Inferring properties of dust within small bodies of the solar system through observations and simulations of the linear polarization of scattered solar light

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Abstract. Measuring properties of solar light scattered by dust on the surfaces of asteroids and within dust clouds (cometary comae, zodiacal cloud) is often a technical challenge, since the signals need to be isolated from any contaminating source on the line of sight. However, measurements of linear polarization are of major interest, since they enable comparisons between data obtained at different distances from the Sun and the observer on a given object or on various objects. They provide some classifications and efficiently complement unique in situ and sample return missions. Some clear observational trends can be pointed out, from the results obtained, mostly on relatively bright objects, by various teams all over the world. It is worth mentioning that all polarimetric phase curves present a shallow negative branch in the backscattering region, with some significant dispersion of the inversion angle for asteroids, and that the wavelength dependence at a fixed phase angle is, for a given object, mostly linear in the visible domain; besides, changes in the properties of the dust within cometary comae are identified through imaging polarimetry. Promising interpretations of the observed variations of the polarization are inferred from experimental and numerical simulations with irregular compact grains and aggregates of dust particles. They already provide information on the structure, composition, and size distribution of dust within the zodiacal cloud and within comae that are monitored over a wide range of phase angles, as well as comparisons between the properties of asteroidal regoliths and those of some meteorites.

Keywords: dust, solar system, comets, asteroids, regolith, albedo, light scattering, linear polarization, optical probe, imaging polarimetry, polarimetric halo

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1. Introduction

1.1. Dust and small solar system bodies

Dust particles are all over the solar system: in cometary comae, tails, and trails: in planetary atmospheres: in the interplanetary dust cloud and meteoroids; as well as on surfaces of planets, satellites, asteroids and cometary nuclei. Learning about the properties of such media is of major importance for the inference of their formation and evolution processes.

Cometary nuclei, the structure and dust-to-ices ratio of which are still unknown (e.g., Kofman et al. 1998; Levasseur-Regourd et al. 2009), are likely to be built of ices and dust particles. In situ studies provide clear evidence for the presence of dust on nuclei surfaces, and within sub-surfaces, as established by the Deep Impact mission (A’Hearn et al. 2005). Dust particles ejected with gases from sublimating ices are found within cometary comae and tails, as already suggested by Arago (1858) through polarimetric observations of comets, and nowadays analyzed through light scattering and spectroscopic observations (e.g., Kolokolova et al. 2004; Bockelée-Morvan et al. 2004; Mishchenko et al. 2010). Finally larger dust particles are present along cometary trails, as monitored by near-infrared observations (e.g., Kelley et al. 2008).

Cometary dust contributes significantly to the replenishment of the zodiacal cloud (e.g., Nesvorny et al. 2010), at least below 1.5 AU. This lenticular circum-solar cloud of interplanetary dust scatters solar light, giving rise to the zodiacal light, visible from the Earth after sunset or before sunrise in the absence of any light pollution. Amongst the interplanetary dust particles collected in the Earth’s stratosphere, so-called IDPs, aggregates (in the size range of a few tens of micrometers) of smaller grains are assumed to be of cometary origin (e.g., Levasseur-Regourd et al. 2001; Jessberger et al. 2001).

Dust particles resulting from successive impacts of meteoroids and micrometeoroids are also found on asteroidal surfaces and on surfaces of other atmosphereless bodies, such as planetary moons and trans-Neptunian objects. They build up a regolith which corresponds to layers of dust and rocks formed over billion years (e.g., Muinonen et al. 2002; Clark et al. 2002). Regoliths may be more or less thick, and have a coarse or fine-grained size distribution.

1.2. Properties revealed by in situ missions

Since the mid 1980s, six comets (1P/Halley, 26P/Grigg–Skjellerup, 19P/Borrelly, 81P/Wild 2, 9P/Tempel 1, and 103P/Hartley 2, all being periodic comets) and about ten asteroids have been explored by space probes. The most conspicuous result is possibly the vast diversity of these objects which are not at all spherical, as opposed to the legendary asteroids imagined in 1943 by Saint-Exupéry for Le Petit Prince, or even to the dirty cometary snowballs cleverly predicted in 1950 by Whipple. More specifically, amongst a wealth of scientific results, space missions to comets have helped to discover that cometary dust parti-