ORBITS OF INTERPLANETARY DUST PARTICLES INSIDE 1 AU AS OBSERVED BY HELIOS

E. Grün, H. Fechtig and J. Kissel
Max-Planck-Institut für Kernphysik
Postfach 10 39 80
D - 6900 Heidelberg
      F.R.G.

ABSTRACT. The in situ dust detectors on board the Helios spaceprobes detected impacts of micrometeoroids between 0.3 AU and 1 AU distance from the sun. Among the measured quantities were mass, impact speed and flight direction of the dust particles. Radial variations of the flux, azimuthal distribution and impact speed are discussed. Significantly different results were obtained for the "apex" particles observed by both ecliptic and south sensors and for the "eccentric" particles detected only by the south sensor. The radial spatial density variation of the "eccentric" particles is compatible with that derived for zodiacal light particles. Whereas the spatial density of "apex" particles peaks at 0.5 to 0.6 AU. From the measured quantities probability distributions of orbital elements were derived for the observed micrometeoroids. About 60% of the observed micrometeoroids ("apex" particles) are on low energy orbits ($a \lesssim 0.6$ AU). About 30% of the particles ("eccentric" particles) had high energy orbits ($a \gtrsim 0.9$ AU). More than 10% of the observed particles show high probabilities for travelling on hyperbolic orbits.

1. INTRODUCTION

The Helios spacecrafts orbit the sun between 0.3 AU and 1 AU. We report on data from the micrometeoroid detector taken during the first 10 orbit revolutions of Helios 1. Preliminary data from Helios 2 support the findings. 235 impacts were recorded in the 5 years time interval. 83 meteoroid impacts were observed by the ecliptic sensor and 152 by the south sensor. Detailed descriptions of the instrument and the data were published by Grün et al. (1980) and Grün (1981). Most of the particles detected by the ecliptic sensor had masses of $10^{-13} \lesssim m \lesssim 10^{-10}$g. The particles observed by the south sensor had masses $10^{-15} \lesssim m \lesssim 10^{-9}$g. This difference has been attributed by Grün et al. (1980) to two different particle populations, one ("apex" particles) made out of material of normal density ($\rho \gtrsim 1$ g/cm³) - only this population of micrometeoroids could be observed by the ecliptic sensor - and another population ("eccentric" particles) of low densities $\rho < 1$ g/cm³ which was, in addition, observed by the south sensor. In this paper we concentrate on the

105

spatial and orbital distributions of micrometeoroids observed by Helios.

2. FLUX DISTRIBUTION

The radial distribution of the dust flux could only be derived after a long integration time. Fig. 1 shows the result for both sensors. Since
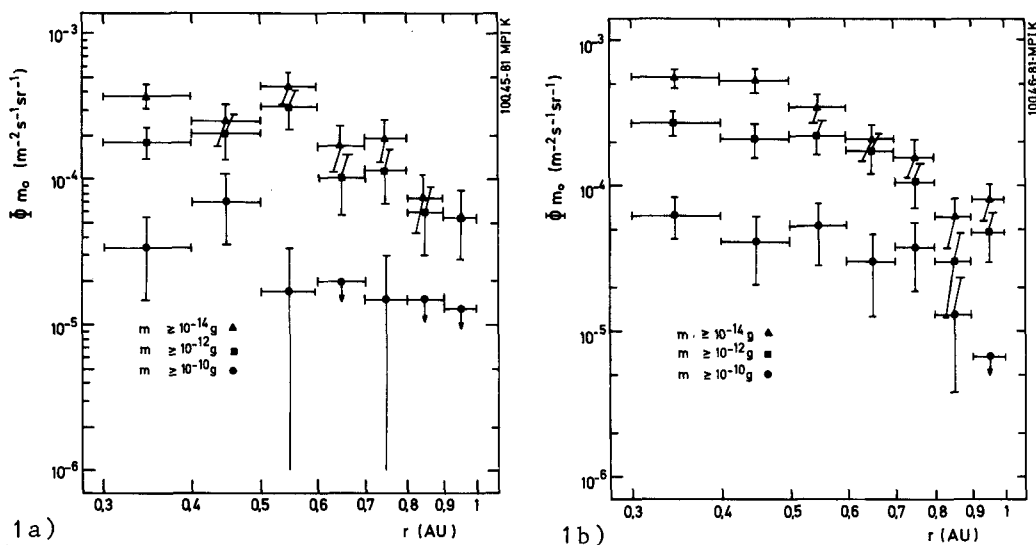

1a)   1b)

Fig. 1: Radial variation of the micrometeoroid flux ob-
served by Helios. The fluxes were averaged over a
0.1 AU interval. The statistical errors correspond to
the particle numbers observed. Upper limits are shown
where no particles were detected. The fluxes given
for $m \geq 10^{-12}$ g and 10^{-14} g are lower limits since
the instrument did not record particles impacting at
speeds $v \lesssim 5$ km/s and 20 km/s, respectively.
a) ecliptic sensor   b) south sensor

Helios is a spinning spacecraft the fluxes shown are averaged over all
directions in the ecliptic plane. Flux values have been calculated from
the number of impacts detected during the corresponding time intervals
and by taking into account the sensitive areas of 54.5 cm² and 66.5 cm²
and effective solid angles of 1.04 sr and 1.39 sr for the ecliptic and
south sensor, respectively. Both sensors measured fluxes increased by a
factor between 3 and 10 going inward from 1 to 0.3 AU. However, there is
a significant difference in the radial variation of the fluxes measured
by both sensors. Besides a somewhat reduced flux in the radial interval
0.8 to 0.9 AU ($m \geq 10^{-12}$ and 10^{-14} g) compared to both adjacent intervals
the flux onto the south sensor is steadily increasing towards the sun.
This is compatible with the steady increase in zodiacal light intensity
reported by Leinert et al. (1981). In contrast to that, the flux recorded

by the ecliptic sensor has its maximum (m $\geq$ 10^{-12} and 10^{-14} g) in the radius interval between 0.5 and 0.6 AU and stays constant or even decreases further in.

3. AZIMUTHAL DISTRIBUTION

During one spin revolution of the Helios spacecraft each sensor scans a full circle in azimuth. Fig. 2 shows the azimuthal distribution of impacts on both sensors in various distance intervals. Outside 0.6 AU
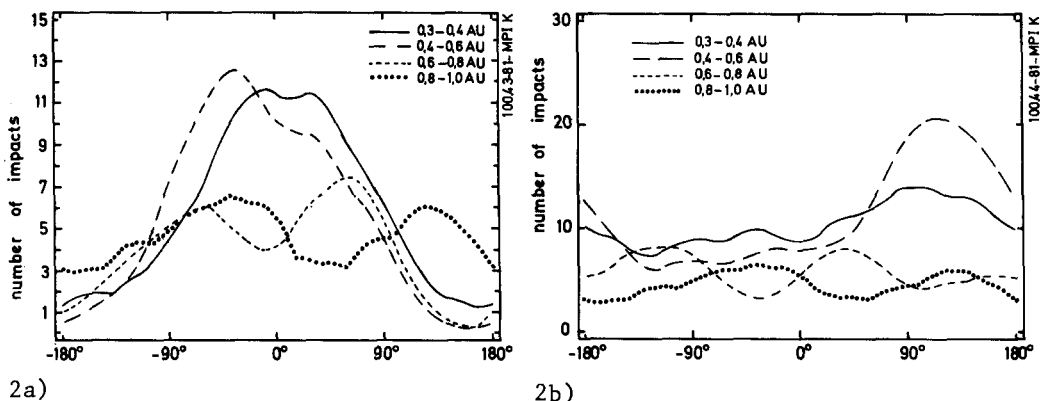
2a)

2b)

Fig. 2: Azimuthal distribution of impacts. An individual impact is represented by the angular probability distribution centered on the actual sensor pointing direction. Apex direction $\approx$ 0°, solar direction = 90°. Azimuthal distributions are shown for 4 different radius intervals.
a) ecliptic sensor   b) south sensor

the azimuthal distributions are generally flat with perhaps a slight enhancement around the apex direction (0°). Inside 0.6 AU the azimuthal distribution from ecliptic sensor is strongly peaked towards the apex direction. Similar distributions have been observed by the micrometeoroid experiments on board the Pioneer 8 and 9 spacecrafts (Berg and Gerloff, 1971) for big particles and the HEOS-2 satellite (Hoffmann et al., 1975). A possible source of these "apex" particles has been discussed by Grün and Zook (1980). A quite different azimuthal distribution has been detected by the south sensor inside 0.6 AU. The number of impacts from the apex direction is smaller than that observed by the ecliptic sensor. This indicates that the average inclination of "apex" particles is smaller than 30°. Most of the impacts were detected when the south sensor was pointing approximately in the solar direction (90°). An even stronger increase of the dust flux from the solar direction has been observed by the Pioneer 8 and 9 experiments for small particles (Berg and Grün, 1973). Zook and Berg (1975) interpreted the "solar" particles to be small fragment particles (β-meteoroids) leaving the solar system

on hyperbolic orbits. The number of β-meteoroids observed by Helios is
much smaller than that detected by the Pioneer spacecrafts.

4.   IMPACT SPEED DISTRIBUTION

The speed of micrometeoroids impacting the Helios detectors has been de-
termined. There is a bias for small particles (m $\lesssim$ 10^{-12}g) towards high
speeds and for big particles (m $\gtrsim$ 10^{-12}g) towards low speeds. Small
particles with low speeds are not detectable and big particles with
high speeds cause saturation of the measurement and no speed value can
be derived. In the mass range 10^{-13}g < m < 10^{-10}g no bias exists for
intermediate impact speeds 10 km/s $\leq \bar{v} \leq$ 20 km/s. Fig. 3a shows the
radial speed distribution for particles observed by the ecliptic sensor.
The average impact speed rises from 7 km/s in the interval 0.9 to 1 AU
to 23 km/s at 0.3 to 0.4 AU.
     With the south sensor the highest average impact speed ($\sim$ 19 km/s)
in the mass range 10^{-13} $\leq$ m $\leq$ 10^{-10}g were observed between 0.8 and
1 AU, the lowest average speed ($\sim$ 8 km/s) at 0.6 to 0.8 AU and further
in a steady increase towards 16 km/s at 0.3 to 0.4 AU had been measured.
In Fig. 3b however we show another subset of the speeds measured with

3a)   3b)
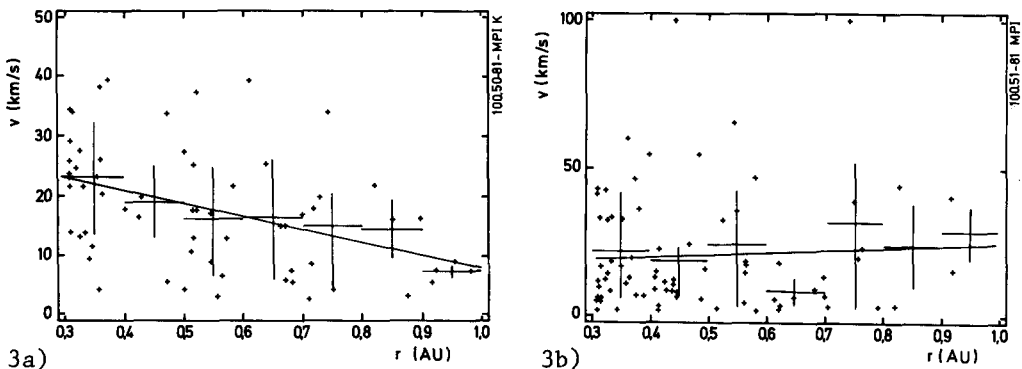
Fig. 3: Radial variation of impact speeds. Small dots are
        values for individual particles. Crosses are average
        values over 0.1 AU intervals with 68% of the measure-
        ments lying within the error bars. Also a linear fit
        through all measurements is shown.
        a) particle with masses 10^{-13} $\leq$ m $\leq$ 10^{-10}g recorded by
           the ecliptic sensor;
        b) "eccentric" particles observed by the south sensor.

the south sensor. Particles on "eccentric" orbits have been identified
by Grün et al. (1980) to be those which are only recorded by the south
sensor and not by the ecliptic sensor. These particles have the highest
average impact speeds ($\sim$ 30 km/s) at 1 AU and slightly lower ($\sim$ 20 km/s)

at 0.3 AU. Such a speed variation together with the flux variation ob-
served by the south sensor is compatible with the spatial density vari-
ation determined by Leinert et al. (1981) according to $n \sim r^{-1.3}$. The
"apex" particles observed by the ecliptic sensor show a quite different
radial spatial density profile. Their spatial density has its maximum
at 0.5 to 0.6 AU and decreases both inwards and outwards.

5. ORBITAL DISTRIBUTION

From the measured impact speed, the actual pointing direction of the
sensor and the position and velocity of the Helios space probe, the
heliocentric velocity of micrometeoroids can be determined. Because of
the large field-of-view of the sensors and the large uncertainty of
the impact speed measurement only probability distributions for the
direction and the amount of the velocity vector are obtained. These
distributions are transformed into probability distributions of orbi-
tal elements for each individual particle, taking into account its radi-
ation pressure constant β. For a more detailed description of the method
and its biases see Schmidt and Grün (1979,1980). Fig. 4 shows the pro-

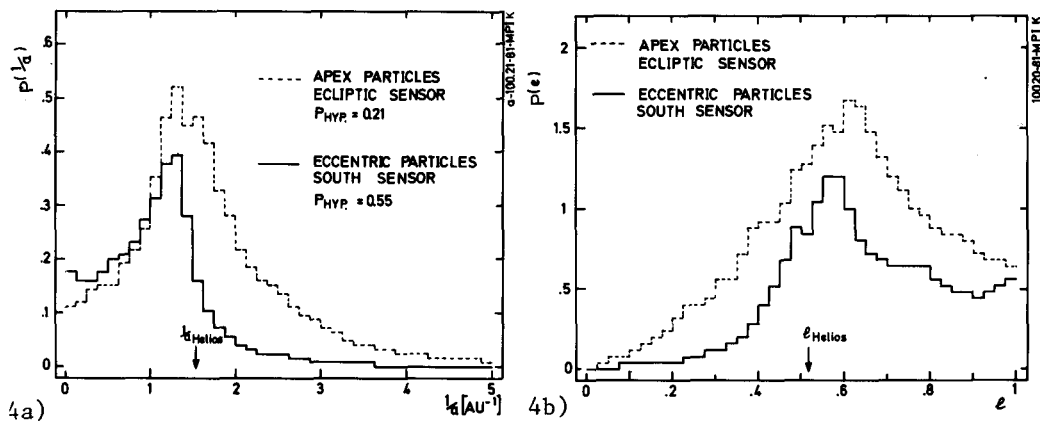4a)   4b)

Fig. 4: Probability distribution of orbital elements for
        "apex" particles and "eccentric" particles. The
        total probabilities are normalized to 1. The strong
        enhancement of the probability at the values of the
        orbital elements of Helios is a bias involved with
        this method.
        a) distribution of the reciprocal semi-major axes.
           The probability for hyperbolic orbits p_{HYP} is indi-
           cated;
        b) distribution of eccentricities.

bability distributions of orbital elements for the two different popu-
lations of micrometeoroids observed by Helios: "apex"-particles and

"eccentric" particles. Because of the biases involved with this method only relative results will be discussed here.

The "apex" particles show a much higher probability for bound orbits than for hyperbolic orbits (p_{HYP} = 0.21). Contrary to that, "eccentric" particles have maximum probability for hyperbolic orbits (p_{HYP} = 0.55). However, the absolute value of this probability will be too high due to a methodical bias. The average reciprocal semi-major axes (Fig. 4a) of "apex" particles is larger than that of Helios (1/a Helios = 1.54 AU^{-1}) in contrast to that of "eccentric" particles which is smaller. "Apex" particles which constitute about 60% of all observed micrometeoroids are on low energy orbits ($\bar{a} \lesssim$ 0.6 AU), whereas 30% of them ("eccentric" particles) are on high energy orbits ($\bar{a} \gtrsim$ 0.9 AU). At least 10% of the observed particles show high probabilities for travelling on hyperbolic orbits.

The probability distributions of the eccentricities are displayed in Fig. 4b. Both distributions have maxima and means above the value of Helios (e_{Helios} = 0.52). This shows that likewise the "apex" particles move on high eccentric orbits with an average eccentricity of $\bar{e}$ = 0.6

REFERENCES

Berg O.E. and Gerloff U. (1971) "More than two years of micrometeorite data from two Pioneer satellites", Space Res. XI, 225.

Berg O.E. and Grün E. (1973) "Evidence of hyperbolic cosmic dust particles", Space Res. XIII, 1047.

Grün E. (1981) "Physikalische und chemische Eigenschaften des interplanetaren Staubes – Messungen des Mikrometeoritenexperiments auf Helios", Bundesministerium für Forschung und Technologie, Forschungsbericht W 81-034.

Grün E., Pailer N., Fechtig H. and Kissel J. (1980) "Orbital and physical characteristics of micrometeoroids in the inner solar system as observed by Helios 1", Planet. Space Sci., 28, 333.

Grün E. and Zook H.A. (1980) "Dynamics of micrometeoroids in the inner solar system", in: 'Solid Particles in the Solar System' (Eds. I. Halliday and B.A. McIntosh), Reidel, Dordrecht, 293.

Hoffmann H.J., Fechtig H., Grün E. and Kissel J. (1975) "Temporal fluctuations and anisotropy of the micrometeoroid flux in the Earth-Moon system", Planet. Space Sci. 23, 985.

Leinert C., Richter I., Pitz E. and Planck B. (1981) "The zodiacal light from 1.0 to 0.3 AU", Astron.Astrophys. 103, 177.

Schmidt K.D. and Grün E. (1979) "The distribution of orbital elements of interplanetary dust in the inner solar system as detected by the Helios spaceprobe", Space Res. XIX, 439.

Schmidt K.D. and Grün E. (1980) "Orbital elements of micrometeoroids detected by the Helios 1 spaceprobe in the inner solar system", in: 'Solid Particles in the Solar System' (Eds. I. Halliday and B.A. McIntosh), Reidel, Dordrecht, 321.

Zook H.A. and Berg O.E. (1975) "A source for hyperbolic cosmic dust particles", Planet. Space Sci. 23, 183.