30TH INTERNATIONAL COSMIC RAY CONFERENCE

Radiodetection of astronomical phenomena in the cosmic ray dedicated CODALEMA experiment

JACOB LAMBLIN[1] AND THE CODALEMA COLLABORATION[1,2,3,4,5,6,7]
[1]SUBATECH, Univ. de Nantes/Ecole des Mines de Nantes/IN2P3-CNRS, Nantes, France. [2]LESIA, USN de Nançay, Observatoire de Paris-Meudon/CNRS, Meudon, France. [3]LAL, Univ. Paris-Sud/CNRS, Orsay, France. [4]LPSC, Univ. Joseph Fourier/INPG/CNRS, Grenoble, France. [5]ESEO, Angers, France. [6]LAOB Univ. de Besançon /CNRS, Besançon, France. [7]LPCE Univ. d'Orléans/CNRS, Orléans, France.
lamblin@subatech.in2p3.fr

Abstract: The main goal of the CODALEMA experiment, located in the Radio Observatory in Nançay, France, is the radiodetection of extensive air showers initiated by high energy cosmic rays using helicoidal log-periodic antennas and short active dipoles in the 1-200 MHz bandwidth. First results showed that both antennas are able to detect the transient radio signals emitted by extensive air showers. In addition to the detection of cosmic rays, astronomic observations have also been performed with these antennas allowing an estimation of the absolute CODALEMA performance and a calibration of the antennas. After a brief introduction, the radio observation of a solar flare during January 2005 is presented and the possibility to use the Sun to estimate the angular resolution is shown. In a second part, the sensitivity to the galactic radio signal is demonstrated and a method to calibrate each antenna with this signal is described.

Introduction

The CODALEMA experiment, located at the Nançay Radio Observatory, is dedicated to the radiodetection of extensive air showers (EAS) initiated by high energy cosmic rays. During an initial phase, up to 11 conical helix log-periodic antennas from the Nançay Decameter Array [1] were associated to 4 particle detectors, allowing to provide firm evidences for a radio emission counterpart of EAS [2] and to start to characterize the radioelectric field pattern on an event-by-event basis [3]. To demonstrate the possibility of measuring the cosmic ray energy from the radio signal, 16 dipole antennas, developed by the CODALEMA collaboration, and 13 particles detectors, providing an estimation of the EAS energy, have been recently implemented. However, such a demonstration needs a good knowledge of antenna response. A way to perform antenna calibration is to use astronomical sources. Two examples are given in the present paper. In a first section, the radio observation of a solar flare is presented and the angular resolution deduced from it is reported. In the second section, the sensitivity to the galactic radio signal is shown allowing an estimation of antenna gain.

Solar flare radio observation

The experimental setup

On January 15th 2005, the CODALEMA setup was composed of six log-periodic antennas (cf. fig 1). Three of them had a right circular polarization (NE, SE, L1) while the other ones had a left circular polarization (NW, SW, L2). Signals were wide band amplified (35 dB) and sent, via low loss coaxial cables (SUHNER S12272-04), to LeCroy digital oscilloscopes (8 bit ADC, 500 MHz sampling frequency, 10 μs recording time). Signals were also band-pass filtered between 24 and 82 MHz to suppress AM and FM emissions. The data acquisition system was triggered by requesting a coincidence on the particle detector installed in between the antennas (cf. fig 1). The mean counting rate was about 0.5 events per minute.

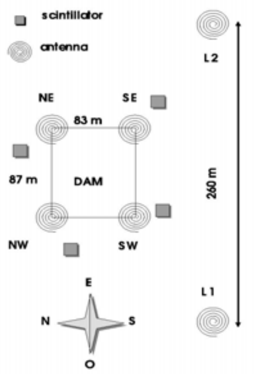

Figure 1: CODALEMA array on Jan 15th 2005.

Data analysis

Since the duration of transient signals corresponding to EAS cannot exceed a few tenths of nanoseconds, the 10 µs signal mainly comes from other sources. Regarding these sources, the trigger is clearly random. Figure 2 shows the mean squared signal for one antenna as a function of time.

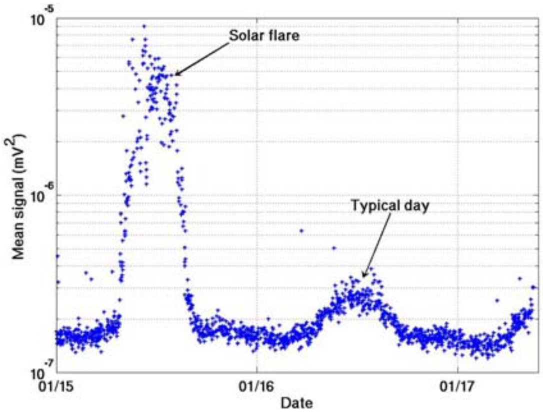

Figure 2: Mean squared signal over 10 µs vs time.

On January the 15th, the mean value is about 20 times higher than a typical day. At the same date, the Nançay Decameter Array, observing the Sun in the 1-100 MHz band, detected a particularly intense solar activity during almost the whole day. To confirm the emission source, we determined the arrival direction. As signals are not transient, individual start times cannot be identified to make a triangulation. However, the correlation function between signals of two antennas gives a peak showing that signals are well correlated and the position of this peak corresponds to the difference of arrival times between the two antennas. Using at least three antennas, triangulation becomes possible. The result of triangulation for all events is plotted on figure 3 and compared to the exact trajectory of the Sun from ephemeredes. The good agreement proves that the signal comes from the Sun.

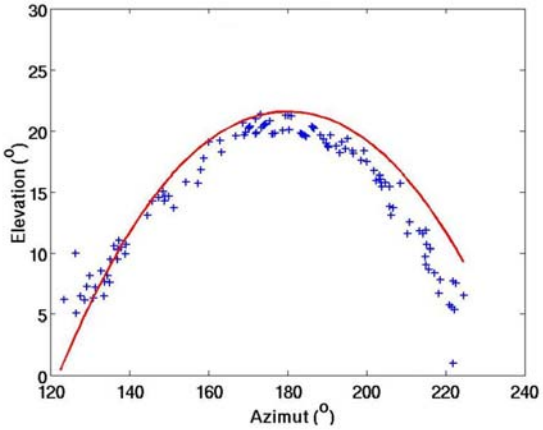

Figure 3: Reconstructed directions (crosses) compared to the Sun trajectory from ephemeredes.

As usually observed by astronomers, the signal was stronger for antennas with left circular polarization. Thus, only these antennas have been used for the triangulation. When all antennas are used together, triangulation still works but correlations are weaker.

Angular resolution

Since the arrival direction of the signal is known, it can be used to estimate the angular resolution.

The standard angular deviation on all events along the trajectory is 2.7°, which is already a good resolution considering that only three antennas have been used. However, a little shift on figure 3 between reconstructed and real Sun position reveals systematic errors. These errors could be explained by the flattened shape of the triangle made by the three antennas used (NW, SW, L2). Figure 4 presents the angular distance distribution after correction for systematic errors, fitted by the expected function, i.e., a Gaussian centered on zero multiplied by a sine function coming from the solid angle factor. The standard deviation of the corresponding Gaussian, which is the angular resolution related to point-like source detection by three log-periodic antennas, part of CODALEMA array, is about 0.7°.

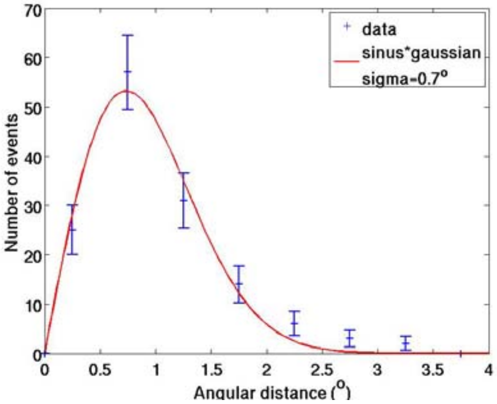

Figure 4: Angular distance distribution.

Galactic radio signal

Gain and directivity constitute the second important aspect to understand the antenna performance. As the distance between the source and the receiver must be higher than several wave lengths, antenna calibration is not simple in the 1-100 MHz band. A way to perform it is to use the galactic radio signal provided that electronic noise and local emitters are not dominant.

Galactic signal sensitivity

The frequency spectrum at Nançay, measured with a log-periodic antenna, is presented on fig. 5.

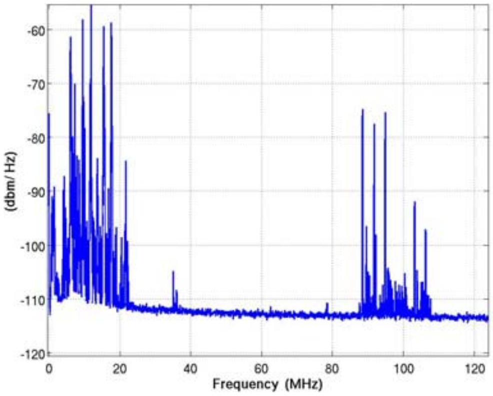

Figure 5: Frequency spectrum at Nançay.

In the following, only data in the 37-70 MHz band, almost free from emitters, will be considered. The base line value in this band is compatible with the galactic signal. Indeed, the signal standard deviation, averaged over all antennas, for each local sidereal hour is calculated over a six months period (cf. figure 6). The signal dependence as a function of the local sidereal time (LST) demonstrates that our antenna setup is sensitive to a galactic signal; otherwise it would have been constant.

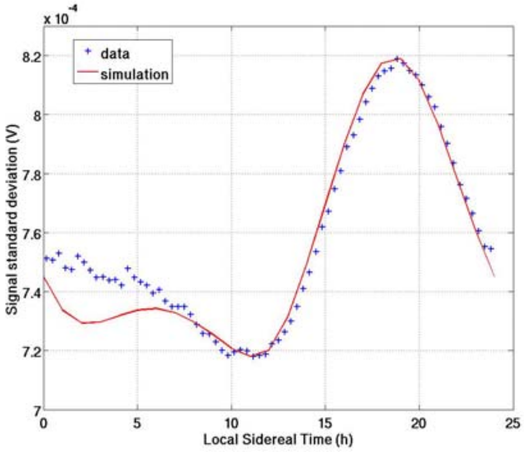

Figure 6: Averaged signal as a function of the local sidereal time over 6 months.

Galactic signal simulation

In order to simulate the data on fig. 6, the radio signal intensity along the galactic plane, in arbitrary units, has been considered [4] (cf. fig. 7).

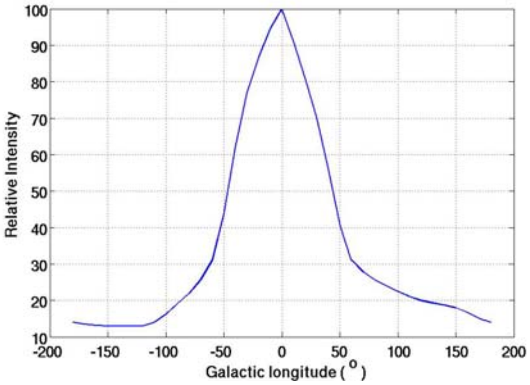

Figure 7: Radio signal intensity along the galactic plane [3].

For each LST bin, the sum over the galactic signal multiplied by the simulated gain in the corresponding directions is calculated (written as I_{gal}). Then, this total expected signal is fitted on the data with two free parameters. The first one is a calibration factor, c, to convert the calculated galactic signal in Volts at the system output, including all the electronic chain. The second one is an offset value S_{const} corresponding to all other signals which are constant in LST, such as:
$S_{measured}{}^2 = c^2 I_{gal} + S_{const}{}^2$.

The fit result is shown on fig. 6. The agreement between data and simulation is very good, proving that the galactic plane is the main origin of the measured signal. Below 7h, the difference could be explained by the emission from other galactic regions which have not been included here. This will be checked in a future study.
The parameter values obtained are:
S_{const} = 0.70 mV and $< c.\sqrt{I_{gal}} >$ = 0.28 mV.

Antenna calibration

Using the formula for converting voltage into electric field discussed in [2], the measured galactic signal corresponds to a field E=7.7 μV/m. Thus, assuming the galactic frequency spectrum in the 37-70 MHz band to be flat, the Fourier coefficient in this band is $(\varepsilon_\nu)_{Meas}$= 0.23 μV/m/MHz.
Starting from the whole sky surface intensity at 50 MHz, I_ν=5.6 10^{-21} $Wm^{-2}Hz^{-1}sr^{-1}$ [4], the flux density is S_ν=2.4 MJy (considering the aperture is 8π/6). Using the formula $S_\nu = \varepsilon_\nu{}^2 \varepsilon_0 c/\Delta t$ [5], with Δt = 2 ns, it gives $(\varepsilon_\nu)_{Th}$ = 0.14 μV/m/MHz, which is of the same order of magnitude as the measured value, particularly as the aperture might be slightly different. This result indicates that the response of our antennas for the galactic noise is under control and can be used for voltage conversion into electric field.

In addition to absolute calibration, the galactic radio signal can be used to make a more precise relative calibration between all antennas requesting that LST signal variations must be the same in each antenna. This relative calibration has been performed on the log-periodic antennas. Fluctuations between antennas are lower than 15%.

Finally, the galactic signal is also a way to test the antenna directivity as the antenna lobe is included in the simulation. The log-periodic simulated lobe is close to a Gaussian function for which the standard deviation is 45°. Indeed, if this value is modified by 10°, the simulation clearly disagrees with the data.

Conclusion and Outlook

Astronomical objects can be used to calibrate and test the ability of antennas. The Sun allows to test the angular reconstruction made from antenna array data. In the case of a point-like source detected by three log-periodic antennas, few tenth meters away from each other, the angular resolution is about 0.7°.
Galactic radio signal allows to calibrate antennas in the 40-70 MHz band and to test their directivity. Applied to the log-periodic antennas, absolute and relative calibrations gave good results.
In the future, the same work will be done with the dipole antennas developed by the CODALEMA collaboration.

Acknowledgments

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