ONE SOME PROBLEMS OF MICROMETEORITE DETECTION

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Abstract. The reliability of micrometeoroid fluxes determined by in situ measurements is statistically examined. Using all available data collected since 1958 by artificial satellites and space probes, mean fluxes of microparticles are determined for the circumterrestrial space, the cislunar and circumlunar space, and the interplanetary space. The resulting differences among these three regions are too small to substantiate the assumption of a denser circumterrestrial dust cloud, or enhancement near the Moon, against the general interplanetary medium at $r = 1$ AU. The dispersion of individual values, the effects of different sensitivity threshold, and the inherent random fluctuations, measuring errors and calibration uncertainties appear to mask any real differences entirely.

1. Introduction

After two decades of in situ measurements of micrometeoroids many of the results are still controversial. The discrepancies are due to a broad variety of the methods applied, as well as to different, and sometimes rather uncritical, approaches to the processing and interpretation of the data. Noise and calibration are still major problems. A significant contribution to understanding this situation was the review paper by McDonnell (1970), treating the subject of micrometeoroid detection in full, and the papers by Nazarova (1965), Wlochowicz (1966), Nazarova and Rybakov (1970), Mazets (1970) and others elucidating individual aspects involved.

The aim of the present paper is to check statistically the reliability of individual experiments using all data now available. The analysis is restricted to the fundamental characteristics of the measurements — the values of the mean flux and detection threshold. Essentially all results published since 1958 are included, and the analysis is made separately for three regions: circumterrestrial, lunar, and interplanetary space. As far as possible, the estimated degree of reliability of each experiment is also taken into account.

2. The Experimental Data

As a basis of our analysis we use all experiments on artificial satellites, lunar and deep-space probes which carried special detectors for measuring the impacts of dust particles in different regions of the solar system, beginning with the first measurement on Explorer 1 in 1958. The experiments on sounding rockets and stratospheric baloons have not been included. Their results are much less homogeneous, a broader range of particle sizes and much shorter exposure periods of the detectors are involved, and a number of additional factors (terrestrial contamination, exhaust contamination by the carrier of the experiment, deceleration and fragmentation of the particles in the upper atmosphere) make the interpretation of the data difficult. It was also decided to leave out all the evidence on micrometeorite flux that had not been obtained with equipment specially designed for this purpose — such as the analysis of the impact cratering on the windows of the Gemini and Apollo spacecraft — even when sophisticated calibration was performed.

The last four or five years are rather poorly represented in our statistics, because there was some decline in the number of missions equipped with micrometeorite detectors after the culmination in 1964—1965, and because it did not appear reasonable to include partial and preliminary results available from the latest missions.

The results of all experiments were converted into the same units. The mean flux was expressed in the number of particles per square meter and second, from a space angle of 2π steradiants. The threshold sensitivities were expressed in the limiting particle mass in grams using, in particular, the conversion rates published by Jennison (1965). This threshold refers to an impact velocity of 20 km s^{-1}, assuming energy-sensitive response, $I = mv^2$ (McDonnell, 1970).

The number of separate experiments considered was 82, and the number of missions during which these took place was 48. Here a "separate" experiment denotes not only the use of another, functionally different detector onboard of the same spacecraft but also the use of the same detector with a significant modification (e.g. measurements after applying a control system, or after a major change in the threshold sensitivity).

3. The Region of Measurement

Each of the 82 experiments mentioned was classified according to the region where the detection took place, and according to the reliability of the results.

Since micrometeoroid detection was not always a permanent task for all the duration of a mission, the region of measurement does not necessarily coincide with its target. Furthermore, the orbital eccentricity of some satellites, and the relative paucity of the data, makes it unreasonable to attempt a detailed division according to the geocentric distance. Hence only three characteristic groups were formed.

1. Measurement in the circumterrestrial space (T), with the range of heights between about 200 and 2500 km. This group includes 55 experiments onboard of 29 satellites. In a few cases (e.g. Explorer 6 and Electron 2) the actual height was outside the range indicated during some periods of the experiment. Since this group represents detection within the closest earth environment, at geocentric distances of 1.03 to 1.4 earth radii, the effects of gravitational focussing, shielding and particle fragmentation are presented. A significant enhancement of impact rates was indicated by the earliest measurements in this zone.

2. Measurements in cislunar and circumlunar space (L) are characterized by geocentric distances of the order of 10^5 km, or tens of earth radii. This group comprises 19 experiments on board of 12 long-period satellites, lunar probes, and lunar orbiters: Pioneer 1, Luna 1, Luna 2, Luna 3, OGO 1, Luna 10, OGO 3, Lunar Orbiter 1, Lunar Explorer 35, Zond 5, Zond 6, and Luna 19. The inclusion of Pioneer 1, OGO 1 and OGO 3 is a little problematical in view of their low perigee. It was taken for decisive that the law of areas makes them spend most of the time at larger geocentric distances characteristic for group L.

3. The deep-space measurements (D) refer to detection of micrometeorites in interplanetary space, far from the Earth—Moon system but generally at about the earth's distance from the Sun. This group includes 8 experiments carried out during 7 missions: Mariner 2, Mars 1, Mariner 4, Zond 3, Venera 2, Pioneer 8, and Pioneer 9.

4. The Reliability of the Data

Any classification of the data according to their quality may be admittedly only tentative. A thorough inspection of the existing accounts of individual missions (propulsion, orbit, stabilization, telemetry), measuring techniques involved (type, control and protection of the sensor, possibility of false responses, outer sources of interference, intermittance in registration or transmission) and other relevant factors allowed to adopt a rough scheme of four quality classes.

The best experiments, perfectly prepared, controlled and functioneering were included into class I (= most reliable). Class II (= reliable) is essentially the same as class I except for transient interference impairing a perfect quality of the results. Class III (= less reliable) includes either measurements lacking on control systems or measurements during which serious disturbances occurred (e.g., frequent failure in telemetry or stabilization, flaws in the electronics of the detectors), or any effects substantiating serious doubts about the reality of some responses. Class IV (= unreliable) includes experiments with major disturbances which reduced the degree of confidence quite substantially (e.g., a full breakdown of registration or transmission, obvious registration of false responses); the results from such experiments were not taken into account for calculating the mean values of the flux.

A summary of the classification of individual experiments is given in Table 1. The numbers in brackets indicate the number of missions involved. It may be noted that the classification of experiments needs not coincide with that of the respective mission. For instance, the mission of Explorer 16

Table 1

Class Group	I	II	III	IV	Total
T	25(8)	14(10)	9(7)	7(4)	55(29)
L	17(10)	2(2)	—	—	19(12)
D	8(7)	—	—	—	8(7)
Total					82(48)

was classified as most reliable (I) due to 7 successful experiments, in spite of the classification of the eighth experiment with CdS detectors as unreliable (IV).

5. The Results and Their Discussion

Cummulative fluxes corresponding to the particle masses for each of the 82 micrometeoroid experiments are shown in Fig. 1 in logarithmic scale. In accordance with the chosen classification introduced above, the following designation was used in Fig. 1 for different groups of experiments: group T — full circles, group L — full squares, group D — full triangles. The four classes of reliability are distinguished by different sizes of the corresponding group marks, the largest ones being used for the most reliable experiments (class I), etc.

For each sample of experiments the mean value of the flux with its corresponding mass value was calculated. The results are given in Table 2, and shown in Fig. 1 by blank marks, corresponding to the particular group (T — circles, L — squares, D — triangles). Since any statistical weighting of the experiments is artificial, the mean values were calculated for samples of experiments including different classes of reliability, as is shown in Table 2. For group T the mean values are given for three samples: whole set of data considered (classes I + II + III), sample of the most reliable and reliable experiments (classes I + II), and sample including the most reliable experiments only (class I). For group L two samples were used: of the classes I + II, and of the most reliable class I. Group D consisted of the most reliable experiments only (class I). We can see that the less reliable experiments are those of higher fluxes of particles with smaller corresponding masses. For further discussions we will use only the data of the classes I + II for group T, and of the class I both for the group L and D.

To find out the nature of the flux-mass distribution, the following procedure was used: With respect to uncertainties in estimation of sensitivity threshold the mean flux values were calculated for three chosen regions of the threshold sensitivity m_0:

a) $m_0 < 10^{-10}$ g,

b) $10^{-10}\,\mathrm{g} \leqslant m_0 < 10^{-7}$ g,

c) $m_0 \geqslant 10^{-7}$ g,

which was done separately for each group, i.e. T, L and D. The results for each group and region are shown in Table 3 and Fig. 1. Practically the same results were derived by the least squares method. For comparison there are shown in Fig. 1 flux-mass distribution derived from some of the most successful missions as e.g. Explorer 8 (group T, class I, acoustic detection),

Explorer 16 (group T, class I, penetration measurements),

Pegasus 1, 2 and 3 (group I, class I, capacitor sensors) and

Luna 1 (group L, class I, acoustic detection).

The calculated mean values for different groups of experiments and their classes of reliability together with extremely broad dispersion of the results for individual experiments in the flux-mass diagram allow to make following conclusions:

a) The great dispersion of data of the experiments (in some cases as much as five orders at the same level of the sensitivity threshold) is most remarkable in T group which includes much more experiments of the lower reliability classes (see Tab. 1) in comparison with groups L or D. It seems likely that the great dispersion and uncertainties in determining the flux-mass distribution are caused mainly by the experiments of the low reliability, but on the other hand there are significant differences (about three orders) also among the data for high reliable samples of experiments in group T as well as in groups L and D.

b) Generally speaking the experiments with lower class of reliability tend to have a higher flux for the corresponding level of sensitivity threshold which is evident especially at group T, but can also be found at group L.

c) The mean cumulative fluxes calculated for the whole groups T, L and D (represented by values marked in Fig. 1 as ○, □ and △) indicate that the resulting differences among the fluxes of the three groups are too small with respect to changes of their respective mean sensitivity threshold and allow no definitive conclusions about such astronomical questions as for instance the assumption of a more dense circumterrestrial dust cloud, or a stronger enhancement of dust concentration in the cislunar and selenocentric space, as compared with the micrometeoric background represented by the flux in interplanetary space.

d) The different slopes of the flux-mass distribution for groups T, L and D indicate that in the vicinity of the Earth the population index is higher than the one in selenocentric and interplanetary

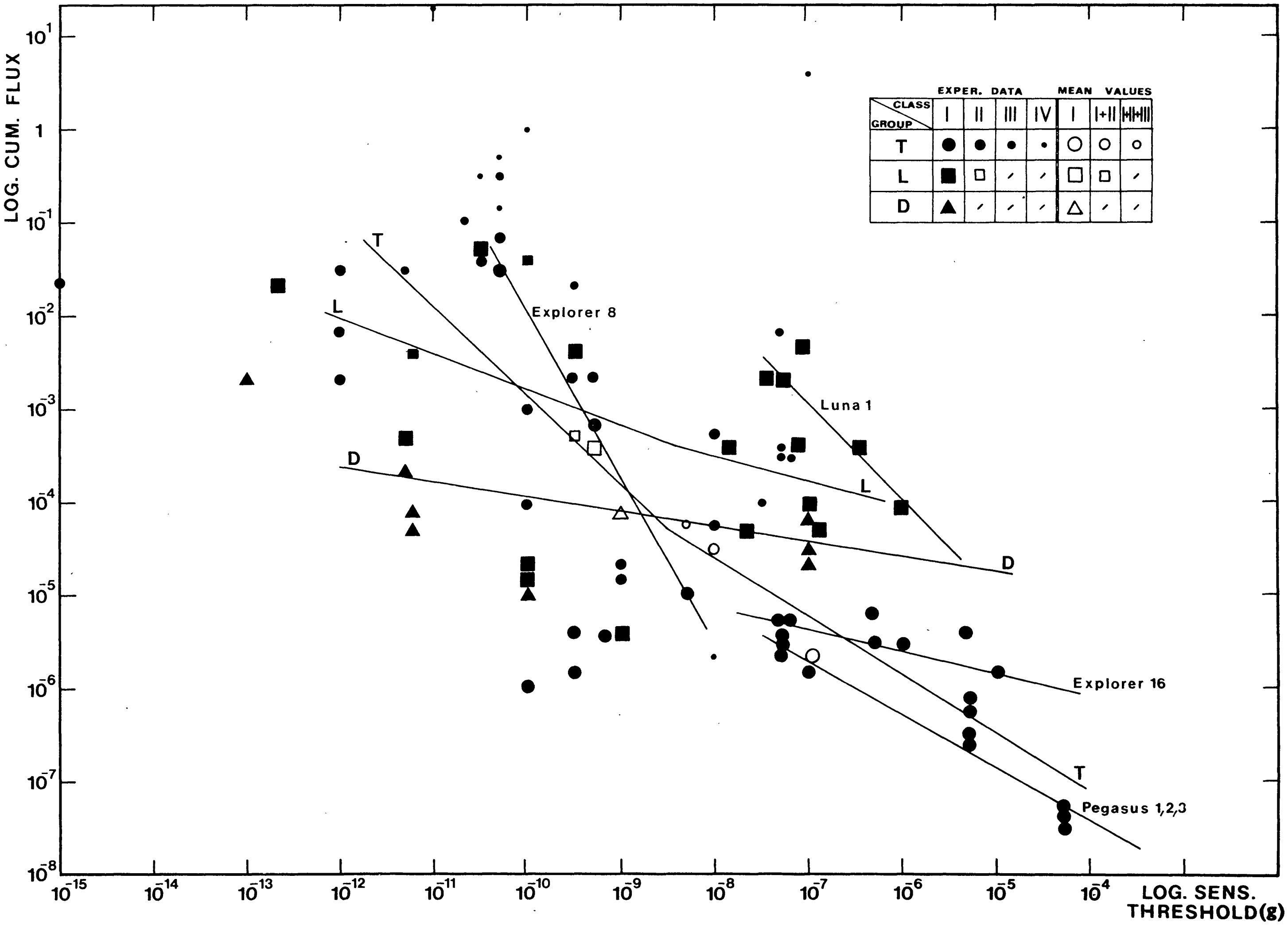

Fig. 1. The mass distribution (in logarithmic scale) for microparticles in the near-Earth, lunar and interplanetary space.

Table 2

Group	Class	Number of experiments	Number of missions	Mean threshold sensitivity [g]	Mean particle flux $[m^{-2} s^{-1} 2\pi \, ster^{-1}]$
T	I+II+III+IV	55	29	5×10^{-9}	6×10^{-5}
T	I+II	39	18	10^{-8}	3×10^{-5}
T	I	25	8	10^{-7}	2×10^{-6}
L	I+II	19	12	3×10^{-10}	5×10^{-4}
L	I	17	10	5×10^{-10}	4×10^{-4}
D	I	8	7	10^{-9}	9×10^{-5}

Table 3

Region	a)		b)		c)	
Group	m_0	Flux	m_0	Flux	m_0	Flux
T	4×10^{-12}	3×10^{-2}	3×10^{-9}	5×10^{-5}	4×10^{-6}	6×10^{-7}
L	4×10^{-12}	6×10^{-3}	4×10^{-9}	4×10^{-4}	2×10^{-7}	$1{,}5 \times 10^{-4}$
D	2×10^{-12}	2×10^{-10}	10^{-7}	4×10^{-5}	10^{-7}	4×10^{-5}

space. This fact can support the assumption about a higher concentration of dust particles around the Earth, but mainly in range of the picogram masses.

There are two possible interpretations, conclusion a) about the great dispersion of the fluxes 1. it is caused by real variation in flux rate which may be brought about by grouping effect of micrometeorids or by micrometeoroid streams, 2. it is caused by total effect of great uncertainties of the devaluable factors in determining both the flux rate and the marginal mass sensitivity.

Since it is very probable that, generally speaking, both interpretations mentioned above are presented in any available measurements, it is highly desirable to minimize the effects of the devaluable factors as much as possible, to be able to come to definite conclusions about the astronomical interpretation of the measured data. Without fulfilling this demand the recording of particle impacts on surfaces of upper-air rockets and of artificial satellites and spacecraft will remain probably one of the most contraversial areas in the study of interplanetary matter for a long time.

Conclusions c) and d) can be confronted with some new measurements, the ones which have not been taken into account in our statistics (except of the Prospero satellite experiment) because of their preliminary and incomplete character. The results from the S-149 experiment on SKYLAB reported by Nagel et al. (1974) and from the experiment on Prospero satellite (Bedford, 1975) indicate in accordance only a small enhancement of the flux from the direction of the Earth's apex and the latter appeared to be a grouping effect of micrometeoroid, too. Hoffmann et al. (1975) reported enhancement of the flux to about two orders from the direction of the apex as compared with the other directions, based on the results of micrometeoroid experiments S-215 on HEOS 2. Grouping effect was also indicated by Prospero experiment. Even results from satellites KOSMOS 470, 502 and 541 indicate higher concentration of dust particles in the near-Earth environment. Some of the preliminary reports (e.g. Humes et al., 1974) of Pioneer 10 mission confirmed local enhancement of the flux rate but other authors (see e.g. Auer et al., 1974) have expressed doubts about the particle concentration measured on Pioneer 10 in asteroidal belt. It seems that the value of concentration should be shifted about two orders lower. Neither preliminary results from Pioneer 11 show any enhancement in asteroidal belt, but on the other hand measurements hitherto show at least increase of the flux rate in distance 1.0—1.15 AU from the Sun and near the Jupiter (Humes et al., 1975).

Apart from the discrepancies in measurements made up to now it is very difficult to solve even the basic issues in micrometeoroid problems because of the fact that up to the present there is no guaranteed model of the mass distribution for dust particles. To avoid misinterpretation in mutual comparison of different experiments it is necessary to take into account the reliability of detection, measuring errors, calibration uncertainties, etc. and to include into further analysis only the most reliable data with respect to the mass sensitivity and the region of measurement. As far as the slope of the log. cumulative flux vs. log. mass threshold concerns, one of the most suitable ways requires an unambiguous counting of impacts down to at least two different mass thresholds for the same highly reliable experiment, as was used e.g. at calculating the mass index *S* for meteoric complex by Millman (1973).

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O NIEKTORÝCH PROBLÉMOCH DETEKCIE MIKROMETEORITOV

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Súhrn

V práci sa vyšetruje spoľahlivosť detekcie mikrometeoritov na umelých kozmických telesách in situ v rozličných oblastiach kozmického priestoru. Všetky dostupné experimenty so špeciálnou detekčnou aparatúrou (82) uskutočnené od r. 1958 (s výnimkou experimentov na výškových raketách) boli rozdelené do troch skupín jednak podľa oblasti, kde sa merania skutočne robili, jednak v rámci týchto skupín do štyroch tried spoľahlivosti podľa individuálneho zhodnotenia každého experimentu. Z takto roztriedeného materiálu sa počítali stredné hodnoty fluxu mikročastíc v okolí Zeme (skupina T), Mesiaca (skupina L) a v medziplanetárnom priestore (skupina D) vzhľadom na príslušné zmeny priemerných citlivostí detekcie. Ďalej sa zisťovali priemerné toky pre rozličné súbory experimentov v rámci každej skupiny podľa ich tried spoľahlivosti. Uvedená schéma delenia experimentov podľa oblasti merania a spoľahlivosti umožnila zistiť, že najväčšia disperzia hodnôt fluxu sa prejavuje v skupine T, kde je aj najviac experimentov so zníženou spoľahlivosťou. Ukazuje sa, že rozdiely medzi strednými fluxami mikrometeoroidov v troch skúmaných oblastiach sú príliš malé na to, aby sa dala na ich základe urobiť definitívna interpretácia takých astronomických otázok, ako je napr. predpoklad o hustom prachovom oblaku okolo Zeme alebo o silnom zvýšení koncentrácie prachových častíc v okolí Mesiaca, v porovnaní s koncentráciou mikročastíc v medziplanetárnom priestore. Analýza indexu populácie funkcie hmotnosti mikročastíc pre jednotlivé oblasti ukazuje, že do úvahy prichádza iba mierne zvýšenie koncentrácie pikogramových prachových častíc v okolí Zeme a Mesiaca, oproti jej úrovni v medziplanetárnom priestore. Ukazuje sa, že priama detekcia mikrometeoroidov je zatiaľ najproblematickejšou oblasťou štúdia medziplanetárnej hmoty vôbec. Problémy súvisiace priamo s kozmickým letom (stabilizácia a orientácia detekčného systému, kontaminačné problémy, telemetria údajov a pod.), ako aj s detekčnou technikou (kalibrácia, kontrola a ochrana detektorov, chyby v určení fluxu samého a hraničnej citlivosti, možnosti rušenia a registrácie falošných impaktov a pod.), znemožňujú spoľahlivo odlíšiť skutočné priestorové a časové fluktuácie vo výskyte mikročastíc. Vzhľadom na to, že dodnes nie je potlačený na minimum vplyv znehodnocujúcich faktorov z technickej stránky, nemožno považovať ani astronomickú interpretáciu výsledkov rozličných meraní za definitívnu. Riešenie treba hľadať okrem iného v používaní iba veľmi spoľahlivých experimentov tých istých detektorov na rozličných úrovniach citlivosti.

ОБ НЕКОТОРЫХ ПРОБЛЕМАХ РЕГИСТРИРОВАНИЯ МИКРОМЕТЕОРИТОВ

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Резюме

В работе анализируется надежность ин-ситу регистрации микрометеороидов при помощи космических аппаратов в разных областях космического пространства. Все доступные эксперименты со специальной аппаратурой для регистрации которые осуществлялись с 1958 года (кроме экспериментов на далеких ракетах) в общем числе 82, были разбиты как в три группы по действительной области измерения так и в четыре классы надежности в рамках этих групп для индивидуальной оценки каждого эксперимента. Из так рассортированного материала вычислялись средние данные потока пылевых частиц в окрестности Земли (группа T), Луны (группа L), и в межпланетном пространстве (группа D) с отношением на соответствующие изменения средних чувствительностей детекторов. Дальше определялись средние потоки разных выборок экспериментов в рамках каждой группы для их классы надежности.

Приведена схема разбиты для области измерения и надежности позволила определить что самая большая дисперзия данных потока проявляется в группе T где тоже находится и самое большое число экспериментов с пониженой надежностью. Оказывается тоже, что разницы между средними потоками микрометеороидов в трех изучаемых областях очень маленьки, чтобы на их основе позволяло делать окончательных объяснений таких астрономических вопросов как напр. предположение о густом околоземном облаке пыли или о большом повышении концентрации пылевых частиц в окрестности Луны по сровнению с концентрацией в межпланетном пространстве. Анализ показателя популации функции массы пылевых частиц для отдельных областей показывает что в рассуждение приходит только умеренное повышение концентрации пикограммовых частиц в окресности Земли и Луны напротив ей уровня в межпланетном пространстве. Прямая регистрация пылевых частиц является до сих пор самой проблематической областью изучения межпланетной материи вообще.

Проблемы которые касаются прямо космического полета (стабилизация и ориентация аппарата, проблемы контаминации, телеметрия данных и т. п.) как тоже техники регистрации (калибрация, проверка и охрана системы детекторов, ошибки в определении потока и порога чувствительности, возможность возмущения и регистрирования ложных сигналов и т. п.) делают невозможным в надежной мере отличить действительные пространственные и временные флуктуации в наличии пылевых частиц. Ввиду того, что до сих пор не было подавено влияние загрязняющих факторов на минимум из технической точки зрения, невозможно считать астрономическую интерпретацию разных измерений окончательной. Решение надо искать в пользовании самыми надежными экспериментами и так-же детекторами работающими на разных уровнях чувствительности.