plied to the data, with experimental episodes (that is, spatial location of the mother's voice) being used as the independent variable. All the Friedman analyses reported herein have 3 degrees of freedom.

The data for the infants' turning the head and looking to left and right were as follows. The 11 infants aged 1 month, 10 of the 4-month-olds, and 11 of the 7-month-olds showed some evidence of this behavior. At all ages most turning and looking occurred during episodes 2 and 3. However, only at 4 and 7 months was the effect significant ($\chi_r^2 = 8.04$, $P < .05$, and $\chi_r^2 = 14.11$, $P < .01$, respectively). At 1 month, only 57 percent of head turns during episodes 2 and 3 were in the direction of the active loudspeaker; the corresponding proportions at 4 and 7 months were 84 and 73 percent, respectively. The difference between proportions is significant ($\chi_2^2 = 7.01$, $P < .05$). These data indicated that our changing the location of the mother's voice from the frontal to the lateral plane significantly influenced the frequency of head turning, at least at 4 and 7 months, and that at these ages, also, sound localization was relatively efficient. This is not to say that youngest subjects did not discriminate phenomenally between the different experimental conditions, but only that any such discrimination was not detected by this particular response index.

The infant's looking toward the mother was in evidence at all ages during all four episodes. Neither frequency of looking toward the mother nor frequency of looking down from the mother was significantly influenced by the direction from which her voice originated. Aronson and Rosenbloom, however, reported that infant distress associated with face-voice separation was such that subjects could not be induced to look again at the mother, even when the straight ahead condition was resumed.

Three of the 1-month-olds, two of the 4-month-olds, and four of the 7-month-olds cried or fretted at least once during the experiment. Most instances of such behavior were brief and transient and there was only one infant—a 1-month-old—who could not be consoled during the experimental session by verbal comforting from the mother. At no age level did differences between episodes approach statistical significance. Thus, nonsignificant results were obtained for the most direct measure of distress employed in this study.

At all age levels the frequency of frowning was unrelated to the spatial location of the mother's voice during the different experimental episodes.

At 1 month, seven subjects manifested overt protrusion of the tongue at least once during the experimental procedure; at 4 months, three of the subjects, and at 7 months, none of the subjects protruded the tongue. Neither at 1 month nor at 4 months did the number of tongue protrusions discriminate between episodes.

Vocalizations, other than those associated with fretting or crying, were recorded for three of the 1-month-olds, eight of the 4-month-olds, and seven of the 7-month-olds. At all ages, differences between episodes were small and were not statistically significant.

Smiling was recorded on the part of four of the 1-month-olds, ten of the 4-month-olds, and nine of the 7-month-olds. At 1 and 7 months the frequency of smiling was relatively even across episodes but at 4 months there was more smiling during the first episode than during the other three episodes ($\chi_r^2 = 11.61$, $P < .01$).

These data, therefore, afford no support for the hypothesis that the very young human infant lives in a perceptually unified audiovisual world, distortion of which is the occasion for distress. The incidence of distress observed here was no greater than that normally witnessed in experimental studies involving very young subjects. Moreover, such upset as did occur was unrelated to the spatial relationships between the mother's location and the direction from which her voice emanated during the different experimental episodes. It should be noted also that the incidence and frequency of smiling were higher than those of fretting or crying. The frequency of tongue protrusions bore no relationship to any of the other indices or affectivity nor was it in any way related to experimental conditions.

The nature and development of audiovisual coordination during early infancy remains an open question. The assumption that such coordination initially occurs within a unified audiovisual space is unsupported by our findings. Similarly, there is no evidence from our study that modifications of the normal spatial relationship between face and voice are experienced by the young infant as violations of a preexisting expectancy for face and voice to occupy the same spatial location.

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21 December 1973; revised 26 April 1974

The Asteroid Belt: Doubts about the Particle Concentration Measured with the Asteroid/Meteoroid Detector on Pioneer 10

Results obtained with the Sisyphus asteroid/meteoroid detector on Pioneer 10 have been presented by Soberman and co-workers (*1*). Auer and Northrop (*2*) criticized these results and concluded that no significant fraction of the events reported as real meteoroid events between 1.0 and 3.3 A.U. is, in fact, due to cosmic meteoroids.

Recently, Soberman *et al.* (*3*) reported the particle concentration in the asteroid belt (that is, from 2.0 to 3.5 A.U.) which is shown in Fig. 1. As will be pointed out, the brightness of the interplanetary light (also known as zodiacal light and gegenschein) measured at high elongations from both the earth and the Pioneer 10 spacecraft is incompatible with such a high concentration of matter. Since both kinds of data depend on optical detection of reflected sunlight from particles, several uncertainty factors, such as particle albedo or mass density, cancel out in the comparison.

The asteroidal debris cannot reflect more light than is observed. On that basis, and attributing all interplanetary light observed from the earth to particles in the asteroid belt, Kessler (*4*) derived an upper limit for the concentration of particles of any single size, a_1, which is

$$N_{\max} = 2.7 \times 10^{-19}\, a_1^{-2} \qquad (1)$$

where $N_{\max}$ is number per cubic meter and a_1 is in meters, for an albedo $p = 0.2$ and solar distances 2.0 A.U. $\leq R \leq 3.5$ A.U. This expression is not a size distribution such as given by Soberman *et al.* (see Fig. 1). Instead, if one assumes that the size distribution is a delta function (that is, that all particles have size a_1), then N_{max} is the density that is required to explain the brightness of interplanetary light at high elongations.

Equation 1 implies that the total light comes from the asteroid belt. From the strong decrease of light intensity which Hanner and Weinberg (*5*) reported from Pioneer 10 between 1 and 2 A.U., however, one must conclude that many particles exist in the space between the earth and the asteroid belt. Zook and Soberman (*6*) have also measured a rapid decrease of the interplanetary light brightness, as a secondary part of the Sisyphus experiment. This part of the experiment is not criticized here. Rather, its results support my critical view of the primary part of the Sisyphus experiment that detects individual particles. The brightness appears to drop by at least a factor of 5 and possibly a factor of 10 between 1 and 2 A.U., according to Hanner (*7*). An upper limit for asteroidal concentrations can therefore readily be set at

$$N_{max} = 5.4 \times 10^{-20}\, a_1^{-2} \qquad (2)$$

This is, like Eq. 1, not a size distribution. We can express Eq. 2 as the inequality

$$N(a_1)a_1^2 \leq N_{max}a_1^2 = 5.4 \times 10^{-20} \qquad (3)$$

where N is a real concentration, or in more general form

$$\int_{a_{min}}^{a_{max}} n(a)a^2da \leq \int_0^\infty n(a)a^2da \leq 5.4 \times 10^{-20} \qquad (4)$$

where

$$\int_a^\infty n(a)da = N(a)$$

is the cumulative number of particles with radii equal to or larger than a per cubic meter; $n(a)$ is the differential concentration. The integral in the middle of Eq. 4 is the total scattering cross section from particles in 1 m^3 of space. Any real spatial concentration must satisfy Eq. 4.

We may consider a range of particle radii a from 5×10^{-6} to 0.1 m, as do Soberman *et al.*, and a distribution of the form $N(a) = N_0a^{-\alpha}$. The curves for some exponents α are shown in Fig. 1. The value $\alpha = 2.0$ is roughly the average slope of the curve from Soberman *et al.*, while $\alpha = 1.3$ and $\alpha = 3.0$ are the two extremes. The slope predicted by Dohnanyi (*8*) is $\alpha = 2.52$. It can be seen that the curve from Soberman *et al.* is at least one to two orders of magnitude higher than any curve that could explain the brightness of the interplanetary light.

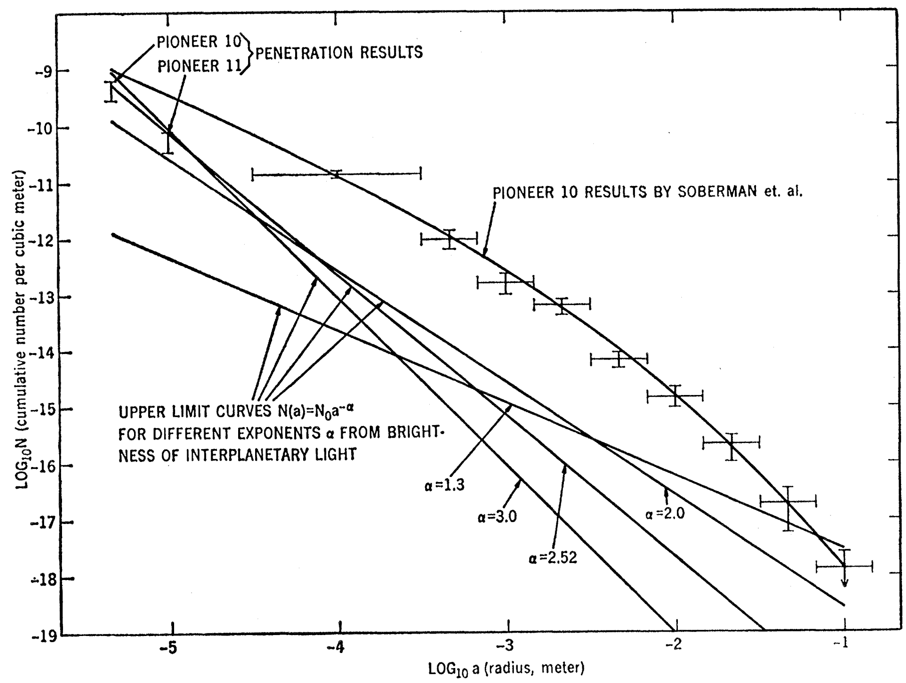

Fig. 1. Comparison between the particle size distribution in the asteroid belt (2.0 to 3.5 A.U.) from Soberman *et al.* (*3*), the penetration results from Humes *et al.* (*9*), and the upper limit distributions $N(a) = N_0a^{-\alpha}$ for $\alpha = 1.3$, 2.0, 2.52, and 3.0 based on the brightness of interplanetary light (*5–7*).

Another, more direct approach is to derive the differential concentration $n(a) = dN/da$ from the curve from Soberman *et al.* and to evaluate numerically the integral

$$\int_{5 \times 10^{-6}\,\mathrm{m}}^{0.1\,\mathrm{m}} n(a)a^2da = 2.6 \times 10^{-18} \qquad (5)$$

Comparing Eqs. 4 and 5, we see that they are incompatible and that the curve from Soberman *et al.* is at least a factor of 48 too high.

The upper limit as defined in Eq. 4 could be reduced further if it were known that at least part of the interplanetary light is contributed by (i) particles with radii smaller than 5×10^{-6} m or larger than 0.1 m, or (ii) particles at distances larger than 3.5 A.U., or (iii) other phenomena.

Figure 1 also shows the concentration of particles in the asteroid belt measured by Humes *et al.* (*9*) in the penetration experiments on Pioneers 10 and 11; a particle mass density of 3.5 g/cm^3 has been assumed; the exponent of -2.7 used in our size distribution corresponds to the exponent of -0.9 in their mass distribution. It can be seen that the results from the penetration experiments are compatible with both the measured brightness of the interplanetary light and a size distribution of the form $N(a) = N_0a^{-\alpha}$, where $2.52 \leq \alpha \leq 3.0$.

I conclude that the real concentration of asteroids must be at least one to two orders of magnitude lower than the concentration reported by Soberman *et al.* and that probably between 90 and more than 99 percent of the reported 123 asteroidal events are not real.

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15 April 1974; revised 19 June 1974

The difference between the interplanetary or zodiacal light brightness as measured, and as calculated from our Pioneer 10 results, has not escaped our attention, and we have published an extensive discussion of this difference in a recent paper (*1*). The essential points are summarized as follows. We conclude that the interplanetary particles are not diffusely reflecting spheres but rather are irregularly shaped, specularly reflecting, and rapidly rotating. Thus, the peak intensity, which we measure with our instrument in the individual particle mode, can be much higher than the average light reflected from a particle, which is the parameter measured by a sky brightness photometer. This conclusion is supported by films taken from the Apollo and Skylab missions which clearly show that sunlight reflected from particles in space varies by orders of magnitude as the particles rotate. Hemenway (*2*) has stated that he would expect such variations from many of the cosmic dust particles he has collected. In addition, Paddack (*3*) has calculated that solar radiation pressure will produce high rotation rates for particles which are not appreciably affected by magnetic spin damping.

That the mean albedo of the particles which are responsible for the interplanetary light must be small has been pointed out by Zook *et al.* (*4*). Assuming a heliocentric radial decrease in cosmic dust concentration according to an inverse 1.5 power, those authors derived a mean albedo of 0.057. The Pioneer 10 and Pioneer 11 penetration measurements (*5*) have shown that the small particle concentration does not decrease appreciably with radial distance. Radio meteor measurements (*6*), our own results (*1*), and asteroid evidence (*7*) show that the larger particles are increasing in concentration with radial distance out to the asteroid belt. Consequently, we have derived a mean albedo value of < 0.02, which would be necessary to make the interplanetary light brightness as derived from many dust concentration measurements agree with the photometer measurements.

In view of the above, Auer's "upper limit" curves are not applicable since they hold only for diffuse spheres with a geometric albedo of 0.2. A lower mean albedo value would cause his curves to move to the right. Similarly, his statement that the derivation of interplanetary brightness from our individual particle results is independent of the albedo would be valid only if the peak and average particle brightness were equal. As far as the Pioneer penetration experiments are concerned, Auer has placed these results slightly lower than do the experimenters (*5*) and has assigned error bars, which have not yet been assigned by the original authors and which are likely to be far larger than shown in Auer's figure 1. It must be borne in mind that our concentration as a function of particle size is based on an assumption of the peak albedo. We chose the value 0.2 partly to agree with the penetration results as originally reported (*8*). A higher value for the peak albedo would cause our concentration curve to move to the left in Auer's figure.

Although the magnitude of the interplanetary light brightness derived from our results appears to be too high (*1*), the variation with heliocentric distance does show the same form as our own photometer measurements (*9*) and those of the imaging photopolarimeter on Pioneer 10 (*10*). This derived brightness shows an initial inverse square decrease with a more rapid falloff in the asteroid belt. Roosen (*11*) was unable to observe the shadow of the earth in the interplanetary light and concluded that the brightness could not fall off that rapidly with heliocentric distance. Our data show a spatial distribution of particle concentrations that is compatible with both of these photometric results.

In summary, we contend that our individual particle measurements are valid and that the difference between the directly measured brightness and the derived brightness of the interplanetary light is due to the difference between the peak and average brightness of the particles. We believe the particles are rotating very rapidly, giving off many specular reflections, and while an average albedo of 0.02 or less is necessary to explain the interplanetary light brightness, the "albedo" associated with the specular peaks may be well in excess of 0.2.

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