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DUST IN THE OUTER SOLAR SYSTEM - REVIEW OF EARLY RESULTS FROM PIONEERS 10 AND 11

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Abstract. The Pioneer 10/11 spacecraft, launched in 1972 and 1973, carried three experiments to measure cosmic dust. A comparison of these first direct measurements of dust in the outer solar system indicates that the sizes, optical properties, and spatial distribution are more complex than previously supposed.

Three interplanetary dust detectors were carried on Pioneers 10 and 11: the Imaging Photopolarimeter (IPP) in the Sky Mapping Mode, the penetration detectors of the Meteoroid Detection Experiment (MDE), and the Asteroid Meteoroid Detector (AMD). Table 1 summarizes for each instrument the measured parameters, the particle size range, and various assumptions used to derive the properties and spatial distribution of the particles. The question marks added to the size range of the zodiacal light detectors are discussed later. In the analysis of the MDE and AMD data, it was necessary to assume relative encounter velocities. From the penetration data it was concluded that the particles have circular or near-circular orbital velocities. For the AMD this was a starting assumption.

The penetration detectors indicate a constant spatial concentration with heliocentric distance, with no apparent indication of asteroid belt passage (Humes, et al., 1975). Early results from both the IPP (Hanner, et al., 1974) and the AMD zodiacal light mode (Zook and Soberman, 1974) have shown that the zodiacal light brightness decreases monotonically with increasing heliocentric distance. The IPP results indicate that the zodiacal light initially decreases faster than the inverse square of the heliocentric distance, R, then more rapidly in the asteroid

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TABLE I
COMPARISON OF PIONEER 10/11 DUST EXPERIMENTS

Experiment	Measurement	Particle Diameter Range	Assumptions	Derived Results
MDE Penetration Detectors	Penetration Rate of Stainless Steel 25 µm 50 µm	 ~10 µm ~20 µm	Distribution of Orbital Parameters for Relative Velocity	Spatial concentration
IPP Zodiacal Light Mode	Polarization & Brightness in 2 Colors	Micron and/or Sub-micron ?	Mie Theory - Constant Size Distribution	Spatial distribution Size Shape Refractive index
AMD Zodiacal Light Mode	Brightness	Micron and/or Sub-micron ?	Mie Theory - Constant Size Distribution	Spatial distribution
AMD Individual Particle Mode	Peak Intensity Transit Time	50 µm and Larger	Circular Orbit Encounter Vel. - Average Transit Thru View Cone - Diffuse Geometrical Reflection From Spherical Particles	Size distribution Spatial concentration Zodiacal light brightness

belt, with no measurable contribution beyond 3.3 AU (Hanner et al., 1976). Based on the assumption that the scattering properties do not change significantly with heliocentric distance, these results suggest that the spatial distribution can be represented by a power law, $R^{-\gamma}$ ($\gamma \approx 1$) or by a two-component model ($\gamma \approx 1.5$) with increased dust in the asteroid belt.

The discrete particle results from the Pioneer 10 AMD (Soberman, et al., 1974) show an increase in the number of particles out to the asteroid belt. There appear to be minima in the vicinity of both the Earth's and Mars' orbits which are more pronounced for the larger particles. Beyond 3.5 AU the event rate drops below instrumental limits, the fall-off occurring first for the larger particles. The size distribution differs significantly from the 1 AU model for the larger sizes and is of the type expected for an asteroidal population (Dohnanyi, 1969). Particle sizes were obtained by assuming a value of 0.2 for the albedo in order to extrapolate to the penetration detector results.

Figure 1 shows the relative change in zodiacal light brightness with heliocentric distance as measured by the IPP and as derived from the AMD discrete particle mode. Although the relative brightnesses are in satisfactory agreement, the absolute brightness derived from the AMD results is more than an order of magnitude too large by comparison with the photometric results from the same instrument and from the IPP. For example, the AMD gives a gegenschein brightness at 1 AU of approximately 2500 $S_{10}(V)^{*}$. This difference is believed to arise from the fact that the AMD measures peak rather than average values for particle brightness when operating in the discrete particle mode, and that the particles contain many reflecting surfaces that give off bright glints of light as the particles rotate (such as observed from sunlit particles in the vicinity of Earth-orbiting vehicles). Because of this glint effect, the planned orbital measurements could not be made with the AMD, and it was necessary to assume particle velocities relative to the instrument to derive sizes and heliocentric variations.

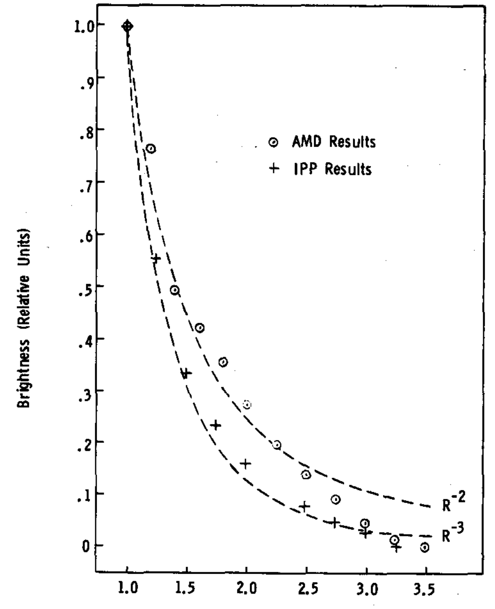

Figure 1. Variation of Zodiacal Light Brightness With Heliocentric Distance

The results from the three dust experiments on Pioneers 10 and 11 seem to be completely discordant. The zodiacal light results indicate that the concentration of dust decreases initially at least as fast as the inverse heliocentric distance and then more rapidly while passing through the asteroid belt. The penetration detectors indicate a uniform spatial concentration with the exception of the gap regions (Humes, et al., 1975). The discrete particle results of the AMD indicate a varying concentration going outward, peaking in the asteroid belt and then dropping off to a negligible value at approximately 3.5 AU. The simplest explanation for this

*Equivalent number of tenth magnitude (V) stars of solar spectral type, per square degree.

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divergence would be that the three sensors were measuring in three different size domains as was indicated in Table 1. This simple explanation cannot be ruled out, although it is not likely that the two extreme sizes are similar in concentration but different from the concentration of the intermediate sizes.

A further question is whether micron or submicron particles contribute appreciably to the zodiacal light. If the concentration of 10 and 20 micron particles measured by the penetration detectors does not change with heliocentric distance, then these particles probably do not contribute significantly to the zodiacal light. Comparing the cross-sections (assuming that the albedo is not a strong function of size), the concentration of one micron particles would have to be two orders of magnitude higher than the concentration derived from the penetration detector results to yield even an equal brightness contribution. Such a concentration of one micron particles is not consistent with the results from Pioneers 8 and 9 (Berg and Grün, 1973), MTS (Alvarez, 1976), HEOS 2 (Hoffmann et al., 1975), and the Lunar Cratering Results (Neukum, 1974). The situation becomes worse if one relies on submicron particles. If we are to believe that the zodiacal light is produced primarily by large particles (radius $>$ 50 microns) additional theoretical calculations and laboratory measurements are required to demonstrate that these particles can produce the observed distribution of polarization with elongation, including polarization reversal.

The zodiacal light and individual particle brightness results from Pioneer 10 suggest the presence of a dust component in the asteroid belt and a negligible concentration beyond. The penetration results show a nearly uniform concentration with no measurable contribution from the asteroid belt and no measurable decrease in concentration beyond. These results suggest different sources for the particles responsible for the penetrations and those which give rise to the individual and aggregate brightness measurements. To explain these differences, additional studies of the sources and sinks for the interplanetary dust beyond 1 AU appear warranted.

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References

Alvarez, J.M. (1976), "The Cosmic Dust Environment at Earth, Jupiter and Interplanetary Space: Results from Langley Experiments on MTS, Pioneer 10 and Pioneer 11", these proceedings.

Berg, O.E., and Grün, E. "Evidence of Hyperbolic Cosmic Dust Particles" Space Research XII, Eds. M. J. Rycroft and S. K. Runcorn (Akademie-Verlag, Berlin, 1973).

Dohnanyi, J.S. "Collisional Model of Asteroids and Their Debris" Jour. Geophys. Res. 74, 2531-2554 (1969).

Hanner, M.S., Sparrow, J.G., Weinberg, J.L., Beeson, D.E. (1976), "Pioneer 10 Observations of Zodiacal Light Brightness Near the Ecliptic; Changes with Heliocentric Distances", these proceedings.

Hanner, M. S. and Weinberg, J. L. "Changes in Zodiacal Light With Heliocentric Distance: Preliminary Results from Pioneer 10" Space Research XIV, Eds. M. J. Rycroft and R. D. Reasenberg, 769-772 (Akademie-Verlag, Berlin, 1974).

Hoffmann, H. J., Fechtig, H., Grün, E., and Kissel, J. "First Results of the Micrometeoroid Experiment S215 on the HEOS 2 Satellite" Planet. Space Sci. 23, 215-224 (1975).

Humes, D. H., Alvarez, J. M., Kinard, W. H. and O'Neal, R. L. "Pioneer 11 Meteoroid Detection Experiment: Preliminary Results," Science 188, 473-474 (1975).

Neukum, G. "Micrometeoroid Erosion of Lunar Rocks" Space Research XIV, Eds. M. J. Rycroft and R. D. Reasenberg, 739-740 (Akademie-Verlag, Berlin, 1974).

Soberman, R. K., Neste, S. L. and Lichtenfeld, K. "Optical Measurement of Interplanetary Particulates from Pioneer 10" Jour. Geophys. Res. 79, 3685-3694 (1974).

Zook, H. A., and Soberman, R. K. "The Radial Dependence of the Zodiacal Light" Space Research XIV, Eds. M. J. Rycroft and R. D. Reasenberg, 763-767 (Akademie-Verlag, Berlin, 1974).