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M. Heydari-Malayeri, C. Reylé and R. Samadi (eds)

DETECTION AND CHARACTERIZATION OF THE COSMIC RAY AIR SHOWER RADIO EMISSION WITH THE CODALEMA EXPERIMENT

Garçon, T.[1] and the CODALEMA collaboration[1, 2]

Abstract. The setup of the CODALEMA experiment installed at the Radio Observatory of Nançay, France, is described. The observed asymmetry, in the arrival direction distribution of radiodetected cosmic ray showers above 10^{17}eV, is interpreted as the signature of the geomagnetic origin of the air shower radio emission. In order to correlate the primary particle energy to the associated radioelectric field, the lateral distribution functions of the radio signals are carefully studied. In this aim, antenna's breakdowns or possible environmental effects modifiying these signals are currently analyzed and will be presented.

1 Introduction

The two major methods for the observation of extensive air showers (EAS) use surface detectors and fluorescence detectors, measuring respectively the charged particles at the ground level and the fluorescence light of the EAS. The advantage for the first one is its high duty cycle when the second one presents a large detection volume efficiency and a lower shower model dependence. The radiodetection technique could combine these advantages.

The idea of EAS radiodetection has been suggested for the first time in the 60's. The charge excess mechanism was first proposed as the origin of the induced radioelectric field (Askar'yan 1962). Today, the geomagnetic induced mechanism, which was suggested by Kahn et Lerche (Kahn 1965), are preferentially investigated (geosynchrotron radiations (Huege 2005), or transverse current induced emissions (Scholten 2008)). The first experiments in the 60's obtained promising but conflicting results, leading to the surrender of the giving up in the 70's. Today, with the improvement of fast electronics, EAS radiodetection becomes an operational technique. Several experiments, like CODALEMA in France (Ardouin 2005) or LOPES in Germany (Falcke 2005), have already observed evidence for a radio emission from EAS.

2 Setup of the CODALEMA experiment

The CODALEMA experiment uses three arrays of detectors : the particle detector array, the antenna dipole array and the Nançay decameter array. This later is dedicated to the study of the electric field with a high spatial resolution (Lecacheux 2009), but its results aren't discussed in the current analysis. The particle detector array is dedicated to the estimation of the shower characteristics (primary energy, arrival time, direction, size and core located of the EAS) using the particle density of the shower at the ground level. It consists in 17 scintillator stations on a grid of 340m × 340m (Fig. 1, left). The number of particles reaching the ground and the core position are calculated from the measured particle densities in these detectors. The lateral distribution is fitted with an analytical Nishimura-Kamata-Greisen lateral distribution using a minimization algorithm. Finally, the energy is computed by the CIC method with a resolution of 30%, from simulations of proton induced EAS run with AIRES (Sciutto 2005). This array produces also a logic signal to trigger the antenna signal acquisition. In order to detect the radio signals seen in coincidence with ground detectors a short active dipole (Fig. 1, right) was developed (Charrier 2007). It is made of two 0.6 m long and 0.1 m wide aluminium slats separated by a 10

[1] SUBATECH IN2P3-CNRS/Université de Nantes/Ecole des Mines de Nantes France

[2] LESIA, Observatoire de Paris-Meudon France - Station de Radioastronomie de Nançay France - LAL, IN2P3-CNRS/Université de Paris Sud Orsay France - LPSC, IN2P3-CNRS/UJF/INPG Grenoble France - ESEO, Angers France - LAOB, INSU-CNRS Besançon France - LPCE, SDU-CNRS Université d'Orléans France

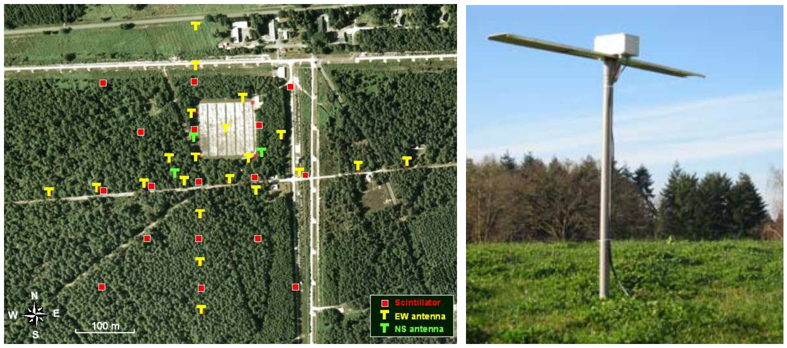

Fig. 1. Left : Schematic aeral view of the Codalema experiment. Plastic scintillators are depicted as squares, antennas as T, oriented in the NS and EW direction. **Right**: One dipole of the antenna array.

mm gap. This antenna, with smooth variations of lobe, is loaded by a dedicated high input impedance low noise amplifier providing a good sensibility and linearity at a high dynamics. The antenna array is made of a 600 × 450 m cross-shaped core of 14 antennas in East-West (EW) polarization, 7 antennas located between these arms and 3 other ones in North-South (NS) polarization (Fig. 1, left). A central shelter houses the acquisition sytem and power supplies and is connected to the detectors by cables. So-called Matacq ADC boards perform a 12-bits digitalization of signals, at a sampling rate of 1 GS/s and with a memory depth of 2560 points (i.e. 2.5 μs of signal). If the 5 central scintillator stations detect a signal in coincidence within a 600 ns gate width, a trigger is produced to record all signals of the two arrays. This trigger condition leads to an event rate of about 7 events per hour. The antenna signals are digitally filtered offline (23-83MHz), to eliminate FM and AM contributions, and corrected for the cable frequency response. Transient radio pulses are searched independently in each antenna waveform using a linear prediction method which eliminates also the emitters whose frequencies lie in the range used for the experiment. When pulses are detected, an absolute time is associated to each of them and corrected for the cable and electronics delays. From this information, the time and the arrival direction of the shower plane can be obtained by simple triangulation. Finally, the radio and particle events are folded into one single event. We limit the angular difference between both to 20 degrees and the time difference to ± 100 ns in order to keep only well reconstructed events and eliminate random radio events. A last criterion is applied if the larger particle density belongs to a scintillator in the middle of the array. For these so-called internal events, the energy and the shower core location can be estimated with a good accuracy. For details, see (Ardouin 2005, 2006, 2009).

3 Results

The energy distribution measured by the ground particle array for internal events is displayed Fig. 2, left, and compared with the same energy distribution of events measured in coincidence by the antenna array. The threshold of the radio detector is clearly visible below 10^{17}eV. Both distributions converge at 10^{18}eV. This reflects the increase of the radio detection efficiency at high energies. Fig. 2, center, represents the arrival directions of the radio events, in local coordinates, detected in the EW polarization. In the azimuthal distribution, a large asymmetry is visible in the observed event density between the North and the South sectors. This South side deficit is not observed on an antenna background (self-trigger) or for the internal scintillator events. This observation is thus not associated to a detector failure or a statistical fluctuation but requires an investigation of the electric field generation mechanism of the EAS. An obvious candidate for symmetry breaking effect in the electric field generation is the geomagnetic field, via the Lorentz force. The electric field magnitude of this contribution should depend on the values of the vector cross product $v \wedge B$ where v is the direction of the primary particle. The predicted event sky map computed with this hypothesis (Fig. 2, right) is very similar to the observed sky map. Especially, simulated zenithal and azimutal distributions are compared to the data and show both good agreement. The polarity (ie. the sign) of the signals and the preliminary results obtained for the antennas detecting in the NS polarization are also in good agreement with simulations. This result confirms the importance of geomagnetic mechanism in the radioelectric field creation process (Ardouin 2009).

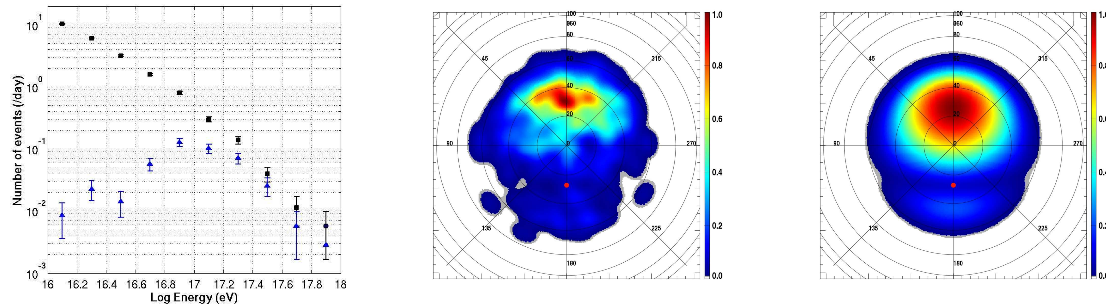

Fig. 2. Left : Energy distributions for internal events measured by the particle detectors (squares) and seen in coincidence by the antennas (triangles). **Center** : Sky map of observed radio events, detected in the EW polarization, using a 10° gaussian smooth (Zenith is at the center, North at the top, West at the left). The direction of the geomagnetic field is indicated by the red dot. **Right**: Sky map calculated by considering the EW component of the Lorentz force convolved by the trigger coverage map, and the antenna lobe. The color scale is normalized to 1 in the direction of the maximum.

4 Monitoring and effects of the environnement

The experimental setup of CODALEMA allows an independent measurement of the radioelectric field for each antenna. The electric field lateral distribution, which is simply the signal amplitude as a function of the distance to the shower axis is computed event by event and has been fitted with an exponential function, $E_0 e^{-\frac{d}{d_0}}$ (Allan's parameterization (Allan 1971)). The fit uses 4 free parameters, E_0, d_0, and the core position (X_0 and Y_0), and d is the distance to the shower axis. The event profiles are well fitted by such an exponential function and permit to study the correlation in energy, but for some of them ($\approx 20\%$), profiles are flat and an exponential fit doesn't make sense. Several detection effects could explain these unexpected profiles. To understand them, monitoring of the antenna array, on the one hand, and study of environnemental effects on the other hand are currently realized. For one year, a monitoring method has been setup to detect with accuracy breakdowns in the antenna array. The monitoring of the noise measured by each antenna during long data taking sequences is especially powerfull to underline breakdowns for one antenna, or an emergence of transmitter close to the array. The detection, the analysis, and the repair of these breakdowns become fast and easy. For several unexpected profiles, the removal from the fit of antennas showing breakdowns allows to increase the quality of the lateral distribution reconstruction (Fig. 3). Independently, it is possible to use an algorithm to ignore, in the analysis, the antenna signals which degrade strongly the profile. Both methods give similar results on profile corrections. A quantitative study is under way to compute the ratio of improved profiles with these methods.

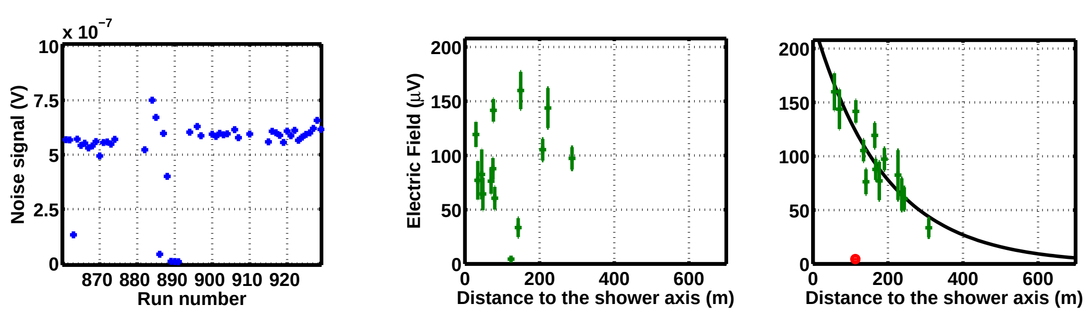

Fig. 3. Left : The monitoring shows a breakdown, between the 875th and 895th run (one month) for one antenna. **Center** The result of the lateral distribution fit for one unexpected profile, during the antenna breakdown. **Right** : Result after the removing of the dysfunctional antenna (red dot at the bottom) during the minimization process of the χ^2. An exponential profile is recovered. Consequently, the location of the shower core can change.

One additionnal correction has been obtained by analyzing the environnements of the antennas, which vary from one to the other. This is found to have an impact on the measured electric field (and consequently on the quality of the lateral distribution). For some arrival directions of events, frequency spectra of few antennas show oscillating features, which seem to be due to interference. One of these typical events showing oscillating patterns in the spectrum is presented Fig. 4. A complete simulation of the environnement of the antenna, with a signal coming from the direction of the shower, was done by the simulation software 4nec2X suggesting that the interference were due to the modification of the antenna lobe by a metallic shelter close to the antenna. The interference effect is well reproduced by the simulation. A personalized antenna lobe for this antenna can especially be used for all analysis processes (under investigation).

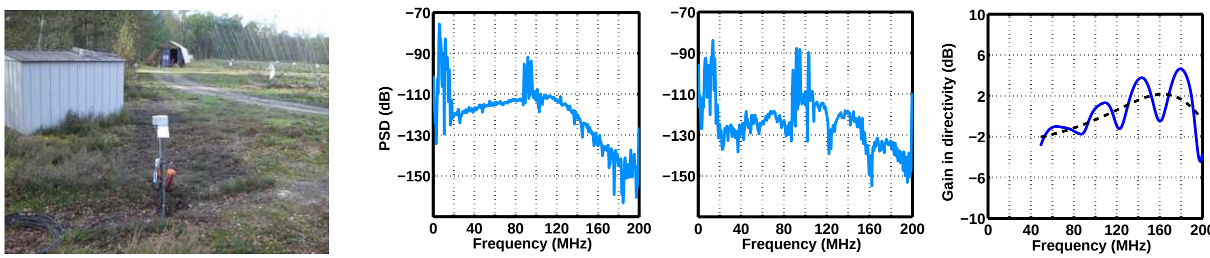

Fig. 4. From left to right **A** : Antenna close to the metallic shelter. **B** : Raw spectrum of a powerful event seen by one normal antenna. **C**: Raw spectrum of the same event seen by the antenna close to the metallic shelter. **D**: Simulated gain vs frequency for two antennas, for a white noise in the arrival direction of the cosmic ray (without considering the amplifier response). Doted lines : without shelter. Solid line : with the metallic shelter.

5 Conclusion

The CODALEMA experiment shows very promising results both in the physical interpretation of the results and in the developpement of the radiodetection method. Improvements in the simulations, and study of fine detection effects are currently under way. Moreover, radio detection with autonomous stations presently in developpement in the CODALEMA collaboration will allow to detect EAS at higher energies (10^{19}eV) and larger impact parameters (1000-2000m vs 400m today), and larger zenith angles. To reach this goal, the first stations are deployed at the same time on the CODALEMA site, and on the Pierre Auger Observatory for the AERA project.

References

Allan, H. R., 1971 , Progress In Elementary Particle And Cosmic Rays Physics, 10, 171

Ardouin, D., & al., 2005, Nucl. Instrum. Meth. A, 555, 148

Ardouin, D., & al., 2006, Astro. Phys., 26, 341

Ardouin, D., & al., 2009, Astro. Phys., 31, 192

Askar'yan, G. A., 1962, Soviet Physics, J.E.T.P., 14, 441

Charrier, D., 2007, & al., Nucl. Instrum. Meth. A, 572, 481

Falcke,H., & al., 2005, Nature, 435, 313

Huege, T., & Falcke, H., 2005, Astro. Phys., 24, 116

Kahn, F. D., & Lerche, I., 1965, *Radiation from cosmic ray showers*, Astronomy Department, University of Manchester

Lecacheux, A., & al., 2009, Proceedings of the 31st ICRC, Lodz

Scholten, O., Werner, K., & Rusydi, F., 2008, Astro. Phys., 19, 477

Sciutto, S.J., 2005, AIRES, version 2.8.0, 2005, http://www.fisica.unlp.edu.ar/auger/aires/