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The Velocity of Faint Meteors

by

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The meteor population is size dependent. McKinley (1961) has summarized the photographic and the radar data, showing that there is a tendency to find short-period orbits among the smaller and fainter meteors. This necessarily implies that the average velocity of a group of meteors depends on the average magnitude, and that small meteoroids tend to move more slowly in space. The comparison of the various orbital distributions is, however, fraught with the effects of observational selection, and it is difficult to establish a quantitative measure for the difference among the various meteor populations.

This paper describes a controlled experiment in which the velocity distribution of meteors was measured at several different limiting magnitudes, with the minimization of the various selection effects.

Observational data

The multi-station radar system, described by Hawkins (1963), is situated at Havana, Ill. A single-trough antenna was used at the transmitting site, and single yagi antennas were used at the five remote sites. The transmitter frequency was 40.92 mcs, and the peak power was varied from 25 kw to 2 Mw. An integration of the ionization curve yields the total number of electrons in the trail. From this the mass and magnitude of the meteoroid can be computed by means of the values of ionizing efficiency of Lazarus and Hawkins (1963). At low power the average magnitude was +6.6 on the visual scale, and at high power the average magnitude was +9.0.

It was not practical to operate the radar system continuously, because the number of meteor echoes recorded would have been astronomical. Therefore an operational schedule based on the days of the week was set up, as follows:

Day	*Hours*
Monday	0000 to 0800 C.S.T.
Tuesday	0000 to 1200 C.S.T.
Wednesday	0800 to 1600 C.S.T.
Thursday	1200 to 2400 C.S.T.
Friday	1600 to 2400 C.S.T.

This schedule was used on alternate weeks, with no observations being made on the other weeks. The observing time was cut further by limiting it to the first 30 minutes of any hour during a run. This schedule gives a uniform diurnal coverage when averaged over a period of one week.

At times it was not possible to adhere strictly to the operating schedule, and observations are not available for the full cycle of 12 months. Thus diurnal and seasonal effects must be taken into account when considering the data. The analysis covers all data available at the present time. The observing periods and power levels are given in table 1. In summer and fall of 1961 the radar system was not fully developed, and observations were made at only three stations. A total of 681 meteors was recorded by the 3-station network. It will be shown that there is no systematic difference dependent upon the number of stations used. A total of 2398 meteors was available in the initial analysis, but of this number 216 Geminids and 17 Quadrantids were excluded from the final analysis. The velocity was derived from measurements at all stations, by use of a program on IBM-7090 digital computer (Southworth, unpublished). The velocity, v_∞, has been corrected for atmospheric deceleration.

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Table 1.—*Velocity at Various Power Levels*

Observational Periods	No. of stations	Power (kw)	Observed velocity	Corrected velocity	No. of meteors	Hours of obs. C.S.T.
15 April–31 August 1961	3	25	39. 8	38. 4	378	03–15
27–28 November 1961	6	25	38. 2	35. 9	39	03–09
Mean		25		38. 1		
4 December 1961	6	700	39. 9	37. 5	49	03–09
15 January–2 February 1962	6	750	34. 9	34. 9	409	00–24
2–5 January 1962	6	900	35. 5	34. 7	93	09–15
19 June–8 August 1961	3	1000	37. 1	36. 1	111	03–15
December 1961	6	1200	40. 6	38. 1	451	03–09
Mean		950		36. 4		
26 February–16 March 1962	6	1750	33. 3	33. 3	463	00. 24
26–30 March 1962	6	1750	31. 4	31. 4	212	00. 24
12–16 February 1962	6	2000	34. 3	34. 3	276	00. 24
9–27 April 1962	6	2500	30. 9	30. 9	173	00. 24
Mean		1900		32. 8		

The diurnal effect

The period 15 January to 30 March 1962 was chosen for a study of the diurnal variation of velocity, because it was during this time that the minimum departure from the operating schedule (see above) occurred. This period was also reasonably free from meteor streams. The data were grouped in 6-hour intervals, as shown in table 2, and the velocity distribution was determined for each interval. It is apparent that the velocity distribution changes during a 24-hour period. This results, of course, from the astronomical selection effect as the earth rotates, and is of no interest in this paper. Rather, the velocity distributions can be used to correct the observations during any period when a complete 24-hour coverage was not available. The correction factors for the period 03–09 hours and 09–15 hours C.S.T. are given in table 2. It was not possible to determine correction factors for

Table 2.—*Diurnal Velocity Distribution*

$V\sim$	Velocity distributions for period 15 January–30 March 1962				Correction factor to reduce to 24 hrs of observation	
V km sec^{-1}	03–09	09–15	15–21	21–03	03–09	09–15
10. 0–14. 9	2	0	7	1	5. 00	-
15. 0–19. 9	16	15	20	15	4. 13	4. 40
20. 0–24. 9	58	56	37	23	3. 00	3. 11
25. 0–29. 9	127	129	26	24	2. 41	2. 37
30. 0–34. 9	148	142	16	8	2. 12	2. 21
35. 0–39. 9	98	109	1	7	2. 19	1. 97
40. 0–44. 9	42	59		3	2. 48	1. 76
45. 0–49. 9	20	27		1	2. 40	1. 78
50. 0–54. 9	15	17			2. 13	1. 88
55. 0–59. 9	26	12			1. 46	3. 17
60. 0–64. 9	22	6			1. 27	4. 67
65. 0–69. 9	16	5			1. 31	4. 20
70. 0–74. 9	3	1			1. 33	4. 00
Total	593	578	107	82		

the period 15–03 hours because of the zeros occurring in the velocity distributions.

Results

For the analysis of the velocity distributions, the results have been divided into the three groups shown in table 1. These groups may be classified as low-, medium-, and high-power runs with nominal peak transmitter powers of 25 kw, 1 Mw, and 2 Mw. The observed velocity distribution was corrected for diurnal effects by use of the correction factor in table 2 for the periods when the operating schedule was not strictly followed. The corrected velocity distributions for the high-power and low-power runs are shown in figure 1. The corrected velocity distributions for the medium-power runs are shown in figure 2. In figure 2 the results have been divided into two groups, the 3-station measurements and the 6-station measurements. All the velocity distributions have been normalized so that the area under the histogram is equal to 100 units.

As an internal check, it is possible to verify the diurnal correction factor. One would expect that proper application of the correction factor would yield the same mean velocity for any period of the day at a fixed power level. In table 3 the observed mean velocity and the corrected mean velocity are shown for the low-power and medium-power observations. It appears that although the observed velocity differs by 1 or 2 km sec^{-1} for different portions of a 24-hour period, the corrected mean velocity differs by less than 0.5 km sec^{-1}.

The two histograms at a peak power of 1 Mw were drawn to ascertain whether there were any systematic differences between the 3-station and the 6-station observations. Figure 2 shows that the histograms are essentially the same and that no systematic effects exist. Furthermore, since the 3-station results were obtained in the summer months and the 6-station results in the winter months, the similarity of the histograms indicates that there are no significant seasonal variations.

The mean velocity, given in table 1, has been used as a measure of the meteor population at various limiting magnitudes. In figure 3 the velocity is plotted as a function of transmitter power; on the same diagram the average magnitudes have been assigned, based on the relation

$$M=40-2.5\log q, \qquad (1)$$

where q is the electron line density in units of electrons per meter. Thus the curve in figure 3 shows a decrease of mean velocity with meteor magnitude. The average decrease is approximately 5 km sec^{-1} for 3 magnitudes. This corresponds approximately to a decrease of 9 km sec^{-1} if one extrapolates to an interval of 5 magnitudes.

Discussion

It is unlikely that these results are affected to any great extent by observational selection. The diurnal effect has been removed, and there are no detectable seasonal effects. It is possible to introduce a bias that is dependent upon the mean height of meteors in the various samples. For example, if the faint meteors were occurring at a greater height, then these meteors might possibly be inadequately observed because of the effects of diffusion of the trail (McKinley, 1963). An analysis of the heights of the echoing points has been made in connection with a study of the physical characteristics of radar meteors (Hawkins and Southworth, 1963). This work shows that the faint meteors occurred

TABLE 3.—*Verification of Diurnal Correction Factors*

Observational Periods	Power (kw)	Observed mean velocity km sec^{-1}	Corrected mean velocity km sec^{-1}	No. of meteors	Hours of observation
15 April–31 August 1961	25	41. 1	38. 6	143	03–09
	25	39. 0	38. 2	236	09–15
19 June–8 August 1961	1000	38. 7	36. 4	20	03–09
	1000	36. 8	36. 0	91	09–15

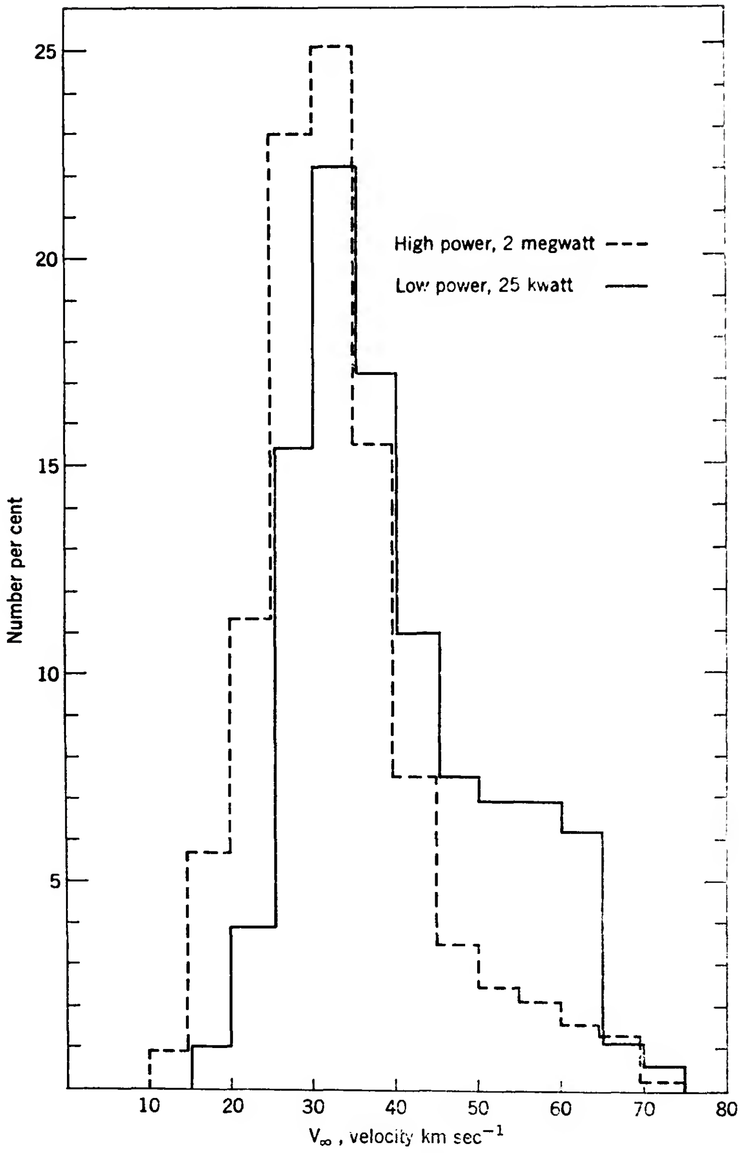

Figure 1.—Corrected velocity distributions for high-power and low-power runs.

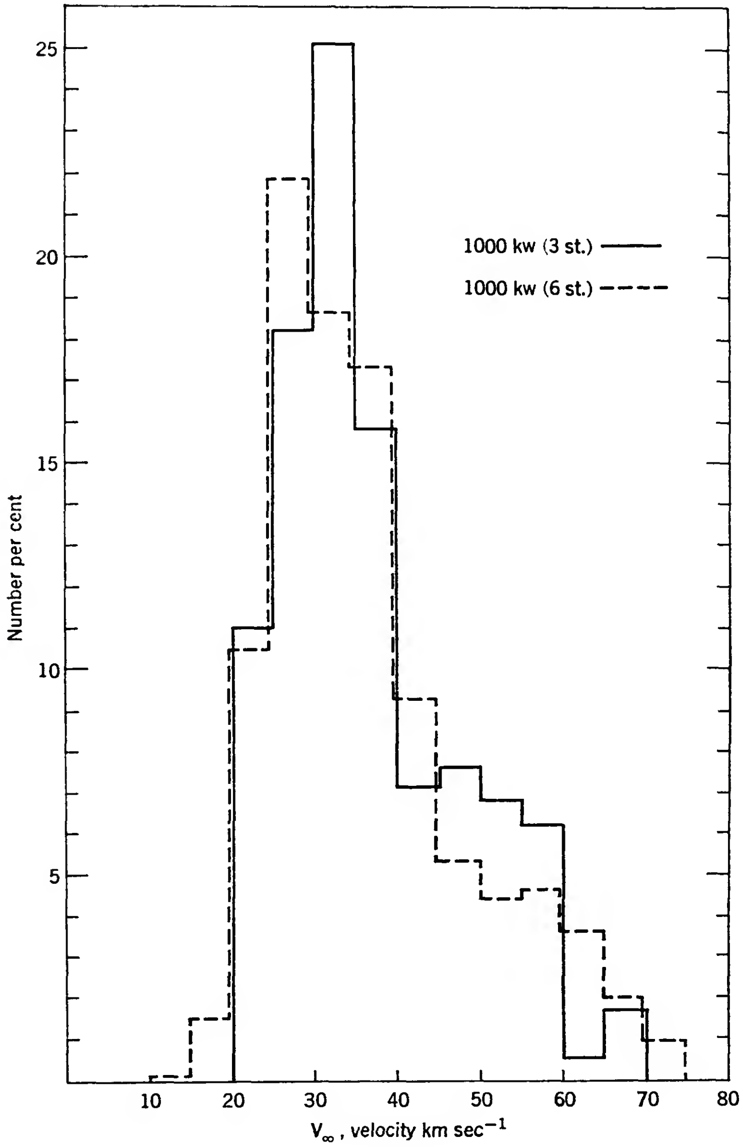

FIGURE 2.—Corrected velocity distributions for medium-power runs.

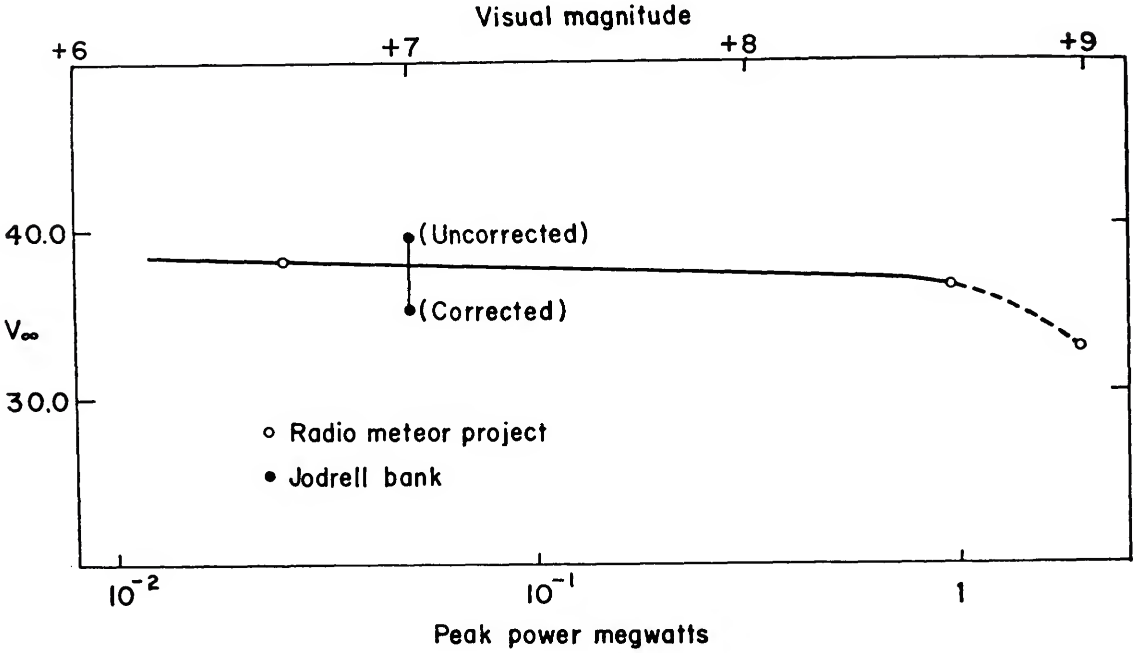

FIGURE 3.—Velocity as a function of transmitter power.

at a lower height in the atmosphere than did the bright meteors. For example, in the velocity range 25–30 km sec^{-1} the mean height was 94.5 km for meteors with magnitudes between +5.7 and +6.9. On the other hand, meteors with magnitudes between +9.0 and +9.9 occurred at a mean height of 88.4 km. This result is in complete disagreement with the single-body classical theory. The discrepancy probably results from the change in physical characteristics that is found as one proceeds to fainter meteors. Whatever the cause, the height distribution is certainly not responsible for the observed difference in mean velocity.

It is interesting to compare the data obtained by the radio meteor project with data from other observatories. The only available data are those of Davies and Gill (1960), who carried out a meteor survey at Jodrell Bank, England. The average magnitude of meteors in their sample was +7, and the radar wavelength was 8 meters, which is close to the 7-meter wavelength used in the radio meteor project. From the published data of Davies and Gill two values for mean velocity have been determined. The first value represents the original observational data. The second is a corrected value, which allows for the difficulties of observing the Fresnel pattern. No correction for pattern visibility has been included in the data in this paper. The Fresnel patterns as recorded are, however, somewhat clearer than the Jodrell Bank records. We consider that our data correspond to an intermediate value between the corrected and the uncorrected data of Jodrell Bank.

Between visual magnitudes of +6 and +9 the average velocity of meteors decreases by approximately 5 km sec^{-1}. Thus in interplanetary space the average velocity of meteoroids will depend to a considerable extent on the mass of the particle. There are indications that the change in the meteoroid population becomes accentuated among the smaller particles. The curve in figure 3 becomes much steeper between magnitude +8.5 and +9. The meteor population may undergo critical changes between magnitude +9 and +12. The hope is to investigate this region of the magnitude scale with a further extension of the sensitivity of the radio meteor project.

Acknowledgment

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Abstract

Preliminary measurements of meteor velocity to a limiting magnitude of +10 have been obtained with a multistation radar system. A systematic change in the average velocity of meteors, which depends on the magnitude and hence on the size, has been found. Between magnitude +6 and +9 the velocity decreases by 5 km sec^{-1}. There are indications that the effect becomes more marked for meteors fainter than +9. This effect is attributed to the difference in orbits within the various meteor populations.

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