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Raman light scattering and thermal infrared spectroscopic studies of Phobos surface analogues: Towards the Martian Moon Exploration mission

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Planetary surface analogues of rocky celestial bodies play a crucial role for understanding the potential for spectroscopy payloads on robotic missions to objects in our solar system. Special surface simulants were developed for the Martian moon Phobos, in order to verify what insights into the history/origin of its formation can be gained from vibrational spectroscopy. The main scenarios considered are: the disintegrating of the parent planet by a giant impact (PGI); the gravitational capture of an asteroid from the inner or outer solar system (PCA) and co-accretion with Mars [1, 2]. The chemical composition of the Phobos soil will be probed in-situ using the Raman Spectrometer instrument (RAX) [2] on board of the lander of the JAXA Martian Moon eXploration (MMX) mission.

In this study, we investigated the ability of Raman scattering spectroscopy and mid-infrared (MIR) reflectance spectroscopy to resolve differences in the chemical composition of selected Phobos surface simulants. Our work shall support the understanding of in-situ Raman spectroscopy data derived during the soon-to-be-launched MMX mission, as well as provide a motivation to develop infrared reflectance and/or emission instrumentation for future missions to rocky celestial bodies, operating over a wavelength range of 8-18 µm.

Phobos simulants. Natural minerals and coal from the collection of the Institut für Planetologie were used to prepare the Phobos surface simulants of the PCA (#711) and PGI (#712) types. The original solid samples were first crushed and sieved to produce size fractions in the range of 63-125 µm. This is consistent to the fine silicates with the thermal inertias like determined by infrared radiometry of Phobos [3]. The powder mixes were then prepared to match the mineral abundances as in [4]. Both simulants contain phyllosilicates, olivine, sulfates, sulfides and oxides as well as carbon, in different weight percentages, while pyroxene at 17 wt% is present only in the PGI simulant.

Simulated space weathering.

The alteration of Phobos surface is likely primarily due to solar wind plasma and small-size hypervelocity impacts from micrometeorites, similar to atmosphere-less planetary bodies. Due to the moon's proximity to Mars, the latter includes also particles ejected from the Martian surface. Micrometeorite bombardment is regularly simulated by pulsed laser irradiation, with the mean impact energy roughly equal to the pulse energy [5]. We used a 8 ns pulsed NdYAG laser operating at 1064 nm. The pulse energy was varied (0.1 mJ, 1 mJ, 10 mJ) for different irradiated areas on the samples (Fig. 1).

The MIR reflectance spectra were recorded in specular reflection mode at 13° angle. The spot size on the sample was varied between 5.2 to 4.6x4.5 mm^2. The choice of the spectral range (2-18 µm) was motivated by coverage of the strongest reflectance features of minerals, such as Reststrahlen bands and Christiansen features (CF) [6].

As the different bands resolved in the PCA to PGI reflectance spectra, we can point out a few weak features of enstatite, that stand out and are distinguishable between the PGI and PCA samples: the Si-O-Si bending modes in the 13-15 μm region and the metal-OH bands at around 2.3 μm (Fig. 2). The most pronounced spectral features, such as stretching absorption bands and the CF of enstatite, cannot be differentiated because of overlapping bands of other silicates present.

Raman spectroscopy of the sample surface was performed in the wavelength range 535-666 nm of Stokes shifted light. The 532 nm laser has a spot of 1.5 μm on the sample; mapping was with different step sizes down to 10 μm. The RAX instrument of the MMX mission uses the same wavelength range, and has a similar spectral but lower spatial resolution (50 μm).

Raman microscopy resolves all phases in both the original and the altered samples (Fig. 3). This includes the observation of metamorphic changes, amorphization, and evolution of the original mixes in the grain size.

Implications to in-situ analytical instrumentation.

For the Phobos simulants in this study, thermal infrared spectroscopy (Fig. 2) shows capability in resolution of pyroxene, limited to relatively weak internal bending modes of silicates, and generally only in areas of low alteration. Given the significant progress in modern development of sensitive, space-qualified MIR detectors or new time-domain spectroscopy approaches [7], one may assume the arrival of advanced instrumentation for fingerprinting infrared-active resonances that can significantly improve accuracy of mineral identification, compared to the visible and near-infrared spectral ranges.

Raman microscopy resolves all phases under spatial resolution below 20-30 μm in the impact craters and around. Averaging spectra across 50-100 μm size areas (the sampling size range of the RAX instrument [2]) can result in reduction of Raman signal contrast at locations with multiple phases, particularly if these are poorly represented or exhibit strong luminescence (Fig. 3).

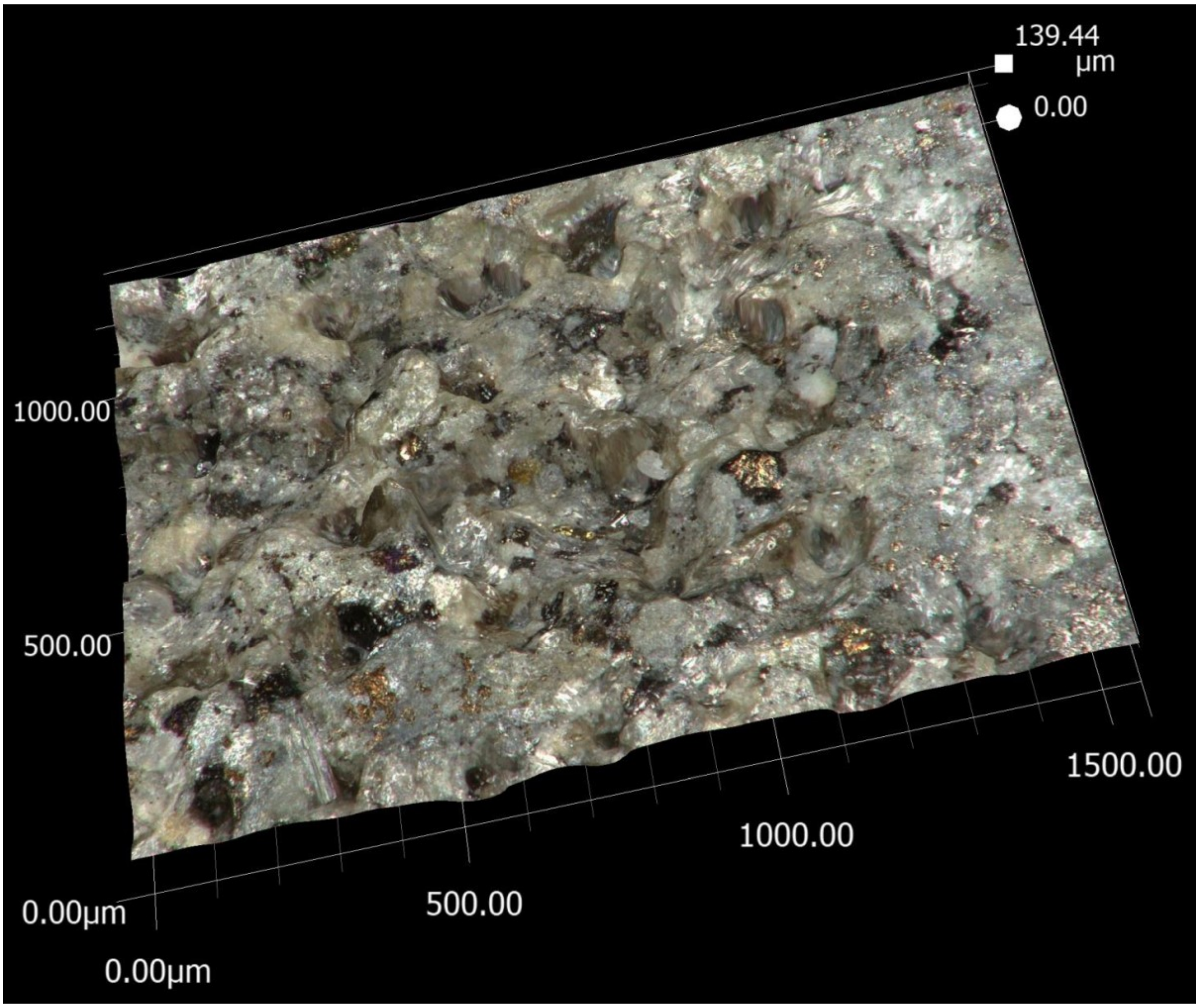

Fig. 1. Microscope image of the section of a Phobos surface simulant (sample 712) after irradiation with 1 mJ pulses in a 250 x 300 µm grid.

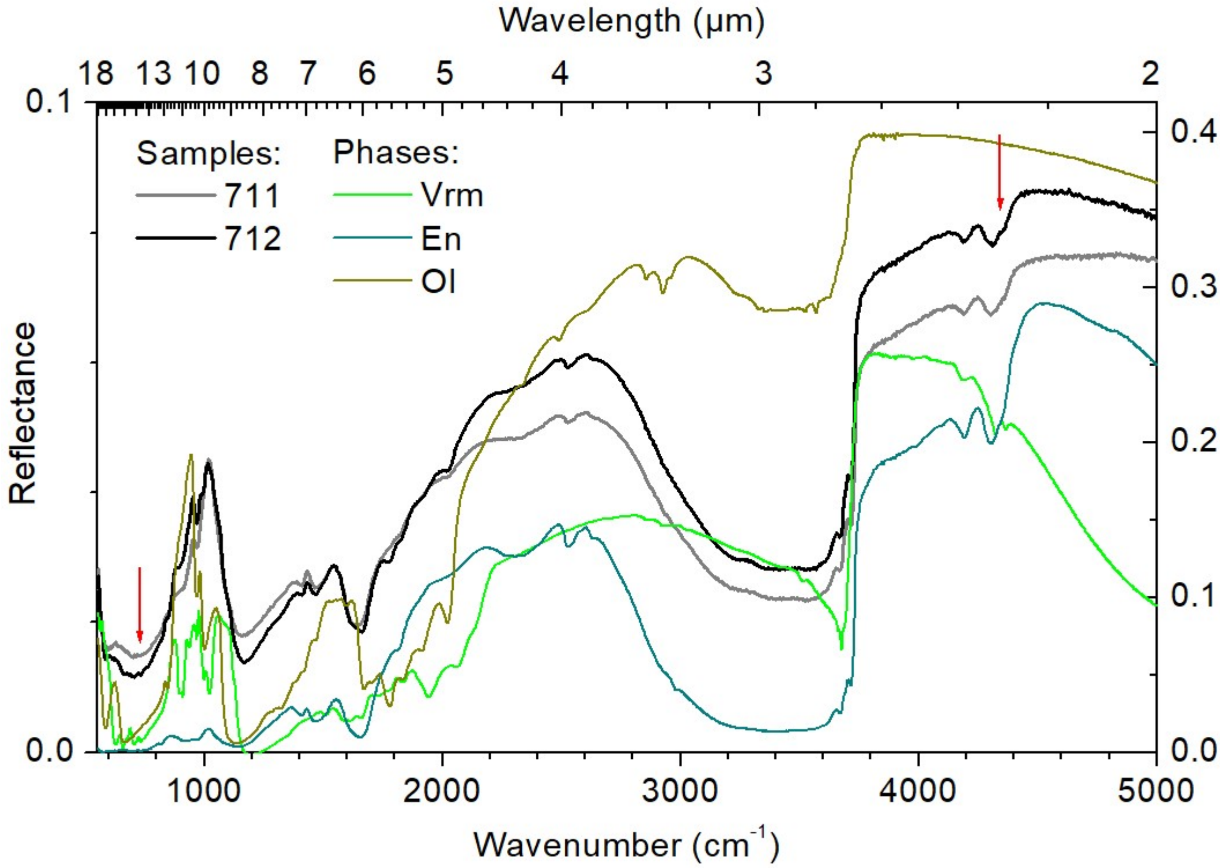

Fig. 2. Infrared reflectance spectra of Phobos surface simulants before compression into pellets used for laser irradiation (left Y-axis), compared with individual spectra of contributing silicates (right Y-axis). The red arrows indicate the selected wavelength ranges in which fingerprints of the characteristic enstatite bands remain distinguishable.

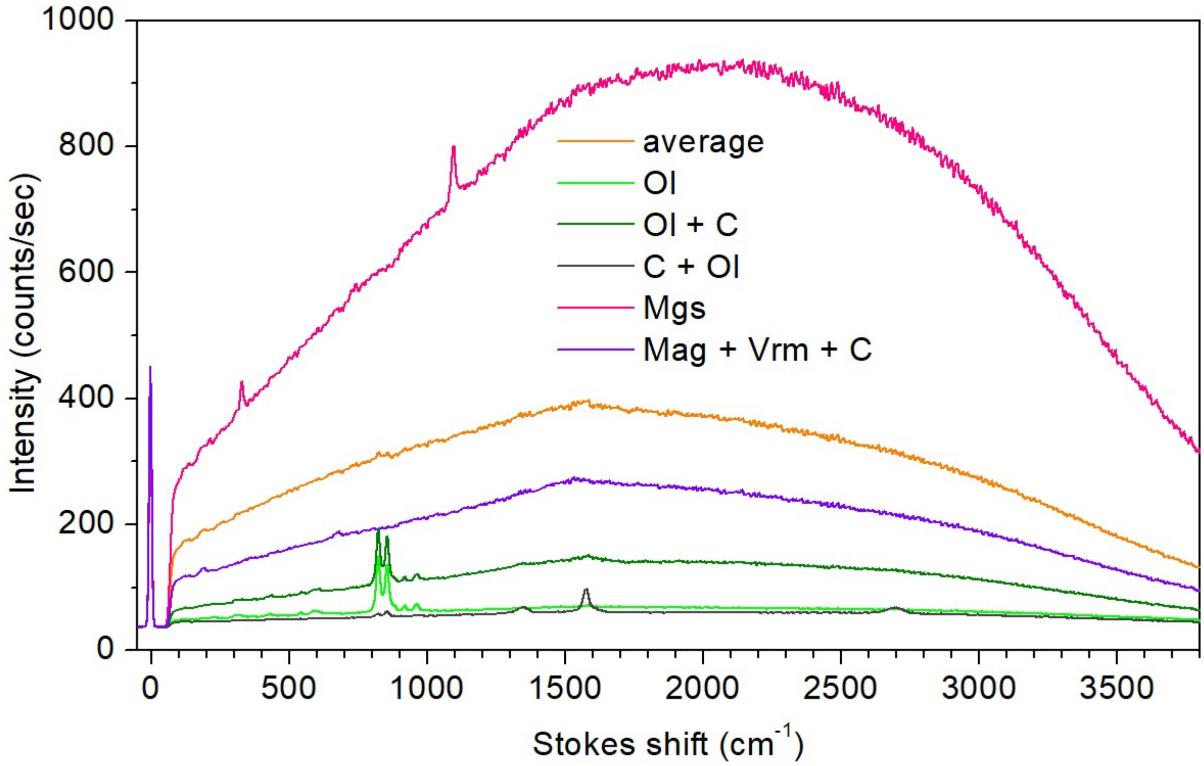

Fig. 3. Raman spectra of the Phobos surface simulant 712 recorded as 100 µm x 100 µm map in a crater produced by the energy 1 mJ, step of 10 µm. The signal averaged over 100 points in the map center loses most of the spectral features of the mineral phases present.

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