Laboratory measurements for small particles in single-scattering conditions

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A brief review is presented of the main experimental techniques for studying the effects of nonsphericity on light scattering by small particles in air.

INTRODUCTION

Small particles exist in a wide variety of scenarios ranging from the Earth atmosphere to other planetary and cometary atmospheres in the Solar System, interplanetary medium, reflection nebulae, atmospheres of brown dwarfs, etc. (see Fig. 1). Those small particles play an important role in the radiative balance of the body under study. Light scattering properties of homogeneous spherical particles can be easily computed from Lorenz-Mie theory. However, in the majority of the above mentioned cases, the assumption of spherical particles is highly unrealistic. Some examples of such nonspherical particles are presented in Fig. 2. Prof. van de Hulst published in 1957 his famous book Light scattering by small particles [1]. By that time it was already clear that many atmospheric and cosmic dust particles presented nonspherical shapes. However, limitations in computational resources inhibited reliable computations of light scattering by non-spherical particles. In the 1960's-1970's, the microwave analog method started shedding some light on the scattering behavior of small irregular particles [2, 3]. Meanwhile, first attempts in the visible part of the spectrum were made to experimentally obtain all 16 elements of the 4×4 scattering matrix of irregular particles [4, 5].

Nowadays, even with ever-increasing computer power and sophistication of algorithms, the characterization of small irregular particles from the observed scattered light remains an extremely difficult task due to the complicated morphology of these particles. Consequently, controlled experimental studies of light scattering by irregular dust particles remain a unique and indispensable tool for interpreting space- and ground-based observations. In addition, combination of measurements with powerful simulation methods allows us to evaluate models used to calculate scattering properties of nonspherical particles (e.g. [6--9]). Once the model is tested, we can perform calculations for certain physical properties of the particles or wavelengths for which experiments are highly difficult or not possible at all.

LIGHT SCATTERING EXPERIMENTS

There are various approaches to study the light scattering by irregular mineral particles. The microwave analog experiment is based on the fact that two particles that only differ in size have the same scattering properties if their ratios of size and wavelength are the same. Thus, for this type of measurements a centimeter-sized scattering target with the refractive index and shape of interest is manufactured. Microwave radiation is then scattered by this object

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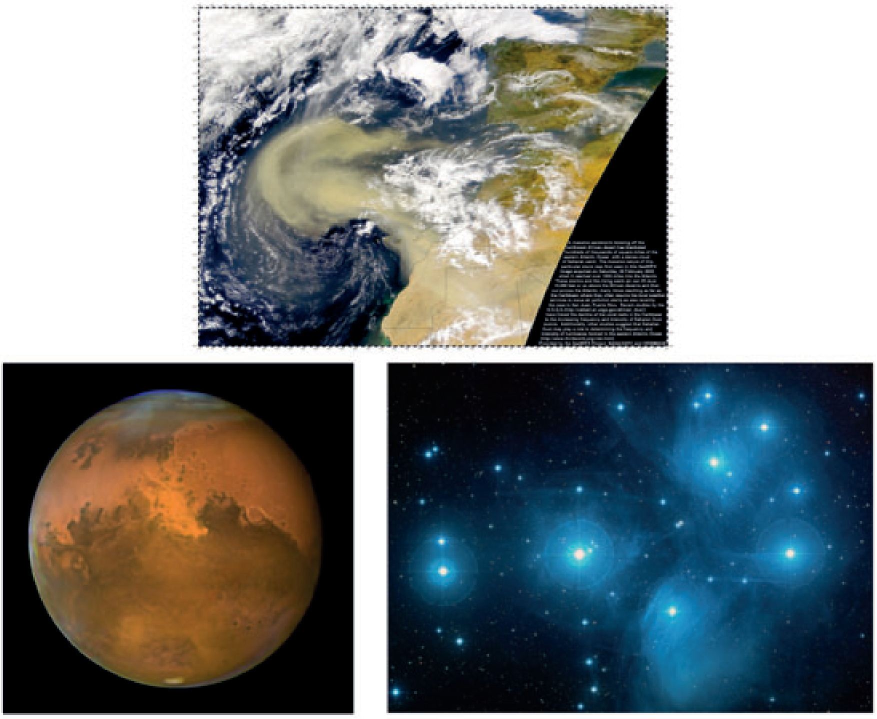

Figure 1. Dust storm sweeps from Africa over the Atlantic (top). Image courtesy Norman Kuring, SeaWifs Project. HST picture of Mars (Bottom left panel), Credit: NASA, ESA, The Hubble Heritage Team (STScI/AURA), J. Bell (Cornell University) and M. Wolff (Space Science Institute); HST image of The Pleiades, one of the nearest examples of a reflection nebula (bottom right panel).

and the results are extrapolated for other wavelengths by keeping the ratio of size and wavelength fixed [2, 3, 10]. The main advantage of this technique is the high control over the shape, size and refractive index of the particle under study. However, the main drawback of microwave measurements is that they can only be performed for one size, shape, and orientation at a time. Therefore, the simulation of a realistic sample of particles in random orientation is almost an impossible task.

Another approach is to let a beam of light be scattered by an ensemble of randomly oriented particles and measure the phase function and/or degree of linear polarization for incident unpolarized light [11--16] , or preferably the full scattering matrix as a function of the scattering angle [4,5,17--23] . The latter approach presents some advantages. For instance, the complete scattering matrix is needed to perform multiple scattering calculations in scattering media such as planetary atmospheres and circumstellar disks. Moreover, measuring all elements of the scattering matrix help us in identifying errors in the electronics or in the alignment of the optics involved in the experiment since all theoretical relationships valid for the elements of the scattering matrix [24] can be applied for tests.

Some measurements performed with various instruments will be presented at the conference to show what can we learn about small irregular particles from laboratory measurements.

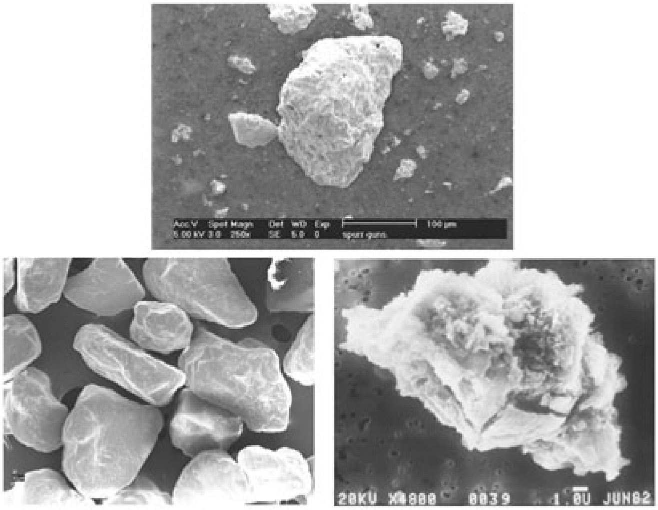

Figure 2. Scanning Electronic Microscope images of different small particles: volcanic ash from Mount Spurr volcano (top panel), desert dust from the Sahara (bottom left panel) (Amsterdam Light Scattering Database), right bottom panel example of an interplanetary dust particle collected at high altitude in the atmosphere of the Earth. Courtesy: NASA/JSC/CDLF.

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