WAVELENGTH DEPENDENT MODELS OF THE ZODIACAL LIGHT

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We discuss the significance of our zodiacal light models, which are based on Mie theory and refractive indices measured in the range $0.15\,\mu m \leq \lambda \leq 100\,\mu m$. The models include scattering and thermal emission. They are absolute, since particle number density at 1 AU, size distribution and radial density gradient in the Ecliptic are fixed by lunar microcrater counts and by Helios and Pioneer results. The only free parameter is the chemical composition of the dust.

1. INTRODUCTION

If one asks: "Why Mie theory in ZL models?", the answer has to be twofold: first, hitherto no Mie calculations have been made in the visual, using those model parameters which are presently known to be relevant to the ZL cloud (although they are useful, at least for comparison with laboratory results). Second, there still is no other way to discuss the wavelength dependence of the ZL. The objection that real dust particles are not perfectly spherical and homogeneous, is granted, but as such it does not help to understand the ZL phenomenon. The purpose of the present study is to see what can be done with Mie theory, and to check the consistency between independently observed quantities as visual ZL brightness and polarization, the radial density gradient of the dust cloud and the size spectrum and absolute number density of the grains. Having verified this consistency to a satisfactory degree, we then predict some characteristic features of the ZL in the IR and in the UV.

Our assumptions are: absolute number density and grain size distribution at 1 AU as given by the "Maximum Model" of Giese and Grün (1976) in the range $0.01\,\mu m \leq s \leq 100\,\mu m$ (s = grain radius); variation of the number density n(R) with heliocentric distance: $n(R) \sim R^{-1.3}$, according to Helios and Pioneer results; no change of the dust properties with R. We consider five materials for which complete measurements of the refractive indices $m(\lambda)$ are available: the silicates obsidian, andesite, olivine, and the strong absorbers magnetite and graphite.

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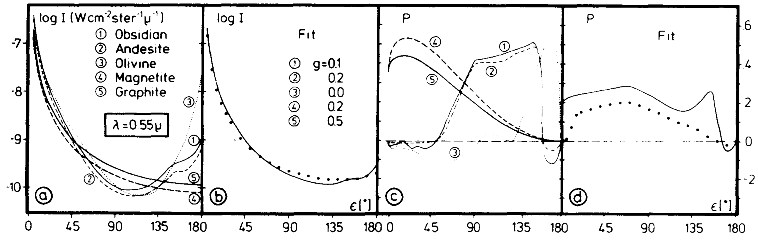

Fig. 1. a,c-calculated ZL brightness and polarization along the Ecliptic for individual materials; b,d-comparison of the results for a mixture with weights g with observations taken from Leinert's review (1975).

2. THE VISUAL ZODIACAL LIGHT

Visual brightness and polarization of the ZL along the Ecliptic, as calculated for the five materials considered, are shown in Fig. 1a and 1c. The mixture of the materials with the weights g yields the fit to the observed data shown in Fig. 1b and 1d. While the absolute number of dust particles is kept constant, the maximum deviation of calculated from observed brightness is less than 30% at all elongations. The polarization maximum at the "rainbow" region ($\epsilon \approx 157^{\circ}$) is due to the idealizing assumptions of Mie theory, but the general shape of p (λ) is well reproduced. We conclude:

- The fit implies that particle number, space gradient and especially size distribution are consistent with ZL brightness. This is strongly supported by Fig. 2, which shows how the absolute curves of Fig. 1a compare with observations of the F-Corona: here the diffraction lobe comes into play, which is determined by the size of the particles, but essentially independent of their shape and composition. In particu-

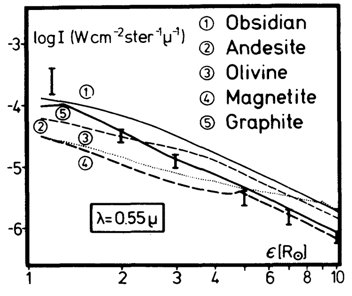

Fig. 2. Calculated brightness of the F-corona along the Ecliptic, compared with data from Leinert (1975)

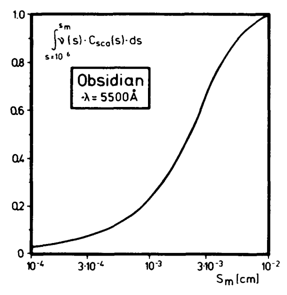

Fig. 3. The normalized integral of the effective scattering cross section over size distribution, as a function of its upper limit s_m

lar: grains with radii $s > 10\,\mu m$ contribute 80% of the ZL, as shown for a special case in Fig. 3.

- The fit is not intended to yield a quantitative chemical analysis of the dust, since the shape of the scattering functions is influenced by surface properties of the grains, and since mixtures of pure grains are not necessarily equivalent to mixtures of materials in the grains. But we note that Mie theory yields the Gegenschein and its negative polarization.

3. THE SPECTRUM OF THE ZODIACAL LIGHT

To extend our model to the IR, we compute the grain temperature T as a function of chemistry, grain radius and heliocentric distance r. As shown in Fig. 4, T depends strongly on all of these parameters in a quite complex way. While the visual ZL is determined mainly by the "geometrical" properties of the dust cloud (radial density gradient, size distribution), the temperature and the thermal emission depend strongly on the chemistry through the refractive index $m(\lambda)$, taken in the whole range from the UV to the IR. Fig. 5 shows that in the range $5\,\mu m \lesssim \lambda \lesssim 12\,\mu m$ differences by up to two orders of magnitude are to be expected for the ZL brightness, depending on the chemical composition of the grains. This result is fairly independent of the shape of the grains, since it rests on their absorption behaviour over the whole spectrum, not on their scattering properties at particular wavelengths. On this basis we suggests that detailed measurements between $\lambda = 5\,\mu m$ and $12\,\mu m$ may clarify the composition of the dust. On the other hand we note the absence of any maximum at $\lambda = 10\,\mu m$ or $18\,\mu m$ in the spectra of the silicates. This is a consequence of the dominance of the large grains ($s > 10\,\mu m$). If the observations of such features (Briotta 1976) should

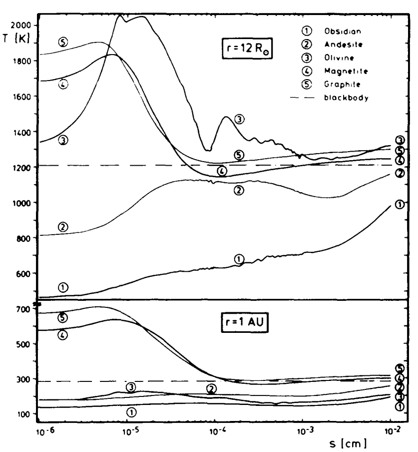

Fig. 4. Size dependence of grain temperature

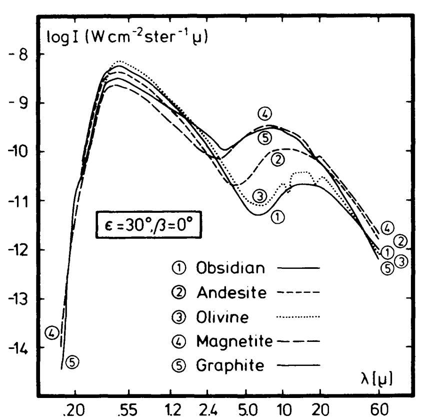

Fig. 5. The computed absolute spectra of the Zodiacal Light

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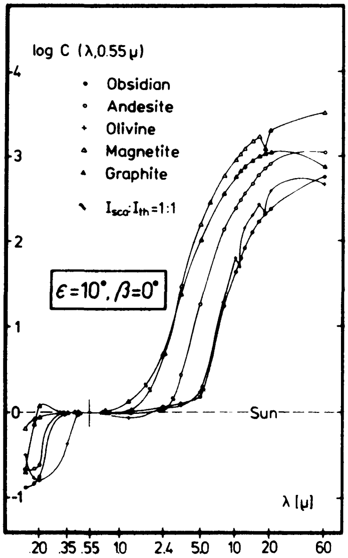

Fig. 6. The computed colour of the Zodiacal Light

be confirmed, this would conflict with our assumed size distribution, which however is needed to explain the visual properties of the ZL. The minima at $\lambda = 10\ \mu$m and 18 μm in the spectrum of olivine depend on minor details of the refractive indices, and are therefore not so significant.

Fig. 6 shows the colour of the ZL, normalized to the sun at $\lambda = 0.55\ \mu$m. In addition to the strong colour differences in the IR mentioned above, and to the almost neutral behaviour in the visual region, a marked darkening of the ZL below 0.3 μm is found for all materials. The relative albedo of the grains (unity at $\lambda = 0.55\ \mu$m) drops to about 0.3 in the UV. In view of this quite general result, which cannot be avoided by assuming larger contribution by submicron particles, we cannot explain observations according to which the UV colour of the ZL is enhanced relative to the sun. More details about our methods and results and complete references are given by Röser and Staude (1978, 1979).

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