"IT'S ONLY A MATTER OF PERSPECTIVE": BIDIRECTIONAL REFLECTANCE SPECTROSCOPY OF SMALL BODIES AND METEORITES. S. Potin[1], P. Beck[1], B. Schmitt[1]. [1]Institut de Planétologie et Astrophysique de Grenoble (IPAG, Université Grenoble Alpes, CNRS), 414 rue de la Piscine, 38400 Saint-Martin d'Hères, France (sandra.potin@univ-grenoble-alpes.fr)

Introduction: Reflectance spectroscopy is commonly used to analyze the composition of distant airless small bodies, as the spectral slope and absorption features, if detected, are characteristics of the mineralogy and structure of the surface. Several asteroid classifications are based on the shape of the reflectance spectra in the visible and near-infrared region [1,2].

It is established that the reflectance of a surface depends on the geometry under which it is measured, the first example being the photometric phase curves, presenting the general albedo as a function to the phase angle [3].

We propose to analyze the geometry dependency of all the spectral characteristics (photometry, slope and absorption bands) using bidirectional reflectance spectroscopy measurements.

Samples: Meteorites are the best "accessible" analogues of the Solar System small bodies. Their reflectance spectra match those of their parent bodies, and each of the different petrologies represents a specific class of asteroids [4].

We chose several meteorites, of different petrologies and alteration histories. All samples were manually ground but not sieved to keep a wide distribution of grain sizes. A few samples were large enough to perform a first BRDF measurement on the intact rock.

Measurements: We used the home-made spectrogonio radiometer SHADOWS [5] at IPAG. This instruments generates a monochromatic light between 340 nm and 5000 nm and illuminates the sample under a given direction (incidence angle). The reflected light is measured by two detectors under another direction (emergence angle). The detectors can also rotate around the sample to measure the reflectance at a given azimuth angle. The three parameters, incidence, emergence and azimuth angles, constitute the geometrical configuration of the reflectance measurement. The phase angle g corresponds to the angle between the direction of illumination and the emergence angle in the plane comprising both vectors and can also be used as a representative of the geometry.

All the meteorites were studied under 70 different geometrical configurations: 14 emergence angles for each of the 4 selected incidence angles (from nadir illumination to 60°) in the principal plane, and 14 emergence angles with an incidence of 20° and an azimuth of 30° outside the principal plane.

The measured reflectance is determined relative to measurements of calibrated Spectralon® and Infragold® reflectance targets.

Results: For each sample, we analyze the effect of the measurement geometry on all the characteristics of the reflectance spectra.

Photometry. The variation of photometry with the geometry is investigated through the bidirectional reflectance distribution function (BRDF). The BRDFs are plotted using a polar representation, where the angular position of the dot corresponds to the geometry of the measurement, and its distance from the center represents the measured value of the reflectance (see Figure **1**). Using this representation, the BRDF of a perfectly lambertian surface will appear as a semi-circle.

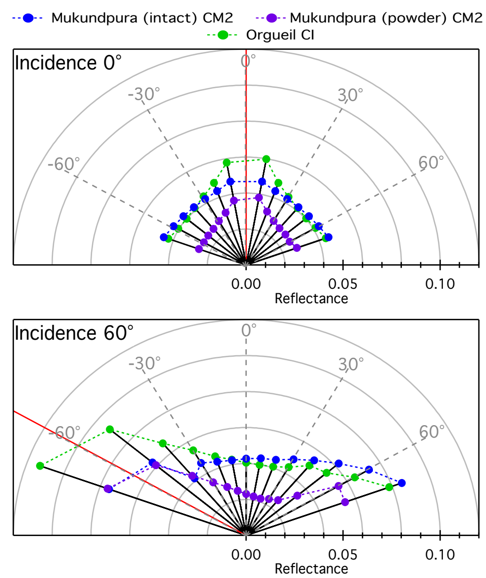

Figure 1: BRDF of the intact sample of Mukundpura (blue) and the ground meteorites Orgueil (green) and Mukundpura (purple). The redline depicts the incidence angle.

The photometric results show that the BRDF of a surface depends mostly on the roughness of the surface, not its mineralogical composition. Two powders will present similar BRDFs behavior with a strong backscattering, independently of its general albedo, but will differ from a intact bloc displaying a stronger forward scattering behavior.

Spectral slope and reddening. The spectral slope is calculated as the ratio between the reflectances measured around 500nm and 2000nm, outside of possible absorption features at these wavelengths. A spectral slope greater than 1 suggests a rather red sample, while a slope smaller than 1 indicates a blue spectrum (see Figure **2**).

The spectral reddening represents the evolution of the slope with the geometry. It is calculated as the ratio between the slopes at a given phase angle g and at the smallest phase angle available.

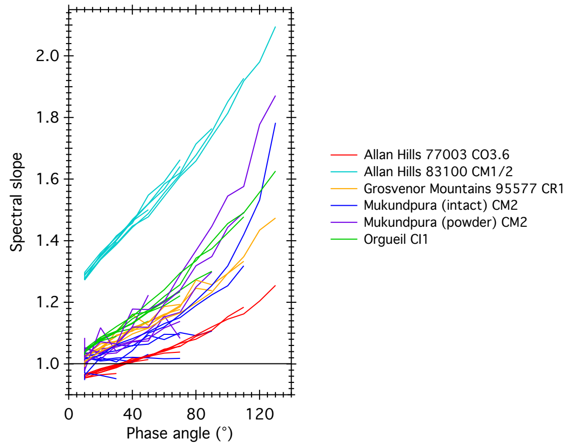

Figure 2: Variation of the spectral slope with the phase angle of the measurement. For a given meteorite, the multiple lines correspond to the forward and backward scattering with different incidence angles.

All samples present an increase of the spectral slope with increasing phase angle. This effect called phase reddening has already been observed on asteroids [6,7].

For a few samples, the reddening does not depend only on the phase angle, but also on the incidence angle. This effect is clearly marked for the intact sample of the Mukundpura meteorite (see Figure 3).

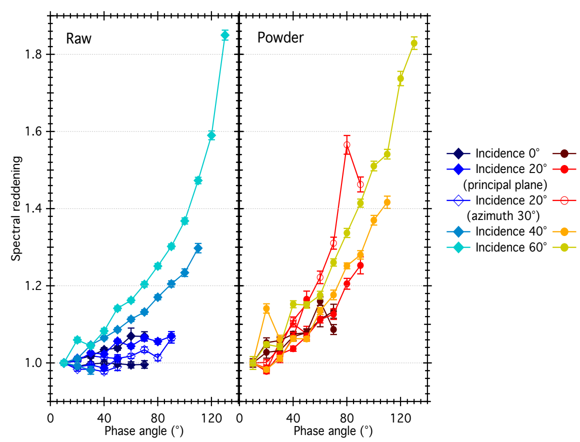

Figure 3: Spectral reddening of the intact Mukundpura meteorite (raw: left panel) and the ground sample (powder: right panel)

Absorption features. The depth of the absorption bands is also geometry dependent. For each feature strong enough to be detected, the band depth is calculated as

$$BD = 1 - R^{band}/R^{continuum}$$

with R^{band} the reflectance of the sample at the center of the absorption feature, and $R^{continuum}$ the calculated reflectance of the continuum at the same wavelength. We considered a linear continuum between the two inflexion points of the band.

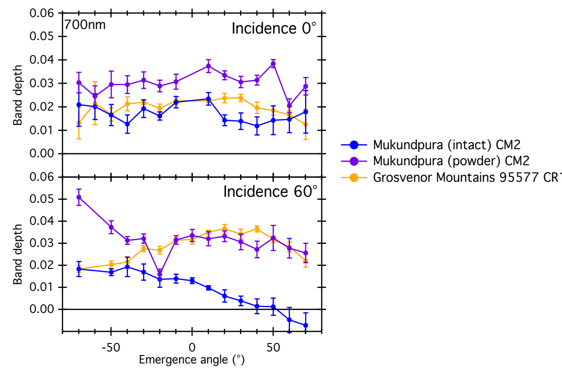

Figure 4: Example of variations of the depth of the 700nm band for two meteorites. Note that the band disappears from the spectra at incidence 60° on Mukundpura (intact).

The depth of the absorption features is impacted by the increasing phase angle, but no general trend is observed. The actual behavior depends on the band as well as the sample. In some cases, such as Mukundpura, the band gets fainter and fainter, until it becomes undetectable.

Conclusion: Bidirectional reflectance spectroscopy of meteorite shows an important dependency on the geometry of the measurement. All characteristics of the spectra are impacted: the photometry changes according to the incidence and emergence angles, and with increasing phase angle, the spectra tend to become redder and sometimes to present shallower absorption features. The geometry affects strongly the shape of a reflectance spectrum and so has to be taken into account during in situ or ground-based spectroscopy.

References: [1] Bus S.J. and Binzel R.P. (2002) *Icarus, 158,* 146-177. [2] DeMeo F.E. et al. (2009) *Icarus, 202,* 160-180. [3] Lane A.P. and Irvine W.M. (1973) *APJ, 78,* 267-277. [4] Vernazza P. and Beck P. (2015) *Planetesimals, chap.16,* 269-297. [5] Potin S. et al. (2018) *Applied Optics, 57,* 8279–8296. [6] Gehrels T. et al. (1970) *APJ, 75,* 186-195. [7] Binzel R.P. et al. (2015) *Icarus, 256,* 22-29.