INDIA'S MARS ORBITER MISSION

Anand Narayanan

It was a proud moment for India, when the Indian Space Research Organisation launched the Mars Orbiter Mission (MOM), the first one ever to successfully position a satellite in an orbit around Mars. Why Mars? What makes this planet more special than our other neighbours in the solar system? What do we hope to learn from exploring another planet? This article explores some of these questions on interplanetary explorations, while also building an understanding of space science in practice.

Introduction

On September 24, 2014, India crossed a major milestone in space exploration. India's first interplanetary mission, MOM, entered into orbit around Mars, putting the Indian Space Research Organization (ISRO) in the same league as the American, European and Russian space agencies, the only ones ever to have accomplished a similar feat.

ISRO described MOM, and its journey of 650 million kilometres, as a technology demonstrator mission and not so much as a science mission. India had never done it before. Technologically more advanced countries, like Japan and China, had attempted, but failed, in placing a satellite in orbit around another planet.

Interplanetary travel is a tricky venture. Designing a trajectory for an eventual encounter with a planet at a distance of a million kilometres from us is no minor task. The fact that we are on a moving launch platform (the Earth), with the target also moving relative to us, increases the complexity of the trajectory calculations involved.

With the success of MOM, and the earlier Chandrayaan mission, ISRO has demonstrated its technological capability for deep space communication and navigation. Along with that, it has also established the reputation of the Polar Satellite Launch Vehicle (PSLV) as a trustworthy carrier of satellites for interplanetary travel.

There are many scientific lessons one can learn from the success of this single mission. This article features a few of those.

1. Why Mars?

From the point of view of distance from the Earth, Venus is closer to us than Mars. Why then did ISRO pick Mars over Venus for its maiden interplanetary mission?

There are two main reasons for this:

1. From a scientific exploration point of view, Earth shares more with Mars than it does with Venus. Mars, thus, provides plenty of opportunities to understand the geological and biological processes that could have shaped the evolution of Mars as well as Earth. Mars also presents an excellent case to search for life outside of Earth.
2. Compared to Venus, it is easier to gather information about the terrain and surface features of Mars from a high altitude orbit.

1.1 An Earth Sibling of the Past

The most compelling reason for investigating Mars is that in many ways in its past, Mars had a close semblance to Earth. Also, Mars rotates once around its axis in approximately the same 24 hour duration as Earth. This means that the day and night cycle on Mars is similar to Earth.

Like Earth, Mars also has seasons, because its spin axis is tilted at an angle of 25 degrees. When it is winter in one of the poles, ice forms and grows in size. During summer when there is more direct sunlight for longer durations, this ice cap melts.

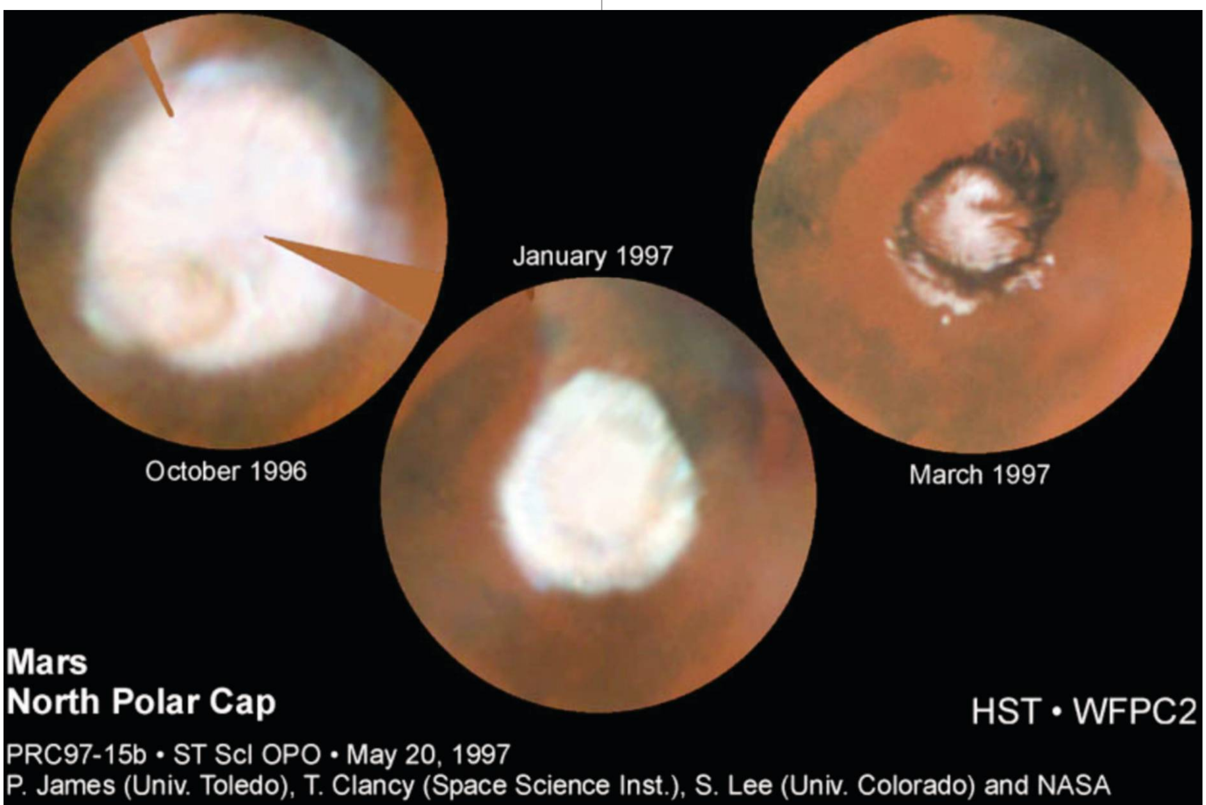
The following image of Mars was taken by the Hubble Space Telescope. It shows how ice caps on the North Pole of Mars grow and recede with winter and summer seasons.

nearly one-third of the Martian surface could very well have been covered with oceans.

The obvious question then is **where did all this water go?**

There are no definitive answers, although the small size of the planet could be a major reason for Mars's global transformation - from a warm and wet planet to the cold, dry environment that we see today.

Mars, presently, has a very thin atmosphere, mostly composed of carbon dioxide (CO_2) gas. The atmosphere is so thin that the pressure on the surface of Mars is only about 1/1000th the atmospheric pressure at sea-level on Earth. But the circumstances may have been quite different in the past.



Mars currently has a dry surface, but there are many pieces of geological evidence on this planet that suggest that there was once liquid water flowing over it. Satellite images show winding channels at several locations on the planet. The winding channels look very much like dried up river beds, lake deltas and gullies carved by flowing water. Geologists hypothesize that the climatic conditions on Mars were, at some time in the distant past, suitable for liquid water. In fact,

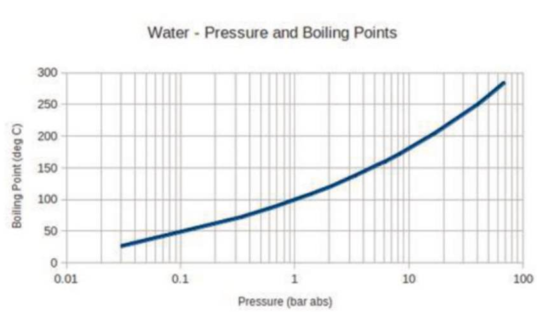
It is most likely that Mars had a dense CO_2 atmosphere (a greenhouse gas) in the past, which kept the temperatures on its surface high enough for water to exist in liquid form. Over time, the strong impact of solar winds (the constant stream of charged particles from the Sun travelling at speeds of several hundreds of kilometres in one second), must have slowly eroded the gases from the Martian atmosphere. Being a small planet, Mars had a very weak magnetic field, insufficient to shield the planet from the charged particles of the solar wind, in the way that the Earth's magnetic field shields our own atmosphere. Furthermore, the low surface gravity of Mars meant that it could not hold onto gases as they gradually drifted out into space.

For a visual account of the atmospheric loss processes, watch the NASA Goddard videos at *https://www.youtube.com/watch?v=ogcaSmofPo4* *Https://www.youtube.com/watch?v=0_iz5Nt0Qc8*

How is Atmosphere Loss measured?

By measuring the ratio of abundance of deuterium to hydrogen (D/H), scientists are trying to estimate the rate at which Mars is currently losing whatever is remaining of its atmosphere. Deuterium, being twice as heavy as hydrogen, will be lost at a slower rate compared to hydrogen. By starting from a realistic assumption of the initial D/H ratio in the Martian atmosphere and by measuring the current value for this ratio, the past rate of atmospheric loss can be assessed.

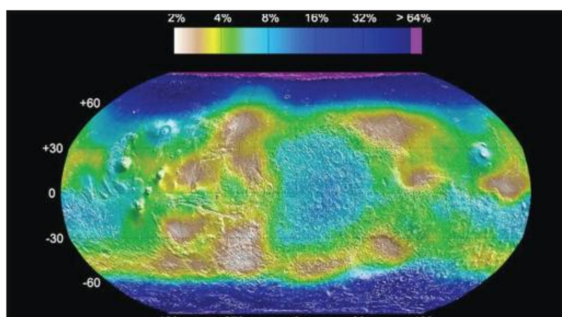
As the density of the atmosphere lowered, water in liquid form would have directly been converted into vapour. The temperature at which water turns from liquid to vapour phase, called its boiling point, is pressure dependant, as shown in the graph below. As the atmospheric pressure on Mars dropped, its ambient temperatures were high enough to evaporate the water on its surface. All the water vapour produced in this way gradually escaped into outer space.



From ice to vapour avoiding liquid

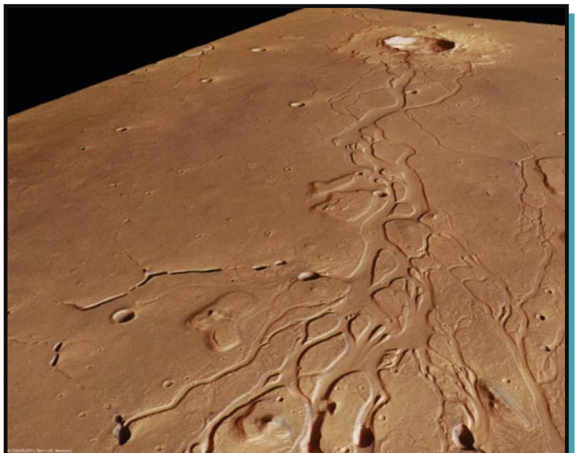
The temperature at which ice turns into water is called the melting point of water, and the temperature at which water turns into vapour is called its boiling point. Both these temperatures of phase transition depend on the ambient atmospheric pressure. Under low pressure conditions, both the melting and the boiling point will get reduced. Pressure on the surface of Mars is less than 1% of the atmospheric pressure at sea level on Earth. Under these low pressure conditions, as the polar ice caps melt, both the CO2 and H2O in ice are directly converted into their vapour form. This process is known as sublimation.

Although, a good fraction of the surface water on Mars has evaporated, scientists speculate that there may still be substantial reservoirs of water in liquid form several thousand meters below the Martian surface. Significant fractions of this water are in the polar regions of the planet, beyond about 60 degrees latitude north or south, as the next figure shows.



Mars_Water_Map: *This is a global map of the Martian soil showing lower limits on the water content. The estimates are derived from the hydrogen abundance measured by the neutron spectrometer component of the gamma ray spectrometer suite on NASA's Mars Odyssey spacecraft. The highest water-mass fractions, exceeding 30 percent to well over 60 percent, are in the polar regions, beyond about 60 degrees latitude north or south. Credit: NASA*

Water is considered an essential ingredient for the emergence and evolution of life as we know it, here on Earth. Hence, finding water or any evidence for its presence on Mars, has remained a major goal for all Mars missions.



Photograph taken by the Mars Global Surveyor robotic spacecraft which is currently orbiting Mars. On the surface are numerous channels that resemble flow channels on Earth. These marks could be a result of flow of water on Mars in the past. *Photo Credit: JPL, NASA.*

Photograph of Martian surface taken by a high resolution stereo camera onboard European Space Agency's Mars Express. Along with flow channels from water that once flowed on the surface. One can also see some impact craters possibly produced by impact of asteroids with Mars. *Credits: ESA/ DLR/ FU Berlin (G. Neukum).*

1.2 A Bird's Eye View of What is Below

Another reason that makes Mars a compelling target, compared to Venus, is the convenience of collecting information about the terrain and surface features once the spacecraft settles into an orbit around the planet.

Venus has a very dense atmosphere. The pressure from the atmosphere on the surface of Venus is estimated to be about 90-100 times the atmospheric pressure on Earth at sea level. Several layers of dense clouds envelop the surface, like a thick blanket. Instruments on board a spacecraft orbiting the planet from a high altitude will not be able to peer through this opaque covering for a clear bird's eye view. This seriously hampers the scientific possibilities of an orbiter mission.

The atmosphere of Venus is also not favourable for landers (spacecrafts that land on a planet surface). The presence of large amounts of CO2 in Venus's atmosphere has created a strong greenhouse effect on the planet. The average temperature on Venus is 450 degree centigrade, making it the hottest planet in the solar system, hotter than even Mercury. In addition, there are also strong winds that blow at speeds of 300 kilometres per hour and more, which keeps the atmosphere highly turbulent. Under such hostile conditions, it is difficult for the equipment on-board the landers to function properly for any duration.

In comparison, Mars offers a clear view through its wispy atmosphere all the way down to its surface.

The Launch Window

The timing of the launch is a crucial decision controlled by several factors. An ideal launch date is one that requires the least amount of propellant (i.e., rocket fuel) to insert the spacecraft into the planned trajectory. Fuel adds to the weight of the whole mission, and fuel is also expensive.

The direction of launch is an important factor impacting fuel costs. We may naively think that the most efficient way to get to outer space is to launch the rocket directly up from Earth. But a straight line trajectory is a very inefficient way of spending energy.

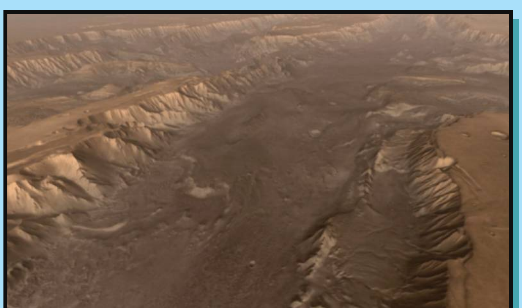
Through its entire journey, the maximum fuel in a rocket is burned out at the very initial stages when the launch vehicle is trying to lift off and speed up away from the Earth's gravitational pull. A great deal of fuel can be conserved at this stage through certain choices.

1. Earth goes around the Sun at a speed of 100,000 kilometres per hour (about 30 km/s). If the launch vehicle can be accelerated in the same direction as Earth's revolution around the

Other Attractions on Mars

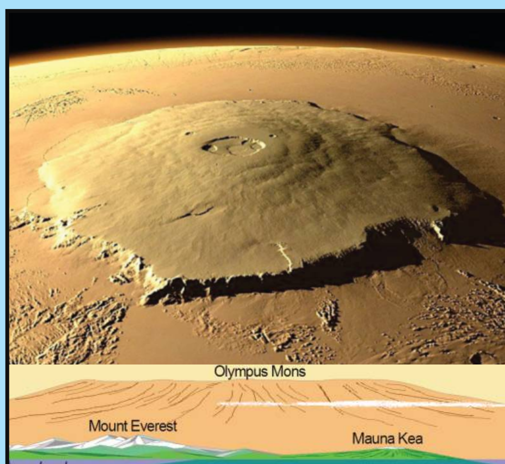
Global Dust Storms: Satellite and telescope observations have shown that large-scale dust storms are a recurring feature on Mars. They develop in a matter of hours and can cover the entire planet in a matter of a few days. Once these dust storms form, because of the low surface gravity of the planet, it takes several weeks for the dust to settle back on the ground. It is not clear, despite a very wispy atmosphere, why the storms become so large or why they last so long on Mars.

Great Canyons: The largest canyon in the solar system is on Mars. Called the Mariner Valley (after the Mariner 9 spacecraft that discovered this valley), this gigantic gorge that runs across the equator of Mars is about 4000 kilometres long, as long as the continent of Asia. This gorge shows many signs of past flooding, including deep channels carved by what could have been water that once gushed from above the chasm.

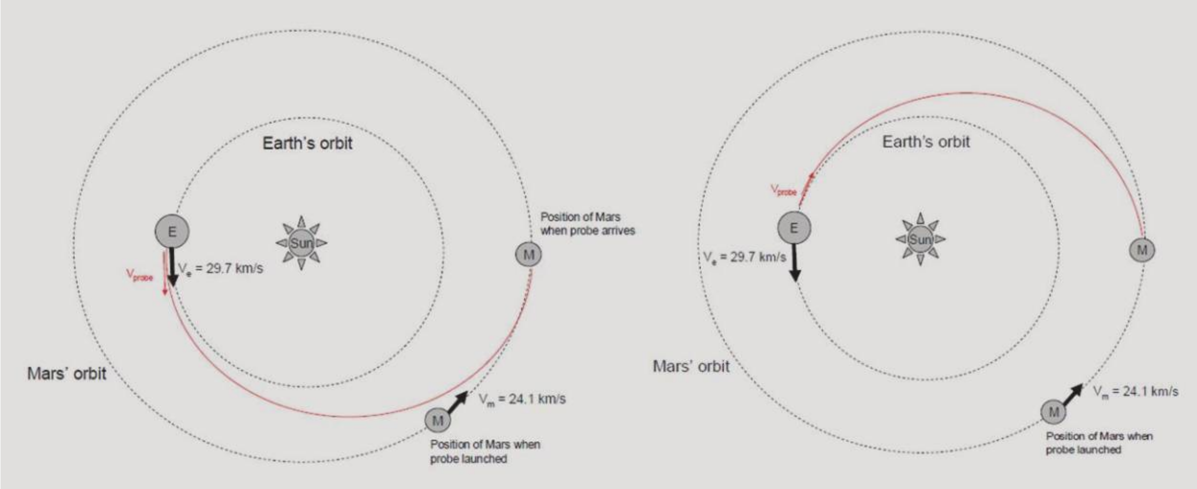


Mars_Mariner_Valley & Mars_Mariner_Valley_artist: The rift region seen along the equator of Mars is the Mariner Valley, the largest canyon in the solar system. The next image is an artist's impression of the Mariner Valley. *Credit: NASA*

Volcanic Mountains: Mars also has the distinction of having the largest known mountain in the solar system. Standing tall with a summit altitude of 22 kilometres and with a base girth of nearly 600 kilometres, Mount Olympus is three times bigger than Mount Everest, the tallest peak on Earth. Mount Olympus is also the tallest among a large number of extinct volcanic mountains on Mars. In addition to these, Mars also has a shield volcano called Olympus Mons. Rather than violently throwing up molten ash and lava, shield volcanoes are created by molten material slowly flowing down their sides.



Mars_Mount_Olympus_1: Mount Olympus, the tallest peak in the solar system, is on Mars. This photograph taken by one of the NASA satellites gives a close-up view of this now extinct volcanic mountain. *Credit: NASA*



Sun, it will give the vehicle a big head start in velocity (just as while jumping off a moving vehicle, we continue to run for some distance in the same direction with some speed).

2. Earth rotates from west to east on its axis. At the equator, Earth's surface is rotating at 1600 kilometres per hour. From an equatorial launching station, if we launch the rocket towards the east, it will get another enhancement in velocity from Earth's rotation.

Thus by launching in the same direction as the Earth's spin and its revolution around the Sun, the launch vehicle can take maximum advantage of these while trying to raise its altitude.

The Launch Vehicle and MOM Payloads

Every satellite or spacecraft requires a launch vehicle, to propel and position the spacecraft into the desired orbit. The launch vehicles are usually unmanned rockets. The Mars Orbiter Mission was launched on the Polar Satellite Launch Vehicle (PSLV). PSLV has four stages to it with propellants that operate at different stages of the flight. The satellite is referred to as the *payload.* In PSLV, the payload is attached to the fourth and the final stage of the rocket (see photograph).

The satellite is enclosed in a heat shield, a protective layer of several materials split into two halves that come together. The heat shield has thermal and acoustic absorption layers padded inside. As the rocket picks up momentum, the parts of the rocket that come into direct contact with the Earth's atmosphere get heated up to several thousands of degrees from friction with the Earth's atmosphere. The shield insulates the satellite from this aerodynamic heating.

Each stage of the rocket burns out, separates and falls off at different times during the rocket's flight. The heat shield with the payload inside is the last to separate from the fourth stage of the PSLV rocket. This separation typically happens about 3 minutes into the flight, when the rocket has climbed to an altitude of 130 kilometres.

Photograph of PSLV-C25, the rocket that carried Mars Orbiter Mission. The rocket has a height of 45 m, a diameter of 3 meters and weighs approximately 300 tonnes. The rocket can deliver payloads of up to 1500 kg weight into geosynchronous orbit. © *ISRO*

Mars Orbiter Mission Spacecraft (covered in gold foil) attached to the 4th stage of PSLV-C25 and ready for heat shield closure. © *ISRO*

The Mars Orbiter Mission has five scientific instruments on-board. These five instruments cover three broad science themes all linked to forge a better understanding of the climate and geology of Mars. The payload instruments and their science objectives are as shown in the table.

1. The Lyman Alpha Photometer, referred to shortly as LAP, has a detector that can sense ultraviolet photons. The instrument has the capability to measure the current deuterium to hydrogen abundance ratio in the Martian atmosphere. This measurement will provide an estimate of how fast Mars is losing its atmosphere.

2. The Martian Exospheric Neutral Composition Analyzer, also called MENCA, is a mass spectrometer equipment that can measure the masses of different molecules in the Martian atmosphere and also analyze the atmosphere's chemical composition.

3. A Methane Sensor for Mars is an instrument to search for the presence of methane molecules in the Martian atmosphere down to concentration levels as low as one part in a billion molecules. Finding methane on Mars could signal the existence of microbial life. A significant fraction of methane on Earth is of biological origin. Certain micro-organisms, called methanogens, produce methane as a result of their metabolism. A similar biotic origin for methane is possible on Mars, if it supports microbial life.

4. A Mars Colour Camera is a 2000 x 2000 pixel array camera that can take high resolution images of the Martian surface at the same energies as normally visible to the human eye. With the camera images, one will be able to see shapes and features on Mars down to a distance scale of 25 kilometres.

5. The Thermal Infrared Imaging Spectrometer's purpose is to map the minerals on Martian surface. It does this by capturing thermal radiation (i.e., heat) emitted by the Martian surface heated by sunlight. The infrared light entering the spectrometer is separated into tiny portions of photon energies and an image is captured at each of those energies.

Conclusion

Mars exploration is an on-going saga. Even as you read this, a cluster of orbiters and robotic rovers are surveying Mars, providing detailed information on Mars's atmosphere, its climate, topography and soil composition, all the while continuing to search for the presence of water and microbial life. Since September 2014, MOM has joined this collective effort.

Of all the planets and minor bodies of the solar system, Earth is the only one that is presently known to harbour life. The process of how our planet evolved into such a safe haven for life is not yet fully understood. An answer to this is likely to come from probing planets like Mars that were once habitable worlds, but have gradually evolved away from it.

To read a great deal more on Mars, visit: *http://mars.nasa.gov/allaboutmars/*

Types of Interplanetary Missions

Interplanetary space-crafts come within one or more of the following three categories: (a) Flyby space-crafts (b) Orbiters (c) Landers

(A) Flyby Space-crafts: are missions that follow an escape trajectory, never to be captured into any planetary orbit. The only opportunity to gather data is when they fly past the objects of interest. Their advantage is that the same spacecraft can be used to acquire information on more than one object (planets, moons, asteroids etc) as long as the spacecraft's trajectory brings it close to the object. The early interplanetary missions were primarily flybys. Voyager 1, 2; Mariner 1 – 10; Pioneer 10 & 11 are all examples.

(B) Orbiters: are space-crafts that enter into an orbit around planets or moons of planets. Many of the later year Mars missions like Mars Global Surveyor, Mars Odyssey, MAVEN all fall in the category of orbiters. ISRO's Chandrayaan and Mars Orbiter Mission belong to this class.

© Landers: are space-crafts which are designed to land on the surface of a planet. Landers are often equipped with cameras to take surface level photographs of the terrain. They also have instruments to carry out in-situ experiments by extracting samples of soil or rock from the surface of the planet. An extension of a lander is a rover, a robotic spacecraft designed to move around and survey a larger area of the planet. Landers are typically deployed from an orbiter. Classic examples are the twin rovers Spirit and Opportunity.

History of Mars Exploration

Human explorations of Mars started way back in the 1960s. In the ten years between 1960 and 1970, there were 12 attempts from the then Soviet Russia and the United States of America. After successive failures, on November 1964, the US spacecraft Mariner 4 became the first spacecraft to successfully flyby Mars.

Since then, these explorations have been a mix of triumphs and let-downs. The following tables offer a timeline summary of the history of Mars explorations. *(Data courtesy: Kiran Mohan, Liquid Propulsion Systems Centre, ISRO)*

Decade	No of Attempts	No of Success/Partial Success	No of Failures
1960s	12	3	9
1970s	11	6 (including 1st orbiter)	5
1980s	2	1	1
1990s	8	3	5
2000s	8	7	1
2010s	3	1	2
Total	**44**	**21 (47%)**	**23(53%)**

1960 – 1970

Mission	Country	Date of Launch	Mission Type	Status
Mars 1M No.1	USSR	10 Oct 1960	Flyby	Launch Failure
Mars 1M No.2	USSR	14 Oct 1960	Flyby	Launch Failure
Mars 2MV-4 No.1	USSR	24 Oct 1960	Flyby	Launch Failure
Mars 1	USSR	1 Nov 1960	Flyby	Some data collected. Lost contact before reaching Mars, flyby at approx. 1,93,000 km
Mars 2MV-3 No.1	USSR	4 Nov 1960	Lander	Failed to leave Earth's orbit

Mission	Country	Date of Launch	Mission Type	Status
Mariner 3	USA	5 Nov 1964	Flyby	Failure during launch disrupted trajectory
Mariner 4	USA	28 Nov 1964	Flyby	Success
Zond 2	USSR	30 Nov 1964	Flyby	Communication lost before Mars transfer
Mariner 6	USA	25 Feb 1969	Flyby	Success
Mariner 7	USA	27 Mar 1969	Flyby	Success
Mars 2M No.521	USSR	27 Mar 1969	Orbiter	Launch Failure
Mars 2M No.522	USSR	2 April 1969	Orbiter	Launch Failure

1970 – 1980

Mission	Country	Date of Launch	Mission Type	Status
Mariner 8	USA	8 May 1971	Orbiter	Launch Failure
Kosmos 419	USSR	10 May 1971	Orbiter	Launch Failure
Mars 2	USSR	19 May 1971	Orbiter, Lander, Rover	Orbiter-Success (27/11/1971) Lander & Rover Crashed on to Mars Surface
Mars 3	USSR	28 May 1971	Orbiter, Lander, Rover	Orbiter-Success (2/12/1971) Lander & Rover partial success as it soft landed, but transmission lost within 15 minutes (First Successful touch down)
Mission	Country	Date of Launch	Mission Type	Status
Mariner 9	USA	30 May 1971	Orbiter	Success (first successful Orbiter 13/11/1971)
Mars 4	USSR	21 July 1973	Orbiter	Close Flyby only
Mars 5	USSR	25 July 1973	Orbiter	Partial Success Entered Orbit but failed within 9 days
Mars 6	USSR	5 August1973	Lander	Partial success. Data returned during descent but not after landing on Mars
Mission	Country	Date of Launch	Mission Type	Status
Mars 7	USSR	9 Aug 1973	Lander	Landing probe separated prematurely; entered a Sun centered orbit. Failure
Viking 1	USA	20 Aug 1975	Orbiter, Lander	Success
Viking 2	USA	9 Sep 1975	Orbiter, Lander	Success

1980 – 1990

Mission	Country	Date of Launch	Mission Type	Status
Phobos 1	USSR	7 July 1988	Orbiter, Lander	Contact Lost during transfer orbit
Phobos 2	USSR	10 July 1988	Orbiter, Landers	Orbiter Successfully entered orbit and returned data Lost contact just before deploying landers

1990 – 2000

Mission	Country	Date of Launch	Mission Type	Status
Mars Observer	USA	25 Sep 1992	Orbiter	Lost contact before arrival on Mars
Mars Global Surveyor	USA	7 Nov1996	Orbiter	Success
Mars 96	USA	16 Nov 1996	Orbiter, Lander, Penetrator	Launch Failure
Mars Pathfinder	USA	4 Dec 1996	Lander, Rover	Success (First successful Rover)
Nozomi (Planet-B)	Japan	3 July 1998	Orbiter	Never Entered Orbit
Mission	Country	Date of Launch	Mission Type	Status
Mars Climate Orbiter	USA	11 Dec 1998	Orbiter	Crashed on surface. Error in the computer program used for correction thrusters
Mars Polar Lander	USA	3 Jan 1999	Lander	Crash landed on surface
Deep Space 2			Hard Landers	

2000 – 2010

Mission	Country	Date of Launch	Mission Type	Status
2001 Mars Odyssey	USA	7 April 2001	Orbiter	Success
Mars Express / Beagle 2	ESA	2 June 2003	Orbiter, Lander	Orbiter Success, Landing failure for Lander
MER-A Spirit	USA	10 June 2003	Rover	Success
MER-B Opportunity	USA	7 July 2003	Rover	Success
Rosetta	ESA	2 March 2004	Gravity assist to comet	Success
Mission	Country	Date of Launch	Mission Type	Status
Mars Reconnaissance Orbiter	USA	12 Aug 2005	Orbiter	Success
Phoenix	USA	4 Aug 2007	Lander	Success
Dawn	USA	7 July 2003	Gravity assist to Vesta	Success

2010 – Till Now

Mission	Country	Date of Launch	Mission Type	Status
Fobos-Grunt	Russia	8 Nov 2011	Lander, Sample Return	Failed to leave Earth orbit. Fell back to Earth
Yinghuo-1	China		Orbiter	
Curiosity	USA	26 Nov 2011	Rover	Success
Mars Orbiter Mission	India	5 Nov 2013	Orbiter	Success
MAVEN	USA	18 Nov 2013	Orbiter	Success

Further Reading

[1] http://www.isro.gov.in/pslv-c25-mars-orbiter-mission - For details on the orbiter mission, the launch vehicle, ground segment operation, and plenty of images from the preparatory stages of the mission.

[2] http://mars.nasa.gov/ - for details on the planet and the history of Mars exploration by NASA.

[3] http://www.marsquestonline.org/ - for a variety of multimedia based learning activities on Mars suitable for school students.

[4] http://phoenix.lpl.arizona.edu/mars101.php - the NASA Phoenix mission site has a detailed write-up on the search for water on Mars and the possibility of finding life.

[5] http://www.jpl.nasa.gov/news/news.php?release=2012-305 - on Curiosity finding evidence water on Mars, finding ancient streambed gravels

Anand Narayanan *teaches astrophysics at the Indian Institute of SpaceScience & Technology. His research is on understanding how baryonic matteris distributed outside of galaxies at large scales. He regularlycontributes to astronomy educational and public outreach activities. Everyso often he likes to travel exploring the cultural history of south India.*