About the jagged Spectrograms of Meteorechoes close to the Quadrantids 2024 Notch – an AI/ML-Investigation

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Abstract: Spectrograms of meteor echoes at different stages of the radiant position of the Quadrantid 2024 shower were examined. The analysis of the January 4th data shows a very surprising result:
Spectrograms of meteor echoes that are close in time to the notch differ significantly from spectrograms of ordinary meteor echoes. They are rather small, have a jagged surface and are similar to the spectrograms of satellites, which have a comb-like structure due to their metal surface. The reason for this could be that, for geometric reasons, only the hot plasma head with similar reflection properties to metal reflects the radar waves. If the meteor trail reflects the waves, the usual soft spectrograms are created.

1 Introduction

I was able to record the Quadrantid 2024 echoes on January 4th without interference, allowing a new study of the notch. Notches in meteor histograms are known from the literature. According to Felix Verbelen (Verbelen 2019) and personal communication with him, there are notches in all major streams. He found that the number of underdense reflections will drastically decrease when the elevation of the meteor radiant becomes high (say above some 60 degrees above the local horizon). At the same time, the number of overdense (and thus long duration reflections) will increase. Wolfgang Kaufmann (Kaufmann, 2020) postulated that due to the Doppler shift, the meteor echo can lie outside the normal receiver bandwidths and is therefore not registered. In my meteor work (Sicking, 2022a) I proposed a mechanism according to which the notch is created by the geometric relationships between transmitter, receiver and radiant. An extensive work by Mike T. German (German, 2023) precisely explains the geometric relationships in meteor observation. The new Quadrantid-2024 data now allows further interesting insights into the notch.

2 Setup

A right hand circularly polarized 4-element cross-Yagi antenna is used to receive the meteor echoes. The elevation is approximately 30° and it faces south towards Dijon in France. My antennas are mounted in the attic so the configuration can be easily changed. A low-noise preamplifier with a frequency range of 140-150 MHz and a noise figure of 0.25 dB is connected directly to the antenna. The receiver is an Icom IC-R8600. Spectrum-Lab (SL) from Wolfgang Buescher (DL4YHF) is used as recording software. SL generates plots at 20 second intervals with corresponding date and time in the file name, which are later analysed using machine learning-based software developed by me (Sicking, 2024). The three-class model mask_rcnn_model.061-0.417564.h5 was used for detection.

The ML-software not only counts the echoes, but also determines their size. The neural network was trained with 3D-spectrograms. If an echo is detected, a box is drawn in debug mode and labeled with the score. The program places a polygon over the detected echo that is filled with a transparent color. The area of this polygon (not the box) is logged as the size of the meteor. The plots generated in debug mode and the original Spectrum-Lab plots were then processed into the figures 4 to 8.

3 Result and Discussion

The first two images, Figures 1 and 2, document the respective day and provide a first impression. The satellite echoes, the interference and the noise floor are also documented. Figure 1 shows the raw data from January 4, 2024. The green dots represent the meteor echoes. The sizes of the echoes are plotted logarithmically. A dip around 8h AM, the notch, is clearly visible. Figure 2 is an hourly histogram. The yellow histogram shows the rate and the red histogram shows the rate weighted by the sizes of the meteors. The size of the meteors is taken from the spectrograms, see Setup chapter. The blue histogram usually shows satellite echoes. Near the notch, the number of echoes detected as satellites by the ML-software increases and decreases with the rise and fall of positively detected meteors. This is obviously an artefact. The following analysis shows that these are also meteor echoes, but due to their unusual surface structure they were mistaken for satellite echoes by the ML-software.

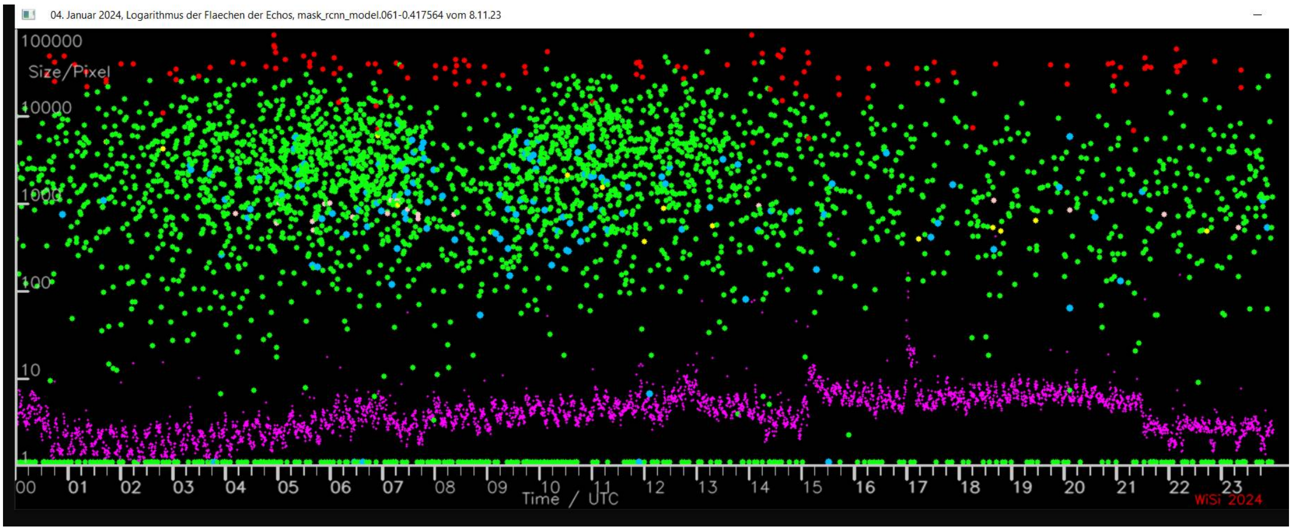

Figure 1 – Measured meteor sizes as a function of time, recorded on January 4, 2024. Each green dot represents an echo. 2960 echoes were recorded. A drastic decrease in the rate can be seen at 8h AM. The blue dots represent satellite echoes. For clarity they were plotted slightly larger than the green meteor echoes. An unusually large number of satellite echoes are registered near the notch. An explanation of this is given in the text. The purple curve shows the background noise. The red and pink dots show detected interference. There were no significant disturbances that could have distorted the result.

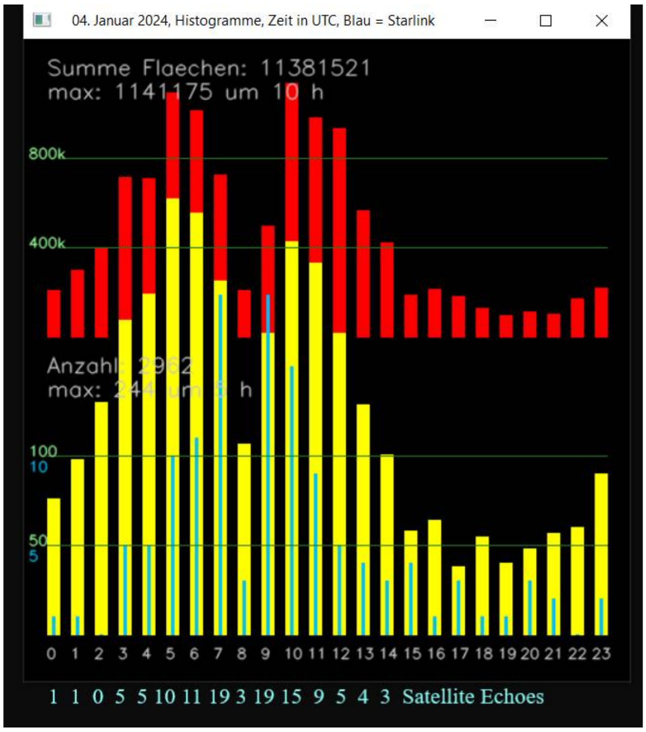

Figure 2 – The yellow histogram shows the rate and the red histogram shows the rate weighted by the sizes of the meteors. The notch at 8h AM is clearly pronounced. The

number of echoes detected as satellites by the ML-software (blue) increases and decreases with the rise and fall of positively detected meteors at the notch. This is an artefact of the ML-software, see text.

About the observation of Quadrantid meteors with the GRAVES RADAR

First, I examined the azimuth of the radiant of the Quadrantids using Stellarium Web. The star 44 Boötis was chosen as the radiant because, according to the CMOR radar, it occupied approximately the position of the radiant of the Quadrantids. At 7h51m AM the azimuth Dijon / 44 Boötis is 0° and the elevation of the star is 89°. At this time the radiant is in front of or over the GRAVES radar, so that the meteor tracks run towards the transmitter. Meteor tracks and radar beams then meet (more or less) head-on in a line.

Although GRAVES and my cross yagi are directional antennas that look south with a certain opening angle, meteor echoes can be received from all directions because of the back- and side lobes, see e.g. Mike T. German (German, 2023) and posts in the Astronomy forum[1] and[2]. There are examples where echoes were received at the GRAVES and BRAMS frequencies at the same time. In my work (Sicking, 2022b) it was shown that an omnidirectional antenna, a vertically polarized Discone, detects significantly more Perseid echoes than the directional antenna. That shows that echoes can also be detected overhead and north of GRAVES. The radiant does not have to be in the main lobes of the antennas. Of course, the observer receives the strongest echoes from the south with the typical GRAVES glitches caused by the fourier-transform of the switching edge. Also because of the high power of the GRAVES radar, meteor detection works in all directions. The fact that the radiant of the Quadrantids is not located in the strong main beam is perhaps one of the reasons why the effect described here is so beautifully visible.

The high elevation angle of the radiant is not the reason for the notch. Deeper angles of elevation produce notches too. For example the elevation of the Arietids at the notch is 66° (Sicking, 2022a).

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1 https://forum.astronomie.de/threads/meteorecho-mit-graves-und-brams-gleichzeitig-erwischt.316517/

2 https://forum.astronomie.de/threads/parallel-aufzeichnung-von-brams-meteor-echos-und-graves-meteor-echos.308016/

The elevations at the notch viewed from Dijon are:
6h = 71° sin(71°) = 0.946
7h = 81° sin(81°) = 0.987
8h = 88° sin(88°) = 0.999
9h = 78° sin(78°) = 0.978
10h = 68° sin(68°) = 0.927

Examination of the notch
The notch of the high-resolution histogram in Figure 3 shows two minima and the In-Line-Peak (Sicking 2022a), see the red dots. The first minimum appears at 8:12 AM, the second minimum at 8:42 AM. The cause of the time difference between the 0° azimuth of 44 Boötis (7:51 AM) and the first minimum of the notch (8:12 AM) is still unclear. From my understanding the times should be identical. Of course, the In-Line-Peak is weak, so the peak and minima could simply be noise like the other peaks. However, I observed the In-Line-Peak in the Arietids (Sicking, 2022a), see for example Figure 8 in the article and also in the Geminids (Sicking, 2024) see Figure 11 in the article, so perhaps they are real signals after all. Further investigations will follow.

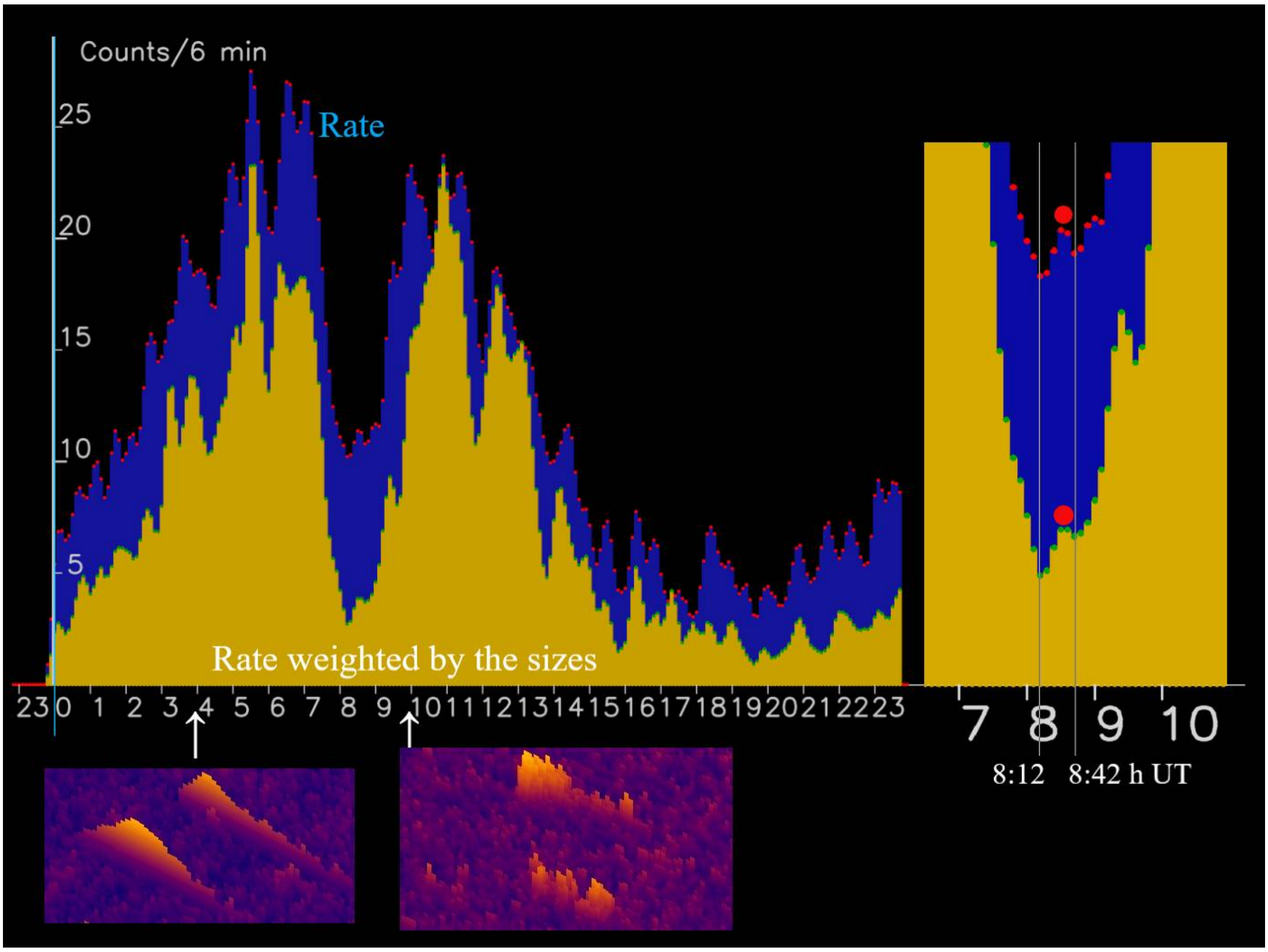

Figure 3 – The figure shows two histograms with a time resolution of 6 minutes. This allows details such as the In-Line-Peak to be displayed.
One spectrogram from 3h54m AM from before the notch (smooth) and one spectrogram from near the notch (jagged) from 9h58m AM have been included, see also the Figures below. The inset on the right shows enlarged the In-Line-Peak, see the red dots.
The histograms are smoothed with a fixed Gaussian like filter with the coefficients 0.31, 0.74, 1.0, 0.74 and 0.31.

Examination of the echoes at the notch

Spectrograms from four times before and one after the notch are shown in Figures 4 to 8. The aim is to examine the change in meteor echoes and the increase in satellite echoes towards the notch. I chose the plots so that as many echoes as possible are combined in one image in order to keep the number of images as low as possible. Because of the importance of the statement, there were five figures.

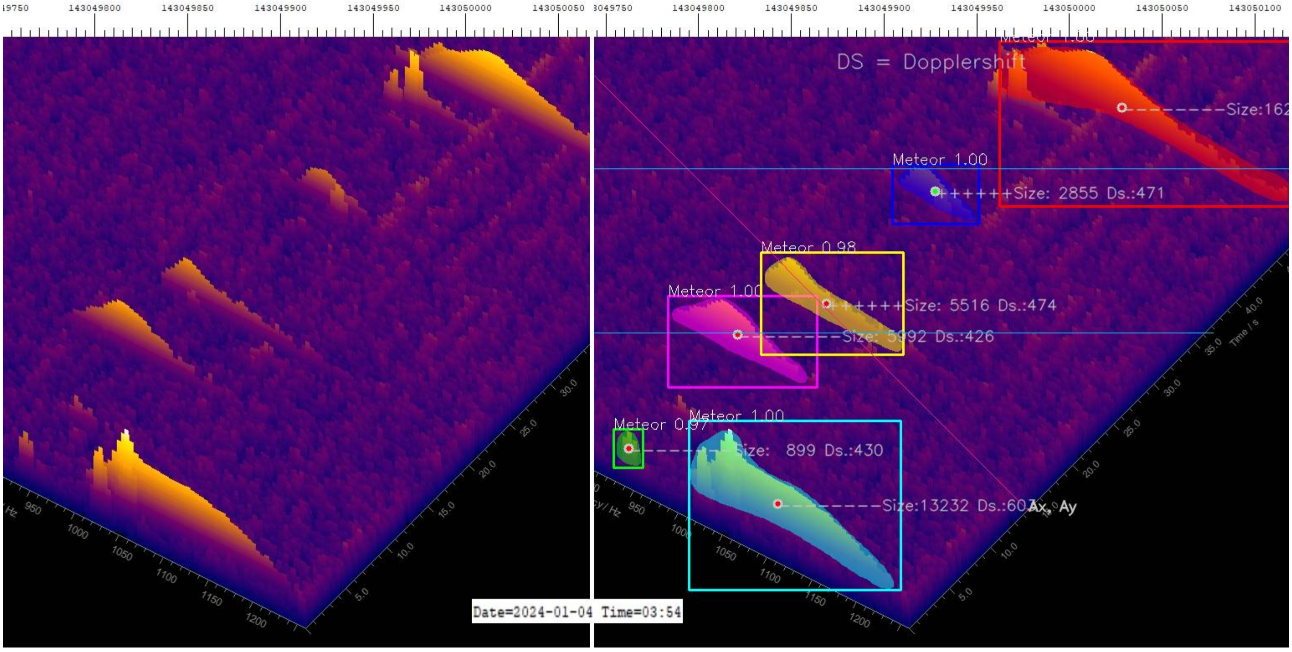

Figure 4 – 3h54m AM. Examples of "normal" echoes. The original Spectrum-Lab Echos are shown in the left half of the picture. The echoes examined with the AI software are shown on the right. The colorful polygons represent the sizes of the echoes. For details see my AI work (Sicking, 2024).

Figure 4 from 3h54m AM shows meteor echoes commonly seen. They have the typical curved, often Gaussian shape and a smooth surface. There are of course other forms of echoes, but they don't play a role here.

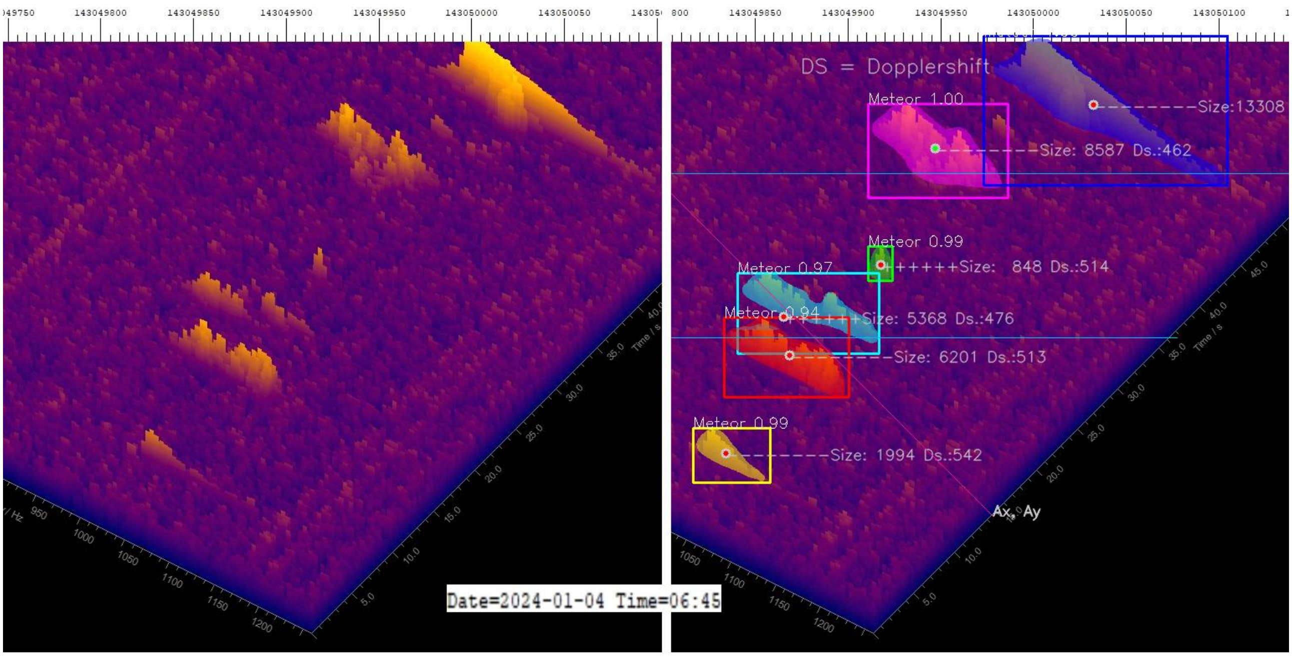

Figure 5 – 6h45m AM. The echoes show clearly a jagged surface, but are still

correctly recognized by the ML software.

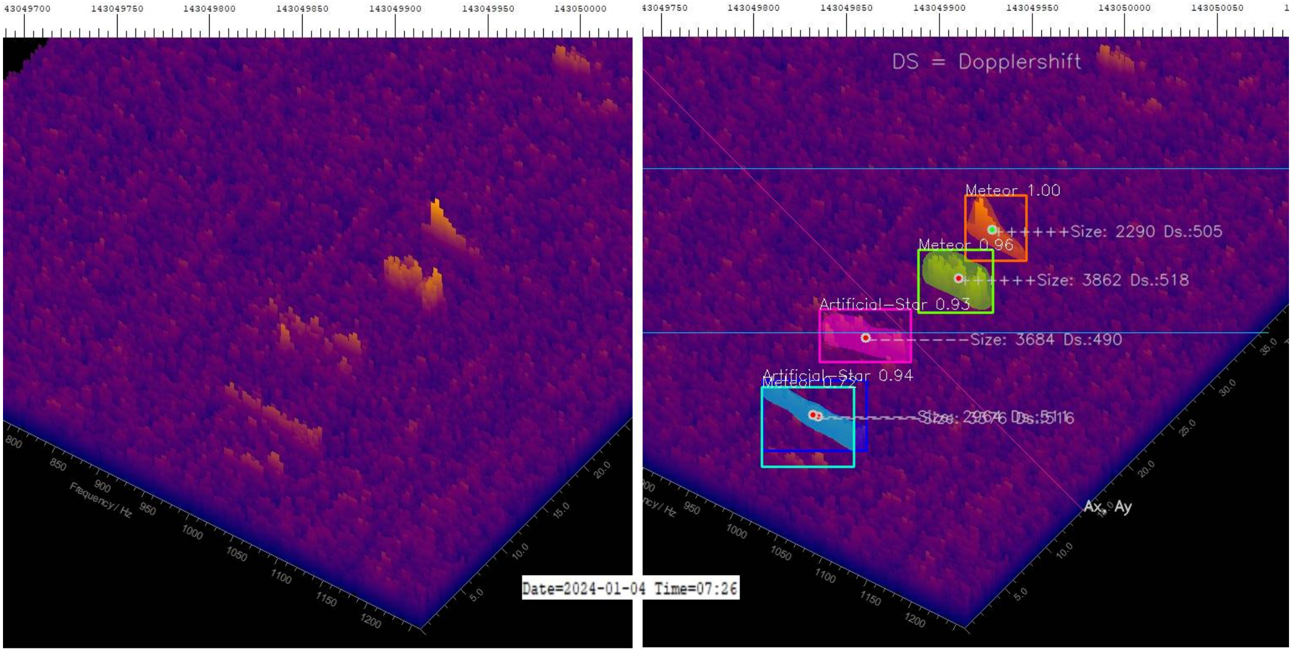

Figure 6 – 7h26m AM. The echoes are very small and are almost no longer observable. Two faint echoes are recognized as satellites.

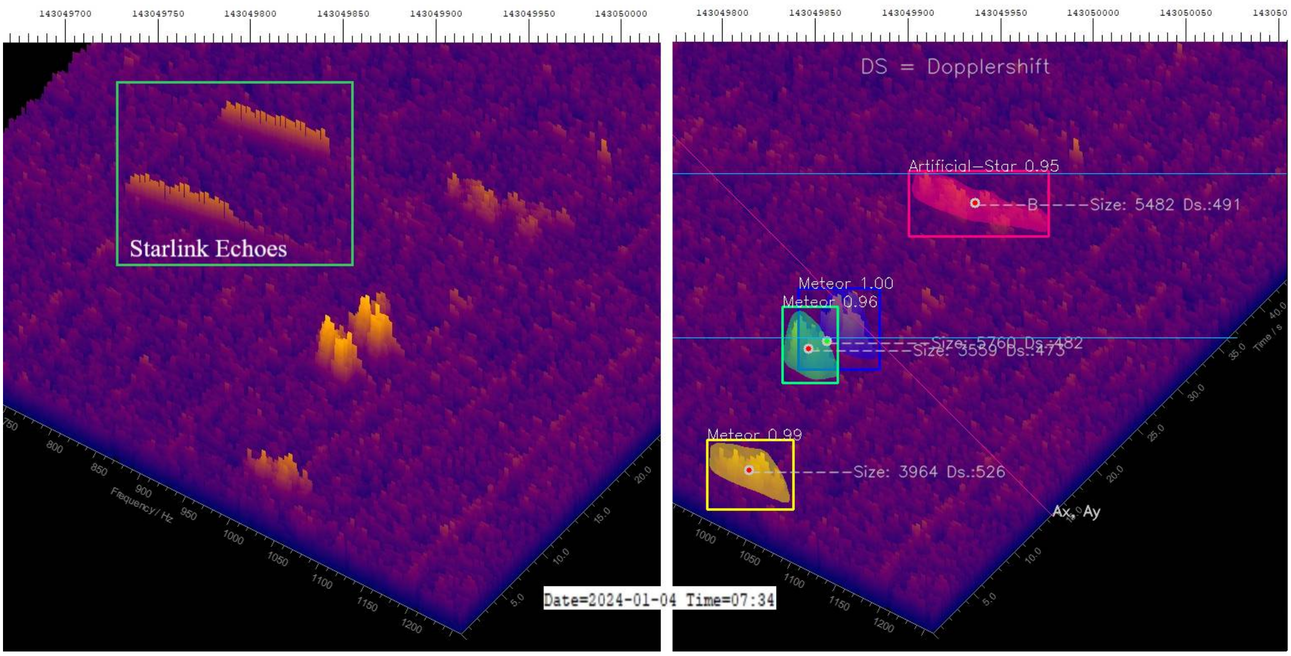

Figure 7 – 7h34m AM. An echo (magenta) is incorrectly recognized as a satellite. The inset at the top left shows real Starlink echoes for comparison.

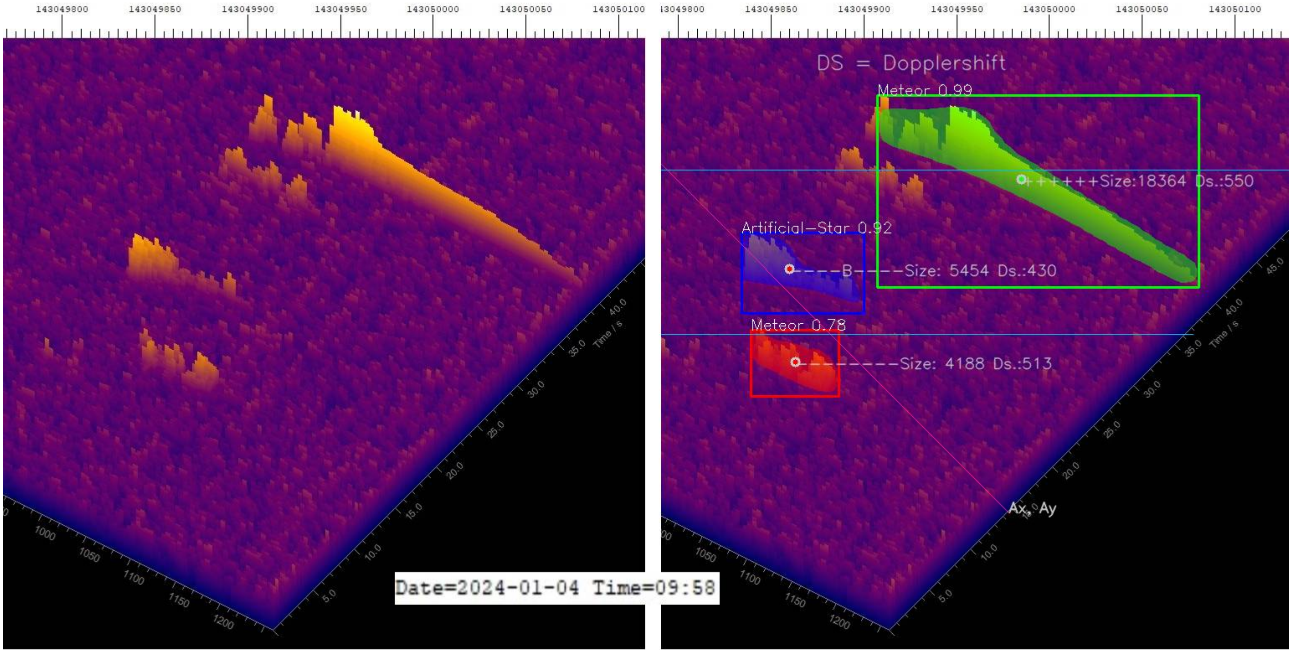

Figure 8 – 9h58m AM. Of the four echoes, only two are recognized as meteors. The red echo also has a bad score of 0.78, the blue echo is recognized as a satellite and an echo is not recognized at all.

The notch occurs because the echoes become smaller and at some point are no longer perceptible. This will be examined in more detail in the next chapter. However, the shape of the echoes also changes drastically towards the notch: they have a jagged surface, see Figures 5, 6, 7 and 8. It is now clear why the number of satellite echoes increases near the notch: some echoes are more similar to satellite echoes, than they look like normal echoes used in training the ML-model.

From this it can be concluded that Figures 5 to 8 show spectrograms of meteor echoes in which essentially only the head was exposed to the radar beams. The hot plasma head apparently has similar reflection properties to the surface of the satellites, which produce echoes with a comb-like structure due to their metal surface (Sicking, 2024). If the trace also reflects, a softer echo is created, according to the hypothesis.
In previous streams I already noticed that echoes near the notch are jagged. The increase in satellite echoes near the notch occurred for the first time in the 2024 Quadrantids.
Finally, the fact that near the notch the number of echoes detected as satellites by the ML-software increases and decreases with the rise and fall of positively detected meteors shows that there is a systematic relationship.

Such spectrograms are not contained in the training data of the ML-model used, or are only contained sporadically. However, the reason for the notch are not the misdetected or undetected echoes. The error is < 10 % at 7h AM and the notch is also recorded by other observers.

Examination of the rates and the rates weighted by the sizes of the echoes
Figure 9 shows the echoes divided into four classes of sizes. The most important result is shown by the yellow trace, which represents the small echoes: The small echoes have a (secondary) maximum at the minimum of the notch, see the yellow dot. The amount of the larger meteors is decreasing. This does not mean that the number of small echoes has increased, but it means that large echoes now appear smaller due to perspective and appear in the class of small echoes. The maximum of the yellow trace in the minimum of the notch is therefore a confirmation of the theory that geometric conditions as described above cause the notch.

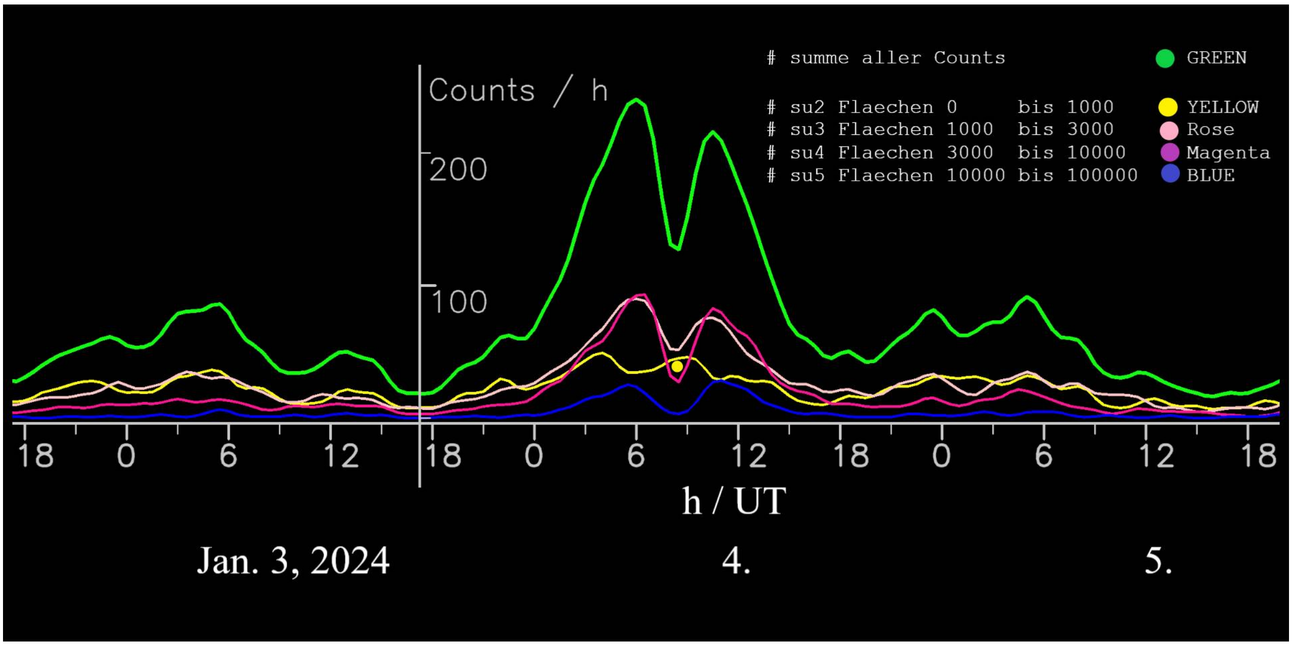

Figure 9 – Meteor rates for different echo sizes of the 2024 Quadrantids over 3 days. The blue line represents the rate of large echoes (10,000 to 100,000 pixels), the purple/magenta line shows the medium sized echoes (3000 to 10,000 pixels), the pink line shows the echoes (1000 to 3,000 pixels) and the yellow line shows the small echoes (below 1000 pixels). Finally, the green curve shows the rate of all echoes summed up. The yellow trace (echoes under 1000 pixels) shows a maximum (see yellow dot) where the notch and all other meteor sizes have a minimum. The histograms are smoothed with a fixed Gaussian like filter with the coefficients 0.25, 0.71, 1.0, 0.71 and 0.25.

4 Conclusion and a remark

Inspired by an obvious artefact, I examined spectrograms at different stages of the radiant position of the Quadrantid 2024 shower. The work shows that spectrograms taken near the notch are different from spectrograms taken at other times. It is concluded that spectrograms could be used to identify meteors where the radar waves hit the meteor head-on and illuminate only the plasma head.
In addition, the theory that geometric conditions cause the notch has been experimentally proven.
It would of course be more elegant and easier for the reader if the article had been written with knowledge about the various echoes. However, I would need to train a new model including Quadrantid data from January 4th, as there are only enough jagged spectrograms on that day. But then I can't study the Quadrantids from January 4th with the new model because the echoes were used in training. That would lead to incorrect results. Therefore, I left this description based on the artefact.
The new model will then be used to study future streams and sporadic meteors. This will be very exciting.

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