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# MICROMETEORITES


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Extended Abstract

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Introduction: Interplanetary space is populated with particles in heliocentric orbits. This interplanetary material is of great interest to astrophysicists and astronautical engineers because meteoritic material may contribute to the understanding of the nature and origin of the solar system and may effect the operation of space vehicles. The small cosmic dust particles are often called micrometeorites. Their characteristics are still poorly known, although recent investigations with satellites and rockets have contributed considerable information. Much of what is known about interplanetary material of relatively large masses, greater than $10^{-4}$ grams, has been obtained from radio and optical observations of meteors and the analysis of meteorites. While meteorites probably have originated from the asteroids, there is considerable evidence that meteors of masses less than a few grams and micrometeorites originated primarily from comets.

The zodiacal light, as well as the Franhofer corona, establishes the existence of interplanetary particles and is an important source of information about fine dust. Dust particles upon separation from the nucleus of comets are highly



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concentrated near the orbits of the comets and are the source of the major meteor streams. The zodiacal cloud is the near equilibrium distribution of interplanetary dust maintained, mainly by the disintegration of new comets. The meteoritic dust is dispersed by several effects in addition to the small injection velocityfrom the cometary nucleus, including light pressure, the solar wind, solar-radiation drag (as Poynting-Robertson effect), planetary interactions, and collisions with other particles. Dust particles are removed from interplanetary space by radiation expulsion from the solar system, by solar capture, and by collisions with the planets. Near the earth at 1 a.u. the heliocentric velocities are about 40 km/sec and the range of geocentric velocities is from 11 km/sec to nearly 75 km/sec.

Extensive investigations of optical and radio meteors have yielded data on the distribution of meteor masses, velocities and orbital elements, the seasonal and diurnal variations in the flux of sporadic meteors, and meteor streams. The cumulative mass distribution obtained from measurement of the populations of meteorites and meteors has been extended to small particles in the micrometeorite range from satellite and rocket measurements. The material presently of most interest in space activities, having sufficiently high impact rates and large enough to damage vehicles are in the mass range below $10^{-4}$ grams, the present radar limit. The largest micrometeorites measured from satellites is about $10^{-7}$ grams, leaving a mass range which must be interpolated. The direct measurements of the mass distribution, structure, and other properties of micrometeorites are reviewed below.

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Satellite Measurements: Direct measurements of the flux of micrometeorites have been made with acoustical impact detectors, photomultipliers and rocket collection systems. Large numbers of impacts were recorded from satellites using microphone detectors beginning with the Explorer measurements in 1958. The measurements were characterized by daily fluctuations of impact rate of about an order of magnitude. On several occasions meteor showers could positively be identified as the non-retrograde, sporadic, micrometeorite stream measured from Explorer I (figure 1). More than ten thousand impacts have been recorded from satellites; nearly all of them have been obtained with the microphone detectors. An average cumulative mass distribution curve for the vicinity of the earth has been derived from most of the available direct measurements obtained with microphone and photomultiplier systems (figure 2), Alexander et al 1963). The size of plotted points is proportional to the estimated statistical weight of the measurements used in defining the curve. The microphone data has been obtained for the mass range from $10^{-10}$ to $10^{-7}$ grams. The photomultiplier impact-flash results allow an extension of the distribution curve to approximately $10^{-13}$ g. The extra high influx rates reported from the rocket collection experiment (Hemenway and Soberman, 1962) were obtained in the altitude region from 80 to 150 km and may contain numerous decelerated micrometeorites. The cumulative mass distribution curve appears to change slope rapidly with decreasing particle size in the mass region near the limit where solar radiation pressure becomes the predominant force on the particle. The result from the Explorer XVI measurements are discussed below.

Cislunar - Interplanetary Space: The spatial density of interplanetary dust inferred from zodiacal light measurements at 1 a.u. is about $10^3$ times less than that obtained from the direct measurements from rockets and satellites. In cislunar space, the influx rate measured from Pioneer I at geocentric distances between 6 and 20 earth radii was found to be about $10^2$ times lower than the average mass distribution curve (figure 2). Results from the Soviet lunar probes do not indicate this type of deviation. The Mariner II measurements in interplanetary space, sensitive to particle impacts of mass $2 \times 10^{-10}$ g, indicated an impact rate $10^4$ times lower than the average mass distribution curve and approximately the value derived from zodiacal light measurements.

Rocket Collections: The recent collections of micrometeorites with sounding rockets in the United States and Sweden beginning in 1962 have resulted in new information about the structure, composition, and flux of particles. For very small dust particles, the deceleration heating in the atmosphere is constrained sufficiently by radiative cooling to keep the particles from melting. Particles recovered using clean, controlled collectors are essentially unchanged structurally because the atmospheric deceleration involves sputtering without melting. The types of particles observed include: (1) extremely irregular, open-structured, fluffy particles; (2) medium density, irregular particles; and (3) high density spherules, which may have melted. The majority of the particles showed no detectable crystal patterns. From electron probe and neutron activation analysis aluminum, silicon, titanium, iron, traces of nickel, magnesium, calcium and other elements were found.

Witt, Soberman, and Hemenway (1964) found $10^3$ times more particles in the rocket collections through a noctilucent cloud in Sweden. Evidence of iron particles with high nickel content was found. Although the particles were probably of extraterrestrial origin, a significant fraction of the particles appears to have been coated with terrestrial ice. A sharp cutoff in particle distribution function was found to be at 0.05 microns diameter.

Cumulative Mass Distribution: The cumulative mass distribution for interplanetary dust particles derived from selected data by McCracken and Dubin (1963) (figure 3), has been obtained from the frequency of meteorite falls, from observations of meteors, and from dust measurements with rockets and satellites. The cumulative flux of mass, m, and larger is plotted as a function of mass. The data obtained from direct measurements and the studies of meteorite falls are plotted directly in terms of particle mass. The data from meteor observations are plotted in terms of visual magnitude, $M_v$, which is a logarithmic measure of luminous intensity. For radio meteors the visual magnitude is expressed in terms of electron line density and may be compared to optical meteors in the region of overlap. Major uncertainties in the mass to visual magnitude relation have existed. The zero magnitude meteor is plotted at a mass of one gram.

The influx rate, I, may be expressed for different portions of the mass distribution as follows:

| | | | | |
|---|---|---|---|---|
| Brown (1961) | $\log I(m)$ | = | $-16.16 - 0.8\ m$ | $10^4 g \leq m \leq 10^{11} g$ |
| Hawkins (1959) | $\log I(M_v)$ | = | $-15.14 + 0.4\ M_v$ | $-10 \leq M_v \leq -3$ |
| Watson (1956) | $\log I(M_v)$ | = | $-13.79 + 0.4 M_v$ | $-3 \leq M_v \leq 10$ |
| Millman & Burland (1956) | $\log I(M_v)$ | = | $-13.66 + 0.57\ M_v$ | $-10 < M_v < 0$ |
| | | = | $-13.66 + 0.5 M_v$ | $0 < M_v < 3$ |
| | | = | $-13.66 + 0.4 M_v$ | $3 < M_v < 10$ |
| Hawkins & Upton (1958) | $\log I(M_v)$ | = | $-14.73 + 0.538\ M_v$ | $0 < M_v < 4.1$ |
| Kaiser (1961) | $\log I(M_v)$ | = | $-14.80 + 0.468\ M_r$ | $8 \leq M_r \lesssim 10.8$ |
| Satellites | $\log I(m)$ | = | $-17.30 - 1.70m$ | $10^{-10} g \leq m \leq 10^{-6} g$ |

The flux of rocket collected particles was found to be proportion to $M^{-x}$ where $x < 4/3$. The results from the photometric studies of zodiacal light of Ingham (1961) and Elsasser (1954) have also been plotted in the appropriate size range. The distribution was integrated to give the cumulative size distribution and converted to a particle flux assuming a mass density of 1 g/cm$^3$ and an average speed of 10 km/sec. This cumulative influx rate as a function of mass curve represents as average of expected conditions near earth and in interplanetary space. The mechanism for the difference in flux measured near the earth is presently not adequately explained. The cumulative mass distribution curve probably does not have any large uncertainties. In the meteor range, although excursions during major meteor showers occur, the sporadic flux on the average contains the majority of particles. The relative intensities of nearly all the showers decrease with decreasing particle mass. The undertainty in the mass of dust particles from direct measurements is small, about a factor of 2.

The mass expected to be required for penetrating these surfaces is less than $10^{-9}$ grams for hard spherical particles. This discrepancy may be partly resolved if the impacting particles are mainly of the type collected with sounding rockets; irregular, elongated, low density particles. Recently an experimental extension of the penetration depths to very small particles has indicated that penetration depth does not extrapolate linearly with the cube root of the particle mass. D'Auitolo (private communication) has computed the decrease in penetration depth expected for cosmic dust particle impacts on Explorer XVI and found good agreement with the cumulative mass distribution curve obtained from the microphone experiment.

<u>Concluding Remarks</u>: The available knowledge about micrometeorites indicates a higher fl[redacted]earth than in interplanetary space. The mechanisms ~~for the transition to~~ the high near-earth flux is not adequately understood. Other measurements support this influx rate. The accretion of interplanetary material by the earth is dominated by dust particles with masses less than $10^{-8}$g and amounts to about $10^4$ tons per day. Further investigations of micrometeorite trajectories, composition and structure are desirable.

Impact Physics: The effects from hypervelocity impacts are of interest to the engineer and for the calibration of the direct measurements. Direct calibration in the meteor range of speeds, 20 to 50 km/sec have not been made, because of the difficulty in simulating the high velocities. The hypervelocity iipact craters and spallation effects are proportional to the velocity, mass, and density of the particle and the properties of the target (and particle). At velocities less than 10 km/sec the depth of penetration, p, is proportional to $v^{2/3}$, where v is the velocity; while at higher speed it may depend on $v^{1/3}$. A dependence on density, $\rho$, has been found. A depth of penetration equation of the form

$$p = A_t \, (m\rho)^{1/3} (v\cos\theta)^{1/2}$$

maybe used to estimate relative penetration characteristics. $A_t$ is a constant depending upon the properties of the target and v cos$\theta$ is the normal component of the particle velocity.

EXPLORER XVI : The rate of penetration of surfaces of large area by micrometeorites was measured by Explorer XVI. D'Auitolo (1964) has reported the results of these measurements. The various penetration detectors covered an area of 2.2 square meters and were exposed in orbit for 220 days. Most of the penetrations were obtained in the pressurized beryllium-copper cans with an initial exposed area of 1.02 square meters for cans of 25 micron (1 mil) thickness (figure 4). The penetration rate of the 25 micron cans was $4.4 \times 10^{-6}/M^2$/sec based on 44 penetrations. A comparison penetration rate based upon 6 penetrations of the 25 micron thick stainless steel plates with an initial exposed area of 0.145 square meters was $3 \times 10^{-6}/M^2$/sec. The influx rates correspond to particles of mass $10^{[illegible]}$ grams (see figure 3).

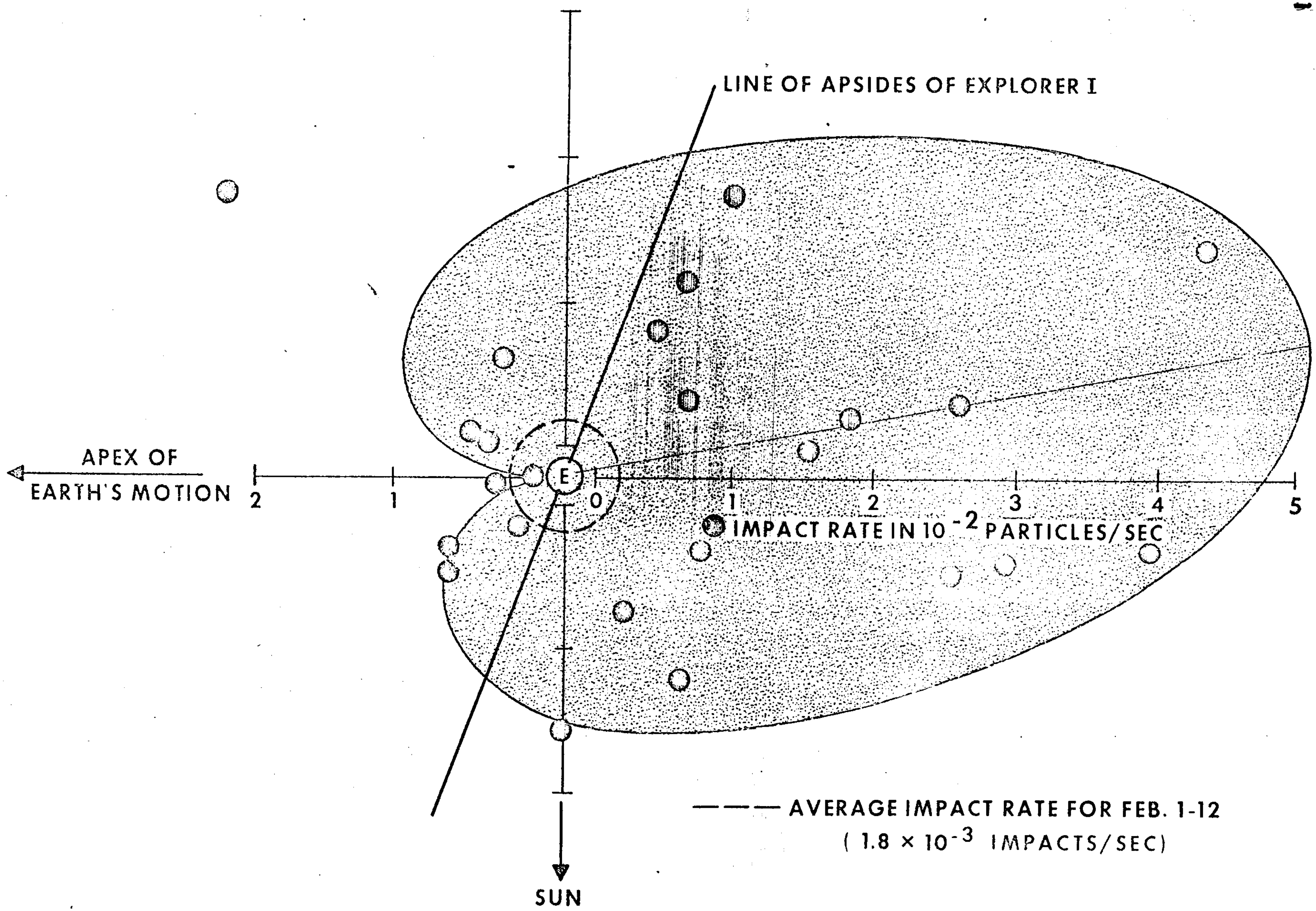
[$10^{-8}$]

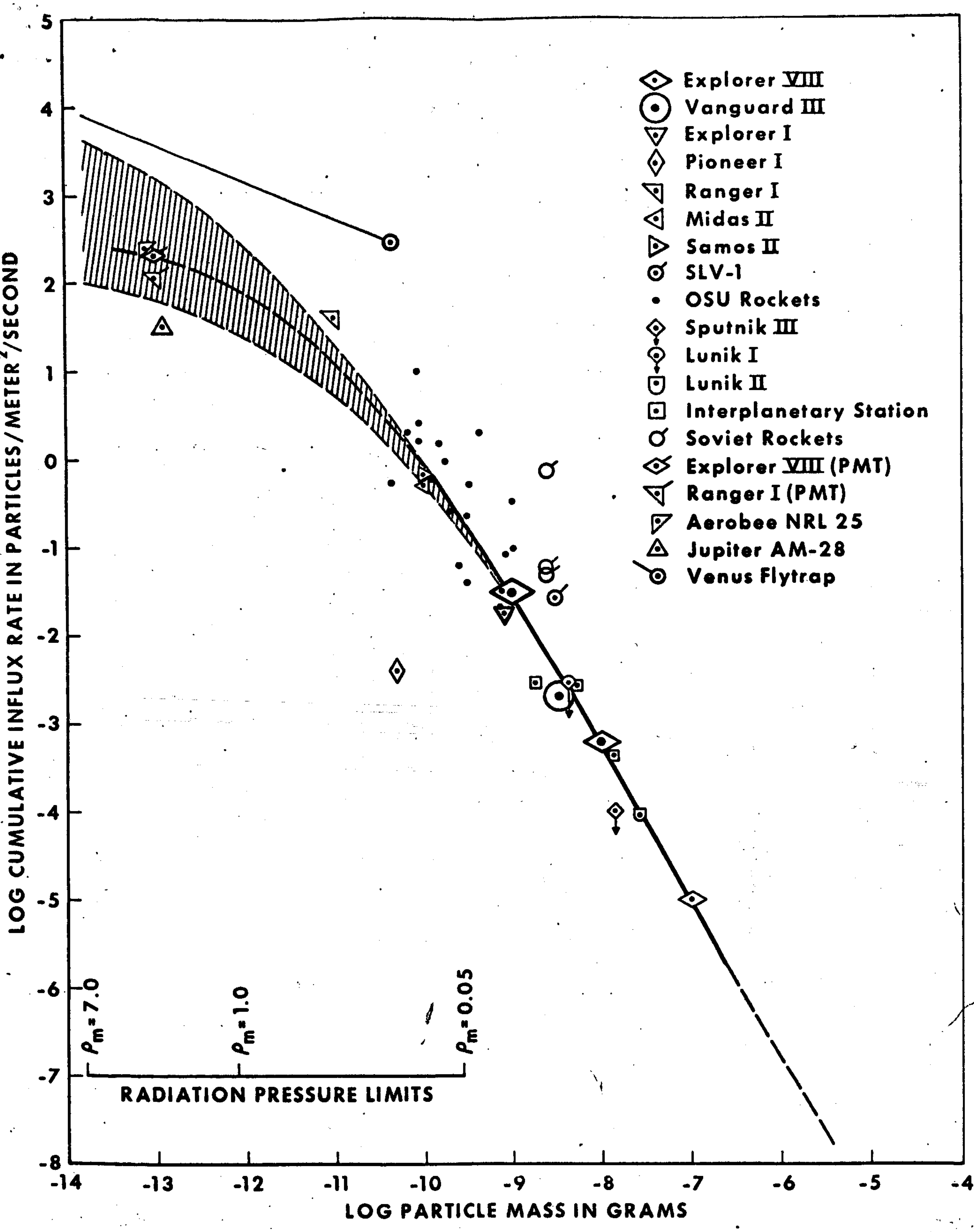
Figure 1. Impact rates during the February 1958 interplanetary dust particle event.

Figure 2. An average cumulative mass distribution curve for the vicinity of the earth derived from available direct measurements obtained with microphone and photomultiplier systems.

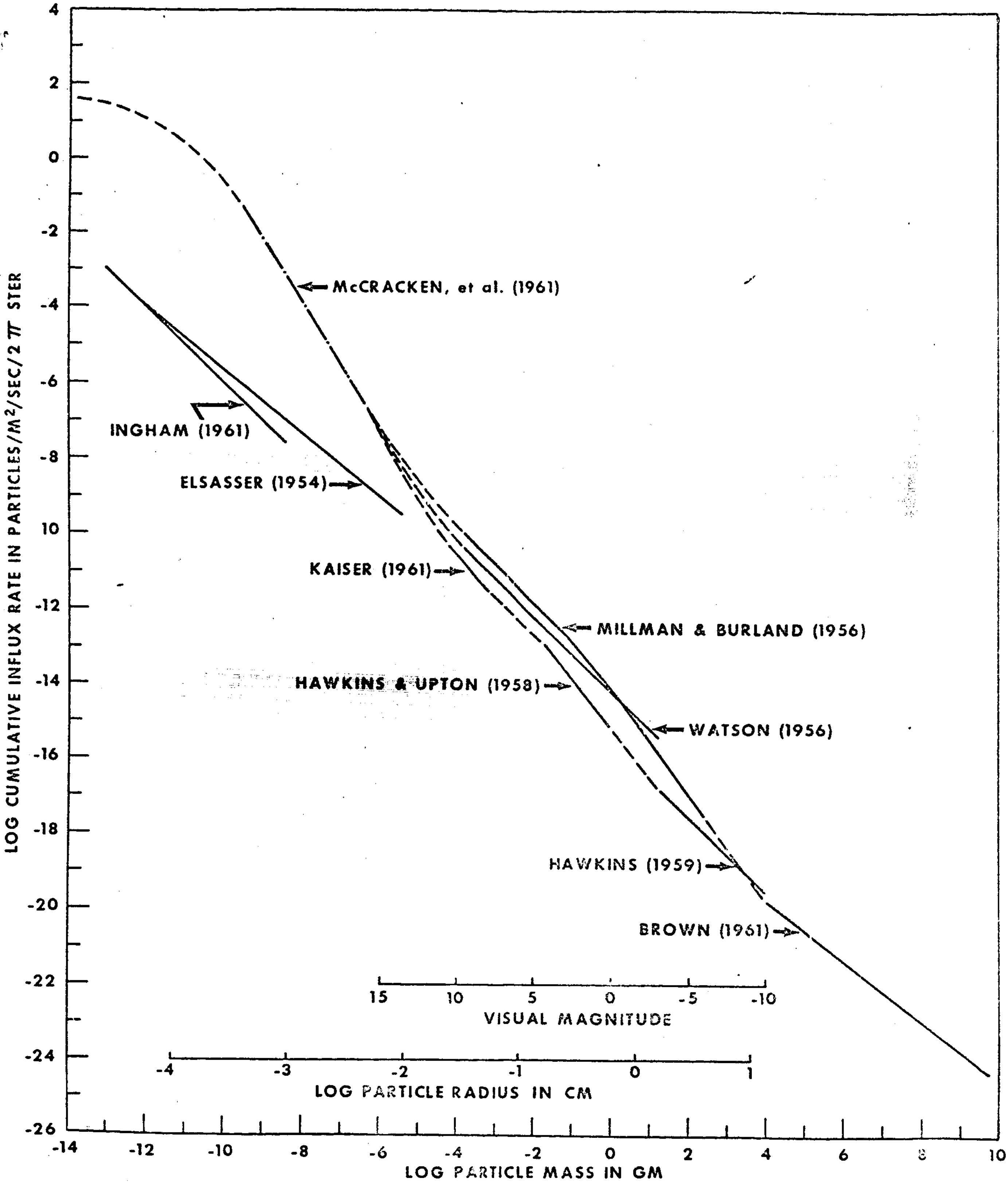
Figure 3. Cumulative mass distribution for interplanetary dust particles, derived from the studies of the frequency of meteorite falls, from observations of meteors, and from direct measurements obtained with rockets and satellites.

Figure 4. Cumulative penetrations recorded on Explorer XVI for the 25 and 51 micron beryllium-copper pressurized cells, the 25 and 76 micron stainless steel plates, and the 51 and 76 diameter copper wire wound cards.


LINE OF APSIDES OF EXPLORER I
APEX OF EARTH'S MOTION
SUN
E
2
1
0
1
2
3
4
5
IMPACT RATE IN 10 -2 PARTICLES/SEC
AVERAGE IMPACT RATE FOR FEB. 1-12
( 1.8 × 10-3 IMPACTS/SEC)

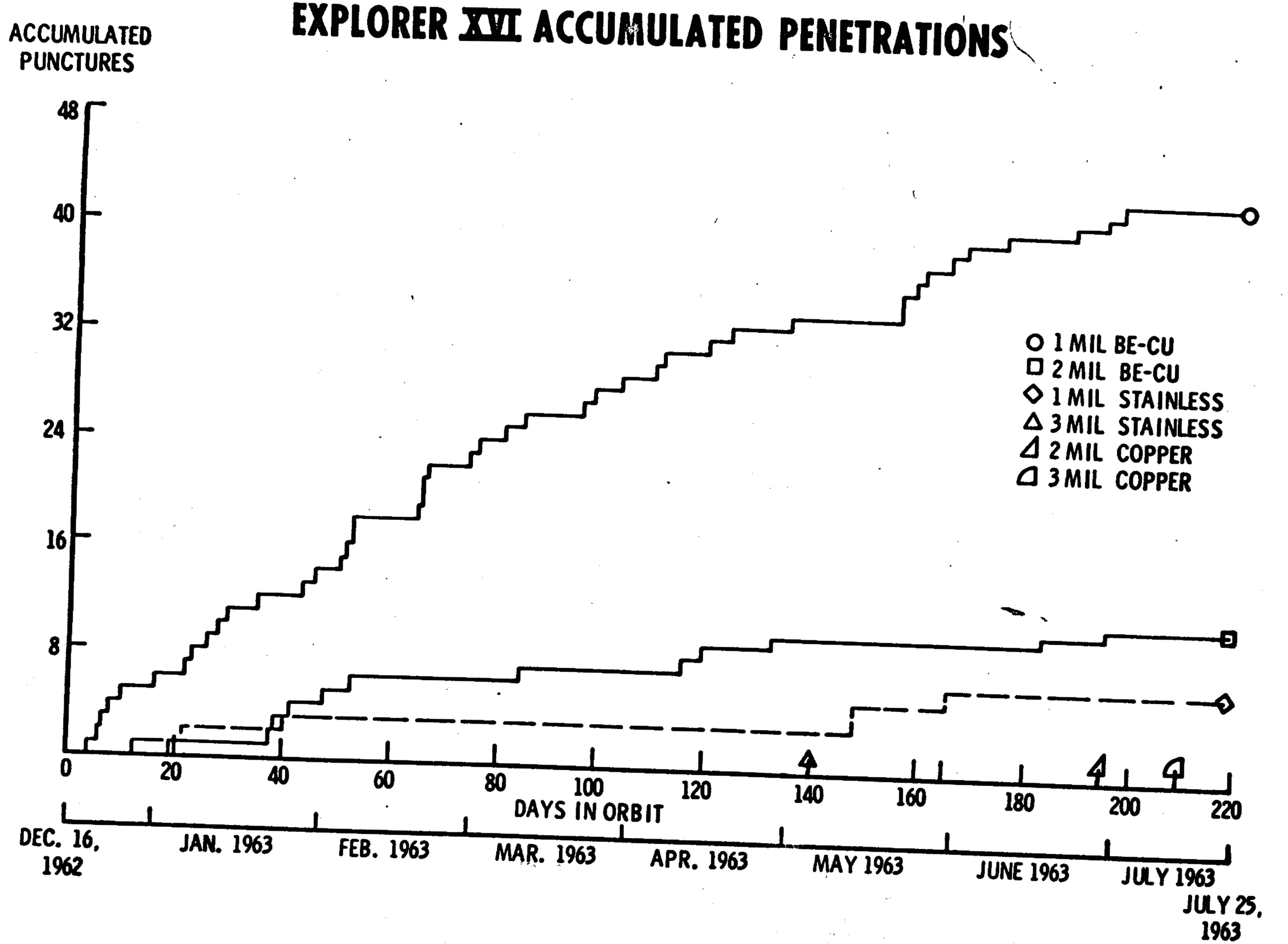


Explorer VIII
Vanguard III
Explorer I
Pioneer I
Ranger I
Midas II
Samos II
SLV-1
OSU Rockets
Sputnik III
Lunik I
Lunik II
Interplanetary Station
Soviet Rockets
Explorer VIII (PMT)
Ranger I (PMT)
Aerobee NRL 25
Jupiter AM-28
Venus Flytrap
$\rho_m = 7.0$
$\rho_m = 1.0$
$\rho_m = 0.05$
RADIATION PRESSURE LIMITS
LOG CUMULATIVE INFLUX RATE IN PARTICLES/METER$^2$/SECOND
LOG PARTICLE MASS IN GRAMS
5
4
3
2
1
0
-1
-2
-3
-4
-5
-6
-7
-8
-14
-13
-12
-11
-10
-9
-8
-7
-6
-5
-4



LOG CUMULATIVE INFLUX RATE IN PARTICLES/M²/SEC/2 π STER
4
2
0
-2
-4
-6
-8
10
-12
-14
-16
-18
-20
-22
-24
-26
McCRACKEN, et al. (1961)
INGHAM (1961)
ELSASSER (1954)
KAISER (1961)
MILLMAN & BURLAND (1956)
HAWKINS & UPTON (1958)
WATSON (1956)
HAWKINS (1959)
BROWN (1961)
15
10
5
0
-5
-10
VISUAL MAGNITUDE
-4
-3
-2
-1
0
1
LOG PARTICLE RADIUS IN CM
-14
-12
-10
-8
-6
-4
-2
0
2
4
6
8
10
LOG PARTICLE MASS IN GM

# EXPLORER XVI ACCUMULATED PENETRATIONS

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