An antenna, a radio and a microprocessor: which kinds of observation are possible in meteor radio astronomy?

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Radio meteors are usually investigated by professional radars. Amateur astronomers cannot have transmitters, so usually they can only listen to sounds generated by a radio tuned to a TV or military transmitter. Until recently, this kind of observation has not produced good data. The experience of "RAMBo" (Radar Astrofilo Meteorico Bolognese) shows which data can be extracted from an amateur meteor scatter observatory and the results which can be achieved.

1 The meteor scatter observatory

Meteor shower observations, traditionally carried out by visual observers, have for several years also used automatically recorded images captured by TV cameras and can also be carried out using radio waves.

At an altitude of around 100 km in the upper atmosphere, the bremsstrahlung begins by the friction of meteoric particles intercepted by the Earth in its movement around the Sun. It is here that meteors appear. The bremsstrahlung by friction leads to extensive overheating of the corpuscle (ablation), the result of which is the vaporization of the material entering the atmosphere, the generation of light, and the ionization of a large number of atmospheric molecules in a radius of some meters along its trajectory. This generates a long, narrow cylinder of ionized molecules of a very short time duration (the time required for recombination of the ionized molecules) which behaves like a reflective object for radio waves, in the same way as aircraft and satellites.

"Radio meteor" observation is not affected by the presence of the Sun or Moon, or by cloud, and can thus be carried out continuously. Meteor observing via radio waves is usually achieved by "traditional" radar, which consists of a transmitter and a receiver. Normally these pieces of apparatus are spaced hundreds of kilometers apart and the antennas point towards the layers of the atmosphere around the 100 km altitude in the midway position between transmitter and receiver. The transmitted signal is directed upwards so it can only be received when a reflective object is placed along the radio electric emission optical path. When this occurs, the signal is reflected and the receiver picks up the presence of the object.

Professional radars, thanks to the fact that they transmit pulsed signals and that they use complex antenna arrays to analyze the reflected signal, are able to calculate the size, speed, direction and position of meteors at the sky. Since amateur observers cannot own transmitters, they commonly use other people's transmitters, e.g. transmitters on VHF (Very High Frequency), possibly on air day and night, with high power and at a great distance. They may be radio or television transmitters, or equipment installed for military aircraft and satellite control.

This situation has two great drawbacks.

Firstly, the exact technical characteristics of the transmitter and its behavior are unknown.

Secondly, the absence of multiple arrays of antennas and the lack of pulsed signals greatly reduce the capabilities of an amateur setup compared to a professional one. The experience of RAMBo (Radar Astrofilo Meteorico Bolognese) shows which data can be extracted from such observations and the results which can be achieved.

2 "RAMBo" set up

The transmitter

Like other European observatories, RAMBo uses a military radar transmitter, GRAVES, that is continuously on air in VHF at great power. Located near Dijon, in France, it is built for spacecraft orbit determination.

Its transmission is directed upwards and due to the Alps, it is not receivable from Bologna directly.

Technical data:

- Frequency 143.050 MHz
- Polarization: circular
- Power = 1MW (RF)
- Irradiation = south ± 90 °
- Height oscillating in an angle of about 25 °

The receiver setup

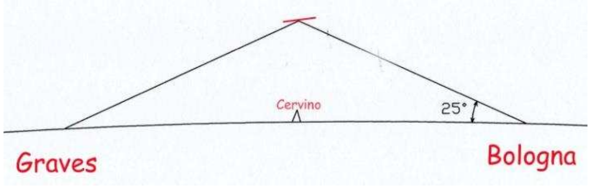

Figure 1 – Calculation of the zenithal angle of view.

The RAMBo receiving set up is composed of a Yagi directive antenna (10 elements) pointed in azimuth in the direction of the transmitter (300°), and in declination about 25 degrees above the horizon (*Figure 1 and 2*), the direction in which we have calculated the reflection point in the upper atmosphere.

Figure 2 – Calculation of the angle of view in azimuth.

Its polarization is vertical. The choice of this polarization is based on the belief that there could be more meteors with horizontal rather than vertical traces.

Since the polarization of the transmitter is circular, and the polarization emerging from the reflection is orthogonal to the plane of reflection, we can expect a greater number of vertically polarized echoes than horizontal ones. In fact, a week of measurements specifically performed with horizontal polarization gave a two-thirds lower result compared to the vertical configuration.

Given the characteristics of the antenna (large directivity), the area of sky that should be investigated consists of an area of twenty to thirty square degrees above the Alps, roughly vertically above the Matterhorn.

The receiver is a Yaesu 897 tuned in SSB (Single Side Band) about 1000 Hz below the Graves carrier. Thanks to the SSB technique, the difference between these two frequencies means that the Graves carrier (not modulated) may be heard as a signal of frequency equal to the difference between the two frequencies. As we will see, this rate is actually affected by the Doppler Effect, both for the body speed when entering the atmosphere and for the speed of movement of the ionized cylinder due to high altitude winds.

The purpose of RAMBo is the analysis of the audio signal generated by the receiver.

3 Sound analysis

Sound is picked up from the direct audio output of the receiver, avoiding the potentiometer controlled headset output, and with the automatic gain control (AGC) disabled.

Normally the audio signal is a continuous rustle (chaotic noise). Over this signal we can occasionally hear three different types of sound:

- Discharge;
- Aircraft and satellites;
- Meteoric echoes.

The discharges are transient pulses: very short in time and of high amplitude, sometimes individual and sometimes in rapid sequences of variable length. These impulses, if measured and counted, represent “false positives” which will affect meteoric data.

There are a lot of causes of discharge: they may come from storms, even far away, or from ionization due to solar activity. Other causes are human activities: combustion engines in the receiver proximity, electric motors or other power transients on the power line feeding the radio receiver, such as neon lighting. These last problems can be overcome by using a power supply with a daytime battery charged by a solar panel. However, this does not completely solve the problems caused by discharges received in the antenna.

Discharges are the biggest problem of meteor scatter receivers. The RAMBo experience led to six different trials with various techniques to avoid this problem. Only the sixth attempt finally solved the problem.

Aircraft and satellite echoes are similar to those generated by meteors, but are generally of lower level, their frequency varies slowly and their duration is high. These echoes could be numerous if we receive with omnidirectional antennas and if the receiver is close to large urban areas with an airport nearby. The use of high-gain antennas (i.e. directive) solves this problem. In our case, aircraft and satellites are almost never received, and the sound level of their echoes is lower than that of meteors.

Meteors produce clear sound characterized by a frequency near 1000 Hz. This frequency, in theory, is generated by the beat between the transmitter’s carrier (in our case the Graves Tx) and the frequency of the radio receiver, tuned in at SSB 1000 Hz below the transmission carrier. The exact value of the echo frequency is not easy to predict, due to both possible instability or radio receiver tolerances, as well as to the speed of high altitude winds which propel and distort the ionization cylinder caused by the meteor’s entry into the atmosphere. Finally, the speed and direction of the meteor could also affect this frequency (Doppler Effect).

Our experience leads us to say that this variability is almost always confined inside a window of approximately 300 Hz centered on the mean frequency.

The sound analysis and data recording are both made with Arduino, the well-known low-cost microprocessor of the “Internet of Things” (IoT) through a program which we have written (*Figure 3*).

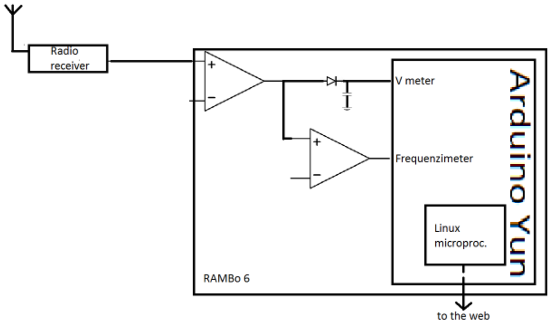

Figure 3 – Block diagram.

RAMBo 6 acts as a preamplifier for the signal coming from the radio output and then splits it into two different channels. After a further amplification, the signal is rectified and integrated. This allows Arduino to measure the received signal amplitude (*Figure 4*).

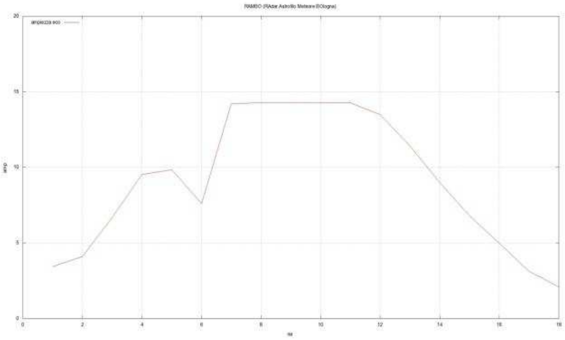

Figure 4 – An overdense meteor profile generated by "Rambo".

In this graph we can see an overdense meteor echo analyzed by RAMBo. In *Figure 5* there is another overdense meteor profile found in literature.

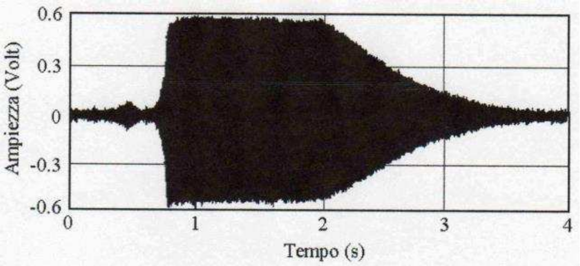

Figure 5 – An overdense meteor profile coming from a professional radar.

As can be seen, the profile is roughly the same.

At the same time, the signal is measured by using Arduino as a frequency meter. Normally, the signal of chaotic noise contains random frequencies. As soon as a meteoric echo arrives, the measured frequency tends to be confined inside a window centered about the mean frequency previously set. When this occurs, RAMBo starts counting time. At the end of this process, when the measured frequency comes back chaotic, Arduino has recorded both the echo duration (in milliseconds) and day and time of the event.

For each echo, RAMBo assigns a serial number. In addition at the zero minute of every hour, Arduino zeroes the meteor/hour count and then starts again from one.

The analysis of the rise time of the initial impulse gives us a figure that is proportional to the meteor speed coming into the atmosphere. The shorter the rise time, the faster the meteor speed, and vice versa.

4 The data logger

The data we now have included:

- Progressive event number;
- Hourly number;
- Date and time (UT);
- Echo length (milliseconds);
- Echo amplitude (millivolts);
- A number proportional to the rise time.

For each echo RAMBo6 creates a CSV-type (common separated values) data string containing the six listed items of information.

Every row generated by an echo is added to a log file.

Every night at 18^h U.T. Arduino sends the file via internet to a cloud site, so it can be analyzed at home.

Graphic layout

The log file is normally represented in a graphic form using math graphic software (e.g.: *gnuplot*). In this graph (*Figure 6*) we can see the result of a weekly recording.

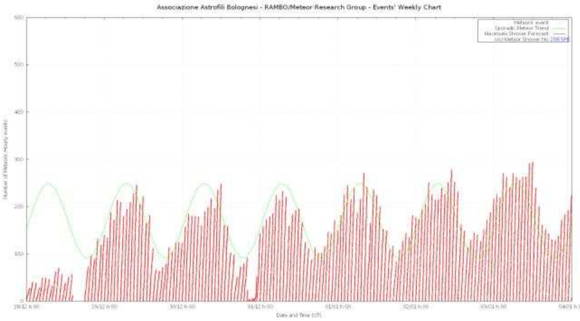

Figure 6 – A weekly "Rambo" hourly rate (HR) layout.

Each red dot represents a meteor echo; on the x-axis there is time, on the y-axis the number of events. In this manner, the height of each column represents the number of meteors per hour (hourly rate). The dot size is proportional to the echo duration logarithm.

The sinusoidal trend is clear, approximated in green, due to the diurnal variation of the apparent speed with which the Earth impacts the meteors. Day 29/12 was the first day in which Rambo6 began to run. The comparison with the previous day shows the sensitivity increase compared to the previous version (RAMBo5).

5 How much it costs

Here is a summary of the cost of RAMBo in Euros:

- Antenna 74;
- Cable 10;
- Connectors 5;
- Radio (2nd hand) 500;
- Sound card 40;
- Arduino Yun 68;

Total 697

As can be seen, a meteor scatter observatory of this kind is well within the reach of many amateur groups.

6 The results

Rambo 6 registers more than 2500 meteorological echoes a day, with an hourly average of about 100.

- Overdense meteors (echoes longer than 800 ms) account for about 1%, according to data in literature.
- In the days without meteor showers, we can recognize the typical sinusoidal sporadic meteor trend, with the maximum at 6 and the minimum at 18 (Local Time).
- In the case of meteor showers we can easily see the beginning time, the maximum and the end.
- We can also evaluate the shower intensity, with reference to the standard sporadic trend (Hourly Rate).

$$ZHR = \frac{HR \cdot F \cdot r^{6.5-lm}}{\sin(hR)}$$

For this purpose we have developed a special program (in Python) for meteor shower analysis. With this program, we first subtract the average value of sporadic days immediately before and after the meteor shower containing only sporadic activity, then we adjust the hourly rate with a number proportional to the tangent of the radiant height on the horizon. We thus obtain a value very similar to the ZHR (Zenith Hourly Rate) commonly used in visual observations. An example of such processing (*Figure 7*) comes from the "RZHR" program, i.e. RAMBo ZHR.

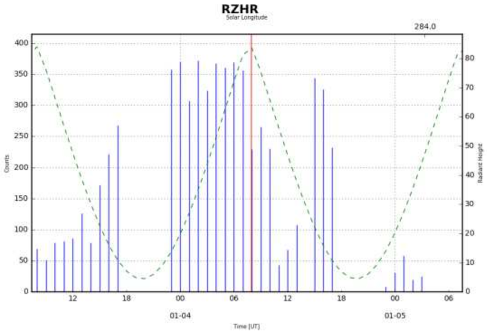

Figure 7 – An RZHR graph.

In this graph we can notice the beginning of the transit of the Earth through the Quadrantids cylinder and the Rzhr value. We can still see that also in this case the Quadrantids have a bipolar structure, similarly to other streams (e.g. Geminids).

The dotted green line shows the radiant height on the horizon. The red line shows the moment in which the shower maximum was expected. RAMBo is thus able to indicate with great accuracy the time difference between predictions and observations.

- RAMBo also allows us to carry out a meteor mass evaluation. Since the echo duration is proportional to the meteor dimension, we can see the mass trend over time.

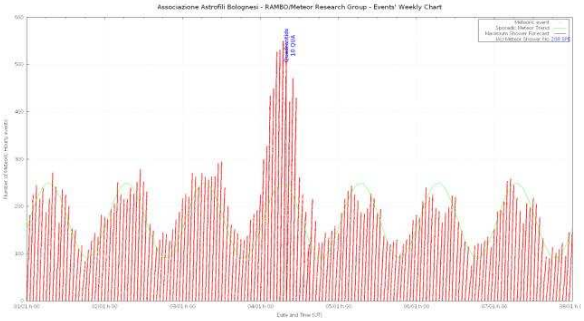

Figure 8 – The 2016 Quadrantids HR.

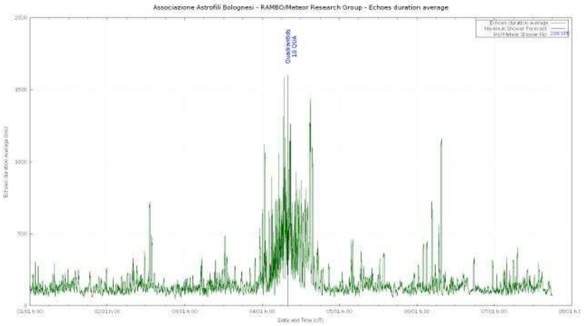

Figure 9 – The 2016 Quadrantids mass trend.

Figures 8 and 9 show the same period of time (a week). In the former we can see an activity increase in the number of echoes (hourly rate) due to the meteor shower. In the latter we note a meteor mass increase due to the echo duration average. Although the time period is the same, the two ordinate values are completely different. So the trend analogy is impressive. In the mass trend graph, the bipolar structure of the swarm is clearly visible, just as can be seen in the hourly rate graph.

7 Future developments

The image of the RZHR graph in the previous chapter concerning the Quadrantids swarm partially shows the shower. Most of the beginning and end of the shower is lacking. This is due to the fact that during the phenomenon the radiant was not always above the horizon.

In essence: if it is true that a meteor scatter observatory can observe night and day, with and without the Moon, in good and bad weather, it is equally true that it can observe a meteor shower if and only if its radiant is above the horizon. It follows therefore that any observer coverage, as with any other type of observation, is partial.

Like visual or video observations, meteor radar observation should also create a global network able to achieve total coverage.

What is primarily needed is a small network of a few observers strategically placed almost 120° apart in the same hemisphere so as to create complete coverage for each radiant.

8 The "Marsadl"

(Meteor Analyzer by Radio receiver, Sound Analyzer and Data Logger)

The RAMBo6 experience was conceived as an example of the "Internet of Things" (IoT) that simplifies the feasibility of many projects in various fields. So this leads us to propose this low-cost, simple project as an idea to set up a meteor scatter observer network. What is needed for every observer can be summarized as follows:

1) The existence hundreds of kilometers away of a VHF transmitter continuously *on air*, whether it is military or television whose carrier can be tuned in amplitude modulation;
2) A Yagi directive antenna (from 6 to 10 elements) with a vertical polarization mount in a fairly unobstructed area, pointing in azimuth in the direction of the transmitter and with a declination pointing above the midpoint of the line between T_x and R_x at about 100 km altitude;
3) A receiver with good input sensitivity tuned in SSB mode 1000 Hz over the carrier (USB: Upper Side Band), with the audio output independent to the squelch and the volume potentiometer, and with automatic gain control (AGC) disabled;
4) An ANALOG power supply (and therefore not a switcher) able to feed all the apparatus 24 hours a day;
5) A network cable with web access for the data uploading.

The circuit diagram, the Arduino software and our data analysis script are available to anyone interested in this experience. The data of all those who join MARSADL will be shared, so to create a network that not only stores data but allows us all to analyze the information together.

With 157 IMC participants, the lecture room always was well filled. (Photo Casper ter Kuile).