Surrounding effects and sensitivity of the CODALEMA experiment

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Abstract

Future autonomous systems of cosmic ray radiodetection will be installed over large areas, encountering various environmental and noise conditions. It is thus essential to check and evaluate the influence of the vicinity on the sensitivity of detection. In this paper, the main environmental influences on the performances of the CODALEMA experiment are presented. It will be shown that the performances and sensitivity of the detector are not affected by the environment, and that the new CODALEMA autonomous detection station can reach the ultimate accessible sensitivity even in a quite noisy environment. This allows deconvolving the detector's response and recovering the real spectral characteristics of the cosmic ray air showers.

Keywords: Cosmic ray radiodetection, CODALEMA, radiodetection sensitivity, environmental influence

1. Screening and surrounding effects

Set up on a 600×450 m area in the Nançay Observatory's forest, the antennas of CODALEMA encounter very various environments. The one with the most extreme environment is installed exactly in the middle of the DecAMetric array telescope (DAM, see Fig. 2). In order to evaluate the impact of various vicinities on a future large array, it is interesting to observe the influence of the environment in the CODALEMA array. As a first test, the arrival direction distribution of detected cosmic ray (CR) events for each antenna was computed and compared to the distribution seen by the global array. The latter presents a north-south asymmetry due to the geomagnetic effect in the emission process [1]. A difference with this weighted distribution can sign a shadowing effect on the antennas. It has then been verified that the antennas, even the one placed in the DAM, show similar distributions in the arrival direction of events (Fig. 1). In the worst case, the ratio of events not detected by one antenna but seen by the others (which may be due to its vicinity) is lower than 10% of the total number of events. It shows that, even if the presence of large metallic objects around an antenna can modify its lobe properties (see below), it does not affect its detection ability at the present level of CR detection.

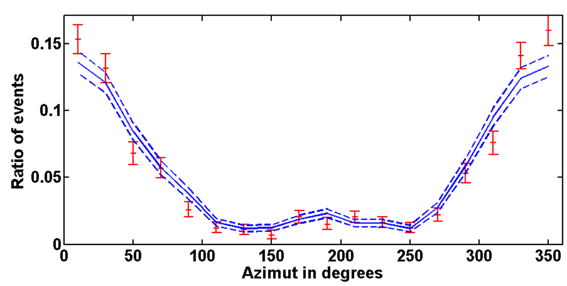

Figure 1: *The arrival distribution of events seen by the antenna in the center of the DAM (crosses) is not disturbed by the vicinity and is very similar to the global distribution (solid line with ±1 σ level in dotted lines), in particular toward west at 90^o and east at 270^o, where the antennas of the DAM are very close to the dipole.*

However, for some event arrival directions, the frequency spectra of one antenna show oscillating features, which seem to be due to interference. A complete simulation of the antenna's environment, with a signal coming from the direction of the shower, was performed with the 4NEC2 software. The interfer-

Figure 2: *Some currently used active dipole antennas of the CODALEMA setup. From left to right : in a clear environnment, close to a metallic shelter, in the center of the DAM, and a picture of the DAM itself.*

ence were due to the modification of the antenna reception diagram by the metallic structure near the dipole. This effect is well reproduced by the simulation (Fig. 3). A specific antenna diagram (in substitution to the standard lobe) is thus used for the analysis processes, smoothing the interference so as the corrected spectrum approach the one observed by the others antennas.

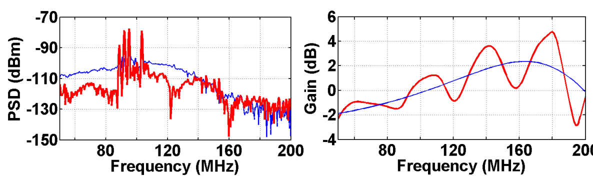

Figure 3: *Left: thin line (blue), raw spectrum of a powerful event seen by a standard antenna ; thick line (red), raw spectrum of the same event seen by the antenna close to the metallic shelter. Right: simulated gain pattern versus frequency for two antenna environments, assuming a white noise in the arrival direction of the cosmic ray (without considering the antenna amplifier response). Thin Line (blue) : without shelter, Thick line (red) : with the metallic shelter. Oscillations in the spectrum are well reproduced and the specific, modified antenna lobe can be used in analysis processes.*

2. Sensitivity of the radio detection

2.1. Radio noise sources

Parasitical signals exist even within the radio-protected area of the Nançay radio Observatory. Their source localization is possible by triangulation using a spherical fit, as soon as at least 4 antennas are fired. The localization and knowledge of the nature of the source can give information on radio-detection sensitivity as well as on direction reconstruction accuracy. During dedicated measurement campaigns, the particle detector trigger traditionally used in CODALEMA [1] was removed and the antenna array was self-triggered by a single antenna, in order to explore exclusively the transient radio environment. Different data sets were produced with this objective:

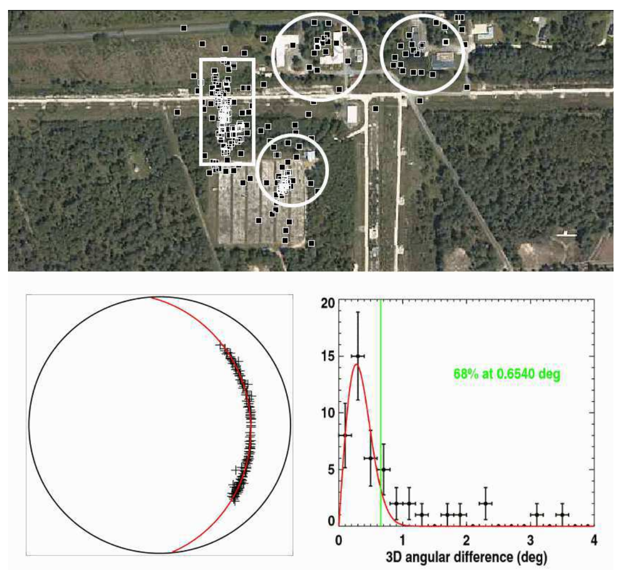

Figure 4: *Examples of results obtained on parasitical signals. Up, map of close source locations reconstructed by antennas (black squares) superposed to aerial view of the Observatory, showing the location of the noise sources. They correspond to some buildings (white circle) and one close antenna of the radioheliograph (white square). Bottom, left: reconstruction of the trajectory of a plane projected on a sky map. Each cross stands for a single reconstructed event, the red line is a fit of a linear trajectory. The plane comes from north to south. It is visible in radio during 2 minutes. Bottom, right: distribution of angular differences between reconstructed points of the trajectory (crosses) and the fitted trajectory. The width of the peak distribution gives a reconstruction accuracy better than 0.7 degree.*

Very close noise sources were found and localized.

They are coming from some buildings at the North of the station, especially those without any electromagnetic shielding (white circles, Fig. 4, top).

The antennas of the radioheliograph (distributed along the T-shaped roads in white on the aerial picture of Fig. 4, top) produce parasitical signals during their repositioning for next day solar observations, which occurs automatically between 0h00 and 0h15 each day. The closest radioheliograph antenna is well localized by our reconstruction (white circle, Fig. 4, top).

During certain periods, a signal occuring each 1.32 s is triangulated at $\simeq$2000 m in the S-SE direction. An electric fence has been found at the predicted position, and is a good candidate for the emission of the parasit, still under investigation.

At last, trajectories of planes passing above Nançay were recognized in the data. The reconstruction of the plane's emission is made with an angular precision better than 1^o (Fig. 4, bottom). Though still under investigation, the emission source is suspected to be the transponder of the plane, used in radar recognition. This last result is very encouraging, because the plane signals can then be used for a relative calibration in time and amplitude between the antennas.

2.2. Self-triggered, autonomous stations

Besides the existing "cabled" antenna array, 3 self-triggered, autonomous radiodetection stations have been installed within CODALEMA in July 2009. Such an autonomous station is composed of a so-called "Butterfly" antenna [2] and an electronic crate embedded in a dedicated, electromagnetically shielded box which also serves as a support for the antenna pole. Antenna signals in dual polarization (EW and NS) feed a trigger board where triggering decision is made on a simple voltage threshold level in a 45-55 MHz filtered band [1]. Events are then dated by a GPS and digitized by an ADC (1 GS/s, 2560 points for 2.56 μs record). An embedded PC masters monitoring, data storage and transmission to the outside world. On the radio-protected site of Nançay, communication with the autonomous stations is operated by optical fiber, though these stations are as well able to be supplied with solar panels and to use a WiFi link for communication. A special effort has been made to reduce the electromagnetic emission of the electronics, to avoid influencing the own antenna measurements and polluting the other radio Observatory instruments. Extensive tests to evaluate the noise produced by the autonomous station (measurements in an anechoic chamber and with the Nançay radioheliograph and radiotelescope themselves) were realized and showed a very limited, if any, emission of the station, and especially nothing in the 1-100 MHz band where cosmic rays are searched. At last, with respect to the former CODALEMA active dipole, the active Butterfly antenna presents improved performances in the 20-80 MHz band, with an excellent sensitivity and a completely flatten low noise amplifier (LNA) frequency response [2].

In normal acquisition mode, the autonomous stations and the cabled array are independent with respect to the trigger induced by the particle detector. However, offline time coincidences can be searched in order to find cosmic rays seen by the autonomous stations. Few "singlets" (one single autonomous station in coincidence with the cabled array) and "doublets" (involving two stations) have occurred (Fig. 5). This shows that the autonomous detection in self-triggered mode is currently operational, and demonstrates the possibility to cover wide areas with autonomous detection stations. Improvements were made on the electronics and software of these devices and CODALEMA will be upgraded in a subsequent phase with 60 such stations [1].

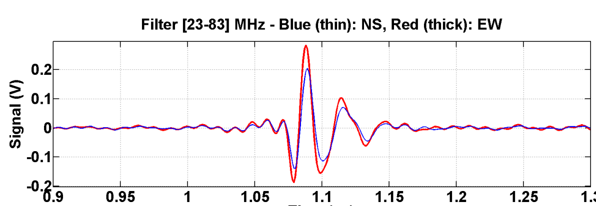

Figure 5: *First CR event autonomously detected by the CODALEMA self-triggered stations at the Nançay observatory. When offline filtered in a clean frequency band (23-83 MHz), the transient appears on both channels.*

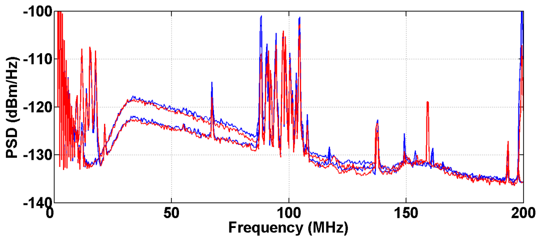

Figure 6: *Spectra obtained with one autonomous station for the minimum (bottom curves) and maximum (top curves) galactic emission. Blue: NS polarization, red: EW polarization. Both encounter similar variations. Note that the local bump around 150 MHz is predicted by simulation and due to the response of the active antenna.*

2.3. Sensitivity of autonomous stations

The galactic background is the ultimate boundary for radio-detection: this signal is emitted by the whole Galaxy, but is clearly higher in the direction of the galactic plane. The linearity and the sensitivity of the active Butterfly antenna and its associated station electronics have furthermore been verified using the galactic temperature as a calibrating source in a test bench qualified by the radio astronomers of Nançay. It consists on continuous acquisitions of spectra during a long time while looking at the galactic background drift. Fig. 6 shows that our autonomous stations detect galactic background variations due to the Galaxy drift during the day: the level of signal between 25 and 80 MHz is clearly varying, of the same amount in both antenna polarizations (EW and NS), between the maximum and the minimum of the galactic plane emission passing in the sky, while man-made emissions (AM below 15 MHz and FM lines between 80 and 100 MHz) are constant, except for AM between 15 and 25 MHz due to daily ionospheric effect.

Thanks to this sensitivity and an accurate knowledge of the antenna response, it becomes possible to reconstruct the cosmic ray air shower electric field frequency spectrum. An example was studied with the most powerful event observed at Nancay. Unfortunately, the energy of this event (more than 10^{18} eV) could not be precisely determined by the particle detector, for the shower core was outside the detector perimeter. However, when corrected by the simulated antenna response, the shape and the power of the spectrum agree with the simulations made with the Selfas2 code [3] for a 10^{18} eV shower with same direction (Fig.7).

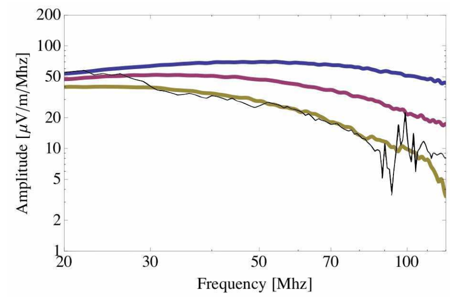

Figure 7: *Thin line : spectrum corrected of the antenna response for a powerfull event observed at the Nancay observatory (200 to 300 m axis). Thick lines: Simulation obtained with Selfas2, for a 10^{18}eV event, at 200, 250, 300 m of the shower axis (top to bottom curves). Real spectrum exhibits FM line residuals around 100 MHz.*

3. Conclusion

We have shown that screening or any environmental effect do not affect seriously event detection statistics. Simulations allow to understand and correct specific rare interference effects, and to understand detector response for signal correction purposes. Thanks to dedicated measurements, most of the local radio noises have been identified and are now well understood. Moreover, the CODALEMA autonomous station is "self-silent" and the sensitivity of the galactic background (ultimate noise) is reached in acquisition mode. Thanks to a well-known instrument, an accurate CR physics becomes possible using a wide detection bandwidth.

References

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[2] D. Charrier et al., this conf

[3] V. Marin et al., this conf