Radio meteors

Enhanced radio detectability of forward scattered head echoes passing zero Doppler shift

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Object of study was the forward scatter radio observation of sporadic meteors providing a wide spread range of mass, speed and trajectories. A broad distribution of head echo Doppler shifts over the frequency range of the receiving system was anticipated but not found. Instead a noticeable accumulation of head echoes passing zero Doppler shift were observed in a forward scatter setup. An explanation of this phenomenon is pending.

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1 Introduction

First the radio properties of meteors shall be shortly outlined. They were taken from Wislez (2006), Belkovich and Verbeek (2006) and Close et al. (2002). Radio observation of meteors is possible through ionisation of atmospheric gas mainly in heights between 140 down to 70 km (Westman et al., 2004). Two ionised regions have been identified:

1. An approximately spherical sheath of plasma surrounding the meteoroid and moving together with it. Radio reflections from this region are named head echoes. They are subject of strong Doppler shift (up to several ten thousands of Hz at 143 MHz) and are of low power because of the small radar cross section (RCS) of this region. The life time of the plasma sheath starts with the ablation process and is finished when the meteoroid has lost its mass/was decelerated/the ionisation process stopped by growing atmospheric gas pressure. Campbell-Brown and Close (2007) examined the whole lifetime of small meteoroids. They found the ionised phase do not last much longer than 0.5 s. They displayed some ionisation curves of the plasma sheath. These curves represent in principle an optimum function which shapes the power profile, among other things.

2. An approximately conical region of ionised gas of several km of length behind the meteoroid along its trajectory. It is named the trail. Reflections are of high power because of a large radar cross section. They are characterised by the absence of noticeable Doppler shift (some tens of Hz caused by high winds shifting or turbulent parts of the trail). The lifetime of the trail depends mainly on the kinetic energy dissipated in the atmosphere by the meteoroid. A massive ablation creates an intense ionised cone that takes a longer time to become unreflective due to diffusion/recombination processes. In case of an underdense trail the power profile is characterised by a steep rise and an exponential decay. An overdense trail exhibits after the steep rise an elongated phase of reflection with strong power oscillations.

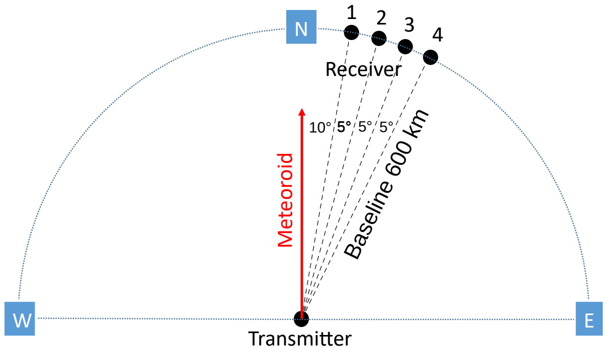

Figure 1 – On top view of the geometry of transmitter, 4 receivers and trajectory of meteoroid.

The forward scatter radio observation of meteor trails is only possible if the geometric arrangement of transmitter, trail and receiving station fulfill the condition of a specular reflection. This is true if the trail is tangent to an ellipsoid with transmitter and receiver as foci. The forward scatter reception of head echoes should be possible at almost all aspect angles due to an approximately isotropically scattering plasma sphere. However it seems to be limited mainly to those head echoes passing zero Hz Doppler shift at the receiving station. It is the aim of this report to analyse this further.

2 Simulation

First a fictive single small meteoroid is investigated during its flight through the atmosphere thereby passing four radio stations. Figure 1 shows a top view on the trajectory of the meteoroid flying straight northward from its starting point in 160 km height directly above the isotropically radiating transmitter. Four receiving station are adopted that have all the same distance from the transmitter but different angles between their baseline and the meteoroid-trajectory. In Figure 2 the Doppler shift curves for these four receiving stations are plotted (speed of the meteoroid is set to 20 km/s, inclination is $-15°$). Ablation shall start in about 100 km height and shall end at about 96 km (time span = 0.8 s) height as indicated in the graph.

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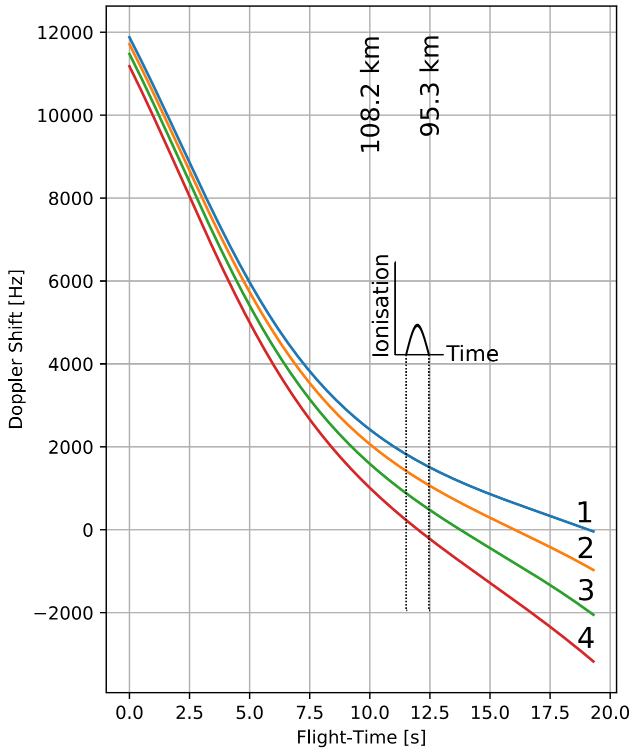

Figure 2 – Doppler shift simulation for the 4 receivers as shown in Figure 1. The indicated ablation phase is picked arbitrarily for demonstration of theoretical considerations.

From Figure 2 we expect head echo reception at the four receiving stations with different Doppler shifted frequencies in the same time period of ablation. The deviation of received power due to different positions of the radio stations is small within this time span: From station 1 to station 4 the decrease in received power is about 15% (calculated on base of the radar equation). Summarised, the same meteoroid produces during its ablation phase at four different stations receivable head echoes with different Doppler shifts and slightly shifted power curves. There is no preference of station 4 where the head echo Doppler shift crosses the zero line.

Generalising we would expect to receive head echoes in a broad Doppler shifted frequency range in form of short duration optimum power curves at an arbitrary radio station. This is strongly supported by the results of a Monte Carlo simulation by German, 2020 (Figure 3). Thereby, the received power will be modulated by the continuously changing transmitter-meteoroid-receiver-distance to a smaller amount and will vary strongly with speed and mass of the meteoroids.

3 Measuring results

Now these assumptions shall be checked against the measured results. Sporadic meteors (SPO) were employed to give a wide spread range of mass, speed and trajectories. Receiving location was Algermissen, Northern Germany. Transmitter was GRAVES-radar in Southern France. In 2018 from January 5 to February 17 continuous head echo monitoring has been performed. Antenna was a HB9CV (theoretical gain 4.2 dbd, no preamp) and the receiver was a software defined radio

Table 1 – Types and proportions of the 34183 meteor signals observed during the 2018 SPO measuring campaign. "off zD" means the meteor signal vanishes before Doppler shift reached zero Hz.

Number of Trail Reflections without Head Echo	Number of Head Echoes without Trail Reflection	Number of Head Echoes with Trail Reflection
29 749	960 + 172 off zD	3 301

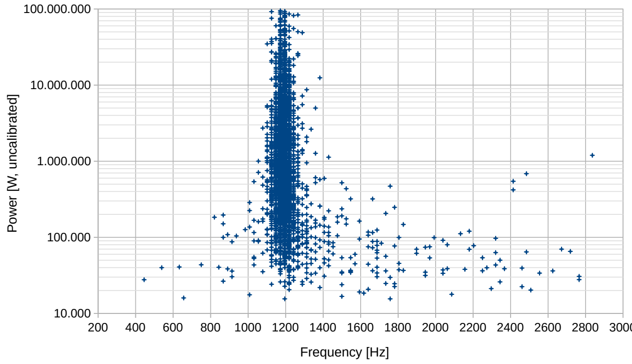

Figure 3 – Received power maximum per head echo versus the associated frequency in a 6 week monitoring session 2018, Jan-Feb. in Algermissen, Northern Germany (4434 head echoes). The measured power is not calibrated.

FUNcube Dongle Pro+[a] running with SDR#[b]. This means all signal processing from digitised radio frequency to demodulated audio frequency is implemented by mathematical algorithms. Especially frequency filtering do not suffer from curved passband characteristics. Recording software was MeteorLogger[c] (Kaufmann, 2017). The USB-demodulation of the unshifted cw signal of GRAVES-radar denotes at 1195.3 Hz.

Head echoes with and without an associated trail reflection and also trail reflections without a head echo were found, proportions see Table 1. These types of meteor signals also are described by Zhou et al., 1998. The identification of head echoes was performed by means of

[a]`http://www.funcubedongle.com`
[b]`https://airspy.com`
[c]`http://www.ars-electromagnetica.de/robs/download.html`

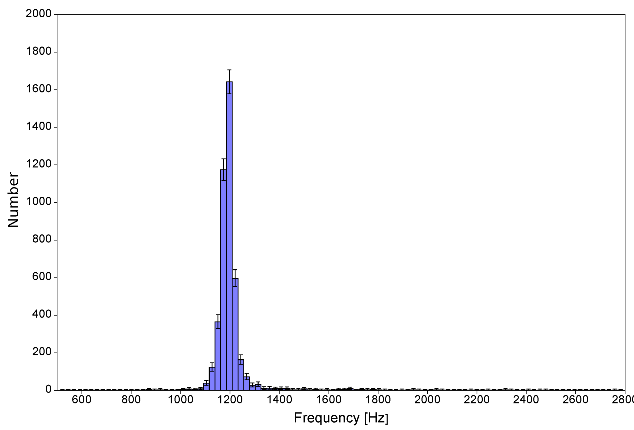

Figure 4 – Frequency distribution of the 4434 head echo frequencies at maximum power from Figure 3.

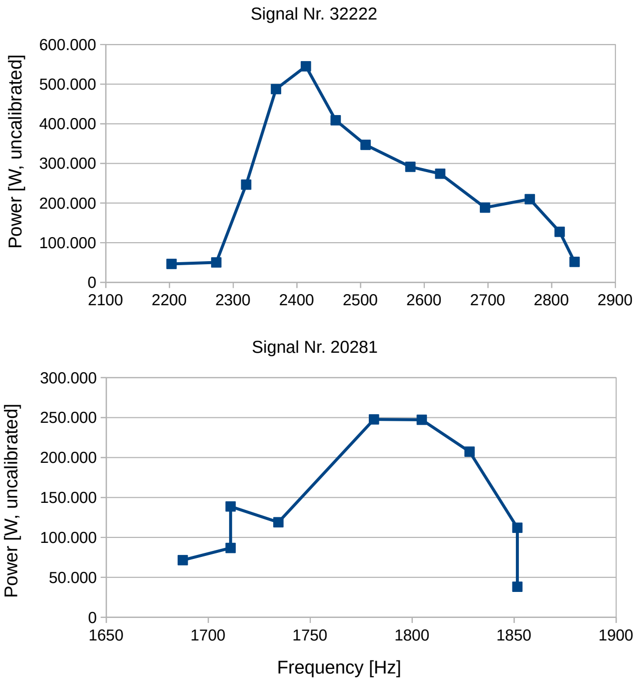

Figure 5 – Examples of received power curves of two head echoes off zero Hz Doppler shift (= 1195.3 Hz), taken from the underlying data set of Figure 3.

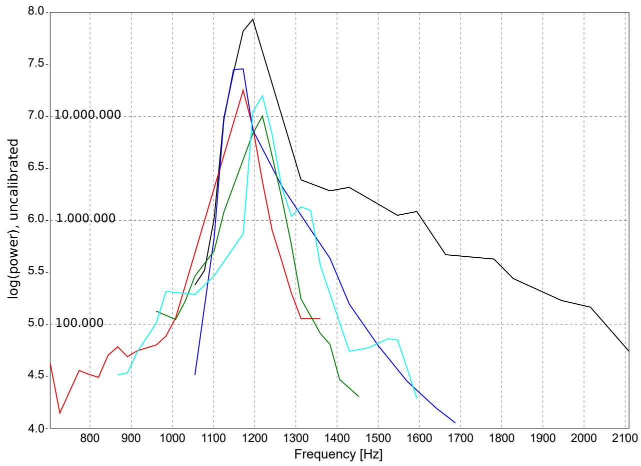

Figure 6 – Examples of received power curves of five head echoes near zero Hz Doppler shift (= 1195.3 Hz) without masking trail reflection, taken from the underlying data set of Figure 3.

a python script (experimental version 1.69 of ProcessData, it is available on request from the author) which traces the head echoes from their first emergence until they vanish or get superimposed by the more powerful trail reflection. Thereby a head echo signal must last at least 50 ms and must show a frequency decline of at least 70 Hz to be counted as head echo (criteria were empirically determined to exclude false positives from rf-noise). Superimposition by the trail reflection causes some under-representation of head echo signals in the frequency range below zero Doppler shift (1195.3 Hz).

Figure 3 shows the received power maximum per head echo versus the associated frequency. Figure 4 displays these data as histogram. Contrary to the expectation, there is no broad spread pattern of received head echo power curves with different power levels and Doppler shifts. Instead, head echo power curves show to be most powerful and hence most numerous near zero Hz Doppler shift. With increasing Doppler shift we find a rapidly decreasing number of head echoes with rapidly decreasing power levels. Figures 5 and 6 show examples of power curves of meteoroids off and at about zero Hz Doppler shift, respectively. Note the different power scaling between the Figures. Figure 7 depicts the distribution of the duration of all recorded head echoes. The dominance of short termed head echoes accounts for prevailing smaller meteoroids. Also the modest sensitivity of the receiving equipment in use and the large distance to the southward directed main beams of GRAVES radar contribute to the observed overall short duration.

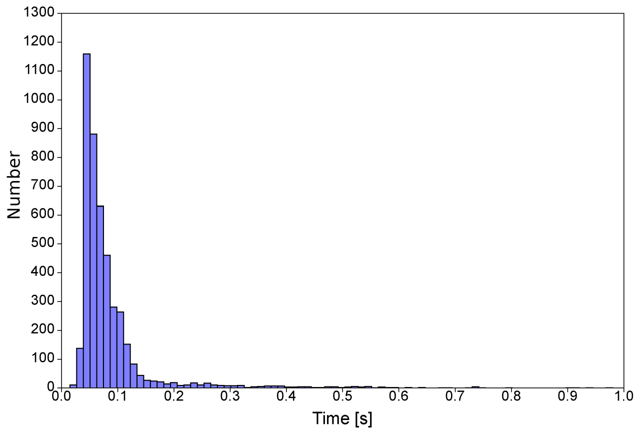

Figure 7 – Distribution of the duration of 4434 recorded head echoes from Figure 3.

4 Discussion

We found the anticipated head echo power curves spread over the receiving frequency range. However, their power maxima and their occurrence are not randomly distributed over the frequency receiving range. The overwhelming number of observed head echo power curves culminate near zero Hz Doppler shift. Their power maxima are by many orders of magnitude larger than the power maxima of head echo power curves received at frequencies off zero Hz Doppler shift. It appears that head echoes reaching zero Doppler shift during the ablation process of the meteoroid have a significantly enhanced chance of reception in a forward scatter set up. Consequently, only the less numerous larger meteoroids with higher RCS could be detected off zero Hz Doppler shift.

At the point where the meteoroid's trajectory is tangent to an ellipsoid with TX and RX as focal points not only a section of the trail becomes reflective towards the receiver but also the Doppler shift of the head echo becomes zero (Verbelen, 2019). From Mathews et al. (2010) the existence of head-trail interference is known. Maybe constructive interference can be an explanatory approach to the enhanced observation of zero Doppler shift passing head echoes.

Besides this unexplained effect two further questions arise from Table 1:

1. There is a small number (960) of head echoes reaching zero Doppler shift without a trail: The ablating meteoroid is tangent to the TX-RX-ellipsoid at the moment the head echo Doppler shift becomes zero. Consequently its ionised trail must also become tangent to the ellipsoid. The trail fulfills the specular condition at this point and a trail reflection should be receivable. The observed aberration may be explained by high gusty winds moving the trail out of the specular condition shortly after its formation.

2. There is an overwhelming number (29749) of trail reflections without head echo: The existence of a trail reflection claims the existence of a meteoroid with a co-moving plasma sheath and a trajectory tangent to the TX-RX-ellipsoid. Therefore, a head echo should be present. This phenomenon may be explained by the mass distribution of the meteoroids. Most are very small and therefore having very small RCS contrary to their trails. Especially when the reflection do not happen in the main beam of GRAVES radar but is produced in its low power side lobes only the head echoes of the much less number of large meteoroids can be detected with the simple radio equipment in use. Also, as described above, a criterion for identification of a head echo was a duration of at least 50 ms. Therefore, all very short termed weak head echoes remained undetected.

5 Conclusion

In this study the detectability of head echoes in a forward scatter setup was found to be significantly increased if their Doppler shift passes zero. This leads to a seemingly concentration of head echoes with zero crossing Doppler shifts whereas the number of observable head echoes never passing zero Doppler shift is comparatively very small. This enhancing effect enables the amateur to receive a substantial number of head echoes with a simple radio equipment compared to professional radar meteor observation stations. The author would like to encourage radio meteor observers to examine their data whether the above described phenomenon is of general validity. May be a meteor scientist is willing to identify the underlying mechanism.

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