EXPERIMENTAL DATA AND HYPOTHESES ON THE ORIGIN OF β MICROMETEOROIDS

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ABSTRACT. Experimental data on β micrometeoroids obtained from different in situ measurements are summarized and critically analysed. It is shown that the sun hypothesis on the origin of submicron particles is rather improbable. They apparently represent a transient phase in the complicated dynamical evolution of originally larger cosmic dust particles.

ЭКСПЕРИМЕНТАЛЬНЫЕ ДАННЫЕ И ГИПОТЕЗЫ ОБ ПРОИСХОЖДЕНИИ β МИКРОМЕТЕОРОИДОВ. В работе сумаризуется и проводится критический анализ данных полученных разными прямыми космическими измерениями β микрометеороидов. Гипотеза происхождения этих субмикронных пылинок из Солнца является довольно невероятной. Скорее всего дело в том, что они представляют собой временное явление в сложном динамическом процессе развития первоначально больших пылевых частиц.

EXPERIMENTÁLNE ÚDAJE A HYPOTÉZY O PÔVODE β MIKROMETEOROIDOV. Previedla sa sumarizácia a kritická analýza experimentálnych údajov získaných rôznymi kozmickými meraniami in situ β mikrometeoroidov. Ukazuje sa, že slnečná hypotéza pôvodu týchto submikrónových častíc je dosť nepravdepodobná. Najskôr ide o prechodné štádium v zložitej dynamickej evolúcii pôvodne väčších prachových častíc.

1. INTRODUCTION

In the complex of interplanetary matter as a whole, micrometeoroids are at the very bottom of the scale of dimensions and mass. Consequently, in detecting them in situ, one frequently has to operate at the very limits even of the most sensitive recording equipment. Following the experiments on space probes Pioneer 8 and 9, a discussion was begun concerning the recording of small meteoroids moving away from the Sun along hyperbolic trajectories. Zook and Berg (1975) called these particles of micron and submicron dimensions βmeteoroids, with a view to the high value of parameter β, and, at the same time, proposed the first hypothesis of their origin as being due to putting the smallest fragments of collisions of larger particals of the Zodiacal cloud into hyperbolic orbits by radiation pressure prevailing over the Sun's force of attraction ($\beta > 1$).

Apart from the fact that the dynamics of micrometeoroids is very complicated as a result of many non-gravitational effects acting on them, little can be said with certainty about the origin of βmeteoroids since the Pioneer 8 and 9 experiments.

This paper summarizes and critically analyses all the experimental data on the basis of which the idea of existence of βmeteoroids was created as a dynamically quite peculiar group of dust particles escaping from the Solar System. The critical analysis of the existing hypotheses of the origin of βmicrometeoroids has led the author to conclude that βmeteoroids if real, are probably only a transitional phase in the dynamic evolution of ordinary dust particles. This conclusion is essentially in agreement with those of other authors (e.g. Le Sergeant and Lamy, 1981; Lamy, 1983).

2. EXPERIMENTAL DATA ON βMICROMETEOROIDS

The existence of βmicrometeoroids began to be discussed as a result of the experiments conducted on space probes Pioneer 8 and 9 (Berg and Grün, 1973; Zook and Berg, 1975; Fechtig, 1976; Whipple, 1976), and on the HEOS 2 satellite (Fechtig, 1976; Hoffman et al., 1975). There were also the experiments on the orbital station Skylab (Hemenway et al., 1975), some studies of microcraters on lunar samples (Fechtig, 1976; Hartung and Storzer, 1973; Le Sergeant and Lamy, 1980) and the results of the observations made by the Helios 1 satellite (Le Sergeant and Lamy, 1978; Grün, 1979; Grün and Zook, 1979).

Space probes Pioneer 8 (launched Dec. 13, 1967) and Pioneer 9 (launched Nov. 3, 1968) carried highly sensitive detection equipment combined with acoustic sensors along heliocentric orbits with perihelia of 0.98 and 0.75 AU and aphelia of 1.08 and 0.99 AU, respectively. Their heliocentric velocities were approximately 30 km/s. The detection equipment on both probes was essentially the same. A more detailed description of this equipment can be found in a number of papers (Gerloff and Berg, 1971; Berg and Grün, 1983; Grün et al., 1973, etc.).In principle, an ingenious system made it possible to determine the kinetic energy, momentum, velocity and direction of motion of microparticles with energies in excess of 10^{-7} J (kinetic energy and direction of particles with energies in excess of $2x10^{-8}$ J).

The probability of false recordings of the particle impact by the basic detector (not the microphone) is estimated at 10^{-7}. This is also one of the reasons why the experiments on Pioneer 8 and 9 are considered to be highly reliable and their results are frequently used to make far-reaching astronomical interpretations. In this first period of activity (more than 2 years) of the Pioneer 9 experiment the value of the recorded microparticle flux $\Phi = (2 \pm 0.5) x 10^{-4} m^{-2} s^{-1} (2\pi sr)^{-1}$ is given for the limiting sensitivity of the detectors of $5x10^{-12}$ g, which is perhaps so far the value with the lowest scatter for in situ measurements. The value of the average flux for the other experiment was approximately the same. A number of authors dealt with the results of these measurements, their processing, analysis and interpretation (e.g. Berg and Gerloff, 1971; Gerloff and Berg, 1971; McDonnell, 1971; Dohnanyi, 1972; McDonnell et al., 1974; Wolf et al., 1976, etc.).

However, the measurements on which the hypothesis of the existence of βmeteoroids is based, are related to a further period of activity of the probes. They involve 319 recordings on the front film-grid (FFG - front film-grid events) made during the seven years of activity of the probes (Berg and Grün, 1973). Table 1 provides information about the preferred directions of the microparticles recorded by the detection equipment as a whole during this period (Fechtig, 1976).

Table 1

Direction	Number of impacts per year	%
Sun	90	56.0
Apex	40	25.0
Antiapex	20	12.5
Antisun	10	6.5
Total	160	100.0

Experiment S 215 on the HEOS 2 earth satellite was very convenient for studying the spatial distribution of microparticles as a function of geocentric distance, because the satellite's orbit was highly eccentric (apogee 240 000 km, perigee 300 to 3000 km). A total of 431 microparticle impacts was recorded between Feb. 7, 1972 and Aug. 2, 1974. The authors divided the records according to the length of the time interval between the individual impacts into three categories: swarms (2 or more impacts during 15 mins), groups (from 2 particles per 15 mins to 2 particles per day) and random particles (frequency less than 2 particles per day). It was found that 80% of all recorded microparticles displayed a tendency to create swarms or at least groups. In the perigee region ($<$67 000 km) 93% of all recorded particles belong to these two categories. The technical details and processing of the records can be found, e.g. in Hoffman et al., 1973; Hoffman et al., 1975; Bedford et al., 1975; Fechtig, 1976

The detection of β micrometeoroids is difficult because the micrometeoroid flux in the direction away from the Sun is not known in this experiment, because the detector could not be pointed at the Sun for technical reasons. The microparticles were most frequent from the direction in which the probe moved. The microparticle flux from this direction $\phi_{apex} = 4x10^{-4}m^{-2}s^{-1}(2\pi sr)^{-1}$. As regards the other monitored directions, the fluxes were at least one order of magnitude smaller. Table 2 gives the number of recordings from four monitored directions per 100 cm^2 of detection area in the region further away from the Earth (> 67 000 km). The table also gives the number of particles belonging to swarms, groups or to the sporadic background. For the perigee region ($<$ 67 000 km) the values are aggregates of all directions (Fechtig, 1976). The 20 recordings to make up the total of 431 were assigned by the authors to meteor showers active at the time of detection (Perseids 1972, Draconids 1972, Perseids 1973, Quadrantids 1973, Ursids 1973).

Tab. 2

Region	Directions	Duration of registration (days)	Swarms (number of particles)	Groups (number of particles)	Number of random particles
Apogeum	Apex	289.0	32	11	32
	Antiapex	55.1	51	4	3
	Ecl. North	263.9	-	7	14
	Ecl. South	114.4	-	5	12
Perigeum	all directions	69.8	206	18	16
	Total :	792.2	289	45	77

The purpose of experiment S 149 on the orbital station Skylab was to determine the flux of dust particles in the vicinity of the Earth, approximately at an altitude of 430 km. Small plates of various materials (aluminium, pyroxene, phosphate glass, stainless steel, silver), on which the impinging particles made microcraters, were put out into space for this purpose. These impact traces were then analysed by means of an electron microscope.

With regard to the problem on hand, the experiment was interesting in that mainly two directions were monitored, i.e. the directions towards and away from the Sun. The preliminary conclusions drawn from the experiment prove a high abundance of micrometeoroids of high velocities.

A more detailed technical description of this experiment (arrangement of detection targets in immobile "pan" and mobile "cover", their orientation, device with the check cassette, etc.) as well as some of the analyses (chemical analysis of the remanents of the microparticles in the craters, rough directional analysis, etc.) can be found, e.g. in Hemenway et al., 1975; Hallgren and Hemenway, 1976; Nagel et al., 1976 .

A concrete example of investigating the impact traces on lunar soil samples is that of specimen No. 15205 on which about 1000 microcraters, diameters from 0.2 to 200 μm were found (Fechtig, 1976). Based on precise laboratory simulation experiments and calibration, the characteristic of the impact traces can be used to derive some of the dynamic and physical parameters of the particles which are responsible for them: e.g. velocity, mass, dimension and direction of motion. In principle, also the microparticle flux can be determined, provided the time for which the specimen involved was subject to space effects is known (for details refer, e.g. to Hartung, 1976; Morrison and Zinner, 1976). The study of specimen No. 15205 led to the conclusion that the analysed craters were probably caused by high-velocity micrometeoroids in which the "apex" component and the component incident away from the Sun can be distinguished (Hartung and Storzer, 1973; Fechtig, 1976).

The micrometeoroid flux roughly estimated from this analysis of the lunar specimen agrees relatively well with the flux derived from the experiments on Pioneer 8 and 9 and HEOS 2, as well as from observations of the brightness of Zodiacal Light. This agreement apparently led to the conviction that, even in the case of particle impacts on the lunar surface, this at least partly involves collisions of the Moon with βmicrometeoroids escaping at hyperbolic velocities away from the Sun.

3. ANALYSIS OF THE EXPERIMENTAL DATA ON βMICROMETEOROIDS

The micrometeoric experiments on space probes Pioneer 8 and 9 may really be considered so far as the most successful observations made in the history of direct micrometeoric detection ever. The experiments on space probes Pioneer 10 and 11 partly tie in with these achievements. The reliability of the measurements of the basic characteristics of micrometeoroids (flux, mass) in the Pioneer 8 and 9 experiments was also proved by more detailed analysis and comparison of these observations with other reliable experiments (Kapišinský, 1979). However, the Pioneer 8 and 9 experiments also had a more exacting task, i.e. to determine the individual trajetories of the detected microparticles, which is not only necessary to supplement our very meager knowledge in this field, but also to contribute to solving some important astronomical problems (e.g. the question of the existence of mirometeoric showers, relation with ordinary meteoric showers and comets, problems of βmicrometeoroids, etc.). In general, it may be said that the experiment did not come up to expectations in this task.

The determination of the complete orbits of microparticles (8 cases) during the first two years of activity of the probes is discussed in detail, e.g. in the paper of Berg and Gerloff (1971). In two cases, the results even indicate certain correlations with the longitude of the ascending nodes and inclinations of the orbits of comets Encke and Grigg-Skjellerup. Berg and Gerloff do not consider just the observed data to be absolutely reliable, but also their astronomical interpretations.

The objections to the reliability of the determined orbits are based on the low probability of the measured elements of these orbits. In comparison with the elements of orbits of ordinary meteoroids, the orbits of the detected particles display small values of the semi-major axis, but namely conspicuously small perihelion distances (with the exception of one case). There is the question whether such a small particle in the close vicinity of the Sun would not evaporate before it could continue in its orbital motion.

Other doubts are associated with the function of the detection system itself. The device used to measure the velocity and direction of the particles is as yet unable to determine these quantities with an accuracy sufficient to determine reliably the individual orbits. The apparatus used in the Pioneer 8 and 9 experiments enables the velocity of the particle to be determined with an error of $\pm 10\%$ and the direction of motion with an error of as much as $\pm 30^{\circ}$.

The precipitate conclusions of Berg and Gerloff were also criticized by Levin and Simonenko (1972) who expressed strong doubts namely with regard to the relation of two microparticles to comets Encke and Grigg-Skjellerup. The authors also pointed out that the small perihelion distances of most detected particles were unrealistic. They consider all these facts to be the result of inaccuracies in determining the particles´direction and velocity. From the point of view of the dynamics of dust particles it also seems to be improbable that the spiralling towards the Sun takes place in the plane of the orbits of the comets mentioned (Kresák, 1976).

One can thus say that the statement concerning the high quality and reliability of the Pioneer 8 and 9 experiments refers only to the determination of the particle flux in dependence on their mass, but that it is not acceptable without exception as regards the measurements of velocity and radiant of the detected particles. In spite of critical exceptions to some of the results of the first two years of the probes´activity, the results of these experiments continue to be considered very reliable with a view to other successful observations. Perhaps this is also the reason why the hypothesis of the existence of βmeteoroids, based on the Pioneer 8 and 9 experiments, is automatically considered to be a fact sufficiently verified. However, closer examination indicates that the matter is not as simple as it would seem.

The directional analysis of 319 recording obtained during the 7 years of activity of the probes, can be used to draw the conclusion that the most micrometeoroids collided with the detector in two basic directions: from the direction away from the Sun and from the direction of the probe´s apex. As regards the direction away from the Sun, the largest number of microparticles were really recorded per year. Also βmeteoroids could have been among these microparticles. However, as more detailed analyses of the experimentators themselves (Berg and Grün, 1973) indicate, the velocities of the particles moving away from the Sun could not be determined. In spite of this, some specialists (in particular, Berg, Gerloff and Grün) came to the conclusion that the particles involved were extremely small (dimater < 1 μm) and that they were moving away from the Sun at high velocities (>50 km/s) and may, thus, represent individual βmicrometeoroids.

In the case of the experiment on the HEOS 2 satellite, the problem of detecting βmicrometeoroids is more complicated. The derived particle flux from the apex direction and direction to the south pole of the ecliptic was about one order of magnitude larger than the fluxes from the other directions (antiapex and northern pole of the ecliptic). Sporadic recordings showed certain increases in frequency (about 5-times as compared to the frequency in interplanetary space (defined by distance $>$ 67 000 km), in the region of the perigee ($<$67 000 km).

The fact that the detectors could not be pointed at the Sun for technical reasons, is important for our problem. We thus have in fact no information about the particle flux from this direction. Moreover, further detailed analysis showed that the abundant flux of micrometeoroids in the direction from the south pole of the ecliptic is formed by particles which are much smaller and faster than the particles coming from the apex direction (Hoffmann et al., 1975). The claim that the HEOS 2 experiment proved the occurrence of β micrometeoroids is, therefore, doubtful to some extent.

No more extensive and mainly clear-cut conclusion can be drawn regarding the reliability of the proof of the existence of β micrometeoroids based on the measurements made on Skylab and Helios I and the information available. However, it seems that this evidence is even more doubtful than in the case of the HEOS 2 satellite.

Obtaining knowledge about β micrometeoroids by studying the impact craters on lunar samples has its specific difficulties. These consist in the amount of auxiliary and by no means simple steps. For example, this concerns the estimation of the time for which the particular specimen was exposed to space effects, estimation of the rate at which impact phenomena are erased and specimens abraded by various effects, the conversion of the surface density of microcraters to microparticle flux, etc. To these steps we have to add also the more complicated simulated laboratory meaurements which involve a number of not particularly certain assumptions. One can also take into account the creation of parasitic effects such as secondary or even tertiary microcraters which occur as a result of the everyday bombardment of lunar specimens (Le Sergeant and Lamy, 1980). In spite of these difficulties and uncertainties, it is generally accepted that lunar microcraters with diameters of less than 1 μm were created by collisions with β micrometeoroids. This opinion is independently supported also by some studies of a theoretical nature (e.g. Dohnanyi, 1976).

4. EXISTING HYPOTHESES OF THE ORIGIN OF β MICROMETEOROIDS

Regardless of the short history of the β micrometeoroid problem, there are already a number of papers at least touch on the possible mechanism of their generation. According to the proposed possibilities of the generation of β micrometeoroids, all the existing hypotheses can be divided into three main groups: 1) collision hypotheses, 2) evaporation and melting hypotheses, 3) solar hypotheses.

1) Collision hypotheses (Dohnanyi, 1976; Fechtig, 1976). Micrometeoroids, moving in heliocentric orbits, gradually spiral towards the Sun as a result of the Poynting-Robertson effect. In the course of this motion, they collide with

each other frequently namely in the space between the Sun and the Earth. These collisions generate many smaller fragments. The hypothesis makes the simplified assumption that many of these fragments may have masses (dimensions) below the limit where $\beta > 1$, and are then, as a result of the predominating pressure of solar radiation, permanently carried away from the Sun and, having achieved sufficient acceleration, they are finally emitted from the Solar System along hyperbolical trajectories. It is in this last stage that they should be recorded by detectors as submicron particles with over-parabolic velocities moving away from the Sun, i.e. as βmicrometeoroids.

2) Evaporation and melting hypothesis (Belton, 1967). As opposed to the preceding collision hypothesis, this hypothesis makes the assumption that the particle is diminished to critical dimension (for $\beta > 1$) mainly by evaporation of the surfaces layers of the meteoroid in the immediate vicinity of the Sun. This process is further supported by fragmentation if the particle consists of chemically variable material with different melting temperatures and evaporation temperatures. The particle may thus achieve its critical dimension close to the Sun either by direct evaporation, or by fragmentation after its heterogeneous components have melted. According to Sekanina (1976), deliberations on the dynamics of microparticles generated in this manner lead to the conclusion that the mechanisms mentioned are capable of explaining the basic characteristics of the occurence of βmicrometeoroids.

3) Solar hypothesis (Hemenway et al., 1972). It is also sometimes referred to as Hemenway's hypothesis after the main author. According to this hypothesis, most β micrometeoroids have their origin directly on the Sun's surface. Later version specified the place of origin of βmeteoroids as the cooler regions above sunspot umbrae (Hemenway, 1976). The solar hypothesis drew most attention and controversies and, therefore, more space will be devoted to its analysis in the next section.

Other alternative possibilities of the origin, or at least explanation of the β micrometeoroid phenomenon, which can be found in the literature, are not given here mainly because they represent versions of one of the hypothesis in the groups mentioned, or because they have not yet been developed to the degree the known hypotheses have. Finally, some possible sources of interplanetary dust and the explanation of the origin of βmeteoroids are discussed in the conclusion of this paper.

5. ANALYSIS OF EXISTING HYPOTHESES OF THE ORIGIN OF βMICROMETEOROIDS

The collision hypothesis as one of the possible mechanisms of the origin of βmicrometeoroids is mentioned in the literature, giving a generally formulated physical concept. There are strong doubts that this single mechanism (collisions between larger meteoroids in heliocentric orbits) is capable of producing a sufficient number of βmeteoroids. The problem is the more complicated in that even after more detailed computations of the probability of mutual collisions, we are unable to determine (with a view to the conclusions about the uncertain experimental base of βmeteoroids) whether the microparticles produced in this way are sufficient in number. On the other hand, a sufficient number of precise theoretical analyses have been made, concerning the collision type of production of dust particles (Dohnanyi, 1978; Le Sergeant and Lamy, 1981) of which at least some lead nearly uniquely to the conclusion that this mechanism of βmeteoroid origin is very improbable (Le Sergeant and Lamy, 1981; Lamy, 1983). This is mainly based on the fact that the collision mechanism is considered apart from other destructive effects, which is hardly able to guarantee the required production of βmeteoroids.

The last mentioned deficiency also fully applies to the evaporation and melting hypothesis. This hypothesis also neglects other destruction effects and concentrates on just two mechanisms (evaporation and meltin of the surface layers of the original meteoroid, and on its disintegration after melting, provided it consists of two or more heterogeneous components). The hypothesis is limited to these two mechanisms apparently in an effort to explain simultaneously the place of origin and the directionality of the βmeteoroids (radial motion away from the Sun´s vicinity). It is indeed probable that in the immediate vicinity of the Sun, where the two mechanisms are most effective, the parameter β will exceed unity for the given meteoroid due to abrupt ablation or ablative disintegration. However, for this to occur, the perihelion distance must be really small, which is not very probable with a view to the distribution of perihelion distances of larger meteoroids. This objection is also supported by the observation made by the solar probe Helios I, the purpose of which was to prove the existence of the so-called "free zone", a region with no dust particles in the inmediate vicinity of the Sun. Preliminary results indicate that, at distances of less than 0.09 AU from the Sun there is no Zodiacal dust cloud (Leinert et al., 1978), and this agrees relatively well with other results (e.g. T. Mukai and S. Mukai, 1973).

Hemenway´s solar hypothesis really drew most controversy. According to Hemenway, Hallgren and Schmalberger (1972) the origin of at least a substantial part of βmicrometeoroids is directly on the Sun. According to the authors of this hypothesis, submicron particles with a high content of rare and heavy elements, detected during rocket flights over Kiruna (Sweden), are generated on the Sun, most probably in regions between granules, or in the regions of sunspots. In spite of the serious problems encountered in this hypothesis, Hemenway (1976) has not discarded it. Within the scope of this hypothesis, the fast submicron particles recorded exclusively at high geographic latitudes can be explained as due to their concentration in the strongly condensed magnetic field of the Earth. This concept of the strong effect of magnetic forces on the charged microparticles was utilized in other connections by Stratford (1976) in explaining the chemical peculiarities of Ap stars.

A whole series of problems arises in connection with the solar hypothesis. First of all, there is the question of polarity and the magnitude of the potential of particles generated on the Sun, as well as the possibility of their interaction with the Earth´s magnetic field. According to earlier and recent studies, it is generally being accepted that the microparticles in interplanetary space most probably have a low positive potential, of the order of +10 V (see, e.g. Spitzer, 1941; Fesenkov, 1965; Belton, 1966; Peale, 1966; Rhee,1967;

Mukai, 1981). However, the situation becomes quite different if one admits that the particle is generated in the solar atmosphere, or directly in a sunspot. Before the particle is able to leave the Sun's gravitational field and reached, e.g., the Earth's atmosphere, it must cover large distances in the medium of the solar atmosphere. In this connection, gas particles of the solar atmosphere cause the particle to "grow" (by accretion of particles of this gas), but also destruction due to bombardment of the surface layers of the particle being generated. The rate of action of both mechanisms depends on the charge which the particle moving in this medium is carrying. A realistic calculation for an actual model of the atmosphere was made by Mullan (1977) who, drawing on Mathews'(1969) study, came to the conclusion that the particle, in the special case of the medium of the solar corona, acquires a low negative charge. The negative charge of the particle in the corona increases the rate of accretion on the part of the positive ions of the solar atmosphere, but this negative charge is not an obstacle to the compensating sputtering effect. For the sake of completeness, it should be mentioned that the probability of the particle acquiring a positive charge in the corona is low. This could only occur under the condition that it would be generated by one of the following elements: Ba, Sc, Eu, K, La, Li, Na, Ra, Rb or Sr. The positive charge would be small anyway and would only have a negligible effect on the rate of the sputtering effect (Mullan, 1977).

We shall now devote our attention to the question of the escape of the charged particle from the Sun's gravitational field due to the pressure of solar radiation. The situation is more complicated in this case. If this pressure dominates over attraction ($\beta > 1$), the particle is able to start escaping from the Sun, however, its escape is decelerated by the resistance of the medium (gas). Moreover, the dimensions of the particle may drop to the limit at which the radiation pressure, as a result of light diffraction, is no longer sufficiently effective and gravity will again become stronger ($\beta < 1$). This situation may occur namely if the rate of destruction of the particle's surface by sputtering (solar sputtering effect) of gas atoms is larger than the compensating mechanism of accretion of the particle material due to these atoms. The escape of the particle from the Sun's gravitational field, therefore, depends on the ratio of the rates with which these two mechanisms act. Otherwise, the situation can be characterized by the question whether the velocity of the particle is sufficient for it to escape the Sun's gravitational sphere before it becomes decelerated by the decreasing effect of the repulsive radiation pressure as a result of light diffraction on too small particles. This problem was studied in detail by Mullan (1977); he chose his assumptions models and parameters for computation to give the particle as much chance of escaping from the Sun as possible, i.e. to create the best conditions possible for the validity of Hemenway's hypothesis. In spite of the procedure he adopted, the author came to the conclusion that the particle would not escape from the Sun's gravitational field, but that sooner or later it would be completely destroyed in hot plasma. There is no realistic way of making the repulsive radiation pressure on the particle prevail over the gravitational force of the Sun for a sufficiently long time. Moreover, it should be added that, for submicron particles, direct sublimation is very serious problem with regard to destruction, not only in the Sun´s atmosphere, but also in its immediate vicinity. By neglecting this effect, Mullan created quite favourable conditions for the solar hypothesis. On the other hand, however, one may object that also the dynamic effect of the solar wind particles may contribute to the particle´s escape. A more detailed analysis has proved that the parameters of the solar wind (in particular the velocity) would have to have quite improbable values to generate any effect at all.

If in spite of these serious objections, we were to accept the fact that at least some particles escape from the Sun, we would be faced with the problem of how they can be trapped and accumulated at high geomagnetic latitudes. This prompts another question: Why were these particles, coming from the Sun, detected at only one place on Earth ? More detailed investigations using the relations for extreme rigidity of the geomagnetic field in the equatorial region and for rigidity at the poles (magnetic rigidity of the particle, or the strength of its material - Haymes, 1971) indicate as highly improbable that the geomagnetic field would be capable of accumulating larger concentrations of charged particles at higher geomagnetic latitudes. On the contrary, one might expect all geomagnetic latitudes to be accessible to these particles (Mullan, 1977). The fact alone that particles with an abundance of rare and heavy elements were recorded only at a single place on Earth calls for a local explanation. First of all, it should be mentioned that Kiruna is a region with rich iron ore deposits in which the content of apatite is abnormally high (Park and MacDiarmid, 1964). However, apatite is one of the ordinary minerals which may contain a considerable amount of rare elements. The same situation can be found in the region of Kirovsk on the Kola Peninsular, just 500 km as the crow flies east of Kiruna. One is thus justified in assuming that the higher local concentration of particles with a higher content of rare elements in the atmosphere over Kiruna may be due to the mining of ores in the Kiruna-Kirovsk region, where the stirred up dust reaches altitudes of about 100 km and may prove to be a false object (even for a longer time), especially with regard to sampling experiments with high-altitude rockets (for details refer to Kapišinský, 1975). Consequently, also this "non-space" local explanation of the origin of the detected particles can be added to the objection to the trapping of particles at high geomagnetic latitudes by magnetic forces. To verify this explanation, Mullan (1977) has proposed similar measurements to be made in a region on the other hemisphere where there is no danger of contamination. He actually proposed the Halley Bay region in the eastern Antarctic (75.52°S,26.79°W) which is conjugate in geomagnetic latitude to the Swedish Kiruna (Kiruna 65.3°N, Halley Bay 65.8°S geomagnetic). If the occurrence of the particles involved were also to be proved in this region, this would give support to the solar hypothesis, however, only to the extent that the particles enter the atmosphere from outer space and that they are concentrated by magnetic forces at high geographic latitudes.

6. DISCUSSION AND CONCLUSIONS

The contents of the preceding sections clearly indicate that there are still serious doubts as to the reliability and even realness of the frequent evidence of βmicrometeoroids in measurements in situ as indicated by some experiments. Naturally, the interpretations of these experiments in an effort to explain the origin of the detected particles are even less clear. One cannot accept the procedures which introduce further, sometimes even very improbable assumptions to explain some of the discrepancies in measuring the flux of βmeteoroids. As an example, one might mention the attempt at explaining why the decrease in the concentration of dust particles with increasing heliocentric distance does not continue in regions 2 to 5 AU distant from the Sun (as indicated by the observations of Pioneer 10) by introducing the hypothesis that many meteoroids at distances of over 3 AU from the Sun are composed nearly exclusively of ice, and also the assumption that they are subject to the complicated sputtering effect due to the solar wind (Zook, 1979).

It is therefore, highly desirable to make as many micrometeoric in situ measurements of high accuracy as possible which would add to our meager knowledge not only of βmicrometeoroids, but also of the other components of the finer constituents of interplanetary matter. Indeed, without accurate measurements of velocity and direction of small meteoroids and without increasing the sensitivity of detectors even substantially below the picogramme region, one would hardly be able to solve reliably the most pressing problems of micrometeoric astronomy. Apart from the problem of the β particles we have discussed, we are actually referring, e.g. to problems of the relationship between comets and micrometeoroids, the existence of micrometeoroid showers, or to problems of the definitive stabilization of the concept of two independent dust populations proposed by Le Sergeant and Lamy (1978, 1980), as well as to problems associated with the dynamically peculiar class of so-called α-meteoroids which should represent a kind of transition between larger meteoroids spiralling to the Sun as a result of the Poynting-Robertson effect and the small βmeteoroids escaping from the Sun (Grün and Zook, 1979).

A quite curious situation now reigns in analysing the hypotheses of origin of βmeteoroids, presented so far. In analysing them, as already mentioned, we do not know with sufficient accuracy the intensity of the flux of βmeteoroids which the mechanism of the presented hypothesis is expected to explain, because of the doubts about the experimental data. However, this is a situation similar to that in solving the general problem of stability of the dust complex of interplanetary matter as a whole. Also in this case the problem of stability and origin of particles of the Zodiacal cloud is immediately complicated by uncertain estimates of its total mass and then by the budget of supplementary sources and mechanisms which empty the cloud. It seems that we should look for the origin of βmicrometeoroids in searching for the sources of interplanetary dust in connection with its more complicated dynamic evolution. This is the trend some authors are now adopting in a number of their papers. One is in fact quite justified in assuming that the primary source of micrometeoroids (the source of the original larger meteoroid) may be represented by a number of objects of the Solar System. In principle, all its objects qualify; because all of them are capable of producing dust particles. Wether this parent body is also the primary source of βmeteoroids can only be decided by the characteristics of the released particles involved: first of all dimensions, direction and heliocentric velocity. A more detailed analysis will then eliminate some parental bodies as direct sources of βmeteoroids, because these bodies in the intensity and mechanisms of release of dust particles, in distribution by dimension and mass of the produced material, as well as in the capability to inject the individual particles into various heliocentric orbits. In this connection, in searching for posiible sources of micrometeoroids, in particular βmicrometeoroids, attention is being turned to comets. This is so apparently because the injection of dust from the cometary nucleus (by transferring the momentum of escaping gases from the core) into interplanetary space is in fact the only observed and verified mechanisms of microparticle release. Although there is still considerable uncertainty in estimating the overall amount and rate of production of cometary dust and in the distribution of the released material by size and velocity, nevertheless recent estimate prove that short-period comets are capable of producing hardly 2 to 3% of the dust material required (Delsemme, 1976; Röser, 1976). This problem was also treated in more detail by Kresák (1979a,b) who proved that the present population of active comets made a small contribution to the present population of meteoroids (less than 1%), the main source being the short-period comet Encke (it contributes 5 times as much as all the other active comets together). The author points out the negligible contribution of dust material from the dissipation of the annual large meteoric showers without known parental bodies and also proves that even the asteroidal origin of the dust material causes serious difficulties (collisions between Apollo-type objects might be considered). It was found that not only in searching for primary sources of βmeteoroids, but also for sources of interplanetary dust in general, several exceptional objects, or mechanisms and effects would most probably be involved. Similarly,it seems most probable that the dust complex as a whole is not in permanent material equilibrium, but that this population is variable in amount and shape over a time period of about 10^4 to 10^6 years (Delsemme, 1976; Kresák, 1979a). However, considerable uncertainty still reigns in the problems of stability of the Zodiacal dust cloud, or of its supplementation mainly by cometary dust. Moreover the whole problem is very complicated (see, e.g. Mukai et al., 1974; Mukai, 1979; Mukai et al., 1982; Leinert et al., 1983; Mukai, 1983; etc.). This frequently leads to controversial conclusion by various authors and, naturally, it may also have an impact on the discussed problems of βmeteoroid sources. If one also realizes that special conditions are imposed (to explain the direction and hyperbolic velocities) upon the primary source of βmicrometeoroids, or freshly produced dust material, the situation is even more serious with a view to the percentages given. Therefore, in spite of the fact referred to as curious in the introduction to the discussion, one is justified in assuming that all the hypotheses of origin of β particles presented so far are incapable of explaining their occurence, as they are attemping to do just within the scope of a single hypothesis, isolated from the other possible alternatives.

The fact mentioned above, have led the author of this paper to the idea of an alternative possibility of the origin of the βmeteoroid phenomenon. Briefly, the idea is that the βmicrometeoroids represent just a certain evolutionary phase ordinary larger meteoroids, to which they were introduced by the co-action of various non-gravitational effects and mechanisms whose character is mostly dissipative. In the first instance, this involves destructive effects, including impact erosion, corpuscular sputtering, processes of melting, ablation and evaporation, as well as processes of incomplete collisional destruction. Further, there is the group of disruptive effects. These also include effects such as the windmill effect, the Radzievski effect, electrostatic explosion, catastrophic collisions, corpuscular breakup due to the solar wind, sublimational and chemical disintegration. One should also consider the group of non-gravitational effects of a disturbing nature which are mainly responsible for changes in the dynamic parameters of larger meteoroids; however, this may lead to the creation of conditions suitable for more intensive action of some of the effects of the preceding two groups on the constant diminishing of dimensions or mass of the original meteoroid. This group of non-gravitational effects includes the direct light pressure, the solar wind corpuscular pressure, the Poynting-Robertson effect, the pseudo-Poynting-Robertson effect, the Jarkovsky-Radzievski effect, the cosmic ray effect, collisional drag, the Coulomb force effect and the Lorentz force effect.

This review of non-gravitational effects, but mainly their more detailed description and analysis (Kapišinský, 1984a) clearly indicate that a sufficient number of effects and mechanisms are available to explain the origin of βmicrometeoroids; assuming that these effects sometimes act simultaneously, one can see that they are capable to bring ordinary meteoric particles, by natural evolution, into a state in which their physical and dynamical properties agree with those of βmicrometeoroids. This again shows that the search for the primary sources of βmeteoroids is in searching for the primary sources of interplanetary dust in general. For a better understanding of this idea of co-action of a number of effects, it is convenient to consider the hypothesis of co-action of effects (Kapišinský, 1980). According to this principle, not only the effects of various types of collisions, evaporation and melting were taken into account in dealing with the problem of the origin of βmeteoroids, but also many other effects, e.g. corpuscular sputtering, impact erosion, the windmill effect, various disintegration mechanisms, etc. The hypothesis of co-action of various non-gravitational effects of a dissipative nature, conceived in this broad manner, certainly has a better chance of explaining the characteristics of βmeteoroids (especially their amount) than existing hypotheses, and at least explain their hitherto obscure origin dynamically. This is proved quite evidently by the analysis of the effect of impact erosion itself on the dynamic evolution of the meteoroid (Kapišinský, 1984b). The analysis has shown that this single effect alone is capable, physically (mass, dimensions) and dynamically (direction, velocity) of bringing the original larger meteoroid in a relatively short time into the evolutionary phase in which it may appear temporarily as a typical βmicrometeoroid. This applies even more if one considers the action of a number of these effects simultaneously in the sense of the co-action hypothesis.

To show how these effects will bring about, e.g. the situation in which parameter $\beta > 1$ for a particular meteoroid, is outside the scope of this paper and discussion. Therefore, let us just point out that a particle may indeed start its hyperbolic escape away from the Sun if it represents a βmeteoroid quite well. However, dissipative processes come to bear constantly, the dimensions continue to diminish and their dynamics becomes quite complicated just as a result of the optical properties of submicron particles (see, e.g. Dohnanyi, 1972; Kresák, 1976; Burns et al., 1979; Mignard, 1982; Mukai and Yamamoto, 1982; Voshchinnikov and Ilin, 1983). The open trajectory of the particle may close again and parameter β may again drop below unity. Moreover, a more comprehensive investigation of this problem leads to the conclusion that even if the particle starts its hyperbolic escape, this need not always involve total escape (escape from the Solar System) and that this start may even take place before the limiting value of $\beta = 1$ is reached. It was even found that the complicated motion of a constantly diminishing meteoroid can be divided into several phase of which sometimes even two are characteristic spiralling outwards and not spiralling towards the Sun according the general trend under the Poynting-Robertson effect (Kapišinský, 1980, 1983). If the detector records the particle in these evolutionary stages, it really does record a particle with characteristics of a βmeteoroid. The same may apply to detecting particle in a certain stage of "hovering" (Kresák, 1976).

The contents of the preceding sections and of the discussion may be summarized in the following conclusions:

a) the experimental data on βmeteoroids (or better βmicrometeoroids) are not sufficiently convincing qualitatively or quantiatively. Drawing just on these data, one is only able to draw very uncertain conclusions about their existence in the sense of a longer lasting, dynamically stable dust component in the complex of interplanetary matter. Practically nothing, or very little, can be deduced from this experimental base about the permanent, primary source of these microparticles.

b) the hypotheses of origin of βmicrometeoroids, so far presented, do not explain, on their own, their origin satisfactorily and, when considered on their own, not one of the groups of hypotheses can be accepted with satisfaction.

c) the serious arguments against Hemenway´s hypothesis of the origin of βmicrometeoroids make this alternative of their origin highly improbable. Even if one were to admit the space origin of the particles detected over Kiruna, their primary source would have to be sought elsewhere and in other mechanisms than direct generation on the Sun.

d) the category of βmicrometeoroids is probably represented by ordinary submicron particles in a particular stage of their dynamic evolution. This evolutionary stage, from the point of view of the overall lifetime and manner of extinction of the particle (complete destruction, total escape, complete spiralling into the Sun) need not play an important role in the general history of an actual particle, being a transitional phenomenon. Therefore, also the task of finding the primary sources of βmeteoroids remains a problem of finding the sources of ordinary dust particles.

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