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Dust Particles Near The Sun

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Abstract. The orbital motion of interplanetary dust grains in the sublimation zone near the Sun has been considered for graphite and silicate. Calculations showed that dust grains with initial radii $s = 0.5 - 5$ μm can form regions of enhanced concentration. The inner corona is slightly enriched with particles $s = 0.3 - 0.6$ μm due to the departure of the evaporated grains onto highly elliptic orbits. However, they may be not recognized due to their small contribution to the total brightness along the line-of-sight compared with the background of the more typical Zodiacal particles. The astrosilicate dust grains do not form zones of enhanced concentration. Finally, particles with initial radii from 0.3 to 4 μm leave the Solar system and become β-meteoroids.

Introduction

Calculations of the dynamics of dust particles such as silicate and graphite (Lamy 1974; Mukai and Yamamoto 1979), made after detecting the excess thermal emission in the F-corona in the near infrared region of the spectrum at $\lambda = 2.2$ and 3.5 μm (Peterson 1967; MacQueen 1968), showed that during the evaporation process the orbital evolution of the dust grains, represented as a dependence of the heliocentric distance on the revolution number, often demonstrates a "turnaround". This means that the infall of the grains onto the Sun under the Poynting-Robertson (PR) effect stops and during some time the return motion (from the Sun) could occur. It appeared that near "turnaround" one could expect an enhancement of the grain concentration.

The model by Mukai and Yamamoto (1979) predicts an increase of the graphite grain concentation by a factor of 10 in the range of distances 4.0 - 4.3 $r_\odot$ and an increase in the silicate grain concentration by a factor of 5 in the range 4.0 - 4.6 $r_\odot$. However, new observations of the thermal emission in the F-corona in 1991 (e.g., Hodapp et al. 1992; Lamy et al. 1992) did not reveal any special features till the distance of 15 $r_\odot$. According to Mann and MacQueen (1993) the brightness distribution in the F-corona at $\lambda = 2.12$ μm is explained by strong thermal emission of the dust with a power law dust distribution typical for the Zodiacal Cloud without an excess concentration.

We carried out dynamical calculations for p- and r-obsidian (with poor and rich content of FeO respectively), basalt, astronomical silicate (ASIL) and graphite. The method is described in detail by Shestakova and Tambovtseva (1995). The goal of the present paper is to check the validity of the models predicting an enhancement of concentration for grains with sizes typical for Zodiacal Light (ZL) in the narrow ring-like zones of the F-corona.

Dynamical evolution of dust grains

The thermal balance was computed using the data on the refractive indices for the grains of interest and the new data on the solar radiation flux in the range of wavelengths 0.15 - 50 μm; the energy contribution beyond this range is negligible (Shestakova and Tambovtseva 1995 and references therein).

The temperature distribution of the silicate grains, whose sublimation rate is computed according to Lamy (1974), reflects the order of location of the sublimation zones for the different types of silicate (Fig. 1). The calculations show that the temperature of the silicate grains near the "turnaround" point lies in the range 1300-1200 K while for graphite grains the same sublimation rate is reached at 2000-1900 K. Particles consisting of mixed materials (e. g., Mann et al. 1994) are not considered here but it should be noted that differences in the sublimation rates could change the chemical composition and other features of the dust approaching the Sun.

Calculations of the orbital evolution show that all grains considered with initial sizes $s_0 > 0.5$ μm make the "turnaround" and after passing a certain distance r_{min} the ellipticity of their orbits increases. This growth is due to rapid increase of the radiation pressure when the radii of the silicate grains reach $s_{\mathrm{max}} = 0.2 - 0.25$ μm, corresponding to the maximal ratio of the radiative force to the gravitational force, β_{max}.

We computed the ratio of the grain lifetime τ in the narrow region (the width is 0.2 $r_\odot$), whose lower boundary coincides with r_{min} of the orbital evolution, to the time of the grain's drift through this region $t_{(\mathrm{PR})}$ under the effect of PR drag for conditions when the grain size does not change. This ratio τ_{PR} reflects the change of number density n of the grains of given composition and initial sizes in the region compared to the normal one corresponding to the undisturbed state n_{u}. It is seen from Fig. 2 that any noticeable increase of n for p- and r- obsidian grains (by factor 2 and more) is possible only in the range of initial sizes s_0= 0.4-3.0 μm with the maximum near s_0= 0.5-0.7 μm.

The possible concentration of dust grains in the narrow region is connected with the value of r_{min} (practically, the position of the boundary of the dust free zone (DFZ) for the grains of a given composition). If for grains with different sizes the points of the "turnaround" (r_{min}) are spatially separated, then one should not expect a real enhancement of the concentration even for the limited range of grain sizes mentioned above. P- and r- obsidian grains have a real possibility to be concentrated in the narrow region since the value of r_{min} for all grains (with $n > 1$) is constant. For the grains of other materials this condition is not fulfilled.

The width of the region of possible concentration of the basalt-like and graphite grains expands to 0.5 - 1.0 $r_\odot$ and for ASIL to 5 - 10 $r_\odot$. Thus, enhancement of the concentration for ASIL-like particles in the narrow region is unlikely.

When the basalt and obsidian grains reach the critical sizes s_{max} their orbital evolution terminates with a steep fall towards the Sun; the graphite particles having evaporated until $s = 0.5$ μm are removed from the Sun. The ASIL grains demonstrate a different behaviour (Fig. 3): those with $s_0 < 0.2$ μm fall towards the Sun and evaporate at about 14 $r_\odot$, those with $s_0 = 0.3 - 3$ μm having evaporated until 0.3 μm leave the Solar System. The larger grains with $s_0 > 5$ μm after approaching r_{min} (near ~10 $r_\odot$) begin to

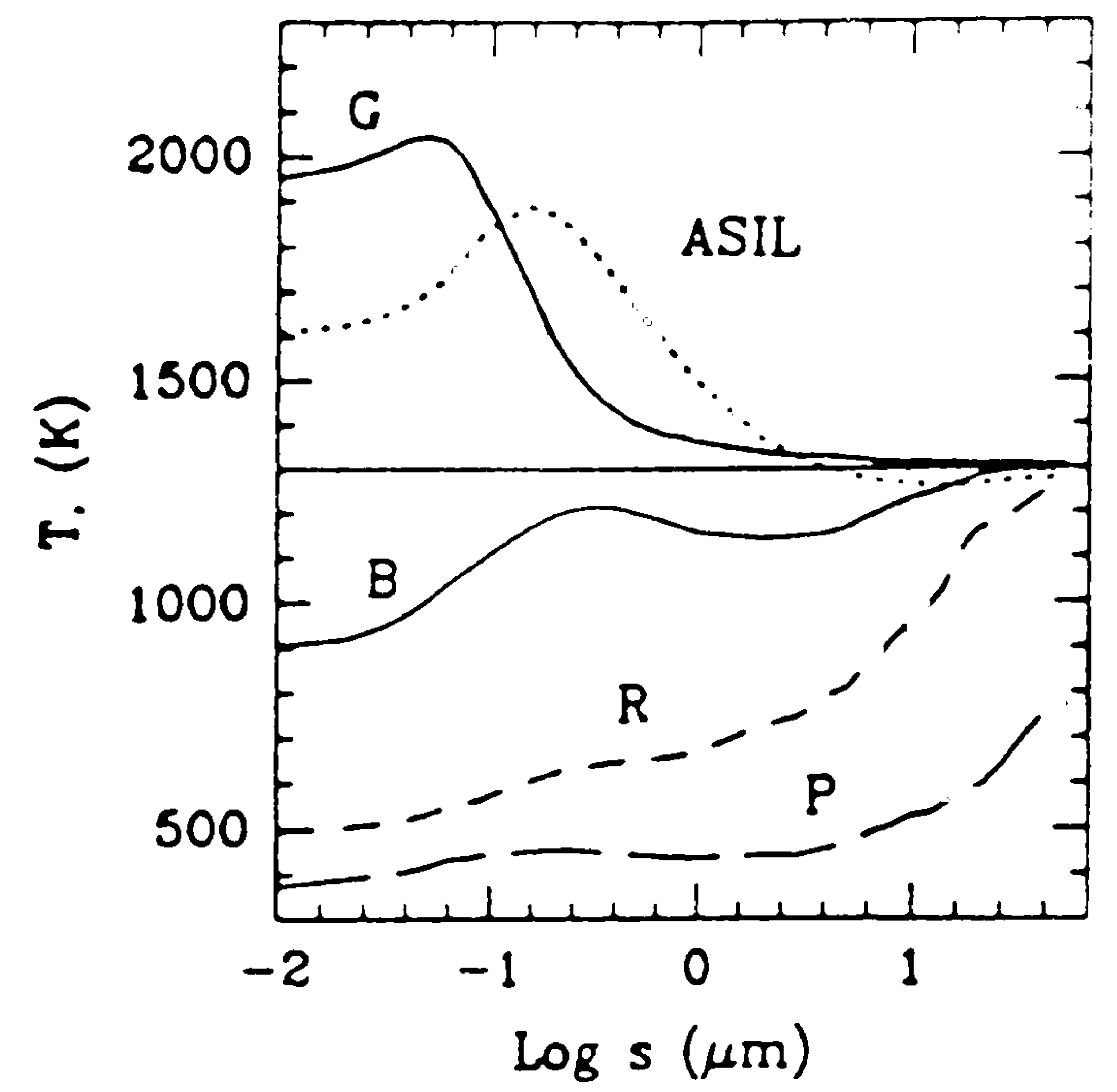

Fig. 1 The grain temperature as a function of grain radius at the distance 10 $r_\odot$ from the Sun for poor obsidian (P), rich-obsidian (R), basalt (B), astronomical silicate (ASIL) and graphite (G). The blackbody temperature (1300 K) is also shown.

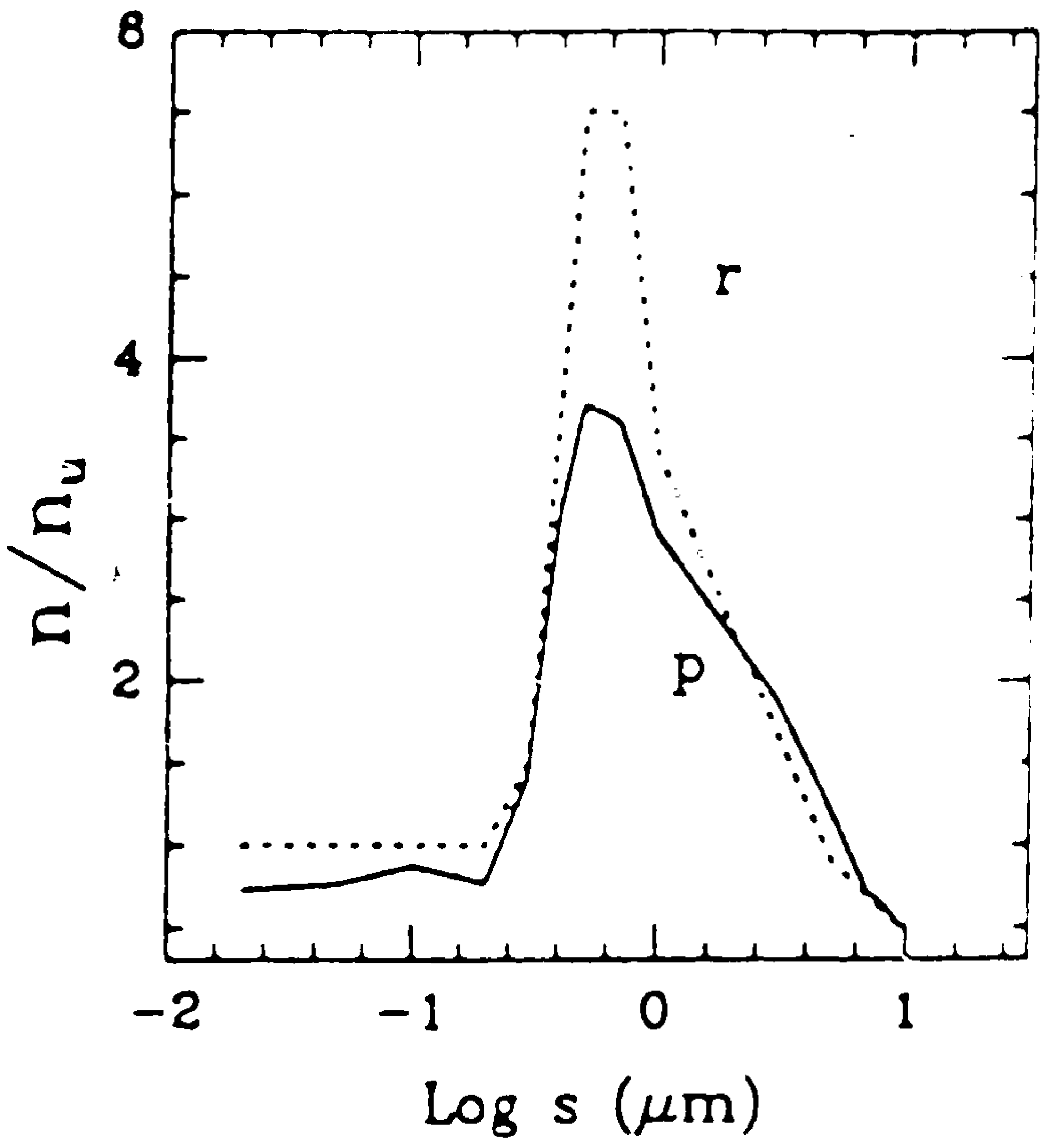

Fig. 2 The ratio of the number density in the narrow region with the width 0.2 $r_\odot$ to the normal one for p- and r- obsidian as a function of the initial grain size. The lower boundary of the region coincides with $\tau_{\min}$ "turnaround" point of the grain orbital evolution (2.6 $r_\odot$ and 4.7 $r_\odot$ for p- and r- obsidian respectively).

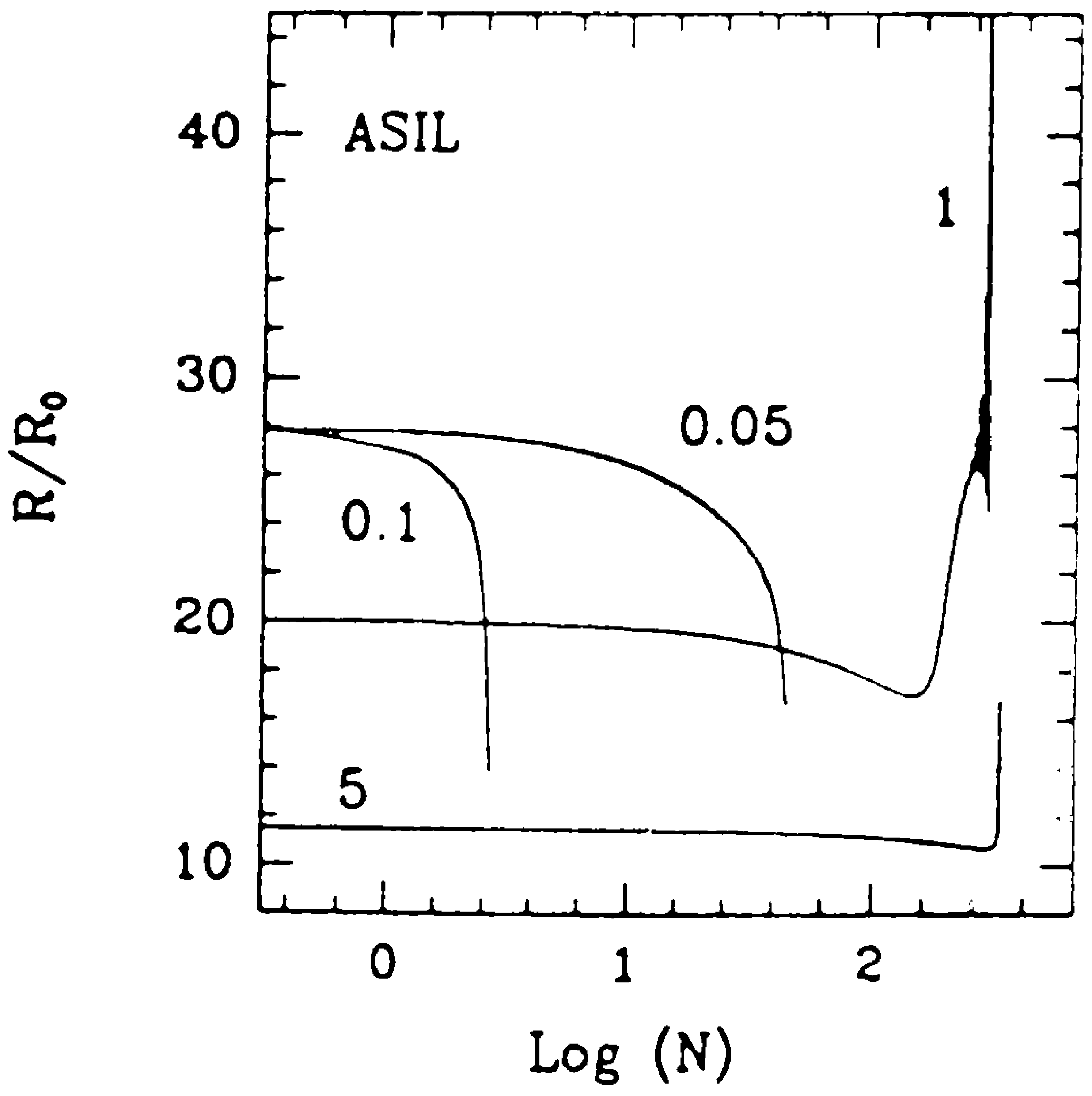

Fig. 3 The orbital evolution of ASIL grains with different initial sizes labelling each curve. N is the number of revolutions, R is the distance from the Sun in solar radii.

move away from the Sun but evaporate completely at the same distances as the smaller grains.

Summary

The calculations show that dust grains of the micronic sizes typical for ZL with the initial sizes $s_0 > 5$ μm can not form dust rings due to the dynamical evolution of their orbits in the sublimation zone near the Sun. The same conclusion refers to the grains with $s_0 < 0.3$ μm. The narrow (0.2 - 0.5 $r_\odot$) dust rings of enhanced concentration can be formed by grains with initial radii $s_0 = 0.4$ -3.0 μm consisting of weakly absorbing sorts of silicate (obsidian and basalt), and also by graphite particles with $s_0 = 0.5$ - 5.0 μm. All of them evaporate at distances $r < 10\ r_\odot$. The maximal growth of the concentration is possible by grains with radii 0.5 - 0.7 μm. It is worth noting that the radial velocity observed in the F-corona in the elongation range 3 - 7 $r_\odot$ indicates that in the circumsolar region along the line-of-sight, beyond the sharp internal boundary, dust grains with $s = 0.4$ - 0.5 μm are predominant (Aimanov et al. 1995).

After departure from the stationary orbit the graphite grains, evaporated till 0.5 μm, and some ASIL grains, evaporated till 0.3 μm, become the β-meteoroids. Before this event they exist as α-meteoroids doing several revolutions. Dust grains with optical properties similar to ASIL sublimating far from the Sun, go onto elliptic orbits and reach the Earth. In this case, near the aphelion of their orbits they can be observed as α-meteoroids or "apex" particles with a small angular momentum and a mass of 10^{-12} - 10^{-13} g. Such particles were observed in the inner Solar System during the Helios 1/2 missions.

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