Chapter 3

Meteors and Meteor Streams

Meteors and meteor streams are a fascinating subject to many amateur astronomers. Their sometimes spectacular transient appearance is like nothing else in astronomy. Although meteors do not emit radio waves, their highly ionized trains are quite efficient at reflecting VHF radio waves. In this chapter we look at the nature of meteors, their motions and origins.

Meteors occur when small dust particles enter the tenuous upper atmosphere at high velocity. Friction with the air molecules creates enough heat to vaporize the meteoroid and form an ionizing column of air in its wake. There is a constant sporadic background of activity, which is enhanced at certain times of the year when Earth passes through streams of particles.

Stream-based meteors appear to radiate in all directions from a small region of the sky known as the radiant. This is simply a perspective effect, in the same way that a straight motorway viewed from the center of a bridge appears to get narrower into the distance. The radiant is not, however, fixed. It moves constantly, usually drifting approximately 1°/day as Earth moves through the stream in its orbit around the Sun.

Meteor streams are named after the constellation in which the radiant is located (at peak activity). For example the Perseids are named after the constellation of Perseus, the Taurids after the constellation of Taurus. One odd one, though, is the Quadrantids, named after the constellation Quadrans Muralis, which no longer exists and is now part of Boötes.

In some cases more than one stream radiant occurs in a constellation, in which case the Bayer letter of the nearest bright star is added to distinguish it, for example the η Aquarids, and the δ Aquarids. Since meteor streams (often referred to as meteor showers) are the remains of comet dust left behind in the wake of a comet passing through the Solar System, a few showers are named after their parent comet. One example is the Giacobinids, named after the periodic comet 21P/Giacobini-Zinner.

In view of their cometary origin, streams can be aged to a certain degree by their rate profile and their duration. Recently deposited dust follows the comet orbit. The individual orbits of the particles are tightly packed close to that of the parent object. As Earth passes though a young stream the rate of activity builds quickly to a peak and sharply falls off afterwards. The duration may be measured in hours, or

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a few days. For older streams, non-gravitational forces such as interaction with the solar wind act to spread the orbits of the particles. These streams are much wider, and the resulting meteoric activity lasts for many days or even weeks. The build up to peak activity is slower and the tail is often afterwards extended. The Perseid stream falls into this category, where detectable activity begins in mid-July, but peak activity does not occur until around August 12.

We should point out here that the Geminid stream has been associated with the object 3200 Phaethon, which was classified as an asteroid. Phaethon is considered to be the dormant core of a comet that has used up all its volatile compounds. The association of meteor streams with parent objects is mainly based on the similarity of the particle orbits with that of the parent object. It is of course possible that Phaethon is just coincidentally in a similar orbit to now-dead comet that spawned the Geminids. The only way to be sure would be to compare the composition of Phaethon by either direct sampling or careful spectral analysis using the spectrum of Geminid meteors. The emission lines seen in meteor spectra clearly demonstrate the chemical composition of the objects.

Meteor streams are quantified by a figure known as the zenithal hourly rate, or ZHR. ZHR is a theoretical calculated value of the number of meteors that would be seen by a single observer on a perfectly clear and dark night if the radiant were placed at the zenith. It is used as a way of directly comparing the hourly rates of one meteor shower with another. Observational effects must therefore be removed from the observed rates. The observational effects to take into account are altitude of the radiant, sky transparency, sky brightness, cloud cover, and obstructions in the field of view.

The calculation of ZHR from observed rates is given by:

$$ZHR = \left(\frac{N}{t}\right)RLC$$

In this equation:

- N is the observed number of meteors
- t is the duration of the observing run in hours
- R is the correction factor for the altitude of the radiant
- L is the correction factor for limiting magnitude
- C is the correction factor for cloud cover or obstructions

Determination of R

Due to atmospheric extinction, which increases with decreasing altitude, the number of meteors observable per hour increases as the radiant rises in the sky, even if the actual rate of the stream does not change. In most cases a given radiant does not pass the observer's zenith, but an estimate can be made. The correction factor is

$$R = 1/\sin(\phi)$$

where $\phi = \textit{the altitude of the stream radiant in degrees}$

Due to the constant diurnal motion of the radiant, the count of meteors should be logged separately for each hour. The radiant altitude is then determined for the center of that hour.

Determination of L

For each hour of observation, the limiting magnitude should be determined in case the conditions slowly change. This reading should be taken at least every half an hour, and an average value used in the correction for that hour's rate. L is calculated from the following formula:

$$L = r^{6.5-LM}$$

where r is the population index for the meteor stream.

The population index for a stream is calculated from the distribution of observed magnitudes; a high value of r suggests a greater population of bright meteors. See the tables in the meteor calendar section. Older meteor streams become depleted of fainter meteors, leading to the higher r values. Younger streams have more of a balance of population across the visible magnitude range.

Determination of C

Where significant cloud cover exists, and only small regions of sky are viewable, rate counting is particularly inaccurate and is not feasible. Although an observing session may start out well, there may be periods when some cloud drifts over. An estimate of the fraction of sky obscured by cloud cover should be recorded for each hour observed. Then the correction C is calculated from

$$C = \frac{1}{1-x}$$

where x = the fraction of sky obscured. If x > 0.2 the ZHR will be unreliable.

Radio Scattering off Meteor Trails

As soon as the Second World War ended, scientists returning to civilian duties began using the equipment designed and built for the war effort. This included the adaptation and use of surplus radar equipment to study the properties of meteors. By transmitting a VHF signal, and observing the backscattering from meteor trains, it was possible to determine the velocity of meteors as they sped through the atmosphere. By then combining the results of a pair of radar units it was possible to determine their true path through the atmosphere, their velocity, and therefore their orbits.

A licensed amateur radio person could attempt to use radar in the same way, but the use of legal levels of output power would severally restrict the useful range, and the effort is unlikely to be very successful. However, the amateur can use forward scatter techniques to study meteors. Forward scatter involves the observer receiving reflections from meteors, where the transmitter is too far away for direct reception and is only heard when it is reflected from a meteor trail.

Although meteor scatter is possible in the HF spectrum, the ionosphere is also reflective there, too, which is counterproductive. The HF spectrum is particularly noisy, too. Best results are obtained from 30 to 100 MHz, although amateur radio enthusiasts regularly encounter activity at up to 145 MHz with reduced efficiency.

Traditionally Band I television transmitters were used by amateur observers, in the range from 51 to 83 MHz, but sadly, with the approach of the digital TV switch-over, these transmitters are disappearing in favor of UHF channels. At the time of writing there are still some operating in Europe and other parts of the world. It is still possible to use the broadcast band FM radio frequencies in the range 83–108 MHz, but lower frequency is still preferable.

Specular Reflection

Radio scatter off meteor trails is entirely specular, which means that the waves follow the same rules as light reflecting from a mirror. The same geometric rules apply, too, so the angle of incidence for incoming radio waves is equal to the angle of reflection as it leaves (see Fig. 3.1).

To understand what that means in practice for the observer, consider initially the case for radar observation. To receive an echo, the wave is transmitted from and received back at the same location, which has to be perpendicular to the path of the meteor (angle of incidence and reflection of 90°). The geometry of this situation is shown in Fig. 3.2.

The geometrical orientation for the radar observer can be imagined as a series of spherical shells, where the observer is at the focal point of the shell. The figure demonstrates that all members of a given meteor stream, whose paths by definition are parallel, generate echoes in a single plane, known as the echo plane.

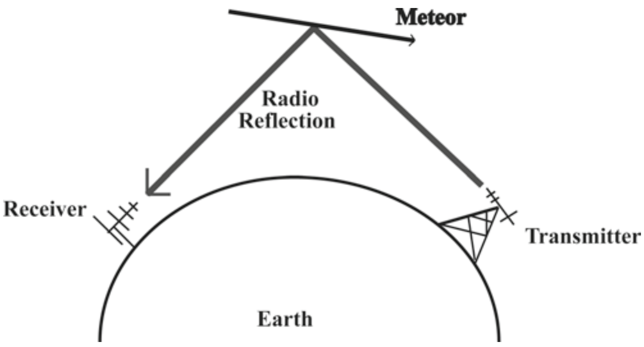


Fig. 3.1. Forward scattering of radio waves from meteor trails.

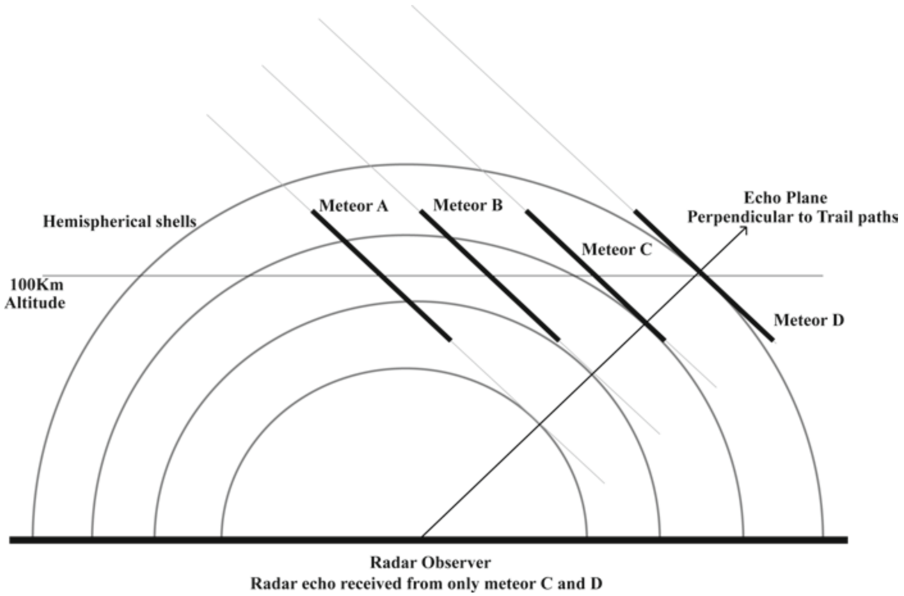


Fig. 3.2. In the case of a radar observer, only meteors occurring across the echo plane will be detected. Meteors A and B will not be seen. The echo plane is a great circle.

This echo plane projects a great circle onto the sky, so that the antenna could be aimed at any point along this great circle to receive data from meteor stream members.

The geometry for the forward scatter situation changes, however, to an ellipse where the transmitter is at one focus of the ellipse and the receiver is at the other focus (see Fig. 3.3).

If the observational baseline between the stations is fairly short, the distribution of reflection events will be fairly evenly spread along the ellipse. However, if the ellipse is long, there will be concentrations of observable echo activity nearer to the ends of the ellipse at locations both near to the transmitting focal point and to the receiving focal point. So by aiming an antenna at a quite high altitude at the receiving station these end point reflections will be obtained. However, this is not the best orientation.

Assume for a moment the sky is filled uniformly with meteor radiants, not such a bad assumption when observing sporadic background meteor activity. Reflections with the greatest signal power and duration will occur for meteors appearing over the midpoint between the transmitting and receiving stations. This is because the longer the baseline distance is between stations the greater will be the reflected power from a meteor occurring over the midpoint. This should not be too much of a surprise.

For example, take a clear pane of glass; when held perpendicular to your line of sight it is transparent. Now tilt the glass slowly. You can see some reflection from the surface. When the angle reaches a certain critical value it reflects all of the light.

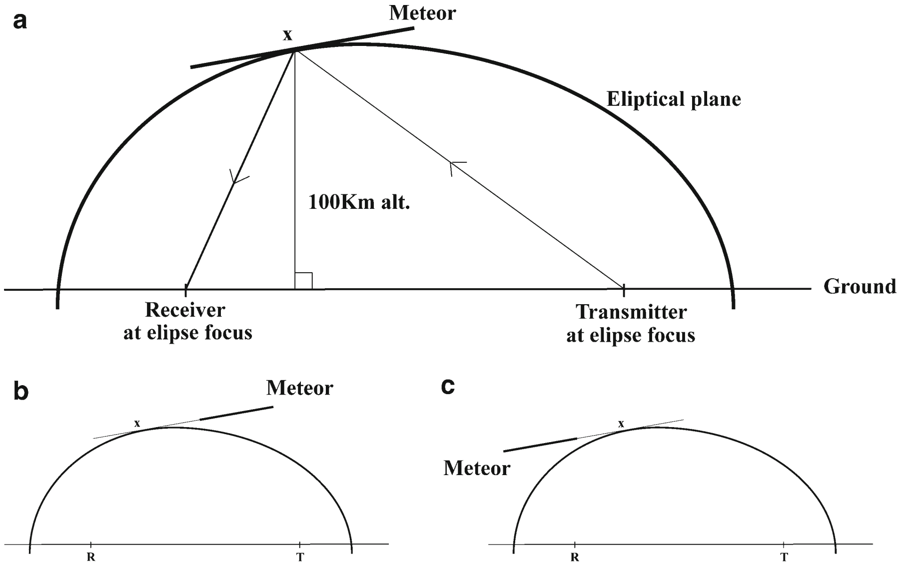


Fig. 3.3. In the forward scatter case, the echo plane is no longer (**a**) great circle. It is a band across the sky. The observer and transmitter are located at the focus of an elliptical shell, which passes through the meteor zone at an altitude of about 100 km. Only meteors occurring tangential to point x can be seen. The meteors in case (**b**) and (**c**) are not seen.

Table 3.1. Suitable antenna azimuth angles for some annual meteor streams (assuming a northern hemisphere location)

Meteor stream	Dates	Azimuth for antenna	Alternate azimuth for antenna
Quadrantids	Jan 1–4	N – NW	S – SE
η Aquarids	May 1–6	NE – E	SW – W
Arietids (daytime stream)	June 1–15	NE – E	SW – W
δ Aquarids	July 26–31	E – SE	SW – W
Perseids	Aug 10–14	NW – E	SE – W
Orionids	Oct 18–23	NE – SE	SW – NE
Leonids	Nov 14–18	NE – E	SW – W
Geminids	Dec 10–14	NE – E	SW – W
Ursids	Dec 21–23	NE – E	SW –W

The maximum amount of energy is then being reflected. This angle is relatively shallow, so in the sense of meteor forward scatter reflections this equates to a transmitting station far in the distance. However, taking into account signal attenuation due to traveling distance, there is a practical compromise on baseline distance. These midpoint reflections occur in two hot spots, roughly 50–100 km either side of the baseline center point. The echoes will be of stronger and longer duration than the end point reflections.

For example, a 1,200 km baseline would provide hot spot echo durations six times longer than a 600 km baseline. The durations over the 1,200 km baseline would be roughly 92 times longer than end point reflections.

In order to set up the equipment to efficiently study a specific meteor stream activity by radio, refer to Tables 3.1 and 3.2 The first table suggests suitable azimuth ranges for the major meteor streams. A suitable transmitter should then be

Table 3.2. Antenna altitudes and offsets for variations in transmitter range

Range to transmitter	Altitude for antenna	Azimuth offset (see text)
500	18	21
550	17	20
600	15	18
650	14	17
700	13	16
750	12	15
800	11	15
850	10	14
900	9	14
950	9	13
1,000–1,100	8	12
1,100–1,200	7	12
1,200–1,300	6	11
1,300–1,400	5	11
1,400–1,500	4	10
1,500–2,000	1	10

determined for the chosen direction. This should not be difficult for broadcast FM radio band, but could prove tricky for Band I TV signals..

Once the station has been chosen determine its azimuth bearing and range. To make this easier there are a number of websites that allow you to type in two locations and provide you with a bearing. Searching with your favorite search engine should easily find one. Bookmark it in your favorites for future use. You may even have a GPS tool that can do this for you. Table 3.2 then gives you the altitude for the antenna, and an azimuth offset from the bearing determined earlier. If the radiant has a positive declination, the offset is to the south, and if the radiant has a negative declination, the offset is towards the north.

This discussion only refers to using directional antennae such as Yagis, log periodic arrays, etc. Some observers successfully use omnidirectional antennae, which are vertically mounted and no special aiming is needed. A worthwhile experiment might be to set up two receivers, one with an omnidirectional antenna and one with a good directional Yagi antenna, and compare the results. It may take a few years of data gathering to determine whether activity of weaker showers is more noticeable in the results of the directional system.

Modeling of Meteor Radio Scatter

A mathematical model is a means by which scientists can learn more about physical processes occurring in nature. The mathematical model is generated based on observational evidence and theoretical ideas and is used to make predictions. The predictions are then compared with observations to see how closely they match reality. Close matches suggest at least the theory is correct; if not, the model is changed, and the cycle begins again.

The first attempts at modeling the specular reflection of meteor streams is the simplest to describe and works reasonably well for the extreme cases of underdense and overdense meteor trails.

Underdense Trails

As the name suggests underdense trails occur for smaller, low-energy meteor trails. The electron density responsible for the specular reflections is relatively low. This model makes several broad assumptions, as follows:

- The trail is a stationary, linear column of free electrons.
- Its diameter is small compared with the wavelength of scattered radio radiation.
- The column does not expand.
- The electrons do not recombine or diffuse.
- The trail is infinitely long.

Most of these assumptions are not true, of course. High-atmosphere winds will distort the trail. The trail will expand as it twists, electrons will recombine, and it can't be infinitely long. Only the second assumption is a good one.

Despite these drawbacks the model does work reasonably well for the extreme cases. The assumptions made are reasonable for the first few fractions of a second involved in radio specular reflection.

In the underdense case the model shows radio waves penetrate into the electron column and excite the electrons into physical oscillation. Electron collisions with other particles are assumed to be zero, so they do not recombine. Whenever an electron is subject to an accelerating force it will radiate radio energy; therefore electrons re-radiate in all directions. Secondary effects are also ignored, so that each electron acts as if there are no others around, although radio is scattered from all parts of the trail and electron-generated energy is emitted in all directions. Constructive interference only occurs in the direction predicted by geometric optics (for reflection off mirrors).

In fact, it turns out that the simple model is not that bad. It can explain the properties of the low energy underdense trails and the very high density overdense trails, but it breaks down for the intermediate cases.

Radar echoes from underdense trails have a fast rise time, a short plateau, and an exponential decay. If the radar system is coherent (so that the transmitted pulses are always in phase relative to each other), the reflections maintain the phase of the pulses. The plateau in the received echo will then exhibit oscillations (caused by interference) on a millisecond timescale, which contains useful information about the velocity of the meteor.

The model only works for a short length of trail centered on the closest point of contact to the receiver. This is not a problem, because the extreme ends of the trail contribute little to the received echo. The model successfully demonstrated that the received echo power will increase with increasing wavelength (decreasing frequency).

The Overdense Trail

For high electron densities, the central core of the trail will be plasma or close to it. In a plasma the electrons are entirely stripped off the atoms. In this case radio energy can't penetrate into the trail and is scattered from the surface. The classical model assumes the electron density is uniform across the trail, but in practice it has a Gaussian distribution across the diameter.

The above assumption does not take into account penetration of radio into the lower density outer regions, or the effect of winds distorting the trail.

In the most extreme cases, the radius of the trail is significant, which means the amount of reflected power for a radar system is directly proportional to the radius of the cylinder. However, this breaks down for lower energy overdense trails, where the radius is small. This model is less useful in the forward scatter case, where extreme reflection angles are often involved.

The definition of an overdense meteor trail is when the electron density exceeds 2.4×10^{14} electrons per meter length of trail. The classical theory works well except for the transition region between the underdense and overdense case. The full wave theory gives overall better results but is much more complex.

Forward Scatter Radio Reflections

The previous discussions on underdense and overdense meteor trails were based on theory developed for backscatter radar observation methods. In this section let us consider the radio reflection by forward scatter. As amateur astronomers this is our only means of studying meteor activity by radio.

Figure 3.4 shows two reflected signals from a meteor trail. Trail y has a longer distance to travel than trail x, but they were both emitted from the same source at the same time, so they started out in phase. However, the different path lengths

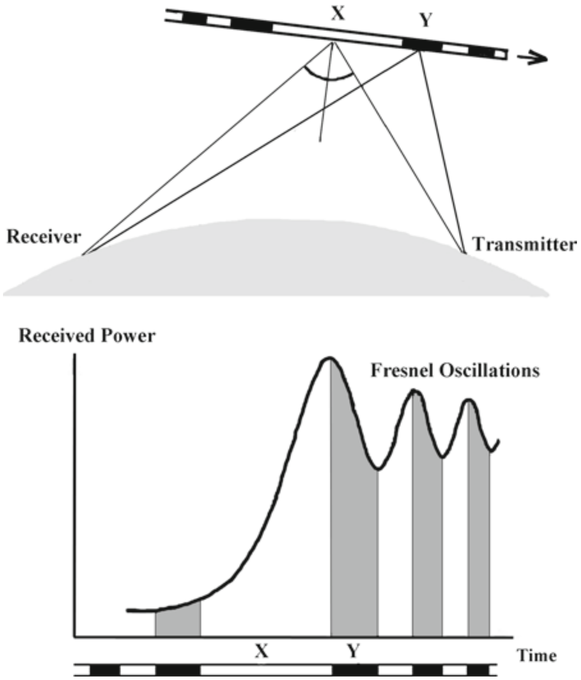


Fig. 3.4. Fresnel oscillations. When multiple reflections are received from different parts of the same meteor trail, interference occurs. When the total path length (in units of radio wavelength) of x and y are similar, reinforcement occurs, and when they are different minima occur.

from the different reflection points mean the radio energy can arrive in phase or out of phase. The receiver therefore sees an interference pattern.

A radio echo first quickly rises to its peak power level. Then as it develops it oscillates and decays. The regions of meteor trails producing in phase and out of phase reflections are known as Fresnel zones. The spacing of the Fresnel zones, and therefore the associated oscillations, carry information about the velocity of the meteor. As in the case of backscatter systems, the measurement of the oscillations requires the data capture system to have a sampling rate of at least 1,000 times/s. The full geometry of the reflection path must also be known to calculate the meteor velocity.

In practice the determination of the oscillation frequency is made much more difficult due to several factors. Distortion or break up of the trail by winds alters the angles of reflection and the resulting interference pattern (mainly affecting long-duration overdense trails). Also deceleration of the meteoroid and the diffusion of the ionized particles complicate matters.

Diffusion of the particles in the trails of meteors will be greater for higher altitudes because the lower density of the atmosphere allows for a greater mean free path for particles. The initial radius of the ionized trail will therefore be greater at higher attitudes than lower down. Taking the case of an underdense high altitude meteor, the initial radius of the trail may be large in comparison to the wavelength of radio frequency used to observe it, thereby seriously reducing or even preventing reflection. This means there is a maximum altitude beyond which it is impossible to detect underdense meteors, known as the echo ceiling. Small, fast meteors that begin their ablation at high altitudes are discriminated against in radio observation techniques. Overdense trails are not affected, because the reflection is from the surface of the trail, and not from within the body of it.

Forward scatter methods have an advantage over radar techniques in that reflection is detectable from underdense trails with a larger radius, and therefore higher altitude.

For a more in depth coverage of the physics of meteor trails and radio scattering refer to the book *Meteor Science and Engineering* by D.W.R. McKinley, which is still one of the best sources available despite its publication date of 1961.

Setting Up a Meteor Scatter Radio Receiving Station

Choosing a Receiver

The radio should be capable of receiving VHF channels from 30 to 108 MHz or even higher. Ideally, it should be a multimode receiver, in other words, capable of receiving signals modulated in the following ways: amplitude, frequency, single sideband (upper and lower), and CW (or Morse). It is important the receiver be sensitive, selective, and stable. For more information on these subjects refer to the radio theory chapter of this book, where receiver specifications are discussed in detail. Model-specific advice may be obtained from local amateur radio clubs; by getting involved in these groups you may be able to try before you buy.

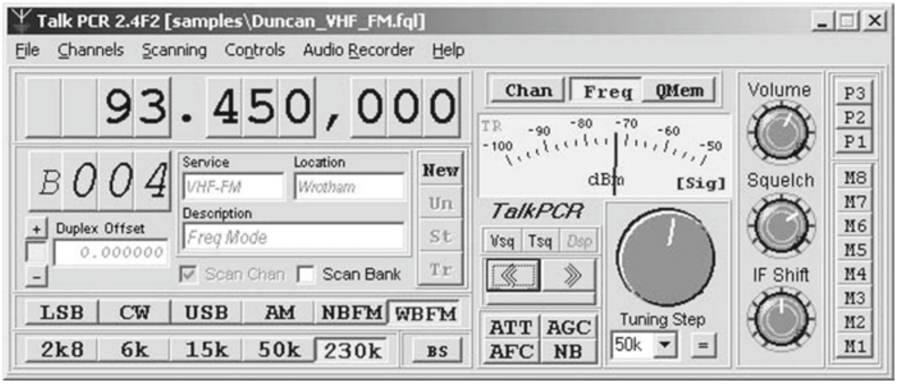
As an alternative to obtaining a wide band receiver, a good quality traditional communications receiver – often called short wave receiver (which covers frequencies up to 30 MHz) – may be used with the addition of a frequency converter to allow it to be used for VHF work. Ideas for constructing frequency converters are covered in the later project chapters of this book. This author, for example, has an Icom IC707 HF amateur radio transceiver. Although this can only transmit on legal amateur bands, it can receive continuously up to 30 MHz. It made sense to construct a frequency converter for meteor scatter experiments. The receiver is stable and multimode capable. So long as the frequency converter is also stable it makes a useful platform for many experiments.

Although there are many receivers on the market capable of receiving HF, VHF, and UHF bands, not all offer multimode options. Some of the receivers (often referred to simply as scanners) don't offer all the modes in all the bands; for example, single side band mode may not be available for the commercial FM broadcast frequencies but present on the HF bands. Clearly there is logic there. No one transmits side band channels in the 88–108 MHz region!

A useful receiver for many radio projects would be the Icom PCR1000. It is a computer-controlled radio covering a wide range from low kHz up to 1,300 MHz and fully multimode. It is not restricted in the VHF bands – any mode of reception can be selected. Many meteor scatter observers use these radios. Sadly it is no longer manufactured. The most important feature for radio work, the AGC (Automatic Gain Control) on/off feature, is not present in its successors, the PCR1500 and PCR2500. The later models list the AGC function as fast or slow, but not off. It should still be possible to easily source a PCR1000 from second-hand dealers, on line auctions, or private sales through amateur radio clubs or magazines.

The ability to switch off automatic gain control is very important in radio astronomy. AGC alters the signal amplification based on signal strength. We need to monitor the raw signal without any compounding instrumental effects (Fig. 3.5).

In order to gain some experience before committing to buy a good multimode receiver, you can start with a good-quality broadcast band FM receiver. You may already have one. While testing such receivers for this book, I needed to make a quick modification to the receiver so I could adequately connect it to my antenna. The Antenna available was a log periodic array, a type of broadband but directional antenna. The fitting was N type, as the antenna was suitable for use up to 1,300 MHz, where the quality of the N type connector was needed. However, the receiver had the standard coax socket of the type only used by commercial FM receivers and hi-fi systems. Since the receiver was obtained free of charge from a friend and was not used for regular listening, I was happy to modify the unit for its new found use. The coax socket was removed and replaced with a chassis mounted BNC socket. A suitable length of coaxial cable was at hand, to which was fitted a BNC plug at one end and an N plug at the other. I always carry some spare coax and a range of plugs for just such eventualities. Experiments during the Perseid meteor shower yielded some success in picking up strong reflections. I took the audio output of the radio to a PC sound card and used Spectrum Lab software to observe it. The interesting thing was I got inverted traces! The average level dropped when an echo was received. This was due to the high level of background hiss you get from an FM receiver when no signal is received. This generated a fairly constant background trace on the audio spectrum. When an echo was received a


Talk PCR 2.4F2 [samples\Duncan_VHF_FM.fql]

93.450,000

B004

Service: VHF-FM

Location: Wrotham

Description: Freq Mode

Duplex Offset: 0.000000

☑ Scan Chan ☐ Scan Bank

Tuning Step: 50k

Fig. 3.5. The Icom PCR-1000 and its software control interface.

short burst of radio signal from the station was heard with a very quiet background level, so the average noise dropped. Spectrum Lab is a very useful piece of software, and its use is discussed in later chapters of this book.

The Antenna

The antenna in any radio system should be of the highest quality, or constructed with the greatest of care and attention. A good antenna constructed specially for the operating frequency and carefully impedance-matched to the receiver will most efficiently pass collected radio signals into the receiver. For more information on choosing or building antennae refer to the antenna chapter of this book. Use Yagi's if you set up a station for a fixed frequency and orientation. If, however, you plan to optimize the antenna aiming in order to best study individual meteor streams, it would be an advantage to use an antenna with a wider frequency bandwidth, such as the log periodic array.

Choosing a Radio Channel

The website http://www.ukwtv.de/tvlist, which at the time of writing was last updated in 2001, contains a listing of a large number of television transmitters around the world. Some further research, however, will be needed to determine whether a given channel is still operating on the lower bands. Another useful source of channel information is the World radio and TV handbook (WRTH), which is published annually. If you are planning on trying the FM broadcast band from 88 to 108 MHz band, the following website is useful for selecting frequencies: http://www.fmlist.org.

Observing Technique

It is important initially when establishing the meteor scatter station that you take time to listen manually for meteor activity. Only by doing this and learning what genuine echoes sound like can you then set up an automated way of counting these events. It is useful to be able to listen to and log data simultaneously, so that the echo profile of genuine events can be seen and heard. This is straightforward when using a PC sound card as the analog to digital converter interface. The PC is the only way to constantly capture and analyze data.

The reason why a multimode radio receiver is recommended for this work is because you need the single side band (this may be upper side band USB, or lower sideband LSB) mode of operation. Nearly all SSB receivers also have at least AM mode alongside, and some have FM, too. We will use the SSB mode regardless of the type of modulation employed by the transmitter, which in most cases will be frequency modulated.

The key thing to remember here is that you are not trying to receive the channel in the normal way. In fact this is not helpful. You want to study the reflection profile of meteor trails. The desired source transmission is an unmodulated carrier wave whose amplitude is constant. That way any changes in amplitude received is due to the properties of the echo. An FM radio or TV channel carrier wave has constant amplitude. An SSB demodulator is based on a form of amplitude modulation; the difference is that an SSB signal has no carrier component. The "carrier wave" is regenerated inside the receiver by what is sometimes referred to as a beat frequency oscillator. The beat frequency oscillator signal is mixed with the radio frequency, generating a sum and a difference of the two (see the radio theory chapter in this book for more information on mixers).

When the adjustable beat frequency oscillator is set close to but not quite equal to RF signal the difference result is an audio tone. The pitch of the tone depends on how close the beat oscillator is to the RF signal. (In practical receivers the demodulator does not work on the original radio frequency but on an intermediate frequency, which is usually lower. The same principle applies because the IF frequency contains the same information as the higher radio frequency.)

So the method of using an SSB receiver to monitor FM channels will provide a tone when a meteor echo occurs. This tone sounds like the "pling" sound of a tuning fork for underdense trails. And can sound like a "bong" sound for overdense trails. The intermediate case known as a transition echo can start out like an overdense dense case, but then it begins to oscillate as it fades.

Underdense trails are generated by fainter meteors, the kind that would be at the limit of visibility to the naked eye, or below. The overdense and transition events are caused by meteors that would be easily visible. However, this is not to say you would be able to see the meteor that creates the overdense trail, if you are observing the midpoint hot spots. These events will be occurring a few 100 km away from you and would not be directly visible, as they would be attenuated by atmospheric extinction close to the horizon.

On the whole the fainter meteors far outnumber the brighter events, so underdense echoes are the most common. In a few rare cases it is possible to observe the head echo of the meteor, which sounds like a descending pitch whistle caused by the Doppler shift of the signal. This is usually followed by either a strong underdense echo, or the bong of an overdense event.

The previous discussions fully rely on the SSB observing technique. Using a conventional FM receiver makes this impossible, and only rate-counting studies can be done. The brief reception of audio from the transmitter is compounded by the variability of the speech or music contained in the signal.

Automating the Observations

Clearly a full 24 h, every day of the year data capture system must be able to automatically reduce and store the data. Old-fashioned methods of data capture such as paper chart plotting requires manual interpretation. The data will accrue far quicker than it can be reduced manually!

The only feasible way to capture and analyze meteor data is by using a computer. One method involves a standard sound card as an audio analog-to-digital converter. The specification of the computer is not at all critical. Older PC's such as Pentium II, III, and IV-based systems can easily be obtained cheaply and sometimes even free of charge. These can be dedicated to one task of logging and analyzing radio astronomy data. At the time of writing this author has eleven computers, several of which are simply in store waiting for tasking.

Software to analyze the collected data could be custom written. Consider using National Instruments LabVIEW software, as well as Mathworks Matlab software and an open source language called Processing. Full discussion of these packages (free alternatives are Octave and Python using libraries such and numpy and scipy) is beyond the scope of this book, but they offer very powerful tools for data capture and signal processing. The software probably best to begin with is Spectrum Lab written by German amateur radio enthusiast Wolfgang Buescher, whose amateur call sign is DL4YHF. The software is freely available from his website: http://freenet-homepage.de/dl4yhf/spectra1.html.

Spectrum Lab is an audio spectrum analyzer and has a built-in scripting language that can be used to identify meteor echoes, count them, and even save a portion of the audio spectrum where specific conditions occur. See the chapter on data logging for details. Andy Smith is a keen active amateur radio astronomer in the UK who is constantly monitoring meteor activity. He offers assistance for this on his website: http://www.tvcomm.co.uk/radio/how-to.html.

The basic principle in setting up spectrum lab to log meteor activity is to define an amplitude threshold condition. When the signal exceeds this threshold value then it can increment a count value. Its duration can be determined and its spectrum recorded. This could pose a problem for transition meteors. The strong oscillations present in the signal may drop below your chosen threshold, and each oscillation may then be counted as a different meteor. The FM receiver technique may also give you inverted traces, because the background hiss of the FM receiver drops away as each piece of radio transmission is received.

There are times when meteor rate counting will be impossible. The phenomena known as Sporadic E and D layer scattering can create reflections for VHF signals that are not associated with meteor activity. Certainly where continuous reception for many minutes (say more than 15 min) is concerned it is most likely due to Sporadic E. This is caused by unusual ionization levels in the E layer of the ionosphere. Although it can occur almost any time of year, it is more common in the summertime during the day. For northern hemisphere observers the probability of occurrence peaks in June, reducing in July and August. During these spells VHF propagation is significantly enhanced for up to several hours at a time, and stations that would not normally be heard can appear as if they were transmitted locally.

Another possible noise source to watch out for is thunderstorms. You can't rely on hearing thunder, either, because the radio noise from thunder can propagate just as well as meteor echoes. This may cause an error in a rate-counting system. Although the audio spectrum of thunder will look very different than that of meteors, it is still hard to discriminate by profile in an automated way.

One way to avoid the confusion is to simultaneously log an empty radio frequency in the range of 2–10 MHz. Where an event occurs simultaneously at both frequencies then thunder is the most likely cause, and this should not be counted by the software. The use of the left and right channels of one sound card can allow both to be monitored together.

How to Confirm If Your System Is Working Properly

When you first set up a new system, you need to be sure it is working correctly. As mentioned earlier both listening and logging can help to confirm this, but you are not always going to be there listening. Are there significant random sources of noise? Is thunder a problem? Tropical areas suffer from regular thunder activity at certain times of day and year.

Well, meteor activity is clearly not uniform throughout the year. You will expect the peaks of activity near stream maxima, but there are other more regular variations in meteor detectability. Firstly there is a significant diurnal variation. Peak activity is expected between midnight and 6 a.m. Rates then fall throughout the day up to 6 p.m., and then they begin rising again.

The reason for diurnal variation is simple. The observer's hemisphere is facing the direction of motion of Earth in its orbit at night. The relative impact velocity is therefore enhanced, generating more friction and greater levels of ionization. The effect occurs for both visual and radio observers.

The second variation is annular, with increased rates of sporadic meteors in the 6 months from July to December. The increase is fairly small compared with the diurnal variations, about 1.31:1. Part of the reason for the annular changes is known as the apex of Earth's way. It is the projection of Earth's orbital motion against the sky and is approximately 90° ahead of the Sun. So that in the latter months of the year this appears in the observer's nighttime sky with again enhanced impact velocities. However, even after removing these effects, there is still a component of annular variation in sporadic rates that is due to the non-uniform distribution of meteoric particles in the vicinity of Earth's orbit. This is weak evidence towards the cometary origin of sporadic meteors.

The Annual Meteor Streams

The International Meteor Organization (IMO) maintains a working list of meteor streams and publishes an annual calendar of the observational prospects for that year. The aspects of observability are aimed mainly towards the optical techniques. Clearly radio astronomy is unaffected by moonlight or even daylight. The working list does not cover all known streams. The weaker ones, which are difficult to observe visually are omitted. Radio detection at low frequencies of around 30–50 MHz are particularly good for detecting underdense (as well as overdense) trails from meteors that would be missed by visual techniques. Sadly, the higher frequencies in the range of 88–108 MHz are not very good for detecting underdense events and will almost exclusively yield overdense results.

Annual Meteor Calendar

The table data included in this section is an attempt to gather a list of potentially observable meteor streams. Where no ZHR value is provided it means that visual observation is very difficult, and rates are extremely low. Those streams in the gray bars are either daylight-only streams or those primarily studied only by radio techniques. Observation of weak streams by radio is most effective with radar equipment, but group studies with forward scatter techniques may prove useful.

The radio meteor data presented are the results of forward scatter observations supplied by Andy Smith G7IZU, a UK-based observer. Comparison of activity from month to month should be done with care. Notice at the right hand side of the diagram is a color scale. The calibration of this color scale changes from month to month. The red end of the spectrum denotes peak hourly rates for that month only and will change from month to month. The consequence of this for a month containing major activity such as January is that weaker activity is subdued somewhat. The diagram is known as a colorgram and is a format used by the informal group based around the website http://www.rmob.org. Software is available from that site to convert text-based data to colorgrams, and observers are encouraged to submit their results.

January

Name	Dates	Peak date	Radiant R.A. hour (s: minutes)	Radiant Dec. (degrees)	Speed (km/s)	HR	Population index
α Aurigids	Dec 11 – Jan 21	Jan 1	05:08	+35			
α Quadrantids	Jan 1–5	Jan 4	15:20	+49	41	120	2.1
α Velids	Jan 1–15	Jan 5	08:20	47	35	2	
α Geminids	Dec 28 – Jan 28	Jan 8–9	07:12	+32			
α Crucids	Jan 6–28	Jan 15	12:48	−63	50	3	
Jan Draconids	Jan 10–24	Jan 13–16	16:23	+62			
η Craterids	Jan 11–22	Jan 16–17	11:44	−17			
Jan Bootids	Jan 9–18	Jan 16–18	15:04	+44			
δ Cancrids	Jan 1–31	Jan 17	08:40	+20	28	4	
α Hydrids	Jan 5 – Feb 14	Jan 19	08:52	−11	44	2	
η Carinids	Jan 14–27	Jan 21	10:40	−59		2	
Canids	Jan 13–30	Jan 24–25	07:27	+10			
α Leonids	Jan 13 – Feb 13	Jan 24–31	10:24	+9			
α Carinids	Jan 24 – Feb 9	Jan 30	06:20	−54	25	2	

January is generally a quiet month for meteor activity, with the exception of the Quadrantid meteor stream in the first few days of the month. The peak activity occurs around solar longitude 283.2°, falling in the early hours of January 4. The peak is short and sharp – the time to decline from peak rate to half peak rate is only about 4 h. For this reason, visual observations can be completely clouded out for the whole year for a single observer. Cloud has no effect on radio detection. ZHR reaches a peak of around 120 for visual observers (Fig. 3.6).

Attributing a parent comet to the Quadrantid stream has proved difficult, owing to the relatively rapid evolution of the stream caused by perturbations by Jupiter near the aphelion of the particles' orbit. Over the last 2,000 years the stream orbit has oscillated back and forth and for some time did not intersect with the orbit of Earth. Z. Kanuchova and L. Neslusan of the Slovak Academy of Sciences published

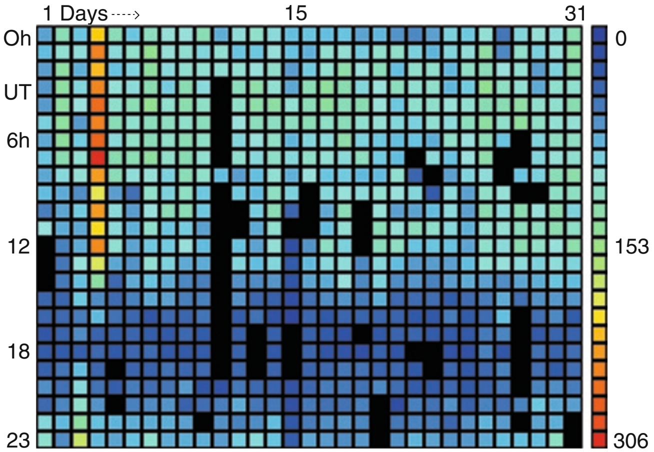


Fig. 3.6. Radio meteor rates for January 2008. Clearly the Quadrantid meteor stream dominates activity in January. *Black squares* indicate times when no data was recorded. (Image courtesy of Andy Smith G7IZU).

a paper in 2007 suggesting the possibility of two objects being parents to the Quadrantids: Comet 96P/Machholz and asteroid 2003 EH1. Uncertainties in the long-term orbital elements and non-gravitational effects meant it was not possible to determine which of the objects is in fact the true parent. Evidence suggested that comet Machholz and asteroid 2003 EH1 may have been a single comet that split, although this is almost impossible to prove.

February

Name	Dates	Peak date	Radiant R.A. (hours: minutes)	Radiant Dec. (degrees)	Speed (km/s)	ZHR	Population index
Capricornids	Jan 13	Feb 1	19:56	−15		15?	
Sagittariids	Feb 28						
δ Velids	Jan 22 – Feb 21	Feb 05	08:44	−52	35	1	
Aurigids	Jan 31 – Feb 23	Feb 5–10	~04:56	~+42			
α Centaurids	Jan 28 – Feb 21	Feb 07	14:00	−59	56	6	2.0
β Centaurids	Feb 2–25	Feb 8–9	13:52	−58			
ο Centaurids	Jan 31 – Feb 19	Feb 11	11:48	−56	51	2	
χ Capricornids	Jan 29 – Feb 28	Feb 13	21:04	+21	27		
Centaurids	Jan 23 – Mar 12	Feb 21	14:00	−41	60	4	
δ Leonids	Feb 15 – Mar 10	Feb 24	11:12	+16	23	2	3.0
σ Leonids	Feb 9 – Mar 13	Feb 25–26	11:17	+14			

There are no major showers in February, but some sources refer to the February to April period as being fireball season. The Capricornids/Sagittariids is a daytime stream only detectable by radio means. Forward scatter detection is challenging, though. There is some recent evidence from the group observations submitted to the International Meteor Organization there is a peak around February 1 at 9:00 UT (Fig. 3.7).

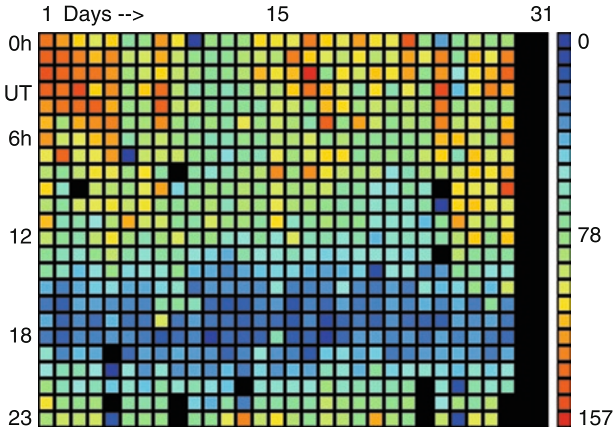


Fig. 3.7. Radio meteor activity for February 2008. Compare this data with the preceding month of January, and it appears there is much more going on in February. This is in fact not true. There is no major activity. The color scale is somewhat stretched; the peak rates this month of 157 per hour are almost half the January peak of 306. (Image courtesy of Andy Smith G7IZU).

The χ Capricornids are also a daytime stream, with evidence of peak activity occurring around 10:00 UT on February 13; once again detection by forward scatter will be challenging, so try it!

There is a question whether the Aurigids are still observable. Historically it was known for bright fireballs, with average magnitude of stream members in the range 3–5. In recent years radiant determination has proved difficult due to low observed rates.

March

Name	Dates	Peak date	Radiant R.A. (hours: minutes)	Radiant Dec. (degrees)	Speed (km/s)	ZHR	Population index
ρ Leonids	Feb 13 – Mar 13	Mar 1–4	10:44	+7			
π Virginids	Feb 13 – Apr 8	Mar 3–9	12:08	+3		2.5	
Leonids/Ursids	Mar 18 – Apr 7	Mar 10–11	11:06	+28			
γ Normids	Feb 25 – Mar 22	Mar 13	16:36	−51	56	8	2.4
March Aquarids	?	Mar 15–18	22:32	−8			
δ Mensids	Mar 14–21	Mar 18–19	03:40	−80		1	
η Virginids	Feb 24 – Mar 27	Mar 18–19	12:20	+3		1	
β Leonids	Feb 14 – Apr 25	Mar 19–21	11:48	+11		3	
θ Virginids	Mar 10 – Apr 21	Mar 20–21	12:56	−2		1	
δ Pavonids	Mar 11 – Apr 16	Mar 30	13:00	−65	31	5	

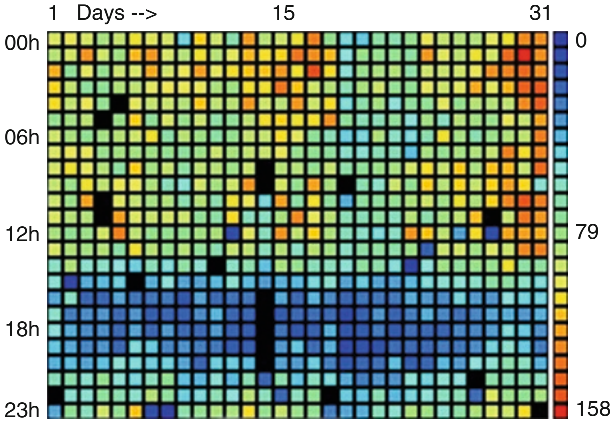


Fig. 3.8. Radio meteor data for March 2008. (Image courtesy of Andy Smith G7IZU).

March is another weak month for meteor observing generally. The Virginid streams are all interrelated and are often referred to as the Virginid complex, which occurs over a 4-month period from February to May. Activity is weak visually, and the extended period of activity makes it difficult to isolate stream activity from sporadic background in forward scatter radio studies (Fig. 3.8).

The March Aquarids is another daylight stream that is little understood and requires more observation.

April

Name	Dates	Peak date	Radiant R.A. (hours: minutes)	Radiant Dec. (degrees)	Speed (km/s)	ZHR	Population index
τ Draconids	Mar 13 – Apr 17	Apr 1–2	19:00	+69			
Librids	Mar 11 – May 5	Apr 17–18	15:28	−16			
δ Pavonids	Mar 21 – Apr 8	Apr 5–6	20:12	−63			
α Virginids	Mar 10 – May 6	Apr 7–18	13:36	−11			
γ Virginids	Apr 5–21	Apr 14–15	12:20	−1			
Apr. Ursids	Mar 18 – May 9	Apr 19–20	09:56	+55			
Apr. Piscids	Apr 8–29	Apr 20–21	00:28	+5			
Lyrids	Apr 15–28	Apr 22	18:04	+34	49	15	2.1
π Puppids	Apr 15–28	Apr 23	07:20	−45	18	Var	2
α Bootids	Apr 14 – May 12	Apr 28	14:32	+19	20	2	
μ Virginids	Apr 1 – May 12	Apr 29	15:08	−07	30	2	

April brings the second major meteor stream of the year, the Lyrids, although peak ZHR only reaches about 15 and constitutes the lower limit of what can be classed major activity (Fig. 3.9).

The Alpha Virginid stream is the strongest branch of this long-duration group of showers, reaching ZHR values of 5–10 in the period April 5–18.

The April Piscid stream is only observable by radio methods, as it is another daytime stream. It was first discovered in a radar survey in 1960 by B.L. Kashcheyev and V.N. Lebedinets in the USSR. It was later observed in another three radar surveys, all yielding inconsistent hourly rates. This leads to the question of whether it undergoes periodic variation in activity.

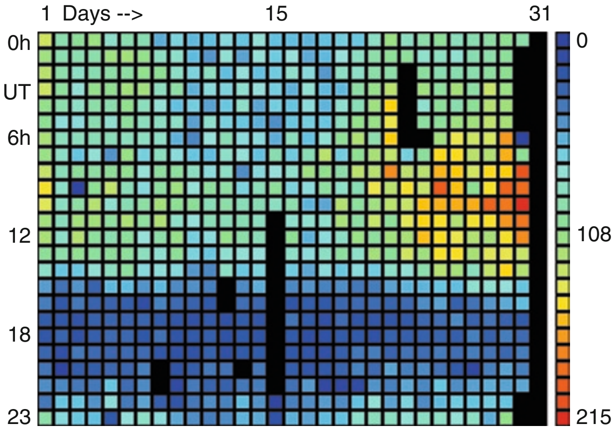


Fig. 3.9. Radio meteor data for April 2008. Meteor activity is low in early April, but significantly picks up towards the end of the month and into June. (Image courtesy of Andy Smith G7IZU).

May

Name	Dates	Peak date	Radiant R.A. (hours: minutes)	Radiant Dec. (degrees)	Speed (km/s)	ZHR	Population index
ω Capricornids	Apr 19 – May 15	May 02	21:00	−22	50	2	
η Aquariids	Apr 19 – May 28	May 06	22:32	−01	66	60	2.4
May Librids	May 1–9	May 6–7	15:32	−18		3	
η Lyrids	May 3–12	May 09	19:08	+44	44	3	3.0
ε Arietids	Apr 25 – May 27	May 9–10	02:56	+21			
May Piscids	May 4–27	May 12–13	00:52	+22			
α Scorpiids	May 1–31	May 16	16:12	−21	35	5	
β Corona Austrinids	Apr 23 – May 30	May 16	18:56	−40	45	3	
May Arietids	May 4 – Jun 6	May 16–17	02:28	+18			
ο Cetids	May 7 – Jun 9	May 14–25	01:52	−3			
Southern May Ophiuchids	Apr 21 – Jun 4	May 13–18	16:48	−23			
ε Aquilids	May 4–27	May 17–18	16:24	+13			
Northern May Ophiuchids	Apr 8 – Jun 16	May 18–19	16:52	−15		2	

The η Aquarids produce major activity peaking around May 6, although this is a challenging meteor stream for visual observers. The radiant does not rise until about an hour before dawn for mid-latitudes, and the situation is even worse for northern or southern latitudes. The bulk of the activity occurs after dawn. This clearly shows as a hot spot in the May colorgram for forward scatter radio observers (Fig. 3.10).

May is a great month for daytime meteor activity. There are four daytime only streams: the ε Arietids, May Arietids, ο Cetids, and May Piscids. The ο Cetids can produce as many as 18 radio echoes per hour near peak time.

The ε Aquilids were discovered by radar surveys in the 1960s. It is not known to have been observed visually.

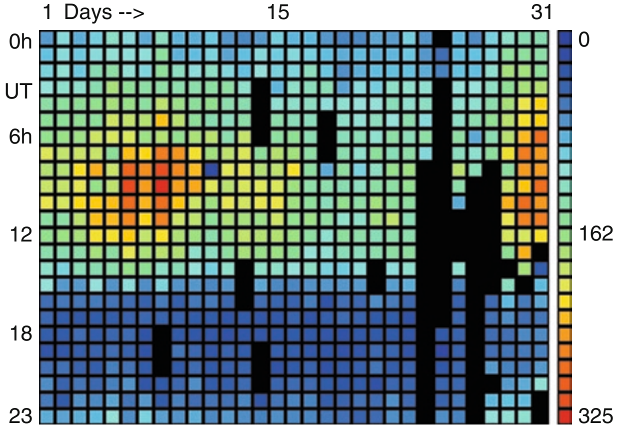


Fig. 3.10. Radio meteor data for May 2008. May sees the peak of one of Halley's Comet derived meteor streams the η Aquarids. There is also lots of daytime activity. (Image courtesy of Andy Smith G7IZU).

June

Name	Dates	Peak date	Radiant R.A. (hours: minutes)	Radiant Dec. (degrees)	Speed (km/s)	ZHR	Population index
χ Scorpids	May 6 – Jul 2	May 28 – Jun 5	16:20	−12			
ω Scorpiids	May 23 – Jun 15	Jun 2	15:56	−20	21	5	
Arietids	May 22 – Jul 2	Jun 7	02:56	+24	38	60	
τ Herculids	May 19 – Jun 19	Jun 9	15:44	+41			
ζ Perseids	May 20 – Jul 5	Jun 13	04:12	+26		40	
June Lyrids	Jun 10–21	Jun 15	18:20	+35		Var 1.3–3.5	
June Aquilids	Jun 2 – Jul 2	Jun 16–17	19:48	−7			
Scorpids Sagittarids	Jun 1 – Jul 15	Jun 19	18:16	−23	30	5	
Ophiuchids	May 19 – Jul 2	Jun 20	17:32	−20		6	
June Scutids	Jun 2 – Jul 29	Jun 27	18:32	−4		2	
τ Cetids	Jun 18 – Jul 4	Jun 27	01:36	−12	66	4	
June Bootids	Jun 28 – Jul 5	Jun 28	14:36	+49	14	Var	2.2
τ Aquariids	Jun 19 – Jul 5	Jun 28	22:48	−12	63	7	
θ Ophiuchids	Jun 4 – Jul 15	Jun 29	16:36	−15	29	2	
β Taurids	Jun 5 – Jul 18	Jun 29	05:17	+21		25	

The Arietids is the best known and the strongest of the daytime only meteor streams, rivaling the η Aquarids of May, which is virtually a daytime stream. This is followed up by the ζ Perseids, giving a significant daytime morning response on forward scatter radio results in the first half of the month. The latter half of the month is dominated by the daytime activity of the β Taurids (Fig. 3.11).

June is a difficult month for many visual observers, especially in high northern latitudes, due to the short nights that never reach full darkness. This is compensated for by the richness of the daytime activity.

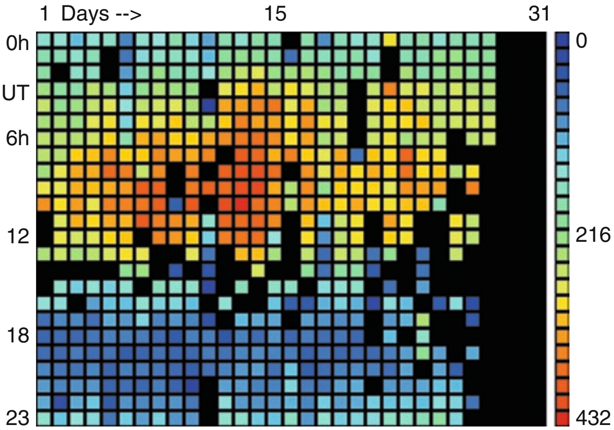


Fig. 3.11. Radio meteor data for June 2008 The strongest daytime activity occurs in June, with three very active daytime showers. It is also a difficult month for forward scatter when Sporadic E interference is common. (Image courtesy Andy Smith G7IZU).

July

Name	Dates	Peak date	Radiant R.A. (hours: minutes)	Radiant Dec. (degrees)	Speed (km/s)	ZHR	Population index
July Pegasids	Jul 7–13	Jul 10	22:40	+15	70	3	
July Phoenicids	Jul 10–16	Jul 13	02:08	–48	47	Var	
τ Capricornids	Jun 27 – Jul 29	Jul 12–13	20:42	–15			
α Lyrids	Jul 9–20	Jul 14–15	18:40	+38		1	
ο Draconids	Jul 6–28	Jul 17–18	18:58	+61			
α Cygnids	Jul 11–30	Jul 18	20:20	+47	37	2	
σ Capricornids	Jul 15 – Aug 11	Jul 20	20:28	–15	30	5	
Piscis Austrinids	Jul 15 – Aug 10	Jul 28	22:44	–30	35	5	3.2
Southern δ Aquariids	Jul 12 – Aug 19	Jul 28	22:36	–16	41	10	3.2
α Capricornids	Jul 3 – Aug 15	Jul 30	20:28	–10	23	4	2.5

The main shower of July is the Southern δ Aquarids, peaking towards the end of the month but not quite a major stream of the year. Once again Sporadic E interference in July is common, making forward scatter work impossible (Fig. 3.12).

The α Lyrid stream is an interesting one; the ZHR barely reaches 2 for naked-eye work, but it is known as a strongly active telescopic shower, where rates of 18 per hour can be seen with binoculars. This should prove a good target for forward scatter study and should yield measurable underdense activity.

Visual records of the ο Draconids are weak, and although Sekanina recorded it in his 1968–1969 session of the Radio Meteor Project, it seems that little observation of it has occurred since then.

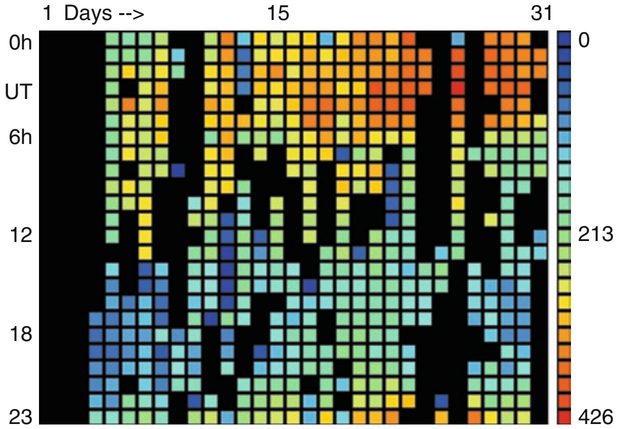


Fig. 3.12. Radio meteor data for July 2008. Once again July is a difficult month for radio observers due to frequent periods of Sporadic E interference. (Image courtesy Andy Smith G7IZU).

August

Name	Dates	Peak date	Radiant R.A. (hours: minutes)	Radiant Dec. (degrees)	Speed (km/s)	ZHR	Population index
α Capricornids	Jul 15 – Sep 11	Aug 1–2	20:26	−8		8	
Southern ι Aquariids	Jul 25 – Aug 15	Aug 04	22:16	−15	34	2	
Northern δ Aquariids	Jul 15 – Aug 25	Aug 08	22:20	−05	42	4	
Perseids	Jul 17 – Aug 24	Aug 12	03:04	+58	59	90	2.6
α Ursa Majorids	Aug 9–30	Aug 13–14	11:00	+63		4	
κ Cygnids	Aug 3–25	Aug 17	19:04	+59	25	3	3.0
Northern ι Aquariids	Aug 11–31	Aug 20	21:48	−06	31	3	
π Eridanids	Aug 20 – Sep 15	Aug 25	03:28	−15	59	4	
γ Leonids	Aug 14 – Sep 12	Aug 25–26					
γ Doradids	Aug 19 – Sep 6	Aug 28	04:36	−50	41	5	

The Perseids dominate the month of August on sheer hourly rates, although there is a lot of other interesting activity going on at the same time. Perseids always give a good show to both visual and radio observers (Fig. 3.13).

This is a great time of year for meteor observing. The α Capricorndid stream produces some spectacular bright and very slow meteors. Although it is always difficult to attribute forward scatter radio echoes to a particular stream, the α Capricorndids should generate some good overdense radio echoes.

Similarly, the κ Cygnids produce a low rate of relatively bright meteors and has always been of interest to radio amateur astronomers. It is all too easy to ignore it, due to the observers' preoccupation with the Perseids. Take time out to identify these weaker August streams visually, and they will reward you.

The α Ursa Majorids is not well studied; although it is not a significant shower to the naked eye there is some evidence it is much more active telescopically and to radar instruments.

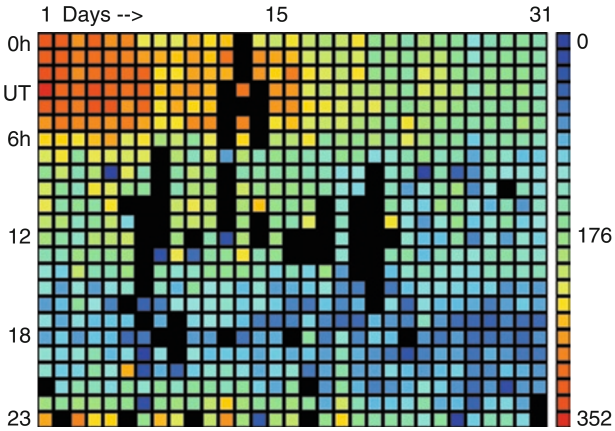


Fig. 3.13. Radio meteor data for August 2008. One of the best known showers the Perseids, peak around August 13. It always puts on a good show for visual and radio observers. (Image courtesy of Andy Smith G7IZU).

The γ Leonid stream is a daylight shower. It was seen for the first time in the 1960s in two radar surveys, and its very weak activity even in radar studies has meant no accurate rate determinations have been made. It is unlikely that forward scatter results will be able to detect it from the background sporadic activity.

September

Name	Dates	Peak date	Radiant R.A. (hours: minutes)	Radiant Dec. (degrees)	Speed (km/s)	ZHR	Population index
α Aurigids	Aug 25 – Sep 8	Sep 01	05:36	+42	66	7	2.6
γ Aquarids	Sep 1–14	Sep 7				2	
September Perseids	Sep 5 – Oct 10	Sep 08	04:00	+47	64	6	2.9
Aries-Triangulids	Sep 9–16	Sep 12	02:00	+29	35	3	
Piscids	Sep 1–30	Sep 20	00:32	+00	26	3	

The α Aurigids, although fairly weak in activity, is the strongest meteor stream of the month, certainly for visual work (Fig. 3.14).

The September Perseids appear as a fairly new stream on the annual calendar, but in fact activity now attributed to this radiant was formerly classed as part of the δ Aurigid stream.

The Aries Triangulids is poorly understood and was first observed by two experienced observers in the 1980s, Gary Kronk and George Gliba.

The Piscid stream is very diffuse, with an ill defined peak of activity in the range September 11 to around September 20. There are suggestions of more than one radiant from this stream, but there are too few observations to be sure.

September is one of those odd months. It suffers from too few active observers, perhaps because at that time people realize the summer is over and winter is coming. The children are back at school, and the weather is getting colder, especially at night. The moral of this story is – get out and observe!

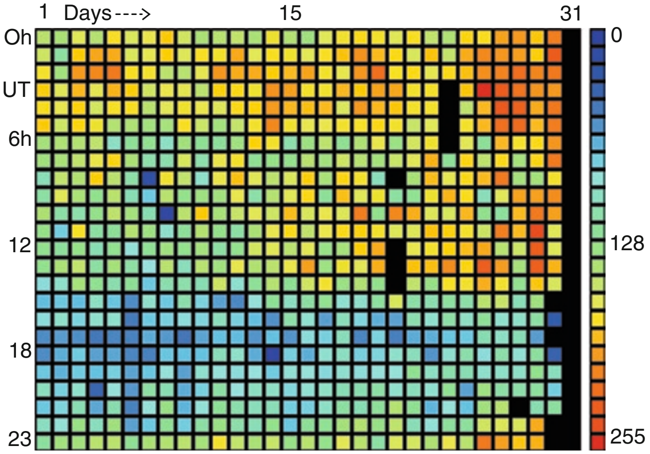


Fig. 3.14. Radio meteor data for September 2008. September is traditionally a poorly observed month by visual workers. Visual streams are weak and complex. (Image courtesy of Andy Smith G7IZU).

October

Name	Dates	Peak date	Radiant R.A. (hours: minutes)	Radiant Dec. (degrees)	Speed (km/s)	ZHR	Population index
Sextantids	Sep 24 – Oct 9	Oct 1–4	10:12	−2			
October Arietids	Oct 1–31	Oct 08	02:08	+08	28	5	
Giacobinids/Draconids	Oct 6–10	Oct 08	17:28	+54	20	Var	2.6
δ Aurigids	Sep 22 – Oct 23	Oct 10	05:40	+52	64	6	
ε Geminids	Oct 14–27	Oct 18	06:56	+27	71	2	3.0
Orionids	Oct 2 – Nov 7	Oct 21	06:20	+16	66	20	2.5
Leo Minorids	Oct 21–23	Oct 22	10:48	+37	62	2	3.0

The month opens with a weak diffuse daylight meteor stream, the Sextantids. However its discovery stems from a radio survey by A.A. Weiss in 1957, when a maximum rate of 30 per hour were recorded. The stream may be periodic in nature, undergoing regular outbursts as Earth encounters the stream every 4–5 years or so (Fig. 3.15).

Another periodic stream is the Giacobinids, also known as the Draconids. Most of the year's activity is low, but several times over the last century outbursts of hundreds or even thousands per hour have been seen. The outburst years were 1933, 1946, 1952, 1985, 1998, and 2005. Rates become high when the parent comet Giacobini-Zinner returns. However, not all comet return have yielded high rates; for example, 1972 was a big disappointment. In more recent times, activity rates in 1998 and 2005 reached as high as 150 per hour.

The only regular major activity in October is the Orionid stream. This is the second of the Halley's Comet dust streams, the first being the η Aquarids. The reason for this dual encounter is that the orbit of the comet is lying almost in the same plane as that of Earth, so we encounter it twice, 6 months apart.

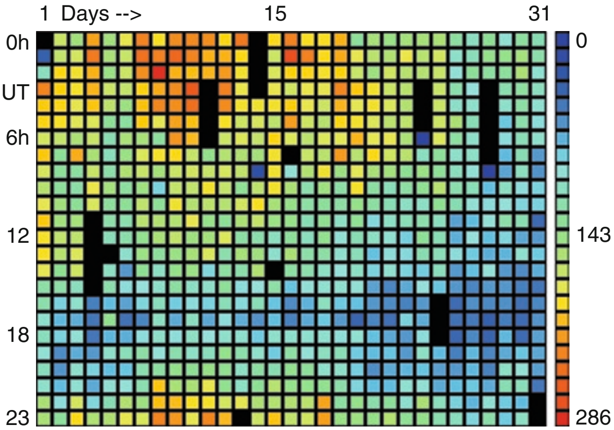


Fig. 3.15. Radio meteor data for October 2008. October sees the return of the Halley's Comet dust stream in the form of the Orionid shower. (Image courtesy of Andy Smith G7IZU).

November

Name	Dates	Peak date	Radiant R.A. (hours: minutes)	Radiant Dec. (degrees)	Speed (km/s)	ZHR	Population index
Southern Taurids	Nov 1–25	Nov 05	03:28	+13	27	5	2.3
δ Eridanids	Nov 6–29	Nov 10	03:52	−09	31	2	
Northern Taurids	Nov 1–25	Nov 12	03:52	+22	29	5	2.3
ζ Puppids	Nov 2 – Dec 20	Nov 13	07:48	−42	41	3	
Leonids	Nov 14–21	Nov 17	10:12	+22	71	Var	2.5
α Monocerotids	Nov 15–25	Nov 21	07:20	+03	60	Var	2.4

The Leonid stream dominates the thoughts of any meteor observers in November, even though most years rates can barely reach the 15 per hour to warrant its major status. Roughly every 33 years shortly after the passage of the parent comet Tempel-Tuttle the peak observable rates increase considerably. It is always difficult to predict which returns may produce storm levels of activity, though. Many people remember the 1999/2000 return of the comet as a period. Predictions of Earth's passage through a filament stream in 1999 had proven remarkably accurate. Video data agreed within 6 min the accepted peak time of the stream for that year from collected group observations (Fig. 3.16).

The α Monocerotids is another of the variable rate streams that undergoes regular outbursts of up to 100 per hour. The details of this stream, however, are still uncertain, due to the normally low rates of faint meteors.

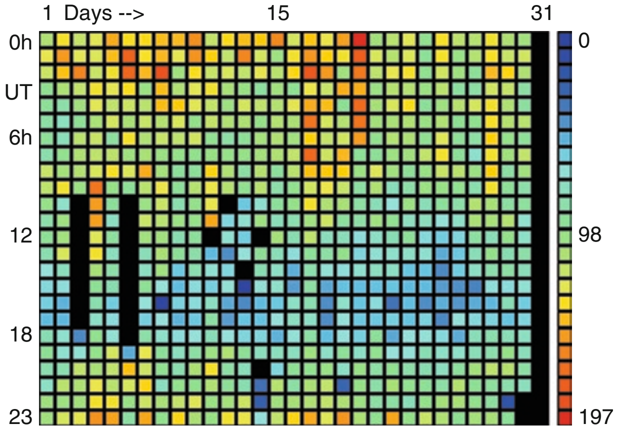


Fig. 3.16. Radio meteor data for November 2008. The only classical major stream of the month is the Leonids, although in most years it fails to deliver major hourly rates. (Image courtesy of Andy Smith G7IZU).

December

Name	Dates	Peak date	Radiant R.A. (hours: minutes)	Radiant Dec. (degrees)	Speed (km/s)	ZHR	Population index
χ Orionids	Nov 25 – Dec 31	Dec 02	05:28	+23	28	3	
α Pupids	Nov 17 – Dec 9	Dec 2–5	08:32	−45			
σ Hydrids	Dec 4–15	Dec 11–12	08:28	+2		3	
Phoenicids	Nov 28 – Dec 9	Dec 06	01:12	−53	18	Var	2.8
Monocerotids	Nov 27 – Dec 17	Dec 09	06:48	+08	43	3	3.0
11 Canis Minorids	Dec 4–15	Dec 10–11	07:48	+13			
Northern χ Orionids	Nov 16 – Dec 16	Dec 10–11	05:28	+23		2	
Southern χ Orionids	Dec 2–18	Dec 10–11	05:52	+20			
Dec. Monocerotids	Nov 9 – Dec 18	Dec 11–12	06:44	+10		1	
σ Hydrids	Dec 3–15	Dec 12	08:28	+02	58	2	3.0
Puppid-velids	Dec 2–16	Dec 12	09:00	−46	40	4	2.9
Geminids	Dec 7–17	Dec 14	07:28	+33	35	120	2.6
Ursids	Dec 17–26	Dec 22	14:28	+76	33	10	3.0
Coma Berenicids	Dec 12 – Jan 23	Dec 30	11:40	+25	65	5	3.0

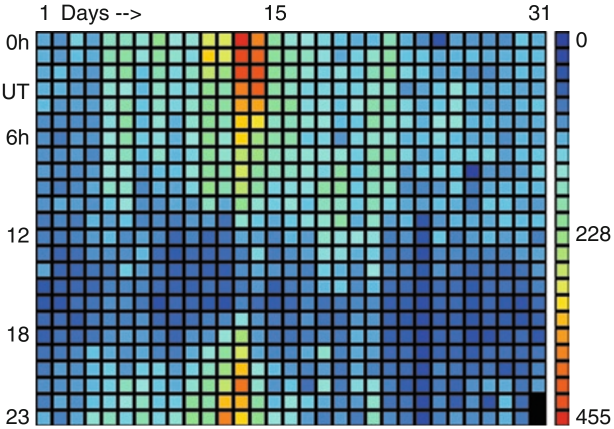


Fig. 3.17. Radio meteor data for December 2008. The Geminid stream dominates the December meteor calendar and is certainly one of the great annual showers to observe. (Image courtesy of Andy Smith G7IZU).

The December meteor activity is dominated by the Geminids, which is probably the best of the annual showers. Activity rates are high shortly after darkness, and the stream puts on a good show from early evening to the early hours of the next day on the peak evening (around December 14). All of the other well known high rate showers are best observed after midnight. Although there are quite a number of minor showers active this month, you can see from the colorgram the Geminids dominate the radio results, too. Similar to January the colorgram technique of displaying meteor radio data does suppress the impact of minor activity for the month (Fig. 3.17).

The Christmas festivities, poor weather, and the cold temperatures of December do tend to reduce the amount of data gathered by visual observers of the late December streams, particularly the Coma Berenicids and the Ursids. Of course, the great advantage of radio observation is that it's completely automated.

The 11 Canis Minorids were first seen in 1964 by Keith B. Hindley, a very active meteor observer of the British Astronomical Association. He was using a short-focus rich-field 5-in. telescope to observe the Geminids telescopically, in order to better determine the Geminid radiant. However, he observed five meteors of magnitude between +6 and +12.

This stream may not be detectable by naked-eye observation. This, of course, lends itself to radio studies, which should produce underdense activity. Once again, though, forward scatter observations make it difficult to attribute echo events to particular streams, and the build up to the Geminids will likely hide its activity in the general background.

The December Monocerotids are extremely weak as a visual meteor stream; however, radar studies show the stream makes a regular annual return, so again a well set up sensitive forward scatter system should detect them, although again the buildup of Geminid activity will likely mask out the Monocerotids.