MARTIAN MOONS EXPLORATION (MMX) CONCEPTUAL STUDY RESULTS. K. Kuramoto[1], Y. Kawakatsu[2], M. Fujimoto[2], and MMX study team, [1]Hokkaido University (Kita 10, Nishi 8, Kita-ku, Sapporo, Hokkaido 060-0810, Japan), [2]Institute of Space and Astronautical Science, Japan Aerospace Exploration Agency (3-1-1 Yoshinodai, Chuo-ku, Sagamihara, Kanagawa 252-5210, Japan).

Introduction: Martian Moons eXploration (MMX) is a mission under study in ISAS/JAXA to be launched in 2020s. This paper presents the results of its conceptual study (pre-Phase A study) conducted by MMX study team.

Objectives of MMX: "How was water delivered to rocky planets and enabled to produce the habitability of the solar system?" This is the basic question to which MMX is going to answer. Solar system formation theories suggest that rocky planets must have been born dry. Delivery of water, volatiles, organic compounds etc. from outside the snow line entitles the rocky planet region to be habitable. Small bodies as comets and asteroids play the role of delivery capsules. Then, dynamics of small bodies around the snow line in the early solar system is the issue that needs to be understood. Mars was at the gateway position to witness the process, which naturally leads us to explore two Martian moons, Phobos and Deimos, to answer to the basic question.

On the origin of Martian moons, there are two leading hypotheses, "Captured volatile-rich primordial asteroid" and "Giant Impact". Current observational facts such as orbital properties and surface reflectance spectra are individually supportive of either hypothesis but insufficient to judge which is true. We decide to collect samples from a Martian moon to conclude this discussion through in-depth sample analyses in combination with close observations of the moons. Depending on the conclusion, we will also investigate to improve our understanding of material distributions and transports at the edge of the inner part of the early solar system as well as of planetary formations.

If the capture hypothesis is true, the Martian moons are remnants of Mars-forming planetesimals and can serve as an anchor to estimate the material properties of Mars building blocks. Even if the moons' compositions significantly deviate from the bulk Mars composition, the transport dynamics estimated from the new exploration would improve our understanding of the formation processes and building blocks of Mars and the other terrestrial planets. Acquisition of constraints on the delivery of water and other volatile to Mars is particularly important because these are difficult to be deduced only from the observations of Mars that has experienced differentiation and volatile escape.

Recent numerical simulations of Martian moon accretion from giant impact ejecta [1] suggest that the moons may be constituted from a mixture of nearly equal proportion of impactor and proto-Mars materials. Ejected materials may experience weak impact-induced heating, avoiding severe homogenization due to melting and vaporization before agglomeration. It would therefore be possible to estimate the material properties of impactor and proto-Mars, separately, from returned regolith samples if the giant impact hypothesis is true. This would provide unique constraints for the physicochemical state of proto-Mars as well as for the material supply to Mars. These constraints are clues to understand the earliest Martian surface environment where chemical evolution toward life expectedly proceeded under the presence of liquid water.

Moreover, circum-Martian environment and the Martian atmosphere will be observed to improve our views of evolutions of Martian moons as well as the transition of Mars surface environment.

Mission Requirements: The mission requirements that corresponds to our break down of mission objectives are digested as follows:

1. *Retrieval of Martian moon regolith samples and determination of the moons' origin from their laboratory analyses*: An enough amount of regolith samples will be retrieved with characterization of relationships of sampling site(s) to bedrocks and surrounding geologic features. To conclude the origin of Martian moons, systematic analysis will be applied to returned samples which may be a mixture of various types of particles,
2. *In-situ observations of independent indicators of the moons' origin*: The followings items are assigned to be observed; the presence or absence of hydrated minerals, the abundance of major elements, the interior density profile and the release rates of water and other volatile species from a moon.
3. *Sample analyses and in-situ observations to reveal the formation of moons' building materials and long-term evolution of the moons*: Isotopic, elemental and mineralogical compositions of sample particles will be examined with chronological analysis. Shock ages of samples will be interpreted in combination with surface cratering structures. Geologic evolution of the moons will be decoded with

renewal data of topography, gravity, material varieties and stratigraphy, and dust flux.

4. *In-situ observation and sample analyses to constrain the Mars system evolution and its elementary processes*: Global circulation of atmospheric water and dust will be monitored utilizing the merit of nearly equatorial and circular orbits of the Martian moons. Composition and flux ratio of escaping atmospheric gases will be also observed to constrain the atmosphere escape processes. Survey and analyses (if available) of materials from Mars such as impact ejecta in samples will also be attempted.

Among both Martian moons, we choose Phobos as the prior sampling target partly because of abundant existing data compared to Deimos. MMX will also explore Deimos with close-up observations to constrain its origin in comparison with Phobos.

The mission definition review of MMX was finalized in January, 2016, including an international review. The evaluation committees strongly support the mission concept of MMX.

Mission Instruments: A set of mission instruments is going to be prepared to achieve major mission goals. A sampler system is studied for acquisition of more than 10g Phobos samples. NGRS (Neutron and Gamma-Ray Spectrometer), WAM (Wide Angle Multiband cameras), NIRS (Near IR Spectrometer), TL (TeLescope camera), LIDAR (LIght Detection And Ranging), CMDM (Circum-Martian Dust Monitor) and MSA (Mass Spectrum Analyzer) are specified as nominal science instruments. Some optional mission instruments are under discussion (a small surface science package, etc.).

Mission Profile: Remote sensing, landing and sample retrieval from a far distant small body is one of the most challenging operations in space missions. Despite our experience and heritage in this area, modification of the sequence and procedure to cope with the new environment and higher mission requirements is a challenging task.

A major engineering issue of the mission is large energy (Δv of 5km/s) required for a round trip to a Martian moon. Trajectory design results show launch opportunity in 2020s with 3 to 9-year trip depending on the choice of propulsion system, and the period of stay. Orbit maneuvers are needed as well to rendezvous with the moon and land on its surface. Total Δv (velocity increment) required through the mission is estimated to be around 5km/s (or more) which is much larger than our former deep space missions.

After injected into the Phobos' orbit, MMX approaches to Phobos by reducing the phase difference with Phobos. MMX is finally injected into a quasi-satellite orbit around Phobos to start its observation.

Figure 1: An example of MMX spacecraft design. Launch mass of 3400kg is composed from three stages system with return module, exploration module and propulsion module. Nominal mission duration is 5 years.

Orbital mechanics around Phobos is an important topic. The sphere of influence of Phobos is small, and the orbital motion is mainly governed by Mars gravity. Phobos' gravity is weak, but stronger than that of Itokawa and Ryugu, which causes differences in the approach and landing sequence from that of Hayabusa2. A few hours' stay is planned on the Phobos' surface, and the rotation of Phobos affects the spacecraft configuration.

Spacecraft Overview and Critical Technologies: The requirement of large energy dominates the mission and system design. Trade-off study has been done among a wide range of system configurations (propulsion system, spacecraft staging, etc.). Figure 1 shows an example of spacecraft configuration in our preliminary study.

Critical technologies are identified from the points of mission criticality and technology readiness level. Detailed development plan is prepared for these technologies starting from the early development phase. The list of the critical technologies include: Guidance/navigation/control in proximity operation (including descent, landing and lift-off); Chemical propulsion system for Mars orbit insertion and Mars orbit escape; Propulsion module separation mechanism; Landing system (landing gear, etc.); Sampling mechanism; Sample return capsule; a part of science instruments.

Project Schedule: In relation to ASTRO-H recovery mission, the launch of MMX is going to be shifted to 2024. A tentative development schedule aims for earlier phase-up to reduce schedule risks.

References: [1] Rosenblatt, P. et al. *Nature Geoscience*, **9**, 581 (2016)