EVIDENCE THAT THE PROPERTIES OF INTERPLANETARY DUST BEYOND 1 AU ARE NOT HOMOGENEOUS

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ABSTRACT

Traditionally, earth-based observations of the zodiacal light (ZL) require two assumptions for further analysis: (A1) the dust density (n) is a power of heliocentric distance (R), $n \propto R^{-\nu}$; (A2) the nature (scattering cross section, σ) of the dust is independent of location, $\sigma(r,h,\theta)=\sigma(\theta)$. Observations from Pioneer 10 do *not* verify these assumptions.

Both two-dimensional inversion techniques (Schuerman, 1979a) and more traditional methods of analysis (Hanner *et al.*, 1976) have been performed on portions of the ZL observations made from Pioneer 10/11 spacecraft. In developing the three-dimensional form of the ZL inversion (Schuerman, 1979b; henceforth called Paper I), it was realized that this more general technique should be applied to the Pioneer data because the velocity vectors of the spacecraft were not confined to the ecliptic plane. The previously mentioned analyses examined data with viewing directions parallel to the ecliptic; the three-dimensional inversion requires viewing along a great circle (see Fig. 1) containing (1) the line (**n**) which is both normal to the observer-Sun line and parallel to the ecliptic and (2) the spacecraft velocity vector (**s**). This great circle is called the inversion plane in Paper I where its geometric construction and the notation used here are defined in more detail. The angle ϕ is the inclination of the inversion plane to the ecliptic, and viewing in the direction of **n**

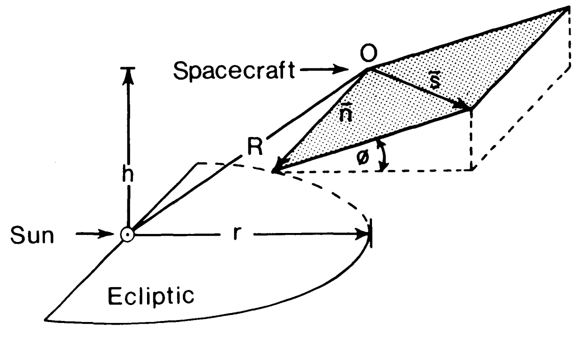

Fig. 1. Definition of the inversion (shaded) plane; it is normal to the r,h plane and contains **s**, the direction of motion of the spacecraft.

I. Halliday and B. A. McIntosh (eds.), Solid Particles in the Solar System, 71–74.

Table 1

COORDINATES OF SPACECRAFT POSITION (r,h in AU) AND VALUES OF THE INCLINATION OF THE INVERSION PLANE (ϕ in deg) AS A FUNCTION OF HELIOCENTRIC DISTANCE (R in AU)

R:	1.010	1.150	1.171	1.349	1.453	1.652	1.865	2.294	2.413	2.467	2.641	2.938
r:	1.010	1.150	1.171	1.349	1.452	1.651	1.864	2.292	2.412	2.465	2.640	2.937
h:	-.009	-.030	-.032	-.045	-.051	-.060	-.067	-.079	-.081	-.082	-.085	-.089
ϕ:	-12.9	-8.60	-8.04	-4.11	-3.29	-2.60	-2.10	-1.19	-1.05	-1.01	-0.82	-0.51

corresponds to an elongation of $\varepsilon = 90°$. The observer (spacecraft) is located by cylindrical ecliptic coordinates (r,h). Table 1 lists the values of ϕ and h as a function of R($\approx$r) for Pioneer 10. Notice that ϕ is small as is the ratio h/r. Nevertheless, we have isolated those Pioneer data having views along the inversion plane and have analyzed those data via both inversion and traditional methods. The former analysis will be published elsewhere. The blue channel brightness data in units of $S_{10}(V)$ are shown in Figure 2. The total ZL brightness (Z) as a function of ε was derived for 12 distinct heliocentric distances in order to generate this Z(R,ε) surface. The values of Z have been smoothed somewhat by a curve-fitting procedure which also yields a measure of the statistical uncertainty (σ_Z) in Z at each point on the surface. Now we can apply the traditional method of ZL analysis: for each value of ε, we fit a power law of the form $Z \propto R^{\alpha}$ where $\alpha = -(1+\nu)$; see, for example, Leinert, (1975). *If assumptions* A1 *and* A2 *are correct, a single value of* α *should apply to all values of elongation.*

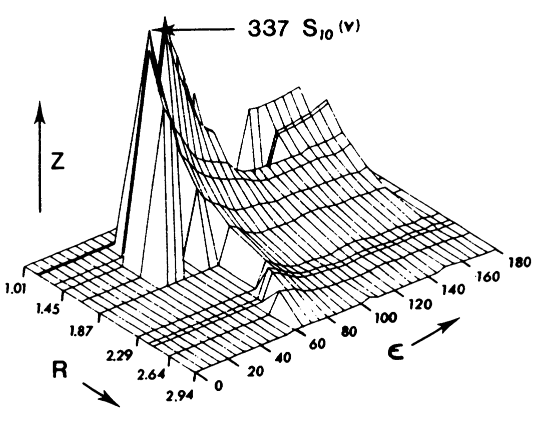

Fig. 2. The brightness (Z) of the ZL as a function of heliocentric distance (R) and elongation (ε). Viewing directions are confined to the inversion plane.

The logZ vs logR plot in Figure 3 shows a typical example of the fitting procedure used to determine α, the slope of the assumed straight line, for $\varepsilon = 115°$. Each data point on the fit is represented by two numbers of the form Z/σ_Z. The vertical error bars represent the corresponding uncertainty in logZ; $\sigma_{\log Z} = \ln(10)\ \sigma_Z/Z$. Notice that even though some data points have remarkably well determined (statistically speaking) values (3/2, 4/1, etc...), the innate mathematical properties of the assumed $Z \propto r^{\alpha}$ relation produce large uncertainties in logZ when Z is small. (Also, Z itself becomes more difficult to separate from the background starlight for

https://doi.org/10.1017/S007418090006650X Published online by Cambridge University Press

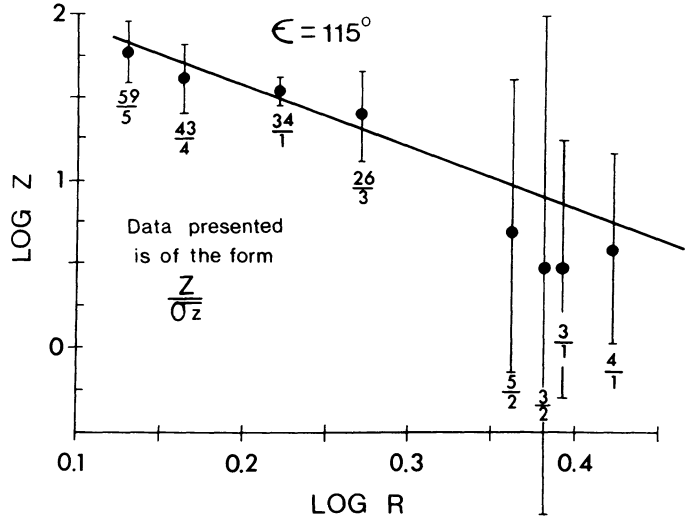

Fig. 3. LogZ vs LogR for $\varepsilon = 115°$. The slope of the fitted line is $\alpha = -(1+\nu)$. The number pairs represent the data in the form Z/σ_Z. The vertical bars are the uncertainty in logZ given by $\ln(10)\ \sigma_Z/Z$.

observations made at large ε and R. In this regard, ZL studies made from outgoing spaceprobes require very different data handling techniques than those used for solar approaching probes like Helios.) Following standard statistical practice, we have weighted each data point by $(\sigma_{\log Z})^{-2}$ in determining the slope α. For the example shown in Figure 3, $\alpha = -3.6 \pm 1.4$.

Fitted values of α were obtained in the above manner for all $70° < \varepsilon < 175°$ in intervals of $\Delta\varepsilon = 5°$. Figure 4 depicts the result of those fits as a function of ε. The vertical bars indicate the uncertainty in α. Earlier and independent Pioneer results by Hanner *et al.* (1976) are shown as the shaded rectangle. Their estimates of α are in agreement with those found here over the limited range of elongation that they considered. However, we find a *systematic decrease in* α *for* $85° \lesssim \varepsilon \lesssim 125°$. It is significant that near $\varepsilon = 90°$ the "dip" in α can not be attributed to viewing in the inversion plane; the line of sight is exactly parallel to the ecliptic for $\varepsilon = 90°$. Yet, it is near this direction that our results differ most from the $\alpha = -2.3$ value reported from Helios (Link *et al.*, 1976). As a final check on our results, we similarly analyzed the in-ecliptic Pioneer data previously published by Schuerman (1979a). The paucity of that data restricts the analysis to $\varepsilon > 110°$. Nevertheless, the same general trend was found as denoted by the x's in Figure 4. The systematic drop of α towards $\varepsilon = 100°$ is evident, and the scatter in those results is well contained within the envelope of our error bars.

Although we are pursuing other explanations, some of which address the fact that h/R is not exactly zero, we tentatively maintain that

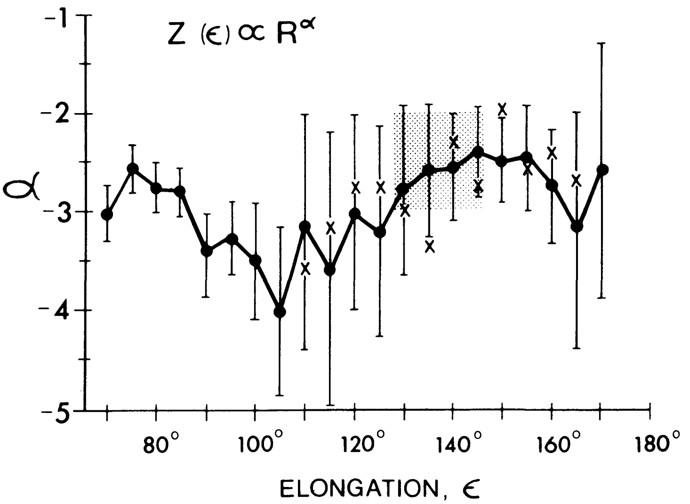

Fig. 4. Values of the index α (in $Z \propto R^{\alpha}$) as a function of elongation (ε). The circles and associated error bars refer to the data shown in Fig. 2. Data points marked by x's refer to *in-ecliptic* Pioneer data previously presented by Schuerman (1979a). The shaded rectangle approximates the earlier and independent Pioneer results of Hanner *et al.* (1976). If the scattering properties of the dust are independent of position, α should have the same value for all ε.

observational evidence now exists that either assumption A1 or A2 or both are incorrect. In fact, assumption A2 has no theoretical support whatsoever. On the contrary, most forces tend to separate the dust particles (as a function of R) according to their charge to mass ratios, surface area to volume, etc. If the results presented here are verified, it means that optical observations from space can truly begin to address the dynamics governing the solar system dust complex.

This work was supported by the Air Force Office of Scientific Research under contract F49620-78-C-0013.

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