RETRAM: recognition and trajectories of meteors

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Meteor detection and tracking is the main activity of the RETRAM group, part of the French ARRL organization. Our project uses passive radar techniques and real-time processing to detect and recognize falling objects and tries to estimate their trajectory to help in fireball recovery. The experiment started in the vicinity of Paris, France. This paper shows our observations and analyses, then it describes our technical approach, our first passive radar station and first meteor 3D localization. Finally, we describe the evolution of the system and subsequently its extension in the form of a network of stations grouping radio and optical detectors.

1 Introduction

RETRAM (as **RE**cognition and **TRA**jectories of **M**eteors) is a group of amateurs working together to make experiments around meteors detection and their trajectories, using radio signals through passive radar techniques. Goals for the RETRAM project – our wishes – are:

- to experiment with new methods for detecting and recognizing meteors using radio signals;
- to design and to test new algorithms and processing to obtain automatic detections;
- to design and to test new techniques to reconstruct a meteor path and to help in fireball recovery;
- to use optical detection if possible to enhance results;
- to cooperate with the scientific community to share the outcome of the project.

RETRAM is built around the use of radio signals because they allow a constant survey in all weather conditions (therefore not limited by the visibility conditions) and at any time (not limited by lighting conditions).

2 Observations and Principle of RETRAM

To avoid electromagnetic hazard and electromagnetic compatibility risks, RETRAM started with classic passive radar techniques using transmitters of opportunity. Starting in 2012, a survey was dedicated to the observation of meteors using the well-known Graves transmitter and some aeronautical VHF VOR beacons. (Some measurement reports are available on our WEB site (RETRAM - Recognition & trajectory, 2014)[1]. These transmitters allowed to confirm:

- the minimum “radar” budget necessary to observe the meteors;
- the various signals we have to measure (signals level, speed, spectrums…).

We were able to confirm previous observations done by amateurs and other works like Close et al. (2002), Close et al. (2011) and to define the criteria we have to measure to develop our project.

Optical and radio observations

Optical observations performed simultaneously by radio measurements and Doppler analysis both revealed the optical trail is correlated (in time) with the radio head echo of the meteor. This head echo is characterized by a huge Doppler slope (or fast Doppler shifting). The head echo was observed using different transmitters and the Figure 1 shows such a correlation. The phenomenon of head echo and its radio detection were also detected using VOR beacon as shown in Figure 2. Figure 3 shows a head echo and non-specular train signals collected at VHF frequencies (Close et al., 2011). The head echo, characterized by a fast Doppler shift (or high penetrating speed in atmosphere) is red circled. The head echo is followed by a long train (depending on the object and environment) presenting a very low Doppler shift (or very low speed) depending also of the environment in high atmosphere.

Principle of RETRAM

Previous observations and measurements were performed with signals (waveforms in radar wording) having no or poor temporal information (named narrow band signals). These waveforms allow integration of the signal over a relatively long time and made Doppler slope measurement possible with good accuracy. But it was impossible to find the location of meteors at any time.

To enhance the meteor path reconstruction, the RETRAM project is based on a larger waveform bandwidth, with a good Range/Doppler ambiguity, permitting to measure temporal information with an enhanced accuracy (better than 1km). The Doppler accuracy is still limited by the integration time. As shown by numerous papers and measurements, the VHF band offers the best results for the

[1] *http://www.retram.org/wpcontent/uploads/2014/06/3D_FM_Results.pdf*

detection of meteors. With a large transmitted power, the FM band (88/108 MHz) seems to be a good candidate (RETRAM – Recognition & trajectory, 2014). This paper gives a list of criteria for the choice of the transmitters. The principle of RETRAM is the following and is shown below in Figure 4 and 5.

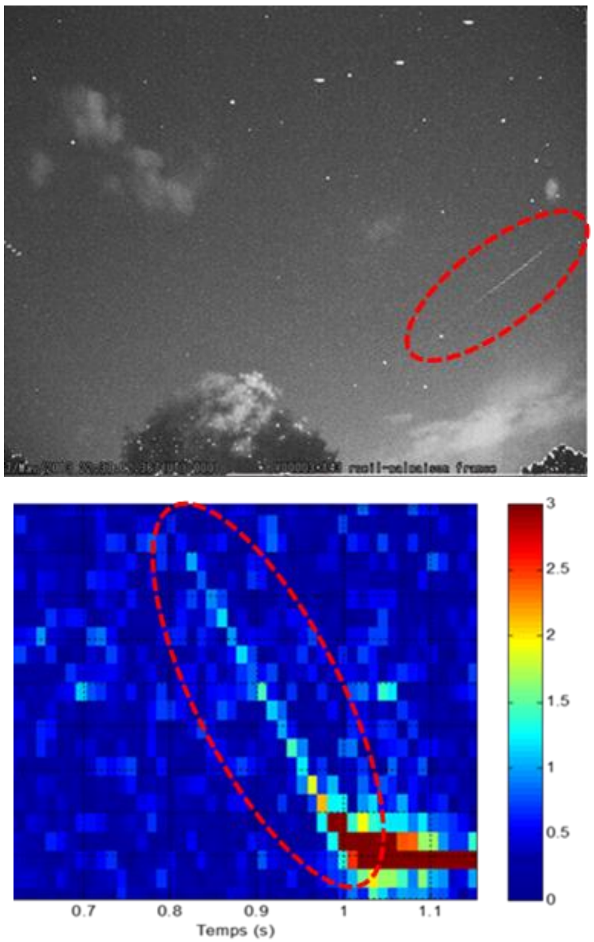

Figure 1 – Optical observation and the radio Doppler slope – both red circled (observation done by Dominique André – Rueil/France).

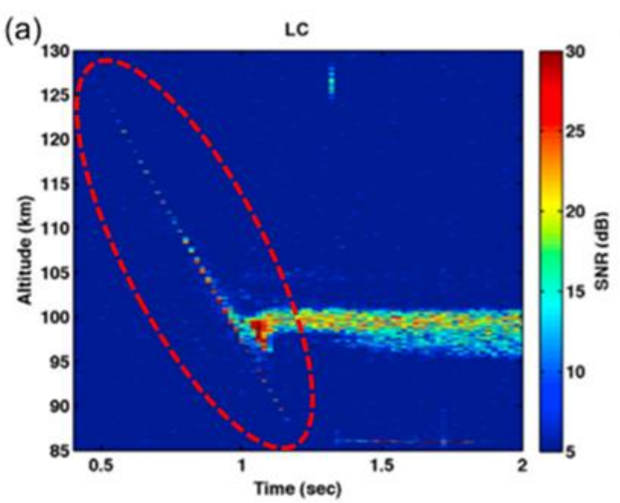

Figure 2 – Head echo and non-specular train.

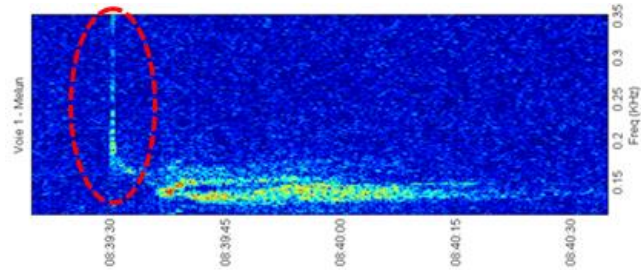

Figure 3 – VOR detection (60s measurement during Leonids2012) by RETRAM.

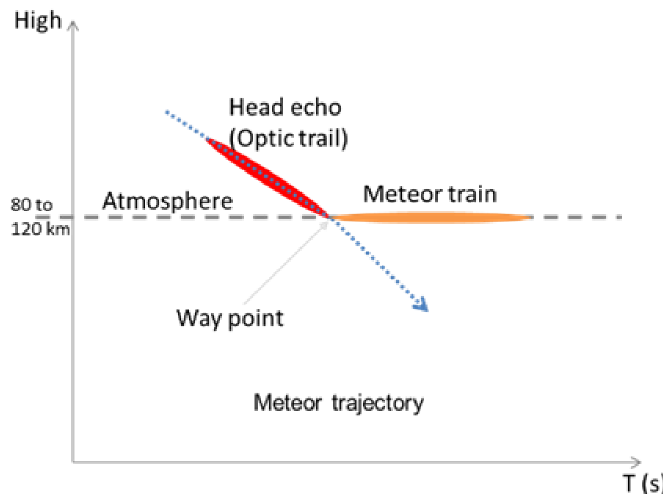

Figure 4 – Meteor penetrating atmosphere.

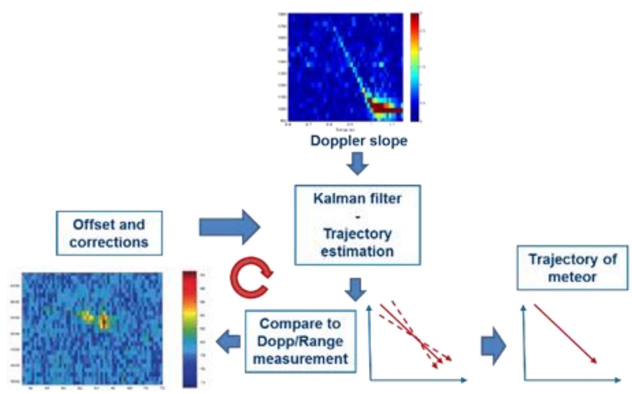

Figure 5 – Processing to align the Doppler slope of head echo on the way point of meteor.

The first step consists in:

- detecting the beginning of the meteor train, to localize a reference point of the meteor trajectory;
- measuring the Doppler slope of the head echo.

Then the process is completed by the projection of the Doppler slope in the 3D bistatic domain and by the comparison to the Doppler / Range measurement of the reference point to find the right trajectory of the meteor during its atmospheric penetration.

3 FM Passive radar

For this project, RETRAM has developed a FM passive radar at the beginning of 2014. As said before, this radar uses the transmitters of the FM broadcasting band (88/108 MHz). The description of the radar is done in a dedicated paper (Azarian et al., 2014). This system delivers bistatic information for each detection. The bistatic distance sets the possible position for the detected meteor to be an ellipsoid whose foci are the transmitter and the receiver locations, as illustrated by Figure 6. This curve is also called the iso-range contour.

To find the right position of a meteor, more than one transmitter/receiver couple must be used to remove any localization ambiguity. By using 3 or more transmitter/receiver couples, the intersections of these ellipsoids give the possible target position as shown by Figure 7.

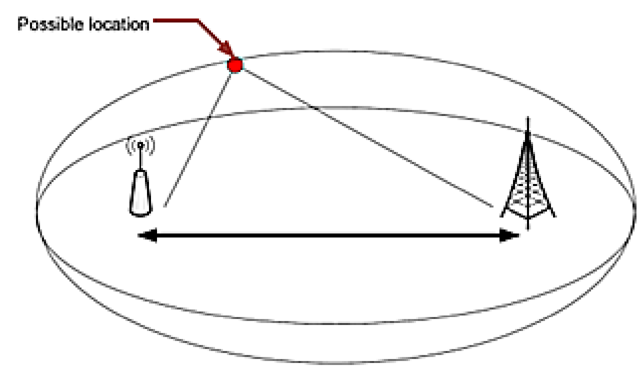

Figure 6 – Bistatic ellipsoid – iso-range contour.

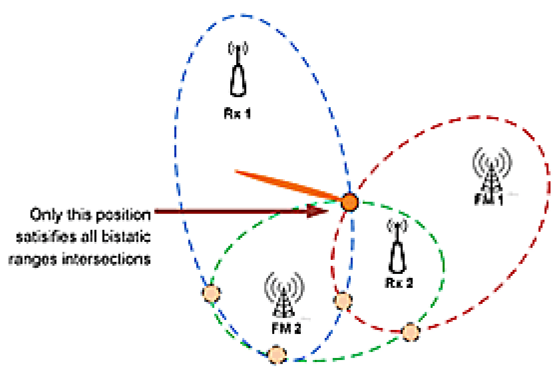

Figure 7 – Multistatic setup for meteor localization (2D cut in altitude).

4 First RETRAM station

To assess the performance of meteor detection using FM broadcast transmitters, RETRAM installed its first station near Paris. To survey the sky of the "Paris" area (Ile de France), an experimental mockup was made of:

- two FM Yagi antennas placed on the top of a shelter (see Figure 8). They are directed towards the sky and oriented so that , by combining the collected signal, they present an omnidirectional pattern in the horizontal plan;
- a two RF ways front-end followed by a 2 ways SDR (software defined radio) receiver. The SDR digitizes four frequency channels corresponding to four FM transmitters located around Paris.
- A real time processing to detect the beginning of the meteor train.

In case of detection, the processor saves the last FIFO (First In First Out) batch of data. It permits to reduce the amount of data by using dedicated criteria of meteor train recognition, such as :

  - range > 70 km corresponding to the frequent altitude of meteors penetrating the atmosphere;
  - Doppler near 0 m/s. Meteor train begins with a very low speed;
  - detection length > 1s to avoid parasitic and very weak detection;
  - SNR (Signal to Noise ratio) > 11 dB to reduce any false detections.

- a hard disk to store raw data and detection plots;
- a dedicated post processing software calculating the Doppler slope of the meteor head echo (currently worked out).

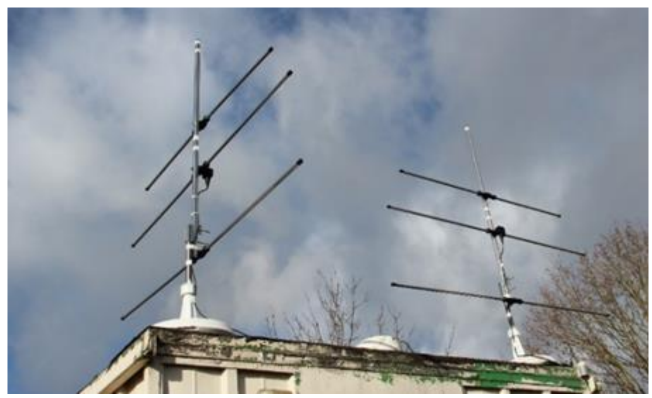

Figure 8 – Two FM Yagi antennas on the top of the shelter.

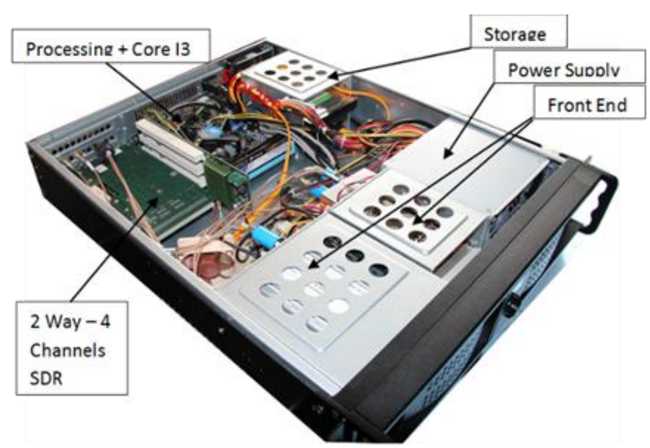

Figure 9 – RF Front End, digital receiver and real time processing.

5 First results

The first detections were performed rapidly. First of all, the processing is able to deliver the range change (but also the Doppler change) during the "life" of the meteor train as shown on Figure 10. These measurements could help to assess the meteor dispersion in the atmosphere and moreover to reveal speed and direction of wind and probably even more data of interest to scientists. Secondly, since May 2014 we collect numerous detections using three or four FM transmitters. We were able to deliver 3D localization and to reveal the waypoint for these meteors, mainly during the path of the dust trails released by comet 209P/LINEAR. Recently, we have started performance assessment. Thanks to BOAM[2], we did a first comparison between an optical detection and a radio 3D localization.

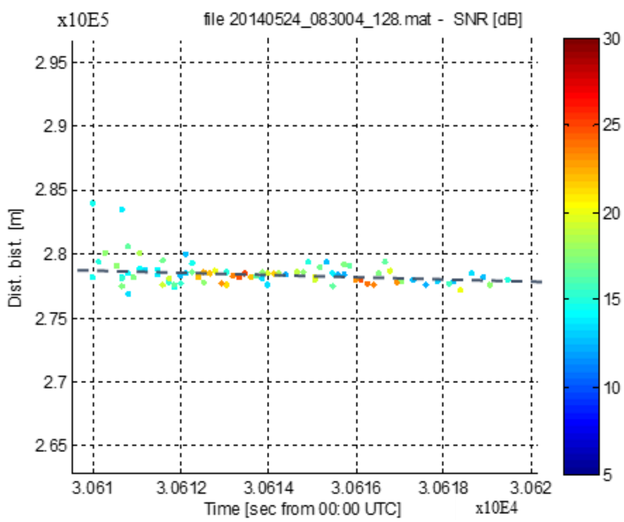

Figure 10 – The processing reveals the bistatic distance evolution (raw data) of the meteor train during a 10s duration (here very low, about only 1 km).

Figure 11 shows this result. To help reading and understanding the ellipsoids interception, Figure 11 shows a cut of 3 ellipsoids at the altitude of 95km (measured altitude of the meteor train). More details are available in the report "RETRAM – 3D results" (2014)[3].

6 RETRAM : to be continued…

We have to continue to assess performance in sensitivity and 3D localization accuracy. The Doppler slope was observed on numerous detections and we are working on the dedicated processing to replace visual estimations by automatic measurements. Then we will work on the complete processing loop to deliver the meteor trajectory (see section 2). As discussed previously and depicted in Figure 7, the best solution for an accurate estimation of the meteor position is to extend the number of receivers and transmitters involved in the signal processing. So RETRAM has planned to build, in the coming months, a first node of a network based on optimized receivers and processors. This node will be used as a mockup for a possibly wider system to cover a much larger area as illustrated by Figure 12. Moreover, radio and optical methods are very complementary and the network should be extended by adding optical devices with the help of the BOAM[2] network.

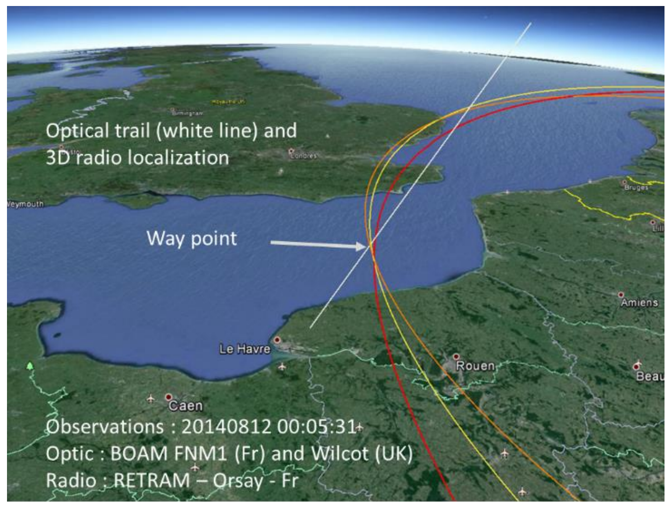

Figure 11 – 3D Interception of 3 ellipsoids (cut @ altitude 95 km) and optical trail calculated by BOAM (white line).

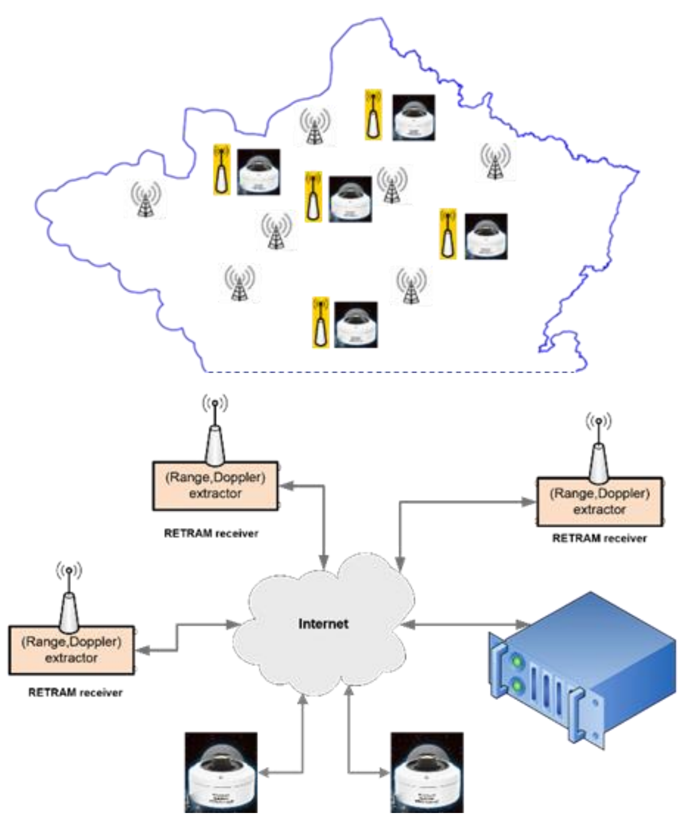

Figure 12 – RETRAM Network.

[2] BOAM: French meteor observers database. See: http://www.boam.fr/?lang=en

[3] "Meteors detection & localization using FM transmitters - First 3D localization results". *http://www.retram.org/wp-content/uploads/2014/06/3D_FM_Results.pdf.*

7 Conclusion

In this paper, we have presented the first results of our meteor detections using FM broadcast signals. The type of processing involved in this paper is very similar to the techniques generally used with success in passive radar.

To enhance the localization capabilities of the system, RETRAM and BOAM groups respectively plan to setup new receivers and sky cameras, interconnected using the Internet. This network should open promising results with continuous and accurate detections.

References

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