Meteor detection on spectrograms by means of computer vision

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Automated detection - intro

Antonio Martínez at the IMC2022:

Narrow pass-band filtering technique for radio meteor automatic detection

Establishing a reliable method for detecting meteors in BRAMS project observations has proven to be an elusive issue. In this paper, a narrow filter-based technique is applied to a series of random spectrograms. The results of this proof-of-concept are promising

Fourteen years of Speclab 5 minutes records (VVS beacon)
Felix Verbelen: 17 years, including .wav files

Automated detection - intro

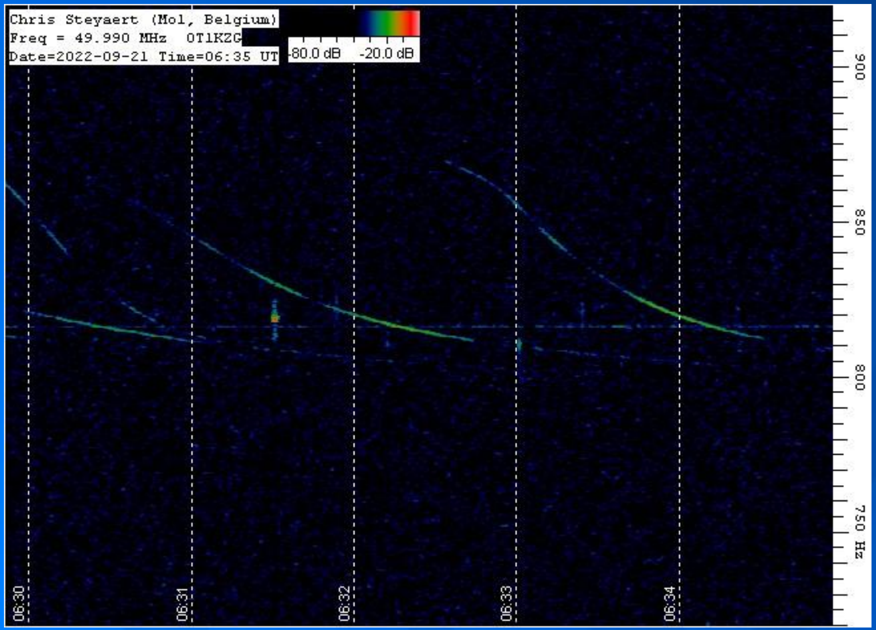
Similar image analysis approach:

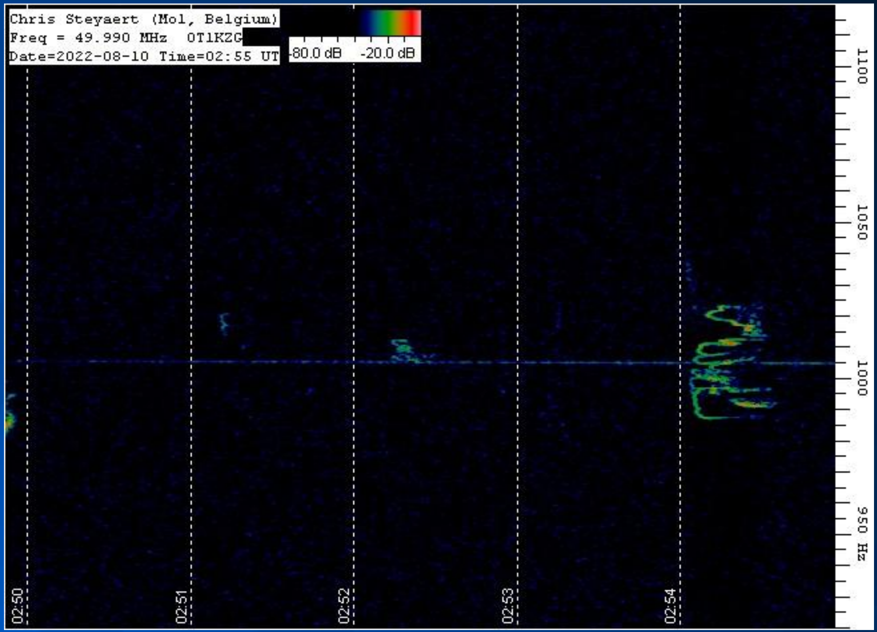
WGN, the Journal of the IMO 47:2 (2019) 55

Automated Spectrogram Analysis for Meteor Head Echoes

C. Powell

Typical cases



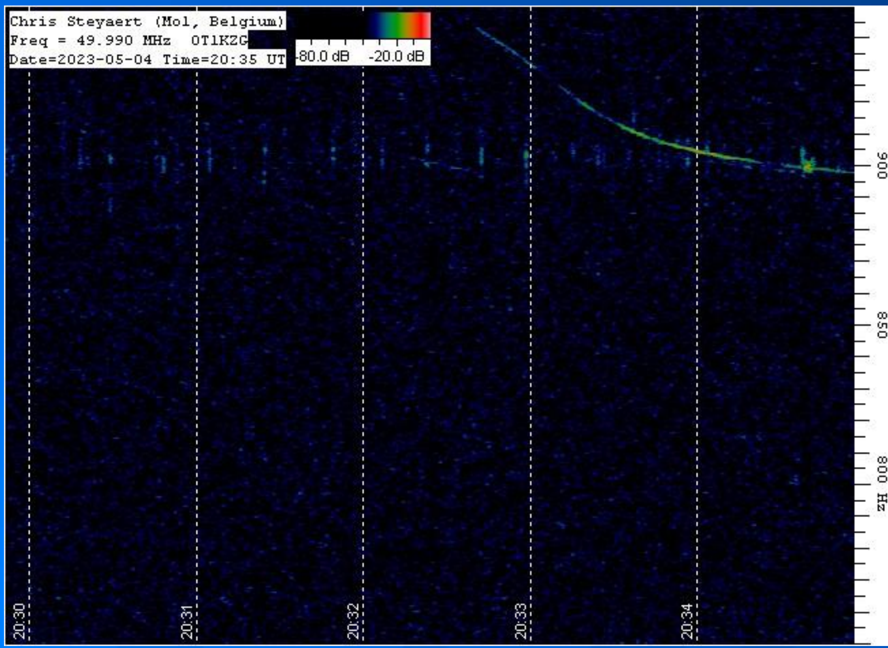


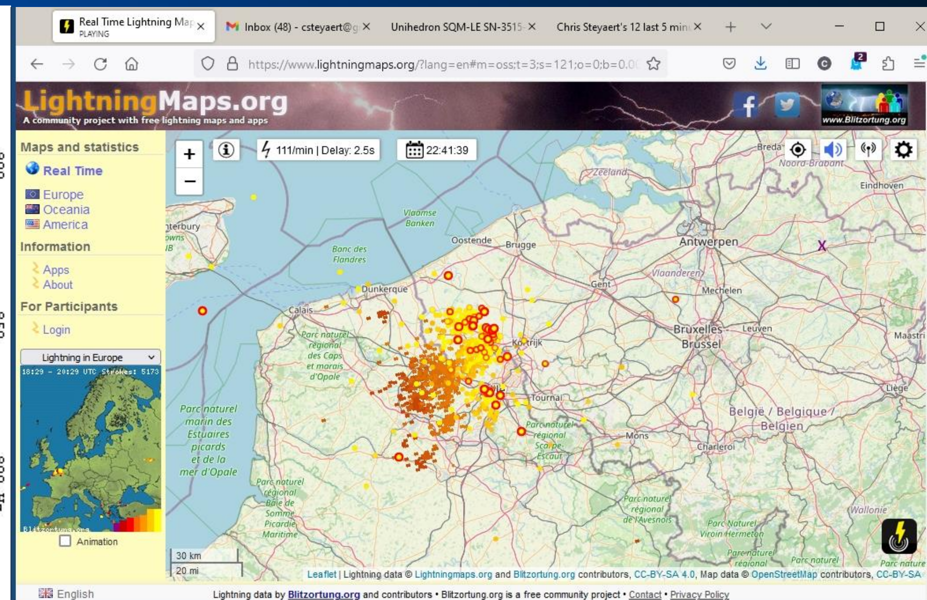
Resolution:

	time	5 min 300 s	600 pixels
	frequency	200 Hz	400 pixels

Minimum ‘duration’ of a reflection: 1 pixel = 0.5 s

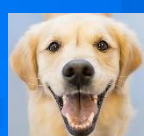
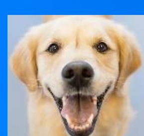
Reflections on lightning





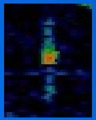
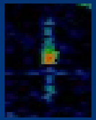
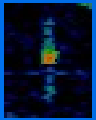
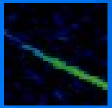
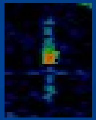
Classification vs Object Detection

It is a cat

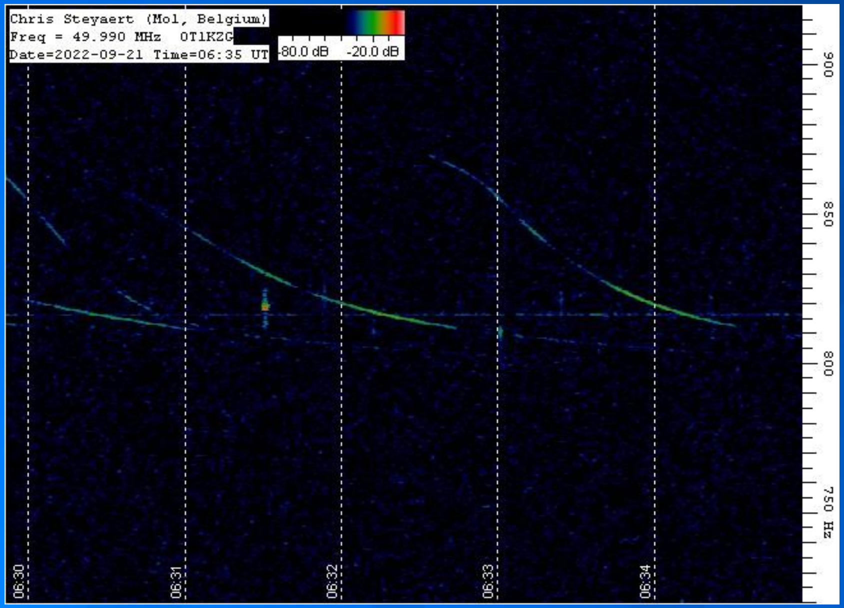
	Specialist	Machine	
	+	True	
	+	False	
	-	False	
	-	True	

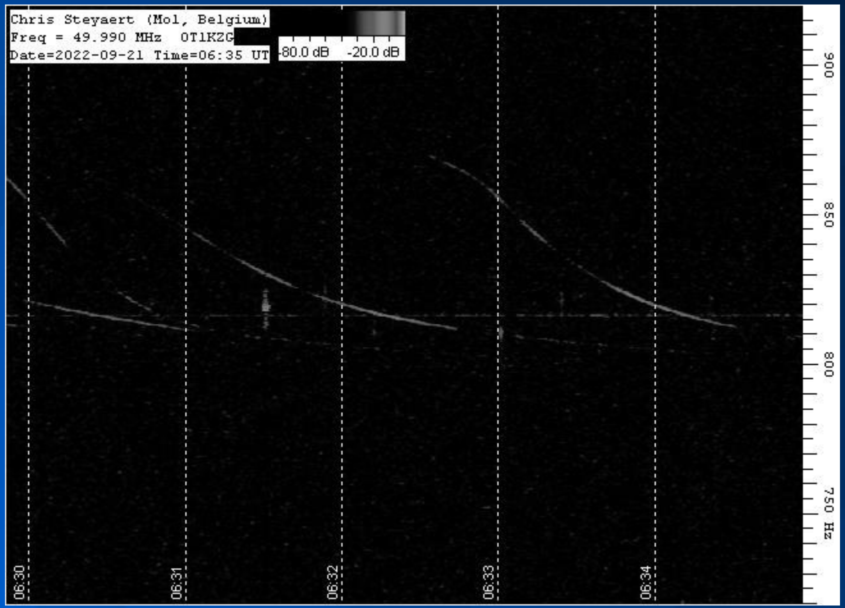
Classification vs **Object Detection**

Found a meteor

	Specialist	*Machine*	
	+	True	
	+	False	
	-	False	
	-	True	

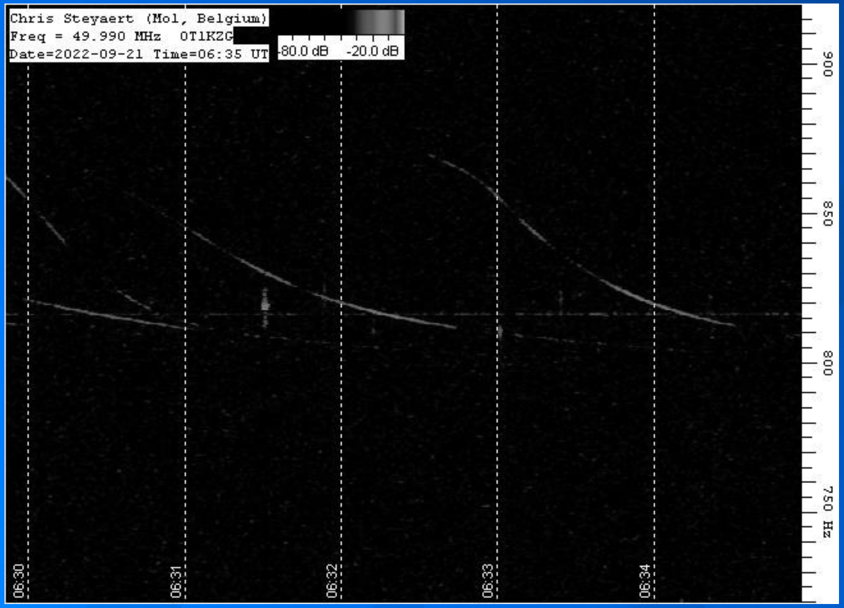
Preparing: convert to B&W





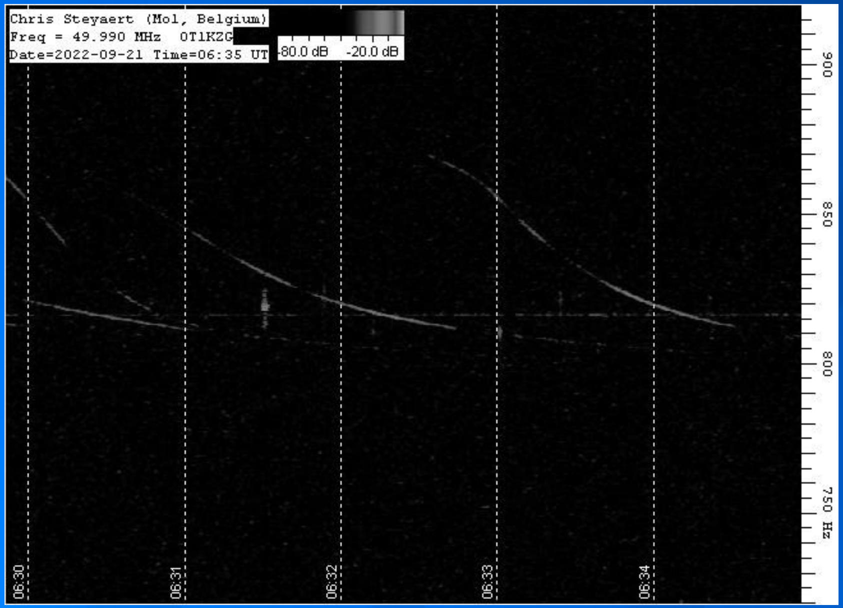
- Color <> amplitude of the sound signal

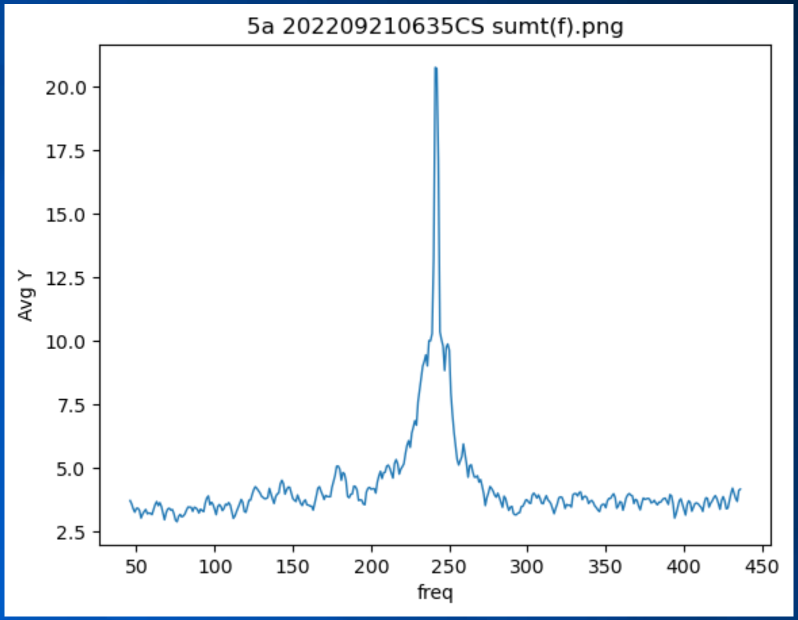
Preparing: getting rid of the 1 minute lines



- 1 x 3 pixels interpolation
- Time calibration

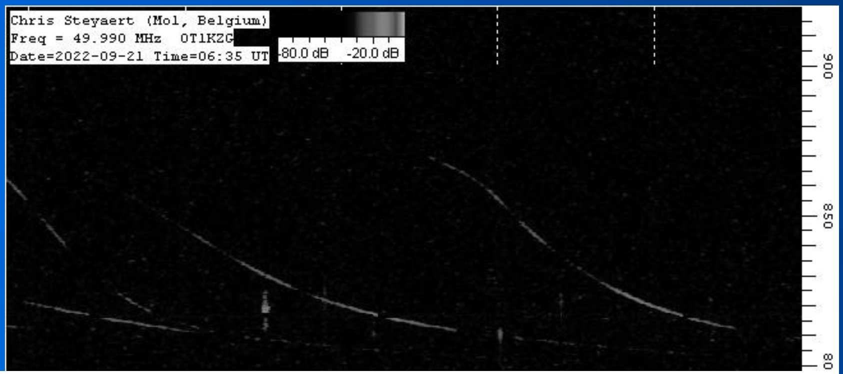
Frequency summation

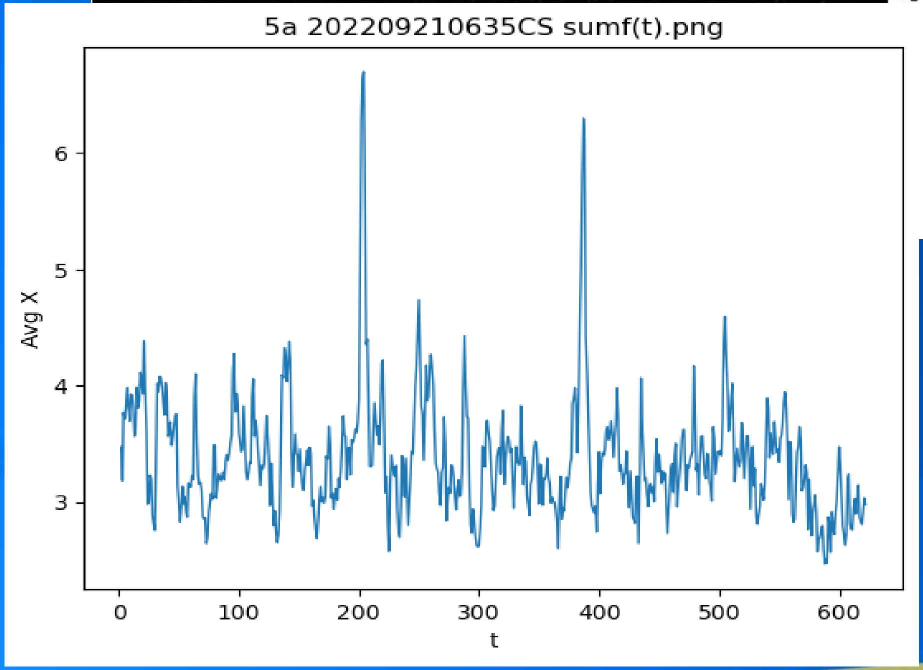




- Carrier removal

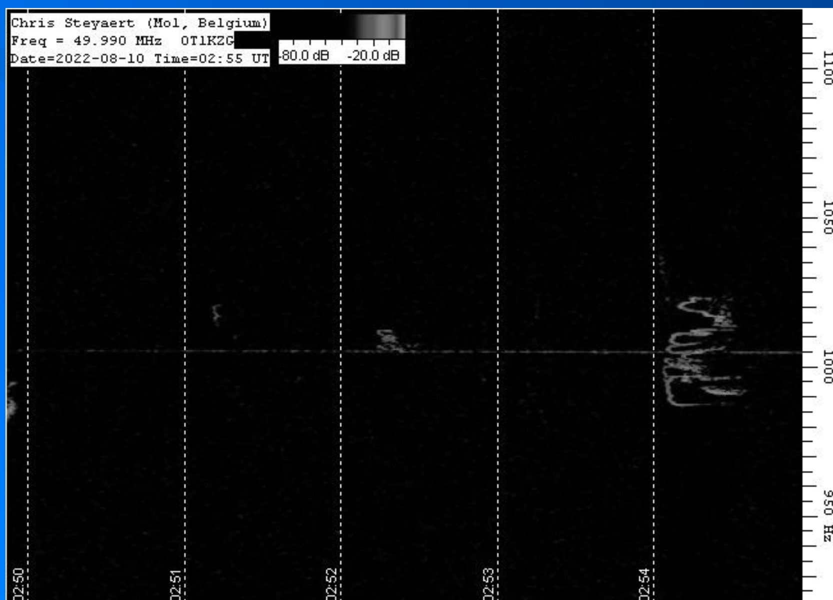
Time summation

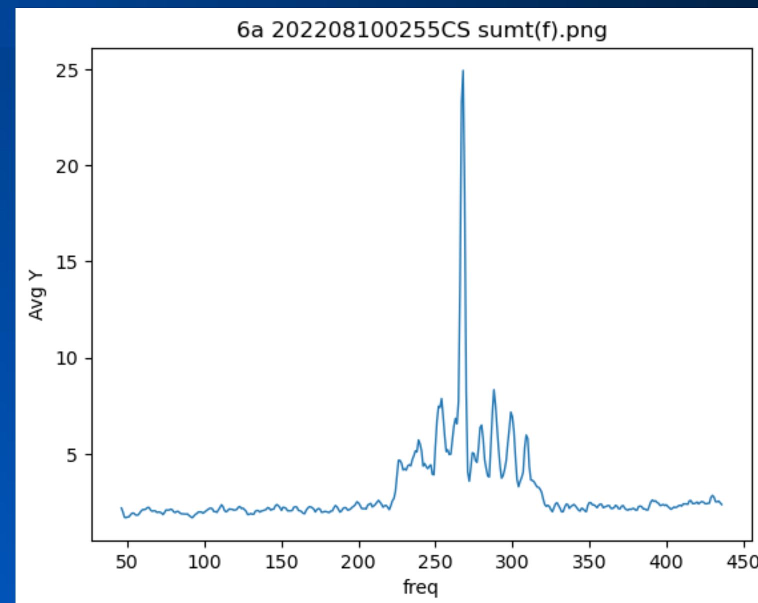




Real time: trigger on amplitude threshold

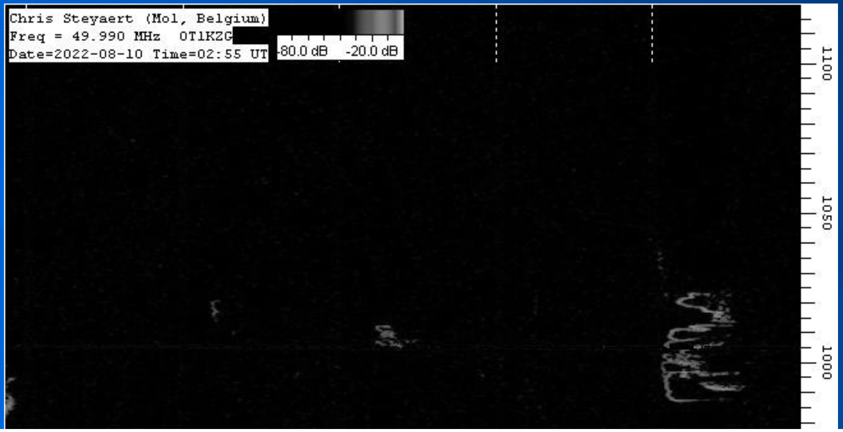
Frequency summation

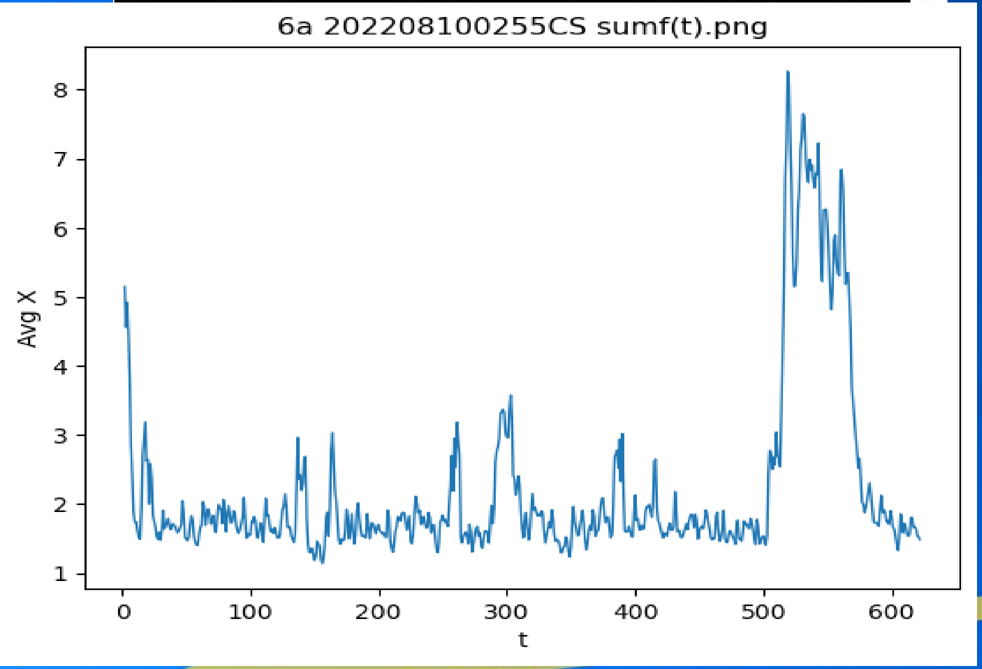




- Carrier removal

Time summation





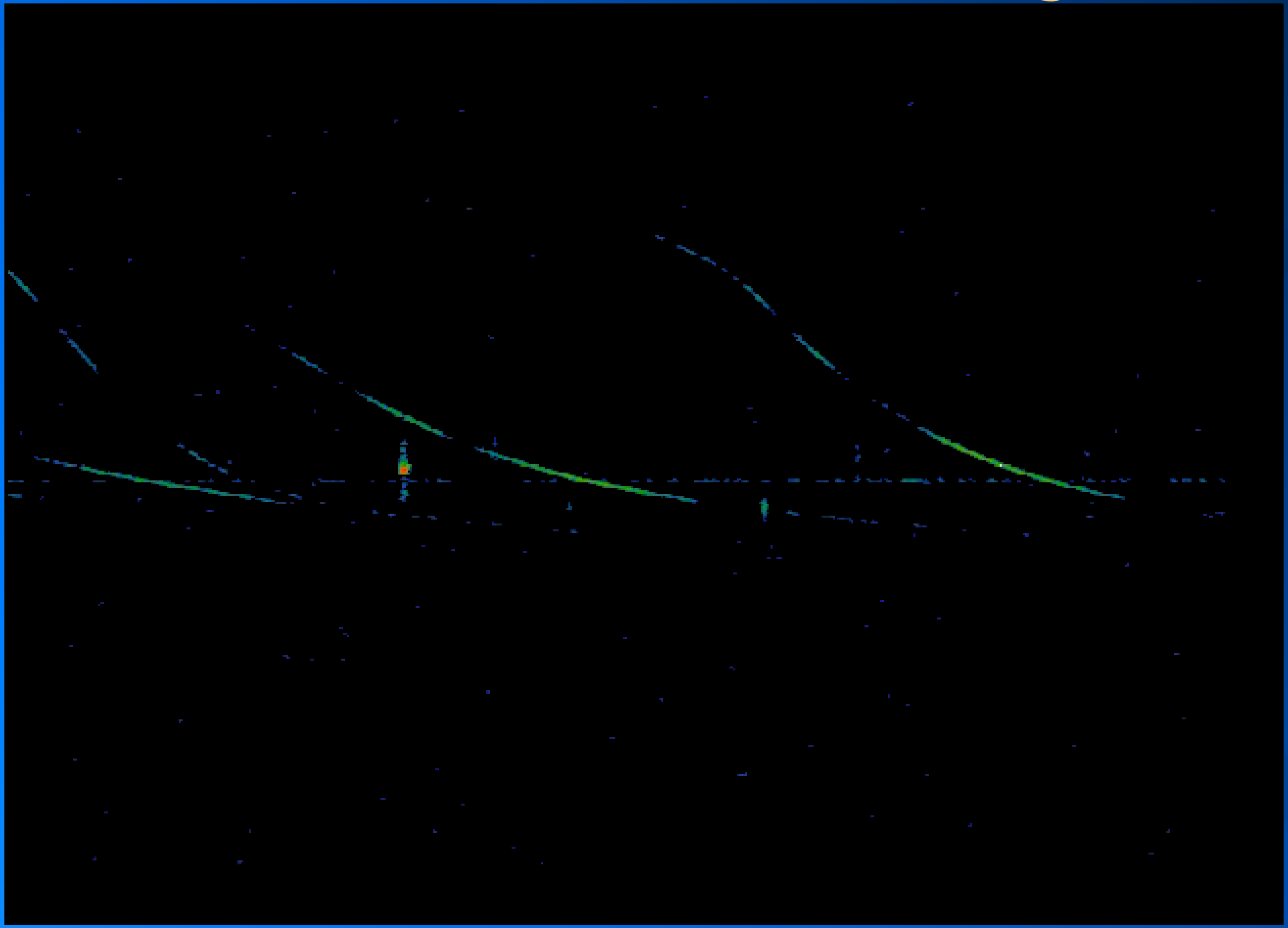
Real time: trigger on amplitude threshold

Computer Vision

OpenCV (**Open** Source **C**omputer **V**ision Library) is an open source **computer vision** and **machine learning** software library.

The library has more than 2500 optimized algorithms, which includes a comprehensive set of both classic and state-of-the-art computer vision and machine learning algorithms. These **algorithms** can be used to detect and recognize faces, **identify objects**, etc

Thresholding



optimum threshold

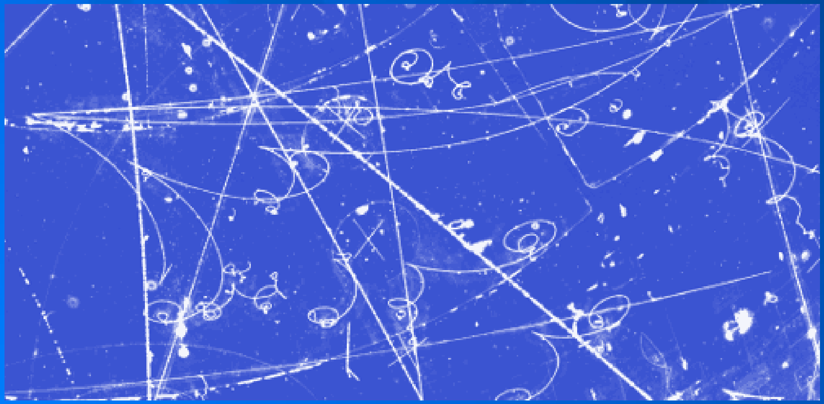
Removal of ‘straight’ lines

Carrier (horizontal line) removal worked well

Possibility to remove plane streaks (not horizontal)?

Hough transform (patent 1962): identification of lines in an image

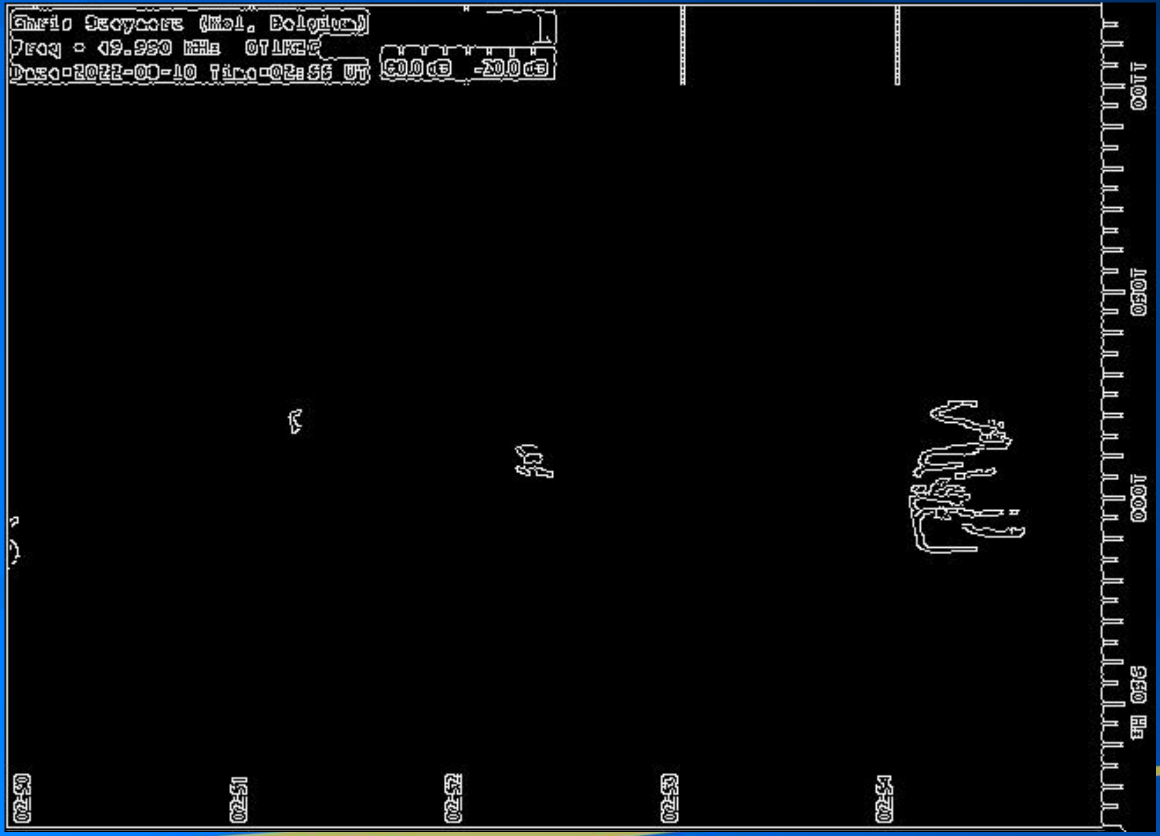
Bubble chamber: charged particles create ionisation track



Removal of ‘straight’ lines

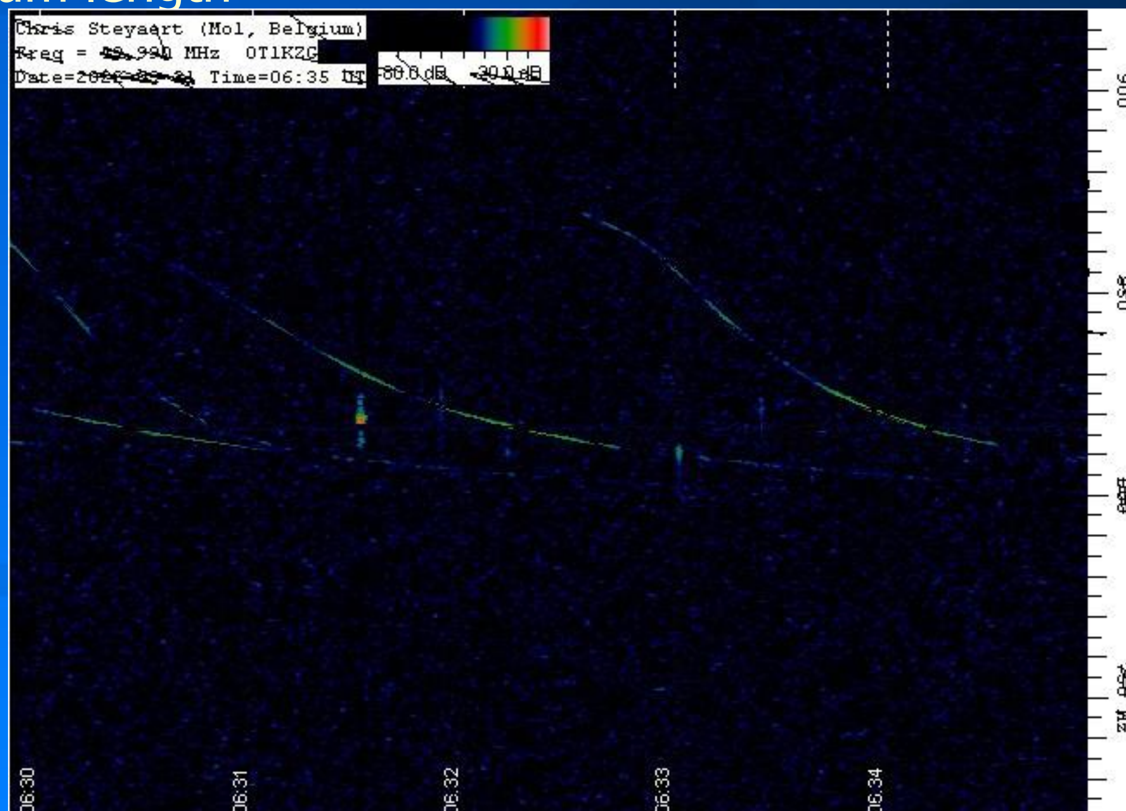
Hough transform on spectrogram → creates far too many lines

Required: edge detection first (Canny, John - 1986)



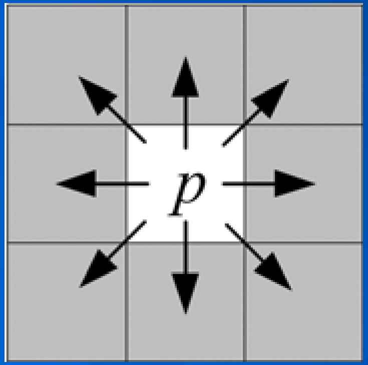
Removal of 'straight' lines

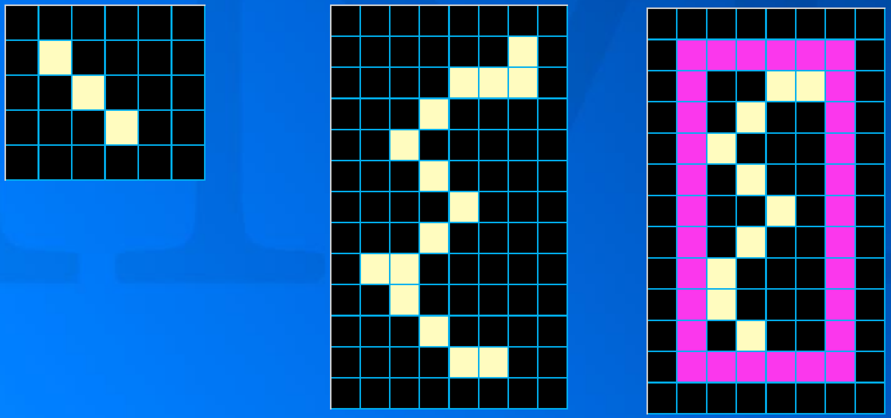
- Do not detect 'vertical' lines = edges of meteors !
- Hough transforms allows 'gaps' (interruptions) in lines and mimimum length



Connected components

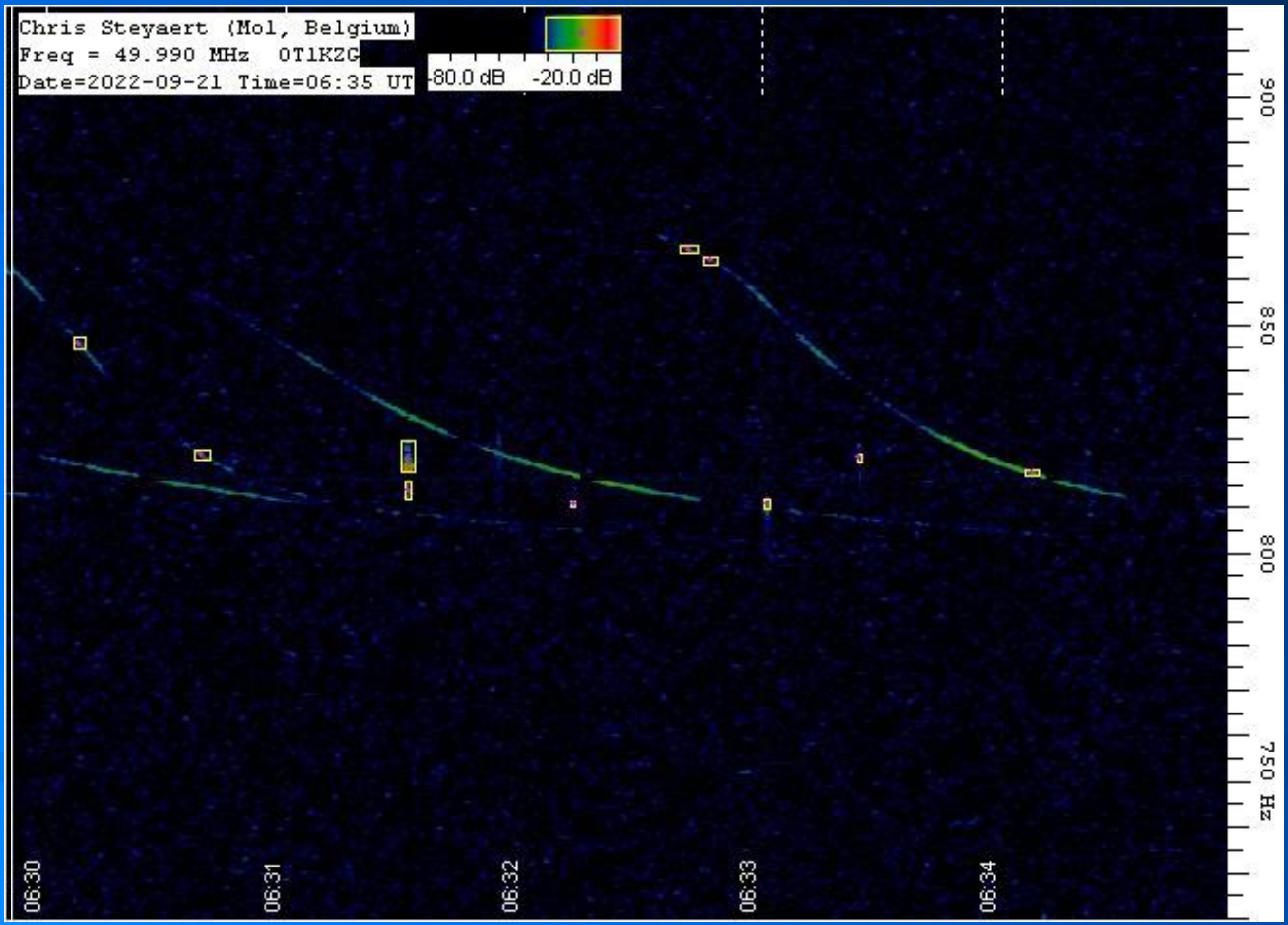
- Connect pixels with one out of the 8 neighbours exceeding a threshold





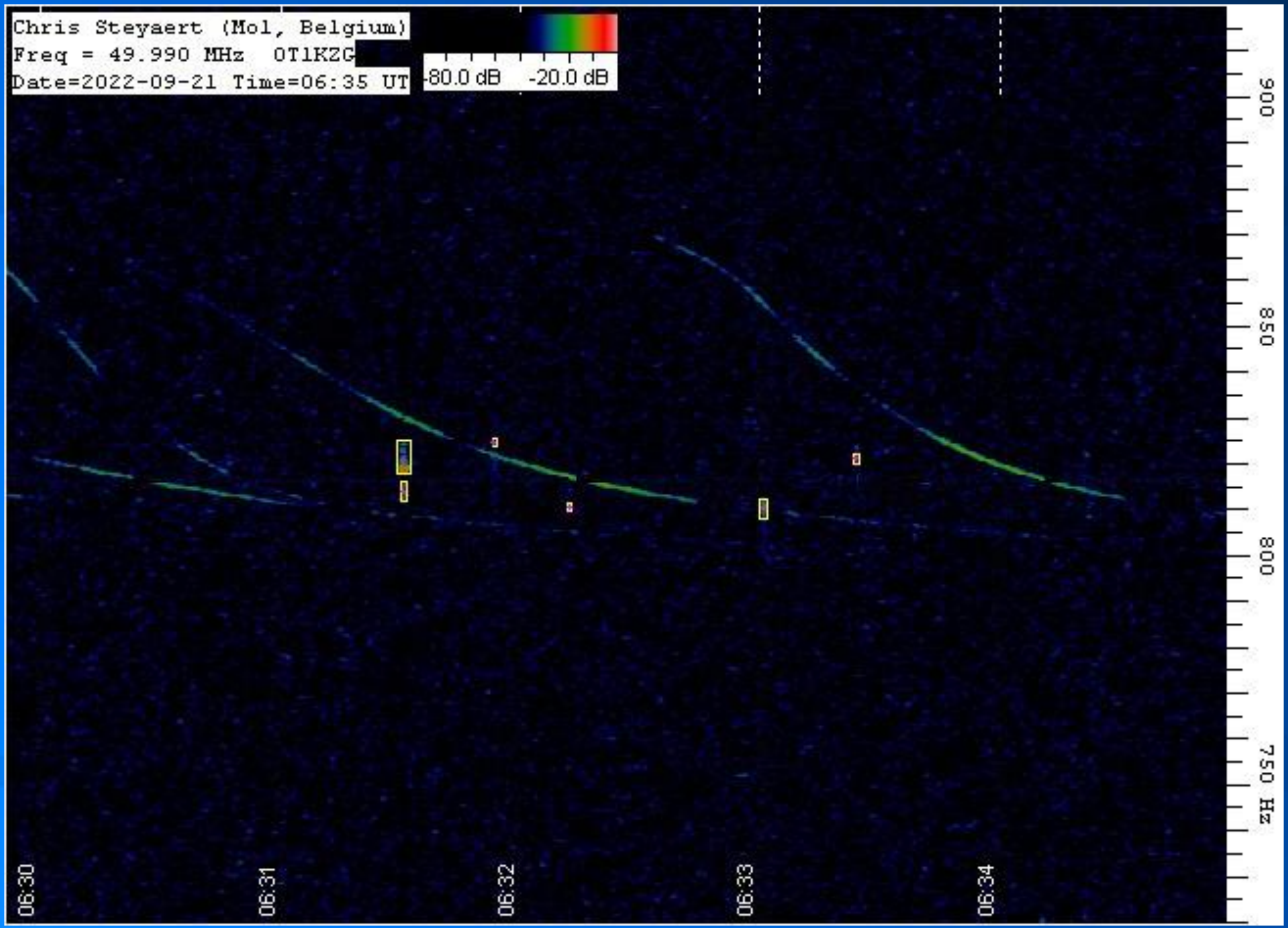
bounding box

Connected components



- Threshold 10, minArea 6
- Threshold 20, minArea 6, Fillfactor 0.1, h/w 0.4
- Threshold 20, minAread 6, Fillfactor 0.2, h/w 0.4

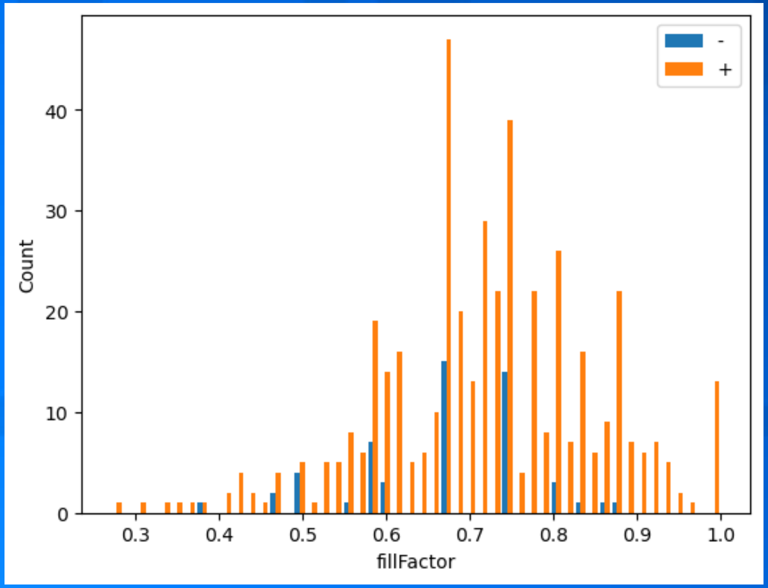
Connected components

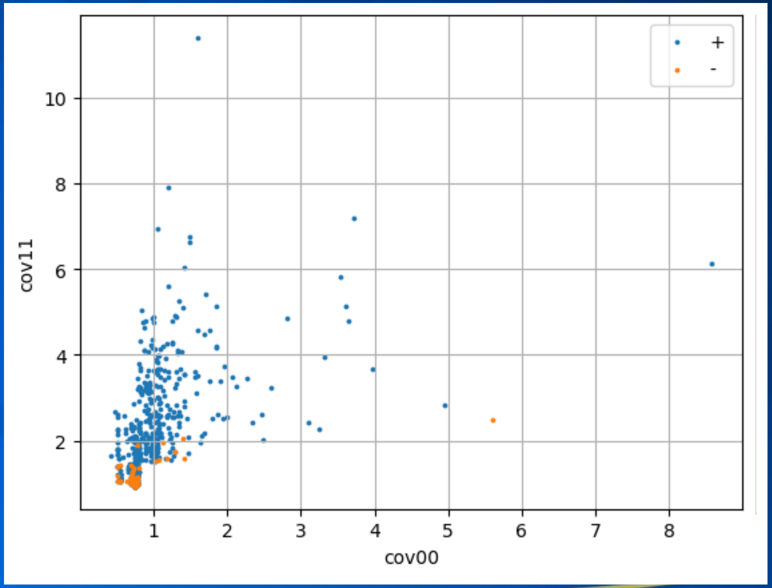


- Threshold 15, minArea 6,
  Fillfactor 0.2,
  h/w 0.4,
  Blur 3x2,
  linear regression
  - slope,
  - correlation,
  - spread

Tuning the model

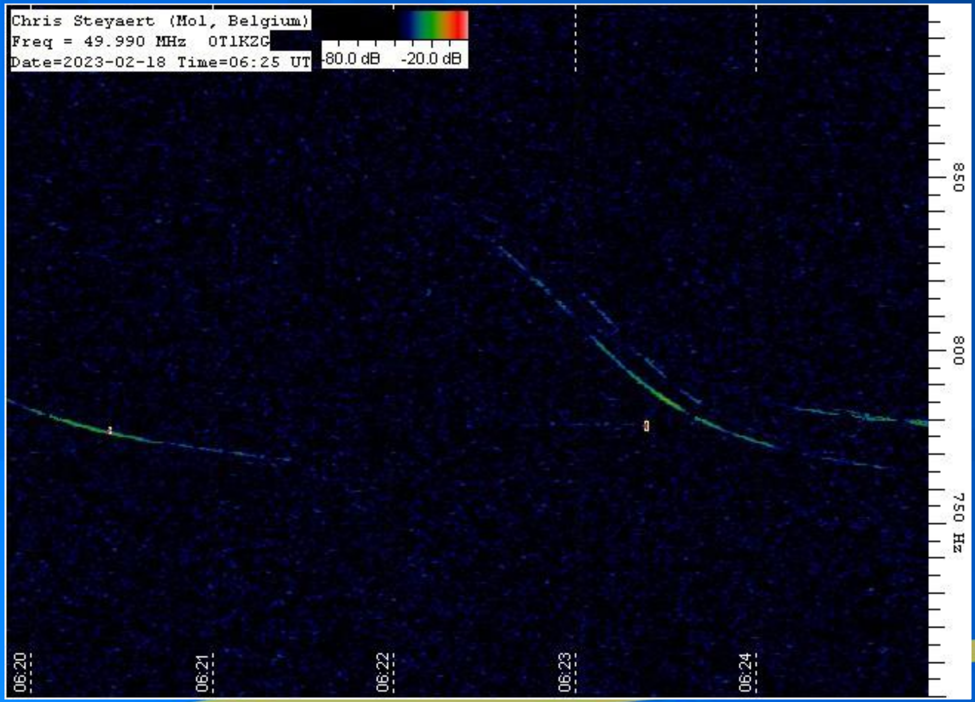
- Few cases → not representative
- Tune (manually) the parameters on a sufficient large **training set** 2023 Febr 16 – 18 (3 days, 493 meteors)
- Annotate true positives and false negatives
- Potential additional criteria: linear regression of the object pixels





Performance metrics

- Recall (sensitivity) = True Pos / (True Pos + False Neg) = 88.8 %
  (False Neg = non meteors misidentified as meteors)
- Any pattern in the False Neg (Feb 18) ?



Yes, 'far' from the central frequency

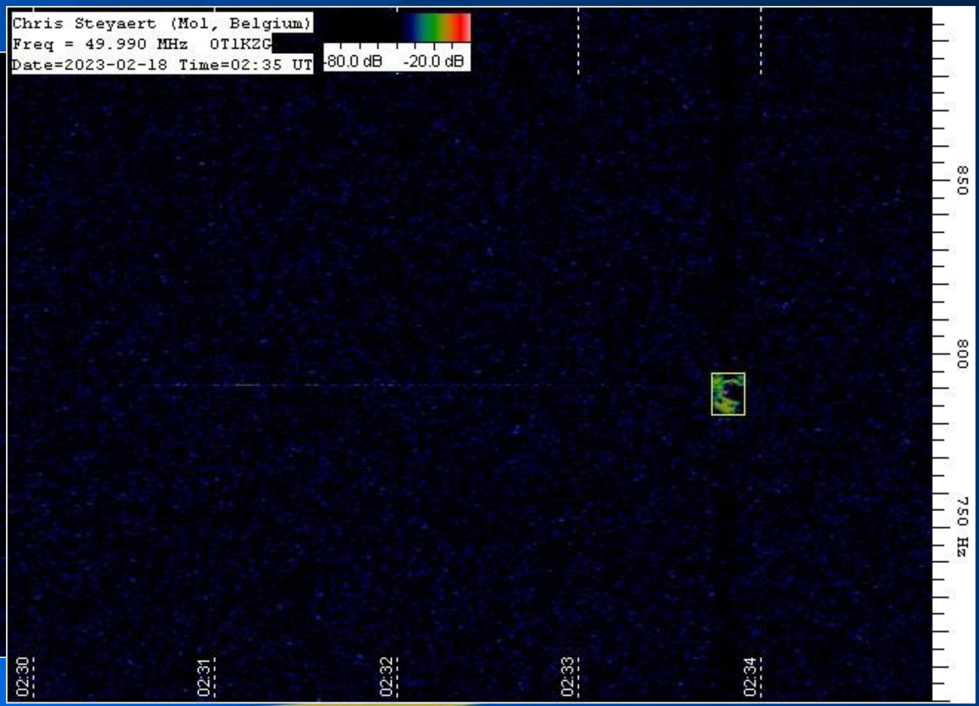
Second pass: eliminate for |Δy| > 60, removes 17 False Neg, looses 3 True Pos

New recall = 96.8 %

Performance metrics

- Precision = True Pos / (True Pos + False Pos) = 92.6 %
  (False Pos = meteors not detected)

- Should have found:



Tuning the model

- 'Final' set of parameters
  - Threshold
  - Canny edge (2)
  - Hough lines (4)
  - Blurring
  - h/w
  - Correlation coefficient
  - Area
  - Covariance (2)
  - Δf

- Grid search / random search

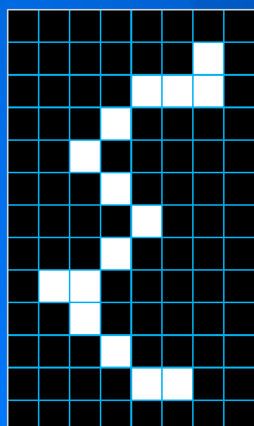
Advantage of automated detection

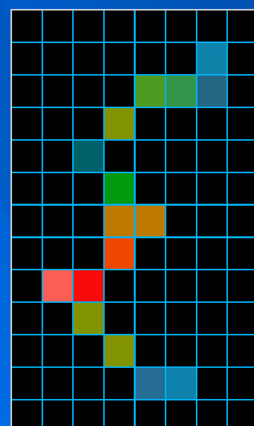
- Consistency
- No ‘positivity bias’
- Analyse vast volumes
- No special hardware required

- This study: only tuned for non-shower meteors
  (analyse Jan 5 – Apr 15, September)

Opportunities of automated detection

- Counts weighted by duration
- Counts weighted by (audio) power





dB scale lookup

$$dB_i = 10 \log P_i \qquad P_i = 10^{\frac{dB_i}{10}} \qquad P_{comp} = \sum_i P_i$$

$$dB_{comp} = 10 \log P_{comp}$$

Opportunities of automated detection

- Power distribution: equivalent of magnitude distribution
- 'Radio' population index: discern sporadics from stream meteors

- With stable frequency or known carrier frequency:

  Doppler shift of centroid → distribution of velocity drifts, stream vs sporadics

Environment and packages

Python 3

Main:

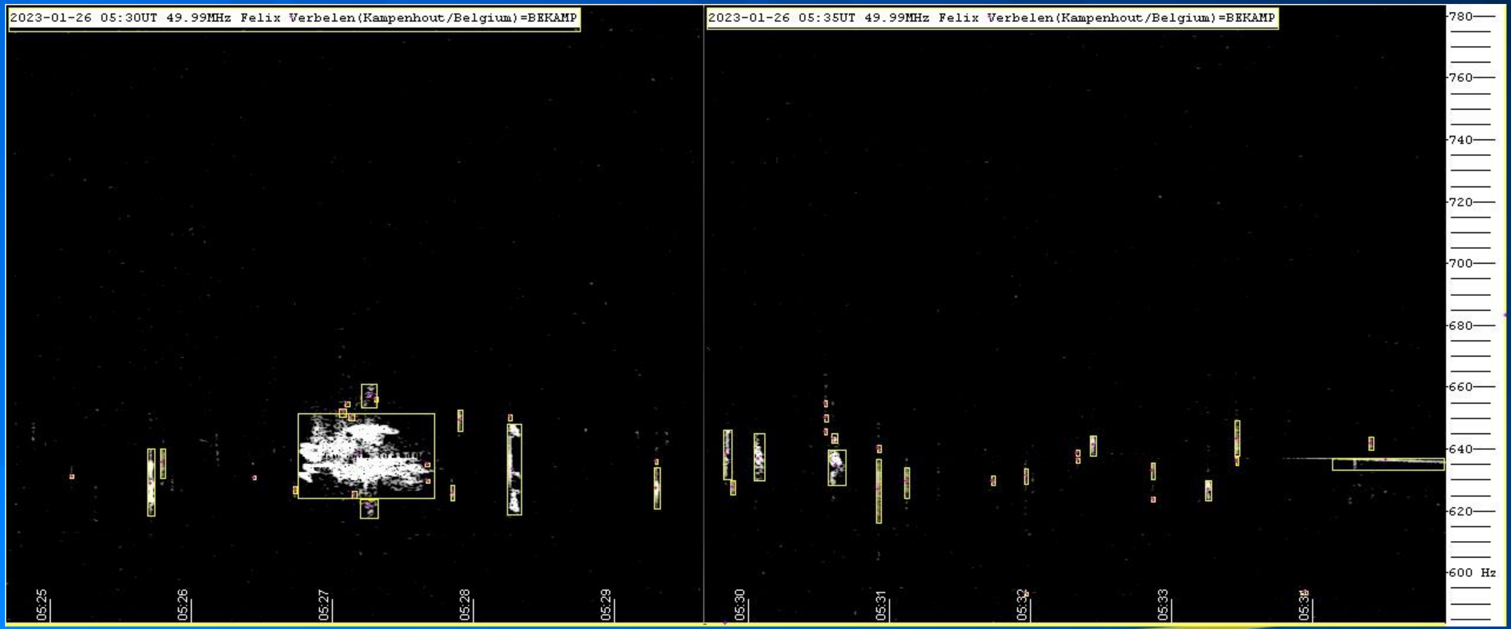
Numpy cv2 Matplotlib

Auxiliary:

Json Os Math Glob Pathlib Tqdm

Other setups

- Source code available 'as is' to try yourself (tuned on mainly sporadic activity, probably performs less well on streams)
- A Felix Verbelen recording, partially tuned:



Thanks to / acknowledgments

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- Pierre Terrier
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- Felix Verbelen

- Aegide Steyaert