

Exploration of Mars



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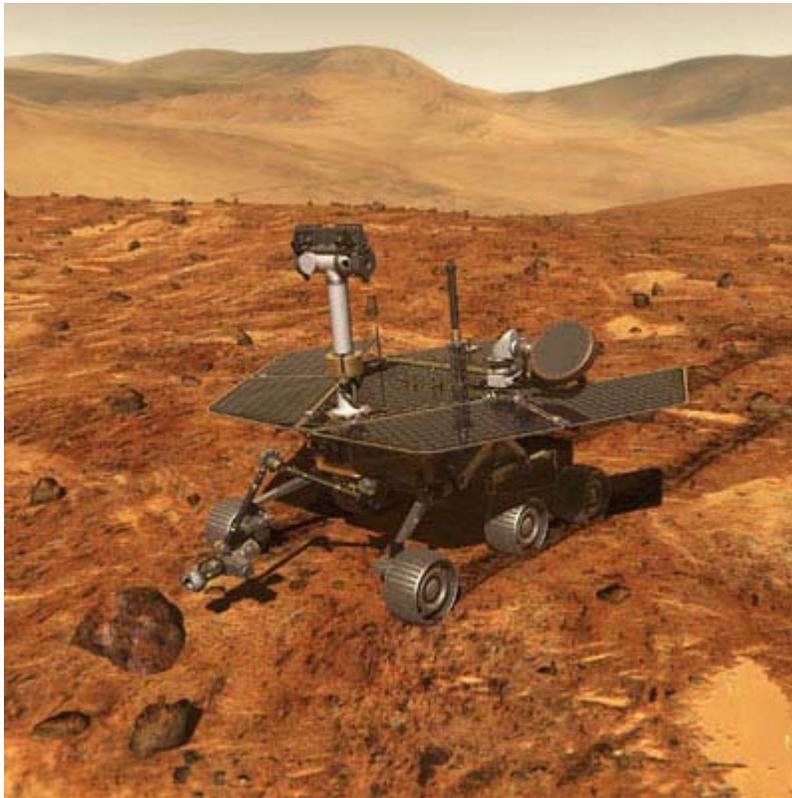
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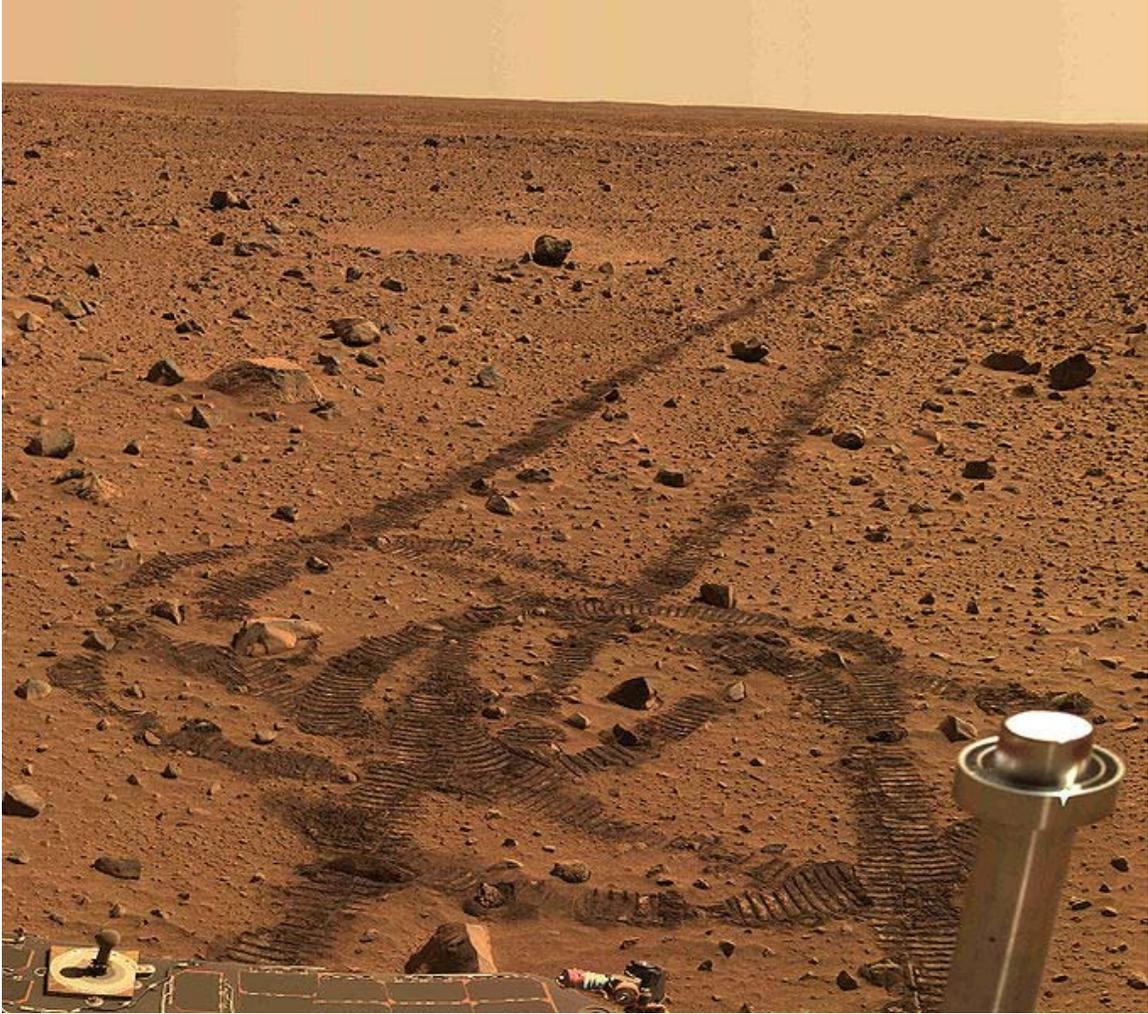
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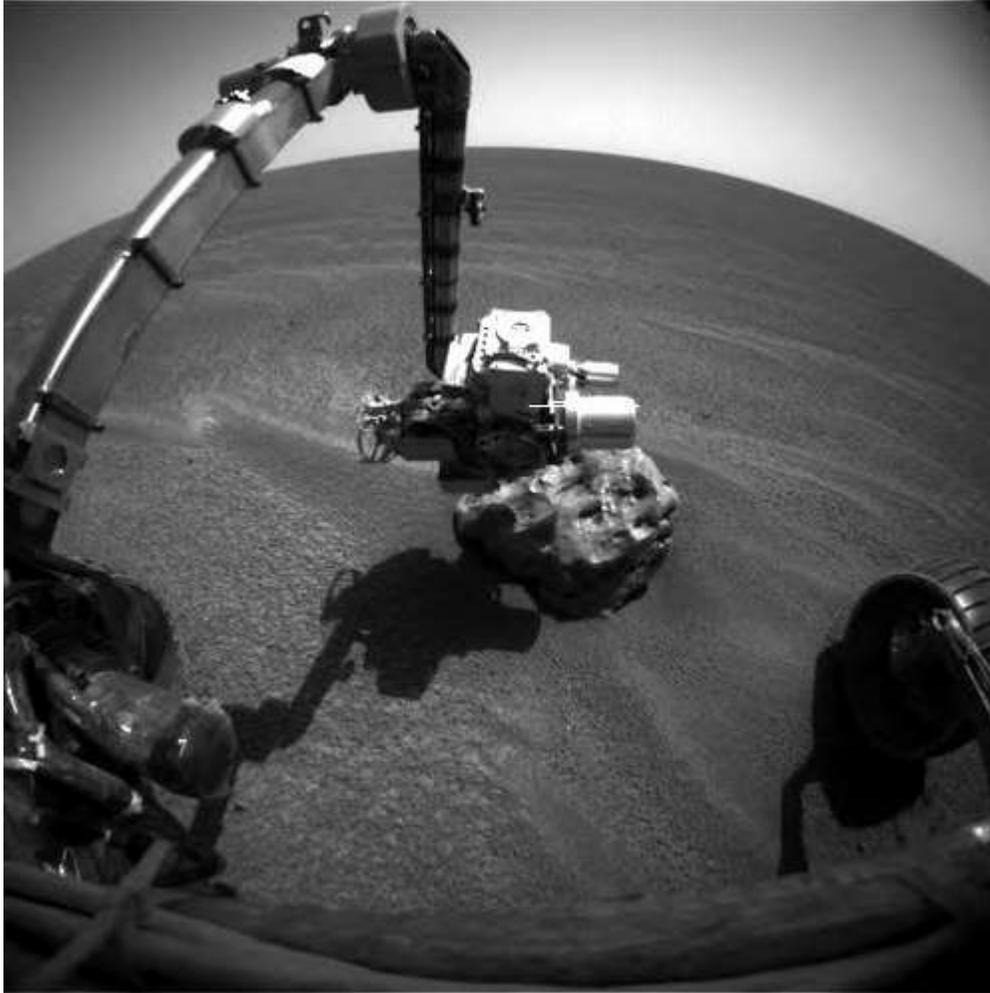
Exploration of Mars



Computer-generated image of Spirit Mars Exploration Rover which touched down in Gusev Crater in 2004.



Real image from Mars, part of a panorama taken by the Spirit rover in 2004



Heat Shield Rock (Meridiani Planum) is examined by Opportunity rover (MER-B) in 2005

The **exploration of Mars** has been an important part of the space exploration programs of the Soviet Union, the United States, Europe, and Japan. Dozens of robotic spacecraft, including orbiters, landers, and rovers, have been launched toward Mars since the 1960s. These missions were aimed at gathering data about current conditions and answering questions about the history of Mars as well as a preparation for a possible human mission to Mars. The questions raised by the scientific community are expected to not only give a better appreciation of the red planet but also yield further insight into the past, and possible future, of Earth.

The exploration of Mars has come at a considerable financial cost with roughly two-thirds of all spacecraft destined for Mars failing before completing their missions, with some failing before they even begin. Such a high failure rate can be attributed to the complexity and large number of variables involved in an interplanetary journey, and has led researchers to jokingly speak of *The Great Galactic Ghoul* which subsists on a diet of Mars probes. This phenomenon is also informally known as the *Mars Curse*. As of

January 2011, there is one functioning piece of equipment on the surface of Mars beaming signals back to Earth: the Opportunity rover.

In October 2009, an agreement was signed between United States' space agency, NASA, and Europe's space agency, ESA in order to increase cooperation and expand collective capabilities, resources and expertise to continue the exploration of Mars; this agreement is named the Mars Exploration Joint Initiative (MEJI).

The planet Mars

Mars has long been the subject of human fascination. Early telescopic observations revealed color changes on the surface which were originally attributed to seasonal vegetation as well as apparent linear features which were ascribed to intelligent design. These early and erroneous interpretations led to widespread public interest in Mars. Further telescopic observations found Mars' two moons - Phobos and Deimos, the polar ice caps and the feature now known as Olympus Mons, the solar system's tallest mountain. These discoveries piqued further interest in the study and exploration of the red planet. Mars is a rocky planet, like Earth, that formed around the same time, yet with only half the diameter of Earth, and a far thinner atmosphere, it has a cold and desert-like surface. It is notable, however, that although the planet has only one quarter of the *surface area* of the Earth, it has about the same *land area*, since only one quarter of the surface area of the Earth is land.

Launch windows

In order to understand the history of the robotic exploration of Mars it is important to note that minimum-energy launch windows occur at intervals of approximately 2.135 years, i.e. 780 days (the planet's synodic period with respect to Earth). This is a consequence of the Hohmann transfer orbit for minimum-energy interplanetary transfer. The slight inclination and eccentricity of Mars' orbit relative to Earth's orbit means that the minimum energy launch date differs from that implied by the synodic period slightly. Launch window width is subject to vehicle constraints but are typically on the order of one month wide. The windows for recent/future years were/will be centred on the following dates:

- 18 November 1996 (MJD 50405)
- 22 January 1999 (MJD 51200)
- 19 April 2001 (MJD 52018)
- 5 June 2003 (MJD 52795)
- 10 August 2005 (MJD 53592)
- 21 September 2007 (MJD 54364)
- 15 October 2009 (MJD 55119)
- 7 November 2011 (MJD 55872)
- 2 January 2014 (MJD 56659)

Minimum energy inbound (Mars to Earth) launch windows also occur at similar intervals.

In addition to these minimum-energy trajectories, which occur when the planets are aligned so that the Earth to Mars transfer trajectory goes halfway around the Sun, an alternate trajectory which has been proposed goes first inward toward Venus orbit, and then outward, resulting in a longer trajectory which goes about 360 degrees around the Sun ("opposition-class trajectory").

Early flyby probes and orbiters

Mars Curse

The high failure rate of missions launched from Earth attempting to explore Mars has become informally known as the "Mars Curse". The "Galactic Ghoul" is a fictional space monster that consumes Mars probes, a term coined in 1997 by Time Magazine journalist Donald Neff.

Of 38 launches from Earth in an attempt to reach the planet, only 19 succeeded, a success rate of 50%. Twelve of the missions included attempts to land on the surface, but only seven transmitted data after landing.

The majority of the failed missions occurred in the early years of space exploration and were part of the Soviet and later Russian Mars probe program that suffered several technical difficulties, other than the largely successful Venera program for the exploration of Venus.

Modern missions have an improved success rate; however, the challenge, complexity and length of the missions make it inevitable that failures will occur.

The U.S. NASA Mars exploration program has had a somewhat better record of success in Mars exploration, achieving success in 13 out of 20 missions launched (a 65% success rate), and succeeding in six out of seven (an 86% success rate) of the launches of Mars landers.

Timeline of Mars exploration

Mission (1960–1969)	Launch	Arrival at Mars	Termination	Objective	Result
 Mars 1960A	10 October 1960		10 October 1960	Flyby	Launch failure
 Mars 1960B	14 October 1960		14 October 1960	Flyby	Launch failure
 Sputnik 22 (Mars 1962A)	24 October 1962		24 October 1962	Flyby	Broke up shortly after launch

 Mars 1	1 November 1962		21 March 1963	Flyby	Some data collected, but lost contact before reaching Mars, flyby at approx. 193,000 km
 Sputnik 24 (Mars 1962B)	4 November 1962		19 January 1963	Lander	Failed to leave Earth's orbit
 Mariner 3	5 November 1964		5 November 1964	Flyby	Failure during launch ruined trajectory.
 Mariner 4	28 November 1964	14 July 1965	21 December 1967	Flyby	Success (first successful flyby)
 Zond 2	30 November 1964		May 1965	Flyby	Communication lost three months before reaching Mars
 Mariner 6	25 February 1969	31 July 1969	August 1969	Flyby	Success
 Mariner 7	27 March 1969	5 August 1969	August 1969	Flyby	Success
 Mars 1969A	27 March 1969		27 March 1969	Orbiter	Launch failure
 Mars 1969B	2 April 1969		2 April 1969	Orbiter	Launch failure
Mission (1970–1989)	Launch	Arrival at Mars	Termination	Objective	Result
 Mariner 8	8 May 1971		8 May 1971	Orbiter	Launch failure
 Cosmos 419 (Mars 1971C)	10 May 1971		12 May 1971	Orbiter	Launch failure
 Mariner 9	30 May 1971	13 November 1971	27 October 1972	Orbiter	Success (first successful orbit)
 Mars 2	19 May 1971	27 November 1971	22 August 1972 27 November 1971	Orbiter Lander / rover	Success Crashed on surface of Mars

			22 August 1972	Orbiter	Success
 Mars 3	28 May 1971	2 December 1971	2 December 1971	Lander / rover	Partial Success. First successful landing; landed softly, but ceased transmission within 15 seconds.
 Mars 4	21 July 1973	10 February 1974	10 February 1974	Orbiter	Did not enter orbit, but made a close flyby
 Mars 5	25 July 1973	2 February 1974	21 February 1974	Orbiter	Partial success. Entered orbit, and returned data, but failed within 9 days
 Mars 6	5 August 1973	12 March 1974	12 March 1974	Lander	Partial success. Data returned during descent, but not after landing on Mars
 Mars 7	9 August 1973	9 March 1974	9 March 1974	Lander	Landing probe separated prematurely; entered heliocentric orbit.
 Viking 1	20 August 1975	20 July 1976	17 August 1980	Orbiter	Success
			13 November 1982	Lander	Success
 Viking 2	9 September 1975	3 September 1976	25 July 1978	Orbiter	Success
			11 April 1980	Lander	Success
 Phobos 1	7 July 1988		2 September 1988	Orbiter	Contact lost while on route to Mars
				lander	Not deployed

 Phobos 2	12 July 1988	29 January 1989	27 March 1989	Orbiter	Partial success: entered orbit and returned some data. Contact lost just before deployment of landers
				Landers	Not deployed
Mission (1990–1999)	Launch	Arrival at Mars	Termination	Objective	Result
 Mars Observer	25 September 1992	24 August 1993	21 August 1993	Orbiter	Lost contact just before arrival
 Mars Global Surveyor	7 November 1996	11 September 1997	5 November 2006	Orbiter	Success
 Mars 96	16 November 1996		17 November 1996	Orbiter / landers	Launch failure
 Mars Pathfinder	4 December 1996	4 July 1997	27 September 1997	Lander / rover	Success
 Nozomi (Planet-B)	3 July 1998		9 December 2003	Orbiter	Complications while on route; Never entered orbit
 Mars Climate Orbiter	11 December 1998	23 September 1999	23 September 1999	Orbiter	Crashed on surface due to metric-imperial mix-up
 Mars Polar Lander	3 January 1999	3 December 1999	3 December 1999	Lander	Crash landed on surface due to improper hardware testing
 Deep Space 2 (DS2)				Hard landers	
Mission (2000–present)	Launch	Arrival at Mars	Termination	Objective	Result
 2001 Mars Odyssey	7 April 2001	24 October 2001	Currently operational	Orbiter	Success
 Mars Express	2 June 2003	25 December	Currently operational	Orbiter	Success

 Beagle 2		2003	6 February 2004	Lander	Lost contact in December 2003 after separation from Mars Express. Fate unknown.
 MER-A Spirit	10 June 2003	4 January 2004	last contact March 2010, stuck	Rover	Success
 MER-B Opportunity	7 July 2003	25 January 2004	Currently operational	Rover	Success
 Rosetta	2 March 2004	February 25, 2007	Currently operational	Gravity assist enroute to comet 67P/Churyumov-Gerasimenko	Success
 Mars Reconnaissance Orbiter	12 August 2005	10 March 2006	Currently operational	Orbiter	Success
 Phoenix	4 August 2007	25 May 2008	10 November 2008	Lander	Success
 Dawn	27 September 2007	17 February 2009	Currently operational	Gravity assist to Vesta	Success
Future missions	Launch schedule	Estimated arrival at Mars	—	Objective	Notes
 Fobos-Grunt	2012			Orbiter, lander, sample return	Will attempt to bring samples of Phobos' soil back to Earth in 2014 (<i>or</i> 2012).
 Yinghuo-1				Orbiter	Will travel with the Russian Phobos-Grunt mission
 MSL Curiosity	Between November 25 and December 18, 2011	2012		Rover	Powered by radioisotopes, it will perform chemical and physical analysis on martian soil and

 MetNet	2011– 2019	Multi-lander network	atmosphere. Simultaneous meteorological measurements at multiple locations.
 Northern Light	2012	Lander / rover	Solar powered, it will perform chemical and physical analysis on Martian soil and atmosphere.
 MAVEN	2013	Orbiter	Part of the Mars Scout Program The ISRO has begun the conceptual phase for an orbiter mission to Mars.
 Mars mission	Between 2013- 2015	Orbiter	Search for life on Mars, water, atmospherics, magnetics
 ARES (martian rocketplane)	Possibly by 2016	aircraft	TGM orbiter will deliver the ExoMars static lander.
 Cesa and  ExoMars	2016	Orbiter, static lander	ExoMars rover and MAX-C rover.
 Cesa and  Mars sample return mission	2018	Two rovers	Being considered but not yet funded or scheduled.
 Mars sample return mission	Possibly by 2020	Orbiter, lander, rover, sample return	

Cancelled missions

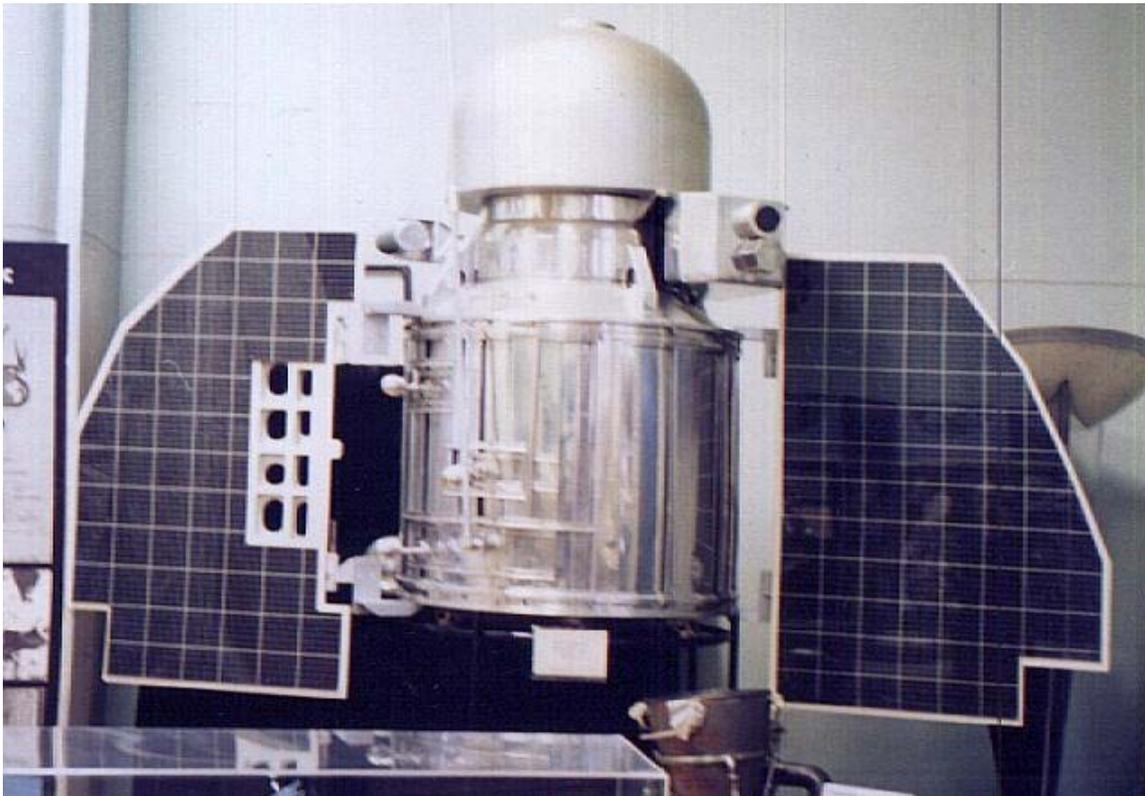
- *Mars 4NM* and *Mars 5NM* - projects intended by the Soviet Union for heavy Marsokhod (in 1973 according to initial plan of 1970) and Mars sample return

- (planned for 1975) missions by launching on N1 rocket that has never flown successfully.
- *Voyager* - USA, 1970s - Two orbiters and two landers, launched by a single Saturn V rocket.
 - *Mars Aerostat* - Russian/French balloon mission, originally planned for the 1992 launch window, postponed to 1994 and then to 1996 before being cancelled.
 - *Mars Environmental Survey* - set of 16 landers planned for 1999–2009
 - *Mars-98* - Russian mission including an orbiter, lander, and rover, planned for 1998 launch opportunity
 - *Mars Surveyor 2001 Lander* - October 2001 - Mars lander
 - *Beagle 3* - 2009 British lander mission meant to search for life, past or present.
 - *NetLander* - 2007 or 2009 - Mars netlanders
 - *Mars Telecommunications Orbiter* - September 2009 - Mars orbiter for telecommunications
 - *Kitty Hawk* - Mars airplane micromission, proposed for December 17, 2003, the centennial of the Wright brother's first flight.

Chapter- 2

Mars 1M and Mars 1

Mars 1M



Mars 1M spacecraft

Mars 1M was a series of two unmanned spacecraft which were used in the first Soviet missions to explore Mars. They were the earliest missions of the Mars program. The Western media dubbed the spacecraft "*Marsnik*", a portmanteau of *Mars* and *Sputnik*.

Mars 1M No.1, known in the west as Marsnik 1, Mars 1960A and Korabl 4, was destroyed in a launch failure on October 10, 1960. In 1962 NASA Administrator James E. Webb informed the United States Congress that NASA believed the mission was an attempt at a Mars flyby probe. Some Soviet scientists involved with the program at that time claim no knowledge of this mission, stating that only the second launch was an intended Mars mission. However V.G. Perminov, the leading designer of planetary spacecraft at the Lavochkin design bureau, states that this mission was indeed intended for Mars, and was identical to the later mission.

Mars 1M No.2, known in the west as Marsnik 2, Korabl 5 and Mars 1960B, was launched on October 14, 1960.

Both Mars 1M spacecraft were launched by Molniya rockets. The third stage pumps on both rockets were unable to develop enough thrust to commence ignition, and as a result neither spacecraft achieved its initial geocentric parking orbit. The spacecraft reached an altitude of 120 km before reentry.

Mission profile

The objectives of the mission were to investigate interplanetary space between Earth and Mars, to study Mars and return surface images from a flyby trajectory, and to study the effects of extended spaceflight on onboard instruments and provide radio communications from long distances.

Spacecraft and subsystems

NASA describes the spacecraft as:

nearly identical to the Venera 1 design, a cylindrical body about 2 meters high with two solar panel wings, a 2.33 meter high-gain net antenna, and a long antenna arm, and had a mass of about 650 kg. It carried a 10 kg science payload consisting of a magnetometer on a boom, cosmic ray counter, plasma-ion trap, a radiometer, a micrometeorite detector, and a spectroreflectometer to study the CH band, a possible indicator of life on Mars. These instruments were mounted on the outside of the spacecraft. A photo-television camera was held in a sealed module in the spacecraft and could take pictures through a viewport when a sensor indicated the Sun-illuminated martian surface was in view. Attitude was controlled by a Sun-star sensor with attitude correction performed by a dimethylhydrazine/nitric acid bipropellant rocket engine. The spacecraft orientation was to be maintained so that the solar panels faced the Sun throughout the flight. Power was provided by the two-square meter solar panels which charged silver-zinc batteries. Radio communications were made using a decimeter band transmitter via the high gain antenna for spacecraft commands and telemetry. Radio bearing was used to maintain the antennas' orientation to Earth. Images were to be transferred using an 8-cm wavelength transmitter through the high-gain antenna. A fourth stage was added to the booster, the Molniya or 8K78, the new launcher was designated SL-6/A-2-e.

Mars 1

Mars 1, also known as *1962 Beta Nu 1*, *Mars 2MV-4* and *Sputnik 23*, was an automatic interplanetary station launched in the direction of Mars on November 1, 1962, the first of the Soviet Mars probe program, with the intent of flying by the planet at a distance of about 11,000 km. It was designed to image the surface and send back data on cosmic radiation, micrometeoroid impacts and Mars' magnetic field, radiation environment, atmospheric structure, and possible organic compounds. After leaving Earth orbit, the spacecraft and the booster fourth stage separated and the solar panels were deployed. Early telemetry indicated that there was a leak in one of the gas valves in the orientation system so the spacecraft was transferred to gyroscopic stabilization. Sixty-one radio transmissions were held, initially at two day intervals and later at five days in which a large amount of interplanetary data were collected. On 21 March 1963, when the spacecraft was at a distance of 106,760,000 km from Earth on its way to Mars, communications ceased, probably due to failure of the spacecraft's antenna orientation system. Mars 1 closest approach to Mars occurred on June 19, 1963 at a distance of approximately 193,000 km, after which the spacecraft entered a heliocentric orbit.

Spacecraft design

Mars 1 was a modified Venera-type spacecraft in the shape of a cylinder 3.3 m long and 1.0 m in diameter. The spacecraft measured 4 meters across with the solar panels and radiators deployed. The cylinder was divided into two compartments. The upper 2.7 m, the orbital module, contained guidance and on-board propulsion systems. The experiment module, containing the scientific instrumentation, comprised the bottom 0.6 m of the cylinder. A 1.7 m parabolic high gain antenna was used for communication, along with an omnidirectional antenna and a semi-directional antenna. Power was supplied by two solar panel wings with a total area of 2.6 square meters affixed to opposite sides of the spacecraft. Power was stored in a 42 ampere-hour cadmium-nickel battery.

Communications were via a decimeter wavelength radio transmitter mounted in the orbital module which used the high-gain antenna. This was supplemented by a meter wavelength range transmitter through the omnidirectional antenna. An 8 centimeter wavelength transmitter mounted in the experiment module was designed to transmit the TV images. Also mounted in the experiment module was a 5-centimeter range impulse transmitter. Temperature control was achieved using a binary gas-liquid system and hemispherical radiators mounted on the ends of the solar panels. The craft carried various scientific instruments including a magnetometer probe, television photographic equipment, a spectroreflexometer, radiation sensors (gas-discharge and scintillation counters), a spectrograph to study ozone absorption bands, and a micrometeoroid instrument.

Scientific results

The probe recorded one micrometeorite strike every two minutes at altitudes ranging from 6000 to 40,000 km due to the Taurids meteor shower and also recorded similar densities at distances from 20 to 40 million km. Magnetic field intensities of 3–4 nanoteslas (nT, also known as gammas) with peaks as high as 6–9 nT were measured in interplanetary space and the solar wind was detected. Measurements of cosmic rays showed that their intensity had almost doubled since 1959. The radiation zones around the Earth were detected and their magnitude confirmed.

This spacecraft is also referenced as *Sputnik 23* and *Mars 2MV-4*. It was originally designated *Sputnik 30* in the U.S. Naval Space Command Satellite Situation Summary.

Chapter- 3

Mariner Program



Launch of Mariner 1 in 1962

The **Mariner program** was a program conducted by the American space agency NASA that launched a series of robotic interplanetary probes designed to investigate Mars, Venus and Mercury. The program included a number of firsts, including the first planetary flyby, the first pictures from another planet, the first planetary orbiter, and the first gravity assist maneuver.

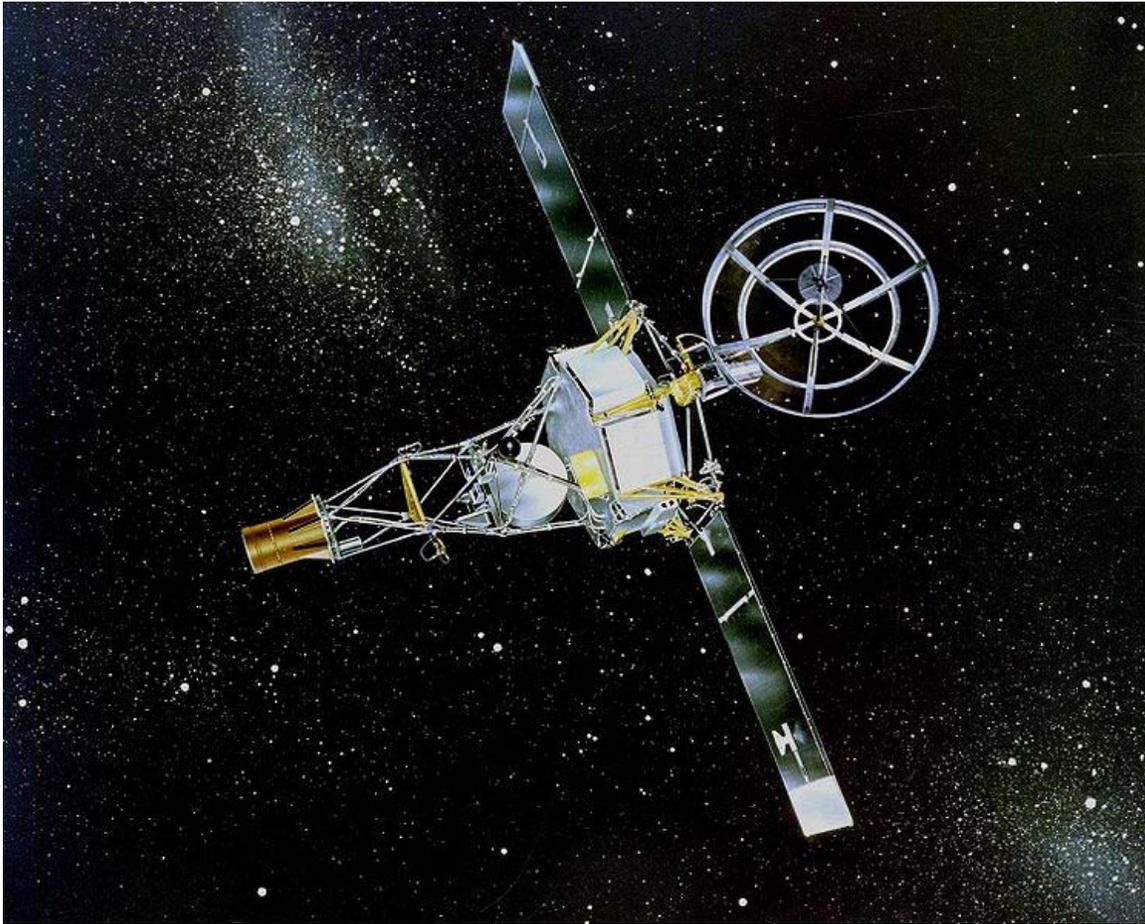
Of the ten vehicles in the Mariner series, seven were successful and three were lost. The planned Mariner 11 and Mariner 12 vehicles evolved into Voyager 1 and Voyager 2 of the Voyager program, while the Viking 1 and Viking 2 Mars orbiters were enlarged versions of the Mariner 9 spacecraft. Other Mariner-based spacecraft, launched since Voyager, included the Magellan probe to Venus, and the Galileo probe to Jupiter. A second-generation Mariner spacecraft, called the Mariner Mark II series, eventually evolved into the Cassini-Huygens probe, now in orbit around Saturn.

Basic layout

All Mariner spacecraft were based on a hexagonal or octagonal "bus", which housed all of the electronics, and to which all components were attached, such as antennae, cameras, propulsion, and power sources. All of the Mariners launched after Mariner 2 had four solar panels for power, except for Mariner 10, which had two, and Mariner 2, which was based on the Ranger Lunar probe. Additionally, all except Mariner 1, Mariner 2 and Mariner 5 had TV cameras.

The first five Mariners were launched on Atlas-Agena rockets, while the last five used the Atlas-Centaur. All Mariner-based probes after Mariner 10 used the Titan IIIE, Titan IV unmanned rockets or the Space Shuttle with a solid-fueled Inertial Upper Stage and multiple planetary flybys.

Mariners 1 and 2



Mariner 1 was intended to fly by Venus. The spacecraft was launched on July 22, 1962, but was destroyed approximately 5 minutes after liftoff by the Air Force Range Safety Officer when its malfunctioning Atlas-Agena rocket went off course. Mariner 2 was built as a backup to Mariner 1 and was launched on August 27, 1962, sending it on a 3½-month flight to Venus. The mission was a success, and Mariner 2 became the first spacecraft to have flown by another planet.

- Mission: Venus flyby
- Mass: 203 kg (446 lb)
- Sensors: microwave and infrared radiometers, cosmic dust, solar plasma and high-energy radiation, magnetic fields

Status:

- Mariner 1 – Destroyed shortly after liftoff.
- Mariner 2 – Defunct after successful mission, occupies a heliocentric orbit.

Mariners 3 and 4



Mariner 3 and Mariner 4 were Mars flyby missions. Mariner 3 was lost when the launch vehicle's nose fairing failed to jettison. Its sister ship, Mariner 4, launched on November 28, 1964, was the first successful flyby of the planet Mars and gave the first glimpse of Mars at close range.

- Mission: Mars flyby
- Mass: 261 kg (575 lb)
- Sensors: camera with digital tape recorder (about 20 pictures), cosmic dust, solar plasma, trapped radiation, cosmic rays, magnetic fields, radio occultation and celestial mechanics

Status:

- Mariner 3 – Malfunctioned. Trapped in a Heliocentric orbit.
- Mariner 4 – Unknown. Communications lost after bombardment by micrometeoroids.

Mariner 5

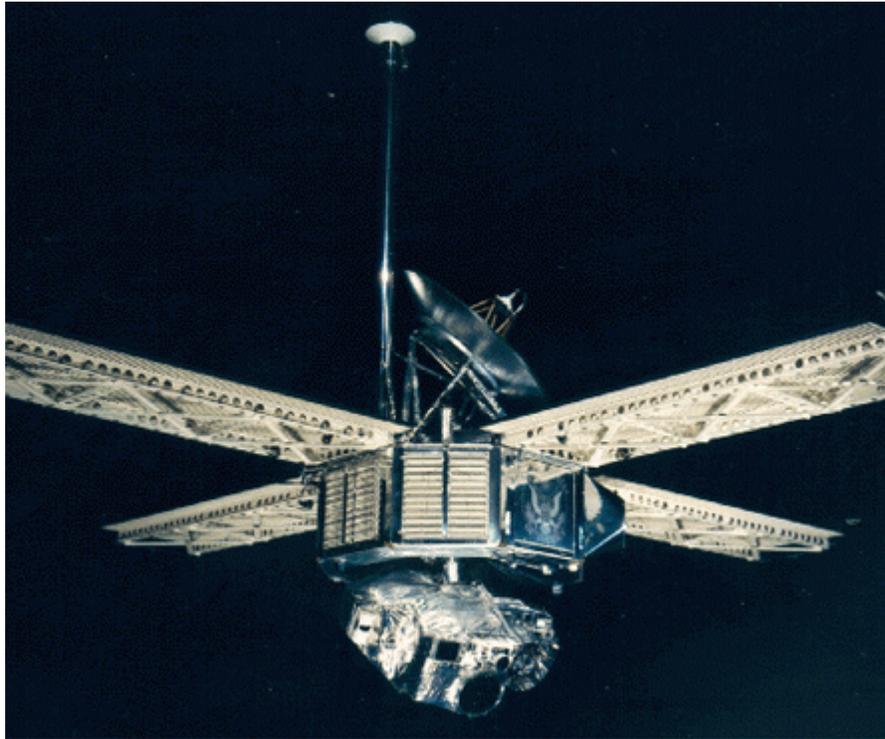


The Mariner 5 spacecraft was launched to Venus on June 14, 1967 and arrived in the vicinity of the planet in October 1967. It carried a complement of experiments to probe Venus' atmosphere with radio waves, scan its brightness in ultraviolet light, and sample the solar particles and magnetic field fluctuations above the planet.

- Mission: Venus flyby
- Mass: 245 kg (540 lb)
- Sensors: ultraviolet photometer, cosmic dust, solar plasma, trapped radiation, cosmic rays, magnetic fields, radio occultation and celestial mechanics

Status: Mariner 5 – Defunct. Trapped in a Heliocentric orbit.

Mariners 6 and 7



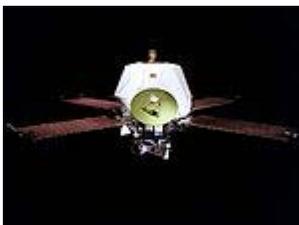
Mariners 6 and 7 were identical teammates in a two-spacecraft mission to Mars. Mariner 6 was launched on February 24, 1969, followed by Mariner 7 on March 21, 1969. They flew over the equator and southern hemisphere of the planet Mars.

- Mission: Mars flybys
- Mass 413 kg (908 lb)
- Sensors: wide- and narrow-angle cameras with digital tape recorder, infrared spectrometer and radiometer, ultraviolet spectrometer, radio occultation and celestial mechanics.

Status:

- Mariner 6 – Defunct. Trapped in a Heliocentric orbit.
- Mariner 7 – Defunct. Trapped in a Heliocentric orbit.

Mariners 8 and 9



Mariner 8 and Mariner 9 were identical sister craft designed to map the Martian surface simultaneously, but Mariner 8 was lost in a launch vehicle failure. Its identical sister craft, Mariner 9, was launched in May 1971 and became the first artificial satellite of Mars. It entered Martian orbit in November 1971 and began photographing the surface and analyzing the atmosphere with its infrared and ultraviolet instruments.

- Mission: orbit Mars
- Mass 998 kg (2,200 lb)
- Sensors: wide- and narrow-angle cameras with digital tape recorder, infrared spectrometer and radiometer, ultraviolet spectrometer, radio occultation and celestial mechanics

Status:

- Mariner 8 – Destroyed in a launch vehicle failure.
- Mariner 9 – Shut off. In Areocentric (Mars) orbit until at least 2022 when it will fall out of orbit and into the Martian atmosphere.

Mariner 10



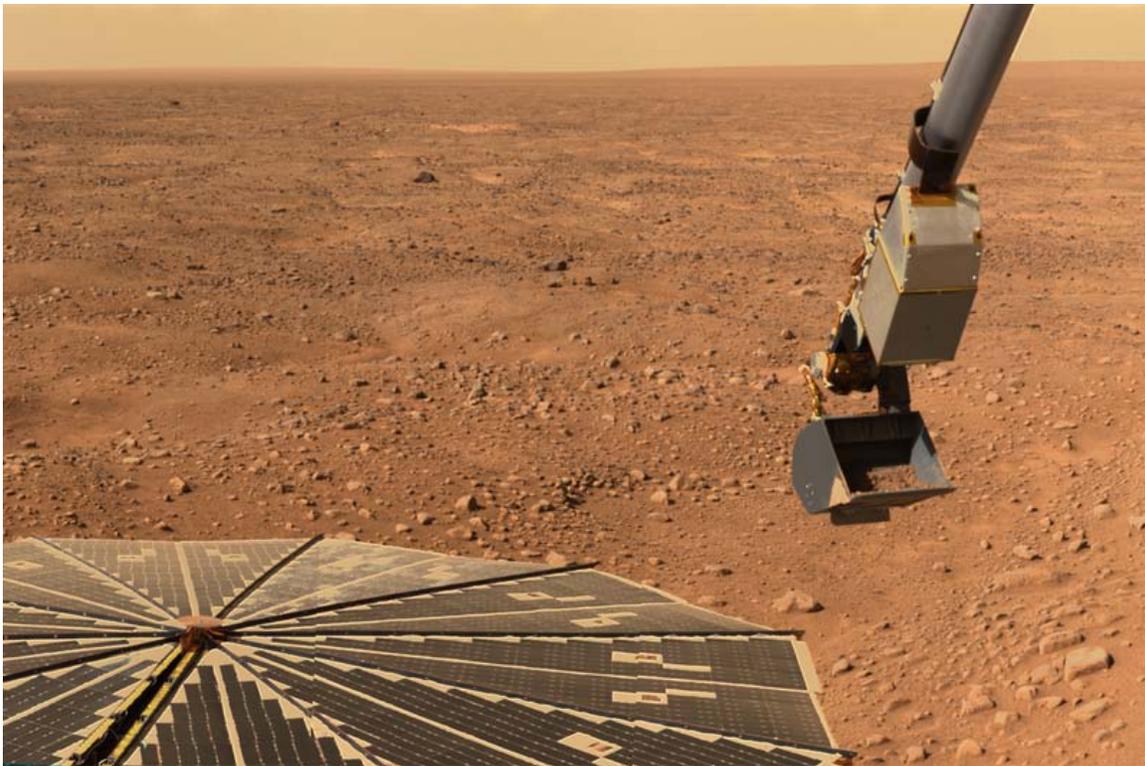
The Mariner 10 spacecraft launched on November 3, 1973 and was the first to use a gravity assist trajectory, accelerating as it entered the gravitational influence of Venus, then being flung by the planet's gravity onto a slightly different course to reach Mercury.

It was also the first spacecraft to encounter two planets at close range, and for 33 years the only spacecraft to photograph Mercury in closeup.

- Mission: Venus and Mercury flybys
- Mass: 433 kg (952 lb)
- Sensors: twin narrow-angle cameras with digital tape recorder, ultraviolet spectrometer, infrared radiometer, solar plasma, charged particles, magnetic fields, radio occultation and celestial mechanics

Chapter- 4

Mars Landing



View from the NASA Phoenix lander in 2008

A **Mars landing** is a landing of a spacecraft on the surface of Mars. Of multiple attempted Mars landings by robotic, unmanned spacecraft, six were successful. There have also been studies for a possible manned mission to Mars, including a landing, but none have been attempted.

Unmanned landings

Mars probe program

In 1969, the Soviet Union prepared a 5-ton orbiter called M-69. Two copies of the probe, Mars 1969A and Mars 1969B, were lost in launch related complications caused by problems with the newly developed Proton rockets.

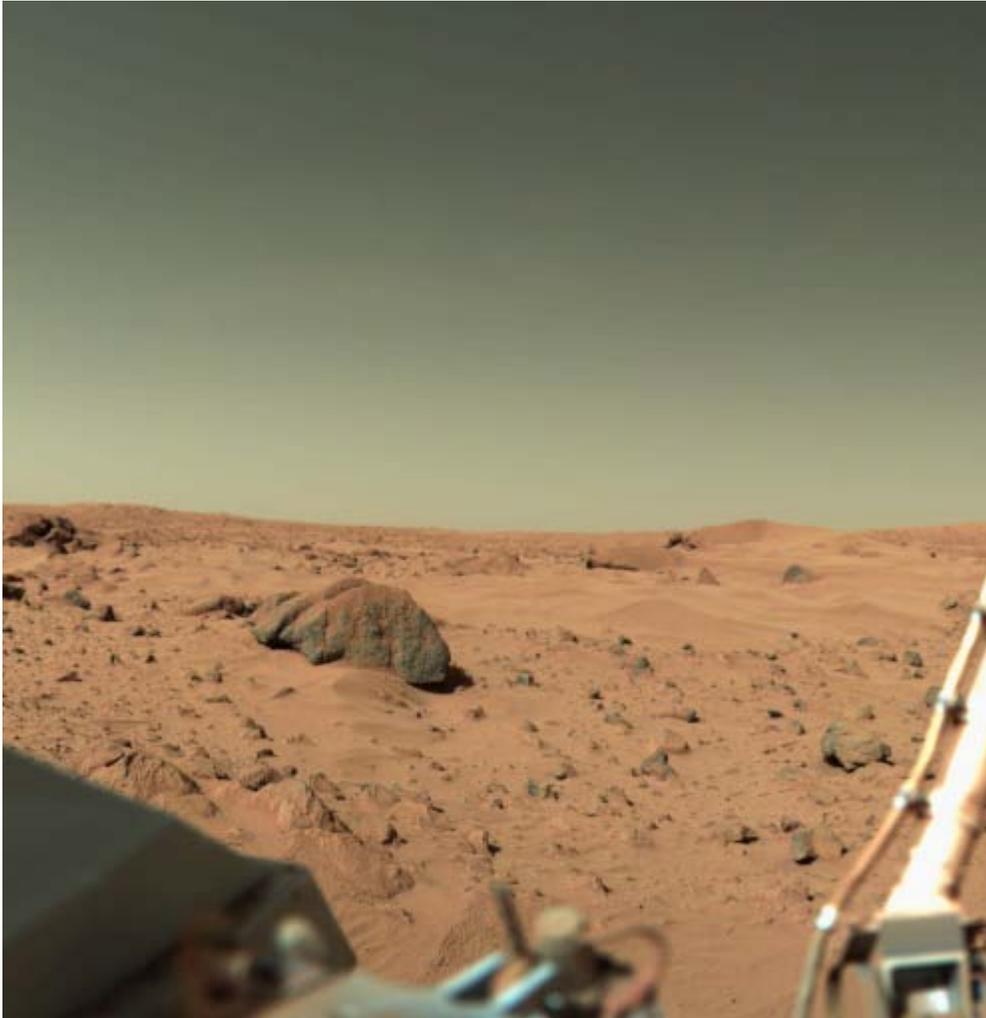
In 1971, shortly after the Cosmos 419 (Mars 1971C), that intended to be a first Martian orbiter, was lost in the fourth stage of the launch due to issues concerning the failure in the separation of Cosmos' payload from the launch vehicle, the Soviet Union successfully sent probes Mars 2 and Mars 3, as part of the Mars probe program M-71. The Mars 2 and 3 probes each carried a lander, both of which failed upon landing. They were the first human artifacts to touch down on Mars. Mars 2 lander impacted on Mars only while Mars 3 was the first Martian lander and was able to transmit from Martian surface during 20 second the first data and a portion of the first picture. These spaceprobes also contained the first Mars mini-rovers, although they were broken on landing.

The Mars 2 and 3 orbiters sent back a large volume of data covering the period from December 1971 to March 1972, although transmissions continued through to August. By 22 August 1972, after sending back data and a total of 60 pictures, Mars 2 and 3 concluded their missions. The images and data enabled creation of surface relief maps, and gave information on the Martian gravity and Magnetosphere.

In 1973, the Soviet Union sent four more probes to Mars: the Mars 4 and Mars 5 orbiters and the Mars 6 and Mars 7 fly-by/lander combinations. All missions except Mars 7 sent back data, with Mars 5 being most successful. Mars 5 transmitted 60 images before a loss of pressurization in the transmitter housing, ended the mission. Mars 6 lander transmitted data during descent, but failed upon impact. Mars 4 flew by the planet at a range of 2200 km returning one swath of pictures and radio occultation data, which constituted the first detection of the nightside ionosphere on Mars. Mars 7 probe separated prematurely from the carrying vehicle due to a problem in the operation of one of the onboard systems (altitude control or retro-rockets) and missed the planet by 1300 km.

Years earlier, in 1970 Soviet Union began the design of Mars 4NM and Mars 5NM missions with superheavy unmanned Martian spacecrafts. First was Marsokhod with planned date of start in 1973 and second was Mars sample return mission planned to 1975. Both spacecrafts intended to launch on N1 superrocket. But this rocket never flew successfully and Mars 4NM and Mars 5NM projects were cancelled.

Viking program



Viking Lander 1 landing site

In 1976 the two American Viking probes entered orbit about Mars and each released a lander module that made a successful soft landing on the planet's surface. The two missions returned the first color pictures and extensive scientific information. Measured temperatures at the landing sites ranged from 150 to 250 K, with a variation over a given day of 35 to 50 K. Seasonal dust storms, pressure changes, and movement of atmospheric gases between the polar caps were observed. A biology experiment produced possible evidence of life, but it was not corroborated by other on-board experiments.

While searching for a suitable landing spot for Viking 2's lander, the Viking 1 orbiter photographed the landform that constitutes the so-called "Face on Mars" on July 25, 1976.

The Viking program was a descendant of the cancelled Voyager program, whose name was later reused for a pair of outer solar system probes.

Phobos program



Artist impression of Phobos spacecraft

Two Soviet probes were sent to Mars in 1988 as part of the Phobos program. Phobos 1 operated nominally until an expected communications session on 2 September 1988 failed to occur. The problem was traced to a software error, which deactivated altitude thrusters causing the spacecraft's solar arrays to no longer point at the Sun, depleting Phobos 1 batteries. Phobos 2 operated nominally throughout its cruise and Mars orbital insertion phases on January 29, 1989, gathering data on the Sun, interplanetary medium, Mars, and Phobos. Shortly before the final phase of the mission, during which the spacecraft was to approach within 50 m of Phobos' surface and release two landers, one a mobile 'hopper', the other a stationary platform, contact with Phobos 2 was lost. The mission ended when the spacecraft signal failed to be successfully reacquired on March 27, 1989. The cause of the failure was determined to be a malfunction of the on-board computer.

Mars Global Surveyor



This image from Mars Global Surveyor spans a region about 1500 meters across. Gullies, similar to those formed on Earth, are visible from Newton Basin in Sirenum Terra (NASA).

After the 1992 failure of NASA's Mars Observer orbiter, NASA retooled and launched Mars Global Surveyor (MGS). This mission was the first successful United States mission, and the first fully successful mission overall, to the red planet in two decades when it launched November 7, 1996, and entered orbit on September 12, 1997. After a year and a half trimming its orbit from a looping ellipse to a circular track around the planet, the spacecraft began its primary mapping mission in March 1999. It has observed the planet from a low-altitude, nearly polar orbit over the course of one complete Martian year, the equivalent of nearly two Earth years. Mars Global Surveyor completed its primary mission on January 31, 2001, and completed several extended mission phases.

The mission has studied the entire Martian surface, atmosphere, and interior, and has returned more data about the red planet than all other Mars missions combined. These valuable data are archived and available publicly.

Among key scientific findings so far, Global Surveyor has taken pictures of gullies and debris flow features that suggest there may be current sources of liquid water, similar to an aquifer, at or near the surface of the planet. 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.

Magnetometer readings show that the planet's magnetic field is not globally generated in the planet's core, but is localized in particular areas of the crust. New temperature data and closeup images of the Martian moon Phobos show its surface is composed of powdery material at least 1 metre (3 feet) thick, caused by millions of years of meteoroid impacts. Data from the spacecraft's laser altimeter have given scientists their first 3-D views of Mars' north polar ice cap.

On November 5, 2006 MGS lost contact with Earth and hasn't been heard from since.

Mars Pathfinder

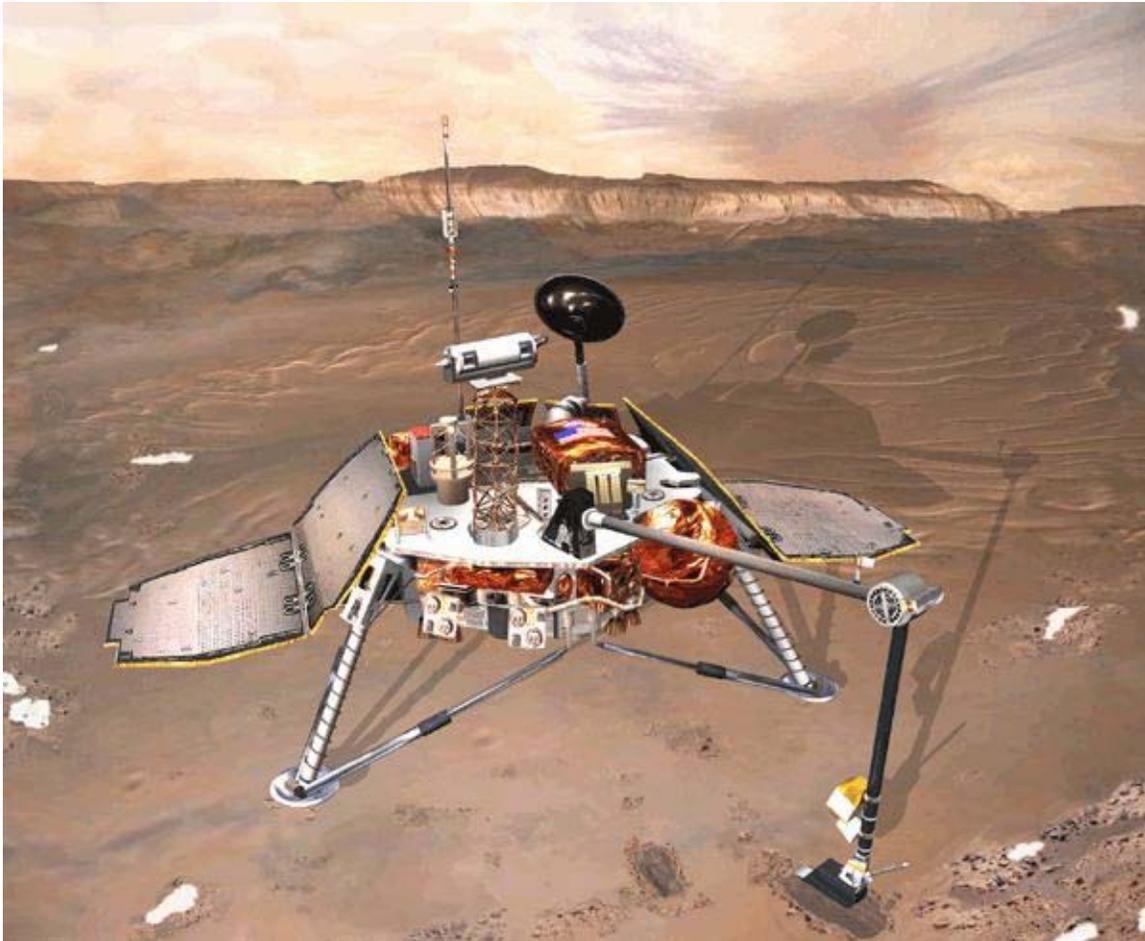


"Ares Vallis" as photographed by Mars Pathfinder

The Mars Pathfinder spacecraft, launched one month after Global Surveyor, landed on July 4, 1997. Its landing site was an ancient flood plain in Mars' northern hemisphere called Ares Vallis, which is among the rockiest parts of Mars. It carried a tiny remote-controlled rover called Sojourner, which traveled a few meters around the landing site, exploring the conditions and sampling rocks around it. Newspapers around the world carried images of the lander dispatching the rover to explore the surface of Mars in a way never achieved before.

Until the final data transmission on September 27, 1997, Mars Pathfinder returned 16,500 images from the lander and 550 images from the rover, as well as more than 15 chemical analyses of rocks and soil and extensive data on winds and other weather factors. Findings from the investigations carried out by scientific instruments on both the lander and the rover suggest that Mars was at one time in its past warm and wet, with water existing in its liquid state and a thicker atmosphere. The mission website was the most heavily-trafficked up to that time.

Spate of failures



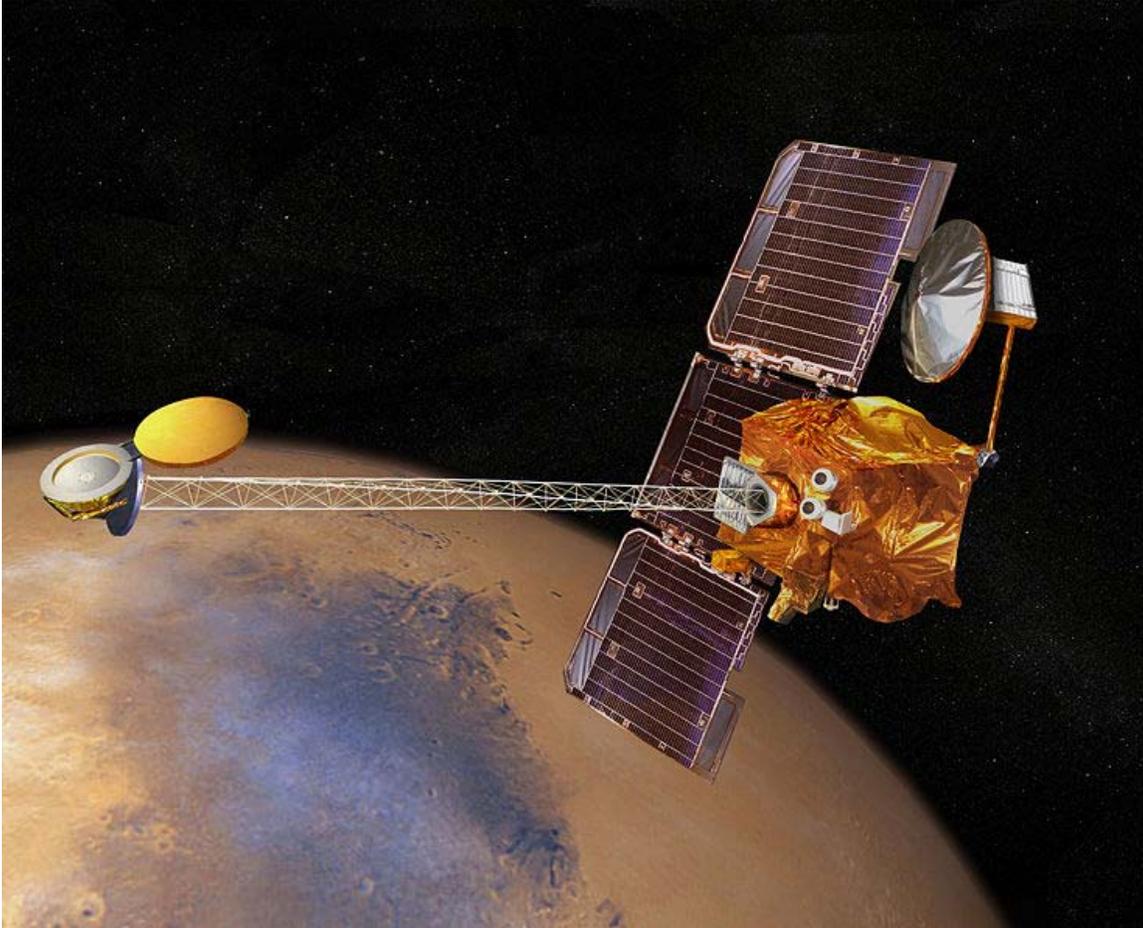
Conceptual drawing of the *Mars Polar Lander* on the surface of Mars.

Mars 96, an orbiter launched on November 16, 1996 by Russia failed, when the planned second burn of the Block D-2 fourth stage did not occur.

Following the success of Global Surveyor and Pathfinder, another spate of failures occurred in 1998 and 1999, with the Japanese Nozomi orbiter and NASA's Mars Climate Orbiter, Mars Polar Lander, and Deep Space 2 penetrators all suffering various fatal errors. Mars Climate Orbiter is infamous for Lockheed Martin engineers mixing up the

usage of English units with metric units, causing the orbiter to burn up while entering Mars' atmosphere.

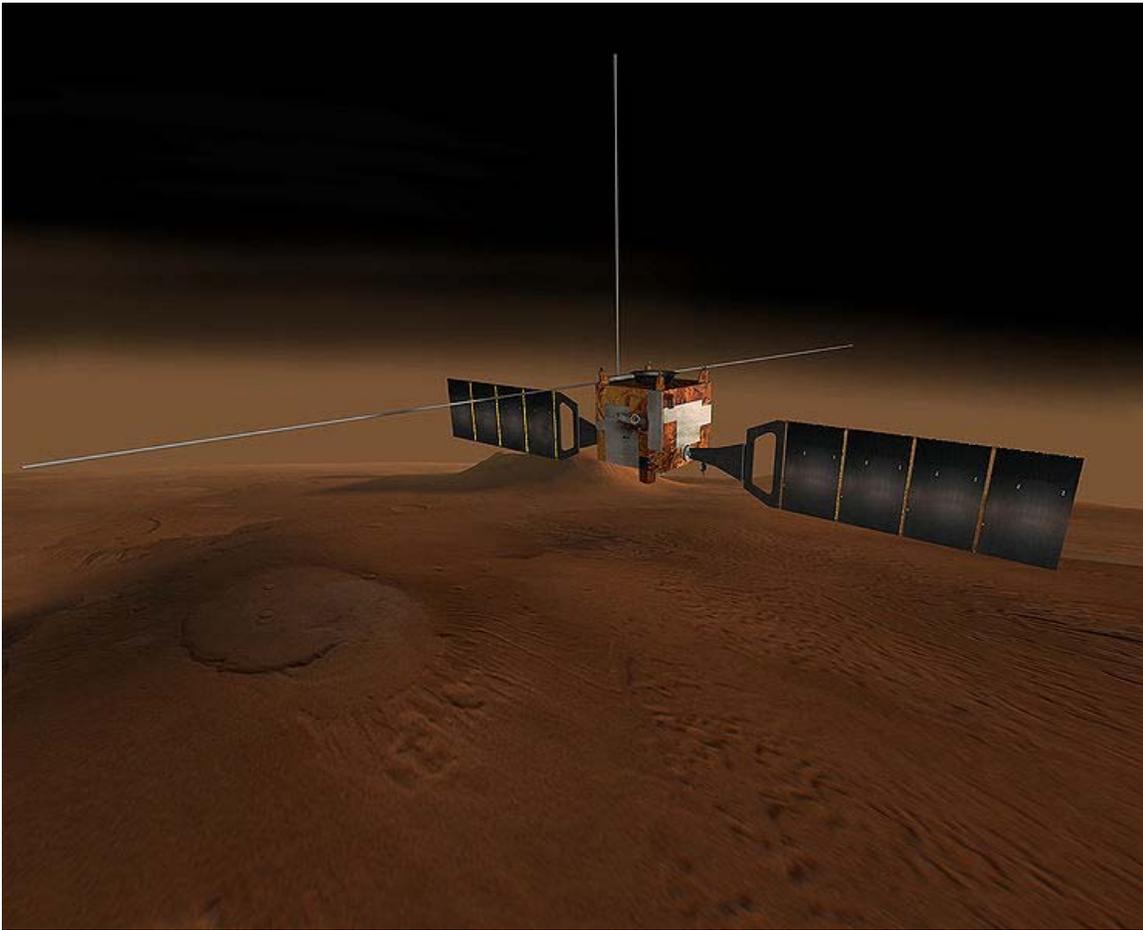
Mars Odyssey



Mars Odyssey drawing

In 2001 the run of bad luck ended when NASA's Mars Odyssey orbiter arrived. Its mission is to use spectrometers and imagers to hunt for evidence of past or present water and volcanic activity on Mars. In 2002, it was announced that the probe's gamma ray spectrometer and neutron spectrometer had detected large amounts of hydrogen, indicating that there are vast deposits of water ice in the upper three meters of Mars' soil within 60° latitude of the south pole.

Mars Express and Beagle 2



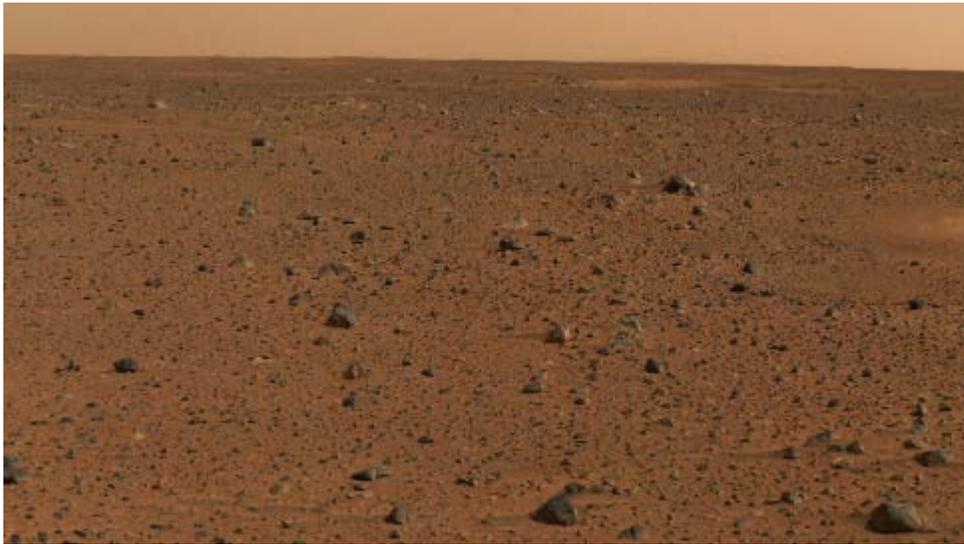
Artists rendering of the Mars Express orbiter.

On June 2, 2003, the European Space Agency's Mars Express set off from Baikonur Cosmodrome to Mars. The Mars Express craft consists of the Mars Express Orbiter and the lander Beagle 2. Although the landing probe was not designed to move, it carried a digging device and the smallest mass spectrometer created to date, as well as a range of other devices, on a robotic arm in order to accurately analyse soil beneath the dusty surface.

The orbiter entered Mars orbit on December 25, 2003, and Beagle 2 entered Mars' atmosphere the same day. However, attempts to contact the lander failed. Communications attempts continued throughout January, but Beagle 2 was declared lost in mid-February, and a joint inquiry was launched by the UK and ESA. Nevertheless, Mars Express Orbiter confirmed the presence of water ice and carbon dioxide ice at the planet's south pole. NASA had previously confirmed their presence at the north pole of Mars.

Mars Exploration Rovers

Shortly after the launch of Mars Express, NASA sent a pair of twin rovers toward the planet as part of the Mars Exploration Rover Mission. On 10 June 2003, NASA's MER-A (*Spirit*) Mars Exploration Rover was launched. It successfully landed in Gusev Crater (believed once to have been a crater lake) on 3 January 2004. It examined rock and soil for evidence of the area's history of water. On July 7, 2003, a second rover, MER-B (*Opportunity*) was launched. It landed on 24 January 2004 in Meridiani Planum (where there are large deposits of hematite, indicating the presence of past water) to carry out similar geological work.



Part of a 360 degree panorama photo of the Gusev crater landing site, taken by NASA's Spirit Rover in 2004

Despite a temporary loss of communication with the Spirit Rover (caused by too many files being stored in its flash memory) delaying exploration for several days, both rovers eventually began exploring their landing sites. The rover *Opportunity* landed in a particularly interesting spot, a crater with bedrock outcroppings. In fast succession mission team members announced on 2 March that data returned from the rover showed that these rocks were once "drenched in water", and on 23 March that it was concluded that they were laid down underwater in a salty sea. This represented the first strong direct evidence for liquid water being on Mars at some time in the past.

Towards the end of July 2005, it was reported by the Sunday Times that the rovers may have carried the bacteria *Bacillus safensis* to Mars. According to one NASA microbiologist, this bacteria could survive both the trip and conditions on Mars. A book containing this claim, *Out of Eden* by Alan Burdick, is due to be published in the United Kingdom. Despite efforts to sterilise both landers, neither could be assured to be completely sterile.

Having only been designed for three month missions, both rovers are still operating as of April 2008, but Spirit and Opportunity are starting to show their age. These rovers have discovered new things, including Heat Shield Rock, the first meteorite to be discovered on another planet.

Mars Reconnaissance Orbiter

Mars Reconnaissance Orbiter is a multipurpose spacecraft designed to conduct reconnaissance and exploration of Mars from orbit. The \$720 million USD spacecraft was built by Lockheed Martin under the supervision of the Jet Propulsion Laboratory, launched August 12, 2005, and attained Martian orbit on March 10, 2006.

The MRO contains a host of scientific instruments such as the HiRISE camera, CRISM, and SHARAD. The HiRISE camera is used to analyze Martian landforms, whereas CRISM and SHARAD can detect water, ice, and minerals on and below the surface. Additionally, MRO is paving the way for upcoming generations of spacecraft through daily monitoring of Martian weather and surface conditions, searching for future landing sites, and testing a new telecommunications system that will enable the orbiter to send and receive information at an unprecedented bitrate. Data transfer to and from the spacecraft will occur faster than all previous interplanetary missions combined and allowing it to serve as an important relay satellite for future missions.

Rosetta and Dawn

The ESA Rosetta space probe mission to the comet 67P/Churyumov-Gerasimenko flew within 250 km of Mars on February 25, 2007 in a gravitational slingshot designed to slow and redirect the spacecraft. The NASA Dawn spacecraft also used the gravity of Mars to change direction and velocity, and did a little science in conjunction with the many probes already there. Dawn passed the red planet in February 2009.

Phoenix Lander



Camera on Mars orbiter snaps *Phoenix* suspended from its parachute during descent through Mars' atmosphere.

Being the latest mission to Mars, *Phoenix* launched on August 4, 2007, and touched down on the northern polar region of Mars on May 25, 2008. It is famous for having been successfully photographed while landing, since this was the first time one spacecraft captured the landing of another spacecraft onto a planetary body (the Moon not being a planet, but a satellite).

Future Missions

Phoenix is to be followed by the Mars Science Laboratory, a rover more capable than *Spirit* and *Opportunity*. Originally the Mars Science Laboratory was intended for a launch during the 2009 opportunity, however the launch has been delayed to 2011. A second Scout mission, MAVEN has been selected for 2013. In the far future there's the proposed Mars Sample Return Mission, but this has been delayed until at least 2016, and more probably to 2024. This mission, a collaboration between ESA and NASA, is part of the Aurora Programme.

Russia plans to launch Phobos-Grunt, a sample return mission to Phobos, along with the joint Chinese Yinghuo-1 Mars orbiter in late 2011 or early 2012.

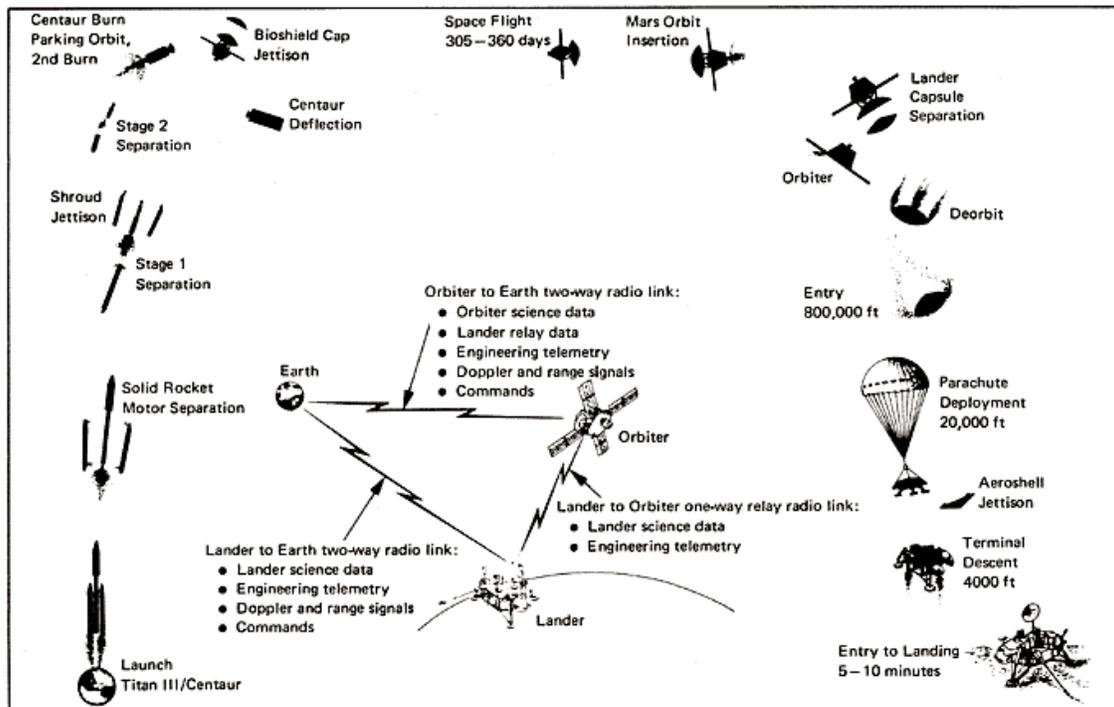
The ESA ExoMars mission is tentatively planned for 2018. ExoMars should obtain soil samples from up to 2 meters depth and make an extensive search for organic and biochemical substances.

Chapter- 5

Viking Program



Viking mission patch.



Viking mission profile.

NASA's **Viking program** consisted of a pair of space probes sent to Mars, Viking 1 and Viking 2. Each spacecraft was composed of two main parts, an orbiter designed to photograph the surface of Mars from orbit, and a lander designed to study the planet from the surface. The orbiters also served as communication relays for the landers once they touched down.

It was the most expensive and ambitious mission ever sent to Mars, with a total cost of roughly US\$1 billion. It was highly successful and formed most of the database of information about Mars until the late 1990s and early 2000s. The Viking program grew from NASA's earlier, and more ambitious Voyager Mars program, which was not related to the successful Voyager deep space probes of the late 1970s. Viking 1 was launched on August 20, 1975, and the second craft, Viking 2, was launched on September 9, 1975, both riding atop Titan III-E rockets with Centaur upper stages. After orbiting Mars and returning images used for landing site selection, the orbiter and lander detached and the lander entered the Martian atmosphere and soft-landed at the selected site. The orbiters continued imaging and performing other scientific operations from orbit while the landers deployed instruments on the surface. The fully fueled orbiter-lander pair had a mass of 3527 kg. After separation and landing, the lander had a mass of about 600 kg and the orbiter 900 kg.

Viking orbiters



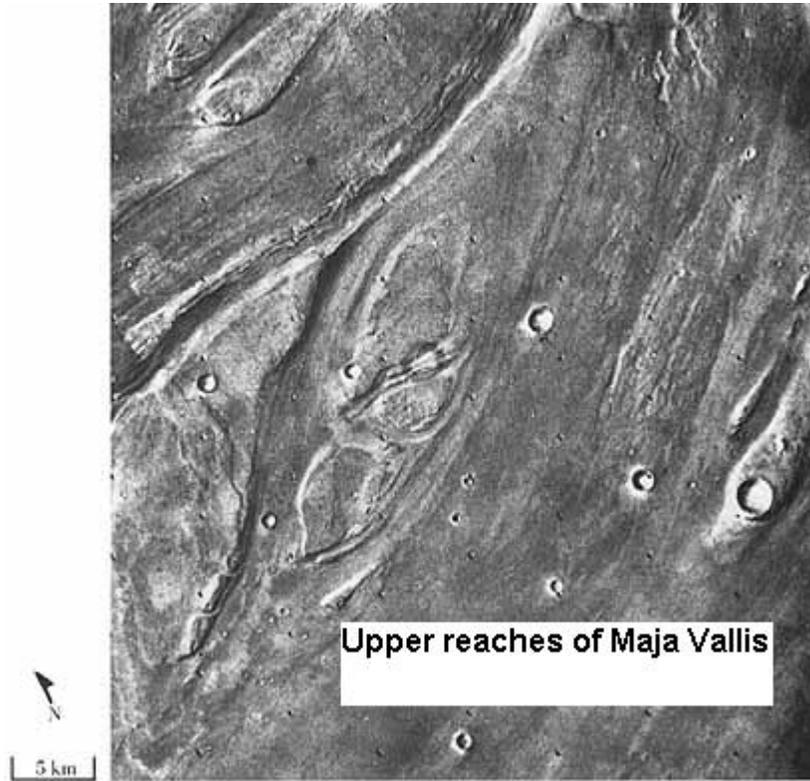
Viking orbiter (NASA)

The primary objectives of the Viking orbiters were to transport the landers to Mars, perform reconnaissance to locate and certify landing sites, act as a communications relays for the landers, and to perform their own scientific investigations. Each orbiter, based on the earlier Mariner 9 spacecraft, was an octagon approximately 2.5 m across. The total launch mass was 2328 kg, of which 1445 kg were propellant and attitude control gas. The eight faces of the ring-like structure were 0.4572 m high and were alternately 1.397 and 0.508 m wide. The overall height was 3.29 m from the lander attachment points on the bottom to the launch vehicle attachment points on top. There were 16 modular compartments, 3 on each of the 4 long faces and one on each short face. Four solar panel wings extended from the axis of the orbiter, the distance from tip to tip of two oppositely extended solar panels was 9.75 m. The power was provided by eight 1.57×1.23 m solar panels, two on each wing. The solar panels were made up of a total of 34,800 solar cells and produced 620 W of power at Mars. Power was also stored in 2 nickel-cadmium 30-A·h batteries.

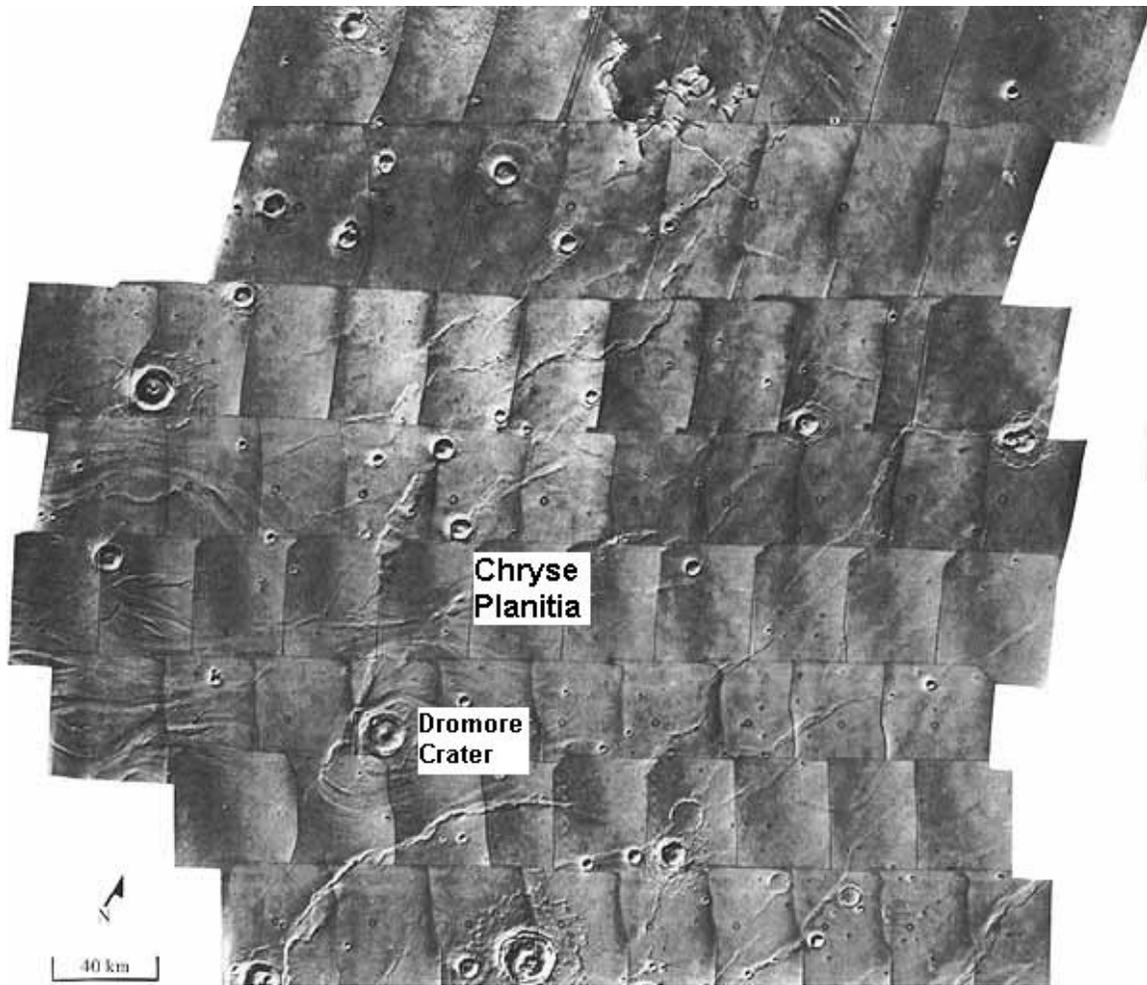
By discovering many geological forms that are typically formed from large amounts of water, they caused a revolution in our ideas about water on Mars. Huge river valleys were found in many areas. They showed that floods of water broke through dams, carved deep valleys, eroded grooves into bedrock, and traveled thousands of kilometers. Large areas in the southern hemisphere contained branched stream networks, suggesting that rain once fell. The flanks of some volcanoes are believed to have been exposed to rainfall because they resemble those caused on Hawaiian volcanoes. Many craters look as if the impactor fell into mud. When they were formed, ice in the soil may have melted, turned the ground into mud, then flowed across the surface. Normally, material from an impact goes up, then down. It does not flow across the surface, going around obstacles, as it does on some Martian craters. Regions, called "Chaotic Terrain," seemed to have quickly lost great volumes of water, causing large channels to be formed. The amount of water involved was estimated to ten thousand times the flow of the Mississippi River. Underground volcanism may have melted frozen ice; the water then flowed away and the ground collapsed to leave chaotic terrain.

The main propulsion unit was mounted above the orbiter bus. Propulsion was furnished by a bipropellant (monomethylhydrazine and nitrogen tetroxide) liquid-fueled rocket engine which could be gimballed up to 9 degrees. The engine was capable of 1323 N (297 lbf) thrust, translating to a delta-V of 1480 m/s. Attitude control was achieved by 12 small compressed-nitrogen jets. An acquisition Sun sensor, a cruise Sun sensor, a Canopus star tracker and an inertial reference unit consisting of six gyroscopes allowed three-axis stabilization. Two accelerometers were also on board. Communications were accomplished through a 20 W S-band (2.3 GHz) transmitter and two 20 W TWTAs. An X band (8.4 GHz) downlink was also added specifically for radio science and to conduct communications experiments. Uplink was via S band (2.1 GHz). A two-axis steerable high-gain parabolic dish antenna with a diameter of approximately 1.5 m was attached at one edge of the orbiter base, and a fixed low-gain antenna extended from the top of the bus. Two tape recorders were each capable of storing 1280 megabits. A 381-MHz relay radio was also available.

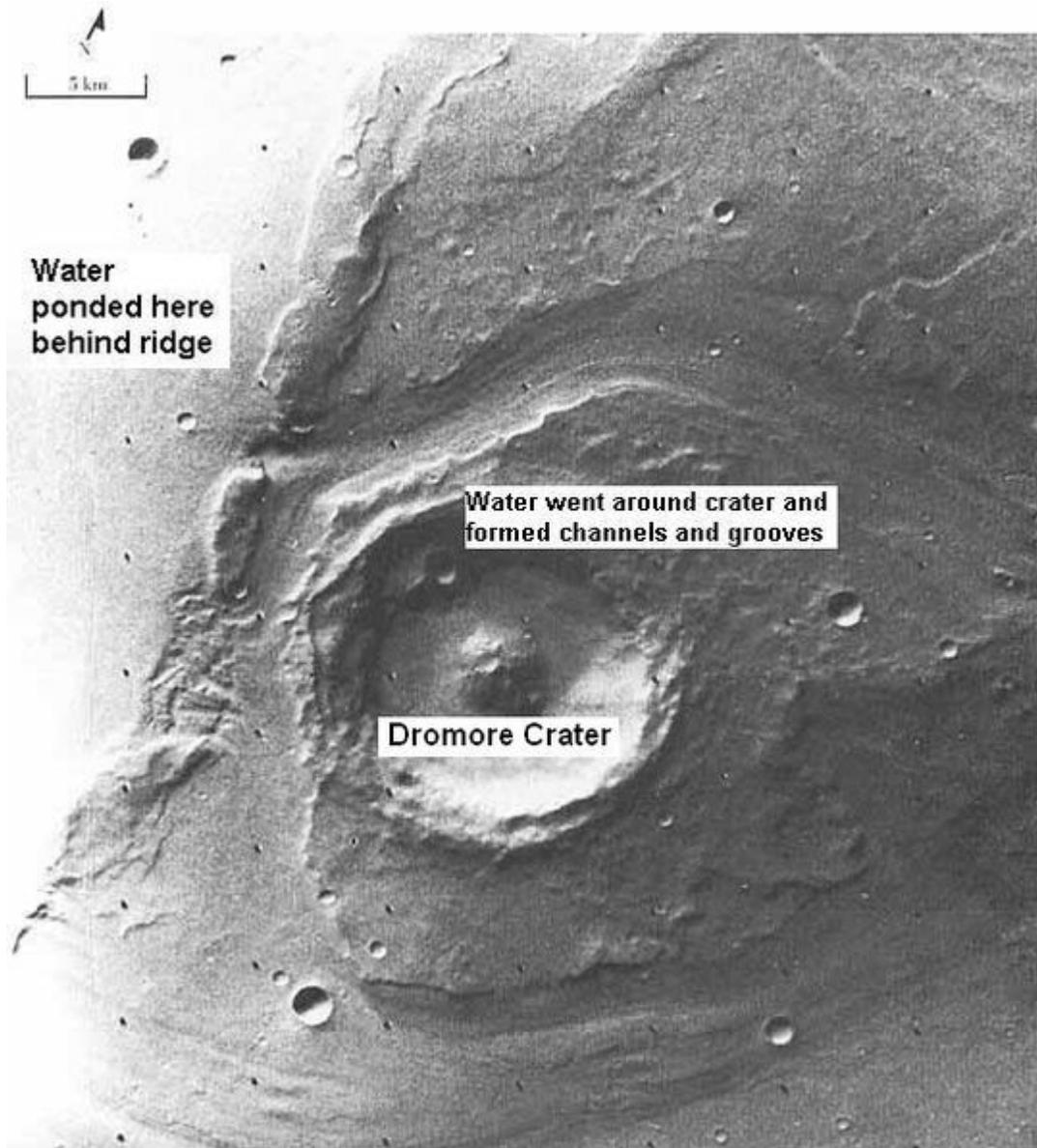
Viking Mosaics



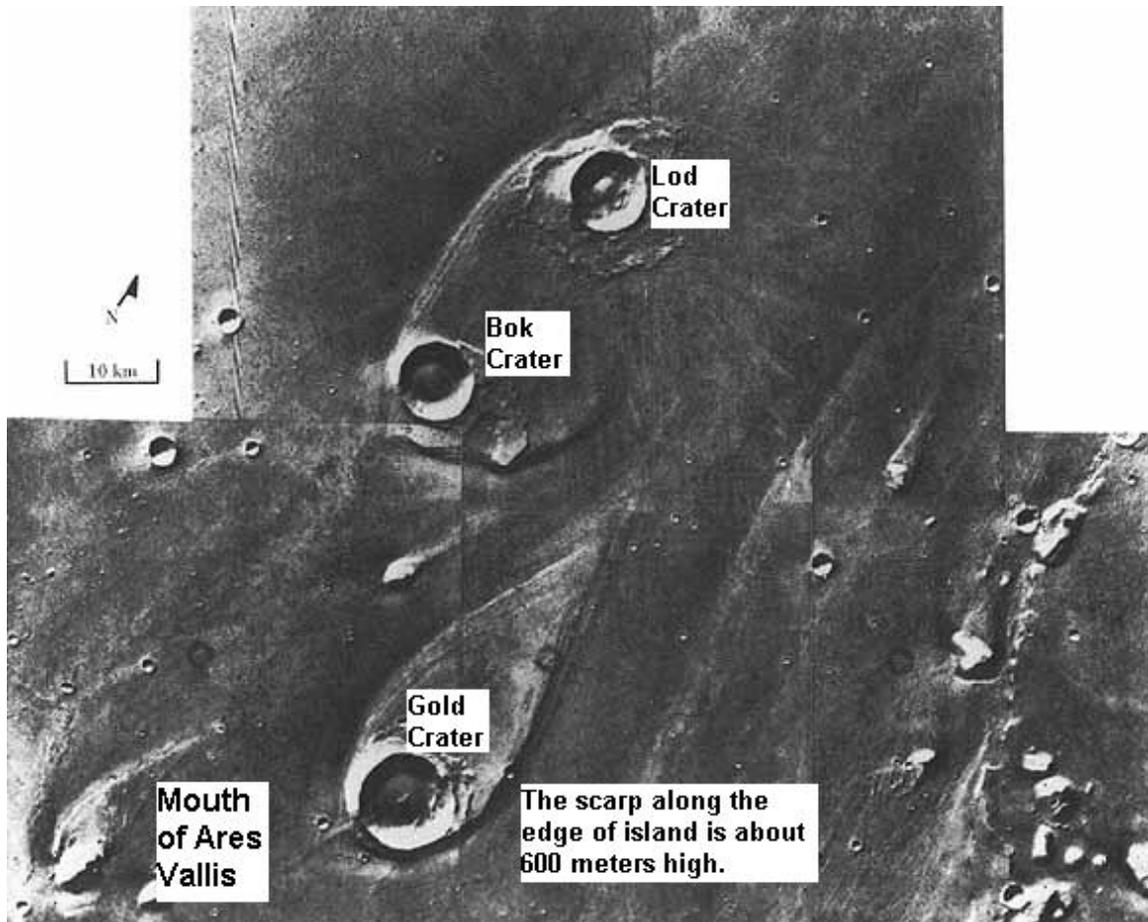
Streamlined Islands showed that large floods occurred on Mars. Image is located in Lunae Palus quadrangle.



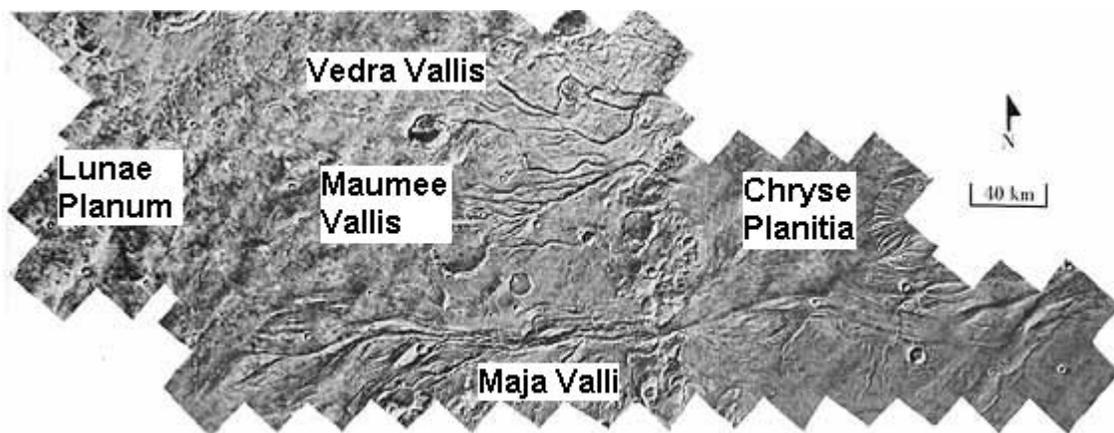
Scour Patterns were produced by flowing water from Maja Vallis, which lies just to the left of this mosaic. Detail of flow around Dromore Crater is shown on another image. Image is located in Lunae Palus quadrangle.



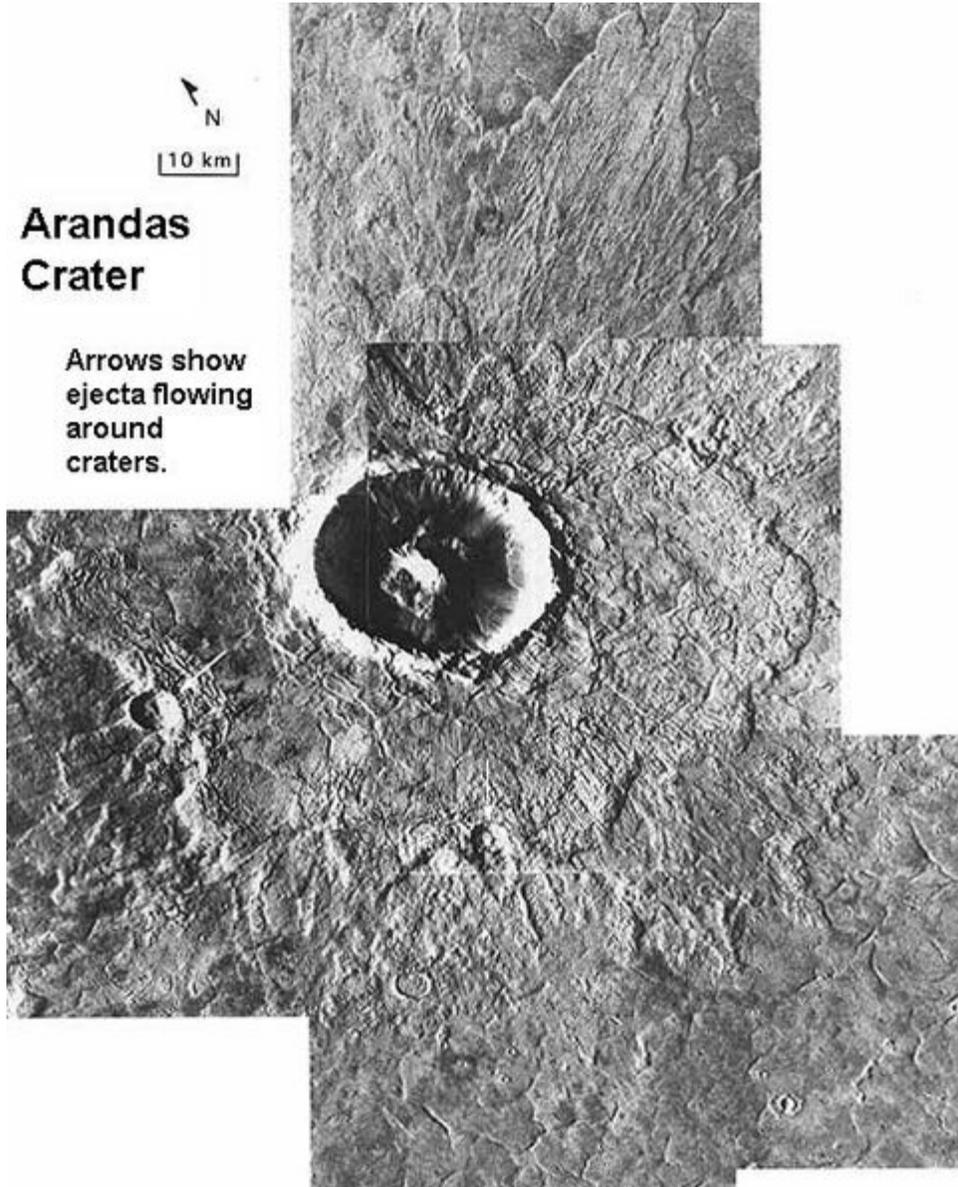
Great amounts of water were required to carry out the erosion shown in this Viking image. Image is located in Lunae Palus quadrangle.



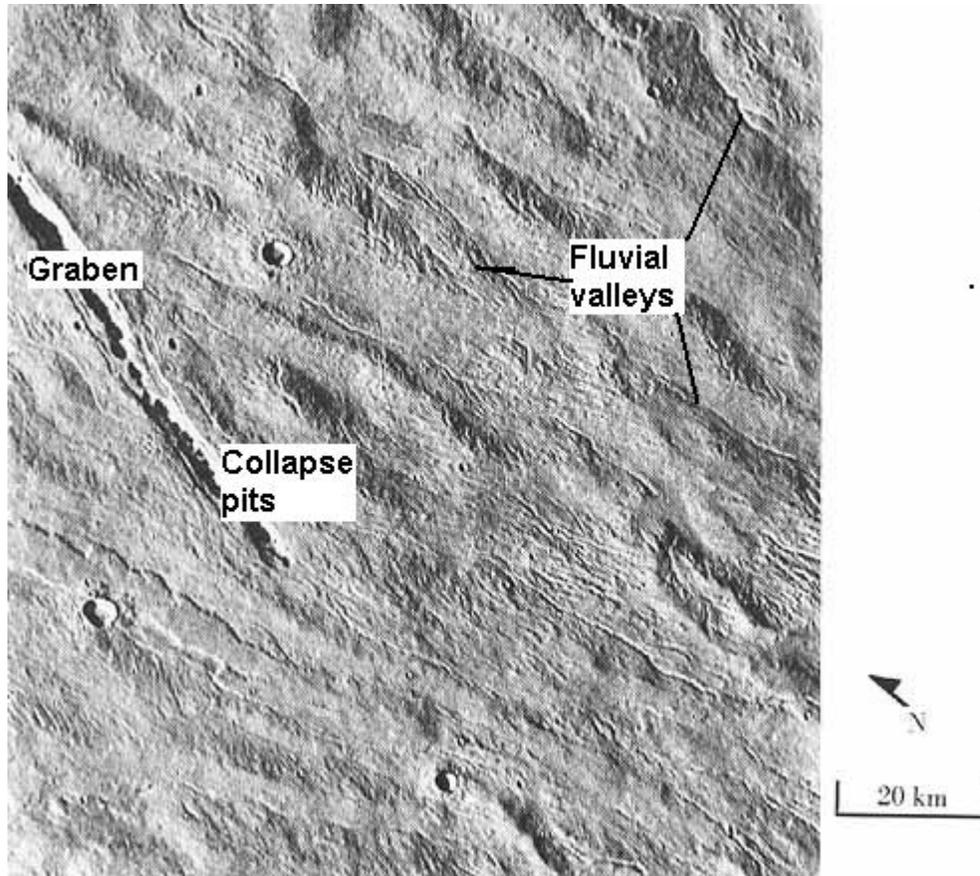
Tear-drop shaped islands caused by flood waters from Maja Valles. Image is located in Oxia Palus quadrangle.



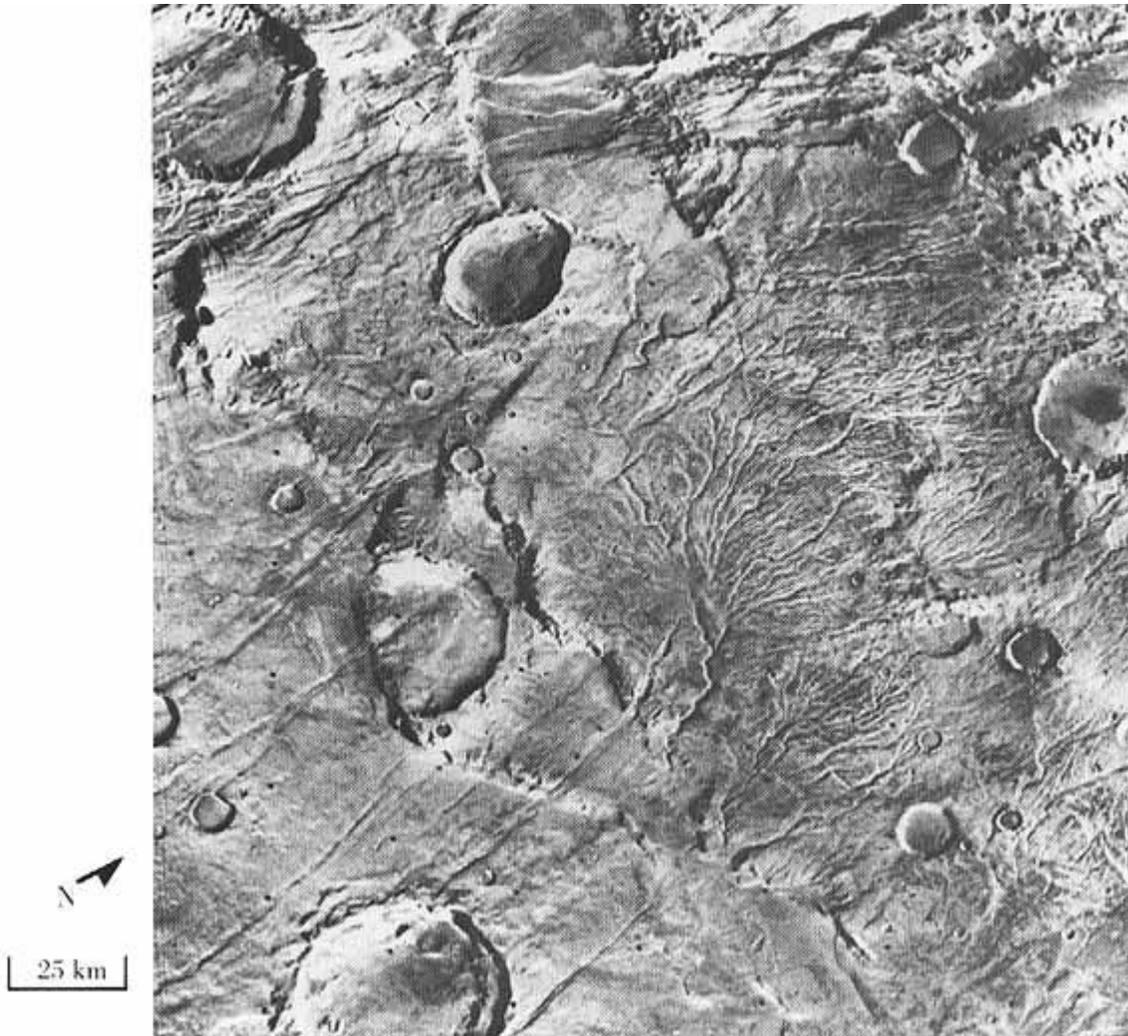
Vedra Vallis, Maumee Vallis, and Maja Valles move from Lunae Planum on the left to Chryse Planitia on the right. Image is located in Lunae Palus quadrangle.



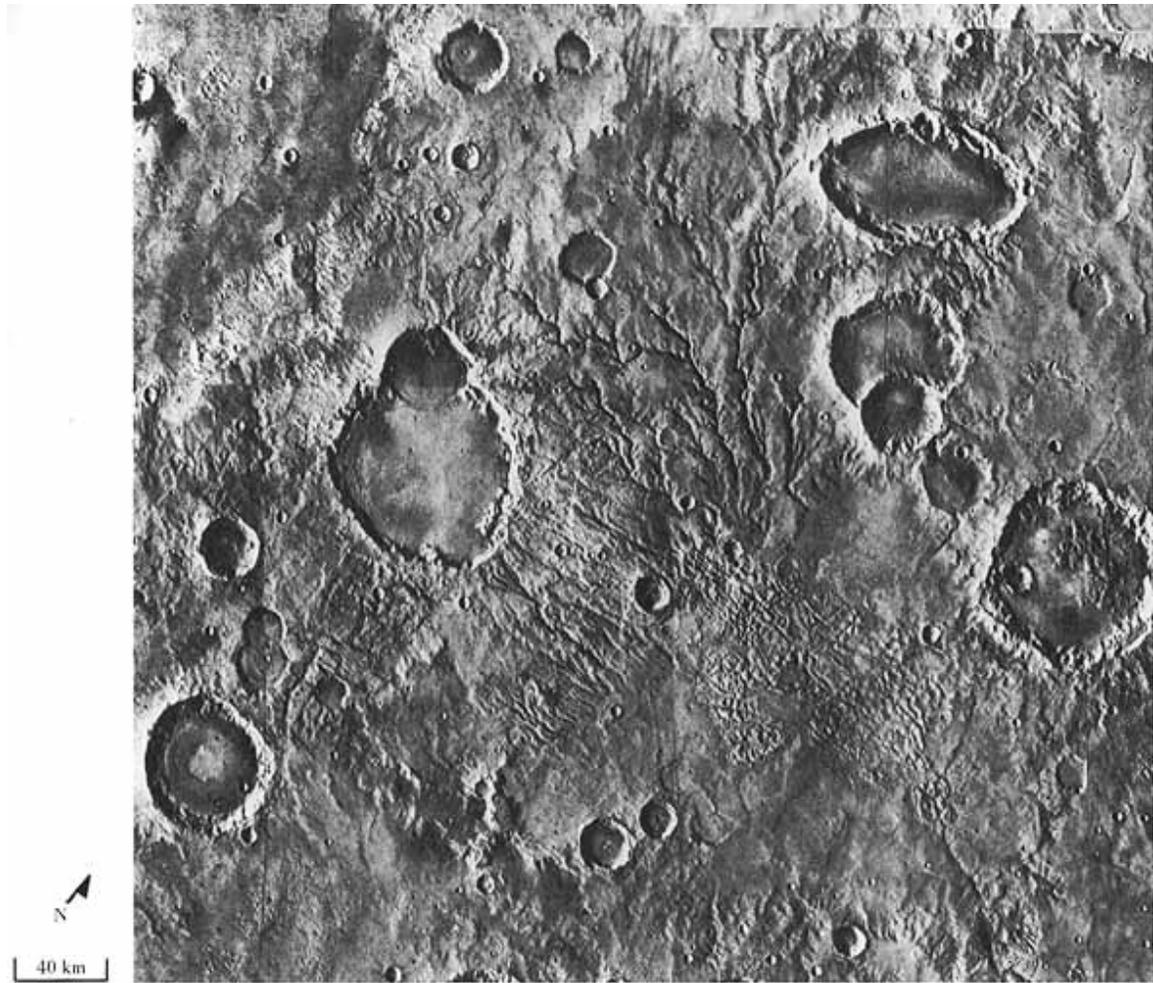
The ejecta from Arandas Crater acts like mud. It moves around small craters (indicated by arrows), instead of falling down on them. Craters like this suggest that large amounts of frozen water were melted when the impact crater was produced. Image is located in Mare Acidalium quadrangle.



This view of the flank of Alba Patera shows several features. Some channels are associated with lava flows; others are probably caused by running water. A large trough or graben turns into a line of collapse pits. Image is located in Arcadia quadrangle.



Branched channels in Thaumasia quadrangle. Networks of channels like this are strong evidence for rain on Mars in the past.



The branched channels strongly suggests that it rained on Mars in the past. Image is located in Margaritifer Sinus quadrangle.



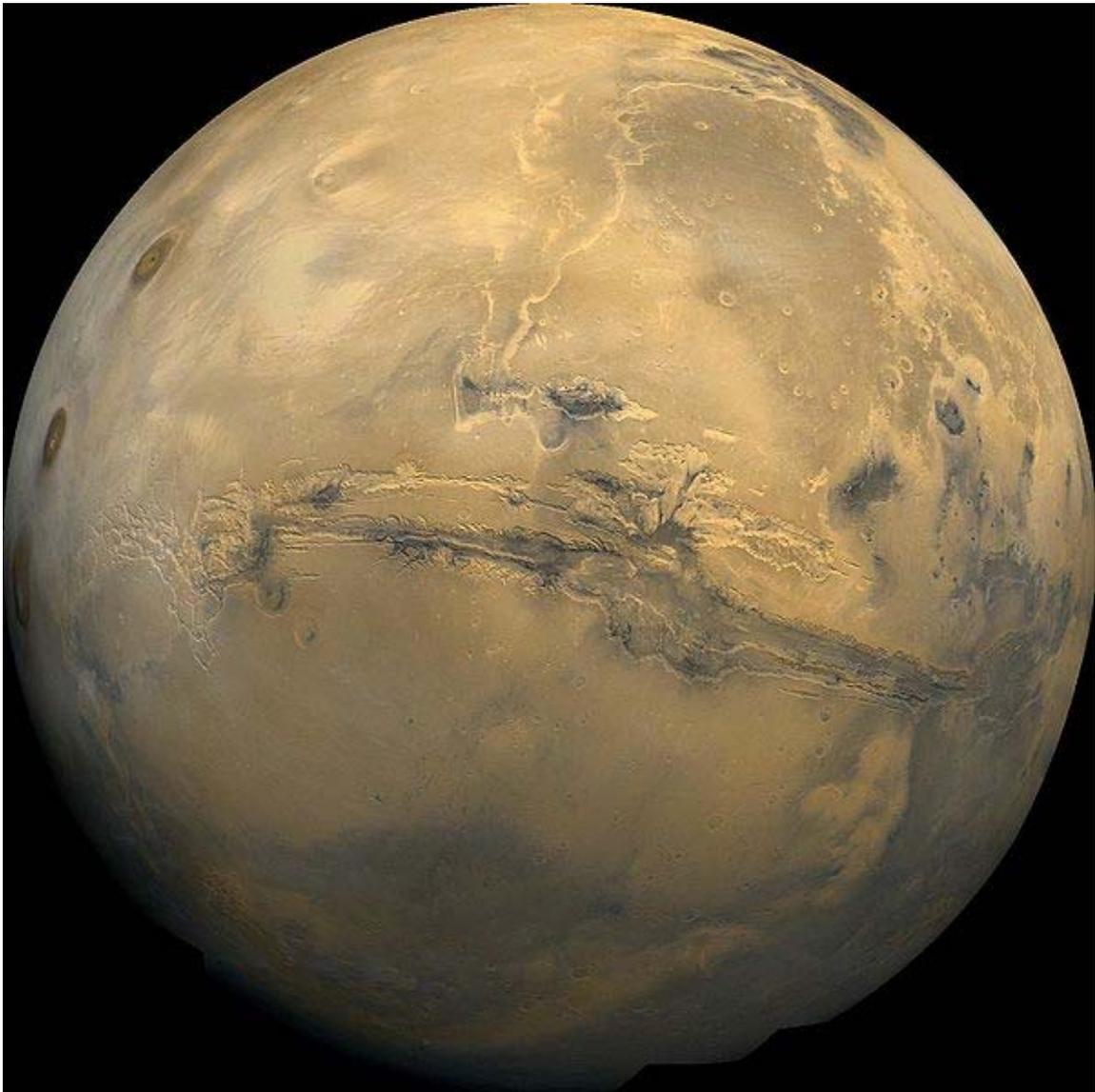
Ravi Vallis. Ravi Vallis was probably formed when catastrophic floods came out of the ground to the right (chaotic terrain). Image located in Margaritifer Sinus quadrangle.

Viking landers



Carl Sagan with a model of the Viking Lander, to scale (NASA).

Each lander consisted of a six-sided aluminum base with alternate 1.09 m (3 ft 7 in) and 0.56 m (1 ft 10 in) long sides, supported on three extended legs attached to the shorter sides. The leg footpads formed the vertices of an equilateral triangle with 2.21 m (7 ft 3 in) sides when viewed from above, with the long sides of the base forming a straight line with the two adjoining footpads. Instrumentation was attached to the top of the base, elevated above the surface by the extended legs. Power was provided by two radioisotope thermal generator (RTG) units containing plutonium-238 affixed to opposite sides of the lander base and covered by wind screens. Each generator was 28 cm (11 in) tall, 58 cm (23 in) in diameter, had a mass of 13.6 kg (30 lb) and provided 30 watts continuous power at 4.4 volts. Four wet cell sealed nickel-cadmium 8 ampere-hours (28,800 Coulombs), 28 volts rechargeable batteries were also onboard to handle peak power loads.



Mars from the Viking Orbiter.

Propulsion for deorbit was provided by a monopropellant called hydrazine (N_2H_4), through a rocket with 12 nozzles arranged in four clusters of three that provided 32 newtons (7.2 lb_f) thrust, providing a delta-V of 180 m/s (590 ft/s). These nozzles also acted as the control thrusters for translation and rotation of the lander. Terminal descent and landing utilized three (one affixed on each long side of the base, separated by 120 degrees) monopropellant hydrazine engines. The engines had 18 nozzles to disperse the exhaust and minimize effects on the ground, and were throttleable from 276 to 2,667 newtons (62 to 600 lb_f). The hydrazine was purified in order to prevent contamination of the Martian surface with Earth microbes. The lander carried 85 kg (190 lb) of propellant at launch, contained in two spherical titanium tanks mounted on opposite sides of the lander beneath the RTG windscreens, giving a total launch mass of 657 kg (1,450 lb). Control was achieved through the use of an inertial reference unit, four gyros, a parachute, a radar altimeter, a terminal descent and landing radar, and the control thrusters.

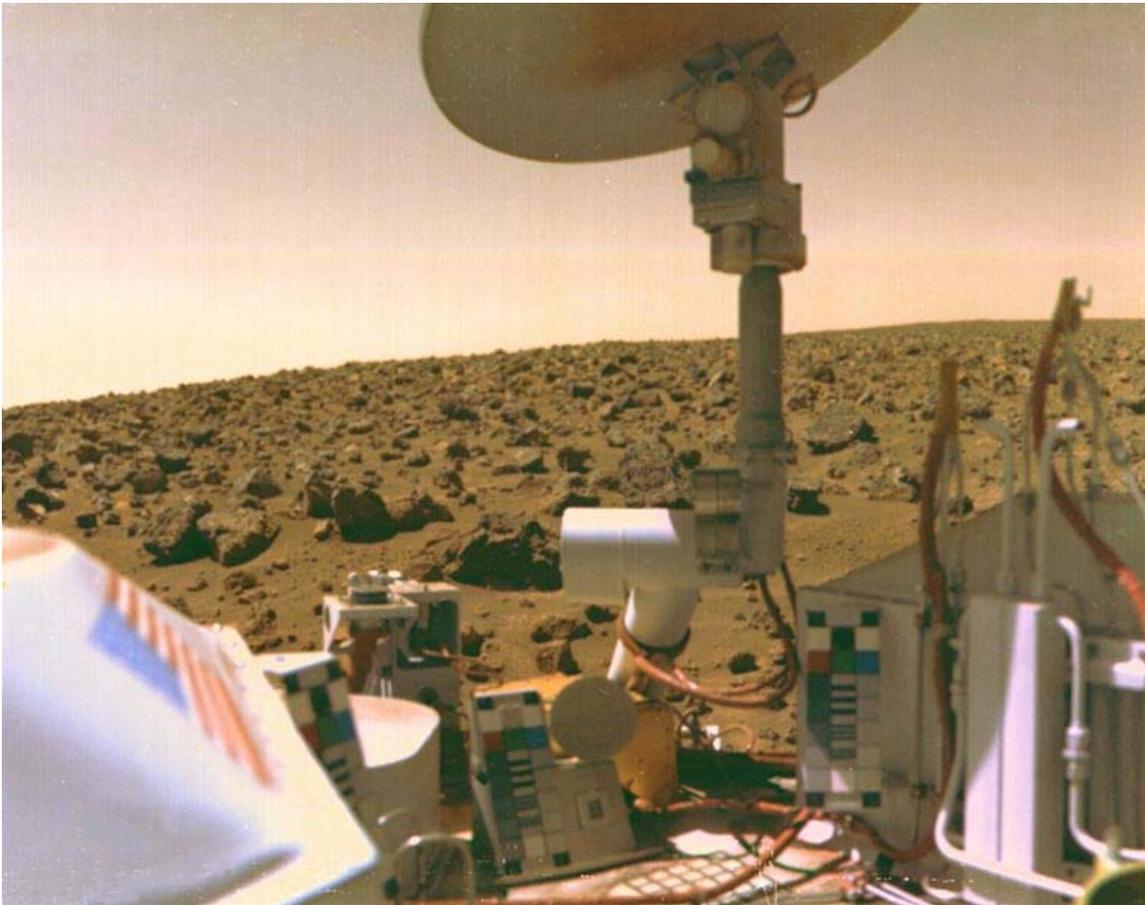


Image from Mars taken by Viking 2.

Each lander was covered over from launch until Martian atmospheric entry with an aeroshell heat shield designed to slow the lander down during the entry phase, and also to prevent contamination of the Martian surface with Earthly microbial life that can survive the harsh conditions of deep space (as evident on the Surveyor 3 moon probe). As a

further precaution, each lander, upon assembly and enclosure within the aeroshell, were "baked" at a temperature of 250 °F (121 °C) for a total of seven days, after which a "bioshield" was then placed over the aeroshell that was jettisoned after the Centaur upper stage fired the Viking orbiter/lander combination out of Earth orbit. The methods and standards developed for planetary protection for the Viking mission are still used for other missions.

Communications were accomplished through a 20 watt S-band transmitter using two traveling-wave tubes. A two-axis steerable high-gain parabolic antenna was mounted on a boom near one edge of the lander base. An omnidirectional low-gain S-band antenna also extended from the base. Both these antennae allowed for communication directly with the Earth, permitting Viking 1 to continue to work long after both orbiters had failed. A UHF (381 MHz) antenna provided a one-way relay to the orbiter using a 30 watt relay radio. Data storage was on a 40-Mbit tape recorder, and the lander computer had a 6000-word memory for command instructions.

The lander carried instruments to achieve the primary scientific objectives of the lander mission: to study the biology, chemical composition (organic and inorganic), meteorology, seismology, magnetic properties, appearance, and physical properties of the Martian surface and atmosphere. Two 360-degree cylindrical scan cameras were mounted near one long side of the base. From the center of this side extended the sampler arm, with a collector head, temperature sensor, and magnet on the end. A meteorology boom, holding temperature, wind direction, and wind velocity sensors extended out and up from the top of one of the lander legs. A seismometer, magnet and camera test targets, and magnifying mirror are mounted opposite the cameras, near the high-gain antenna. An interior environmentally controlled compartment held the biology experiment and the gas chromatograph mass spectrometer. The X-ray fluorescence spectrometer was also mounted within the structure. A pressure sensor was attached under the lander body. The scientific payload had a total mass of approximately 91 kg (200 lb).

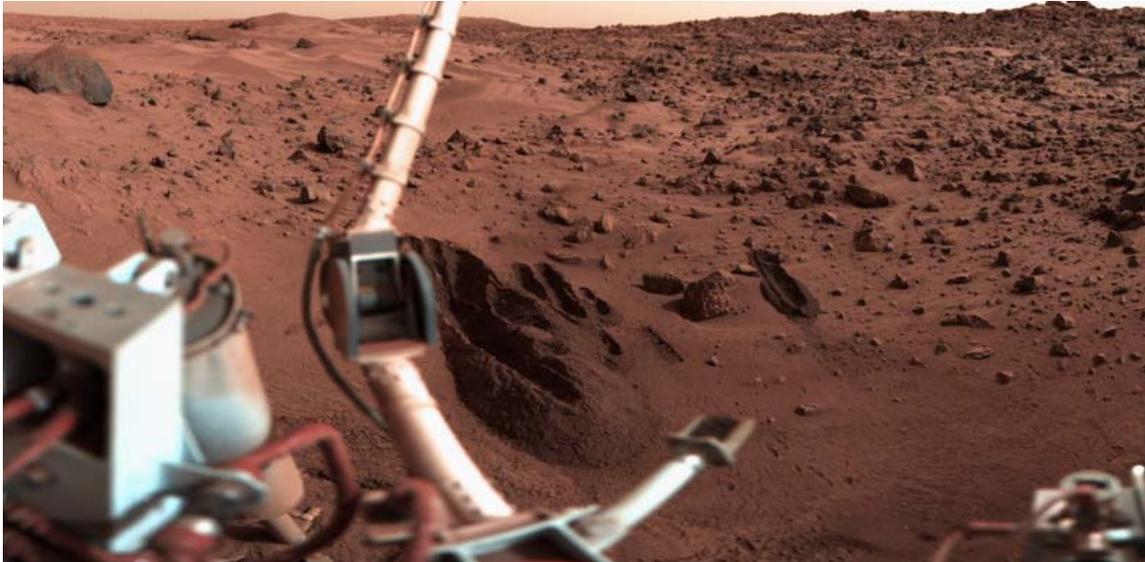
Control systems

The Viking landers used a Guidance, Control and Sequencing Computer (GCSC) consisting of two Honeywell HDC 402 24-bit computers with 18K of plated-wire memory, while the Viking orbiters used a Command Computer Subsystem (CCS) using two custom-designed 18-bit bit-serial processors.

Biological experiments



Dust dunes and a large boulder taken by the Viking 1 lander.



Trenches dug by the soil sampler of the Viking 1 lander.

The Viking landers conducted biological experiments designed to detect life in the Martian soil (if it existed) with experiments designed by three separate teams, under the direction of chief scientist Gerald Soffen of NASA. One experiment turned positive for the detection of metabolism (current life), but based on the results of another test that failed to reveal any organic molecules in the soil, most scientists became convinced that the positive results were likely caused by non-biological chemical reactions from highly oxidizing soil conditions.

Although there is general consensus that the Viking Lander results demonstrated a lack of robust microorganism biotas in soils at the two landing sites, the test results and their limitations are still under assessment. The validity of the positive 'Labeled Release' (LR) results hinged entirely on the absence of an oxidative agent in the Martian soil, but one was recently discovered by the Phoenix lander in the form of perchlorate salts. The question of microbial life on Mars remains unresolved.

Research, published in the Journal of Geophysical Research in December 2010, proposed that organic compounds could have been present in the soil analyzed by both Viking 1 and 2. NASA's Phoenix lander in 2008 detected perchlorate which can break down organic compounds. The study's authors found that perchlorate will destroy organics when heated and will produce chloromethane and dichloromethane, the identical chlorine compounds discovered by both Viking landers when they performed the same tests on Mars. Because perchlorate would have broken down any Martian organics, the question of life on Mars becomes more probable.

Mission end

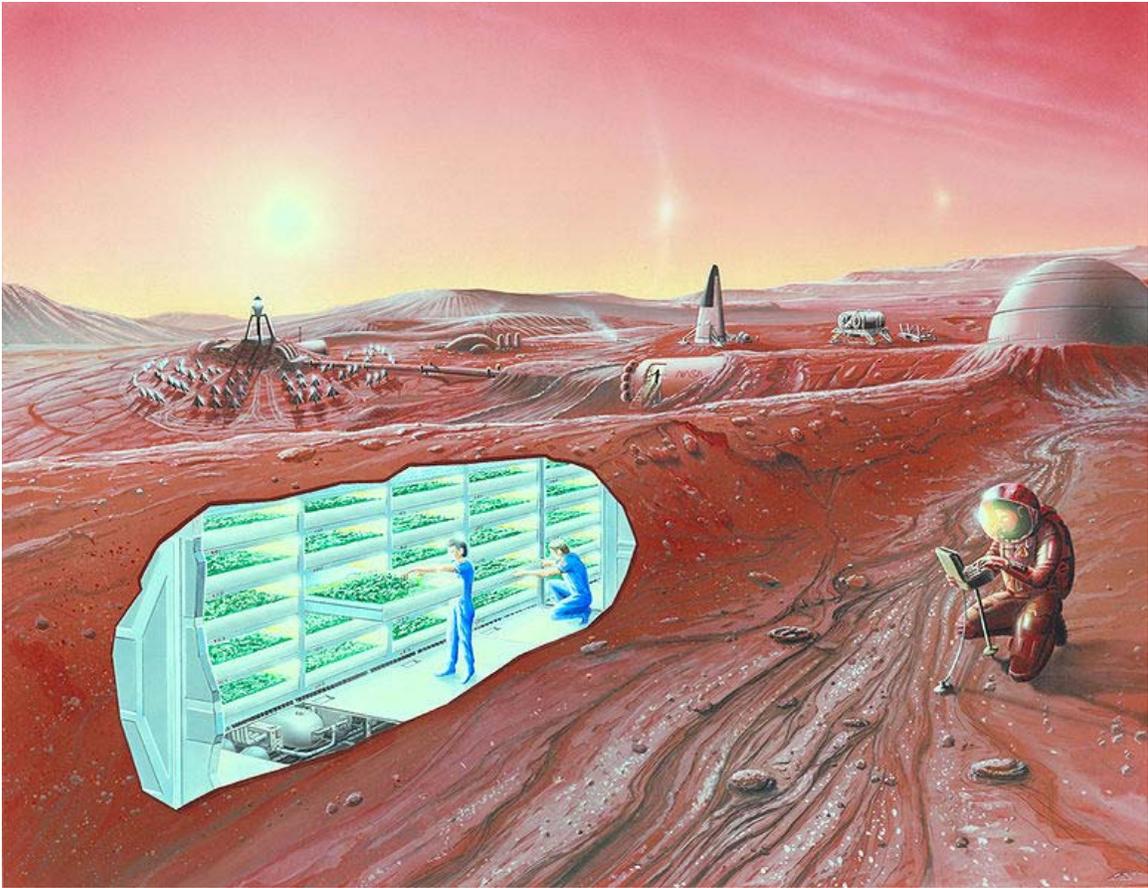
The crafts eventually failed, one by one, as follows:

Craft	Arrival date	Shut-off date	Operational lifetime	Cause of failure
Viking 2 orbiter	August 7, 1976	July 25, 1978	1 year, 11 months, 18 days	Shut down after fuel leak in propulsion system.
Viking 2 lander	September 3, 1976	April 11, 1980	3 years, 7 months, 8 days	Battery failure.
Viking 1 orbiter	June 19, 1976	August 17, 1980	4 years, 1 month, 19 days	Shut down after depletion of attitude control fuel
Viking 1 lander	July 20, 1976	November 13, 1982	6 years, 3 months, 22 days	Human error during software update that caused the antenna to go down causing the termination of communication with the lander.

The whole of the Viking program was finally shut down on May 21, 1983.

Chapter- 6

Colonization of Mars



An artist's conception of the colonization of Mars, with a cutaway showing part of the interior (NASA Ames, 2005)

The **colonization of Mars** by humans is the focus of speculation and serious study because the surface conditions and availability of water on Mars make it arguably the most hospitable planet in the solar system other than Earth. The Moon has been proposed

as the first location for human colonization but Mars has an atmosphere, giving it the potential capacity to host human and other organic life.

Relative similarity to Earth

The Earth is very like its "sister planet" Venus in bulk composition, size and surface gravity but Mars' similarities to Earth are arguably more compelling when considering colonization. These include:

- The Martian day (or **sol**) is very close to Earth's. A Mars solar day is 24 hours 39 minutes 35.244 seconds.
- Mars has a surface area that is 28.4% of Earth's, only slightly less than the amount of dry land on Earth (which is 29.2% of Earth's surface). Mars has half the radius of Earth and only one-tenth the mass. This means that it has a smaller volume (~15%) and lower average density than Earth.
- Mars has an axial tilt of 25.19°, compared with Earth's 23.44°. As a result, Mars has seasons much like Earth, though they last nearly twice as long because the Martian year is about 1.88 Earth years. The Martian north pole currently points at Cygnus, not Ursa Minor.
- Mars has an atmosphere. Although it is very thin (about 0.7% of Earth's atmosphere) it provides some protection from solar and cosmic radiation and has been used successfully for aerobraking of spacecraft.
- Recent observations by NASA's Mars Exploration Rovers, ESA's Mars Express and NASA's Phoenix Lander confirm the presence of water ice on Mars. Mars appears to have significant quantities of all the elements necessary to support Earth-based life.

Differences from Earth

- The surface gravity on Mars is 0.38 of that on Earth. It is not known if this is enough to prevent the health problems associated with weightlessness.
- Mars is much colder than Earth, with a mean surface temperature of -63°C and a low of -140°C. The lowest temperature ever recorded on Earth was -89.2°C, in Antarctica.
- There are no standing bodies of liquid water on the surface of Mars.
- Because Mars is further from the Sun, the amount of solar energy reaching the upper atmosphere (the solar constant) is less than half of what reaches the Earth's upper atmosphere or the Moon's surface. However, the solar energy that reaches the surface of Mars is not impeded by a thick atmosphere like on Earth.

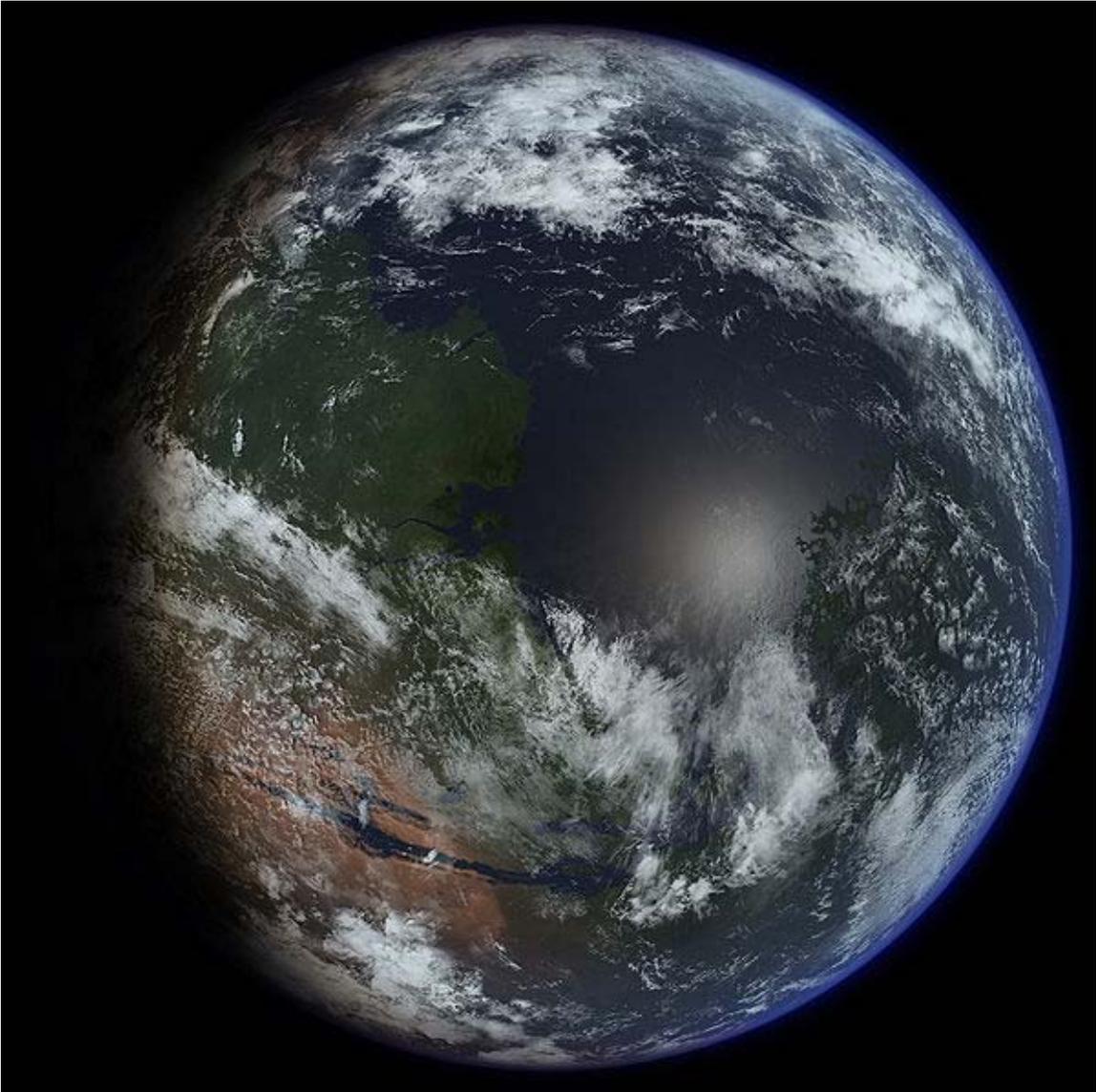
- Mars' orbit is more eccentric than Earth's, exacerbating temperature and solar constant variations.
- The atmospheric pressure on Mars is ~6 mbar, far below the Armstrong Limit (61.8 mbar) at which people can survive without pressure suits. Since terraforming cannot be expected as a near-term solution, habitable structures on Mars would need to be constructed with pressure vessels similar to spacecraft, capable of containing a pressure between a third and a whole bar.
- The Martian atmosphere consists mainly of carbon dioxide. Because of this, even with the reduced atmospheric pressure, the partial pressure of CO₂ at the surface of Mars is some 52 times higher than on Earth. It also has significant levels of carbon monoxide.
- Mars has a very weak magnetosphere, so it deflects solar winds poorly.

Habitability

Conditions on the surface of Mars are much closer to habitability than the surface of any other known planet or moon, as seen by the extremely hot and cold temperatures on Mercury, the furnace-hot surface of Venus, or the cryogenic cold of the outer planets and their moons. Only the cloud tops of Venus are closer in terms of habitability to Earth than Mars is. There are natural settings on Earth where humans have explored that match most conditions on Mars. The highest altitude reached by a manned balloon ascent, a record set in May 1961, was 34,668 meters (113,740 feet). The pressure at that altitude is about the same as on the surface of Mars. Extreme cold in the Arctic and Antarctic match all but the most extreme temperatures on Mars.

NASA Deputy Administrator Shana Dale said, "We also hope to discover if Mars can provide a second home for humans—an extension of our civilization—40 million miles from Earth."

Terraforming



An artist's conception of a terraformed Mars (2009)

It may be possible to terraform Mars to allow a wide variety of living things, including humans, to survive unaided on Mars' surface.

Radiation

Mars has no global magnetic field comparable to Earth's geomagnetic field. Combined with a thin atmosphere, this permits a significant amount of ionizing radiation to reach the Martian surface. The Mars Odyssey spacecraft carried an instrument, the Mars Radiation Environment Experiment (MARIE), to measure the dangers to humans. MARIE found that radiation levels in orbit above Mars are 2.5 times higher than at the International Space Station. Average doses were about 22 millirads per day (220

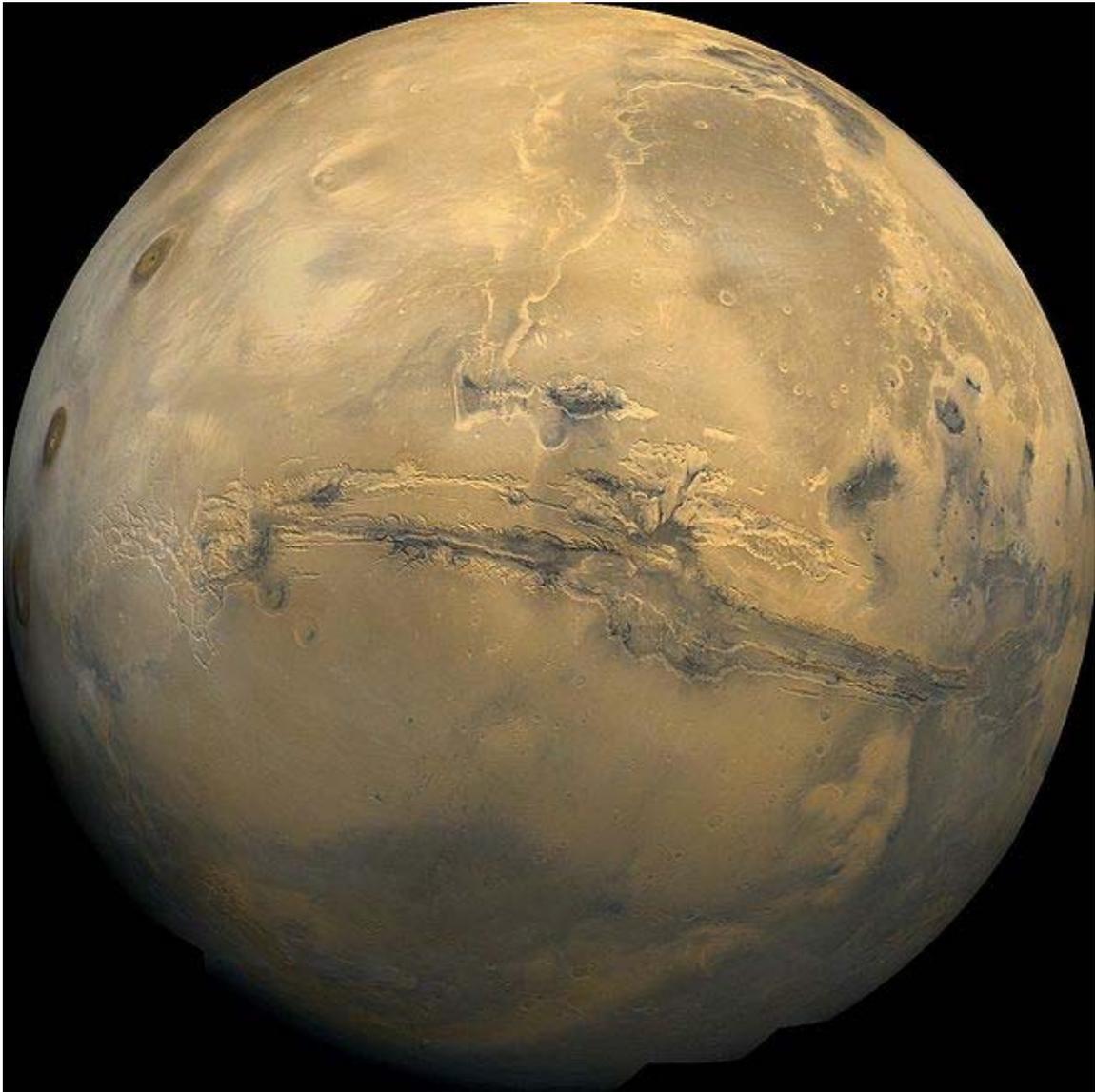
micrograys per day or 0.08 gray per year.) A three year exposure to such levels would be close to the safety limits currently adopted by NASA. Levels at the Martian surface would be somewhat lower and might vary significantly at different locations depending on altitude and local magnetic fields.

Occasional solar proton events (SPEs) produce much higher doses. Some SPEs were observed by MARIE that were not seen by sensors near Earth due to the fact that SPEs are directional, making it difficult to warn astronauts on Mars early enough.

Much remains to be learned about space radiation. In 2003, NASA's Lyndon B. Johnson Space Center opened a facility, the NASA Space Radiation Laboratory, at Brookhaven National Laboratory that employs particle accelerators to simulate space radiation. The facility will study its effects on living organisms along with shielding techniques. There is some evidence that this kind of low level, chronic radiation is not quite as dangerous as once thought; and that radiation hormesis occurs. The consensus among those that have studied the issues is that radiation levels, with the exception of the SPEs, that would be experienced on the surface of Mars, and while journeying there, are certainly a concern, but are not thought to prevent a trip from being made with current technology.

Transportation

Interplanetary spaceflight



Mars (Viking 1, 1980)

Mars requires less energy per unit mass (ΔV) to reach from Earth than any planet except Venus. Using a Hohmann transfer orbit, a trip to Mars requires approximately nine months in space. Modified transfer trajectories that cut the travel time down to seven or six months in space are possible with incrementally higher amounts of energy and fuel compared to a Hohmann transfer orbit, and are in standard use for robotic Mars missions. Shortening the travel time below about six months requires higher Δv and an exponentially increasing amount of fuel, and is not feasible with chemical rockets, but would be perfectly feasible with advanced spacecraft propulsion technologies, some of which have already been tested, such as VASIMR, and nuclear rockets, in the formers

case, a trip time of forty days could be attainable, and in the latter, a trip time down to about two weeks. Another possibility is constant-acceleration technologies such as space proven solar sails and ion drives which permits passage times at close approaches on the order of several weeks. Both of these propulsion systems have been deployed and could readily obtain a constant acceleration of 0.1g.

During the journey the astronauts are subject to radiation, which requires a means to protect them. Cosmic radiation and solar wind cause DNA damage, which increases the risk of cancer significantly. The effect of long term space travel in the interplanetary space is unknown, but scientists estimate up to 19% probability for male persons to die of cancer because of the radiation during the journey to Mars and back to Earth. Together with the base probability of 20% for a male person on Earth to die from cancer this gives a probability of 39%. For women the probability is even higher due to their larger glandular tissues.

Landing on Mars

Mars has a gravity 0.38 times that of the Earth and the density of its atmosphere is 1% of that on Earth. The relatively strong gravity and the presence of aerodynamic effects makes it difficult to land heavy, crewed spacecraft with thrusters only as was done with the Apollo moon landings, yet the atmosphere is too thin for aerodynamic effects to be of much help in braking and landing a large vehicle. Landing piloted missions on Mars will require braking and landing systems different from anything used to land crewed spacecraft on the Moon or robotic missions on Mars.

If one assumes carbon nanotube construction material will be available with a strength of 130 GPa then a space elevator could be built to land men and material on Mars. A space elevator on Phobos has also been proposed.

Communication

Communications with Earth are relatively straightforward during the half-sol when the Earth is above the Martian horizon. NASA and ESA included communications relay equipment in several of the Mars orbiters, so Mars already has communications satellites. While these will eventually wear out, additional orbiters with communication relay capability are likely to be launched before any colonization expeditions are mounted.

The one-way communication delay due to the speed of light ranges from about 3 minutes at closest approach (approximated by perihelion of Mars minus aphelion of Earth) to 22 minutes at the largest possible superior conjunction (approximated by aphelion of Mars plus aphelion of Earth). Telephone conversations or Internet Relay Chat between Earth and Mars would be highly impractical due to the long time lags involved. NASA has found that direct communication can be blocked for about two weeks every synodic period, around the time of superior conjunction when the Sun is directly between Mars and Earth, although the actual duration of the communications blackout varies from mission to mission depending on various factors - such as the amount of link margin

designed into the communications system, and the minimum data rate that is acceptable from a mission standpoint. In reality most missions at Mars have had communications blackout periods of the order of a month.

A satellite at either of the Earth-Sun L_4/L_5 Lagrange points could serve as a relay during this period to solve the problem; even a constellation of communications satellites would be a minor expense in the context of a full colonization program. However the size and power of the equipment needed for these distances make the L_4 and L_5 locations unrealistic for relay stations, and the inherent stability of these regions, while beneficial in terms of station-keeping, also attracts asteroids, which could pose a severe risk to any satellite.

Recent work by the University of Strathclyde's Advanced Space Concepts Laboratory, in collaboration with the European Space Agency, has suggested an alternative relay architecture based on highly non-Keplerian orbits. These are a special kind of orbit produced when continuous low-thrust propulsion, such as that produced from an ion engine or solar sail, modifies the natural trajectory of a spacecraft. Such an orbit would enable continuous communications during solar conjunction by allowing a relay spacecraft to "hover" above Mars, out of the orbital plane of the two planets. Such a relay avoids the problems of satellites stationed at either L_4 or L_5 by being significantly closer to the surface of Mars while still maintaining continuous communication between the two planets.

Robotic precursors

The path to a human colony could be prepared by robotic systems such as the Mars Exploration Rovers *Spirit* and *Opportunity*. These systems could help locate resources, such as ground water or ice, that would help a colony grow and thrive. The lifetimes of these systems would be measured in years and even decades, and as recent developments in commercial spaceflight have shown, it may be that these systems will involve private as well as government ownership. These robotic systems also have a reduced cost compared with early crewed operations, and have less political risk.

Wired systems might lay the groundwork for early crewed landings and bases, by producing various consumables including fuel, oxidizers, water, and construction materials. Establishing power, communications, shelter, heating, and manufacturing basics can begin with robotic systems, if only as a prelude to crewed operations.

Early human missions

Early human missions to Mars, such as those being tentatively planned by NASA, FKA and ESA would not be direct precursors to colonization. They are intended solely as exploration missions, as the *Apollo* missions to the Moon were not planned to be sites of a permanent base.

Colonization requires the establishment of permanent bases that have potential for self-expansion. A famous proposal for building such bases is the Mars Direct plan, advocated by Robert Zubrin. The Mars Society has established the Mars Analogue Research Station Programme at sites Devon Island in Canada and in Utah, United States, to experiment with different plans for human operations on Mars, based on Mars Direct. Modern Martian architecture concepts often include facilities to produce oxygen and propellant on the surface of the planet.

Economics

As with early colonies in the New World, economics would be a crucial aspect to a colony's success. The reduced gravity well of Mars and its position in the solar system may facilitate Mars-Earth trade and provide the rationalization for continued settlement of the planet.

Mars' reduced gravity together with its rotation rate makes it possible for the construction of a space elevator with today's materials, although the low orbit of Phobos could present engineering challenges. If constructed, the elevator could transport minerals and other natural resources extracted from the planet.

A major economic problem is the enormous up-front investment required to establish the colony and perhaps also terraform the planet.

Some early Mars colonies might specialize in developing local resources for Martian consumption, such as water and/or ice.

Another main inter-Martian trade good during early colonization could be manure. Assuming that life doesn't exist on Mars, the soil is going to be very poor for growing plants, so manure and other fertilizers will be valued highly in any Martian civilization until the planet changes enough chemically to support growing vegetation on its own.

Solar power is a candidate for power for a Martian colony. Solar insolation (the amount of solar radiation that reaches Mars) is about 42% of that on Earth, since Mars is about 52% farther from the Sun and insolation falls off as the square of distance. But the thin atmosphere would allow almost all of that energy to reach the surface as compared to Earth, where the atmosphere absorbs roughly a quarter of the solar radiation.

Nuclear power is also a good candidate, since the fuel is very dense for cheap transportation from Earth. Nuclear power also produces heat, which would be extremely valuable to a Mars colony.

Heating requirements could be lowered if the colonists use domes to trap solar heat, especially for greenhouses.

Possible locations for colonies

Mars can be considered in broad regions for discussion of possible colony sites.

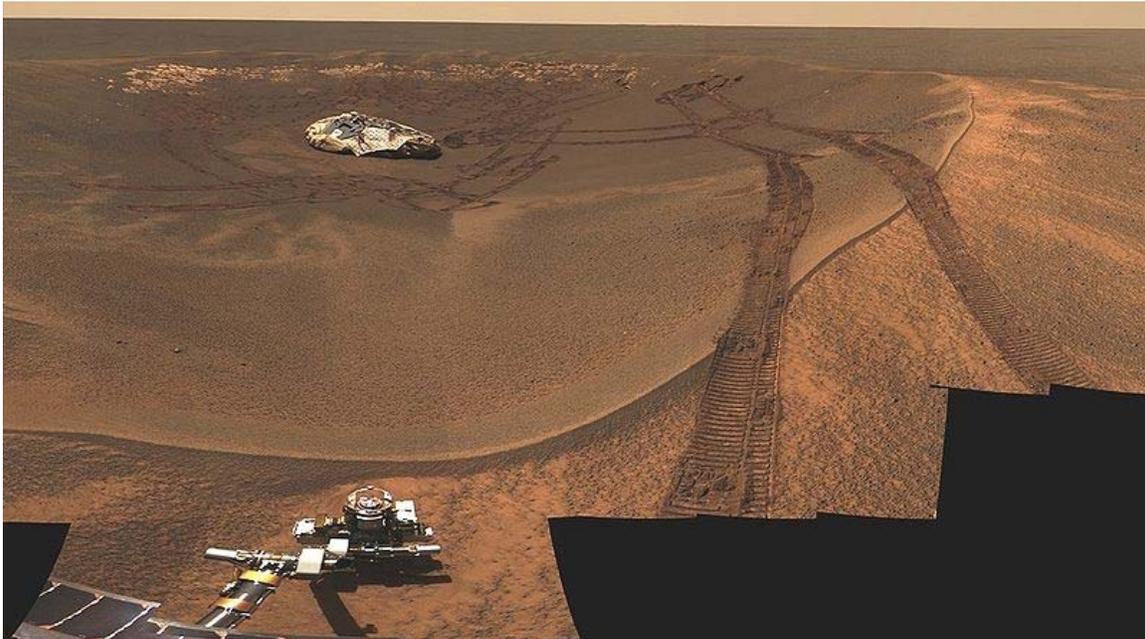
Polar regions

Mars' north and south poles once attracted great interest as colony sites because seasonally-varying polar ice caps have long been observed by telescope from Earth. Mars Odyssey found the largest concentration of water near the north pole, but also showed that water likely exists in lower latitudes as well, making the poles less compelling as a colony locale. Like Earth, Mars sees a midnight sun at the poles during local summer and polar night during local winter.

Equatorial regions

Mars Odyssey found what appear to be natural caves near the volcano Arsia Mons. It has been speculated that colonists could benefit from the shelter that these or similar structures could provide from radiation and micrometeoroids. Geothermal energy is also suspected in the equatorial regions.

Midlands



Eagle Crater, as seen from *Opportunity* (2004)

The exploration of Mars' surface is still underway. The two Mars Exploration Rovers, *Spirit* and *Opportunity*, have encountered very different soil and rock characteristics. This suggests that the Martian landscape is quite varied and the ideal location for a colony

would be better determined when more data becomes available. As on Earth, seasonal variations in climate become greater with distance from the equator.

Valles Marineris

Valles Marineris, the "Grand Canyon" of Mars, is over 3,000 km long and averages 8 km deep. Atmospheric pressure at the bottom would be some 25% higher than the surface average, 0.9 kPa vs 0.7 kPa. The canyon runs roughly east-west, so shadows from its walls should not interfere too badly with solar power collection. River channels lead to the canyon, indicating it was once flooded.

Lava Tubes

Several lava tube skylights on Mars have been located. Earth based examples indicate that some should have lengthy passages offering complete protection from radiation and be relatively easy to seal using on site materials, especially in small subsections.

Advocacy

Making Mars colonization a reality is advocated by several groups with different reasons and proposals. One of the oldest is the Mars Society. They promote a NASA program to accomplish human exploration of Mars and have set up Mars analog research stations in Canada and the United States. Another group is Marsdrive, which is dedicated to private initiatives for the exploration and settlement of Mars.

Concerns

Besides the general criticism of human colonization of space, there are specific concerns about a colony on Mars:

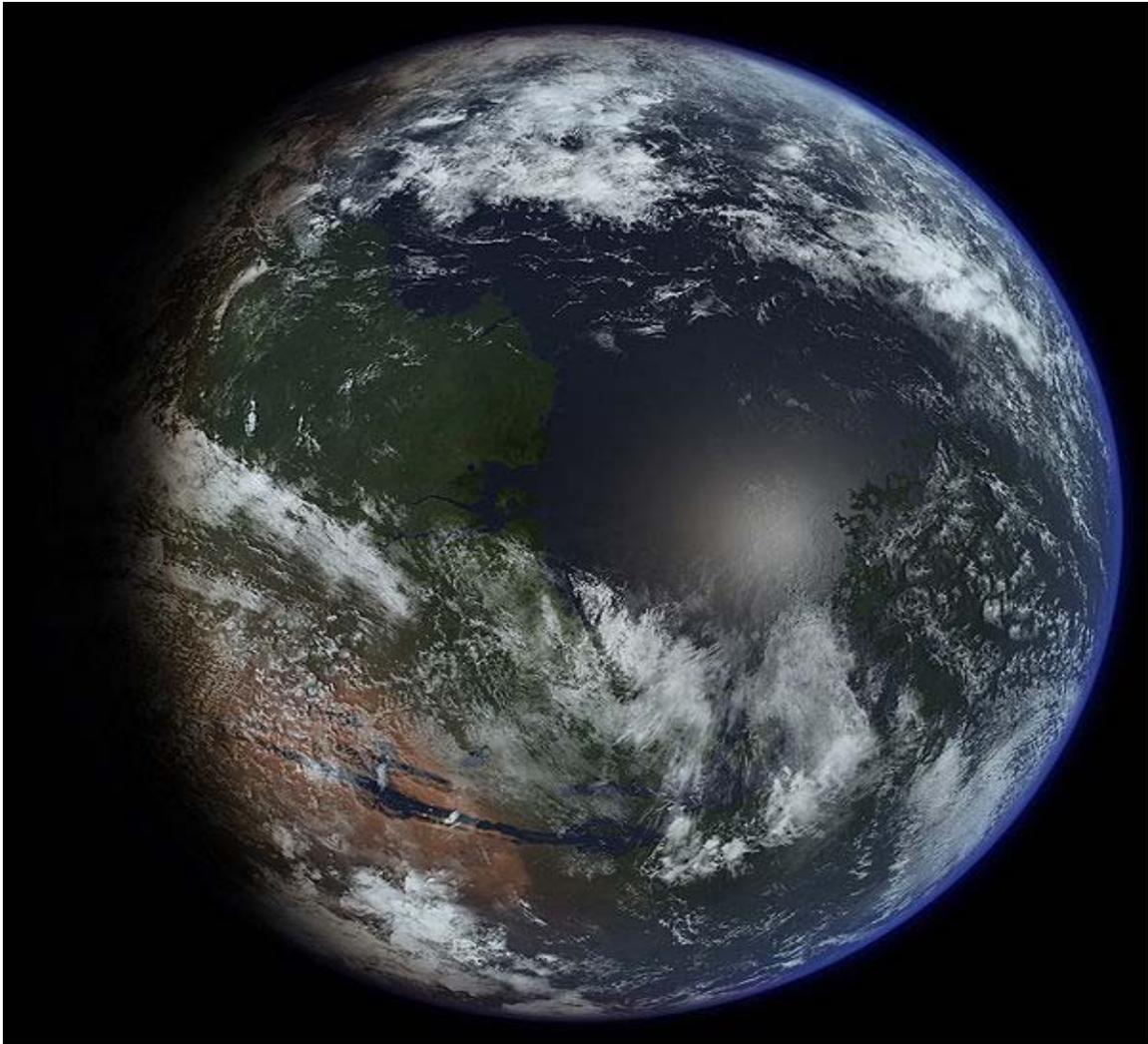
- Mars has a gravity 0.38 times that of the Earth and a density of the atmosphere of 1% that on Earth. The stronger gravity than the Moon and the presence of aerodynamic effects makes it more difficult to land heavy, crewed spacecraft with thrusters only, yet the atmosphere is also too thin to get very much use out of aerodynamic effects for braking and landing. Landing piloted missions on Mars will require a braking and landing system different from anything used to land crewed spacecraft on the Moon or robotic missions on Mars.
- The question of whether life once existed or exists now on Mars has not been settled, raising concerns about possible contamination of the planet with Earth life.
- Advocates of a return to the Moon say the Moon is a more logical first location for a first planetary colony, perhaps using it as practice for future manned missions to Mars. However, in several ways experience gained on the moon would not be applicable to the task of colonizing Mars. The moon has no

atmosphere, no analogous geology and a much greater temperature range and rotational period. These differences make Mars more in common with Earth than the Moon. Antarctica or desert areas of Earth provide much better training grounds at vastly lesser cost. Also, the Moon is extremely poor in several of the key elements required for life, most notably hydrogen, nitrogen and carbon (50 – 100 ppm), and has only 47.2% of the delta-v requirement for launching to orbit that Mars has.

- It is unknown whether Martian gravity can support human life in the long term (all experience is at either $\sim 1g$ or zero gravity). Space medicine researchers have theorized on whether the health benefits of gravity rise slowly or quickly between weightlessness and full Earth gravity. One theory is that sleeping chambers built inside centrifuges would minimize the health problems. The Mars Gravity Biosatellite experiment was due to become the first experiment testing the effects of partial gravity, artificially generated at 0.38 g to match Mars gravity, on mammal life, specifically on mice, throughout the life cycle from conception to death. However, in 2009 the Biosatellite project was cancelled due to lack of funds.
- Mars' escape velocity is 5 km/s, which, though less than half that for Earth, is reasonably high compared to the Moon's 2.38 km/s or the negligible escape velocity of most asteroids. This could make physical export trade from Mars to other planets and habitats less viable economically.
- There is likely to be little economic return from the colonization of Mars while Lunar and Near Earth Asteroid industry is likely to be exporting to Earth.
- Mars has dust storms which can reduce solar power. The largest of these storms can cover much of the planet.

Chapter- 7

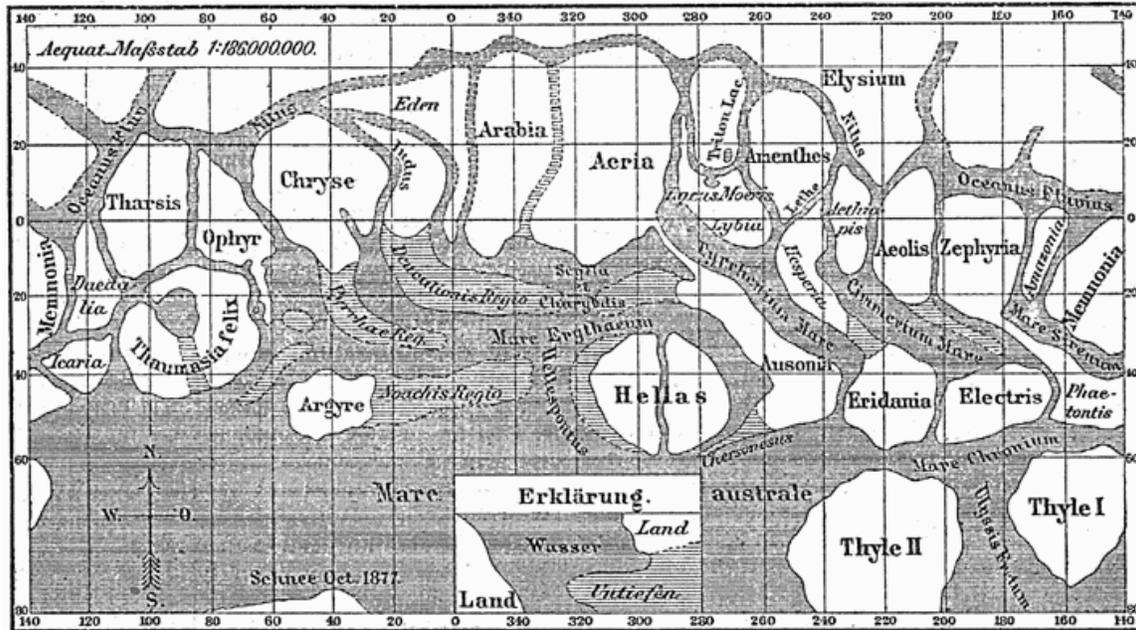
Life on Mars



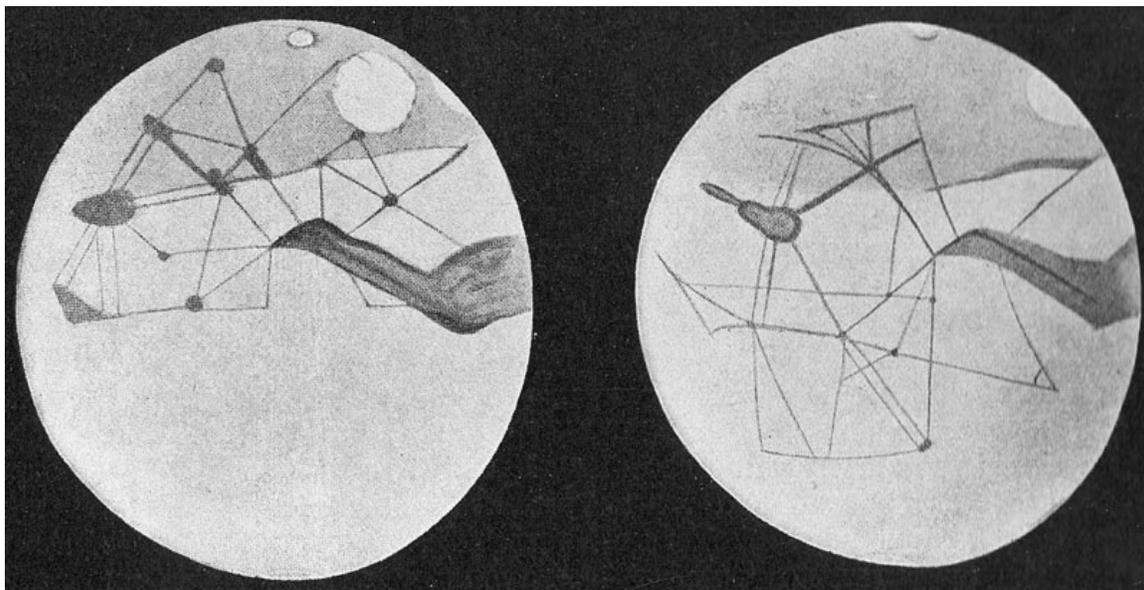
An artist's impression of what Mars' surface and atmosphere may look like if Mars were terraformed.

Scientists have long speculated about the possibility of **life on Mars** owing to the planet's proximity and similarity to Earth. Although fictional Martians have been a recurring feature of popular entertainment, it remains an open question whether life currently exists on Mars, or has existed there in the past.

Early speculation



Historical map of Mars from Giovanni Schiaparelli.



Mars canals, as seen by astronomer P. Lowell, 1898.

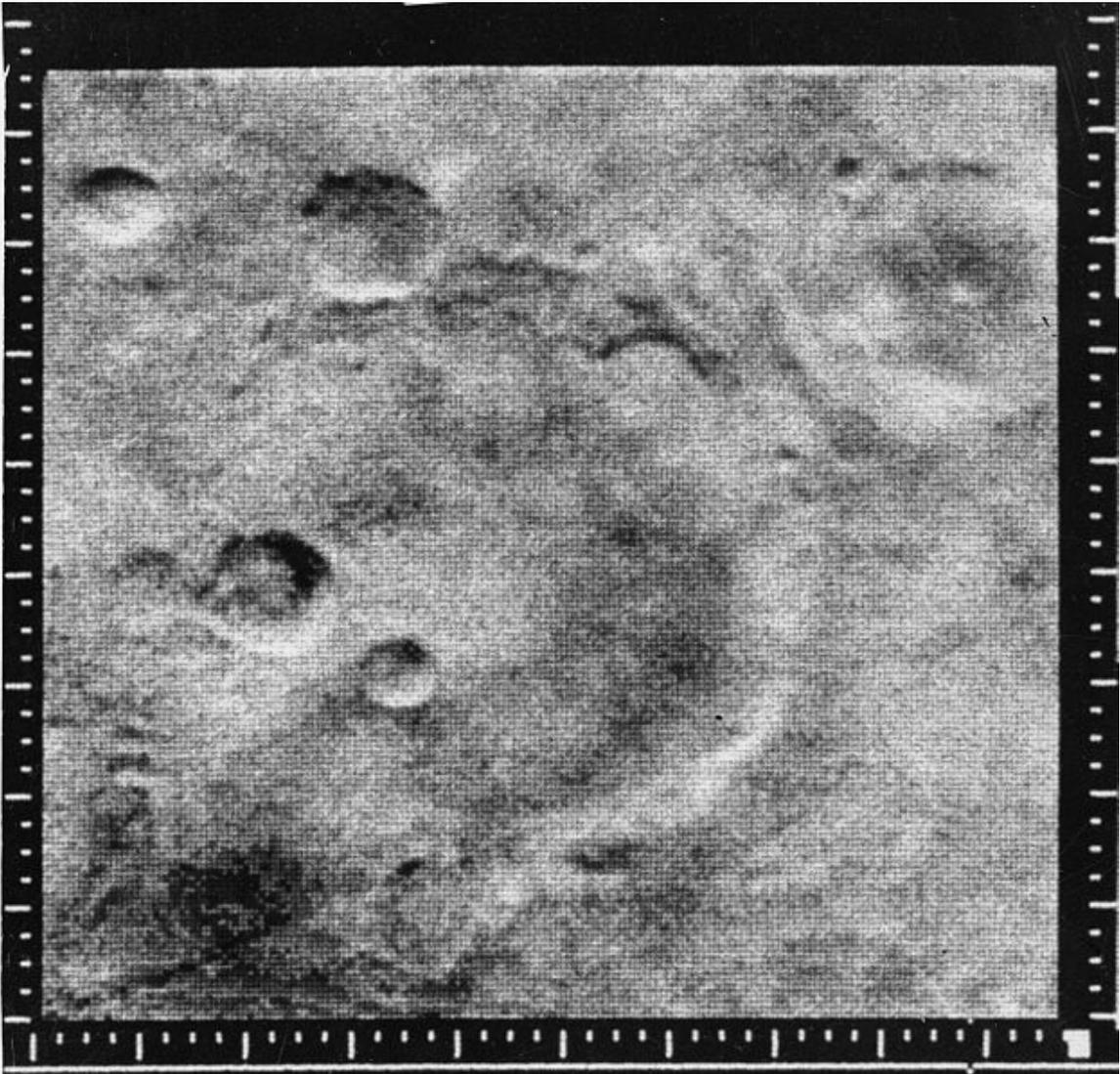
Mars' polar ice caps were observed as early as the mid-17th century, and they were first proven to grow and shrink alternately, in the summer and winter of each hemisphere, by William Herschel in the latter part of the 18th century. By the mid-19th century, astronomers knew that Mars had certain other similarities to Earth, for example that the length of a day on Mars was almost the same as a day on Earth. They also knew that its axial tilt was similar to Earth's, which meant it experienced seasons just as Earth does - but of nearly double the length owing to its much longer year. These observations led to the increase in speculation that the darker albedo features were water, and brighter ones were land. It was therefore natural to suppose that Mars may be inhabited by some form of life.

In 1854, William Whewell, a fellow of Trinity College, Cambridge, who popularized the word *scientist*, theorized that Mars had seas, land and possibly life forms. Speculation about life on Mars exploded in the late 19th century, following telescopic observation by some observers of apparent Martian canals — which were however soon found to be optical illusions. Despite this, in 1895, American astronomer Percival Lowell published his book *Mars*, followed by *Mars and its Canals* in 1906, proposing that the canals were the work of a long-gone civilization. This idea led British writer H. G. Wells to write *The War of the Worlds* in 1897, telling of an invasion by aliens from Mars who were fleeing the planet's desiccation.

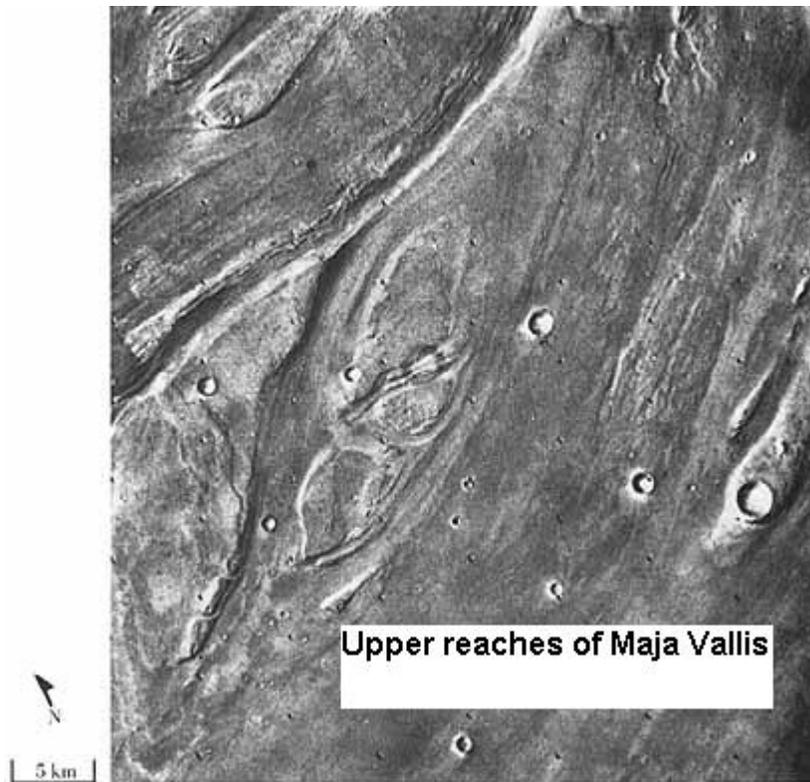
Spectroscopic analysis of Mars' atmosphere began in earnest in 1894, when U.S. astronomer William Wallace Campbell showed that neither water nor oxygen were present in the Martian atmosphere. By 1909 better telescopes and the best perihelic opposition of Mars since 1877 conclusively put an end to the canal theory.

Missions

Mariner 4



Mariner Crater, as seen by Mariner 4 in 1965. Pictures like this suggested that Mars is too dry for any kind of life.

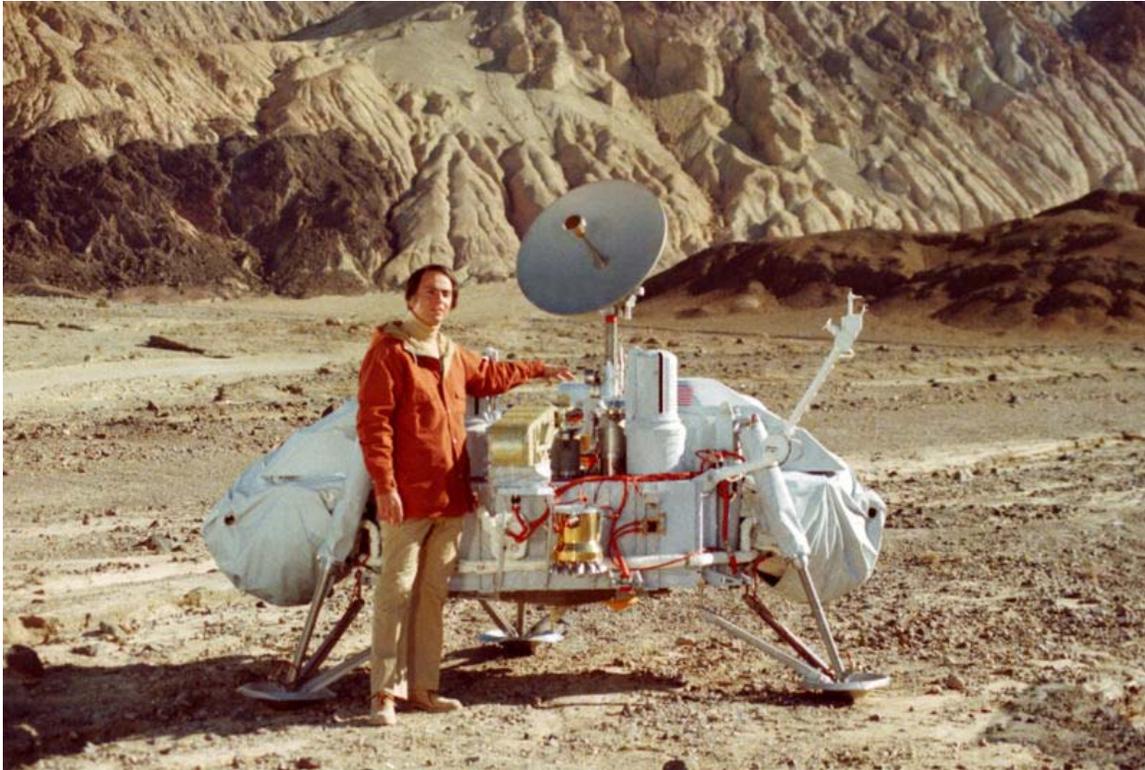


Streamlined Islands seen by Viking orbiter showed that large floods occurred on Mars. Image is located in Lunae Palus quadrangle.

Mariner 4 probe performed the first successful flyby of the planet Mars, returning the first pictures of the Martian surface in 1965. The photographs showed an arid Mars without rivers, oceans or any signs of life. Further, it revealed that the surface (at least the parts that it photographed) was covered in craters, indicating a lack of plate tectonics and weathering of any kind for the last 4 billion years. The probe also found that Mars has no global magnetic field that would protect the planet from potentially life-threatening cosmic rays. The probe was able to calculate the atmospheric pressure on the planet to be about 0.6 kPa (compared to Earth's 101.3 kPa), meaning that liquid water could not exist on the planet's surface. After Mariner 4, the search for life on Mars changed to a search for bacteria-like living organisms rather than for multicellular organisms, as the environment was clearly too harsh for these.

Viking orbiters

Liquid water is necessary for life and metabolism, so if water was present on Mars, the chances of it having supported life may have been determinant. The Viking orbiters found evidence of possible river valleys in many areas, erosion and, in the southern hemisphere, branched streams.



Carl Sagan poses next to a replica of the Viking landers.

Viking experiments

The primary mission of the Viking probes of the mid-1970s was to carry out experiments designed to detect microorganisms in Martian soil. The tests were formulated to look for life similar to that found on Earth. Of the four experiments, only the Labeled Release (LR) experiment returned a positive result, showing increased $^{14}\text{CO}_2$ production on first exposure of soil to water and nutrients. All scientists agree on two points from the Viking missions: that radiolabeled $^{14}\text{CO}_2$ was evolved in the Labeled Release experiment, and that the GC-MS detected no organic molecules. However, there are vastly different interpretations of what those results imply.

One of the designers of the Labeled Release experiment, Gilbert Levin, believes his results are a definitive diagnostic for life on Mars. However, this result is disputed by many scientists, who argue that superoxidant chemicals in the soil could have produced this effect without life being present. An almost general consensus discarded the Labeled Release data as evidence of life, because the gas chromatograph & mass spectrometer, designed to identify natural organic matter, did not detect organic molecules. The results of the Viking mission concerning life are considered by the general expert community, at best, as inconclusive.

In 2007, during a Seminar of the Geophysical Laboratory of the Carnegie Institution (Washington, D.C., USA), Gilbert Levin's investigation was assessed once more. Levin

maintains that his original data were correct, as the positive and negative control experiments were in order.

Ronald Paepe, an edaphologist (soil scientist), communicated to the European Geosciences Union Congress that the discovery of the recent detection of phyllosilicate clays on Mars may indicate pedogenesis, or soil development processes, extended over the entire surface of Mars. Paepe's interpretation views most of Mars surface as active soil, colored red by eons of widespread wearing by water, vegetation and microbial activity.

A research team from the Salk Institute for Biological Studies headed by Rafael Navarro-González, concluded that the equipment used (TV-GC-MS) by the Viking program to search for organic molecules, may not be sensitive enough to detect low levels of organics. Because of the simplicity of sample handling, TV-GC-MS is still considered the standard method for organic detection on future Mars missions, Navarro-González suggests that the design of future organic instruments for Mars should include other methods of detection.

Gillevinia straata

Table 2. Life's major domains (*) and formal systematic position of the active agent characterized by its reported behavior as responsible of the results of the 1976 Viking Mission's Labeled Release experiment.

<i>Organic Life System</i>	<i>Biosphere</i>	<i>Domains</i>	<i>Middle taxa</i>	<i>Known Genera & Species</i>
Solaria	Terrestria		...	Many
	Marciana	Jakobia	...	Levinia straata

* Observational knowledge about Solaria's biospheres is unbalanced; about extra-Solaria biospheres, unexisting.

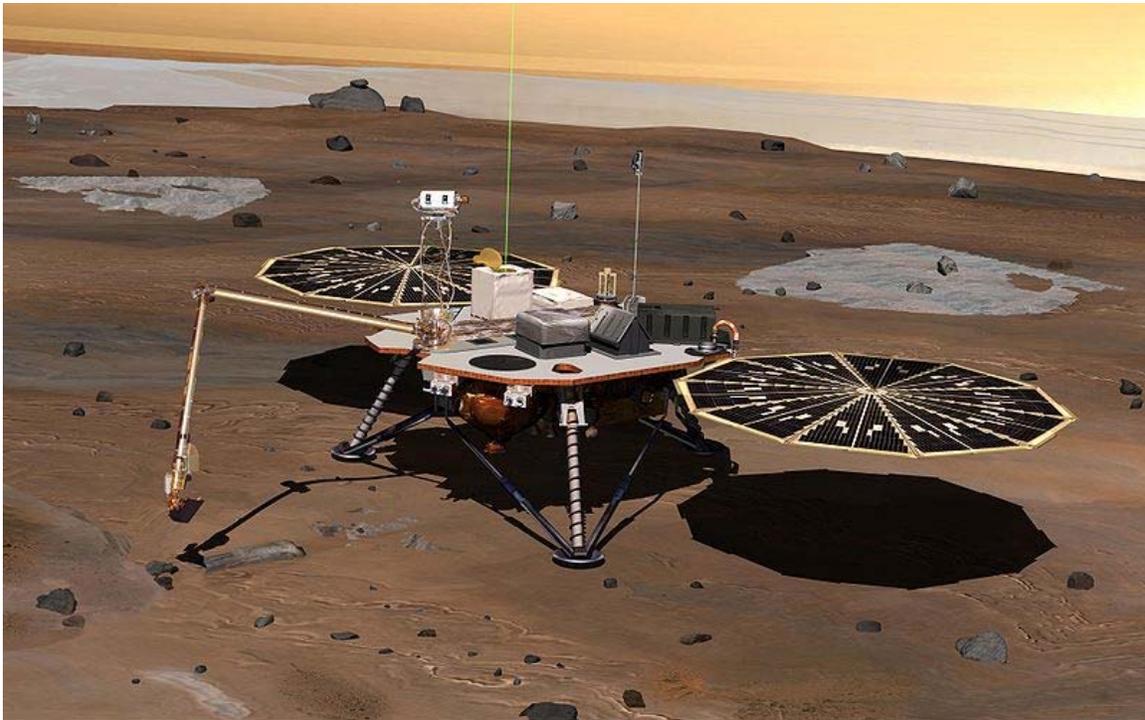
Newly proposed taxonomic system.

The claim for life on Mars, in the form of *Gillevinia straata*, is based on old data reinterpreted as sufficient evidence of life, mainly by professors Gilbert Levin, Rafael Navarro-González and Ronalds Paepe. The evidence supporting the existence of *Gillevinia straata* microorganisms relies on the data collected by the two Mars *Viking* landers that searched for biosignatures of life, but the analytical results were, officially, inconclusive.

In 2006, Mario Crocco, a neurobiologist at the Neuropsychiatric Hospital Borda in Buenos Aires, Argentina, proposed the creation of a new nomenclatural rank that classified the Viking landers' results as 'metabolic' and therefore belonging to a form of life. Crocco proposed to create new biological ranking categories (taxa), in the new kingdom system of life, in order to be able to accommodate the genus of Martian microorganisms. Crocco proposed the following taxonomical entry:

- Organic life system: Solaria
- Biosphere: Marciana
- Kingdom: Jakobia (named after neurobiologist Christfried Jakob)
- Genus et species: *Gillevinia straata*

As a result, the hypothetical *Gillevinia straata* would not be a bacterium (which rather is a terrestrial taxon) but a member of the kingdom 'Jakobia' in the biosphere 'Marciana' of the 'Solaria' system. The intended effect of the new nomenclature was to reverse the burden of proof concerning the life issue, but the taxonomy proposed by Crocco has not been accepted by the scientific community and is considered a single *nomen nudum*. Further, no Mars mission has found traces of biomolecules.



An artist's concept of the Phoenix spacecraft.

Phoenix lander, 2008

The Phoenix mission landed a robotic spacecraft in the polar region of Mars on May 25, 2008 and it operated until November 10, 2008. One of the mission's two primary objectives was to search for a 'habitable zone' in the Martian regolith where microbial life

could exist, the other main goal being to study the geological history of water on Mars. The lander has a 2.5 meter robotic arm that was capable of digging shallow trenches in the regolith. There is an electrochemistry experiment which analysed the ions in the regolith and the amount and type of antioxidants on Mars. The Viking program data indicate that oxidants on Mars may vary with latitude, noting that Viking 2 saw fewer oxidants than Viking 1 in its more northerly position. Phoenix landed further north still. Phoenix's preliminary data revealed that Mars soil contains perchlorate, and thus may not be as life-friendly as thought earlier. The pH and salinity level were viewed as benign from the standpoint of biology. The analysers also indicated the presence of bound water and CO₂.

Future missions

- Mars Science Laboratory, a NASA project planned for launch in late 2011, will contain instruments and experiments designed to look for past or present conditions relevant to biological activity.
- ExoMars is a European-led multi-spacecraft programme currently under development by the European Space Agency (ESA) and NASA for launch in 2016 and 2018. Its primary scientific mission will be to search for possible biosignatures on Mars, past or present. Two rovers with a 2 m core drill each will be used to sample various depths beneath the surface where liquid water may be found and where microorganisms might survive cosmic radiation.
- Mars Sample Return Mission — The best life detection experiment proposed is the examination on Earth of a soil sample from Mars. However, the difficulty of providing and maintaining life support over the months of transit from Mars to Earth remains to be solved. Providing for still unknown environmental and nutritional requirements is daunting. Should dead organisms be found in a sample, it would be difficult to conclude that those organisms were alive when obtained.

Meteorites

NASA maintains a catalog of 34 Mars meteorites. These assets are highly valuable since they are the only physical samples available of Mars. Studies conducted by NASA's Johnson Space Center show that at least three of the meteorites contain potential evidence of past life on Mars, in the form of microscopic structures resembling fossilized bacteria (so-called biomorphs). Although the scientific evidence collected is reliable, its interpretation varies. To date, none of the original lines of scientific evidence for the hypothesis that the biomorphs are of exobiological origin (the so-called biogenic hypothesis) have been either discredited or positively ascribed to non-biological explanations.

Over the past few decades, seven criteria have been established for the recognition of past life within terrestrial geologic samples. Those criteria are:

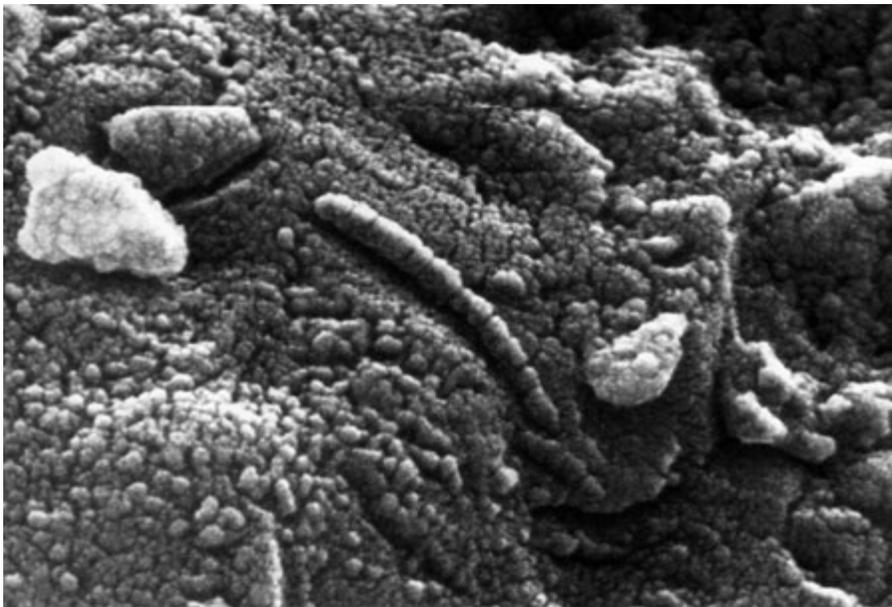
1. Is the geologic context of the sample compatible with past life?

2. Is the age of the sample and its stratigraphic location compatible with possible life?
3. Does the sample contain evidence of cellular morphology and colonies?
4. Is there any evidence of biominerals showing chemical or mineral disequilibrium?
5. Is there any evidence of stable isotope patterns unique to biology?
6. Are there any organic biomarkers present?
7. Are the features indigenous to the sample?

For general acceptance of past life in a geologic sample, essentially most or all of these criteria must be met. All seven criteria have not yet been met for any of the Martian samples, but continued investigations are in progress.

As of 2010, reexaminations of the biomorphs found in the three Martian meteorites are underway with more advanced analytical instruments than previously available. The scientists conducting the study at Johnson Space Center believed that before the end of the year they would find in the meteorites definitive evidence for past life on Mars.

ALH84001 meteorite



An electron microscope reveals bacteria-like structures in meteorite fragment ALH84001

The ALH84001 meteorite was found on December 1984 on Antarctica, by members of the ANSMET project; the meteorite weighs 1.93 kilograms (4.3 lb). The sample was ejected from Mars about 17 million years ago and spent 11,000 years in or on the Antarctic ice sheets. Composition analysis by NASA revealed a kind of magnetite that on Earth, is only found in association with certain microorganisms; Then, in August 2002, another NASA team led by Thomas-Keptra published a study indicating that 25% of the magnetite in ALH 84001 occurs as small, uniform-sized crystals that, on Earth, is associated only with biologic activity, and that the remainder of the material appears to be normal inorganic magnetite. The extraction technique did not permit determination as

to whether the possibly biological magnetite was organized into chains as would be expected. The meteorite displays indication of relatively low temperature secondary mineralization by water and show evidence of preterrestrial aqueous alteration. Evidence of polycyclic aromatic hydrocarbons (PAHs) have been identified with the levels increasing away from the surface.

Some structures resembling the mineralized casts of terrestrial bacteria and their appendages (fibrils) or by-products (extracellular polymeric substances) occur in the rims of carbonate globules and preterrestrial aqueous alteration regions. The size and shape of the objects is consistent with Earthly fossilized nanobacteria, but the existence of nanobacteria itself is controversial.

In November 2009, NASA scientists said that a recent, more detailed analysis showed that the meteorite "contains strong evidence that life may have existed on ancient Mars".



Nakhla meteorite

Nakhla Meteorite

The Nakhla meteorite fell on Earth on June 28, 1911 on the locality of Nakhla, Alexandria, Egypt.

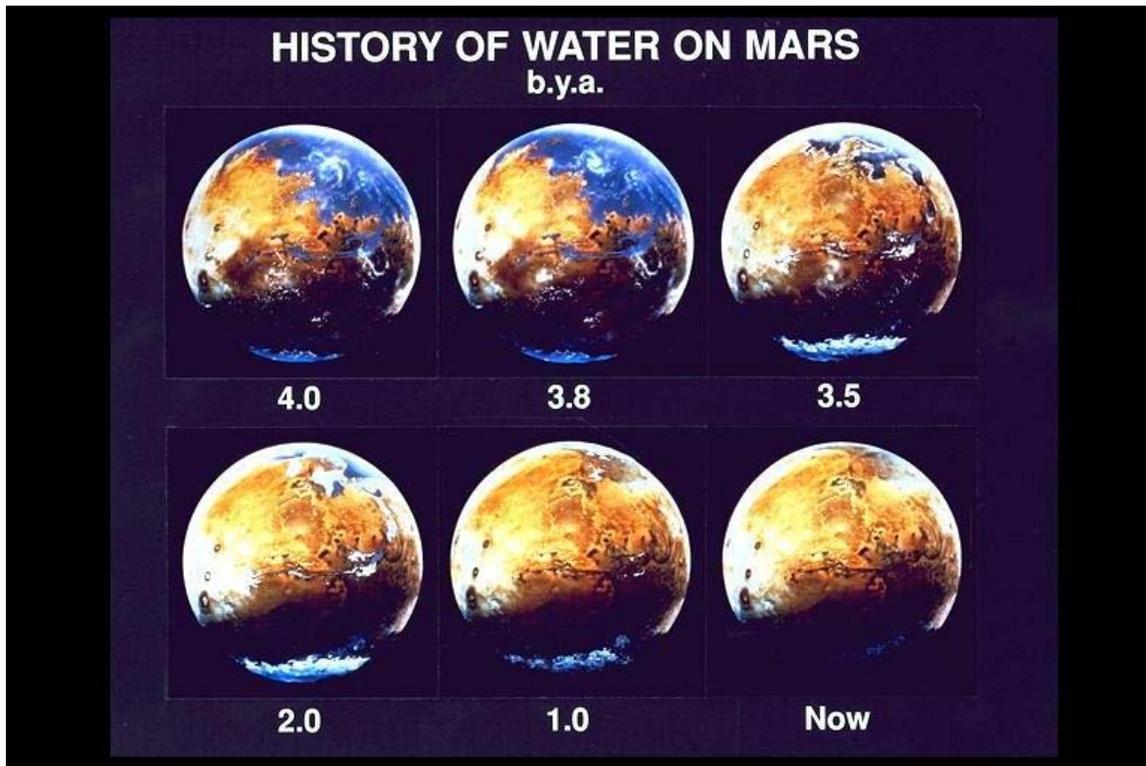
In 1998, a team from NASA's Johnson Space Center obtained a small sample for analysis. Researchers found preterrestrial aqueous alteration phases and objects of the size and shape consistent with Earthly fossilized nanobacteria, but the existence of nanobacteria itself is controversial. Analysis with gas chromatography and mass spectrometry (GC-MS) studied its high molecular weight polycyclic aromatic hydrocarbons in 2000, and NASA scientists concluded that as much as 75% of the organic matter in Nakhla "may not be recent terrestrial contamination".

This caused additional interest in this meteorite, so on 2006, NASA managed to obtain an additional and larger sample from the London Natural History Museum. On this second sample, a large dendritic carbon content was observed. When the results and evidence were published on 2006, some independent researchers claimed that the carbon deposits are of biologic origin. However, it was remarked that since carbon is the fourth most abundant element in the Universe, finding it in curious patterns is not indicative or suggestive of biological origin.

Shergotty meteorite

The Shergotty meteorite, a 4 kg martian meteorite, fell on Earth on Shergotty, India on August 25, 1865 and was retrieved by witnesses almost immediately. This meteorite is relatively young, calculated to have been formed in Mars only 165 million years ago from volcanic origin. It is composed mostly of pyroxene and thought to have undergone preterrestrial aqueous alteration for several centuries. Certain features in its interior suggest to be remnants of biofilm and their associated microbial communities. Work is in progress on searching for magnetites within alteration phases.

Liquid water



A series of artist's conceptions of hypothetical past water coverage on Mars.

No Mars probe since Viking has tested the Martian regolith specifically for metabolism which is the ultimate sign of current life. NASA's recent missions have focused on another question: whether Mars held lakes or oceans of liquid water on its surface in the ancient past. Scientists have found hematite, a mineral that forms in the presence of water. Thus, the mission of the Mars Exploration Rovers of 2004 was not to look for present or past life, but for evidence of liquid water on the surface of Mars in the planet's ancient past.

Since Mars lost most of its magnetic field about 4 billion years ago, the Martian ionosphere is unable to stop the solar wind or radiation, and it interacts directly with exposed soil, making life, as we know it, impossible to exist. Also, liquid water, necessary for life and for metabolism, cannot exist on the surface of Mars under its present low atmospheric pressure and temperature, except at the lowest shaded elevations for short periods and liquid water does not appear at the surface itself.

In June 2000, evidence for water currently under the surface of Mars was discovered in the form of flood-like gullies. Deep subsurface water deposits near the planet's liquid core might form a present-day habitat for life. However, in March 2006, astronomers announced the discovery of similar gullies on the Moon, which is believed never to have had liquid water on its surface. The astronomers suggest that the gullies could be the result of micrometeorite impacts.

In March 2004, NASA announced that its rover *Opportunity* had discovered evidence that Mars was, in the ancient past, a wet planet. This had raised hopes that evidence of past life might be found on the planet today. ESA confirmed that the Mars Express orbiter had directly detected huge reserves of water ice at Mars' south pole in January 2004.

On July 28, 2005, ESA announced that they had recorded photographic evidence of surface water ice near Mars' North pole.

In December 2006, NASA showed images taken by the Mars Global Surveyor that suggested that water occasionally flows on the surface of Mars. The images did not actually show flowing water. Rather, they showed changes in craters and sediment deposits, providing the strongest evidence yet that water coursed through them as recently as several years ago, and is perhaps doing so even now. Some researchers were skeptical that liquid water was responsible for the surface feature changes seen by the spacecraft. They said other materials such as sand or dust can flow like a liquid and produce similar results.

Recent analysis of Martian sandstones, using data obtained from orbital spectrometry, suggests that the waters that previously existed on the surface of Mars would have had too high a salinity to support most Earth-like life. Tosca *et al.* found that the Martian water in the locations they studied all had water activity, $a_w \leq 0.78$ to 0.86 —a level fatal to most Terrestrial life. Haloarchaea, however, are able to live in hypersaline solutions, up to the saturation point.

The Phoenix Mars lander from NASA, which landed in the Mars Arctic plain in May 2008, confirmed the presence of frozen water near the surface. This was confirmed when bright material, exposed by the digging arm of the lander, was found to have vaporized and disappeared in 3 to 4 days. This has been attributed to sub-surface ice, exposed by the digging and sublimated on exposure to the atmosphere.

Methane

Trace amounts of methane in the atmosphere of Mars were discovered in 2003 and verified in 2004. The presence of methane indicates, as it is an unstable gas, that there must be an active source on the planet in order to keep such levels in the atmosphere. It is estimated that Mars must produce 270 ton/year of methane, but asteroid impacts account for only 0.8% of the total methane production. Although geologic sources of methane such as serpentinization are possible, the lack of current volcanism, hydrothermal activity or hotspots are not favorable for geologic methane. It has been suggested that the methane was produced by chemical reactions in meteorites, driven by the intense heat during entry through the atmosphere. However, research published in December 2009, ruled out this possibility.

The existence of life in the form of microorganisms such as methanogens are among possible but as yet unproven sources. If microscopic Martian life is producing the

methane, it likely resides far below the surface, where it is still warm enough for liquid water to exist.

Since the 2003 discovery of methane in the atmosphere, some scientists have been designing models and *in vitro* experiments testing growth of methanogenic bacteria on simulated Martian soil, where all four methanogen strains tested produced substantial levels of methane, even in the presence of 1.0wt% perchlorate salt. The results reported indicate that the perchlorates discovered by the Phoenix Lander would not rule out the possible presence of methanogens on Mars.

A team led by Levin suggested that both phenomena—methane production and degradation—could be accounted for by an ecology of methane-producing and methane-consuming microorganisms.

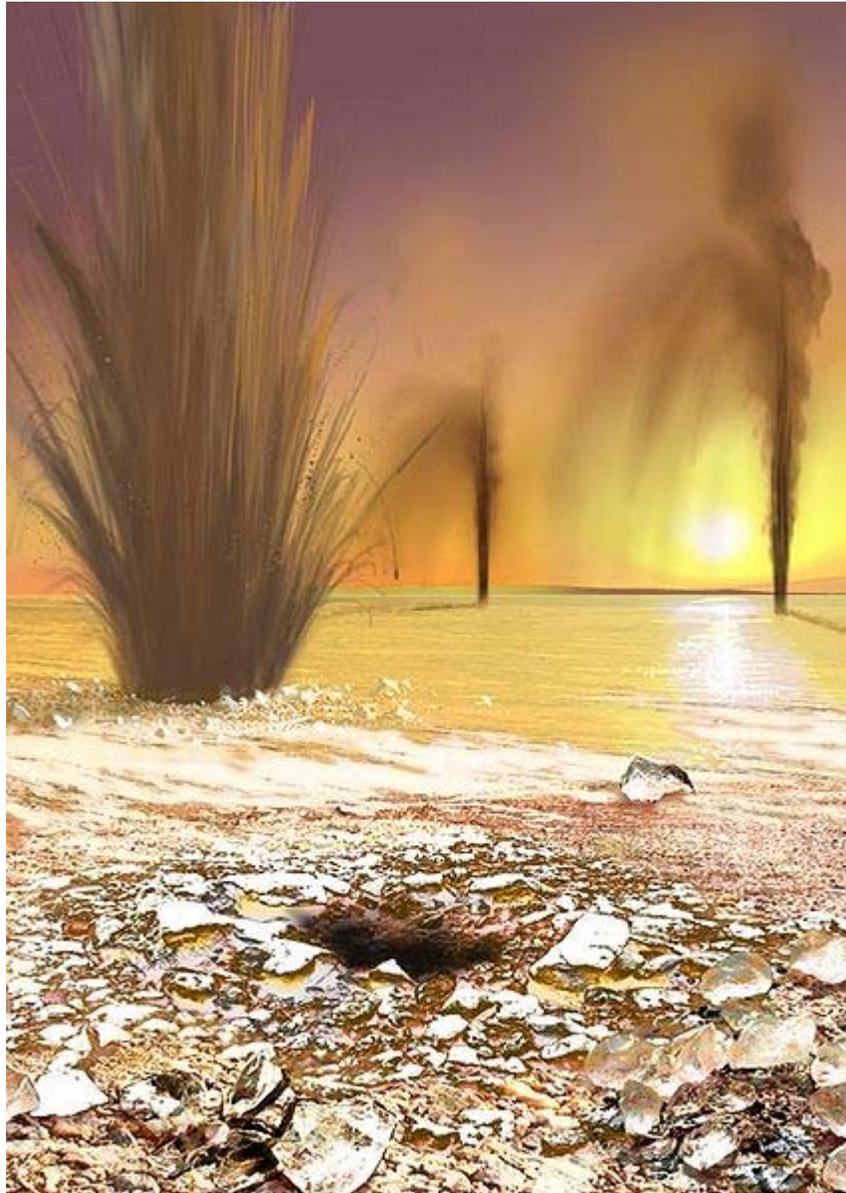
Formaldehyde

In February 2005, it was announced that the Planetary Fourier Spectrometer (PFS) on the European Space Agency's Mars Express Orbiter, detected traces of formaldehyde in the atmosphere of Mars. Vittorio Formisano, the director of the PFS, has speculated that the formaldehyde could be the byproduct of the oxidation of methane, and according to him, would provide evidence that Mars is either extremely geologically active, or harbouring colonies of microbial life. NASA scientists consider the preliminary findings are well worth a follow-up, but have also rejected the claims of life.

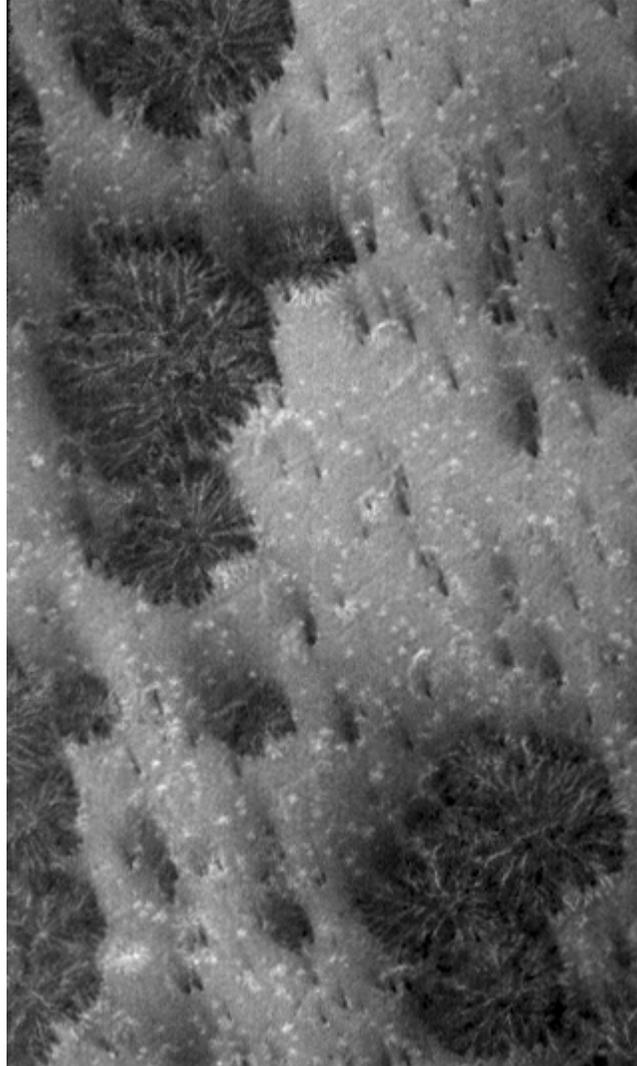
Silica

In May 2007, the Spirit rover disturbed a patch of ground with its inoperative wheel, uncovering an area extremely rich in silica (90%). The feature is reminiscent of the effect of hot spring water or steam coming into contact with volcanic rocks. Scientists consider this as evidence of a past environment that may have been favorable for microbial life, and theorize that one possible origin for the silica may have been produced by the interaction of soil with acid vapors produced by volcanic activity in the presence of water. Another possible origin could have been from water in a hot spring environment.

Geysers on Mars



Artist concept showing sand-laden jets erupt from geysers on Mars.



Close up of dark dune spots, likely created by cold geyser-like eruptions.

The seasonal frosting and defrosting of the southern ice cap results in the formation of spider-like radial channels carved on 1 meter thick ice by sunlight. Then, sublimed CO₂ - and probably water- increase pressure in their interior producing geyser-like eruptions of cold fluids often mixed with dark basaltic sand or mud. This process is rapid, observed happening in the space of a few days, weeks or months, a growth rate rather unusual in geology - especially for Mars.

A team of Hungarian scientists propose that the geysers' most visible features, dark dune spots and spider channels, may be colonies of photosynthetic Martian microorganisms, which over-winter beneath the ice cap, and as the sunlight returns to the pole during early spring, light penetrates the ice, the microorganisms photosynthesise and heat their immediate surroundings. A pocket of liquid water, which would normally evaporate instantly in the thin Martian atmosphere, is trapped around them by the overlying ice. As this ice layer thins, the microorganisms show through grey. When it has completely

melted, they rapidly desiccate and turn black surrounded by a grey aureole. The Hungarian scientists believe that even a complex sublimation process is insufficient to explain the formation and evolution of the dark dune spots in space and time. Since their discovery, fiction writer Arthur C. Clarke promoted these formations as deserving of study from an astrobiological perspective.

A multinational European team suggests that if liquid water is present in the spiders' channels during their annual defrost cycle, they might provide a niche where certain microscopic life forms could have retreated and adapted while sheltered from solar radiation. A British team also considers the possibility that organic matter, microbes, or even simple plants might co-exist with these inorganic formations, especially if the mechanism includes liquid water and a geothermal energy source. However, they also remark that the majority of geological structures may be accounted for without invoking any organic "life on Mars" hypothesis.

Cosmic radiation

In 1965, the Mariner 4 probe discovered that Mars had no global magnetic field that would protect the planet from potentially life-threatening cosmic radiation and solar radiation; observations made in the late 1990s by the Mars Global Surveyor confirmed this discovery. Scientists speculate that the lack of magnetic shielding helped the solar wind blow away much of Mars's atmosphere over the course of several billion years.

In 2007, it was calculated that DNA and RNA damage by cosmic radiation would limit life on Mars to depths greater than 7.5 metres below the planet's surface. Therefore, the best potential locations for discovering life on Mars may be at subsurface environments that have not been studied yet.

Chapter- 8

Mars to Stay

Mars to Stay is the proposal that astronauts sent to Mars for the first time should stay there indefinitely, both to reduce mission cost and to ensure permanent settlement of Mars. Among many other notable Mars to Stay advocates, former Apollo astronaut Buzz Aldrin has been particularly outspoken, suggesting in numerous forums "Forget the Moon, Let's Head to Mars!" The Mars Underground, Mars Homestead Foundation, and Mars Artists Community have also adopted Mars to Stay policy initiatives. The earliest formal outline of a Mars to Stay mission architecture was given at the Case for Mars VI Workshop in 1990, during a presentation by George Herbert titled "One Way to Mars."



Concept for NASA Design Reference Mission Architecture 5.0 (2009)

Proposals

Original Aldrin Plan

Under a Mars to Stay mission architecture the first humans to travel to Mars would be composed of a six-person team. After this initial landing subsequent missions over five

years will raise the number of persons on the Martian surface to 30, thereby beginning an organically evolving Martian settlement. Since the Martian surface offers all the natural resources and elements necessary to sustain human society—unlike, for example the moon—a permanent Martian settlement is thought to be the most effective way to ensure humankind becomes a space-faring, multi-planet species. Through the use of digital fabricators and in vitro fertilization it is assumed a permanent human settlement on Mars can grow organically from an original thirty to forty pioneers.

A Mars exploration program following Aldrin's Mars to Stay initiative would enlist astronauts in the following timeline:

- Age 30: an offer to help settle Mars is extended to select pioneers
- Age 30-35: training and social conditioning for long-duration isolation and time-delay communications
- Age 35: launch three married couples to Mars; followed in subsequent years by a dozen or more couples
- Age 35-65: development of sheltered underground living spaces; artificial insemination ensures genetic diversity
- Age 65: an offer to return to Earth or retire on Mars is given to first generation settlers

As Aldrin has said, "...who knows what advances will have taken place. The first generation can retire there, or maybe we can bring them back."

"Hundred Year Starship Initiative"

On October 2010 NASA Ames Research Center Director Pete Worden introduced the Hundred Year Starship initiative, a project to embark on a one-way mission from Earth to Mars by 2030. The astronauts would be sent supplies from Earth on a regular basis. The mission is planned to take place no earlier than 2030. Controversy immediately arose over the name of the enterprise, given that Mars settlement could have begun within five years of the announcement -- rather than portrayed as an exotic "100 year" fantasy.

"To Boldly Go: A One-Way Human Mission to Mars," Journal of Cosmology

The October-November, 2010, Journal of Cosmology reprinted an article by Dirk Schulze-Makuch (Washington State University) and Paul Davies (Arizona State University) from the book "The Human Mission to Mars. Colonizing the Red Planet." Highlights of their mission plan are:

- No base on the Moon is needed. Given the broad variety of resources available on Mars, the long-term survival of Martian settlers is much more feasible than Lunar settlers.
- Since Mars affords neither an ozone shield nor magnetospheric protection, robots would prepare a basic modular base inside near-surface lava tubes and ice caves for the human settlers.

- A volunteer signing up for a one-way mission to Mars would do so with the full understanding that he or she will not return to Earth; Mars exploration would proceed for a long time on the basis of outbound journeys only.
- The first human contingent would consist of a crew of four, ideally (if budget permits) distributed between two two-man spacecraft for mission redundancy.
- Over time humans on Mars will increase with follow-up missions. Several subsurface biospheres would be created until there were 150+ individuals in a viable gene pool. Genetic engineering would further contribute to the health and longevity of settlers.

Initial and permanent settlement

Initial explorers leave equipment in orbit and at landing zones scattered considerable distances from the main settlement. Subsequent missions therefore are assumed to become easier and safer to undertake, with the likelihood of back-up equipment being present if accidents in transit or landing occur.

Large subsurface, pressurized habitats would be the first step toward human settlement; as Dr. Robert Zubrin suggests in the first chapter of his book *Mars Direct* these structures can be built as Roman-style atria in mountainsides or underground with easily produced Martian brick. During and after this initial phase of habitat construction, hard-plastic radiation- and abrasion-resistant geodesic domes could be deployed on the surface for eventual habitation and crop growth. Nascent industry would begin using indigenous resources: the manufacture of plastics, ceramics and glass could be easily achieved.

The longer-term work of terraforming Mars requires an initial phase of global warming to release atmosphere from the Martian regolith and to create a water-cycle. There would be no cost issue associated to terraforming as it would be in the best interest of settlers to make sure that their daily activities positively influence the improvement of the environment. Three methods of global warming are described by Zubrin, who suggests they are best deployed in tandem: orbital mirrors to heat the surface; factories on the ground to pump halocarbons into the atmosphere; and the seeding of bacteria which can metabolize water, nitrogen and carbon to produce ammonia and methane (these gases would aid in global warming). While the work of terraforming Mars is on-going, robust settlement of Mars can continue.

The Case for Mars acknowledges any Martian colony will be partially Earth-dependent for centuries. However, Zubrin suggests Mars may be profitable for two reasons. First, it may contain concentrated supplies of metals equal to or of greater value than silver, which have not been subjected to millennia of human scavenging; it is suggested such ores may be sold on Earth for profit. Secondly, the concentration of deuterium—an extremely expensive but essential fuel for the nuclear power industry—is five times greater on Mars. Humans emigrating to Mars, under this paradigm, thus have an assured industry; it is assumed the planet will be a magnet for settlers as wage costs will be high. Because of the labor shortage on Mars and its subsequent high pay-scale, Martian

civilization and the value placed upon each individual's productivity is proposed as a future engine of both technological and social advancement.”

Risks



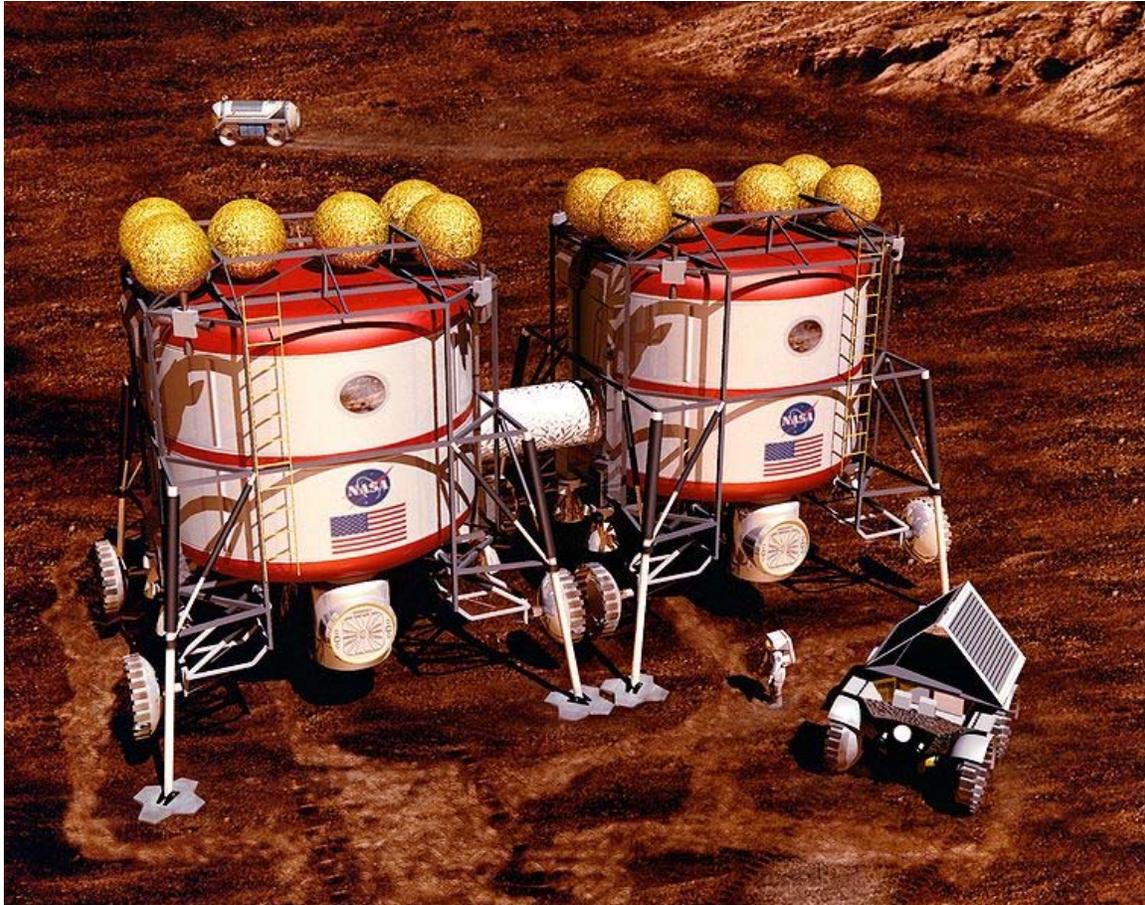
Artist's conception of a human mission on Mars
1989 painting by Les Bossinas of Lewis Research Center for NASA

In the fifth chapter of "Mars Direct", Zubrin dismisses the idea that radiation and zero-gravity are unduly hazardous. He claims that cancer rates *do* increase for astronauts who have spent extensive time in space, but only marginally. Similarly, while zero-gravity presents challenges, near total recovery of musculature and immune system vitality is assumed once on the Martian surface. Back-contamination — humans acquiring and spreading Martian viruses — is described as "just plain nuts", because there are no host organisms on Mars for disease organisms to have evolved.

In the same chapter, Zubrin decisively denounces and rejects suggestions that the Moon should be used as waypoint to Mars or as a preliminary training area. "It is ultimately much easier to journey to Mars from low Earth orbit than from the moon and using the latter as a staging point is a pointless diversion of resources." While the Moon may superficially appear a good place to perfect Mars exploration and habitation techniques, the two bodies are radically different. The moon has no atmosphere, no analogous geology and a much greater temperature range and rotational period of illumination. It is argued Antarctica, desert areas of Earth, and precisely controlled chilled vacuum

chambers on easily accessible NASA centers on Earth provide much better training grounds at lesser cost.

Public reception



Artist's conception of a Mars Habitat
1993 by John Frassanito and Associates for NASA

"Should the United States space program send a mission to Mars, those astronauts should be prepared to stay there," said Lunar astronaut Buzz Aldrin during a high-profile, widely reported interview on "Mars to Stay" initiatives. The time and expense required to send astronauts to Mars, argues Aldrin, "warrants more than a brief sojourn, so those who are on board should think of themselves as pioneers. Like the Pilgrims who came to the New World or the families who headed to the Wild West, they should not plan on coming back home." While the Moon is a shorter trip of two or three days, according to Mars advocates, it offers virtually no potential for independent settlements. Studies have found that Mars, on the other hand, has vast reserves of frozen water, all of the basic elements, and more closely mimics both gravitational and illumination conditions on Earth. "It is easier to subsist, to provide the support needed for people there than on the Moon." In an interview with reporters, the second man to set foot on the Moon said the Red Planet offered far greater potential than Earth's satellite as a place for habitation.

"If we are going to put a few people down there and ensure their appropriate safety, would you then go through all that trouble and then bring them back immediately, after a year, a year and a half?" Aldrin asks. "They need to go there more with the psychology of knowing that you are a pioneering settler and you don't look forward to go back home again after a couple of years," he said.

The most comprehensive statement of a rationale for "Mars to Stay" was laid out by Dr. Aldrin in a May 2009 Popular Mechanics article, as follows:

"The agency's current Vision for Space Exploration will waste decades and hundreds of billions of dollars trying to reach the moon by 2020—a glorified rehash of what we did 40 years ago. Instead of a steppingstone to Mars, NASA's current lunar plan is a detour. It will derail our Mars effort, siphoning off money and engineering talent for the next two decades. If we aspire to a long-term human presence on Mars—and I believe that should be our overarching goal for the foreseeable future—we must drastically change our focus. Our purely exploratory efforts should aim higher than a place we've already set foot on six times. In recent years my philosophy on colonizing Mars has evolved. I now believe that human visitors to the Red Planet should commit to staying there permanently. One-way tickets to Mars will make the missions technically easier and less expensive and get us there sooner. More importantly, they will ensure that our Martian outpost steadily grows as more homesteaders arrive. Instead of explorers, one-way Mars travelers will be 21st-century pilgrims, pioneering a new way of life. It will take a special kind of person. Instead of the traditional pilot/ scientist/engineer, Martian homesteaders will be selected more for their personalities—flexible, inventive and determined in the face of unpredictability. In short, survivors."

The Mars Artists Community has adopted Mars to Stay as their primary policy initiative. During a 2009 public hearing of the U.S. Human Space Flight Plans Committee at which Dr. Robert Zubrin presented a summary of the arguments in book *The Case for Mars*, dozens of placards reading "Mars Direct Cowards Return to the Moon" were placed throughout the Carnegie Institute. The passionate uproar among space exploration advocates - both favorable and critical - resulted in the Mars Artists Community creating several dozen more designs, with such slogans as, "Traitors Return to Earth" and "What Would Zheng He Do?"

In October 2009, Eric Berger of the Houston Chronicle wrote of 'Mars to Stay' as perhaps the only program which can revitalize America's space program:

"What if NASA could land astronauts on Mars in a decade, for not ridiculously more money than the \$10 billion the agency spends annually on human spaceflight? It's possible, say some space buffs, although there's a catch. The astronauts we'd send would never come home. Relieving NASA of the need to send fuel and rocketry to blast humans off the Martian surface, which has slightly more than twice the gravity of the moon, would actually reduce costs by about a factor of 10, by some estimates."

Hard Science Fiction writer Mike Brotherton has found "Mars to Stay" appealing for both economic and safety reasons, but more emphatically, as a fulfillment of the ultimate mandate by which "our manned space program is sold, at least philosophically and long-term, as a step to colonizing other worlds." Two thirds of the respondents to a poll on his website expressed interest in a one-way ticket to Mars "if mission parameters are well-defined" (not suicidal).

In June 2010 Buzz Aldrin gave an interview to Vanity Fair in which he restated Mars to Stay:

"Did the Pilgrims on the Mayflower sit around Plymouth Rock waiting for a return trip? They came here to settle. And that's what we should be doing on Mars. When you go to Mars, you need to have made the decision that you're there permanently. The more people we have there, the more it can become a sustaining environment. Except for very rare exceptions, the people who go to Mars shouldn't be coming back. Once you get on the surface, you're there."

The October-November, 2010, Journal of Cosmology reprinted an article by Dirk Schulze-Makuch (Washington State University) and Paul Davies (Arizona State University) from the book "The Human Mission to Mars. Colonizing the Red Planet." The following summarizes their rationale for Mars to Stay:

"A human mission to Mars is technologically feasible, but hugely expensive requiring enormous financial and political commitments. A creative solution to this dilemma would be a one-way human mission to Mars in place of the manned return mission that remains stuck on the drawing board. Our proposal would cut the costs several fold but ensure at the same time a continuous commitment to the exploration of Mars in particular and space in general. It would also obviate the need for years of rehabilitation for returning astronauts, which would not be an issue if the astronauts were to remain in the low-gravity environment of Mars. We envision that Mars exploration would begin and proceed for a long time on the basis of outbound journeys only."

"New York Times" op-eds

"Mars to Stay" has been explicitly proposed by two op-ed pieces in the "New York Times".

"A One-Way Ticket to Mars" Krauss, Lawrence. New York Times Op-Ed, Sept 1, 2009:"

Following a similar line of argument to Buzz Aldrin, Lawrence Krauss asks in an Op-Ed, "Why are we so interested in bringing the Mars astronauts home again?". While the idea of sending astronauts aloft never to return may be jarring upon first hearing, the rationale for one-way exploration and settlement trips has both historical and practical roots. For example, colonists and pilgrims seldom set off to the New World with the expectation of

a return trip. As Lawrence Krauss writes, "To boldly go where no one has gone before does not require coming home again."

Dr. Krauss modifies the standard "Mars to Stay" architecture by "restricting the voyage to older astronauts, whose longevity is limited. Here again, I have found a significant fraction of scientists older than 65 who would be willing to live out their remaining years on the red planet or elsewhere." This initial first generation of elderly astronauts would accept higher radiation doses while building eventual subsurface habitats, presumably, because the effects of increased radiation would not affect them during the remainder of their lives.

"If it sounds unrealistic to suggest that astronauts would be willing to leave home never to return alive, then consider the results of several informal surveys I and several colleagues have conducted recently. One of my peers in Arizona recently accompanied a group of scientists and engineers from the Jet Propulsion Laboratory on a geological field trip. During the day, he asked how many would be willing to go on a one-way mission into space. Every member of the group raised his hand." Krauss, Lawrence. New York Times Op-Ed "A One-Way Ticket to Mars"

Additional immediate and pragmatic reasons to consider one-way human space exploration missions are explored by Krauss. Since much of the cost of a voyage to Mars will be spent on coming home again, if the fuel for the return is carried onboard, this greatly increases the mission mass requirement - which in turn requires even more fuel. "Human space travel is so expensive and so dangerous" according to Krauss, "we are going to need novel, even extreme solutions if we really want to expand the range of human civilization beyond our own planet." Delivering food and supplies to pioneers via unmanned spacecraft is less expensive than designing an immediate return trip.

"Life (and Death) on Mars," Davies, Paul. New York Times Op-Ed, January 15, 2004:"

In an earlier 2004 Op-Ed for the New York Times, Paul Davies motivation for the less expensive, permanent "one-way to stay option" arises from a theme common in "Mars to Stay" advocacy: "Mars is one of the few accessible places beyond Earth that could have sustained life [...and] alone among our sister planets, it is able to support a permanent human presence."

"Why is going to Mars so expensive? Mainly it's the distance from Earth. At its closest point in orbit, Mars lies 35 million miles away from us, necessitating a journey of many months, whereas reaching the Moon requires just a few days' flight. On top of this, Mars has a surface gravity that, though only 38 percent of Earth's, is much greater than the Moon's. It takes a lot of fuel to blast off Mars and get back home. If the propellant has to be transported there from Earth, costs of a launching soar. Without some radical improvements in technology, the prospects for sending astronauts on a round-trip to Mars any time soon are slim, whatever the presidential rhetoric. What's more, the president's suggestion of using the Moon as a base — a place to assemble equipment and produce

fuel for a Mars mission less expensively — has the potential to turn into a costly sideshow. There is, however, an obvious way to slash the costs and bring Mars within reach of early manned exploration. The answer lies with a one-way mission."

Under Davies' plan an initial colony of four astronauts equipped with a small nuclear reactor and a couple of rover vehicles would make their own oxygen, grow food, and even initiate building projects using local raw materials. Supplemented by food shipments, medical supplies, and replacement gadgets from Earth, the colony would be indefinitely sustained. Davies argues that since, "some people gleefully dice with death in the name of sport or adventure [and since] dangerous occupations that reduce life expectancy through exposure to hazardous conditions or substances are commonplace," we ought to not find the risks involved in a Mars to Stay architecture unusual.

"A century ago, explorers set out to trek across Antarctica in the full knowledge that they could die in the process, and that even if they succeeded their health might be irreversibly harmed. Yet governments and scientific societies were willing sponsors of these enterprises." Asks Davies, "Why should it be different today?"

Chapter- 9

ExoMars

ExoMars

Operator	ESA, NASA
Mission type	Orbiter, lander and 2 rovers
Orbital insertion date	2017 and 2019
Launch date	2016 and 2018 from Florida, USA
Launch vehicle	Two Atlas V rockets.
Mission duration	Few days for the static lander; 6 months for the ExoMars rover, one year for the MAX-C rover.
Homepage	ExoMars programme
Mass	TGM: 3,130 kg; Lander: 600 kg; ExoMars rover: 270 kg; MAX-C rover: 65 kg.
Power	Solar power

ExoMars (Exobiology on Mars) is a European-led robotic mission to Mars currently under development by the European Space Agency (ESA) and NASA. Originally conceived as a rover with a static ground station, ExoMars was planned to launch in 2011 aboard a Soyuz Fregat rocket. Within the framework of the new Mars Joint Exploration Initiative signed by NASA and ESA in July 2009, the drastically delayed ExoMars mission was combined with other projects to a multi-spacecraft programme divided over two Atlas V-launches: the Mars Trace Gas Orbiter (TGM) was merged into the project,

piggybacking a static meteorological lander being slated for launch in 2016. In 2018 the original robotic ESA-rover will be launched, possibly together with a smaller NASA rover called Mars Astrobiology Explorer-Cacher (MAX-C).

Background and mission history



An outdated ExoMars rover model at the ILA 2006 in Berlin



Another outdated representation of the rover from the Paris Air Show 2007

Since its beginnings in the early 2000s, ExoMars was subject to massive political and financial strife. Originally, the ExoMars concept consisted of one single, large robotic rover being part of ESA's Aurora programme as a *Flagship mission* and was approved by Europe's space ministers in December 2005. Initially planned to launch in 2011, Italy, a leading nation on the ExoMars mission, decided to limit its financial contribution, causing the first of three delays.

In 2007 Canadian-based technology firm MacDonald, Dettwiler and Associates Ltd. (MDA) announced that it has won a one-million-euro contract with EADS Astrium of Britain to design and build a prototype Mars rover chassis for the European Space Agency, which will be used in the upcoming ExoMars mission. Astrium is also contracted to design the final rover itself.

In July 2009 NASA and ESA agreed upon a new Mars Joint Exploration Initiative, significantly altering the technical and financial setting of the ExoMars mission. On June 19, when the rover was still planned to piggyback on the Mars Trace Gas Orbiter, it was reported, that a prospective agreement would require that ExoMars lose enough weight to fit aboard the Atlas vehicle with NASA's orbiter.

In August 2009 it was announced that the Russian Space Agency Roscosmos and ESA had signed a collaboration agreement that includes cooperation on two Mars exploration projects: Russia's Phobos-Grunt project and ESA's ExoMars. Specifically, ESA secured a

Russian Proton rocket as a backup launcher for the ExoMars rover, which should also include Russian-made parts.

In October 2009 it was reported that under the agreed Mars Joint Exploration Initiative, the mission will be split into two parts: a lander/orbiter mission in 2016 and a rover mission in 2018, each with a significant NASA role, including the use of two Atlas V rockets. This initiative would apparently reconcile technological and science goals with available budgets.

On December 17, 2009, the ESA governments gave their final approval to a two-part Mars exploration programme to be conducted with NASA, confirming their commitment to spend €850 million (\$1.23 billion) on missions in 2016 and 2018. Another €150 million needed for operating the mission will be solicited during a meeting of ESA government ministers in late 2011 or early 2012. Unlike some ESA programmes, the ExoMars financing will not include a 20 % margin for cost overruns, however.

Mission objectives

The ExoMars mission's scientific objectives, in order of priority, are:

- to search for possible biosignatures of Martian life, past or present.
- to characterise the water and geochemical distribution as a function of depth in the shallow subsurface.
- to study the surface environment and identify hazards to future manned missions to Mars.
- to investigate the planet's subsurface and deep interior to better understand the evolution and habitability of Mars.
- achieve incremental steps ultimately culminating in a sample return flight.

The technological objectives to develop are:

- landing of large payloads on Mars.
- to exploit solar electric power on the surface of Mars.
- to access the subsurface with a drill able to collect samples down to a depth of two metres (just below the degrading reach of UV light, oxidants and ionizing radiation.)
- to develop surface exploration capability using a rover.

Mission architecture

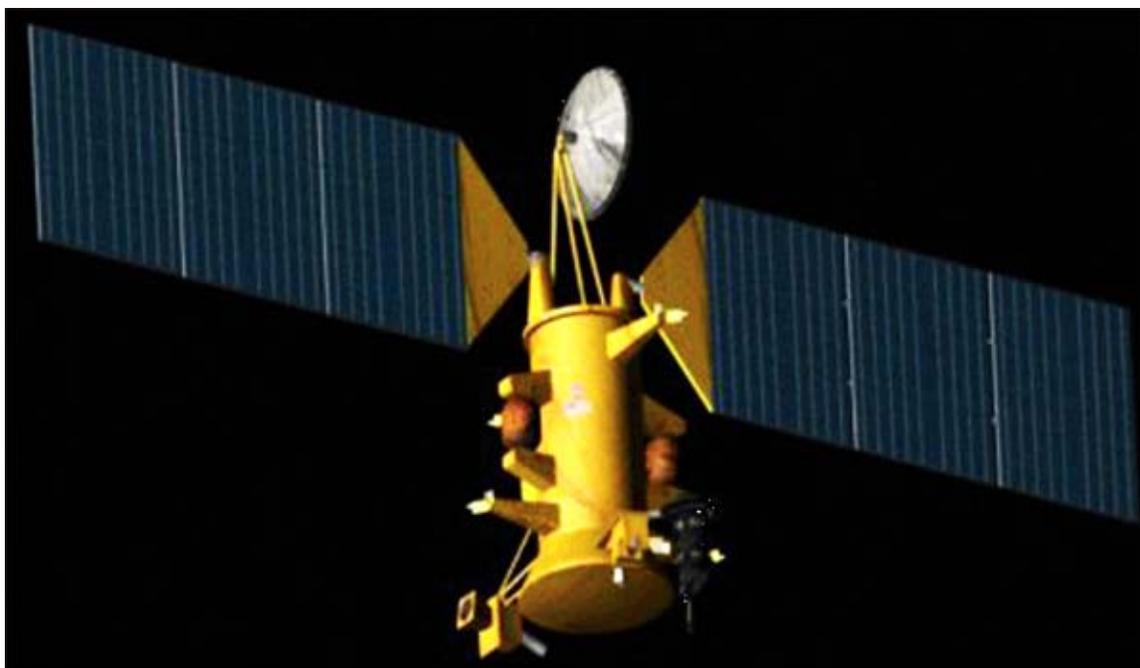
According to current plans, the ExoMars mission will comprise three, possibly four, spacecraft elements sent in two launches, both from Florida:

Contributing agency	First launch in 2016	Second launch in 2018
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	Launch vehicle: Atlas V 411	Launch vehicle: Atlas V 551
	One unspecified TGM-payload	Landing system: Sky-crane
		65 kg Mars Astrobiology Explorer-Cacher (Max-C)-rover
	Trace Gas Mission (TGM) orbiter	270 kg ExoMars rover
	600 kg static meteorological lander	
	Entry, descent and landing system (EDL)	

2016 launch

Mars Trace Gas Mission orbiter



The Mars Trace Gas Orbiter.

The Mars Trace Gas Mission (TGM) orbiter, to be launched on January 2016, will deliver the ExoMars static lander (a meteorological station) and then proceed to map the sources of methane on Mars and other gases, and in doing so, help select the landing site for the ExoMars rover to be launched on 2018. The presence of methane in Mars' atmosphere is intriguing because its likely origin is either present-day life or geological activity. Upon the arrival of the rover(s) in 2018/2019, the orbiter would be transferred

into a suitable lower orbit where it would be able to perform analytical science activities as well as operate as a data-relay satellite. Its operation may be extended to serve future missions well into the 2020s.

Static lander

Originally, this static lander was planned to carry a group of eleven instruments collectively called the "Humboldt payload" that would be dedicated to investigate the geophysics of the deep interior, but a payload confirmation review in the first quarter of 2009 resulted in a severe descope of the lander instruments, and the Humboldt geophysical suite of lander instruments was cancelled entirely. Although the recent partnership with NASA and the decision to launch all mission elements with two rockets has generated new payload reviews, it was decided to first demonstrate ESA's new descent and landing system technology on the lander, so its payload will be very limited.

The Entry, Descent and Landing Demonstrator Module (EDM) will provide Europe with the technology for landing on the surface of Mars with a controlled landing orientation and touchdown velocity. After entering the Martian atmosphere, the module will deploy a parachute and will complete its landing by using a closed-loop Guidance, Navigation and Control system based on a Radar Doppler Altimeter sensor and on-board Inertial Measurement Units. The latter will guide a liquid propulsion system which will produce a semi-soft touchdown on the surface of Mars by the actuation of clusters of thrusters to be operated in pulsed on-off mode.

The EDM lander is expected to survive on the surface of Mars for a short time (about 8 sols) by using the excess energy capacity of its batteries. Its proposed landing site is the Meridiani Planum because it is almost flat and without too many rocks, ideal for its airbag landing system.

2018 launch

Current plans call for the use of NASA's sky crane entry, descent and landing (EDL) system to deliver both rovers together on the surface of Mars.

If there will be two rovers delivered to the same location on Mars, Their science objectives and instruments will be complementary in order to minimise duplication. Advantages of operating two rovers in the same area are: rover to rover imaging, cross analysis of similar geological targets, may include a low-frequency ground-penetrating radar on MAX-C and listen with WISDOM on ExoMars to construct rover to rover subsurface transects, and the MAX-C could receive and cache some of the most valuable subsurface samples collected by ExoMars.

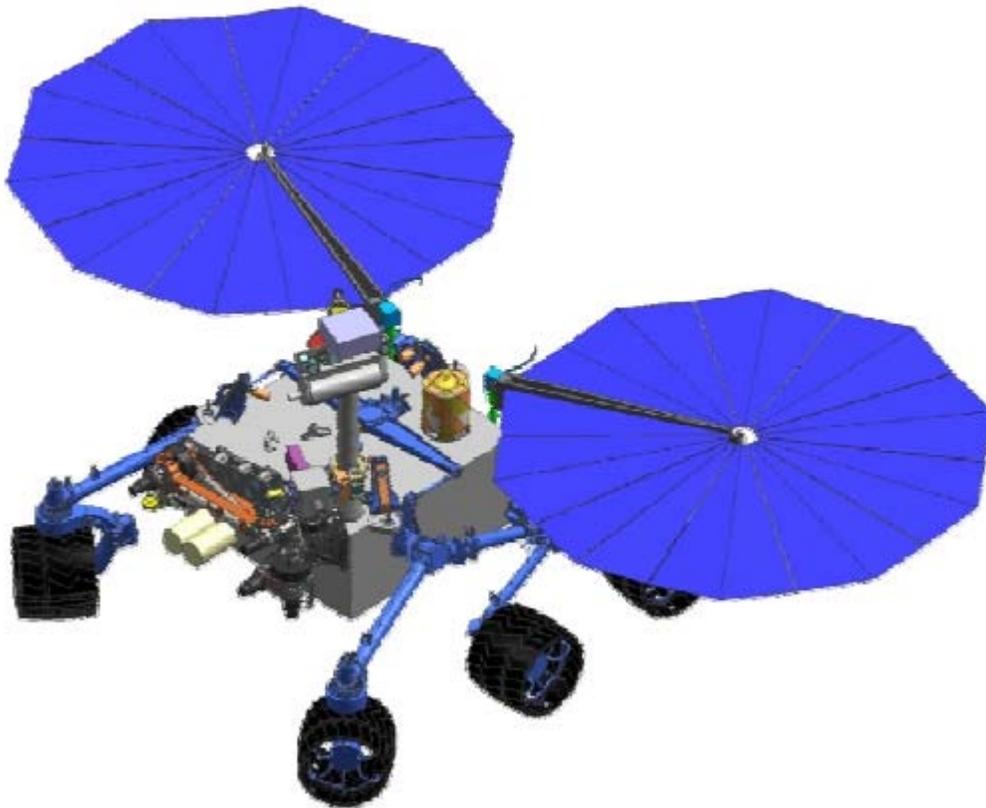
ExoMars rover

The ExoMars rover is a highly autonomous six-wheeled terrain vehicle and will weigh 270 kg, ca. 100 kg more than NASA's Mars Exploration Rovers *Spirit* and *Opportunity*.

Temporary plans considered a downsized version with a reduced weight of 207 kg. Instrumentation will consist of the 10 kg 'Pasteur Payload' containing, among other instruments, a 2 meter sub-surface drill.

The carrier module will deliver the descent module to Mars from a hyperbolic approach trajectory after which the Sky-crane landing system will ensure a soft landing with high accuracy. Once safely landed on the Martian surface the solar powered rover would begin a 180-sol (6 months) mission. To counter the difficulty of remote control due to communication lag, ExoMars will have autonomous software for visual terrain navigation using compressed stereo images from mast mounted panoramic and infrared cameras and independent maintenance. For this purpose it creates digital maps from navigation stereo pair cameras and autonomously finds the adequate trajectory. Close-up collision avoidance cameras are used to ensure safety enabling the vehicle to navigate and safely travel approximately 100 meters per day. After the lander has been released and landed on the surface of Mars, the Mars Trace Gas Orbiter will operate as the rover's data-relay satellite.

MAX-C rover



Schematic depiction of the proposed Mars Astrobiology Explorer-Cacher (MAX-C)-Rover

The current proposal is that ExoMars may be joined by a slightly smaller NASA rover; this additional rover may be the Mars Astrobiology Explorer-Cacher (MAX-C). The fact

that for the first time two rovers will be active at the same location is expected to lead to synergies, such as bistatic radar surveys between the two rovers. The MAX-C rover would collect, analyse, and cache the most valuable samples in a manner suitable for return to Earth by a future mission.

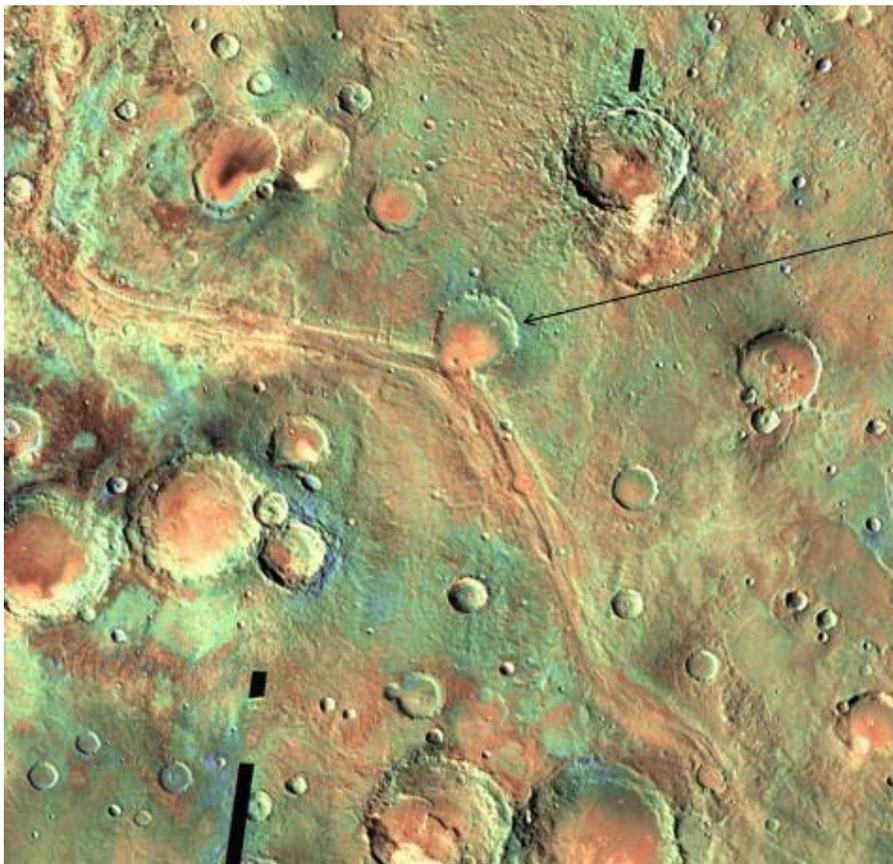
Launch vehicle

Under the agreed collaboration, NASA will provide two Atlas V rockets, as it was decided to divide the weight of the ExoMars system in two launches.

ESA has already worked out a framework agreement with the Russian Space Agency that would allow it to cooperate on ExoMars, including provision of backup launch services and a payload contribution, along with mission support. The backup launcher is the Proton rocket, which is a four-stage rocket that was previously used to launch the Salyut 6, Salyut 7, Mir and some International Space Station components.

Landing system and proposed landing sites

If the collaboration with NASA takes place as proposed, it would be possible to implement NASA's new sky crane entry and descent system, as used on the Mars Science Laboratory rover.



Twenty four mile wide crater may have held a lake.

Mawrth Vallis with its potential clues on the history of water on Mars is a landing site-candidate.

As of November 2007, the potential landing sites are:

- Mawrth Vallis
- Nili Fossae
- Meridiani Planum
- Holden Crater
- Gale Crater

However, the 2009 discovery of methane sources on the planet makes them a high value target for exploration. The presence of methane is intriguing because its likely origin is either present-day life or geological activity; confirmation of either would be a major discovery. Methane occurs in extended plumes, and the profiles imply that the methane was released from discrete regions. The profiles suggest that there may be two local source regions, the first centered near 30° N, 260° W and the second near 0°, 310° W. To determine the optimal landing site and secure telecommunications, it was decided to include the Mars Trace Gas Mission orbiter in the 2016 launch in order to map beforehand what appears to be seasonal methane production. The rover could then investigate the methane sources identified by the orbiter.

Instrumentation of the ExoMars rover

The present environment on Mars is exceedingly hostile for the widespread proliferation of surface life: it is too cold and dry and receives large doses of solar UV radiation as well as cosmic radiation. Notwithstanding these hazards, basic microorganisms may still flourish in protected places underground or within rock cracks and inclusions. The science package in the ExoMars rover will hold a variety of instruments to study the environment for past or present habitability and possible biosignatures on Mars. The first instrument proposal (2004) is as follows:

Imaging system

The **Panoramic Camera System (PanCam)** has been designed to perform digital terrain mapping for the rover and to search for morphological signatures of past biological activity preserved on the texture of surface rocks. The PanCam assembly includes two wide angle cameras for multi-spectral stereoscopic panoramic imaging, and a high resolution camera for high-resolution colour imaging. The PanCam will also support the scientific measurements of other instruments by taking high-resolution images of locations that are difficult to access, such as craters or rock walls, and by supporting the selection of the best sites to carry out exobiology studies.

Drill

The ExoMars core drill is devised to acquire soil samples down to a maximum depth of 2 metres, in a variety of soil types. The drill will acquire a core sample (1 cm in diameter x 3 cm in length), extract it and deliver it to the inlet port of the Rover Payload Module, where the sample will be distributed, processed and analyzed. The ExoMars Drill embeds the Mars Multispectral Imager for Subsurface Studies (Ma-Miss) which is a miniaturised IR spectrometer devoted to the borehole exploration. The system will complete experiment cycles and at least 2 vertical surveys down to 2 metres (with four sample acquisitions each). This means that a minimum number of 17 samples shall be acquired and delivered by the drill for subsequent analysis.

Analytical laboratory instruments

These instruments are placed internally and used to study collected samples:

- **Mars Organic Molecule Analyzer (MOMA)** consists of a laser desorption ion source and a GC-MS spectrometry. The laser desorption ion source is capable to evaporate organic molecules even if they are not volatile, while the GC separates the highly volatile small molecules within the gas chromatograph. The final analysis of both instruments is done with an ion trap mass spectrometer.
- **Infrared imaging spectrometer (MicrOmega-IR)** is an infrared imaging spectrometer that can analyse the powder material derived from crushing samples collected by the drill. Its objective is to study mineral grain assemblages in detail to try to unravel their geological origin, structure, and composition. These data will be vital for interpreting past and present geological processes and environments on Mars. Because MicrOmega-IR is an imaging instrument, it can also be used to identify grains that are particularly interesting, and assigned them as targets for Raman and MOMA-LDMS observations.
- **Mars X-Ray Diffractometer (Mars-XRD)** - Powder diffraction of X-Rays will give exact composition of the crystalline minerals. This instrument includes also an X-ray fluorescence capability that can provide useful atomic composition information.
- **Raman spectrometer (Raman)** will provide geological and mineralogical context information complementary to that obtained by MicrOmega-IR. It is a very useful technique employed to identify mineral phases produced by water-related processes.
- **Ground-penetrating radar, called WISDOM** (for Water Ice and Subsurface Deposit Information On Mars) will explore the subsurface of Mars to identify layering and help select interesting buried formations from which to collect samples for analysis. It can transmit and receive signals using two, small Vivaldi-antennas mounted on the aft section of the rover. Electromagnetic waves

penetrating into the ground are reflected at places where there is a sudden transition in the electrical parameters of the soil. By studying these reflections it is possible to construct a stratigraphic map of the subsurface and identify underground targets down to 2 to 3 m depth, comparable to the 2-m reach of the rover's drill. These data, combined with those produced by the PanCam and by the analyses carried out on previously collected samples, will be used to support drilling activities.

- **Mars Multispectral Imager for Subsurface Studies (Ma-MISS)** is an infrared spectrometer located inside the drill. Ma-MISS will observe the lateral wall of the borehole created by the drill to study the subsurface stratigraphy, to understand the distribution and state of water-related minerals, and to characterize the geophysical environment. The analyses of unexposed material by Ma-MISS, together with data obtained with the spectrometers located inside the rover, will be crucial for the unambiguous interpretation of the original conditions of Martian rock formation.

Autonomous navigation

The ExoMars Rover is designed to navigate autonomously across the surface. A pair of stereo cameras allow the Rover to build up a 3D map of the terrain, which the Navigation software then uses to assess terrain around it so that it avoids obstacles and find the most efficient route.