PRESS MAP

Study of the moons of Mars, Phobos and Deimos, at the Royal Observatory of Belgium under the Mars Express Mission

Royal Observatory of Belgium
Av. Circulaire, 3 – Ringlaan 3
B-1180 BRUSSELS, BELGIUM

Contacts:

Pascal Rosenblatt, 02/373.67.30, p.rosenblatt@oma.be
Véronique Dehant, 02/373.02.66, v.dehant@oma.be

Introduction

Mars has two moons: Phobos and Deimos. They were discovered by Asaph Hall in 1877, while astronomers thought that Mars had no satellite. Both moons have asteroid shape, but their origin is still a mystery. Have they been formed in the vicinity of Mars, or formed elsewhere in the solar system and then captured when flying by the planet?

Phobos's study is a particular priority of the “extended” mission of Mars Express. This mission starts in December 2003 and should stop in 2009. It was possible to extend it, so that one can learn more about Phobos, and, by this way, about Mars.

The various probes that have succeeded and are still orbiting today around Mars or will be orbiting around Mars have the objective to study its properties in general, its atmosphere, its surface, its internal composition and the interaction with the interplanetary environment. This will allow in the long-term to better understand the formation process of planets, their evolution and the solar system as a whole.

Exploration of Mars began in 1960 with the launch of a Russian orbiter: ***Marsnick 1***. The United States followed in 1964 with ***Mariner 4***, which transmitted the first images of Mars. From that time, Soviet and U.S. have succeeded in implementing many research projects on this planet. If failures were numerous, other missions have been a great success. We owe, among other things, the first maps of Mars with ***Mariner 9*** mission (launch in 1971) and ***Viking*** (launching two probes ***Viking 1*** and ***2*** in 1975). Another success is the ***Mars Pathfinder*** (1996), probe of 259 pounds with a small automatic rover "Sojourner", which analyzed and photographed the Martian soil near the landing site.

The ***Mars Global Surveyor*** (MGS) orbiter has operated between 1996 and 2006. ***Mars Odyssey*** and ***Mars Reconnaissance Orbiter*** (MRO) still provide a wealth of impressive data still under interpretation. To these two U.S. orbiters a European orbiter, Mars Express, has been added in orbit around Mars since December 25, 2003.

In the past, the ***Viking*** orbiters ***1*** and ***2*** came close for a short time to Phobos and Deimos, providing the first photographs of the surface of these two moons. Two Soviet probes had a specific mission to approach Phobos: ***Phobos 1*** and ***Phobos 2*** (launches in July 1988). ***Phobos 2*** provided new photos of Phobos while contact was lost with ***Phobos 1*** before his arrival near Mars. Today only the ***Mars Express*** probe allows us to get close to Phobos, so as to continue collecting data of this small solar system body.

Why study the moons of Mars?

Main characteristics

Phobos has the look and shape of an asteroid size: 27 x 21.6 x 18.8 km^3, which corresponds to a mean radius of 11 km. Its surface is very dark and has craters of different sizes. The largest, Stickney, (diameter of 10 km) probably created at the impact a redistribution of mass within Phobos.

Deimos is slightly smaller than Phobos (15 x 12.2 x 11 km^3), but it looks like an asteroid as well.

The ***Viking*** missions and especially ***Phobos 2*** were used to make spectrum measurements of sunlight reflected from the surface of these two moons. Scientists have found that these spectra showed similarities with the spectra of the surfaces of some asteroids. However, these spectral measurements are not decisive enough to give the exact composition of the surface of Phobos and Deimos (and by extrapolation of their interior). It's not excluded that the material of these two moons is closer to the rocks constituting the surface of Mars.

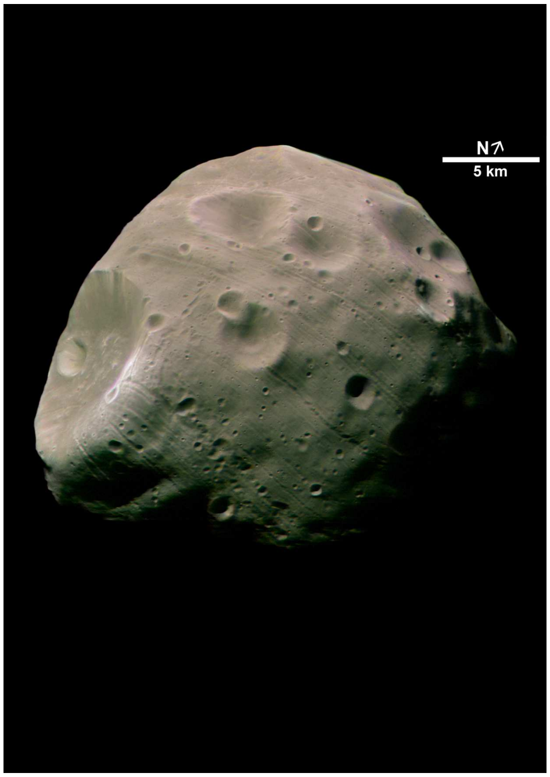
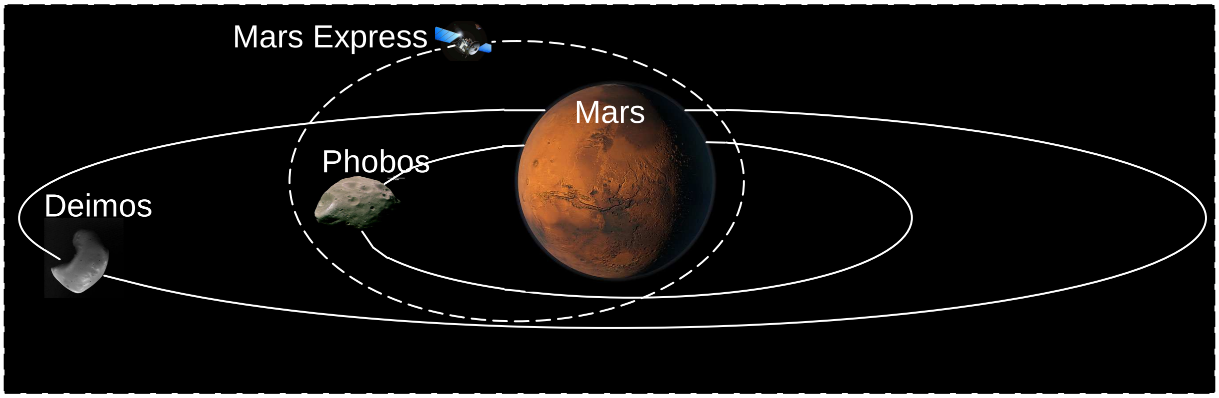


Image of Phobos taken by Mars Express (ESA)

The two moons of Mars orbit on a circular trajectory in the equatorial plane of Mars, but at different distances: Phobos is located at 5978 km from the surface while Deimos is farther away (20059 km). In the solar system, no planet has natural satellite as close Phobos is to Mars.

Phobos is the closest; it makes a complete revolution around Mars in 7 hours 39 minutes and Deimos, in 30 hours 18 minutes.



Mars, its two moons and Mars Express

The trajectories of Phobos and Deimos depend on the gravitational field of Mars. This field may take different values depending on the location above the surface, and varies over time. The most important time-variations are the seasonal ones because the values of the gravitational field depend on the proportion of CO_2 in the atmosphere and condensed in the polar caps. About a quarter of the atmosphere is involved in this seasonal cycle of sublimation and condensation of CO_2.

We observe also diurnal, semi-diurnal and long periodic variations in the trajectory of both moons; these variations are caused by the tides induced by the Sun. Like Earth, Mars is slightly deformed due to the gravitational attraction of the Sun. These deformations cause a slight redistribution of mass within Mars, which, in turn, slightly alters the gravitational field of the planet, and consequently the orbit of the moons. This affects particularly the long-term evolution of these orbits. In particular, it has been calculated that Phobos is approaching Mars at about 20 meters per century and that it should, in about 40 million years, crash on the Martian surface or break under the effect of the tidal forces before reaching the surface. Conversely, Deimos slowly moves away from Mars at a rate of 2 millimeters per year, as the Moon moves away from Earth at a rate of 3 centimeters per year

Scientific goals of the radio-science experiment

The main purpose of the study of Phobos by the instrument of radio-science on board ***Mars Express*** is precisely to determine its mass and later the mass distribution in its interior.

The ***Viking*** and ***Phobos 2*** orbiters were able to determine for the first time the mass of Phobos, when measuring the deflection of the trajectory experienced by the probes during passages near Phobos (flybys). Approximately 17 flybys close to Phobos were made, with a distance between the probes and Phobos between 100 and 300 km. Such passage only lasted 5 minutes. A single flyby near Deimos has been achieved at a distance of only 30 km. ***Mars Express*** is currently the only spacecraft in orbit around Mars capable of flybys close to Phobos.

Since the ***Viking*** or ***Phobos 2*** missions, the technology has advanced and the Doppler shift measurements provided by ***Mars Express*** are ten times more accurate than those realized by the old space probes. It is therefore possible to get the best measurements ever made for the determination of the mass of Phobos especially when the ***Mars Express*** probe flies by at close distance to the moon.

Besides the determination of the mass of Phobos, the precise determination of its volume is also an objective of Mars Express. The calculation of the volume of this body needs to know the precise shape. The stereoscopic camera aboard Mars Express provides and will provide 3D images of the Phobos surface with a resolution better than ever before.

The combination of data from the experience of radio-science MaRS (Mars Radio-Science experiment) for the mass and from the stereoscopic camera for the volume will allow accurately calculation of the mean density of Phobos. This density is presently estimated at 1.85 g /cm3 with an accuracy of 3.2%, which is much less dense than the rock surface in Mars (estimated between 2.7 and 3.3 g/cm^3). The average density of Deimos is estimated at 1.65 g /cm^3 with an accuracy of only 17 %. These low densities are close to those of some asteroids in the solar system and favor the hypothesis that Phobos and Deimos are asteroids captured by the gravitational attraction of Mars and therefore did not form near Mars.

However, the accuracy with which the average density of Phobos is known does not allow us to identify precisely where these asteroids come from in the solar system. In alternative, the low density of Phobos and Deimos may also be explained by the presence of light elements within the body such as water ice or empty spaces between the blocks of material which form the body. Thus, Phobos and Deimos like some asteroids could consist of an aggregate (rubble pile) of material and not a monolith of rock and ice mixed. New more accurate data from ***Mars Express*** will provide further evidence to clarify this issue.

By compiling as much information on Phobos, scientists can try to determine its origin, and what was its evolution. If Phobos has a certain kinship with the asteroids (from its density, its mineralogical composition ...), scientists will be able to deepen the study of asteroids through the moons of Mars.

Indirectly, information about the interior of Mars could be gathered in parallel since the trajectory of Phobos depends on the gravitational field of Mars.

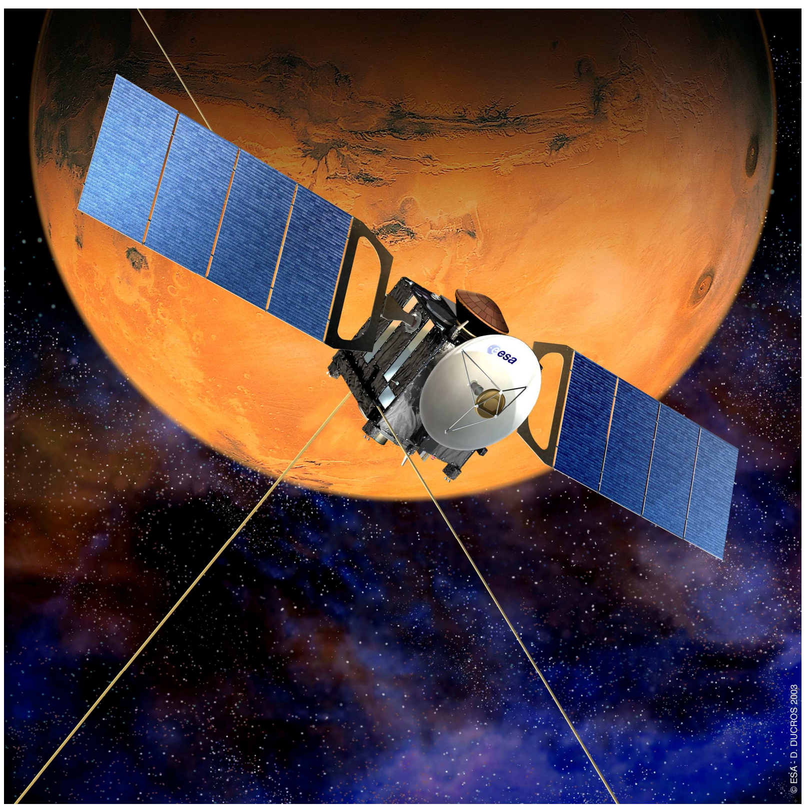
Why Mars Express?

Overview

Mars Express is the first ESA mission to the red planet. It is also the first European mission to any planet. First "flexible-mission"[1] in the scientific program of ESA, it was developed in a record time: it took only 5 years from concept to launch. Taking technology from the ***Mars-96*** missions and ESA's ***Rosetta***, ***Mars Express*** will, once the data will all be collected and processed, answer to fundamental questions asked about the geology of Mars, its atmosphere, its environment, its surface, the history of water and possible life on Mars.

It should be noted that there is close collaboration between the various ongoing missions around Mars. The various instruments on the spacecraft provide different measurements, which complement each other.

The ***Mars Express*** mission was scheduled for a nominal duration of two years, which corresponds to one Martian year (or 687 Earth days). But due to the quality of the initial results, ESA has decided to extend the mission (probably until 2010).



Representation of Mars Express around Mars

1 Flexible-mission: mission relatively cheap and rapidly designed and constructed.

Particularities with respect to the other probes

Three NASA probes are or have recently been in orbit around Mars: ***Mars Global Surveyor (MGS)*** (until 2006), ***Mars Odyssey (ODY)*** and ***Mars Reconnaissance Orbiter (MRO)***. The orbiter ***ODY*** and ***MGS*** have both helped to determine the masses of Phobos and Deimos, but with an accuracy less than the precision obtained by the ***Viking*** flybys and by the analysis of the trajectory of ***Mars Express*** (for the mass of Phobos).

These three NASA probes have a near-polar and near-circular orbit around Mars at an altitude of 400 km for ***MGS*** and ***ODY*** and 285 km for ***MRO***. The orbit of ***Mars Express*** is also near-polar but is much more elongated than those of the NASA probes, covering altitudes between 250 and 11 000 km for each revolution of the spacecraft around Mars. Thus, the trajectory of ***Mars Express*** feels more the attraction from the mass of Phobos, allowing a more precise estimation of this mass. The Royal Observatory of Belgium team has already dealt with 4 years of radio-science data from **Mars Express** and has determined the mass of Phobos with accuracy better than that obtained with the probes ***MGS*** and ***Mars Odyssey***.

The trajectory of ***Mars Express*** also offers the opportunity to fly by Phobos at very short distances (as close as 50 km). Until now, ***Mars Express*** has provided images at very high resolution of Phobos during these close flybys. Recently, during the close flybys in June 2006 and July 2008, the European probe has provided measurements of changes in frequency (Doppler effect) of the radio-link between the Earth and ***Mars Express***, thus allowing the best determination of the mass of Phobos ever made before.

Scientific instruments

Of the 7 instruments on board ***Mars Express*** the following are used for the study of Phobos:

Radio-science (radio link between the orbiter[2] and the Earth (MaRS, Mars Radio-Science experiment)) is based on the radio signal between the probe and the Earth, sent from the Earth and observe with large antennas such as the one located at New Norcia (near Perth, Australia), or those of the U.S. network (DSN for Deep Space Network) located in Madrid (Spain), Goldstone (California) and Canberra (Australia). This network of antennas is used to monitor the probes in orbit around the planets of the solar system. Measurements of Doppler shifts are used to reconstruct the trajectory of the probe in order to plan the mission (navigation) or to determine geophysical parameters such as the gravity field of Mars. The Royal Observatory of Belgium participates in this experiment, for more details, see below.

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2 Orbiter: space probe that studies a planet or a satellite orbiting around it, as opposed to a lander that is deposited on the surface.

The high-resolution camera (High Resolution Stereo Camera HRSC) takes images of Phobos in three dimensions with a resolution of 10 meters. It infers, among other information, the volume of Phobos.

Infrared spectrometer (OMEGA): this instrument provides a mapping of the mineralogy of Phobos from measurements of sunlight reflected by Phobos in different “colors” or spectral bands. It has already been established that the spectrum of the surface of Phobos is different in each hemisphere, suggesting that the composition of surface rock varies from one hemisphere to the other.

The MARSIS instrument is a radar / altimeter. It sends radio-waves to Phobos that can penetrate to a depth of 5 km. As soon as a reflective layer is reached, ice for example, the waves are reflected and the scientists can determine how deep this layer is located in the interior of Phobos.

Radio antenna for space probes from Earth (copyright NASA)

Belgian participation to the Mars Express Mission

The Royal Observatory of Belgium (ROB) is involved in the processing of the radio-science experience, MaRS (Mars Radio-Science experiment), to improve the knowledge of the gravity field of Mars, its atmosphere and its interior as well as to determine precisely the masses of the moons of Mars, and of Phobos, in particular.

The radio-science experience of Mars Express uses radio signals emitted/received at given frequencies between the orbiter and the Earth. The signals emitted from the Earth (from stations located precisely) to the orbiter are reflected by a transponder[3] placed on board the orbiter. These radio signals have a slightly different frequency when received on Earth. Apart from the transponder ratio, the measured frequency shifts are due to the relative motion between the orbiter and the Earth, which corresponds to the Doppler effect.

The measurements are used to reconstruct the trajectory of the orbiter around Mars and thus to deduce the exact position of the probe in space. In reconstructing the orbit of the spacecraft, the scientists from the Royal Observatory of Belgium determine also the gravitational field at global, regional and local scales of the planet Mars, and its temporal variations.

It will be possible to characterize the seasonal variations in the distribution of mass in the atmosphere and polar caps. Indeed, the atmosphere of Mars is composed mainly of CO_2 (approximately 95%). About a quarter of the total mass of the atmosphere solidifies by condensation in the polar caps in winter. The reverse ($C0_2$ becomes gas by sublimation) takes place in summer, giving rise to a seasonal cycle.

The ROB uses as well these data to study the Martian gravitational field and the associated mass distribution in the subsurface of Mars, polar caps and the internal structure of Mars.

In addition, changes in position of the probe caused by the tidal effects provide information on the interior of Mars. The study of the trajectory of Phobos around Mars may also provide valuable information on the interior of Mars because its orbit is influenced by long-term deformation of Mars and in particular the inelastic/viscous properties of Mars.

The determination of the gravitational field of Phobos allows, among others, to better understand the internal composition of Phobos and hence its origin.

Belgian Co-Investigators of MaRS: Prof. V. Dehant, Dr P. Rosenblatt
Principal Investigator MaRS: Prof. M. Pätzold (Germany)

Belgian Scientist Team:
Prof. V. Dehant, Prof. T. Van Hoolst, Dr. M. Yseboodt.
Scientists under PRODEX contract awarded by the Federal Science Policy BELSPO strengthen the team: Dr. M. Beuthe, Dr. Ö. Karatekin, Eng. S. Le Maistre, Dr. P. Rosenblatt.

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3 Transponder: device that receives a radio signal and retransmits it in a coherent phase on the same or different frequencies

Recent Opportunities

As the mission has been extended until the end of 2012 and will be extended most probably after 2010, more data about Mars and its moon Phobos will be collected. In particular, radio-science data acquired during flybys at very close distances to Phobos (100 km or less) will again help to assess for the first time the distribution of masses within Phobos through the determination of variations of gravity at its surface. These data will provide additional evidence that will support more knowledge about the origin and orbital evolution of Phobos.

The nearest opportunity is that of March 3, 2010. Very recently, the "Flight Dynamics" team of ESA has provided its latest predictions of the orbit of Mars Express Phobos flyby. Its predictions are based on data received until yesterday from ground stations tracking the spacecraft. These data were acquired by the NASA Deep Space Network (DSN) station in Goldstone, California, and that of the Deep Space Antenna (DSA) of ESA in New Norcia, Australia. The predicted closest approach time to Phobos remains unchanged at 20:55:40 UTC (21:55:40 our time) on March 3, 2010, with a distance of 77 km from the center of Phobos. This implies that Mars Express will pass 66 km above the surface of Phobos (which has an average radius of 11.1 km).

The scientists of ROB will quickly analyze these data to confirm that distance and deduce the mass and mean moment of inertia of Phobos. They then will be able to answer the question of the origin of this little moon.