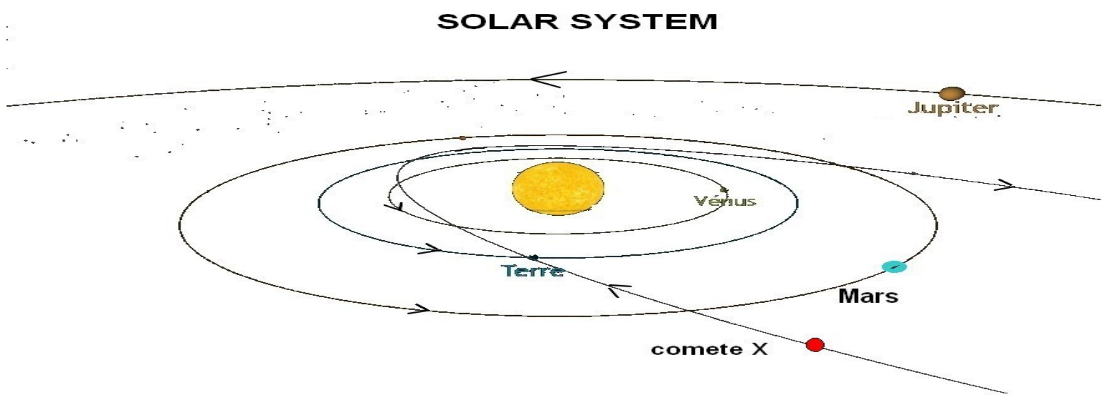
Listening to Shooting Stars

Observing shooting stars on a beautiful summer evening is not only an opportunity to enjoy the beauty of the sky and, incidentally, make wishes, but it can also be combined with listening to radio signals coming from these shooting stars. To be precise, these are radio signals reflected on the ionized trail left by these tiny meteorites (most weighing less than 100 grams) that burn upon contact with the upper atmospheric layers. As we will see, this only requires minimal equipment.

_This article can be shorten according to editorial constraint

ORIGIN OF SHOOTING STARS



The sun is surrounded by a procession of planets orbiting in nearly circular paths in the same direction. Venus, the closest (period 0.6 years), Earth (period 1 year), Mars (period 1.87 years), Jupiter (period 11.8 years), to name a few of the most well-known.

In addition to these planets, the solar system includes comets, much smaller objects that share the commonality of having highly flattened orbits traversed with very long periods. The plane of their orbit is mostly different from the plane of the planets' evolution.

For example, Comet Swift-Tuttle reappears every 130 years; its last visible passage from Earth was in 1992. These comets leave behind various debris of small dimensions (at most a few kilograms). When the Earth in its orbit around the sun encounters this debris, it manifests in the sky as shooting stars due to their high-speed entry into the atmosphere.

On its orbit around the sun, Earth has a speed of 29 km/sec, and the comet Swift-Tuttle moves even faster, along with the debris it leaves behind. Comet debris is not the only thing falling to Earth. The planet is occasionally impacted by more massive objects originating from various areas of the solar system. In practice, as we will see later and as can be measured, the entry speeds of all these objects range between 12 and 60 km/sec.

THE OBSERVATION CALENDAR

Thus, the Earth is bombarded throughout the year by meteorites of varying sizes, but there are periods during the year when there is an upsurge in activity. These periods recur very regularly from year to year when the Earth encounters residues left by various comets, named after their discoverers.

Meteor name	maximum	Date	Count (meteor/hour)	meteor origin
Quadrantids	Jan 3-4	Jan 1-6	60	
Lyrids	April 22	April 16-25	10-15	Comet Thatcher
Eta Aquarids	May 5	Apr 24-May 20	35	Comet Halley
Capricornids	July 8-26	July-August	5	
Alpha Capricornids	Aug 2	July 15-Aug 25	5	
Perseids	Aug 12-13	July 23-Aug 20	75	Comet Swift-Tuttle (1737, 1862, 1992)
Orionids	Oct 22	Oct 16-27	25	Comet Halley
Taurids	Nov 4	Oct 20-Nov 30	10	
Leonids	Nov 17-18	Nov 15-20	Variable (30-300)	Comet Tempel-Tuttle
Geminids	Dec 14	Dec 7-16	75	FIGURE 1

It is customary to give the name "swarm" to these periods when there is an increase in shooting stars. Thus, we speak of the Leonid swarm, which occurs between November 17 and 18, or the

Quadrantid swarm on January 3 and 4 (Figure 1).

The most favorable period in every respect is undoubtedly the month of August or specifically from August 12 to 15 for the Perseid swarm. It is challenging to miss it because most national media, hungry for information during this period, never fail to mention it. Additionally, during this time, there is an optimal chance of avoiding inconvenience due to bad weather, with the main hindrance for visual observation being cloud cover and the moon, especially if it is full and poorly positioned on the horizon.

THE PRINCIPLE OF METEORITE DETECTION

When a meteorite approaches Earth, it creates a luminous trail through friction with the upper layers of the atmosphere, starting at approximately 100 km in altitude. The trail is highly ionized and is capable of reflecting radio waves of a sufficiently high frequency. In practice, any frequency higher than 50 MHz is likely to be reflected.

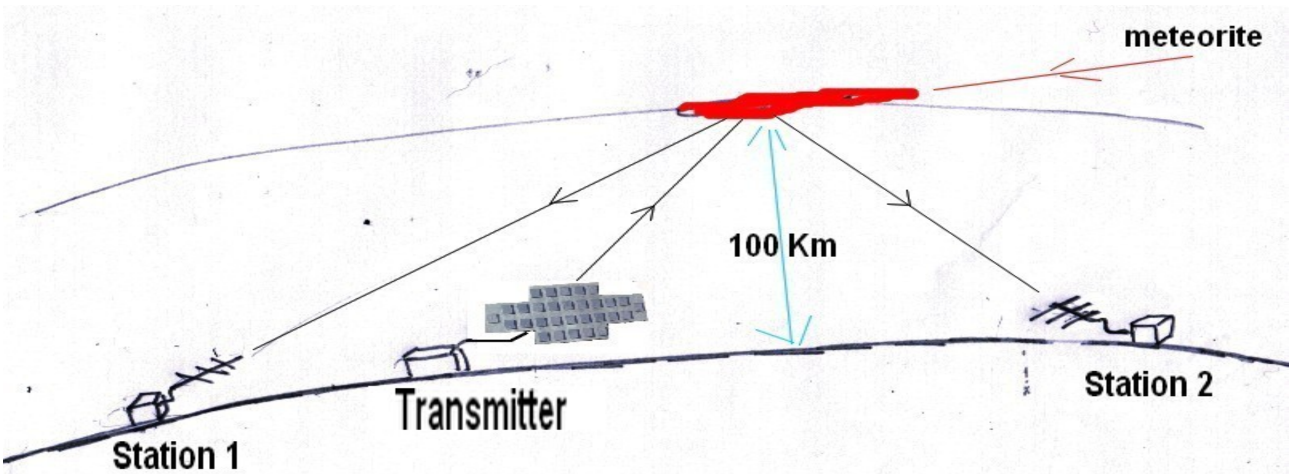


FIGURE 2

We detect meteorites that are invisible to the naked eye, and we are not hindered by clouds, light pollution, or the moon. This meteorite detection principle is also possible worldwide by using continuous radio emission sources, such as television transmitters operating in Band 1 (frequency 47-68 MHz), or certain beacons, as done by enthusiasts in Belgium, the USA, Japan, and elsewhere (see Figure 2 bis for the frequencies used in different countries).

Frequency used in various country

Country	Frequency (Mhz)
Poland	143.050
Japon	52.905 / 97.000
Australia	50.057
USA Illinois	55.239
USA Puerto Rico	181.249
USA New Mexico	54.310
China	55.250
Korea	97.000 / 89.4000
Mexico	174.310 / 54.309
Bresil	67.249
Tchequie	145.050
U.K.	143.050
France	143.050
Hongrie	143.050
Belgium	49.990 / 143.050
Spain	143.050

Figure 3

In Western Europe, a preferred transmitter for this purpose is an air force radar operating at 143.050 MHz.

THE PORTABLE RECEIVING STATION

To listen signals reflected by meteorite trails, there is no need for a complex setup. A simple receiver capable of picking up a signal on the frequency of the transmitter in the region is sufficient. It should be able to receive a signal in Single Sideband (SSB) to shift the received frequency into an audio signal. The easiest way is to use an SDR (Software-Defined Radio) dongle connected to a laptop (Figure 4).

FIG 4

To keep a record of the observations, the simplest method is to record the audio signal on a tape recorder or, preferably, on a digital voice recorder. As we will see, it is easy to analyze the received signal afterward to extract various informations. It is also possible to visualize the received signal in real-time on a tablet that does not generate radio frequency noise.

At the reception antenna level, a simple dipole may suffice. If one wishes to enhance it and detect faint meteors not observable visually, improvements can be made by installing a directional antenna, such as a compact YAGI 4-elements antenna, providing substantial gain. The pointing direction is not indifferent and depends on the geographical position and the observation period.

Once again, it is worth emphasizing that the great advantage of a portable station is its ability to seamlessly combine visual observation with radio observation.

RECORDING MODES FOR RECEIVED SIGNALS

To keep a record, even just as a memento, it is wise to record the received audio signal. This is a good opportunity to dust off the good old tape recorders for those who have them in working condition. It must be acknowledged that they may struggle to compete with modern devices such as digital voice recorders, both in terms of recording capacity and power consumption. With currently available digital voice recorders, one can easily have 100 hours of recording on an 8-gigabyte SD card, with the two AAA batteries providing about 20 hours of usage.

While the digital voice recorder is perfect for sporadic recordings, challenges arise for long-duration recordings that require automatic file fragmentation for convenient analysis. In such cases, a microcontroller (such as a RASPBERRY Pi or ORANGE PI), coupled with a USB sound card, a microphone, the ARECORD software, and a Python script, can provide a customizable solution adaptable to specific needs .

ANALYSIS OF RECEIVED SIGNALS

To analyze audio recordings, it is useful to use software that allows for spectral analysis of signals. They enable (through Fourier analysis) the plotting of frequency content over time on the screen. As we will see later, these curves provide a lot of information about the behavior of the meteor, such as its speed over time. The simplest method is likely to use ARGO (available at http://weaksignals.com) .Ir is is very intuitive and sufficient for real-time analysis. A bit more complex and powerful is SPECTRAN (available at https://www.sdradio.eu/weaksignals/spectran.html) , which, in addition, allows the analysis of audio files in .WAV format. The pinnacle of these free software options is undoubtedly SPECTRUMLAB, with which you can even program recordings for external events (https://www.qsl.net/dl4yhf/spectral.html). However, a careful reading of its documentation is absolutely necessary to make the most of its multiple features. All these software programs work on PCs. Similar functional software can be found in the Android world. The choices are plentiful on GOOGLE PLAY, such as SPECTROID, SPECTRALVIEW, and many others. The advantage of these programs lies in the fact that they can be used on tablets, which are energy-efficient and do not generate radioelectric interference, making them suitable for portable use.

VIRTUAL RECEIVING STATION

Meteor detection is also possible without a radio station, regardless of one's physical location anywhere in the world. All that is needed is an internet connection to visit a Spanish website located in Barcelona, operated by a team of academics/students (address http://websdr.housing.salleurl.edu:8901/) . It is a conventional WEB SDR that allows listening to the frequency 143.050 MHz and its surroundings in SSB (Single Sideband) with adjustable filters. This web sdr listen the signals from a radar located in the center of France, reflected on the trails of meteorites. One can directly record the audio in .WAV format and transfer it to their computer for subsequent analysis. Real-time analysis is feasible by simultaneously running the web browser connected to the Spanish site and the software SPECTRAN or SPECTRUMLAB on their PC.

RECEIVED SIGNAL PROCESSING CHAIN

When listening to the signals reflected off meteorites, one primarily hears noise (over 99% of the time). To focus on the interesting signals, it is necessary to perform preprocessing before analyzing them on SPECTRAN or another spectral analysis software. This is particularly easy and quick using the free software AUDACITY. (figure 8)

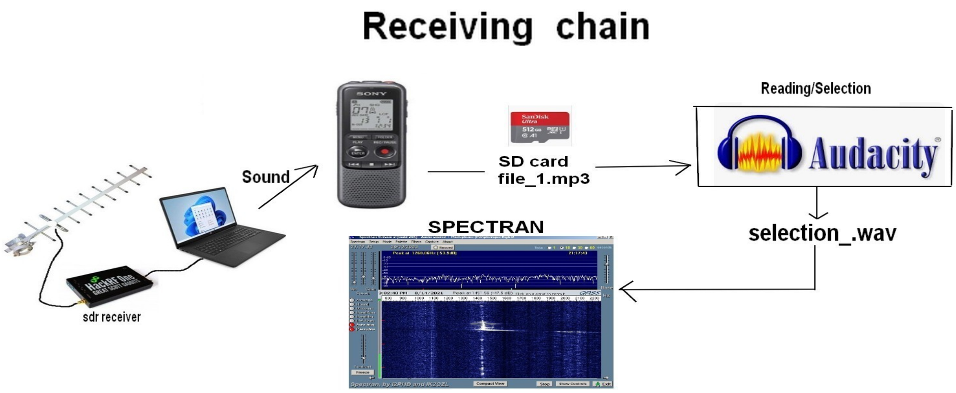
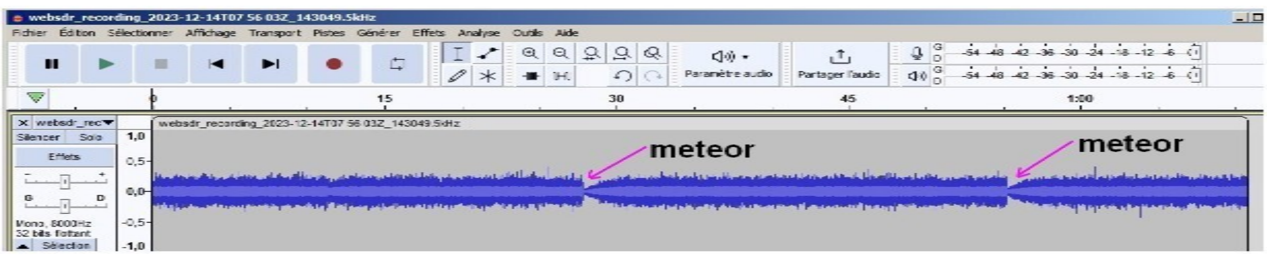


Fig 8

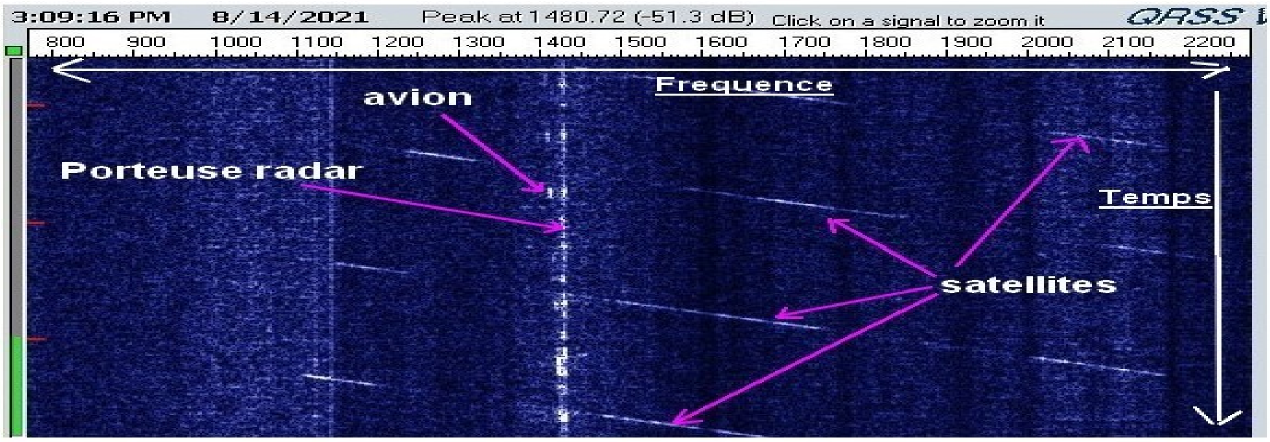
We load the audio file into AUDACITY. It is easy to identify areas where a meteor passes, which is manifested by a decrease in noise (see Figure 9). With the commands built into the software, it is sufficient to eliminate the noisy areas. A one-hour recording file can be reduced to 30 seconds or even less. The selected file can then be saved in .WAV format for analysis.



Signal processing with AUDACITY   Fig 9

RECEPTION STATION TEST

At any time, one can test their control over the various components of the station, both in terms of hardware and software. To do this, it is sufficient to listen to signals reflected by airplanes and satellites within the optical visibility of the transmitter and your listening station. These signals exhibit a variable frequency shift (DOPPLER effect) over time, as illustrated in Figure 10.



Receiver test with airplane/satellites **Fig 10**

The DOPPLER shift is proportional to the speed of the moving object and the frequency of the transmitter (see Figure 11). For an airplane flying at 900 km/h, the maximum DOPPLER shift is 120 Hz. For a satellite (speed of 27,000 km/h), this maximum shift increases to 3600 Hz, all of this in the case of a transmitter operating at 143 MHz. For a television transmitter operating at 72 MHz, these shifts will be divided by 2. The observed shifts are always lower than these values except in the case where the mobile object moves along a line connecting the radar position and the observation position. If the mobile object approaches, the shift is positive, and it becomes negative as it moves away. What can be measured locally is the radial velocity, which allows determining the direction of the mobile object in relation to the line connecting the transmitter position and the observation position. The calculation of the DOPPLER shift is not complicated (see Figure 11). The shift is proportional to the frequency of the transmitter and the speed.

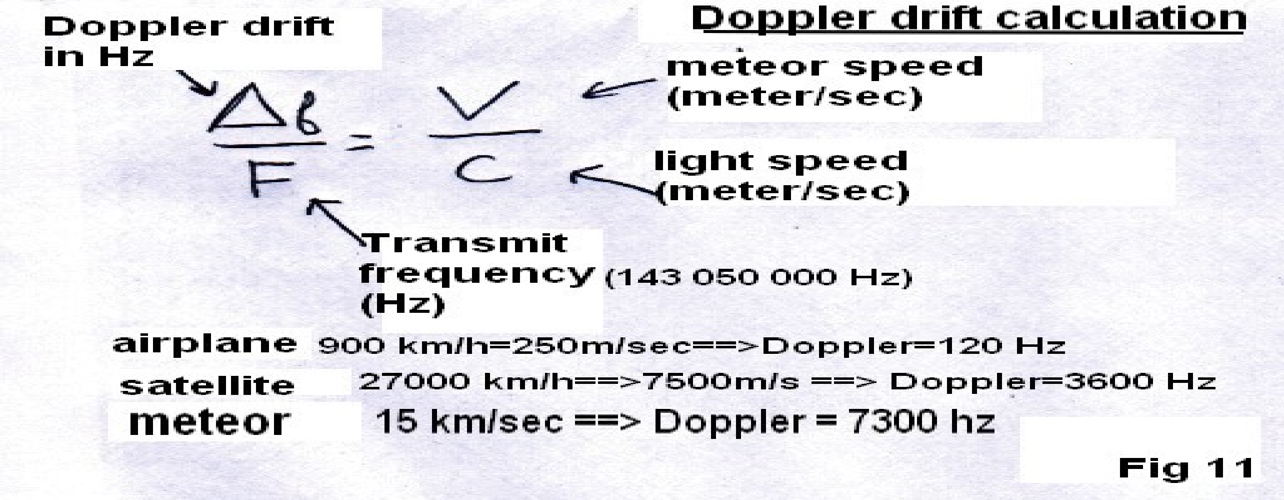


Fig 11

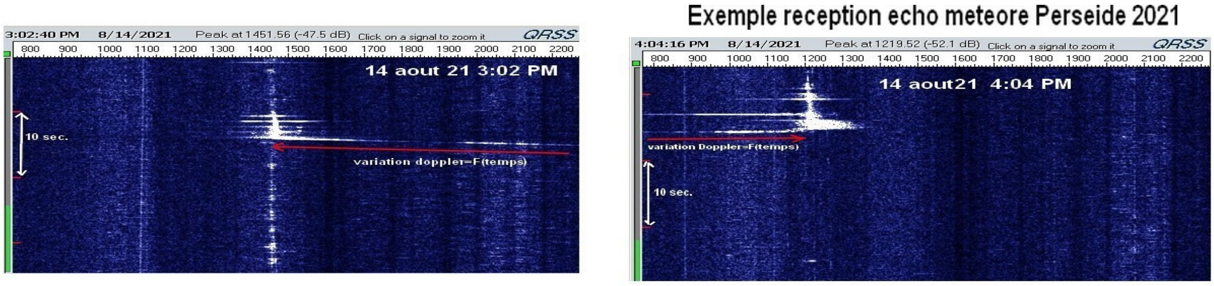
It is easy to determine the satellites passing through the area. Simply retrieve this data using the numerous software options available on the web that allow you to visualize their positions on a map and verify the accuracy of your calculations. Some are online (http://www.isstracker.com/home, https://www.n2yo.com, ...) and are likely to be regularly updated. If you choose a local version installed on your PC (such as PREVISAT, GPREDICT, ...), don't forget to update the orbital elements, especially if you are interested in the International Space Station (ISS), which produces strong echoes.

EXAMPLES OF RECEIVED METEOR SIGNALS

The reception of meteor echoes is much briefer than that of signals reflected by satellites. To observe them more conveniently, it is necessary to increase the scrolling speed. An echo typically lasts only a few seconds. Auditorily, the echoes are easy to recognize by ear because they begin with a very rapid frequency variation (lasting less than 0.3 seconds), followed by a period where the frequency is fixed and can last for a few seconds (see Figure 12 for examples recorded on August 14, 2021, during the passage of the Perseids from the southwest of France). In the case of joint optical and radio observation, it is always noted that the radio signal lasts much longer than the light trail.

Even during a period of abundant meteor activity, most echoes are briefer than those in Figure 12 (see Figure 13-A for the same period at the end of the Perseids' passage in 2021).

Exemple reception echo meteore Perseide 2021



Perseides august 2021 Reception example

Fig 12

If one is interested in the period of rapid frequency variation that allows determining the radial velocity of the meteor at the end of its course, it is advisable to record the received audio signal at a sufficient sampling rate (sampling at 42 Kb/s is adequate).

In this case, when replaying the audio file, the rapid decay in velocity is clearly visible (see Figure 13 B). In this recording, it is observed that in 0.3 seconds, the Doppler shift goes from 3000 Hz to 0. Translated into the radial velocity of the meteor (knowing that 3000 Hz corresponds to a velocity of 15 * 3000/7300 = 6.1 km/second, see Figure 11), this means that the meteor went from 6.1 km/s to 0 in 0.3 seconds. We leave it to the attentive reader to calculate the G-force to which the meteor was subjected in its terminal phase, considering that 1 G = 9.8 m/s² (G = acceleration due to Earth's gravity).

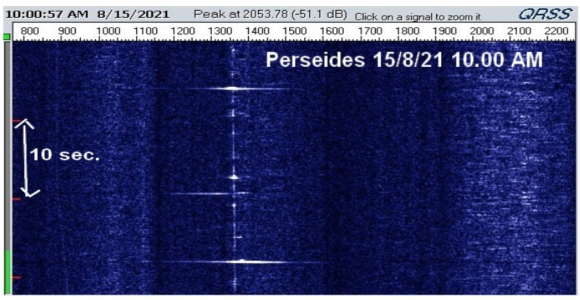


Figure 13-A

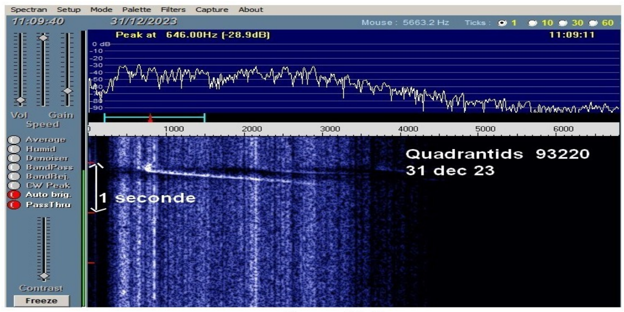


Figure 13-B

In the case of meteors leaving a substantial ionized trail, one may occasionally observe a frequency spreading of the signal at a fixed average frequency (see example in Figure 12-B). This spreading is sometimes attributed to the strong winds present in the upper parts of the stratosphere, at around 30 km altitude, where meteoroids conclude their brilliant fall before, for the larger ones, embarking on a more discreet descent before reaching the ground.

The intensity of the echo is related to the mass of the meteoroid. The relationship is highly nonlinear, and this intensity also depends on the initial velocity of the meteoroid, which can vary between 15 and 70 km/s, as well as the angle of arrival of the meteoroid. For meteoroids with sufficient mass, the observed trail typically extends between 80 km and 20 km in altitude.

METEOR MONITORING NETWORKS

Meteors, due to their high velocity, possess significant energy. It is customary to quantify this energy in kilograms of TNT, a well-known explosive (acronym for Tri Nitro Toluene).

A meteoroid weighing 1 kilogram, traveling at 15 km/s (the minimum speed of a meteor, with the maximum reaching around 70 km/s), has a destructive energy equivalent to 29 kg of TNT and 464 kg if it travels at 60 km/s. It poses a risk, although this risk is very infrequent on a human scale.

Nevertheless, this risk justifies surveillance, especially for massive asteroids orbiting in the solar system. Another compelling reason to monitor meteors is to accumulate scientific knowledge to better understand the genesis of the solar system. Numerous networks exist worldwide for this purpose, with varying motivations and resources, which we will detail.

Meteor Surveillance Network: IMO Network

The IMO network is a visual observation network organized by the International Meteor Organization. It centralizes on its website observations from individuals who have registered on their site and transmit via the internet a visual observation of any unusual luminous object (https://fireballs.imo.net). These observations are centralized and accessible online in the form of a map indicating the position of the observers. See, for example, in Figure 19, a luminous object #480-2024 reported by 10 observers from Massachusetts,New York, Rhode Island on January 21, 2024, around 09:05 UTC. Note that the reported objects are not only meteors or similar phenomena.

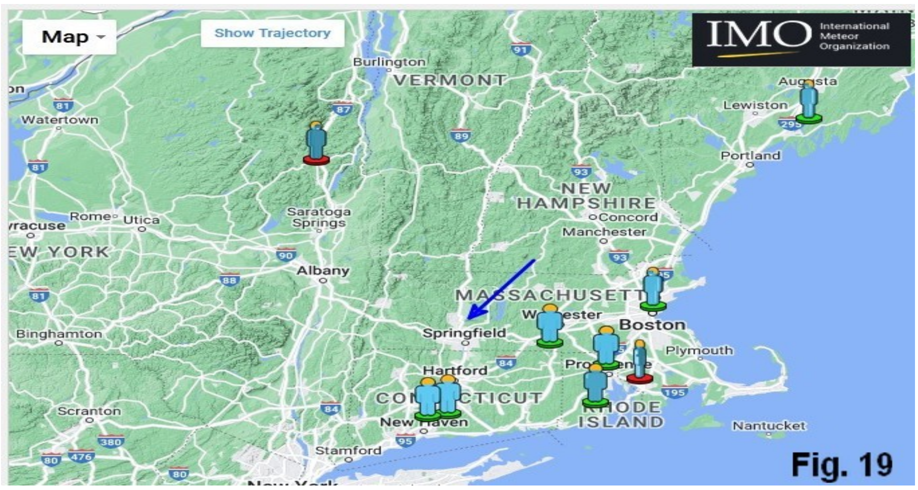
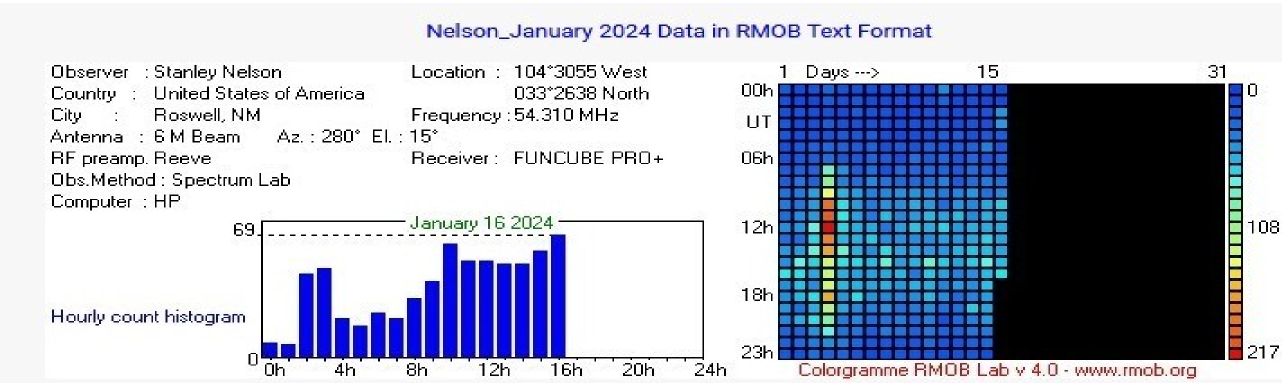


Fig. 19

Meteor Surveillance Network: RMOB Network

The RMOB network currently consists of around fifty stations, primarily located in Western Europe and operated by enthusiasts, often self-taught, with diverse motivations. The goal is to tally the average meteorite flux in the airspace of the listening station. To achieve this, detection is done by measuring the number of echoes received per hour. Many stations in western Europe use the GRAVES radar signal (143.050 MHz) , while others located in areas not covered by this radar use various beacons, television transmitters, or FM stations. The counting results are transmitted in near-real-time on a central website that consolidates these measurements, making them accessible to everyone. The counting results for each station are synthesized in the form of a grid representing the current month's results (see Figure 15): horizontally, the day within the month; vertically, the hour within the day; and the color of each small square is proportional to the meteorite flux. Additionally, the observation conditions of each station and its geographical location are indicated. For example, you can see (Figure 15) the report from a station in the New Mexico USA for january 2024 clearly showing the increase in meteorites around january 4 following the Quadrantis meteor shower. All measurements since 1994 are accessible on the web (https://www.rmob.org).



Report example from New Mexico (USA)

Meteor Surveillance Network: FRIPON Network

A network more focused on accumulating scientific knowledge is the FRIPON network, an acronym for Fireball Recovery and InterPlanetary Observation Network (see Figure 16). It consists of a set of 150 cameras that detect the arrival of meteorites through optical observations. This network was launched at the initiative of French academics in 2016. Each station has a wide-angle camera periodically calibrated in reference to known stars. This allows connecting each pixel to a known direction in space. When a meteorite is visible from multiple stations, it is possible, through triangulation, to calculate the trajectory of the meteorite at the beginning and end of its entry into Earth's atmosphere. Knowing its entry trajectory makes it possible to determine from which part of the solar system it comes, and knowing its final trajectory makes it possible to define its landing point for recovery and study of its structure and composition. The system operates only at night and under clear sky conditions.

Locating a meteorite is no easy task. These objects are typically small in size (mass on the order of a kilogram) and are situated in an area of a few square kilometers. The first meteorite discovered by the FRIPON network was in January 2020, and the latest was on January 23, 2023, in Normandy (more information at www.fripon.org). Similar networks exist in other countries, including Australia, the USA (especially on the West Coast), Morocco, the United Kingdom, Saudi Arabia, and more, with this list not being exhaustive. These networks, excluding the one in the UK, monitor desert areas where it is easier to locate meteorites on the ground. For more information on the

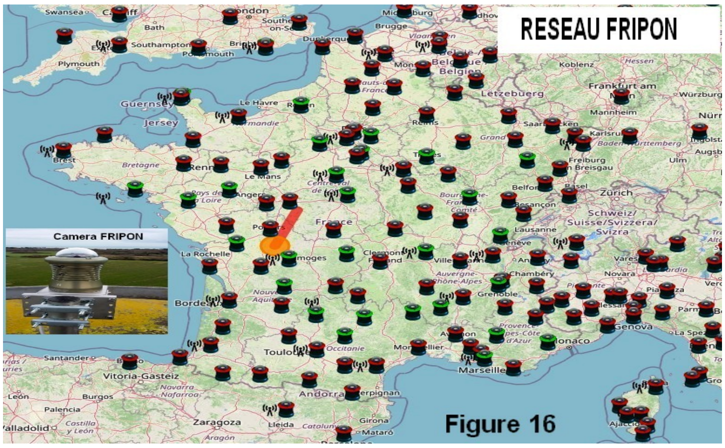


Figure 16

various techniques used by these networks, one can visit the website of the Australian network at https://dfn.gfo.rocks/.

Meteor Surveillance Network: NASA Network

This is a worldwide network for observing meteors from space, utilizing various satellites, whether in low Earth orbit or geostationary, operated by the United States' space agency, NASA. The analysis is conducted in visible light or infrared. A significant advantage is the global coverage and the ability to operate without being hindered by atmospheric conditions. Analyzing images over time also allows for the calculation of the impact point, and the intensity of the luminous signal provides an estimate of the meteor's size, allowing for the quantification of its energy in kilotons of TNT. As seen in Figure 17, which catalogs meteors that have fallen to Earth from April 1988 to November 21, 2023, the distribution is uniform. The largest meteor during this period is the one that fell in the Ural region on 2/15/2013 (Chelyabinsk meteor), with its energy estimated at 440 kilotons of TNT. Fortunately, most others had much lower energy (on the order of 0.1 kiloton of TNT).

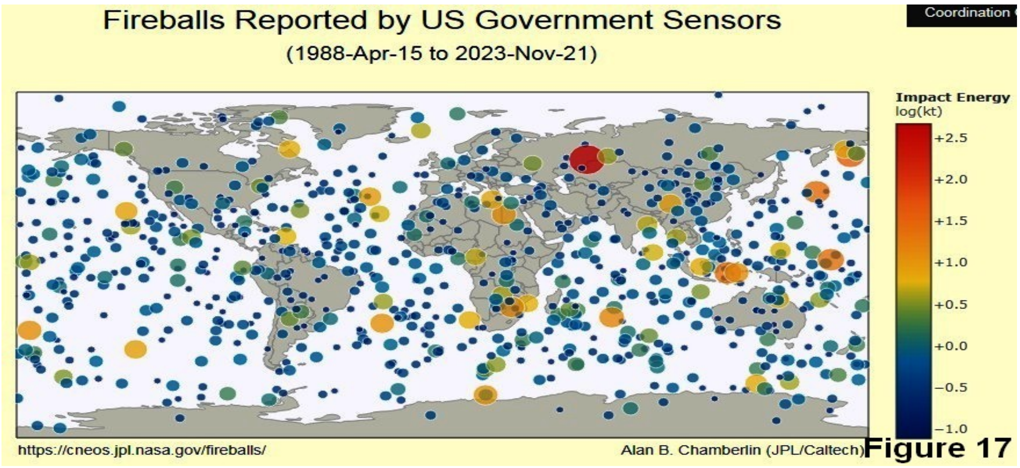
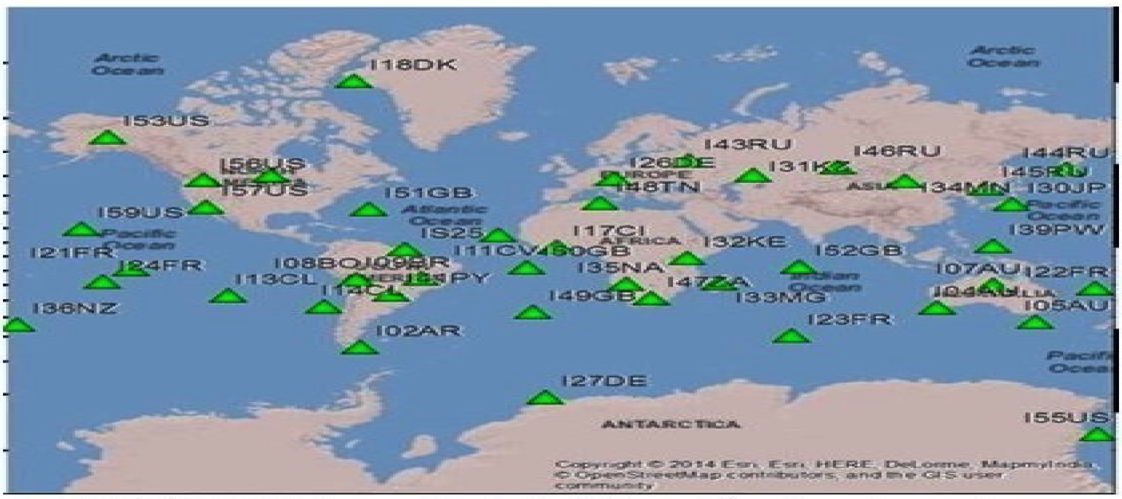


Figure 17

For more infos https://cneos.jpl.nasa.gouv/fireballs/

Meteor Surveillance Network: CTBTO Network

The CTBTO (Comprehensive Nuclear-Test-Ban Treaty Organization) is an international organization, a spin off UN, tasked with monitoring clandestine nuclear tests. To accomplish this, it has a substantial annual budget (approximately 130 million US dollars) and supports a global network of various sensors. One sensor of particular interest to scientists is its infrasound detection network (see Figure 18). The arrival of a meteor generates infrasound emissions (frequency between 0.1 and 4 Hz) that propagate over long distances with minimal attenuation in the air. When at least 3 stations detect the same phenomenon, it is possible, through triangulation, to define the emission zone. For example, the meteor that fell in the Ural region on 2/15/2013 was detected and located by 20 stations in the network. For more information, visit: https://www.ctbto.org/our-work/monitoring-technologies/infrasound-monitoring



CTBTO Infra sound detection network
Fig 18

Another widespread network is that of weather radars, responsible for locating and tracking cloud formations, rainfall, and atmospheric disturbances in general. These radars continuously emit signals at frequencies between 5 and 10 GHz and can also be used to detect and locate the impact point of meteorites in their terminal phase. Meteorites have a distinctive radar signature, but it doesn't seem to be widely utilized by scientists so far.

The fallout of meteorites is extensively monitored by a broad global community of enthusiasts and scientists. They are not the only ones; the community of radio amateurs also monitors and uses them to establish improbable communications through reflection: this is known as METEOR SCATTER traffic. But that is another story.

73 from F1OK

For more information:

- www.fripon.org: Optical meteor surveillance network
- www.rmob.org: Radio meteor surveillance network
- www.meteornews.net, www.imo.net, www.amsmeteors.org: General meteor information
- https://cneos.jpl.nasa.gov/fireballs/: NASA meteor information
- https://www.ctbto.org/our-work/monitoring-technologies/infrasound-monitoring: Meteor detection by infrasound
- https://www.vigie-ciel.org: Meteor news in French, citizen science
- https://dfn.gfo.rocks/: Meteor surveillance network in Australia
- https://www.lpi.usra.edu/meteor/: Meteorite encyclopedia
- https://digitalcommons.unl.edu/cgi/viewcontent.cgi?article=1097&context=usafresearch: Weather radar for meteor location
- https://fireballs.imo.net: IMO meteor signaling network