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Experimental light scattering by ultrasonically controlled small particles — Implications for Planetary Science

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Abstract

We present the results obtained with our newly developed 3D scatterometer — a setup for precise multi-angular measurements of light scattered by mm- to µm-sized samples held in place by sound. These measurements are cross-validated against the modeled light-scattering characteristics of the sample, i.e., the intensity and the degree of linear polarization of the reflected light, calculated with state-of-the-art electromagnetic techniques.

We demonstrate a unique non-destructive approach to derive the optical properties of small grain samples which facilitates research on highly valuable planetary materials, such as samples returned from space missions or rare meteorites.

1. Introduction

Electromagnetic scattering is a fundamental physical process that allows inferring characteristics of an object studied remotely. This possibility is enhanced by obtaining the light-scattering response at multiple wavelengths and viewing geometries, i.e., by considering a wider range of the phase angle (the angle between the incident light and the light reflected from the object) in the experiment.

Planetary environments represent numerous examples of scattering media composed of particles. There is a fundamental difficulty, however, in bridging the gap between the light-scattering theory and experiment: while existing theoretical models can be used reliably to simulate scattering by a fixed finite object or random particles [1], thorough experimental work has mostly been performed with light scattered from surfaces, see e.g. [2-4].

2. Bridging the gap

Within the ERC Advanced Grant project SAEMPL (http://cordis.europa.eu/project/rcn/107666_en.html) we have assembled an interdisciplinary group of scientists to develop a fully automated, 3D scatterometer that can measure scattered light at different wavelengths from small particulate samples [5, 6]. The setup comprises: (a) a PXI Express platform to synchronously record data from several photomultiplier tubes (PMTs); (b) a motorized rotation stage to precisely control the azimuthal angle of the PMTs around 360°; and (c) a versatile light source, whose wavelength, polarization, intensity, and beam shape can be precisely controlled. An acoustic levitator is used to hold the sample without touching it.

To interpret laboratory measurements, we model the light-scattering characteristics of the sample, i.e., the intensity and the degree of linear polarization, by our novel multiple-scattering methods for dense random media, including SIRIS [7] and R^2T^2 (radiative transfer with reciprocal transactions). The R^2T^2 method solves the ensemble averaged Foldy-Lax equation. For example, a near-field correction is implemented in terms of the incoherent volume element that contains all the scattering diagrams that do not cancel out in the near-zone [8]. The incoherent scattering parameters of the volume elements are solved exactly by the fast superposition T-matrix method [9]. This approach extends the applicability of the radiative transfer technique to dense random media.

3. Scattering characteristics of the Chelyabinsk meteorite

To demonstrate our approach we performed detailed measurements of light scattered by a Chelyabinsk

LL5 chondrite particle, derived from the light-colored lithology sample of the meteorite [10].

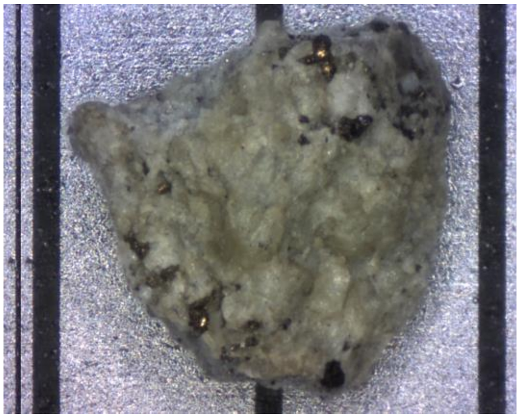

Figure 1: Zoomed-in on particle separated from the light-colored lithology of the Chelyabinsk meteorite. 1-mm scale is given in the background.

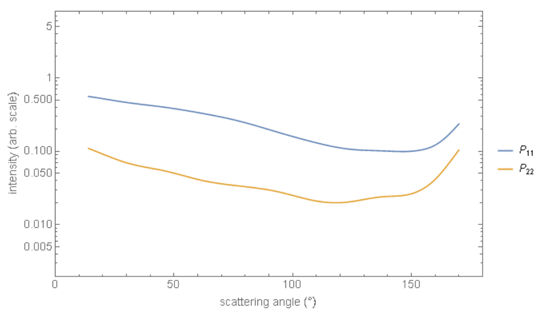

Figure 2: Measured Mueller scattering matrix elements P_{11} and P_{22} for the Chelyabinsk meteorite particle obtained with 530-nm wavelength.

4. Summary and Conclusions

The 3D scatterometer is a valuable tool to measure optical properties of ultrasonically held small particles. The tool can be used to validate theoretical models. It provides unique measurement data to gain new knowledge about the optical properties of both, individual and groups of small particles, including planetary materials.

The device is the first of its kind, since it measures controlled spectral angular scattering including all polarization effects, for an arbitrary object in the µm-cm size scale. It permits a non-destructive, disturbance-free measurement with control of the orientation and location of the scattering object.

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