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Observations of Zodiacal Light from Helios 1 and 2

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Abstract. A short description of the instrument is given. The inflight performance during the first one and a half years was stable. The observations are compatible with a radial dust distribution $n(r) \sim r^{-\nu}$ with $\nu \approx 1.3$. The symmetry plane of interplanetary dust is observed to be inclined to the ecliptic. No effect of a zone of reduced dust density near the sun was found.

Key words: Zodiacal light photometry — Spatial distribution of interplanetary dust — Dust free zone.

1. Introduction

Zodiacal light, which is sunlight scattered from the interplanetary dust grains, is well suited to probe the average spatial distribution of the dust, since the observed zodiacal light intensity is composed of the scattering from dust particles distributed over a large volume in interplanetary space (see Fig. 1). The relationship between zodiacal light intensity $I(\varepsilon)$, solar flux at 1 A.U. F_0, number density $n(r)$ and average scattering function $\sigma(\theta)$ of the dust,

$$I(\varepsilon) = \text{const.} \cdot \int_0^\infty \frac{F_0}{r^2} \cdot n(r) \cdot \sigma(\theta)\, d\Delta, \tag{1}$$

shows that earth-based observations do not allow a unique separation of the spatial distribution from the angular dependence of scattering by the dust particles. This separation can be achieved only by varying the heliocentric distance of the observing instrument. In this case, with the additional assumption that the average scattering function is independent of heliocentric distance, radial dependence of zodiacal light intensity and spatial distribution of dust are related by

$$I(\varepsilon, R) \cdot R = \text{const.}\ (\varepsilon) \cdot n(R), \tag{2}$$

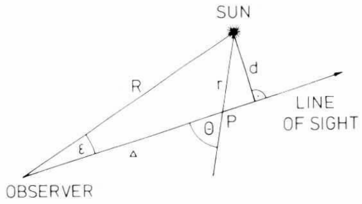

Fig. 1. Geometry of scattering for a dust particle at point P

which follows from Equation (1) and the geometry of Figure 1. Therefore one important goal of the zodiacal light experiment on Helios is deriving the spatial distribution of dust within 1 A.U. from the sun and of detecting any changes in the average properties of dust with heliocentric distance. A second important goal is the study of temporal changes in zodiacal light, from locations well removed from earth-related disturbances.

The information on large-scale distribution of dust given by this experiment and the data of the micrometeoroid detector on Helios which measures mass, velocity and chemical composition of individual dust particles encountered during flight, mutually complement each other.

2. Instrument

The zodiacal light photometer consists of three separate $f/5.5$ lens telescopes with apertures of 30 to 36 mm and EMR 541 N photomultipliers as pulse counting detectors. In each sensor intensity and polarization of zodiacal light are measured in visual, blue and ultraviolet ($\lambda_{\mathrm{eff}}=540$ nm, 420 nm, 360 nm). The polarization foils (Polacoat 105 UV) and the Schott filters defining the band pass (GG 10, BG 3 + GG 385, UG 2) are exchanged by stepping motors.

The sensors are mounted on Helios with viewing directions of approximately 15°, 30° and 90° below the spacecraft equatorial plane xy (see Fig. 2). As the spacecraft spins (1 rps) with the spinaxis perpendicular to the ecliptic plane, two of them scan on circles of constant ecliptic latitude, $\beta \approx 15°$ and $\beta \approx 30°$, while the third one remains oriented toward the ecliptic pole. The scans are divided into 32 sectors 5.6° to 22.5° long to provide adequate angular resolution in longitude. The width of the strips is 1° and 2°, respectively. The signal is accumulated simultaneously for the 32 sectors of one scan over 513 s. For the 90° sensor the field of view is 3° diameter and the accumulation period 126 s. The 8 sectors of this sensor are used to measure polarization by the method of rotating polaroid, the rotation being provided by the spacecraft.

Because of the reversed orientation of the two Helios spacecraft, the viewing directions are south of the ecliptic for Helios 1, north for Helios 2. This situation is advantageous for determining the plane of symmetry of the dust distribution.

Calibration has been done on the ground with a diffusely attenuated tungsten filament lamp calibrated – in several steps – against the black body of Landessternwarte Heidelberg (Klüppelberg, 1975) and in flight by bright stars (α CMi, β Ori, γ Ori) crossing the field of view. Both methods agree within 10%.

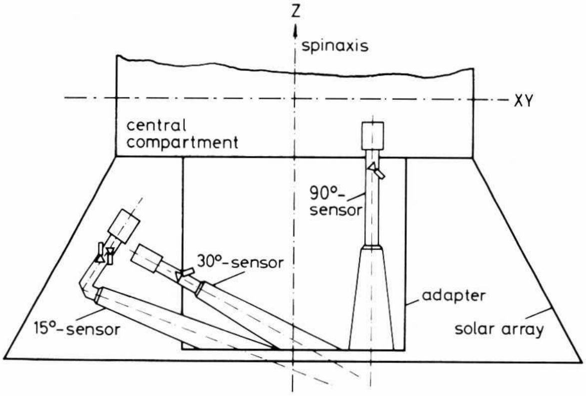

Fig. 2. Schematic view of the lower spacecraft cone with the mounting positions of the experiment sensors

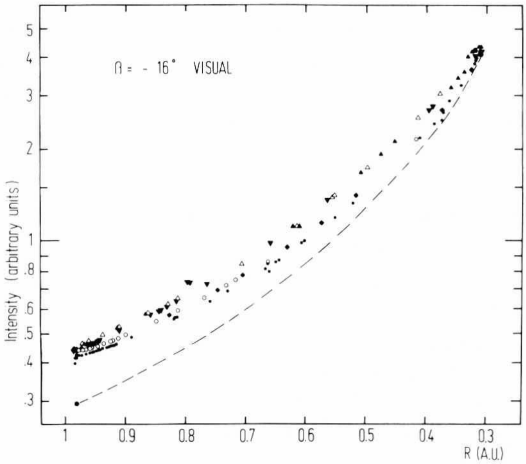

Fig. 3. Integrated total brightness observed with the 15°-sensor of Helios 1, visual band. Different symbols refer to the first (●, ○, ◆) and second half (▲, △, ▼) of the first three orbits, respectively. Brightness after star background correction is given by *broken line*

The method to account for the changes of calibrating source and instrument sensitivity over the broad bandpasses (50 nm–100 nm) is described by Leinert et al. (1974).

Protection from stray light is provided by the coronagraph-like optical design, by large baffle systems and by mounting the sensors completely in the shadow of the solar array. The darkness of this shadow and hence the amount of residual stray light is a function of the angle between spinaxis and spacecraft – sun line. From the constancy of the observed signal during attitude maneuvers, when this angle changed up to 1°, it follows that any remaining stray light contribution to the measurements of Helios 1 and Helios 2 must be smaller than a few percent.

3. Results

In this paper we limit ourselves to discuss data of the 15°-sensors which yield the observations closest to the sun. Figure 3 shows the increase in total brightness observed with the 15°-sensor on Helios 1, which amounts to a factor of 10 between 1 A.U. and Perihelion at 0.31 A.U. Each data point gives the total observed brightness integrated over the circle of constant ecliptic latitude scanned by this photometer. This quantity was chosen because then the contribution of star background to the observed signal is essentially constant, independent of the position of Helios in its orbit, thus reducing the influence of uncertainties in the value of background starlight. After subtraction of the star background, as determined from the tables of Roach and Megill (1961) and the Catalogue of Bright Stars (Hoffleit, 1964), the resulting zodiacal light brightness (broken line) can be fitted by a power law $R^{-2.3}$. Provided the average scattering properties of interplanetary dust do not change over the involved range of heliocentric distances, the spatial distribution according to Equation (2) is given by a power law, $n(r) \sim r^{-\nu}$, where the uncertainty in the exponent $\nu = 1.3$ probably does not exceed ± 0.2. This is similar to the Pioneer 10 zodiacal light results (Hanner et al., 1976), where the best fit to the data between 1 A.U. and 2 A.U. was with a power law $n(r) \sim r^{-1}$ to $n(r) \sim r^{-1.5}$. It is practically equal to the value $\nu = 1.2$ which Dumont and Sanchez (1975) deduced from a discussion of brightness gradients in the zodiacal light and the F corona as given by ground-based observations in comparison with the results of Pioneer 10. Since the other Helios sensors gave the same power law increase of zodiacal light intensity, the above assumption of constant scattering properties seems justified. This is further supported by the fact that the same increase of zodiacal light intensity is found in U, B and V.

Figure 3 illustrates the good reproducibility of the data from one orbit to the next, indicating that over one and a half years both the experiment and the zodiacal light were quite stable. The short-term stability of the measurements is illustrated in Figure 4 for the viewing direction $\beta \approx -16°$, $\varepsilon \approx 16°$. The experiment stability is probably even better than depicted in Figure 4, since some fluctuation in the total brightness is caused by the varying stellar background as the orbital position of Helios changes. Therefore the experiment is well suited to search for short period brightness fluctuations in the zodiacal light which are reported by Levasseur and Blamont (1975) to last a few days. It will also be important to look for any changes related to solar activity during the current rising branch of the solar cycle.

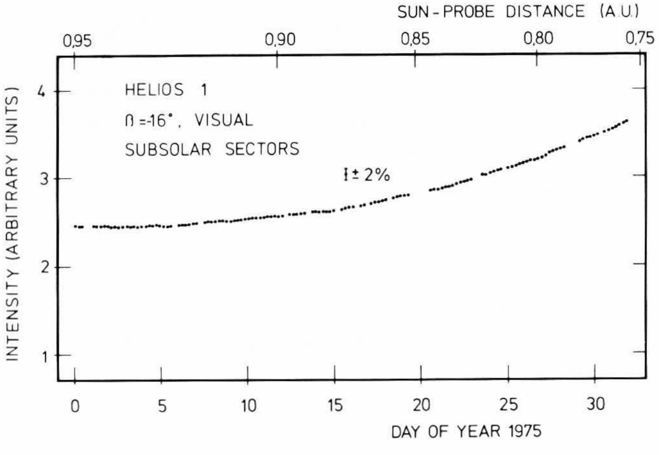

Fig. 4. Variation of the observed total brightness for January 1975. The data points represent the average signal of the two sectors closest to the sun, $\varepsilon = 16°$

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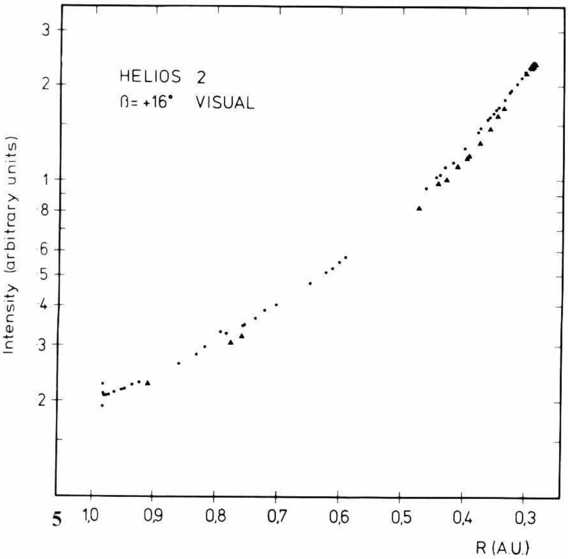

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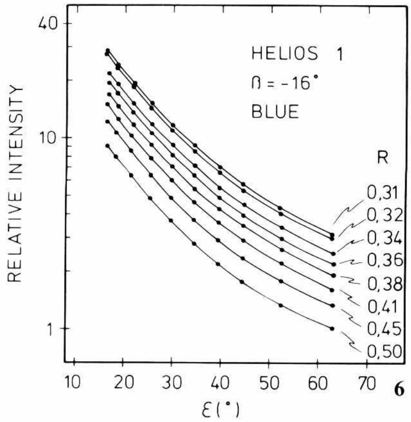

Fig. 5. Integrated total brightness observed with the 15°-sensor of Helios 2. Points refer to the inbound, triangles to the outbound half of the first orbit

Fig. 6. Observed intensity profiles of the zodiacal light for heliocentric distances 0.50 A.U. to 0.31 A.U.

It is evident from Figure 3 that the zodiacal light brightness was systematically lower during the first half of the Helios 1 orbits. We interpret this as an effect of the tilt between ecliptic and plane of symmetry of interplanetary dust, with the ascending node near the perihelion of Helios 1 ($\lambda = 78°$). Then Helios 1 would be south of the plane of symmetry for the first half of its orbit and the photometers would miss the region of highest dust concentration, while Helios 2 should show the opposite effect, because the sensors are pointing northward. This is indeed apparent in the Helios 2 data shown in Figure 5. Model calculations have shown that the inclination of the invariable plane of the solar system ($i = 1.6°$) is too small to account for the size of the observed effect. Further model calculations are in process.

Infrared observations by MacQueen (1968) and Peterson (1967) have detected emission peaks near $3.5\,R_\odot$ and $4.0\,R_\odot$. These peaks have been interpreted as thermal emission from silicate grains just outside a zone of decreased dust density. The zodiacal light experiment on Helios does not reach those "dust-free" zones. However, for spacecraft positions near 0.3 A.U. it is possible to search the region of heliocentric distances $R \geqq 19\,R_\odot$ for a zone of dust depletion. Heliocentric distance $R \approx 24\,R_\odot$ is predicted by Lamy (1974) to be the extent of a "dust-free" zone for iron particles. The presence of a dust free zone would lead to a reduction in brightness when the line of sight intersects the zone, i.e. for small heliocentric distances of Helios and small elongations. Quantitative predictions have been given by Hanner and Leinert (1972). In Figure 6 brightness profiles taken with Helios 1 at different heliocentric distances are shown, corrected for dark current, temperature effects, background starlight and scattering by the electrons of the solar wind. To get rid of the influence of the inclination of the plane of symmetry and of slight changes in the spin axis of Helios, profiles before and after perihelion taken at the same heliocentric distance, were averaged. To the estimated accuracy of $\pm 3\%$ there is no change in the brightness profiles.

In conclusion the Helios observations discussed in this paper are compatible with a steady dust distribution, increasing as a power law $n(r) \sim r^{-\nu}$, $\nu \approx 1.3$, from 1 A.U. to 0.09 A.U. the smallest distance observable from Helios 1. Strictly speaking this result applies to the scattering cross section per unit volume which, however, is proportional to the spatial density of dust if the scattering properties of dust particles do not change considerably with heliocentric distance.

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