REFRACTIVE INDEX OF ALLENDE METEORITE. Evgenij Zubko[1,2], Gorden Videen[3,4], Yuriy Shkuratov[2], and Olga Muñoz[5], [1]School of Natural Sciences, Far Eastern Federal University, Vladivostok, Russia, evgenij.s.zubko@gmail.com, [2]Institute of Astronomy, V. N. Karazin Kharkov National University, Kharkov, Ukraine, [3]Space Science Institute, 4750 Walnut Street, Suite 205, Boulder, CO 80301, USA, gorden.videen@gmail.com, [4]Army Research Laboratory, 2800 Powder Mill Road, Adelphi, MD 20783, USA, [5]Instituto de Astrofisica de Andalucia, CSIC, Granada, Spain, olga@iaa.es

Introduction: The goal of remote sensing of cosmic dust is to characterize target particles through their light scattering. In general, the interaction with incident sunlight is dependent on particle shape, size distribution, and refractive index. The latter parameter describes the ability of the constituent material to absorb and scatter the electromagnetic radiation. Once the refractive index is inferred from astronomical observations, it can be further compared with what is known about cosmic dust materials and, thus, one can retrieve/constrain chemical composition of target particles. However, this algorithm requires reliable information of the refractive index of numerous known and plausible species of cosmic dust. Although the refractive index of various cosmic materials has been measured and reported in the literature, a number of materials still require investigation. For instance, the refractive index of Allende meteorite remains poorly known. In this short paper, we estimate the refractive index in Allende meteorite through modeling laboratory measurements of the single-scattering response from its micron-sized particles.

Optical Measurements of Single-Scattering Allende Meteorite Particles: A beam of light can be fully characterized with a four-dimensional *Stokes vector* [1]. Within this approach, the interaction of light with a target is described through a product of a (4×4) *Mueller matrix* with the Stokes vector of the incident light. The *Mueller scattering matrix* [1] is dependent of the specific target properties. The product yields another Stokes vector characterizing the scattered light. If the target particles are randomly oriented and have randomly irregular shape, the Mueller matrix takes on a block-diagonal form with only six independent elements: M_{11}, $M_{12}=M_{21}$, M_{22}, M_{33}, $M_{34}=-M_{43}$, and M_{44}. It is significant that all these elements have been measured in Allende meteorite samples over a wide range of phase angle $\alpha = 7° - 175°$ at two wavelengths $\lambda = 0.442$ μm and 0.633 μm [2]. These measurements are publically available through the *Amsterdam-Granada database* [3].

In natural conditions, the target is illuminated with unpolarized sunlight. This places an important limitation on astronomical observations, making accessible only two characteristics of the scattered light, the intensity ($I \propto M_{11}$) and the degree of linear polarization ($P = -M_{21}/M_{11}$). Laboratory optical measurements provide considerably more information on the light-scattering response from target particles. However, more information is simultaneously involved, and the resulting analysis implies greater confidence in the retrieved refractive index.

Sample particles investigated in [2] were prepared by crushing large pieces of the Allende material to a fine-grained powder. The size distribution of the obtained particles was measured with a particle sizer based on a Fraunhofer diffraction retrieval. This method suffer limitations, since not all measured particles satisfy the assumptions of Fraunhofer theory that is restricted to particles larger than the wavelength of the incident beam. This uncertainty suggests keeping the size distribution as a free parameter in our modeling. In Fig. 1 we reproduce the non-zero Mueller matrix elements measured from the Allende particles at $\lambda = 0.442$ μm [2].

Modeling the Light-Scattering Response from Allende Meteorite Particles: We model the shape of the Allende particles using the so-called *agglomerated debris particles*. Six examples are shown on the top panel of Fig. 1. These shapes appear visually consistent with the SEM images of the Allende particles reported in [2]. We note that the agglomerated debris particles are capable of reproducing the light-scattering response measured in feldspar [4] and forsterite [5] particles. The previously investigated feldspar and forsterite particles were prepared in a similar way as the Allende particles. It is reasonable, therefore, to suggest the agglomerated debris particles are also a suitable model particle for the Allende particles.

We compute the light scattering by agglomerated debris particles using the discrete dipole approximation (DDA). We refer to [4] for more details of the algorithm of particle generation, desciption of the DDA technique, validation of numerical results, and control of quality of the shape averaging.

As an initial guess of the refractive index m of the Allende material we use $m = 1.7 + 0.02i$ that is consistent with the range inferred in [6]. However, in addition, we also consider 40 other refractive indices that have been discussed in [6].

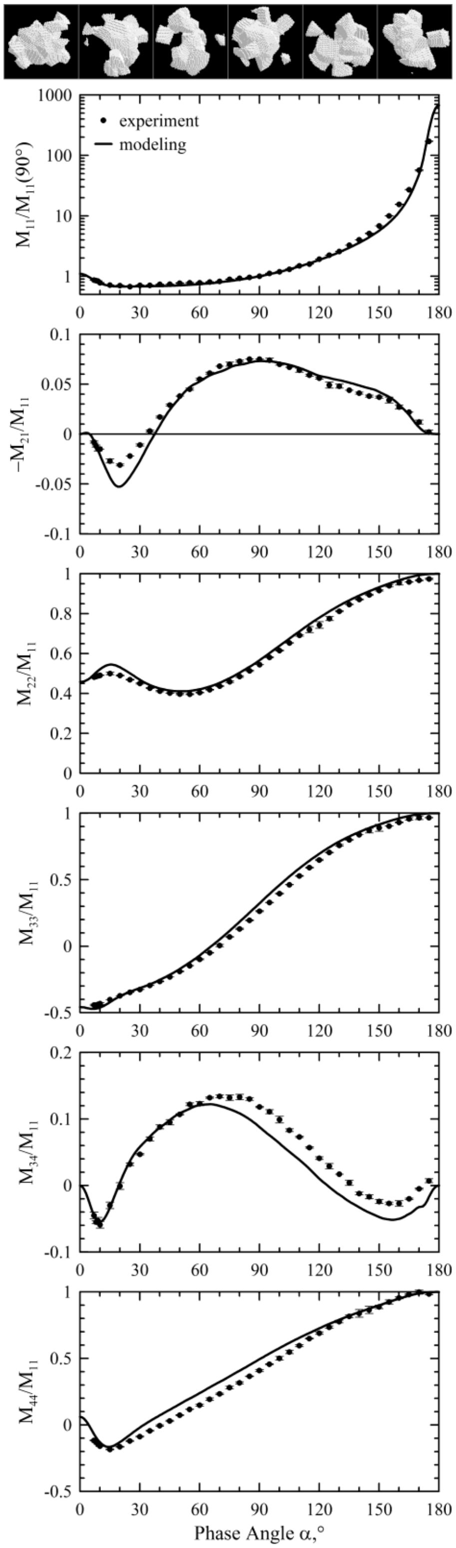

Fig. 1. Sample agglomerated debris particles (top) and the six non-zero Mueller matrix elements measured from Allende meteorite particles at λ = 0.442 μm (points). Modeling results are shown with the solid line.

In the vast majority of studied refractive indices, including $m = 1.7 + 0.02i$, we consider particle radii spanning the range from $r \approx 0.07$ μm to 2.25 μm. Previously, such a range was demonstrated to be sufficient in order to satisfactorily reproduce the light-scattering response of feldspar and forsterite particles [4,5]. Note that the present analysis is limited only to measurements in blue light with λ = 0.442 μm, and analysis of the measurements in red light is currently in progress.

We take into account the polydispersity of the Allende meteorite particles. First, we investigate all available refractive indices with size distribution directly measured in the Allende particles. Not surprising, it turned out that neither the Fraunhofer-theory approach nor the Mie-theory approach agreed with the results. We then adapted the truncated power-law size distribution r^{-n} that worked in application to feldspar and forsterite particles. We considered the power index n as a free parameter varying over the range $n = 1$–4.

What emerges from our analysis of all available refractive indices is as follows. Agglomerated debris particles with $m = 1.7 + 0.02i$ and $n = 1.7$ provide the best cumulative fit to all six non-zero elements of the Mueller matrix over a wide range of phase angles measured from the Allende meteorite particles. The modeling results are shown in Fig. 1 with the solid line. As one can see, except for some tenuous deviations in the elements $-M_{21}/M_{11}$, M_{34}/M_{11}, and M_{44}/M_{11}, the modeling indeed quite satisfactorily reproduces the measurements. Note, the quality of this fit is similar to what was previously obtained for feldspar and forsterite particles [4,5]. This suggests that the retrieved refractive index $m = 1.7 + 0.02i$ can be attributed to the constituent material of Allende meteorite with great confidence.

Finally, it is important to note that the retrieved refractive index appears in good accordance with estimations made in [6]. However, unlike the present analysis of all non-zero elements of the Mueller matrix, the estimation in [6] was done using solely the phenomenon of negative polarization at small phase angles.

References:

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