Meteor Recognition & Trajectory
Approach and Principle

- <u>Version 5 – April 2014</u>
- Previous results :
  - Comparison Optic / Radio detections
- Characteristics and choice of transmitters
  - Comparison on active system using beacon versus passive radar
- Passive radar using FM transmitter
  - Mockup
  - Processing
- First results during Perseids 2013
  - Detection on 12/08/2013 à 03:41:08 - Optic and radio
- Tracking of the meteor tail
- Comments - Conclusion
- RETRAM – Principle

Doppler shift is referenced to « 0 » (direct path of transmitter)
Time is UTC
RCS = Radar Cross Section (in m²)
Maps are done with Google-Earth

Previous results

- Comparison optic / radio detections

  - 06 Mai 2013 - http://www.retram.org//wp-content/uploads/2013/05/Resultats_Eta-Aquarides_20130506.pdf

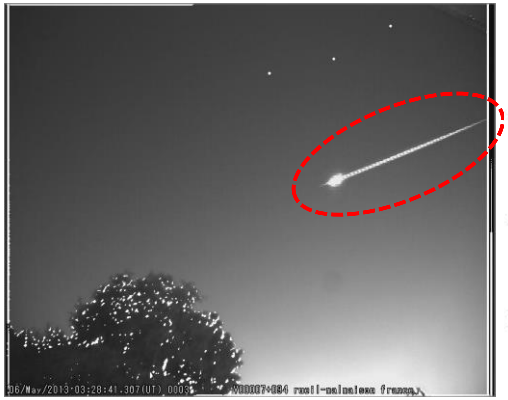
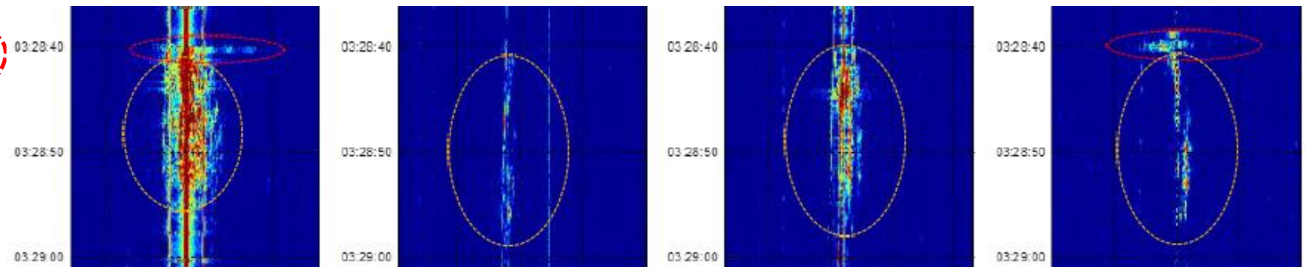


Image D.André



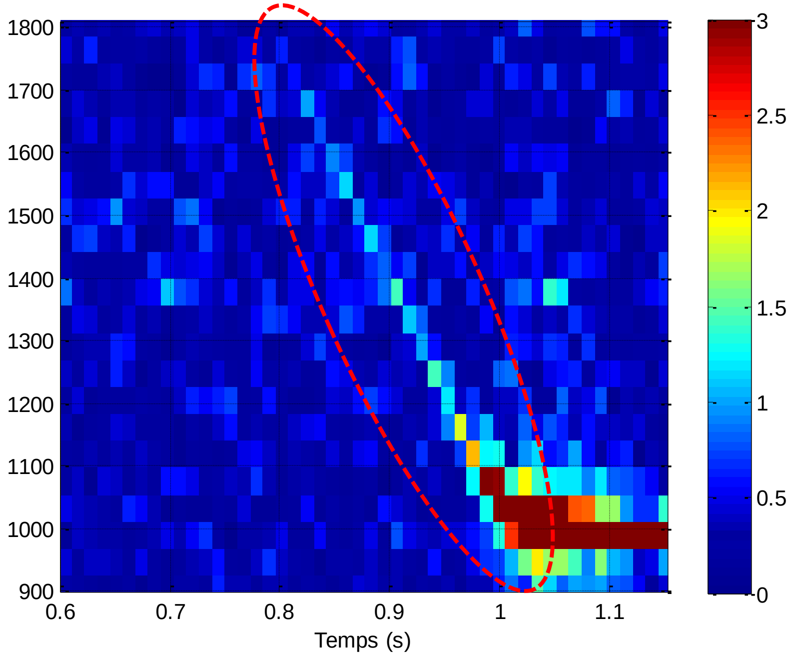
VOR radio detection

- The optic detection bring to light the head echo of meteor penetrating the atmosphere. These signal are also detectable on radio and are characterized by a fast Doppler shift (Doppler slope).

- Then the radio detection shows the meteor tail (few or not visible by optic system without a long integration time – long exposure).

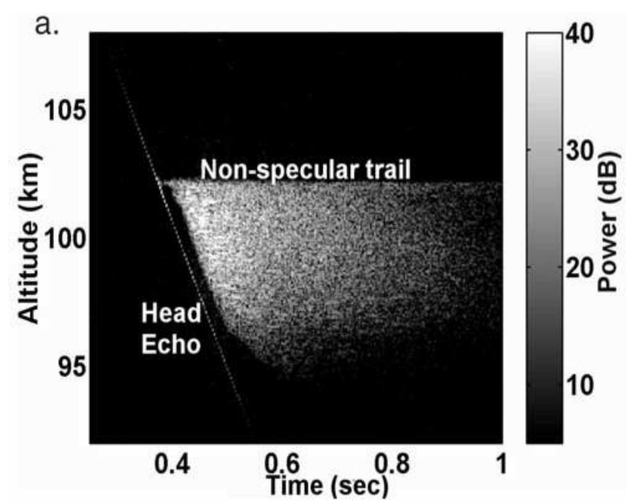
Another correlation Optic / Radio (27/05/2013)

Recorded by Dominique André (radio and optic). Transmitter is the BRAMS beacon radio.
The meteor trail (Optic detection) was corresponding to the head echo Doppler slope of radio signal.



The estimated Doppler slope is around 1KHz/0.25s or 4KHz/s. With lambda = 6m, the bistatic speed slope is then 24 km/s (v = -Lambda * Fdop)

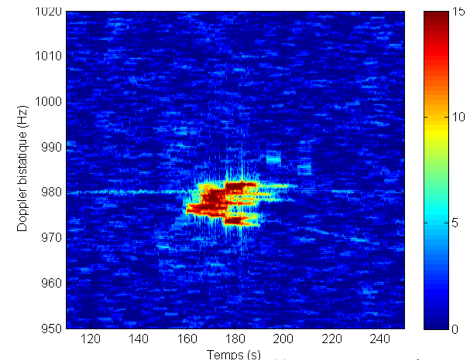
http://www.retram.org/quisommesnous/configuration-geographique/



Reference : "Scattering characteristics of high-resolution meteor head echoes detected at multiple frequencies"
S. Close,1,2 M. Oppenheim,2 S. Hunt,1 and L. Dyrud2

Previous results

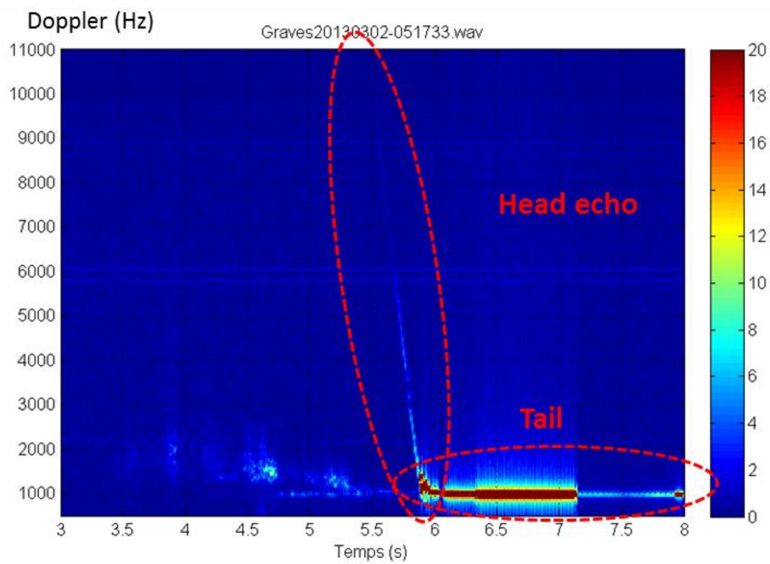
- Meteor trail and head echo bring out (http://www.retram.org/les-meteores-cest-beau/)
  - ✓ Optic photography with long exposure (meteor trail on left and its dipersion on center. The dispersion is detectable/observable on radio (meteor tail on right)

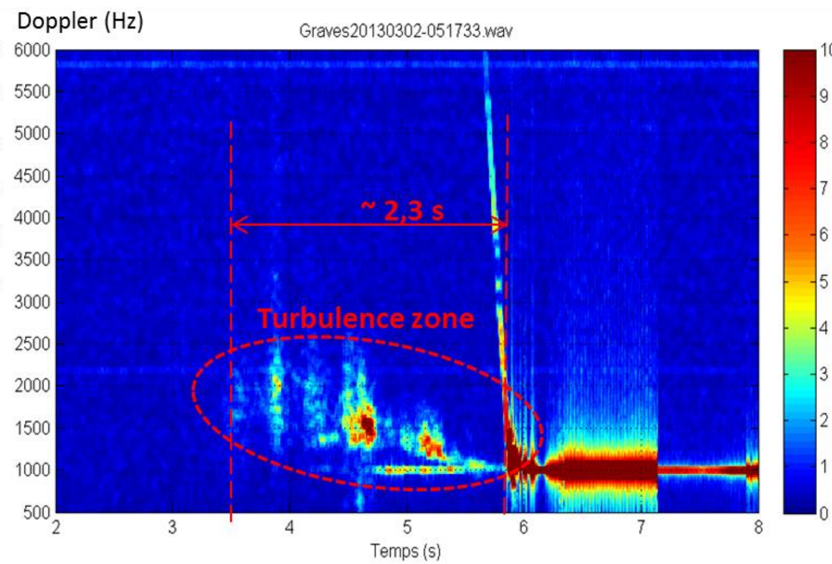


Pictures done by Fabrice Noel - AAV

Detection : B.Kieffer F1EHX (Brams)

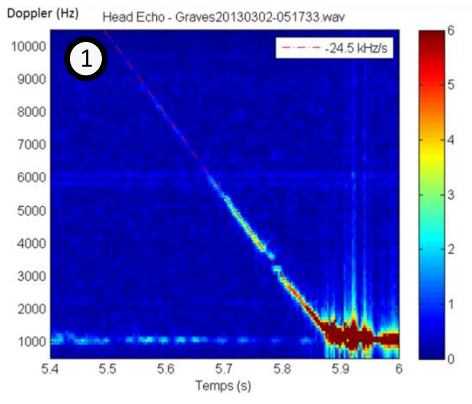
  - ✓ Below, the radio detection shows a great Doppler slope corresponding to a meteor head echo followed by a huge signal on meteor tail.

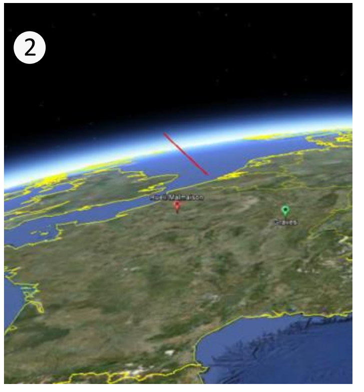


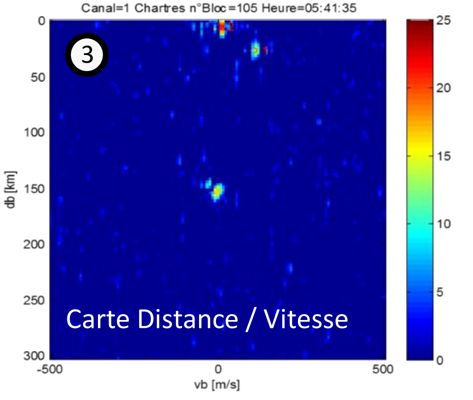


Conclusion about these previous works

- Metor trajectory assessment (Objectif RETRAM)
  - ✓ With using the Doppler slope measured on head echo (fig 1) it could be possible to calculate the meteor trajectory (fig 2) but this calculation need to know the meteor location and its speed at an accurate time (fig 3).



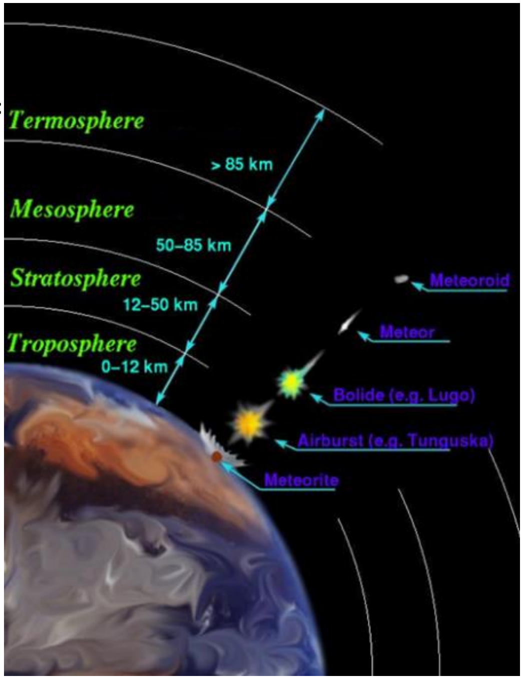




  - ✓ The current transmitters used to make meteor detection on radio, i.e Belgium BRAMS beacons and GRAVES in France, use continuous wave. VOR is using narrow band waveform (about 30Hz). So these signals or waveforms don't permit to measure range of a meteor.
  - ✓ Range measurement could be done with signals having larger waveform bandwidth.
  - ✓ The principle is detailed at the end of this paper (slides 18 & 19)

Characteristics and choice of transmitters

- The goal is recognition and trajectographies of meteors (RETRAM project) with an ability to detect at low altitude
- The Earth rotundity limits the wave propagation at low altitude (h= 10km at about 300 km). So, we have to use local transmitters.
- The deployment of beacons was studied but we listed too much difficulties :
  - Energy consumption : for about 500W/h and permanent running
    - ✓ 4380 kWh / year => about 570 Euros / year for 1 beacon, 57 kEur for 100 beacons.
  - Electro Magnetic Compatibility
  - EMC Safety (EMC radiating) => hard to find free places
  - Waveform bandwidth - Spectral density : hard to find free frequencies

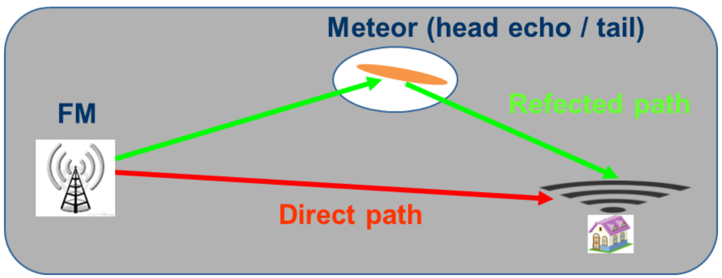


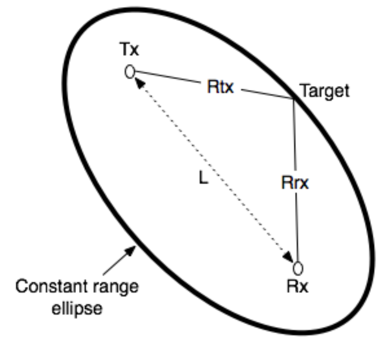
- So, we searched around these criteria :
  - Existing transmitter (free energy consumption)
  - Signal bandwidth > 100 KHz and low Range/Doppler ambiguity
  - Available on large areas (France and more)
  - Frequency between 30 to 150 MHz
  - RF Radiated power over 1KW

✓ **FM transmitters are full compliant with RETRAM needs**

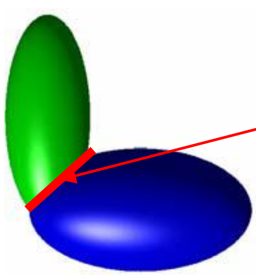
Passive radar principle

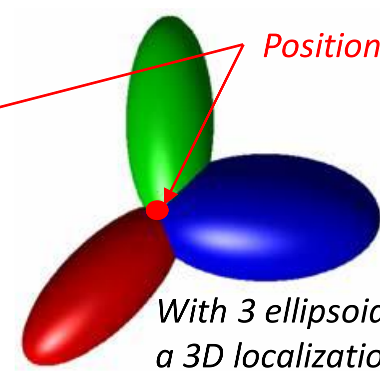
- Principle of passive Radar using FM Transmitter
  - The RF signal radiated by the transmitter is received directly by the receiver (Direct path) and reflected by the flying objets (as meteor) and then received by the same receiver. After filtering and correlating (signal processing), the receiver is able to deliver a delay (named range) and frequency shift (named Doppler shift), This delay or Doppler shift are named “bistatic” because the transmitter and receiver are not in the same location. It could be demonstrated the delay (or bistatic range) is located on a ellipsoid (below in 2D - ellipse) having transmitter and receiver location as foci.



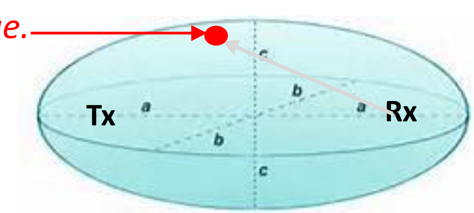


  - With using a few couple of Transmitter/Receiver (or bistatic bases), the ellipsoids interception give a 3D localization of the detected object (for 3 or more bistatic information).





Position possible en rouge.



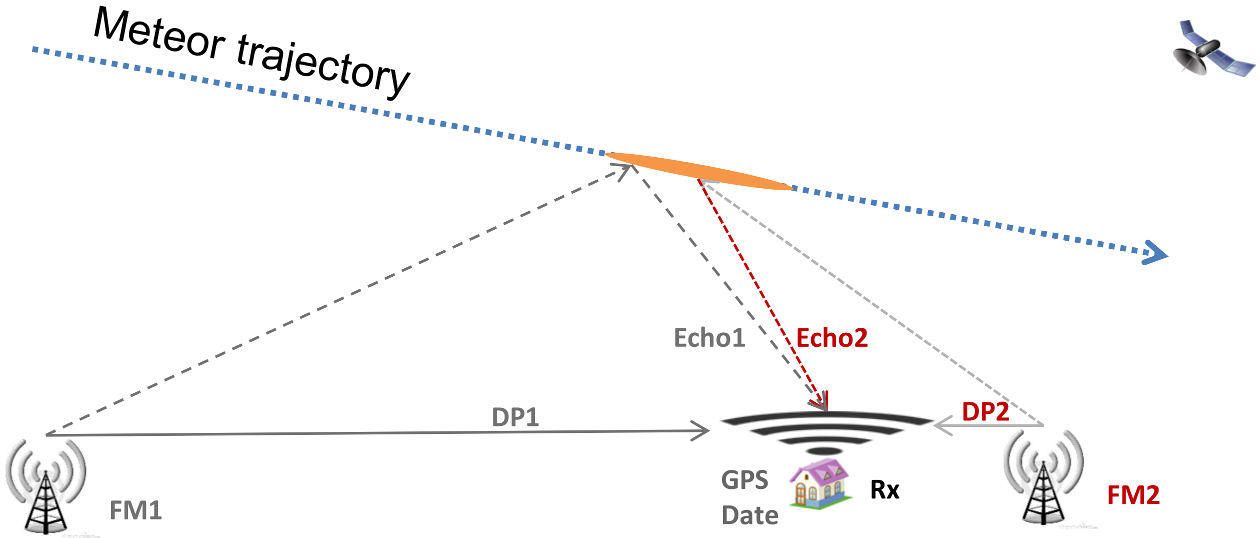
With 2 ellipsoids, the result is 2D information and we cannot solve the ambiguity without external information

With 3 ellipsoids, the result is a 3D localization.

With 1 or 2 ellipsoids, with adding an angular detection with optic device the result is also a 3D localization.

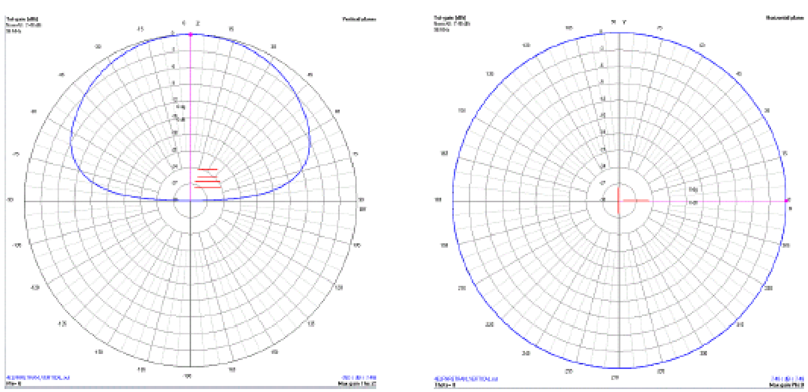
FM Meteor Passive detection (« Passive radar »)

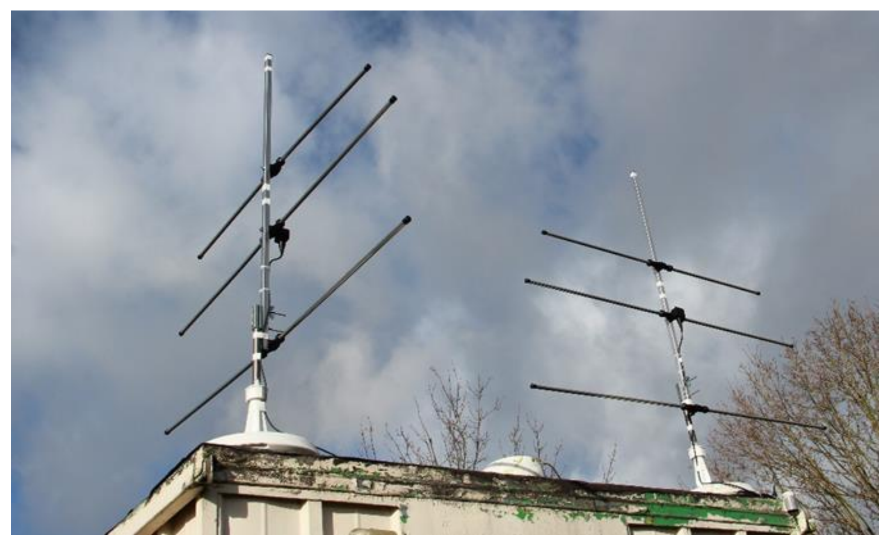
- MOCKUP (2 RF ways and 2 to 4 frequency channels)



DP : Direct Path
Rx : Receiver
FM : FM transmitter

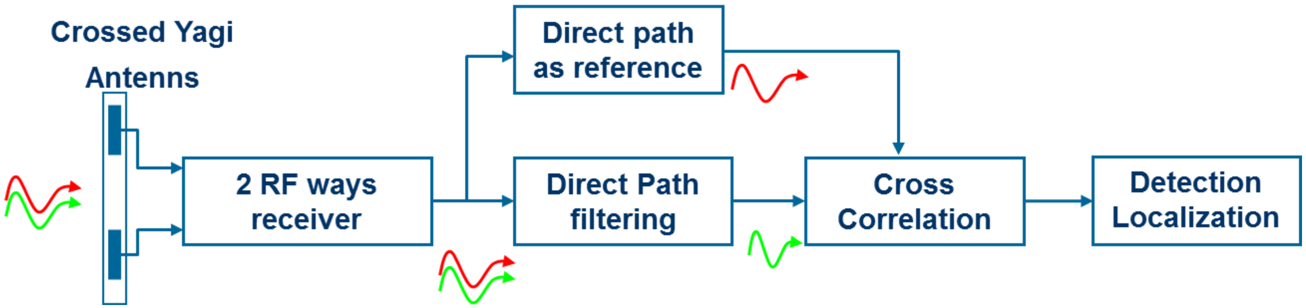
The goal is to cover the sky over the Paris area. 2 * 3/4 elts YAGI antenna beamed to the sky. The radiated diagram is :



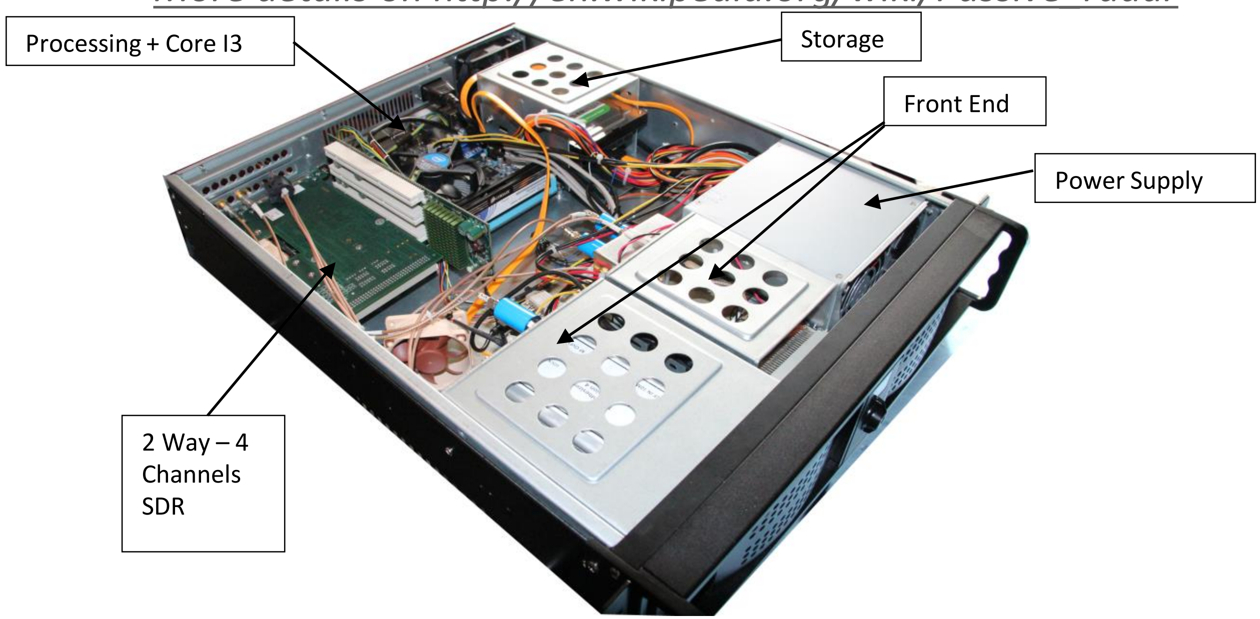


FM Meteor Passive detection (« Passive radar »)

- Analog Front End and Digital receiver (SDR) using 2 RF ways and 2 to 4 frequency channels and real time processing



[More details on http://en.wikipedia.org/wiki/Passive_radar](http://en.wikipedia.org/wiki/Passive_radar)



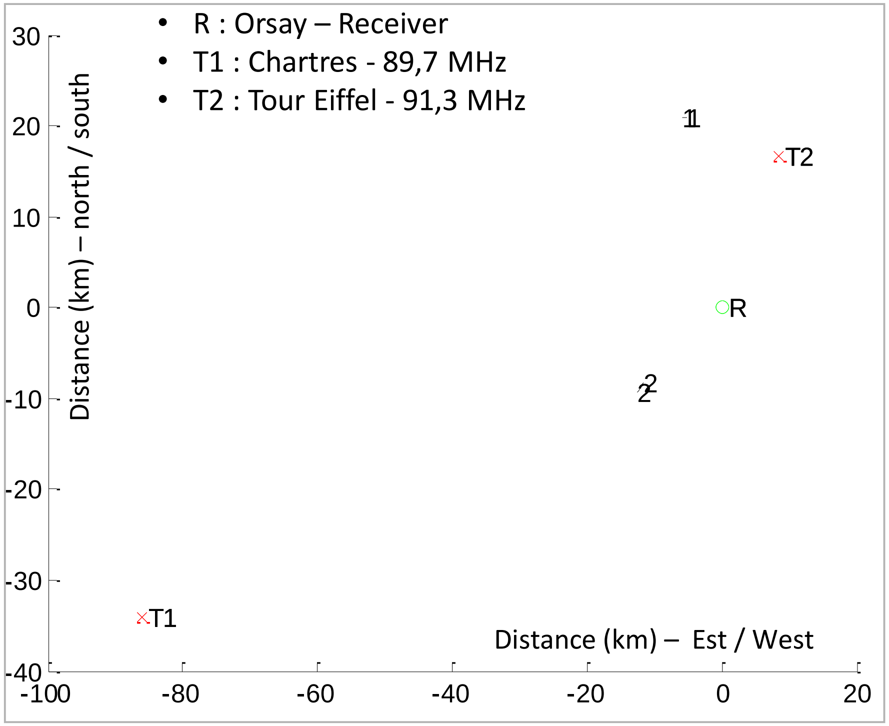
FM Meteor Passive detection (« Passive radar »)

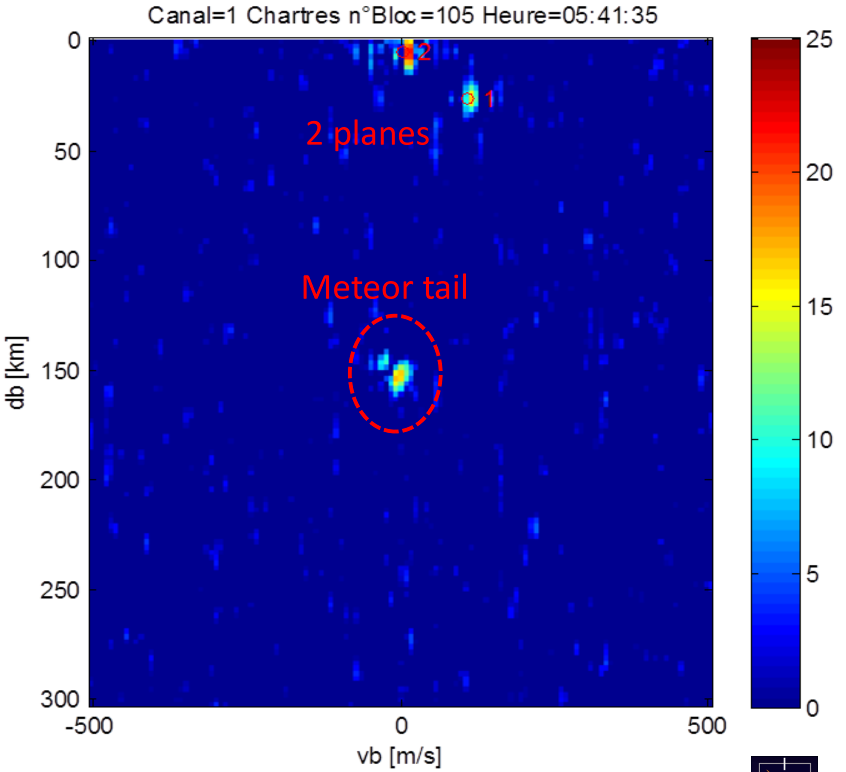
❑ Processing and tests

The test consists to compare the localization of planes / liners done with the Passive Radar and positions given by an ADSB receiver. Positions are projected in the bistatic domain of the couple Tx/Rx.

- ✓ Accuracy is good (see .
- ✓ System is also very sensitive. The radar budget is as good as calculated,

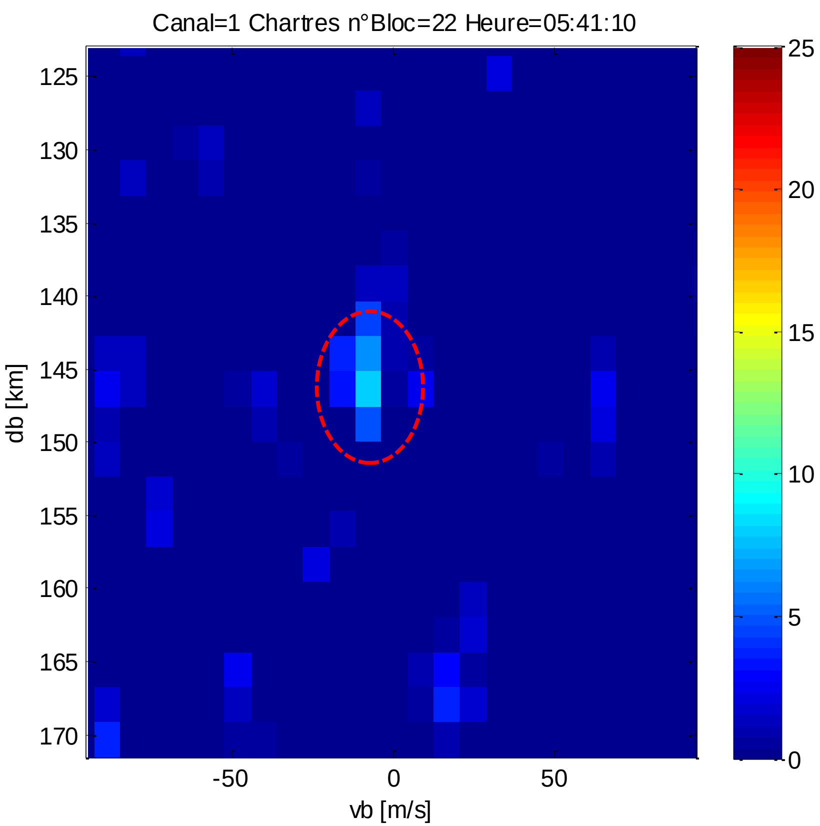
Below the figure 2 shows the detection of 2 planes (1 et 2) during the detection of a meteor tail.
The figure 1 (left) gives the location of transmitters Tx (T1 and T2) and Receiver Rx (R).

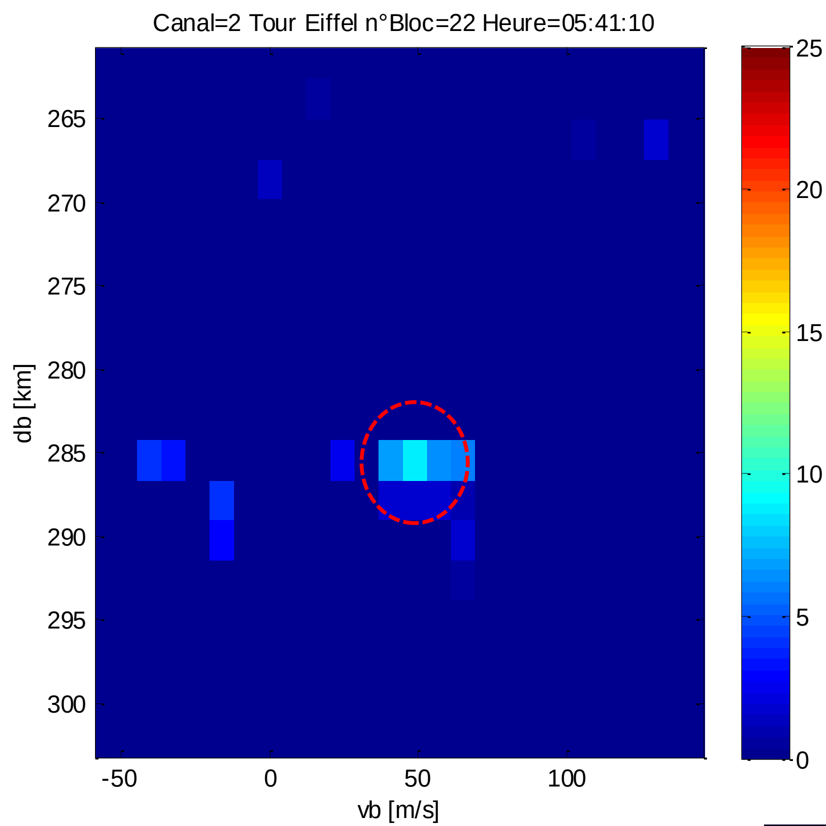




First results - Perseids 2013 : 12/08/2013 03:41:08

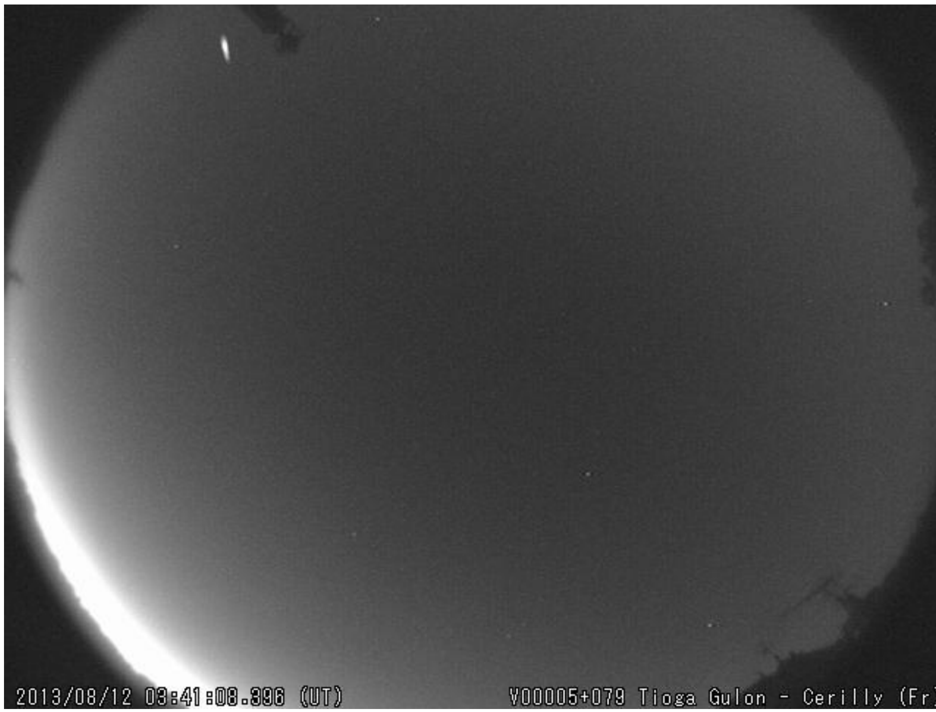
- FM Passive detection using 2 frequency channels
  - The tail is detected simultaneously on both channels.
  - The measured bistatic distances are 145 km on Chartres Tx and 285 km on Tour Eiffel Tx
  - 3D localization is not available for this 1st tests (Only 2 bistatic bases)
  - The 3rd information was found on the BOAM database (http://www.boam.fr/)





First results - Perseids 2013 : 12/08/2013 03:41:08

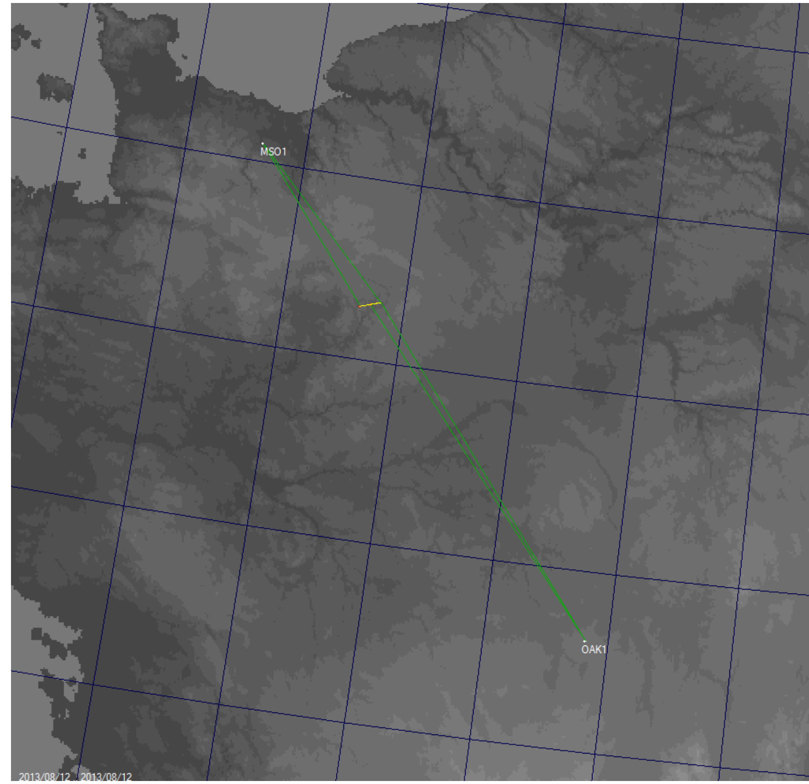
- Optic detection (BOAM)
  - The meteor was detected by 2 stations OAK1 (on left) et MSO1 J2D (on right)
  - See data on the chart below (http://www.boam.fr/)



Date	Heure (UTC)	type	caméra	durée (s)	vitesse (°/s)	mag	az db	ev db	az fin	ev fin
12/08/2013	03:41:08	PER	OAK1	0.233	13.05	-3.2	321.86	21.60	320.71	18.81
12/08/2013	03:41:08	PER	MSO1 J2d	0.600	17.54	-3.9	134.35	40.09	139.92	30.61

First results - Perseids 2013 : 12/08/2013 03:41:08

- Optic detection
  - 3D localization is available (Comptutation done by par Tioga – OAK1)
  - Trail coordinates at the beginning:
    - Latitude : 48,3298 °
    - Longitude : 0,7999°
    - Altitude : 105,5 km
  - Trail coordinates at the end :
    - Latitude : 48,2939 °
    - Longitude : 0,6382
    - Altitude : 71,0 km



_localtime temps local	_sol longitude solaire	_amag magnitude absolue	_stream essaim	_ra_o ascension droite observée	_dc_o declinaison observé	_ra_t asc dt corrigé	_dc_t declinaison corrigé	_vo vitesse observé	_vg vitesse geocentrique	_vs vitesse héliocentrique	_dv12% erreur sur la vitesse	_dur durée
				deg	deg	deg	deg	km/s	km/s	km/s	%	s
_20130812_034108	139,422	-5,2	spo	47,97	50,47	47,82	50,57	62,7	61,6	40,2	1,4	0,600

_lng1 longitude debut	_lat1 latitude debut	_H1 hauteur debut	_lng2 longitude fin	_lat2 latitude fin	_H2 hauteur fin	_LD21 distance parcouru	_evrt angle d'elevation du radiant	_Y_ut année obs UT	_M_ut mois obs UT	_D_ut jour obs UT	_h_ut heure obs UT	_m_ut minute obs UT	_s_ut secondes obs UT
deg	deg	km	**deg**	**deg**	**km**	km	deg						
0,7999	48,3298	105,5	**0,6382**	**48,2939**	**71,0**	37	70,42	2013	8	12	3	41	8,390

First results - Perseids 2013 : 12/08/2013 03:41:08

Maps of results

Computation using the altitude information of the optic detection gives a 3D localization by passive radar very near to the optic localization :

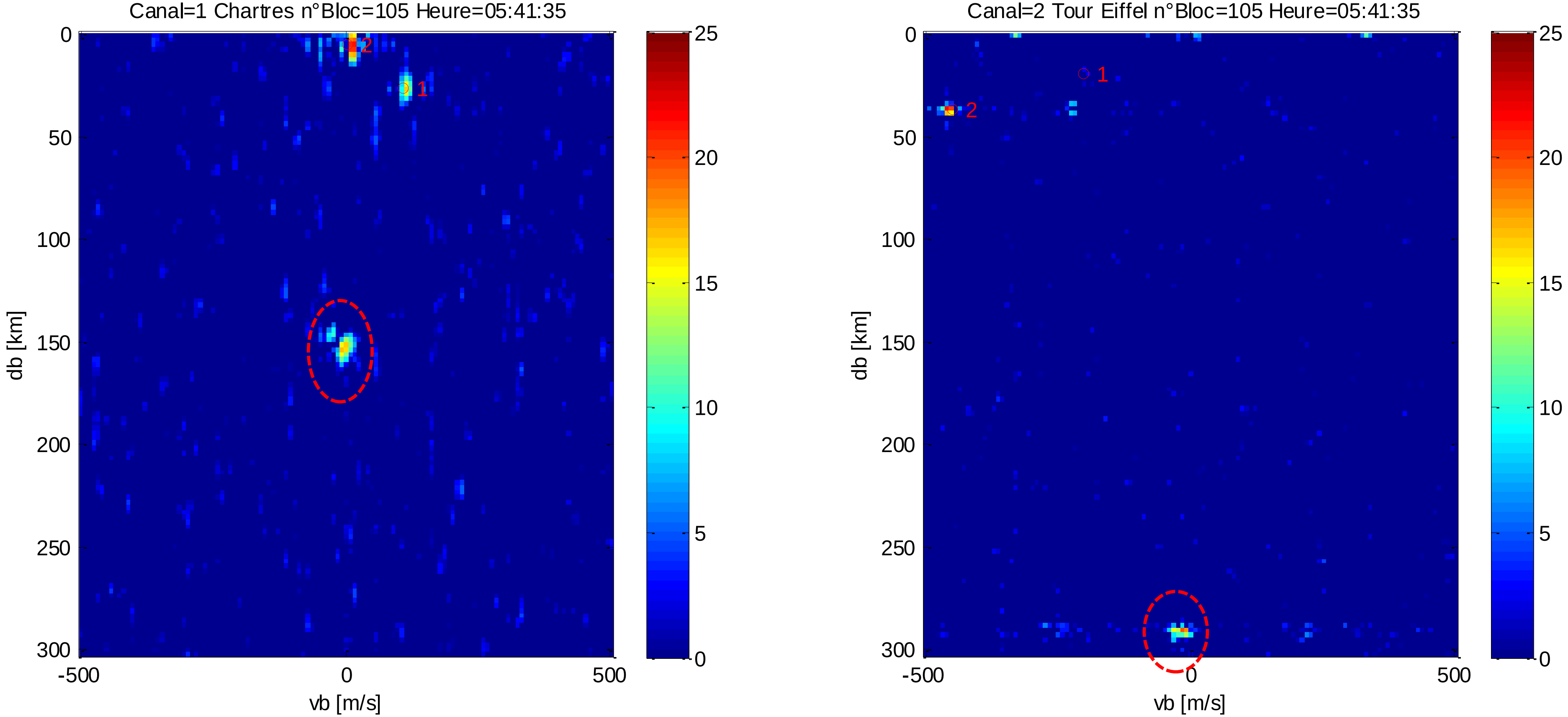
- Latitude : 48.269°
- Longitude : 0.744°
- Altitude : 85 km

The error is very low regarding the condition of this first results. We can probably improve time dating.

Optic and radio give very near results, The meteor was over the "Basse Normandie" country.

First results - Perseids 2013 : 12/08/2013 03:41:08

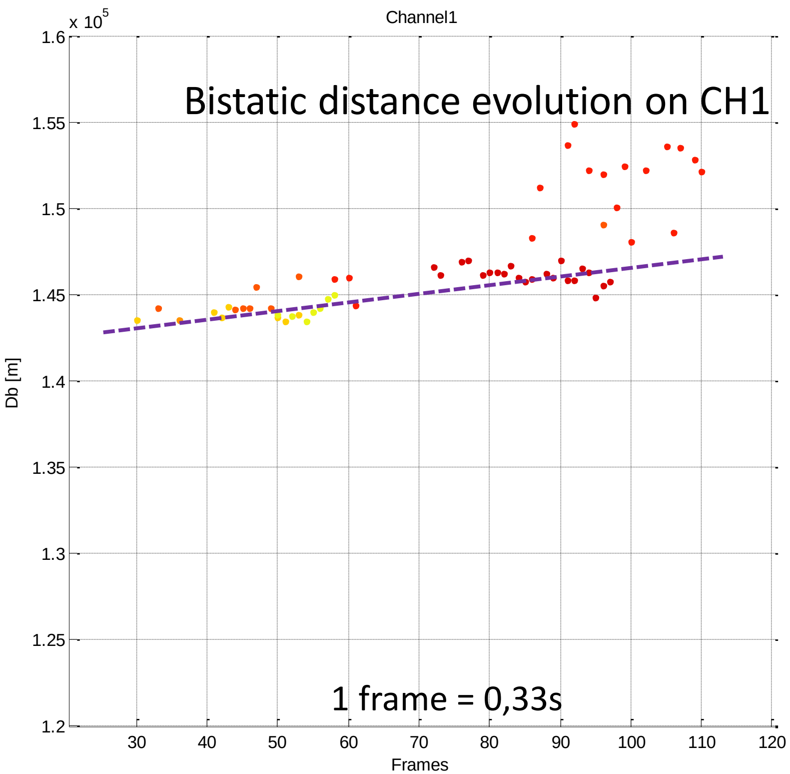
❑ FM Passive detection (End of the tail)

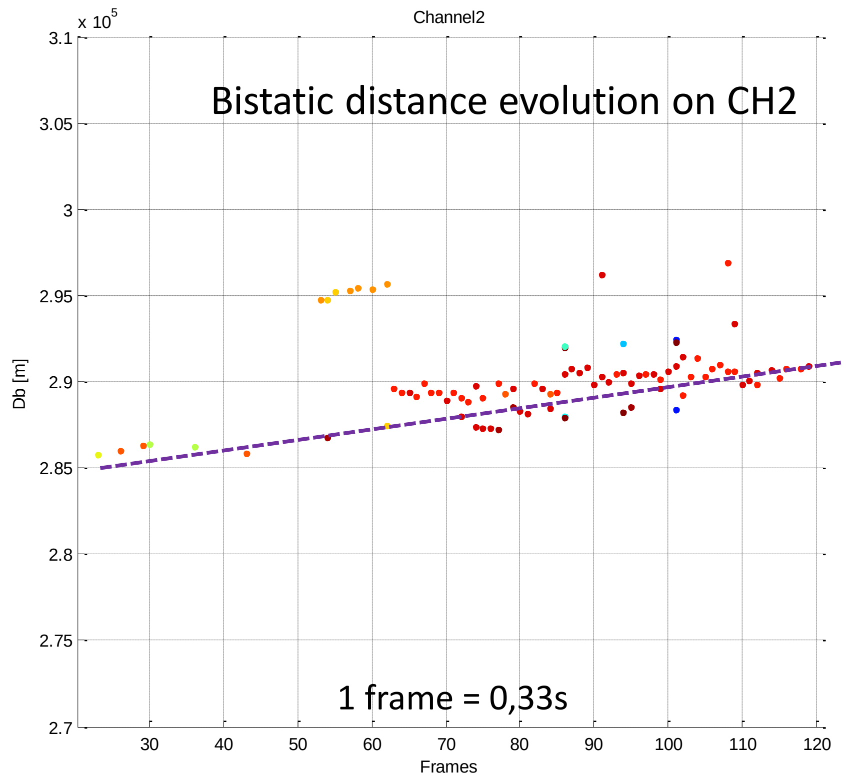


This figure shows the detection is still done with a comfortable SNR (Signal to Noise Ratio). The range has evolved from 145 to 152km on Ch1 and to 290 km on Ch2.

Other measurements

- TRACKING OF THE TAIL
  - The processing is able to deliver the range but also Doppler change during the “life” of the meteor tail (about 30 sec / 90 frames into the example below).
  - This measurement could help to assess the meteor dispersion on atmosphere and moreover to reveal speed and direction of wind and probably more data interesting for the scientific people.



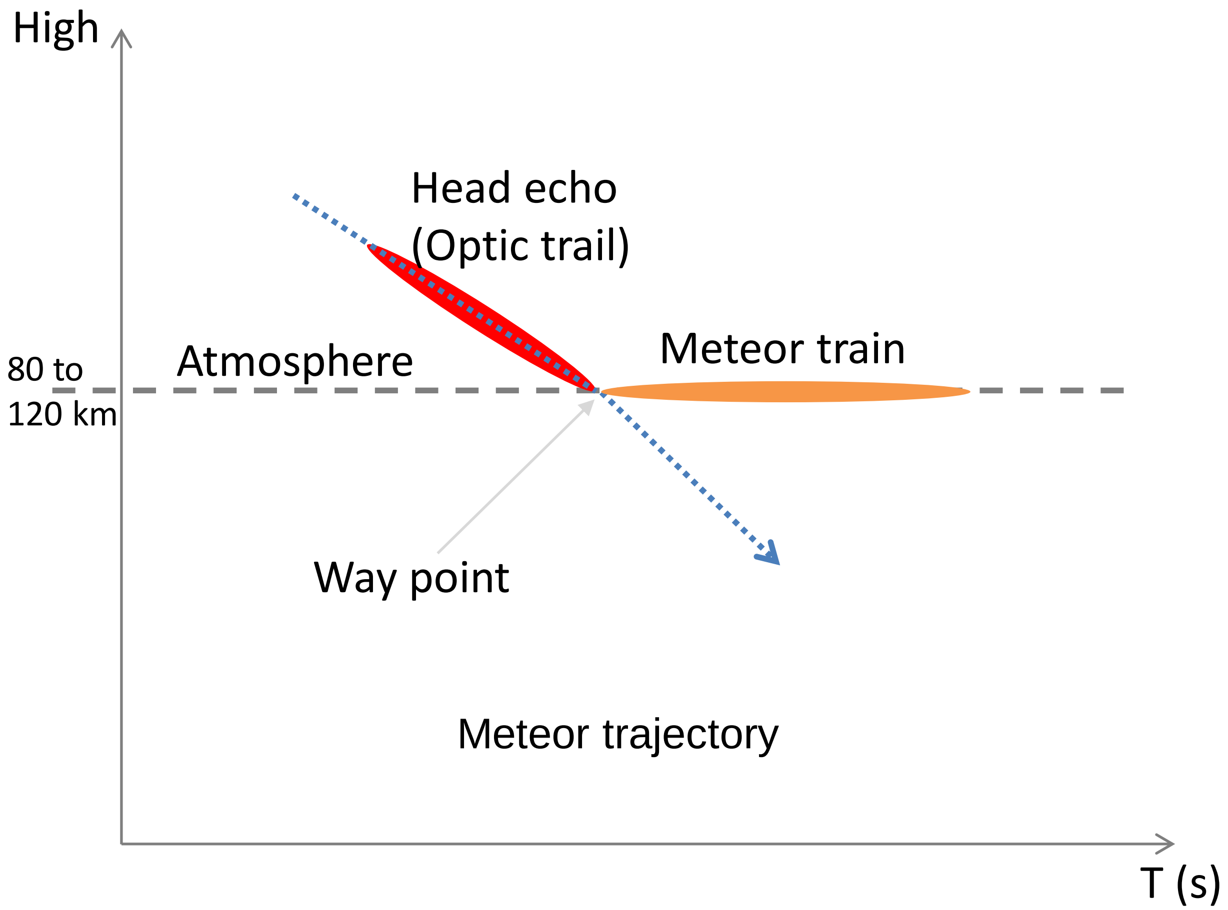


Project updates

- The mockup setup will be tuned to process up to 4 frequency channels.
- The goal is to obtain 3D detection to confirm the choice of FM transmitters
- A second station will be deployed to enhance the number of detection and the covered area. It will be a first step toward the RETRAM network
- Then a development of the digital receiver will be done to deliver a low cost solution (HW & SW)
- Continue the correlation Optic / Radio to assess the performance of the RETRAM network

RETRAM - Principle

- RECOGNITION
  - The processing detect the beginning of the meteor tail with using some criteria as altitude, Doppler, Detection length and Signal to Noise Ratio. It deliver the 3D localization of a way point.



RETRAM - Principle

- TRAJECTOGRAPHY
  - With projecting the Doppler slope in the 3D bistatic domain and comparison to the Doppler / Range measurement of the way point to find the right trajectory of the meteor during its atmosphere penetrating.