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MARTIAN MOONS EXPLORATION (MMX) MISSION

SCIENCE REQUIREMENTS DOCUMENT FOR

ALL INSTRUMENTS

REVISION AND HISTORY PAGE

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1. INTRODUCTION

The purpose of this document is to describe scientific objective of the Japan Aerospace Exploration Agency (JAXA) Mars Moons Exploration (MMX).

2. OUTLINE OF THE MMX MISSION

Mars is the outermost planet among the rocky planets in the solar system. Phobos and Deimos are the two moons of Mars. Martian Moons eXploration (MMX) by Japan Aerospace Exploration Agency (JAXA) will make close-up remote sensing and in-situ observations of both moons, and return samples from Phobos.

With this MMX mission, we will give a boost to planetary science by adding new information on planetary formation and evolution processes in the part of the solar system linking its inner- and outer- part. The origin of Phobos and Deimos itself is a nice question to answer, but revealing the origin will enable us to step further forward to constrain the behavior of small bodies in the close proximity to the border between the inner- and outer-part of the solar system in it making. Small bodies in the internal boundary part of the early solar system are considered to have played a key role in providing habitability to the rocky planets. Focusing on the moons will also provide a vantage point from which new insight on how the Mars system, including its surface environment, involved in time.

There are two leading ideas for the origin of the two moons: captured asteroid or giant impact. While not a small amount of remote sensing data exist for Phobos, not enough has been gained to judge between the two ideas for its origin. It is likely that remote sensing data alone would not lead us to a definitive conclusion. Returning of samples which represents the original building blocks for detailed analysis to be performed on the ground is the way to give the end to the debate that would otherwise last forever. That is, a sample return mission to Phobos is what should be done to reveal its origin and to male substantial steps beyond. Our goal is to enhance our understanding of planetary formation processes at the outer-edge of the rocky planet region in our solar system.

A sample return mission requires more time and faces more technical challenges and risks. Yet, the merit brought-in due to outstandingly superior analytical capability provided by ground facilities, especially compared to the quality of data expected from instruments onboard a spacecraft, overrides the unfavorable aspects of a sample return mission. Indeed, remote sensing data becomes more valuable when credibility in their interpretation is supported by sample analysis results.

Sample return from Phobos would enable us to reveal its origin. Close-up observations of Deimos, and that with reference to the ground-truth results from Phobos, would enable us to give strong constraint to the idea for its origin. That is, the mission aims to deploy an integrated study on the origin of the two moons and to open a new window for our understanding of the formation processes in this critical part of the solar system. If the origin of Phobos is known to be captured primordial asteroid (D-type as has been inferred from visible-wavelength and the limited near-IR spectroscopic remote sensing data), detailed analysis of the samples allows us to study how the primordial materials, namely, water and organic compounds, are brought into the inner-part of the solar system from the outer-part across the border (so-called snow line). Sample analysis also allows us to unveil the migration history of the small body that behaved as a capsule which carried water and organic compounds into the inner-solar system. These studies will constrain the initial condition of the Martian surface environment and of rocky planets in the solar system. If the origin of Phobos turns out to be giant impact, samples will be composed of ancient Mars and impactor materials. In a sense, Mars sample return is realized. Their analysis will reveal the impact size and allow us to evaluate how the initial evolution of Mars surface environment was affected by the violent satellite formation process.

Due to its close orbit to Mars, Phobos would have been showered by debris generated by impact events on the surface of Mars. That is, we may find samples from ancient Mars surface among samples to be collected from Phobos (even if its origin does not turn out to be giant impact). The Mars samples may span over a wide range in time and may enable us to read-out the evolution history of Mars surface environment. The orbit of the Martian moons mission also provides an interesting vantage point allowing global perspective to inspect how water in the present Mars ground-air system is cycled, which would be a critical element in the mars climate system and its evolution. The mission orbit also provides occasions to male in-situ observations of particles to learn about atmospheric escape mechanisms of the present Mars, which helps us develop our idea for the huge loss of the atmosphere that happened in the past. That is, the mission is not only about the moons but also is our first approach to Mars itself, with the scientific focus on its surface environment transition.

<Engineering aspect of the mission>

As symbolically indicated by the success of the Hayabusa mission that returned samples from Asteroid Itokawa, it is the style of Institute of Space and Astronautical Science (ISAS, JAXA) that engineering and science departments work together to make a cutting-edge space science mission happen. This was true for the development of Hayabusa2 and applies to this Martian moons mission as well. The opportunities offered by this mission to space engineering are: trajectory control to arrive at Mars moons, landing and sampling on the surface of Phobos, return trip from Mars to Earth and upgrading the deep-space communication technology.

3. SCIENCE BACKGROUND

Here the background leading to the science goals of this Martian moons mission is described.

In a document issued in February 2015, Japanese planetary science community expressed its interest in setting the theme of pre-biotic environmental evolution as the commonly shared grand theme to be pursued by the community members. In addition to the intrinsic attraction that the theme has, success of Hayabusa and the fact that Hayabusa2 is ongoing are the drivers behind this statement. ISAS has completed an asteroid sample return mission and is running another one to a primordial asteroid (the C-type asteroid of Ryugu) from which more hints are expected to be gained on the origin of water and organic compounds brought to the habitable zone of the solar system (including, of course, Earth). That is, Japanese community is at a stand point where it can make a strong contribution to the pre-biotic environment evolution theme from an interesting angle.

This Martian moons mission is aligned with the idea to return samples from small bodies to learn more on the making of the solar system. The transition of the Mars environment has been and is one of the focal points in the world-wide planetary science. There has been and will be huge resources invested into this topic. Orbiters making high-resolution remote sensing of Mars and rovers exploring its surface are revealing the dramatic transition that the Mars surface environment went through. There has been no successful ISAS mission to Mars, however, the interest in the Japanese community has been naturally always strong. While it may take some more time before ISAS is ready to send a rover to the surface of Mars, this Martian moons mission will enable us to approach the same grand theme from a different angle in a carefully fabricated way.

Beautiful synergy between remote sensing from orbiters and geological/geochemical exploration by landers/rovers has revealed what Mars used to be 3.5 billion years ago: Huge amount of water must have been present on the surface of Mars. In contrast, more than 3.8 billion years ago, some evidence exists to show that water amount on the Mars surface was limited and instead large-scale hydro-thermal processes were taking place in the sub-surface world. Little is known on the yet older times when Mars was in its initial evolution stage. It is also important to understand how water was brought to the planet, that is, the process that set the initial condition. Mars is the outermost rocky planet and sits at the gateway position to the outer-part of the solar system. In addition to the interest in the Mars history itself, understanding the water delivery to the planet located at the outer-boundary of the rocky planet region is very important for our understanding of the initializing process of the habitable zone in our solar system.

ISAS's way to approach the attractive target of Mars is to focus on its initial evolution and investigate it from the viewpoint of <How was the primordial material delivered to the planet?> When one looks at Phobos and Deimos from this perspective, the question of their origin becomes upgraded. That is, once we understand their origin, we would know what information related to the initial evolution of Mars that the moons retain. Sample return from Phobos and/or Deimos is the way to read-out the retained information. Hayabusa2, a sample return mission to the C-type asteroid Ryugu, will conclude if primordial asteroids were the reservoirs of pre-biotic organic compounds and water that were transported to Earth. We may locate this Phobos sample return mission along the same line in the planetary exploration roadmap: Phobos may turn out to be the direct evidence for the delivery process taking place across the border (the snow line) between the inner- and the outer-solar system. This Martian moons mission with the overarching goal would be a compelling way for ISAS to make its first step into the world of Mars exploration.

Sample return from Phobos is needed to conclude definitely its origin that is being debated. Sample return is needed to step beyond simply pinning-down the origin and to reveal the formation processes (either capturing of a water-delivery capsule or giant impact on the ancient Mars) that had substantial impact on the initial evolution of Mars. Sample return from Phobos does not necessarily require too large resources and is one of the best mission ideas by which ISAS's expertise in sample return from small bodies is rewarded most.

The February 2015 document issued by Japanese planetary scientists lists five paths to reach the grand theme of pre-biotic environment evolution. Among the five, the Martian moons mission contributes to the grand theme via the following four paths:

(A) Prebiotic synthesis and evolution of building blocks of life in the early solar system

(B) Migration and delivery of building blocks of planets and life in the solar system

(C) Initial evolution and differentiation of planets and satellites

(D) Surface environment evolution under energy input from the Sun

(A) becomes available when the origin of Phobos is known to be captured primordial asteroid.(D) is available because remote sensing observations of Mars itself will be performed from the unique global vantage point in the proximity of the moons. The fact that (D) also applies to this mission indicates that the Martian moons mission also enables Mars science to be deployed from the data it will acquire.

4. SCIENTIFIC REQUIREMENTS OF THE MMX

4.1. Science Goals

The MMX project defines two science goals as follows:

(Goal 1) To reveal the origin of the Mars' moons, and then to make a progress in our understanding of planetary system formation and of primordial material transport around the border between the inner-and the outer parts of the early solar system.

(Goal 2) To observe processes that have impact of the evolution of the Mars system from the new vantage point and to advance our understanding of Mars surface environmental transition.

Corresponding to these goals, the science objectives are subdivided as follows;

(Goal 1.1) To determine whether the origin of Phobos is captured asteroid or giant impact;

(Goal 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;

(Goal 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;

(Goal 1.3) To constrain the origin of Deimos;

(Goal 2.1) To obtain a basic picture of surface processes of the airless small body on the orbit around Mars;

(Goal 2.2) To gain new insight on Mars surface environment evolution;

(Goal 2.3) To better understand behavior of the Mars air-ground system and the water cycle dynamics;

4.2. Mission Requirements

The science objectives are broken down at a sub-layer and each item at the layer has a mission requirement (MR) associated with it.

<Goal 1> To reveal the origin of the Mars moons, and then to make a progress in our understanding of planetary system formation and of primordial material transport around the border between the inner- and the outer-part of the early solar system.

<Science Objective 1.1>

To determine whether the origin of Phobos is captured asteroid or giant impact.

[1.1.1] To characterize the materials that constitute Phobos via spectroscopy in order to evaluate a sampling site candidate from the view point of Science Objective 1.1.

MR1.1.1: Spectroscopic mapping of major regions of Phobos at 20m spatial resolution, with emphasis on hydrated mineral features, and with intention to select an appropriate sampling site. The same mapping but at 1m resolution of the area within 50m from a selected sampling spot. Measurement of globally-averaged elemental abundance ratios of Ca/Fe and Si/Fe.

[1.1.2] To identify genesis samples among those collected from Phobos and to perform sample analysis in order to constrain the origin of Phobos.

MR1.1.2: Acquisition of more than 10g samples from deeper than 2cm below the surface after selecting carefully the sampling site that meets Science Objective 1.1. Analyze the samples by texture inspection and by mineralogical /elemental/isotopic composition measurements at the precision that meets Science Objective 1.1.

[1.1.3]: To obtain indirect information on the Phobos internal structure in order to constrain the origin of Phobos independent of the sample analysis results.

MR1.1.3: With special attention to possible presence of water-ice inside Phobos, (1) Measurement of ions related to possible outgassing from the internal ice, at the detection limit corresponding to the outgassing rate of 10^{22} /sec or lower equivalent to H_2O molecules. (2) Search for signatures indicating the presence of ice concentration whose mass is more than 10% of the Phobos mass, (3) Search for signatures indicating substantial mass density heterogeneity near the surface.

<Science Objective 1.2a>

(In the case of captured asteroid origin) To understand the primordial material delivery process (composition, small body migration process, etc.) to the rocky planets of the solar system and to constrain the initial condition of the Mars surface environment evolution.

[1.2a.1]: To design and perform an analysis plan that extracts information pointing to small body evolution around the slow line in the early solar system and to the capture process of Phobos by Mars.

MR1.2a: Analyze the samples by texture inspection, by elemental/isotopic composition measurements and by formation age dating, at the precision that meets Science Objective 1.2a. Analyze hydrated minerals and organic compounds. Obtain statistical distribution of impact ages of samples and perform crater chronology in order to read-out the collisional history of Phobos.

<Science Objective 1.2b>

(In the case of giant impact origin) To understand the satellite formation via giant impact and to evaluate the how the initial evolution of the Mars environment was affected by the moon forming event.

[1.2b.1]: To design and perform an analysis plan that extracts information pointing to the giant impact that formed Phobos and to the nature of the impactor.

MR1.2b: Analyze the samples by texture inspection, by elemental/isotopic composition measurements and by metamorphic age dating, at the precision that meets Science Objective 1.2b. Obtain the highest temperature that the samples experienced during the impact. Obtain the mixing ratio between the Mars differentiated material and the impactor material.

<Science Objective 1.3>

To constrain the origin of Deimos.

[1.3.1]: To characterize the materials which constitute Deimos via spectroscopy, in order to compare the results with those from Phobos.

MR1.3: Spectroscopic mapping of major regions of Deimos at 100m spatial resolution, with emphasis on hydrated mineral features.

<Goal 2> To observe processes that have impact on the evolution of the Mars system from the new vantage point and to advance our understanding of Mars surface environment transition.

<Science Objective 2.1>

To obtain a basic picture of surface processes of the airless small body on the orbit around Mars.

[2.1.1]: To characterize the space environment and the surface features of Phobos, with the intention of comparison with asteroids.

MR2.1: Monitor the space environment around Phobos. Image surface features (craters, blocks, sedimentary feature in regolith layers, etc.) at 20m resolution. Study space weathering processes via sample analysis.

<Science Objective 2.2>

To gain new insight on Mars surface environment evolution.

[2.2.1]: To identify Mars samples among those collected from Phobos and to perform sample analysis in order to learn the environment evolution of the Mars surface.

MR2.2.1: Search for Mars samples. When detected, analyze the samples by elemental/isotopic composition measurements and by impact age dating. Measure remnant magnetization of samples.

[2.2.2]: To understand the mechanism of atmospheric escape from the present Mars in order to constrain the huge atmospheric loss process in the past.

MR2.2.2: Measurements of isotopic ratios of major ion species (O+, C+, N+, Ar+) escaping from Mars with 50% precision.

<Science Objective 2.3>

To understand better the behavior of the Mars air-ground system and the water cycle dynamics.

[2.3.1]: To obtain a global picture of dust and water vapor spatial distribution and its temporal variation.

MR2.3: Continuously observe global characteristics of dust storms, ice clouds and water vapor spatial patterns at mid-latitudes with an image cadence shorter than one hour.

5. SCIENCE PAYLOAD AND MISSION SCENARIO

5.1. Science Payload

Among the ten Mission Requirements, four (MR1.1.2, 1.2a, 1.2b, 2.2.1) are related to sample analysis. The first one (MR1.1.2) sets requirements for the sampling scheme. Three (MR1.1.1, 1.1.3, 2.1) out of the remaining six issue requirements for remote sensing and in-situ observation instruments onboard the spacecraft. The remaining three (MR1.3 (Deimos), 2.2.2 (Mars in-situ), 2.3 (Mars remote sensing)) do not necessarily need new instruments but only issue requirements for science operation.

A list of model payloads that would achieve the science goals is as follows,

[Sample science]

- Sampler and Re-entry Capsule: Acquisition of more than 10g Phobos genesis samples and Earth return from Mars orbit

[Remote-sensing observation]

- Neutron and Gamma-ray spectrometer: For measurement of silicate and volatile components.
- Wide angle multiband camera : For spectroscopy of hydrated and non-hydrated silicate minerals and space weathering
- Near-Infrared spectrometer: For spectroscopy of hydrated minerals and/or organic matter
- Telescopic camera: To image geologic features and construct detailed shape model/albedo map
- Light detection and ranging: To measure topographic features and construct detailed shape model
- Circum-Martian dust monitor: For Phobos space environment theme
- Ion mass spectral analyzer : To detect degassing from possible ice inside Phobos and for Phobos space environment theme

5.2. Mission Scenario

In order to show how the objectives in 4.2. are achieved, the mission scenario is described here.

(1) Mars orbit insertion

(2) Transfer to a quasi-satellite orbit around Phobos for close-up observations

(3) Landing and sampling from Phobos

(4) Transfer to Deimos for multi-flyby observations (or from a quasi-satellite orbit).

(5) In-situ space observations and Mars remote sensing observations for Mars atmospheric

science themes while the spacecraft is within the Mars gravitational sphere.

(6) Departure from Mars and return to Earth

(7) Recovery of samples and initial analysis

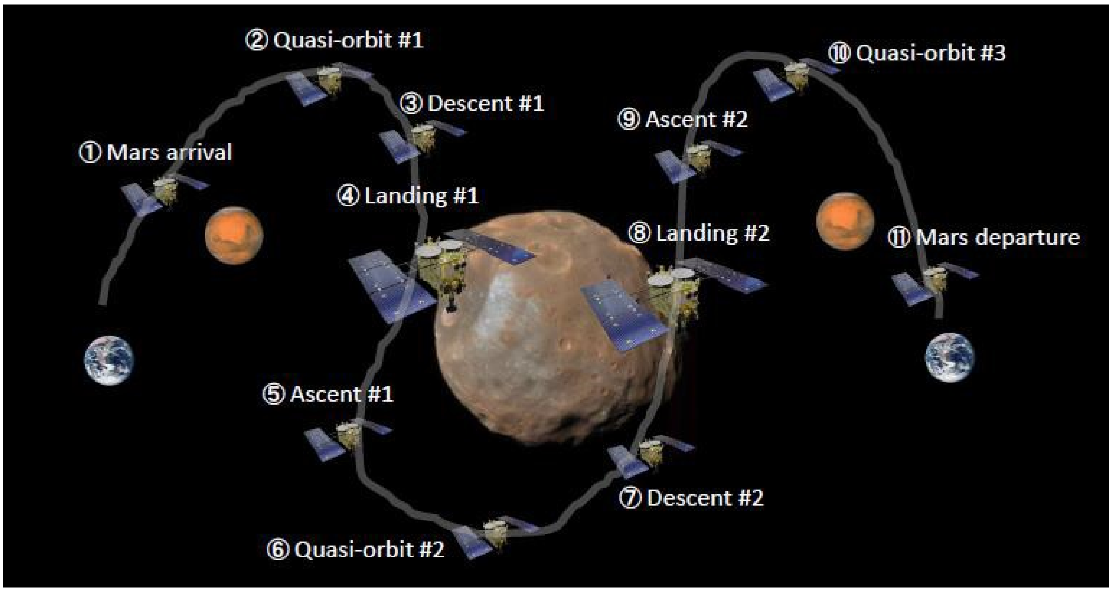

Figure 5.2-1 Mission profile

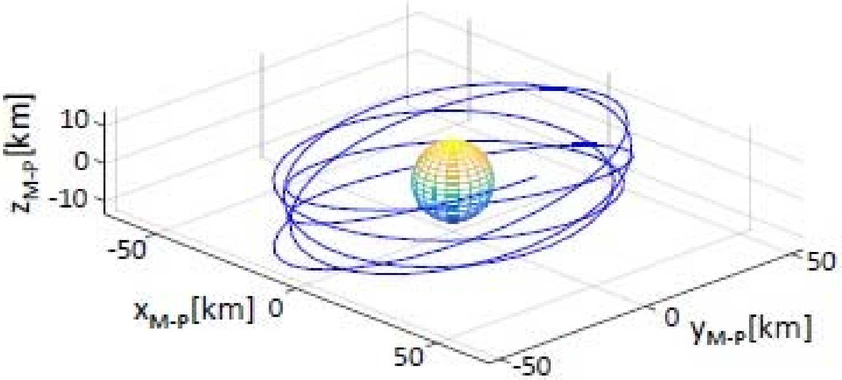

Figure 5.2-2 A quasi-satellite orbit around Phobos

Figure 5.2-3 Landing and sampling

In Phase (2), remote sensing observations will characterize the surface of Phobos and enable us to select the landing site(s) from where samples are collected. In order to resolve the origin enigma, samples should contain original building blocks of Phobos while some part of its surface may be covered by materials of external origin that were attached to the surface later in the Phobos history. Spectroscopic mapping will enable us to avoid the area which is covered heavily by materials of external origin and to select the right spot where genesis samples can be collected. Spectroscopic observations alone, however, will not be able to completely determine the origin of Phobos because of the obstacles set by space weathering. In this sense, spectroscopy of not only space-weathered regolith but of a fresh surface of a boulder, which will be tried in the mission, may make a breakthrough. The space weathering effects can be easily separated during sample analysis on the ground and is not regarded as an obstacle at this stage of the mission. Another role of remote sensing is to record the sampling site information that is to be coupled to sample analysis studies. Thermal inertia is the property that is tightly coupled to the regolith particle size and can be constrained by remote sensing observations as well. It is nice to have a nice inference of the regolith particle size prior sampling operations.

In-situ observations performed during Phase (2) are, (a) search for water-related ions originating from H2O outgassing from possible water-ice inside Phobos, (b) search for large-scale high-mass density contrast inside Phobos and (c) elemental composition measurements. Both (a) and (b) are targeted at indirect detection of possible ice inside the moon. If positive, it gives a strong support to the idea that Phobos is a captured asteroid. (c) is designed so that the obtained data will tell the mixing ratio between the chondritic component and the differentiated Mars material. In an extreme case, the Phobos origin may be well constrained by the data.

In Phase (3), the spacecraft will land on the surface for ~1 hour and collect samples. The sample amount is 10g as requested by the analysis plan that is set so that the objectives of the mission will be achieved. Not only the Phobos genesis samples but also debris from the ancient Mars are expected to be included in those collected from the regolith.

In Phase (4), remote sensing of Deimos will be performed to obtain spectroscopic mapping of regions of interest. Limitations would apply due to the nature of the spacecraft orbit, but elemental composition measurements will be tried during the Phase (4) as well. Information gathered by these observations, with assist from knowledge and insight gained at Phobos, will enable us to constrain the origin of Deimos.

In Phase (5), in-situ observations of Mars atmospheric ions are made to constrain the atmospheric escape mechanism. Remote sensing of Mars will be made so that global monitoring of water-cycle and dust interaction in the Mars air-ground system will be available. The new global perspective would add key information for a better understanding of the climate system.

In Phase (7), various analysis scheme will be applied to judge the origin of Phobos, to decipher the whichever major event in the early history of Mars and, if found, to inspect ancient Mars samples that keep the records of what the surface environment used to be. Experience with Hayabusa and Hayabusa2 missions sets the basis for the sample analysis plan.

6. ACRONYMS

JAXA	Japan Aerospace Exploration Agency
MMX	Martian Moons eXploration