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Martian Moons eXploration (MMX): architecture of its science

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Abstract

This paper describes the progress of conceptual study for Martian Moons eXploration (MMX) science including proximity observations.

Science objectives

The scientific objectives of MMX (Table 1) stems from two major goals; 1) To reveal the moons' origin and then to make a progress in our understanding of early solar system evolution around the border between hot and dry inner solar system and chilled but fertile outer one, 2) To observe processes that influence the evolution of the Martian system. Overall, MMX will provide us new views how Mars formed and evolved with their moons as a planet having a habitable environment.

Table 1. Science objectives of MMX

1.1. To determine whether the origin of Phobos is captured asteroid or giant impact.
1.2a. **(In the case of captured asteroid origin)** To understand the primordial material delivery process (composition, migration history, etc.) to the rocky planet region and to constrain the initial condition of the Mars surface environment evolution.
1.2b. **(In the case of giant impact origin)** To understand the satellite formation via giant impact and to evaluate how the initial evolution of the Mars environment was affected by the moon forming event.
1.3. To constrain the origin of Deimos.
2.1. To obtain a basic picture of surface processes of the small airless body on the orbit around Mars.
2.2. To gain new insight on Mars surface environment evolution.
2.3. To better understand behavior of the Mars atmosphere-ground system and the water cycle dynamics.

Sample science

MMX will carry out sampling from multiple sites on Phobos inferred to have compositional heterogeneity from surface reflectance spectra. Regolith samples more than 10g enough for detailed analyses of Phobos-indigenous materials will be collected with characterizing sampling sites in relation to bedrocks and geologic features. Samples will be served for systematic analyses combining textural, mineralogical, elemental, isotopic and chronological ones, from which the origin and cosmochemical nature of Phobos will be revealed. If Phobos-indigenous materials are carbonaceous chondritic, capture origin is concluded. Such samples also tell us the birthplace and migration processes of Phobos precursor before the capture event. If indigenous-materials are igneous with compositions as a mixture of the Martian mantle and an exotic body, giant impact origin is concluded. The source region of the moon-forming impactor, the age and processes of the giant impact event, and the physico-chemical state of primordial Martian mantle may be estimated from such samples. Survey and analyses (if available) of younger materials ejected by cratering events on Mars would give clues on the evolution of the Martian surface environment.

Mission Instruments

MMX will be equipped with TENGOO (telescope camera), OROCHI (wide angle multi-band cameras), MacrOmega (near IR spectrometer), MEGANE (gamma-ray and neutron spectrometer), LIDAR (light detection and ranging), CMDM (circum-Martian dust monitor) and MSA (mass spectrum analyzer). An international rover is under consideration to make in-situ observation of physical and mineralogical properties of Phobos surface layer.

Complementary close-up observations by these instruments will reveal the global properties of Phobos and Deimos and search for clues of the moons' origin, building materials and long-term evolution independently of sample analyses. For instance, imaging with high spacial resolution of sub-m scale by TENGOO will be used to search for young geologic structures on which fresh bedrock materials are exposed. Visible to near IR multispectral imaging for such fresh structures by OROCHI and MacrOmega will constrain the mineralogical composition of bedrock with a focus on whether hydrous minerals exist or not, a possible diagnostic clue for Phobos origin. Those instruments are also used for the landing site selection, sampling site characterization, geologic studies, and observation of Mars atmosphere.

MEGANE will determine abundance of hydrogen and other elements in the surface layer averaged over several tenths m depth with a spacial resolution of hemisphere-scale or better, which enables us to cross-check the bedrock composition(s) estimated by sample analyses and other observations. Elemental abundance ratios such as Si/Fe provide another evidence for satellite origin. MSA will attempt to detect ion particles originated from H_2O possibly outgassing from the moon's interior as well as the sputtered ions including rock-forming elements from the satellite surface. If a significant flux of H_2O-derived ion components is detected as expected for an ice-bearing Phobos, its cold origin, or capture origin is favored.

LIDAR, along with the landform imaging by TENGOO, measures the global topography of Phobos, which contributes to studies of geologic features such as grooves and craters and estimation of mass distribution inside Phobos in combination with gravity field analyses using orbital tracking and positioning data. CMDM monitors the dust particle flux around the moons, which provides basic data to understand space weathering, gardening processes on the moon's surface, and possible dust ring formation. This also helps to understand the nature of returned sample grains, the long-term evolution of the surface of the Martian moons, and the interplanetary dust particle flux into the Martian system.

Scientific Operation Scenario

After the launch in September 2024, the spacecraft will arrive Mars August 2025 and depart from Mars August 2028. During about 3 years stay around Mars, the spacecraft will largely maintain the proximity to Phobos by taking quasi-satellite orbits (QSO) around this moon, which can be achieved by taking eccentricity slightly different from that of Phobos around Mars. A QSO forms an ellipse relative to Phobos at the center.

Operations for observation and landing are required to avoid the effects of solar conjunctions and shadowing. Solar conjunctions will occur January 2026 and March 2028. Because of its equatorial orbit around Mars, the shadowing frequency and duration by Mars and Phobos grow when Mars locates near its equinoxes during its revolution around Sun. Mars will reach equinoxes in late November 2025 and after every half of the Martian year. During about three months across each conjunction, operation is restricted to large QSO with minor and major radii no smaller than 50km and 100km around Phobos to avoid the spacecraft damage by long duration of shadowing. During time periods around the Martian solstices, MMX will take smaller QSO with radii about 30km and 50km or smaller which is needed for gamma-ray and neutron spectroscopy and zoom-up imaging from low altitudes. From QSOs around Phobos, global imaging of Mars atmosphere will also be conducted.

The landing sites shall be selected considering safety for landing operations and geologic context by using zoom-up data including local topographic undulations and spectral properties. Timings for landing are supposed to be between late 2026 to mid-2027, taking advantage of relatively short Earth-Mars distance. The time duration to stay on the surface is supposed to be 2.5 hours each by taking a 1-hour margin to 3 hours 50 minutes day time of Phobos, and the time duration allocated for the sampling operation is 1.5 hours. Taking also into account the communication delay, ~10 min is allowed for the decision of a sampling point based on the high-resolution surface image transferred to the Earth from the landing site.

To conduct close-up observation of another moon, multiple flybys of Deimos will be conducted after the orbit expansion of the spacecraft in preparation for the return cruise to Earth. When all the observation, landing and sampling operations are completed, the spacecraft will escape from Mars and send back the sample capsule to Earth in July 2029.