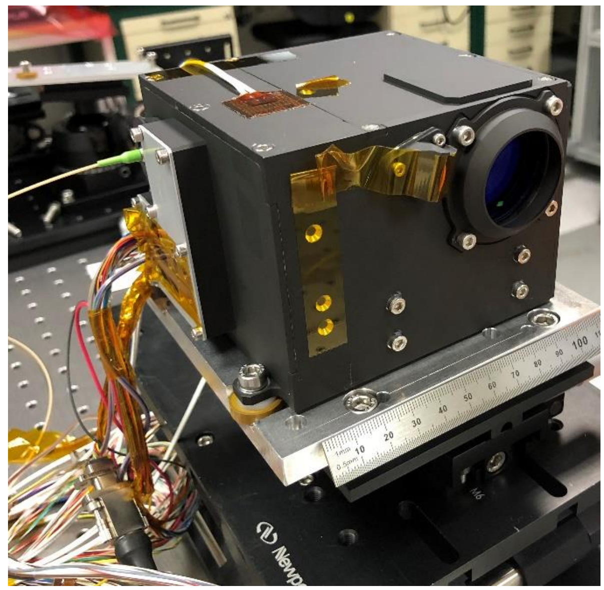
MEASUREMENTS WITH THE RAMAN SPECTROMETER FOR MMX (RAX) DEVELOPMENT MODEL. S. Schröder[1]*, U. Böttger[1], M. Buder[1], Y. Bunduki[1], Y. Cho[2], E. Dietz[1], T. Hagelschuer[1], H.-W. Hübers[1], S. Kameda[3], E. Kopp[1], A. G. Moral Inza[4], S. Mori[2], M. Pertenais[1], G. Peter[1], A. Pohl[1], O. Prieto-Ballesteros[5], S. Rockstein[1], S. Routley[1], S. Rufini[1], F. Rull[6], C. Ryan[1], T. Säuberlich[1], F. Schrandt[1], K. Westerdorff[1], K. Yumoto[2]. [1]German Aerospace Center (DLR), Institute of Optical Sensor Systems, Berlin, Germany. [2]Department of Earth and Planetary Science, The University of Tokyo, Tokyo, Japan. [3]Department of Physics, College of Science, Rikkyo University, Tokyo, Japan. [4]Instituto National de Técnica Aerospacial (INTA), Torrejón de Ardoz, Spain. [5]Centro de Astrobiologia (CAB-INTA-CSIC), Torrejón de Ardoz, Spain. [6]Universidad de Valladolid –Unidad Asociada UVa-CSIC Centro de Astrobiologia, Valladolid, Spain. (*Susanne.Schroeder[at]dlr.de).

Introduction: In 2024, JAXA's Martian Moons eXploration (MMX) mission will be launched with an orbiter and a rover dedicated to study Phobos and Deimos. The focus of the mission is on shedding light on the moons' origins [1,2] and samples will be brought from Phobos back to Earth. The small rover (about 29 kg) is a joint contribution of the Centre National d'Etudes Spatiales (CNES) and the German Aerospace Center (DLR) and will be delivered to Phobos presumably in 2027 to study in-situ the regolith at the surface [3]. The Raman spectrometer for MMX (RAX) [4,5] to study the mineralogy of Phobos' surface is jointly developed by DLR, Instituto Nacional de Tecnica Aerospacial (INTA), University of Valladolid (UVa) and JAXA, University of Tokyo, and Rikkyo University. We will report here on the first optical measurements done with the RAX Development Model (DM) at DLR.

Raman spectroscopy: Incoming photons of a laser are inelastically scattered by the sample and the spectral features in a typical Raman spectrum can be attributed to vibrational modes, giving information on the substance's structure and bonds. The fingerprint spectra can be measuered from minerals and molecules which allow for a straightforward identification. There is increasing interest in applying Raman spectroscopy in-situ for the analysis of extraterrestrial surfaces. Three Raman instruments with very different configurations have been developed for the two Mars rovers by NASA and ESA: NASA's Mars 2020 rover Perseverance has been analyzing its landing site at Jezero crater with a continuous wave (cw) deep UV Raman spectrometer attached to the robotic arm with a working distance of 48 mm [6] as well as a pulsed (532 nm) Raman instrument integrated into the SuperCam instrument suite on the rover's mast for remote analyses at distances of up to 12 m [7] since its landing in February 2021. The Raman Laser Spectrometer (RLS) on ESA's Rosalind Franklin ExoMars rover is designed to analyze samples obtained with the rover's drill, crushed and prepared inside the rover with a cw 532 nm laser, covering a spectral range of up to 3800 cm^{-1} with a spectral resolution of < 8 cm^{-1} [8] and will be launched to Mars in 2022.



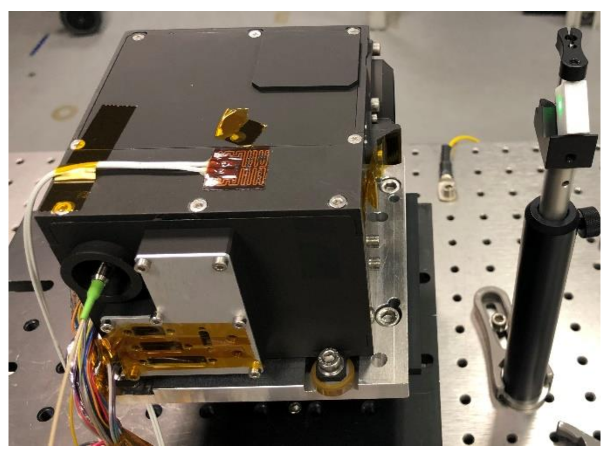


Figure 1. Top: *Picture of the RAX Spectrometer Module (RSM) Development Model (DM) close-up and* ***Bottom:*** *during measurement of the RAX instrument verification target.*

Raman spectrometer for MMX (RAX): RAX is a very compact, low-mass Raman instrument with a volume of approximately 81x98x125 mm³ (see Fig. 1) and a mass of less than 1.5 kg. Excitation is done in a cw configuration at 532 nm with a miniaturized laser unit that was initially developed by INTA and UVa for the RLS instrument aboard the Rosalind Franklin ExoMars rover. The optical design was driven by 1) the tight constraints of volume and mass available on the MMX rover and 2) optimizing the collection and detection capabilities of the Raman signal from a sample at several centimeters distance below the rover's body. The result is a highly sophisticated and very compact confocal optical assembly enabling the coverage of a spectral range up to 4000 cm^{-1} (535-680 nm) with a resolution of 10 cm^{-1}. The RAX instrument consists of two physically separated units, the RAX Laser Assembly (RLA) and the RAX Spectrometer Module (RSM). A multimode optical fiber with a core diameter of 50 µm is used to transfer the laser emission from the RLA to the RSM. Details on the instrument system and optical design can be found for instance in [4,9]. RAX will perform Raman spectroscopic measurements at a working distance of approximately 8 cm, which is roughly provided by the rover. The precise focus is then found with an integrated auto focusing system (AFS).

A lightweight, already space qualified CMOS detector with a mass of only 64 g and a volume of approximately 35 × 35 × 23 mm³ (3DCM734, 3Dplus [10]) is used for the detection of the Raman light. The CMOS sensor consists of 2048 × 2048 pixels with a pixel pitch of 5.5 µm.

Status: The RAX project is currently in its phase D with an expected delivery for the assembly, integration and testing (AIT) campaign on the MMX rover level in May 2022. The RAX Protoflight Model (PFM) is currently in its final AIT stages and will be subject to a protoflight level testing campaign. The optical performance of the RAX instrument has been already verified with a respresentative, optically equivalent, Development Model (DM) during earlier stages of the project.

Here, we will present Raman spectra obtained with the RAX DM (see Fig. 1) from different materials including the RAX verification target (VT). For the latter, polyethylene terephthalate (PET) was chosen as a relatively stable organic sample following its selection as a SuperCam calibration target on Mars in the form of the commercially available ertalyte [11]. The RAX VT will be measured in flight during the MMX cruise phase to Phobos to verify that the RAX instrument is working well after launch. Since it will be attached to the Mechanical Electrical Communication and Separation Subsystem (MECSS), which is a direct physical interface between the rover and the MMX spacecraft, the VT will not be accessible after rover separation which takes place prior to the landing on Phobos. RAX operations on Phobos are currently planned for 2027. The Raman spectra recorded by RAX will allow for the determination of the surface mineralogy on Phobos. Furthermore, a comparison of the RAX data with the results obtained by the RLS instrument during the ExoMars rover mission opens the path for revealing the origin of Mars and one of its moons.

Acknowledgements
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References:
[1] Kuramoto, K., Kawakatsu, Y., Fujimoto, M. and MMX study team, Martian Moon Exploration (MMX) Conceptual Study Results, 48th Lunar and Planetary Science Conference, Abstr. #2086, 2017. [2] Kawakatsu, Y., Mission Definition of Martian Moon Exploration (MMX), 70th Int. Astronautical Congress, 2019. [3] Michel P., Ulamec, S., Böttger, U., et al., The MMX rover: performing in situ surface investigations on Phobos, Earth, Planets and Space 74:2, 10.1186/s40623-021-01464-7, 2022. [4] Hagelschuer, T., Belenguer, T., Böttger, U., et al., The Raman spectrometer onboard the MMX rover for Phobos, 70th Int. Astronautical Congress, 2019. [5] Cho, Y., Böttger, U., Rull, F., Hübers, H-W. et al., In situ science on Phobos with the Raman spectrometer for MMX (RAX): preliminary design and feasibility of Raman measurements, *Earth Planets Space*, 73, 232, 2021. [6] Beegle, L., Bhartia, R., White, M., et al., SHERLOC: Scanning Habitable Environments with Raman & Luminescence for Organics & Chemicals, IEEE Aerosp. Conf. Proc., 2015. [7] Wiens, R., Maurice, S., Rull Perez, F., The SuperCam remote sensing instrument suite for the Mars 2020 rover mission : A preview, Spectroscopy 32, 2017. [8] Rull, F., Maurice, S., Hutchinson, I., et al., The Raman laser spectrometer for the ExoMars mission to Mars, Astrobiology 17, 627-654, 2017. [9] Rodd-Routley, S., Belenguer, T., Böttger, U., et al., Optical design and breadboard of the Raman spectrometer for MMX – RAX, 52nd Lunar and Planetary Science Conference, Abstr. #2548, 2021.[10] Sellier, C., Gambart, D., Perrot, N., et al., Development and qualification of a miniaturized CMOS Camera for Space Applications (3DCM734/ 3DCM739), Int. Conf. on Space Optics – ICSO, 2018. [11] Cousin, A., Sautter, V., Fabre, C., et a.., SuperCam calibration targets on board the Perceverance rover: fabrication and quantitative characteriziation, Spectrochim. Acta B, 106341, 2021