SPATIAL DISTRIBUTION AND ORBITAL PROPERTIES OF ZODIACAL DUST

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ABSTRACT. Within the recent years the spatial distribution of Zodiacal dust has been subject to a variety of modelling approaches. Whereas models derived from observations in the visual range tend to demand for an increase of interplanetary matter above the solar poles (bulges), models based on infrared measurements and extended to small r seem to favor a decrease there (holes). The models are reviewed, and the dynamical structure implicated in the models is outlined.

1. Spatial Distribution of Zodiacal Dust

The observed brightness of zodiacal dust particles in the optical and infrared wavelength range results from all volume elements along the line of sight (LOS) together with the scattering or thermal properties of grains. Facing the ambiguities in the knowledge of particle properties a variety of different models describing the distribution of interplanetary dust in terms of global properties have been proposed by researchers. They are shown as lines of equal number density n in terms of n_0 ($r = 1$ AU, $\beta_0 = 0$) in figure 1. The discussed models are based on the assumption that the number density can be expressed by two factors: one factor is a function that increases with solar distance r as a power law of r with exponent ν and another one that varies only with helioecliptic latitude β_0. The additional assumption of a change of the albedo with exponent μ results in an exponent $\nu^* = \nu + \mu$. A Comparison of the different models (references for the compared models are listed in table 1, for further descriptions see Giese and Kneißel 1989) shows that predictions of different authors derived from optical respectively infrared observations have a converging run of the relative distributions close to the Earth. But most of the models, devised on the basis of visible observations, suggest an increase of number density towards the Sun, whereas the models derived from infrared observations demand for a decrease above the solar poles. Even if one questions the validity of models derived from measurements at large elongations for the sunward regions the difference in the absolute scale of particle number densities (see Giese and Kneißel 1989) has to be explained.

2. Orbital Properties of Zodiacal Dust

The number density of particles of each volume element in the interplanetary space is given by the position probability of orbiting grains. Then one can obtain distributions of orbits from the number densities. These distributions are given in terms of the distribution density of orbital

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elements such as major axis: d(a), eccentricity: d(e), and inclination: d(i) (Kneißel and Giese 1987). Due to the rotational symmetry of the cloud, lines of nodes and perihelion distances should be distributed isotropically in space. As there is assumed to be a separation between the in-ecliptic n(r) and the out-of-ecliptic fraction $f(\beta_o)$ of number density, inversion of dynamical structure leads to a separation between the orbital distribution densities d(a,e) and d(i).

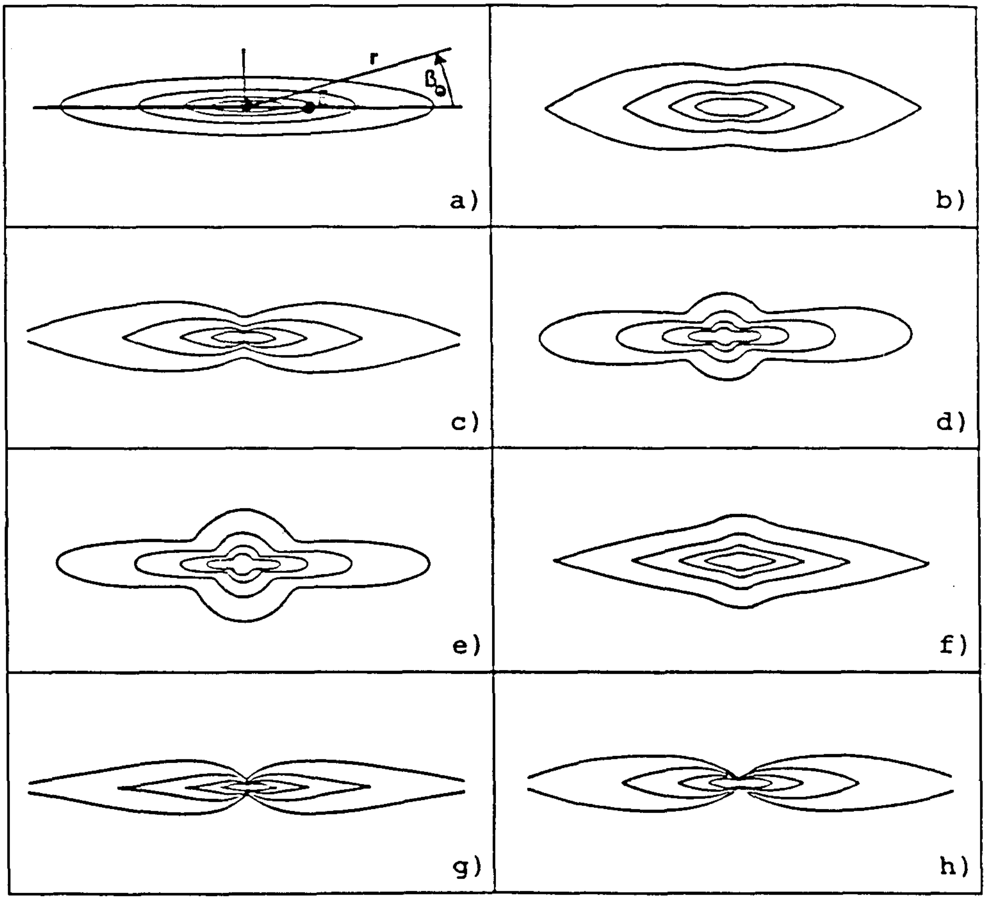

Figure 1: Spatial distribution of the Zodiacal Dust Cloud suggested by a) Giese et al. 1969 b) Leinert et al. 1976, c) Deul & Wolstencroft 1987, d) Dumont 1976, e) Rittich 1986, f) Lumme and Bowell 1985, g) Lamy and Perrin 1986, h) Good et al. 1986

The distribution of particles with solar distance r is related to d(a,e). Dealing with the three-dimensional structure of the cloud the distribution of inclinations d(i) is of most interest. In general, inversion of spatial distributions leads to a bimodal distribution of inclinations. The main component has its maximum close to the ecliptic plane and another one isotropically distributed gives a background to the first component. This background covers to the same amount both the orbits with prograde and the ones with retrograde orientation. The average inclination of orbits derived for the different models and the contribution of retrograde orbits, representing the isotropic component, are listed in table 1. The aligned inclination density distribution for 3 typical models of the spatial distribution is shown in figure 3.b). Since the main component represents the near-ecliptic dust and the second one dust forming the bulge, the isotropic background component is negligible for pole hole models whereas in the case of bulge models the background component contributes considerably. The exponent ν^* (including also the change of albedo) amounts 1 to 1.3 for the models listed in table 1.

model	$<i>/°$	$N/N_{ret}/\%$
Giese et al. 1969	30	4
Leinert et al. 1976	36	6
Deul & Wolstencroft 1987	31	3
Dumont 1976	32	8
Rittich 1986	38	10
Lumme & Bowell 1985	37	8
Lamy & Perrin 1986	28	2
Good et al. 1986	23	1

Table 1: average orbital inclination <i> and contribution of retrograde orbits $N/N_{ret}/\%$ (N: whole number of orbits, N_{ret}: number of orbits in retrograde motion) for different models.

3. Comparison with Sources of Interplanetary Dust

The interplanetary dust originates from comets emitting dust during perihelion passage or collision of asteroids, as illustrated in figure 2. The particles make their way in the inner parts of solar system due to the decelerating Poynting-Robertson drag. Especially fragments of colliding meteoroids related to comets and asteroids fill up the zodiacal dust cloud. A Comparison with orbital elements of the meteoroids (with mass $m > 10^{-4}$ g) shows that they are more inclined, with an average inclination $<i> = 39°$ and have a relative strong isotropic component. Thus the zodiacal dust cloud cannot result directly out of this population.

One has to consider the dynamical conditions for the fragments produced by colliding meteoroids. Near perihelion, where most of the collisions should take place (Dohnanyi 1978), the condition for an unbound state is directly dependant on the eccentricity of orbits and the ratio Q_{PR}/d (Q_{PR}: efficiency for radiation pressure, d: bulk density in g/cm^3, see Kneißel and Giese 1987). According to Ceplecha (1977) the isotropic component called C2 meteorids ($m \geq 10^{-3}$ g) among the meteoroid population has randomly distributed orbits with very long semimajor axis and eccentricity ≈ 0.99, amounting to 30% of the whole distribution. Fragments of these particles of the zodiacal dust size will be in unbound states (cf. Kneißel and Giese 1987) and blown off from the solar system. Other meteoroids, with eccentricities $e < 0.9$, will stay in bound orbits after fragmentation (Kneißel 1988) and may contribute to the zodiacal dust cloud as for example the class of the C3 meteoroids ($e = 0.6$-0.7, Ceplecha 1987).

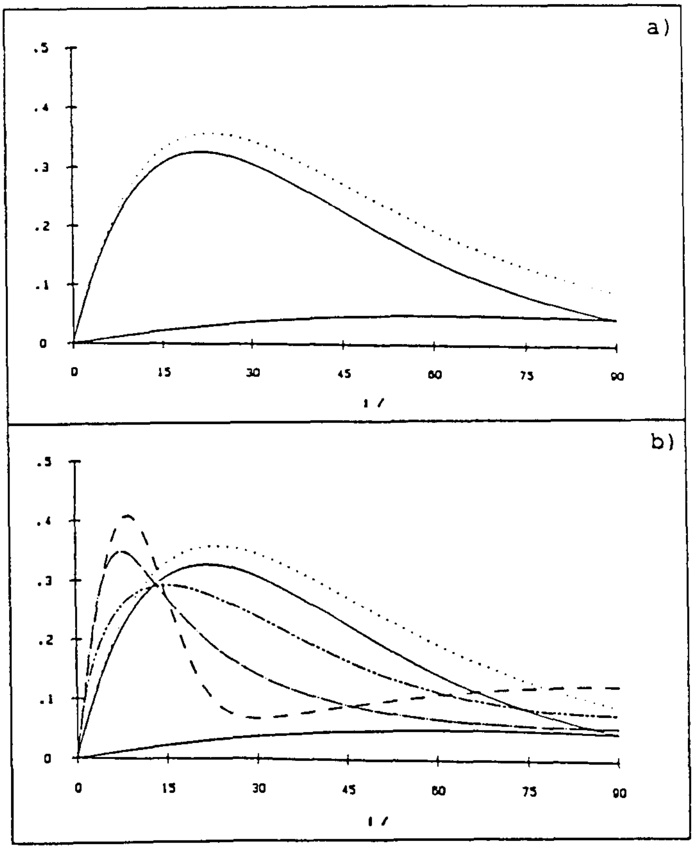

Figure 2 a): Relative distribution of inclinations of meteoroid particles (Andreev and Belkovich 1985), dotted line: whole distribution, upper solid line: distribution for inclinations 0° < i < 90°, lower solid line: distribution for 90° < i < 180° folded into that interval, b): comparison with distributions related to the models suggested by Rittich 1986 (--), by Leinert et al. 1976 (··-··) and by Giese et al. 1969 (·-·-).

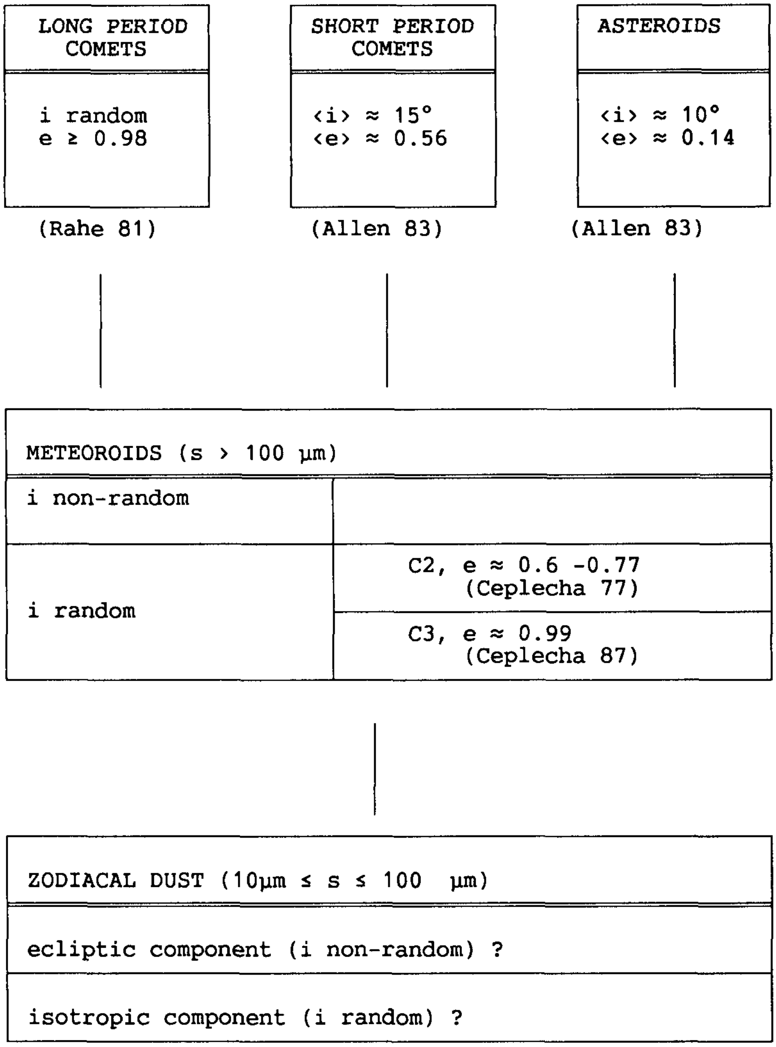

Figure 3: the zodiacal dust in the meteoritic complex

Deceleration of particles due to Poynting-Robertson effect goes along with a change of eccentricity and a change of the major axis. This orbital elements are related to the variation n(r) of the number density with solar distance. Not only additional sources, but also the reduction of the eccentricity results in an exponent $\nu > 1$ for the spatial distribution of particles. That is valid for particles that are replenished from particles on high eccentricity orbits. On the other hand particles of asteroid origin have small eccentricities $e < 0.15$ and are mainly in circular orbits when they are decelerated to 1 AU around the Sun.

As according to Fechtig (1989) at least 2/3 of all ecliptic concentrated grains are of asteroid origin, the ecliptic component of the zodiacal cloud might have not only different orbital, but also different optical properties from those of the isotropic component. As cometary dust can be extremely dark (cf. Hanner and Newburn 1989) and may show strong variations of the optical properties due to the particle structure (cf. Greenberg and Grim 1986), especially particles that where not heated before are candidates to explain a change of albedo. This change of albedo was derived from an extensive analysis of different optical and infrared data by Dumont and Levasseur-Regourd (1988, see also Levasseur-Regourd 1991). Based on our discussion of different orbital elements and different sources of the dust particles, one may regard the distribution of particles to be bimodal (Kneißel and Mann 1989). The component concentrated to the ecliptic has a high amount of asteroid particles whereas the second component has randomly distributed orbits (presumably) filled up by long period comets. Whereas the number density of the isotropic component is constant with the helioecliptic latitude, the radial dependant part is increasing with decreasing solar distance. In addition the observed brightness is influenced by the change of albedo. The first approach gives the distribution of the number density weighted with the optical efficiency to be:

$$\frac{<s>n}{<s_o>n_o} = \frac{3}{4} r^{-\nu_1^*} \cos^{40}\beta_o + \frac{1}{4} r^{-\nu_2^*} \qquad (1)$$

The expression gives the variation of the volume scattering function with respect to the volume scattering function at 1 AU $<s_o>n_o$. For further explanations see Giese and Kneißel (1989). There is no separation included between the change of scattering properties and the change of number density. Modelling the brightness integral with the volume scattering function given with equation (1) including $\nu_1^* = 1$ and $\nu_2^* = 2$ the average deviation to observational data is smaller than 10%. That means that the ecliptic component may show a spatial variation with 1/r for the particle number density and no significant change of albedo. Nevertheless, particles of the isotropic component, described by the second part of equation 1, contribute to the ecliptic brightness due to their orbits crossing the ecliptic plane. In agreement with results regarding only one population, the combination of the two components gives a run with $\nu^* \approx 1.3$ within the ecliptic.

4. Summary

The interplanetary dust cloud may be regarded as a superposition of one component mainly concentrated to the ecliptic plane with more or less the regular properties known from the zodiacal dust and a second one that is isotropically distributed and may result from long period comets. Although some interesting work remains to be done on this point, this scenario seems to be compatible with both visual and infrared observations. Beside this separation of components, the different properties of the cometary material itself mentioned by Greenberg (1990), have to be considered for further investigations. One example for this may be the difference between original cometary particles and processed cometary material.

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