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Spacecraft exploration of Phobos and Deimos

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ABSTRACT

We review the previous exploration of Phobos and Deimos by spacecraft. The first close-up images of Phobos and Deimos were obtained by the Mariner 9 spacecraft in 1971, followed by much image data from the two Viking orbiters at the end of the 70s, which formed the basis for early Phobos and Deimos shape and dynamic models. The Soviet Phobos 2 spacecraft came within 100 km of landing on Phobos in 1988. Mars Global Surveyor (1996–2006) and Mars Reconnaissance Orbiter (since 2005) made close-up observations of Phobos on several occasions. Mars Express (since 2003) in its highly elliptical orbit is currently the only spacecraft to make regular Phobos encounters and has returned large volumes of science data for this satellite. Landers and rovers on the ground (Viking Landers, Mars Pathfinder, MER rovers, MSL rover) frequently made observations of Phobos, Deimos and their transits across the solar disk.

1. Introduction

It was nearly 90 years after the discovery of Phobos and Deimos by Asaph Hall in 1877 at the US Naval Observatory before spacecraft were sent to Mars to explore the red planet and its moons. This section describes the many spacecraft sent to Mars that observed Phobos and Deimos and the data sets that they produced that will keep researchers busy for decades trying to answer the most basic questions of origin, evolution and current states.

The fleet of spacecraft that have observed the two Martian moons include:

Mars flyby missions:
- NASA Mariners 4, 5 and 6
- ESA Rosetta (still operating)

Mars orbiter missions:
- NASA Mariner 9
- Viking Orbiters 1 and 2
- Soviet Phobos 88
- NASA Mars Global Surveyor
- NASA Mars Odyssey Orbiter (still operating)
- ESA Mars Express (still operating)
- NASA Mars Reconnaissance Orbiter (still operating)

Mars lander/rover missions:
- Viking Landers 1 and 2
- Mars Pathfinder
- Mars Exploration Rover Spirit and Opportunity (still operating)
- Mars Surface Laboratory Curiosity (still operating)

NASA spacecraft data for Phobos are available from the Planetary Data System (PDS) [1] and the National Space Science Data Center (NSSDC) [2]. Data from European Space Agency (ESA) missions can be found at [3]. Ancillary data such as trajectory, ephemerides, spacecraft attitude and clock, instrument pointing and models, etc. are available at [4]. Sample images of Phobos and Deimos taken by different missions and instruments can be found at [5] and [6].

2. Mariners 4, 6 and 7

NASA's Mariners 4, launched in 1965, and 6 and 7, launched in 1969, were Mars flyby missions. The objectives of these missions were focused on Mars with no goals to observe Phobos and Deimos. The Mariner 4 vidicon camera, with a $1.05^\circ \times 1.05^\circ$ field of view, obtained 21 Mars images that can be found at [7]. Other related Mariner 4 publications are: Nicks (1967), Sloan (1968), Anderson (1965), and NASA (1967).

In 1969, Mariner 6 and Mariner 7 completed the first dual mission to Mars, flying by over the equator and south polar regions and analyzing the Martian atmosphere and surface with remote sensors, as well as recording and relaying hundreds of

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pictures. By chance, both flew over cratered regions and missed seeing the giant northern volcanoes and the equatorial grand canyon that was discovered later. The two spacecraft each carried the Mars Wide and Narrow Angle TV Cameras, the IR Spectrometer, the Two-Channel IR Radiometer, the UV Spectrometer, the Thermal Control Flux Monitor and the Celestial Mechanics/Relativity Experiments.

It is expected that Phobos and Deimos were captured by Mariners 6 and 7 during the approach to Mars as point source images off of the Mars limb or possibly with Phobos in transit across Mars. However, the Mars approach and flyby images were not archived so one cannot go back and search for these point source images. Such observations would have extended the time span of spacecraft observations by two years, very important in determining the orbits, including secular accelerations/deceleration of the Martian moons. Publications giving more information on Mariners 6 and 7 include: Collins (1971) and NASA (1969).

3. Mariner 9

In 1971, Mariner 9 became the first spacecraft to orbit another planet. It carried an Infrared Radiometer (IRR), an Ultraviolet Spectrometer (UVS), an Infrared Interferometer Spectrometer (IRIS), a Television System and a Celestial Mechanics/S-Band Occultation Experiments. The objectives of these experiments were to analyze the surface and atmosphere of Mars. However bonus science was obtained when these instruments were able to view the Martian moons during close flybys.

Mariner 9 was able to map 85% of the Martian surface at a resolution of 1–2 km (with 2% mapped at a resolution of 100–300 m) in addition to gathering abundant information about the surface and atmosphere. Mariner 9 carried a wide-angle camera having a $11^\circ \times 14^\circ$ field of view for systematic mapping of Mars and a narrow angle camera having a $1.1^\circ \times 1.4^\circ$ field of view for viewing local Martian features. Seven thousand three hundred twenty nine images were taken, included the first detailed views of Olympus Mons, the solar system's largest volcano; Valles Marineris, a vast canyon system that dwarfs the Grand Canyon and was named for this spacecraft; the polar caps; and the moons Phobos and Deimos.

The Martian moons were imaged on Mars approach, against star fields, as a technical flight demonstration of a new technique for interplanetary navigation. The demonstration exceeded expectations and optical navigation has been included on many follow-on Mars, outer planet, comet and asteroid missions. Once in Mars orbit, the highly elliptic and large Mariner 9 orbit that went outside of the Deimos orbit would periodically fly near the Martian moons where images were taken anytime the range was less than 7000 km. Images as close as 1200 km were taken where a narrow angle pixel covered about 30 m.

A total of 214 images of Phobos and Deimos were obtained in greyscale from the narrow angle camera and in color using the red, green and blue filters of the wide-angle camera. These images were the first to resolve the global shapes and surface topographies showing the two Martian moons to be highly irregularly shaped and regolith-covered surface saturated with craters. The images showed Phobos and Deimos to be in synchronous rotation with Phobos having a forced rotational libration amplitude at the 1° level. A controlled drawing of the Phobos surface features was the first cartographic map of a moon of another planet with some craters given names by the IAU Nomenclature Committee. The orbital speeds of Phobos and Deimos confirmed that Phobos was speeding up as it was spiraling in toward Mars while Deimos was spiraling away from Mars due to tidal forces raised by the moons on Mars. Hints of crater chains were seen that were later resolved by Viking orbiter images to be part of the global groove network.

A summary of the entire Mariner 9 image archive, including the Phobos and Deimos images, is given by Cutts, 1974. The atlas contains a description of each image plus a thumbnail image. Digital versions of Mariner 9 images are available from the PDS at [8]. The entire image collection is also archived in photographic and digital formats at the NASA GSFC NSSDC [9].

Other websites hosting Mariner 9 data include:

UVS Data Files, Mariner Mars 1971 (MM71/M9) Ultraviolet Spectrometer (UVS) Data [10]
Experimenter Data Records files: [11]
Supplemental Experimenter Data Record files: [12]
General descriptions are at [13].

Additional information on the project and images can be found in: Steinbacher et al. (1972), Hartmann and Raper (1974), Steinbacher and Haynes (1973), Cutts (1974), Duxbury et al. (1974), Pollack et al. (1972,1973), Gatley et al. (1974), Simmons and Hendrix (1999), and Pang et al. (1987).

4. Viking orbiters/landers

The Viking project placed two spacecraft into Mars orbit and two landers on the Martian surface in 1976. Both orbiters carried Imaging Systems, Infrared Thermal Mappers (IRTM), Mars Atmospheric Water Detectors (MAWD) and Radio Science experiments, all of which observed Phobos and Deimos during close flybys. The Lander Stereo Cameras viewed Phobos and Deimos from the surface of Mars. The Viking project elevated Phobos and Deimos exploration as a high science objective during its extended mission phase and targeted many close flybys of the Mars moons. Additionally, the shadow of Phobos passing over Viking Lander 1 was observed simultaneously three times from the lander and Viking Orbiter 1. The Viking orbiter/lander datasets stood as the most exhaustive data on the Martian moons for almost 40 years, only recently being exceeded by the ESA Mars Express mission.

Viking had many new discoveries related to Phobos and Deimos:

The global network of grooves;

Complete global coverage of the entire surfaces with significant coverage in color, UV and IR;

The first digital terrain model (DTM) of another planet's moon (Phobos) and the first global image mosaic (also Phobos);

The first mass determinations of the two moons showing that they were anomalous to Mars and asteroids by having densities of less than 2 g/cm^3;

Phobos and Deimos surfaces were covered by fine-grained regoliths, tens of meters or thicker; and

Phobos had a forced rotational libration of about 1° amplitude and that this amplitude was consistent with Phobos having a homogeneous interior (low density material or loosely compacted Mars primordial disk material or crater ejecta), covered by regolith.

All Viking Orbiter and Lander data of Phobos and Deimos are archived at NASA's PDS and NSSDC facilities: [14] (Viking Orbiter) and [15] (Viking Lander).

A photo journal of the close flyby images of Phobos is given in Duxbury et al. (1984). A detailed report of the IR results can be found in Lunine et al. (1982).

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