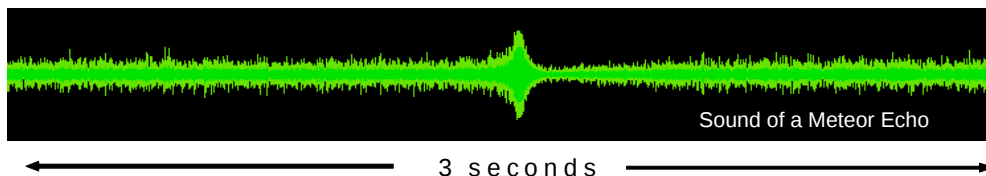


Detection of Meteors by RADAR

Detection & Analysis of Meteors by RADAR

(Using the GRAVES space surveillance transmitter)



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- 1 Introduction
- 2 Meteors
- 3 Radar Basics
- 4 Graves Space Surveillance Radar
- 5 Meteor Receiving System
- 6 Radar Echo Characteristics
- 7 Echo Fading
- 8 Meteor Numbers and Velocities
- 9 Conclusions
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Appendix A Analysis of Leonid Shower 2010

1 Introduction

1.1 Why develop a RADAR system to detect Meteor Trails

Traditionally meteors have been studied optically, initially by counting the number of visible trails per minute or hour and logging the intensity and direction from which they seem to arrive. Latterly, sensitive film was able to be used with all sky camera lenses to collect data for subsequent analysis. In recent years sensitive video cameras have been brought to bear to record and store meteor trail images.

During World War 2 and the development of RADAR, it was noticed that meteors could generate 'false echoes' and subsequent adaptation of war surplus equipment led to considerable work on the detection and analysis of meteors.

The RADAR detection of the ionised trails left by meteors is relatively straight forward and a great deal of information can be deduced from the details of the return signal. The analysis of the sometimes complex returns is quite challenging and much effort has been devoted to determining the statistics of meteor numbers, mass, trajectories and the manner in which ionisation trails develop, break up and decay.

The RADAR techniques employed by professional observers has generated a huge amount of information on these topics and today much is understood that could not be deduced from optical or photographic means alone.

Amateur RADAR observations of meteors has developed over the years and is well within the capability of amateur radio enthusiasts, for example, who regularly use meteor trails for long range communications (if only for brief periods).

1.2 How amateurs can set up a Meteor Radar

Some experienced radio amateurs are capable of building a complete RADAR system with both transmitter and receiver. Fortunately for most people it is not necessary to own and use a high power transmitter with all the issues that this involves. The existence of high power broadcast transmitters in various countries means that there is no lack of signals reaching the ionosphere and capable of interacting with meteor trails.

Many amateurs make use of old VHF analogue TV transmitters, but with the advent of specialist very high power continuous wave (CW) transmitters in several countries including France and the US, it is now possible to use these as the basis of a Meteor Radar system.

1.3 Scope of this Article

This article is intended for amateur radio astronomers who wish to build a low cost receiving system to detect meteors using the French Space Surveillance Radar known as GRAVES.

In section 2 we examine the nature of meteor particles and their origins. The difference between sporadic and meteor showers is examined and the dates

Detection of Meteors by RADAR

of major meteor showers through the year are listed. In 2.3 the nature of meteor dust particles is discussed and the type of ionised trails they generate through ablation is examined. An example is given of the height distribution of meteor trails in the upper atmosphere.

In section 3 we look at the basics of pulsed RADAR and how a CW Doppler radar is different.

Section 4 explores the Graves RADAR in France and shows how the beam geometry intersects the lower ionosphere some 100km from the southern UK.

Section 5 gets to the heart of what is needed to construct a receiver with sufficient frequency stability and sensitivity to receive echoes from the Graves RADAR. It then deals with the nature of echoes received and their relationship to the physics of their generation.

Section 5.5 shows how automatic echo counting can be conducted with the aid of a computer and freely available software specially configured for this purpose. Also in this section, we show some amateur echo detection rate results and how the signal strengths of echoes follow a logarithmic distribution with numbers. Finally, we present data gathered by the author during the 2010 Orionid shower using the equipment previously described, showing that detection of up to a thousand meteors during a shower is possible with amateur equipment.

Section 6 is concerned with classification of echo types based on their endurance and frequency behaviour.

Section 7 explores the nature of echo fading diffraction.

In section 8 we look at meteor head echo velocity distribution and the diurnal variation in echo numbers together with an example of peak echo rates during a meteor shower and the long term variability of echo rates over several years.

Section 9 contains a number of conclusions and observations about the radar detection of meteors by amateurs.

2 Meteors

2.1 What are they – where do they come from?

There are two main sources of small particle debris that constitute meteoroids. These are asteroids and comets as indicated in Figure 2.1.

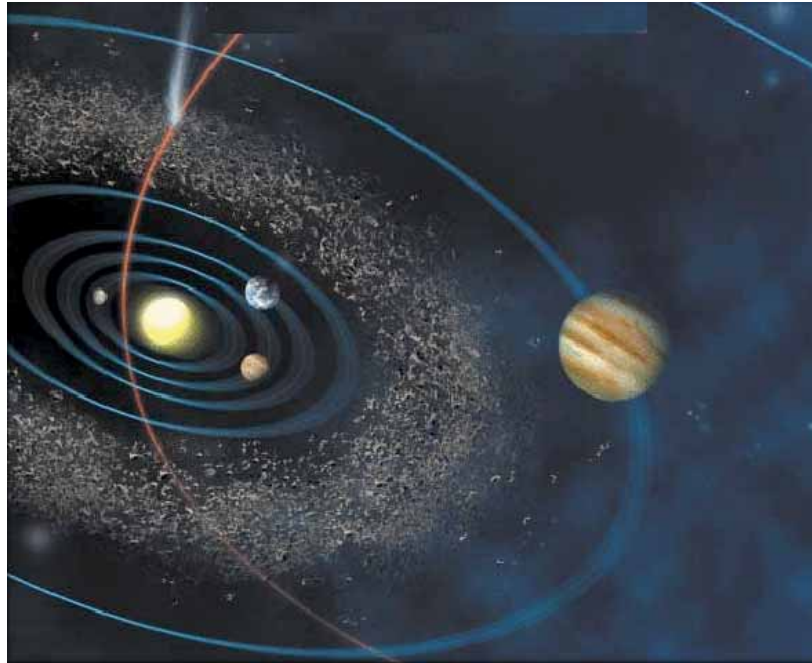


Figure 2.1 Illustration of Comets and Asteroids as the source of Meteoroids

The asteroid belt between Mars and Jupiter contains many asteroids with a very large range of sizes from small planetoids down to dust the size of particles in smoke. We can see in Figure 2.2 the recent break up of a medium- sized asteroid photographed in 2009.

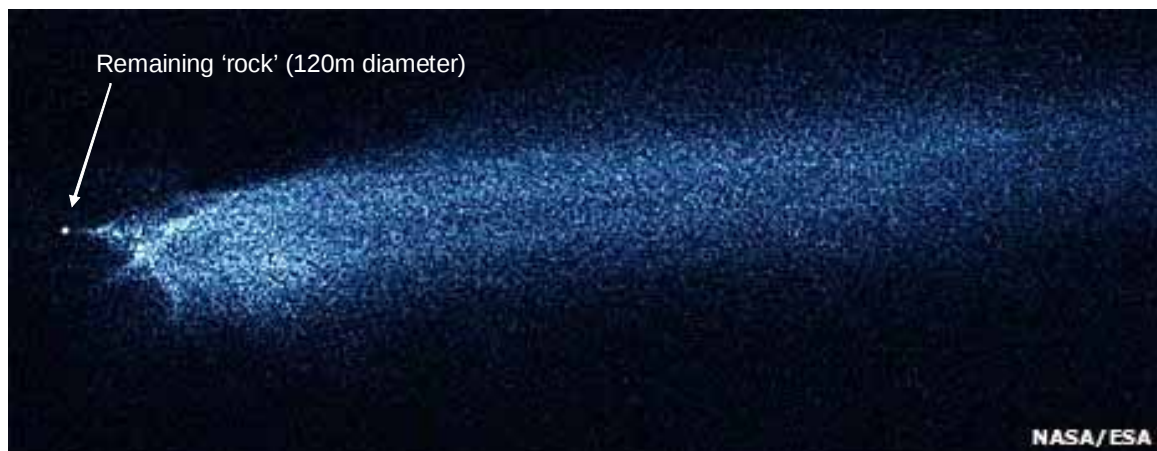


Figure 2.2 Debris trail from an Asteroid (P/2010 A2) collision in March 2009

Detection of Meteors by RADAR

2.2 Showers and sporadic meteors

Meteors rain down into the Earth's atmosphere at all times in a sporadic – variable manner. Thus they are termed the 'sporadic meteor background' and visible trails can occasionally be observed in any given hour. At certain times of the year however, the Earth moves on its orbit into a concentration of meteoroids that may be associated with particular comets or asteroids. At these times the rate of meteor impacts on the upper atmosphere increase considerably – to a few hundreds per hour – and these are termed meteor 'showers'. The meteors appear to come from a single region of the sky called a 'radiant' and the shower usually takes the name of the constellation in which the radiant is to be found.

The main meteor showers are listed in Table 2.1

Shower Name	Date of Maximum	Normal Limits	Rate / Hour	Description
Quadrantids	Jan 3-4	Jan 1-6	60	Blue meteors with fine trains
Lyrids	April 22	April 16-25	10-15	Bright fast meteors, some with trains. Associated with Comet Thatcher
Eta Aquarids	May 5	Apr 24-May 20	35	Low in sky. Associated with Comet Halley
Capricornids	July 8-26	July-August	5	Bright meteors
Alpha Capricornids	Aug 2	July 15-Aug 25	5	Yellow slow fireballs
<u>Perseids</u>	Aug 12-13	July 23-Aug 20	75	Associated with Comet Swift-Tuttle (1737, 1862, 1992)
Orionids	Oct 22	Oct 16-27	25	Associated with Comet Halley
Taurids	Nov 4	Oct 20-Nov 30	10	Very slow meteors
<u>Leonids</u>	Nov 17-18	Nov 15-20	Variable (30-300)	Fast bright meteors with fine trains. Associated with Comet Tempel-Tuttle
Geminids	Dec 14	Dec 7-16	75	Plenty of bright meteors, few trains

Table 2.1 Meteor Showers

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2.3 Meteor trails

Meteor trails are formed when tiny particles, maybe the size of a grain of sand or smaller – (see Figure 2.3), impact the Earth's upper atmosphere at a height of around 90km and generate a strong shock wave in the air. There is a huge temperature differential generated across the shock boundary and the radiant heat vaporizes the surface of the particle. This causes the ablation of the particle and ionisation of the atoms of the material, producing radiation across a broad optical spectrum.

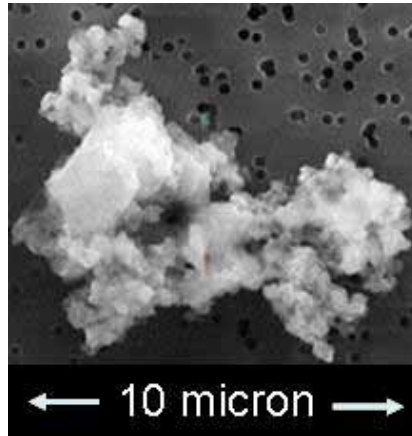


Figure 2.3 Example of a Meteoroid Particle

The vaporised material and ionised air play a large part in reflecting electromagnetic waves at radio frequencies – thus enabling their detection by VHF radar.



Figure 2.4 Example of Meteor Trail

The larger the meteoroid, the longer and brighter is the meteor trail, with some very large particles producing intense trails called 'fireball events'.

Detection of Meteors by RADAR

Using radar techniques it is possible to measure the height of a meteor trail and a distribution of heights can be produced. It can be seen from Figure 2.5 that most trails are produced at a height of ~ 85 to 90 km, with the 'wings' of the distribution from 70 to 110km.

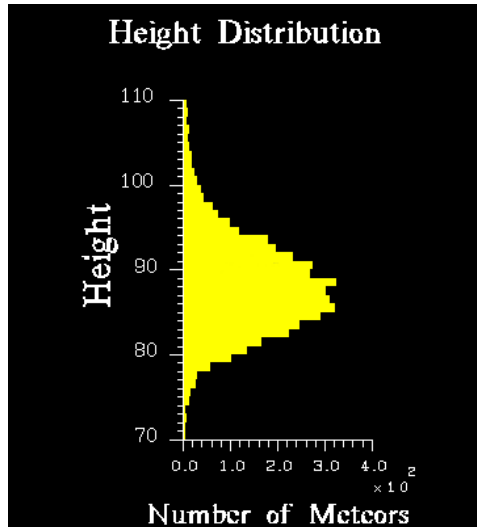


Figure 2.5 Height distribution of Meteors⁵

It is also possible with multiple, carefully calibrated meteor radar stations to measure the range of meteor velocities. Figure 2.6 shows how these vary with numbers of meteors observed. The mean velocity is ~16km/s.

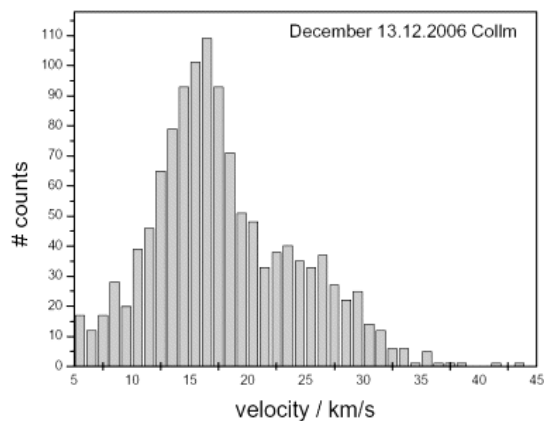


Figure 2.6 Meteor Velocity Distribution

With this limited introduction to what meteors are, we now move on to discuss how they can be detected by Radar. We begin by looking at the basis of a conventional pulsed Radar such as was developed in World War 2.

Detection of Meteors by RADAR

3 RADAR

3.1 Radar Basics

Early Radar was based on the transmission of short radio pulses from a directional antenna toward a target. The radiation was scattered by the metallic target and some of the energy returned to a receiver tuned to the frequency of the transmitter. Often the transmitter and receiver were co-located.

The pulses had to be short enough to give a clear sharp echo and the time between pulses had to be long enough for the 'round trip' to and from the target to finish before the next pulse was sent out. This classic pulsed Radar waveform is shown in Figure 3.1 being transmitted from a typical array of phased VHF dipoles towards an aeroplane target.

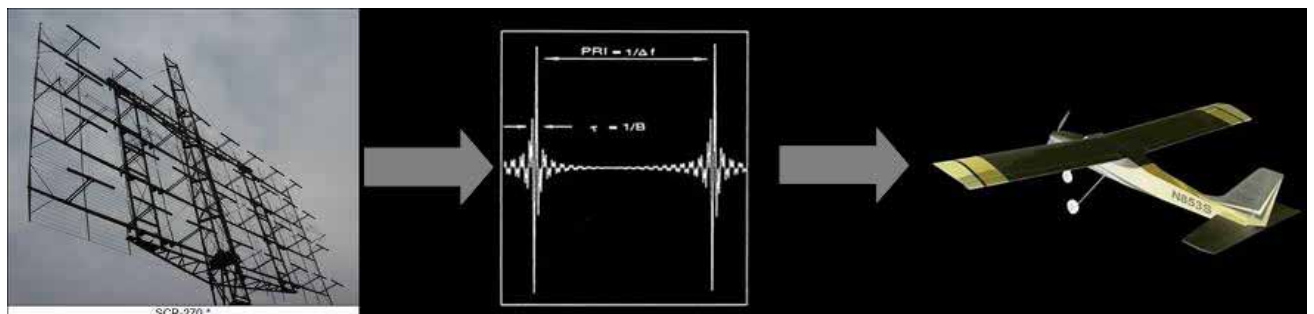


Figure 3.1 A Pulsed Radar

The received signal strength was usually displayed on an oscilloscope, with the signal strength plotted in the vertical axis and time / range running horizontally. This is shown in Figure 3.2.

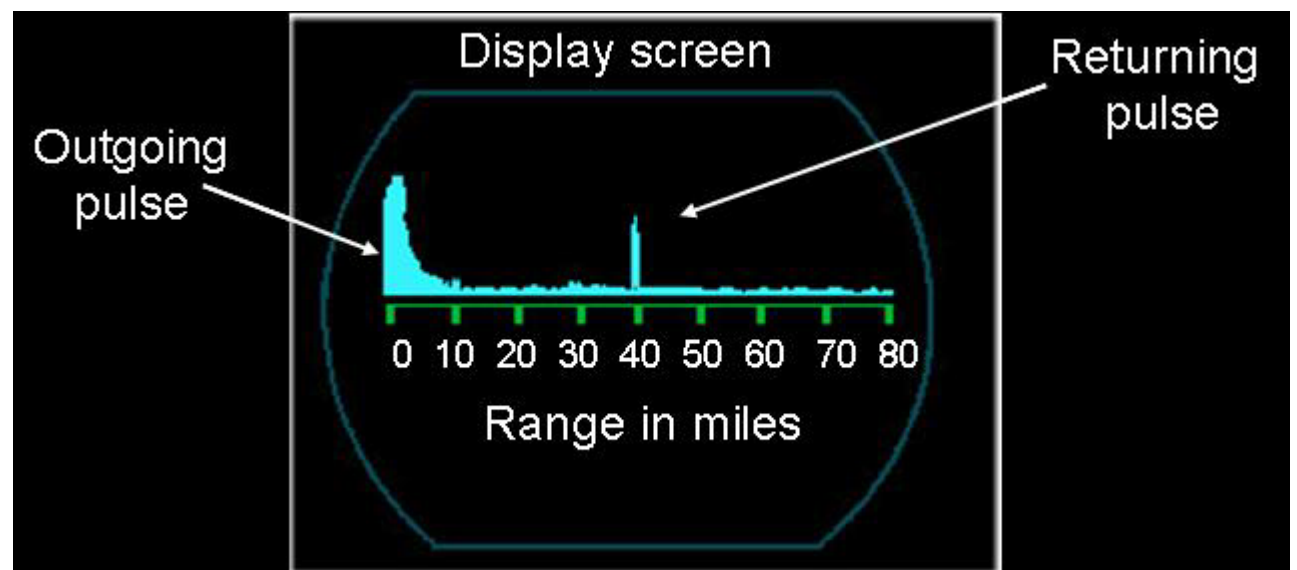


Figure 3.2 A typical Pulsed Radar Plot

Detection of Meteors by RADAR

3.2 Radar Scatter from Ionised Meteor trail

We mentioned in Section 2 how the kinetic energy of the meteoroid is transferred to optical and heat radiation by the braking process in the upper atmosphere. Here we examine the way the incident radar wave interacts with the ionised trail.

In Figure 3.3 we see the wave approaching a stream of ionised particles represented by a mix of positive ions, negative electrons and neutral molecules. It is only the electrons that respond significantly to the electric field in the incident wave. The ions are heavy and do not move a significant amount and play little part in re-radiation of the pulse. The neutral molecules carry no net charge and cannot interact with the wave electric field. The strength of the returned signal is dependent on the electron density in the trail and as this varies with time, so does the signal strength.

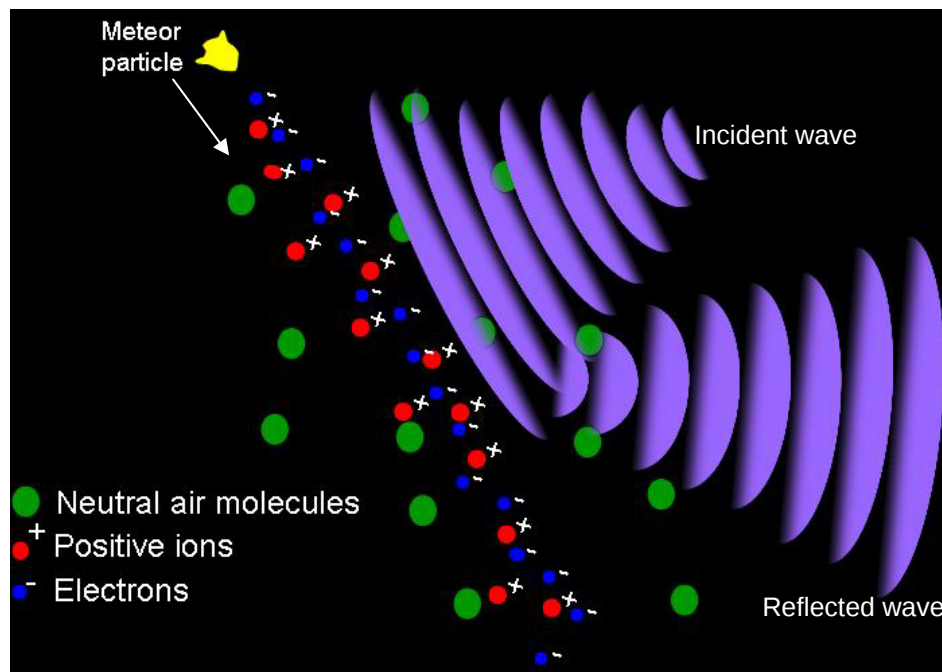


Figure 3.3 Wave interaction with the Ionisation Trail

The number of electrons created varies as the meteoroid descends through the atmosphere, reaching a peak somewhere along the trail. The rate of recombination of electrons and ions varies with air density and therefore with height. These factors combine to produce a sometimes complex electron density profile along the trail and therefore the return signal strength from parts of the track also varies. As we shall see later, different parts of the trail contribute signals at different distances from the receive antenna and may be in – or out – of phase leading to a radio diffraction effect.

It is clear that a great deal of information about the generation of the electron trail can be gathered by carefully analysing the return signal as a function of time.

Detection of Meteors by RADAR

3.3 Doppler shift

Unlike a pulsed radar, the best signal for detecting meteor trails is a continuous wave train. The outgoing sinusoidal wave is Doppler-shifted to higher or lower frequencies by the ionised meteor trail according to whether it has a line of sight (LOS) velocity towards or away from the receiver. This is shown in Figure 3.4.

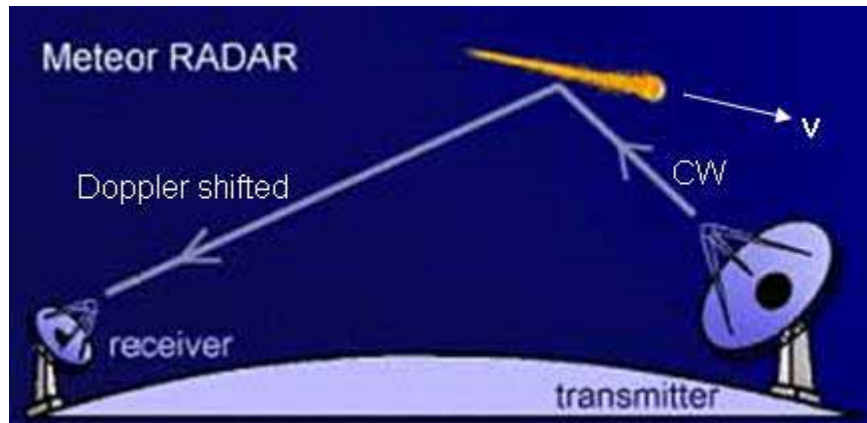


Figure 3.4 Doppler shifted signal from Meteor Trail

If the LOS velocity is towards the observer (+ve velocity) the signal is shifted to a higher frequency, if the velocity is -ve, the signal frequency is lower as suggested in Figure 3.5

The formula that relates the frequency shift to the trail LOS velocity is shown below:

$$f/F = V/c \quad \text{where}$$

- F is the change in frequency
- F is the transmitted frequency
- V is the LOS velocity of the trail
- C is the speed of light (3×10^8 m/s)

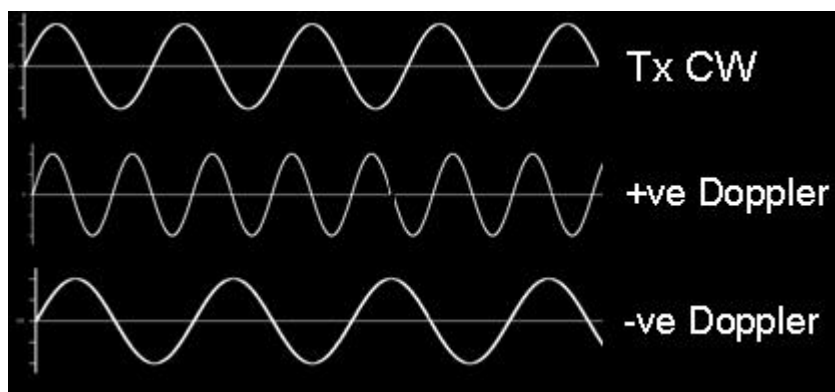


Figure 3.5 Doppler shifted frequency

4 Graves Radar

It is fortunate that there is a CW radar signal beamed into the upper atmosphere that is detectable in the UK. This is operated on behalf of the French Air Force to detect spacecraft and space debris as it crosses the French airspace over the Mediterranean. This is known as the GRAVES RADAR and details can be found on the internet¹.

4.1 Location

The radar is located near Dijon in central France as shown in Figure 4.1. There are a number of receiving stations to the south of the county that are used to plot the tracks of satellites and derive their orbital parameters.



Figure 4.1 Location of the Graves Radar

The transmitter is located some 850km from the author's amateur receiving station that was used to produce data shown later in this article. There are four phased array antennas that direct their beams upward at about 25° and each one scans a sector of the full 180° field of regard as indicated in Figure 4.2.



Figure 4.2 The Graves Phased Array

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A close up – overhead view of the antennas – with depictions of the beams is shown in Figure 4.3. The transmitter is based on an old disused airfield.



Figure 4.3 Overhead view of the Graves Radar Transmitter

4.2 Beams & geometry

The southward pointing beams will intersect a meteor trail at an altitude of about 90km and a Doppler-shifted return will be scattered in many directions. Some portion of the scattered return will arrive at the receive antenna as shown in Figure 4.4

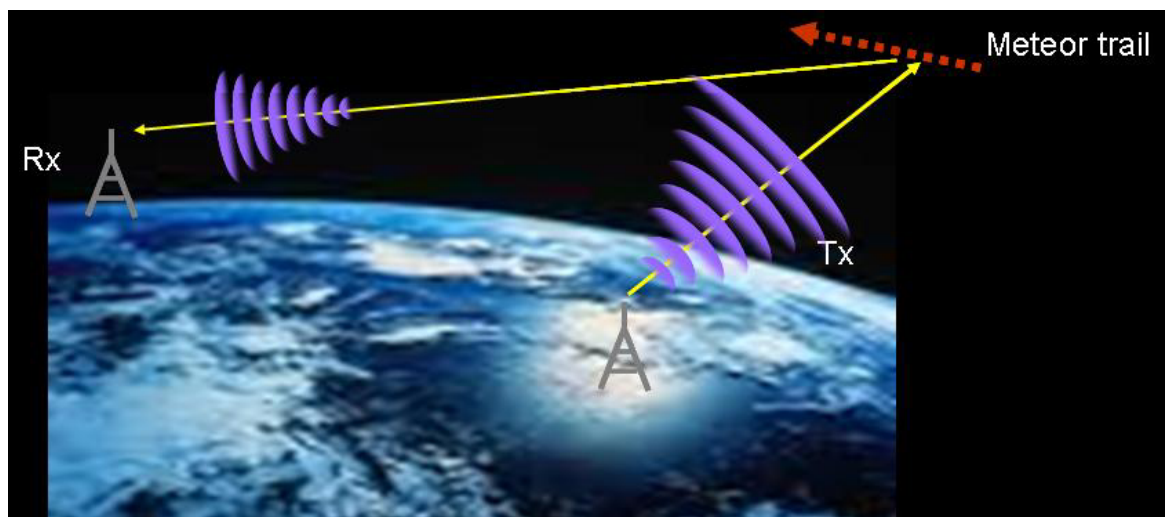


Figure 4.4 Reflection from a meteor trail

The detailed geometry of the interaction of the Graves beams with a meteor trail is shown in Figure 4.5. The total range from the meteor trail to the receiver is ~1100km.

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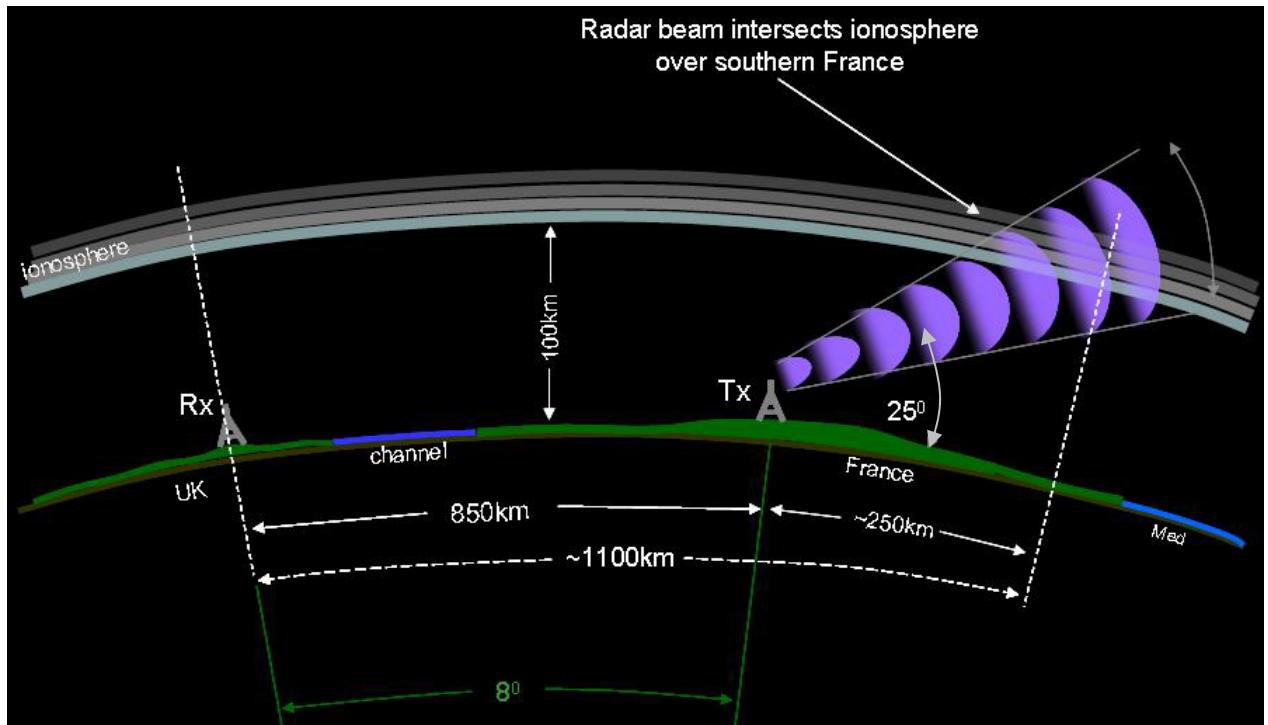


Figure 4.5 Detail of Meteor Trail Interaction with Graves Beam

5 Receiving System

5.1 Equipment and signal displays

The receiving system consists of a simple antenna and a communications receiver capable of receiving 143.050MHz with a single side band (SSB) demodulator. The simple antenna shown in Figure 5.1 is a 3 element Yagi², but it is possible to obtain radar returns with an even simpler monopole antenna.



Figure 5.1 3 Element Yagi



Figure 5.2 ICOM-R7000 Receiver

The SSB detector is required in order to generate an audio signal with a frequency related to the Doppler shift of the radar return. This audio signal can then be analysed in a spectrum analyser to reveal the many frequency – time forms, of the meteor trail signal.

The most convenient spectrum analyser to perform this task is based on Fast Fourier Transform (FFT) software - of which there are a number of examples freely available from the internet^{3 4}.



Figure 5.3 PC based Spectrum analyser

An example of the output from the Spectrum Lab software³ is shown in Figure 5.4. In this picture we see a spectrum of the signal on the right (in yellow) with frequency rising from 300Hz to 1.7kHz with a 10dB/division amplitude scale. In this plot of course, frequency equates to line of sight velocity of the meteor and is shown in the waterfall plot. The horizontal axis is time, with the markers at 5 second intervals.

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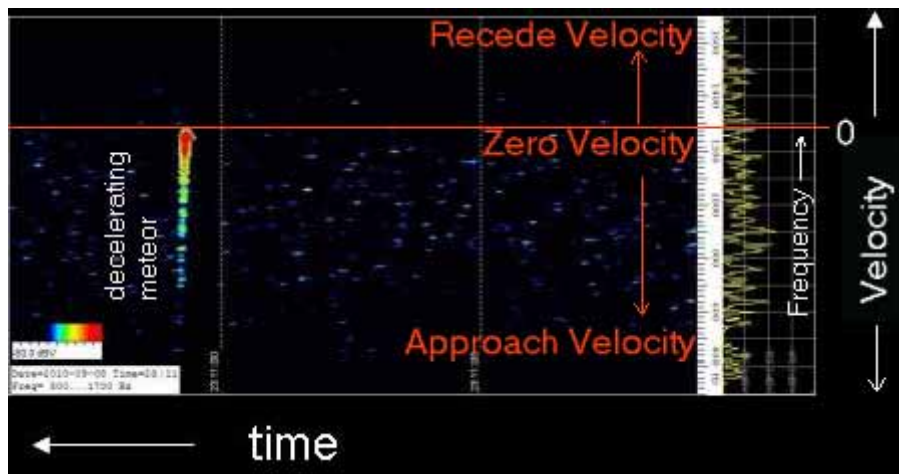


Figure 5.4 Spectrum & Waterfall Plot of Meteor Return Signal

In this result we see a meteor 'entering the plot' from below (which in this case represents a high approach velocity) and decelerating to a zero velocity in a fraction of a second. The intensity of the echo is marked by false colours from blue (low intensity) to red (high intensity).

The 'direction' of the velocity arises due to the behaviour of the single sideband (SSB) demodulator used to reveal the presence of a CW signal echo from a meteor. In this particular case, the higher Doppler shifted frequencies appear at a lower demodulated frequency than the central zero velocity frequency. Frequencies above this represent meteors with receding line of sight (LOS) velocities.

It is possible to calibrate the frequency axis using an accurate stable signal source (such as a synthesiser) and produce plots shown in Figures 5.5 & 5.6. In Figure 5.5 we see the zero Doppler frequency of 143.050MHz appears at a demodulated frequency of ~1290Hz, with higher and lower RF frequencies appearing above and below this value – but in the opposite sense.

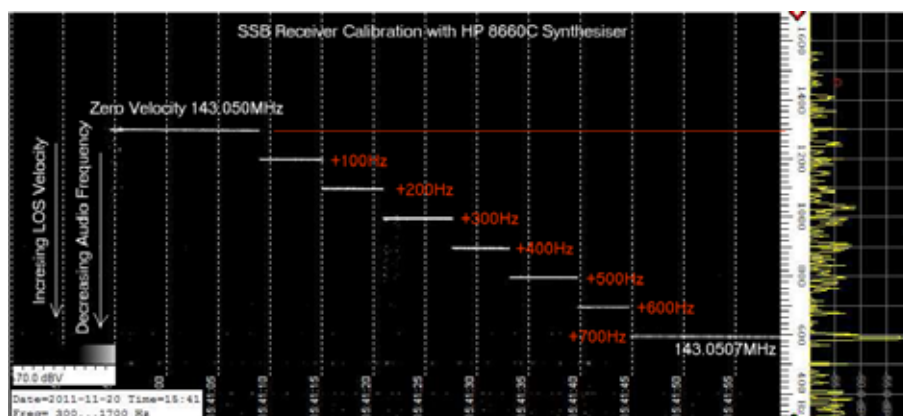


Figure 5.5 Synthesiser calibration of Velocity Display

Detection of Meteors by RADAR

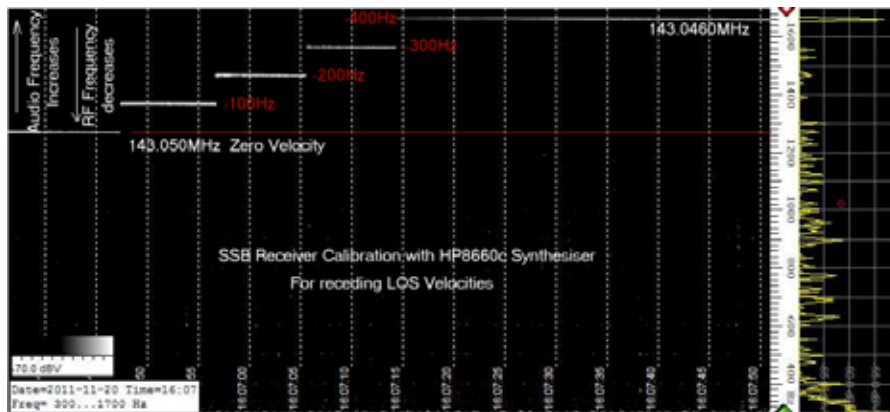


Figure 5.6 Synthesiser calibration of Velocity Display

5.2 Data collection & analysis

There are numerous echoes every few seconds during a meteor shower and it would be onerous to manually capture a waterfall plot for each one. Fortunately the Spectrum Lab software has a feature called 'Conditional Action' where one can set up a signal level 'trigger' point which, once crossed, will automatically execute a script to capture the echo in a waterfall plot. A thousand or more echoes are captured during a shower and these can all be analysed individually, or on a statistical basis following the shower.

5.3 Examples of meteor echoes

In Figure 5.7 below we see the most common type of echo. This is rather faint and short, produced by a weakly ionised meteor trail that only exists for a very short time. It may have no significant velocity at the time when the echo is strong enough to observe.

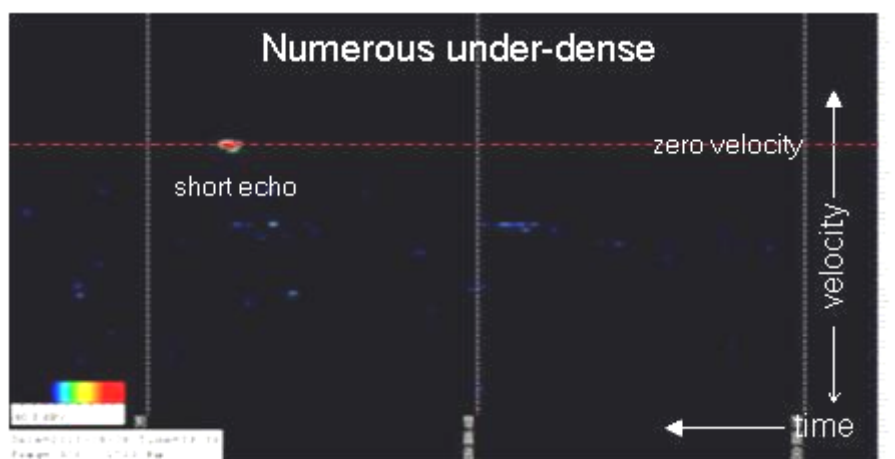


Figure 5.7 A weakly ionised Meteor Trail Echo

In Figure 5.8 we see a long echo lasting some seconds but with no line of sight (LOS) velocity. This is an echo from an ionised trail classified as 'over dense' – a term which will be explained later in the text.

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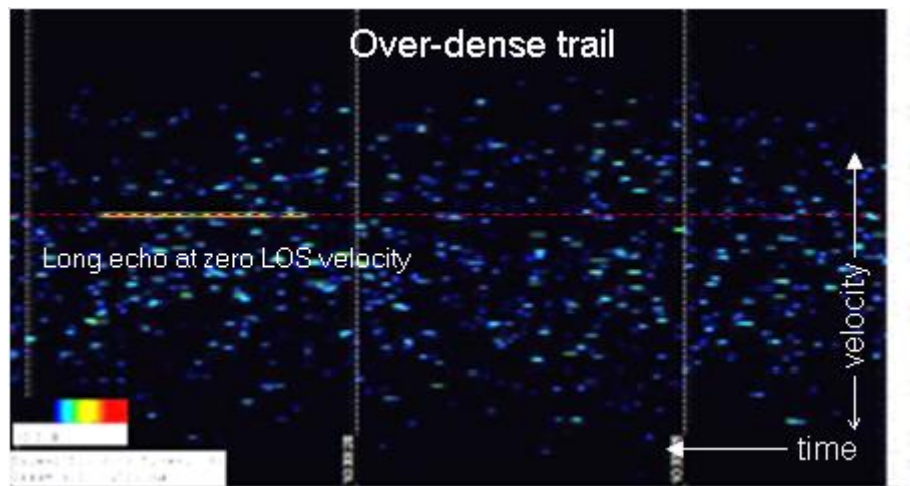


Figure 5.8 A long Meteor Trail Echo

In the next example, shown in Figure 5.9, we see a very strong echo which displays a rapidly reducing (decelerating) LOS velocity, eventually coming to stop at zero LOS velocity. This type of record is relatively uncommon and may be observed on only a few occasions per hour in a meteor shower.

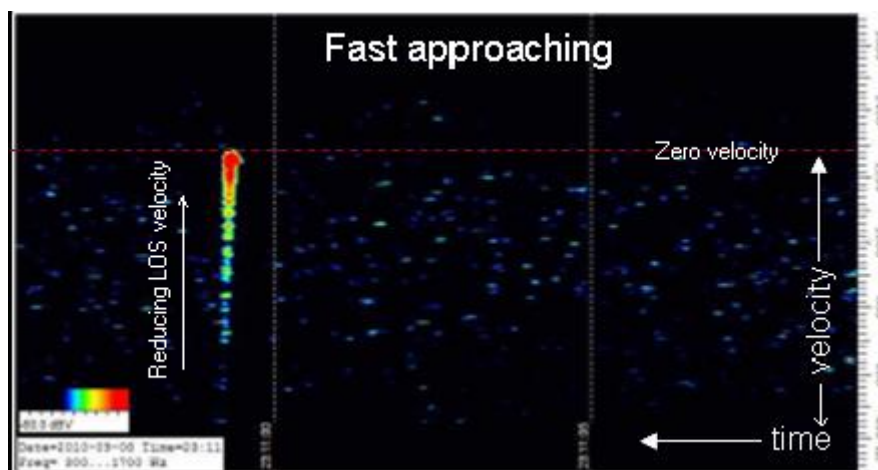


Figure 5.9 A rapidly decelerating Meteor trail

Finally in Figure 5.10 we see an example of an unusual echo. The strongest return has a zero LOS velocity but there are signals at regularly spaced intervals of frequency (velocity) either side of this. The signals corresponding to approach velocities seem to be stronger than those for receding velocities. It is difficult to see how a physical trail can move with these separate velocity components. It is probable that this type of echo arises from some form of diffraction effect along the length of the meteor trail.

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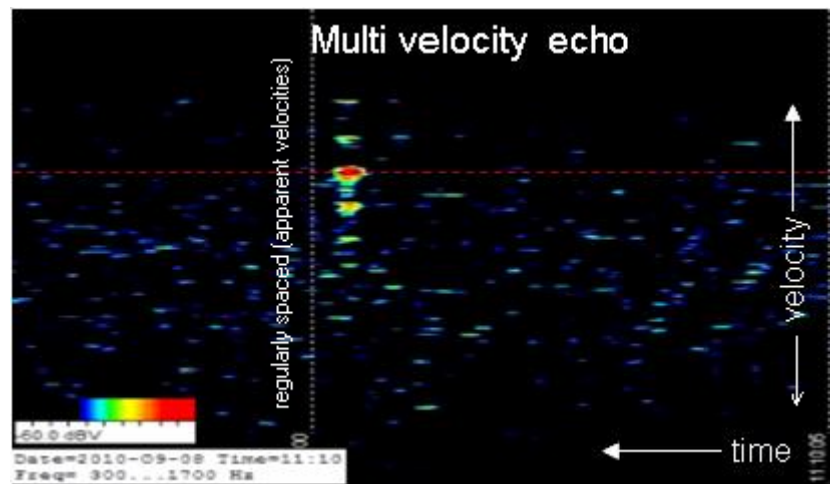


Figure 5.10 'Multi-velocity' Meteor Echo

5.4 Interpretation of echo data

In this section we examine some of the work done by professional observers to understand how the features of the echoes shown above may arise. The formation and dispersal of an ionised meteor trail is a complex evolving process and fundamentally depends on the energy in the meteoroid that is available to produce ionisation. This is of course related to the mass of the particle.

If we were to plot the electron / ion density as a cross section of a meteor trail we may see something like the distribution shown in Figure 5.11.

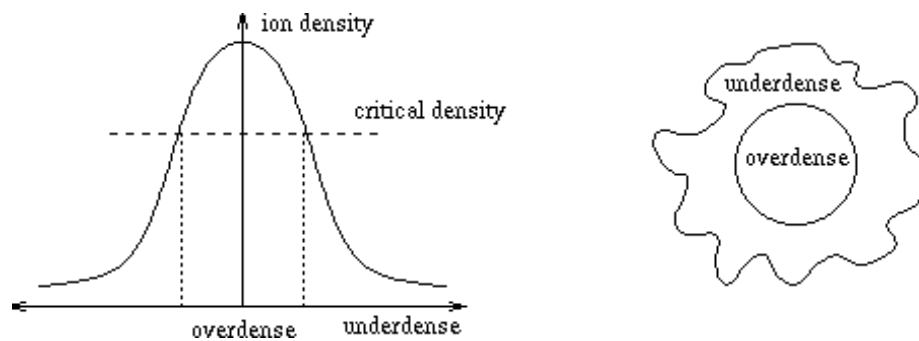


Figure 5.11 Ion / electron Density⁶

The ionisation is greatest in the centre of the meteor trail and falls off either side. At some critical value the ionisation density classification changes from 'under dense' to 'over dense'. If the meteoroid has low mass the central region of the trail may not reach the critical density and the whole trail will be 'under dense' and very short lived, as the weak ionisation disperses rapidly by recombination and results in the weak short echo. An accepted definition⁷ of the two regimes is as follows: Under dense trails have low electron density $q < 10^{14}$ electrons/metre and the scattering is done by individual electrons. These trails are formed by micrometeors with masses from 10^{-5} g to 10^{-3} g. 90% of echoes are under dense, with durations of tenths of a second. Over dense trails have electron density of $q > 10^{14}$ e/m and fully reflect the incident wave as the trail is treated as a cylinder reflector. 10% of events arise from over dense conditions and last for a few seconds.

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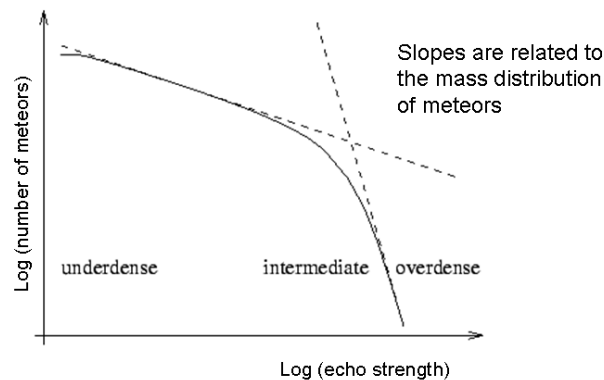


Figure 5.12 Observed numbers of Meteors related to Meteoroid Mass

The graph in Figure 5.12 shows a plot of the number of meteors observed as a function of echo strength. It shows that a large number of weak echoes are observed – these being from under dense trails that recombine quickly. The number of strong, long lasting echoes from over dense trails is much smaller. There are two clear regimes here (linear slopes on a Log/Log basis) for under dense and over dense classes, with an intermediate section between. These slopes are related to the mass distribution of meteoroids in a particular shower.

Professional meteor radar measurements for 'head echoes' where the meteoroid is travelling directly into the radar beam, show a clear distribution of meteoroid mass, with the most frequently occurring mass of around 10^{-5} g. There is a slow tail on the meteoroid mass above the norm and some particles have a mass approaching 1 g.

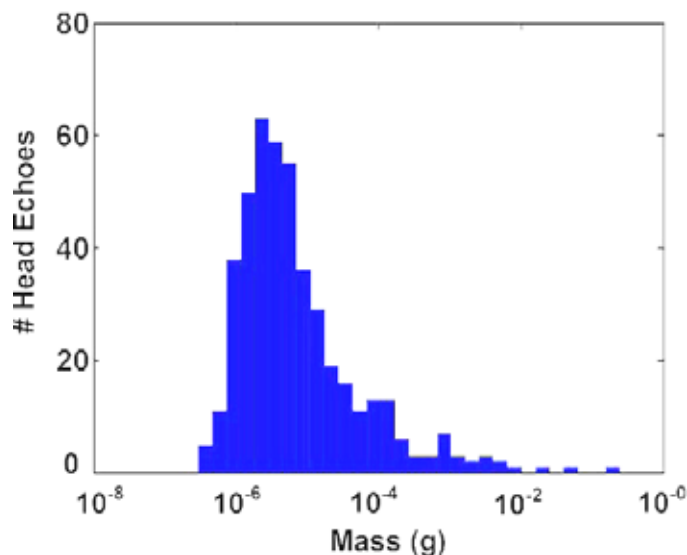


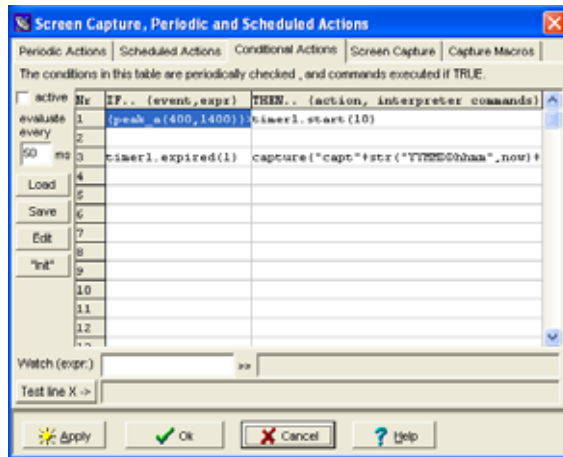
Figure 5.13 Distribution of Meteoroid Mass*

From this data we would expect to observe a larger number of short faint echoes rather than strong, long lasting ones. This is also true when using the simple amateur equipment discussed earlier (with limited sensitivity) to observe echoes from the Graves CW transmitter.

Detection of Meteors by RADAR

5.5 Automatic echo capture

It is not practical for an observer to receive an echo and record it manually over a period of 12 – 24 or more hours during a meteor shower. Some automatic means is required. Fortunately the Spectrum Lab software³ has a feature that enables this.



This screen shot shows how conditions can be set to automatically capture a waterfall plot of a received meteor trail.

Firstly, a signal level threshold is set so that when exceeded by an echo, a timer is started, to allow the waterfall plot to continue to run until the echo trace is roughly in the centre of the plot. After this time an instruction is given to activate a 'capture macro' that saves the plot as a jpeg file.

Figure 5.14 Conditional Action Window

* (see reference 19)

The effect of this conditional action is shown in Figure 5.15. The incoming signal data is shown as the bottom trace in red with peaks extending above the baseline noise. The threshold level specified in the conditional action window (-43dB) is shown by the yellow dotted line. When this is exceeded the software produces a spike (green trace) to show that it has captured a jpeg shot of the waterfall plot. These captured plots contain all relevant data such as date and time (to one second), the spectrum frequency range (therefore velocity range) and an image of the echo trace.



Figure 5.15 Automatic Echo Capture

5.6 Automatically captured echo data

Using the system outlined above, thousands of echoes were captured during August / September 2010. An example is shown in Figure 5.16. Here detections are marked by a black vertical line – these being taken from the green trace in Figure 5.15. It can be seen that the frequency of detection of meteor echoes is not constant – there is significant statistical variation over the period of ~ 22:00hrs on 31/8/10 to ~07:00 on 1/9/10.

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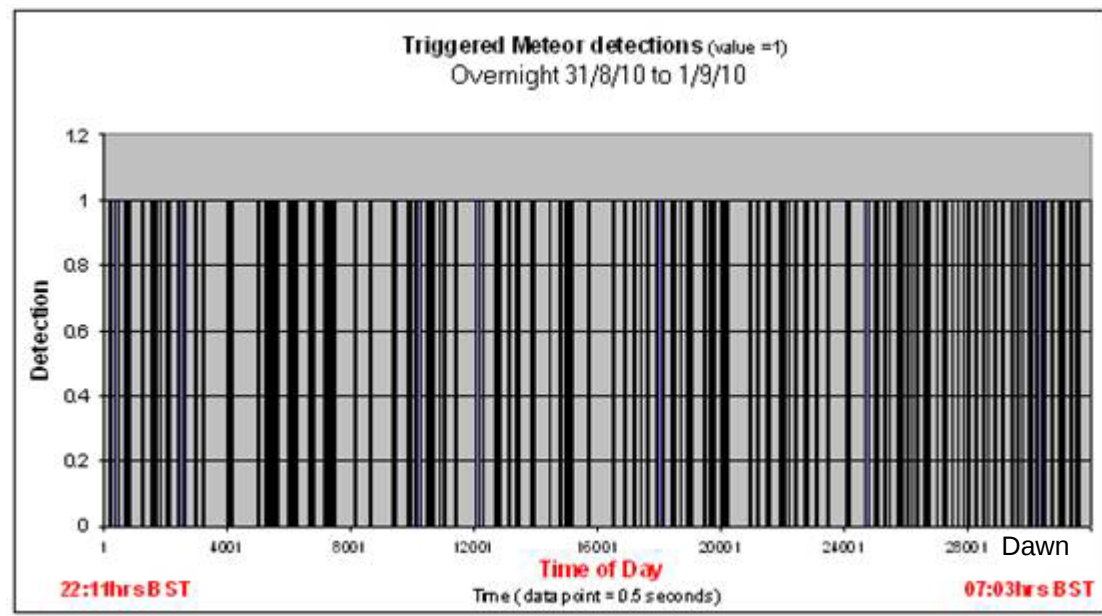


Figure 5.16 Time of Meteor Echo Detection

It is possible to differentiate between true meteor echoes and spurious interference by looking at the nature of the signal trace in Figure 5.15, where interference will appear quite different from a genuine echo – and also by examining the waterfall plot of any signal that is suspected of being interference. Any interference detections can be deleted from the records.

Using Microsoft Excel we can turn this plot into a rate plot shown in Figure 5.17. Here we see the number of echoes detected in each 30 minute period during the observation. The rate varies from 23 per 30 minutes to 53 per 30 minutes, peaking around dawn.

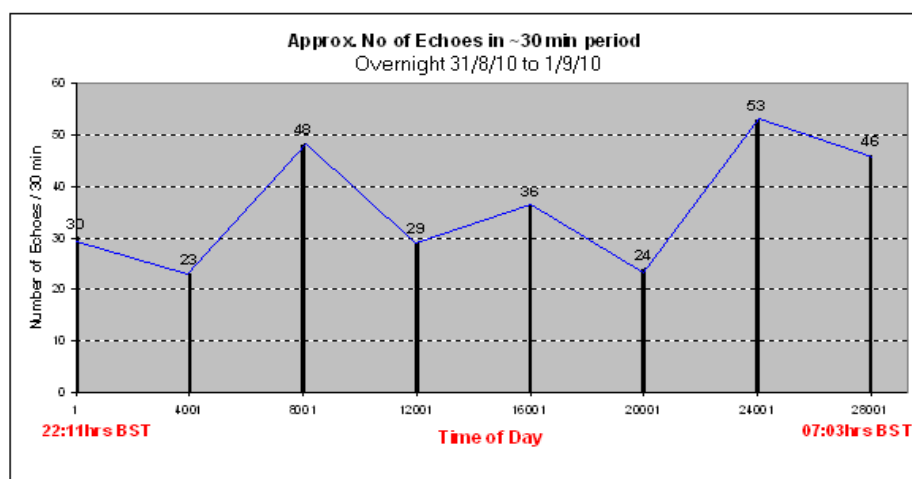


Figure 5.17 Variation in the rate of detection of Meteors

These figures are only representative of the particular receiver sensitivity / baseline noise level and the threshold set in the software. For other systems and on other occasions these figures will vary. This example is given to show how automatic detection and analysis can be carried out.

Detection of Meteors by RADAR

5.7 Observations of the Orionid Meteor shower October 2010

The equipment described above was set up to observe the 2010 Orionids. An example of the signal strength plot for the 25th of October 2010 is shown in Figure 5.18.

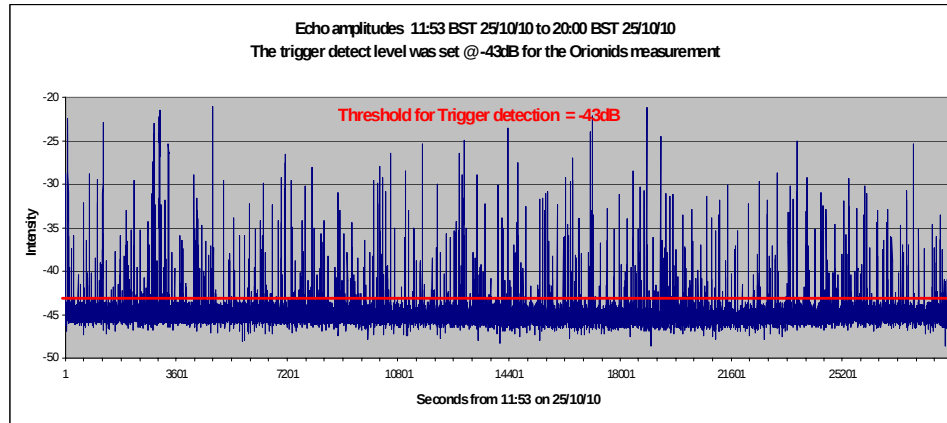


Figure 5.18 Echoes received on 25/10/2010

The data was manipulated in an Excel spreadsheet to yield the number of echoes falling into various ranges of signal strength. The signal strength 'bins' were as shown in Figure 5.19. The five bins contained all echoes within a 5db band from < -35dB to < -20dB. (the dB values are entirely arbitrary and depend on the receiver settings for this case).

We can see a clear relationship between number of echoes received in each signal strength bin and the value of the signal strength. A logarithmic fit is satisfactory and resembles the Log/ Log plot in Figure 5.12. where the number of echoes versus signal strength is related to meteoroid mass.

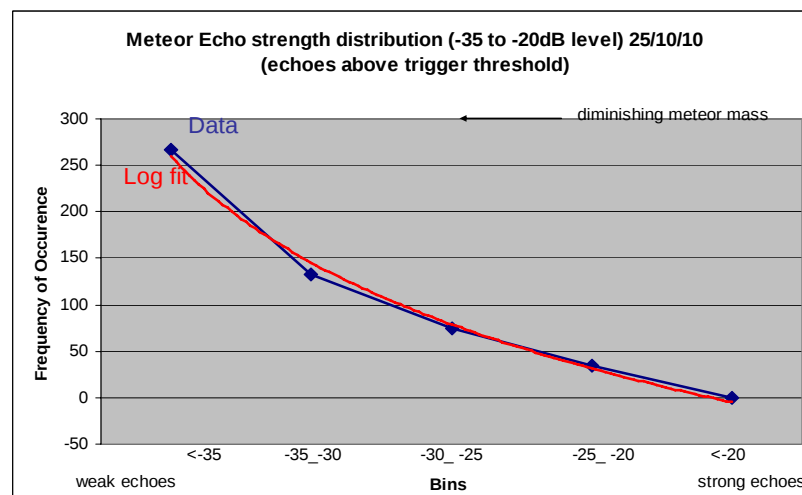


Figure 5.19 Relationship between Echo numbers and echo strength

The hourly rate of meteor detections (of all strengths) is plotted over the 10 day period of observation from 18/10/10 to 28/10/10 in Figure 5.20 and shows distinct variability correlated with dawn each day. The highest counts occur in

Detection of Meteors by RADAR

the middle of the Orionid shower – on this occasion from the 20th to the 25th of October 2010.

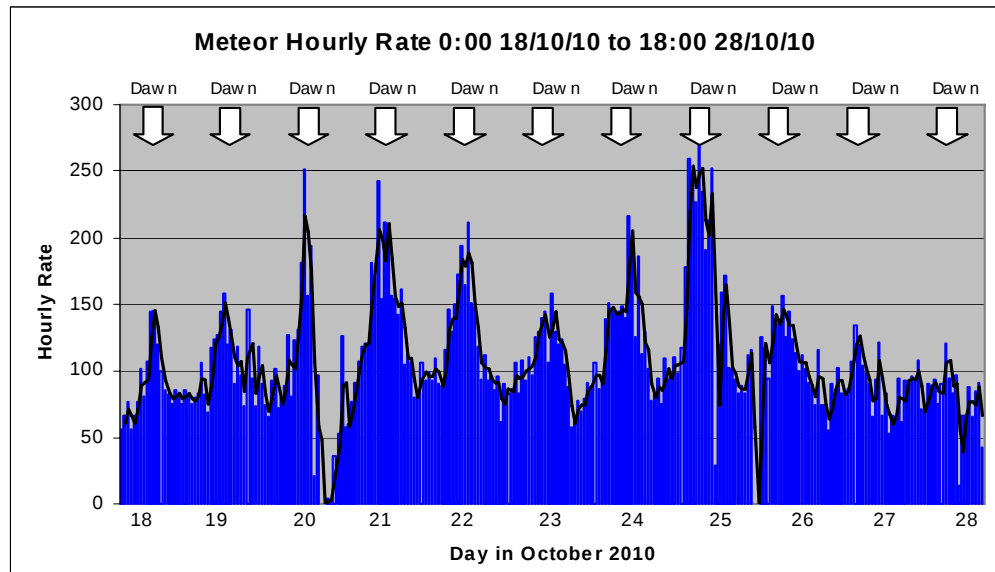


Figure 5.20 Meteor detection rates - showing peaks each dawn

This diurnal behaviour is often observed and is well understood. It is explained later in this document.

The average hourly rate of detections for each day during the observation period is plotted in Figure 5.21 and shows the overall nature of the Orionids for that year. There seem to be two peaks within the overall increase between the quiet non-shower periods before the 18th of October 2010 and after the 28th of the month.

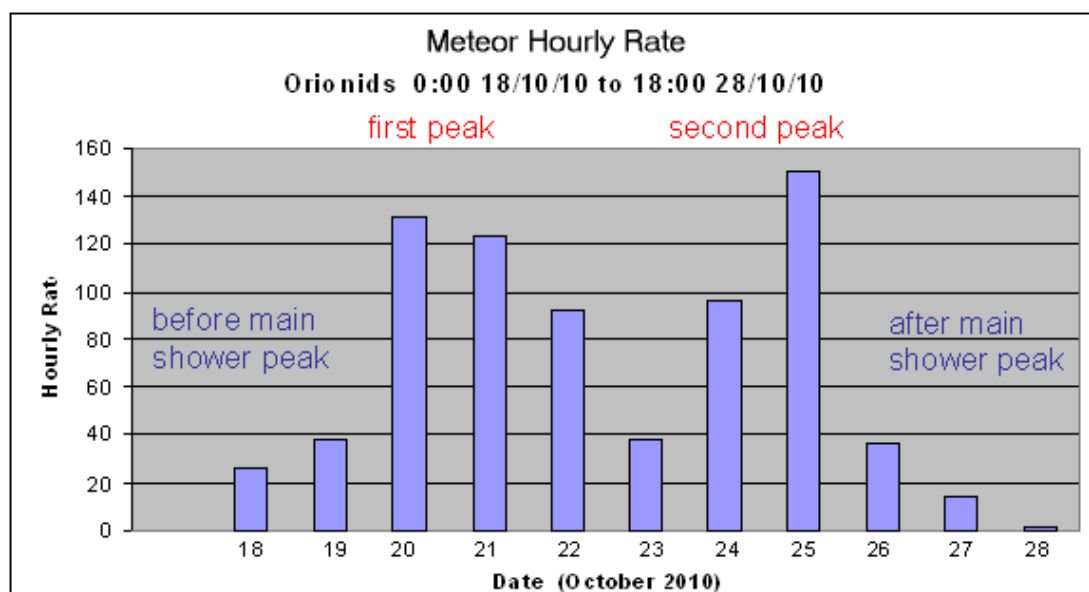


Figure 5.21 Average daily hourly rate during Orionids 2010

Detection of Meteors by RADAR

This section has demonstrated that it is possible for the amateur observer to construct a meteor radar receiver with very simple equipment and free software that is capable of automatically capturing thousands of meteor echoes with an intriguing range of Doppler shifts and durations.

In the next section we will look at some of these echoes and examine the velocity / time waterfall plots in some detail to understand the way in which the echoes may have been generated.

Whilst many amateurs may wish to build the equipment or to observe and collect a library of echo shapes, additional value and enjoyment is to be had from working toward an understanding of the physics of echo generation and relating this to the mass, velocity and geometric distributions of meteoroids entering the Earth's atmosphere.

6 Echo Spectral characteristics

As we have seen, there are a variety of echo returns that when displayed on a frequency / velocity vs time waterfall plot present some fascinating shapes that may be indicative of the way the echo has formed. In what follows we look at some general types or groups of echoes and attempt an interpretation of the echo 'shapes'.

6.1 Short simple echoes

We see a classic short simple echo in Figure 6.1. The red dotted line marks zero LOS velocity. This is probably an example of an under dense meteor trail formation. In this case it either has no LOS velocity or exists for such a short time at a density that causes a good reflection, that no velocity change is observed. The vast majority of echoes received are of this type and are created by low mass particles with $m < 10^{-3}g$.

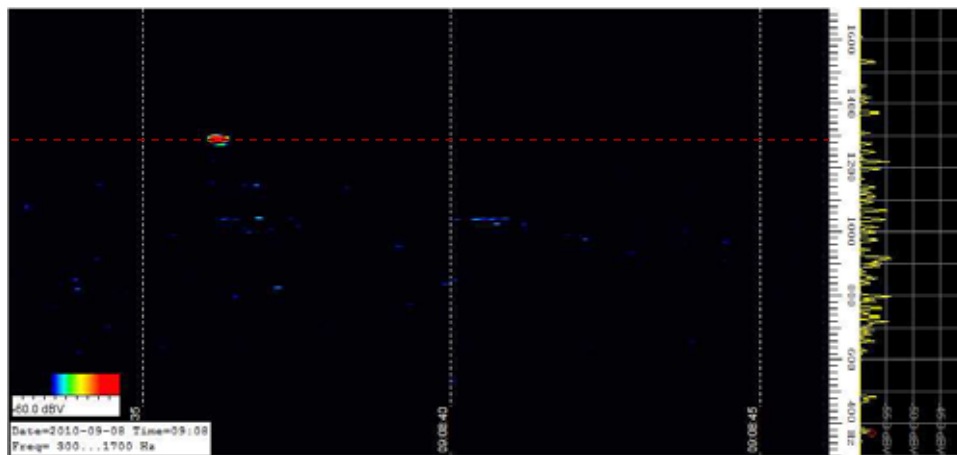


Figure 6.1 Example of short under dense echo

6.2 Decelerating trails

Figure 6.2 shows a good example of a meteor that is rapidly decreasing its velocity. The trail lasts for 0.12 seconds (at the sensitivity of this equipment) and the frequency change is $1290\text{Hz} - 560\text{Hz} = 730\text{Hz}$.

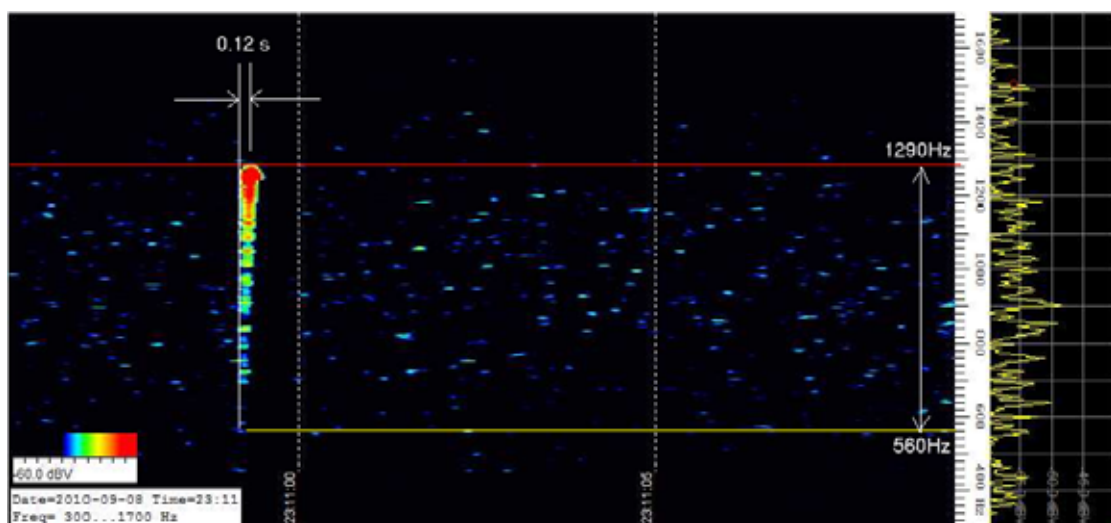


Figure 6.2 Example of a Fast Decelerating Meteor Trail

Detection of Meteors by RADAR

Using the Doppler shift formula given in section 3.3 we calculate that the LOS velocity at which the meteor is first detected is 1.5km/s. This is rather a low value and suggests that either the trail was formed at a considerable angle to the LOS, or more likely, that the receiver is not sensitive enough to detect the ionised trail while it is still weak, at the start of its formation when the particle velocity is high.

6.3 'L' shaped echoes

During the observation of the 2010 Orionids many 'L' shaped echoes were observed – an example is shown in Figure 6.3. The form of the velocity profile suggests that an approaching meteor decelerates very quickly as in Figure 6.2, but that there is sufficient ionisation to maintain a stationary echo with zero LOS velocity for a few seconds.

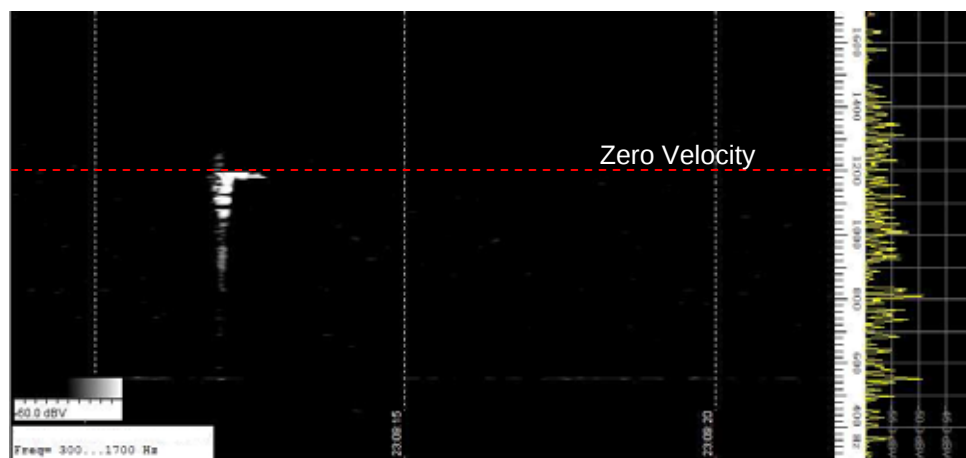


Figure 6.3 Example of 'L' shaped echo

6.4 Long Echoes

On occasions echoes lasting a few seconds are observed with no LOS velocity. These tend to be intense echoes and suggest strong ionisation from an over dense meteor trail that has been generated by a particle with a mass greater than 10^{-3} g.

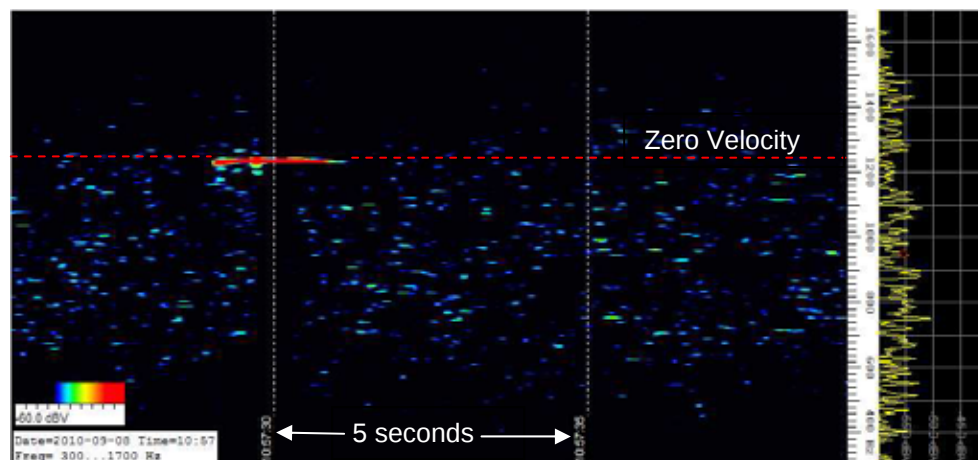


Figure 6.4 Zero LOS velocity echo of several seconds duration

6.5 Very long Echoes

Figure 6.5 shows an example of a very long, strong echo that lasts for ~ 8 seconds. This type of echo is unusual – only a few have been observed during any day. This is probably a genuine meteor echo as it has some change in velocity over the period of its existence. This may be attributed to a drifting trail, possibly due to high speed – high altitude winds. It is not an aircraft. The echo from an aircraft usually shows no appreciable Doppler shift and the velocity profile of spacecraft or space debris can be clearly differentiated from this long echo.

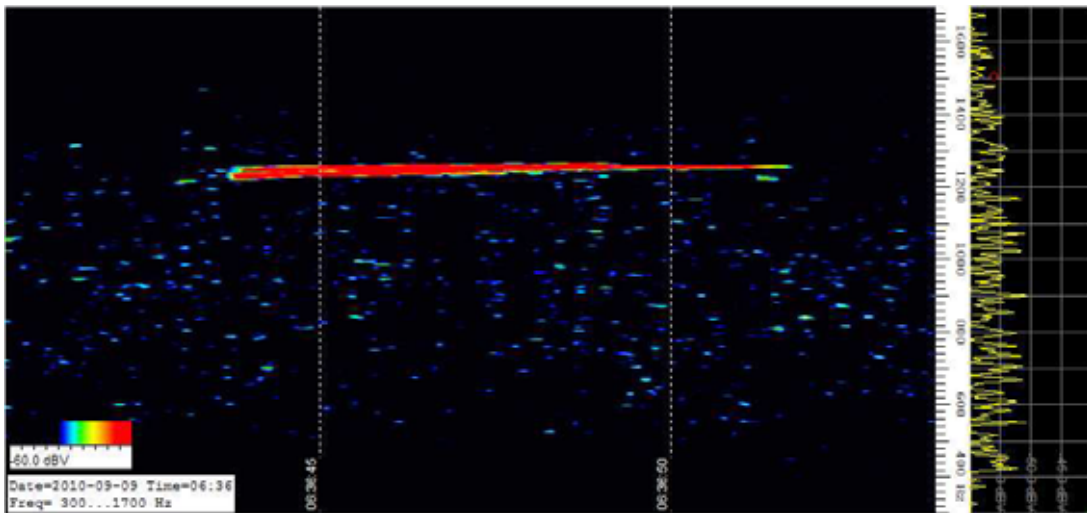


Figure 6.5 Probably a strong Meteor echo

6.6 Artificial Satellites

Satellites are easily distinguished from meteor echoes as they present a clean almost linear velocity profile over a few seconds. An example is shown in Figure 6.6. A short zero LOS velocity meteor echo can also be seen in this figure.

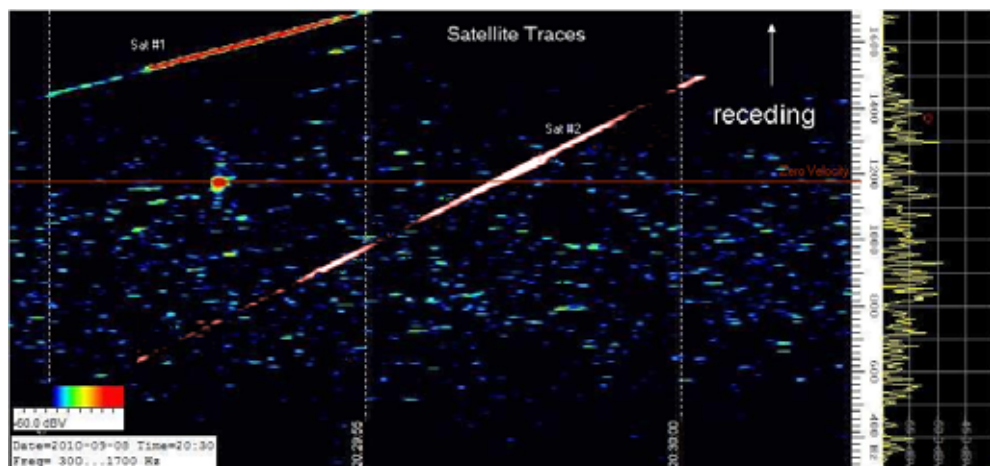


Figure 6.6 Artificial Satellite echoes

Detection of Meteors by RADAR

6.7 Multiple Branch Echoes

Usually during any period of observation complex echoes such as that shown in Figure 6.7 are recorded. They present a challenge to interpret them and visualise what is happening during their generation. The forms are very variable, but there are some common features. There are components at different frequencies (velocities) , they start at a defined time, they fade and may reappear at the same frequency and they may, as a collective, last for several seconds. It would be hazardous to propose a single explanation for the production of these forms and it is probable that a mix of processes contribute to their generation. For example the meteor may 'break up' and produce regions of ionisation that become disconnected and move with differing velocities.

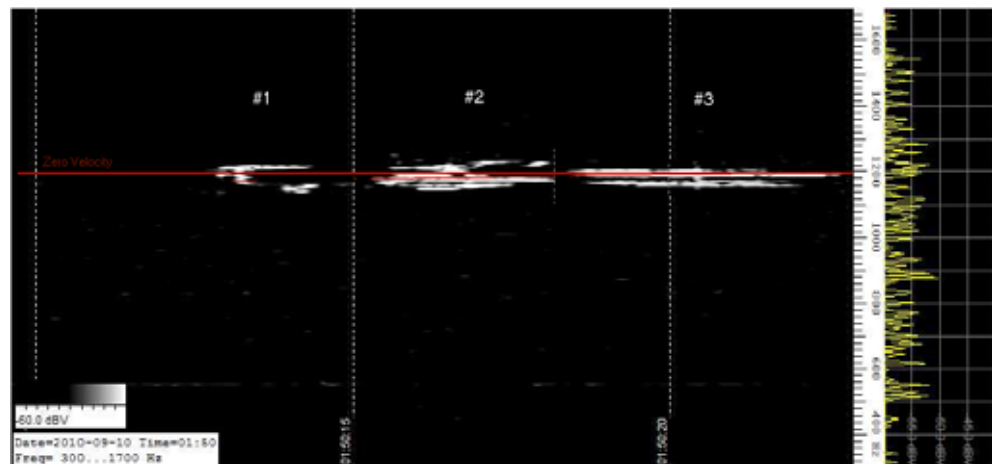


Figure 6.7 Examples of complex branched echoes

6.8 Diffracted Echoes ?

In many of the echoes produced by fast decelerating meteors that present a significant LOS velocity to the observer the frequency / time waterfall trace shows a regular pattern of signal variation. The regularity of the fading of the signal may be a clue to the mechanism involved. It is probable that the incident transmitter signal is being diffracted by a long ionised trail during its formation. This mechanism is discussed in more detail in Section 7.

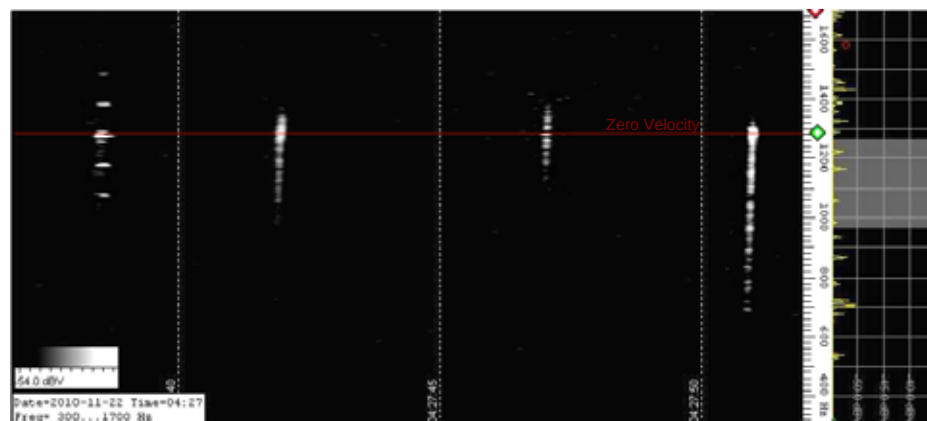


Figure 6.8 Possible example echoes from diffracted meteor trails

7 Echo fading

7.1 Intensity profiles

In order to examine the variety of meteor echo traces observed, it is useful to have a software tool that can produce a graph of signal intensity as a function of echo duration. Software packages such as IRIS[®] can perform this task. The software enables the user to place a 'marker line' through the echo trace on the waterfall plot that defines the axis along which the intensity of the echo will be measured. An example of this operation is shown in Figure 7.1 where a 'marker line' shown in red is placed through a black to white graded 'calibration' panel.

The software measures the intensity at each point along the line and plots a corresponding graph.

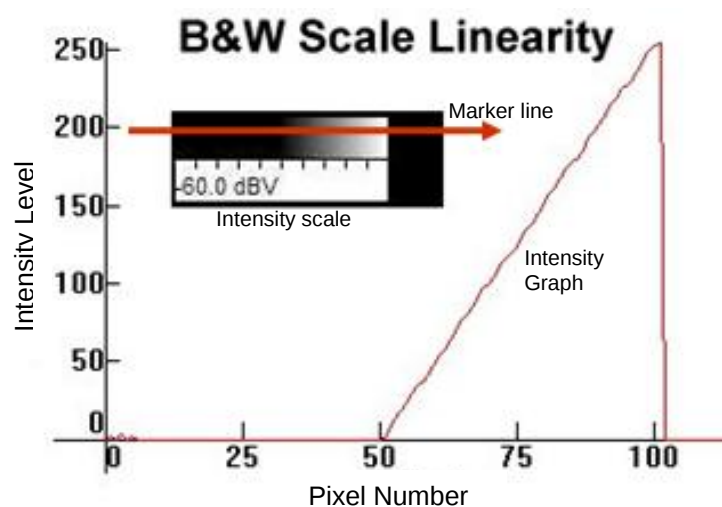


Figure 7.1 Using IRIS Software intensity profile feature

The use of this profiling tool on a real meteor echo is shown in Figure 7.2 where satisfactory operation can be seen.

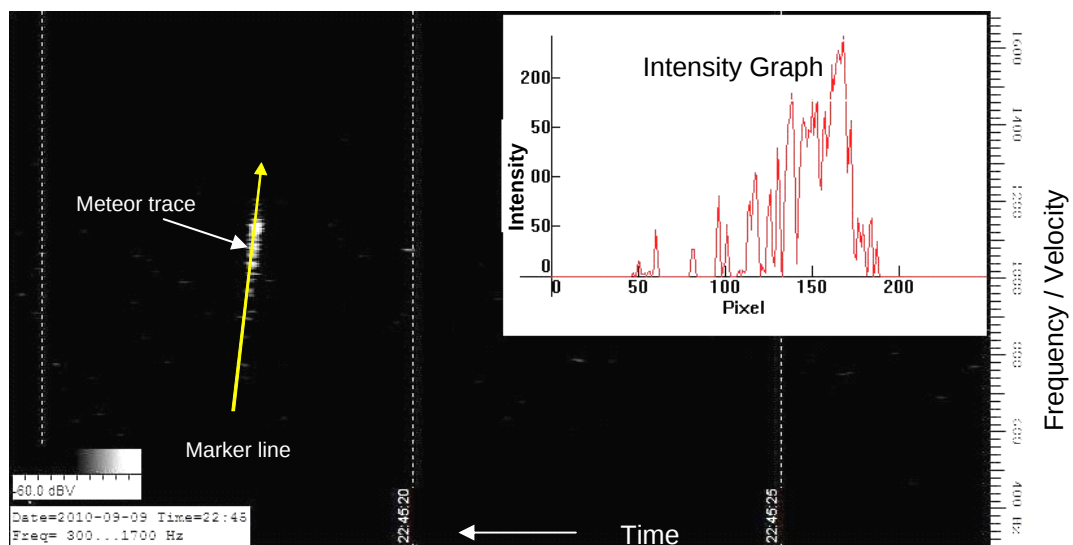


Figure 7.2 Intensity Profiling of a Meteor Echo

Detection of Meteors by RADAR

This tool can be used on any echo that has a linear feature along which the 'marker line' can be drawn. An example of measuring the signal intensity of an aircraft echo is shown in Figure 7.3. We see that the very long lived echo is 15 seconds long and has significant fading at periods during its life.

The IRIS profiling tool has been used to generate the intensity graph shown in blue in the lower pane. This tool is key to analysing the signal fading produced by diffraction of a meteor trail whilst forming. Diffraction effects are discussed in the next section.

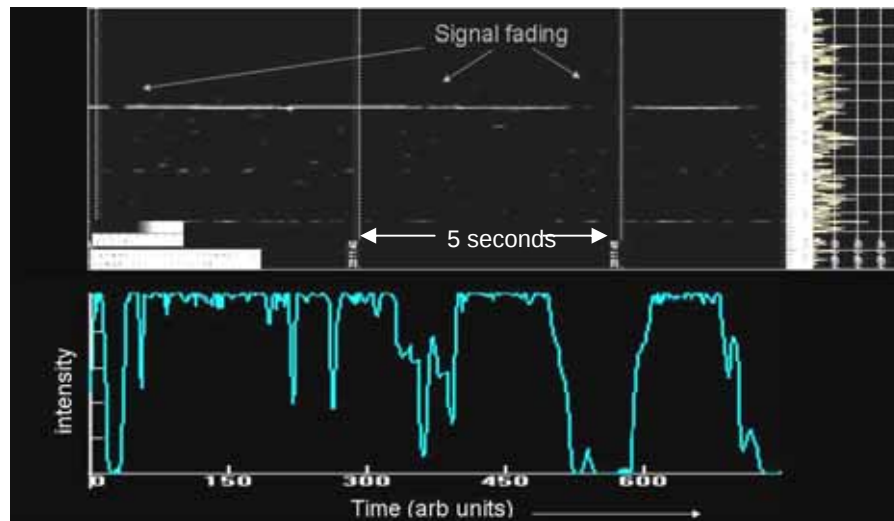


Figure 7.3 Intensity profile of an aircraft echo

7.2 Diffraction of Meteor Trails

This is a complex subject and much effort has been devoted to it by professional observers^{9 10 11 12}. For a full understanding, the reader is directed to the numerous scientific publications available on the internet. What follows here is a simple introduction to the topic that highlights some of the important meteor echo diffraction effects that can be observed with amateur equipment.

As an ionised trail forms, the incident transmitter radiation is reflected back to the receiver by the growing length of the trail. For a given observing geometry the total returning signal will be composed of reflections from different parts of the trail at different times. The sum of all the reflections as they develop will not be constant, as parts of the trail will produce 'in phase' and 'out of phase' components. This acts much like a diffraction grating and produces strong and weak intensities at different points in space. As however the trail is forming with a changing velocity, the variation in intensity will also be seen as a function of both frequency and time.

Figure 7.4 shows a diagram of how this diffraction effect forms. The meteor enters the frame from the top right with a high velocity and starts to create an ionised reflective trail such that a return signal is observed. This will have some defined path length to the observer. At some later time when the path length to the observer has changed by $\lambda/2$ the signal from this new section

Detection of Meteors by RADAR

will tend to nullify the return from the pre-existing component of the trail. The returned signal will therefore diminish in strength as cancellation occurs. This process repeats along the length of the meteor trail resulting in a periodic fading of the return signal. The physical situation here can be described as Fresnel scattering and the meteor trail can be thought of as being composed of a number of Fresnel zones.

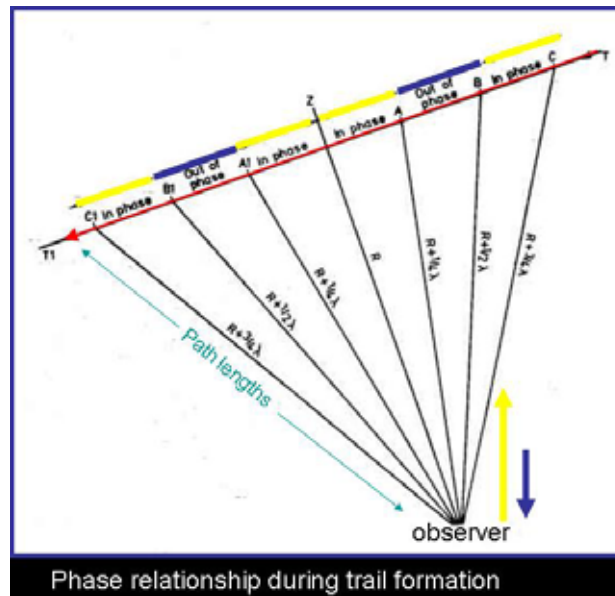


Figure 7.4 Diffraction fields from a Meteor Trail

A representation of the way the return signal strength varies as a function of time is shown in Figure 7.5. The signal rises as the first part of the trail is formed, this rises to a peak and then diminishes as the return from the newly formed out-of-phase section of the trail interferes with the existing return. The process continues on a periodic basis until the trail decays away. As the Doppler frequency is changing as the particle / ionisation decelerates, the periodicity appears as signal modulation as a function of Doppler shifted frequency.

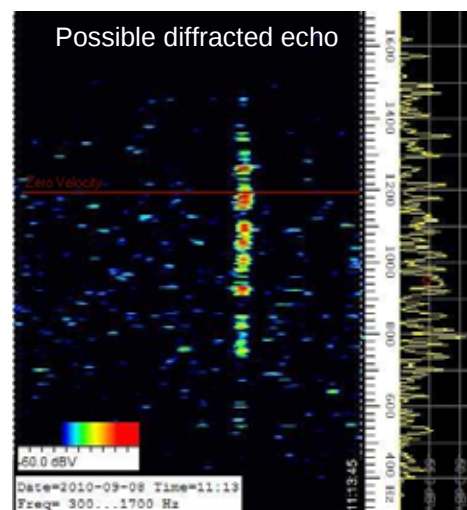
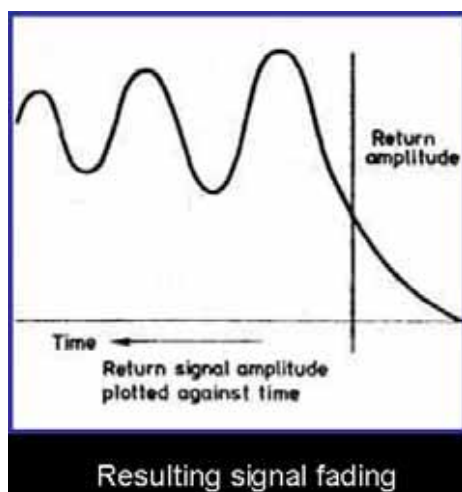


Figure 7.5 Signal fading due to meteor trail diffraction effects

Detection of Meteors by RADAR

A good example of a possibly diffracted echo can be seen in Figure 7.6. The signal strength is seen to peak and fade on a regular basis with a defined periodicity. Professional meteor scientists use this to calculate the true velocity of the meteor trail, sometimes from several stations observing the same event.

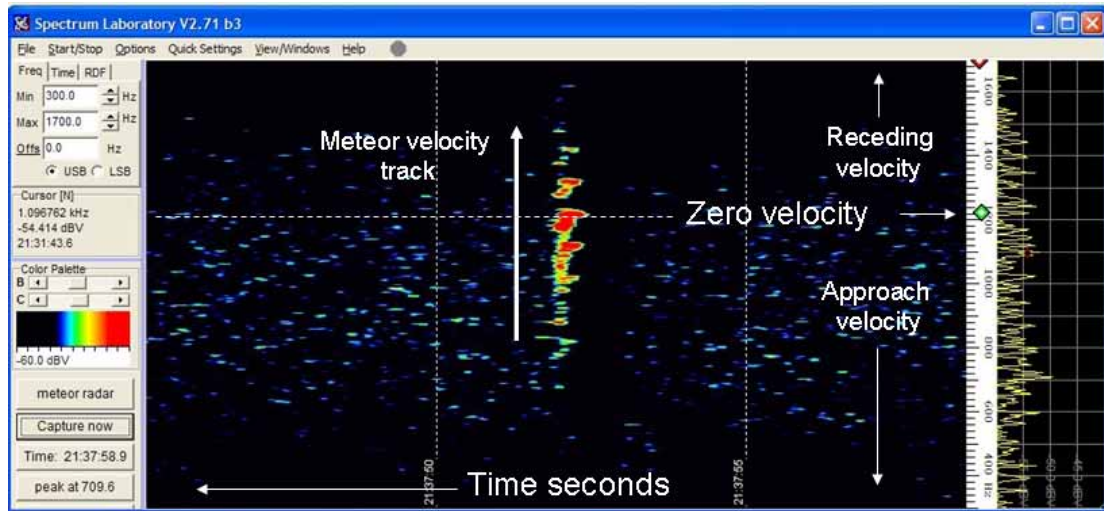


Figure 7.6 Periodic fading of a meteor return

7.3 Broken Trails

Complex or multiple echoes such as those in Figure 6.7 can sometimes be generated by shearing of the meteor trail by fast high altitude winds. The trail becomes distorted or broken up into sections that are displaced from each other, providing the opportunity for changes in the diffraction pattern of the returned signal. If the parts of the return become separated they may act as distinct 'reflectors' or 'glints' moving at different speeds in the wind and thereby generating a collection of separate echoes. The analogy would be the multiple images of an object in broken mirror. See Figure 7.7.

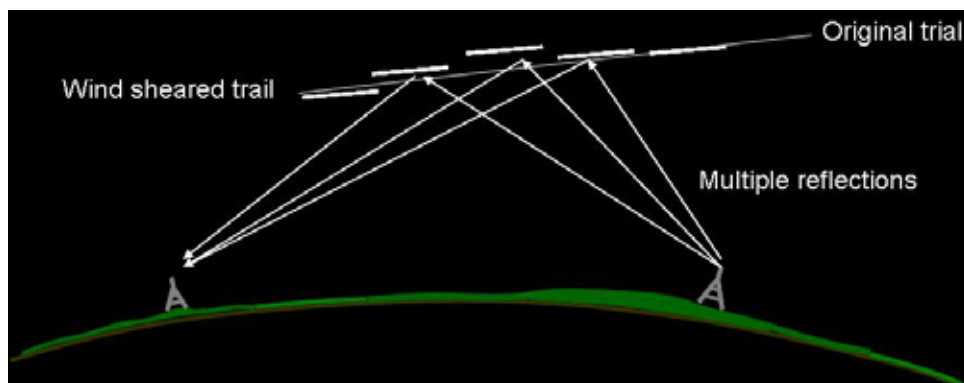


Figure 7.7 Broken meteor trail due to high altitude winds

These separately moving patches will create a complex diffraction pattern at the receiver, with the received signal strength fluctuating in a pulsating manner through the duration of the meteor event. Because Sporadic E (Es) and afternoon D-layer scatter can also create such complex events, distinguishing true meteor trails of this type can sometimes be difficult.

8 Meteor numbers & velocities

8.1 Determination of meteor velocities

Meteor head echoes occur most frequently when the meteor has a very low inclination angle to the Earth's atmosphere. This causes the meteor path length to increase, and the meteor to remain in the zone where radio wave reflections occur for a longer period of time. For meteor showers this type of event occurs most frequently when the radiant point is very low in the sky⁹. Professional meteor scientists use head echoes and trail diffraction effects to calculate the distribution of true meteor velocities.

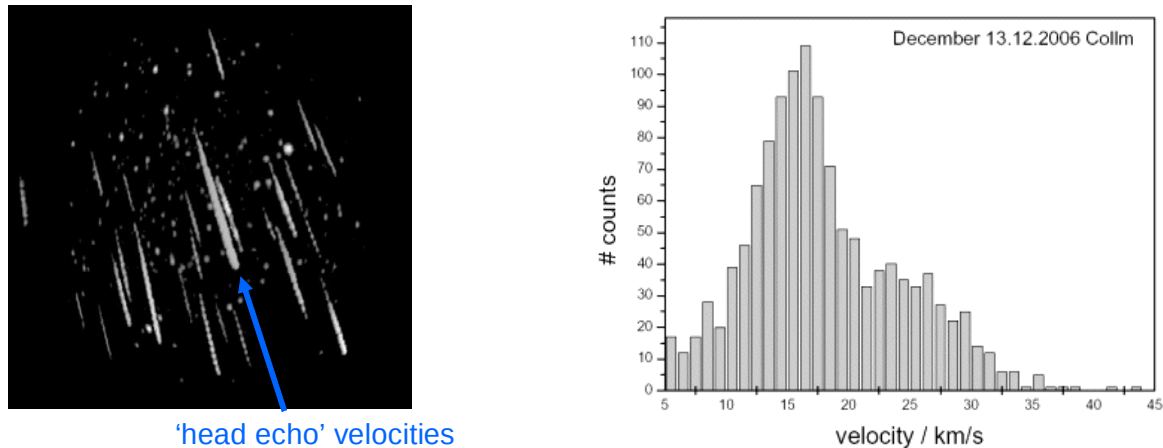


Figure 8.1 Distribution of Meteor Velocities

One such result is shown in Figure 8.1 where the most common velocity is around 16km/s. It is technically very difficult to determine these velocities absolutely – the result depends greatly on the characteristics of the radar, including transmitter power, receiver sensitivity, antenna beam shape and time resolution of the echo. Making measurements of this sort is probably beyond the grasp of most amateur meteor astronomers.

8.2 Daily variation of sporadic meteors

There are two classes of meteors: sporadic and showers – they are defined in section 2.2. The sporadic meteors which shower the Earth all the time have no strong preferred direction of arrival, but the numbers of such meteors observed varies through the day as their intercept velocity with the Earth changes due to the orbital velocity of the planet. This is shown in Figure 8.2.¹³

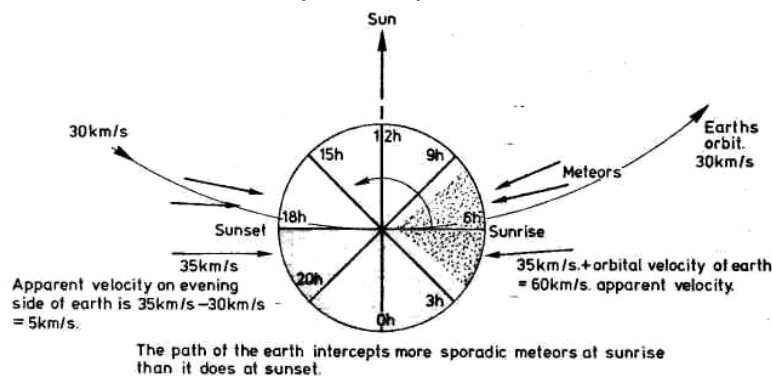


Figure 8.2 Diurnal Variation of Meteor numbers

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Much research has been conducted into the daily, yearly and long term variability of meteors by academics with a wide variety of radars.^{14 15 16 17}

There is an accepted way to plot the numbers of meteors / hour though a day and for many days in the form of a 'colourgram' as shown in Figure 8.3¹⁸.

This is a time-date graph, where the activity at a certain time is indicated with a colour code. The particular record shown below derives from the Prometeos setup at the University of Ghent in Belgium. The dark band that runs across all days, is the dusk sector with the bright regions predominantly around dawn. There is clear evidence of a few days of increased activity approximately two thirds of the way through this record. This probably results from shower activity.

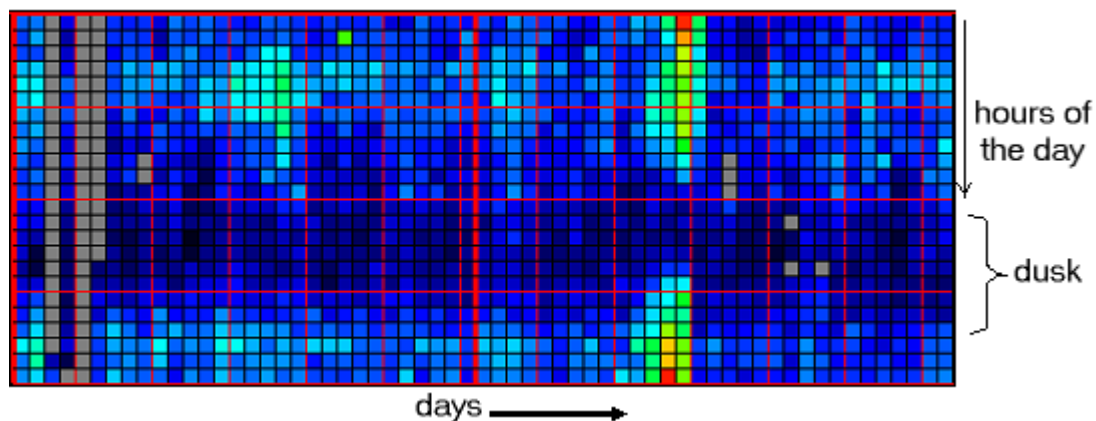


Figure 8.3 Colourgram representation of daily meteor count data

8.2 Meteor showers

During a strong meteor shower the rate of meteors can rise substantially by perhaps as much as 10 times. There are a number of showers throughout the year as indicated in Table 2.1. An example of a strong meteor shower is shown in Figure 8.4 for the Perseids in 2010, peaking during August 13th. These are exciting times to run an amateur meteor radar and collect a large quantity of data for later analysis.

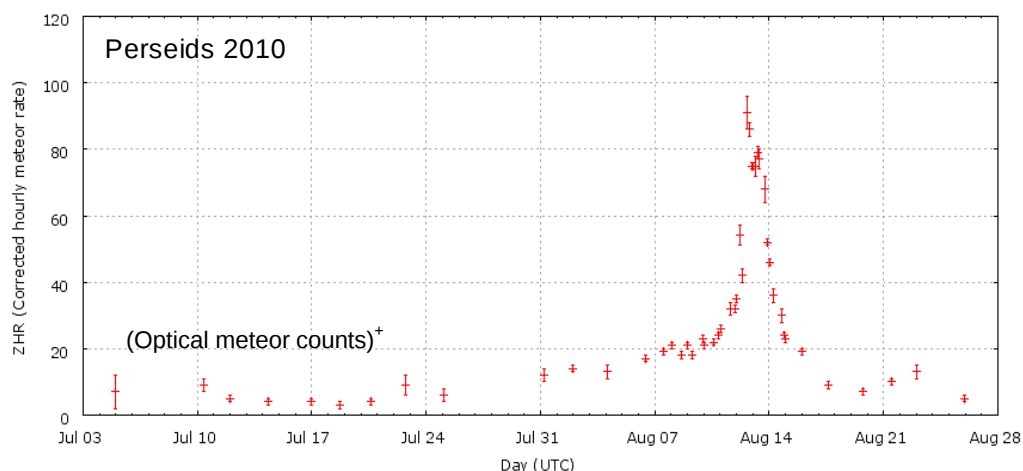


Figure 8.4 Example of a strong meteor shower

⁺ Reference ²⁰

Detection of Meteors by RADAR

8.3 Long term variation

A number of observers keep long term records of meteor hourly and daily rates. From this data it is possible to see at a glance where the main activity arises throughout the year and how variable rates can be from year to year. One of the best meteor radar observers is Andy Smith G7IZU¹⁶. He produces superb long term records, such as that shown in Figure 8.5 where we can pick out the main meteor showers through the year, but also see this large variability in intensity from year to year.

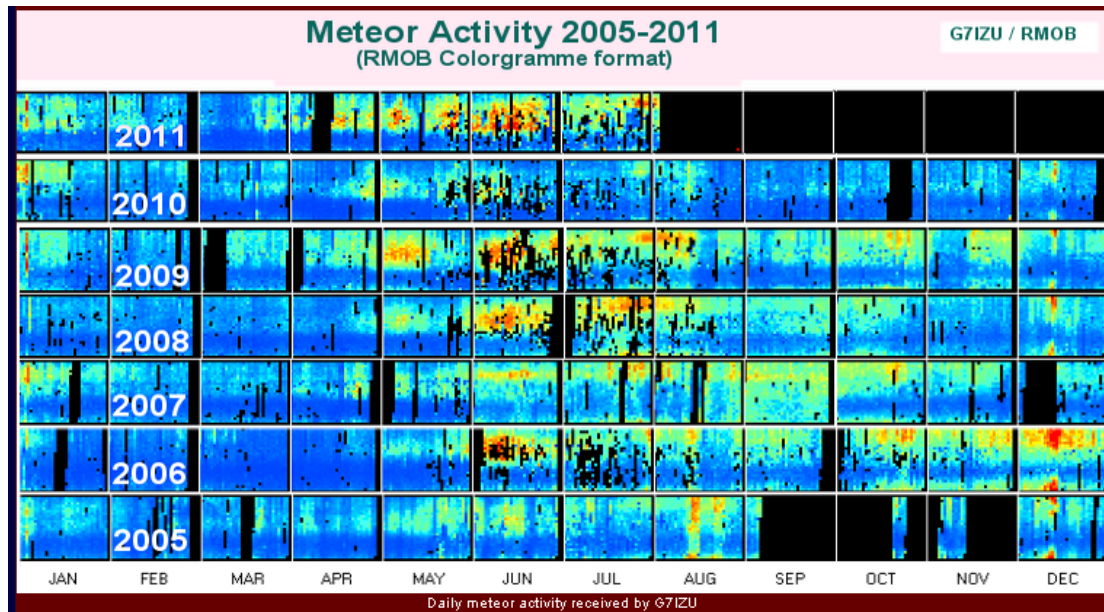


Figure 8.5 Long term records of meteor activity

Every amateur meteor radar observer could aim to provide data as good as Andy Smith's, but it is clear that this involves a significant commitment of time and resources.

For the beginner, it is still a thrill to set up the equipment and start recording meteor events as described in this article. Over time an amateur station can hope to compile results for the major showers and perhaps produce a stunning data set such as that in Figure 8.5.

9 Conclusions

- Amateur observers can easily build a simple meteor radar receiving station that is tuned to the French space surveillance radar transmitter located near Dijon on 143.050MHz CW.
- The equipment required consists of: a 3 element Yagi antenna, a communications receiver or a software defined radio device such as the FUNcube Dongle²¹ and a PC or laptop computer with suitable free software.
- It is possible to use other VHF transmitters such as broadcast stations that are over the horizon as the source of the 'radar' signal, but these usually have some modulation imposed on the signal and can be more difficult to use in resolving the echo return from a meteor trail.
- Echo signals contain a great deal of information about the generation of the ionised meteor trail that can be extracted by suitable software tools. A waterfall display of the spectral analysis of the echo signal is very revealing – yielding information on Doppler shifted line of sight velocities.
- There are many forms of echo signal that can be received and analysed by the amateur observer leading to understanding of the formation and destruction processes related to meteor trails.
- Amateur observers can set up software tools to automatically count the rate of detection of meteors. These records can be amassed to generate a useful database that can be of value to others, including visual observers.
- Setting up a meteor radar receiver is a good way to enter the world of radio astronomy. Many of the techniques and much of the equipment and software can be used directly to develop expertise in the wider field.



References

- 1 Graves Radar www.onera.fr/synindex-en/graves-radar.html
- 2 3 element Yagi www.southgatearc.org/techtips/3ele_2m_yagi.htm
- 3 Spectrum Lab www.qsl.net/dl4yh/spectra1.html
- 4 SpectraVue www.moetronix.com/spectravue.htm
- 5 www.physics.uwo.ca/~whocking/axonmet/radarsites/ferraz/flux.shtml high
distribution
- 6 <http://www.imo.net/radio/reflection>
- 7 <http://indico.cern.ch/getFile.py/access?contribId=28&sessionId=4&resId=0&materialId=slides&confId=59397>
- 8 <http://astrosurf.com/buil/us/iris/iris.htm>
- 9 Meteor types: <http://www.amsmeteors.org/audio/index.html>
- 10 Fine structure in Meteor showers:
<http://digital.library.adelaide.edu.au/dspace/bitstream/2440/37976/3/01front.pdf>
- 11 Meteor observations chapter 5 thesis:
<http://digital.library.adelaide.edu.au/dspace/bitstream/2440/37976/1/03chapter5-bibliography.pdf>
- 12 <http://www.atmos-chem-phys.org/4/911/2004/acp-4-911-2004.pdf>
- 13 http://www.qsl.net/g3wzt/g3wzt_ms.html
- 14 <http://www.atmos-chem-phys.org/4/1355/2004/acp-4-1355-2004.pdf>
- 15 <http://www.ta3.sk/caosp/Eedition/FullTexts/vol4/pp46-62.pdf>
- 16 <http://www.tvcomm.co.uk/radio/>
- 17 <http://www.kolumbus.fi/oh5iy/msobs/msobs.html>
- 18 <http://www.imo.net/radio/reduction>
- 19 S. Close P. Brown, M. Campbell-Brown , M. Oppenheim , P. Colestock
*Los Alamos National Laboratory, Space and Remote Sensing Sciences, Mail Stop
D436, Los Alamos, NM 87545, USA*
*Department of Physics and Astronomy, University of Western Ontario, London, ON
N6A 3K7, Canada*
*Center for Space Physics, Boston University, 725 Commonwealth Avenue, Boston,
MA 02215, USA*
- 20 Perseid Optical count: www.imo.net/live/perseids2010/
- 21 FUNcube Dongle www.funcubedongle.com

Note

The Leonid data has been analysed in some detail and is presented in Appendix A of this document

APPENDIX A - Analysis of Leonid 2010 Meteor Shower Data

A1 Introduction

The aim of the analysis is to sort the echoes by type into a number of categories or classes, in order to examine how the number of echoes of each class vary throughout the day and throughout the period of the Meteor shower.

It is not known if the type of meteor echo – and therefore the mass, velocity and direction of the meteoroids - changes with time through the shower. The statistics of numbers of echoes in a class may change with time and this analysis could help show if this is the case.

A2 Classification of Types

It is proposed to list several classes of echo defined by their length and shape. They will include the following classes:

- 1 Short point-like echoes. These are thought to be the most numerous.
- 2 Slightly longer short linear echoes of less than 1 second length.
- 3 Long linear echoes of up to 5 seconds long.
- 4 Very long linear echoes of any length over 5 seconds.
- 5 Hooked echoes of any length.
- 6 Fast incoming echoes with near vertical traces.
- 7 Long slanting echoes of any length – probably satellites.
- 8 Complex multi-line plots of any length.
- 9 Miscellaneous echoes that do not fit any category above - or have multiple echoes of different types on the same plot.

A3 Method of Classification

Analysis is to be carried out on the Leonids 2010 data

The echo data is in files for each day of observation – from 20:00hrs to 19:58hrs the following day. This is one day's data (a Data Day) – even though it crosses midnight from one day to the next.

The analysis will be carried out for each (Data Day) separately.

Files will be created for categories 1 through 9 and the echo images (jpegs) for that (Data Day) will be placed in the appropriate class file.

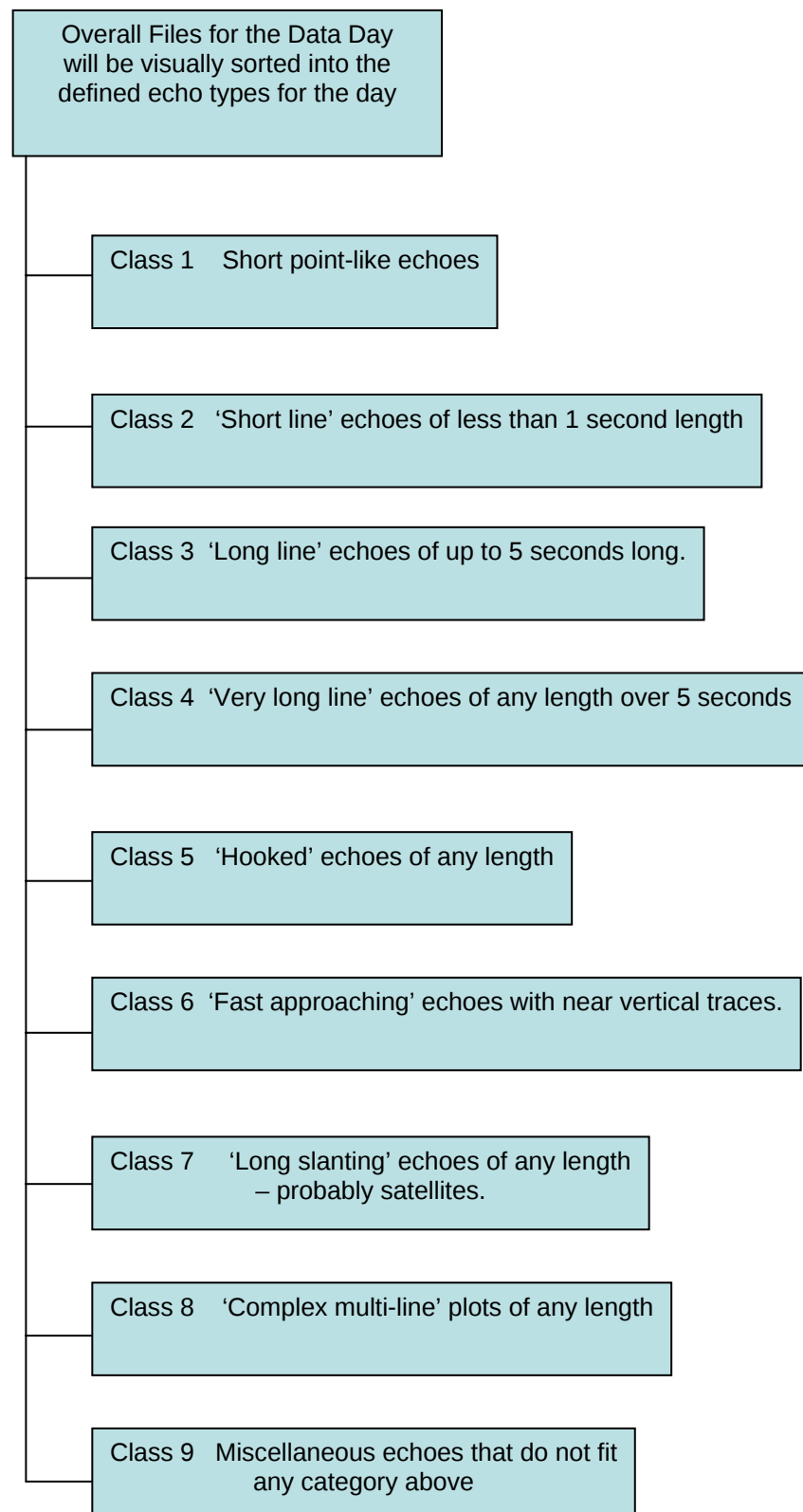
The files will be inspected in date and time order so that the files for each category for each (Data Day) have jpegs in time order (from 20:00 on day n to 19:58 on day $n+1$).

The choice of 20:00 hr for the changeover of daily records was determined by availability of operator to manually change files

A series of histograms will be plotted for all classes for each day.

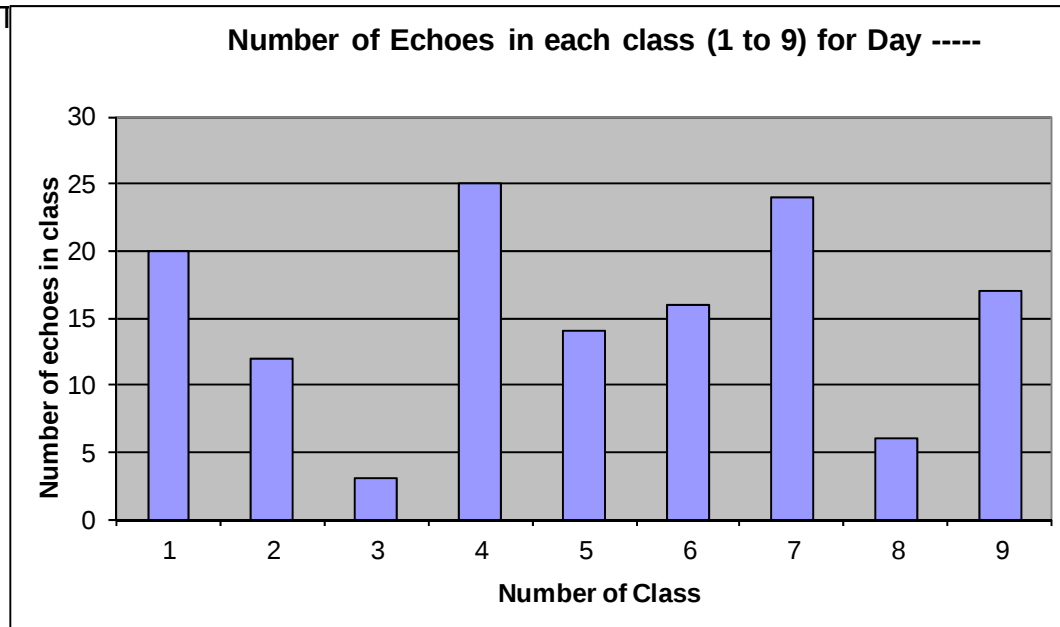
A4 File Structure

The file structure will be that shown below:



A5 Plotting Results

When the echoes have been sorted into different classes (files) the number of echoes in that class (file) will be counted and a histogram plotted of the number in each class against the class of echo. This will result in a plot with 9 columns



This analysis is entirely experimental and does not rest on academic or previously published information. It is simply an example of an amateur radio astronomer interested in finding any significance in the data captured and to understand any instrumental artefacts that it may contain.

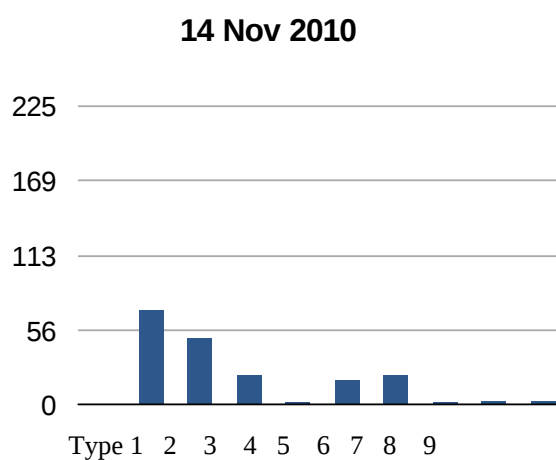
It is offered as an example for others in the field who may wish to look into the potential meaning that may lie within the large amount of data that can be captured with an automated meteor radar receiver.

Detection of Meteors by RADAR

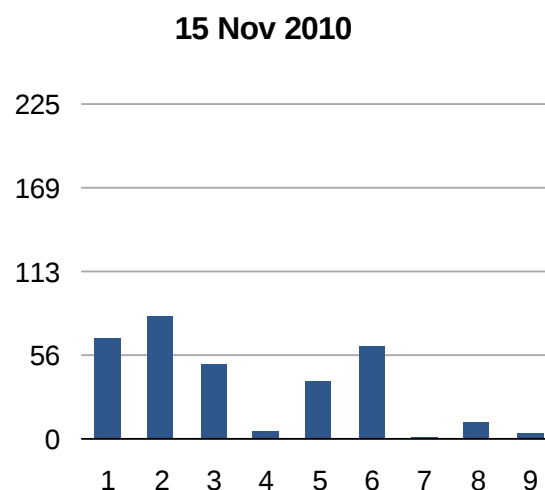
A6 Analysis of Leonid Meteor Shower 2010

(Conducted by Noah Hardwicke)

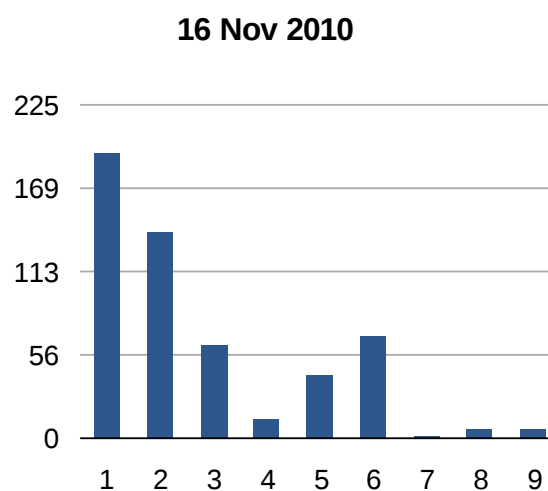
14 Nov 2010	
Type	Number
1	71
2	51
3	22
4	2
5	18
6	22
7	1
8	3
9	3



15 Nov 2010	
Type	Number
1	67
2	82
3	50
4	5
5	39
6	63
7	1
8	11
9	4

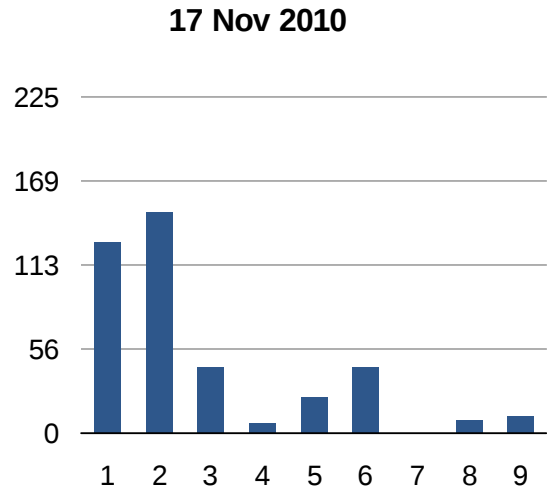


16 Nov 2010	
Type	Number
1	193
2	139
3	62
4	12
5	43
6	69
7	1
8	6
9	6

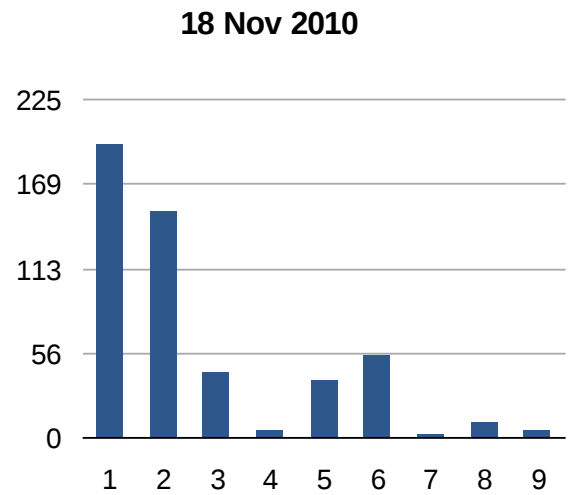


Detection of Meteors by RADAR

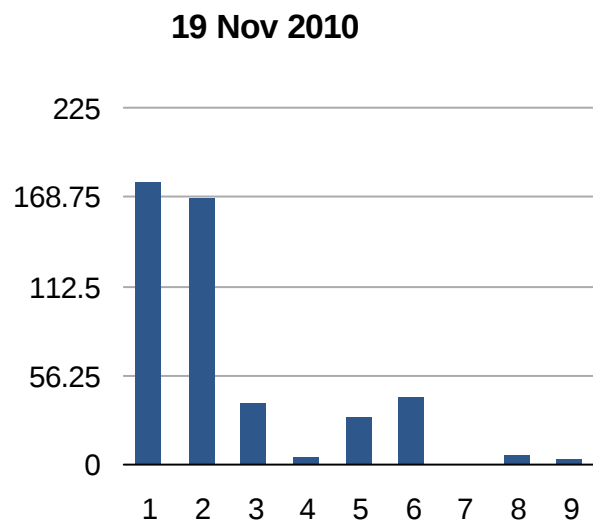
17 Nov 2010	
Type	Number
1	128
2	148
3	44
4	6
5	24
6	44
7	0
8	9
9	11



18 Nov 2010	
Type	Number
1	195
2	151
3	44
4	5
5	39
6	55
7	2
8	10
9	5

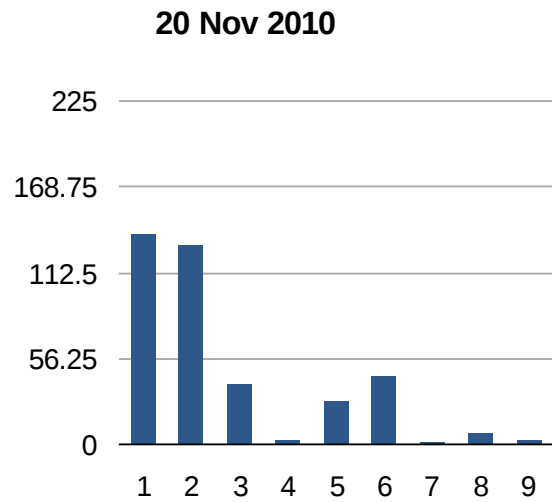


19 Nov 2010	
Type	Number
1	178
2	168
3	39
4	5
5	30
6	42
7	0
8	6
9	4

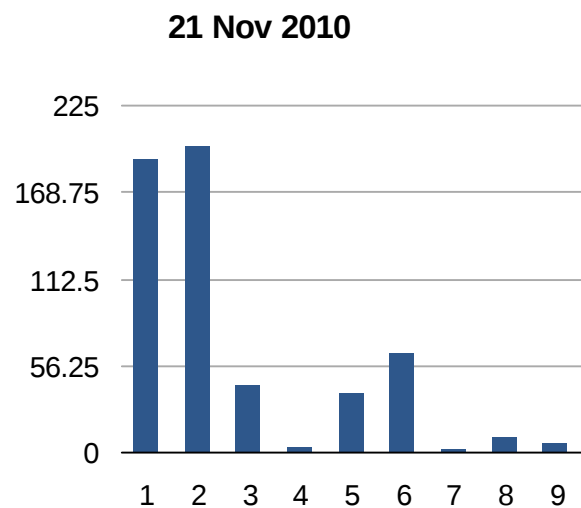


Detection of Meteors by RADAR

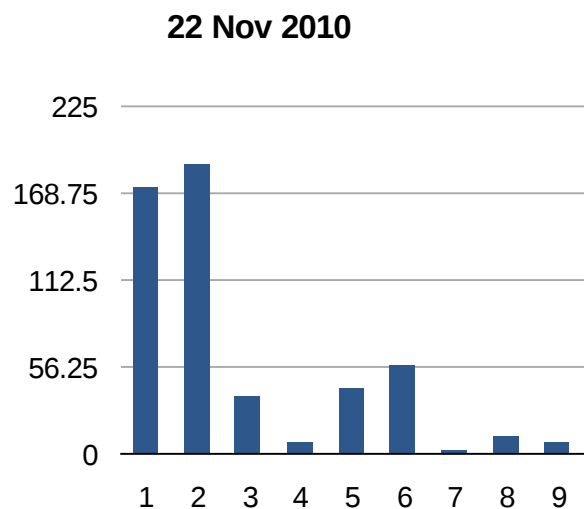
20 Nov 2010	
Type	Number
1	138
2	131
3	40
4	3
5	29
6	45
7	1
8	7
9	2



21 Nov 2010	
Type	Number
1	190
2	199
3	44
4	4
5	39
6	65
7	3
8	10
9	6

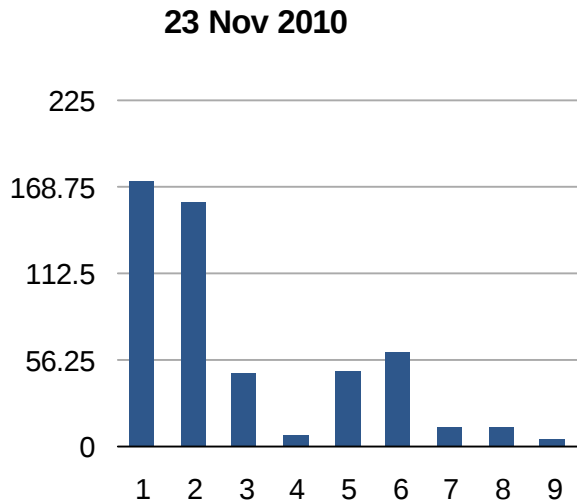


22 Nov 2010	
Type	Number
1	172
2	187
3	37
4	7
5	42
6	57
7	3
8	11
9	7

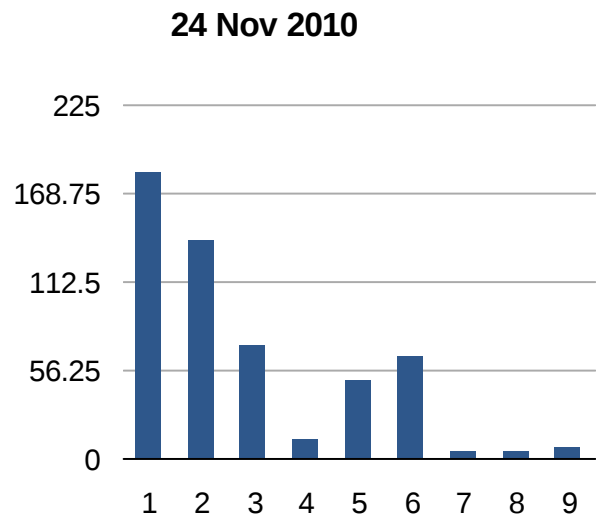


Detection of Meteors by RADAR

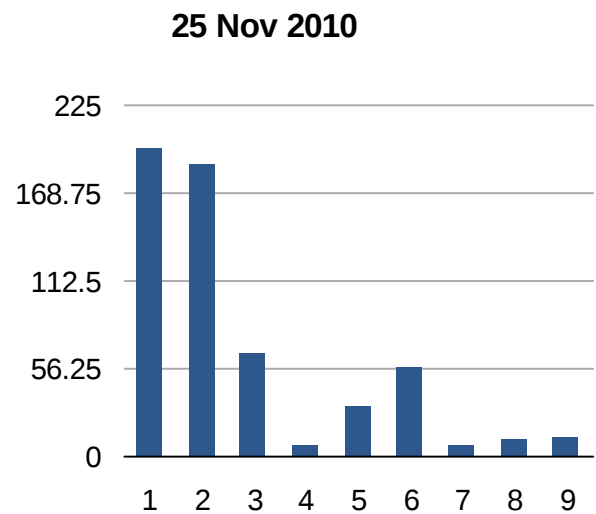
23 Nov 2010	
Type	Number
1	173
2	159
3	47
4	8
5	49
6	61
7	12
8	12
9	5



24 Nov 2010	
Type	Number
1	183
2	139
3	72
4	13
5	50
6	65
7	5
8	5
9	7

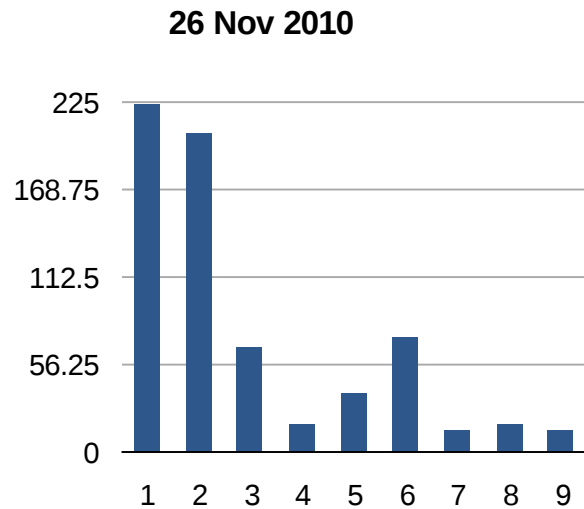


25 Nov 2010	
Type	Number
1	198
2	188
3	66
4	8
5	32
6	58
7	8
8	11
9	13



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26 Nov 2010	
Type	Number
1	224
2	205
3	68
4	17
5	37
6	74
7	14
8	17
9	14



The author is particularly grateful to Noah Hardwicke (currently a pupil at Monmouth Haberdashers School) for conducting this painstaking analysis.

There is obviously some human interpretation of each echo involved in deciding into which class it falls. Embedded factors of this type are inevitable when the selection of echoes is made by eye. Interestingly, some factors would remain even if the classification was done by a computer, based on pre-programmed rules. Such rules might not be flexible and complex enough to avoid arbitrary classifications on some occasions.

By inspection of the charts we can see that:

- Classes 1 & 2 (points and < 1 second echoes) have the greatest number
- There are significant numbers of class 3 echoes (up to 5 seconds long)
- There are only a small number of class 4 echoes (longer than 5 seconds)
- There are steady numbers of class 5 (hooked echoes)
- There are slightly more class 6 fast echoes
- Classes 7,8 & 9 have only small numbers of echoes.
- The numbers of echoes- especially class 1&2 seem to increase throughout the period of observation.

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A7 Investigation of class numbers over the period of the Leonid shower

7.1 This is the first time the author has attempted to plot the difference – if any exists - between the types of echoes received over the period of a meteor shower. In a previous measurement campaign concerned with the 2010 Orionids, only the daily average of the hourly rate for all echoes received was plotted. This is shown in Figure 7.1 and numbers do peak during the dates of the expected shower maximum.

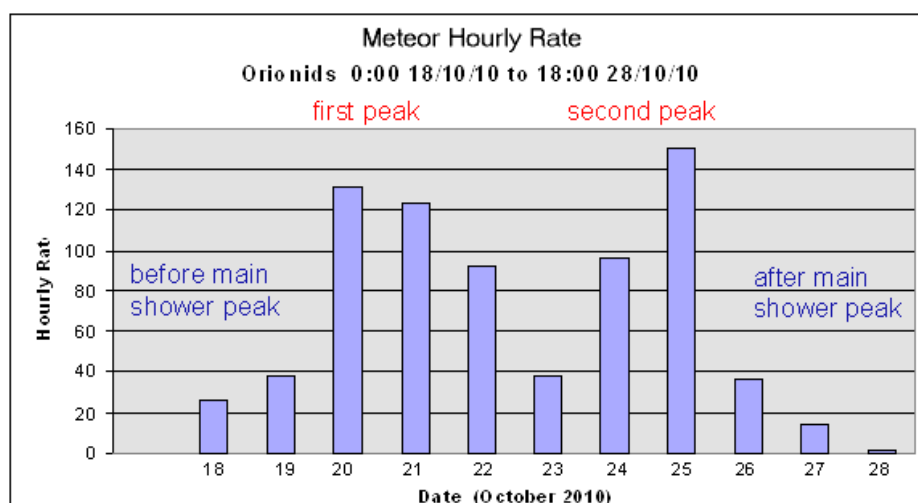


Figure 7.1 2010 Orionids average detected meteor hourly rate each day

It is not currently understood (by the author) if there will be any significance that can be attached to the distribution of echo classes during the period of the Leonid shower. It is, however interesting to see what might be found.

7.2 The first exercise is to plot the daily count for each class of echo through the period of the shower. The data can be taken from the tables given above and may be compiled as shown in Table 7.1.

Daily Data for Leonids Shower 2010													
Date	November												
	14	15	16	17	18	19	20	21	22	23	24	25	26
Class													
1	71	67	193	128	195	178	138	190	172	173	183	198	224
2	51	82	139	148	151	168	131	199	187	159	139	188	205
3	22	50	62	44	44	39	40	44	37	47	72	66	68
4	2	5	12	6	5	5	3	4	7	8	13	8	17
5	18	39	43	24	39	30	29	39	42	49	50	32	37
6	22	63	69	44	55	42	45	65	57	61	65	58	74
7	1	1	1	0	2	0	1	3	3	12	5	8	14
8	3	11	6	9	10	6	7	10	11	12	5	11	17
9	3	4	6	11	5	4	2	6	7	5	7	13	14

Table 7.1 Daily numbers of echoes in each class throughout the 2010 Leonids

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When plotted, the curves are as shown in Figure 7.2. The 'series' number in the legend is the same as the 'class number'. The dates of the expected Leonid shower maximum are the 17th & 18th of November.

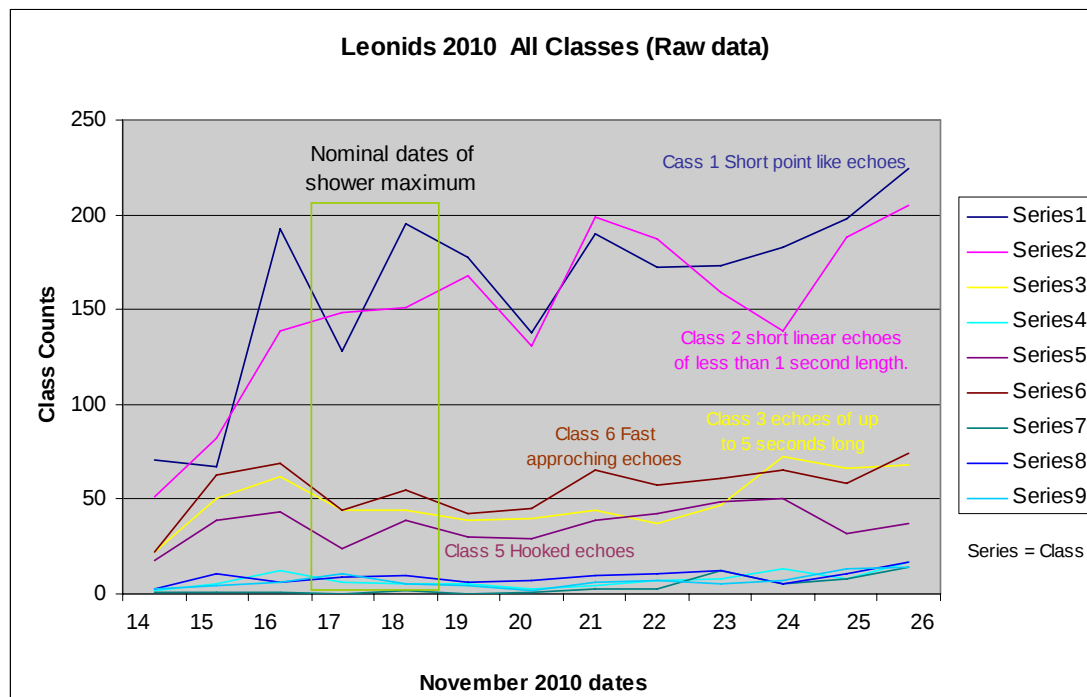


Figure 7.2 Daily numbers for each class through the meteor shower

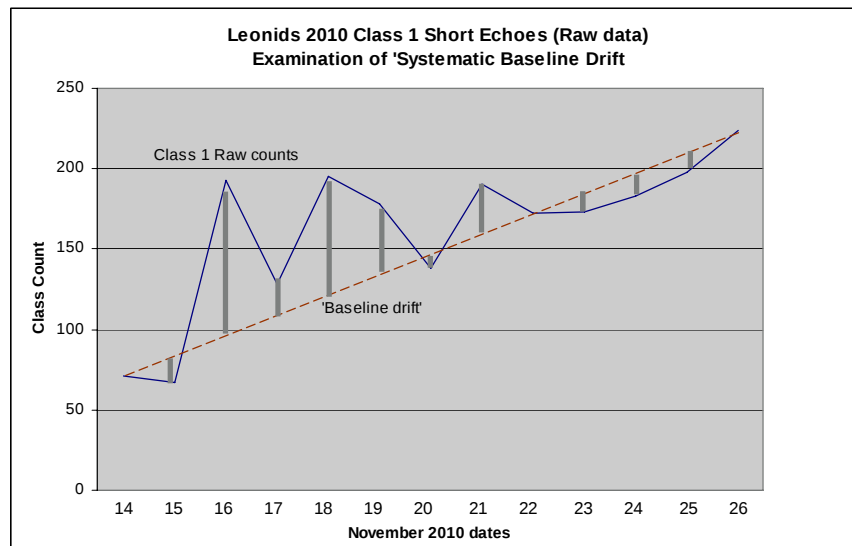
Inspecting Figure 7.2, there are a few points that stand out:

- Based on numbers of echoes, there appear to be three groups of echo classes, class 1&2, classes 3,5 &6 and the remaining classes 4,7,8 &9
- Class 1 (short point-like echoes) and Class 2 (extended echoes lasting < 1 second) appear to be much more numerous than those of the other classes – especially toward the end of the observation period.
- The numbers for both Class 1 and Class 2 seem to increase steadily through the period of observation.
- The numbers for Classes 3 through 9 seem to remain fairly constant compared with Classes 1 & 2.
- Classes 3 to 9 also have a slight tendency to increase gradually through the period of observation.

7.3 Recognising artefacts in the data

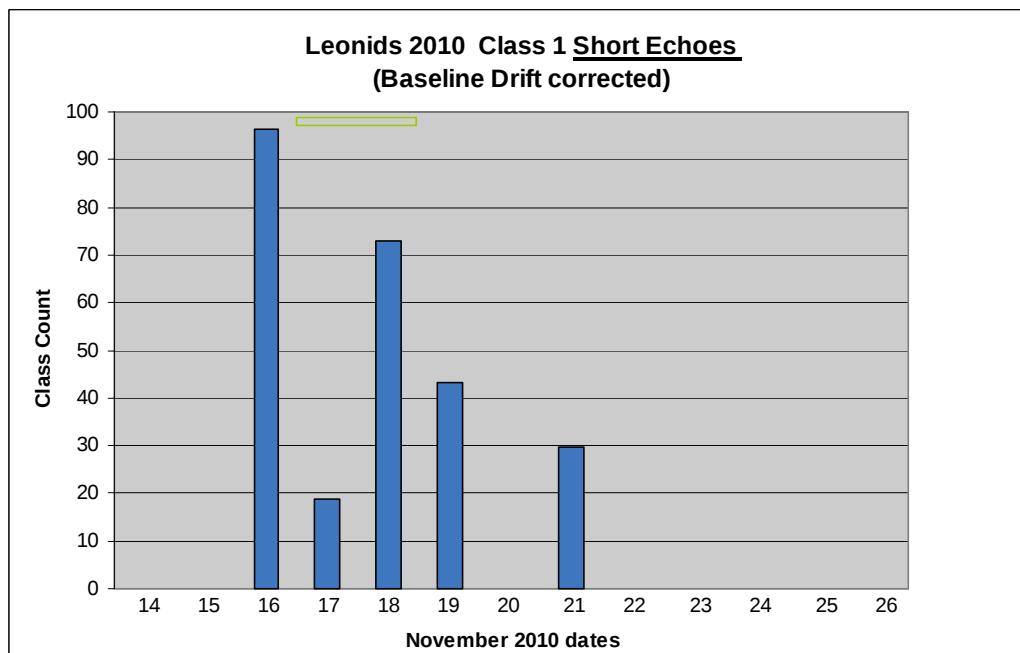
The clear increase with time of numbers for Classes 1&2 suggest some type of systematic process or artefact. There is no reason to believe that such behaviour is 'real', which leaves the probability of a measurement artefact. If we consider that the record shows a 'real' variation from day to day superimposed on a baseline drift artefact, then we can view the data for Class 1, for example, as shown in Figure 7.3.

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In this case the 'real' variable information, once the baseline drift is removed, is denoted by the grey bars. This process of data correction is clearly a speculative experiment, justified to some extent by instinct, but may lead to some clarification of the meaning behind these data.

If we correct the raw data for the 'assumed baseline drift' we can obtain the result shown in Figure 7.4. This shows a clear excess of echoes above the baseline, close to the period of the expected shower maximum on the 17th & 18th of November 2010 and denoted by the green bar on the graph.



The fact that there is an excess of echo numbers over the baseline during the most intense period of the shower suggests that there may be some 'reality' embedded in the measurements. The question then arises however, as to possible causes for the baseline drift. It should be remembered that these Class

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1 Short echoes and probably the Class 2 < 1 second echoes are mainly rather weak returns that may be at or close to the amplitude set for the detection threshold (as described in the main article in Figure 5.15) and shown again below as Figure 7.5.

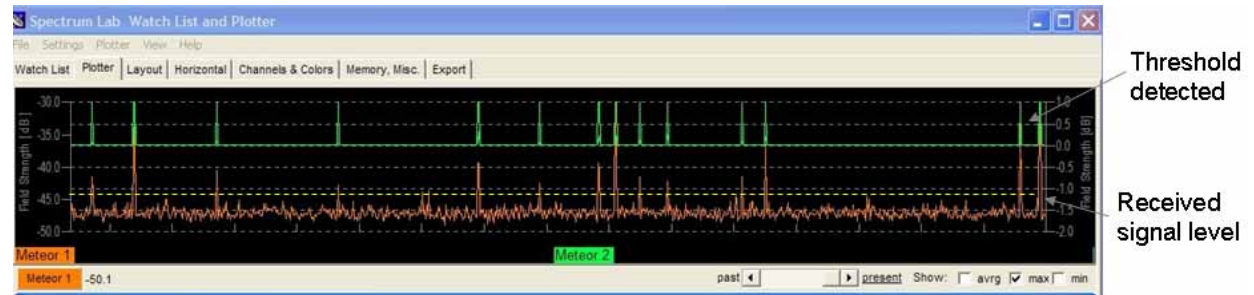


Figure 7.5 Setting of echo detection threshold in Spectrum Lab Software

It can be seen that near the middle of the record there are several low level signals that just cross the threshold. If the receiver noise or gain were to vary slightly over time, the numbers of these weak detections would increase. The numbers of strong signal detections would not be expected to show such a large increase – if at all – as the threshold shift is far below the signal level and would not significantly affect the action of detection.

This seems to be born out in the data. Only the weak short (under-dense) echoes show a marked baseline drift while the stronger but much less frequent echoes show only a small baseline drift effect.

7.4 Shifting Threshold

The possible conclusion here, is that the receiving system has shifting sensitivity or noise output over the period of some days and this is causing more detection to be made of low level Class1 & 2 echoes. This issue was in fact noticed at the time the records were being made, with the red signal line in Figure 7.5 getting closer to the threshold level over time. It was thought that this was a small effect and was unlikely to affect the measurement. The analysis carried out and reported here suggests that this is not correct and that some automatic receiver gain / noise to threshold ratio control is required to remove this artefact and leave a 'clean' measurement of meteor echo numbers over the period of a week to 10 days.

Figure 7.6 shows a drift corrected count for Class 2 (<1 second echoes) and shows a similar peak in numbers broadly around the time of the expected shower maximum.

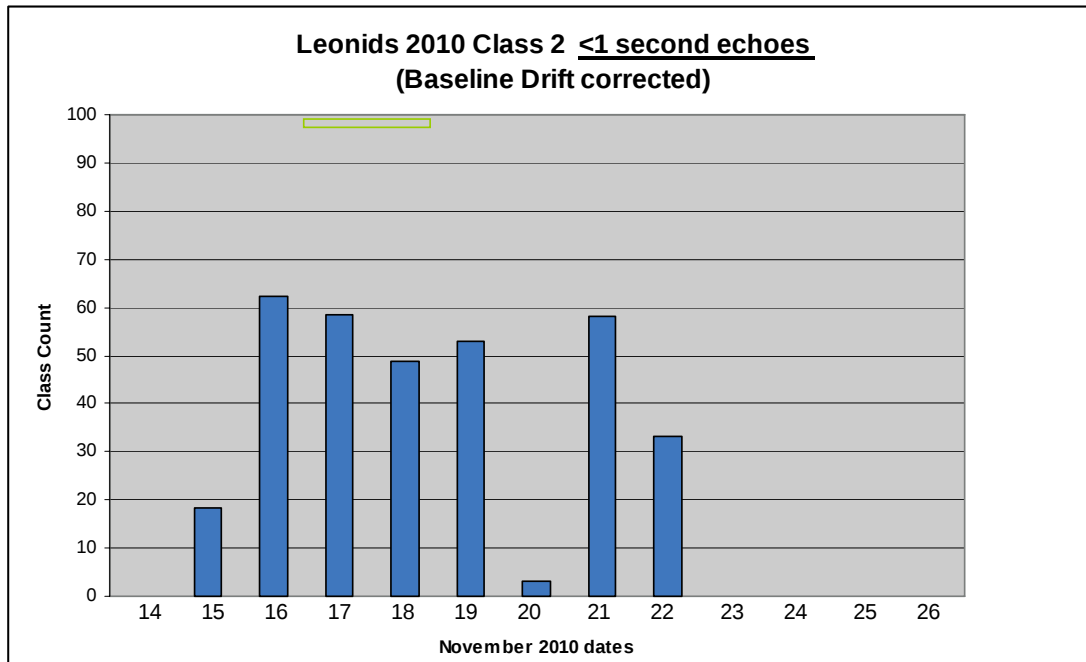


Figure 7.6 Class 2 (<1 second echoes) corrected for baseline drift

If the baseline drift for Class 3 (strong, long echoes <5 seconds) is removed from the raw data we have the plot shown in Figure 7.7 where there is again some evidence of numbers maximising around the time of the expected show peak activity.

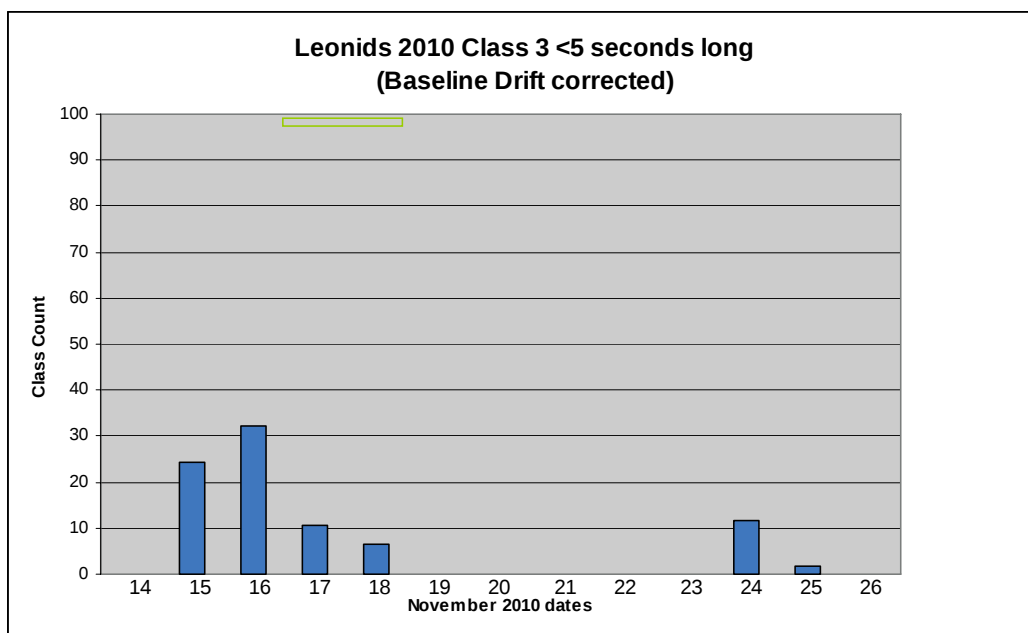


Figure 7.7 Class 3 (long echoes <5 seconds) corrected for baseline drift

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7.5 A test of the baseline drift hypothesis

To give some support to this contrived process of removing baseline drift to reveal the 'real' echo activity, we can carry out the process on Class 7 echoes for satellites. This should show no correlation with the Leonid meteor shower.

The result is shown in Figure 7.8 and shows no marked peaking around the 17th or 18th of November.

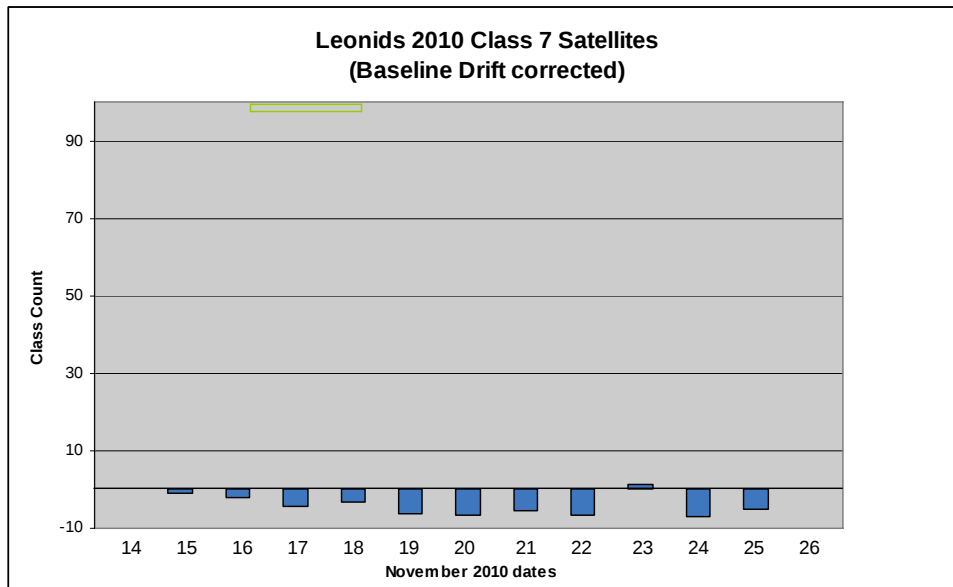


Figure 7.8 Class 7 (Satellites) baseline corrected

More detail of numbers in classes 3 to 9

Figure 7.9 shows the daily variation of numbers in classes 3 to 9 in more detail.

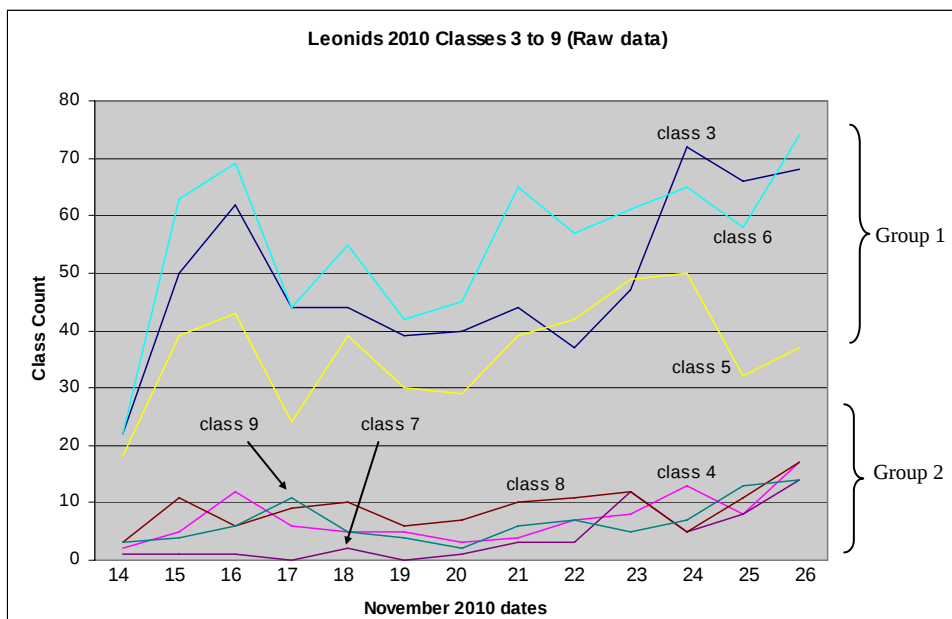


Figure 7.9 Numbers of echoes in classes 3 to 9

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It is interesting to speculate whether there is any significance in the apparent grouping of some classes of echo. To do this we need to list the echo types by class in each group and consider if there may be physical causes for the apparent grouping.

Group 1

- Class 3 Long linear echoes of up to 5 seconds long
- Class 5 Hooked echoes of any length
- Class 6 Fast incoming echoes with near vertical traces

Group 2

- Class 4 Very long linear echoes of any length over 5 seconds
- Class 7 Long slanting echoes of any length – probably satellites
- Class 8 Complex multi-line plots of any length
- Class 9 Miscellaneous echoes that do not fit any category above

A very tentative conclusion that may be drawn here, is that echo forms in group 1 are easily identified as resulting from typical over dense meteors that are approaching with high velocity or are strong and reasonably long lasting.

Group 2 is made up of unusual or 'odd ball' echoes including satellites, very long echoes that may not be from meteors, multi line echoes and miscellaneous echoes.

Much more data and investigation is required to support the speculation that Group 1 echoes are from 'regular' meteors and that Group 2 may be due to other causes or rare meteor events.

The above is included only to show that amateur radio astronomers have the opportunity to investigate data sets that they collect and attempt to find meaning in them, leading to a greater understanding of the phenomena being observed.

Simply collecting data from observations for its own sake can be a somewhat uninspiring pursuit.

A8 Conclusions & recommendations

This is a report of Leonid meteor echo observations where for the first time (for the author) an analysis has been performed in an attempt to understand the significance of the considerable quantity of information recorded. The following points are of note:

- A thousand or so meteor echoes were recorded automatically.
- These have been allotted into 9 classes depending on the duration and shape of the Doppler-shifted return echo, when displayed on a frequency / velocity versus time waterfall plot.
- The analysis of echo numbers by class shows that, as expected, the short weak echoes of classes 1&2 are the most numerous – following the logarithmic relationship between numbers and signal strength as discussed in the main document (Figure 5.19).
- The numbers recorded in the remaining classes 3 to 9 are much smaller than for Classes 1&2.
- A simple analysis of numbers of echoes per day in all classes, but particularly in classes 1&2, shows an apparent ‘baseline drift’ artefact that causes the numbers of echoes to steadily increase over the 13 days of observation.
- Some evidence suggests that this is caused by a drift in either the receiver sensitivity or noise level, resulting in the base signal level edging closer to the fixed trigger threshold for detection and recording of a meteor echo.
- It is just conceivable that a real increase in environmental electromagnetic noise reaching the antenna (from interference or solar activity) could be responsible, but the steady increase over 13 days makes this unlikely.
- The analysis indicates that a modification is required to the receiving system to automatically adjust the signal to threshold margin, such that it remains constant over approximately two weeks, to enable unbiased echo numbers to be collected.
- It is anticipated that a software fix can be developed in Spectrum Lab to facilitate the automatic threshold adjustment.
- If the baseline drift is removed the results tend to show a maximum number of radar echoes roughly coincident with the expected peak of the Leonid shower.
- Application of the baseline correction process to the number of satellite echoes, shows no correlation with the meteor shower, lending some support to the validity of the correction process.
- When this amateur meteor radar receiving system is further developed and the threshold correction fix is applied, it is hoped that some collaboration can be arranged with visual observers to pool data and learn more about the nature of sporadic meteors and shower events.

