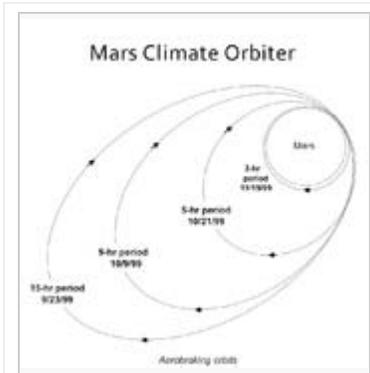
Exploded diagram of Delta II launch vehicle with *Mars Climate Orbiter*



Launch of *Mars Climate Orbiter* on a Delta II 7425 launch vehicle.



Interplanetary trajectory of *Mars Climate Orbiter*.



Aerobraking procedure to place *Mars Climate Orbiter* into orbit.

Encounter with Mars

Mars Climate Orbiter began the planned orbital insertion maneuver on September 23, 1999 at 09:00:46 UTC. However, due to complications, the spacecraft encountered Mars at a lower than anticipated altitude and disintegrated due to atmospheric stresses. **Mars Reconnaissance Orbiter** has since completed most of the intended objectives for this mission.



The only image acquired by *Mars Climate Orbiter* on September 7, 1999.

Communications loss

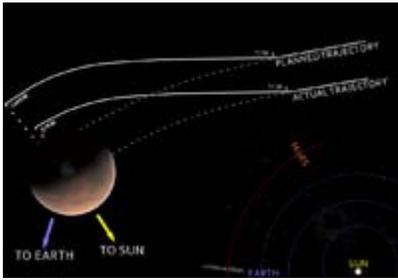


Diagram comparing the intended and actual trajectories of the *Mars Climate Orbiter*.

On **September 23, 1999**, during the Mars orbital insertion maneuver, *Mars Climate Orbiter* went out of radio contact when the spacecraft passed behind Mars at 09:04:52 UTC, 49 seconds earlier than expected, and communication was never reestablished.

On **November 10, 1999**, the Mars Climate Orbiter Mishap Investigation Board released a Phase I report, detailing the suspected issues encountered with the loss of the spacecraft. Previously, on September 8, 1999, Trajectory Correction Maneuver-4 was computed and then executed on September 15, 1999. It was intended to place the spacecraft at an optimal position for an orbital insertion maneuver that would bring the spacecraft around Mars at an altitude of 226-kilometers on September 23, 1999. However, during the week between TCM-4 and the orbital insertion maneuver, the navigation team indicated the altitude may be much lower than intended at 150-kilometers to 170-kilometers. Twenty-four hours prior to orbital insertion, calculations placed the orbiter at an altitude of 110-kilometers; 80-kilometers is the minimum altitude that Mars Climate Orbiter was thought to be capable of surviving during this maneuver. Final calculations placed the spacecraft in a trajectory that would have taken the orbiter within 57-kilometers of the surface where the spacecraft likely disintegrated because of atmospheric stresses. The primary cause of this discrepancy was human error, caused when the flight system software on board *Mars Climate Orbiter*, was written to calculate thruster performance in metric Newtons (N) while the ground crew was inputting course corrections using the Imperial measure, Pound-force (lbf). This error has since been known as the *metric mixup* and has been carefully avoided in all missions since by NASA.

Quoted from the report

The MCO MIB has determined that the root cause for the loss of the MCO spacecraft was the failure to use metric units in the coding of a ground software file, “Small Forces,” used in trajectory models. Specifically, thruster performance data in English units instead of metric units was used in the software application code titled SM_FORCES (small forces). The output from the SM_FORCES application code as required by a MSOP Project Software Interface Specification (SIS) was to be in metric units of Newtonseconds (N-s). Instead, the data was reported in English units of pound-seconds (lbf-s). The Angular Momentum Desaturation (AMD) file contained the output data from the SM_FORCES software. The SIS, which was not followed, defines both the format

and units of the AMD file generated by ground-based computers. Subsequent processing of the data from AMD file by the navigation software algorithm therefore, underestimated the effect on the spacecraft trajectory by a factor of 4.45, which is the required conversion factor from force in pounds to Newtons. An erroneous trajectory was computed using this incorrect data.

Chapter- 3

Deep Space 1

Deep Space 1



Artist rendering of *Deep Space 1*'s flyby of comet
19P/Borrelly

Operator	NASA / JPL
Major contractors	Spectrum Astro
Mission type	Flyby
Flyby of	Braille, Borrelly
Launch date	1998-10-24 12:08:00 UTC (12 years and 4 months ago)
Launch vehicle	Delta II 7326
Launch site	Space Launch Complex 17A Cape Canaveral Air Force Station

July 29, 1999 - December 18, 2001

**Mission
duration**

Braille flyby
(completed 1999-07-29)
Borrelly flyby
(completed 2001-09-22)

COSPAR ID

1998-061A

Homepage

Deep Space 1

Mass

373 kg (822 lb)

Power

2500 W (Solar Concentrator
Array/batteries)

Orbital elements

Eccentricity

0.143

Inclination

0.4°

Apoapsis

1.32 AU

Periapsis

0.99 AU

Orbital period

453 days

Instruments

**Main
instruments**

Miniature Integrated Camera
Spectrometer (MICAS)
Plasma Experiment for Planetary
Exploration (PEPE)
The Ion Propulsion System (IPS)
Diagnostic Subsystem (IDS)



Deep Space 1 (DS1) of the NASA New Millennium Program is a spacecraft dedicated to testing its payload of advanced, high risk technologies. Launched on 24 October 1998, three of twelve technologies on board had to work within a few minutes of separation from the carrier rocket for the mission to continue. The Deep Space mission carried out a flyby of asteroid 9969 Braille which was selected as the mission's science target. Its mission was extended twice to include an encounter with Comet Borrelly and further engineering testing. Problems during its initial stages and with its star tracker led to repeated changes in mission configuration. While the flyby of the asteroid was a partial success, the encounter with the comet retrieved valuable information.

The Deep Space series was continued by the Deep Space 2 probes, which were launched in January 1999 on Mars Polar Lander and were intended to strike the surface of Mars.

Technologies

Autonav

The Autonav system, developed by NASA's Jet Propulsion Laboratory, takes images of known bright asteroids. The asteroids in the inner Solar System move in relation to other bodies at a noticeable, predictable speed. Thus a spacecraft can determine its relative position by tracking such asteroids across the star background, which appears fixed over such timescales. Two or more asteroids let the spacecraft triangulate its position; two or more positions in time let the spacecraft determine its trajectory. Existing spacecraft are tracked by their interactions with the transmitters of the Deep Space Network (DSN), in effect an inverse GPS. However, DSN tracking requires many skilled operators, and the DSN is overburdened by its use as a communications network. The use of Autonav reduces mission cost and DSN demands.

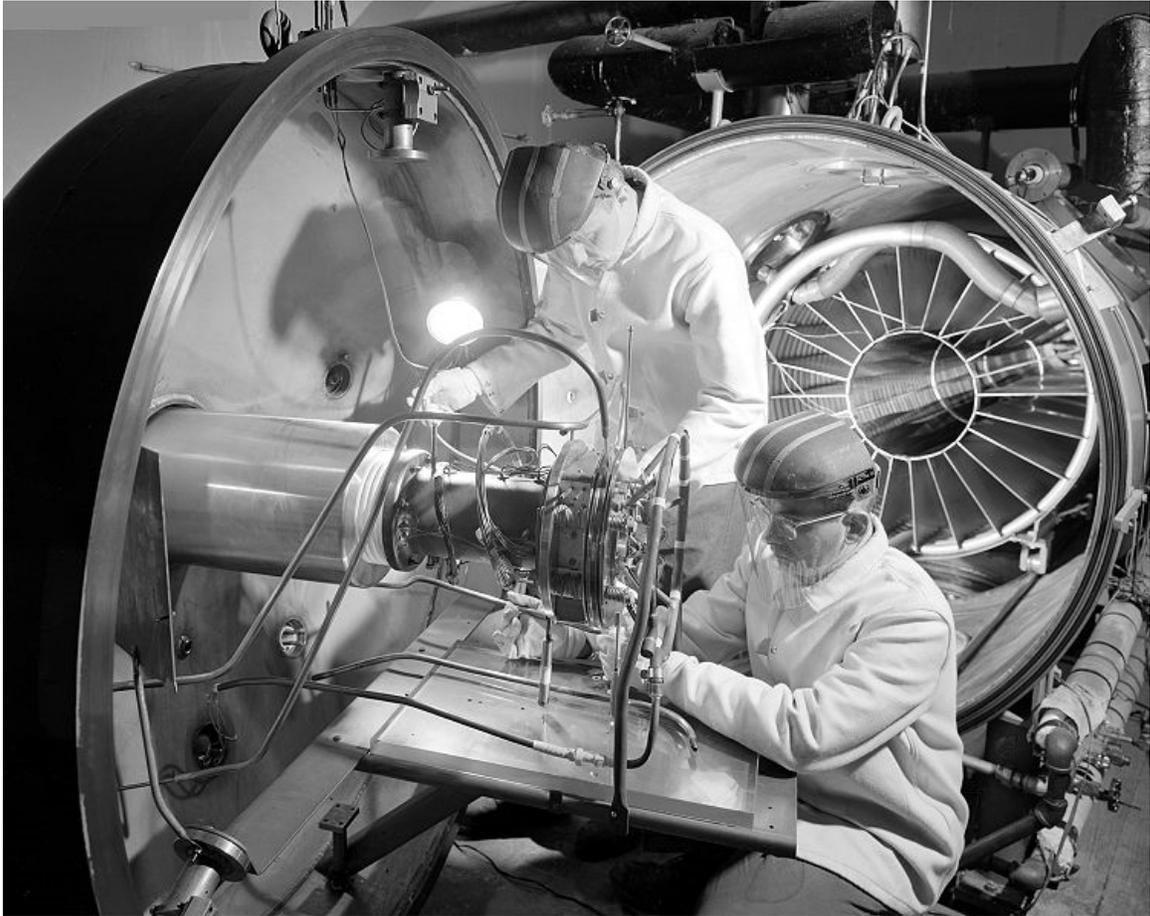
The Autonav system can also be used in reverse, tracking the position of bodies relative to the spacecraft. This is used to acquire targets for the scientific instruments. The spacecraft is programmed with the target's coarse location. After initial acquisition, Autonav keeps the subject in frame, even commandeering the spacecraft's attitude control. The next spacecraft to use Autonav was Deep Impact.

SCARLET concentrating solar array

Primary power for the mission was produced by a new solar array technology, the Solar Concentrator Array of Refractive Linear Element Technologies ("SCARLET") solar arrays, developed at NASA's Glenn Research Center. These use linear Fresnel lenses made of silicone to concentrate sunlight onto solar cells. The concentrating array technology was combined with dual-junction solar cells, which had considerably better performance than the GaAs solar cells that were the state of the art at the time of the mission launch.

The SCARLET arrays generate 2.5 kilowatts at 1 AU, with less size and weight than conventional arrays.

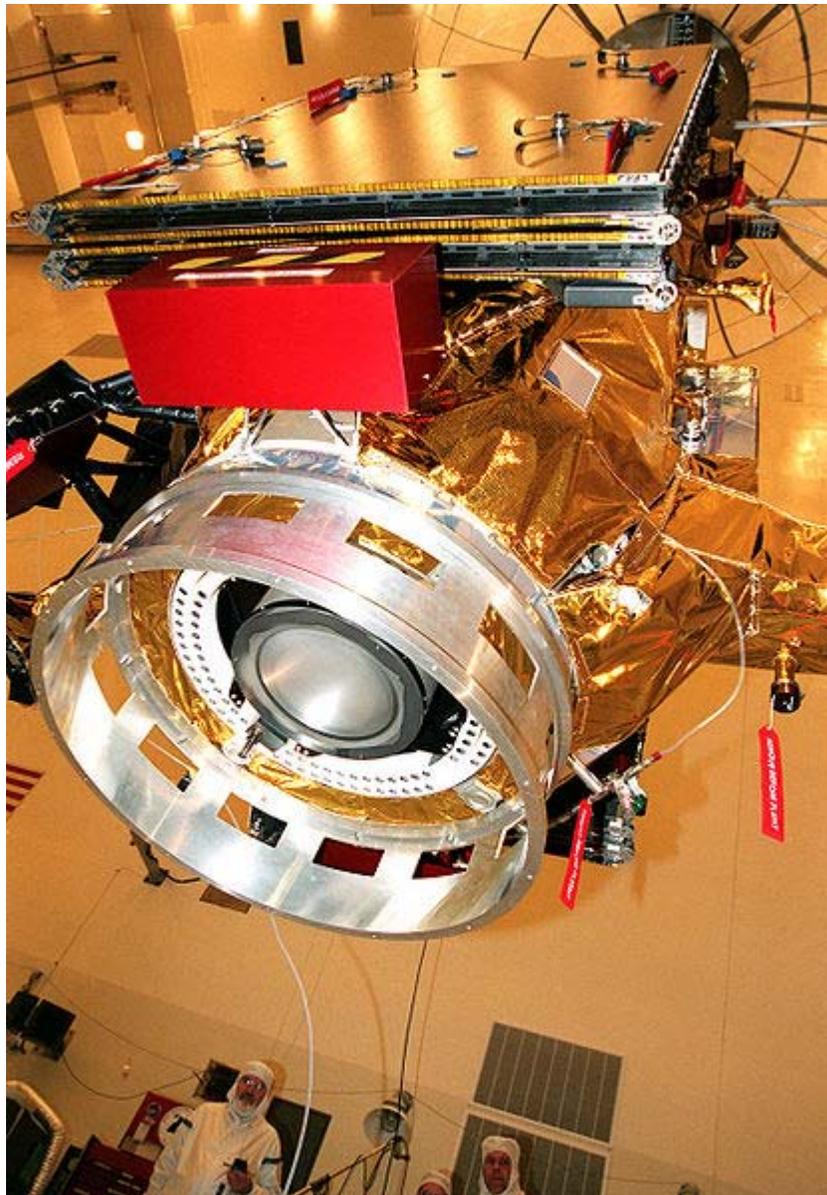
NSTAR ion engine



Technicians are installing ion engine #1 in the High Vacuum Tank in the Electric Propulsion Research Building in this image from 1959.



The fully assembled Deep Space 1 probe



The Deep Space 1 experimental solar-powered ion propulsion engine

Past, Present, Future

Although ion engines had been developed at NASA since the late 1950s, with the exception of the SERT missions in the 1960s, the technology had not been demonstrated in flight. This lack of a performance history in space meant that despite the potential savings in propellant mass, the technology was considered too experimental to be being used for high-cost missions. It was a primary mission of the Deep Space 1 demonstration to show long duration use of an ion thruster on a science mission. Deep Space 1 was the first use of ion engines on an operational science spacecraft.

The NSTAR electrostatic ion thruster, developed at NASA Glenn, achieves a specific impulse of one to three thousand seconds. This is an order of magnitude higher than

traditional space propulsion methods, resulting in a mass savings of approximately half. This leads to much cheaper launch vehicles. Although the engine produces just 92 millinewtons (0.331 ounce-force) thrust at maximum power, the craft achieved high speeds because ion engines thrust continuously for long periods. The engine fired for 678 total days, a record for such engines. The next spacecraft to use NSTAR engines was the Dawn Mission, with three redundant units.

Remote Agent

Remote Agent (remote intelligent self-repair software)(RAX), developed at NASA Ames Research Center and JPL, was the first artificial intelligence control system to control a spacecraft without human supervision. Remote Agent successfully demonstrated the ability to plan onboard activities and correctly diagnose and respond to simulated faults in spacecraft components. Autonomous control will enable future spacecraft to operate at greater distances from Earth, and to carry out more sophisticated science-gathering activities in deep space. Components of the Remote Agent software have been used to support other NASA Missions. Major components of Remote Agent were a robust planner (EUROPA), a plan execution system (EXEC) and a model-based diagnostic system (Livingstone). EUROPA was used as a ground-based planner for the Mars Exploration Rovers. EUROPA II was used to support the Phoenix Mars Lander and will support the upcoming Mars Science Laboratory. Livingstone2 was flown as an experiment onboard Earth Observing 1, and an F-18 at NASA Dryden Flight Research Center.

Beacon Monitor

Another method for reducing DSN burdens is the Beacon Monitor experiment. During the long cruise periods of the mission, spacecraft operations are essentially suspended. Instead of data, the craft emits a carrier signal on a predetermined frequency. Without data decoding, the carrier can be detected by much simpler ground antennas and receivers. If the spacecraft detects an anomaly, it changes the carrier between four tones, based on urgency. Ground receivers then signal operators to divert DSN resources. This prevents skilled operators and expensive hardware from babysitting an unburdened mission operating nominally. A similar system is used on the New Horizons Pluto probe to keep costs down during its ten-year cruise from Jupiter to Pluto.

SDST

The Small Deep Space Transponder (SDST) is a compact and light weight radio communications system. Aside from using miniaturized components, the SDST is capable of communicating over the K_a band. Because this band is higher in frequency than bands currently in use by deep-space missions, the same amount of data can be sent by smaller equipment in space and on the ground. Conversely, existing DSN antennas can split time among more missions. At the time of launch, the DSN had a small number of K_a receivers installed on an experimental basis; K_a operations and missions are increasing.

PEPE

Once at a target, DS1 senses the particle environment with the PEPE (Plasma Experiment for Planetary Exploration) instrument. It maps the objects with the MICAS (Miniature Integrated Camera And Spectrometer) imaging channel, and discerns chemical composition with infrared and ultraviolet channels. All channels share a 10 cm telescope, which uses a silicon carbide mirror.

Achievements



Comet 19P/Borrelly imaged just 160 seconds before Deep Space 1's closest approach.

The ion propulsion engine initially failed after 4.5 minutes of operation. However, it was later restored to action and performed excellently. Early in the mission, material ejected during launch vehicle separation caused the closely-spaced ion extraction grids to short-circuit. The contamination was eventually cleared, as the material was eroded by electrical arcing, sublimed by outgassing, or simply allowed to drift out. This was

achieved by repeatedly restarting the engine in an engine repair mode, arcing across trapped material.

It was thought that the ion exhaust might interfere with other spacecraft systems, such as radio communications or the science instruments. The PEPE detectors had a secondary function to monitor such effects from the engine. No interference was found.

Another failure was the loss of the star tracker. The star tracker determines spacecraft orientation by comparing the star field to its internal charts. The mission was saved when the MICAS camera was reprogrammed to substitute for the star tracker. Although MICAS is more sensitive, its field-of-view is an order of magnitude smaller, creating a greater information processing burden. Ironically, the star tracker was an off-the-shelf component, expected to be highly reliable.

Without a working star tracker, ion thrusting was temporarily suspended. The loss of thrust time forced the cancellation of a flyby past Comet Wilson-Harrington.

The Autonav system required occasional manual corrections. Most problems were in identifying objects that were too dim, or were difficult to identify because of brighter objects causing diffraction spikes and reflections in the camera, causing Autonav to misidentify targets.

The Remote Agent system was presented with three simulated failures on the spacecraft and correctly handled each event.

1. a failed electronics unit, which Remote Agent fixed by reactivating the unit.
2. a failed sensor providing false information, which Remote Agent recognized as unreliable and therefore correctly ignored.
3. an attitude control thruster (a small engine for controlling the spacecraft's orientation) stuck in the "off" position, which Remote Agent detected and compensated for by switching to a mode that did not rely on that thruster.

Overall this constituted a successful demonstration of fully autonomous planning, diagnosis, and recovery.

The MICAS instrument was a design success, but the ultraviolet channel failed due to an electrical fault. Because MICAS was reprogrammed for use as a star tracker, no usable scientific data was returned.

The flyby of the asteroid 9969 Braille was only a partial success. Deep Space 1 was intended to perform the flyby at 56,000 km/h (34,797 mph) at only 240 m (787 ft) from the asteroid. Due to technical difficulties, including a software crash shortly before approach, the craft instead passed Braille at a distance of 26 km (16 mi). This, plus Braille's lower albedo, meant that the asteroid was not bright enough for the autonav to focus the camera in the right direction, and the picture shoot was delayed by almost an hour. The resulting pictures were disappointingly indistinct.

However, the flyby of Comet Borrelly was a great success and returned extremely detailed images of the comet's surface. Such images were of higher resolution than the only previous pictures, of Halley's Comet taken by the Giotto spacecraft. The PEPE instrument reported that the comet's fields were offset from the nucleus. This is believed to be due to emission of jets, which were not distributed evenly across the comet's surface.

Despite having no debris shields, the spacecraft survived the comet passage intact. Once again, the sparse comet jets did not appear to point towards the spacecraft. The spacecraft eventually ran out of hydrazine fuel for its attitude control thrusters. The highly efficient ion thruster had a sufficient amount of propellant left to perform attitude control in addition to main propulsion, thus allowing the mission to continue.

Current status



Launch of Deep Space 1 from Cape Canaveral Air Force Station Space Launch Complex 17-A on the Delta II 7326-9.5 Star 37FM

Deep Space 1 succeeded in its primary and secondary objectives including flybys of the asteroid Braille and of Comet Borrelly, returning valuable science data and images. DS1's ion engines were shut down on 18 December 2001 at approximately 20:00:00 UTC, signaling the end of the mission. However, on-board communications remain active in case the craft is needed in the future.

Statistics

- the mass of the craft: 486.3 kg (1072 lb 2 oz) (with fuel)
- total cost: US\$149.7 million
- development cost: US\$94.8 million
- prime contractor: Spectrum Astro, later acquired by General Dynamics
- launch site: Cape Canaveral Air Station, Florida
- launch vehicle: Boeing Delta II model 7326
- maximum power: 2,500 W (of which 2,100 W powers the ion thrust engine)
- project manager: Dr. Marc Rayman

Chapter- 4

Orbiting Carbon Observatory

Orbiting Carbon Observatory



Artist rendition of the OCO satellite as it would have looked
in orbit

Mission type	Climatology
Launch date	2009-02-24, 09:20 GMT
Carrier rocket	Taurus-XL 3110
Launch site	Vandenberg LC-576E
Mission duration	Launch failure Planned: 2 years

Orbital elements

Regime	Sun-synchronous (planned)
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The **Orbiting Carbon Observatory (OCO)** is a NASA satellite mission intended to provide global space-based observations of atmospheric carbon dioxide (CO₂). The original spacecraft was lost in a launch failure on February 24, 2009, when the payload fairing of the Taurus rocket which was carrying it failed to separate during ascent. The added mass of the fairing prevented the satellite from reaching orbit. It subsequently re-entered the atmosphere and crashed into the Indian Ocean near Antarctica. The FY 2010 NASA budget request includes US\$170 million for NASA to develop and fly a replacement for the Orbiting Carbon Observatory.

Mission description

OCO's measurements would have been accurate enough to show for the first time the geographic distribution of carbon dioxide sources and sinks on a regional scale. The data would have improved the understanding of the global carbon cycle, the natural processes and human activities that influence the abundance and distribution of the greenhouse gas. This improved understanding was expected to enable more reliable forecasts of future changes in the abundance and distribution of carbon dioxide in the atmosphere and the effect that these changes may have on Earth's climate.



The A-Train satellite constellation

The OCO spacecraft was provided by Orbital Sciences Corporation. It was launched from Vandenberg Air Force Base in California on a dedicated Taurus XL rocket. However, the payload fairing — a clam shell-shaped covering that protects the satellite during launch — apparently failed to separate from the spacecraft. "We have not had a successful launch tonight and will not be able to have a successful OCO mission," NASA commentator George Diller said.

During its two-year mission, OCO would have flown in a near polar orbit which would have enabled the instrument to observe most of Earth's surface at least once every sixteen days. It would have flown in loose formation with a series of other Earth-orbiting satellites known as the Earth Observing System Afternoon Constellation, or the A-train. This coordinated flight formation was intended to enable researchers to correlate OCO data with data acquired by other instruments on other spacecraft. In particular, Earth scientists could have compared OCO data with nearly simultaneous measurements acquired by the Atmospheric Infrared Sounder (AIRS) instrument, flying on NASA's Aqua satellite.

The cost of the mission was US\$280 million. It was sponsored by NASA's Earth System Science Pathfinder Program. NASA's Jet Propulsion Laboratory in Pasadena, California, manages OCO for NASA's Science Mission Directorate.

Technology

The satellite carried a single instrument that would have taken the most precise measurements of atmospheric carbon dioxide ever made from space. The instrument consisted of three parallel, high-resolution spectrometers, integrated into a common structure and fed by a common telescope. The spectrometers would have made simultaneous measurements of the carbon dioxide and molecular oxygen absorption of sunlight reflected off the same location on Earth's surface when viewed in the near-infrared part of the electromagnetic spectrum, invisible to the human eye.

As sunlight passes through Earth's atmosphere and is reflected from Earth's surface, molecules of atmospheric gases absorb very specific colors of light. If the light is divided into a rainbow of colors, called a spectrum, the specific colors absorbed by each gas appear as dark lines. Different gases absorb different colors, so the pattern of absorption lines provides a telltale spectral "fingerprint" for that molecule. OCO's spectrometers were designed to detect these molecular fingerprints.

Each of the three spectrometers was tuned to measure the absorption in a specific range of colors. Each of these ranges includes dozens of dark absorption lines produced by either carbon dioxide or molecular oxygen. The amount of light absorbed in each spectral line increases with the number of molecules along the optical path. OCO's spectrometers would have measured the fraction of the light absorbed in each of these lines with very high precision. This information was then to be analyzed to determine the number of molecules along the path between the top of the atmosphere and the surface.

If the amount of carbon dioxide varies from place to place, the amount of absorption will also vary. To resolve these variations, the observatory's instrument was to record an image of the spectrum produced by each spectrometer three times every second as the satellite flies over the surface at more than four miles per second. This information would then have been transmitted to the ground, where carbon dioxide concentrations would have been retrieved in four separate footprints for each image collected. These spatially varying carbon dioxide concentration estimates would then have been analyzed using global transport models, like those used for weather prediction, to infer the locations of carbon dioxide sources and sinks.

The OCO instrument was developed by Hamilton Sundstrand Sensor Systems in Pomona, California, and the Jet Propulsion Laboratory.

Launch data



Launch of OCO's Taurus XL rocket

- Date: February 24, 2009, 1:55 a.m. PST
- Launch Vehicle: Orbital Sciences Taurus XL
- Launch Site: Vandenberg Air Force Base – Launch Pad SLC 576-E

The OCO launch failed because the Taurus-XL launcher payload fairing failed to separate. A payload fairing is a clamshell-shaped cover that encloses and protects a payload on the pad and during early flight. Fairings are a standard component of expendable launch vehicles, and they are always jettisoned as soon as possible after a

rocket has climbed high enough for heating from air friction to no longer risk damaging the payload. On this flight, the fairing should have been jettisoned several seconds after Stage 2 ignition. The extra mass of the fairing was not a significant factor during the flight of the larger lower stages, but it kept the relatively small Stage 3 from adding enough velocity to reach orbit, so the resulting sub-orbital ballistic path took the payload into the ocean near Antarctica, 17 minutes after liftoff.

The Orbital Taurus program manager John Brunschwyler said, "We could not make orbit. ... Initial indications are the vehicle did not have enough [force] to reach orbit and landed just short of Antarctica in the ocean. ... Certainly for the science community, it's a huge disappointment."

On July 17, 2009 NASA released a summary of its Mishap Investigation Board report. In the report the board provided recommendations to prevent any future problems associated with the four hardware components that could have caused the failure.

Proposed reflight

Three days after the failed February 2009 launch, the OCO science team sent NASA headquarters a proposal to build and launch an OCO "carbon copy", which planned to have the replacement satellite launched by late 2011. On February 1, 2010, the FY 2010 NASA budget request did include US\$170 million for NASA to develop and fly a replacement for the Orbiting Carbon Observatory.

On June 23, 2010 NASA selected Orbital Sciences for OCO 2 to launch in February 2013 on a Taurus XL 3110 from Vandenberg Air Force Base in California.

Chapter- 5

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 18 days ago)
Launch vehicle	Delta 7925

	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>
Mission duration	
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

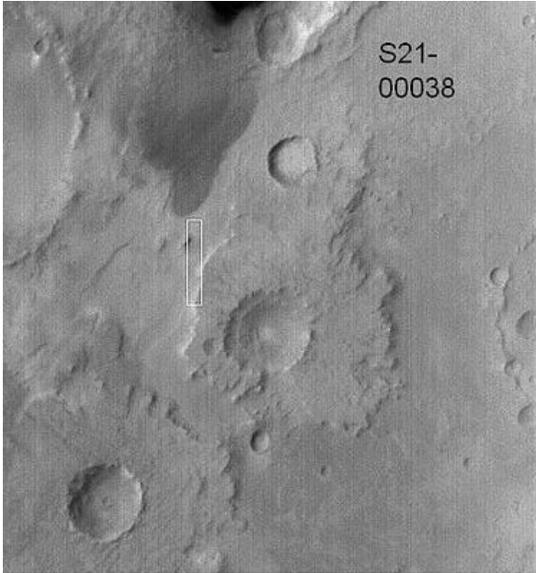


The *Mars Global Surveyor (MGS)* was a US spacecraft developed by NASA's Jet Propulsion Laboratory and launched November 1996. It began the United States's return to Mars after a 10-year absence. It completed its primary mission in January 2001 and was in its third extended mission phase when, on 2 November 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.

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.

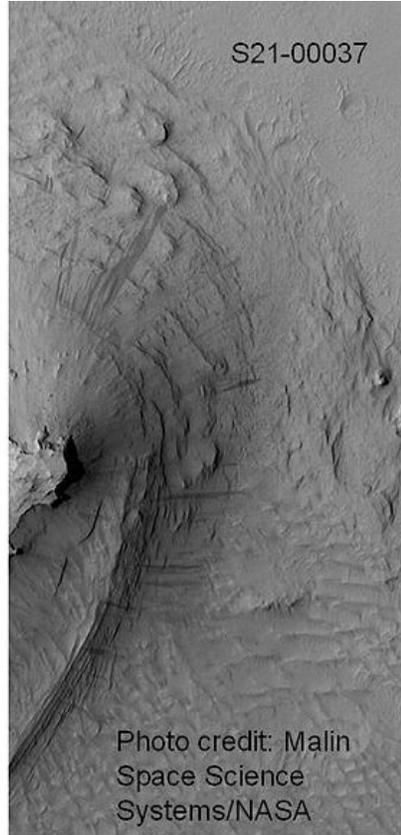
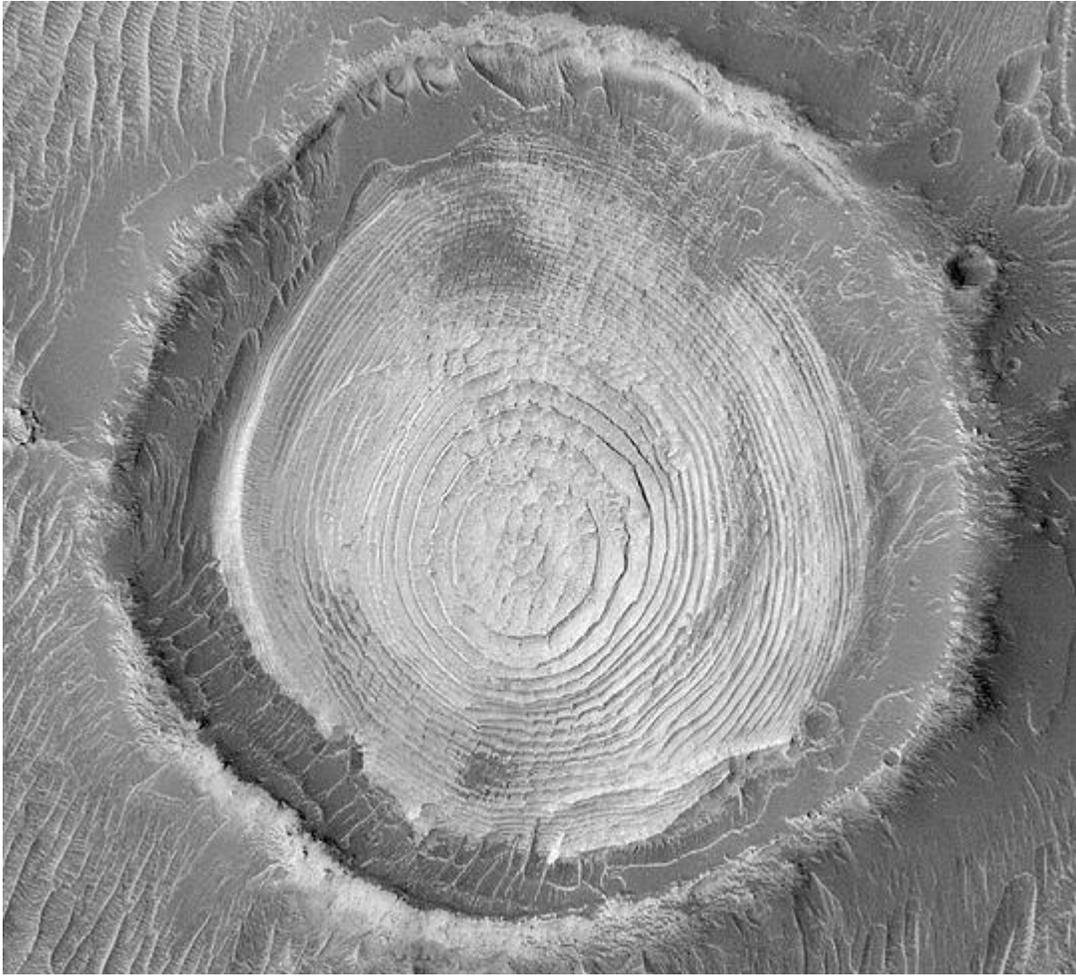


Photo credit: Malin Space Science Systems/NASA

- 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.



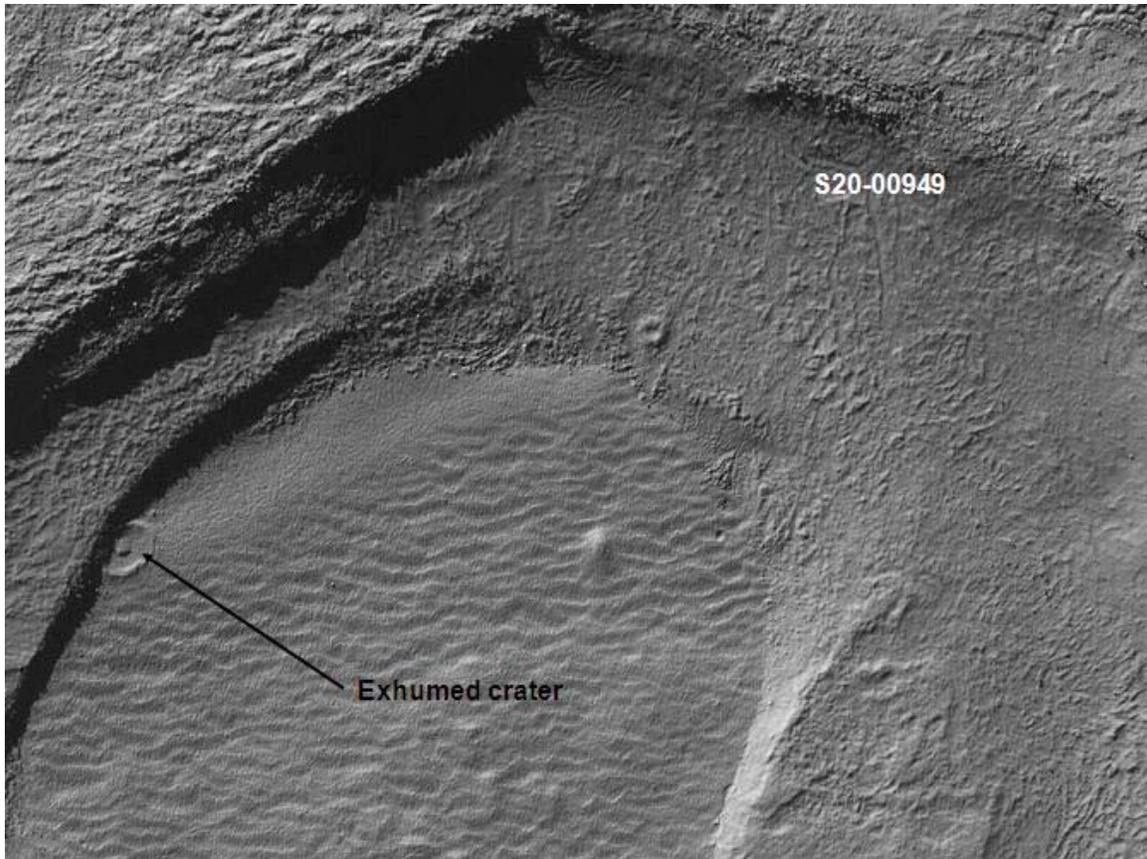
- Layers in crater found within the Schiaparelli crater basin as seen by Mars Global Surveyor. Image from the Sinus Sabaeus quadrangle.



- 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.
- The northern hemisphere is probably just as cratered as the southern hemisphere, but the craters are mostly buried.
- Many features, like impact craters, were buried, then recently exhumed.



- 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.

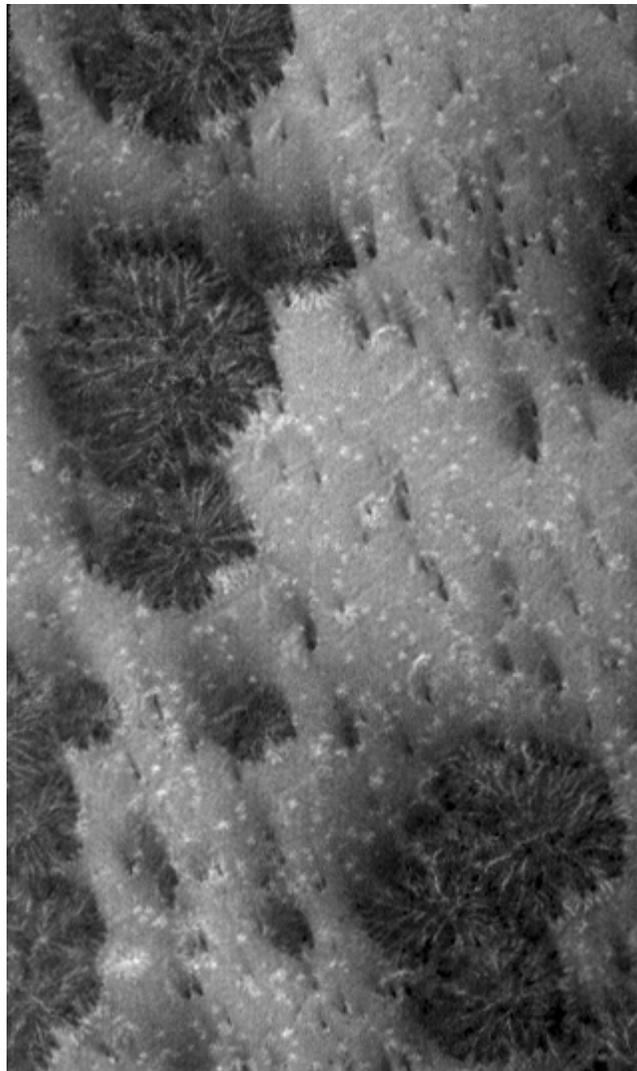
Scientific instruments

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.



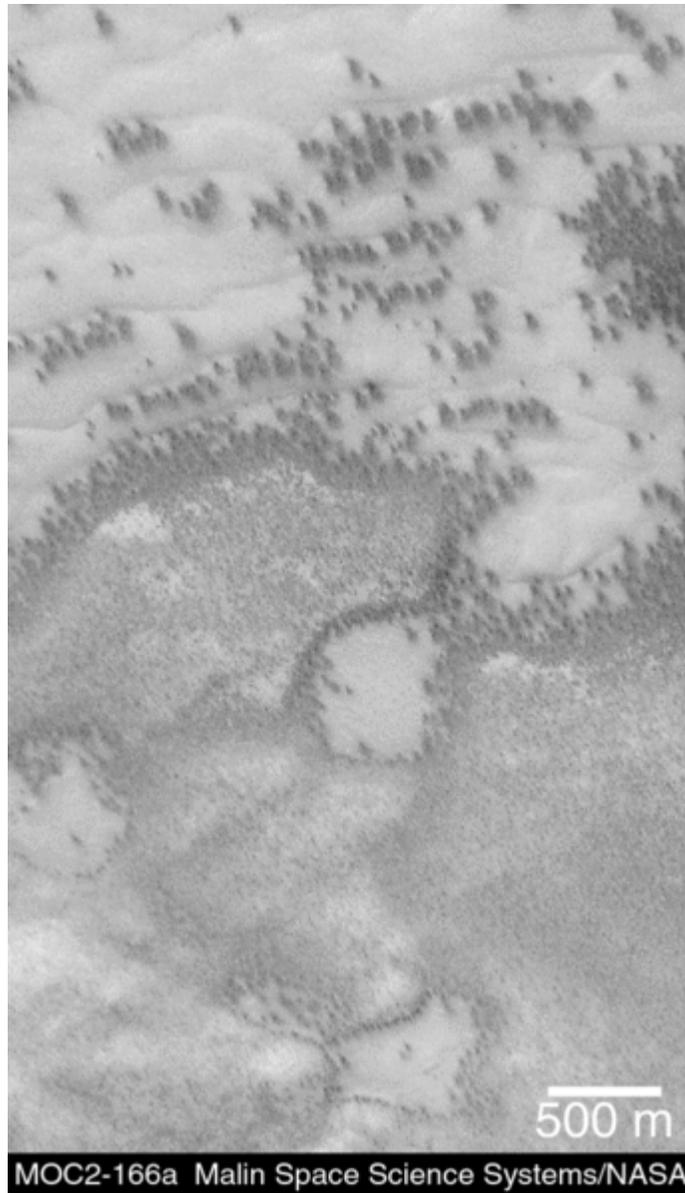
Surface of Mars taken by the Mars Global Surveyor and released on 16 October 2000.



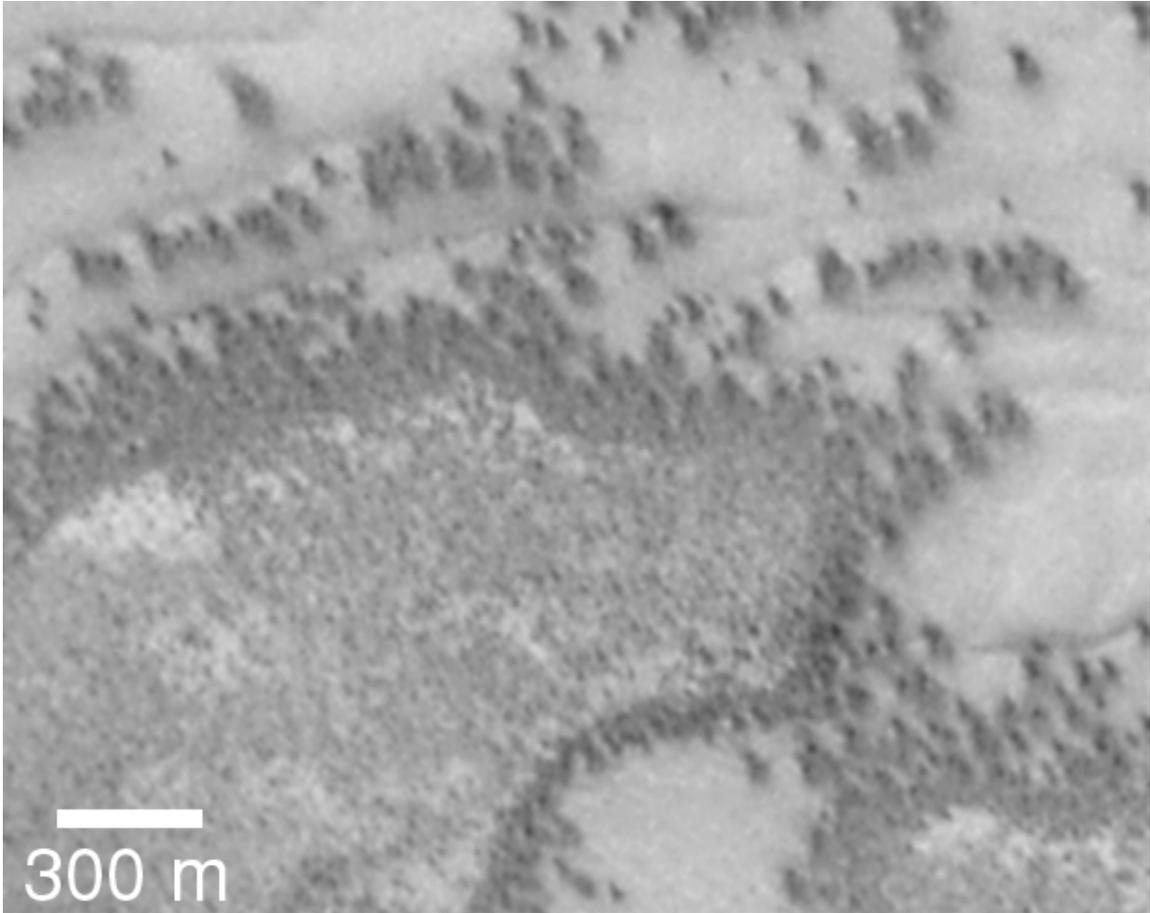
Surface of Mars taken by the Mars Global Surveyor.



Surface of Mars taken by the Mars Global Surveyor.



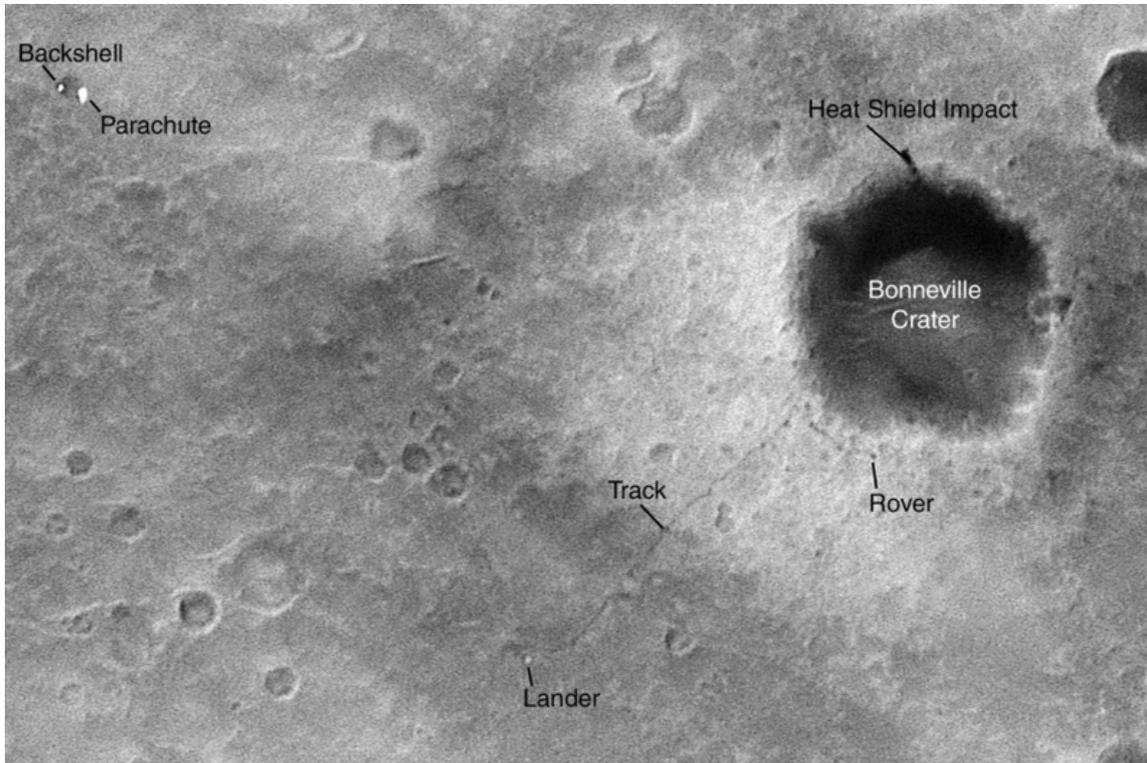
Surface of Mars taken by the Mars Global Surveyor on 10 August 1999.



300 m

MOC2-166b Malin Space Science Systems/NASA

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*.

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.

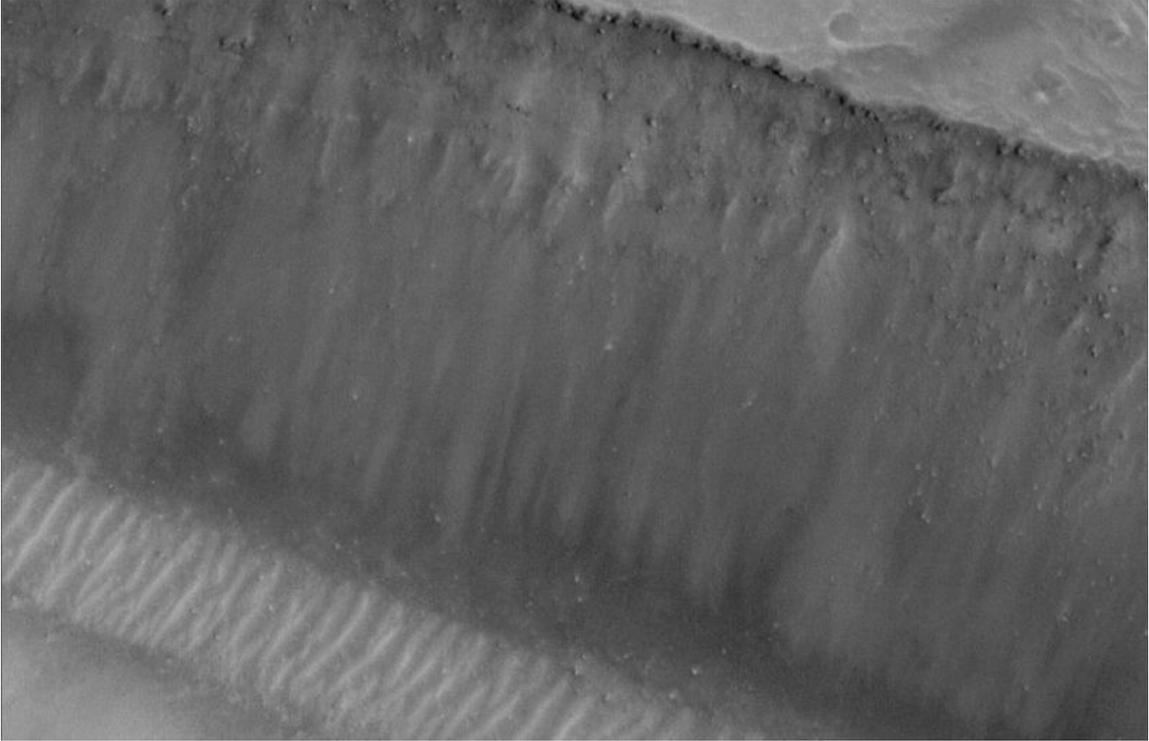
Upon reaching Mars, *Surveyor* fired its main rocket engine for the 22-minute Mars orbit insertion (MOI) burn. This maneuver slowed the spacecraft and allowed the planet's gravity to capture it into orbit. Initially, *Surveyor* entered a highly elliptical orbit that took 45 hours to complete. The orbit 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.

Aerobraking

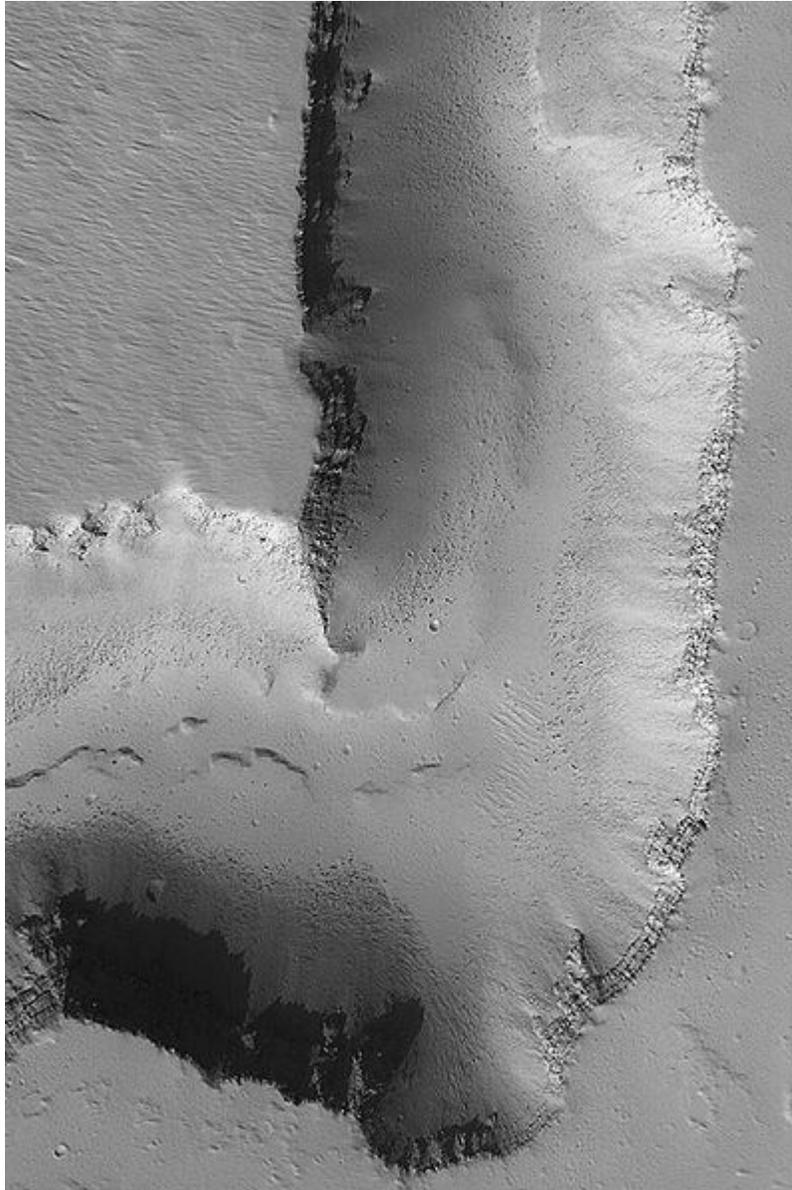
After orbit insertion, *Surveyor* performed a series of orbit changes to lower the periapsis of its orbit into the upper fringes of the Martian atmosphere at an altitude of about 110 km (68 mi). During every atmospheric pass, the spacecraft slowed down by a slight amount because of atmospheric resistance. 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).



- 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 from lava flows.

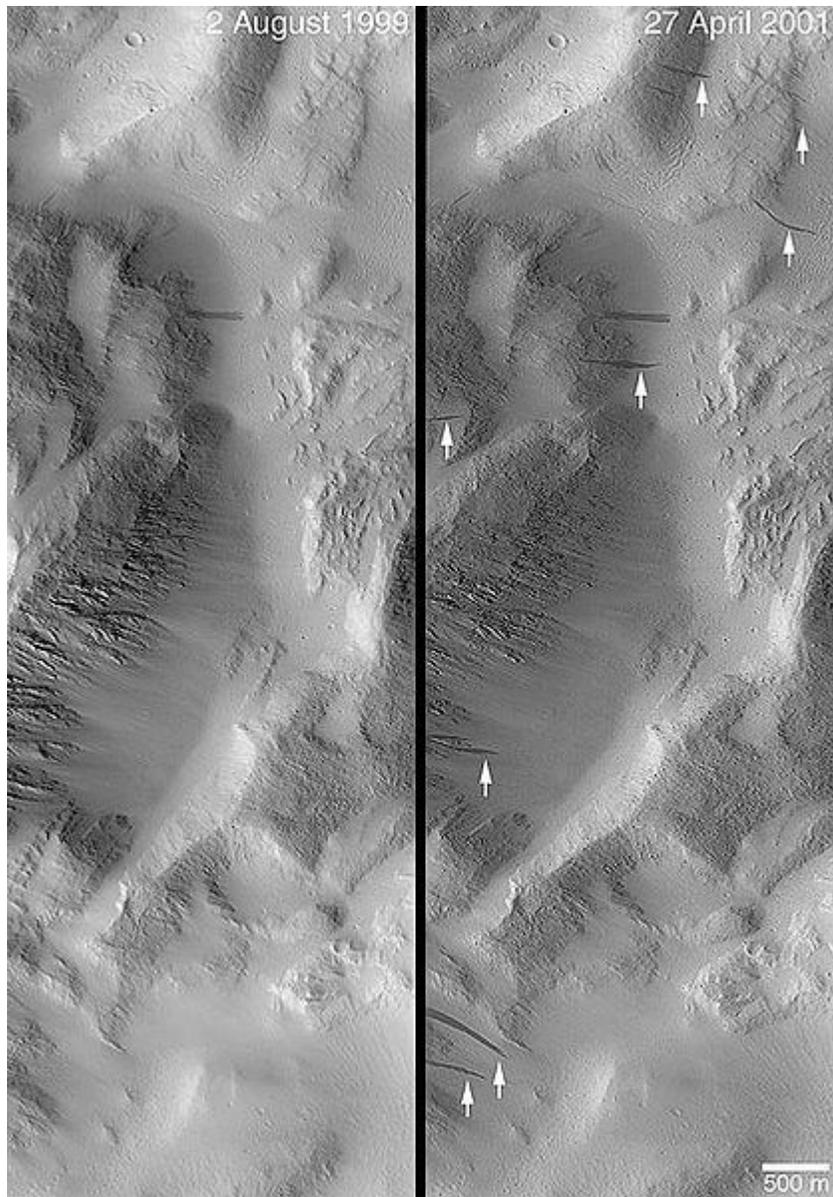


- House-sized boulders are scattered throughout this image.



- 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.
- Labeled Streaks

Dark streaks were discovered with the sensitive camera of the MGS.



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

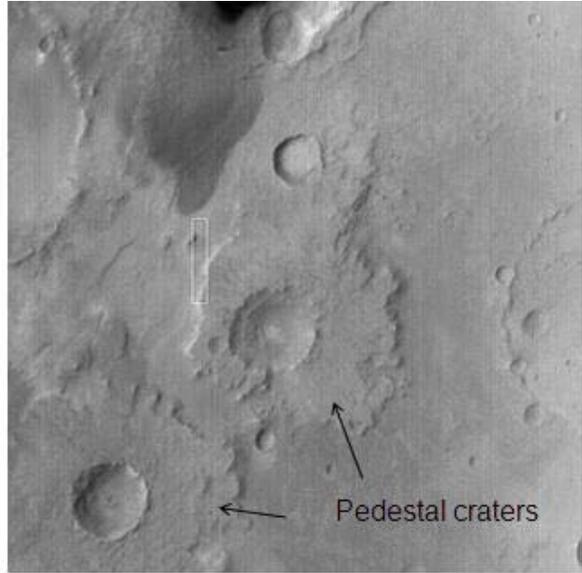
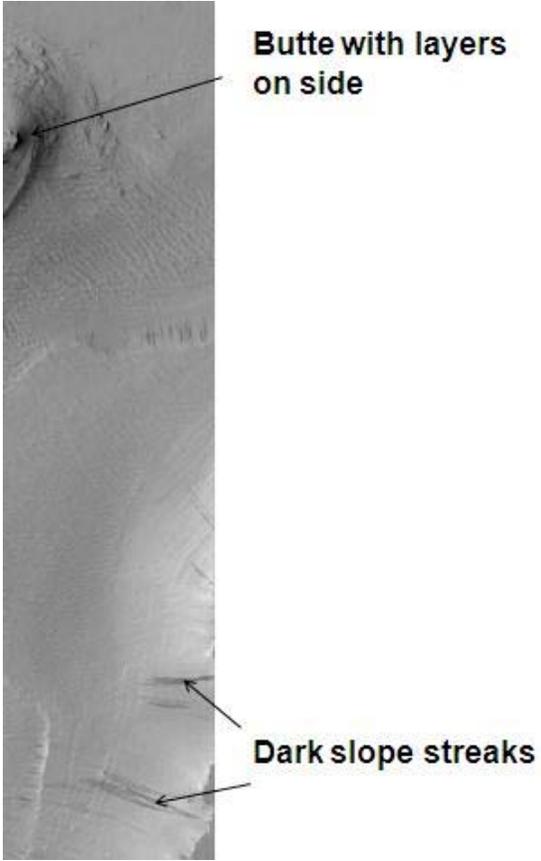


Image on left is inside white box.

- Tikonravev Crater Floor, as seen by Mars Global Surveyor.



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

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.

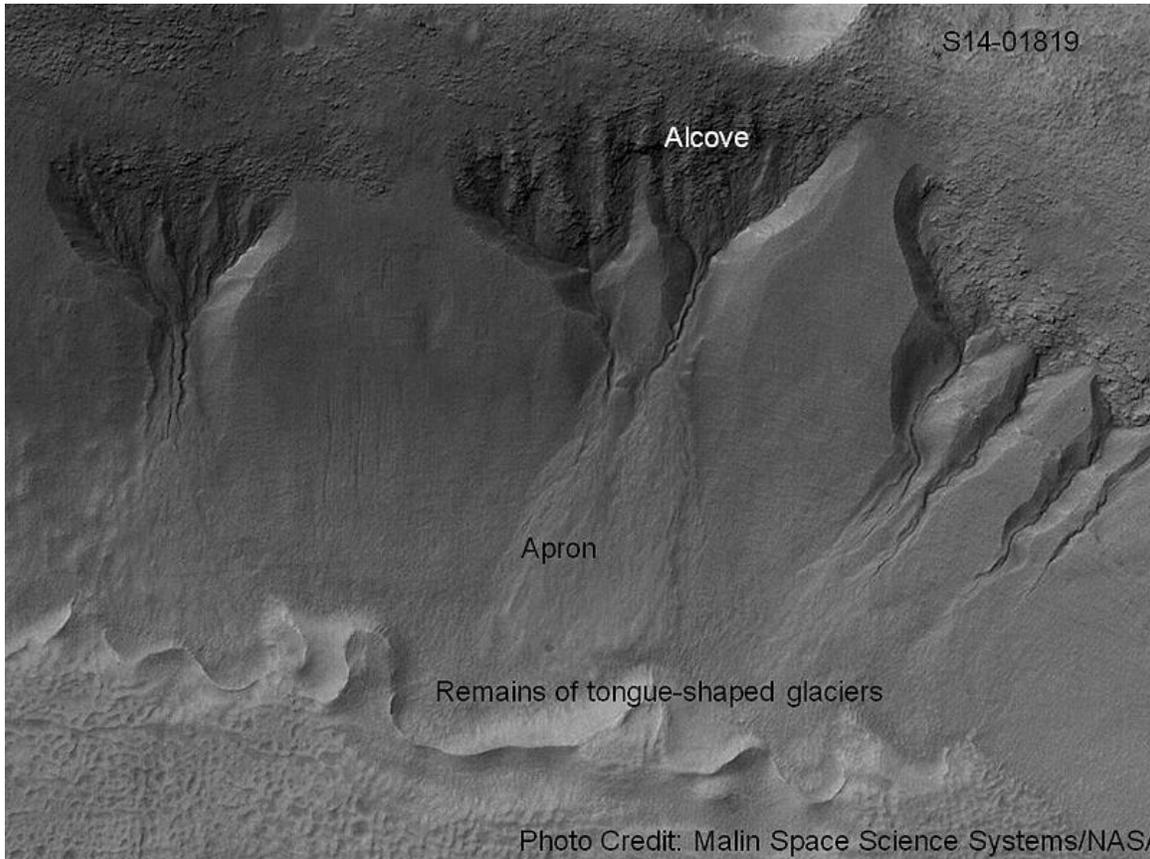
From May to November 1998, aerobraking was temporarily suspended to allow the orbit to drift into the proper position with respect to the Sun. Without this hiatus, 'Surveyor'

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.

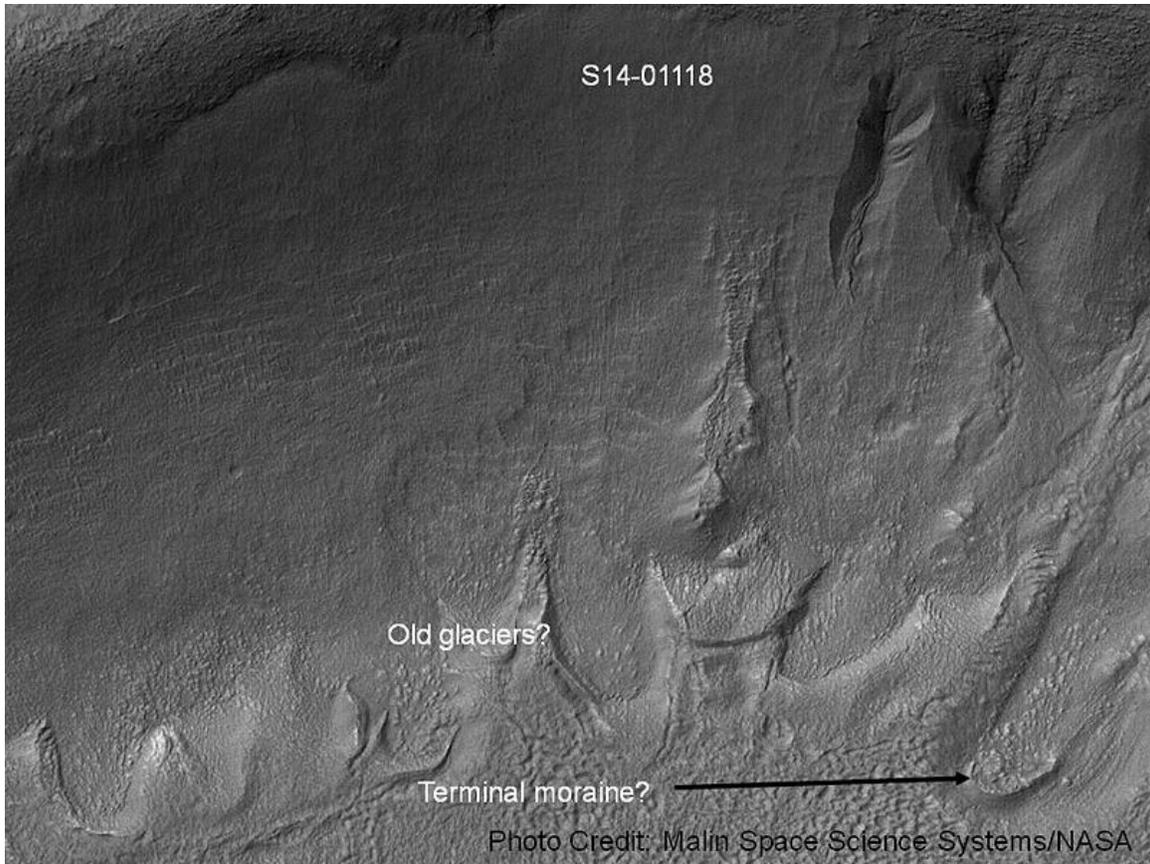
Finally, from November 1998 to March 1999, aerobraking continued and shrank the high point of the orbit down to 450 km (280 mi). At this altitude, *Surveyor* circled Mars once every two hours. Aerobraking was scheduled to terminate at the same time the orbit drifted into its proper position with respect 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.



- 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.



- 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.

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.

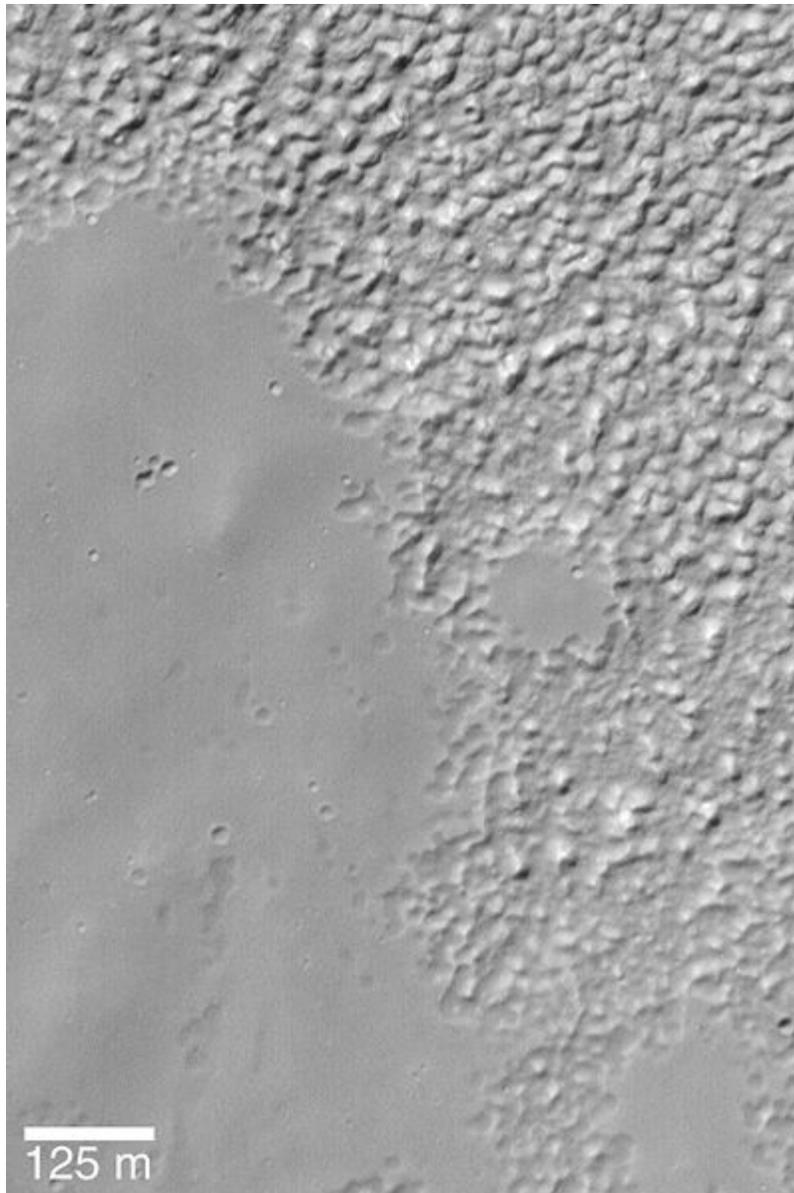
Results from the Mars Global Surveyor primary mission (1996–2001) were published in the *Journal of Geophysical Research* by M. Malin and K. Edgett. Some of these discoveries are:



- 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.

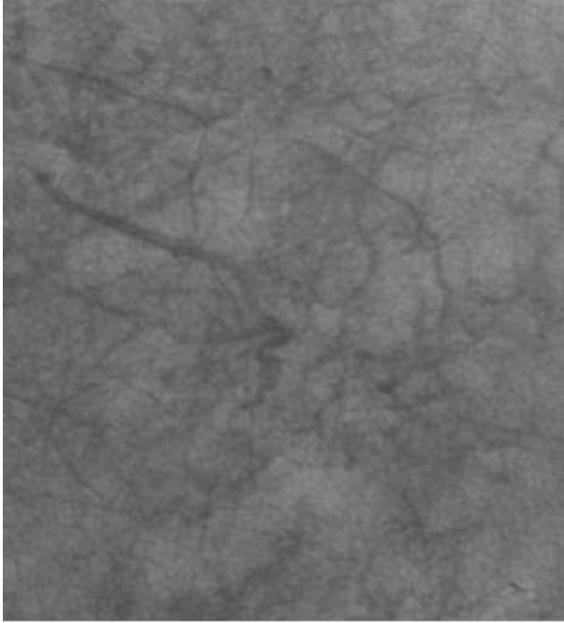


Photo credit: Malin
Space Science
Systems/NASA

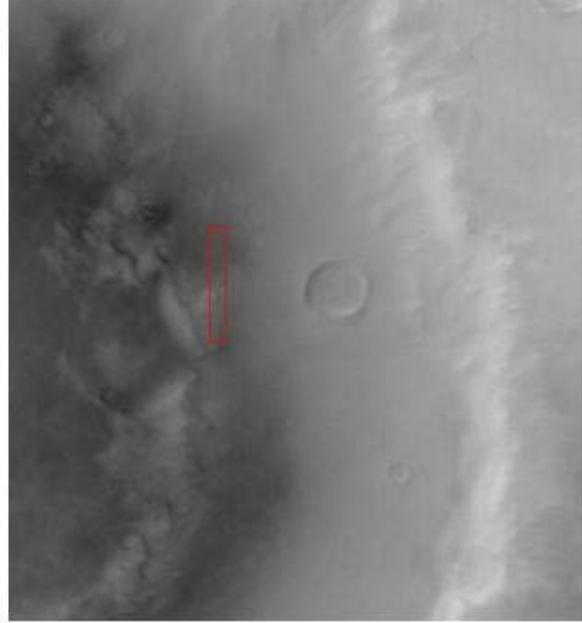
- Steep Cliff in Ismenius Lacus quadrangle with smooth mantle covering its face.
- Some areas are covered by hematite-rich material. The hematite could have been put in place by liquid water in the past.
- Dark streaks were found to be caused by giant dust devils. Dust Devil Tracks were observed to frequently 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.

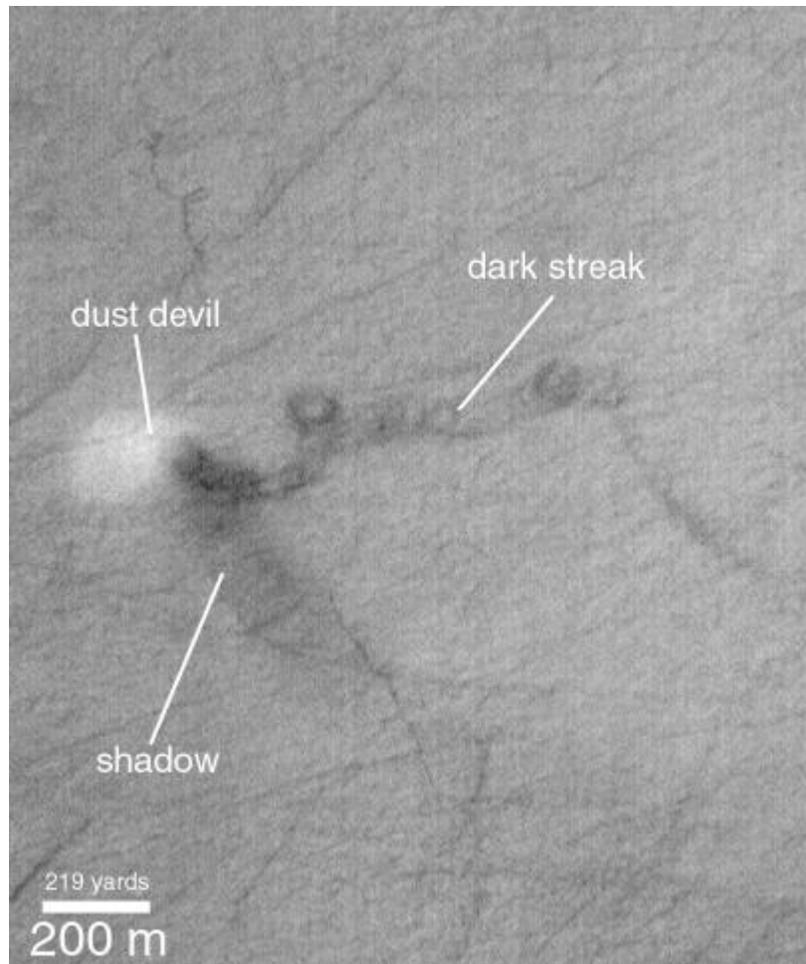


Dark curvy lines are dust devil tracks.

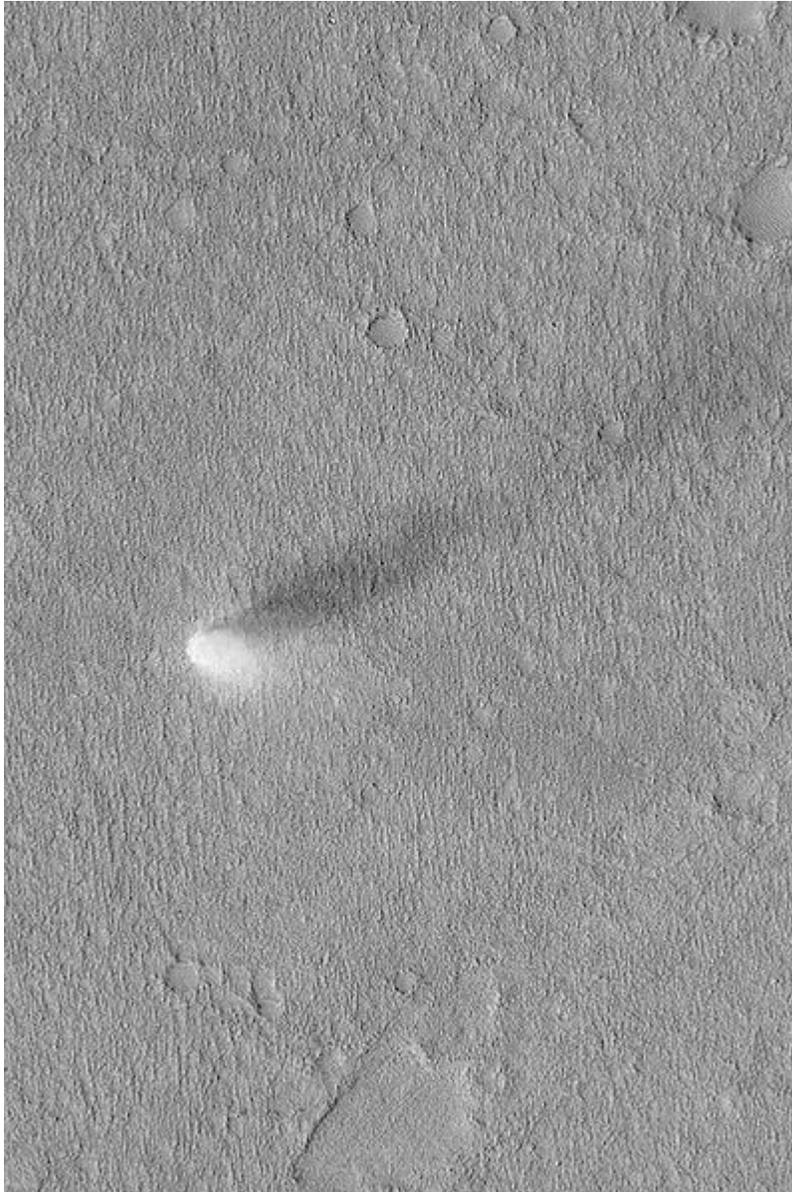


Context for image on left

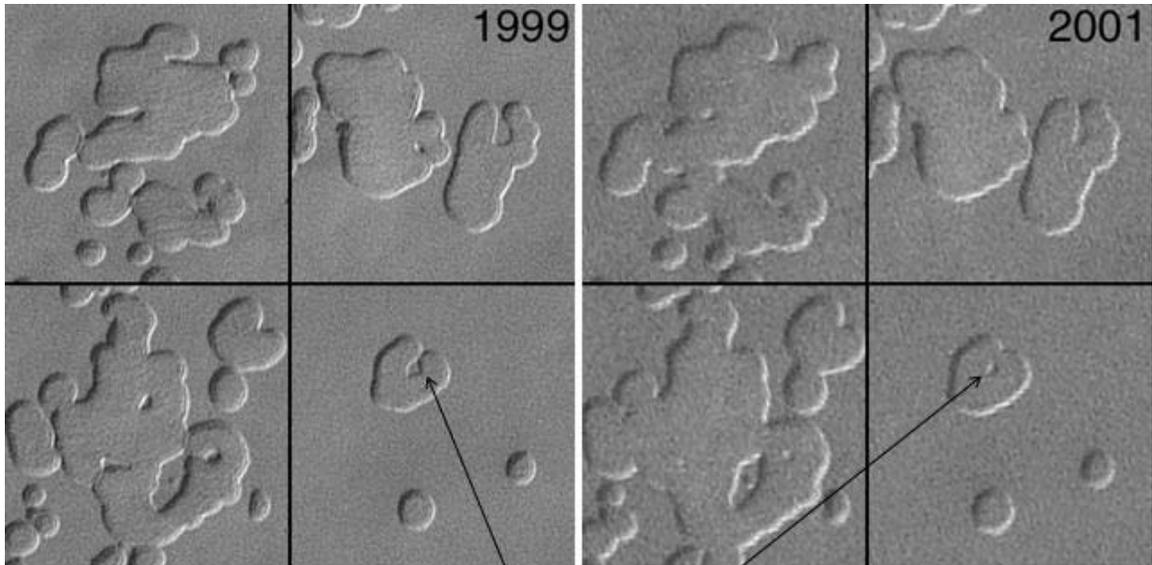
- Kepler (Martian crater) showing dust devil tracks, as seen by Mars Global Surveyor. Kepler is a large crater in the Eridania quadrangle.



- Dust Devil, as seen by MGS.

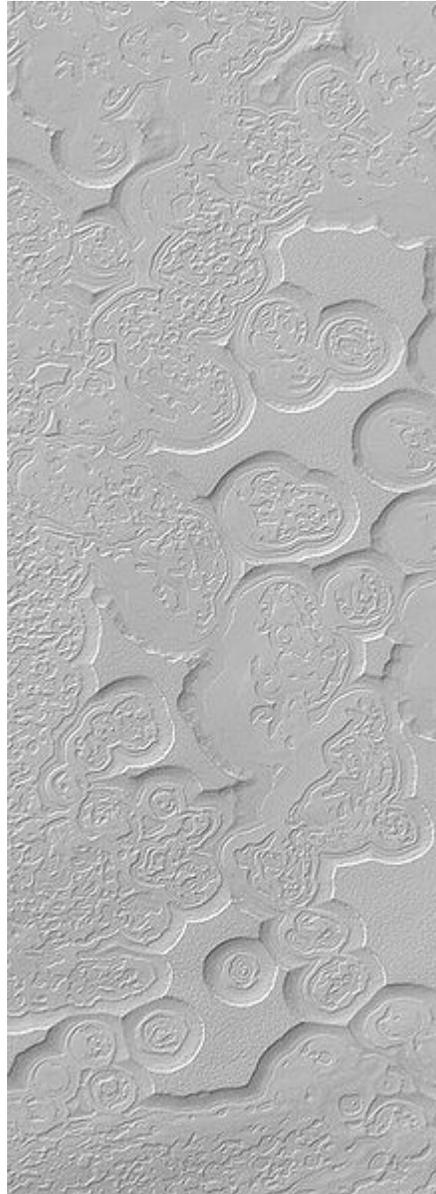


- Dust Devil in action showing shadow to the right. Image located in Cebrenia quadrangle.
- The south pole's residual cap was observed to look like Swiss cheese. The holes are generally a few meters deep. The holes get bigger each year, so Mars may be warming.

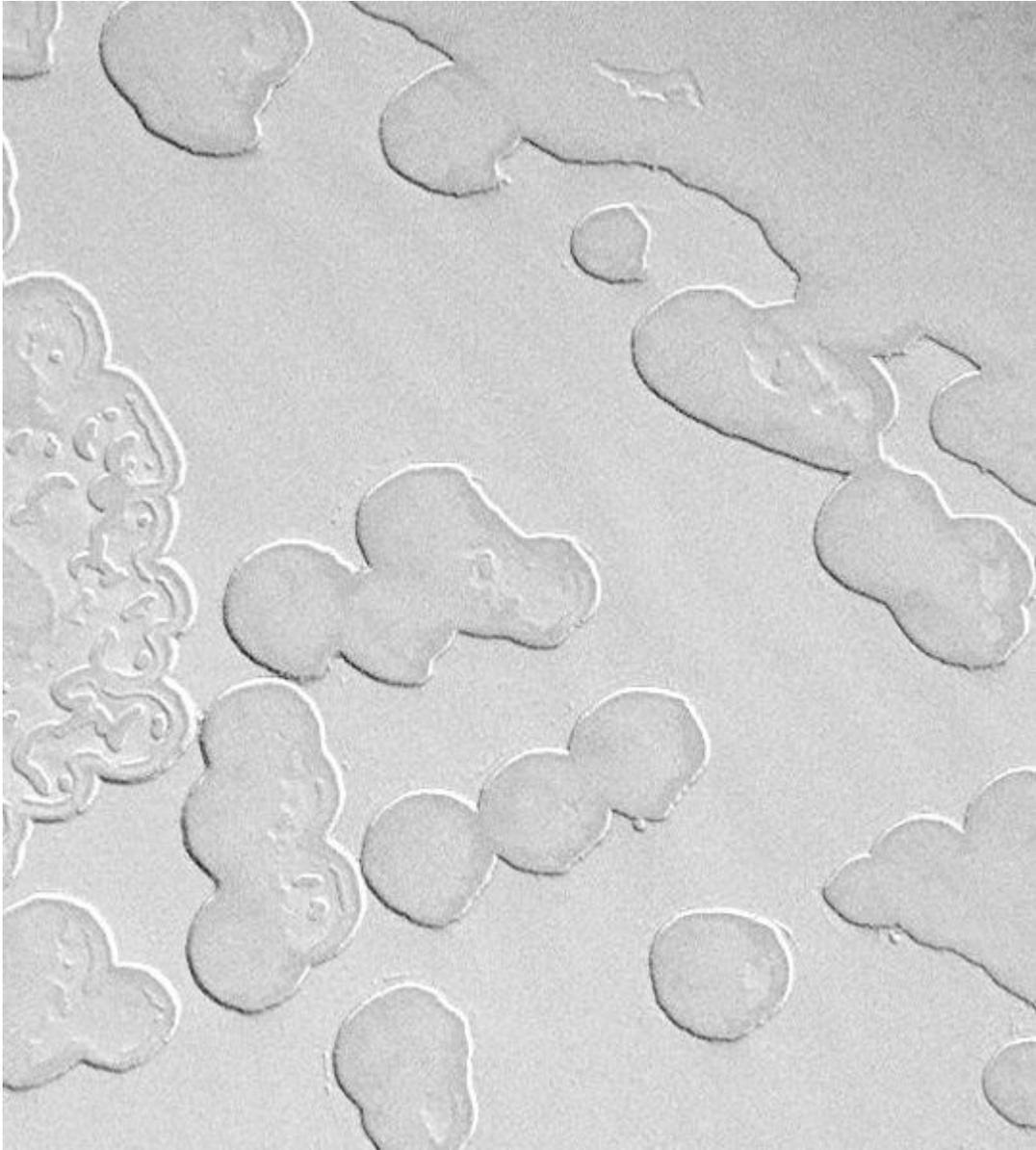


Notice many changes in two years time.

- 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.



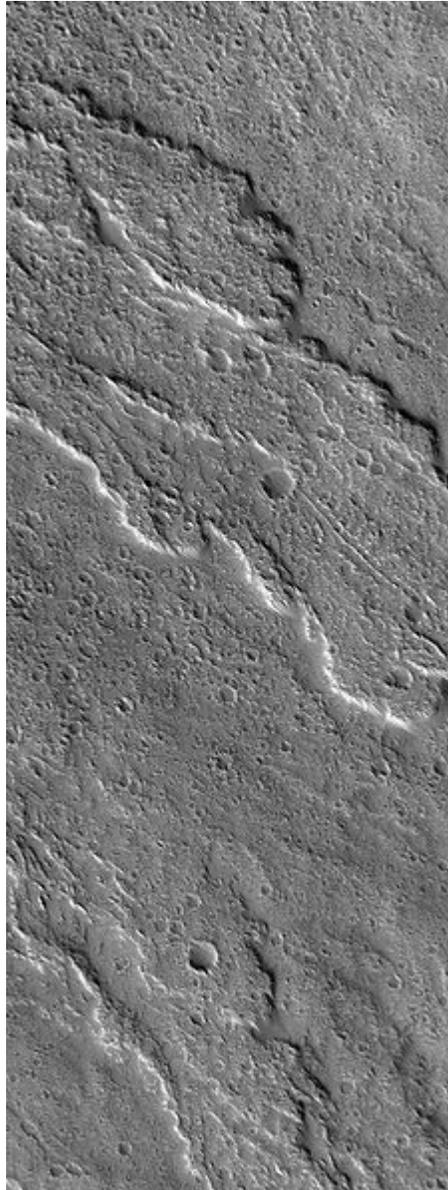
- Layers in Swiss Cheese Terrain. There is a bright upper layer and a darker lower layer.



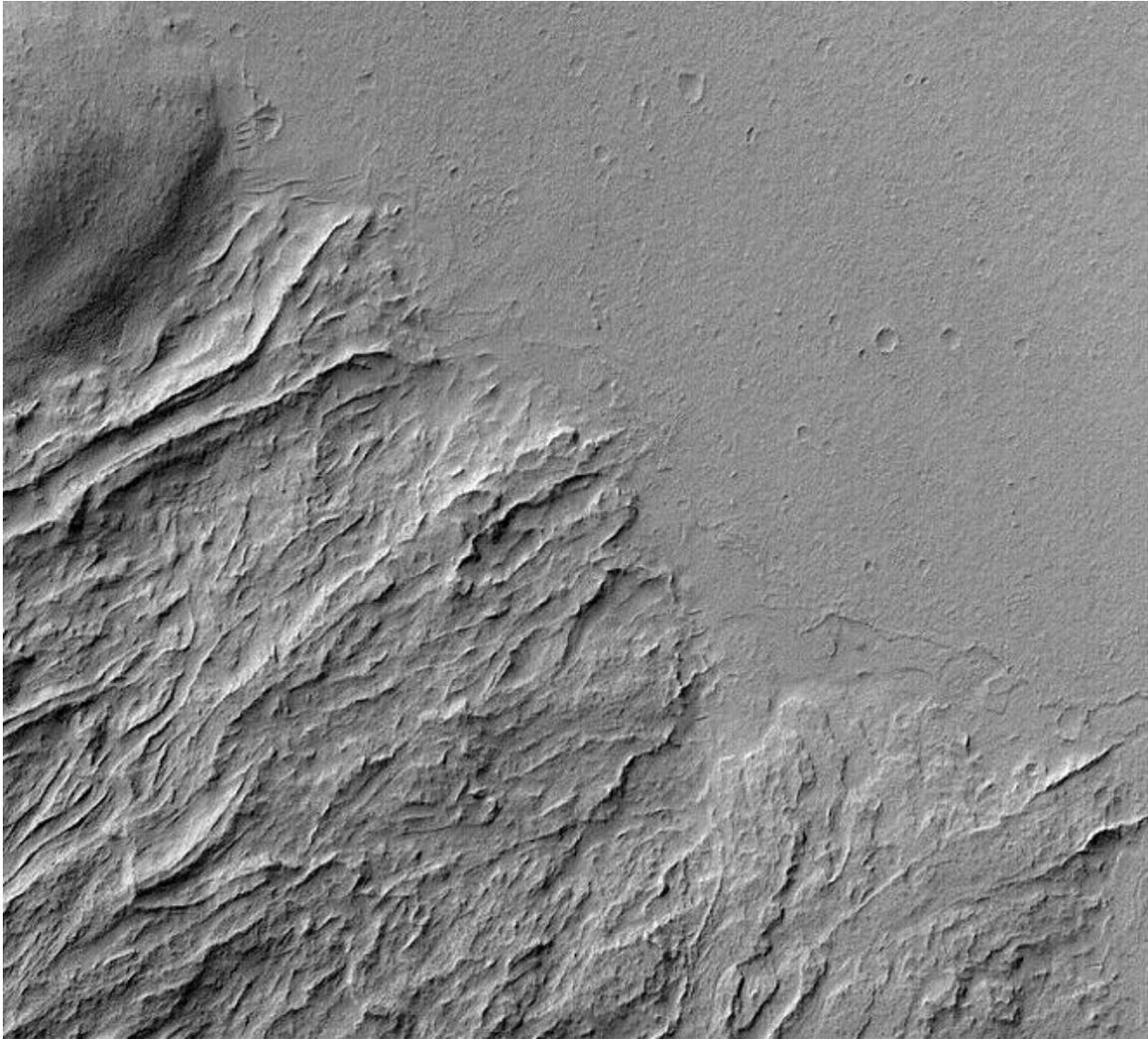
- Close-up view of Swiss Cheese Terrain. Polygonal pattern was probably formed by shallow troughs.
- The Thermal Emission Spectrometer found that just about all of the surface of Mars is covered with volcanic rock.



- 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

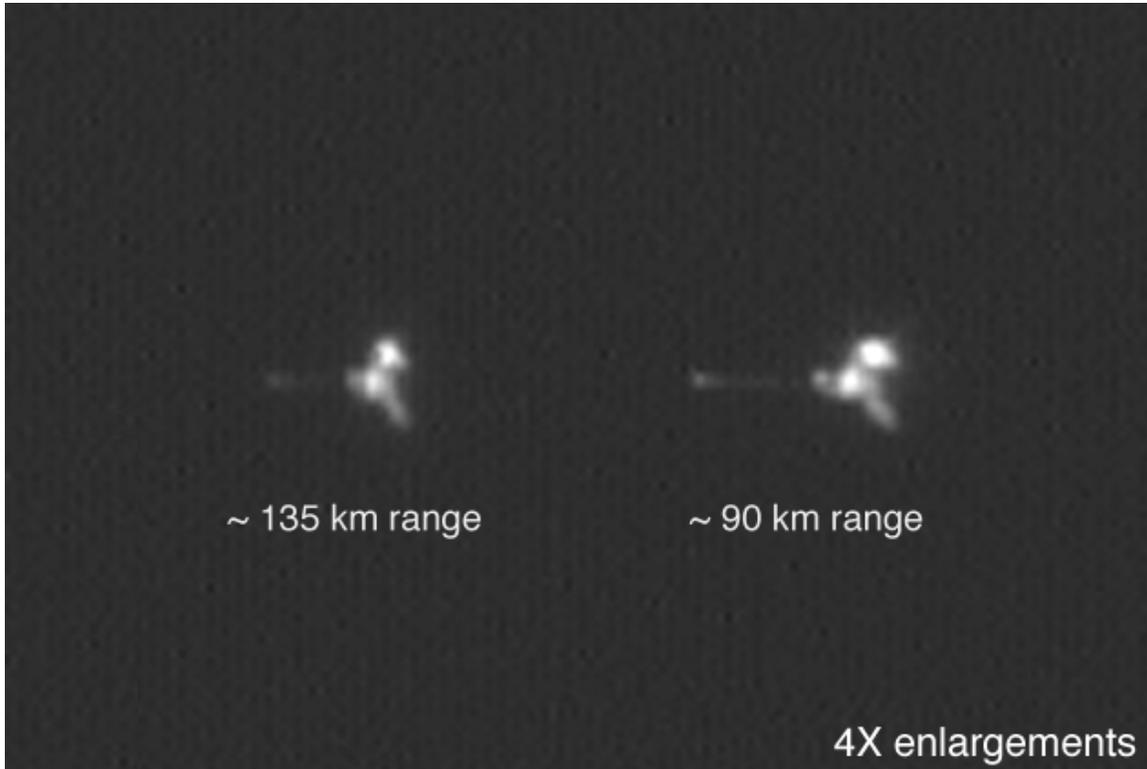
Mars Global Surveyor functioned as a communications satellite relaying data back to Earth from the MER surface landers. Portions of MGS had been scheduled to remain active until at least September 2008 to support MER.

Loss of contact

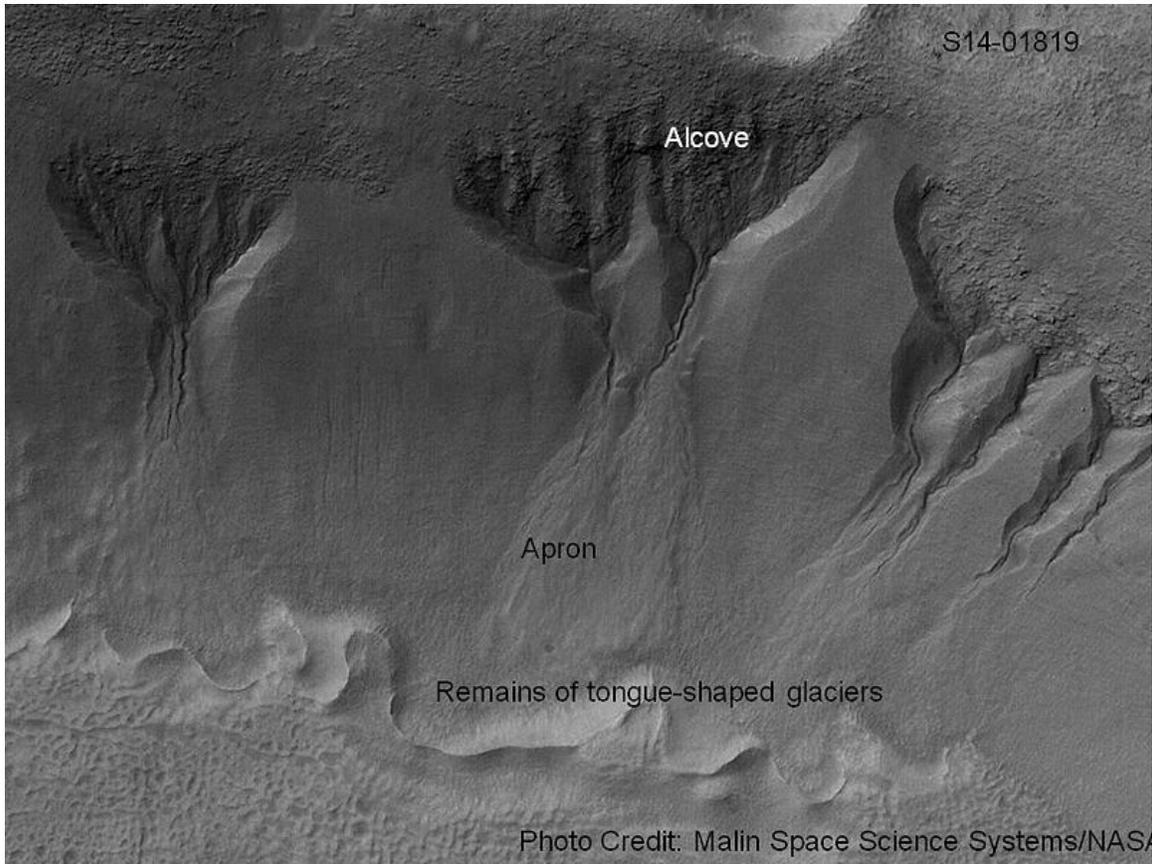
On **November 2, 2006**, NASA lost contact with the spacecraft after commanding it to adjust its solar panels. Several days passed before a faint signal was received indicating that the spacecraft had entered safe mode and was awaiting further instructions.

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.

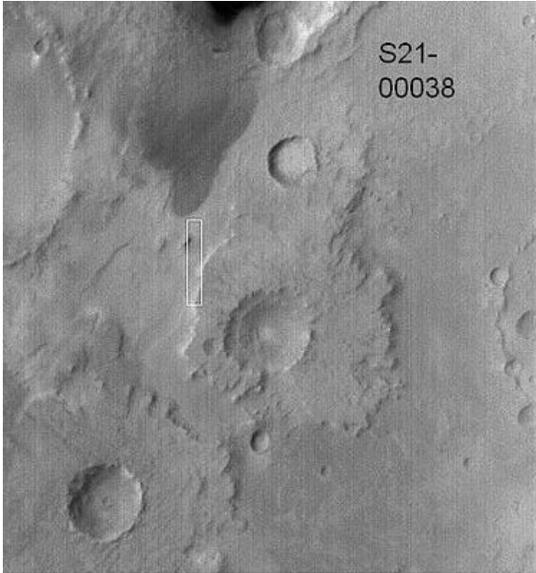
On **November 21 and 22, 2006**, *Mars Global Surveyor* failed to relay communications to the Opportunity rover on the surface of Mars. In response to this complication, Mars Exploration Program manager Fuk Li stated, "Realistically, we have run through the most likely possibilities for re-establishing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



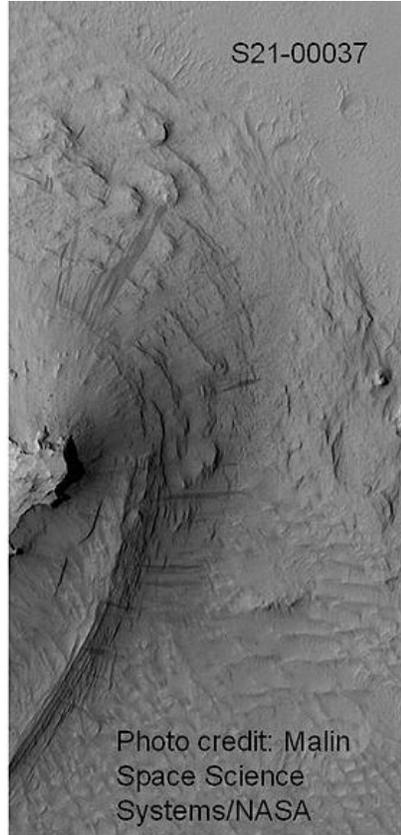
The Mars Odyssey spacecraft image taken by *Mars Global Surveyor*.



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.



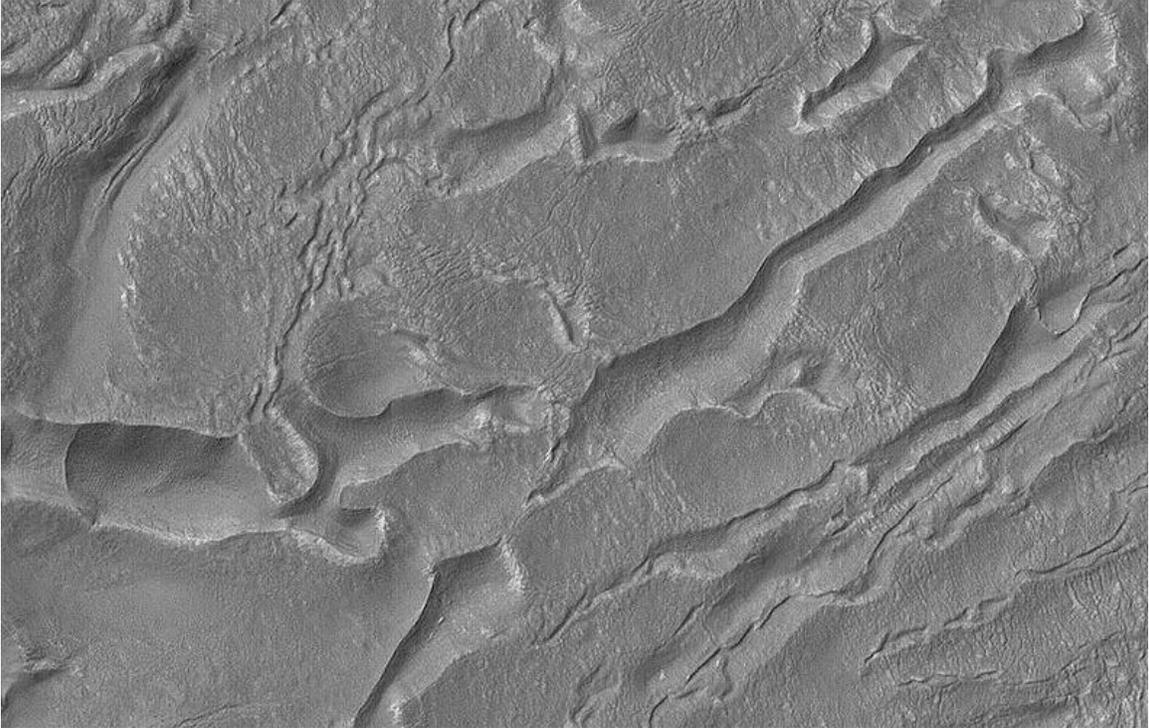
This set of images from the public target request program shows many layers on a butte near the top of the image rectangle. These craters are within the much larger crater called Tikhonravov.



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.



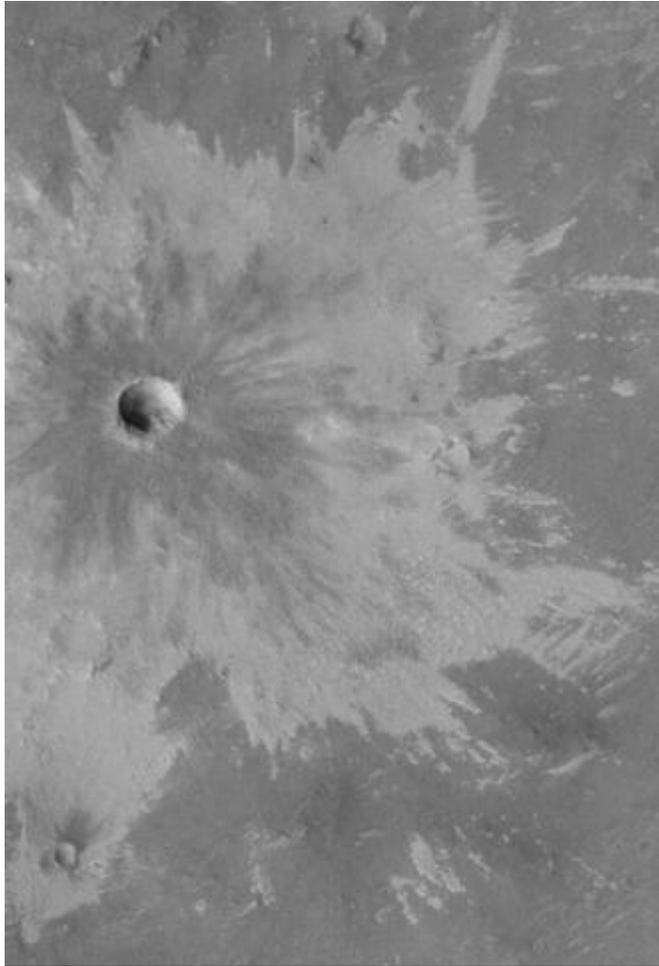
Layers in the canyon wall in Coprates quadrangle, as seen by Mars Global Surveyor.



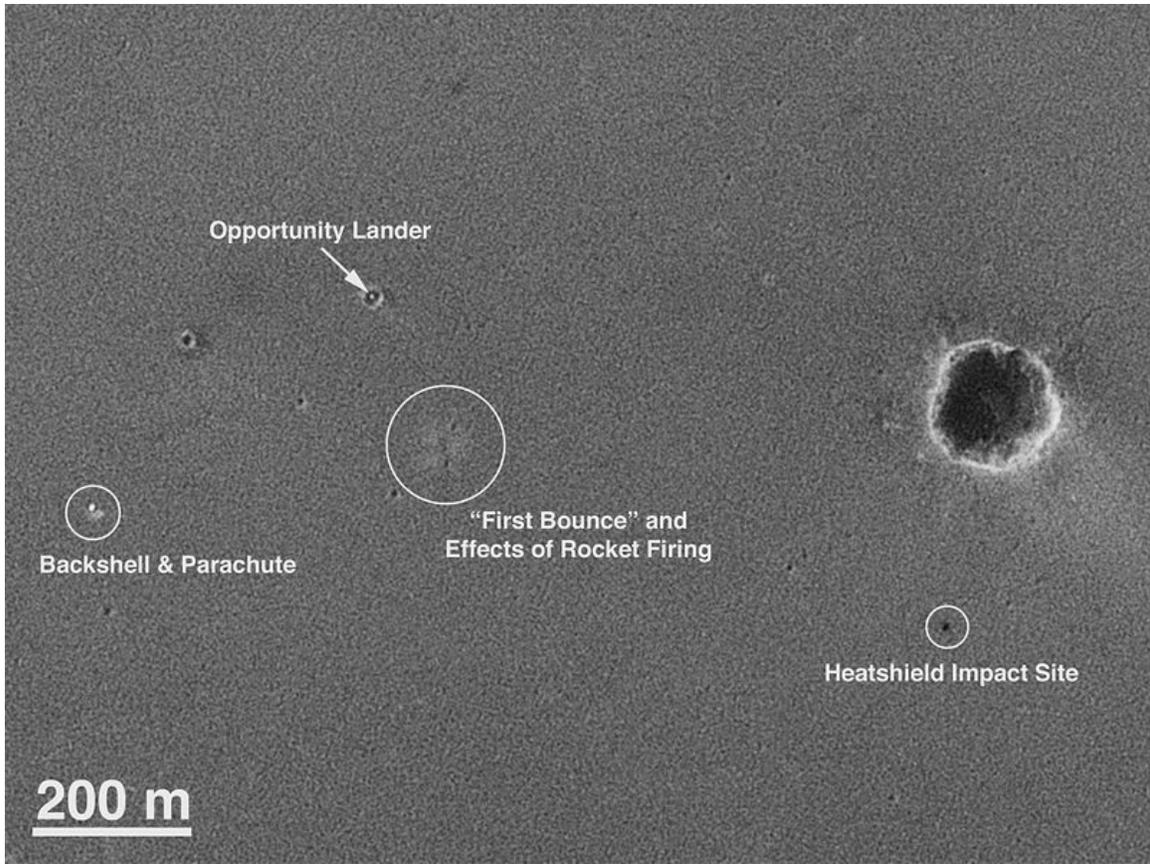
Banded or taffy-pull terrain in Hellas, as seen by Mars Global Surveyor. Origin is unknown at present.



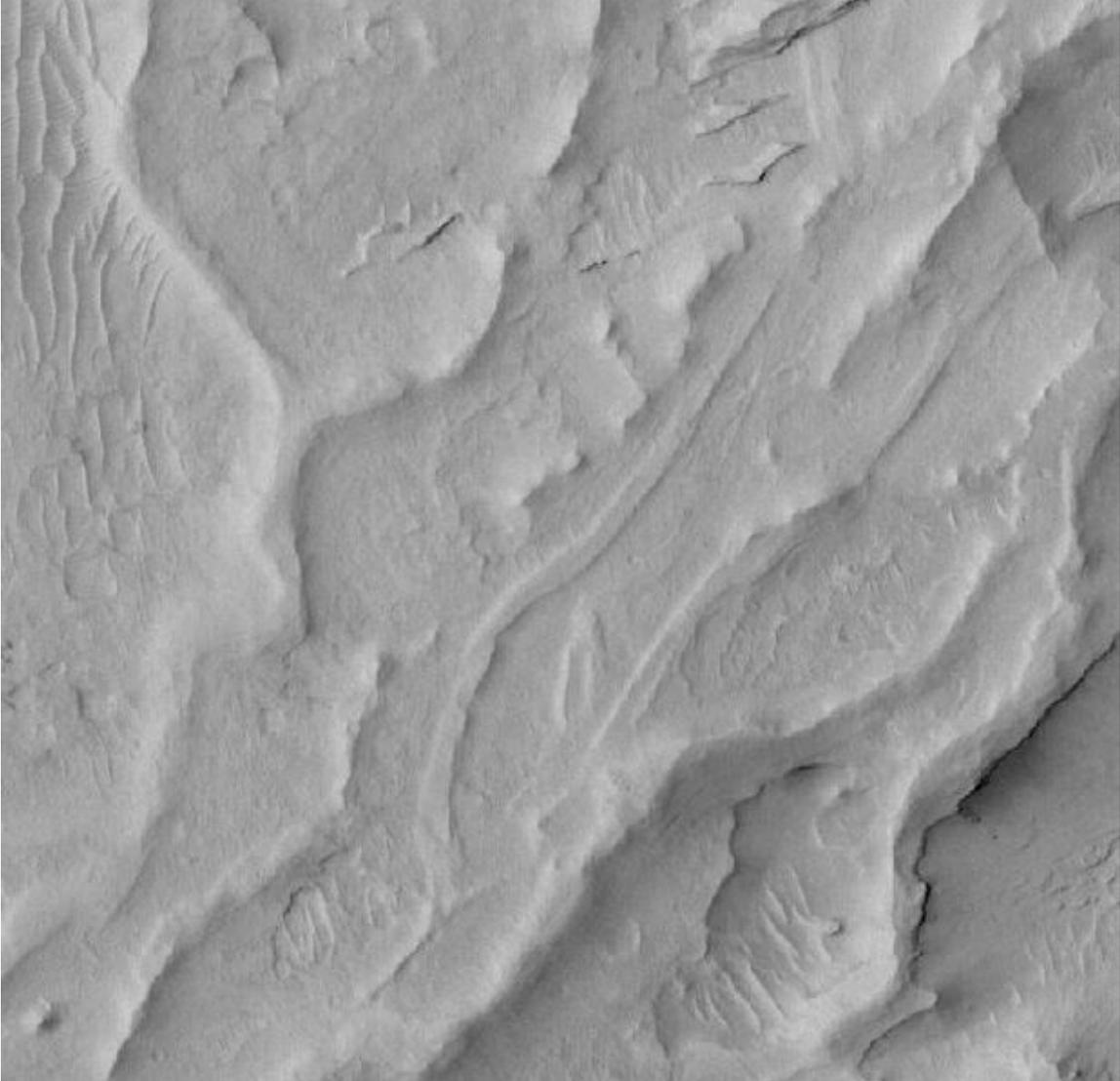
Lava flow in Elysium. There are many lava flows in the Elysium quadrangle. In this one, the lava flowed toward the upper right. Image taken by Mars Global Surveyor.



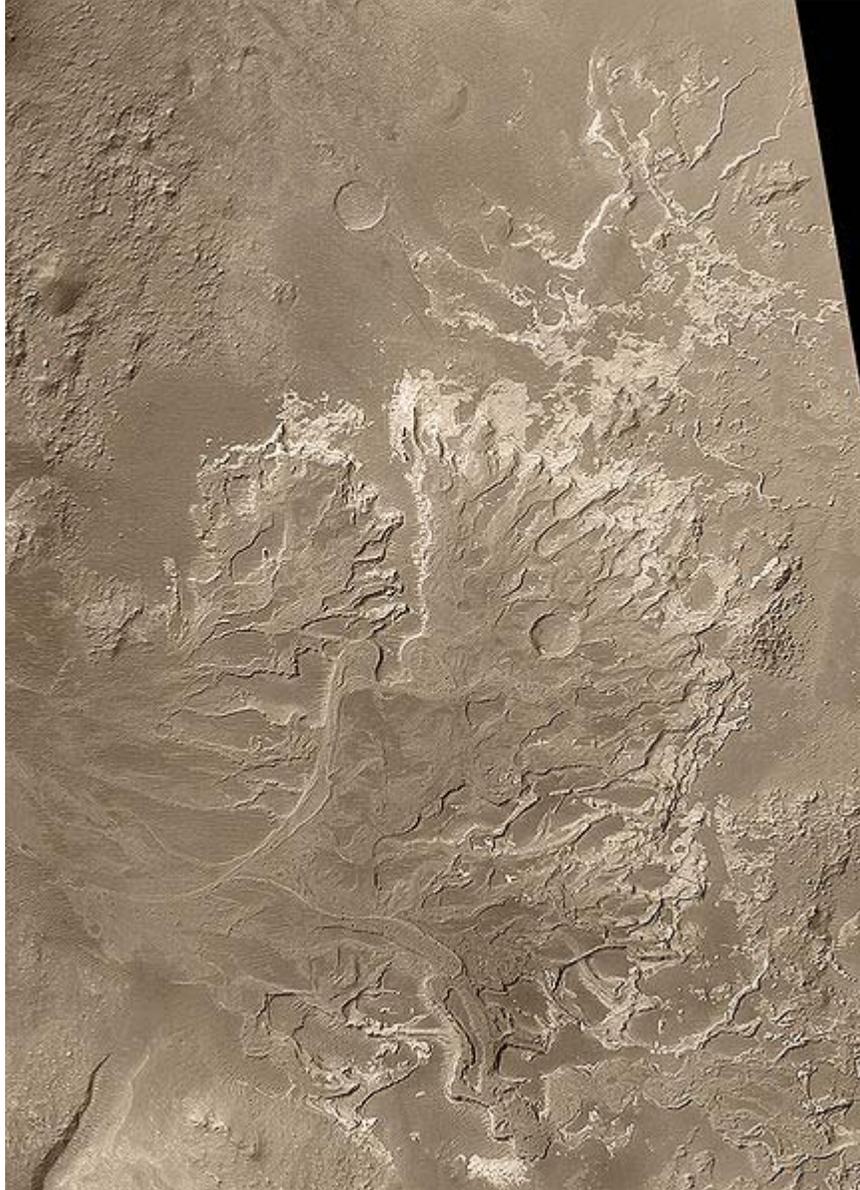
Bright rays caused by impact throwing out a bright lower layer. Some bright layers contain hydrated minerals. Picture taken with Mars Global Surveyor. Location is Memnonia quadrangle.



Mars Global Surveyor orbiter's photograph of Opportunity Rover's landing site showing "hole in one."



Inverted Channels in Aeolis quadrangle. It is believed that stream channels became raised features after coarse materials were deposited and cemented.



Picture probably is of a delta that formed in a huge lake. The area is of great interest to geologists. Evidence of life may be found in this location.



Pavonis Mons, located on the equator in Tharsis quadrangle.

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- 6

Mars Polar Lander

Mars Polar Lander



Operator	NASA / JPL
Major contractors	Russian Space Research Institute
Mission type	Lander / impactor
Launch date	1999-01-03 20:21:10 UTC
Launch vehicle	Delta II 7425
Launch site	Space Launch Complex 17B Cape Canaveral Air Force Station
Mission duration	(failure in transit) Last contact on day 334 1999-12-03 20:00:00 UTC
Landing site	Ultimi Scopuli, 76°S 195°W / 76°S 195°W (projected)

COSPAR ID	1999-001A
Homepage	mpfwww.jpl.nasa.gov/msp98
Mass	290 kg (640 lb)
Power	200 W (Solar array/NiMH batteries)

Instruments

	Deep Space 2 probes
Main	MVACS
instruments	MARDI
	LIDAR

Mars Polar Lander (sometimes referred to as the *Mars Surveyor '98 Lander*) is one of two exploration vehicles of the NASA Mars Surveyor '98 program. Launched on 3 January 1999, 23 days after its partner, the *Mars Climate Orbiter*, the mission ended in failure with the loss of both craft in separate incidents. After attempts to re-establish communications failed following entry into Mars atmosphere, the lander was declared lost, with the presumption that the vehicle did not survive the descent.

Scientific objectives

Conveyed on the *Mars Polar Lander* was the *Deep Space 2* surface-penetrator mission to Mars. The two missions were designed to study the Martian weather, climate, water and carbon dioxide concentrations, in order to understand the reservoirs, behavior, and atmospheric role of volatiles and to search for evidence of long-term and episodic climate changes.

The lander was to touch down on the southern polar layered terrain, between 73°S and 76°S in the region Planum Australe, less than 1,000 km from the south pole, near the edge of the carbon dioxide ice cap in Mars' late southern spring. The terrain appears to be composed of alternating layers of clean and dust-laden ice, and may represent a long-term record of the climate, as well as an important volatile reservoir.

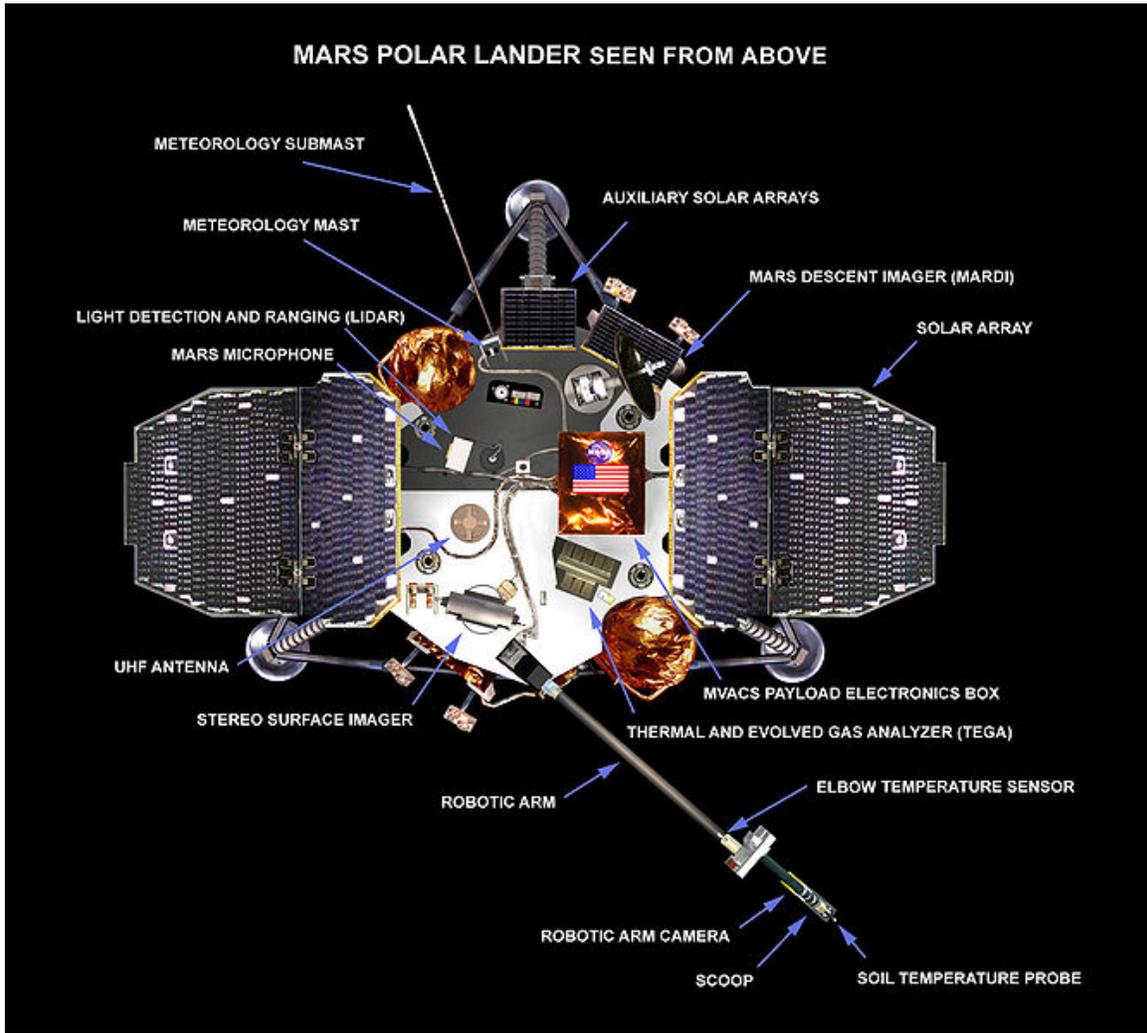
Mission science objectives

- Log local meteorological conditions near the martian south pole, including temperature, pressure, humidity, wind, surface frost, ground ice evolution, ice fogs, haze, and suspended dust
- Analyze samples of the polar deposits for volatiles, particularly water and carbon dioxide
- Excavate trenches and image the interior to look for seasonal layers and analyze soil samples for water, ice, hydrates, and other aqueously deposited minerals

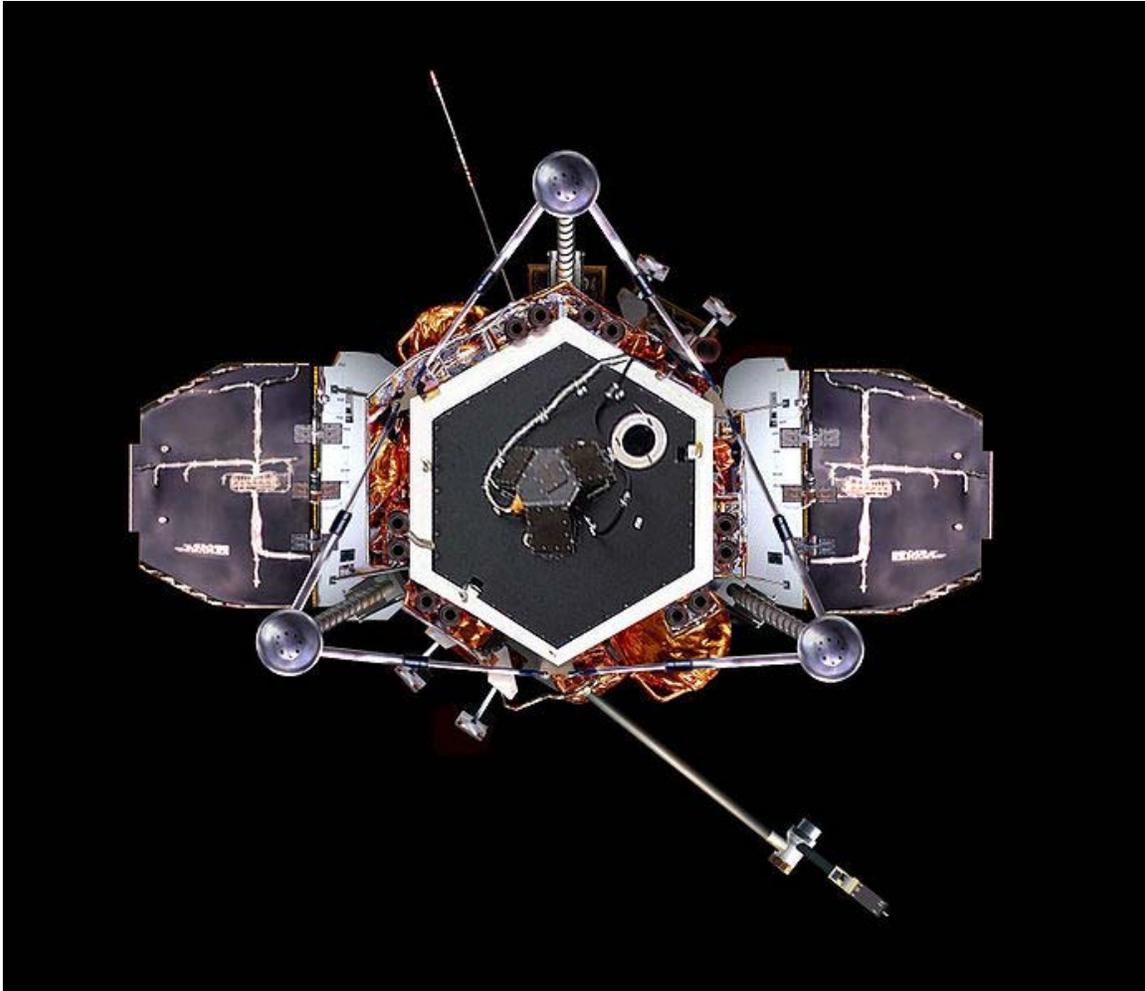
- Image the regional and immediate landing site surroundings for evidence of climate changes and seasonal cycles
- Obtain multi-spectral images of local regolith to determine soil types and composition.

These goals were to be accomplished using a number of scientific instruments, including a Mars Volatiles and Climate Surveyor (MVACS) instrument package which was composed of a robotic arm and attached camera, mast-mounted surface stereo imager and meteorology package, and a gas analyzer. In addition, a Mars Descent Imager (MARDI) was planned to capture regional views from parachute deployment at about 5 miles (8 km) altitude down to the landing. The Russian Space Agency provided a laser ranger (LIDAR) package for the lander, which would be used to measure dust and haze in the Martian atmosphere. A miniature microphone would also be on board to record sounds on Mars. Attached to the lander spacecraft were a pair of small probes, the Deep Space 2 Mars Microprobes, which were to be deployed to fall and penetrate beneath the martian surface when the spacecraft reached Mars.

Spacecraft and subsystems



Mars Polar Lander viewed from above



Mars Polar Lander viewed from below

The *Mars Polar Lander* consisted of a hexagonal base composed of aluminum honeycomb with composite graphite epoxy face sheets supported on three aluminum landing legs. The lander, when fully deployed stood 1.06 m tall and approximately 3.6 m wide. The launch mass of the spacecraft was approximately 583 kg, including 64 kg of fuel, an 82 kg cruise stage, a 140 kg aeroshell/heatshield, and the two 3.5 kg microprobes. A thermally regulated interior component deck held temperature-sensitive electronic components and batteries and the thermal control system. Two solar panels extended from opposite sides of the base. Mounted on top of the base were the robotic arm, the stereo imager and mast, a UHF antenna, the LIDAR, the MVACS electronics, the meteorology mast, and the medium-gain dish antenna. The MARDI was mounted at the base of the lander, and the propellant tanks were affixed to the sides. During cruise, the lander was attached to the cruise stage and enclosed in the 2.4 m diameter aeroshell.

The spacecraft was three-axis stabilized during cruise using star cameras and sun sensors in conjunction with inertial measurement units. Four hydrazine cruise reaction engine modules, each consisting of one 5-lb_f (22 N) trajectory correction maneuver thruster and one canted 1-lb_f (4 N) reaction control system thruster, provided attitude control. The

descent and landing propulsion system consisted of three groups of four pulse-modulated 266 N hydrazine engines. Control and knowledge for descent and landing was provided by a four-beam Doppler radar system and an AACS subsystem. The hydrazine was stored in two diaphragm tanks with a total capacity of 64 kg for both cruise and descent systems.

Communications between Earth and the spacecraft during cruise to Mars were via X band using two solid state power amplifiers and a fixed medium-gain antenna mounted on the cruise stage and backed up by a receive-only low-gain antenna. During surface operations communications (downlink and uplink) would have been via the UHF antenna on the lander to the Mars Climate Orbiter, which would function as a relay to Earth. Eight to ten relay passes over the lander would have been available from the orbiter each day, but the number of communications sessions would be limited by power demands. Uplink-only communications to Earth were to be provided by the medium-gain DTE (direct to Earth) two-axis articulated antenna.

Power was provided during cruise phase by two gallium arsenide solar array wings with a total area of 3.1 m² attached to the cruise stage. After landing, two gallium arsenide solar array wings with a total area of 2.9 m² would have been deployed. Power is stored in 16 A·h nickel metal hydride common pressure vessel batteries for peak load operations and night time heating. The payload is allocated 25 W of continuous power when operating.

Mission profile

Mars Polar Lander and the attached *Deep Space 2* probes were launched on a Delta II 7425 lite launch vehicle with four strap-on solid-rocket boosters and a Star 48 (PAM-D) third stage, which placed them into a low-Earth parking orbit. The third stage fired for 88 seconds at 20:57 UT 3 January 1999 to put the spacecraft into a Mars transfer trajectory and the spacecraft and third stage separated at 21:03 UT. Trajectory correction maneuvers were performed on 21 January, 15 March, 1 September, 30 October, and 30 November 1999.

After an 11-month hyperbolic transfer cruise, the *Mars Polar Lander* reached Mars on 3 December 1999. A final 30 minute tracking session began at 12:45 UT (7:45 a.m. EST) and was used to determine if a final thruster correction was necessary. Final contact to retrieve data on the status of the propulsion system was made from 19:45 UT to 20:00 UT. At 20:04, 6 minutes before atmospheric entry, an 80 second thruster firing was to turn the craft to its entry orientation. The cruise stage was to be jettisoned at about 20:05 UT, and about 18 seconds later the microprobes were to be dropped from the cruise stage into the martian atmosphere (also targeted at the southern polar layered terrain). The lander was to make a direct entry into Mars' atmosphere at 6.8 km/s at about 20:10 UT (3:10 p.m. EST). Because of lack of communication, it is not known at this time whether all these steps following last contact were executed, nor whether any of the descent plan described below took place as designed.

Initial deceleration would be simple aerobraking using the 2.4 m ablation heat shield. The maximum time from atmospheric entry to landing would be 4 minutes 33 seconds. The inertial measurement unit would estimate the velocity throughout the entry and descent phase and the thrusters would keep the craft aligned. At an altitude of about 7.3 km at 500 m/s the parachute would be deployed by a mortar followed by heat shield separation. Just before heat shield separation, the descent imager (MARDI) would turn on. The landing legs would be deployed 70 to 100 seconds before landing and the descent engines warmed up with short pulses. Then the parachute would be jettisoned and the descent engines fired, regulated by the spacecraft control system and the Doppler radar. The backshell would separate from the lander at about 1.4 km altitude at 80 m/s and the descent engines turned on to slow the descent and turn the flight path to vertical.

At 12 meters altitude the 2.4 m/s terminal descent phase was to begin. Engine shutoff would occur when one of the landing legs touched the ground. The landing velocity would be less than 2.4 m/s vertical and 1 m/s horizontal. The orientation of the lander is controlled by the AACS subsystem to maximize solar array efficiency and minimize obstruction of the DTE antenna. The lander would have touched down at 20:15 UT Earth received time (3:15 p.m. EST) in the late southern spring season, during which the Sun will always be above the horizon at the landing site. The other times listed above are also Earth received times; light travel time from Mars at that point was approximately 14 minutes.

Immediately after landing the solar panels were to be deployed. The first signal from the lander was to reach Earth at 20:39 UT (3:39 p.m. EST), but was never received. This was to be the start of a 45 minute communications session. After this session the lander was to recharge its batteries for about six hours. On 4 December at 04:30 UT (11:30 p.m. EST December 3) a communications session was to begin which would have lasted about 2.25 hours. This session would have included images, including pictures from the Mars Descent Imager, but again no transmission was received. The first sounds from the Mars Microphone were to be released as early as 4 December and the first robot arm dig was to occur on 7 December. Science experiments would continue over the 90-day primary mission, with an extended mission to follow based on lander performance.

Mission failure

The last telemetry from the *Mars Polar Lander* was sent just prior to atmospheric entry on December 3, 1999. No further signals have been received from the lander. The cause of the communication loss is not known. The investigation that followed concluded that the most likely cause of the failure of the mission was a software error that mis-identified vibrations caused by the deployment of the lander's legs as vehicle touch-down on the Martian surface. The resulting action was the shut-down of the vehicle's descent engines while still 40 meters aloft. Although it was known that leg deployment could create the false indication, the software's design instructions did not account for that eventuality.

In addition to the premature shutdown of descent engines, the following failure modes were also assessed as plausible by the Failure Review Board convened to study the loss

of Mars Polar Lander and Deep Space 2. Although thought less likely than the premature engine shutdown, they could not be ruled out due to the lack of telemetry.

- Surface conditions exceed landing design capabilities.
- Loss of control due to dynamic effects.
- Landing site not survivable.
- Backshell/parachute contacts lander.
- Loss of control due to center-of-mass offset.
- Heatshield fails due to micrometeoroid impact.

Attempts were made in late 1999 and early 2000 to search for the remains of the *Mars Polar Lander* using images from the *Mars Global Surveyor*. These attempts were unsuccessful, but re-examination of the images in 2005 led to a tentative identification described in the July 2005 issue of *Sky and Telescope*. However, higher resolution photos taken later in 2005 revealed that this identification was incorrect, and that the *Mars Polar Lander* remains lost. NASA is hoping that the higher resolution cameras of the *Mars Reconnaissance Orbiter*, currently in Martian orbit, will finally locate the lander's remains.

Legacy

The *Phoenix* spacecraft successfully landed on May 25, 2008, carrying some instruments derived from those on the *Mars Polar Lander*.

The failure of the Mars Polar Lander took place two and a half months after the loss of the Mars Climate Orbiter. Inadequate funding and poor management have been cited as underlying causes of the failures. According to Thomas Young, chairman of the Mars Program Independent Assessment Team, the program "was under funded by at least 30%."

Chapter- 7

Ocean Surface Topography Mission

OSTM/Jason-2



Artist's interpretation of the Jason-2 satellite

Operator	NASA, CNES, NOAA, EUMETSAT
Mission type	Earth orbiter
Launch date	June 20, 2008
Launch vehicle	Delta II
Mission duration	Three years with provision for two-year extended mission
Homepage	Ocean Surface Topography from Space

Orbital elements

Orbital period	6754.0s
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The launch of OSTM



Jason-2 after separation from its carrier rocket

The **Ocean Surface Topography Mission (OSTM)** on the **Jason-2** satellite is an international Earth observation satellite mission that continues the sea surface height measurements begun in 1992 by the joint NASA/CNES TOPEX/Poseidon mission and followed by the NASA/CNES Jason-1 mission launched in 2001.

Like its two predecessors, OSTM/Jason-2 uses high-precision ocean altimetry to measure the distance between the satellite and the ocean surface to within a few centimeters. These very accurate observations of variations in sea surface height—also known as ocean topography—provide information about global sea level, the speed and direction of ocean currents, and heat stored in the ocean.

Jason-2 was built by Thales Alenia Space using a Proteus platform, under a contract from CNES, as well as the main Jason-2 instrument, the Poseidon-3 altimeter (successor to the Poseidon and Poseidon 2 altimeter on-board TOPEX/Poseidon and Jason-1)

Scientists consider the 15-plus-year climate data record that this mission will extend critical understanding how ocean circulation is linked to global climate change.

OSTM/Jason-2 was launched at 07:46 UTC on June 20, 2008, from Space Launch Complex 2W at the Vandenberg Air Force Base in California, USA, by a Delta II 7320 rocket. The spacecraft separated from the rocket 55 minutes later.

It is now in a 1,336 km (830 mi) circular, non-sun-synchronous orbit at an inclination of 66 degrees to Earth's equator, allowing it to monitor 95 percent of Earth's ice-free ocean every 10 days. Jason-1 has been moved to the opposite side of Earth and now flies over the same region of the ocean that Jason-2 flew over five days earlier. Jason-1's ground tracks fall mid-way between those of Jason-2, which are about 315 kilometers (195 miles) apart at the equator. This interleaved tandem mission provides twice the number of measurements of the ocean's surface, bringing smaller features such as ocean eddies into view. The tandem mission also helps pave the way for a future ocean altimeter mission that would collect much more detailed data with its single instrument than the two Jason satellites now do together.

With OSTM/Jason-2, ocean altimetry makes the transition from research into operational mode. Responsibility for collecting these measurements moves from the space agencies to the world's weather and climate forecasting agencies, which use them for short-range, seasonal, and long-range weather and climate forecasting.

Science objectives

- Extend the time series of ocean surface topography measurements beyond TOPEX/Poseidon and Jason-1 to accomplish two decades of observations
- Provide a minimum of three years of global ocean surface topography measurement
- Determine the variability of ocean circulation at decadal time scales from combined data record of TOPEX/Poseidon and Jason-1
- Improve the measure of the time-averaged ocean circulation
- Improve the measure of global sea-level change
- Improve open ocean tide models

Ocean altimetry

Spaceborne radar altimeters have proven to be superb tools for mapping ocean-surface topography, the hills and valleys of the sea surface. These instruments send a microwave pulse to the ocean's surface and time how long it takes to return. A microwave radiometer corrects any delay that may be caused by water vapor in the atmosphere. Other corrections are also required to account for the influence of electrons in the ionosphere and the dry air mass of the atmosphere. Combining these data with the precise location of the spacecraft makes it possible to determine sea-surface height to within a few centimetres (about one inch). The strength and shape of the returning signal also provides information on wind speed and the height of ocean waves. These data are used in ocean models to calculate the speed and direction of ocean currents and the amount and location of heat stored in the ocean, which, in turn, reveals global climate variations.

Atomic clock synchronization

Another payload aboard Jason-2 is the T2L2 (Time Transfer by Laser Link) instrument. T2L2 is used to synchronize atomic clocks at ground stations, and to calibrate the on-board clock of the Jason-2 DORIS instrument. On 6 November 2008 CNES reported the T2L2 instrument was working well.

Joint effort

OSTM/Jason-2 is a joint effort by four organizations. The mission participants are:

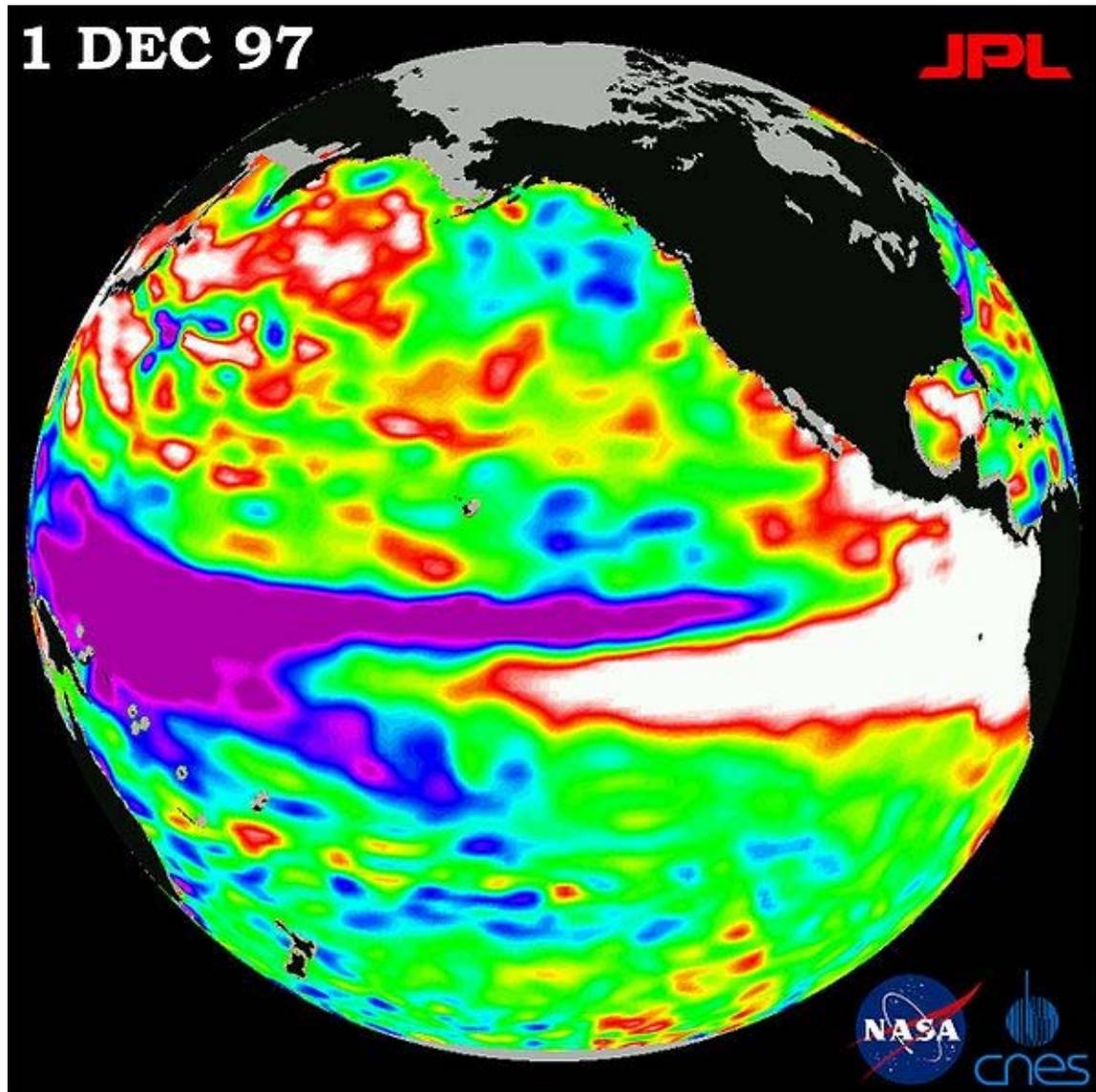
- National Oceanic and Atmospheric Administration (NOAA)
- National Aeronautics and Space Administration (NASA)
- France's Centre National d'Études Spatiales (CNES)
- European Organisation for the Exploitation of Meteorological Satellites (EUMETSAT)

CNES provided the spacecraft, NASA and CNES jointly provided the payload instruments and NASA's Launch Services Program at the Kennedy Space Center was responsible for the launch management and countdown operations. After completing the on-orbit commissioning of the spacecraft, CNES handed over operation and control of the spacecraft to NOAA in October 2008.

CNES will process, distribute and archive the research-quality data products that will become available in 2009. EUMETSAT will process and distribute operational data received by its ground station to users in Europe and will archive the data. NOAA will process and distribute operational data received by its ground stations to non-European users and archive that data along with the CNES data products. NOAA and EUMETSAT will generate the near-real-time products and distribute them to users.

NASA will evaluate the performance of its instruments: the advanced microwave radiometer, the Global Positioning System payload, and the laser retroreflector assembly. In addition, NASA and CNES will validate scientific data products. NASA's Jet Propulsion Laboratory in Pasadena, California, manages the mission for NASA's Science Mission Directorate in Washington.

Prior similar missions



OSTM/Jason-2's predecessor TOPEX/Poseidon caught the largest El Niño in a century seen in this image from Dec. 1, 1997.

The two previous altimetry missions TOPEX/Poseidon and Jason-1 have led to major advances in the science of physical oceanography and in climate studies. Their 15-year data record of ocean surface topography has provided the first opportunity to observe and understand the global change of ocean circulation and sea level. The results have improved the understanding of the role of the ocean in climate change and improved weather and climate predictions. Data from these missions are used to improve ocean models, forecast hurricane intensity, and identify and track large ocean/atmosphere phenomena such as El Niño and La Niña. The data are also used every day in applications as diverse as routing ships, improving the safety and efficiency of offshore industry operations, managing fisheries and tracking marine mammals.

Some of the areas in which TOPEX/Poseidon and Jason 1-have made major contributions, and to which OSTM/Jason-2 will continue to add, are:

- Ocean Variability

The missions revealed the surprising variability of the ocean, how much it changes from season to season, year to year, decade to decade and on even longer time scales. They ended the traditional notion of a quasi-steady, large-scale pattern of global ocean circulation by proving that the ocean is changing rapidly on all scales, from huge features such as El Nino and La Nina, which can cover the entire equatorial Pacific, to tiny eddies swirling off the large Gulf Stream in the Atlantic.

- Sea Level Change

Measurements by TOPEX/Poseidon and Jason-1 show that mean sea level has been rising by about three millimeters (.12 inches) a year since 1993. This is about twice the estimates from tide gauges for the previous century, indicating a possible recent acceleration in the rate of sea level rise.

The data record from these altimetry missions has given scientists important insights into how global sea level is affected by natural climate variability, as well as by human activities.

- Planetary Waves

TOPEX/Poseidon and Jason-1 made clear the importance of planetary-scale waves, such as Rossby and Kelvin waves. No one had realized how widespread these waves are. Thousands of kilometers wide, these waves are driven by wind under the influence of Earth's rotation and are important mechanisms for transmitting climate signals across the large ocean basins. At high latitudes, they travel twice as fast as scientists believed previously, showing the ocean responds much more quickly to climate changes than was known before these missions.

- Ocean Tides

The precise measurements of TOPEX/Poseidon's and Jason-1 have brought knowledge of ocean tides to an unprecedented level. The change of water level due to tidal motion in the deep ocean is known everywhere on the globe to within 2.5 centimeters (one inch). This new knowledge has revised notions about how tides dissipate. Instead of losing all their energy over shallow seas near the coasts, as previously believed, about one third of tidal energy is actually lost to the deep ocean. There, the energy is consumed by mixing water of different properties, a fundamental mechanism in the physics governing the general circulation of the ocean.

- Ocean Models

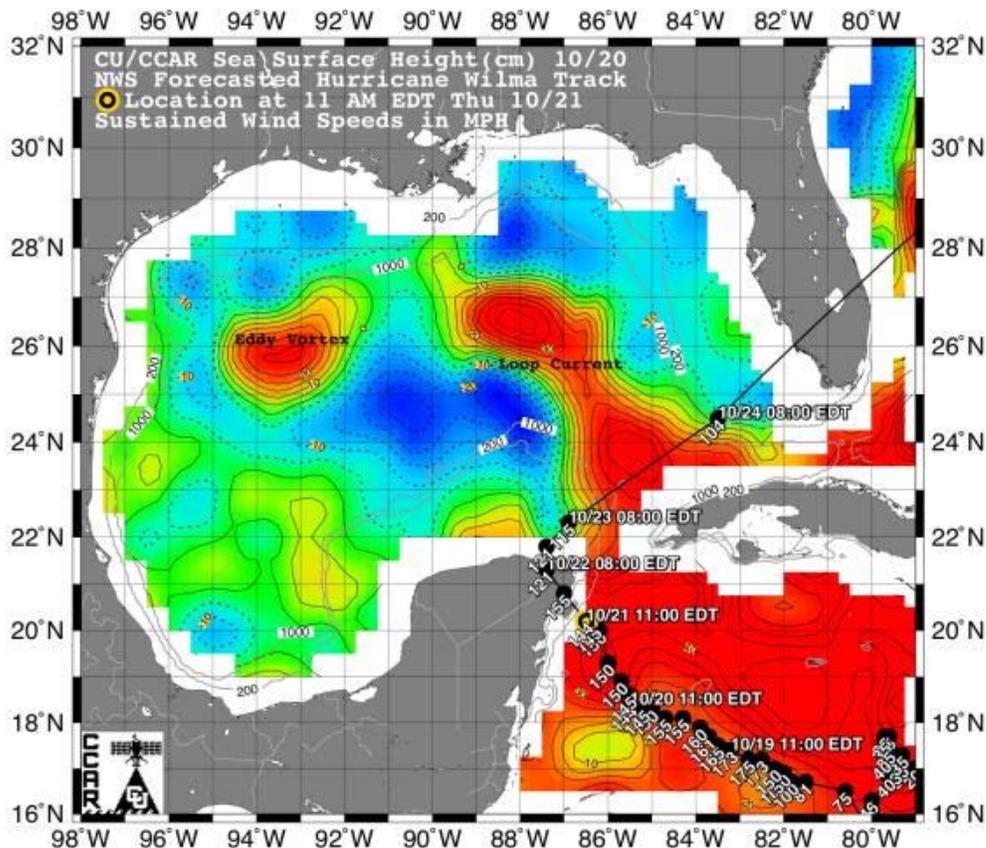
TOPEX/Poseidon and Jason-1 observations provided the first global data for improving the performance of the numerical ocean models that are a key component of climate prediction models.

Data use and benefits

The mission's first validated data products in support of improved weather, climate and ocean forecasts are now being distributed to the public within a few hours of observation. Beginning in 2009, other data products for climate research will be available a few days to a few weeks after observations are taken by the satellite.

Altimetry data have a wide variety of uses from basic scientific research on climate to ship routing. Applications include:

- Climate research: Altimetry data are incorporated into computer models to understand and predict changes in the distribution of heat in ocean, a key element of climate.
- El Niño and La Niña forecasting: Understanding the pattern and effects of climate cycles such as El Niño helps predict and mitigate the disastrous effects of floods and drought.



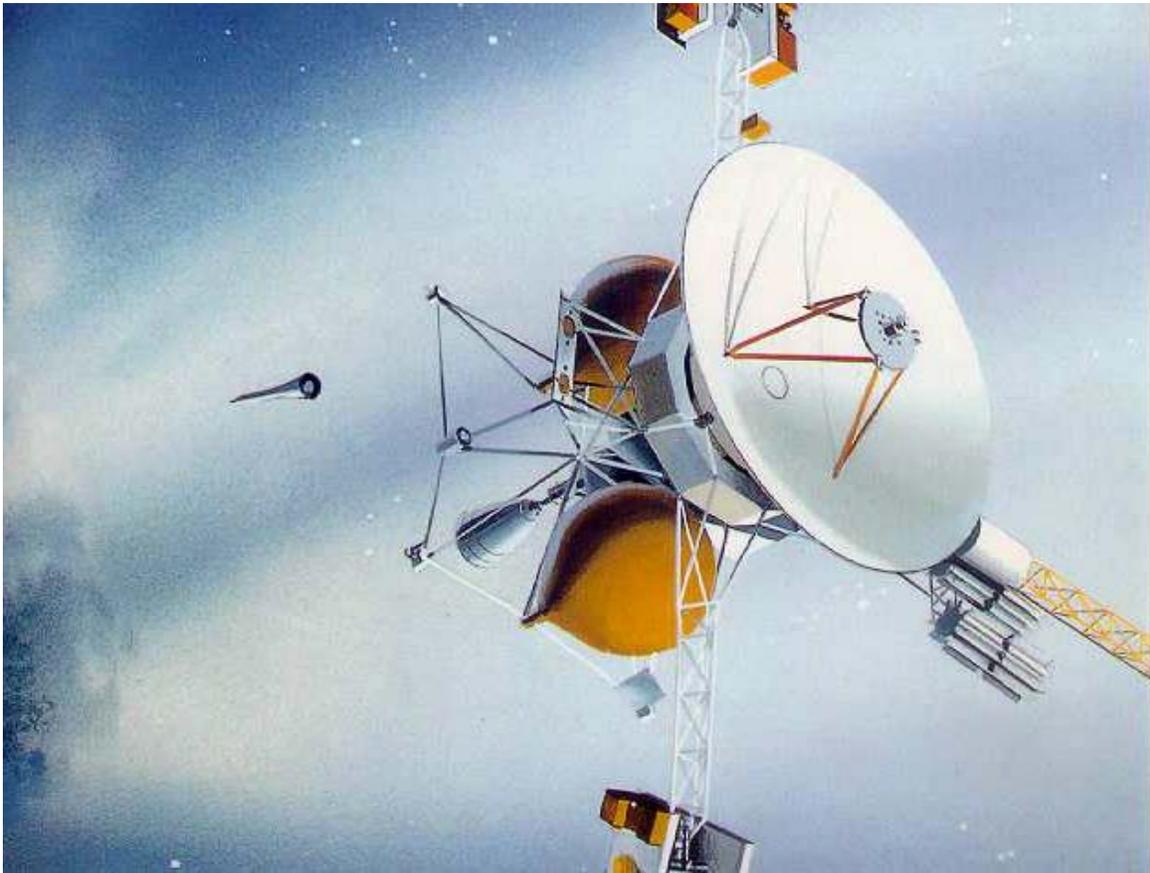
Altimetry reveals the ocean heat that can fuel hurricanes.

- Tropical cyclone forecasting: Altimeter data and satellite ocean wind data are incorporated into atmospheric models for hurricane season forecasting and individual storm severity.
- Ship routing: Maps of currents, eddies, and vector winds are used in commercial shipping and recreational yachting to optimize routes.
- Offshore industries: Cable-laying vessels and offshore oil operations require accurate knowledge of ocean circulation patterns, to minimize impacts from strong currents.
- Marine mammal research: Sperm whales, fur seals, and other marine mammals can be tracked, and therefore studied, around ocean eddies where nutrients and plankton are abundant.
- Fisheries management: Satellite data identify ocean eddies which bring an increase in organisms that comprise the marine food web, attracting fish and fishermen.
- Coral reef research: Remotely sensed data are used to monitor and assess coral reef ecosystems, which are sensitive to changes in ocean temperature.
- Marine debris tracking: Altimetry can help locate hazardous materials such as floating and partially submerged fishing nets, timber, and ship debris.

Chapter- 8

Other Space Probes and Missions

Mariner Mark II



Conceptual artwork of the CRAF spacecraft based on Mariner Mark II



SOTP a Mariner Mark II spacecraft concept, drawing from 1988. Later redesigned to the Cassini-Huygens spacecraft

Mariner Mark II was NASA's planned family of unmanned spacecraft for the exploration of the outer solar system that were to be developed and operated by JPL between 1990 through the year 2010.

After the “flagship” multibillion-dollar missions of the 1970s, in the 1980s NASA was looking for a new, more affordable direction for the 1990s and beyond. Two projects were conceived by NASA's Solar System Exploration Committee in 1983, the Planetary Observer program, and Mariner Mark II.

The Observer program, starting with the Mars Observer, was envisioned as a series of low-cost missions to the inner solar system, based on commercial Earth satellites, while

the Mariner Mark II was to be a series of large spacecraft for the exploration of the outer solar system.

Mariner Mark II spacecraft were to utilize common design, hardware and software solutions, much of it derived from previous missions such as Voyager and Galileo as well as select new technologies, such as advanced gyroscopes, all with the aim of cutting costs. It was hoped that this new approach would reduce the mission costs to about \$400 million each, about half the price of Galileo.

The first two missions of the project were to be a mission to Saturn and its moon Titan, the **Saturn Orbiter/Titan Probe**, or **SOTP** (later Cassini) and the **Comet Rendezvous Asteroid Flyby**, or **CRAF**, both of which were approved by Congress in 1990.

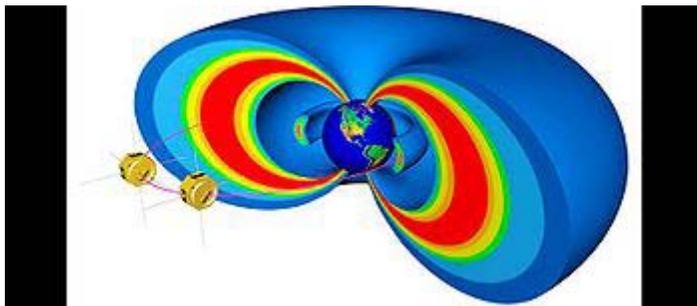
Other planned Mariner Mark II based spacecraft were an ESA led follow-on to CRAF, the Comet Nucleus Sample Return or CNSR (later Rosetta), Pluto Flyby, a flyby of Pluto and a Neptune orbiter with an atmospheric probe (Neptune Orbiter).

However, Congressionally imposed reductions to FY 1992-93 funding requirements forced NASA to terminate the CRAF mission and to delay the Cassini launch from April 1996 to October 1997. In order to save it, NASA was forced to significantly redesign Cassini to reduce the total program cost, mass and power requirements, while maintaining the October 1997 launch aboard a Titan IV launch vehicle.

NASA would replace the Mariner Mark II program with the lower cost Discovery Program.

Radiation Belt Storm Probes

Radiation Belt Storm Probes



Operator	NASA
Major contractors	Applied Physics Laboratory
Mission type	Two Earth orbiters operating within Earth's

	radiation belts
Launch date	Currently 2012
Launch vehicle	EELV Class
Mission duration	2-years
Homepage	RBSP at APL
Mass	<1500 kg for both

Orbital elements

Inclination	~10 degrees
Apoapsis	~5.8 Earth Radii
Periapsis	~700 kilometers
Orbital period	~9 hours

The **Radiation Belt Storm Probes (RBSP)** is a NASA mission under the Living With a Star (LWS) program. The goal of the LWS program is to develop the scientific understanding necessary to effectively address those aspects of the connected Sun-Earth system that directly affect life and society. The mission of RBSP is to gain scientific understanding (to the point of predictability) of how populations of relativistic electrons and ions in space form or change in response to changes in solar activity and the solar wind.

General

The RBSP mission is currently scheduled for 2012. The Critical Design Review for the mission was completed in December 2009. NASA's Goddard Space Flight Center manages the overall Living With a Star program of which RBSP is a project, along with Solar Dynamics Observatory (SDO). The Applied Physics Laboratory is responsible for the overall implementation and instrument management for RBSP. The primary mission is scheduled to last 2 years, with expendables expected to last for 4 years.

Launch vehicle

On Mar. 16, 2009 United Launch Alliance (ULA) announced that NASA had awarded ULA a contract to launch RBSP using an Atlas V 401 rocket. RBSP will launch from NASA's Kennedy Space Center (KSC).

Spacecraft

RBSP consists of two spin stabilized spacecraft. Both spacecraft will launch from a single EELV-class Launch Vehicle.

Instruments

NASA Funded Investigations:

1. Energetic Particle, Composition, and Thermal Plasma (ECT) Instrument Suite ; The Principal Investigator is Harlan Spence from Boston University. Key partners in this investigation LANL, Southwest Research Institute, Aerospace Corporation, LASP
2. Electric and Magnetic Field Instrument Suite and Integrated Science (EMFISIS); The Principal Investigator is Craig Kletzing from the University of Iowa.
3. Electric Field and Waves Instrument (EFW); The Principal Investigator is John Wygant from University of Minnesota. Key partners in this investigation include the University of California at Berkeley and the University of Colorado at Boulder.
4. Radiation Belt Storm Probes Ion Composition Experiment (RBSPICE); The Principal Investigator is Lou Lanzerotti from the New Jersey Institute of Technology. Key partners include the Applied Physics Laboratory and Fundamental Technologies, LLC .

Government Furnished Equipment:

1. Relativistic Particle Spectrometer (RPS) from the National Reconnaissance Office

Milestones

- 1) Mission Concept Review (MCR) successfully completed, January 30-31, 2007
- 2) SR-MDR successfully completed, October, 2007
- 3) Preliminary Design review, October, 2008
- 4) Confirmation review, January, 2009

Active Cavity Radiometer Irradiance Monitor Satellite



ACRIMSAT

ACRIMSAT is the acronym for **Active Cavity Radiometer Irradiance Monitor Satellite**. It is a dedicated satellite and instrument that is one of the 21 primary observational components of NASA's Earth Observing System program. ACRIMSAT was launched on 20 December 1999 from Vandenberg Air Force Base as the secondary payload on a Taurus rocket along with KOMPSAT and placed into a high inclination, 700 km. sun-synchronous orbit from which the ACRIM3 instrument monitors the total solar irradiance (TSI).

The ACRIM3 instrument has made state of the art measurements of the TSI since the start of its Science Mission in April 2000. It extends the TSI measurement database begun by earlier ACRIM instruments on the NASA Solar Maximum Mission (ACRIM1: 1980-1989) and Upper Atmosphere Research Satellite (ACRIM2: 1991-2001).

Richard C. Willson is the principal investigator for the experiment and leads the Science Team. Instrument Scientist Roger Helizon, Mission Manager Sandy Kwan of the ACRIMSAT group at the Jet Propulsion Laboratory (JPL) and Principal Investigator Richard Willson collaborated on the design and implementation of the ACRIM3 instrument. The JPL ACRIMSAT Group operates the ACRIMSAT/ACRIM3 mission via the ACRIM tracking station at the JPL Table Mtn. Observatory. Co-Investigators are: Hugh Hudson (solar physics), Alexander Mordvinov (solar physics), Nicola Scafetta (climate impact of solar variability) and Roger Helizon (ACRIM3 Instrument Scientist).

ACRIMSAT (international designator 1999-070B) is a spin-stabilized, single-purpose satellite constructed by Orbital Sciences Corporation. The end-to-end cost of the ACRIMSAT satellite, the ACRIM3 instrument, launch, ground station, operations and the science team activities during its 8 year mission to date has been less than \$30 million - a good example of the efficacy of NASA's 'Better, Faster, Cheaper' initiative.

ACRIMSAT/ACRIM3 tracked the TSI during a 2004 transit of Venus, and measured the 0.1% reduction in the solar intensity caused by the shadow of the planet.

Astrobiology Field Laboratory

Astrobiology Field Laboratory



Astrobiology Field Laboratory

Operator	NASA
Mission type	Rover
Mission duration	One Martian year
Homepage	
Mass	450 kg (1000 lb) maximum
Power	RTG

The **Astrobiology Field Laboratory (AFL)** was a proposed NASA unmanned spacecraft that would have conducted a robotic search for life on Mars. This proposed mission, which was not funded, would have landed a rover on Mars and explore a site thought to be a habitat. Examples of such sites are an active or extinct hydrothermal deposit, a dry lake or a specific polar site.

Had it been funded, the rover was to be built by NASA's Jet Propulsion Laboratory, based upon the Mars Science Laboratory rover design, it would have carried astrobiology-oriented instruments, and ideally, a core drill. The original plans called for a launch in 2016, however, budgetary constraints caused funding cuts.

Mission

The rover could have been the first mission since the Viking program landers of the 1970s to specifically look for the chemistry associated with life (biosignatures), such as carbon-based compounds along with molecules involving both sulfur and nitrogen. The

mission strategy was to search for habitable zones by "following the water" and "finding the carbon." In particular, it was to conduct detailed analysis of geologic environments identified by the 2011 Mars Science Laboratory as being conducive to life on Mars and biosignatures, past and present. Such environments might include fine-grained sedimentary layers, hot spring mineral deposits, icy layers near the poles, or sites such as gullies where liquid water once flowed or may continue to seep into soils from melting ice packs.

Planning

The Astrobiology Field Laboratory (AFL) would have followed the Mars Reconnaissance Orbiter (launched in 2005), Phoenix lander (launched in 2007), Mars Science Laboratory (to launch in 2011), the Trace Gas Mission orbiter (to launch in 2016), and the ExoMars (to launch in 2018) projects in this strategic effort. The AFL 'Science Steering Group' developed the following set of search strategies and assumptions for increasing the likelihood of detecting biosignatures:

1. Life processes may produce a range of biosignatures such as lipids, proteins, amino acids, kerogen-like material or characteristic micropores in rock. However, the biosignatures themselves may become progressively destroyed by ongoing environmental processes.
2. Sample acquisition will need to be executed in multiple locations and at depths below that point on the Martian surface where oxidation results in chemical alteration. The surface is oxidizing as a consequence of the absence of magnetic field or magnetosphere shielding from harmful space radiation and solar electromagnetic radiation—which may well render the surface sterile down to a depth greater than 7.5 metres (24.6 feet). To get under that potential sterile layer, a core drill design is currently being studied. As with any trade, the inclusion of the drill would come at the mass expense available for other payload elements.
3. Analytical laboratory biosignature measurements require the pre-selection and identification of high-priority samples, which could be subsequently subsampled to maximize detection probability and spatially resolve potential biosignatures for detailed analysis.

Payload

The conceptual payload included a Precision Sample Handling and Processing System to replace and augment the functionality and capabilities provided by the Sample Acquisition Sample Processing and Handling system that is currently part of the 2009 Mars Science Laboratory rover. The AFL payload was to attempt to minimize any conflicting positive detection of life by including a suite of instruments that provide at least three mutually confirming analytical laboratory measurements.

For the purpose of discerning a reasonable estimate on which to base the rover mass, the conceptual payload was to include:

- Precision Sample Handling and Processing System.
- Forward Planetary Protection for Life-Detection Mission to a Special Region.
- Life Detection-Contamination Avoidance.
- Astrobiology Instrument Development.
- MSL Parachute Enhancement.
- Autonomous safe long-distance travel.
- Autonomous single-cycle instrument placement.
- Pinpoint landing (100–1000 m) (if necessary to reach specific science targets in hazardous regions).
- Mobility for highly sloped terrain 30° (if required to reach science targets).

Power source

It was suggested that the Astrobiology Field Laboratory use radioisotope thermoelectric generators (RTGs) as its power source, like the ones to be used on the Mars Science Laboratory. The radioactive RTG power source was to last for about one Martian year, or approximately two Earth years. RTGs can provide reliable, continuous power day and night, and waste heat can be used via pipes to warm systems, freeing electrical power for the operation of the vehicle and instruments.

Science

Though the AFL science justification did not include a pre-definition of potential life forms that might be found on Mars, the following assumptions were made:

1. Life utilizes some form of carbon.
2. Life requires an external energy source (sunlight or chemical energy) to survive.
3. Life is packaged in cellular-type compartments (cells).
4. Life requires liquid water.

Within the region of surface operations, identify and classify Martian environments (past or present) with different habitability potential, and characterize their geologic context. Quantitatively assess habitability potential by:

- Measuring isotopic, chemical, mineralogical, and structural characteristics of samples, including the distribution and molecular complexity of carbon compounds.
- Assessing biologically available sources of energy, including chemical, thermal and electromagnetic.
- Determining the role of water (past or present) in the geological processes at the landing site.
- Investigate the factors that will affect the preservation of potential signs of life (past or present) This refers to the potential for a particular biosignature to survive and therefore be detected in a particular habitat. Also, post-collection preservation

- may be required for later sample retrieval, although that would necessitate a further assessment of precision landing of Mars sample return mission mission.
- Investigate the possibility of prebiotic chemistry on Mars, including non-carbon biochemistry.
 - Document any anomalous features that can be hypothesized as possible Martian biosignatures.

It is fundamental to the AFL concept to understand that organisms and their environment constitute a system, within which any one part can affect the other. If life exists or has existed on Mars, scientific measurements to be considered would focus on understanding those systems that support or supported it. If life never existed while conditions were suitable for life formation, understanding why a Martian genesis never occurred would be a future priority. The AFL team stated that it is reasonable to expect that missions like AFL will play a significant role in this process, but unreasonable to expect that they will bring it to a conclusion.