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Review

Light scattering in the Solar System: An introductory review

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ABSTRACT

We present a concise survey of light scattering by small particles in the atmospheres and surface layers of various Solar System bodies, comets, the interplanetary medium, and in planetary rings. Current issues and recent developments are emphasized. Special attention is given to experimental and numerical approaches for solving problems of light scattering by non-spherical particles. References to more detailed papers, websites and books are presented. Key areas for further research are pointed out.

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1. Introduction

Light scattering by small particles has grown to a very extensive and diverse field with many applications [1–9]. In the Solar System the Sun acts as a powerful source of light illuminating small particles, not only in the atmospheres and on the surfaces of various objects, but also in the space between them and in comets as well as planetary rings. By carefully analyzing the intensity and polarization of the scattered light at various wavelengths much information can be obtained about the nature and location of the scattering particles. That is the principal reason why light scattering in the Solar System is an important subject in astronomy.

The main purpose of this paper is to provide non-specialists with a brief introductory review of light scattering in the visible part of the spectrum by particles in the Solar System, focusing on particles in the atmospheres of planets and

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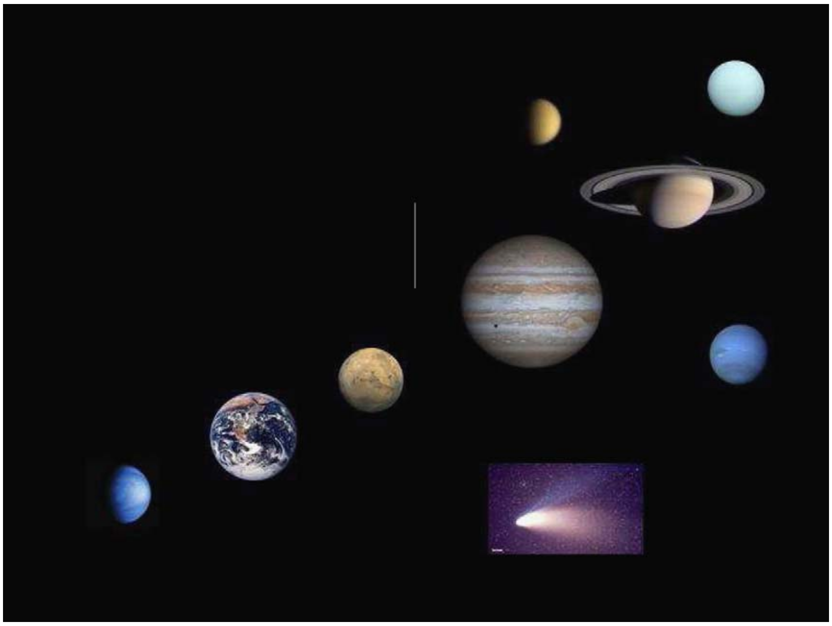

Fig. 1. Overview of planets in the Solar System. From lower left to upper right color pictures are shown of Venus, Earth, Mars, Jupiter, Saturn, and Uranus. Neptune is below Saturn and Titan left of Saturn. Also shown is comet Hale Bopp with two tails. Images of Venus, Mars, Jupiter, Saturn, Uranus, Neptune and Titan courtesy of NASA/JPL-Caltech. Image of Earth courtesy of NASA. Image of comet Hale Bopp courtesy of Tim Printy. (Color differences can be seen in the web version of this article).

satellites, comets, particulate surfaces, asteroids, interplanetary dust particles and particles in planetary rings. We will discuss these topics in separate sections, but there are no sharp boundaries between them. No attempt has been made to discuss the entire literature on the subject. Instead we point out some current issues and key areas for further research. References to specialized reviews and books are also given.

2. Atmospheres of planets and their satellites

The eight planets Venus through Pluto in the Solar System have a significant atmosphere and so do some of their satellites (moons). Titan, a satellite of Saturn, for example, has such a dense atmosphere that the air pressure at its surface is even larger than on Earth. These atmospheres exhibit a great variety, in thickness, composition, and physical structure. An overview is presented in Fig. 1.

In the atmospheres of planets and satellites liquid particles may occur in the form of clouds, hazes, fog and rain. The liquid can be water, but also a quite different material like, e.g. sulphuric acid. Liquid particles occur for instance in the atmospheres of the Earth and Venus. They are (nearly) spherical and often approximately homogeneous, so that Mie theory [1,2,4] can be used to compute their scattering and absorption properties for arbitrary sizes, refractive indexes and wavelengths. Similar calculations can be performed for inhomogeneous particles with spherical symmetry.

There is, however, also a large variety of non-spherical particles in the atmospheres of planets and satellites. This is well known for the Earth's atmosphere due to numerous studies of ice clouds and solid aerosols. Other examples are provided by mineral particles in dust storms on Mars as well as solid particles of condensed material in clouds and hazes in the atmospheres of giant planets like Jupiter and Saturn [10]. In the past few decades enormous progress has been made in developing methods for computing light scattering by non-spherical particles, such as the discrete dipole approximation, the T-matrix method, the separation of variables method and the finite difference time domain method [3,11]. By using such methods it has become clear that for all kinds of non-spherical particles Mie theory generally provides insufficient accuracy for computing their absorption and scattering properties, not only in the visible part of the spectrum, but also for larger wavelengths [12]. This means that one should be careful with accepting particle and atmospheric properties, based on using Mie theory, when the atmospheric particles of a planet or satellite are likely to be non-spherical. This warning holds in particular for relatively old publications.

Instead of computing light scattering properties of non-spherical particles one can also employ experimental results, like the phase functions and the scattering angle dependence of all other elements of the scattering matrix for various kinds of randomly oriented natural particles. Such measurements have been performed in Amsterdam, The Netherlands [13,14] with a setup including lasers as light sources [15]. Fig. 2 shows a schematic overview of this experimental setup, as seen from above. The data have been stored in digital form in The Amsterdam Light Scattering Database at http://www.astro.uva.nl/scatter, together with scanning electron microscope (SEM) images and information about the origin,