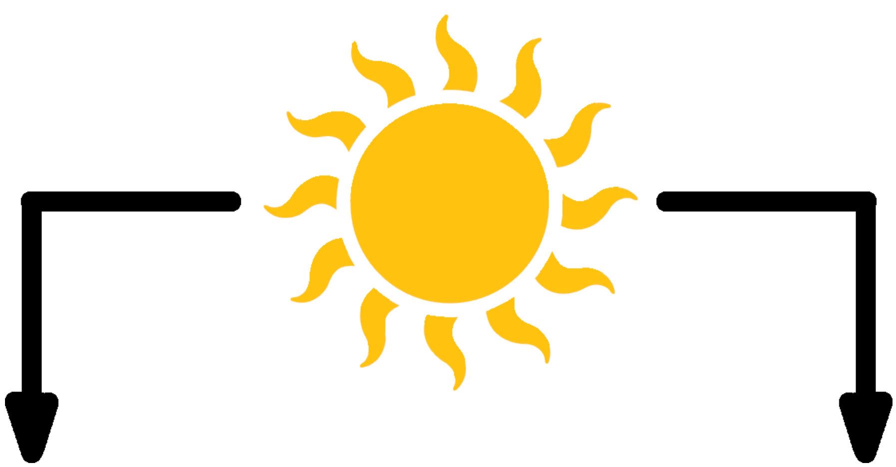
Authors: Thomas Mazzi - Matteo Fortini


# HELIOS VLF SOLAR TELESCOPE



# Abstract

Telecommunications systems of the early 1900s used shortwave for long-distance connections and understanding the behavior of the ionosphere was very important for transoceanic communications. With the arrival of satellite technologies, the study of the ionosphere has decreased to become a small research area. The Helios system, thanks to the use of modern low-cost digital technology, allows amateur associations to undertake the journey to discover the ionosphere again, to study how it reacts to the influence of the Sun and more generally to ionizing radiation arriving from space.

# Project goal

The purpose of Helios is the study of the ionosphere and how it reacts to solar flares, cosmic rays, eclipses, meteor showers, etc… maintaining an affordable cost for associations. The cost of large systems (satellites, radio telescopes, ionosondes, etc...) is completely out of reach fore associations, amateurs and students who at bestare able to see these systems in action without being able to touch it. Learning also means putting your hands on facilities and understanding what is happening in the field. Helios fills this gap by making this kind of studies available to all at reduced costs.

# Background physics

VLF electromagnetic waves have a frequency between 3 kHz and 30 kHz. These waves are reflected by the ionosphere, so they can reach much greater distances than those achievable only by direct transmission. The ionosphere is the part of the atmosphere typically located from 60 to 1000km of altitude, in which there are gasses ionized by solar radiation. The ionosphere can be divided into further layers, depending on chemical characteristics. In particular, the D layer extends between 60 and 90 km of altitude, while the E layer extends between 90 and 130 km of altitude. There is an additional F layer located in the highest parts of the atmosphere which acts as an interface between the atmosphere and space. This layer is splitted in F1 and F2 during the day and it recombines into a single F layer during the night.

Simplifying for a better understanding of what happens, we can imagine that the electromagnetic waves of the VLF band are traveling inside the earth-ionosphere channel as they would inside a wave guide. However, his is true only if both layers are conductive. In reality these are not perfect conductors: the ground has a good and constant conductivity while the ionosphere changes its conductivity according to the percentage of ions it contains. When the sun rises, the lower layers of the ionosphere (E and D) pass from an insulating neutral state to a conducting one. In these intermediate phases they are mediocre conductors: this implies that the waveguide formed by low conductivity materials is not able to efficiently transport electromagnetic energy, and it dissipates it instead. Following this concept, the Helios VLF solar telescope system samples and observes how the signals from existing radio navigation systems are received. By considering constant the power of the signal transmitted by the VLF stations and taking them as a reference, it is possible to measure the daily variations of the received signal and attribute them to the change in efficiency of the earth-ionosphere waveguide. Except for very slow changes, the ground has an almost constant conductivity so the variations in signals are totally attributable to changes in the conduction of the ionosphere. It is interesting to see how these changes are coordinated with the rising and setting of the sun and how they sometimes have spikes during the day in correspondence with solar flares confirmed by satellite data. During the night the D layer disappears completely while the E layer has still a weak ionization. The top layer F remains ionized even during the night due to both the slowness of the recombination and the arrival of cosmic rays.

| Call sign | Frequency (Hz) | Location |
|---|---|---|
| GBZ | 19580 | Anthorn, UK |
| ICV | 20270 | Isola di Tavolara, Italy |
| FTA | 20900 | Sainte-Assise, France |
| GQD | 22100 | Skelton, UK |
| HWU | 22600 | Rosnay, France |
| DHO38 | 23400 | Rhauderfehn, Germany |
| NAA | 24000 | Cutler, Maine, USA |
| NRK/TFK | 37500 | Grindavik, Iceland |

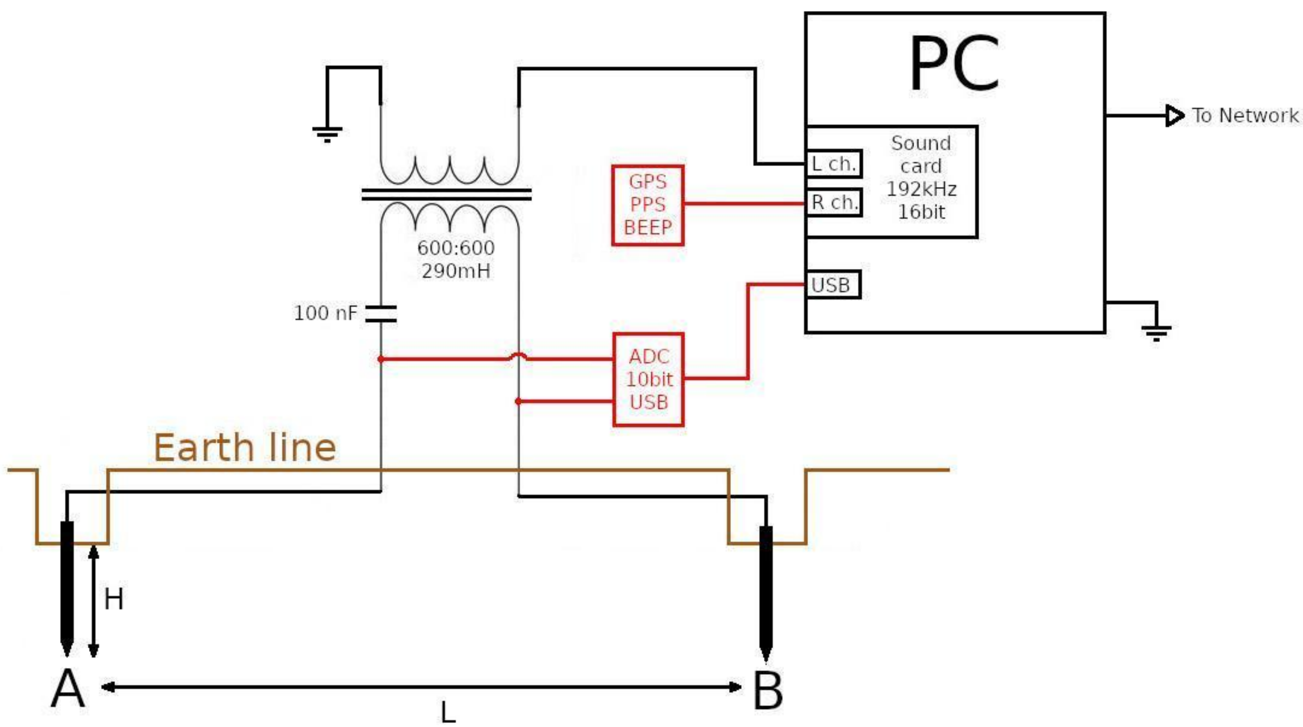
Some available frequencies

# Project description

Helios uses a particular ground plug sensor. This is an antenna design which was used on the WWI battlefields by the Italian army and whose technology had almost been forgotten. Reading old documents, we learned of this antenna which was used to eavesdrop on Austrian field telephones' communications. Some plug or slabs were buried near the enemy trenches and special filters and amplifier circuits allowed the enemy conversations to be heard.

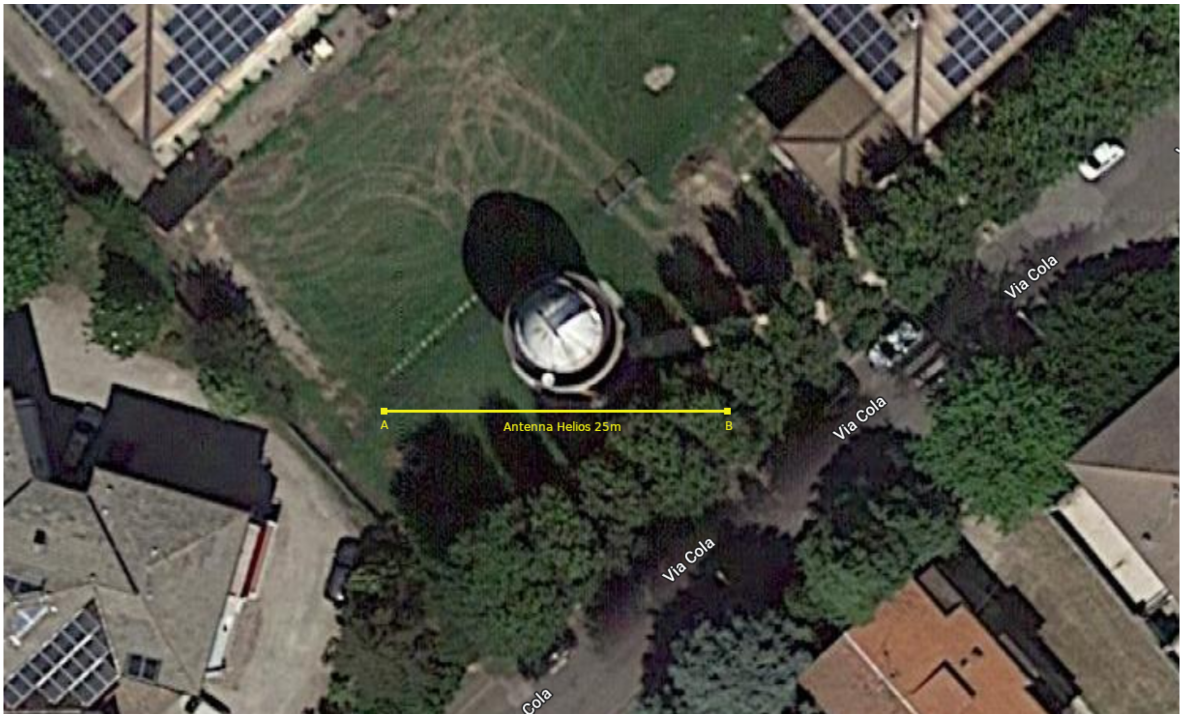
For the construction of Helios, given the limited budget available, it was necessary to have the greatest amount of information to be able to minimize development costs. We therefore proceeded to search for documents that could give technical and design information on ground plug antennas, obtaining poor results. More specific documents searched for at length

and later found are those written by Lieutenant Aurio Carletti of the 2nd army [Carletti]. In these documents he explains how these technologies were used on the battlefields but without going into too much technical detail since it was still a military technology. The problem with these documents was the deliberate vagueness of the technical data, which made our design work more complicated.
It was necessary to proceed with a reverse engineering of the antenna. We spent a few months using test models to understand how the results were changed as the construction parameters changed such as: arm lengths, stakes lengths, etc ... It was necessary to understand how the antenna was working! It was necessary to understand if it had main radiation lobes, if there were currents along the circuit due to the galvanic difference between the rods and the ground, what was its bandwidth, etc ... The best reception results were found by orienting the antenna in the east-west position and burying the rods (A and B) for 1/40 of the length (L) of the antenna (see diagram below).




Block diagram of the Helios system

In the specific case of the prototype installed in Cento astronomy observatory, a 25 m antenna was used with 75 cm rods driven into the ground for about 62 cm.




Top view of the installation


Installation photos

This antenna is very particular of its kind. It immediately showed its excellent characteristics: invisible to the eye of the observer, perfectly integrated with the surrounding urban design, immunity to electrostatic disturbances, excellent sensitivity, high gain, an SNR ratio higher than many other types of antennas tested during the prototyping period and a low cost of realization. Obviously, several different types of antennas have been made (loops, rows, etc.) and they were all field tested at the same time and of these the ground rods antenna solution was the best.
Also the orientation of the antenna was tested and the EAST-WEST arrangement was found to be the most performing one.

| Antenna type | Pro | Contro |
| --- | --- | --- |
| Wire antenna | Bandwidth, simplicity of construction, low cost of construction | Loud background noise due to static, tendency to collect static electricity, visual impact |
| Loop antenna | Silent, compact and easy to install | Low bandwidth, cost to build, sensitive to parasitic capabilities |
| Ground rods antenna | Excellent bandwidth, immune to discharges and immune to electrostatic charges therefore low SNR, completely invisible, large possible dimensions and high sensitivity | Construction cost, installation with excavation in the ground, low Q, characteristics to be sized according to the terrain |

Helios's antenna allows a good reception of signals from 0-2 MHz and the first tests have shown that it is possible to receive near-DC ground currents due to solar storms also known as GIC, the VLF range from lightning to transmissions for radio navigation, clearly hear LF band aeronautical beacons and receiving broadcasting stations in medium wave with excellent signal power. The purpose of the system is to receive and monitor the quasi DC currents and the VLF / low LF band for the study of the ionosphere and how it is affected by solar and space radiation.
During the day, solar rays ionize the upper layers of the atmosphere, changing its electrical characteristics. Waves at different frequencies can be reflected or absorbed depending on the density of ions present and indirectly by incident ionizing radiations. Solar flares emit large amounts of energy in the form of ionizing radiation that can disrupt the ionosphere for several tens of minutes. The signals in the VLF band are reflected or absorbed according to the state of the ionosphere, carrying important information with them.

The VLF / LF bands are received by a PC sound card after passing through a filter and a ground separator consisting of the 100nF capacitor and the 600: 600 Ohm transformer. The circuit obtained works as a band pass filter that allows the passage of frequencies from 1 kHz due to the LC group up to about 120 kHz of transformer cut-off frequency. In addition to functioning as a filter, the capacitor has the important task of completely blocking the continuous current that could saturate the transformer. The data acquired by sound card at 192 kHz are processed by a sw that filters the target bands, measures the RMS value and generates the spectrogram. The results obtained are recorded on a file which is sent periodically on the internet (github) where specific scripts display the graphs and generate the HTML code.

# Software description

The software used is based on open source tools. The computer used does not require special calculation powers. The operating system used is Linux xubuntu 18.04. Scripts based on the sox tool were used for the acquisition and filtering. The software used is available on an MIT licensed GitHub repository. The system stores the data on a local git repository, which it synchronizes with the GitHub repository. This allows robust storage in case of temporary network issues. At each variation of the data, GitHub actions are used to carry out some processing and produce the files that are the basis of the data visualizations. The web pages are statically created using Jekyll. The design framework used is the Bootstrap Italia toolkit and the charts are created using the Plotly library.

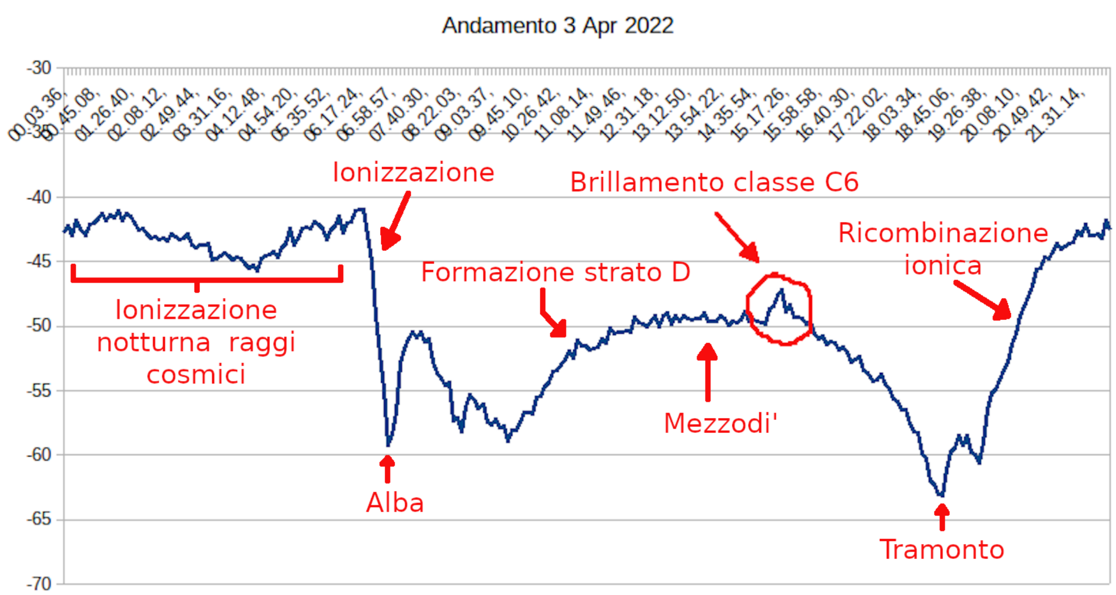
# Future and next developments

The red parts on the diagram highlight areas where further development of the project is taking place. The acquisition and monitoring of quasi-DC currents due to solar storms takes place via an amplifier and a high impedance 10bit ADC connected directly to the antenna and transmitted to the PC via a USB connection. During a solar storm, strong currents are generated in the upper parts of the atmosphere and by induction also in the ground below. The metal rods of Helios are able to perceive the generated currents and the system is able to record the trend of these. A further development concerns the possibility of recording a GPS timestamp (GPS PPS Beep) on the second channel of the sound card which will allow the creation of a network of Helios antennas on the territory and to be able to synchronize them with high precision.

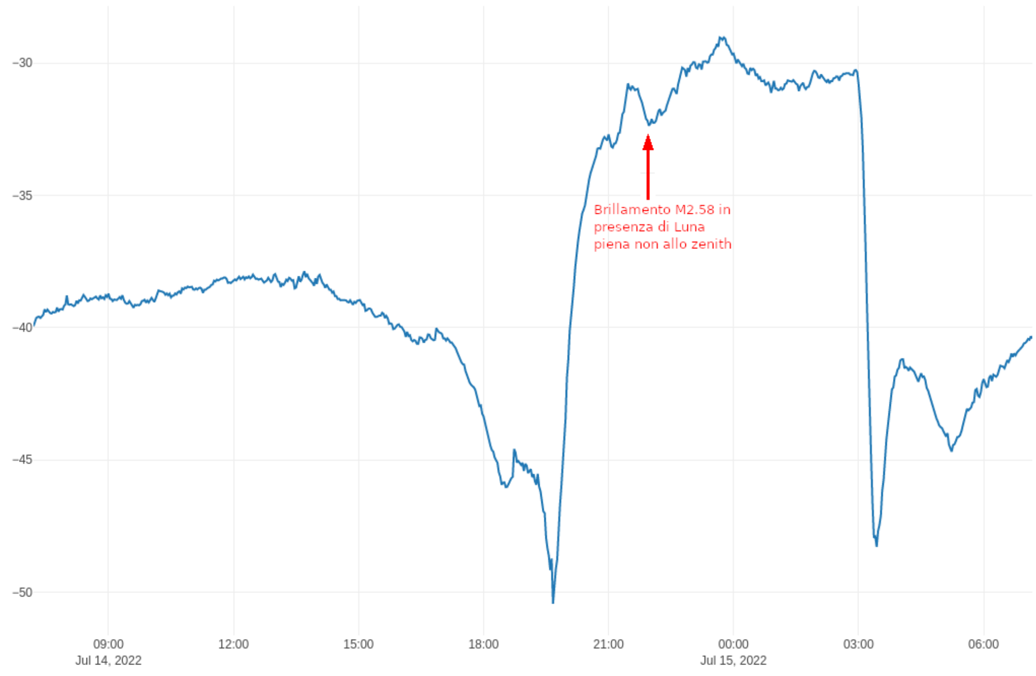
# Initial results

The Helios system has been officially in operation since 21 May 2022 and a few months of acquisition are not enough to validate some observations with certainty. To confirm the observations with sufficient accuracy, it is necessary to verify the actual cause and effect link many times as suggested by the scientific method. However, it is interesting to note that some of the observations described below have already been verified a few times and others are in line with effects already verified in the past by other tools:

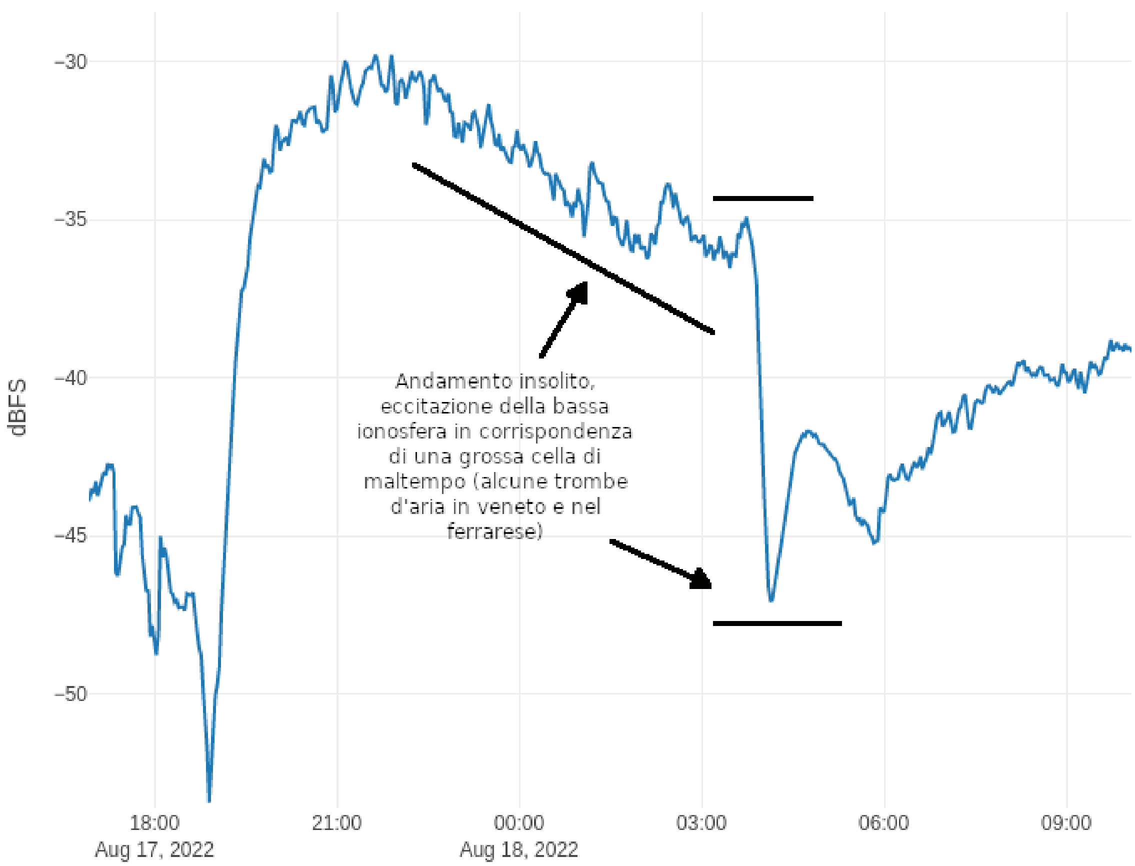
1. Perfect correlation with satellite data on solar flares, ionospheric probes and magnetometers of large research centers.
2. High intensity nocturnal flares are able to excite the ionosphere in the part not illuminated by the Sun in the presence of a full Moon. It seems that the Moon can act as a mirror (being tested).
3. More intense nocturnal disturbances during the nights of the perseids (effect hypothesized and verified at vhf by other instruments)
4. Disturbances of the ionosphere in the presence of strong atmospheric events (known effect)
5. Different behavior of the D layer as a function of the incident frequencies (known effect).
6. Variations of GIC currents as a function of solar activity (known effect)



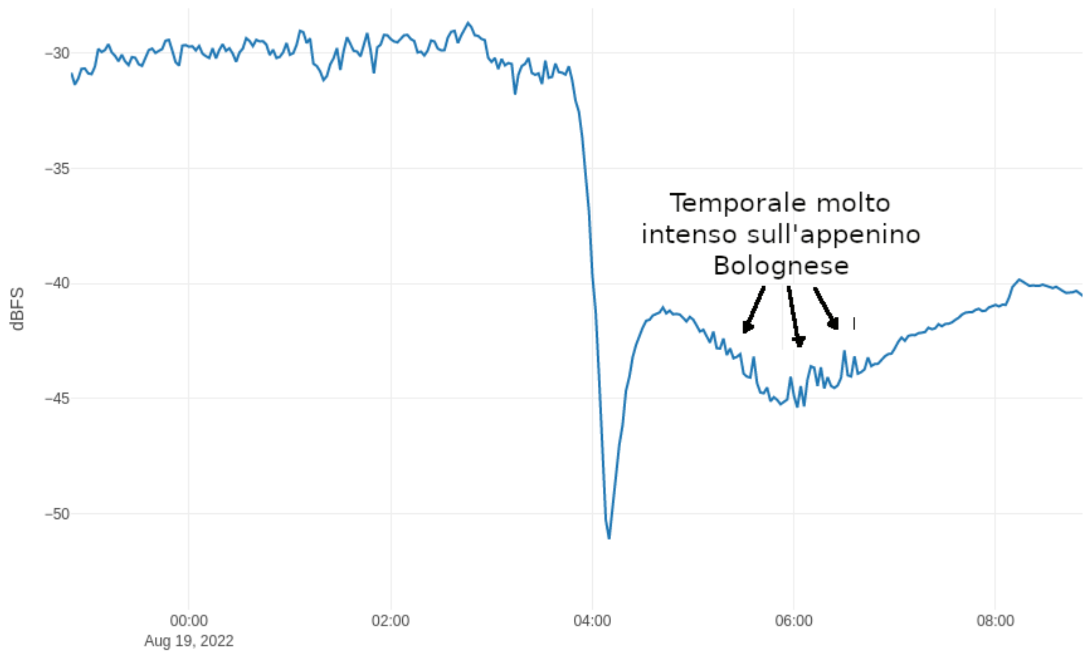

Typical daily graph obtained with Helios showing a class C6 flare




Class M2.58 night flare at the full moon




Weather situation correlated with Helios




Very intense storm at 50 km

# Conclusion

Helios is a highly educational, expandable and open tool that allows everyone to enter this magical world, capable of collecting interesting information. The characteristics of sensitivity, cost-effectiveness, sturdiness, simplicity of installation and its total invisibility in the place of installation make it an extremely versatile tool, available to everyone and repeatable in almost all situations, even in those protected by landscape constraints.

# The bill of material

The following BOM refers to a general installation of 25m like the one in Cento astronomy observatory:

- 3x plastic inspection pit
- 25m corrugated sheath
- 25m electric wire 1x1.5
- 2x 75cm copper rods
- 1x capacitor 100nF
- 1x transformer 600:600 Ohm 290mH
- Many meters of coaxial cable like RG58
- Couplers and cases as necessary

The total cost is around 150 euro

# Bibliography

[Carletti] Aurio Carletti. “Il servizio delle intercettazioni telefoniche durante la guerra” (pag. 16-26). Telegrafi e telefoni Anno II – n°1 gennaio febbraio 1921 https://archive.org/details/aurio_carletti_intercettazioni_guerra_1915-18

http://www.carlobramantiradio.it/intercettazioni.htm

[Priestley] RE Priestley, MC, BA, "Il servizio di segnalazione nella guerra europea dal 1914 al 1918 (Francia)"