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Scatterometer for measuring intensity and polarization phase functions of levitating regolith analogue samples

A. Penttilä (1), G. Maconi (1), P. Helander (1), J. Martikainen (1), M. Gritsevich (1), A. Salmi (1), I. Kassamakov (1), E. Hæggström (1), and K. Muinonen (1,2)
(1) Department of Physics, University of Helsinki, Finland (antti.i.penttila@helsinki.fi), (2) Geospatial Research Institute FGI, National Land Survey, Finland.

Abstract

Here we present the novel instrument capable of performing a full 4π light scattering measurement for a levitating sample. By 4π we are referring to the capability of measuring in one plane with varying phase angle, but controlling and manipulating the orientation of the millimeter-sized sample. Therefore, we are measuring the scattering properties over the full 4π solid angle. This is enabled by a non-contacting sample holder based on acoustic levitation, which allows for a disturbance-free measurement of an orientation-controlled sample. The instrument employs polarized visible light (400–700 nm). It also measures beam and sample stability as well as temperature and humidity, to ensure consistency of measurements.

We demonstrate the 4π capabilities of the instrument by measuring the intensity and polarization phase curves by small meteorite and planetary regolith analogue samples in fixed and in orientation-averaged setups. The upper left 2×2 submatrix of the Mueller matrix is measured. Our results can provide input for the light scattering modeling of planetary surfaces.

1. Introduction

Light scattering measurements from samples of particles (including stable aggregated structures) provide important experimental information about their optical properties, e.g., the single-scattering albedo, as well as scattering and polarization phase functions. These properties will be needed when modeling their effect on larger systems, such as dust in atmospheres, planetary regolith, cometary coma, etc.

Current setups of scatterometers and databases of measurements include, at least, the device in the IAA cosmic dust laboratory in Granada[1] and the Amsterdam-Granada light scattering database[2]. The difference with respect to our setup is that, in the IAA device, the measurement is done for sample particles in laminar airflow, so the result is averaged over particles and orientations. In our case, the measurement is done for single sample in fixed orientation.

2. Measurement system

The scatterometer is designed to measure light scattered by a mm-sized sample, covering any solid angle, with the exception of narrow two cones around the forward- and backscattering directions. Four polarization configurations are required along the optical path with linear polarizers before and after the sample [3].

The sample is trapped inside the levitator using ultrasound. The levitator is mounted in the center of the horizontally aligned rotation stage. The polar angle (in relation to the incident beam) is scanned by moving the detector on a rotational stage, while the azimuth is controlled by rotating the sample around the beam axis. The instrument is divided into three enclosed compartments that are covered by a diffuse black velvet-like material, which prevents specular reflections from the environment and minimizes stray light.

Our instrument features a modular fiber-coupled beam collimator, which permits the use of different light sources. Our primary light source is an Energetiq EQ-99 laser-driven plasma source. It features a smooth, continuous spectrum in the entire visible range. The beam is focused onto the sample by a planoconvex spherical lens and polarized by a birefringent calcite polarizer on a motorized mount. The beam is then passed into the second chamber, where the scattering measurement is done.

The sample is suspended in midair with no other structural parts interfering with the light scattering. Additionally, this allows full manipulation of fragile samples without the risk of deformation or breakage. Orientation control is achieved by digitally adjusting the shape of the acoustic field. The levitator comprises two hemispherical transducer arrays opposing each other and creating a standing wave acoustic field in the center. The transducer elements on each hemisphere are grouped into 12 phase-controlled channels, allowing precise computer control of the field shape. The standing waves are adjusted to form an asymmetric potential well, where the largest physical dimension of the sample aligns itself with the axis of lowest gradient. While most acoustic levitators allow the sample to spin freely around one axis, this asymmetric trap design keeps the sample stable and minimizes any movement.

The analyzer is used to obtain the specified polarization data with the scatterometer instrument. The sensor is a Hamamatsu microPMT H12403-01 photomultiplier tube (PMT) module, connected to a Thorlabs TIA60 amplifier. The PMT provides both high sensitivity and high dynamic range. It is integrated into a measurement head, featuring a motorized film polarizer (Thorlabs LPVISE100-A). The measurement head is mounted on a circular breadboard (Ø=600 mm) which is turned by a motorized rotation stage (Standa 8MRB240-152-59D) with a resolution of 15’. Both the breadboard and the rotation stage have a central 150-mm aperture for mounting the sample holder.

The sample monitoring system is closely related to the acoustic levitator, in that its main purpose is to measure the position and rotation stability of the levitating sample. An additional feature arising from this is that a 3d-model of the sample surface can be reconstructed from the footage using the Structure from Motion (SfM) algorithm [4]. The sample is recorded while levitating by a Phantom v611 hi-speed camera. The sample monitoring system uses its own light source to provide sufficient illumination. It consists of two 850-nm near-IR LEDs. Near-IR illumination was chosen because the hi-speed camera sensor is sensitive in that range, and because it can be filtered out from the analyzer without affecting the measurement, which is conducted in the visible range.

3. Samples

We intend to measure several samples relevant to planetary sciences, including lunar and Martian dust analogues, and meteorites. We have already conducted some calibration measurements using controlled SiO_2 aggregate sample. The results from that measurement is shown below.

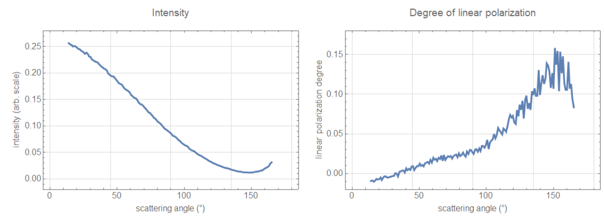

Figure: The intensity and linear polarization phase functions measured from a SiO_2 aggregate.

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