

Development of the Raman spectrometer for MMX (RAX): Delivery of the flight model

*Yuichiro Cho¹, Susanne Schröder², Olga Prieto-Ballesteros⁵, Heinz-Wilhelm Hübers², Tomás Belenguer⁵, Maximilian Buder², Yuri Bunduki², Enrico Dietz², Till Hagelschuer², Shingo Kameda⁷, Nobuo Kenmochi³, Emanuel Kopp², Guillermo Lopez-Reyes⁵, Andoni G. Moral⁵, Shoki Mori¹, Martin Pertenais², Peter Gisbert², Kazunori Ogawa³, Steve Rockstein², Selene Rodd-Routley², Conor Ryan², Yasutaka Satoh³, Thomas Säuberlich², Seiji Sugita¹, Haruhisa Tabata¹, Stephan Ulamec⁸, Tomohiro Usui³, Iris Weber⁶, Koki Yumoto¹, Ute Böttger², Fernando Rull⁴

1. Department of Earth and Planetary Science, University of Tokyo, 2. German Aerospace Center, Institute of Optical Sensor Systems (DLR-OS), 3. JAXA, 4. University of Valladolid, 5. INTA, 6. WWU Münster, 7. Rikkyo University, 8. German Aerospace Center

MMX Rover and RAX: JAXA's Martian Moons Exploration (MMX) mission carries a compact rover that will explore the surface of Phobos [Michel et al. 2022, Ulamec et al. 2022]. The MMX rover is being developed by CNES and DLR and will land on Phobos in 2027. The Raman Spectrometer for MMX (RAX) is one of the four scientific instruments onboard the rover. The main objective of RAX is to study the mineralogy of Phobos' surface to contribute to the discussion on the origin of Phobos. Raman spectroscopy identifies the minerals and molecules by their fingerprint inelastic scattering. Taking advantage of the rover's mobility, RAX will investigate the heterogeneity of the material distribution on the surface. The Raman data will be compared with those from ongoing Mars missions, such as SHERLOC and SuperCam on NASA's Perseverance rover and RLS on ESA's Rosalind Franklin Rover. The Raman spectra obtained in situ on Phobos will support the interpretation of the returned samples and verify their representativeness.

Development of RAX: RAX is a compact and lightweight Raman spectrometer with a volume of approximately 1000 cm³ and a mass of 1.5 kg [Hagelschuer et al. 2022], consisting of two modules connected by a multimode optical fiber: the RAX Laser Assembly (RLA) and the RAX Spectrometer Module (RSM). The RLA is a highly miniaturized (51 × 61 × 19 mm) continuous-wave laser module with an excitation wavelength of 532 nm and a typical optical output of 20-30 mW. RLA was developed by the Spanish team led by the Instituto Nacional de Técnica Aeroespacial (INTA) and the University of Valladolid. The RSM is a compact spectrometer module equipped with a transmission grating, CMOS detector, and other relevant optics and electronics. It was evolved by the DLR Institute of Optical Sensor Systems (DLR-OS). RAX is designed to measure soil and rock beneath the rover at a working distance of 80 mm. Since the distance from RAX to the Phobos soil is unknown a priori, it is critical to finely focus the laser beam on the sample to obtain any Raman spectra. To achieve this, JAXA, the University of Tokyo, and Rikkyo University jointly developed a high-quality light collecting lens and laser focusing mechanism (Autofocusing Subsystem, AFS) as a part of the RSM. The AFS enables focus adjustment with a stroke of 13 mm and a precision of 20 μm. In addition to this fine-focusing capability, the rover locomotion system, including legs and wheels, raises and lowers the rover body to bring the sample into the stroke of the AFS. Taken together, the RAX instrument has a spectral range of 535 to 680 nm, corresponding to the Raman shift of 90-4000 cm⁻¹. This spectral range allows the identification of silicates, organics, and hydrous minerals. The spectral resolution of RAX is approximately 10 cm⁻¹ FWHM [Rodd-Routley et al. 2021]. This resolution is sufficient to resolve the strongest Raman band of olivine at 820 cm⁻¹ and 850 cm⁻¹. To test the performance of RAX during the cruise phase, a verification target (VT) made of KBr and deuterated PET is mounted on the MMX Rover Mechanical Electrical Communication and Separation Subsystem

(MECSS) [Moral et al. 2022]. The VT was provided by INTA and the University of Valladolid.

Verification and delivery of RAX: A study using a RAX-compatible breadboard model (BBM) showed that the Raman spectra of Phobos-relevant minerals can be obtained with a signal-to-noise ratio (SNR) of up to 100, depending on the mineral species [Cho et al. 2021]. The RAX-FM verification campaign showed that high-quality Raman spectra of the VT and other Phobos-relevant minerals were obtained under thermal vacuum condition at - 45°C [Hagelshuer et al. 2022; Schröder et al. 2023]. The RAX-FM was delivered to the rover in August 2022 and successfully integrated into the MMX rover in October 2022. The RAX development model (DM), which is the most FM-like instrument at DLR-OS [Schröder et al. 2022], will be used to measure Phobos-relevant samples in the laboratory to build the spectral library. The MMX rover will be delivered to JAXA in summer 2023.

[1] Michel P. et al. (2022) *Earth, Planets and Space* 74, 2. [2] Ulamec S. et al. (2022) 73rd Int. Astronautical Congress, IAC-22-A3.4A.7, [3] Hagelshuer T. et al. (2022) 73rd Int. Astronautical Congress, IAC-22-A3.4A.8. [4] Rodd-Routley S. et al. (2021) 52nd Lunar and Planetary Science Conference, 1923, [5] Moral A. G. et al. (2022) EPSC, 784. [6] Cho Y. et al. (2021) *Earth Planets and Space*, 73, 232. [7] Schröder et al. (2023) 54th Lunar and Planetary Science Conference, 2549 [8] Schröder et al. (2022) 53rd Lunar and Planetary Science Conference, 1915

Keywords: MMX, Raman spectroscopy