CLUSTERING OF METEORS AS DETECTED BY THE USE OF RADIO TECHNIQUE

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INTRODUCTION

For the past three years the authors have been observing the effect of meteors on radio propagation by monitoring transmissions from the Bureau of Standards radio station WWV in Washington, D. C. The presence of a meteor was detected by an instantaneous burst of signal strength caused by an oblique reflection from a highly ionized meteor trail. Using this technique it was discovered that clusters of meteors strike the upper atmosphere of the earth.

Observations were made with a conventional short-wave receiver, oscilloscope, and pen recorder. During the early stages of the work, observations were made out-of-doors where sky and equipment could be observed simultaneously and the visual passage of a meteor could be associated with a rapid increase in the field strength of the WWV signal. Coincidence between visual detection and radio detection was established many times during two meteor showers and thirty-four times during one non-shower night. Many bursts were observed on the radio when no meteors were seen. The ratio of radio bursts without visual detection to radio bursts with visual detection was eight to one. This indicated that a much higher rate of meteor detection was available using the radio technique.

During the course of observations several characteristics were noted, as follows: 1. Both radio bursts and visual meteors occurred in clusters. The clusters were separated by periods of time when there was little or no activity. 2. After a cluster had been detected visually and on the radio the signal strength from WWV was greatly increased. The strong signal persisted for anywhere from a few minutes to two hours. 3. During the Perseid shower there was a delay of several seconds between seeing the meteor in the sky and observing the associated burst on the radio. 4. No particular direction of the meteor with respect to the transmitter and receiver locations was required to produce a burst on the radio. The only requirement was that the orientation of the meteor trail should be such that an oblique reflection from the transmitter to the receiver was possible.

The most significant characteristic is the clustering of meteors. A possible theory for the persistence of a strong signal for long intervals of time may be that a cluster strikes the upper atmosphere and the combination of individual ionized columns forms a cloud of ionization which acts as a reflecting medium. Later clusters maintain the ionization. The propagation characteristics associated with the sporadic E layer are then present. If an attempt is made to prove that clusters of meteors produce the characteristic cloud of sporadic E ionization, it must first be proved that meteors strike the upper atmosphere of the earth in clusters. It is the purpose of this paper to prove meteoric clustering.

MEASURING TECHNIQUE

The reception of radio waves transmitted in the 3 to 30 megacycle band at locations remote from the transmitter is highly dependent upon the ionosphere. If a propagation path is to exist between given transmitter and receiver locations, several factors, such as distance between transmitter and receiver, time of day, month, and the phase of the sunspot cycle must be considered. For any given set of conditions there is a theoretical maximum usable frequency which cannot be exceeded if a propagation path is to exist. At frequencies higher than the maximum usable frequency the energy penetrates the ionosphere instead of being reflected to the receiver location. If the angle between the incident ray and the normal to the ionospheric surface is increased, the energy is reflected back to the earth, but it returns to the earth at a distance too great for reception at the receiver location. Figure 1 shows the relationship between the various factors at sunspot maximum as accepted for general radio communication. With decreasing sunspot numbers the maximum usable frequency decreases.

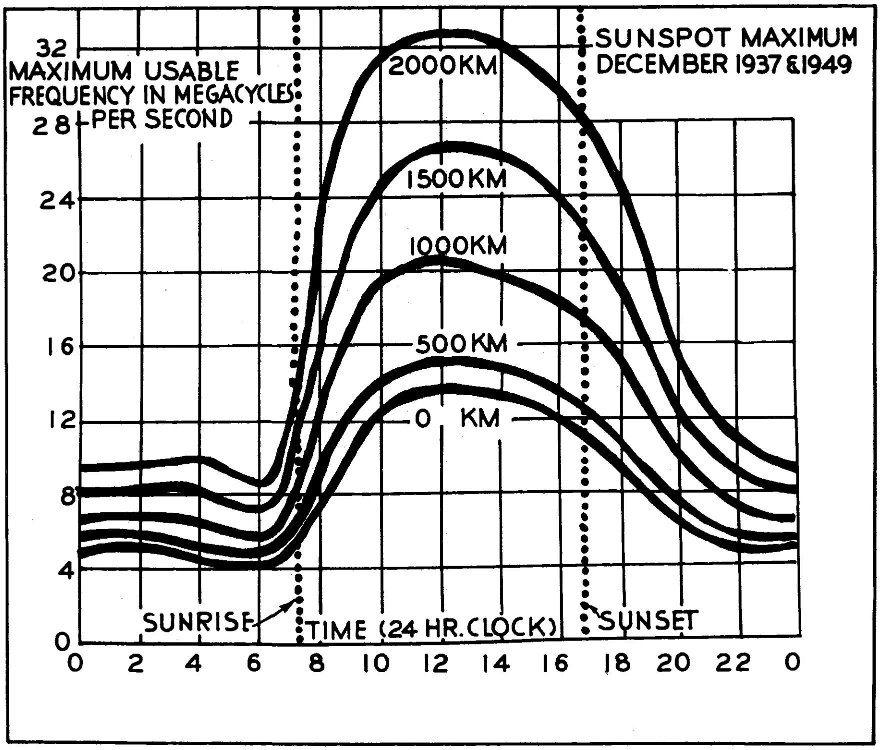

FIGURE 1. Maximum usable frequency at sunspot maximum. Reprinted with permission from "Reference Data for Radio Engineers," 3rd ed. 1949. Federal Telephone and Radio Corporation, New York.

The data for this paper were taken over the 608 kilometer path between Washington, D. C. and Springfield, Ohio. The observations were made between 0200 and 0300 hours. Figure 1 shows that between 0200 and 0300 hours the maximum usable frequency over the 608 kilometer path is about six megacycles at the time of sunspot maximum. The data for this paper were collected using the 20 megacycle signal at less than sunspot maximum. Non-standard conditions caused by localized meteoric ionization made this possible. Lovell (1954) has stated that a representative figure for the degree of ionization present near the E region (100 kilometers) at midnight is 8 x 10^3 electrons per cubic centimeter. This is the degree of ionization accepted for conditions of standard propagation. Lovell (1954) also stated that with the passage of a meteor the ionization present at the E region is approximately 10^8 electrons per cubic centimeter. This instantaneous rise in ionization has the effect of briefly raising the maximum usable frequency for a given path by several megacycles. It produces a burst of signal strength that lasts as long as the ionized column will reflect to the receiving station. Figure 2 shows the meteor burst phenomenon. The noise level of the receiver is observed when the effect of the meteor is not present. When a meteor strikes there is an instantaneous rise in signal strength, followed by rapid decay as the column of ionized gas dissipates.

The 20 megacycle signal is the highest frequency on which the WWV signal can be detected over the 608 kilometer path, if an omnidirectional antenna is used. The time required for decay of a burst is less at the higher frequencies than it is at the lower frequencies; consequently, the resolving power of the recording system is better when the higher frequencies are used. Bursts have been detected on the 10 and 15 megacycle signals of WWV; however, since the decay time is greater at the lower frequencies, the saturation point of the recording system is reached sooner than it is on the 20 megacycle signal and the individual bursts cannot be as readily separated.

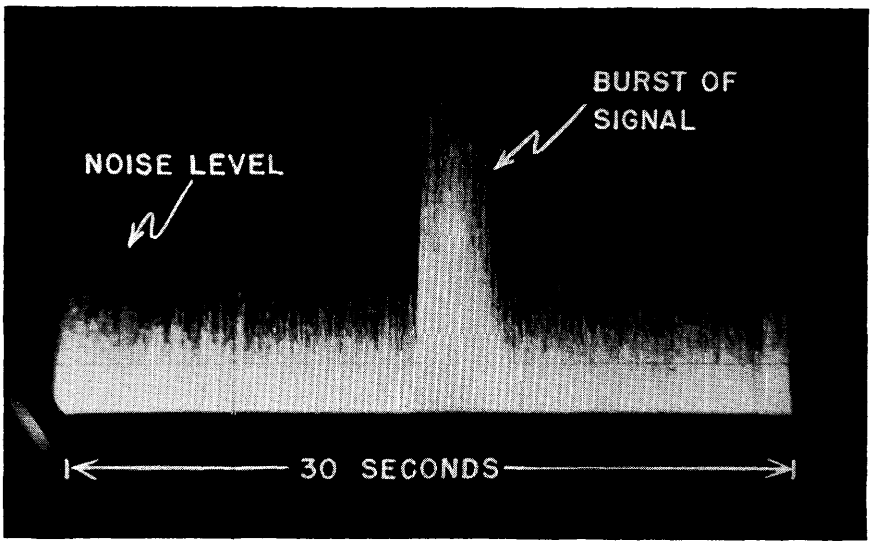

FIGURE 2. Meteor burst phenomenon.

Observations were made from 0200 to 0300 hours because there are more meteors in the morning sky than in the evening sky, and because there is less interference after the TV stations go off the air. Non-shower nights were chosen because the probability of clustering is inherently greater on shower nights than on non-shower nights. Also, on shower nights the recording equipment is frequently saturated for long intervals of time and the individual bursts cannot be detected. Consequently, no observations on shower nights are included in this discussion.

The equipment employed to detect and record meteor bursts is shown in block diagram form in figure 3. The antenna was the long wire type. It was one wave length long and was oriented in the direction of Washington, D. C. It was one-quarter wave length above ground. Because such an antenna has no pronounced directional characteristics, it was possible to observe meteors in all quadrants of the sky. A conventional short-wave type Collins Radio Company model 51J receiver was used. This receiver has the excellent frequency stability characteristics required for the work. At 20 megacycles, less critically designed receivers have a tendency to drift off frequency, making it impossible to determine whether there were no bursts or whether the receiver was no longer tuned to the transmitting station. Only during bursts can the less critically designed receivers be tuned to the correct frequency. The Collins model 51J can be adjusted in the absence of a signal. The automatic volume control was not used; therefore, rapid changes in the input level of the receiver gave a true indication of the burst amplitude. The audio tone is omitted from the WWV signal during the fourth and fifth minutes of each five-minute interval, but unmodulated energy is still radiated. To obtain data during the fourth and fifth minutes the beat frequency oscillator characteristic of the receiver was used. This injected a signal into the receiver that would mix with the incoming energy and produce an audio tone. Therefore, the tone was present whenever either modulated or unmodulated energy was received. The receiver audio was monitored on a speaker. In order

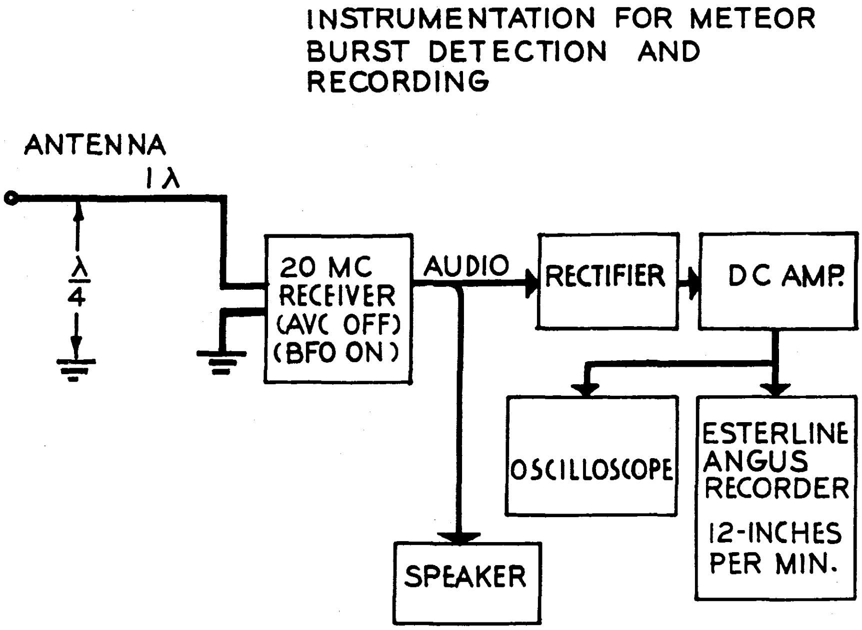

FIGURE 3. Block diagram of meteor detecting and recording system.

to have a permanent record and to establish time relationships between bursts, the receiver audio was rectified using a crystal bridge network amplified by a single stage transistor and applied to a conventional five milliampere Esterline-Angus recorder, which was operated at its highest speed of twelve inches of paper per minute. A marker was placed on the paper each six seconds, a different marker being used to designate the beginning of the minute. In this way the time of each burst became known to the hundredth of a minute.

All information recorded was observed on an oscilloscope. This proved very helpful in eliminating extraneous signals caused by interference from local TV receivers and from power line arcs due to wind and wet weather. The equipment used is shown in figure 4. The second receiver, tuned to the five megacycle signal of WWV, was used to obtain and record the time. With the exception of the recorder, all equipment was of conventional laboratory type. With this equipment it was possible to record as many as fifteen bursts per minute. Figure

5 displays typical recordings of the meteor burst phenomenon. Six intervals of thirty seconds each are shown. The intervals have respectively no bursts, one burst, two bursts, three bursts, four bursts, and five bursts.

EVALUATION OF DATA

The observations of the present discussion were taken on January 10, 1956, and on eight nights thereafter. The discussion includes 1308 meteoric bursts. Bursts were noted at the average rate of 175 per hour, or nearly three per minute. Most of the meteors were doubtless too small and too faint to be seen visually. There was no significant change in rate within the hour. The mean rate for the nine nights was 2.9 bursts per minute for the first five minutes; at 20 to 25 minutes the mean rate was 2.8 bursts per minute; at 40 to 45 minutes the

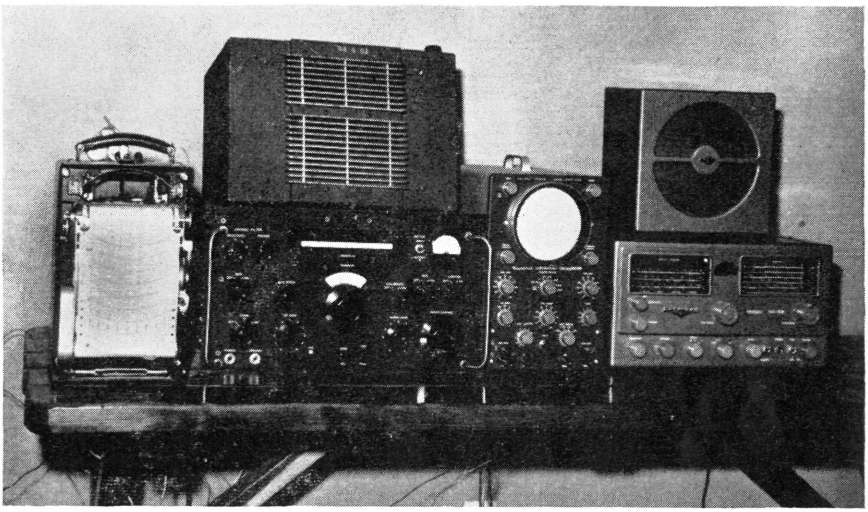

FIGURE 4. Photograph of meteor detecting and recording system.

mean rate was 3.0 bursts per minute; at the close the mean rate was 2.8 bursts per minute. It is seen that there was no diurnal effect within the hour. The variation within the five-minute interval was a little greater than the variations occurring over the hour. The five minute variations ranged from a high of 3.1 bursts per minute during the second and third minutes to a low of 2.5 bursts per minute during the fifth minute of the five-minute intervals. A test by analysis of variance indicates that the variation is without significance. The overall mean interval between bursts was 0.344 minutes, or 20.6 seconds, for the nine nights.

When the hour is divided into a series of equal intervals and the number of bursts per interval is counted, it can be shown that if the bursts are randomly distributed in time the frequency distribution of bursts will follow the Poisson exponential series. A Poisson distribution was fitted to the observed data. One-half minute was chosen as the length of the interval because it was desirable to have intervals short enough that many intervals would have no bursts in them, yet long enough that most intervals would have one or more bursts in them. At 175 bursts per hour the average would be about $1\frac{1}{2}$ bursts per interval.

The observations on nine additional nights were not used. On three of the nights power line arcs due to wind and wet weather caused so much interference

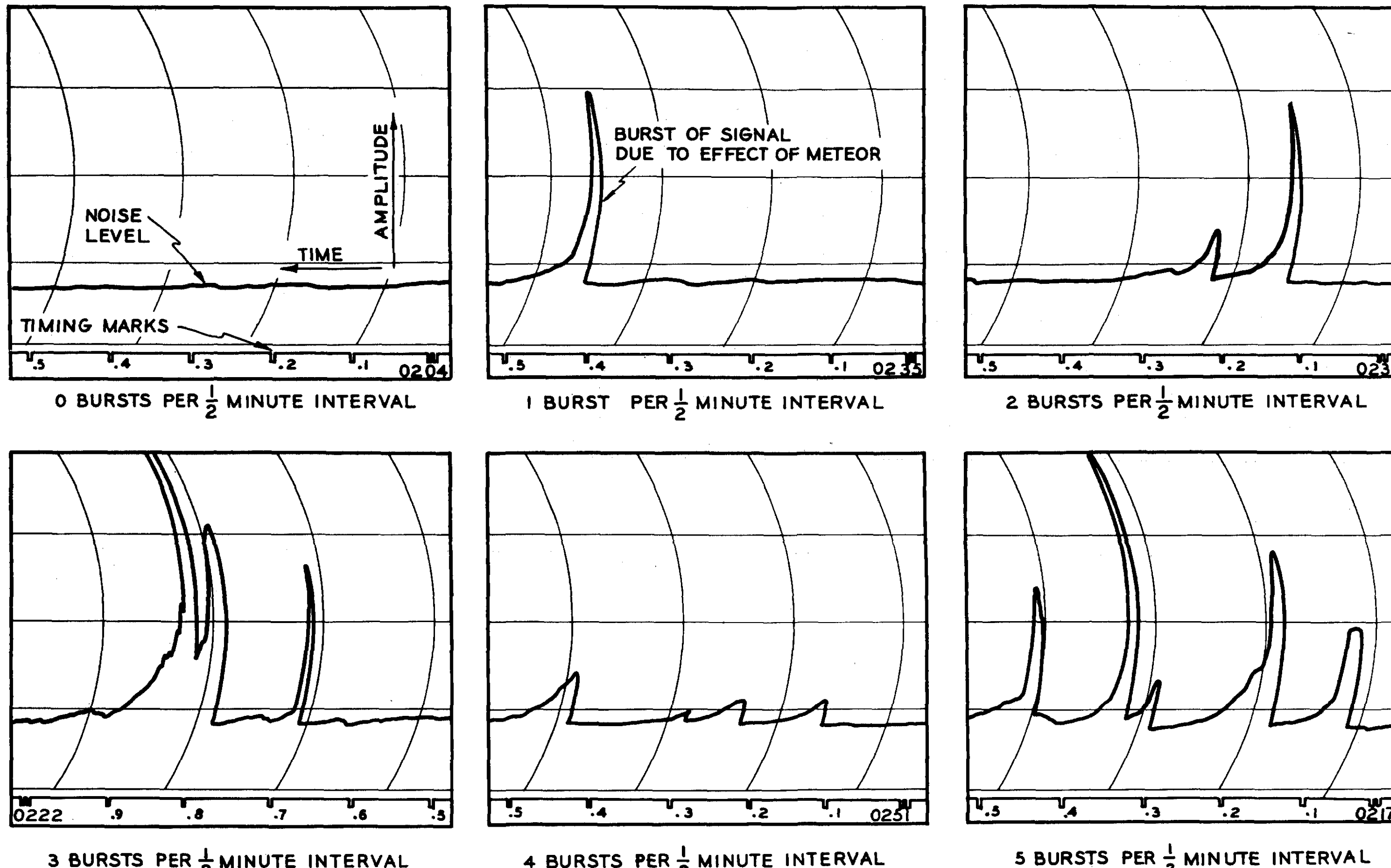

FIGURE 5. Typical meteor burst recordings.

that many bursts were obscured. On two nights bursts noted were too few, and on four nights they were too numerous. On the four nights the recording equipment was saturated much of the time, apparently caused by unrecorded showers. An analysis of variance indicated that on the two nights the probability of the occurrence of a burst in a given time interval was significantly low, while on the four nights the probability was significantly high when compared to the probability on the nine nights used.

The first hundred good intervals were used on each night's work. The reasons for not using all good intervals were twofold. On each night some intervals were always lost when large meteors came in and the resulting strong ionization saturated the recording equipment. No additional meteors could be detected until the effect of the large meteor had dissipated. Furthermore, some time between January 16, 1956, and January 21, 1956, the Bureau of Standards ceased to transmit for the five-minute interval from 0245 to 0250, thus eliminating ten intervals. It was impossible to have more than 110 good intervals and the number was always less than that. To achieve balance for all nights, it was decided to use only the first hundred good intervals. The results are shown in table 1.

TABLE 1

Bursts per interval in the first hundred good intervals

Bursts per Interval	Date, 1956									
	1/10	1/14	1/21	1/23	1/31	2/5	2/6	2/19	2/21	Total
0	24	26	26	23	26	20	21	33	24	223
1	36	36	41	33	35	39	39	39	29	327
2	22	22	22	19	19	23	18	16	22	183
3	14	9	6	10	14	10	13	4	18	98
4	3	4	4	4	1	3	6	7	6	38
5	1	2	0	7	3	3	2	0	1	19
6	0	1	1	4	1	2	0	1	0	10
7	0	0	0	0	1	0	1	0	0	2
	100	100	100	100	100	100	100	100	100	900
Total Bursts	139	139	125	176	147	154	155	117	156	1308

Table 1 shows that 25 percent of the intervals had no bursts in them; 36 percent had one burst; and 39 percent had two or more bursts in them. Four or more bursts were in 8 percent of the intervals. The number of intervals having a particular number of bursts did not vary greatly from night to night. The number of bursts in the first hundred good intervals varied from a low of 117 on February 19, to a high of 176 on January 23, so that there was some difference in the probability of the occurrence of a burst in an interval on the different nights. A test by the analysis of variance indicated that the difference in probability was too small to have significance. As was previously shown, there was no significant difference in the probability of a burst as the hour progressed. These two conditions are important since together they imply that the probability of a burst occurring within a given interval is independent of the time. This is an essential requirement for the Poisson distribution.

The theoretical frequency of intervals with no bursts, one burst, two bursts, three bursts, etc., is given by the Poisson exponential series. If the observed frequency of intervals with the various number of bursts closely parallels the Poisson frequency of intervals with the same number of bursts, the distribution of meteors is purely random. A comparison of the observed and Poisson frequencies is given in table 2.

Table 2 shows that the observed frequency is higher than the Poisson frequency at no bursts and at one burst per interval. At two bursts and at three bursts per interval the trend is reversed. At four bursts per interval the observed and Poisson frequencies are about equal. At five bursts per interval and higher, the observed frequencies are appreciably greater.

TABLE 2

Observed and Poisson frequency of intervals with the number of bursts indicated

Bursts per interval	Observed frequency of intervals	Poisson frequency of intervals	$\frac{(\text{Observed—Poisson})^2}{\text{Poisson}}$
0	223	210.41	0.753
1	327	305.80	1.470
2	183	222.21	6.919
3	98	107.65	0.865
4	38	39.11	0.032
5	19 }	11.37 }	17.770
6	10 }	2.75 }	
7	2 } 31	0.57 } 14.81	
8	0 }	0.10 }	
9	0 }	0.02 }	
			$\chi^2 = 27.809$

The last column of table 2 is Karl Pearson's (1900) criterion for determining whether the differences between the observed and Poisson frequency of intervals may be assigned to chance. The quantity chi square is

$$\sum_{1}^{n} \frac{(\text{Observed-Poisson})^2}{\text{Poisson}}$$

and the criterion gives the probability that the series represents fluctuations between the observed and Poisson frequencies that may reasonably be ascribed to random motion. The chi square for this series is 27.809 and the probability that it would result from chance is 0.00003. Not more than three times in 100,000 would a random arrangement produce the observed distribution of bursts. This demonstrates that the observed distribution is not random, and that on non-shower nights many clusters of meteors strike the upper atmosphere of the earth.

It should be recalled that on each night some intervals were rejected because the recording equipment suddenly became saturated and the strong ionization persisted through two or more intervals. The saturations were attributed to large meteors. It is entirely possible that the rejected intervals actually represented sizable clusters of meteors striking the upper atmosphere of the earth. It may well be that the clustering is even more marked than these data show.

The definition of a cluster must be entirely arbitrary. If a cluster is defined as a series of two or more bursts separated by the mean interval of 0.34 minutes or less, there were 186 clusters that entered the earth's atmosphere between 0200 and 0300 hours on the nine nights. The greatest number of meteors in a cluster was 20 and the average number was 4.14. The average duration of a cluster was 34 seconds and the average time between clusters was 1.55 minutes, or 93 seconds. At this stage we cannot say what our results mean as to the number of clusters that enter the earth's atmosphere daily. At present we do not have an opinion on the seasonal and latitudinal characteristics. Present results only show that during the early morning hours on non-shower nights the distribution of meteors striking the upper atmosphere of the earth is not random, but clustered.

Meteoric clusters must represent debris of some sort. The dimming and reddening of remote stars and star clusters indicate that the debris is distributed throughout space, and that most of the particles are very small. The particles of this discussion are the larger meteoric particles, large enough that their motion is controlled by gravity rather than radiation. It would seem that, in the main, the members of such a group would be following the same orbital path, thus indicating a common source for them. Since comets in the solar system are composed of gases and meteoric particles, many of the clusters must be of cometary origin. Due to the operation of Kepler's third law the swarm of particles in the head of the comet would, in time, be spread all the way around the orbit, and each year, when the earth comes close to the comet orbit, some of the particles would be drawn to the earth. Fragmentary groups of particles from extinct comets would also contribute to the influx of meteoric clusters. No one knows the origin of comets but their number is thought to be very great, so that the earth can be close to cometary orbits at all times. There is no generally accepted theory for the origin of meteoric particles. We cannot say how the clusters came into being, but observations show that they exist.

SUMMARY

The presence of meteors striking the upper atmosphere of the earth was detected by monitoring the 20-megacycle transmission of the National Bureau of Standards radio station WWV in Washington, D. C. over a 608 kilometer path. A meteor produces an ionization column which results in a burst of signal strength that cannot be explained by normal ionospheric propagation theory. A statistical study of the meteoric bursts occurring between 0200 and 0300 hours shows that the distribution of bursts is not random, but clustered. Visually noted clusters have been followed by the formation of sporadic E-type propagation. It is suggested that the ionized columns of a cluster unite to form a cloud of ionization, thus making possible the use of higher radio frequencies for more distant communication than would otherwise be possible. Observations show that meteoric clusters exist, but the origin of the clusters is not known.

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