OPTICAL MODELS OF THE THREE DIMENSIONAL DISTRIBUTION OF INTERPLANETARY DUST

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ABSTRACT. Several models of three dimensional distributions of the interplanetary dust number densities are compared with observational values. It is shown that a comparatively satisfying fit can be achieved by distributions similar to the "Sombrero-Model" of Dumont and that multilobe models as recently proposed by Buitrago et al. can be rejected due to discrepancies with rocket photometry of the inner zodiacal light.

1. INTRODUCTION

In general, there is agreement that the zodiacal cloud is concentrated towards a plane (or surface) of symmetry, which is close to but not identical with the ecliptic plane. Furthermore one assumes rotational symmetry with respect to an axis (z) originating in the sun and perpendicular to the symmetry plane. But it is still in question how the interplanetary dust is distributed off the plane of symmetry referred to above. In the following the models in discussion are compared and one model will be definitely ruled out. For this discussion we neglect possible variations of the dust population (size distribution, physical characteristics cf. Schuerman, 1980; Dumont,this volume) and the difference between the ecliptic plane and the symmetry plane. The local dust density $n(\vec{r})$ is described in helioecliptical coordinates $(r, \beta_\odot)$ of the position vector $\vec{r}$, which has its origin in the sun. In this coordinates the ecliptical plane (here: plane of symmetry), is $z = r \sin\beta_\odot = 0$ since $\beta_\odot = 0$ (see Fig.1).

Because of the rotational symmetry with respect to z (pole axis) the introduction of a 3-rd coordinate can be avoided (cf. Fechtig et al., 1981).

2. MODELS

From interpretation of earth based observations (Dumont, 1976), measurements by Helios 1/2 (Leinert, 1978) and Pioneer 10/11 (Hanner

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et al., 1976) a power law $n(r) \sim r^{-\nu}$ $(1,2 \leq \nu \leq 1,5)$ was derived as a first one-parameter-approach for the density distribution in the ecliptic plane. For the three dimensional distribution $n(\vec{r})$, most authors adopt an analytical form $n(r,\beta_\odot)=n_o \cdot (\frac{r}{A})^{-\nu} \cdot f(\beta_\odot)$, where n_o is the number density near the earth's orbit (r=Å =1 A.U. and $f(\beta_\odot=o)=1$). Layer models $(n=n\, r^{-\nu}f(z))$ are ruled out by rocket photometry of the inner zodiacal light (Leinert et al., 1976). Models presently most under consideration are based on different analytical expressions for $f=f(\sin\beta_\odot)$. Fig. 1 presents some examples. In the following discussion $\nu=1.3$ (cf. Leinert 1981) is adopted. The numerical value of the parameters are selected to achieve some optimum fit to the observations of the zodiacal light.

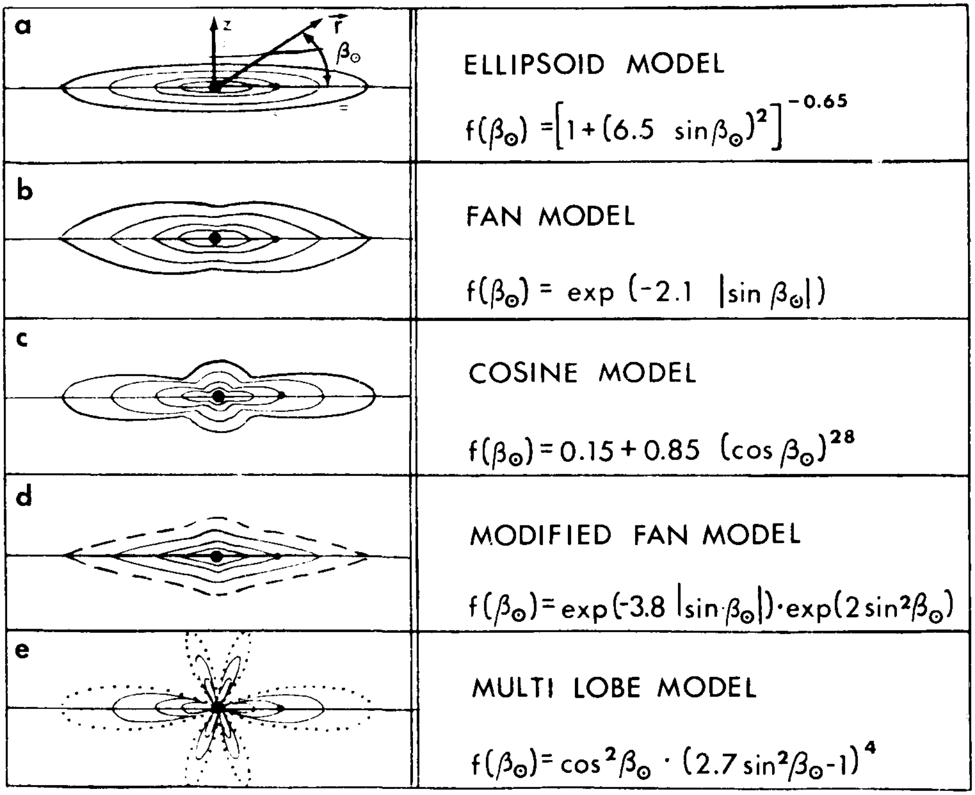

Figure 1. Isdodensity curves of particle number densities for different models.

In the "Ellipsoid Models" (Giese and Dziembowski 1969, Dumont 1976) the surfaces of equal number density are ellipsoids. They are shown in Fig. 1a (same in b, c, d, e) for $n=2n_o$, $n=1n_o$, $n=0.5n_o$, and $n=0.3n_o$.

"Fan-Models", like Fig. 1b, were proposed by Leinert (1978) as a best fit to observations of the inner zodiacal light and for interpretation of the Helios results. Furthermore they have been adopted for theoretical studies (e.g. Fahr at al. 1981, Leinert et al. 1983).

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To improve the fit to zodiacal light observations Dumont first proposed at the IAU General Assembly 1976 and later modified (Dumont, 1984) his "Sombrero-Model", which is characterized by a bulge at the z-axis caused by an additional, radially symmetric component. Even though the "Cosine-Model" (Fig. 1c) proposed in the present paper is based on a more simple analytical form it can be considered to be a Sombrero-Model.

A "modified Fan-Model" (Fig. 1d) was very recently proposed by Lumme and Bowell (Icarus, in print). Contrary to the original Fan-Models it shares with the Sombrero-Models the enhancement of $n(\vec{r})$ close to the z-axis.

All models referred to above have in common a monotonic decrease of $n(\vec{r})$ with increasing z. In contrast to this Buitrago et al. (1982) derived from zodiacal light data in the helioecliptical meridian for elongations $\varepsilon > 90°$ a bimodal function $f(\sin\beta_\odot)$. They solved the inversion of the zodiacal light brightness integral by transforming it to a Volterra integral of the second kind and arrived at a model similar to Fig. 1e (Multilobe model), which we defined here by means of an analytical expression and using $\nu=1.3$ instead of $\nu=1$ and the numerical table as Buitrago et al. provide. If models of this type could be confirmed, the orbital distribution of the zodiacal grains should have in addition to the usual population of micrometoroids concentrated towards the ecliptic plane a second component with inclinations clustered about some angle i with $45° < i < 90°$, a very challenging situation.

3. COMPATIBILITY WITH OBSERVATIONS

3.1 Viewing directions along selected great circles

To compare the different types of models integration along the line of sight was performed using Leinerts empirical volume scattering function (Leinert, 1978). The surface brightness $I(\ell,\beta)$ of the zodiacal light was calculated as a function of ecliptic latitude β and longitude ℓ (with respect to the sun as seen from the observers position). It was then compared with observational values (Levasseur-Regourd and Dumont, 1980) along the helioecliptic meridian plane ($\ell = 0$) and for a circle $\ell = 90°$ from the ecliptic to the ecliptical pole. In the latter directions the ellipsoid model provides an exellent fit. Also the deviations of the "Cosine-Model" and of the modified Fan-Model stay within 10% of the observed values. On the other hand the multilobe Model yields maximum deviations of about 20% at ecliptic latitudes about $\beta=60°$ and the Fan-Model predicts too much brightness from $\beta \approx 30°$ increasing to a deviation of about 40% near the pole.

In the helioecliptic circle the brightness of the Cosine-Model stays everywhere within about 10% of the observed values. The Ellipsoid-Model yields too low intensity for elongations $\varepsilon = \beta < 90°$ (40% near $\varepsilon=45°$) and the Fan-Model too high intensities between $\varepsilon=60°$ and $\varepsilon=130°$. For $\varepsilon < 60°$ the fit of the Fan-Model is exellent (5%).

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The modified Fan-Model stays within deviations of 10% up to ε =120° but then deviates by more than 20%. The multilobe Model generally stays within 20% but produces much too low intensities (about 40%) near ε = 120°. Generally the Sombrero-Models (cf. Cosine-Model) yield the best fit. Fan-Models are satisfying for the inner zodiacal light, but not elsewhere. The fit by the multilobe Model is not worse than the behaviour of the celebrated Fan- or Ellipsoid-Models in unfavourable viewing directions.

3.2 Inner zodiacal light

The agreement of different models with a rocket photometry of the inner zodiacal light along circles at ε =15°, 21°, and 30° about the sun was discussed by Leinert et al., 1976 (cf. their Fig. 2). It was found, that only the Fan-Model yields a satisfying fit in this region.

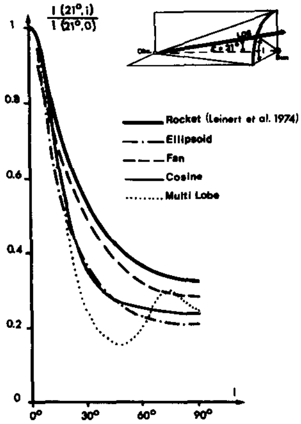

Figure 2. Measured Intensity I(ε,i) of the inner zodiacal light compared to predictions from models.

It is tempting to investigate now if multilobe models show diagnostic signatures in this domaine. In viewing direction on the great circles as discussed in section 3.1 the line of sight passes through both lobes of dense and well illuminated material. Therefore the drastic differences between multilobe and ordinary models are smoothed out because of the integration along the line of sight. On the other hand at low elongations and moderate inclinations (i) of the scattering plane with respect to the ecliptic one expects that the line of sight misses to penetrate the second lobe of an additional concentration of material outside the ecliptic plane. For viewing directions towards these gaps a decrease would be expected in the zodiacal light. As a test we calculated the intensity along a circle with ε=21° about the sun (corresponding to Leinert et al., 1976, Fig. 2) expected for the multilobe Model (Fig.2). Contrary to the monotonic decrease of brightness from i=0 to 90° as found for all other models, only the multilobe Model shows a strong minimum close to i=45° and a secondary maximum near i=75°. This definitely is in disagreement with the rocket observations of Leinert et al., 1976.

4. CONCLUSIONS

None of the existing models shows a perfect agreement with the brightness distribution of the zodiacal light. However, for a first approach sombrero type models provide a best compromise for a simple approximation of $n(\vec{r})$ by few parameters. Multilobe models as proposed by Buitrago et al. are in strong contradiction to observations of the inner zodiacal light and should be rejected. The preliminary results referred to above are presently complemented by investigations including other viewing directions and possible observations from space probes.

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