Multi-wavelength observation of cosmic-ray air-showers with CODALEMA/EXTASIS

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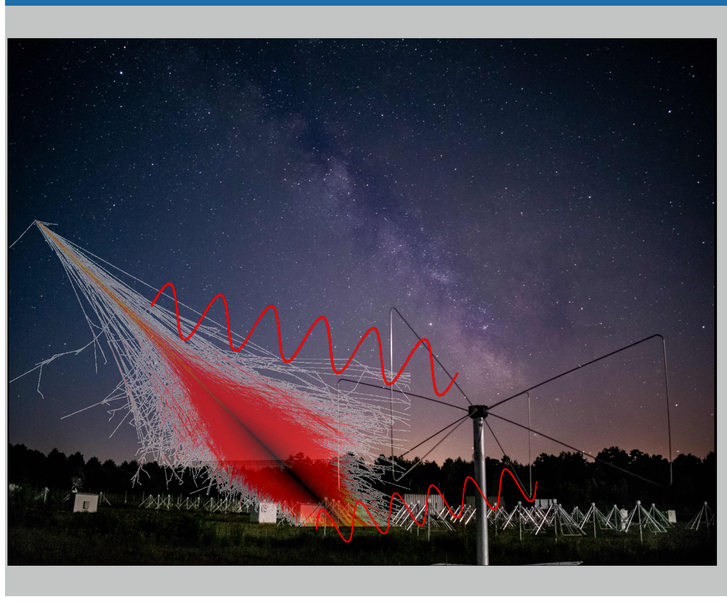
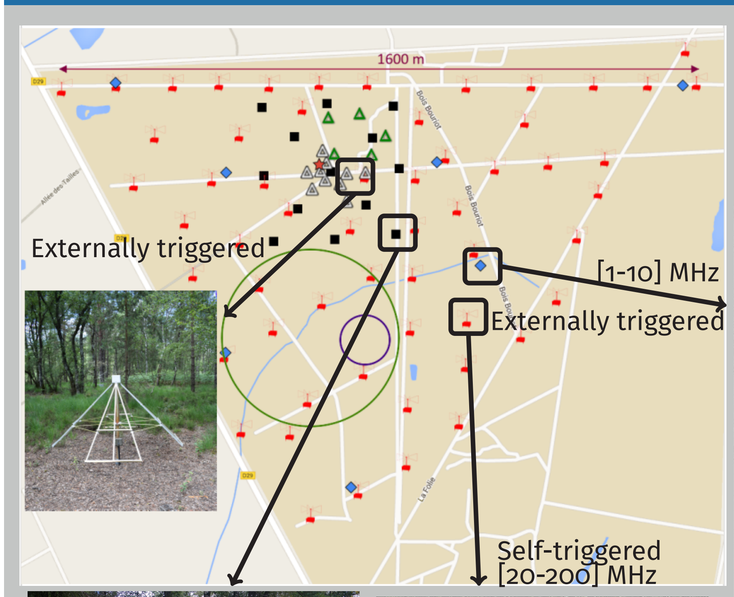
Radio signal from cosmic-ray showers



- A primary CR arrives in the atmosphere, and creates an extensive air shower (EAS)
- Charged particles (e^+/e^-) in the EAS create electric field (geomagnetic + negative charge excess mechanisms)
- Electric field is measured (usually above 20 MHz)

CODALEMA & EXTASIS facilities in Nançay



0.1 km^2, 13 particle detectors (scintillators).

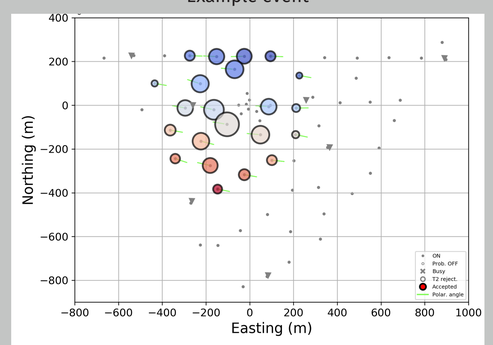
57 standalone butterfly antennas over $\sim$ 1 km^2. Frequency band $[20 - 200]$ MHz.

Butterfly type, vertical and EW polarizations. 7 antennas $\sim$ 1 km^2. Frequency band $[1 - 10]$ MHz. Externally triggered by the scintillators.

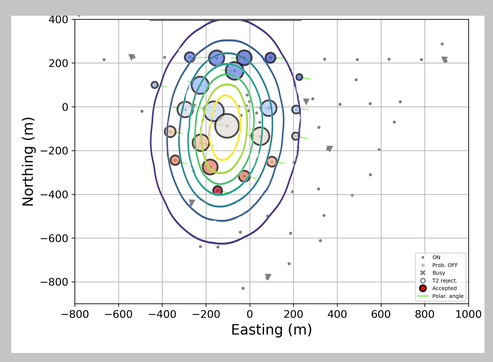
Estimating the shower parameters via the radio signal

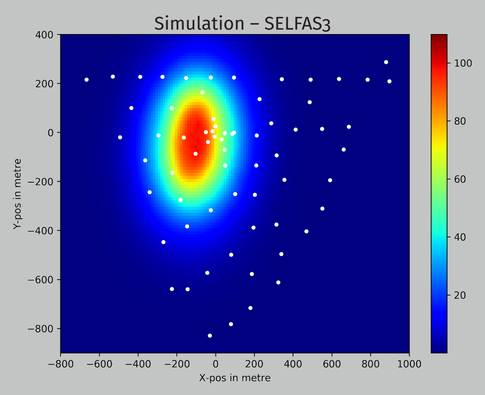
Method:

Example event



- θ, ϕ reconstructed using arrival times
- Core position, composition (X_{max}) and energy reconstructed trough MC simulations





$$\chi^2 = \frac{1}{N_{dof} - 3} \sum_{ant} \left(\frac{\left(A^{EW}_{ant} - \alpha \mathscr{F}^{EW}(x_{ant} - x_{core}, y_{ant} - y_{core})\right)^2}{\sigma^{EW\,2}_{ant}} + \frac{\left(A^{NS}_{ant} - \alpha \mathscr{F}^{NS}(x_{ant} - x_{core}, y_{ant} - y_{core})\right)^2}{\sigma^{NS\,2}_{ant}} \right)$$

- Hybrid reconstruction: use of different detectors of CODALEMA/EXTASIS
- Multi-wavelength reconstruction: use of $[20 - 80]$ MHz and $[120 - 200]$ MHz
- Increasing the dof: take into account the information of both polarizations

Results:

- Estimation of the shower core : $\Delta x_{core} = \sim 10$m, $\Delta y_{core} = \sim 10$m
- Estimation of the primary cosmic ray energy: α scaling factor
- Estimation of the X_{max} : $\Delta X_{max} = \sim 20\text{g} \cdot \text{cm}^{-2}$

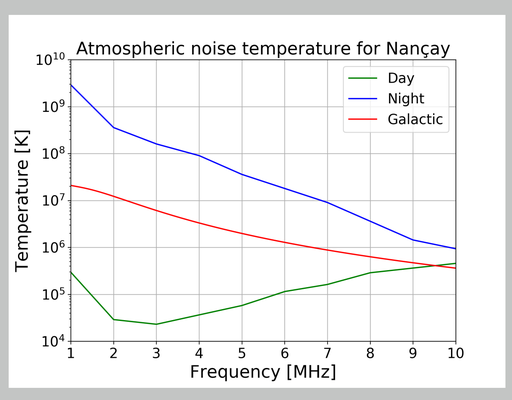
Low frequency band ($<$ 10MHz) – EXTASIS experiment

Why ?

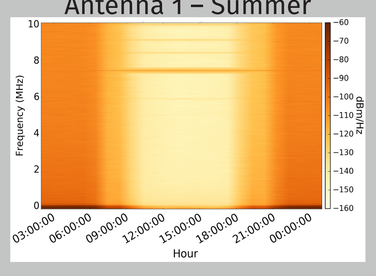
- LF counterpart of shower development + Sudden Death Pulse (SDP) radiated by the shower front when hitting the ground
- Larger detection range

But:

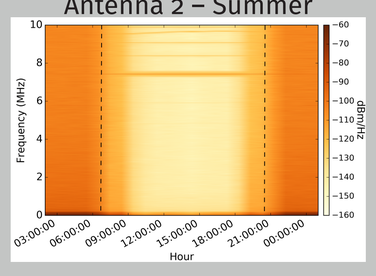
- Dominated by atmospheric noise
- Day/night + seasonal variations of atmospheric noise temperature $\Longrightarrow$ duty cycle $< 50\%$
- Absorption of radio transmitters at these frequencies in the ionosphere (*J. S. Seybold. Introduction to RF Propagation*)



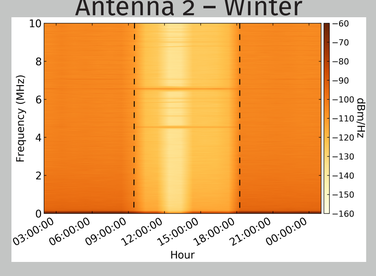
Antenna 1 – Summer



Antenna 2 – Summer

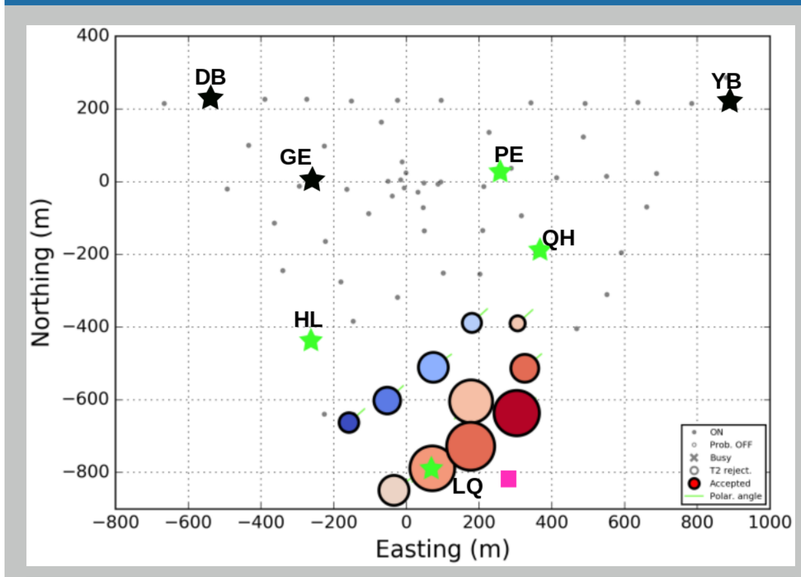


Antenna 2 – Winter



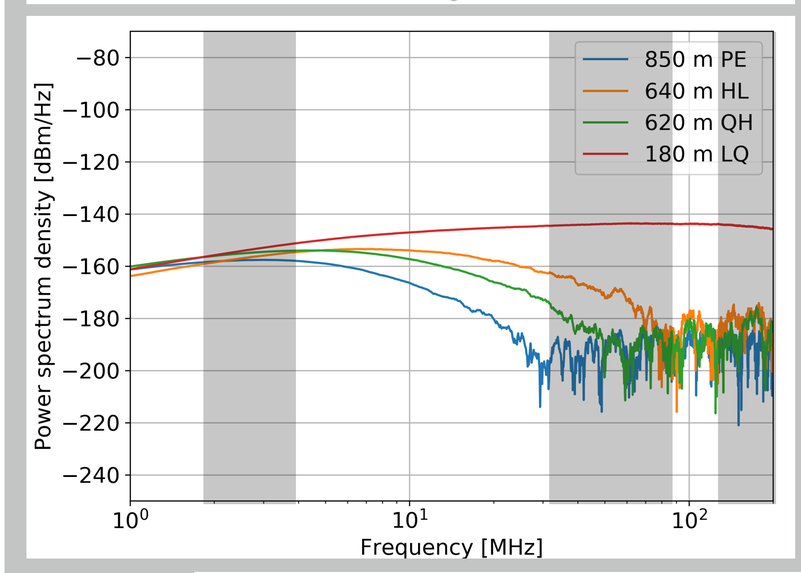
- LF counterpart of shower development detected: larger detection range, weaker signal
- Sudden death signal still not seen by EXTASIS
- LF signal seems not very promising: 18 LF events seen since March 2017
- Strong correlation with atmospheric electric field (9 over 18 events)

Multi-wavelength detection of cosmic-ray air-shower



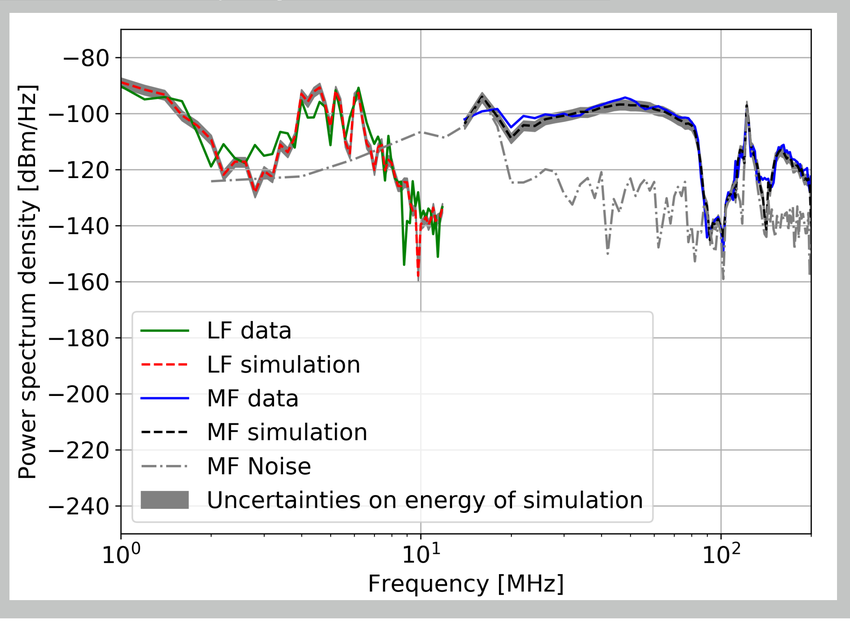
Arrival directions

- θ_{LF} =31°, Φ_{LF} =146°
- θ_{SA} =40 ± 1°, Φ_{SA} =145 ± 1°
- θ_{SC} =33 ± 6°, Φ_{SC} =143 ± 7°



Detection range

- PE at 850 m $\Longrightarrow$ only LF signal (23 µV/m)
- QH at 620 m $\Longrightarrow$ only LF signal
- HL at 640 m $\Longrightarrow$ only LF signal
- LQ at 180 m $\Longrightarrow$ HF & LF signal



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