An Analysis of Forward Scatter Radio Meteoroid Head Echoes Using Video Meteor Trails

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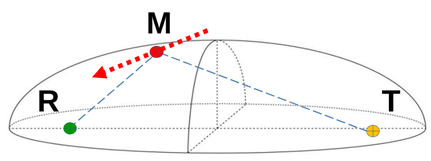
Abstract

Radio meteoroid head echoes were analysed with help of video camera trails. Radio detection numbers were found to be constrained by meteor stream direction and location of transmitter and receiver. Radio meteoroids were generally detected at lower heights than video camera meteors detections.

1 Introduction

Radio waves are scattered from electrons freed by collision of high speed meteoroids with atmospheric gases. Forward scatter occurs when the radio waves from a transmitter (**T**) are detected at a remote receiver (**R**). Some meteoroids initially approach and then recede from **T** and **R** passing through a *Point of Closest Approach* (PCA) at **M**. These points can be calculated from video meteor trails and the location of transmitter and receiver. Geometrically, the PCA occurs when the meteoroid trail is at a tangent to an ellipsoid with foci at **T** and **R**. (see Figure 1)



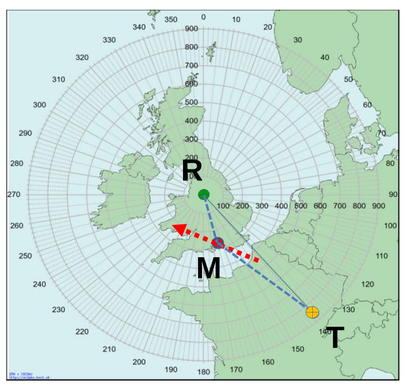


Fig. 1 . Great Circle map centred at radio receiver site **R** showing Transmitter **T** and Meteoroid trail making tangent with an ellipsoid at **M**

Radio meteoroid signatures are commonly characterized by a *Head Echo* with a relatively low signal level and rapidly changing frequency followed by a more intense signal at a steady frequency (Figure 2) known as the *Specular Scatter Trail*. The Zero Doppler and PCA times are concomitant and thereby provide a link between radio meteoroids and video meteors (see Figure 3)

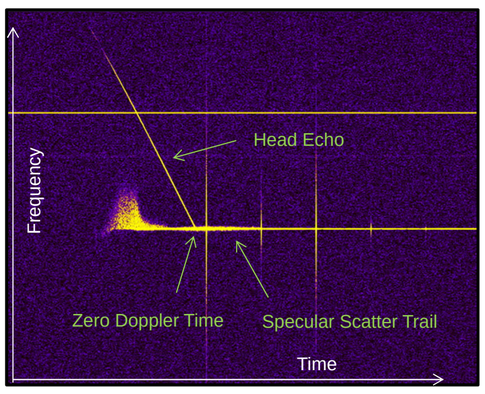


Fig. 2 Spectrogram of Radio Meteoroid Signature. Courtesy Jean-Louis Rault [‡]

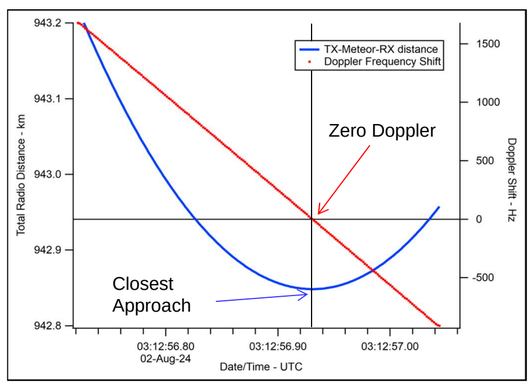


Fig. 3 Point of Closest Approach and simulated Doppler shift derived from UKMON Video data [#]

2 Experimental Outline

The GRAVES transmitter **T** and the Hayfield receivers **R** are roughly 860km apart. The relative locations are shown in Fig. 1. The main beams of the four planar array antennas cover a 180° sector to the South of Dijon are shown in the Figure below.

Fig. 4 The 143.050MHz GRAVES planar array antennas near Dijon, France.

The Hayfield receiving and calibration hardware are shown below. The antennas, Figure 5, fed three Software Defined Radios (SDR) Figures 6a and 6b. The SDRs are frequency locked by a GPS Reference Oscillator. Time, frequency and relative power levels were calibrated from a 1pps GPS clock pulse and a GPS disciplined frequency source. Further details are given in Reference [1]

Fig. 5 Two vertically pointing Yagis (L) and vertical ground plane antenna (R).

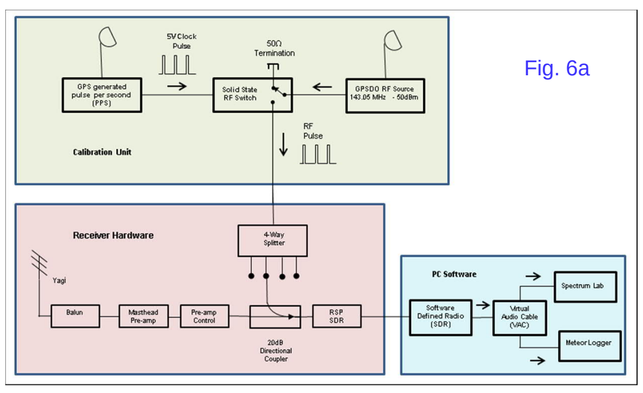


Fig. 6a

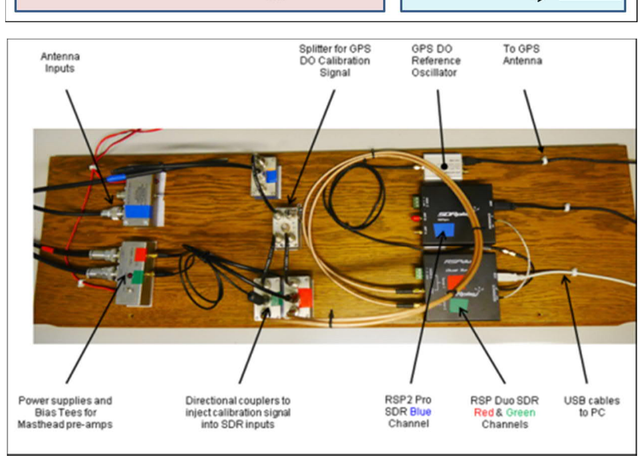


Fig. 6b Receiver and Calibration Hardware

Radio metoeoroids were recorded during August 2024 on the three SDR systems. Recorded data were filtered to remove radio interference and satellite reflections. Head echoes within the hours of darkness were selected for matching with meteor events from UKMON [#] and GMN [§] video meteor networks.

The Doppler Zero (DZ) times of head echoes and the times of video events with Points of Closest Approach were matched.

4 Results

Video meteor trail data were obtained from UKMON [#] and GMN [§]. UKMON cameras covered UK, Irish Republic and parts of Netherlands and Belgium. GMN additionally covered Germany, Denmark and Luxembourg and parts of France. Table 1 shows the numbers of events from the relevant sources.

	Totals	Potential Matches	Actual Matched	
			Count	Streams
Radio	15151	5998		
UKMON	20520	764	354	21
GMN	30700	834	406	24

Table 2. Sources, Counts, Matches and Meteor Streams

The 30700 GMN meteors are plotted in Figure 7 and identify the wide area of camera coverage. UKMON cameras cover fewer countries as indicated above. Many of the cameras are common but trail resolutions are carried out separately. Both networks provide meteor trail positions (latitude, longitude and heights), velocity and meteor streams. UKMON gives detailed, timed trail positions and estimated Absolute Magnitude, mass, entry angle and azimuthal direction (from North). GMN and UKMON trail positions are based on the EGM96 (Earth Gravitational Model) which includes the WGS84n standard (World Geodetic System). WGS84 takes into account the oblate spheroidal shape of Earth and EGM96 the variations in surface height above and below WGS84 datum. (see Ref. [1] for details) Points of closest approach are calculated from these trail positions and the locations of the transmitter and receiver.

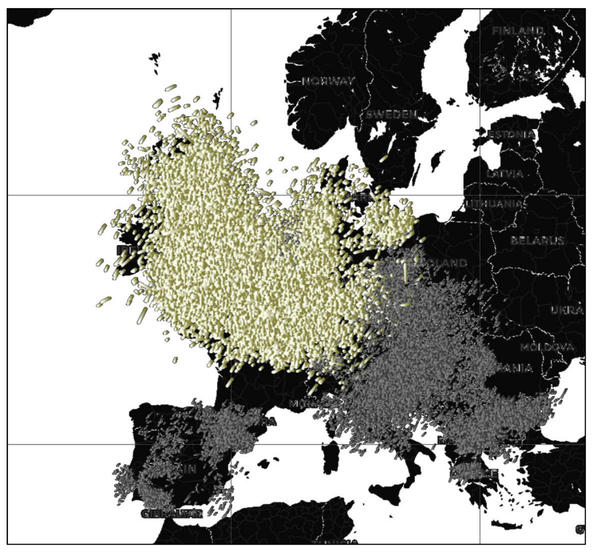


Fig. 7 Distribution of all GMN meteors (off-white markers)
Acknowledgements to Tamo Jan Dijkema for Map and plot

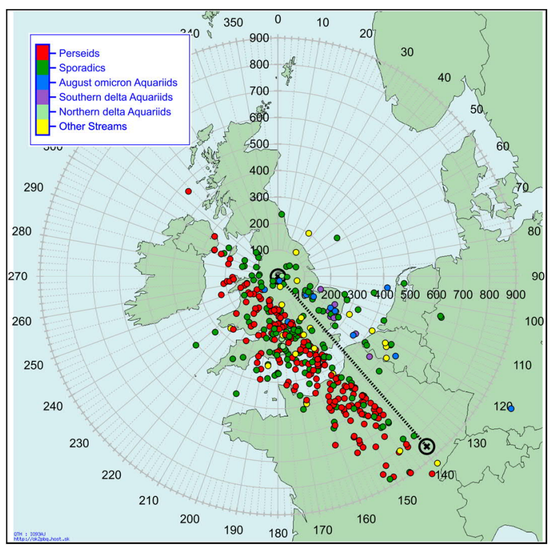


Fig. 8 Radio Head Echoes matched with GMN PCA meteor events. Colours indicate the top 5 out of 21 meteor streams

The range and azimuth from the receiver of matched radio-GMN meteors are shown in Fig. 8. The azimuthal directions of matched Perseids were from 22° to 67° North (0°). Thus trails can only be tangential with ellipsoids below the dotted TR line. Perseid detected on cameras above the line are nor detected by radio. Sporadic meteors a from widely dispersed sources (probably Antihelion) and spread either side of the line. The Southern δ Aquariids had azimuth directions from 127° to 183° and hence are matched for meteors above the line. The constraints on radio detection can be clearly seen.

The height of radio detection was calculated by aligning the DZ and PCA times and scaling video trails heights. Fig. 9 shows a comparison between UKMON and radio detection times. Generally, radio detections were found to be less than video detections. The highest meteoroid detected was from the Perseids shower, had an entry angle of 24°, velocity of 60km/s, estimated mass of 1.4g and absolute magnitude -4,2; radio power profile showed it to be underdense. Analysis of radio signatures with video trail data provide a possible means of radio meteoroid characterisation.

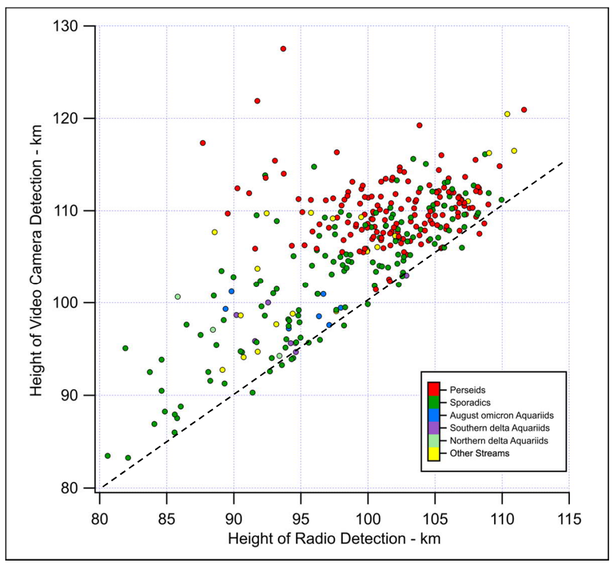


Fig. 9 Comparison of radio and video detection heights

Take away points and stats.

- Analysis of radio meteoroids with video meteor trails is possible, but a dearth of matching events
- The radio meteoroid trajectory and radio geometry have strong influence on radio detection
- The most distant matched meteoroid from Hayfield was at 1013 km and the highest at 111km
- ~ 40% of radio meteoroid events had Head Echoes and < 4% of video trails had PCAs
- There were roughly 4 times more Head Echoes than Video trails with PCA.

Acknowledgements: [‡] Jean-Louis Rault and FRIPON for Figure 2. [§] GMN *https://tammojan.github.io/meteormap/?* for meteor video data used under CC-BY 4.0 International License and to Mark McIntyre for assistance with data extraction of video data from [#] UKMon (UK Meteor Network) *https://archive.ukmeteors.co.uk/reports/2024/orbits/202408/index.html* under CC-BY 4.0 International License

Reference: [1] German, M. T "Utilizing Video Meteor Trails to Understand Radio Meteor Detection" WGN, the Journal of the IMO 51:4 (2023)

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