

# What does CARMELo see

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## Abstract

CARMELo (Cheap Amateur Radio Meteor Echoes Logger) is a project designed for the observation of radio meteors, developed within the amateur community. It is entirely digital and directly measures the physical parameters of meteor echoes, moving beyond the traditional analogue monitoring method that relies on radio receivers operating in SSB (Single Sideband) mode. Because the system is fully digital and the receivers are calibrated, the data produced by various observatories are consistent; through a dedicated network, this data is fed into a centralized database, enabling comparisons, profile analysis and statistical studies.

## The receiver

CARMELo is based on an entirely digital receiver device capable of:

- a) Tuning into the continuous carrier frequency of a transmitter, selected by the observer
- b) Sampling the received signal at a frequency of approximately 250 Hz
- c) Performing an FFT (Fast Fourier Transform) on each sample to measure frequency and amplitude
- d) Automatically identifying meteor echoes
- e) Eliminating false positives, such as those caused by aircraft, satellites, lightning, or power supply transients
- f) Sending a small log file to a server containing all physical and geometric parameters of the meteor echo, including radio signal amplitude, frequency, duration, precise timestamp (down to the millisecond), the potential presence of a "head echo" and the observer's name and coordinates.

All CARMELo receivers are calibrated using reference signal generators, ensuring that measurements are consistent, comparable and based on a unified standard.

A CARMELo receiver unit consists of the following components: an optional band-pass filter, an optional LNA (Low Noise Amplifier), an SDR (Software Defined Radio) dongle, a Raspberry Pi microcomputer (which works with the dongle to perform the aforementioned tasks), a 5V power supply and an optional monitoring board that displays the receiver's operational status to the user.

The project is designed to allow any observer to purchase and assemble the receiver themselves, at a cost - excluding optional modules - of less than 200 euros.

Those unable to build it themselves can reach out to an amateur astronomer willing to do so for a similarly modest fee.

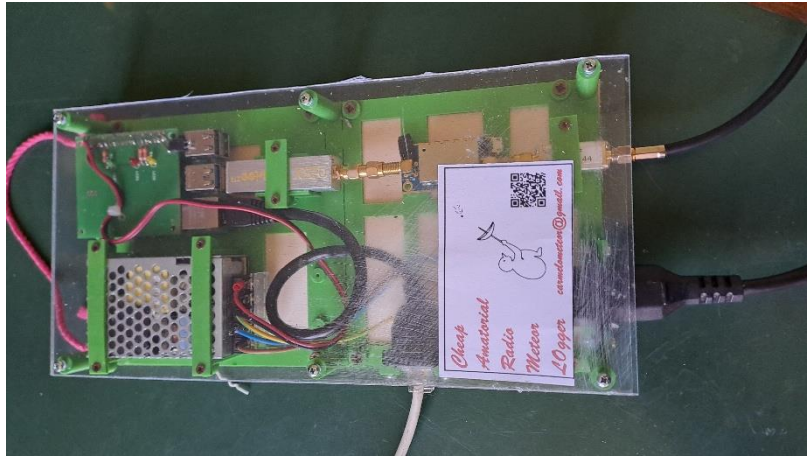


*Fig 1 a CARMELO receiver*

The software is available free of charge and can be easily installed by the user.

The software is written in the Python programming language.

Data generated by the device is transmitted over the Internet via an Ethernet cable; the Raspberry Pi's Wi-Fi functionality has been intentionally disabled to reduce radio-frequency emissions.

In the event of an Internet connection failure, data is not lost; instead, it is stored in a temporary folder and subsequently transmitted once the connection is restored.

Software updates are provided by the CARMELO group and each receiver updates automatically, requiring no intervention from the user.

For those located relatively close to a continuous-carrier transmitter operating at 50 MHz, it is advisable to tune to that frequency; for others in Europe, it is possible to tune to 143.05 MHz, the frequency used by the Graves military radar.

The number of meteor echoes detected depends on the quality of the antenna system and the absence of noise both in the surrounding environment and within the power supply. With a moderately directional antenna that is correctly oriented, a CARMELO receiver can detect nearly 2,000 meteor echoes per day.

## **The network**

CARMELO receivers were initially developed in Italy; the network subsequently expanded to include Spain, Switzerland, the United Kingdom, and the USA. At present, there are 21 CARMELO receivers; the locations of those currently in operation are shown on page: [http://www.astrofiliabologna.it/obs\\_on\\_line](http://www.astrofiliabologna.it/obs_on_line)

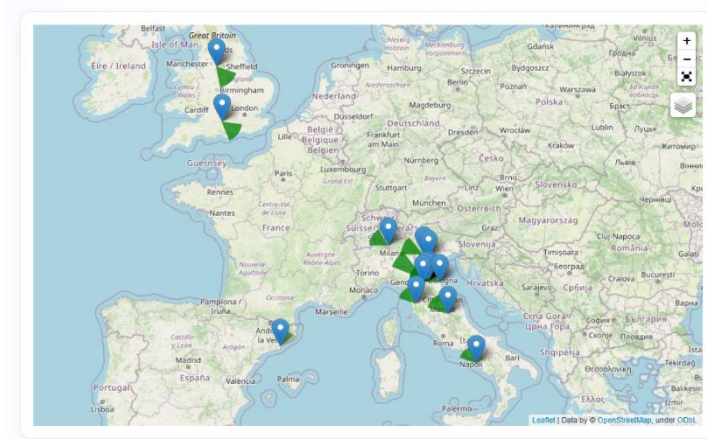


Fig 2. CARMelo network map

## The Server

Every 5 minutes, each receiver transmits any recorded data to the server, which then:

- Stores the data in a dedicated database. As of today (September 27), 1.3 million meteor echoes have been recorded this year; the final figure is therefore expected to exceed the 1.6 million recorded in 2025. Despite the high number of recorded meteors, it is worth noting that the database size is only around 300 MB.
- Displays the echo on the designated “events” page in near real-time.

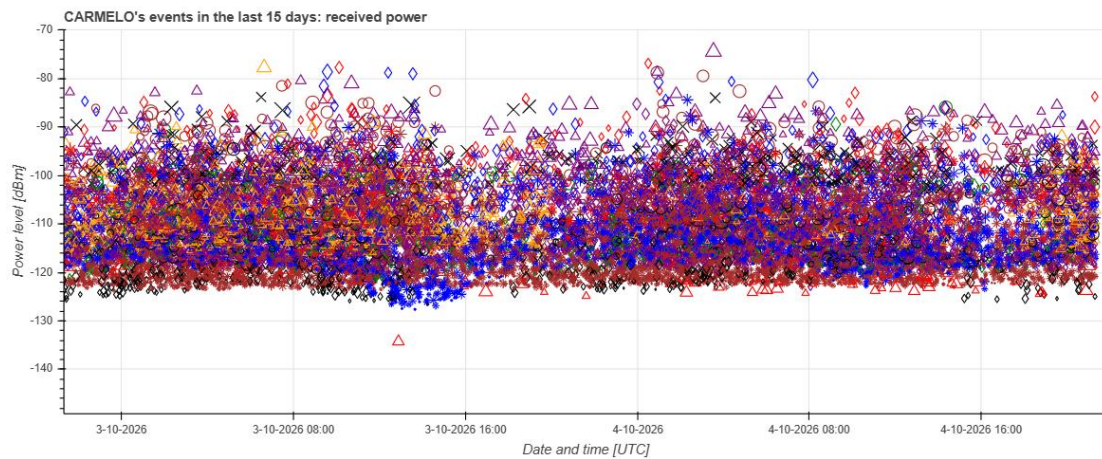


Fig 3. “Events” page.

- Display the profile of each meteor echo when the user clicks on the event, thereby plotting all the physical parameters contained in the submitted file.

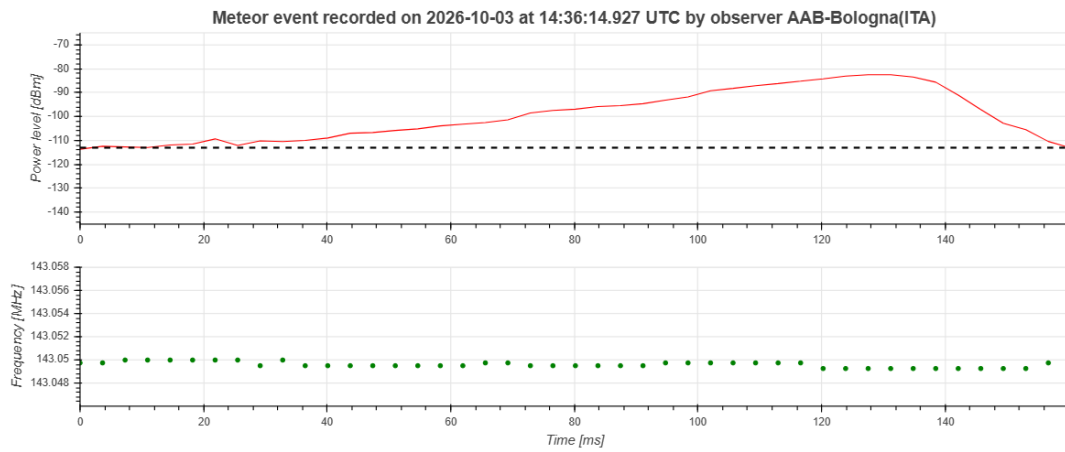


Fig 4. An echo profile. It is an under dense meteor

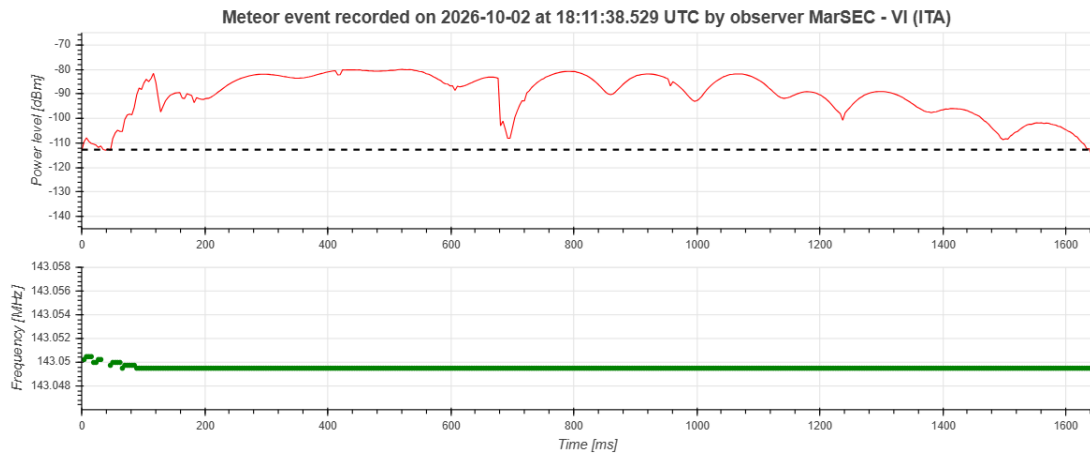


Fig 5. An over dense meteor profile: it is possible to see the head echo before the beginning of the specular reflection. It is possible to see some Fresnel zones too.

d) Determine whether the event in question has been observed by multiple stations; if so, the system provides the user with an overlay of the n meteorological profiles, while also plotting the geographical locations of the n observatories. In this way, one can observe how the chronological sequence of reception times both in terms of the order of events and the time delays clearly reflects the spatial distribution of the stations across the territory.

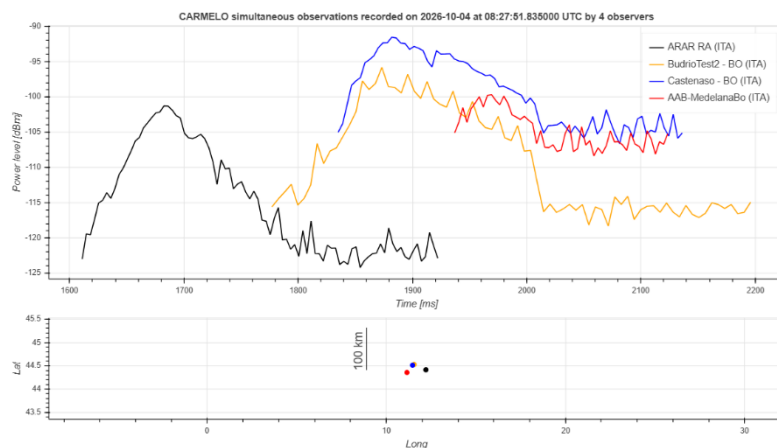


Fig 6. The same meteor seen by four observers. In the upper plot the time delay of every echo, bottom the observers position.

e) Calculate the hourly rate (with a 15-minute temporal resolution) of meteoric activity and make it available on the dedicated “statistics” page. This same page also features a graph showing the average duration of echoes and the maximum received radio power. All three graphs are presented with the date - as well as the solar longitude - plotted on the horizontal axis.

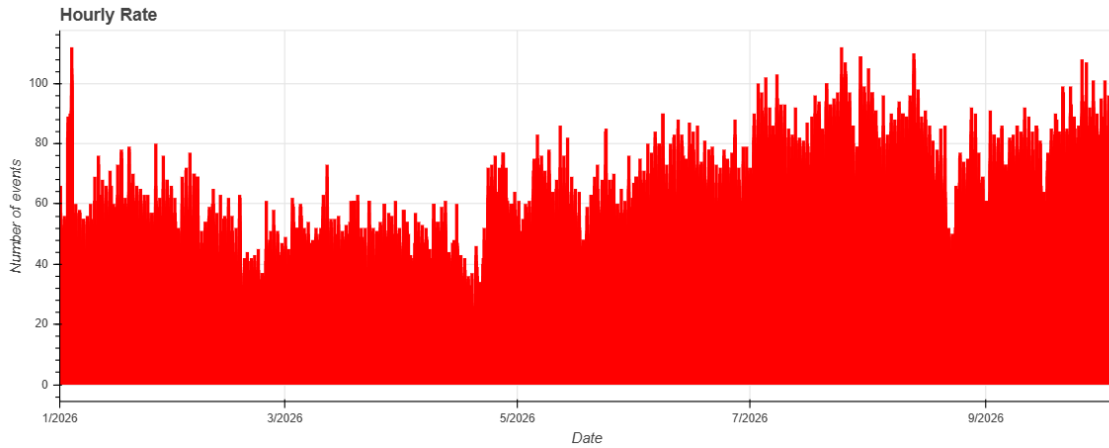


Fig 7. In the “Statistical” page the hourly rate.

## The RZHR

The CARMELO group has developed a pipeline to analyse the potential presence of meteor showers and to investigate their temporal profiles.



Fig 8 The RZHR pipeline

The first step in this process is to identify event by event all meteors observed simultaneously from multiple observation sites; if an event is recorded by more observers, it is counted as a single event.

The data are then aggregated into 15-minute bins: the total number of events within each of these bins represents the activity rate, or  $Ar_{comp}$

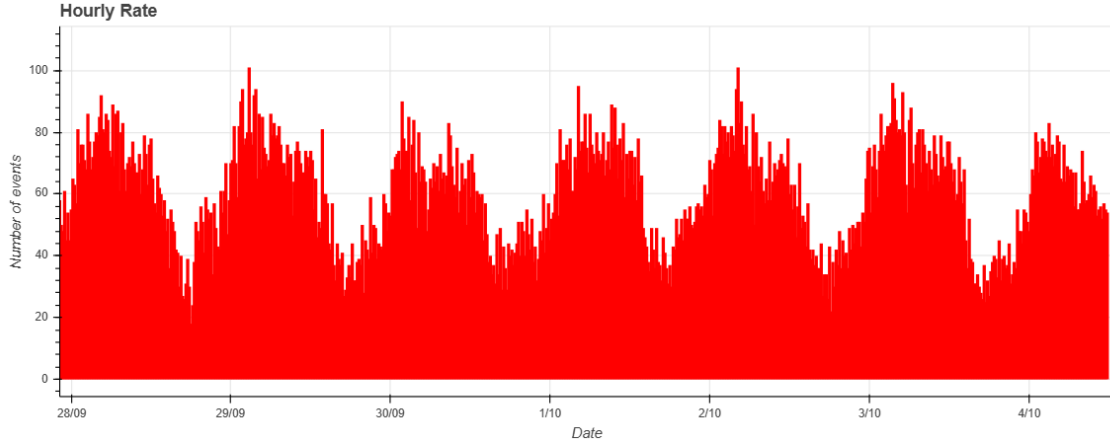


Fig 9. The activity rate: a one-week period is shown

The second step of the process aims to remove the contribution of so-called “sporadic” meteors from the data that is, all those meteors that, over millennia, have lost any correlation with their parent body due to gravitational interactions within the solar system. For this reason, they form a kind of continuous background which, by introducing an arbitrary approximation, we assume to be constant from day to day.

The method therefore seeks out daily data from periods devoid of known or particularly active meteor showers, operating on the further arbitrary assumption that the average of the data from these days can serve as a reliable representation of the daily pattern of sporadic meteors, this data is  $Ar_{spo}$ .

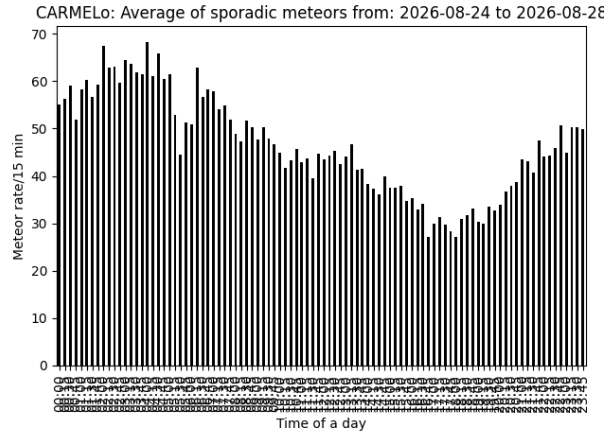


Fig 10. The sporadic activity

The analysis then proceeds by subtracting the average number of sporadic meteors from the data for the selected days, thereby obtaining the temporal trend of the meteor shower's activity to be analysed  $Ar_{shower}$ .

For every  $i$  bin in the selected days, we perform:

$$Ar_{shower(i)} = Ar_{comp(i)} - Ar_{spo(i)}$$

Introducing a third approximation, we consider the mean latitude and longitude of the observers under study and determine the altitude of the meteor shower's radiant above the horizon: a factor used to account for what some term an “observability function”. In this regard, it should be noted that the method allows the operator to select which observers to include, making it possible to exclude those whose geographical location is unfavourable for observing a particular shower.

To achieve this much like the equation used by visual observers to calculate the ZHR (Zenithal Hourly Rate) we divide the activity rate by the sine of the radiant's altitude ( $h_R$ ), calculated for each specific moment in time.

The resulting value is what we have termed the RZHR.

$$RZHR_{(i)} = \frac{Ar_{shower(i)}}{\sin h_{R(i)}}$$

The three approximations described above make this pipeline increasingly effective the more the meteor showers in question meet the following criteria:

- 1) They are “young” that is, limited to a span of just a few days having not yet undergone the spatial and temporal dispersion that older showers experience due to interactions with major bodies in the solar system.
- 2) They have a radiant with a declination high enough to ensure sufficient observability for the observers under consideration.
- 3) There are no “interfering” showers that is, other showers active during the same period.
- 4) There are days relatively close to the period under study, during which no known meteor showers are active.
- 5) The receivers in the CARMELo network have operated continuously, without any interruptions caused by malfunctions or other issues

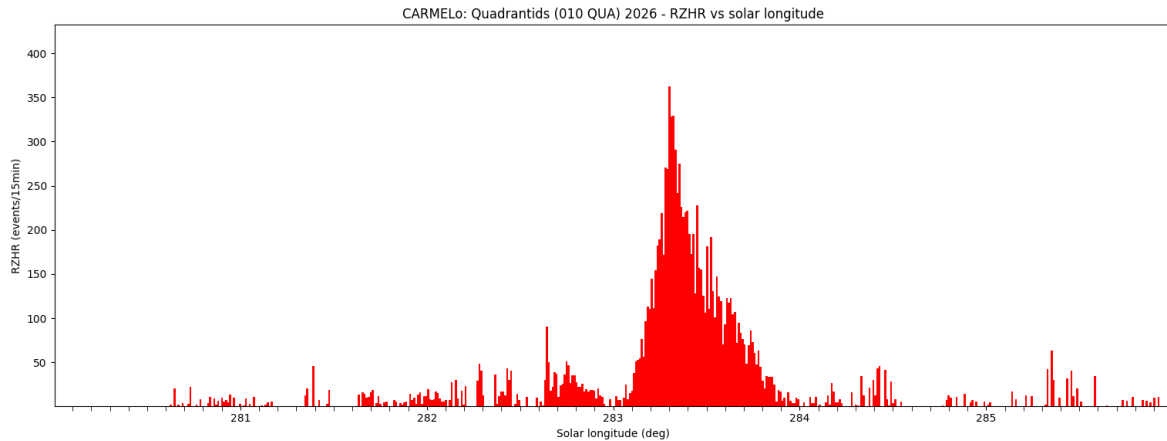


*Fig 11. The 2026 Quadrantids RZHR*

If these criteria are met, the result is remarkable: the reconstructed activity pattern rivals the ZHR (Zenithal Hourly Rate) data produced by networks of visual observers whether using the naked eye or video cameras. A temporal resolution of 15 minutes allows for a highly accurate reconstruction.

## Conclusions

The CARMELo network is the first entirely digital network of observers in the field of radio meteors. For the first time, amateur astronomers even those lacking a pulsed transmitter and receivers capable of triangulation can go beyond simply listening to the sounds produced by a radio or viewing the "waterfall" displays generated by specialized software.

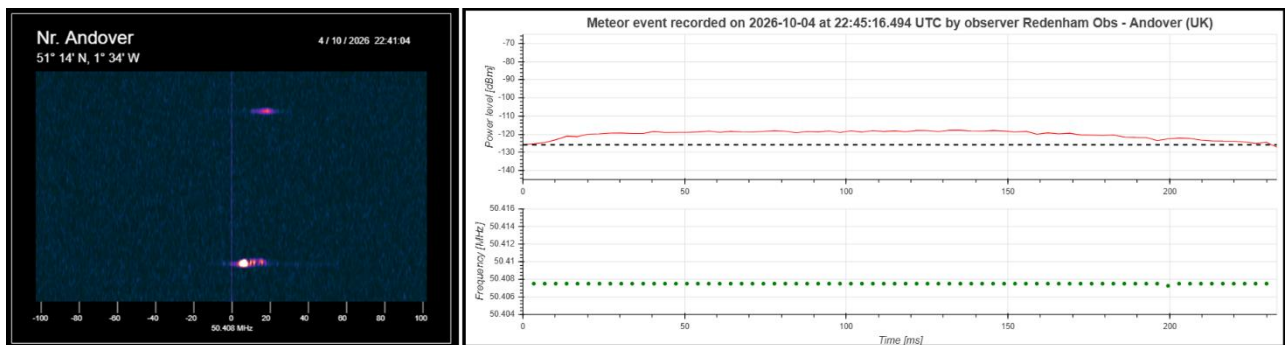


*Fig 12. Left: a typical “waterfall” resulting from an analogue observation. Right: the same observation made by CARMELo. This meteor was observed at the Redenham Observatory in UK.*

Having a unified standard and calibrated receivers allows for the creation of a homogeneous database containing recorded physical parameters of radio meteors that can be used to study meteor showers.

It is hoped that other observatories and enthusiasts will also adopt this observational technique, helping to expand the existing network by both increasing the number of available observations and broadening the geographical distribution.

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