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DIRECT MEASUREMENTS OF COSMIC DUST SHOWERS

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SUMMARY

Over the past several years direct measurements of cosmic dust by means of rockets and satellites have yielded two separate sets of data indicative of interplanetary dust showers consisting of particles whose mass is less than 10^{-8}gm. These cosmic dust showers were observed with micrometeorite detectors consisting of piezoelectric crystals and photomultipliers for detecting the light flashes from particle impacts. The Explorer I interplanetary dust stream was detected for about a 10-hour period beginning on February 2, 1958. The peak impact rate was nearly 50 times the average rate over the remainder of the 12-day period of the experiment. From the limited data it may be shown that this stream was nearly in the ecliptic in a direct heliocentric orbit. This shower does not correspond to a known annually recurring meteor shower.

A second stream of interplanetary dust has been detected with satellites and a sounding rocket. This stream appears to recur annually with a peak intensity on November 17. It was first detected in 1955 from an Aerobee rocket and was recognized in the November 1959 data from the Vanguard III satellite. Preliminary analysis of the Explorer VIII data indicates that it probably was also detected in 1960. The dust stream characteristics correspond to those of the Leonids which have a heliocentric velocity of 72 km/sec. The data supporting the detection of these two interplanetary dust streams are presented and discussed, and the physical significance of these measurements reviewed. Although direct measurements from satellites have been made over a period of about four months and during the time of other known meteor streams, only these two interplanetary dust streams have been detected thus far by direct measurements.

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DIRECT MEASUREMENTS OF COSMIC DUST SHOWERS *

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INTRODUCTION

The cometary origin of meteor streams is well established by the fact that the orbits of several meteor streams have been associated with comets. During the process of comet disintegration, particles are dispersed along the heliocentric orbit, and it appears reasonable to assume that for annually recurring meteor streams the age of the meteor stream is related to the uniformity in the counting rate of shower meteors. The tremendous number of meteors observed in the Draconid display in 1946 is evidence of the recent formation of the stream from the common comet Giacobini-Zinner. Dispersion of dust particles in the meteor stream from interplanetary forces resulting from the Poynting Robertson effect, corpuscular bombardment, and other radiative forces, is expected to be increasingly pronounced with decreasing dimensions of the dust particles. The extension of the range of measurements of meteoritic material to smaller masses by direct measurements with satellites may, therefore, improve our knowledge of the history and age of meteor streams.

The number distribution of meteors has been measured as a function of visual magnitude by visual and optical methods, and as a function of electron line density along the trail by radar. Browne et al. (Reference 1) have determined such distributions for the Perseids, Quadrantids and the Arietids. For the Perseids it was found, for example, that relative to the distribution of sporadic meteors, there was a depletion of the small meteors for visual magnitudes greater than 7. Weiss (Reference 2) has measured distribution functions for the Geminids, the δ Aquarids, and the η Aquarids, as well as the sporadic meteors. Although the distribution function was found to vary for different meteor streams, only the daytime Arietids has an "s" value† equal to 2.7, compared to an s of 2.0 for sporadic meteors, and was the only shower with an s greater than 2.0

*Presented at the Symposium on the Astronomy and Physics of Meteors, Smithsonian Astrophysical Observatory, Cambridge, Massachusetts, August 28 - September 1, 1961.

†An exponent in the distribution function which indicates the rate of increase in number with decreasing mass.

Direct measurements of micrometeorites or interplanetary dust have been made by the United States with a number of satellites, rockets and probes. Significant data samples have been obtained on four satellites: Explorer I (1958α), launched February 1, 1958, perigee 355 km, apogee 2550 km; Vanguard III (1959η), launched September 18, 1959, perigee 509 km, apogee 3751 km; Explorer VI (1960δ), launched August 7, 1959, perigee 186 km, apogee 39,000 km; and Explorer VIII (1960ξ), launched November 3, 1960, perigee 425 km, apogee 2300 km. The results from Explorer I have been reported by Dubin (References 3, 4 and 5) and Hibbs (References 6 and 7). The results from Vanguard III have been reported by LaGow and Alexander (Reference 8), and data from Explorer VIII, with distribution functions and reviews of the data have been reported by McCracken et al. (References 9 and 10).

The direct measurements of cosmic dust refer to particles of masses less than 10^{-8} gm or greater than + 20 on the visual magnitude scale. Daily variations in the flux of cosmic dust particles greater than an order of magnitude are often observed. There is excellent evidence that two cosmic dust showers or streams have been detected by these direct measurements. One of these dust streams, detected by Explorer I, permitted a determination of an approximate radiant; the other, however, has been detected on more than one occasion and apparently is related to an annually recurring meteor stream.

RESULTS OF MEASUREMENTS

Cosmic Dust Shower, February 1958

Evidence of a cosmic dust shower was apparent for a 10-hour period beginning on February 2, 1958 from Explorer I data. The detector was a piezoelectric crystal with an average threshold sensitivity to micrometeoroid impact of 2.5×10^{-3} dyne-sec and could detect particles of masses 8×10^{-10} gm and greater with an average impact velocity of 30 km/sec. The data from Explorer I was in real time, and it was recorded only while the satellite was over a telemetry receiving station. The data in the interval from February 2, 1512 hours to February 3, 1405 hours Greenwich time has been tabulated in Table 1 for each pass over a telemetry station. Impacts were recorded for every pass, except one, during the interval of the cosmic dust shower. Included in Table 1 are the station location, the number of hits during each pass, the time of each pass, and the number of hits per second.

The impact rate from Table 1 has been replotted, in polar coordinates, as a function of time (Figure 1). The inner cross-hatched circle represents the zero level, or zero hits per second and the next ring the average impact rate of the latter 8 days of the 12-day period that the experiment was operative; i.e., 0.43×10^{-3} hits/sec. The average impact rate over the 12-day period is the next circle and was 1.5×10^{-3} hits/sec. The plotted points are the real-time readout rates during the shower period. From this figure, it is quite evident that the impact rates during the shower period were nearly two orders of magnitude greater than the average of the latter two-thirds of the measurement period.

The dots in Figure 1 represent the impact rate for all stations except for Woomera, Australia, which is represented by squares. All of the dots in Figure 1 refer to receiving stations in

Table 1

Impacts per Station Pass for 1958 Alpha.

Universal Time	Number of Hits	Duration of Pass (sec)	Station	Impact Rate $\left(\frac{\text{hits}}{\text{sec}} \times 10^3\right)$
Feb. 2,				
1512	2	687	Santiago, Chile	2.9
1833	5	159	Woomera, Australia	31
1930	2	233	Quito, Ecuador	8.5
1933	1	69	Fort Stewart, Georgia	14.5
2033	4	787	Woomera, Australia	5.1
2139	2	221	Fort Stewart, Georgia	9.1
2238	2	691	Woomera, Australia	2.9
2338	5	192	Ehrlick, Kansas City, Mo.	26.3
2339	11	366	Fort Stewart, Georgia	30.0
2340	7	174	Havana, Cuba	40.0
Feb. 3,				
0043	7	832	Woomera, Australia	8.4
0132	2	213	Temple City, California	9.3
0138	4	259	Blossom Point, Maryland	15.5
0139	5	187	Ehrlick, Kansas City, Mo.	26.5
0141	12	261	Fort Stewart, Georgia	46.0
0142	2	7	Havana, Cuba	286
0258	3	180	Woomera, Australia	16.7
0334	4	213	Temple City, California	18.7
0338	1	126	Ehrlick, Kansas City, Mo.	8.1
0344	1	71	Fort Stewart, Georgia	14.0
0344	2	192	Havana, Cuba	10.4
0349	1	-	Antigua, B. W. I.	
0539	7	338	Jet Propulsion Lab., Calif.	20.8
0750	2	142	Quito, Ecuador	7.0
0958	2	527	Santiago, Chile	3.8
1200	0	952	Santiago, Chile	0
1405	5	663	Santiago, Chile	7.5
Average February 2-12, 11 days				1.5
Average February 5-12, 8 days				0.43

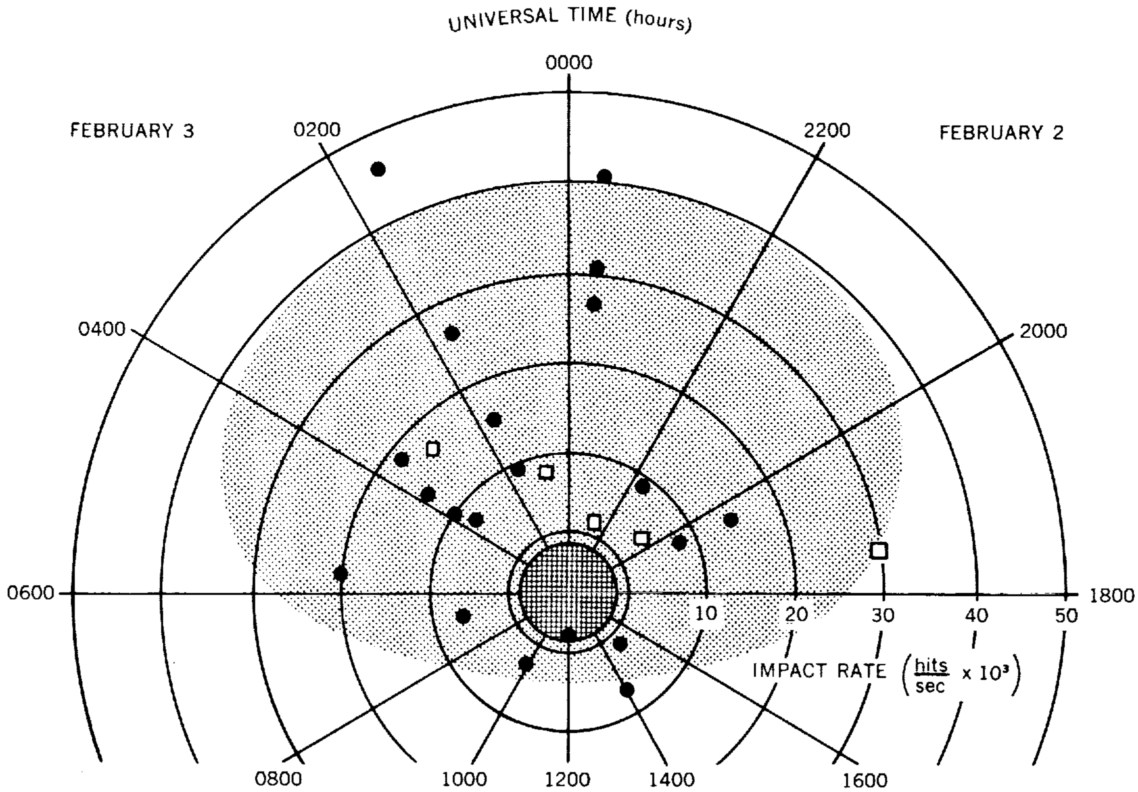

Figure 1—Impact rates during the February 1958 interplanetary dust particle event

essentially the same time zone covering about a three-hour period. During the maximum of the shower intensity the local time for the stations in the United States and South America was early evening, which is indicative of a meteor stream in a direct heliocentric orbit. Evidence for the stream being in the ecliptic is derived from the fact that the stream was detected by northern as well as southern hemisphere receiving stations.

The Australian data from five passes provide additional evidence for a meteor stream with a direct heliocentric orbit, for it may be noted that the impact rate at Woomera as a function of time is at first high, then decreases, and again increases. The Woomera impact rate was near a minimum when the impact rate at the other stations was near a maximum. Since the longitude at Woomera differs from that of the other stations by about 180°, the earth should have shielded the satellite over Woomera from the meteor stream. The apogee (2550 km) of Explorer I was near Woomera on this date and hence, the effect of the earth's shielding at Woomera would be incomplete. Figure 1 has been shadowed to indicate approximately the extent of the meteor stream which appeared to have lasted about 10 hours. There was no known meteor stream related to the cosmic dust shower detected by Explorer I.

Annually Recurring Cosmic Dust Shower in November

In November a cosmic dust shower was detected by both satellites and sounding rockets. It was first recognized from the micrometeoroid data of Vanguard III, although it was first detected in 1955 from an Aerobee rocket. The analysis of additional data from Explorer VIII is still in the preliminary stage, but it supports the fact that this shower reoccurs annually.

A number of rocket flights were carried out by Berg in 1955 and 1960, using a micrometeorite detector which detected the impact-flash of light resulting from the hypervelocity impact of the particle on an aluminum-coated lucite, or quartz surface. The results of the rocket flight in 1955 have been described by Berg and Meredith in Reference 11.

Figure 2 schematically presents the detectors used on three separate rocket firings. The first of these firings was made with Aerobee NRL-25 on November 17, 1955 at 0215 MST. A 1P21 photomultiplier tube was used to detect the light flashes from impacts on an aluminized lucite cone with a light sensitivity of 10^{-4} lumen-sec/m^2. Assuming that 0.002 percent of the impact energy is transformed into visible light, a detector would be able to detect particles of mass greater than 10^{-13} gm. Berg found that 101 impacts had been observed on the telemetry record in the 84-second period when the rocket was above an altitude of 85 km. Below this altitude the impact rate decreased fairly symmetrically on both the upward and the downward trajectory. The area of the detector was 75 cm^2 and the impact rate was 1.6×10^2 impacts/m^2-sec.

This rather high impact rate observed on NRL-25 remained an anomaly for a number of years. This experiment was repeated by Lovering (Reference 12) in Australia; no impacts were observed on a single rocket flight. In 1960, Berg repeated the experiment on an Aerobee NASA 4.12 and on a Jupiter AM-28. Aerobee NASA 4.12 with a 75 cm^2 detecting surface and with the 1P21 and 6199 photomultipliers was launched on March 25, 1960, at 1340 EST. One impact was observed on the 1P21 and two events were observed on the 6199. The impact rate was 1.2 impacts/m^2-sec and the exposure area-time 2.4 m^2-sec. On the NRL-25 Rocket the exposure area-time was 0.64 m^2-sec. Similarly, on the Jupiter AM-28 fired on January 25, 1960, a space-oriented detector with 185 cm^2 was exposed at 1947 EST. The 6199 photomultiplier was used with a quartz cone. Also included was a calibrated light source which gave a 50 microsecond light pulse every 26 seconds and indicated that

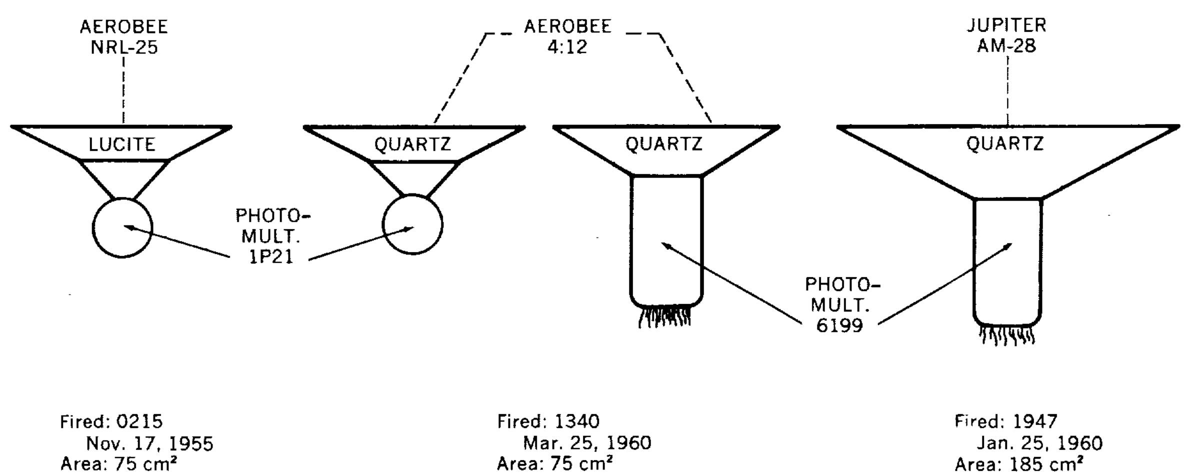

Figure 2—Light-flash micrometeorite detectors used on sounding rocket flights

the experiment was working correctly. The area-time of the exposure was 2.4 m^2-sec. Four events were detected which gave an impact rate of 1.6 impacts/m^2-sec. Thus, three separate rocket flights of an experiment similar to that flown in 1955 were carried out and not one of them was able to confirm the results of the 1955 flight within a factor of 100 for the impact rate.

Although it had been surmised that the rocket data could be explained by a dust shower; this hypothesis was rather clearly confirmed by Alexander (Reference 13) using the micrometeorite data from Vanguard III. The Vanguard III micrometeoroid experiment consisted of four piezoelectric crystals with a threshold impact sensitivity of 1×10^{-2} dyne-sec. Assuming an average impact velocity of 30 km/sec, particles of mass greater than 3.3×10^{-9} gm. could trigger the counter on the satellite. Data were recorded for 78 days with the total number of events approximating 5,000 impacts. Real-time data were not obtained on Vanguard III except in rare instances, although the data sample was much greater than on Explorer I.

Figure 3 presents the impact rate as a function of the data from November 10 through November 20. The impact rate marked C is the average rate from September 18 through October 9; B the average from November 10 to November 20, and A the average from November 16 to November 18. It is quite evident that in the period from November 16-18, there are periods when the impact rate was two orders of magnitude greater than the average marked C (also the average of the 78-day period). It is interesting to note there were rapid fluctuations in impact rate during the period of the

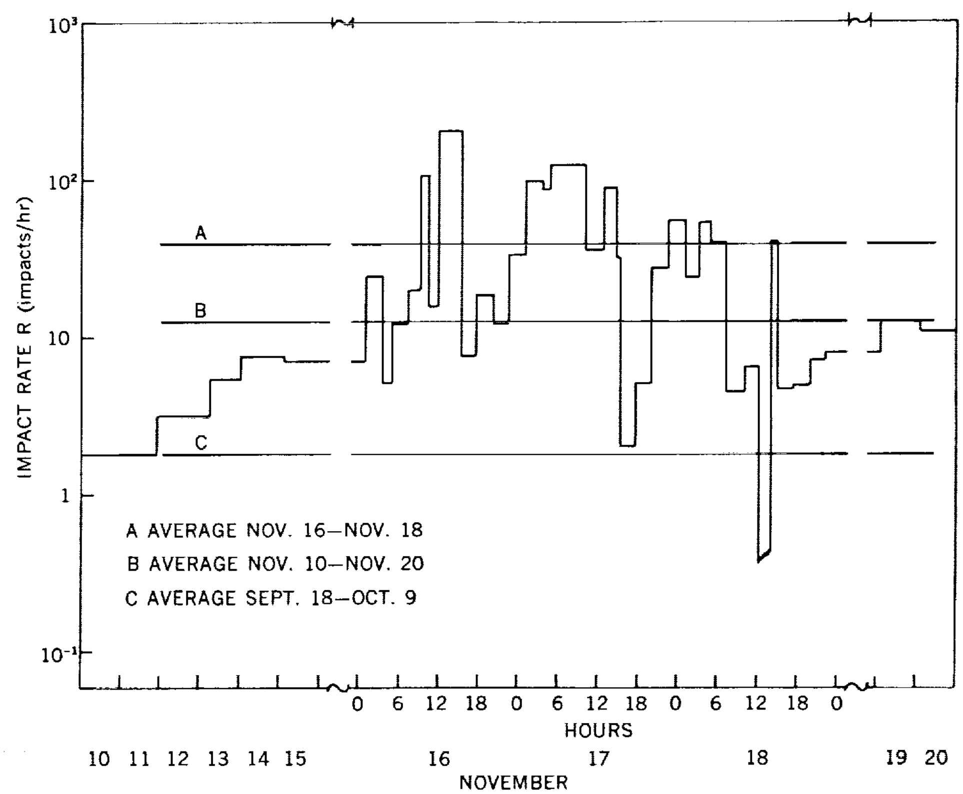

Figure 3—Impact rates during the November 1959 interplanetary dust particle event

shower, and that several orbits showed no or very few impacts, even though extremely high impact rates were observed for small segments of the orbit. These rapid fluctuations in the impact rate are probably real fluctuations in the spatial density of interplanetary dust particles.

The Aerobee NRL-25 was fired on November 17, 1955 at 0215. This is the same time interval of the intense impact rate as observed on Vanguard III and leads to the hypothesis that both measurements detected a shower and that this cosmic dust shower recurs annually. From the times of the Vanguard III data and the Aerobee NRL-25, it is possible that that shower is related to the Leonid meteor stream. Preliminary analysis of the Explorer VIII data from the light-flash micrometeorite experiment using a 6199 photomultiplier with 1000 A evaporated layer of aluminum indicates than an impact rate similar to that observed on NRL-25 was also observed in November 1960 during approximately the same time period. However, these data are still being analyzed and are not in a form which could be used to prove or disprove the annual recurrent nature of this cosmic dust shower. The piezoelectric experiment on Explorer VIII was oriented so as to be shielded from the Leonid radiant; and, in fact, the microphone of this spin-stabilized satellite did not detect a shower at this time.

DISCUSSION AND CONCLUSIONS

Evidence for large fluctuations in the flux of cosmic dust has been presented from the available data on direct measurements of cosmic dust using satellites and rockets. In addition to daily variations often greater than an order of magnitude in the cosmic dust flux, two sets of conditions have occurred which may be attributed to cosmic dust streams. Large fluctuations are also apparent in the streams themselves.

Although the total amount of data available from direct measurements is still fairly small, these two cosmic dust streams represent a large fraction of the total number of impacts recorded on all the satellites. The total number of impacts recorded on Explorer I was 145 and the number of impacts which may be associated with the cosmic dust shower is 66 — nearly half Similarly, on Vanguard III, of a total number of approximately 5000 impacts, about 2800 of these impacts occurred during the cosmic dust shower between November 16 and November 18. Even if the number of impacts recorded thus far on Explorer VIII and on all other space vehicles were included in the total, the number of events occurring in these streams represent a considerable fraction of this total. By comparison, the number of meteors in meteor streams observed by optical, visual and radar detectors is only about 10 percent of the number of sporadic meteors similarly observed. On the other hand, Gallagher and Eshelman (Reference 14) have reported that a large fraction of the meteors observed with the highly sensitive radar equipment capable of detecting meteors of approximately visual magnitude (+ 14) appear to be in streams. Thus we wonder whether this supports the hypothesis that there is a continuous generation of dust by disintegration of conglomerates of interplanetary material and that the lifetime of the dust in interplanetary space is quite short—and thereby explains the relative unimportance of the space density or background density of sporadic dust particles. On the other hand, if the rate of dispersion of dust particles after disintegration from a large conglomerate were rather rapid, and if the rate of removal of dust were slow, then the large majority of the dust particles would be isotropically dispersed; and the variations in the cosmic dust flux as detected with satellites would be small and the number of sporadic dust particles would far outweigh the component of dust in showers. Additional measurements are certainly required to determine the generative and destructive characteristics of interplanetary dust.

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