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Automated Meteor Detection and the Leonid Shower

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ABSTRACT. A computer-automated radio system for monitoring meteor activity is described. The receiver is tuned to the frequency of a television video carrier whose transmitter is located beyond the horizon. The system registers only a weak signal except when the ion trail from a meteor reflects additional power to the receiver. A sudden power increase alerts the computer to a possible meteor. Our system employs a unique method for distinguishing between meteors and false alerts due to lightning and other noise. Using the receiver's audio output, a meteor echo is identified by increased audio signal autocorrelation, whereas electrical noise is recognized by a decreased correlation. The system has now accumulated more than a year of observations. The data show clearly the expected diurnal variation in meteor count rate, as well as most of the stronger meteor showers. We have also obtained evidence of some new showers. Analysis of the data from 1997 November 15–20 reveals Leonid meteor shower activity with a peak at November 17.5 ($\pm$0.2) UT or solar longitude 235°.3 ($\pm$0.2). Leonid meteors are of current interest because the shower may be building toward a supermaximum or "meteor storm" in 1998 or 1999.

1. INTRODUCTION

Radar permitted daylight meteor observations for the first time and led to the discovery of several intense streams of meteors. During the past few decades, various groups have monitored meteors with radar from time to time, and a good summary is given by Baggaley (1995). However, the variability of meteor showers from year to year, and the likelihood that the Earth will cross additional streams, suggests that observations should be made as continuously as possible. Such monitoring may even be important to the safety of humans and satellites in space and for predicting large impacts on the Earth's surface. Baggaley does not list any northern hemisphere observation since 1975, although he has run a southern hemisphere radar from 1990 onward. Part of the reason for the interrupted history of radar meteor observation is the expense of running a radar facility.

Forward scattering (FS) is another observational method similar to conventional radar. Although FS does not currently give precise orbital information on individual meteoroids, it is capable of monitoring meteor activity rates, and it is far less costly to run. This technique uses the meteoroid's ionized trail in the atmosphere to reflect radio waves like radar, but unlike radar the transmitter and receiver are beyond the horizon from one another. Our application of FS does not require a dedicated transmitter. There are broadcasting transmitters already operating in most population centers, so it is possible to use one of these.

The frequency should be high enough to ensure that the signals are not significantly reflected by the ionosphere, since it would be impossible to distinguish the signals reflected from the meteor trails. However, the higher the frequency used, the higher the electron density has to be in the trails to provide an adequate reflected signal. The bursts of reflected signal would be weaker, rarer, and of shorter duration. The best frequencies for detecting FS from meteor trails are from about 40 to 70 MHz. Fortunately, many countries have powerful radio and television stations broadcasting continuously in this frequency range, and they can be used in FS work.

Modeling of FS meteor returns has been carried out by Mawrey & Broadhurst (1993), and observations have been reported by Koseki (1990) and others. Computerized data acquisition has been accomplished more recently by Meisel & Richardson (1998). In this paper we describe the use of signal autocorrelation to enhance the quality of automated data acquisition, and we summarize observations of the 1997 Leonid meteor shower.

2. SYSTEM DESCRIPTION

Our Automated Meteor Counting Apparatus (AMCA) is illustrated schematically in Figure 1. We calibrated the

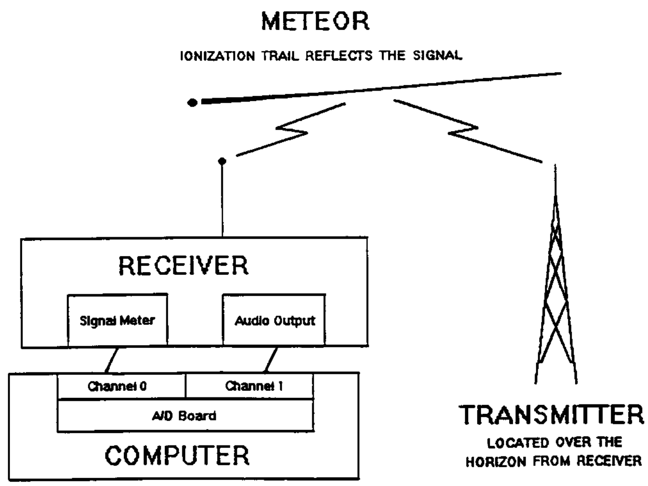

FIG. 1.—The AMCA system counts meteors by sensing radio transmissions reflected from their ionization trails.

automatic gain control (AGC) voltage of the ICOM R8500 receiver against input signal strength using an RF power generator standard. The AGC output is connected to a Data Translation DT2811-PGL analog-to-digital (A/D) board, which is polled at 10 Hz by a Pentium PC. A sudden signal power increase by 3 dB or more alerts the system of a possible meteor echo in progress. A meteor of visual magnitude 6 or 7 will trigger the system. A separate A/D channel is connected to the receiver's audio output. This interface serves to distinguish true meteor FS from other types of signal enhancements based on analysis of the audible tone. Spurious electrical activity such as lightning and circuit switching would otherwise be counted along with the meteor echoes and would invalidate the results. AMCA is unique in combining signal intensity with audio tone analysis for meteor echo detection.

The audio signal is sampled at 9000 Hz. After 0.1 s the samples are autocorrelated in order to find the frequency and power of the video carrier's tone. Broadcast signals usually have spectral structure, which produces peaks in the autocorrelation spectrum. Correlations of the data spaced from 12 to 24 samples apart are computed, thus covering the audio frequency range 375–750 Hz. Tones at high frequencies can also be recognized owing to aliasing. Because tropospheric refraction, ionospheric reflection, and ground diffraction will usually ensure the presence of a faint signal, the correlation coefficient will normally be small but positive (a few percent). This sampling and analysis is repeated at intervals of 10 s to update the reference correlation, which drifts with time.

Signal enhancements during the subsequent 10 s may be due to additional FS or noise. If such enhancements are detected, the analysis program tests them to establish their origin. If the signal increase is due to FS, the faint video carrier tone rises above the noise background and the correlation coefficient will increase. On the other hand, a signal enhancement due to electrical noise reduces the correlation, because noise is largely devoid of spectral structure. Thus, triggering due to a meteor may be distinguished from that due to noise by a comparison of the triggered audio correlation coefficient with that of the reference correlation. A flowchart of the system's logic and timing is presented in Figure 2.

During thunderstorms, lightning discharges can produce over 100 strong bursts of noise per hour. However, the incoherent nature of lightning and other forms of interference due to sparks and current interruption make it clearly identifiable and removable by means of the autocorrelation test. Audio autocorrelation therefore provides a powerful means of ensuring that the meteor count rates are uncontaminated by natural and man-made interference.

Signals reflected from aircraft show varying intensity due to changes in the reflection geometry. This can trigger audio sampling and will pass the autocorrelation test. However, they can be distinguished from meteor trail FS signals because they begin with a very small intensity echo, then gradually build to larger strength and greater variability. AMCA eliminates airplane echoes by requiring 1 s of quiet signal before allowing a trigger.

Our receiver is tuned to channel 3 at 61.24 MHz. Measured from our location at W76°8, N39°0, the nearest trans-

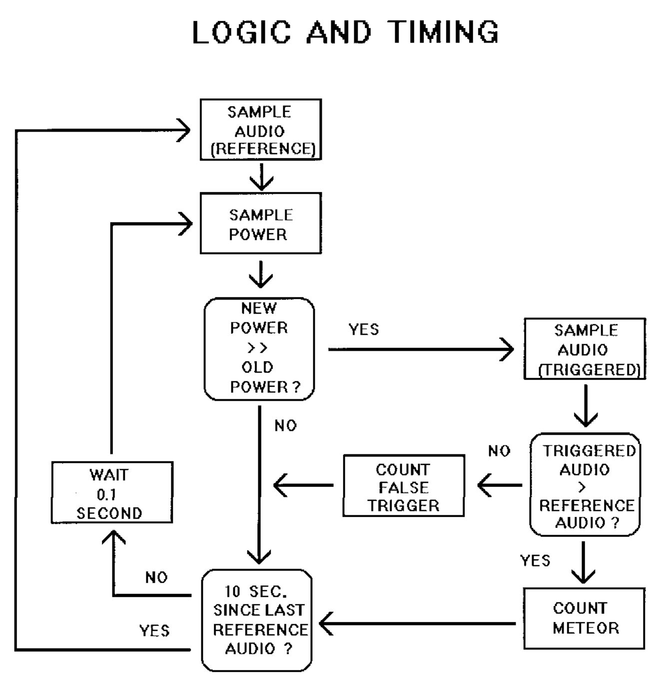

FIG. 2.—Timing and logic flow chart. The loop containing "sample power" and "wait 0.1 second" is at the heart of the system. If "new power ≫ old power?" is true, control is passed to "sample audio (triggered)." AMCA then compares the autocorrelation of the newly triggered audio sample to that of the latest reference to determine whether to count a meteor or a false hit.

mitter at this frequency is about 200 km away at azimuth 256°; however, it is a weak station of only 8 kW power. At about 500 km distance there are two 100 kW stations at azimuths 9° and 192°. The receiver rejects channel 3 broadcasts at 61.25 and 61.26 MHz.

3. OBSERVATIONS

The AMCA started operation in 1997 February and has run continuously since then. Figure 3 shows a plot of meteor count rates through 1998 January. The diurnal variation of meteor rates with local mean time is clearly visible. A maximum in rate would be expected at 6 A.M., when the apex of the Earth's motion around the Sun is highest above the horizon. This is the time when the observer is looking closest to the direction of the Earth's motion. At that time the meteors being observed include all those with velocities in the Earth's direction, plus those moving slowly enough to be overtaken. At 6 P.M., the antapex is highest above the horizon, when the only meteors seen would be those moving fast enough to overtake the Earth. At times between, intermediate situations exist. The fact that this method of meteor observation is biased toward a particular range of track positions with respect to the transmitter and observer does not mask this effect, which demonstrates its utility as a method of meteor counting. The hourly meteor count rate equals the hourly count divided by the duty cycle, which in turn is the percentage of time that the system passed the "1 s of quiet" criterion described in § 2. The data gaps in Figure 3 correspond to times when radio interference reduced the duty cycle to 10% or less and when the system was down for maintenance and testing.

The year of data reveals the presence of about 10 known meteor showers. There were also unexpectedly high meteor rates recorded during September 23–26, October 11–13, and November 25–27 when no strong showers are known. This activity may be due to outbursts from ordinarily weak showers or could be caused by the Earth encountering new meteor streams. A month-by-month summary is given in Table 1.

Figure 3 shows a fairly strong Leonid shower in November. There is always a chance that this shower will produce far higher rates of meteors for a few hours. These Leonid meteor "storms" have historically occurred at intervals of

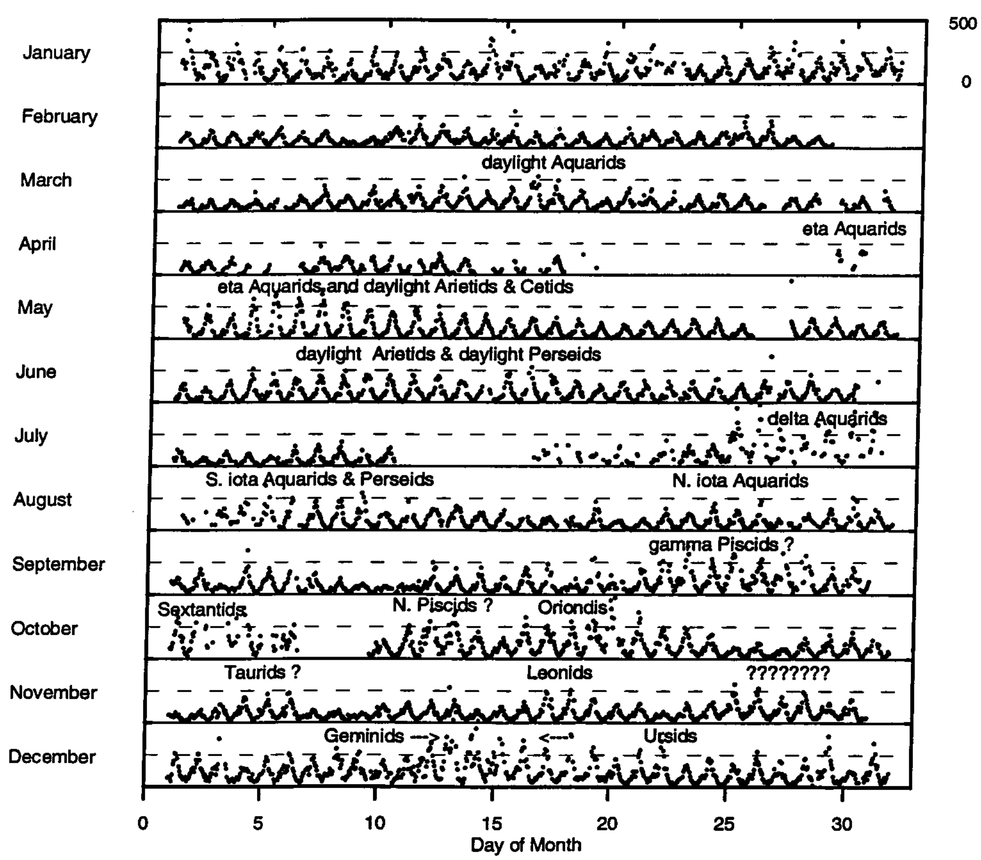

FIG. 3.—Meteor counts on a scale of 0–500 hr^{-1} reveal the diurnal cycle of activity. The question marks indicate possible new showers or uncertain identifications of known showers. The dotted arrowed lines for the Geminids bracket their observed duration. Also see Table 1.

TABLE 1

SUMMARY OF OBSERVATIONS

Month	Description of Meteor Activity Logged by AMCA
January	Activity is strong at times throughout the month. "Strong" in this table refers to a daily peak of about 250 meteors hr^{-1} or more.
February	Rates are less than in January. The counts provide a good sampling of the diurnal variation in sporadic meteor rates.
March	Strong activity from the 15th through the 17th is due to the March Aquarid daytime shower.
April	The period of data loss was caused by a noisy electrical component. There is evidence for early η Aquarid activity on the 29th and 30th.
May	Very strong activity early in the month is due to the η Aquarid stream as well as the daytime Arietids and Cetids. The daytime showers stay active throughout the month.
June	There is continued daytime activity. The Arietids and the ζ Perseids showers are particularly strong early in the month.
July	Rates are low from the 1st through the 10th. Ionospheric interference begins around the 10th. There is some evidence of the δ Aquarids from the 25th through the 31st amid continuing interference.
August..........	Interference from ionosphere is diminishing during the first several days. The southern ι Aquarids are evident from the 5th through 10th. The Perseids on the 11th and 12th are weak, owing to unfavorable geometry between the transmitter, receiver, and shower radiant. Enhanced activity from the 24th through the 26th is associated with the northern ι Aquarids.
September......	Activity is strong from the 23th through the 26th. There are no powerful showers at this time, but the activity could due to an outburst from the normally weak γ Piscid stream.
October	The very strong activity on the 1st is likely due to the daytime Sextantids. Interference from another computer prevented some data acquisition from the 2nd until the 8th. Activity is strong from the 11th through the 13th, when there is no major shower. The activity could be from abnormally high numbers of northern Piscid meteors. Orionid activity is strong again from the 16th through the 23d.
November......	The high rates on the 4th and 5th may be due to Taurid meteors. The Leonids shower produced more enhanced activity on the 16th and 17th. A third outburst beginning on the 25th is not attributable to any strong shower and suggests a new meteoroid stream.
December	Rates are elevated throughout this month. Geminid shower activity is very strong from the 11th through the 14th, extending 14 hours per day. The Ursids appear to be active on December 22.

about 33 years, but not every such interval produces one.[1] Since the last great storm was in 1966 (10^5 meteors hr^{-1}),[2] there is considerable speculation whether another one will be visible in 1998 or 1999 and at what date and time.[3] We performed the following analysis to investigate the most recent Leonid meteor activity.

Potential Leonid data from November 15–20 were removed from the other observations for that month. The non-Leonid data were binned into hourly samples to derive the average diurnal rate of sporadic meteors. Then the hourly sporadic function was subtracted from the data of November 15–20, leaving the contribution from Leonid meteors shown in Figure 4. Our observations show strong Leonid activity on November 17 with additional shower meteors on November 18 and 19. The diurnal variation of hourly rates during this time interval is consistent with the rising and setting of the shower radiant at our site, shown by the dashed line.

[1] See the Estimation of Meteoroid Flux for the Upcoming Leonid Storms page, produced by William Cooke, at http://see.msfc.nasa.gov/see/mod/leonids.html.

[2] See the Leonids page, produced by Gary Kronk, at http://medicine.wustl.edu/~kronkg/leonids.html.

[3] See the 1997 Leonid Model Prediction page, produced by Peter Brown, at http://leroy.cc.uregina.ca/%7Eastro/Leonids/Leo_5.html.

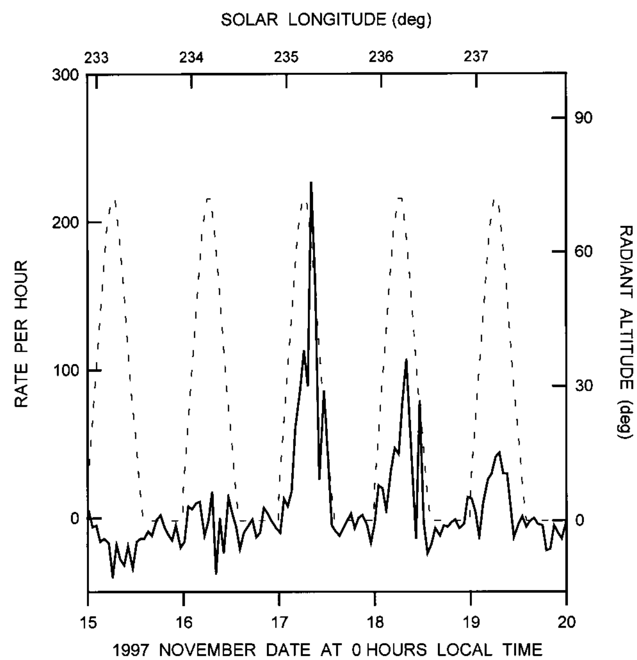

FIG. 4.—Leonid meteor rates (*solid line*) as a function of date and of solar longitude. The peak occurred on November 17 at about 08:00 local time or 13:00 UT. The altitude of the radiant in the sky is shown as a dashed line.

Predictions for the time of highest Leonid activity have been made by Yeomans, Yau, & Weissman (1996) based on the Earth's crossing through the plane of the orbit of the Leonid's parent comet, Tempel-Tuttle, and by Beech et al. (1997) based on numerical modeling of the Leonid meteor stream. The peak of the 1997 Leonid shower was observed to be on November 17 at about 13:00 (November 17.5) UT when the solar longitude at was $235^{\circ}.3$. We estimate the uncertainty at ± 4 hr or $\pm 0^{\circ}.2$. This compares reasonably well to the prediction of November 17 at 13:34 UT by Yeomans et al. and to that of November 17.32 UT by Beech et al.

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