26. THE FLUX OF METEORS AND MICROMETEOROIDS IN THE NEIGHBORHOOD OF THE EARTH

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ABSTRACT

1. Radio meteor rates for a calculated mass range 10^{-6} gm to 10^{-4} gm have been recorded semi-continuously at Havana, Ill., since July 1965. Automatic equipment samples the rate at four different levels of sensitivity each half hour. A flux vs. mass power law has been derived from these data for each of a number of different weeks of observation. Between September 1965 and December 1966 the mean cumulative influx I of meteors/m²/sec/2π ster can best be described by the equation:

$$\log I = -14{\cdot}1 - 1{\cdot}05 \log m,$$

where m is the lower mass limit in grams.

2. A micrometeoroid detection system, which hopefully was to have measured particle velocities and directions of arrival for masses greater than 10^{-12} gm, has been flown on the OGO-II satellite. A comprehensive in-flight calibration system has confirmed the correct operation of the experiment for more than one year in space. 700 hours of data have been analyzed and no micrometeoroid events have been observed. This excludes several hundred spurious events from the microphone sensors. The effective detection area of the instrument is 0·8 cm² ster. Thus, to a probability of 0·86, the average flux of particles of mass greater than 10^{-12} gm must be less than 6×10^{-2} particles/m²/sec/2π ster.

1. Introduction

This paper presents some results concerning the cumulative influx of meteors and micrometeoroids during the period 1965–67. The meteor data were obtained from the Havana meteor equipment run by the Smithsonian Astrophysical Observatory, Cambridge, Mass.; the micrometeoroid data are from a detector on the Orbiting Geophysical Observatory, OGO-II, launched in October 1965 from California into a polar orbit of low eccentricity.

The technique of measuring micrometeoroid flux with the detector described in Section 3 is very straightforward, but the method of measuring the influx of meteors with the Havana radio meteor equipment warrants some introductory remarks.

With a given transmitter power and preset limiting receiver sensitivity, the meteor equipment will count a meteor every time the returned radar echo from the meteor trail exceeds the appropriate magnitude. There are many factors to consider in order to relate these echo counts to meaningful meteor influx values.

First, one has to relate the electron density of a meteor trail to the strength of the received echo. This relation depends on the various radar parameters, including an-

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tenna gain in the appropriate direction. As individual echo directions are not recorded, the echo counts represent the integrated system response over all the sky. Thus, for example, to determine theoretically the variation of echo counts with time, it is necessary to know the distribution of meteor radiants over the celestial sphere. Elford and Hawkins (1964) have discussed these problems in some detail for the Havana meteor equipment and have derived numerical relations between echo counts and meteor influx, F, as a function of equipment sensitivity, S. It is the purpose of this paper to treat the latest echo-count data in terms of their work, and so derive the latest influx values. If we are to relate influx to meteor mass, it is necessary to know the relation between meteor mass and electron trail density. This is a separate and difficult problem, and we simply use the latest figures derived by Verniani and Hawkins (1965).

2. Meteor Influx

2.1. Equipment

The observed meteor rates are recorded automatically from an 'Echo Analyzer' designed and built by M. Schaffner for this project. This device counts the number of meteor echoes received in given intervals of time down to four different limiting receiver sensitivities which cover the useful dynamic range of the system. This is about two orders of magnitude in receiver sensitivity. The data for each day include the echo counts for each receiver level sampled at least once every half hour, the peak transmitter power (measured rather poorly within the transmitter), and the limiting receiver sensitivities at each level.

2.2. Methods of analysis

A typical period of recording consists of about five days in which meteor counts at the four levels have been continuously recorded for about 10 hours each day. From this period of recording one usually has adequate coverage over the full 24 hours, albeit by having to combine several days' data. An observed diurnal variation of rate is thus obtained representative of the week as a whole, and the sums of counts of each half hour over the total recording period of each day at each level of sensitivity are then normalized with respect to this observed diurnal rate curve. This allows for the fact that these sums of counts are obtained over different and incomplete periods of the day, during which time the meteor-detection rate varies quite markedly. These normalized sums of the half-hourly counts at each level for each day constitute the basic measures used to determine the absolute influx. Now, for selected days of the year, Elford and Hawkins (1964) have related absolute influx to meteor counts, using a mean radiant distribution referred to the ecliptic and the apex that was derived from Havana observations, and using antenna gain patterns derived from measurement of model antennas. It only remains to normalize our daily sums with respect to their data for the appropriate day of the year, and our now fully normalized sums represent values of F, the absolute mean influx per unit solid angle, at each level of sensitivity, for each day of observation. $4\pi F(q)$ is the cumulative flux (supposing the Earth removed) from the entire celestial sphere, producing trails with line densities greater than a given value, q. Five days' observations thus give us about 20 values of F as a function of sensitivity, S, the latter being directly proportional to the minimum observable line density q.

2.3. Discussion of results

A least squares fit of $\log F$ against $\log S$ has been made for each week of observations, and the variation of the best value of $\log F$ at about the centre of the dynamic range of the system is shown in Figure 1. Major showers have been excluded from the data.

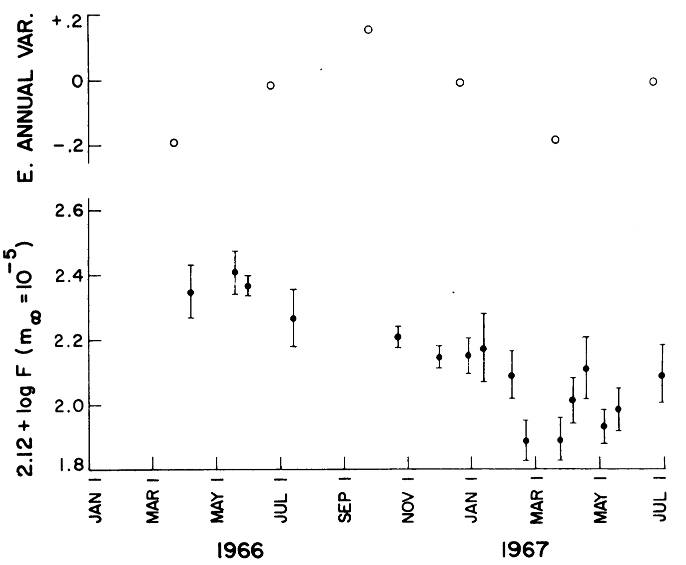

FIG. 1. *Top: The expected annual variation of meteor rate for constant F, plotted on the same scale as below. Bottom: Calculated values of F in meteors/km²/hr, the flux per unit solid angle of the celestial sphere producing trails of maximum line densities* $> 3{\cdot}9 \times 10^{11}$ *elec/m.*

Verniani and Hawkins (1965) discussed a random sample of Havana meteors; we have related the limiting value of q in electrons per meter to a limiting mass m_∞ in grams by adopting the average ratio of q to m_∞ in their sample:

$$\log m_\infty = \log q - 16{\cdot}6 .$$

The values of $\log F$ in fact correspond to a calculated minimum meteor mass

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of 1×10^{-5} gm. Considering our present poor knowledge of ionization probability, there is substantial uncertainty in this value of limiting mass. It can be seen that there is slightly more than a factor of 2 variation in calculated influx during 1966, with a suggestion of a minimum in March 1967. The error bars represent statistical values of the 95 % confidence limits, based only on the numerical data.

One should treat these figures very cautiously. Although we monitor the transmitter and receiver levels, there are other items of the equipment which affect the counting rates. For example, the antennas and associated feeder lines have not been monitored closely, and some deterioration was discovered in 1967. Elford and Hawkins (1964) considered the changing position of the ecliptic in the sky, but not a variation of meteor density along the Earth's orbit.

We have normalized our counts on the basis of their calculated rate variations throughout the year. These expected counts, for a constant value of influx F, are shown at the top of Figure 1 on a relative scale of the same amplitude as the computed values of $\log F$ below. We see that one expects a minimum in meteor rate around March 21, which is when we have a suggestion of a minimum in the actual measures of the absolute influx F. This suggests that perhaps we have not allowed sufficiently for the annual variation; on the other hand it may only be a coincidence. In any event, our data do not prove any variation in meteor influx from one year to another.

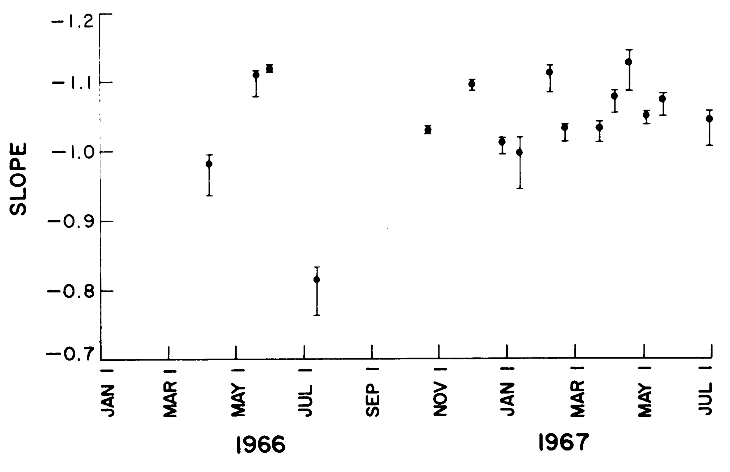

FIG. 2. *The calculated values of slopes of the cumulative flux vs. sensitivity regression analyses.*

The regression analyses of $\log F$ on $\log S$ give values of the slope of cumulative flux versus trail density for each weekly period of observation. These values generally fall between $-1{\cdot}0$ and $-1{\cdot}1$, as can be seen from Figure 2. There does not appear to be any obvious regular variation over the year.

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If we pool all the data we find that the cumulative influx I of meteors onto the surface of the Earth per m^2 sec is given by

$$\log I = -14{\cdot}0 - 1{\cdot}05 \log m_\infty .$$

3. Micrometeoroid Flux

3.1. Equipment

The experiment flown on the second Orbiting Geophysical Observatory consists basically of four tubular detectors, each one of which is as shown in Figure 3. Each tube is about 10 cm long and has a 2·5-cm diameter. This forms a crude collimating system which restricts the angle of arrival of a particle detected on the rear sensors. Three of the four tubes point in mutually perpendicular directions. There are three sensors to each tube. A particle first passes through the two very thin films – each about 1500 Å thick – at the front of each tube, giving rise to a small plasma pulse which is used to start an oscillator to measure the time of flight down the tube.

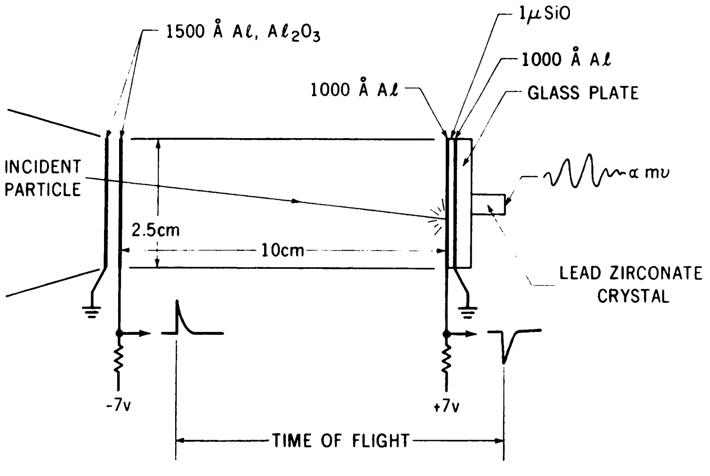

FIG. 3. *The basic OGO-II micrometeoroid detector tube.*

At the rear of the tube the particle impacts destructively on a thin film capacitor deposited on a glass disk. The pulse from this capacitor is used to stop the time-of-flight oscillator, and, hopefully, to provide some measure of the energy of the particle. A microphone crystal is bonded to the rear of each glass disk to measure the momentum of the particle. The limiting sensitivity of the latter sensor is about 1×10^{-4} dyne-sec; the capacitor sensor has been shown to respond to iron particles of 10^{-11} gm impacting at speeds of less than 3 km/sec. There are data to indicate it would respond to particles of mass less than 10^{-12} gm at higher velocities, although the exact velocity dependence of this sensor has not been properly established. It is certainly the most sensitive sensor of the three in each tube.

A continuous in-flight calibration system has monitored all these sensors and the associated electronics for the year during which the experiment was operated. One rear capacitor sensor shorted out during this time, but this could not have been due to particle impact, as the detector in question was the one used for noise control, and was shielded from particle impact by a metal disk placed ahead of the front films. From these and other data we are sure the experiment has operated properly from launch in October 1965 at least through March 1966, the period for which data have been analyzed.

Sensor-output data are recorded if either of the two rear sensors responds to an event. Noise or micrometeoroid events affecting only the front sensors would not appear in the OGO-II data. Thus we have chosen as a criterion for the recognition of a micrometeoroid impact a response from at least the rear capacitor sensor. Furthermore, this event must not coincide with a command radioed to the spacecraft, as some of these commands give rise to interference which is detected by the instrument.

3.2. Results to Date

More than a thousand events from the microphone sensors have been recorded. These events have not been associated with any genuine response from the other sensors, and have been shown to be due to noise generated within the instrument itself under conditions of changing temperature (Nilsson, 1966). This conclusion, at least for this instrument, has been verified beyond any reasonable doubt by laboratory and in-flight tests.

Several hundred events, masquerading as micrometeoroid impacts, were recorded on the rear capacitor sensors in 1300 hours of data. In all but two cases, these events were traceable to electronic interference arising from commands sent to the spacecraft. Disallowing these events, we are left with two possible micrometeoroid impacts in 1240 hours of data. It still remains to check with other experimenters on the satellite concerning other types of interference at these times, but at any rate the probability of these two events being real must be considered low. The total effective area of all the rear sensors is $0{\cdot}8\ \text{cm}^2$ ster; hence if we use these two possible events as an upper limit to the flux, we have that the average flux of particles of mass greater than 10^{-12} gm during the period October 1965 – March 1966 is less than 3×10^{-2} particles/m^2/sec/2π ster.

More data remain to be analyzed, and an improved instrument has recently been launched on the OGO-IV satellite. This latter instrument will record any events occurring on any of the sensors, alone or in conjunction with other sensor responses. Thus particles impacting the front films, but not reaching the rear sensors, will be recognized and counted. Owing to the increased angle of acceptance, this raises the effective area for flux-measurement purposes to about 30 cm^2 ster. This may eventually provide us with a reliable satellite measure of the flux of these small particles in the neighborhood of the Earth.

4. Conclusion

Figure 4 shows the radio-meteor flux plotted relative to some well-published cumulative flux vs. mass curves, along with the satellite penetration data of Naumann (1966) and the data point from OGO-II, which is really only an upper limit. From these three results, it appears that there is still no radical departure from the constant mass per magnitude distribution of meteoric material in the neighborhood of the Earth.

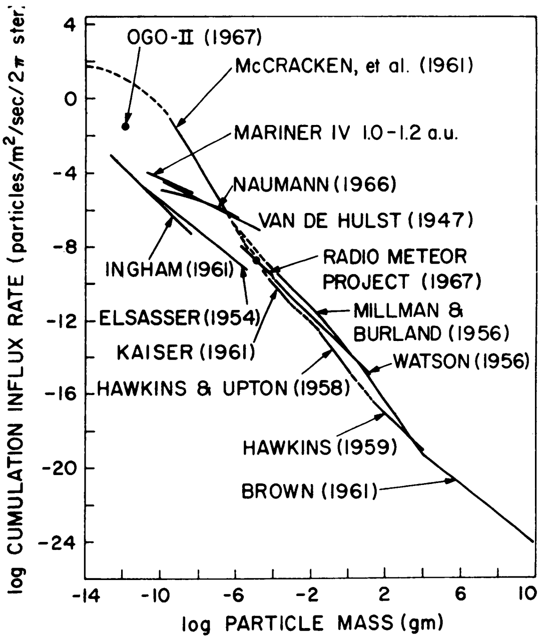

FIG. 4. *Cumulative flux vs. mass plots for various data – originally drawn by C. W. McCracken and M. Dubin, NASA Tech. Note X-613-63-185 (1963).*

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DISCUSSION

Dohnanyi: What method was used to determine the slope of the radar flux?

Southworth: In each week of observation, we obtained about 20 values of flux – down to a limiting sensitivity S, usually 5 values at each of four sensitivities. $\log_{10} F$ is fitted to $\log_{10} S$ by least squares.

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