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Spectro-polarimetry as a tool for characterizing small cosmic dust grains

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Abstract

In this work we show how experimental data of intensity and polarization of the scattered light of different cosmic dust analogues can be used to shed some light on the nature of dust particles. The experimental data are performed at various wavelengths (447, 520 and 647 nm) covering the scattering angle range from 3 to 177 degrees.

1. Introduction

Small dust particles are present in different scenarios in the Solar system like in the atmospheres of planets, satellites, and comets. Those particles can modify the temperature profile, dynamics, and chemical composition of the corresponding atmosphere. By analyzing the solar light scattered by those particles we can retrieve valuable information about their physical properties (shape, size, and composition). However, the quantification of the influence of dust particles in the atmosphere is far from trivial. Apart from its variable distribution in time and location, they usually present very irregular shapes. This introduces a serious difficulty in the radiative transfer modeling. While the treatment of the scattering processes from spherical dust particles is straightforward using Lorenz-Mie theory, it becomes much more complicated, or even impossible, for realistic poly-dispersions of irregular dust particles. Therefore, measurements of the full scattering matrices (including polarization) of realistic poly-dispersions of dust particles in the laboratory remain an extremely valuable tool for interpreting astronomical observations.

2. Experimental Apparatus

The scattering matrices of our samples are measured at the IAA COsmic DUst LABoratory (CODULAB) located at the Instituto de Astrofísica de Andalucía, Granada, Spain. For a detailed description of the experimental apparatus, calibration process, and data acquisition we refer to [Muñoz et al. (2010)]. Briefly, we use an Argon-Krypton laser as light source that can emits at three different wavelengths, 488, 520, and 647 nm. The laser beam passes through a polarizer and an electro-optic modulator. The modulated light is subsequently scattered by an ensemble of randomly oriented dust particles located in a jet stream produced by an aerosol generator. The scattered light passes through a quarter-wave plate and an analyzer (both optional) and is detected by a photomultiplier tube which moves along a ring. In this way a range of scattering angles from 3° to 177° is covered in the measurements. Another photomultiplier tube located at a fixed position is used to correct from fluctuations of the signal. We employ polarization modulation in combination with lock-in detection to obtain the entire four-by-four scattering matrix up to a constant. All matrix elements (except F_{11} itself) are normalized to F_{11}, that is, we consider F_{ij}/F_{11}, with i, j=1 to 4 with the exception of $i = j$ =1. The values of $F_{11}(\theta)$ are normalized so that they are equal to 1 at θ=30°. The function $F_{11}(\theta)$, normalized in this way, is called the phase function or scattering function in this work. The reliability of the apparatus has been tested by comparing measured scattering matrices of spherical water droplets at 488 nm, 520 nm and 647 nm with Lorenz-Mie computations [Muñoz et al. (2010)]. In addition, special tests have been performed to ensure that our experiment is performed under the single scattering regime [Muñoz et al. (2011)].

3. Measurements

The experimental data can be used in a direct manner, e.g. by comparison with astronomical observations of light scattered in single scattering conditions. An interesting example is related to cometary dust. As is observed in various comets the spectral dependence of the degree of linear polarization might be an indication of the composition of the sample under study [Mishchencko et al. (2010)]. In Figure 1, we present the measured degree of linear polarization

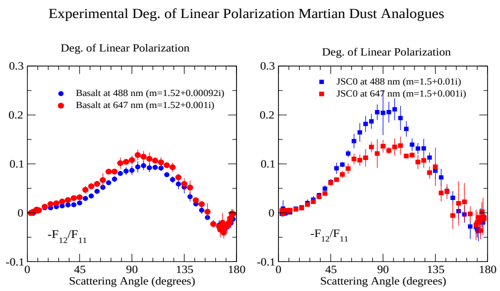

Figure 1: Measured degree of linear polarization for a Basalt sample (left panel) and JSC Mars-1 simulant (right panel).

Table 1: Estimated refractive indices ($m = n + ik$) of our Basalt and JSC Mars-1 samples [Pollack et al (1973)], [Clancy et al (1995)].

Sample	m(488 nm)	m(647 nm)
Basalt	1.52 + 0.00092i	1.52 + 0.001i
JSC Mars-1	1.5 + 0.01i	1.5 + 0.001i

of two martian dust analogs, namely, basalt and JSC Mars-1 simulant [Dabrowska et al (2015)]. In table 1, we present the refractive index of the samples. The measurements are performed at 448 and 647 nm. As shown, the maximum of the degree of linear polarization for incident unpolarized light for the basalt sample shows higher values at 647 nm than at 488 nm i.e. they present a red polarization color. That seems to be also the color for silicate-type samples with low iron content as shown in many of the samples presented in the Amsterdam-Granada Light Scattering Database ([Muñoz et al. (2012)]).The imaginary part of the refractive index of basalt show a flat wavelength dependence. However, the JSC Mars-1 that presents a significantly higher imaginary part of the refractive index at 488 nm than at 647 nm shows a blue polarization color. The polarization color is directly dependent on the refractive index of the particles showing a red polarization color those particles with a flat dependence of the imaginary part of the refractive index at visible wavelengths and blue polarization color if it is significantly higher at blue than at red wavelengths.

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