

Cosmic Ray Measurements with LOFAR

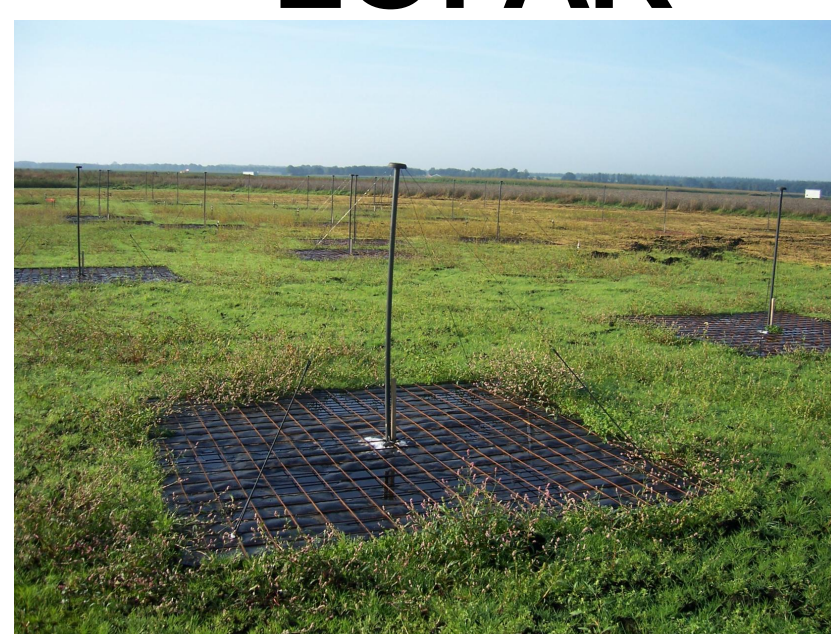
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Abstract

LOFAR is a new radio telescope, that is being built in the Netherlands. It can detect cosmic particles by measuring radio pulses from air showers and by searching for radio pulses from particle cascades in the moon. The high density of radio antennas in the core and the excellent calibration will make LOFAR an unique tool to study the radio properties of single air showers. When observing the Moon LOFAR will have an unprecedented sensitivity to cosmic rays or neutrinos at energies around 10^{22} eV.

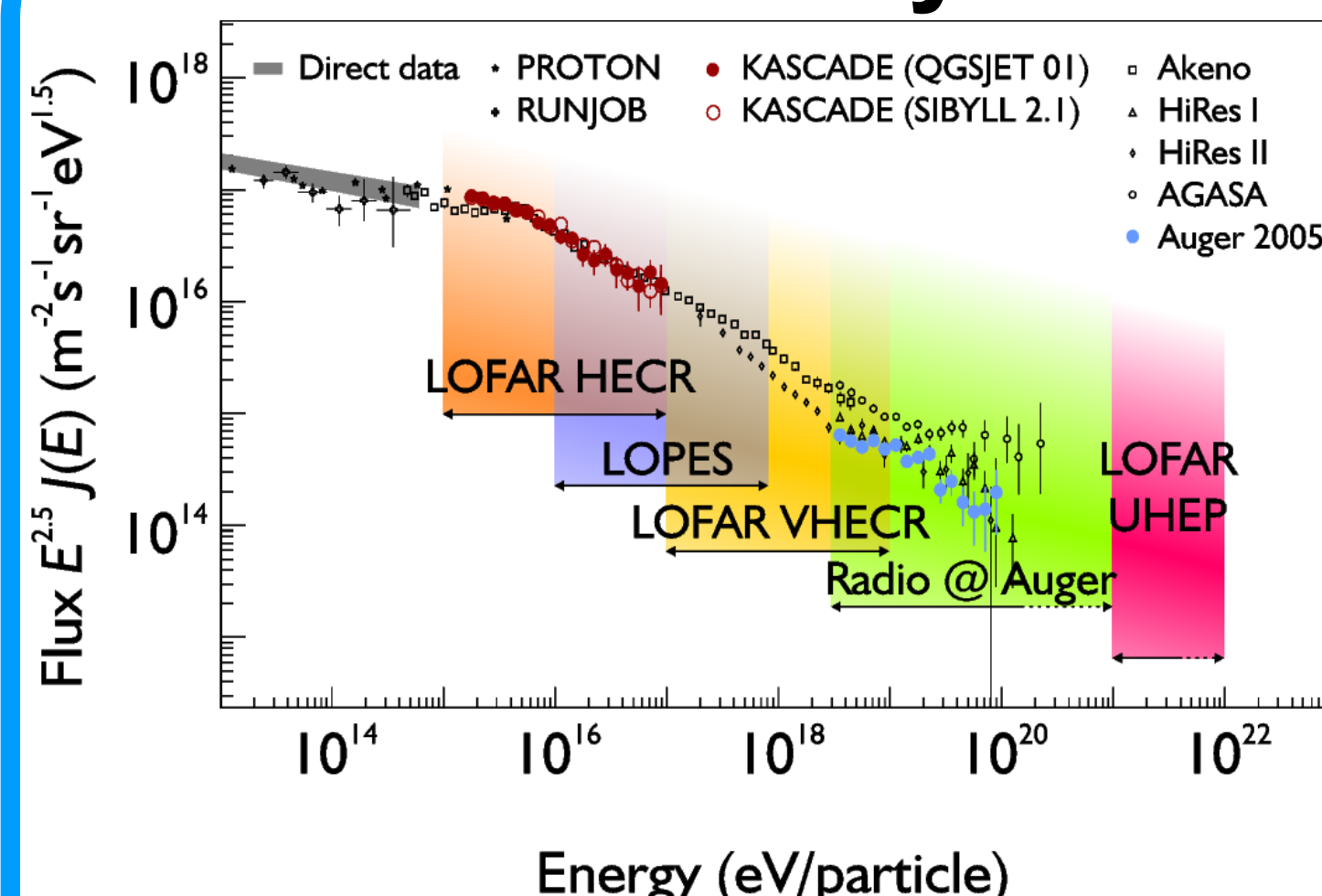
LOFAR



Left: Artists impression of the European LOFAR layout.
Right: LOFAR low band antennas in the field.

- + digital interferometer for 10-240 MHz
- + 36+ Dutch stations with 48 dual polarization antennas each (96 antennas LB-single polarization)
- + 8+ international stations with 96 dual-pol. antennas
- + Stations are close (touching) in the core and at larger distances further outside

Cosmic Ray Observation Modes

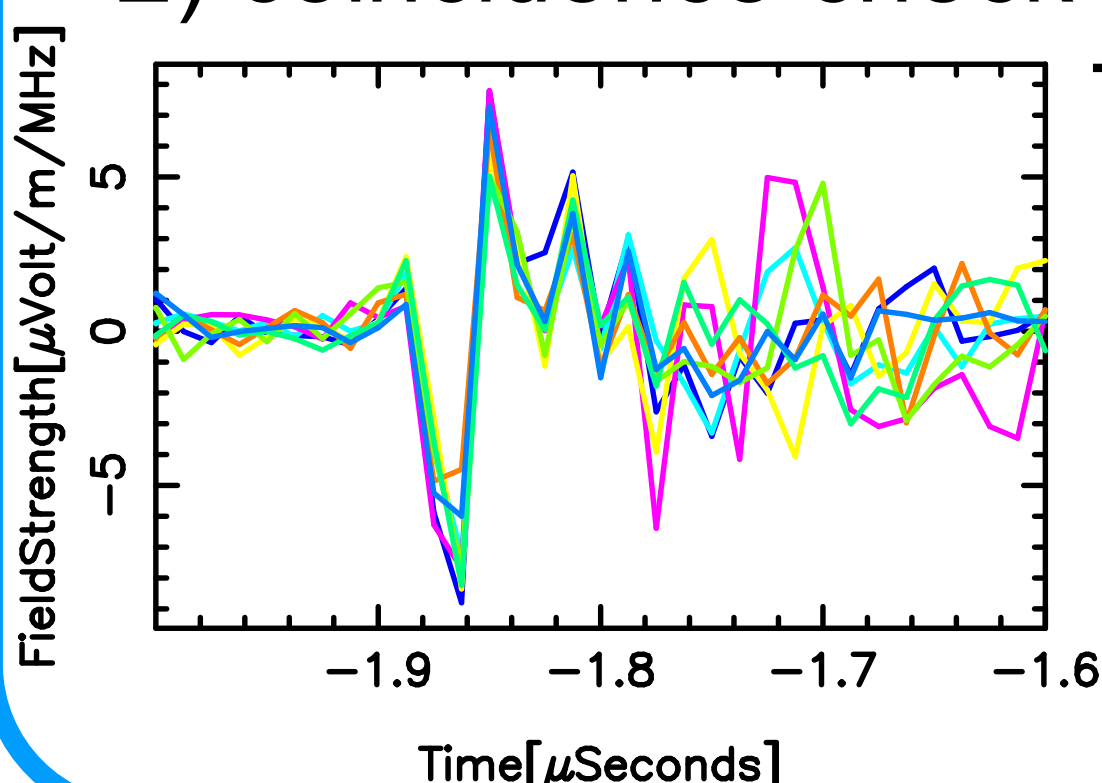


Cosmic ray spectrum with the LOFAR CR observation modes highlighted. LOPES and RADIO@Auger are related experiments.

- + HECR: Air showers with in-beam triggering
- + VHECR: Air showers with single channel triggering
- + UHEP: Observing particle cascades in the Moon

Air Shower Measurements

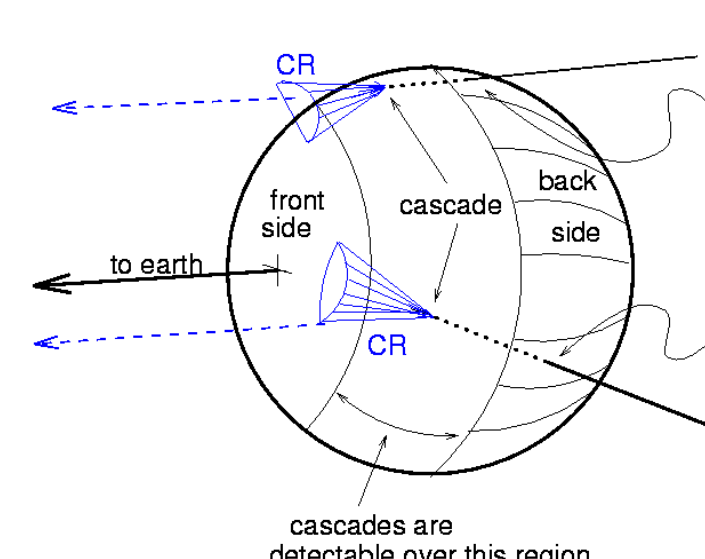
- + Measuring air shower radio pulses at 10-80 MHz
- + Two modes that share the analysis pipeline, and only differ in triggering
- + VHECR Mode (triggering on single dipoles):
 - 1) FPGA searches for pulses in single dipoles
 - 2) coincidence check at station- and 3) LOFAR level



- + HECR Mode (in beam triggering): search for pulses in station beam (implemented similar to UHEP triggering)

Single antenna traces of an air shower radio pulse (from the LOPES experiment)

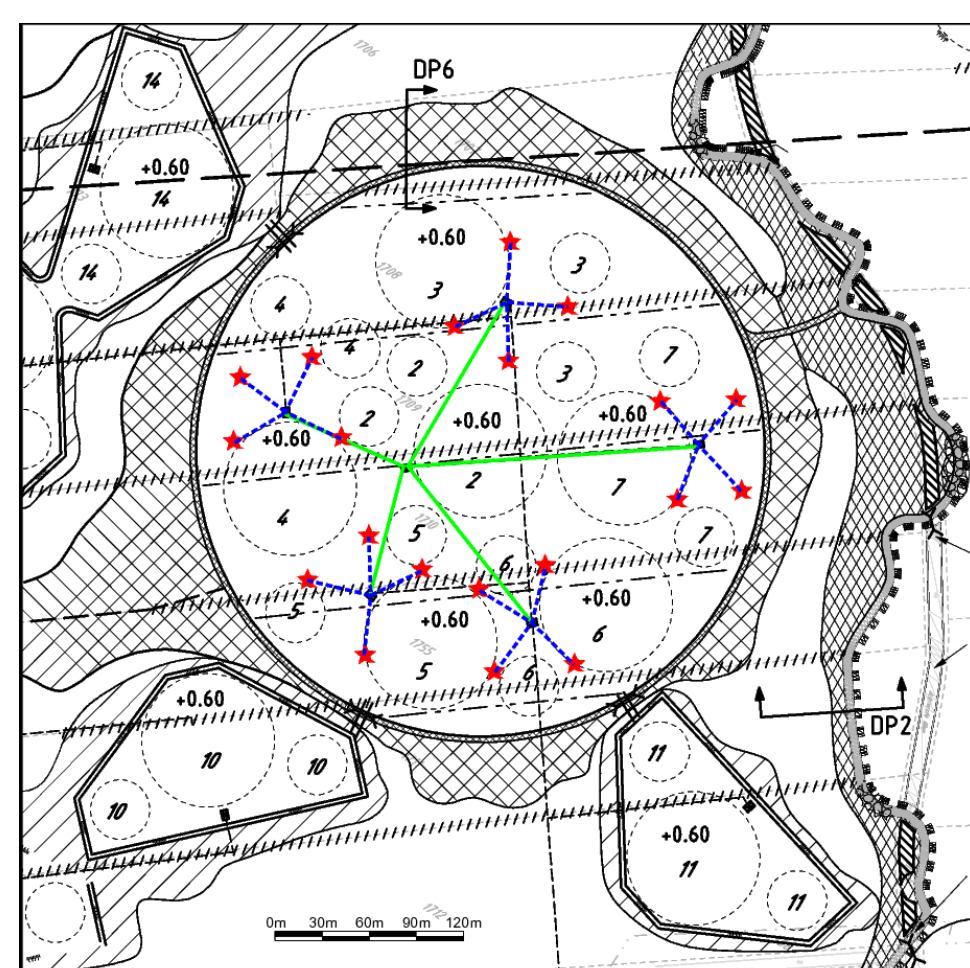
Observing the Moon



- + Particle cascades (from neutrinos or cosmic rays) in the lunar rock generate Cherenkov radio pulses
- + The directed emission is more omni-directional at low frequencies

- + Triggering:
 - 1) Stations form beam on the Moon
 - 2) At the central processing several "tied array beams" are formed to cover all of the moon
 - 3) Ionospheric effects are corrected for
 - 4) The data is converted back to full time resolution
 - 5) The resulting data stream is searched for pulses

Particle Detector Array



- + Small particle detector array
- + Inside the central super-station
- + 5 station with 4 detectors each
- + Help for the development of the radio-only trigger and additional data for hybrid measurement
- + Main Goal: Proof the we indeed detect air showers.

Layout of the LOFAR air shower array: The small and big dashed circles show the LOFAR antenna fields, the red stars the particle detectors and the blue and green lines the connection inside and between stations.

Current Status

The first 20 LOFAR stations are currently being rolled out. The dipole level trigger and a preliminary version of the station level trigger of the VHECR mode are already implemented. Key modules of the UHEP/HECR trigger are done and being tested. A prototype particle detector was made and successfully tested for compatibility with LOFAR.

References

- H. Falcke et al. *A very brief description of LOFAR - the Low Frequency array*, Highlights of Astronomy, vol.14, pp.386 (2007)
- K. Singh et al. *Detection of Ultra High Energy Cosmic Rays with LOFAR*, ECRS Proceed. (2008)
- A.Horneffer et al. *Air Shower Measurements with LOFAR*, ARENA Proc. (2008), doi:10.1016/j.nima.2009.03.027