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## Space weathering of nontronite and goethite minerals simulated by laser irradiation: preparation for future MIRS observations on Phobos and Deimos

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**Introduction:** The hyper-spectral imaging spectrometer MIRS [1] is part of the Martian Moon eXploration (MMX, [2]) probe, scheduled to be launched toward the Martian system in 2026. MIRS will observe Phobos and Deimos' surfaces in the 0.9-3.6  $\mu\text{m}$  spectral range to bring new constraints on their surface composition. Up to now, VNIR observations of the two satellites revealed red spectra, with only weak absorption features at about 1  $\mu\text{m}$  [3] and 1.9  $\mu\text{m}$  [4] probably linked with mafic minerals; as well as weak ones at 0.65 and 2.8  $\mu\text{m}$  [5], possibly due to structural OH- in a desiccated phyllosilicate such as nontronite, or by OH- implanted from solar wind. CRISM spectra also revealed an absorption at 3.2  $\mu\text{m}$  whose origin remains unclear [6], possibly linked either to calibration artifacts or mineral species (e.g., organic compounds or goethite [7]). Thermal infrared observations (10-35  $\mu\text{m}$ ) show several spectral features consistent with feldspars/feldspathoids, along with phyllosilicates [8] for which, biotite and antigorite provide very good spectral matches.

For air-less bodies, like Phobos and Deimos, the optical/chemical/mineralogical properties of the surface can be modified by space weathering effects that include micrometeoritic bombardment and charged particle irradiation. Previous studies have shown that micrometeoritic bombardment simulation can result in darkening and/or reddening of the reflectance spectra, reduce the intensity of particular absorption bands or slightly shift the position and width of absorption bands (e.g., [9, 10, 11]).

In this experimental study, we explore the effect of micrometeoritic bombardment on some mineral phases relevant to Phobos and Deimos surfaces, in order to prepare future investigations of the moons surface with the MIRS.

**Method:** Two samples were selected including one iron-bearing phyllosilicate (nontronite) and one iron oxyhydroxide (goethite). To simulate micrometeorite impacts on these samples, we performed pulse-laser shock experiments (figure 1) using the LIBS suite of the SuperCam spare [12, 13] from the IRAP laboratory (Toulouse, France). The samples are located in a vacuum chamber, enabling to

reach a pressure of around  $10^{-3}$  mbar and approach the low oxygen fugacity conditions at the surface of the martian moons. The Nd: YAG laser beam of SuperCam delivers energy pulse of 10.7 mJ at 1064 nm, with a pulse duration of 4 ns and a laser spot of  $\sim 300$   $\mu\text{m}$  in diameter. A matrix of 9x9 shots was realized on each sample. We carried out grids of 1 shot and 3 laser shots repeated at the same location. Before and after irradiation, the reflectance spectra of the samples were acquired from 0.5 to 3.6  $\mu\text{m}$  using the SHADOWS spectrogoniometer at IPAG (Grenoble, France) with an illumination spot of  $\sim 1.3 \times 1.7$  mm in diameter [14].

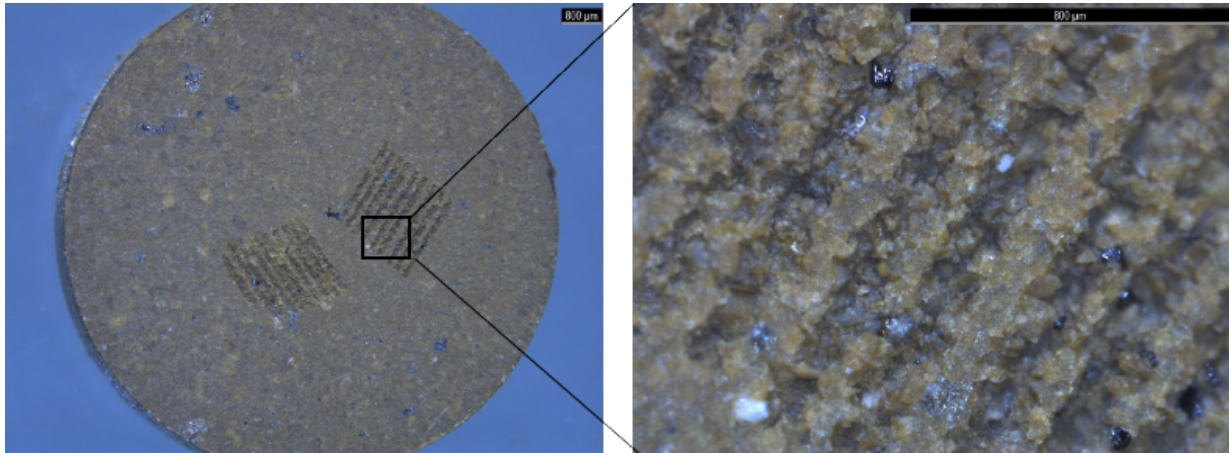


Figure 1: Nontronite pellet irradiated showing the laser pits for 9x9 matrix of 1 and 3 shots at the same location. The image on the left shows a zoomed-in version of the 3 shots grid.

**Preliminary results:** A comparison between unaltered and irradiated samples is presented in figure 2. For irradiated nontronite, the VNIR part of the reflectance spectra displays a decrease in the overall intensity as the number of shots increases. The strength of the absorption band linked to the  $\text{Fe}^{3+}$  electronic transition near 0.65  $\mu\text{m}$  is reduced by 10.6% and 20.5%, after simulated irradiation of 1 and 3 shots respectively. In addition, we observed a slight shift of 10 nm of the band center after 3 shots (0.64  $\mu\text{m}$ ). Similar observation holds for the  $\text{Fe}^{3+}$  associated absorption near 0.97  $\mu\text{m}$ , with the same band depth reduction (10.0% and 20.8%), and a similar small shift of 10 nm toward lower wavelength after 3 shots. Conversely, we notice no shift of the 1.43  $\mu\text{m}$  ( $\text{H}_2\text{O}/\text{OH}$  features), 1.92  $\mu\text{m}$  ( $\text{H}_2\text{O}$  features), and 2.29  $\mu\text{m}$  ( $\text{Fe}^{3+}$ -OH vibrations) band positions. If the strength of the 1.43  $\mu\text{m}$  decreases with an increasing shot number (5.3% and 18.9%), for the 1.92 and 2.29  $\mu\text{m}$ , 1 shot produces no significant change, and 3 shots slightly reduces the depth of the bands (respectively 7.0% and 5.9 %). The effect of irradiation on goethite is much more drastic. Spectra show flattening and darkening in the visible–near-infrared range. The iron band at 0.66  $\mu\text{m}$  is reduced by 72.5% after 1 shot, and by 90.8% after 3 shots with a shift of 20 nm toward lower wavelength for the latter. The 0.97  $\mu\text{m}$  absorption band broadens after irradiation, and the minimum shifts to 1.04 and 1.0  $\mu\text{m}$  after 1 and 3 shots. Absorption bands linked to water and hydroxyl seem to have mostly disappeared, or strongly reduced as for the  $\text{H}_2\text{O}/\text{OH}$  features at 1.43 and 3.1  $\mu\text{m}$  corresponding to the stretching mode of the hydroxyl groups. In this area, there is an upturn at 3.13  $\mu\text{m}$  for unaltered goethite, which begins at 3.2  $\mu\text{m}$  after irradiation.

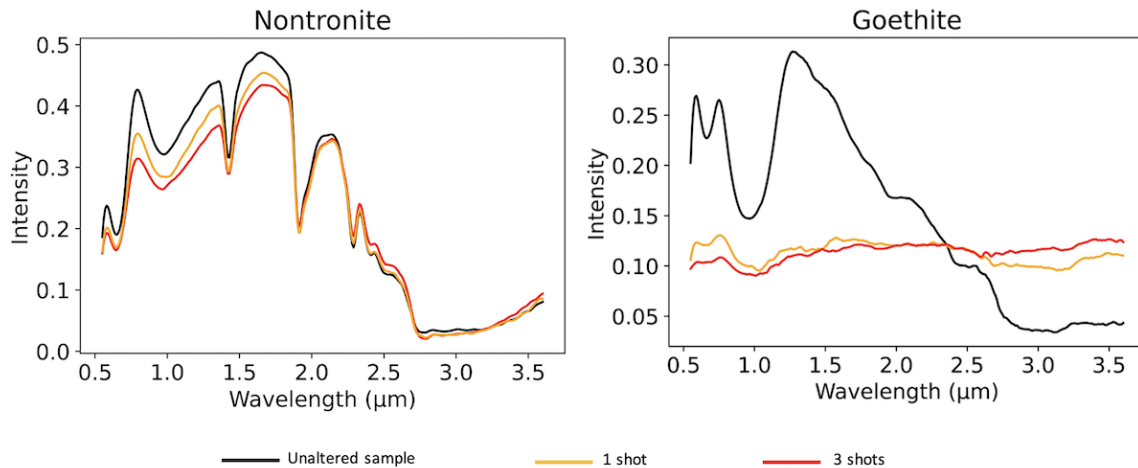


Figure 2: Spectra of nontronite and goethite minerals before and after laser ablation experiments.

**Summary and perspective:** Our experiments show different behaviors between nontronite and goethite after laser shock alteration. In the case of nontronite, the absorption bands linked to  $\text{Fe}^{3+}$  are more impacted by irradiation than  $\text{H}_2\text{O}/\text{OH}$  features. Conversely, in the case of goethite, the two iron bands at 0.65 and 0.97  $\mu\text{m}$  are strongly impacted but remain visible whereas  $\text{H}_2\text{O}/\text{OH}$  features mostly disappear. This result suggests that the observation of  $\text{H}_2\text{O}/\text{OH}$  features related to goethite on airless bodies exposed to micrometeorite impacts like Phobos and Deimos, is unlikely.

Additional samples will be studied in the future using the same protocol, in particular other phyllosilicates (biotite, antigorite and montmorillonite), as well as an unweathered basalt, to investigate further the effect of micrometeorite bombardment into mineral phase signatures.

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