VISIBLE SPECTRO-PHOTOMETRY OF DRY, WET AND FROZEN MARS SOIL ANALOGS. A. Pommerol[1], N. Thomas[1], B. Jost[1], P. Beck[2], C. Okubo[3], A. S. McEwen[4], M. Massé[5], M. R. El-Maarry[1], [1]Physikalisches Institut, Universität Bern (antoine.pommerol@space.unibe.ch), [1]IPAG, CNRS/Université Grenoble 1, France, [3]U.S. Geological Survey, Flagstaff, AZ, USA, [4]Lunar and Planetary Laboratory, University of Arizona, Tucson, AZ, USA, [5]IAS, CNRS/Université Paris 11, Orsay, France.

Introduction: Many observations of the Martian surface rely on the analysis of the solar light scattered by materials that compose its uppermost layer. Therefore, a good understanding of this process, through physical modeling and/or laboratory experiments, is crucial for detailed analyses of remote-sensing datasets. We report here on a series of laboratory measurements of analog materials, which addresses the following questions of prime interest for the Mars remote-sensing community:

- Is it possible to distinguish compositional and textural effects when studying the bidirectional scattering behavior of dry analogs of the Martian surface?
- How reproducible are the bidirectional reflectance curves measured in the laboratory and reported in the literature?
- What changes of color, albedo, and bidirectional behaviour would result from the transient presence of concentrated brines in the Martian regolith?
- Can one find unambiguous photometric signatures of the presence of liquid water in regolith analogs, in the bidirectional scattering behavior of visible light?
- What can the bidirectional scattering behavior of icy samples tell us about the physical state of the ice in the regolith?

Our own interest for these questions is essentially motivated by the analysis of images currently returned by the HiRISE and CRISM instruments on board MRO, and by the current development and construction at the University of Bern of the CaSSIS imaging system for the Exomars 2016 Trace Gas Orbiter. Of particular relevance for this work is the interpretation of the Recurring Slope Linae (RSLs) observed by HiRISE [1].

Methods: Data presented here were all measured in the Planetary Ice Laboratory at the University of Bern [2] on two complementary instruments. The PHIRE-2 radio-goniometer operated either at -30°C in a cold room for icy samples or at ambient temperature (+20°C) for ice-free samples was used to measure bidirectional reflectance over wide ranges of incidence, emission and phase angles. Reflectance values were measured inside six discrete bandpasses between 400 and 1100nm. To complement these data, we have recently built a laboratory spectral imager able to record hyperspectral images of 10cm-wide samples in the spectral range: 400-2400nm, thus offering higher spectral resolution than the PHIRE-2 instrument but restricted to a few fixed incidence and emission directions, at low to moderate phase angle. The samples can be placed in a chamber where temperature and pressure conditions are controlled and imaged through a transparent window.

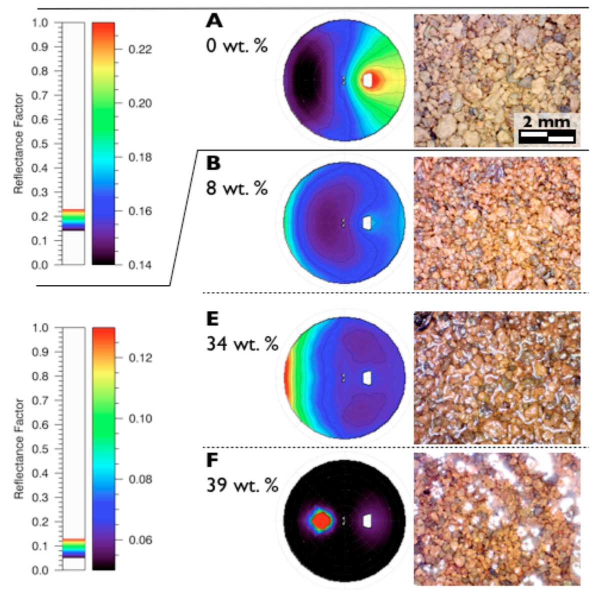

Figure 1: Evolution of the bidirectional reflectance of the JSC Mars-1 regolith simulant for increasing amounts of liquid water (four selected steps, A to F). The polar plots represent the reflectance of the surface for various emission and azimuth angles and for a fixed incidence angle: i=30° (see also the 3D representation on figure 2). The white spot on the right of the polar plot is the direction of incidence where no measurement was possible at the time of this study.

Samples were all prepared from two rocky components: the JSC Mars-1 regolith simulant [3] and Hawaiian basaltic sand. The samples were wetted by spraying fine droplets of liquid water over the surfaces. For experiments involving brines, we used ferric sulfate, sodium and calcium chloride as salts. Various techniques were used to produce different types of icy samples, for example by freezing wet samples or by letting atmospheric water condense onto cold mineral surfaces. The measured reflectance data were then fitted by the Hapke reflectance model to retrieve sets of parameters that can be used to reproduce our data and interpolate them to non-measured geometries [4].

Results and discussion: The comparison of dry surfaces prepared from the same JSC Mars-1 regolith simulant but with different preparation procedures illustrates the influence of the surface texture at millimetre-scale on the bidirectional reflectance of samples.

These effects certainly account for the slight differences seen when comparing measurements of JSC Mars-1 obtained by different teams with different instruments and procedures (for example: [5]).

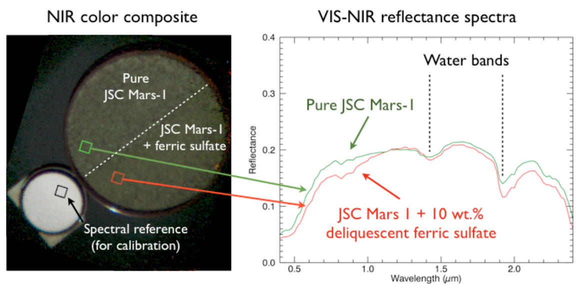

Figure 2: Example of hyperspectral data showing a comparison between the spectrum of pure JSC Mars-1 and the spectrum of JSC Mars-1 mixed with 10 wt. % of deliquescent ferric sulfate.

The results of measurements on wet samples complement the previous study by [6] and show the strong influence of water not only on the overall level of reflectance of the samples but also on the shape of their phase function (Figure 1). Our observations provide interesting opportunities for placing additional constraints on the presence of liquid water in the Martian regolith from sets of images obtained under different measurement geometries. In particular, it appears that the opposition peak is extremely sensitive to the presence of water, even in low amount. Its absence would thus be a good indicator of the presence of liquid water. The presence of liquid water also results in the appearance of a forward scattering peak whose intensity depends on the amount of water. However, observations of the Martian surface in the forward scattering direction are more difficult to interpret because of the stronger contribution of atmospheric aerosols to the observed reflectance in this geometry.

In addition to measurements of samples wetted with pure water, we have started to characterize samples wetted with concentrated brine solutions. We would like to complement the new VIS measurements of the study performed in the NIR by [7]. Figure 2 shows an example of hyperspectral measurement of a sample of JSC Mars-1, partially mixed with ferric sulfate. As the relative humidity in the chamber was increased above 60%, the ferric sulfate became deliquescent and the spectrum of the sample changed in subtle ways, both in the visible and near-infrared ranges. We use these hyperspectral data to simulate the color that would be observed by HiRISE or CaSSIS when imaging such a material to facilitate the comparison with current and future color images of RSL areas.

Associations between water ice and minerals can result in very diverse photometric behaviors depending on the state of water ice in the sample. In particular, ice deposited as frost on the surface of the grains results in the appearance of a forward scattering peak whereas samples prepared by freezing surfaces containing liquid water all show a specular peak and a significant side scattering. The most characteristic photometric behavior observed for dry, wet and frozen samples are summarized in figure 3.

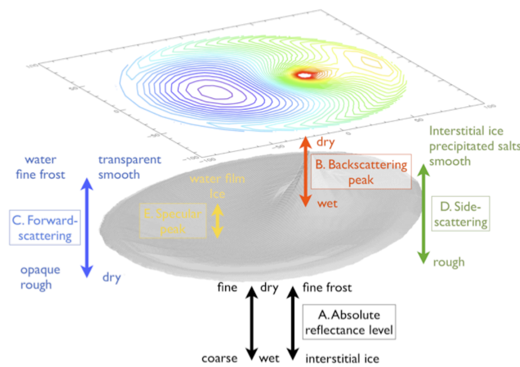

Figure 3: Schematic summary of the various photometric effects evidenced in this study. The 3D surface represents the typical bidirectional reflectance of a JSC Mars-1 dry sample for incidence: i=30°.

Future observations: At equatorial latitudes, briny water is only stable at the surface in the early morning [8], which prevents its direct observation over RSLs by MRO (which can observe only in the mid-afternoon). The CASSIS camera on ESA's Trace Gas Orbiter will have the capability to observe the surface of Mars at different times of day and will be able to observe the backscattering peak for regions within 25° of the equator where many RSLs are found [1], providing new clues about the possible role of liquid water.

References: [1] McEwen A. S., et al. (2013) Nat. Geo., 7, 53-58. [2] Pommerol, A., et al. (2011) Planet. and Space Sci, 59, 1601-1612. [3] Morris, R. V., et al. (2001) JGR, 106, 5057-5083. [4] Pommerol, A., et al. (2013) JGR, 118, 2045-2072. [5] Johnson, J. R., et al. (2013) Icarus, 223, 383-406. [6] Gunderson, K., et al. (2007) Planet. and Space Sci., 55, 1272-1282. [7] Massé et al. (2012) LPSC #43, Abstract #1649. [8] Gough, R. V. et al. (2011) Earth and Planet. Sci. Let., 312, 371-377.