METHOD FOR THE DETERMINATION OF DENSITY AND PHASE FUNCTIONS OF INTERPLANETARY DUST

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SUMMARY: A method of determination of the scattered light intensity, $\mathfrak{J}(r,\varepsilon)$, by a unit-volume of interplanetary space is presented. From ground base Zodiacal Light measurements and the experimental results of Pioneer X the density, $\rho(r)$, and phase, $\sigma(\theta)$, functions are obtained without any previous assumptions about them.

METHOD: In the present work we develop a method following Dumont(1973) in which $\mathfrak{J}(r,\varepsilon)$ is determined from a previously assumed $Z(r,\varepsilon)$ in the symmetry plane of the cloud where Z is taken to be a continuous and differentiable function of r and ε.

In the polar coordinate diagram (r,ε) of fig.1 the values of Z for $30° \leq \varepsilon \leq 180°$ in the semicircles belonging to r = 1 A.U. are known -Dumont and Sánchez(1975), Frey et al.(1974), Gillet(1967), Peterson(1967), Smith et al.(1965)- The values of Z for r = 2.41 A.U. and r = 3.27 A.U. as well as on the segments belonging to ε = 140° and ε = 180° for 1A.U. r = 3.27 A.U. are also known -Hanner et al.(1974), Soberman et al.(1974).

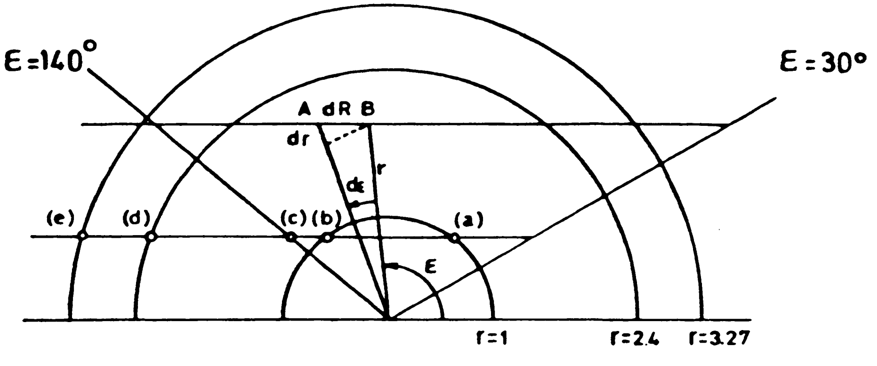

Fig. 1: Basic geometric diagram

I. Halliday and B. A. McIntosh (eds.), Solid Particles in the Solar System, 55–60.

In fig.2 the photometer is located at F while observing in the direction FP. All points along this viewing direction satisfy the equation

$$r_o \sin \varepsilon_o = r \sin \varepsilon \tag{1}$$

which is a parallel line to the polar axis.

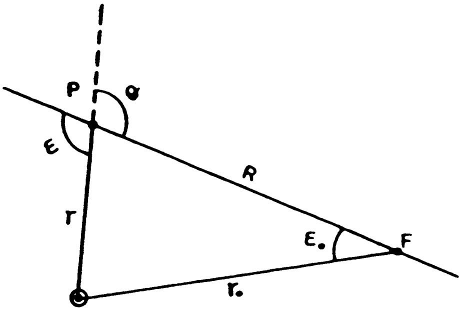

Fig. 2: Geometric relation for defining a viewing direction.

For the brightness distribution along these directions, we only know the values corresponding to the sections with the semicircles and segments mentioned before – points (a), (b), (c), (d) and (e) for a given direction in fig.1– . Take $Z^*(\varepsilon)$ to be the function describing the brightness values taken by $Z(r,\varepsilon)$ along an arbitrary line of sight.The variation of $Z^*(\varepsilon)$ between points A and B in fig.1 is given by

$$dZ^* = - \mathfrak{I}\, dR \tag{2}$$

where $\mathfrak{I}$ is the scattered intensity per unit volume. From the same figure it can be seen that

$$dR = r\, d\varepsilon / \sin \varepsilon$$

which together with (2) gives

$$\mathfrak{I}(r,\varepsilon{=}\theta) = - \frac{\sin \varepsilon}{r} \frac{dZ^*(\varepsilon)}{d\varepsilon} \tag{3}$$

Therefore, the problem of finding $\mathfrak{I}(r,\varepsilon{=}\theta)$ is reduced to the determination of the functions $Z^*(\varepsilon)$ at all viewing directions.

As mentioned above we know the values of $Z^*(\varepsilon)$ at a few selected points; furthermore this function must be decreasing and for $r \leq 1$ AU and a given ε its value is greater than that corresponding to $Z(1,\varepsilon)$. Various functions of $Z^*(\varepsilon)$ fitting these requirements can be found but not all of them yield permissible functions of $\mathfrak{I}$. For a given $\mathfrak{I}$ the scattering function $\mathfrak{I}^+$ for $r=r_o$ is now defined as

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$$\mathfrak{J}^{+}(r_o,\varepsilon=\theta) = \frac{\mathfrak{J}(r_o,\varepsilon=\theta)}{F_\odot / r_o} \qquad (4)$$

where $F_\odot$ = solar flux at 1 AU.

If for differing values of r these functions (once normalized) were found to be consistent it could be inferred that the phase function is the same for any heliocentric distance, which implies homogeniety in the composition of the medium.

In this case it can be written

$$\mathfrak{J}^{+}(r,\varepsilon=\theta) = \rho(r)\ \sigma(\varepsilon=\theta) \qquad (5)$$

where $\rho(r)$ is the density function of the medium and $\sigma(\theta)$ the phase function.

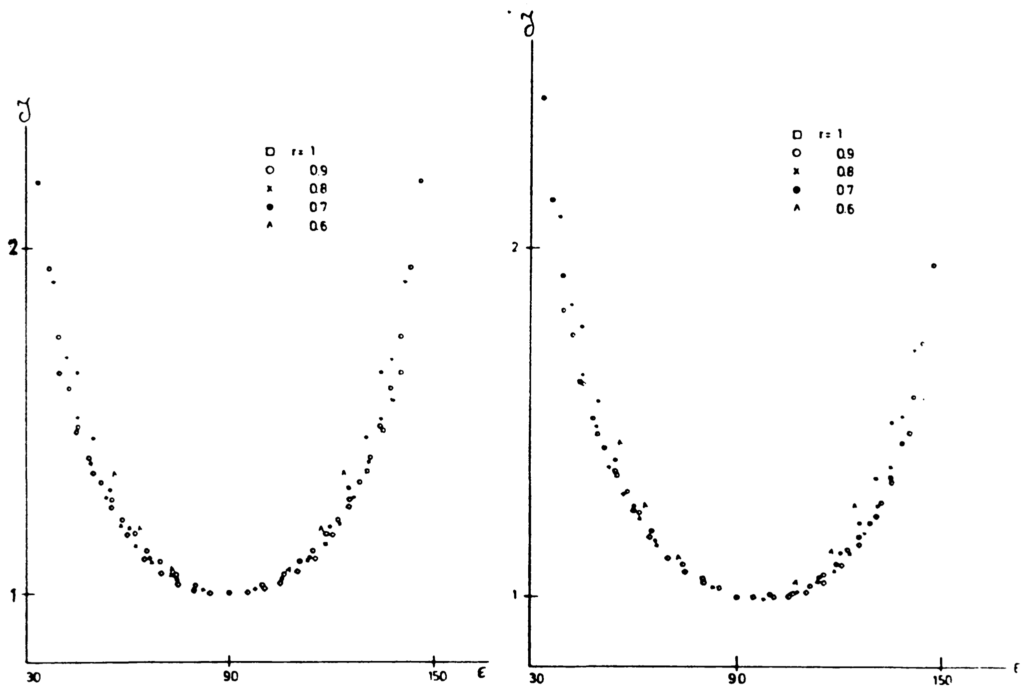

Fig. 3a Fig. 3b

Fig. 3: Phase functions normalized to 90° for different heliocentric distances and the following different kinds of curves Z*:

fig. 3a: straight lines
fig. 3b: parabolas

For r >1 AU the results are similar.

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If we take in expression (5) $\rho(1) = 1$, then

$$\mathfrak{J}^{+}(1,\varepsilon=\theta) = \sigma(\varepsilon=\theta) \tag{6}$$

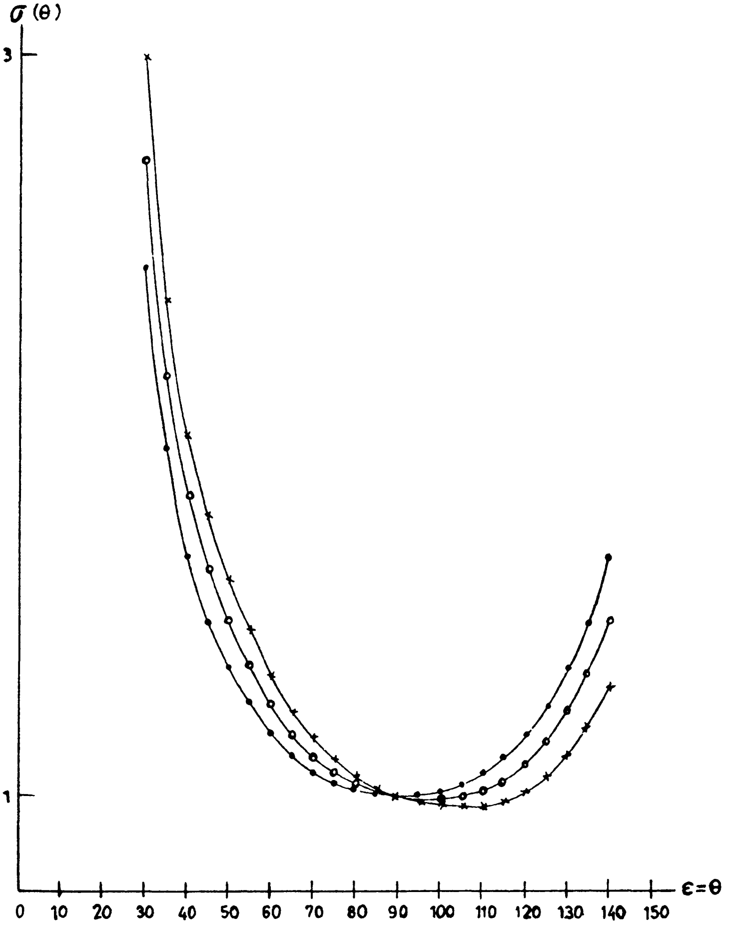

Fig. 4: Phase functions normalized to 90° for the following different kinds of curves Z^*:

dotted line (·): Z^* is represented by straight lines

crossed line (x): Z^* is represented by parabolas

circles (o) : Z^* is represented by parabolas with more curvature

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From (5) and (6) and taking into account (4) we finally derive the density function

$$\rho(r) = \frac{\mathcal{J}(r,\varepsilon_o)}{\mathcal{J}(1,\varepsilon_o)}\ r^2 \tag{7}$$

RESULTS: Several calculations of Z^* have been performed for several differing geometric focus (straight lines and parabolas).

Values of Z^* for each of the chosen curves were based on measurements at 1 AU taken of the observatorio del Teide (I.A.C.) by Dumont and Sánchez (1975) and are presented in fig. 3. The results show that the medium can be assumed to be homogeneous which justifies the use of equations (5), (6) and (7).

In fig. 4 the phase functions obtained for angles between 30° and 140° are given. For angles greater than 140° Pioneer X provides the only available data; for the same kind of curves Z^*, the results are presented in fig.5

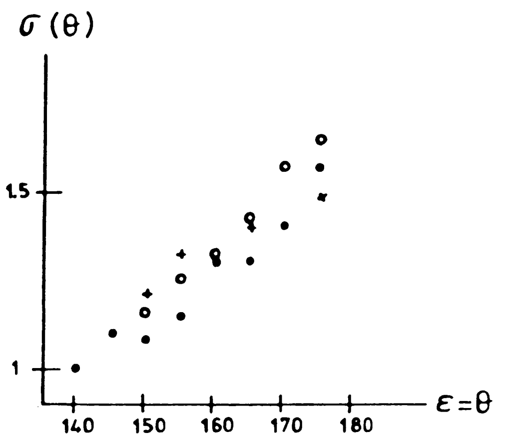

Fig. 5: Phase functions for scattering angles >140° and normalized to 140°.

For each of the phase functions presented in figs. 4 and 5 the density functions, $\rho(r)$, given by (6), for $0.6\ AU \leq r \leq 3\ AU$ were obtained. These functions together with the $\rho(r) = r^{-1.2}$, which is commonly used, are given in fig. 6. As can be expected the agreement for $r \leq 1.5$ AU is fairly good. However for $r > 1.5$ AU the results are not so consistent. The differences are smoothed at 3 AU where the values taken for $\rho(r)$ vary from 0.11 to 0.13.

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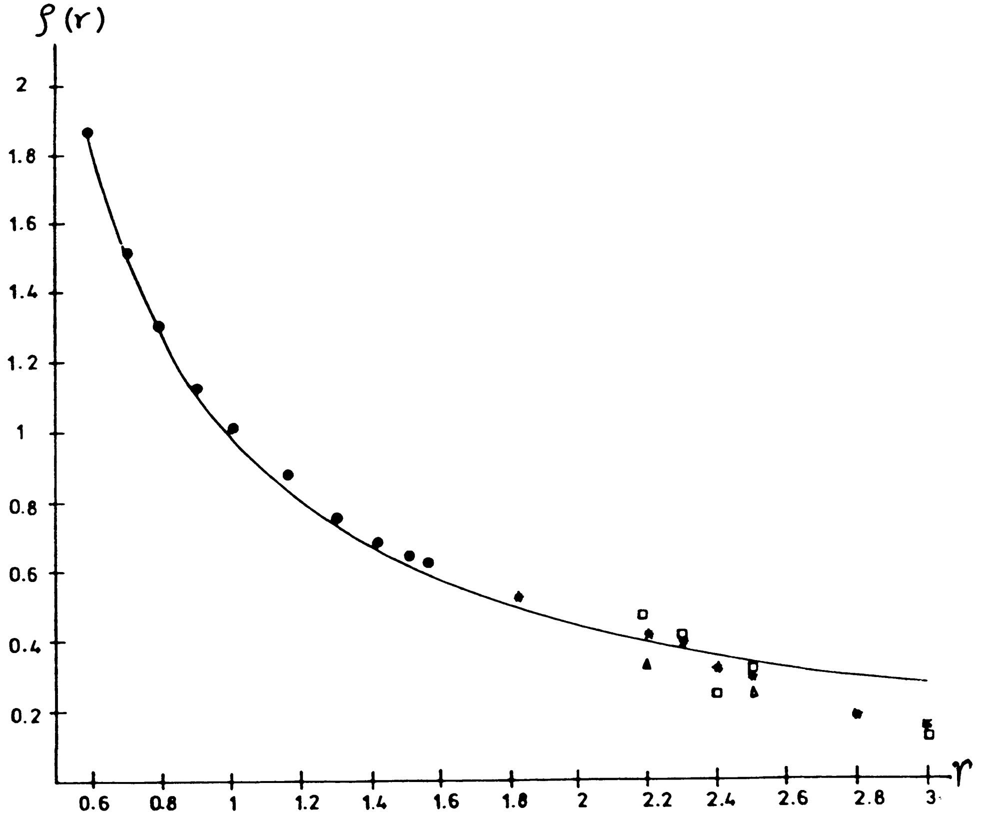

Fig. 6: Density functions obtained with the scattering functions of figs. 4 and 5. The full line corresponds to the function $\rho(r) = r^{-1.2}$.

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