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Light Scattering as a Clue to Cometary Dust Structure

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Abstract. The linear polarization of comets depends upon the cometary dust physical properties, as well as upon the phase angle and the wavelength. The observed similarities and discrepancies provide drastic constraints on the physical properties of the dust. A series of measurements of light scattering properties on clouds of particles and of the aggregates they form under microgravity conditions should allow the interpretation of the observations in terms of physical properties of the dust.

1. Introduction

Images of IPDs collected in the Earth's stratosphere suggest that cometary dust particles are built up of aggregates of submicron-sized grains (Jessberger et al. 2001). Analysis of simultaneous local light scattering and impact data during 1P/Halley flyby indicates that the dust density was very low, possibly of about 100 $kg\ m^{-3}$ (Fulle et al. 2000). However, the actual physical properties of cometary dust particles and their changes within different cometary comae regions are unknown. Estimating them would provide constraints on their formation processes, and suggest strategies for future missions to comets.

Remote observations of the light emitted and scattered by the dust are available for numerous comets, leading to information on the temperature and composition of the dust, as well as on its light scattering properties. The latter observations provide clues to the physical properties of the dust particles.

2. Properties of light scattered by cometary dust

Solar light scattered by low concentration dust comae is partially linearly polarized. The polarization neither depends upon the Sun and Earth distances, nor upon the concentration, but only varies with the phase angle α, the wavelength λ, and the dust physical properties. High resolution polarization images actually reveal halos corresponding to a lower polarization around the nucleus and jet-like structures with a polarization higher than the average (Levasseur-Regourd 1999, Hadamcik and Levasseur-Regourd 2003). Polarization data also allow us to compare data obtained on a comet at different times and on different comets.

The phase angle dependence corresponds to smooth $P_\lambda(\alpha)$ phase curves, with a small negative branch below about 20° and a wide positive branch with a near 90° to 100° maximum. Classes of comets are pointed out by these phase curves. Comets with a low maximum (of about 10% to 15%, depending upon the wavelength), comets with a high maximum (of about 25% to 30%), and comet 1995 O1 Hale-Bopp, the polarization of which was the highest (Levasseur-Regourd 1999). Comets with a high maximum in polarization usually present a significant silicate emission feature that could be induced by submicron-sized grains in low-density aggregates (Levasseur-Regourd et al. 1996, Hanner 2003).

The $P_\alpha(\lambda)$ curves are linear, at least in the visible domain and for phase angles in the 20° to 90° range. The rate of increase of the wavelength dependence varies with the object, and is actually higher for Hale-Bopp than for Halley. The polarization slope always increases with increasing wavelength, although an opposite effect may take place in the inner coma of bright comets, as illustrated by data recently retrieved from the OPE experiment on board Giotto (Fig. 1).

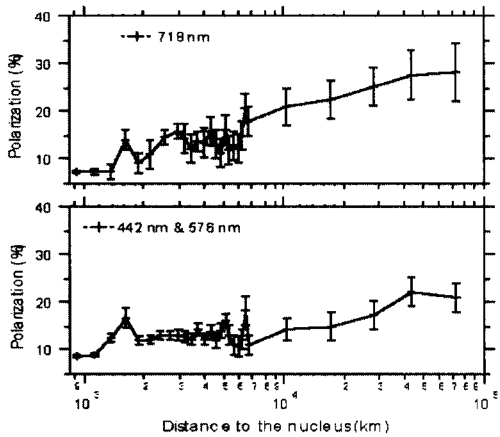

Figure 1. Variation of P ($\alpha = 73°$) with distance to Halley nucleus along Giotto trajectory. Above 7000 km, P is higher in red than in blue, while the effect is opposite in the innermost coma (with good S/N ratio).

3. Laboratory simulations under microgravity conditions

Drastic constraints on the properties of the dust are provided by the phase and wavelength dependences (Levasseur-Regourd and Hadamcik 2003). They need to be interpreted through numerical and/or experimental simulations. A series of experimental simulations under microgravity conditions (on board aircraft, rockets or spacecraft) is being developed. Such experiments avoid sedimentation of the dust and may allow (with sufficient microgravity duration) the formation of realistic particles through aggregation/fragmentation and condensation/evaporation processes (Levasseur-Regourd et al. 1998, Ehrenfreund et al. 2003).

The PROGRA^2 experiment provides polarization measurements on illuminated levitating dust samples at different phase angles, in the laboratory as well as during parabolic flights (Worms et al. 1999). The already available data base indicates, amongst other results, that cometary dust properties are reproduced by low-density aggregates of submicron-sized grains (Hadamcik et al. 2002). The

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CODAG-SRE experiment provides a monitoring of the brightness and polarization phase curves of levitating dust samples (Levasseur-Regourd et al. 1999). The ESA MASER-8 rocket flight allowed us to demonstrate the feasibility of such measurements while ballistic aggregation processes were taking place.

The ICAPS (Interactions in Cosmic and Atmospheric Particles Systems) has been proposed for the initial Columbus utilization phase on board the ISS. It should, amongst other objectives, simulate aggregation processes and formation of regoliths during long microgravity flights, and translate the light scattering observations in physical properties of the dust. It is now in phase B at ESA and a precursor rocket experiment (so-called ICAPS-SRE) will take place in 2004-2005. This MASER-10 experiment will be used to test critical ICAPS subsystems, with a Light Scattering Unit performing measurements over a large number of phase angles (including the near backscattering region) and three wavelengths. It will monitor the formation of bi-disperse aggregates of micron-sized grains of high and low albedos.

In conclusion, comets observations suggest the existence of very fluffy dust aggregates. Differences have been observed in the dust light scattering properties, e.g. structure of the comae, polarization phase curves maxima and minima, polarization colors. The series of experimental simulations should provide, in the coming years, a unique approach to derive the physical properties of the dust particles from their light scattering properties.

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