ZODIACAL LIGHT: A PROBE OF THE PROPERTIES AND EVOLUTION OF INTERPLANETARY DUST

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Abstract - A brief discussion is presented on the use of zodiacal light observations to derive information on the optical and physical properties of interplanetary dust and its spatial distribution.

There is only one source of information on the integrated properties of the "steady state" small particle ensemble of interplanetary objects: the zodiacal light. Although brightest in the zodiacal band (hence, its name), the zodiacal light extends over the entire sky and is caused by sunlight scattered or absorbed by interplanetary grains. In terms of the scattering or photometric characteristics, the zodiacal light cannot be seen "by itself" except close to the sun where it is very bright compared to the starlight background. This paper will briefly describe several aspects/properties of the zodiacal light that contain information on the properties, origin, and evolution of the grains. More comprehensive reports can be found in Leinert (1975), Weinberg and Sparrow (1978), and triennial IAU Reports on Astronomy (Commission 21).

Analysis of Doppler-shifted lines in the faint solar Fraunhofer spectrum of the zodiacal light can provide information as to whether the grains are in prograde or retrograde orbits. Observations of brightness, polarization, and color of the scattered radiation (and of the thermal emission) contain information on size, shape, composition, and overall properties of the grains. Observations made from different locations in the solar system provide data on the change in zodiacal light with heliocentric distance and, therefore, on the spatial distribution of the dust and on changes in its optical properties as functions of sun-particle distance and height above or below the plane of maximum concentration. During the past decade two factors have significantly increased our knowledge of the interplanetary dust/zodiacal light cause/effect: the development and use of inversion (optical probe) techniques, and photometric experiments from the Pioneer 10/11 and Helios 1/2 probes.

Before the Pioneer 10/11 and Helios 1/2 missions, the interplanetary dust cloud (i.e., zodiacal light) had only been viewed from 1 AU, and

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thus only column brightness (Z) along the line-of-sight could be obtained. The column brightness or brightness integral is given by

$$Z \propto \int \frac{n\sigma}{R^2}\, dL, \tag{1}$$

where n = dust density
σ = scattering cross section
R = heliocentric distance
dL = elemental line-of-sight.

If it is assumed that (1) the dust density is a power of heliocentric distance, $n \propto R^{-\nu}$, and (2) the nature (scattering cross section) of the dust is independent of location, observations at different R (e.g., from Pioneer and Helios) make it possible to solve for n and σ (Hanner and Leinert, 1972). In so doing, the latter assumption *a priori* denies any dynamical process which would selectively act on different characteristics (size, shape, albedo, etc.) of the dust.

During the past decade, Dumont (1972, 1973), Schuerman (1979), and others have developed inversion techniques based on differentiating equation (1). Figure 1 illustrates this technique in one dimension (L) for observations from a space probe. The sun (⊙), probe (o), and line-of-sight (→) are imbedded in a column of interplanetary dust of length x=L.

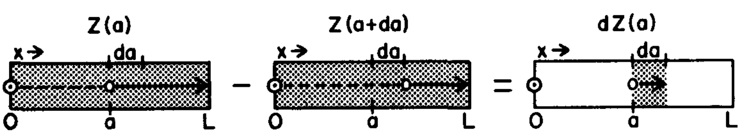

Figure 1. Inversion concept in a 1-dimensional geometry.

The probe, at x=a, looks in the antisun direction and records a brightness Z(a). The probe then moves a small distance da and makes another measurement, Z(a+da). The difference, dZ(a), then yields all the brightness information from the material in the distance da. By doing this in 3 dimensions for all points (a) traversed by the probe, brightness information for each traversed *volume element* is recovered, instead of averages over the line-of-sight. No *photometric* measurements can yield more information than this brightness/unit volume.

Figure 2 outlines a methodology whereby column brightnesses obtained from a space probe are used to derive information on particle properties. In this case, Pioneer 10 in-ecliptic column brightnesses as a function of heliocentric distance (R, in AU) and angular distance (ε) from the sun are inverted to obtain brightness/unit volume (Schuerman, 1980a). The associated scattering functions are compared, volume element by volume element, to theoretical and laboratory (microwave analog measurements) dust models to infer the nature of the dust as a function of R.

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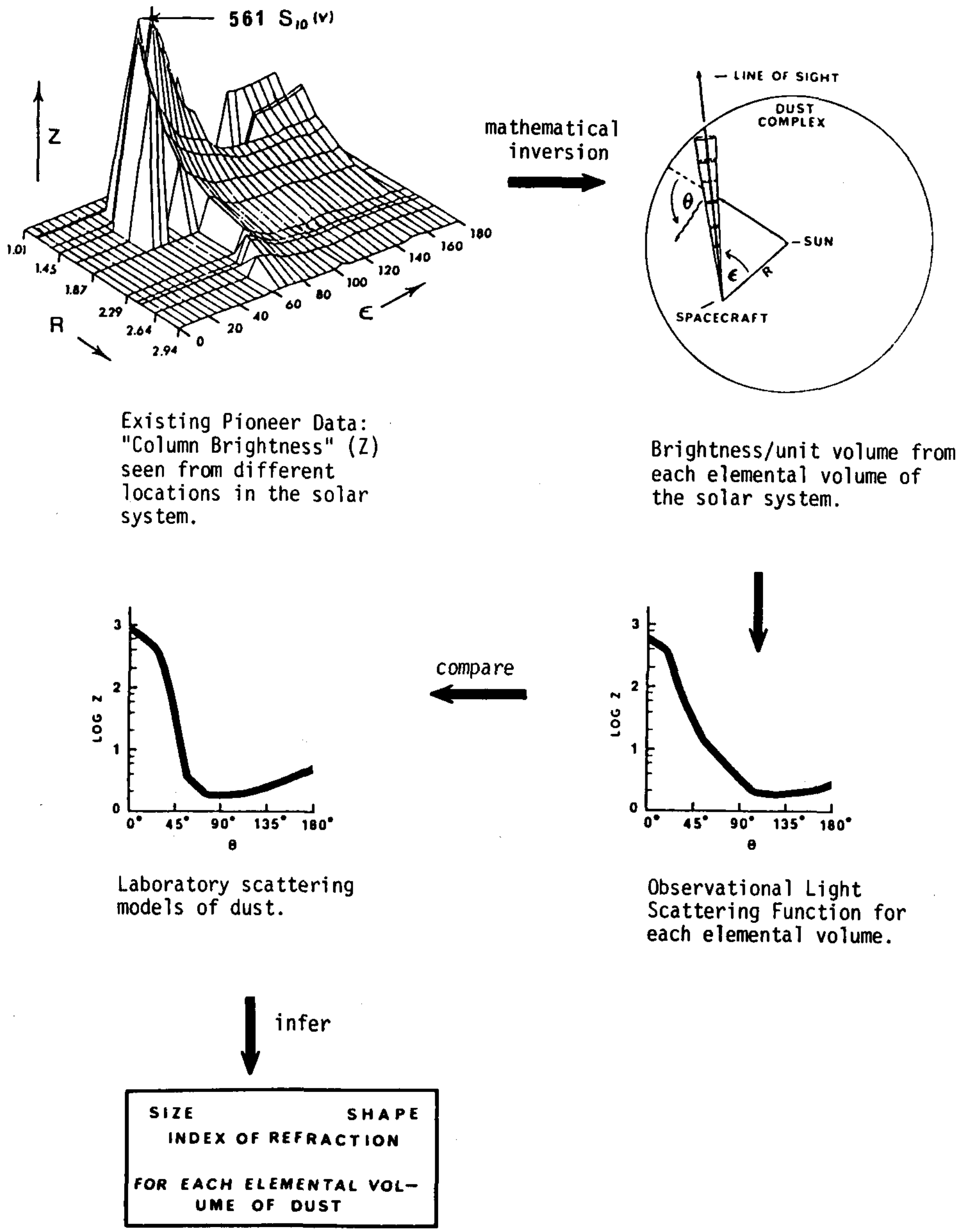

Figure 2. Schematic methodology for deriving volume element properties from space probe line-of-sight photometric data.

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If it is assumed that the same type of particle is arbitrarily distributed throughout the solar system, it can be shown that

$$Z(\varepsilon,R) = R^{\alpha}f(\varepsilon,R), \tag{2}$$

where α is an index independent of ε. To test this assumption, Schuerman (1980a) used the traditional method of fitting a power law to Pioneer 10 column brightnesses for values of ε shown in Figure 2. The data showed a systematic dependence of α on ε; i.e., the particles *cannot* be the same throughout the solar system. This may also account for changes in polarization with heliocentric distance observed from Helios (Leinert, et al., 1981) and from Pioneer 10 (Clarke and Weinberg, unpublished). This suggests that we may have optically observed the results of competing dynamical processes which may maintain the interplanetary dust complex in an inhomogeneous state.

Most inversion formulas require the assumption of circular symmetry of the zodiacal dust. It was planned to test this assumption by using the zodiacal light photopolarimeter (Schwehm, et al., 1981) of the planned NASA/ESA International Solar Polar Mission to scan the zodiacal cloud when the NASA spacecraft was near solar polar passage(s). This opportunity was lost when NASA cancelled its spacecraft. In a search for mechanisms which might produce circular asymmetries, Schuerman (1980b) found new solutions of the restricted three-body problem which may produce "dust arcs" which do not have circular symmetry about the sun. The combined effects of sunlight and gravity extend the classical Lagrangian points L_4 and L_5 into circular arcs extending from L_4 through the sun to L_5. A dust arc, if one exists, would produce an asymmetry in the Gegenschein during the Earth's biannual passage through the arc. Attempts will be made from Mt. Haleakala, Hawaii, to detect arcs associated with Jupiter and Saturn during 1983-84 viewing opportunities. If an arc is detected, it will be modelled to see if it can explain the aforementioned dependence of α on ε.

Although it is outside the scope of this paper, there are a number of other "linkages" between zodiacal light and the properties and evolution of interplanetary dust. Current evidence finds the zodiacal light to have solar color from UV to IR (i.e., the particles are primarily tens of microns in diameter), except for a slight reddening near the sun, and to be remarkably constant (Leinert, et al., 1982). The heliocentric dependence of interplanetary dust was found from Helios 1/2 zodiacal light data to vary as $R^{-1.3}$ between 0.3 and 1.0 AU (Leinert, et al., 1981). Pioneer 10 data suggest a steeper decrease for heliocentric distances beyond 1 AU (Schuerman, 1980; Weinberg and Sparrow, 1978). Ground (Misconi, 1980) and space (Leinert, et al., 1980) observations of zodiacal light have been used to locate the position(s) of maximum dust number density. Studies are ongoing to evaluate the relative strengths of electromagnetic effects (Grün and Morfill, 1980) and of long-term gravitational effects by the planets on the dust distribution (Gustafson and Misconi, in preparation). Zodiacal light, observations and analysis, has proven to be an effective and unique *probe* of the interplanetary dust.

It is doubly tragic to have lost in a relatively short time the unique scientific opportunities afforded by the ISPM NASA spacecraft, and Dr. Donald W. Schuerman, who forged much of the linkage methodology, zodiacal light/interplanetary dust, that made the ISPM zodiacal light observations so important for our understanding of the interplanetary dust complex. This paper was to have been presented in Patras by Dr. Schuerman; it contains some of his thoughts and approach and is dedicated to his memory.

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