Cosmic Ray Physics with the LOFAR Radiotelescopes


ECRS 2018
The LOw Frequency ARray

- Fully digital radio telescope
- 50+ Stations throughout Europe
- Dense core of 24 stations in the Netherlands
- 96 Low-Band (10 – 90 MHz) antennas
- 768 High-Band (110 – 240 MHz) antennas
Trigger from Particle Array LORA

Particle Detector at LOFAR

LOFAR Cosmic Rays:
- ~300 m diameter
- 20 Scintillators
- 7 x 48 LBA antennas

COincidence Trigger (13 / 20)

5s Buffer (2 ms readout)

Offline Analysis of Voltage Traces
Radio Emission From Air Showers

Geomagnetic Emission

Charge Excess

Sketch by C. Glaser
Cosmic Ray Air Shower with LOFAR

Intensity in every Antenna → Intensity Distribution on Ground

Position along $\mathbf{v} \times \mathbf{B}$ axis (m)

Signal
Envelope
RMS
Footprint Size Depends on $X_{\text{max}}$

$X_{\text{max}} = 630 \text{ g/cm}^2$

$X_{\text{max}} = 700 \text{ g/cm}^2$

Deeper shower $\rightarrow$ Smaller footprint
Xmax Reconstruction

Simulate + reconstruct showers with varying Xmax to fit observation

Systematic uncertainty: -10 / +14 g/cm^2
Mean statistical uncertainty: ±16 g/cm^2
Results Composition Measurement

2 component models are not sufficient
Strong light component between 0.1 and 0.5 EeV
H + He fraction is larger than 40% (@ 99% confidence)
Improved Atmospheric Corrections

$X_{\text{max}}$ measurement depends on index of refraction

Simplified Picture: All radiation from Xmax

- Implemented support for refractivity profiles in Coreas / CORSIKA
- Use data from GDAS in simulations to correct refractivity
- Analysis in progress …
- Tool to download GDAS data and create profiles now part of CORSIKA (src/utils/gdastool)
Improved Antenna Calibration To Allow Analysis of Spectral Shape

Consistency in Slope

\[ C^2(\nu) = \frac{P_{\text{expected}}(\nu)}{P_{\text{measured}}(\nu)} \]

OLD

NEW

preliminary

\[ X_{\text{max}} (\text{sim}) = 711.8 \text{ g/cm}^2 \]

\[ X_{\text{max}} = 700.7 \text{ g/cm}^2 \]
2018 Upgrade of LORA Particle Array

- 20 more Detectors
  - Increase detection rate of high energy events
  - Better showers: contained core, refined trigger, …
New and Advanced Trigger

- Hybrid Trigger: Drop low energy showers without radio
- Self Trigger based on polarisation, timing and signal strength
- 20% efficiency above 0.1 EeV within 200m
- RFI 1/hour

Particle Detector at LOFAR

LOFAR LBA Antenna

Coincidence Trigger (X / 20)

Particle + Radio Power

5s Buffer (2 ms readout)

Offline Analysis of Voltage Traces

(Probably Airplane)
Lunar Detection Mode

- Using Moon to target highest Energies proposed by Askaryan 1962

Expected Sensitivity

\[ J(E) \cdot E^{2.00} \text{ [eV m}^{-2} \text{s}^{-1} \text{sr}^{-1}] \]

- Telescope Array
- Bray 2016
- Auger
- This Work

Preliminary

Dedicated Talk on July 8
Beyond Cosmic Rays: Lightning Physics

LOFAR is most sensitive lightning mapping array!
LOFAR can measure electric fields in thunderstorm clouds!

Tobias Winchen - Cosmic Rays @ LOFAR
Conclusions

- LOFAR gives precision measurements of cosmic ray induced radio emission
  - Composition and energy around $10^{17}$ eV: ankle and second light component
  - Radio emission process in air shower

- Future:
  - Even higher precision
  - More data + increased energy range
  - Lunar observation mode

- Technology developed for cosmic rays enables research on lightning