Friedrich-Alexander-Universität
Erlangen-Nürnberg

Detecting extensive air showers with SKA-low

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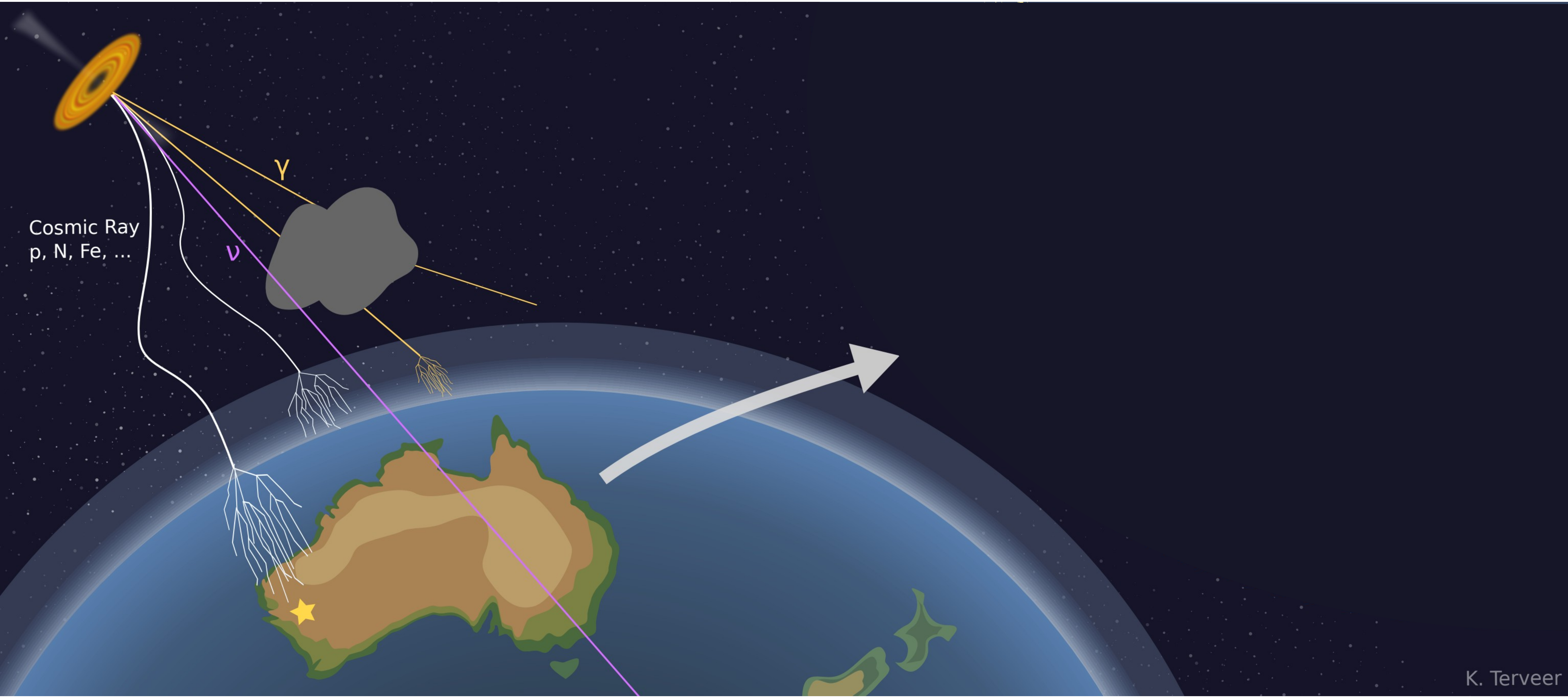
Cosmic particles



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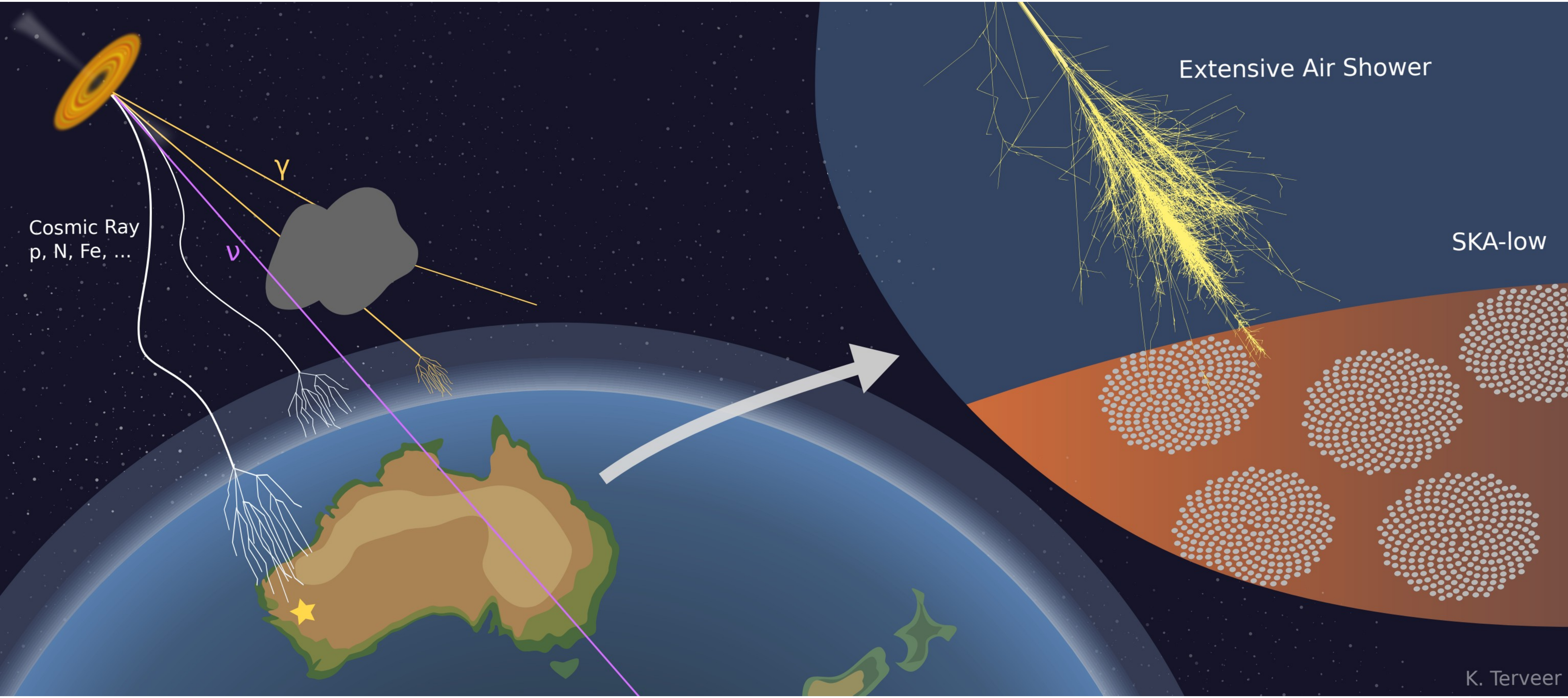
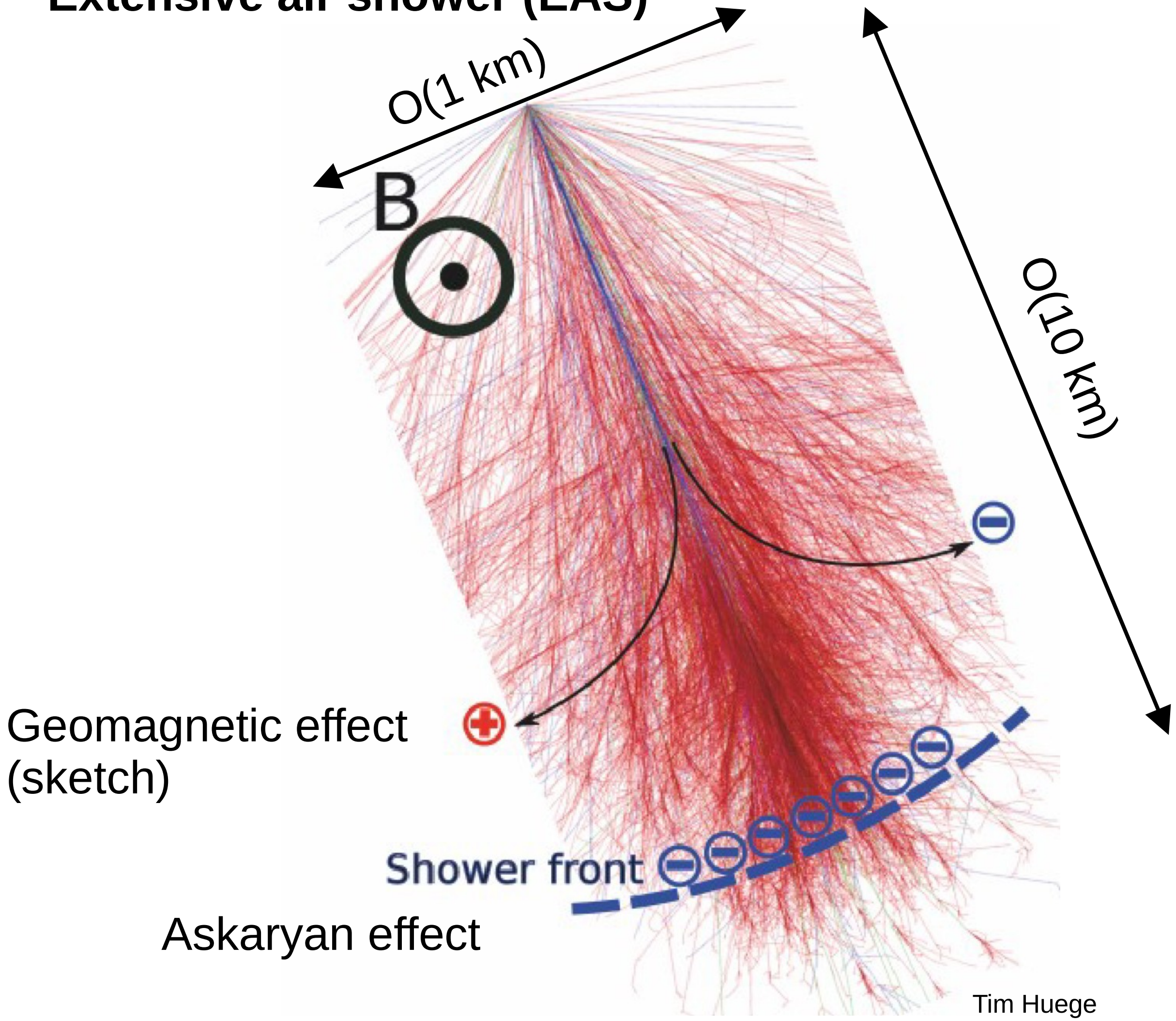


Radio detection of cosmic particles

Extensive air shower (EAS)



Tim Huege

Radio detection of cosmic particles

Buitink et al. PoS(ICRC2015)369

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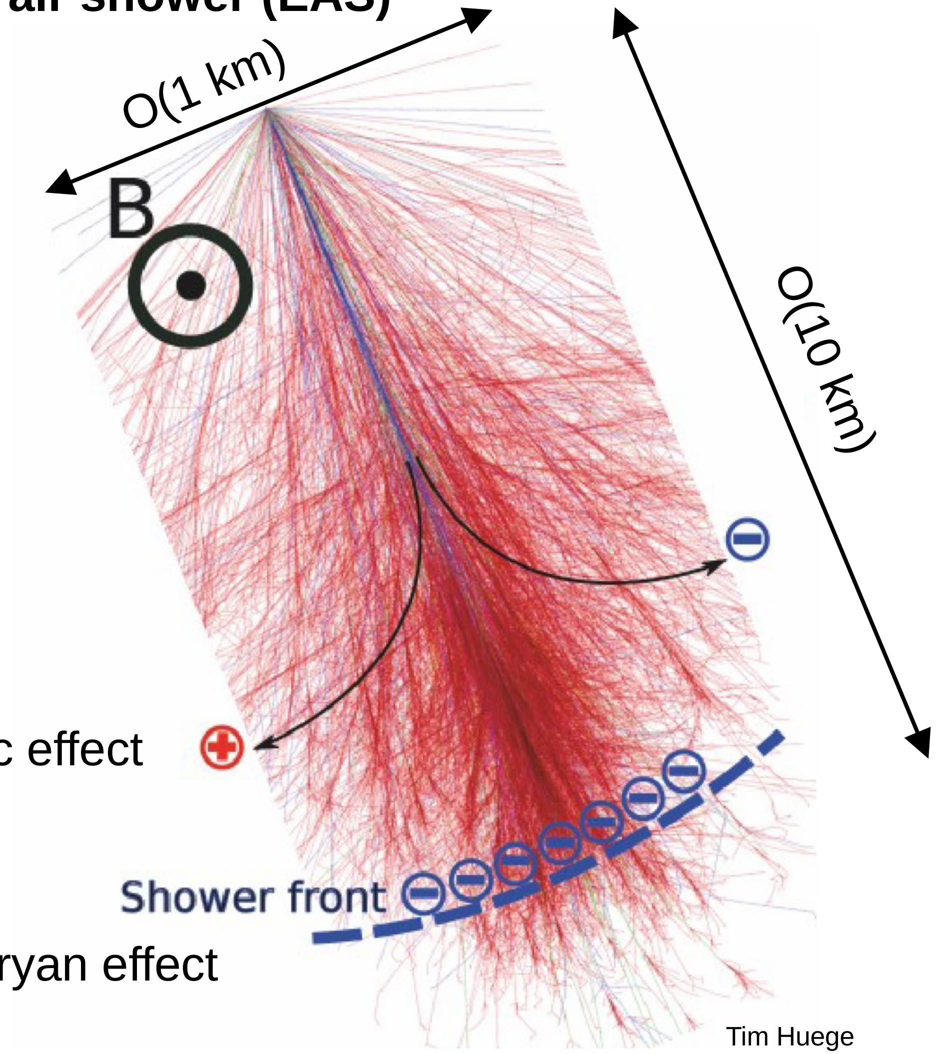
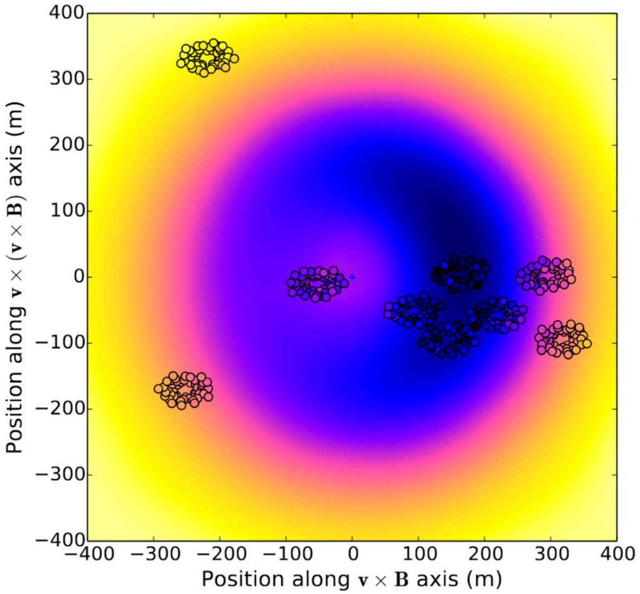
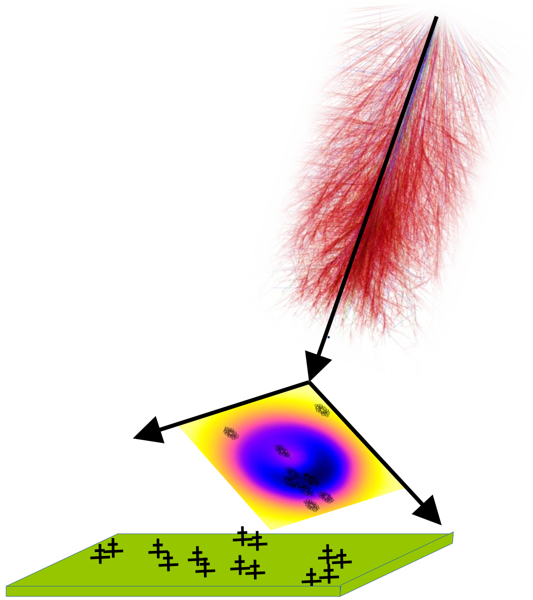


Geomagnetic effect (sketch)

Askaryan effect

Tim Huege





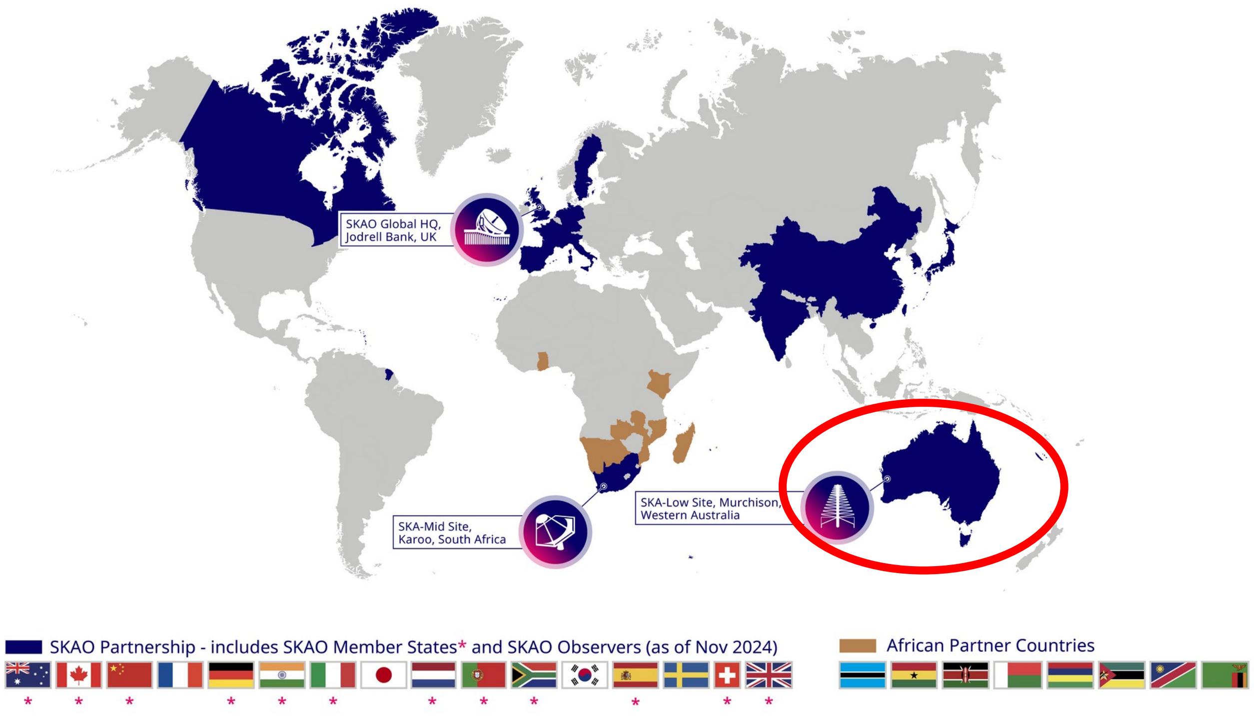
Why radio?

- Observable 24/7
- Almost no attenuation in air
- Inexpensive detectors

SKA

The Square Kilometre Array

- 2 parts (construction started!):
  - Mid-frequency array SKA-mid in South-Africa
  - Low-frequency array **SKA-low** in Western Australia



SKAO

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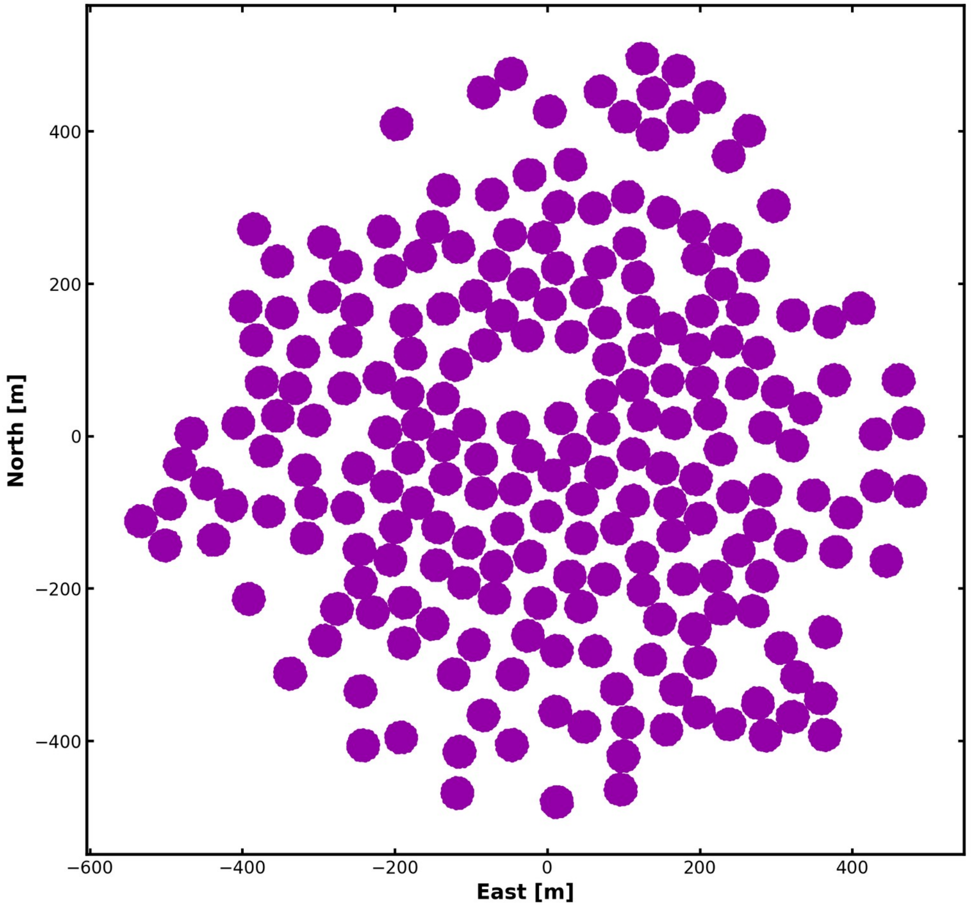
  - Mid-frequency array SKA-mid in South-Africa
  - Low-frequency array **SKA-low** in Western Australia
- SKA-low:
  - 512 stations with 256 antennas each
  - Dense core with 3 spiral arms
  - Core: ~ 57,344 log-periodic antennas
  - Core area: ~ 1 km^2
  - Frequency band: 50 MHz – 350 Mhz
  - Energy range: 10^{16} eV – 10^{18} eV



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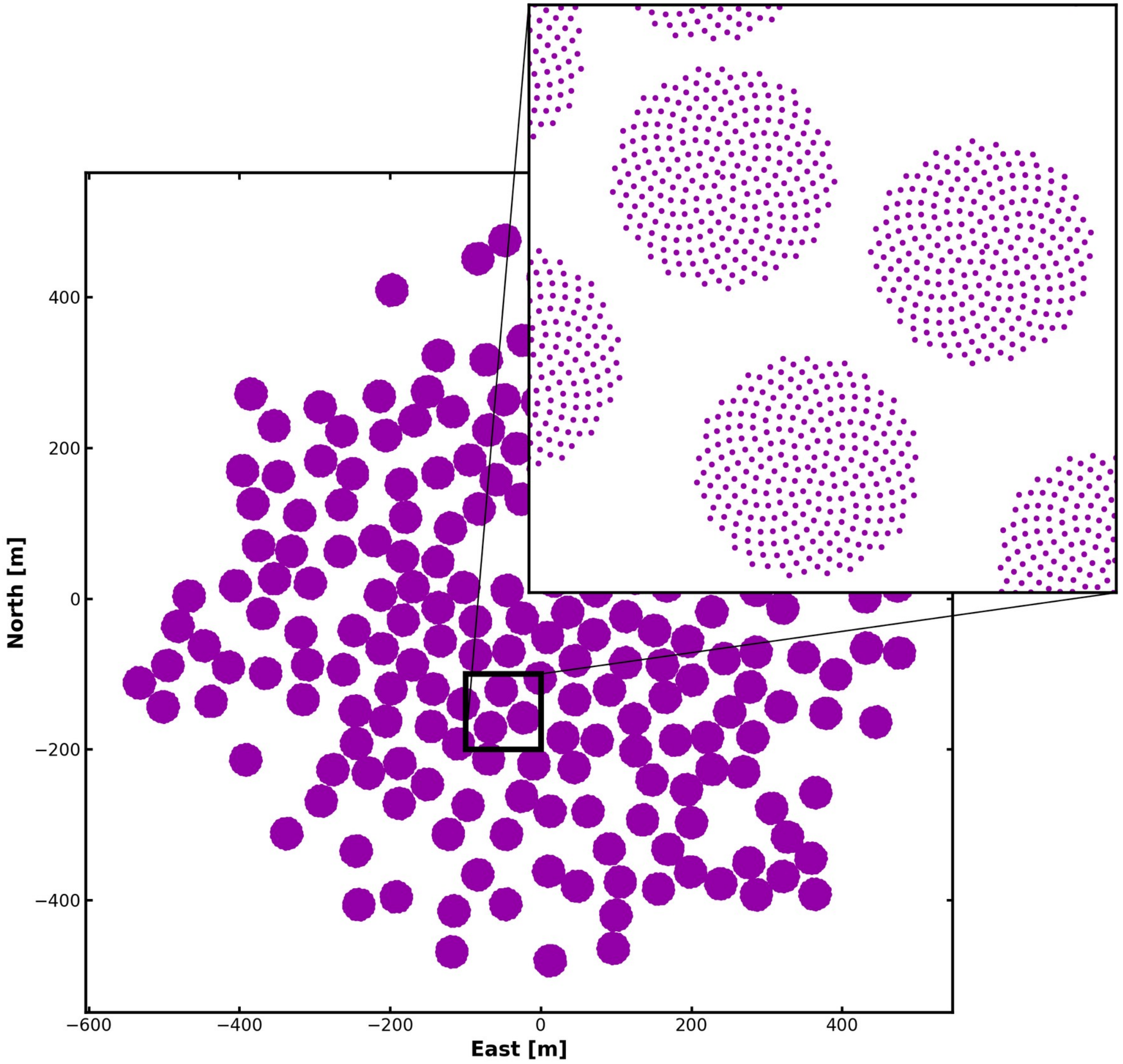

SKA

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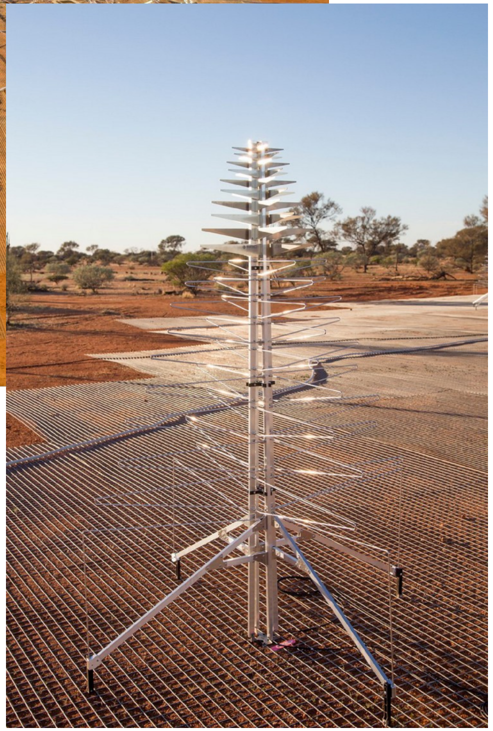


SKALA4.1 antenna

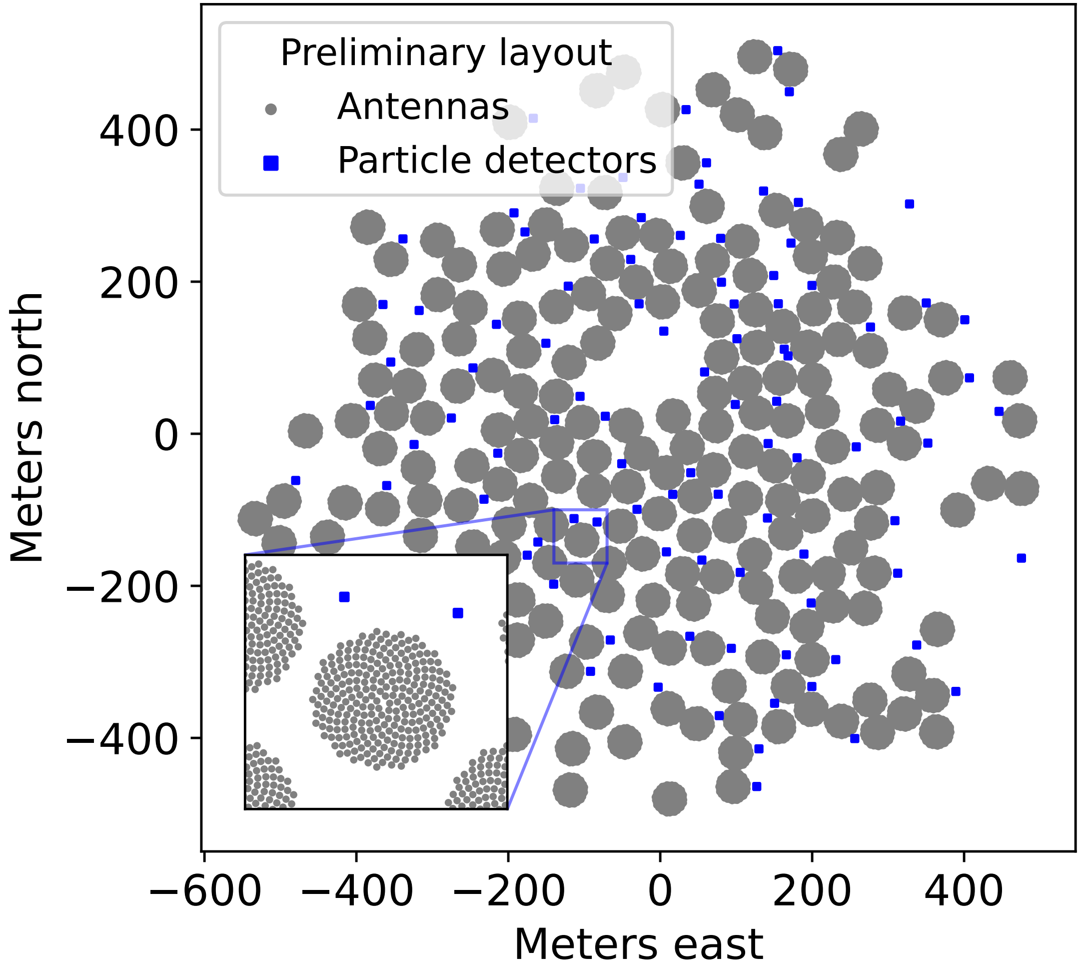
SKA

The Square Kilometre Array

SKA-low:

- 512 stations with 256 antennas each
- Dense core with 3 spiral arms
- Core: ~ 57,344 log-periodic antennas
- Core area: ~ 1 km²
- Frequency band: 50 MHz – 350 Mhz
- Energy range: 10^{16} eV – 10^{18} eV
- Particle detector (scintillator) array funded (and currently constructed at KIT)!

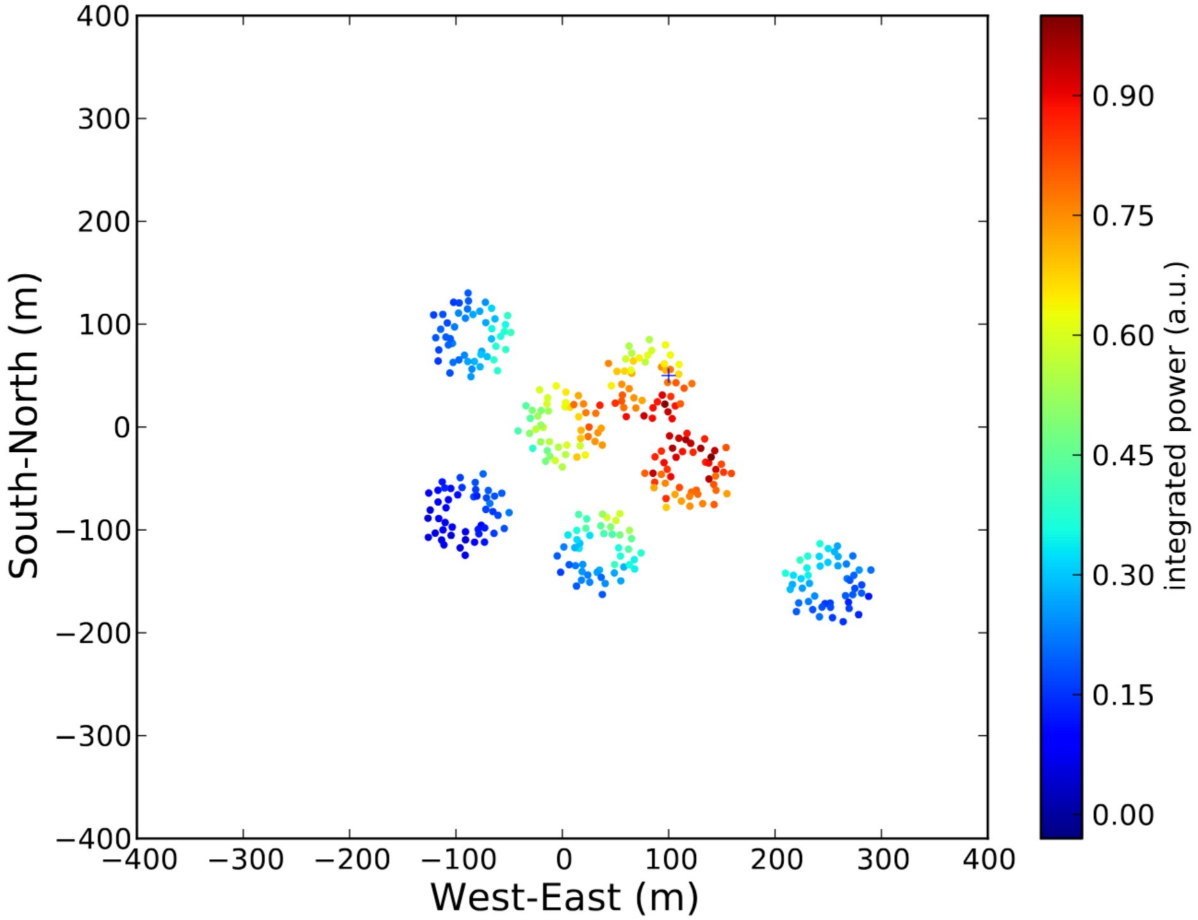
  → Particle trigger
  - Triggers on electrons/muons
  - Robust against radio noise



SKA

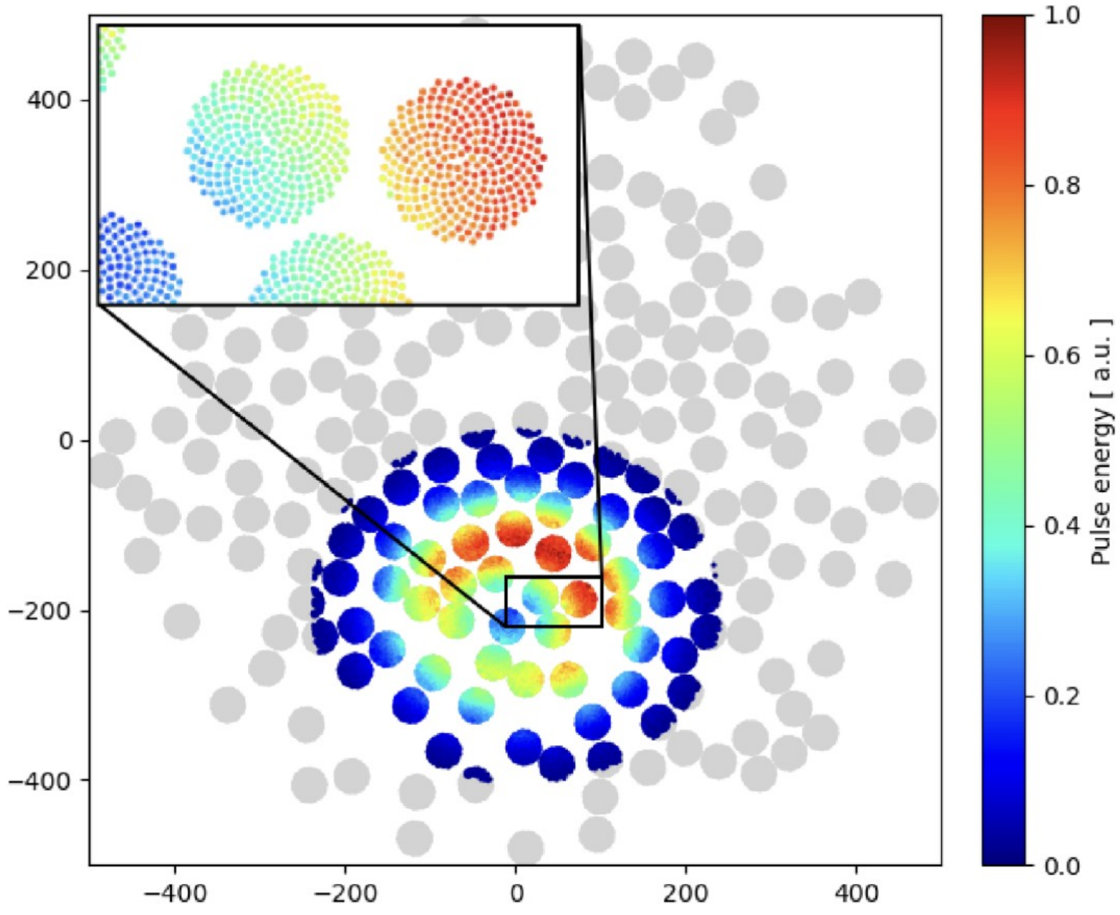
Maximum precision

LOFAR (core)



A. Zilles et al., EPJ Web Conf. Volume 135 (2017) 02004

SKA-low (core)

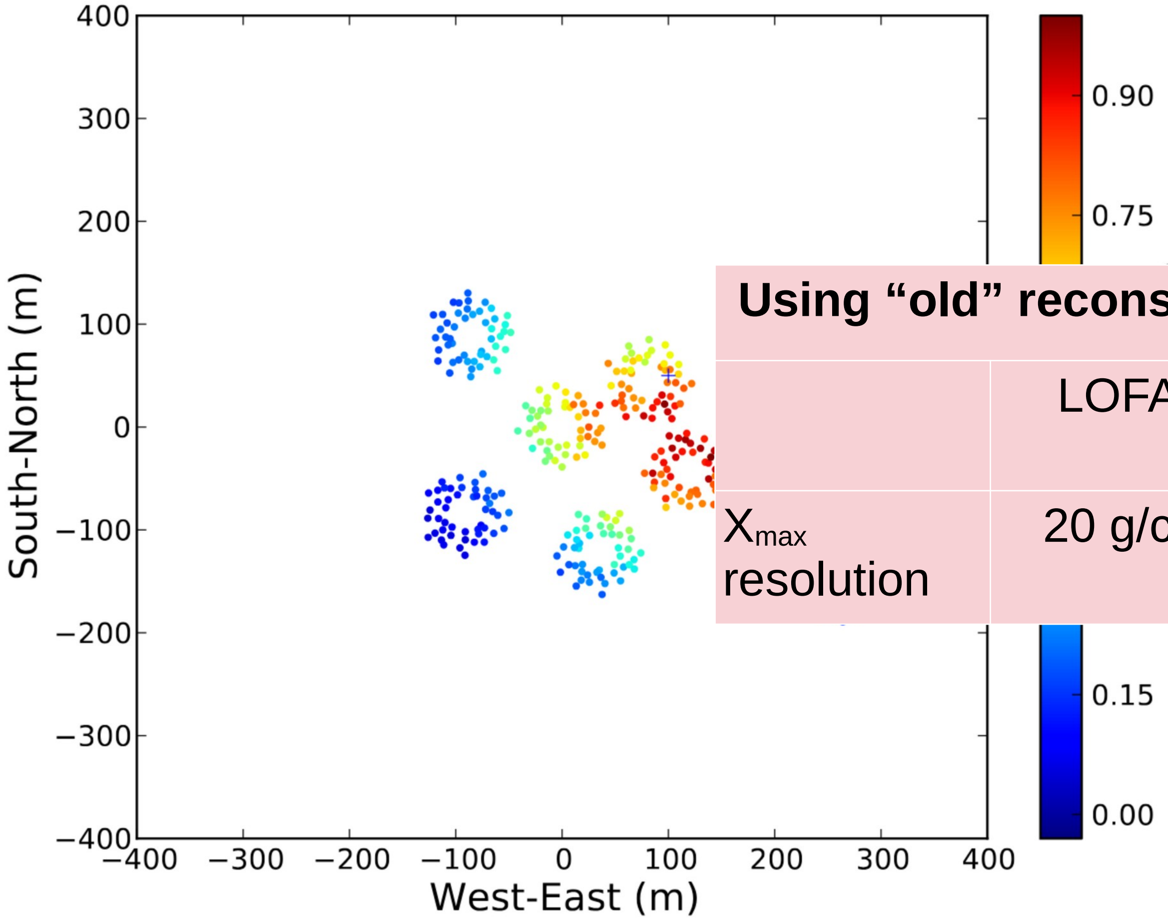


S. Buitink et al. PoS(ICRC2023)503

SKA

Maximum precision

LOFAR (core)



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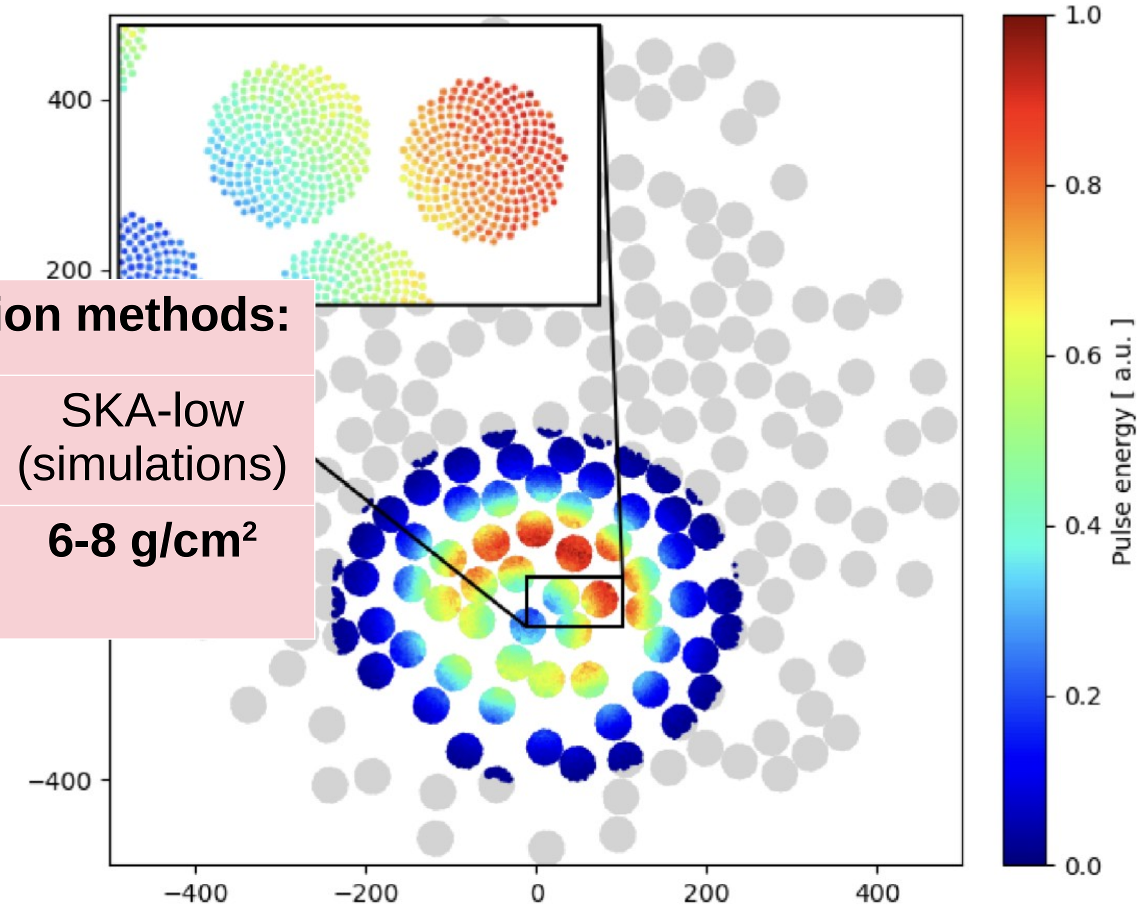
SKA-low (core)



S. Buitink et al. PoS(ICRC2023)503

Using “old” reconstruction methods:

	LOFAR	SKA-low (simulations)
X_{max} resolution	20 g/cm^2	**6-8 g/cm^2**

Beamforming

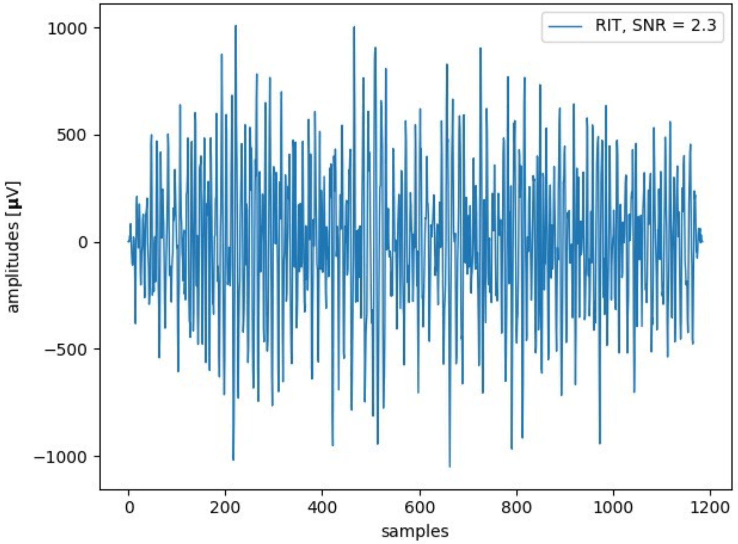
How to exploit SKA's high antenna density?

- At low energies: signal « noise :(
- **Beamforming**:
  - Calculate travel time shifts for each antenna to a position *j*
  - Combine many antennas together to add signal coherently

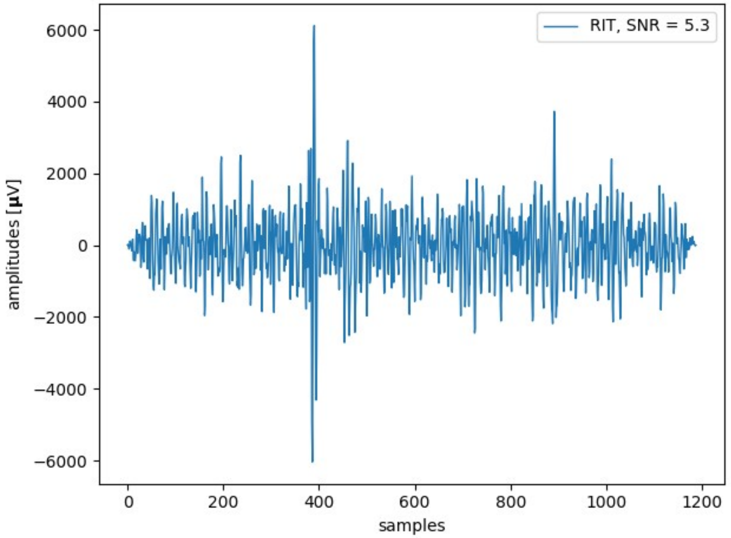
→ SNR scales with square root of #antennas (*ideally*...)

Beamformed signal at pos *j*:

$$\boxed{B_j(t) = \sum_{i}^{n_\mathrm{ant}} S_i(t - \underbrace{\Delta_{i,j}}_{\text{time shift}})}$$



Factor 8 more antennas



Project : Gamma ray detection

SKA-low (amongst others) designed to detect UHE *hadronic* cosmic rays

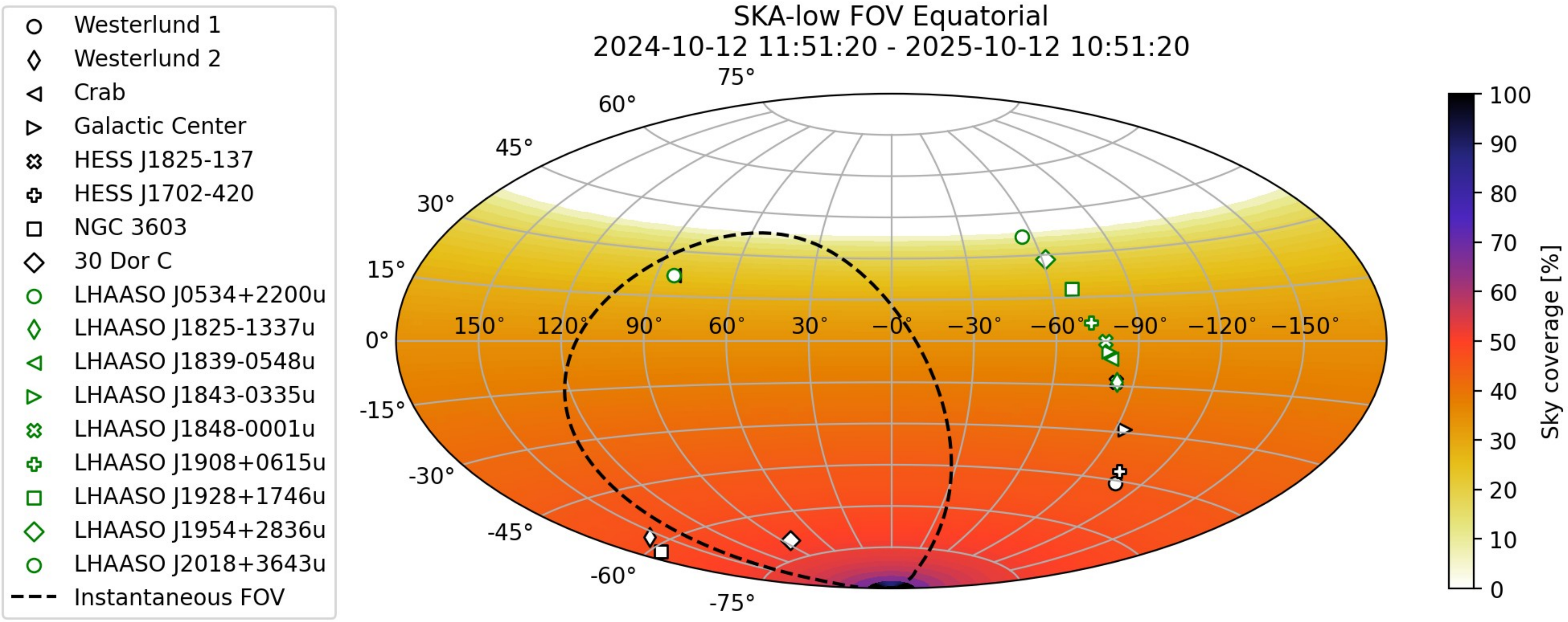
→ Can it be used to detect **UHE gamma rays**?

- Highest energy gamma ray ever detected: **1.4 PeV** (LHAASO)
- Higher energies unexplored

Project : Gamma ray detection

FOV and sources (selection)

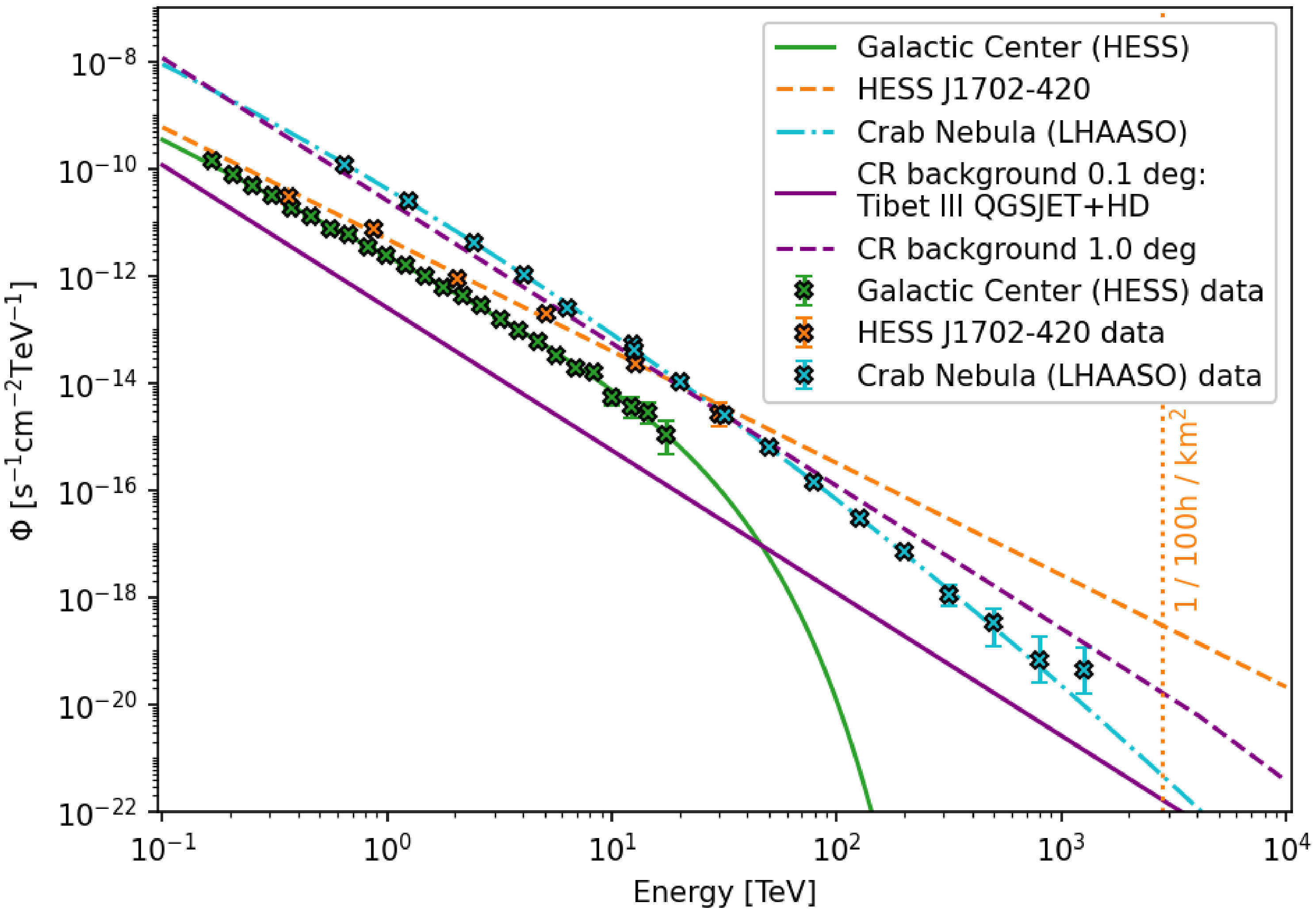
SKA-low field of view (FOV): (assume that SKA can see sources up to 65 degree zenith angle, 1 year)



Project: Gamma ray detection

Flux estimation

Trigger?



Gamma-hadron separation?

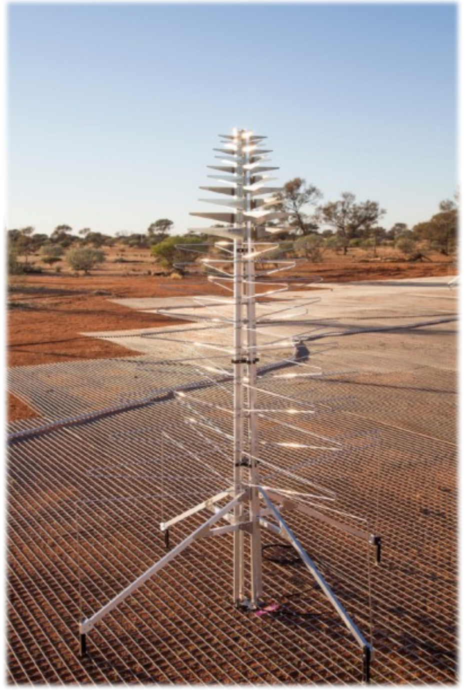
Does not look good, but there is hope!
=> Beamforming!

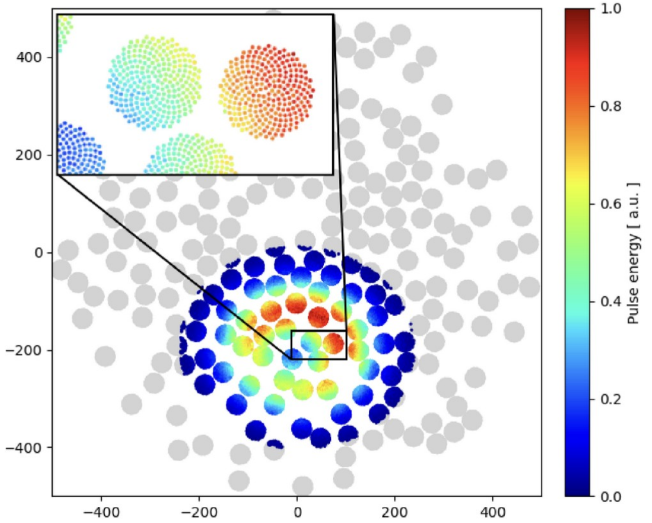
Summary

- **SKA** currently under construction!
  - High antenna density
  - Broad frequency band
  - Extreme precision measurements

    → Next-gen radio telescope!

- Detection of cosmic particles
  - Beamforming
  - Mostly hadrons
  - Gamma rays?





$$B_j(t) = \sum_{i}^{n_{\mathrm{ant}}} S_i(t - \Delta_{i,j})$$