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Laboratory measurements of scattering matrix elements of randomly oriented Mars analog palagonite particles

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Abstract

We present laboratory measurements for Martian analog particles, consisting of palagonite. We measured all elements of the scattering matrix as functions of the scattering angle from 3 to 174 degrees at a wavelength of 632.8 nm. The results may be used in studies of the Martian atmosphere.

1 Introduction

Dust from the Martian surface is regularly swept up by winds and becomes suspended in the atmosphere of Mars, sometimes covering the whole planet. These airborne dust particles scatter and absorb solar radiation and are therefore very important for the thermal structure of the thin Martian atmosphere.

The material palagonite is believed to occur on Mars with considerable abundances in the form of dust particles, both on the surface and in the atmosphere (e.g. [1,2,3]). The scattering properties of these dust particles are an important diagnostic tool containing essential information about the nature of the grains. Unfortunately, numerical techniques alone are not adequate to simulate efficiently light scattering by particles with realistic shapes and internal structures. Therefore, light scattering experiments are crucial for determining the scattering properties of real particles. We present laboratory measurements of the angular distributions of scattering properties of randomly oriented Martian analog palagonite particles. The material palagonite is believed to be a reasonable, but not perfect, analog for the abundant Martian surface and atmospheric dust particles.

2 Sample characteristics

Palagonite is a fine-grained weathering product of basaltic glass. It has a refractive index that is typical for silicate materials, namely about Re(m)=1.5 and Im(m) in the range 10^{-3} -10^{-4} [4]. The irregular shapes of the palagonite particles are illustrated in Figure 1. This Martian analog material is described more extensively by Banin et al. [5] (palagonite sample 91-16).

The measured size distributions of the palagonite particles used in this study are illustrated in Figure 2 (see [6] for the definitions of the size distributions). The effective radius and variance are, respectively, 4.5 micrometer and 7.3.

3 Experimental Method

We studied the palagonite particles with an experimental setup that can determine the full scattering matrix as a function of scattering angle θ. A detailed description of the set-up has been given by Hovenier

[7] and Hovenier et al. [8]. One advantage of measuring all 6 non-vanishing elements of the scattering matrix instead of only one or two is that systematic experimental errors can be quickly observed, identified and removed. Another advantage is that the results can be used for multiple scattering calculations with polarization included.

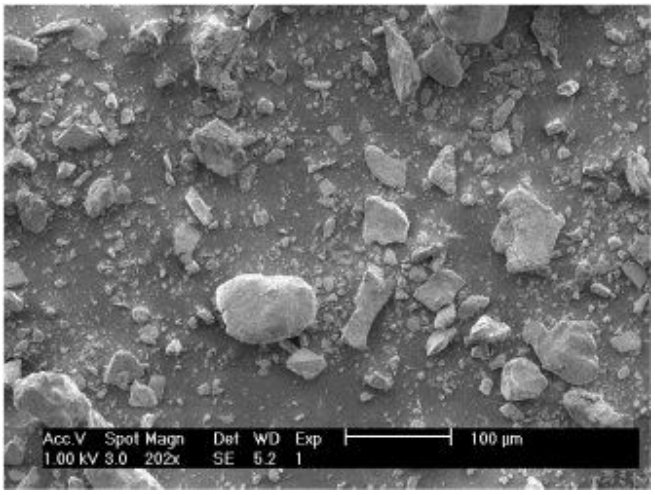

Figure 1: Scanning electron microscope (SEM) image of palagonite particles. We note that SEM images generally give a good indication of the typical shapes of the particles, but not necessarily of the sizes.

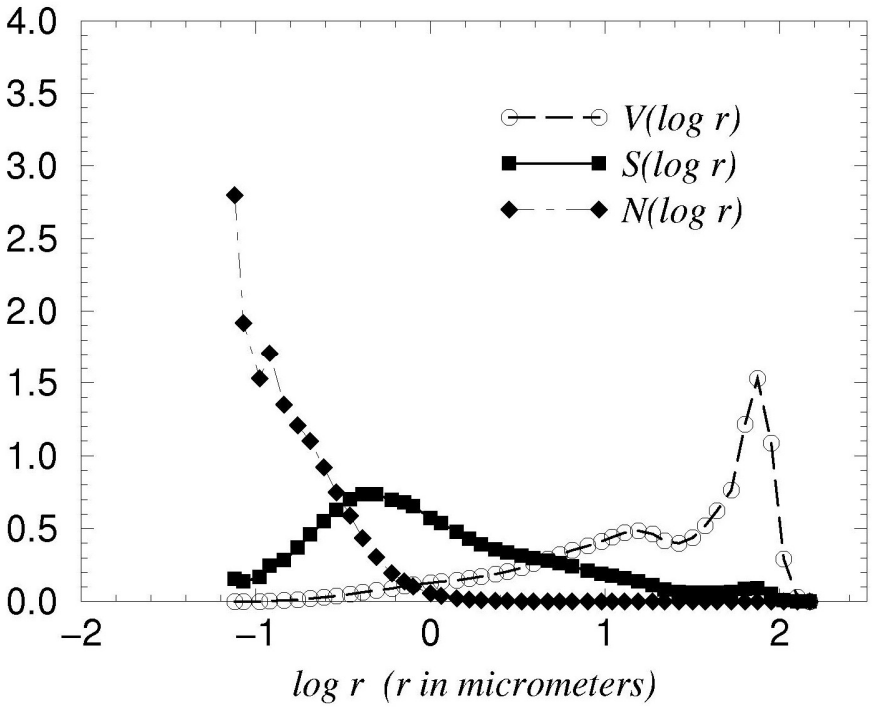

Figure 2: Measured size distributions of palagonite particles. We show V(log r), S(log r) and N(log r) i.e. the volume, projected surface and number distributions, respectively, as a function of log r where r is expressed in micrometers.

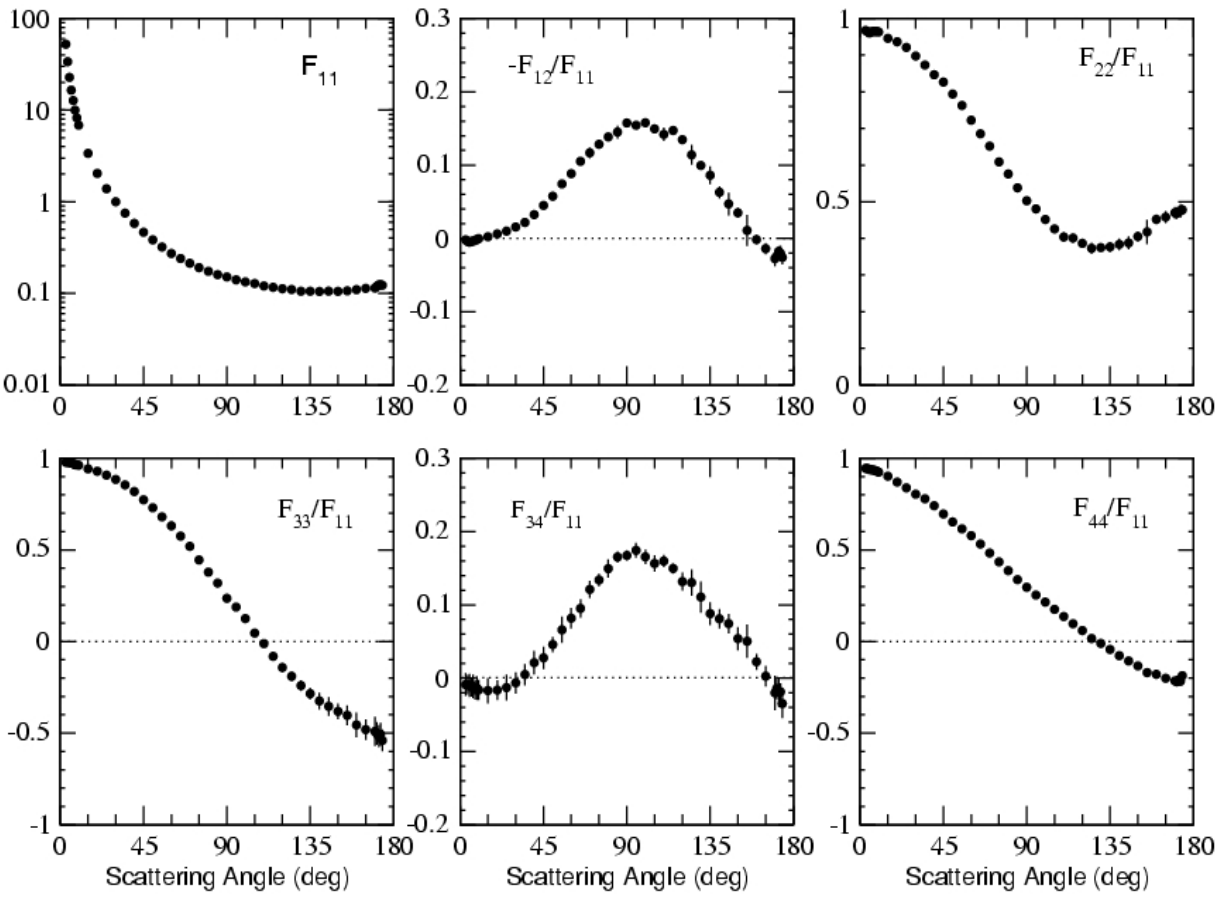

Figure 3: Measurements of the scattering matrix elements as functions of the scattering angle for randomly oriented micron-sized dust particles of Martian analog palagonite at a wavelength of 632.8nm. The scattering function is normalized to unity at 30 degrees. Experimental errors are shown by error bars or within the size of the symbols.

4 Results

Fig. 3 shows results of measurements for palagonite. We measured scattering matrix elements of the scattered light as functions of the scattering angle. The palagonite particles present a scattering behavior quite similar to that of (terrestrial) irregular mineral aerosol particles (e.g. [9,10,11]). It has a scattering function $F_{11}(\theta)$ that ranges over almost three orders of magnitude for the angles covered in the measurements, being strongly peaked towards smaller angles. It has a rather flat side-scattering and backscattering behavior. The degree of linear polarization for unpolarized incident light, $-F_{12}(\theta)/F_{11}(\theta)$, shows a characteristic bell shape, and a negative branch for large scattering angles. The scattering matrix element ratio $F_{22}(\theta)/F_{11}(\theta)$, is often used as a measure for the nonsphericity of the particles, since for spheres this function is 1 at all scattering angles. This is clearly not the case for the Martian analog particles, the deviation from 1 is large at large scattering angles, with a maximum of about 0.6. Also the matrix scattering element ratios $F_{33}(\theta)/F_{11}(\theta)$, and $F_{44}(\theta)/F_{11}(\theta)$ are not identical, as would be expected for

spheres. In contrast they show the typical behavior for nonspherical particles where the scattering matrix element ratio $F_{44}(\theta)/F_{11}(\theta)$, is greater than $F_{33}(\theta)/F_{11}(\theta)$, at large scattering angles. The shallow bell-shape found for $F_{34}(\theta)/F_{11}(\theta)$, is also commonly found for irregularly shaped silicate particles.

5 Conclusion

The results may be used in theoretical work and for studies of the Martian atmosphere. The data can be found in tabular form in the Amsterdam Light Scattering Database at www.astro.uva.nl/scatter.

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