ZODIACAL LIGHT AND THE SPATIAL DENSITY OF INTERPLANETARY GRAINS

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ABSTRACT. Using our model of light scattering by large rough grains, the compatibility of the observed properties of the zodiacal light with models of the spatial density of interplanetary grains is investigated. The agreement is not yet satisfactory and probably calls for further revision of the density distribution function. Our previous conclusion that submicronic grains gives a non-negligible contribution (Lamy and Perrin, 1980) is confirmed.

I. INTRODUCTION. The possibility to derive the differential spatial density ("DSD") of interplanetary grains from lunar microcraters and direct space measurements has prompted several investigations of its compatibility with the observed properties of the zodiacal light. The analysis performed by Giese and Grün (1976) and Giese et al. (1978) relied on the microcrater distribution function of Fechtig et al. (1974). Lamy and Perrin (1980) tested the DSD obtained by Le Sergeant and Lamy (1980). Likewise the above studies, ours was limited by the lack of an appropriate theory for the scattering of light by non-spherical grains and the subsequent use of approximations. Since 1980, we have devoted considerable effort to this aspect of the problem and proposed a new model which applies to the scattering by large rough spherical grains (Perrin and Lamy 1983). The present analysis closely follows our previous one (Lamy and Perrin, 1980) but incorporates our new scattering model and also tests the new DSD of Grün et al. (1984 and this volume).

II. THE DIFFERENTIAL SPATIAL DENSITY AT 1 AU

The DSD used here are therefore those of Le Sergeant and Lamy (1980) and Grün et al. (1984) illustrated in Figure 1. In comparison with the former solution, the latter one differs on the following points:

i) a larger density of micronic grains resulting from different absolute calibrations (solar flares lunar clock and Pegasus data);

ii) a lower density of submicronic grains;

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iii) a steeper gradient for large grains ($s \gtrsim 100$ µm) resulting from a different calibration law for the ratio of crater to grain diameter.

However, it can be noted that the solution of Le Sergeant and Lamy (1980) is compatible with the large errror bars of the Heos and Pegasus data as given by Grün et al. (1984).

III. THE OBSERVED AND CALCULED VOLUME SCATTERING FUNCTION (VSF) AND POLARIZATION

The "observed "VSF" and polarization are deduced from the observed brightness of the Zodiacal light assuming a power law $r^{-\nu}$ for the dependence of the spatial density upon the heliocentric distance (see, for example, Dumont and Sanchez, 1975, and Leinert et al. 1976).

We performed a separate analysis of a set of carefully selected data (Lamy and Perrin, in preparation) and obtained an acceptable VSF - as well as polarization - only for $\nu = 1$. These results at $\lambda = 6328$ Å are plotted in figures 2 to 3 in order to be compared with the calculated models.

Several assumptions must be made for the calculations of the VSF. We split the size distribution in two parts by introducing a boundary at a radius $s_0 = 3$ µm. The purpose is twofold: first, this corresponds to the two populations 1 and 2 introduced by Le Sergeant and Lamy (1980) and second, to the ranges of validity of the scattering models.

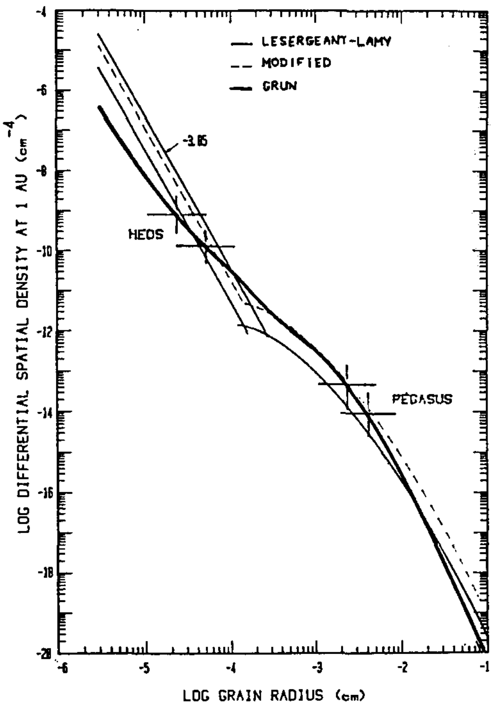

Figure 1. The differential spatial density.

i) large grains ($s > 3$ µm) are rough being aggregates of submicron grains as observed by Brownlee (1978). We felt that the scattering properties of a grain extracted from the Allende matrix experimentally studied by Weiss-Wrana (1983) and successfully modelled by Perrin and Lamy (1983) should be appropriate for this population. A refractive index of $1.803 - 2.5 \times 10^{-3}$ i at 6328 Å was finally retained (see Egan and Hilgeman, 1979) and the integration over the size distribution function extended to $s = 100$ µm.

ii) small grains ($s < 3$ µm): we consider two cases.

First, following Le Sergeant and Lamy (1980), this population is considered independent and connected to the homogeneous, nearly spherical FSN grains collected by Brownlee (1978). The closest analog is probably pyrrhotite, a non-stoichiometric iron sulfur often found in meteorite, whose refractive index was measured by Egan and Hilgeman (1977) and is 1.77 - 1.94 i at 6328 Å. As a second alternative, we follow Grün et al. (1984) and consider that this population is dominated by collisional fragments. Its composition is therefore the same as the population of large grains, namely the above grain of the Allende matrix.

In both cases, these small particles are very likely to be smooth (at least, with respect to the visible wavelength of interest here) either resembling the FSN collected grains or being collisional fragments. We felt therefore that the Mie theory should apply to them. Finally, the integration over the size distribution extends from 3 μm down to 0.025 μm.

IV. RESULTS AND DISCUSSION

Figure 2a shows the result for the VSF using the Grün et al. (1984) model. An important point is that both populations contribute significanly to the VSF: the contribution from small grains even dominates at scattering angles below ≃ 75° while the situation is reversed above. At intermediate angles, the total calculated VSF falls below the observed one by a factor 2. Let us suppose that we allow for this correction on the DSD; then, the forward and, mainly, the backward enhancements appear too strong, the second effect being entirely caused by the small silicate grains. As a matter of curiosity, we performed the calculation assuming that the submicronic grains (s < 3 μm) are composed of pyrrhotite (figure 2b). The contribution from the large grains dominates at scattering angles larger than 50° but is equal to that of small grains below. The discrepancy with the observation is still a factor of 2 but the overall behaviour appears more satisfactory than the first solution, except for too strong forward scattering. Figure 3a shows the polarization for both solutions: none appears really satisfactory and one has the feeling that some "intermediate" solution may improve the fit.

Turning now to the Le Sergeant - Lamy model, we essentially confirmed our preliminary results (Lamy ant Perrin, 1980). In order to analyze the implication of the observed VSF, we allowed ourselves to modify their model by

i) increasing their population 1 by a factor 4 so as to agree with the Pegasus data, and consequently, with the Grün et al. (1984) model, except for the largest grains;

ii) decreasing their population 2 by a factor 2 (Figure 1). This correction results in a very good agreement with the observed VSF as illustrated in Figure 2c. We further note that the scattering at angles below 120° is dominated by the population of small pyrrhotite grains, which becomes equal to that of large grains beyond 120°.

However, the results for polarization (Figure 3b) is not satisfactory. Although the theoretical tools are now available, an in-depth analysis is beyond the scope of the present article. We may however present several directions for further investigations:

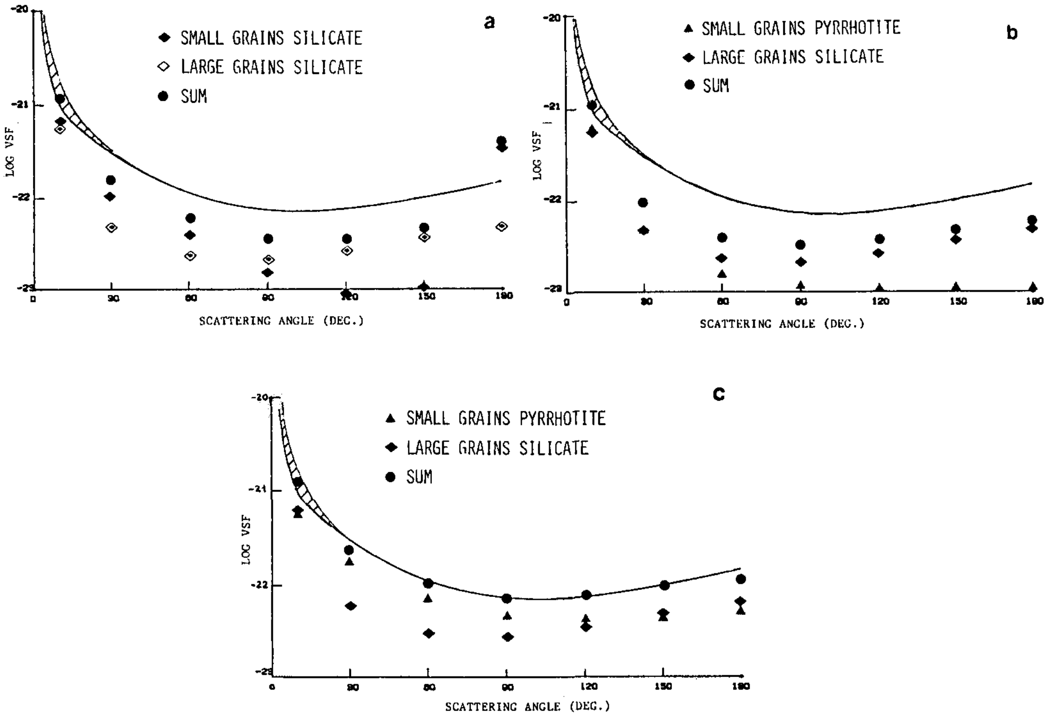

Figure 2. Comparison of the observed VSF (solid line and hatched band) in unit of cm^2 st^{-1} cm^{-3} with different models of DSD
a) and b) Grün et al. (1984)
c) Le Sergeant and Lamy (1980)

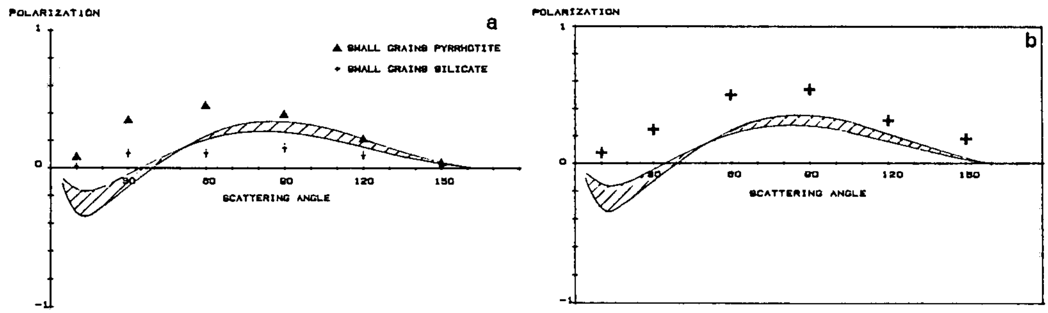

Figure 3. Comparison of the range of observed polarization (hatched band) with different models of DSD
a) Grün et al. (1984)
b) Le Sergeant and Lamy (1980)

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i) the importance of the contribution of small particles to the VSF as already established by Lamy and Perrin (1980) is fully confirmed, even for the low flux of Grün et al. (1984). The exact relative importance of the contributions from the two populations is, in part, a matter of assumptions in particular on the albedo of the grains. Our scattering model gives a geometric albedo of the order of 5 % for the large rough grains, a value consistent with the dark appearance of collected aggregates (Brownlee et al. 1976) and the measurements on C1 and C2 carbonaceous chondrites of Johnson and Fanale (1973).

ii) the upward correction proposed by Grün et al. (1984) on the basis of the Pegasus data considerably eases the compatibility with the brightness of the Zodiacal Light; a further increase may even be necessary as seen above.

iii) the pyrrhotite solution for the small grains gives a better fit to the observed VSF than the silicate solution but the polarization still poses problem. We feel that a combination of the two solutions may improve the situation. This is supported by various evidences as silicate collisional fragments are certainly present while FSN grains are collected and an "absorbing" component is implied by the infra-red observations of comets (Liu &Kimura,this vol.).This alternative would indicate that population 2 is not entirely composed of collisional fragments. The model of Grün et al. (1984) would then be too low and the true flux would lie somewhere between their curve and the modified Le Sergeant - Lamy model.

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