ON THE PROBLEM OF THE ORIGIN OF β METEOROIDS

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ABSTRACT. The critical analysis of experimental data and of the existing hypotheses of the origin of β meteoroids (Kapišinský, 1985) is extended by adding the hypothesis of co-action, expressing the possibility that these particles originated as a result of the integration of numerous non-gravitational effects, mostly of a destructive nature. In the sense of this hypothesis, it also seems that the β meteoroids only represent a transient phase in the dynamical and physical evolution of ordinary, originally larger meteoroids.

К ПРОБЛЕМЕ ПРОИСХОЖДЕНИЯ β МЕТЕОРОИДОВ. Критический анализ данных и доныне предложенных гипотез о происхождении β метеороидов (Капишинский, 1985) был допольнен о гипотезу совместной деятельности эффектов, представляющей возможность возникновения этих частиц сложением действий нескольких негравитационных эффектов, преимущественно деструктивного характера. В смысле этой гипотези кажется тоже, что β метеороиды представляют себой только временную, динамическую фазу развития, обычных, первоначально больших метеороидов.

K PROBLÉMU VZNIKU β METEOROIDOV. Kritická analýza experimentálnych údajov a doterajších hypotéz o vzniku β meteoroidov (Kapišinský, 1985) je doplnená o hypotézu súčinnosti, vyjadrujúcu možnosť vzniku týchto častíc integráciou účinkov viacerých negravitačných efektov prevážne deštrukčného charakteru. Aj v zmysle tejto hypotézy sa zdá, že β meteoroidy predstavujú iba prechodnú fázu v dynamickej a fyzikálnej evolúcii bežných, pôvodne väčších meteoroidov.

1. INTRODUCTION

When Zook and Berg (1975) introduced the term β particles or β meteoroids for submicron to micron dust particles moving at hyperbolic velocities away from the Sun, they also expressed an opinion as to their origin. They assumed that the particles of the Zodiacal cloud, after mutual collisions, adopting hyperbolic orbits as a result of solar radiation pressure prevailing over the attractive force of the Sun ($\beta > 1$). Later, several hypotheses of the origin of β particles were presented, of which the hypothesis of the solar origin of the β particles, supported mainly by Hemenway (1976) drew the most attention. Mullan (1977) criticized this theory in detail.

The analysis of all available experimental data and the critical analysis of the hitherto presented hypotheses of the origin of β meteoroids led to the conclusion (Kapišinský, 1985) that, provided the β meteoroids are real at all, they only represent a transient phase in the dynamical and physical evolution of ordinary dust particles. This conclusion essentially agrees with the conclusions drawn by other authors (e.g. Le Sergeant and Lamy, 1981; Lamy, 1983). However, the opinions as to the way in which ordinary meteoroids attain this transient condition, i.e. as to the problem of the origin of β particles, are in no way uniform. The mechanisms, which have been so far considered in explaining the origin of the β particles, if taken separately, are unable to explain the generation of a sufficient number of particles with the characteristics required of β meteoroids (micrometeoric size, hyperbolical velocity, direction of escape from the Sun).

This paper presents a brief outline of the possible origin of β particles by the co-action of destructive effects and mechanisms. This hypothesis essentially contains the idea of the integration of various non-gravitational effects of a destructive nature on meteoroids of ordinary size, which enables sufficient numbers of them to attain the phase of β meteoroids.

2. EXPERIMENTAL DATA AND HYPOTHESES OF THE ORIGIN OF β MICROMETEOROIDS

The existence of β meteoroids was first mentioned in connection with the observations made by the interplanetary space probes Pioneer 8 and 9 (Berg and Grün, 1973; Zook and Berg, 1975; Fechtig, 1976; Whipple, 1976), after the S 215 experiment on the HEOS-2 satellite (Fechtig, 1976; Hoffman et al., 1975) and after the S 149 experiment on the orbital laboratory Skylab (Hemenway et al., 1975). Also some of the studies of microcraters on lunar samples contributed, in particular on sample no. 15205 (Fechtig, 1976; Hartung and Storzer, 1974; Le Sergeant and Lamy, 1980) and the results of the observations of the HELIOS I satellite (Le Sergeant and Lamy, 1978; Grün, 1979; Grün and Zook, 1979).

Critical analyses of the data from the experiments mentioned and objections to the explicit interpretation of the recorded impacts in the sense of β particle detection can be found in a number of papers (Levin and Simonenko, 1972; Kresák, 1976; Le Sergeant and Lamy, 1980; Kapišinský, 1985). Based on these critical analyses, one may draw the conclusion that the experimental data on β meteoroids as yet neither qualitatively nor quantitatively convincing enough. These data only allow tentative statements to be made about existence of β particles in the sense that they are a special dust component which is manifest over longer periods of time in the whole complex of interplanetary matter. The situation is even more obscured as regards the problem of the origin of β particles.

With regard to the possible origins of β meteoroids assumed, all the existing hypotheses can be divided into three groups:

1) Collision hypotheses (Dohnanyi, 1976; Fechtig, 1976);
2) Evaporation and melting hypotheses (Belton, 1967);
3) Solar hypotheses (Hemenway et al., 1972).

A more detailed description of the hypotheses in the individual groups and their critical analysis was presented earlier (Kapišinský, 1985), with reference to the studies by other authors (e.g. T. Mukai and S. Mukai, 1973; Leinert et al., 1978; Le Sergeant and Lamy, 1981; Lamy, 1983). More attention has been devoted to the criticism of the solar hypothesis as originally formulated by Hemenway, Hallgren and Schmalberger (1972), because Hemenway (1976) still advocates it in spite of the extensive critical analysis by Mullan (1977) in connection with Mathew´s study (1969).

3. ANOTHER SOLUTION TO THE PROBLEM OF THE ORIGIN OF β METEOROIDS

Since none of the hypotheses on their own is capable of giving a satisfactory explanation of the origin of β meteoroids, a source of "ready-made" β particles can hardly exist, although, in exceptional cases, one cannot exclude the possible existence of such source (e.g. a sudden explosion of a cometary nucleus and subsequent dispersion of particles of various sizes in different directions and at different speeds). The problem of searching for the primary sources of β particles can be reduced to the problem of searching for sources of dust particles in general. Various objects, in fact all objects of the Solar System may act as the primary sources of micrometeoroids (and, consequently, also of β micrometeoroids), because all these objects are capable of producing dust particles. However, comets are usually considered to be the main source, also because the ejection of dust from the cometary nucleus into the ambient space is so far the only observed and verified mechanism of releasing micromaterial from larger bodies. The extensive experiments on automatic space probes, designed for studying Halley´s comet, should in the near future make the estimates of the velocity, manner and total amount of cometary dust production more reliable. At present, we have to be satisfied with the theoretical estimates of the amounts of dust produced by comets. Some estimates concern short--period comets (e.g. Delsemme, 1976; Röser, 1976), other concern the whole present population of active comets (Kresák, 1979a,b). Contributions from the dissipation of large annual meteoric showers with known parental bodies, as well as asteroids have been considered as the source of micromaterial. All analyses bring evidence that the sources hitherto considered are capable of providing but a small percentage of the amount of dust particles required. The probability that these sources can explain the origin of the β particles is thus, of course, decreased to a minimum. It is also evident that the discussed problem of searching for sources of interplanetary dust is closely related, if not identical, to the problem of the stability of the Zodiacal cloud, i.e. to the problem of equilibrium in the production (accretion) and loss of the microparticles of this cloud, as discussed in a number of papers (e.g. Mukai et al., 1974; Delsemme, 1976; Kresák, 1979a; Mukai, 1979; Mukai et al., 1982; Leinert et al., 1983; Mukai, 1983).

One can, therefore, agree with the opinion of Le Sergeant and Lamy (1983) that β meteoroids represent but a certain phase in the overall evolution of ordinary meteoroids. However, there is still the possibility that several exceptional objects are the source of interplanetary dust. However, various effects and mechanisms of a destructive nature, which aid the meteoroid in question to attain the β particle phase, will undoubtedly play an important part in this respect.

One is justified in assuming that the evolution of at least a part of the ordinary meteoroids will reach a stage which is characteristic of β meteoroids. This process can be effected namely by non-gravitational effects, of which there are more than twenty, and which can be divided into groups of destructive, disruptive and disturbance effects, depending on the final effect on the meteoroid being studies. The classification and more detailed characteristics of the separate effects can be found in an earlier paper (Kapišinský, 1984a). They way in which these effects act and their efficiency indicate that effects of the destructive group are most probably the most effcient in effecting the transition of the ordinary meteoroids into the β phase.

As an example of these effects, one can give the impact erosion, corpuscular sputtering, melting, ablation and evaporation processes, or collision processes with incomplete collisional destruction. However,a sudden transition of a larger meteoroid into the β phase may suddenly occur, but is less probable, due to the action of the effects of the disruptive group. This involves the windmill effect, Radzievski's effect, electrostatic explosion of the meteoroid, catastrophic collisions, corpuscular break-up, disintegration of the meteoroid after partial sublimation, or the so-called chemical break-up. But one must not forget the group of non-gravitational effects of the disturbance nature which mainly cause a change in the dynamic parameters of the original body, but may also contribute to creating conditions which facilitate the action of the effects of the two other groups, directly reponsible for the diminishing of the original size and mass of the meteoroid. This group of disturbance effects includes direct light pressure, the solar wind corpuscular pressure, the Poynting-Robertson effect, the pseudo-Poynting-Robertson effect, the Yarkovski-Radzievski effect, the cosmic ray effect, collisional drag, the Coulomb force effect, as well as the Lorentz force effect.

These remarks on the non-gravitational effects alone indicate that a sufficient number of effects and mechanisms is available for explaining the origin of β meteoroids, or the origin of this phase of evolution. But a more detailed investigation and the preliminary calculations of the intensities of the separate effects (particularly of the destructive group) indicates that none of them on their own is capable of producing a sufficient number of particles in the β phase. This is also supported by the more detailed analysis of the efficiency of the impact erosion itself (Kapišinský, 1984b). However, it seems possible to explain the evolutionary β phase of meteoroids by combining the various destruction effects.

4. THE COMBINATION HYPOTHESIS

Let us assume that the destruction process of larger meteoroids is not due to just one effect (mechanism), but that a number of the effects mentioned above act simultaneously, the evolution of the object being investigated is accelerated into the β phase. The origin of the particles could then be explained by the integration of various effects, mostly destructive. In this connection, one would have to consider the random, but sometimes significant contributions of the effects of the disruptive group as well as the additional effect (in the preparatory phase) of the effects of a disturbance nature.

According to the hypothesis of combining non-gravitational effects, an ordinary meteoroid is able to attain a condition in which, with regard to its physical parameters (its size and mass has become critical), the force of the repulsive radiation pressure is larger than the gravitational force of the Sun ($\beta > 1$) and, in terms of dynamics, this meteoroid is manifest as a β meteoroid (it has attained the β phase). However, we must not forget that the situation has been complicated by the parameter β being dependent not only on the size and density of the particles, but also on other physical and optical properties of the particles (complex index of refraction, surface morphology, dielectrical and chemical properties, etc.). Finally, when the original size is decreased further (since the destructive and dissipation processes act practically permanently) parameter β depends on the size in a very complicated way and the attraction of the Sun may again prevail ($\beta < 1$) In general, therefore, the dynamic of a separate particle in the micron and submicron regions is very complicated. This can best be seen if the dynamics is treated not only with regard to the chemical, optical and dimensional properties, but also to the influence of three or four non-gravitational effects (e.g. Dohnanyi, 1972; Kresák, 1976; Burns et al., 1979, Morfill and Grün, 1979; Mignard, 1982; Mukai and Yamamoto, 1982; Voshchinnikov and Ilin, 1983, etc.).

With regard to the problems we are concerned with, it is most important that situations in which $\beta > 1$ may occur in the evolution of the separate particle, The particles may then indeed start to escape hyperbolically away from the Sun, and may be recorded as β micrometeoroids. However, as already mentioned, the open orbit may close again ($\beta < 1$), for example, as a result of refraction phenomena alone (under extremely small dimensions). Consequently, under the condition that $\beta \geqq 1$, complete escape of the meteoroid from the Solar System need not always be involved. Moreover, the particles may begin to escape (definitely or temporarily) before they attain their critical size for which the condition β = 1 is satisfied. The motion of meteoroids of micron and submicron dimensions is complicated and can have several phases, some of which are characteristic not only by their classical spiralling towards the Sun as a result of the Poynting-Robertson effect, but also by spiralling away from the Sun (Kapišinský, 1980, 1983). The detection of particles in these phases of motion can also be included among the recordings of β meteoroids. This may also apply to the detection of particles at a certain stage of "hovering" (Kresák, 1976).

One may expect, therefore, β meteoroids to represent but a particular phase in the dynamical and physical evolution of ordinary meteoroids which have attained this phase due to the integration of various destructive effects temporarily, and, with regard to the overall lifetime, relatively quickly and for a negligibly short interval. The so-called β phase in the evolution of meteoroids as a whole may, therefore, be considered a very exceptional short--lived phenomenon. In this sense, one may also view the lower probability of recording this evolutionary phase of the meteoroids, as well as the small number and inconclusiveness of the existing records of β meteoroids.

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