Low frequency observation of cosmic-ray air-shower radio emission by EXTASIS

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What ? Low frequency detection

- Radio emission from kHz up to GHz
- Commonly used band [30-80] MHz (CODALEMA, AERA, LOFAR, TREND, Tunka-Rex, Yakutsk)
- Low frequency (LF): no current experiment until now < 10 MHz
- Expected signal from shower development (geomagnetic + charge excess) + « sudden death » signal
Why? New signal

Proton $10^{17}$ eV
Vertical shower $d_{\text{antenna}} = 300$ m
For Nançay site

[arXiv:1307.5673]
[arXiv:1211.3305]

Talk from D. García-Fernández-CRI103
Why ? Larger detection range

Simulated footprints of electric field for different frequency bands

Limited detection range in classical band [30-80] MHz

Larger at low frequencies (<5 MHz) (sparse, cost effective array)
How? New antennas
How?

9m height

Regular Butterfly antennas with a modified LNA for [1-10] MHz

Externally triggered by scintillators
Environment and sky

Dominated by man-made and atmospheric noise

Atmospheric noise lower during day than during night \(\Rightarrow\) duty cycle \(\sim 50\%\)
Preliminary results
Low frequency events (I)

Arrival direction reconstructions:
- $\Theta_{SA} = 60^\circ$, $\phi_{SA} = 153^\circ$
- $\Theta_{SC} = 61^\circ$, $\phi_{SC} = 154^\circ$
- $\Theta_{LF} = 66^\circ$, $\phi_{LF} = 155^\circ$

We see atmospheric air showers at **low frequency** ([1.7-3.7] MHz)

Detection range seems indeed larger at low frequency
Low frequency events (II)

Arrival direction reconstructions:
- $\Theta_{SA} = 41^\circ$, $\phi_{SA} = 145^\circ$
- $\Theta_{SC} = 32^\circ$, $\phi_{SC} = 144^\circ$
- $\Theta_{LF} = 31^\circ$, $\phi_{LF} = 146^\circ$

SELFAS reconstruction (radio):
- estimated shower core: $x = 260$ m, $y = -810$ m
- estimated $X_{\text{max}} = 710$ g/cm²
- estimated energy: $3,6 \times 10^{18}$ eV

Scintillators reconstruction (radio core):
- estimated energy: $2,8 \times 10^{18}$ eV

L. Martin, in proceedings of this conference
Low frequency events (II)

PE antenna: 850 m ⇒ only LF
QH antenna: 620 m ⇒ only LF
HL antenna: 640 m ⇒ only LF
LQ antenna: 180 m ⇒ HF & LF

Larger detection range at low frequency

Conclusion & Outlook

- LF antenna operational: low frequency events seen (agreement between the different arrival direction reconstructions & low rate of random signals)

- Larger detection range at low frequency than at high frequency

- Complete analysis is underway...

- Still waiting for the sudden death signal (high energy, vertical shower)
Thank you for listening!
Back-up slides
Radio emission of Extensive Air Showers

- Pioneers of the 70s up to 90s: EASRADIO, Akeno, AGASA...
- AERA, CODALEMA, LOPES, LOFAR...
- ANITA, CROME, MIDAS, AMBER, EASIER...

EXTASIS project

Few events
- Transition radiation
- Other mechanism?

~6000 events
- Geomagnetic
- Charge excess

~50 events
- Geomagnetic
- Charge excess
- Cherenkov

- Strong electric field and signal measured very far-away…
  (Allan, Clay, Hough, Pidcock, Prescott, Stubbs…)
- …but detection limited by atmospheric noise and artificial emitters
- Secondary charged particles hit the ground ⇒ strong low-frequency radio emission ⇒ measured far away from the impact point, linked to the remnants of the shower ⇒ « Sudden death »

D. García-Fernández for a theoretical approach

L. Martin this afternoon
B. Revenu, poster

Key frequencies:
- [3-3000] kHz
- [3-30] MHz
- [30-300] MHz
- [0.3-3] GHz

Electric field in μV/m in the vertical polarization

Graph showing electric field vs. time in ns.

Antony Escudie
ICRC2017, Bexco, Busan, Korea
Radio detection optimization

Detection range in classical band [30-80] MHz too small

Look at low frequency:

- Better detection range (sparse, cost effective array)
- New mechanism in simulations: «sudden death»
  (D. García-Fernández-CRI103)
- Precise core position determination, absolute time scale of the shower
  (B. Revenu-board #047)
LF antennas

Externally triggered by the scintillators
Butterfly antennas, East-West and Vertical polarizations, on a 9 m mast
Active antenna with adapted LONAMOS (D.Charrier)
low noise amplifier to the band [2 – 6] MHz

Antony Escudie
How?

Objective:

● observed a pulse in the associated CODALEMA HF
● observed the same pulse in the EXTASIS HF
● use the timing of the pulse to find it in the EXTASIS LF

(make sure that we observe “shower” signal)
Low frequency events 1

Filtered traces

Traces after LPC processing
Short overview of low frequency studies

<table>
<thead>
<tr>
<th>Year</th>
<th>Reference</th>
<th>Frequency</th>
<th>Take home message</th>
</tr>
</thead>
<tbody>
<tr>
<td>1969</td>
<td>Prescott, Hough, Pidcock, 11th ICRC 3, 717</td>
<td>3.6 MHz, 10MHz and 22MHz</td>
<td>Calgary (1049 m asl), signal at 3.6 MHz 3 times larger than at 22 MHz, no signal larger than noise at 10 MHz. Results consistent with previous studies made by Spencer, Allan et. al</td>
</tr>
<tr>
<td>1970</td>
<td>Allan, CLay, Naure 225, 253</td>
<td>2 MHz and 408 MHz</td>
<td>Signal at 2 MHz 200 times larger than at 32 MHz and 375 times larger than at 44 MHz</td>
</tr>
<tr>
<td>1971</td>
<td>Stubbs, Nature 230, 172</td>
<td>2 MHz</td>
<td>Signal at 2 MHz 250 times larger than at 44 MHz</td>
</tr>
<tr>
<td>1971</td>
<td>Hough, Prescott, Clay, Nature 232, 14</td>
<td>3.6 MHz</td>
<td>Signal at 3.6 MHz 1 order of magnitude larger than in [20-60] MHz, but less by a factor of 3-4 than at 2 MHz</td>
</tr>
</tbody>
</table>

- Strong electric field and signal measured very far-away ...
- … but detection limited by atmospheric noise and artificial emitters
- Secondary charged particles hit the ground ⇒ strong low-frequency radio emission ⇒ measured far away from the impact point, linked to the remnants of the shower ⇒ « Sudden death »
Event rate at Nançay

• For $E > 10^{16}$ eV: 0.5 shower per km$^2$ per str and per min

• Divide by 128 for each decade => $2.5 \times 10^{-5}$ shower per km$^2$ per str and per min for $E = 10^{18}$ eV

• At Nançay, 1 km$^2$ => 0.2 shower with $E = 10^{18}$ eV per day

=> So, few events at $10^{18}$ eV per month
Linear predictive coding
Daily variation of ionosphere layers

Properties ionosphere: function of the free electron density ⇒ altitude, latitude, season, and primarily solar conditions

D and E bands disappear at night and F1 and F2 combine

D layer: absorbs and attenuates RF from 0.3 to 4 MHz. Below 300 kHz, RF above 4 MHz will be passed unaffected. The D layer is present during daylight and dissipates rapidly after dark. The E layer will either reflect or refract most RF and also disappears after sunset. The F layer is responsible for most sky-wave propagation (reflection and refraction) after dark.
LF antenna environment
Coincidence at Nançay

Per month :

- Few millions of L1 triggers per autonomous station
- ~ 40,000 events for the scintillators
- ~ 40,000 for the LF antennas (externally triggered…)

Build of coincidence between SA and SC :

- Only ~60 coincidences remaining !

Build of coincidence between SA, SC and LF :

- Only 1 coincidence per month since April, 2017

Probably more events if we build only coincidences between SC and LF: detection range larger at LF, so maybe some LF events exist in our database without a coincidence with the SA ! Work in progress…