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Scattering Properties of Dust Particles in Weightlessness

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Abstract. Polarimetric measurements of the light scattered by irregular dust particles are essential to interpret observations of solar system dust in terms of its physical properties. We developed a light scattering unit to retrieve polarimetric phase curves of dust samples in microgravity conditions. Preliminary results suggest that the values for the maximum polarization are higher under 1 ``g'' than under 0 ``g'' This can be compared to ground-based measurements which exhibit higher values for packed dust than for sifted dust. The unit is operational and is used to help design a related orbital experiment.

1. Relevance of microgravity to polarimetric measurements

Many solar system objects are made up of particles forming dust clouds, dust aggregates or fluffy regoliths. The solar light scattered by these particles is partially linearly polarized as measured by its degree of polarization P The evolution of P with the phase angle α enables the computation of polarimetric parameters (maximum or minimum polarization, slope at inversion of the polarization curve, angle at inversion and at maximum) which are likely indicators of some of the physical properties of solar system dust particles, e.g., albedo, size distribution or porosity (McGuire & Hapke 1995).

Typical phase curves obtained in remote sensing of asteroidal regoliths (Goidet-Devel *et al.* 1995), cometary dust particles (Chernova *et al.* 1993) or the interplanetary dust cloud (Levasseur-Regourd *et al.* 1990, Renard *et al.* 1995) are significantly different from those obtained from Mie scattering by spheres or spheroids. They rather seem typical of fluffy or irregular dust particles with sizes in the 1-100 µm range. Microwave analog experiments on individual particles or aggregates (Gustafson 1996) have been very successfull but have not been used for the investigation of scattering by surfaces or clouds of particles. Laboratory measurements on surfaces are not easy to relate to remote sensing data of solar system dust because the physical properties of low-density dust clouds or dust aggregates in space may be different from the physical properties of more closely packed samples on the ground. Furthermore, mechanical, optical or electromagnetic levitation techniques (Weiss-Wrana 1983, Zerull 1985, Combet & Lamy 1996) could either disturb the polarization (elongated grains in an air stream), alter the grains (organic samples levitated by a laser), or forbid the use of certain particles (electromagnetic levitation of metallic samples). On the other hand, microgravity appears to be a sensible way to achieve conditions close to those prevailing in space. The PROGRA^2 experiment has therefore been designed to determine polarimetric phase functions of various terrestrial and extra-terrestrial dust samples during parabolic flights on board the Caravelle ``zero g'' aircraft (Worms *et al.* 1995).

2. Description of the PROGRA^2 experiment for parabolic flights

The PROGRA^2 light scattering unit operates with an unpolarized He-Ne laser (632.8 nm), a glass vial containing the samples and a photodiode detector block. The laser light is brought upon the sample using fiber optics and a rotating collimator. The scattered light is collected on a beam-splitter polarizing cube for simultaneous measurement and recording of the two perpendicular components of the scattered intensity (Figure 1).

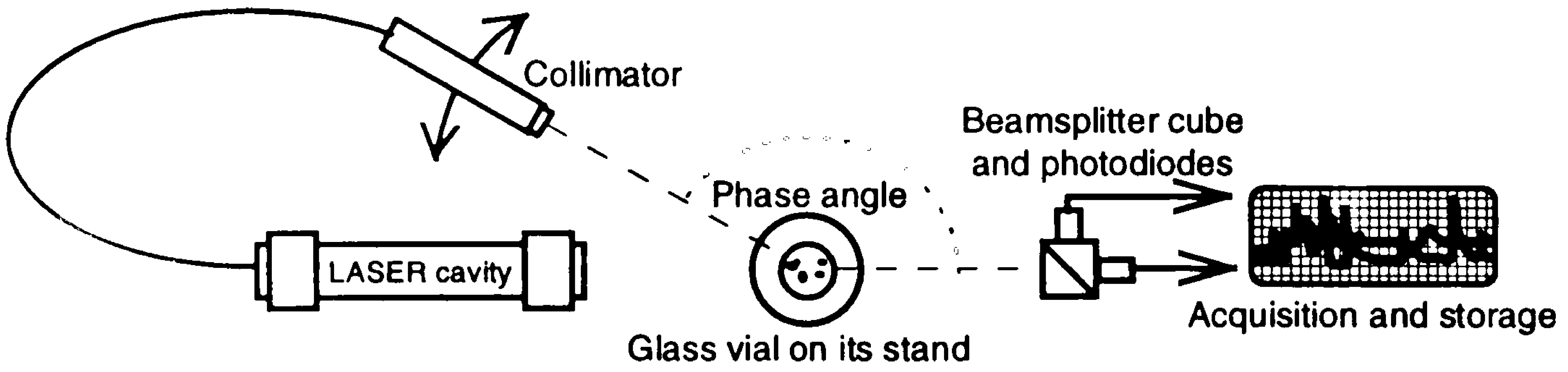

Figure 1. Synoptic view of the PROGRA^2 instrument.

The instrument was designed to operate primarily in the medium and large phase angle range. The aircraft provides microgravity by flying along parabolic paths. The microgravity phase lasts 20 seconds with a level of ±5 10^{-2} "g". The two perpendicular components of the scattered intensity are measured continuously during each parabola, at a constant phase angle. After each parabola, the collimator is rotated to another phase angle position while the gravity level has returned to normal. The flight profile (31 parabolas) constrains the phase angle step to between 5° and 10° at a yield of a full phase curve per flight. The actual recording starts a few seconds before the microgravity phase to measure the stray light contribution. Since the gravity level is roughly 2 "g" at this time ("pull-up" phase), it can be ascertained that no dust is levitating in the beam. The stray light was found to depend only upon the geometry of the vial and can therefore be substracted from the raw data. A video recording shows that the observed peaks of intensity correlate well with levitating dust particles or loose agglomerates crossing the laser beam. The intensity is resampled using 10 digital levels for the whole dynamic range, and P is computed within each of these intervals at each phase angle. A series of phase curves is therefore obtained for each intensity level. P is computed in regions of varying brightness levels, i.e., with different quantities of dust in the observed volume. This variation is a consequence of the residual acceleration of the plane which leads to a variable and highly inhomogeneous dust distribution. In addition, it cannot be ascertained that the observed polarization is the result of single-particle scattering. Despite this uncertainty on the structure of the particles, P appears to be fairly stable for different values of the intensity. The error in P is the rms error of all the measured values. On this first version of the instrument, the sample does not undergo a specific preparation before each parabola. This aspect will be improved in future flights with the implementation of a dust dispersion device.

3. First results obtained in microgravity

Values of the degree of polarization P corresponding to a phase angle range of 10°-160° have been obtained for several terrestrial samples. For the boron carbide (CB_4) sample (flight in March 1995) for which results are presented hereafter, the grain size range was 80-95 μm. It is possible to derive an empirical phase curve by fitting the data with a trigonometric function (Lumme & Muinonen, 1993) of the same form as we used with asteroidal and cometary data. Measurements were made on the ground using the same samples and apparatus to compare the phase curves obtained under 0 "g" and under 1 "g" (Figure 2).

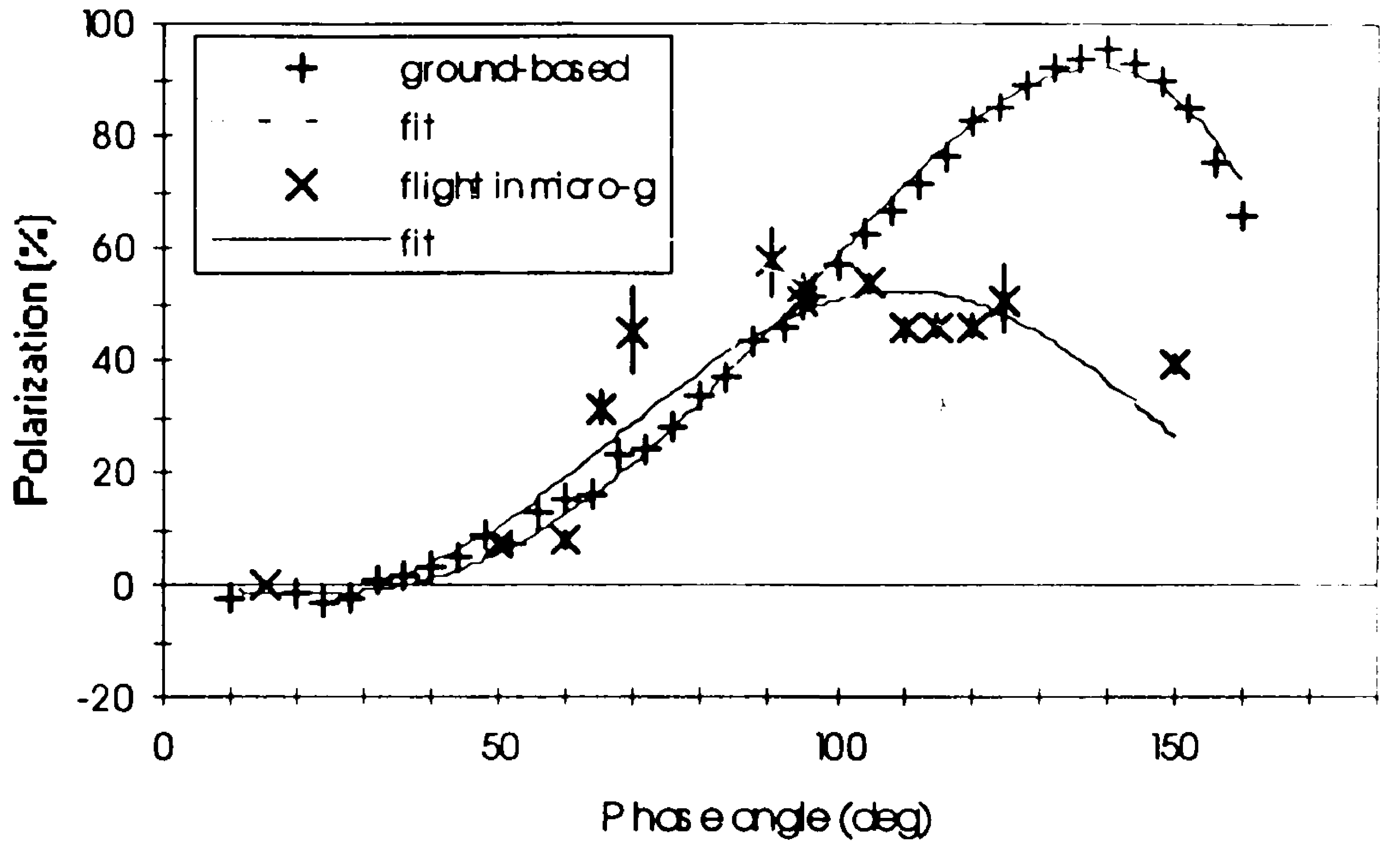

Figure 2. Comparison of polarization phase curves for a sample of ground boron carbide (80-95 μm) obtained under microgravity and under 1 "g"

Two striking features are noticed. First, the angle of maximum polarization (α_{max}) is higher when measured under ground conditions. Such a high value for α_{max} is in fair agreement with previous laboratory measurements (Killinger 1987). The corresponding value obtained under microgravity is close to 90°-100° and reminiscent of observations of S-type asteroidal regoliths, interplanetary dust particles and cometary dust (Levasseur-Regourd *et al.* 1994). Then, the value of maximum polarization (P_{max}) is significantly lower under 0 "g" than under 1 "g" (Levasseur-Regourd *et al.* 1995). This trend seems to be consistent with higher values of P_{max} for packed grains than for sifted grains (Figure 3).

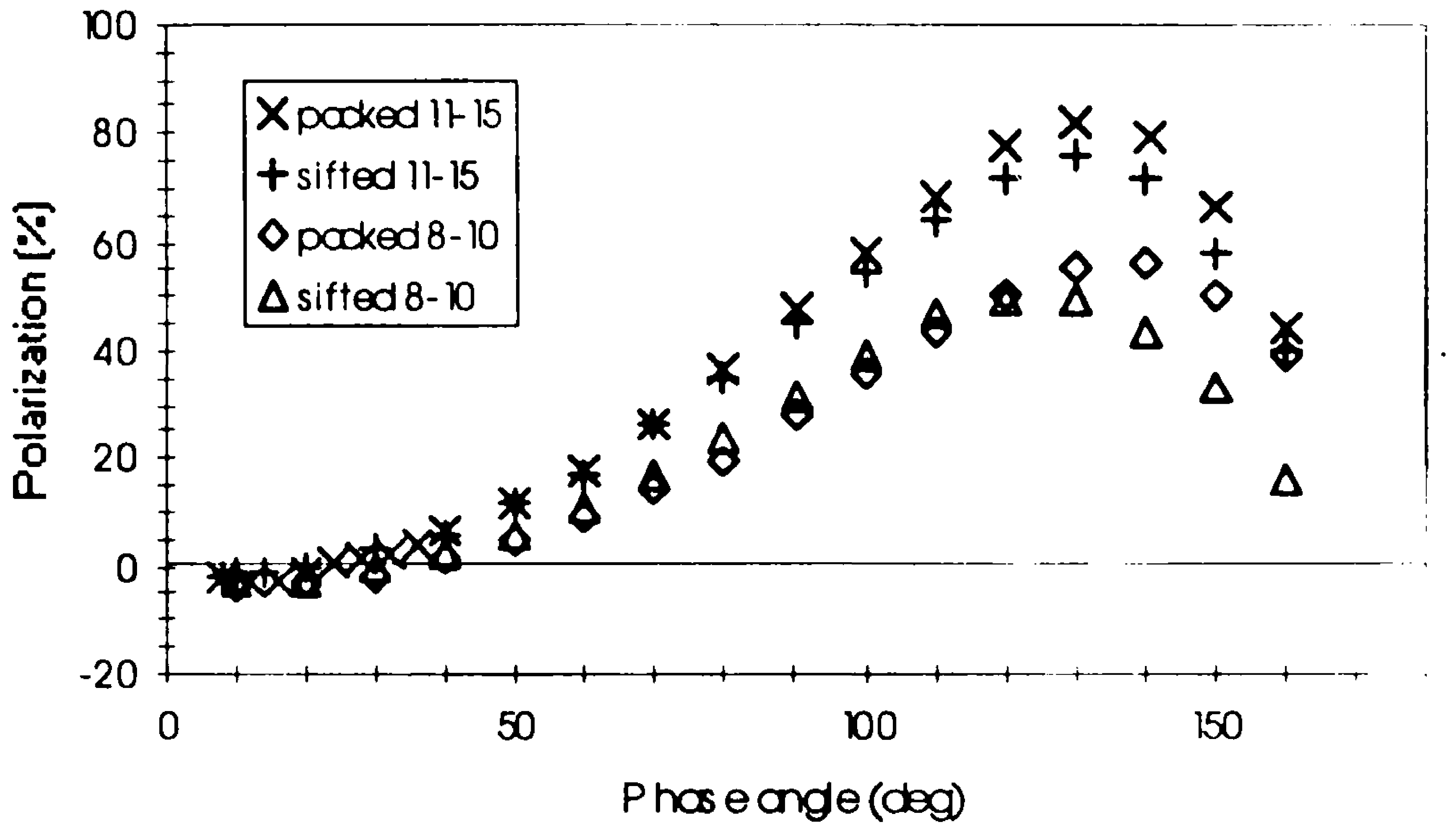

Figure 3. Polarization phase curves of sifted and packed grains of boron carbide (8-10 μm and 11-15 μm). Measurements are conducted under 1 "g"

Polarization phase curves have been measured on the ground for several samples and sizes (Hadamcik *et al.* 1996), yielding two data sets for each size distribution. One set is obtained by packing the dust sample, the second one by sifting the dust to allow for a larger separation of the grains. The second case is comparable to an asteroidal regolith and could be viewed as an intermediate state between surface-packed particles and freely-suspended grains as far as shadowing effects and roughness are concerned. An example of this comparison between packed and sifted dust is depicted in Figure 3 for two sizes of CB_4 particles.

4. Future developments and conclusion

The $PROGRA^2$ instrument is fully operational and will be used in future parabolic flight campaigns to build a reference data base of polarimetric phase curves of various samples and to correlate their polarimetric parameters with related physical data. This would allow polarimetry to become an accurate remote sensing tool and could provide keys to the physical properties of solar system dust. A dispersion mechanism will be developed for the next flight campaign to disaggregate the samples before each parabola. In addition, the evolution of the state of aggregation of the dust cloud will be monitored to estimate the mean number of particles in the aggregates. Future developments aim at making use of longer, better and more stable conditions of microgravity. The OPAL (Optical Properties of Aggregates in Levitation) orbital experiment is being designed to operate under levels of 10^{-4} "g" during several weeks, wherewith the evolution of the polarization will be measured. Other developments include measurements on icy samples which would be of great interest in preparing the forthcoming ROSETTA mission.

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