2 Laboratory measurements of the light scattered by clouds of solid particles by imaging technique

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2.1 Introduction

2.1.1 Astronomical and atmospheric context

Clouds of solid particles are found in numerous regions in the solar system: in comets (comae and tails), in planetary and satellite atmospheres (Earth, Mars, Titan), in the interplanetary dust complex built up from dust released by comets and by asteroidal collisions (Grün et al., 2001; Levasseur-Regourd et al., 1990; Levasseur-Regourd, 1999; Levasseur-Regourd and Hadamcik, 2003). Space missions are rare and many objects cannot be visited (e.g. new comets). Although most dust clouds have very low number densities, they may be remotely detected by the light they scatter. Their properties are known by \textit{in situ} observations, remote observations or by the interplanetary dust particles (IDPs) collected in the atmosphere of the Earth (Hanner and Bradley, 2004). Asteroidal and cometary nuclei surfaces are layers of loosely connected grains made of fragmentary debris produced by, for example, meteoritic impacts (regolith) or by gaseous species evaporation (Sullivan et al., 2002; Levasseur-Regourd et al., 2006). When released, these particles are irregular, compact or aggregated. Cometary particles, as confirmed by, for example, the particles captured by Stardust, are mainly made of silicates and carbonaceous compounds with aggregates and compact grains in a large range of sizes from a tenth up to hundreds of micrometres (Hörtz et al., 2006; Zolensky et al., 2006). Titan solid aerosols, as observed by the Cassini–Huygens \textit{in situ} space probe, are made of aggregates of submicrometre-sized organic grains (Tomasko et al., 2005). As far as Earth atmospheric solid particles are concerned, ice crystals, soot produced by biomass burning, industrial or aircraft combustions, sands lifted by winds, volcano ashes or extraterrestrial particles have been identified (Renard et al., 2003). Light scattering and polarization measurements are one of the tools used to study such particles and to access their physical properties (Herman et al., 1986; Santer et al., 1988; Gayet et al., 2002; Brogniez et al., 2003).

Light scattering by clouds of particles can be studied using different techniques such as in a steady-state gas flow or in jet streams (West et al., 1997; Muñoz et al., 2004; Volten et al., 2007). These techniques are suitable for submicrometre-sized or micrometre-sized particles but not for large ones (hundreds of micrometers). Microwave analogue experiments on individual or aggregated grains (Gustafson and
Kolokolova, 1999) have validated numerous numerical models although the particles are purpose-built and clouds of particles cannot be obtained. Reduced gravity can be a sensible way to achieve conditions close to those prevailing in space for the laboratory experiment measurements which are requested to relate remote or in situ observations to physical parameters (Worms et al., 1996, 1999a,b; Levasseur-Regourd, 2003). The choice of parabolic flights to achieve these conditions is determined by the fact that light scattering measurements can be made within seconds for any kind of particles without discrimination by weight or composition. The PROGRA2 experiment (PRopriétés Optiques des Grains Astronomiques et Atmosphériques) has been developed to study the light scattered by realistic ‘natural’ (opposed to purpose-built) dust clouds with the PROGRA2-vis instrument (‘vis’ for visible). The second instrument PROGRA2-surf (‘surf’ for surface) is used for comparison with the light scattered by the same grains deposited on layers on the ground and for the study of regolith analogues.

Samples are chosen for two main reasons: (1) astronomical analogues (e.g. lunar or Martian, Titan’s aerosols, cometary, asteroidal) or purpose studies for atmospheric applications (soot, sands); (2) to have different samples with only one change of parameter (e.g. size of grains, of particles, structure, absorption).

2.1.2 Polarization measurements

2.1.2.1 Definitions

The linear polarization value depends on the phase angle, the wavelength and the physical properties of the particles. The phase angle (180°-scattering angle) is the angle between the direction of the light source and the observer’s line of sight at the scattering particle, in the scattering plane (Fig. 2.1). The plane of observations is perpendicular to the line of sight at the scattering object.

![Diagram of polarization measurements](image)

**Fig. 2.1.** Geometry of observations. Scattering plane defined by line of sight and illumination directions. Plane of observations perpendicular to the line of sight. \( \alpha \) = phase angle. \( R \) = light source to object distance (Sun-object distance in case of observations), \( \Delta \) = object to detectors distance (object-Earth distance in the case of observations).