Frequency-optimised radio arrays for air-shower detection

(Based on Eur. Phys. J. C (2018) 78: 111)

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ICRC 2019


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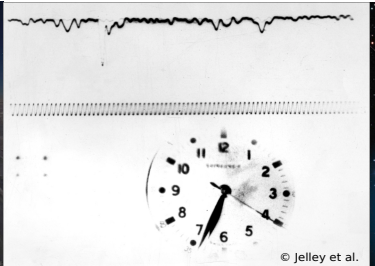
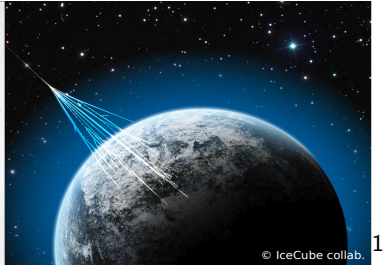

© Jelley et al.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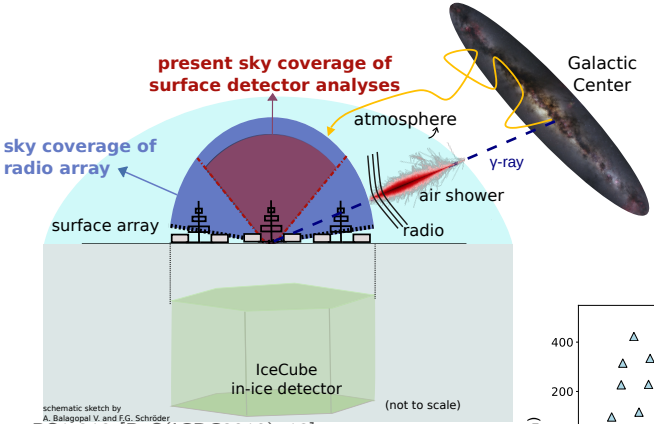
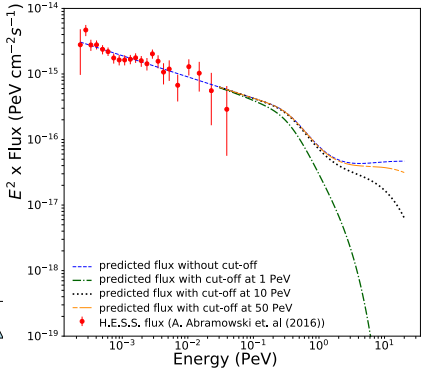
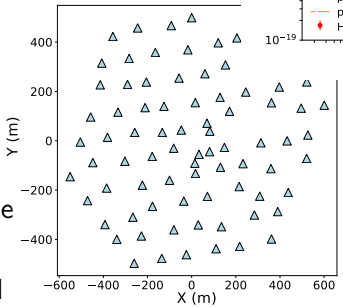
Motivation



PS1-210 [PoS(ICRC2019)418]



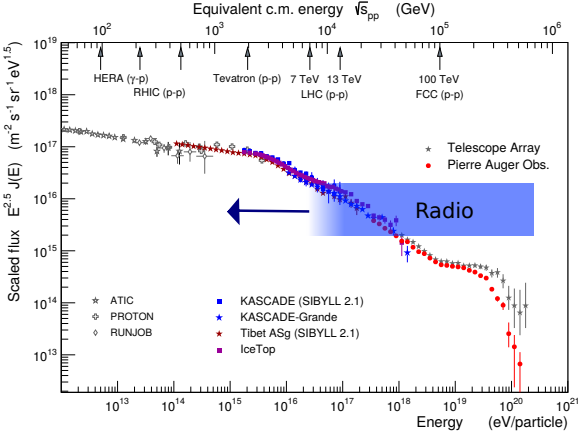
H.E.S.S. flux extrapolated from Nature 531, 476-479(2016)



antenna spacing ≈125 m
array area ≈ 1 km^2

- To measure air showers from PeV γ-rays from the Galactic Centre at the South Pole ($\theta = 61°$)
- Radio signals survive until the ground

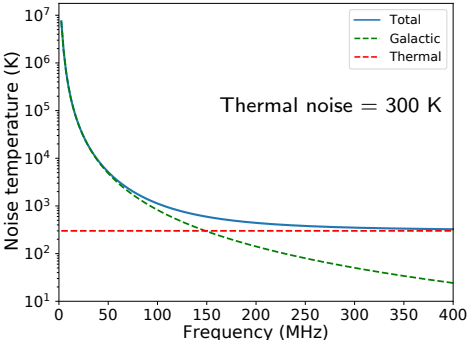
Radio at PeV energies



arXiv:1601.07426

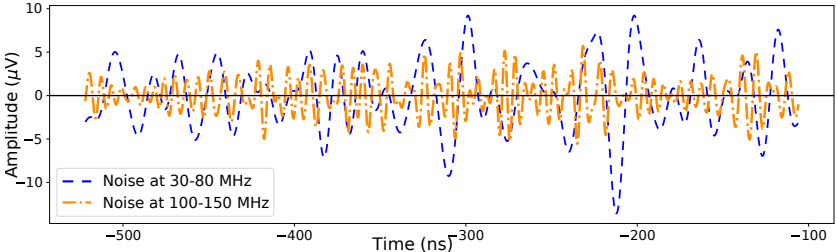
- Successful air shower detection with radio only above $10^{16.5}$ eV
- Required: lowering of energy threshold by an order of magnitude
- Need to measure radio signals above noise at PeV energies

Noise model



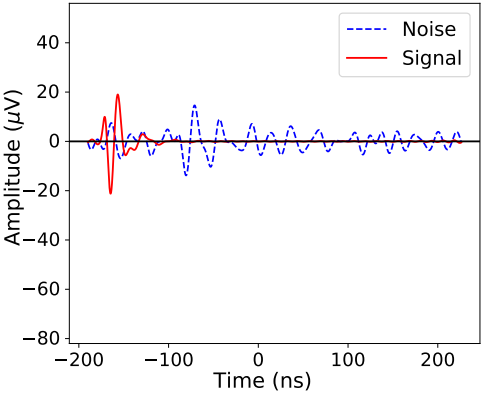
- Total noise = Galactic noise* + thermal noise (valid for radio-quiet zones)
- Noise temperature → power delivered to the antenna: $P = \mathrm{k_B} T \delta\nu$

*H.V. Cane, MNRAS 189, 465478 (1979)

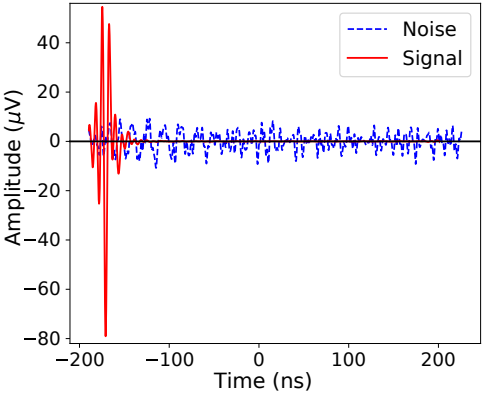


Comparison of noise and signal

CoREAS simulation of radio signals (γ-ray, $\theta = 61°$, $\phi = 0°$, E = 10 PeV)



30-80 MHz (SNR $\approx$ 37)

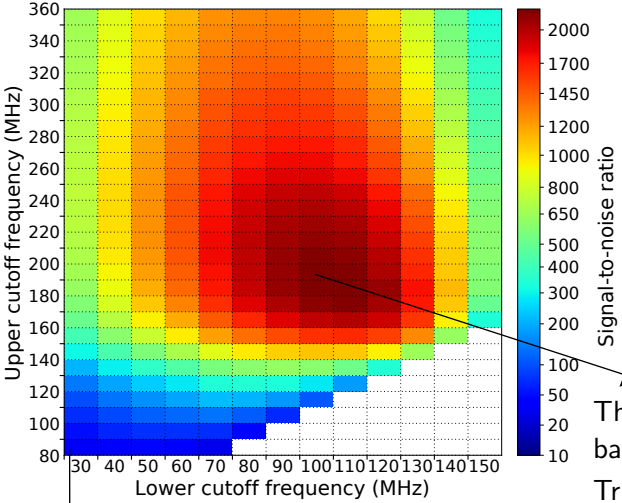


50-350 MHz (SNR $\approx$ 480)

- Signal-to-noise ratio, $\mathrm{SNR} = \frac{S^2}{N^2}$
- S = max of the signal envelope, N = rms noise

Frequency optimisation

Eg: Station at the Cherenkov ring



100-190 MHz

This is the best frequency band

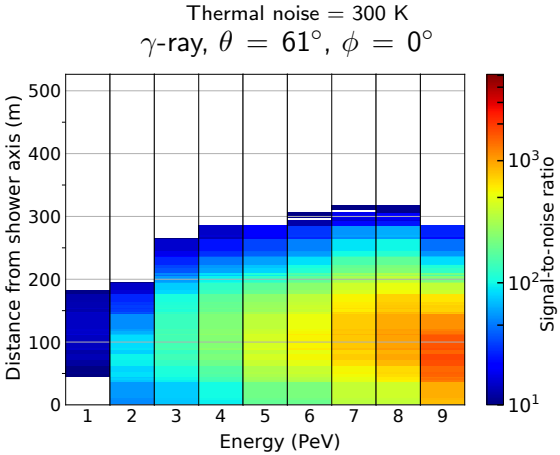
True for all stations/all regions of the footprint

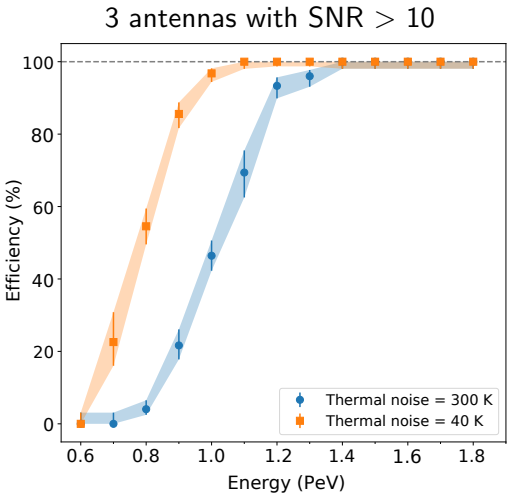
30-80 MHz

A. Balagopal V. et al, Eur. Phys. J. C (2018) 78: 111

Energy threshold

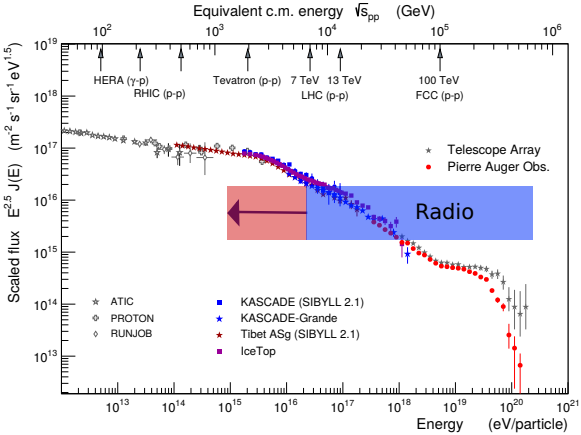
Threshold can be lowered to 1 PeV at 100-190 MHz



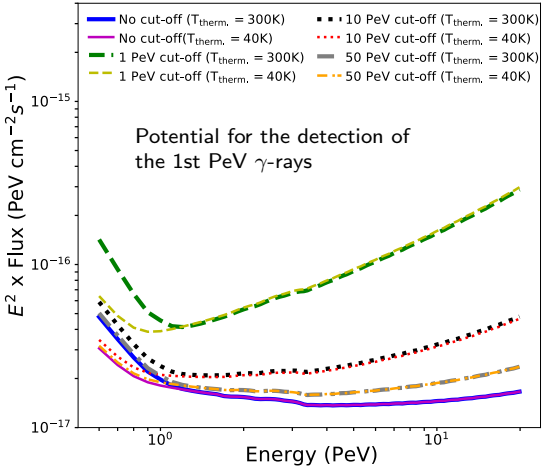


arXiv:1907.04171 (ARENA 2018 proc.)

Performance

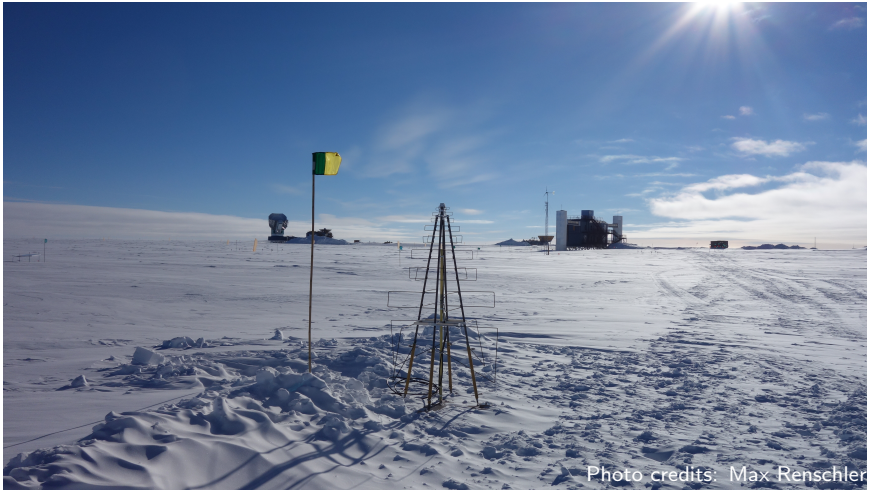


Threshold lowered by an order of magnitude in the optimal band 100-190 MHz



Integral sensitivity (5σ) to detect PeV γ-rays from the GC(Using H.E.S.S. flux [Nature 531, 476(2016)]

IceTop Radio Enhancement

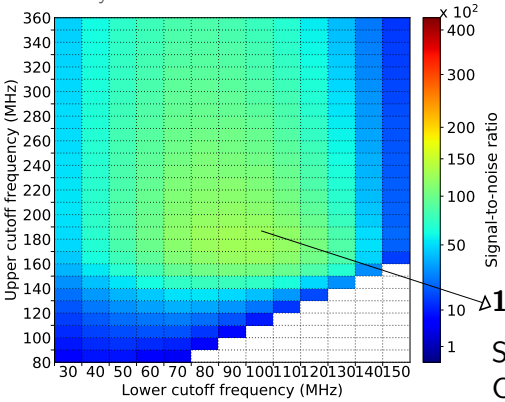


- Prototype antennas deployed, first air-shower measurements expected in the next season
  PS1-210 [PoS(ICRC2019)418], PS3-207
- SKALA antennas developed for SKA (50-350 MHz)

Other locations: GRAND

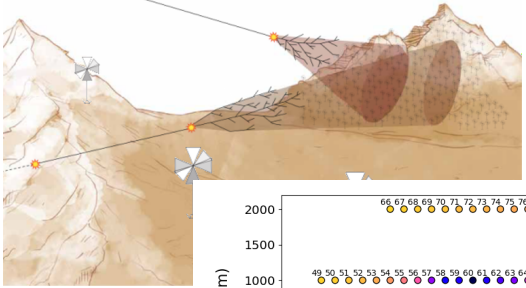
- Neutrino shower, E = 0.5 EeV, 3° below the horizon
- Planned: 50-200 MHz

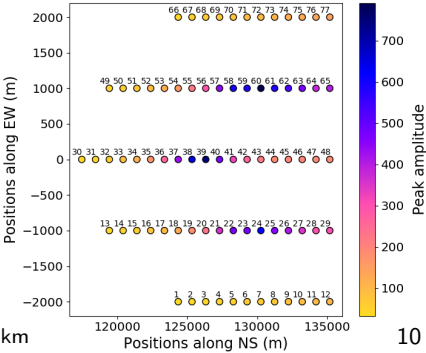
Already for GRANDProto300: CRI1f



100-180 MHz

Station outside the Cherenkov ring



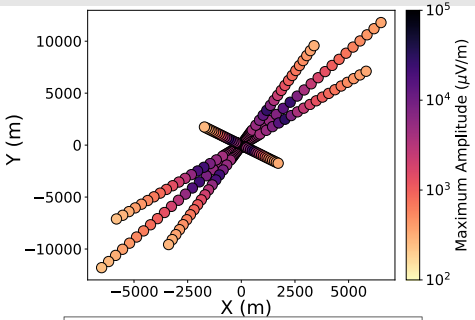


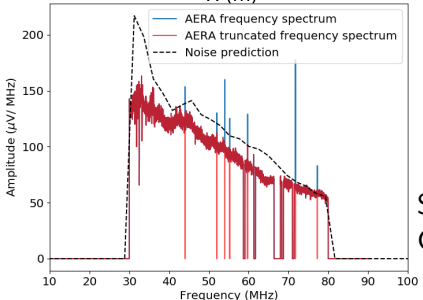
J. Alvarez Muniz et al, arXiv:1810.09994

About GRAND: NU10b

antenna spacing: 1 km

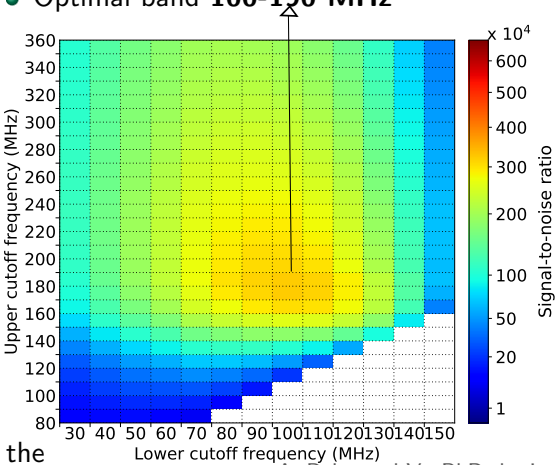
Other locations: Pierre Auger Observatory





Station inside the Cherenkov ring

- Proton shower, E = 7.5 EeV, $\theta = 80°$
- Optimal band **100-190 MHz**



A. Balagopal V., PhD thesis, DOI: 10.5445/IR/1000091377

Conclusion

- Optimal band 100-190 MHz consistently obtained for IceTop, GRAND, Auger
- Improves efficiency, lowers energy threshold
- Difference between locations: magnetic field, observation level, atmosphere
- Nature of radio emission is the same
- Same noise is considered in all studies

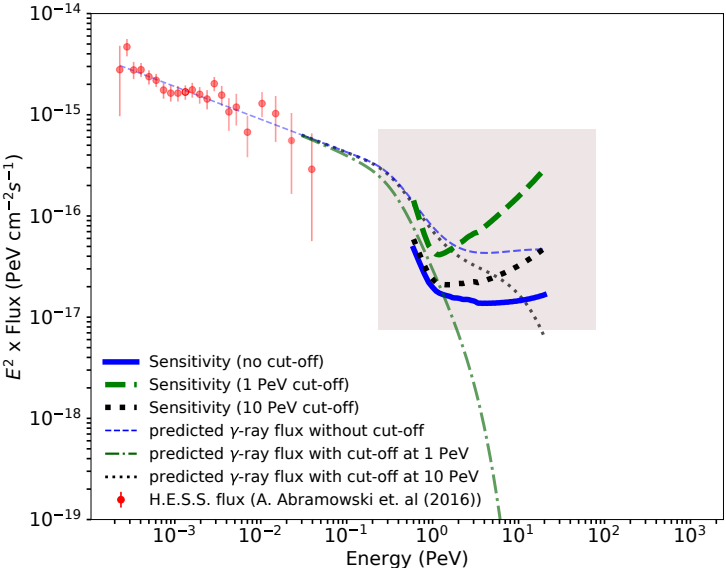
$\Rightarrow$ Same optimal band

- Advantageous to perform frequency optimisation for future expts.

Backup

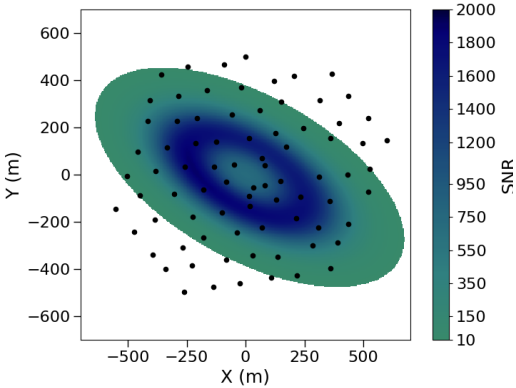
Sensitivity of the radio array

For 5σ detection within 5 years

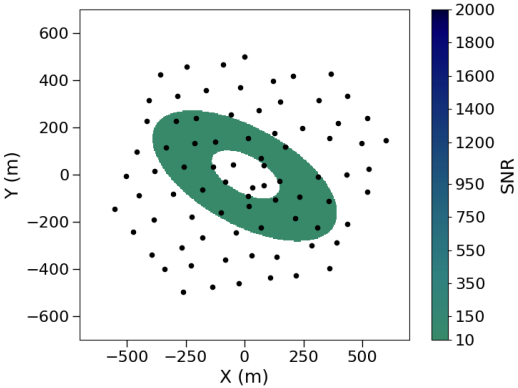


$\geq$ 3 antennas, with direction and energy reconstruction

Footprint of 61° γ-ray showers



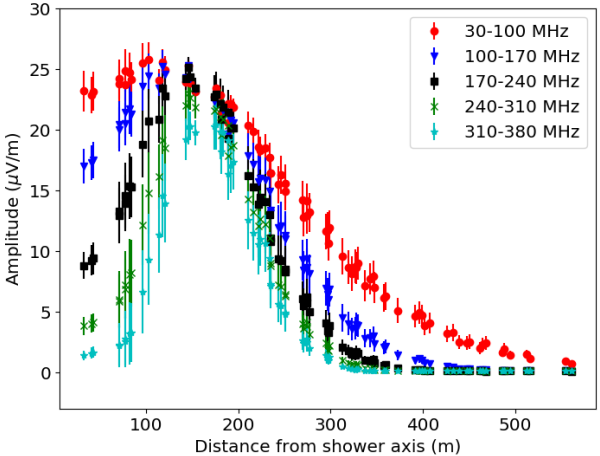
Footprint of a 10 PeV shower



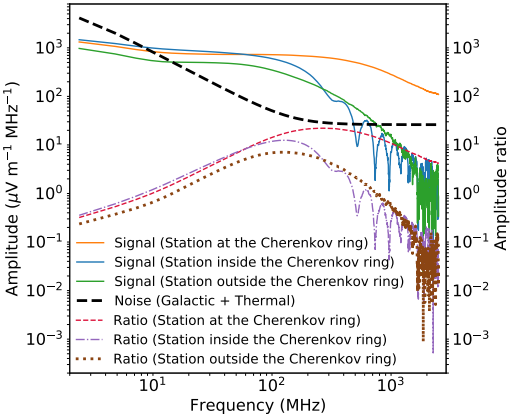
Footprint of a 1 PeV shower

Lateral distribution

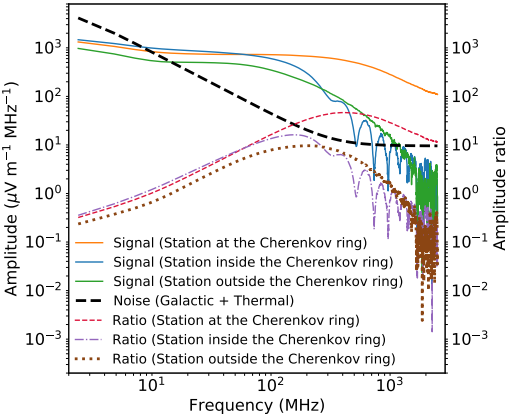
Filtered to different bands of 50 MHz width



Frequency behaviour



(a) Thermal noise = 300 K



(b) Thermal noise = 40 K