The Mars-moon Exploration with GAmma rays and NEutrons (MEGANE) Investigation for the Martian Moon eXploration (MMX) Mission.

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Introduction: The inner solar system contains three moons, two of which – Phobos and Deimos – orbit Mars. Compared to what we currently know about Earth's Moon, our understanding of Phobos and Deimos is relatively sparse. They appear to resemble outer solar-system objects more than inner solar system objects, yet formation theories favor formation in Mars orbit. A comprehensive exploration of both bodies is necessary and promises to significantly add to our understanding of terrestrial planet formation [1].

The fundamental question regarding Phobos and Deimos concerns how they came to be in orbit about Mars; namely are they captured asteroids [2], or were they formed via an impact of a larger body into Mars [3]? The limiting factor in addressing these questions is the lack of chemical composition information for these moons. The Japan Aerospace Exploration Agency (JAXA) is planning the Martian Moon eXploration (MMX) mission to answer this and other key questions regarding Phobos and Deimos. MMX will accomplish its objectives by making comprehensive remote sensing measurements of Phobos and Deimos, and then returning to Earth regolith samples of Phobos.

A key measurement objective of the MMX mission is to remotely determine the elemental composition of Phobos. Here, we describe the Mars-moon Exploration with GAmma rays and NEutrons (MEGANE) investigation that was recently selected by NASA to fly onboard the MMX mission. MEGANE will make elemental composition measurements using gamma-ray and neutron spectroscopy.

MMX Mission: The MMX mission addresses two primary science goals, which are summarized as: 1) Reveal the origin of Mars' moons and gain a better understanding of planetary formation and material transport in the solar system; and 2) Observe processes that impact the Mars system and Mars surface environment. To achieve these science goals, the MMX mission will carry out a comprehensive set of measurements aimed at understanding the geology, geophysics, and chemical composition of Mars' moons, as well as their environment around Mars. In addition, the mission will collect and return to Earth 10 g or more of Phobos material for detailed characterization using Earth-based laboratory instrumentation.

MMX will acquire elemental composition data of Phobos using gamma-ray and neutron spectroscopy. To accomplish these measurements, the MMX spacecraft will orbit Phobos at a low enough average altitude (~1 Phobos radius, or ~11-km altitude) to provide robust gamma-ray and neutron data. Limited composition data may also be acquired at Deimos from some number of low-altitude flybys of Deimos.

MEGANE Instrumentation: MEGANE uses gamma-ray and neutron spectrometers (GRS, NS) that will make comprehensive measurements of Phobos' surface elemental composition. These sensors measure gamma rays and neutrons created when energetic galactic cosmic ray (GCR) protons impact Phobos' surface. Gamma-ray and neutron spectroscopy has become a standard technique for measuring planetary surface compositions, having successfully made composition measurements of the Moon, Mars, Mercury, and the asteroids Eros, Vesta, and Ceres. MEGANE is a high-heritage design based on the successful MESSENGER gamma-ray and neutron sensors [4] and the Lunar Prospector NS [5]. Gamma rays are measured with a cryocooled high-purity Ge (HPGe) sensor surrounded by a borated-plastic anticoincidence shield (ACS). The HPGe sensor employs modifications from the MESSENGER GRS based on lessons learned from operations around Mercury [6]. These include: 1) a vent-to-space encapsulation for the Ge sensor to reduce contamination build up from annealing operations; 2) higher temperature anneals to better mitigate radiation damage from solar and galactic cosmic rays [7]; and 3) reading and processing the Ge signals using all-digital electronics. These features are also being implemented on the Psyche GRS [8]. The ACS provides charged-particle background rejection in the Ge sensor, and measures epithermal and fast neutrons as was done on prior missions. Thermal and lower-energy epithermal neutrons are measured with two ^{3}He gas proportional counters as on the Lunar Prospector [5] and Psyche missions [8].

MEGANE Science Goals: MEGANE science goals mirror those of the MMX mission, and are designed to complement other MMX measurements, to assist the sample site selection, and provide compositional context for the returned samples.

MEGANE's first science goal will use global average elemental compositional data to determine if Phobos is a captured asteroid or was formed by an impact of a larger body onto Mars. The spectral resemblance between Phobos and Deimos and primitive outer solar system objects suggests that these moons may be captured objects from elsewhere in the solar system [2]. If true, Phobos and Deimos are predicted to have elemental compositions similar to the carbonaceous chondrites. In contrast, the impact formation theory is motivated by the difficulty in capturing two objects into circular, equatorial orbits about Mars [3]. In this scenario, Phobos and Deimos will have elemental compositions similar to Mars' crust, or a mix of Mars' crust plus the composition of the impactor, and be depleted in volatiles like Earth's moon. MEGANE will make multiple, redundant elemental (H, O, Na, Mg, Si, K, Cl, Ca, Fe, Th, U) and neutron-based (neutron absorption, atomic mass) composition measurements to determine if Phobos has a chondritic or achondritic (Mars-like) composition. Figures 1 and 2 provide examples of how particular gamma-ray and neutron measurements address this science goal.

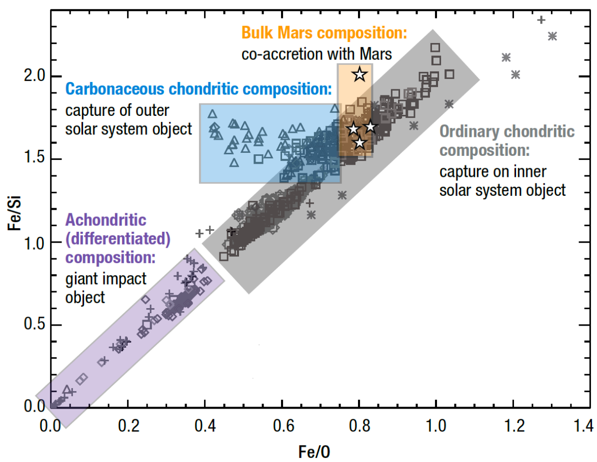

Fig. 1. Fe/Si vs. Fe/O measurements separate achondrites from chondrites, and classes/clans therein, direct analogs to compositions predicted for each origin hypothesis.

MEGANE's second science goal will use compositional variations across Phobos' surface to understand surface processes on airless bodies in Mars' orbit. Phobos' surface shows evidence for compositional diversity via two distinct spectral units. A "blue unit" is associated with the ejecta of the large Stickney crater, and the remainder of the surface forms a "red unit" [9], which also covers Deimos' entire surface. Spatially resolved compositional data from gamma rays and neutrons will be used in concert with other MMX data to better understand the processes that are responsible for Phobos' spectral diversity. Figure 3 shows an example of the spatial scale of compositional variability that can be characterized with MEGANE measurements.

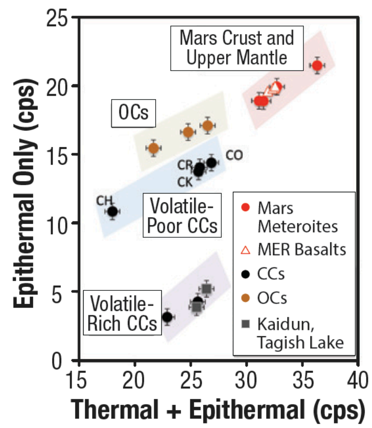

Fig. 2. Illustration of how MEGANE neutron measurements provide compositional discrimination using different end members for possible theories of Phobos' origin.

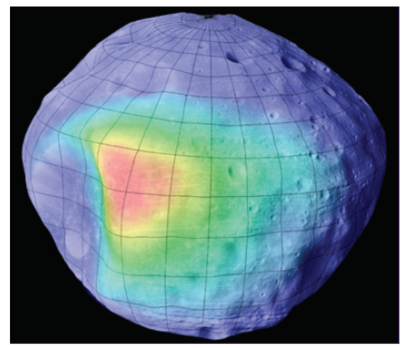

Fig. 3. The spatial footprint (bright colors) of MEGANE measurements is similar in size to the blue spectral unit around Stickney crater.

MEGANE's third science goal will be to support the primary MMX mission goal of Phobos sample return by providing input to the sample site selection process and supplying compositional context for the returned samples. MEGANE compositional maps can be used to resolve varied petrologic materials [e.g., 10], and will be combined with higher spatial resolution spectral unit maps to develop inter-instrument criteria for sample site selection. The full MEGANE dataset will also be used to understand how well the MMX returned sample represents Phobos' surface.

Summary: MEGANE will carry out a comprehensive investigation of Phobos' elemental composition, as well as support the MMX mission in its overall goals to answer foundational questions of solar system formation and understand the Mars environment.

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