Photometry of particulate mixtures: new insight from simulations of light scattering in a compact granular medium. C. Pilorget[1], J. Fernando[2], B.L. Ehlmann[1,3] and S. Douté[4], [1]California Institute of Technology, 1200 E. California Blvd., MC150-21, Pasadena CA 91125 USA, [2]IDES, Université Paris-Sud 11, Orsay 91405 France, [3]Jet Propulsion Laboratory, Caltech, Pasadena, CA 91109, USA, [4]Institut de Planétologie et d'Astrophysique de Grenoble, Univ. Joseph Fourier, Grenoble 38041, France. (cpilorge@caltech.edu)

Introduction: As solar light penetrates into the surface, it is partially reflected back by interaction with its constituents and structures. The amplitude and angular distribution of this signal, as well as its evolution with the light wavelength give essential information about the physical and compositional properties of this surface. A body of work has been made through the development of models and experimental work to better understand how the surface properties affect the light scattering (e.g. [1,2,3,4,5,6,7,8]). In particular, it has been shown that looking at the amplitude and angular distribution of the scattered light at a single wavelength (generally in the visible) gives constraints on: 1) the absorptivity of the medium, 2) the size, shape and internal structure of the grains and 3) the spatial organization of the grains through different parameters (single scattering albedo, phase function, surface roughness, opposition surge and porosity). Photometry has therefore been used for decades to characterize the surface of the Moon (e.g. [9,3,10,11]), asteroids (e.g. [12,13,14,15,16,17]) and planets (e.g. [18,19,20,21,22,23]).

In particular, the forward/backward scattering behavior of the surface, characterized through the shape of the phase curve, is directly related to the grain shape and internal structure [24,25,26,27,28,29], and therefore to the formation and alteration history of the grains. These properties are thus critical to interpret the geological and climatic processes that were or are currently at stake on the parent body. However, little is known about what controls the overall phase curve in a natural sample made of different grains with specific composition, phase function and grain size distribution. We tend to address this question in this study using numerical modelling to simulate the radiative transfer within different kinds of mixtures (spatial, intimate and layered).

Model: The radiative transfer model from [8] is used to perform the different simulations. The model simulates light scattering in a compact granular medium using a Monte-Carlo approach. The approximation of geometric optics is assumed. The physical and compositional properties of the sample are specified at the grain scale, thus allowing to simulate different kinds of heterogeneities/mixtures within the sample. The radiative transfer is then calculated using a ray tracing approach between the grains, and probabilistic physical parameters such as a single scattering albedo and a phase function at the grain level. The bidirectional reflectance is then computed for different geometries covering the entire upper half-space, as illustrated in Fig. 1. The single scattering albedo ω is calculated from [1] and a two-lobe Henyey-Greenstein phase function is used in the model:

$$p(\beta) = \frac{1+c}{2}\frac{1-b^2}{(1+2b\cos\beta+b^2)^{3/2}} + \frac{1-c}{2}\frac{1-b^2}{(1-2b\cos\beta+b^2)^{3/2}} \quad (1)$$

with $0 \leq b < 1$. The first term of Eq. 1 describes a back scattered lobe and the second term a forward scattered lobe. The parameter b describes the angular width of each lobe, whereas the parameter c describes the amplitude of the back scattered lobe relative to the forward. The reflectance, obtained for various geometric configurations, are then inverted to obtain the photometric parameters of the mixture (ω, b, c). We focus in what follows on the phase curve shape, thus on the parameter c, which is particularly affected by the grain shape and internal structure.

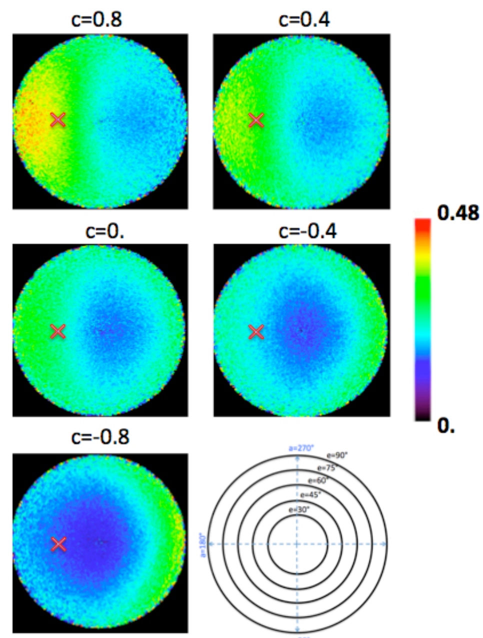

Fig 1. Spatial evolution (emergence and azimuth) of the reflectance factor for different forward and backward scattering media assuming a two-lobe Henyey-Greenstein phase function, as described by Eq.1, with parameter b=0.2 and various c. The grain size distribution follows a lognormal law centered in 70 µm. The optical index is given by n=1.4+2.10^{-4}i and the porosity is set to 0.5. Emergence angle is radial from the center of the plot, 0° at center, 90° at perimeter. Azimuth angle is clockwise from far right. The direction of the incident light is indicated by a red cross (incidence

angle of 45°).

Results: Various spatial, intimate and layered mixtures were tested. We discuss here the case of spatial and intimate mixtures.

Spatial mixtures are referred to as mixtures where a large majority of photons only interacts with one of the compounds. The resultant number of scattered photons in a specific direction is equal to the sum of the photons scattered by each fraction of the sample (A and B here) in this direction. The overall phase curve is therefore a linear combination of the phase curve of each fraction of the sample. In the case where both fractions A and B have similar optical index and grain size (and thus the same single scattering albedo) and similar parameter b, simulations results show that the overall photometric behavior of the spatial mixture is equivalent to: 1) an homogeneous sample with $c = f_A c_A + f_B c_B$ (with f_A and f_B the fractions of the compounds A and B), 2) the linear combination of the phase curves of the different compounds taken separately. In case the grain size or the optical index is different for A and B (thus affecting the single scattering albedo), the previous expression is weighted by the single scattering albedo ω.

Intimate mixtures are referred to as mixtures where a majority of photons interacts with several of the different compounds (two compounds, A and B, here). In the case where both fractions have similar optical index and grain size (and thus the same single scattering albedo) and similar parameter b, Fig. 2 shows that the parameter c of such intimate mixtures is given by $c = f_A c_A + f_B c_B$, similarly to the spatial mixture case. Simulations with various optical index and grain sizes have shown that the parameter c of the sample and thus the overall phase curve shape is controlled by: 1) the brightest grains (Fig. 3), 2) the fraction composed by the smallest grains.

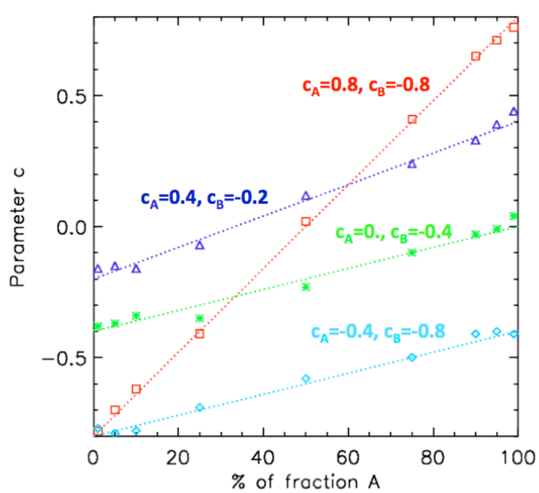

Fig 2: Evolution of the observed parameter c in an intimate mixture made of 2 compounds A and B, with the fraction of material A. A and B have a similar grain size distribution (centered in 70 µm), similar optical index ($n_A = n_B = 1.4+2.10^{-4}i$) and similar parameter b=0.2.

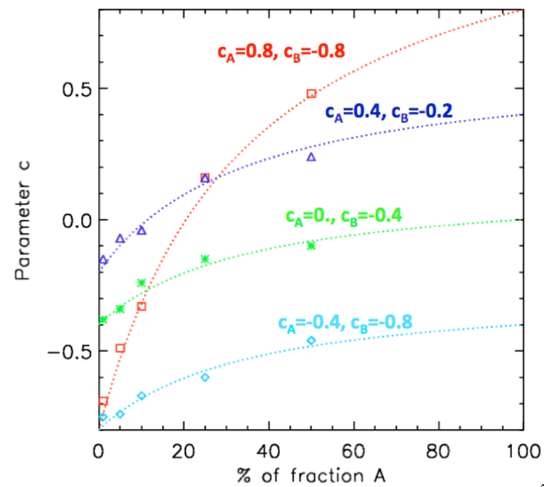

Fig 3: Same as Fig. 2, except that $n_A = 1.4+10^{-5}i$ and $n_B = 1.4+10^{-3}i$.

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