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Solar observations with a low frequency radio telescope

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Abstract: We have set up a low frequency radio monitoring station for solar bursts at the Observatory of the Aristotle University in Thessaloniki, Greece. The station consists of a dual dipole phased array antenna, a shortwave radio receiver and a dedicated computer with the necessary software installed. We constructed the antenna and the radio receiver following the NASA's Radio JOVE project design. The station operates continuously, since July 2010, observing in a narrow band of frequencies (~ 5 kHz) around 20.1 MHz. The system is properly calibrated, so that the recorded data are expressed in antenna temperature.

Despite the high interference level of an urban region like Thessaloniki, we have detected several low frequency solar radio bursts and correlated them with solar flares, X-ray events and other low frequency solar observations. The received signal is monitored and archived in ordinary ASCII format and also as audio signal, in order to investigate and exclude man-made radio interference.

We will be able to exclude narrow band and local interference signals as well as calculate the spectral indices of the observed solar bursts, after the ongoing construction of a second monitoring station, working at 36 MHz, at the village of Nikiforos near the town of Drama, about 130 km away of Thessaloniki. Finally, we plan to construct a third monitoring station at 58 MHz, in Thessaloniki. This frequency was revealed to be relatively free of interference, after a thorough investigation of the region.

1 Introduction

As we know from many introductory books for Radioastronomy (e.g. Seiradakis, [8]), solar radio emission appears to originate from various layers of the solar atmosphere, depending on the observing frequency. The lowest frequency at which we can observe a certain solar atmospheric layer is given by its plasma frequency,

$$\nu_p = \frac{e}{2\pi}\sqrt{\frac{N_e}{\varepsilon_0 m_e}} \tag{1}$$

where e is the electron's charge, m_e its mass, ε_0 is the electric permitivity of free space and N_e is the layer's electron density. For frequencies lower than that the refractive index of the layer,

$$n = \sqrt{1 - \frac{\nu_p^2}{\nu^2}} \tag{2}$$

becomes imaginary and thus electromagnetic waves at these frequencies (ν) cannot propagate through it. When we move from higher to lower observing frequencies we observe higher layers of the solar atmosphere because the plasma frequency, as can be deduced from Eq.(1), is proportional to the layer's electron density which decreases with height above the photosphere. The low frequency radio telescope we constructed, is able to conduct observations around the frequency of 20.1 MHz, a value which corresponds to a layer located at a distance of about 3.8 solar radii above the photosphere.

In addition to this background of solar radio emission, we often observe strong, localized radio outbursts around the position of sunspots. These outbursts induce a variability at the solar radio emission, which has a periodicity that follows closely the well-established 11-year cycle of the solar sunspot activity. The solar radio emission during these outbursts can reach that of a black body with a temperature of 10^{10} K, a value which implies that non-thermal emission mechanisms are involved. These radio outbursts are classified into five principal types, according to their observational characteristics. Type I are noise-storm bursts, type II slow-drift bursts, type III fast-drift bursts, type IV is a broadband continuum emission and type V is a continuum emission at meter wavelengths. Most of these types are associated with the several physical phenomena that take place in the solar atmosphere after the occurence of a solar flare. Types II and III drift down in frequency with drift speeds of 20 MHz/min and 20 MHz/sec respectively.

With the radio telescope we constructed we observe only a narrow band of frequencies around 20.1 MHz. Therefore, we cannot classify the solar radio bursts that we observe, due to lack of information in the frequency domain. Nevertheless, we managed to correlate them with solar flares, X-ray events and other low frequency solar observations as they were recorded by various experiments around the globe and above it.

2 Technical Aspects

In order to observe and record solar radio emission around the frequency of 20.1 MHz, we constructed and set up a low frequency radio monitoring station at the Observatory of the Aristotle University in Thessaloniki. The station consists of a dual dipole phased array antenna, a low frequency radio receiver and a dedicated computer with the necessary software installed. This setup is based mainly on NASA's Radio JOVE project and thus the electronic parts we used to construct the receiver were purchased via the project's web page [4].

The antenna is made of two half-wave dipoles in a phased array configuration. The dipoles run on an East-West direction and the signals that they both receive are added together in a power combiner. The combiner's output signal is fed into the receiver, where it is further processed. We can adjust the elevation of our telescope's main lobe, which lies on the meridian plane of our observing site, by introducing a phase offset between the signals that the two dipoles receive. In our case, we wanted our main lobe to intersect with the Sun's trajectory in the sky, thus we installed a phasing cable between the southern dipole and the power combiner, which adds a 135° phase offset between the two signals. This phase offset, combined with the height of the dipoles ($\sim$ 4.6 m) which favors ground reflections of the incoming radiation, produces a strong, south-facing antenna pattern with its maximum gain located at an elevation of about 45° which is adequate for solar observations during most time of the year. We can compensate for the Sun's trajectory elevation extrema just by adjusting the phasing cable's length.

The low frequency radio receiver we constructed is a shortwave superheterodyne receiver, designed for the Radio JOVE project. It can amplify and convert the weak celestial radio signals our antenna receives to audio signals of sufficient strength to drive a loudspeaker. The receiver operates at a middle frequency of 20.1 MHz, it has a tuning range of 300 kHz and a bandwidth of about 5 kHz. The receiver's output audio signal is fed through the sound card's line-in port into our computer where we can record and process it accordingly.

The software we used for our observations consists of two programs. The first one is called Radio SkyPipe II [7] and it was developed by the Radio JOVE team for data acquisition and storage. Radio SkyPipe's main task is to produce a real-time graph of the received signal's power and store these files in ASCII format. In order to investigate and exclude man-made or natural interference, we recorded the audio output of the receiver in a 24-hour basis. For this task, we used a program called Loop Recorder Pro 2.06 [6]. Solar radio bursts produce a distinct sound profile which we identified either by the examples which can be found in the Radio JOVE web site or by the experience we gained over time.

The final stage of the system setup was its calibration. First, using a frequency generator, we calibrated our receiver to know the exact observing frequency with kHz accuracy. Then we calibrated the Radio SkyPipe program in order to obtain our results in antenna temperature and not in the arbitrary power units that it uses originally. Since the receiver exhibits linear operation over a wide range of input signal strengths, we are able to convert the arbitrary units of Radio SkyPipe into antenna temperature units using a single noise signal of known temperature. The calibrated noise source we used is called RF2080 C/F and generates a signal of 25000 K, similar to the temperature of the ambient signal a shortwave receiver located at a very radio-quiet site receives. After the antenna temperature calibration we measured the background noise level of our observing site to be around 50000 K, a value which is adequate for solar observations, since most radio bursts can exceed 200000 K in antenna temperature at these frequencies.

3 Observations and results

The calibrated noise source contains also a narrow-band filter around the central observing frequency of 20.1 MHz that helped in the mitigation of strong out-of-bound interference which blocked our observations for a few hours every day before its installation. This strong interference was caused by a strong international broadcasting shortwave radio station. During the broadcast, no extraterrestrial signal could be detected resulting in a few useless observing hours every day. Other sources of interference that we recorded are: local thunderstorms, which we were able to identify, periodic experimental signals, CBs and other low-power devices.

Since July 2010, we managed to observe and record over 100 solar radio bursts and correlate most of them with solar flares, X-ray events and other low frequency solar observations. The number of the recorded bursts seems to follow closely the solar activity cycle, since it has risen during the last few months of increasing sunspot appearance (Fig.1).

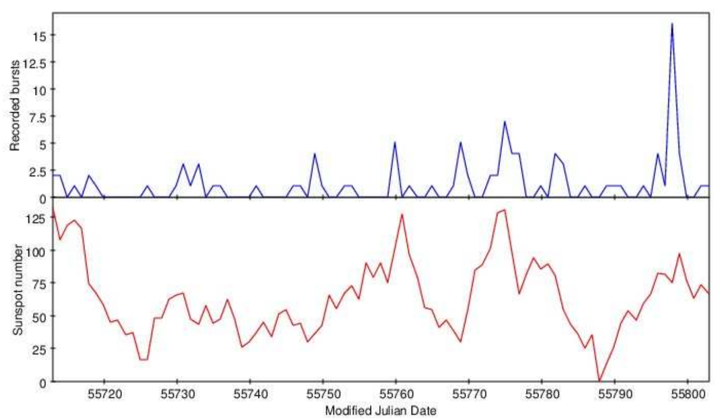

Figure 1: A comparison between our recorded bursts' number and solar activity. **Top:** The number of the observed and verified solar radio bursts we recorded during summer 2011. **Bottom:** The sunspot number for the same period.

As an example, we will describe the solar radio burst we observed and recorded on the 7^{th} of June 2011 at about 06:30 UT. The burst had a duration of about 30 minutes, the maximum antenna temperature that we recorded during that period was 657000 K and the burst's signal to noise ratio was about 65 (Fig.2). We correlated that burst with many solar observations in other parts of the electromagnetic spectrum most of which can be found at the solar events report that NOAA[1] published for that day [2]. In Fig.2, you can also see a photograph of a solar flare taken by AIA[2] on the SDO[3] satellite and an M2 type X-ray event as it was recorded by NOAA's GOES[4] satellites during the burst.

4 Conclusions

The monitoring station we constructed and set up at the Observatory of the Aristotle University in Thessaloniki is able to conduct solar radio observations in a narrow band of frequencies around 20.1 MHz. Furthermore, as a monitoring station, it stores these observations continuously together with the receiver's audio output in order to exclude interference signals by their sound. After the system's calibration, the obsevational data we record are expressed in antenna temperature. So far, we have

[1] National Oceanic and Atmospheric Administration
[2] Atmospheric Imaging Assembly
[3] Solar Dynamics Observatory
[4] Geostationary Operational Environmental Satellites

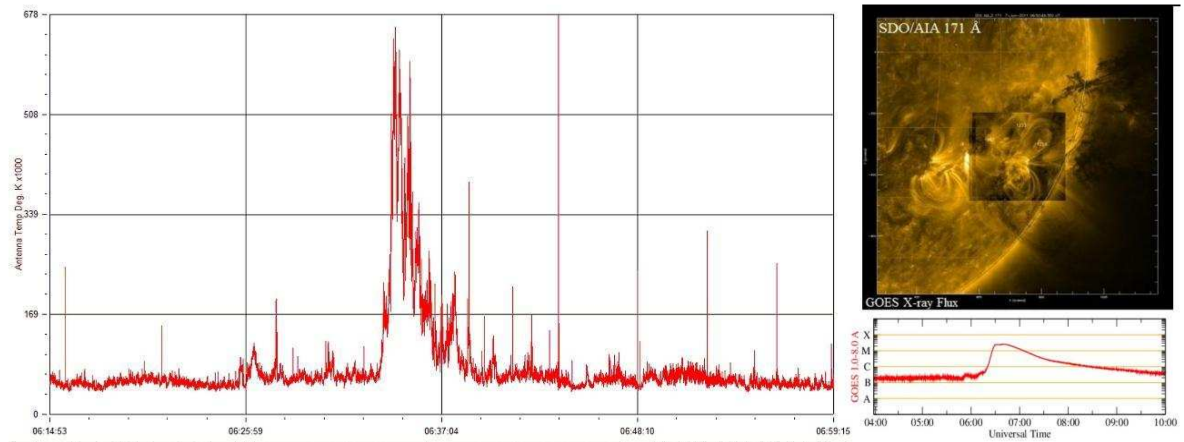

Figure 2: The solar radio burst we observed on 7 June 2011. **Left:** Our recording of the burst. The very narrow spikes is man-made interference. **Right:** A photograph taken by the SDO satellite (at 171 Å) of the solar flare that we correlated our radio burst with. At the bottom, you can also see the X-ray flux density (at 1-8 Å) as it was recorded by the GOES satellites during the solar flare. SDO images and GOES X-ray data are publically accessible at [5] and [1] respectively.

observed and verified over 100 solar radio bursts most of which were correlated with solar flares, X-ray events and other low frequency solar observations.

We will be able to exclude local interference after the completion of a second monitoring station at the village of Nikiforos, near the town of Drama. This station will operate at the frequency of 36 MHz, giving us the opportunity to exclude narrow-band interference and calculate the spectral indices of solar radio bursts. A third station, which is planned to be placed in Thessaloniki, will operate at 58 MHz, a frequency which revealed to be radio-quiet for this region.

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