Geomagnetic effect observed by the Codalema experiment

Lilian Martin
SUBATECH
CNRS/Université de Nantes/ École des Mines de Nantes
Outline

• The CODALEMA experiment
• Some examples of radio signals
• Radio detection efficiency and angular asymmetry
• Interpretation in terms of a geomagnetic effect
• Hardware developments
• Upgrades
**CODALEMA goals**

- To measure the radio signal associated to the atmospheric shower produced by highly energetic cosmic rays reaching the Earth

- To revisit a technique unsuccessfully explored 40 years ago by:
  - understanding the radio production mechanisms
  - Identifying key observables correlated to the air shower and the primary cosmic particle features

- To develop a detection technique competitive with conventional surface detectors in terms of:
  - Quality of data (sensitivity, resolution)
  - Efficiency and duty cycle
  - Simplicity, robustness and COST
The CODALEMA collaboration

8 French laboratories (IN2P3 and INSU)
1 experimental site

2002: first tests with logarithmic antennas

2009: large arrays routinely taking data
The Decametric array (DAM): 144 log-periodic antennas (80x80 m²)

24 dipole antennas (two arms of 600m)

17 Surface Detectors (340x340 m²)
Some pictures
The CODALEMA short active dipole

- Simple and cheap
- Smooth radiation patterns
- Frequency response at Nançay
- Aluminum dipole antenna
- A dedicated LNA(ASIC)

- Low noise
- Wide bandwidth
- High dynamic
- Good linearity
**Trigger and data acquisition**

- Trigger logic: Custom board allowing to remotely change:
  - threshold values
  - coincidence conditions
- MATACQ ADC: 300 MHz, 12 bits, 1 GS/s, 2500 samples, 4 channels, VME or GPIB
- Slow trigger rate:
  - GPIB reading
  - LabVIEW for DAQ and monitoring

Coincidence of the 5 central SD:
Trigger rate of ~200 events/day
Data processing

SD Antennas
  \[\text{Filtering} \rightarrow \text{Corrected signals}\]
  \[\text{Tagging} \rightarrow \text{Times, amplitudes}\]
  \[\text{Positioning*} \rightarrow \text{Arrival directions}\]
  \[\text{Amplitudes} \rightarrow \text{Shower core position}\]
  \[\text{Lateral distribution}\]
  \[\text{CIC} \rightarrow \text{UHECR energy}\]
  \[\text{Coincidences} \rightarrow \text{Selection of well reconstructed UHECR}\]

* positioning by computing the time difference of arrival (TDOA) of the signal received by three or more SD/antennas.

Filtering 23-83+110-130 MHz

Tagging and positioning

North

South

Tag

Prediction from SD

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**Measured data: some examples**

**Time signals**
- Pulses restricted to some antennas

**Variations in the lateral distribution of amplitudes**

**Low energy event:**
- Clear transient signal in filtered time series
- No clear contribution in the frequency domain

**Frequency spectrum**
- Not that much besides the AM and FM bands

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*Subotech*

Lilian Martin, RICAP'09, Rome, Italy
**Measured data: some examples**

Very large event:
- Transient signal in raw data
- Large contribution in the spectrum

Unfiltered!
Information on the shower:
- arrival direction
- shower core position
- Energy estimate (CIC method)

2 classes of SD events for the analysis

**Internal events**: Station with the maximum signal not on one edge of the array. Correct estimate of shower energy and core position.

**External events**: Unreliable estimate of shower energy and core position. Correct arrival direction.

Coincidences (SD and Antennas):
- angular difference < 20°
- time offset < 100 ns
**Radio detection efficiency**

CODALEMA is performing radio measurements at the detection threshold $\rightarrow E_{th} \sim 5 \times 10^{16}$ eV

Full efficiency is not observed

<table>
<thead>
<tr>
<th>Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Effective data taking time</td>
<td>355 days</td>
</tr>
<tr>
<td>Trigger (SD events)</td>
<td>61500</td>
</tr>
<tr>
<td>Reconstructed antenna events</td>
<td>750 (2.1/day)</td>
</tr>
<tr>
<td>Coincidences (SD and antennas)</td>
<td>620 (1.7/day)</td>
</tr>
<tr>
<td>Coincidences (Internal)</td>
<td>157 (0.4/day)</td>
</tr>
</tbody>
</table>

Extend the SD array!
The deficit is clearly in the southern region:
\[ \frac{N_{\text{south}}}{N_{\text{total}}} = 0.17 \]

The SD azimuthal distribution is flat: not a trigger effect

Independent subsets of events give similar results.

Larger effects on smaller energy events.

Geomagnetic field direction.
**Hypothesis:**
- The electric field is proportional to the Lorentz force \( E \propto |v \times B| \)
- Charge particles in the shower are deflected by the geomagnetic field (At Nançay: +q toward East and −q toward West)
- Electric field polarization in the direction of the Lorentz force: linear polarization is assumed \( E // v \times B \)
- The number of count (ie the efficiency) depends on the electric field magnitude: a simple linear dependence is assumed

**Predicted covering map:**
Total Lorentz force \( (E \propto \sin(\alpha)) \)  
Trigger acceptance (zenithal angle distribution)  
Antenna lobe (EZNEC simulation)  
Projection on East-West axis (CODALEMA antenna polarization)
The model reproduces quite well the observed distributions:
- The maximums and local maximum
- The minimums

Azimuthal asymmetry: comparisons
At $10^{17}$ eV and Nançay, the efficiency scales linearly with $|v \times B|_{EW}$:
Assumption of detection proportional the field amplitude is OK

$$E' = E \cdot |(v \times B)_{EW}|$$
Energy weighted by the cross product. Efficiency tends to reach 100%
This linearity is probably only valid at threshold. Must be different at other energies.
**Measuring the NS polarization**

Is this picture valid for the NS polarization?

The statistic is lower but at the first look: **YES**

Most of the events are coming from East and West directions.
The model assumes the electric field magnitude to be proportional to $| (v \times B)_{EW} |$. Is the signal polarity given by $(v \times B)_{EW}$?

Event Signal:
- antenna tag are signed
Event sign: given by the majority of signed tags

In the NS polarization
CODALEMA upgrade: improving the antenna

New prototype more suited for: robustness, easy production, 2 polar. measurements

Measurement with a prototype
Simplified half antenna (one polar.)
Improved sensitivity (galactic noise dominated) and stronger radio-diffusion suppression

Galactic noise
System noise
French efforts to develop an **autonomous** system:

- first prototypes were built with commercial material and existing Auger electronics: in used at Radio Auger (first cosmic events self triggered on radio signal)
- development of a custom made new system is under test at CODALEMA and soon at Radio Auger

**CODALEMA upgrade : autonomous station**

- Support for the antenna (top)
- Batteries (back)
- Metallic box for protection and electric shielding
- Electronics crate (front)
- Autonomous in terms of power, trigger, DAQ, coms.
New electronic crate

Onboard PC (fits in the rack)
Foreseen upgrades of the antenna array

- Replacement of the existing dipole antennas by butterfly antennas.
- Installation of (semi)-autonomous station in the current array for testing and debugging.
- Extension of the current array
  - Higher antenna density at the center
  - Extension at larger scales
- Installation for testing in Argentina

Tentative implementation of new stations at Nançay