Highlights from LOFAR & SKA

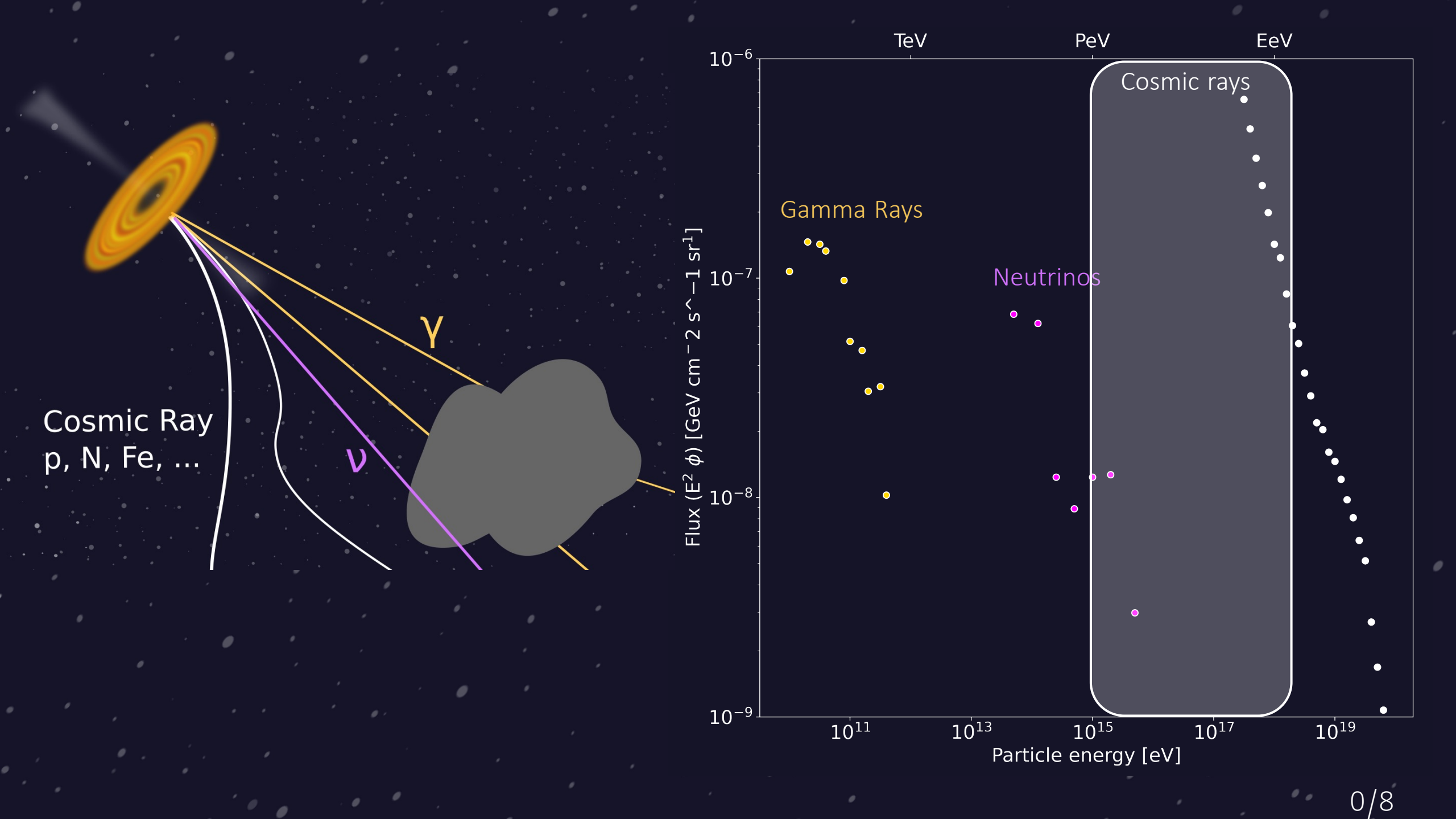
LOFAR cosmic ray Key Science Project

SKA High Energy Cosmic Particles Science Working Group

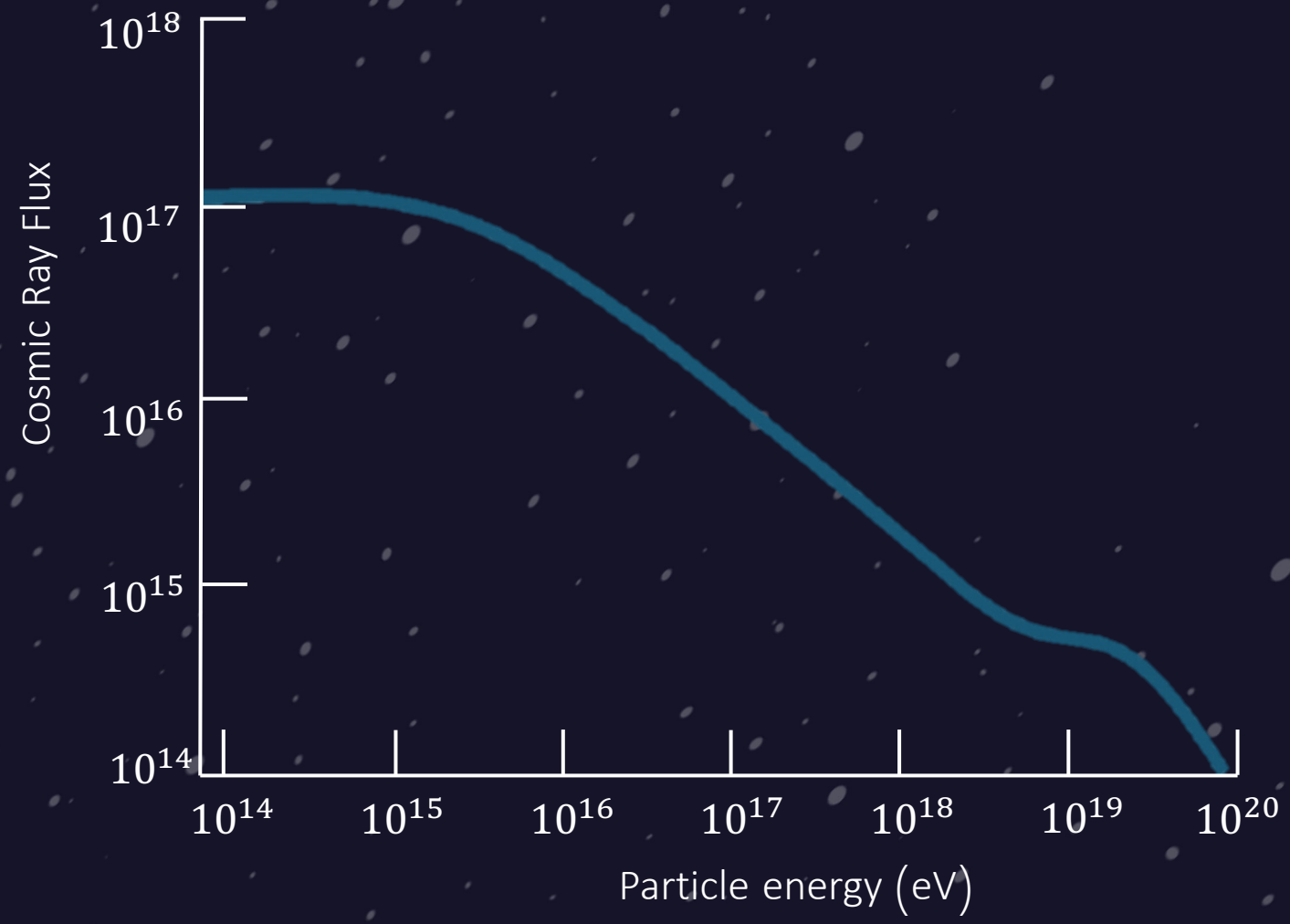
VUB members: Stijn Buitink, Arthur Corstanje, Vital De Henau, Tim Huege

10 November 2025, IIHE Annual meeting, Brussels

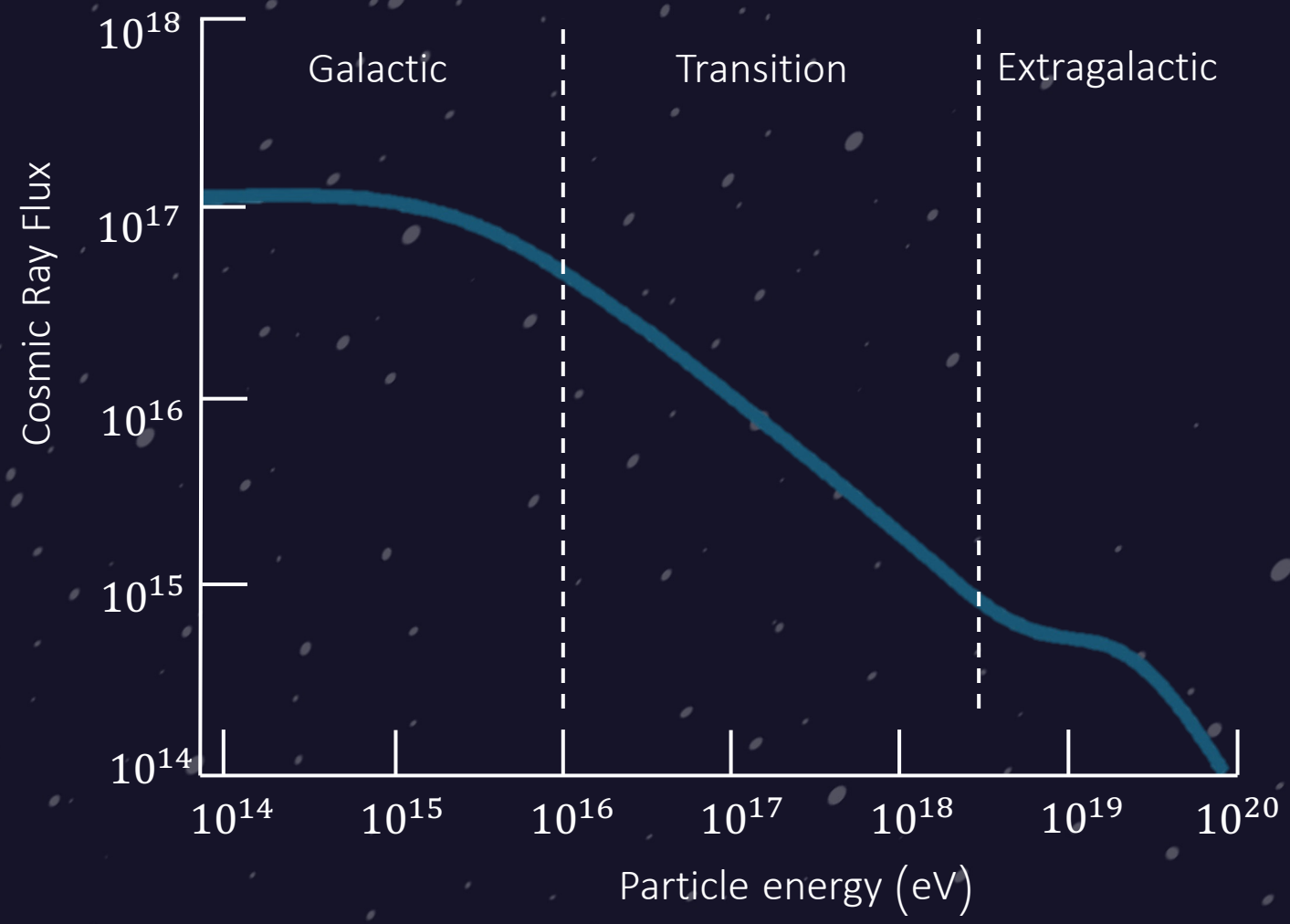
LOFAR cosmic-ray SKAO


Cosmic Ray
p, N, Fe, ...
γ
ν
TeV
PeV
EeV
Cosmic rays
Gamma Rays
Neutrinos
10^{-6}
10^{-7}
10^{-8}
10^{-9}
Flux (E^2 ϕ) [GeV cm⁻ 2 s^−1 sr^{-1}]
10^{11}
10^{13}
10^{15}
10^{17}
10^{19}
Particle energy [eV]

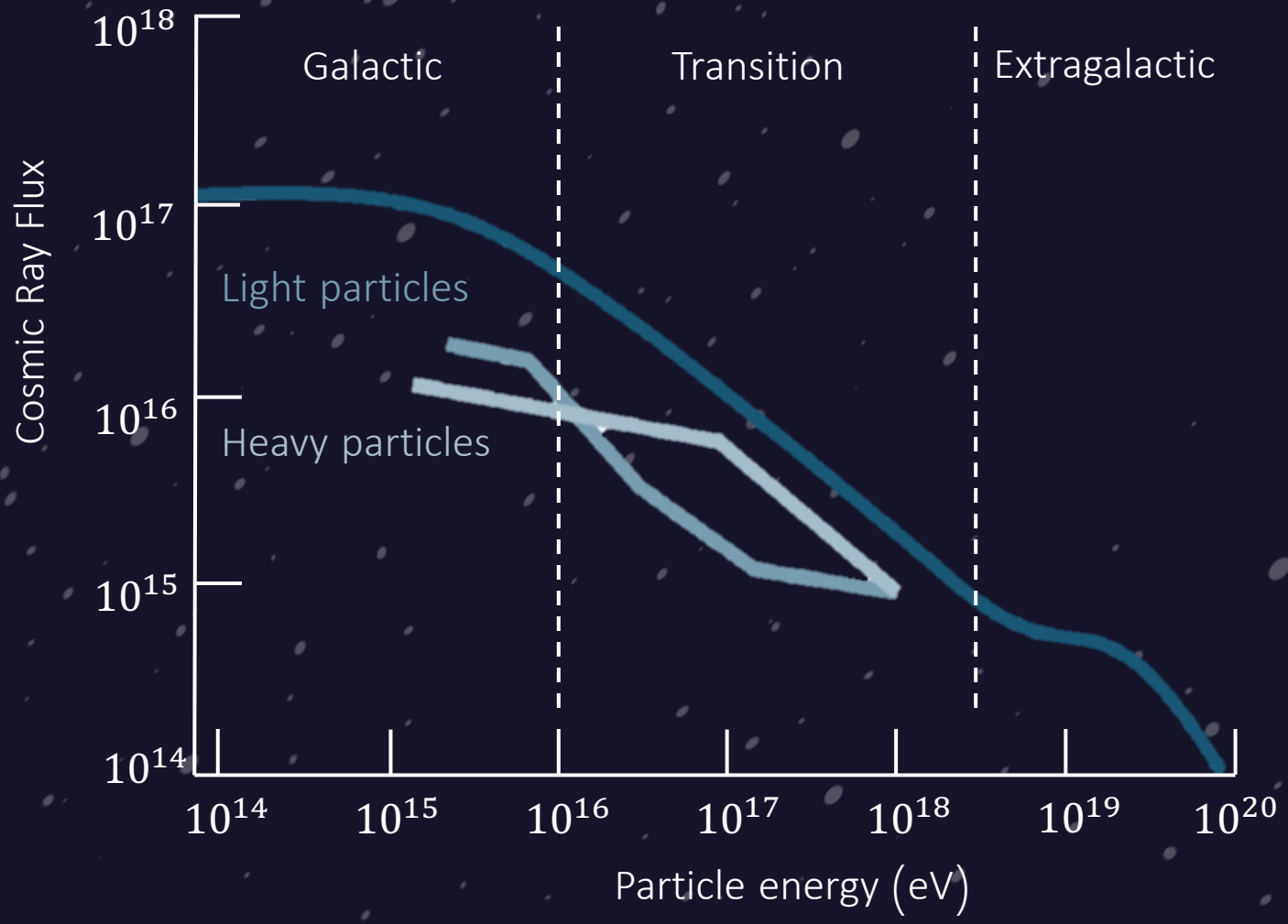
Cosmic rays act as probes of the most extreme physical processes in the universe.



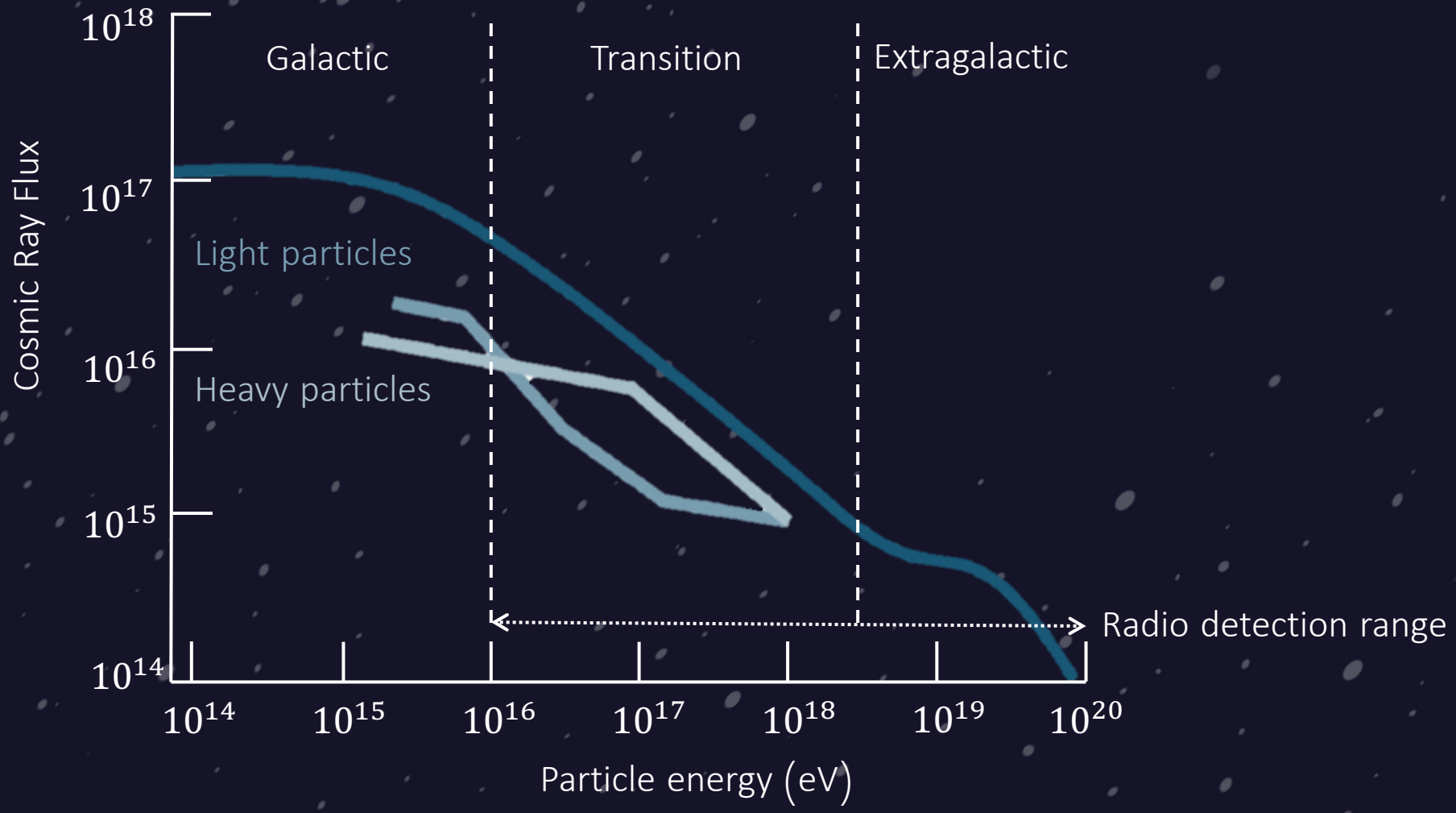
They span orders of magnitude. The flux Slope changes, indicating different origins.



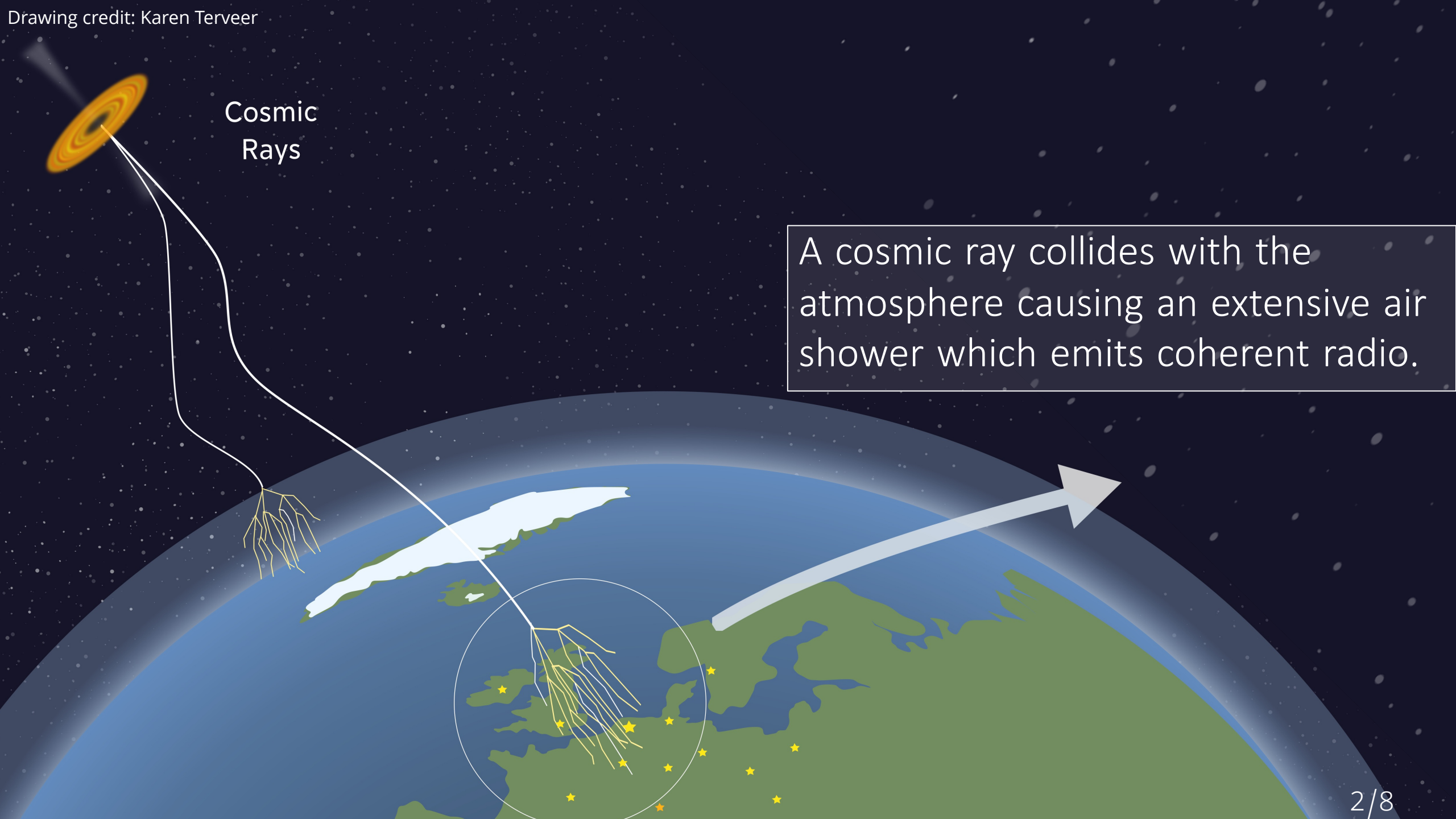
Measuring the type of particles informs us about the sources.



Cosmic rays within the transition region are detectable by radio experiments.

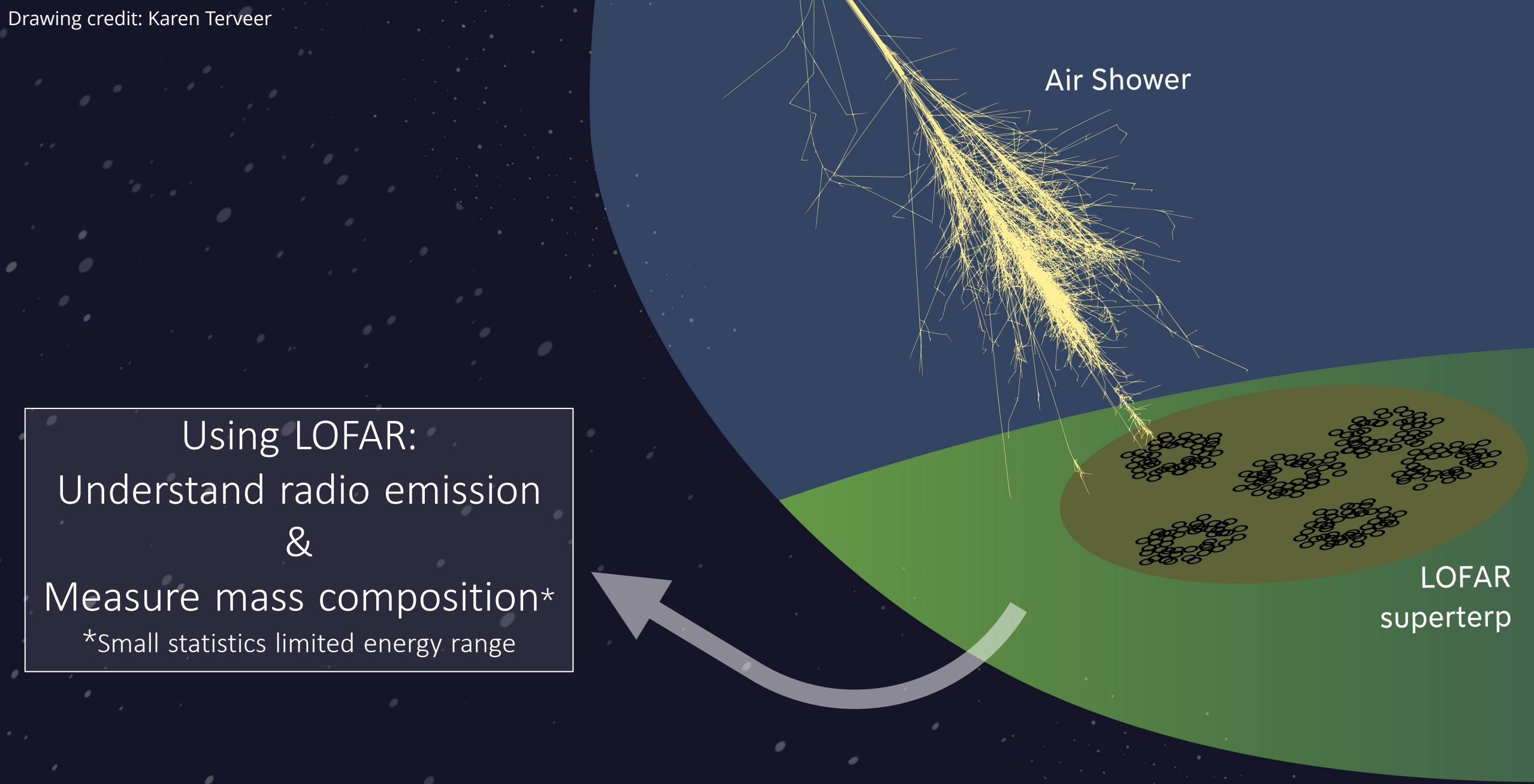


Drawing credit: Karen Terveer



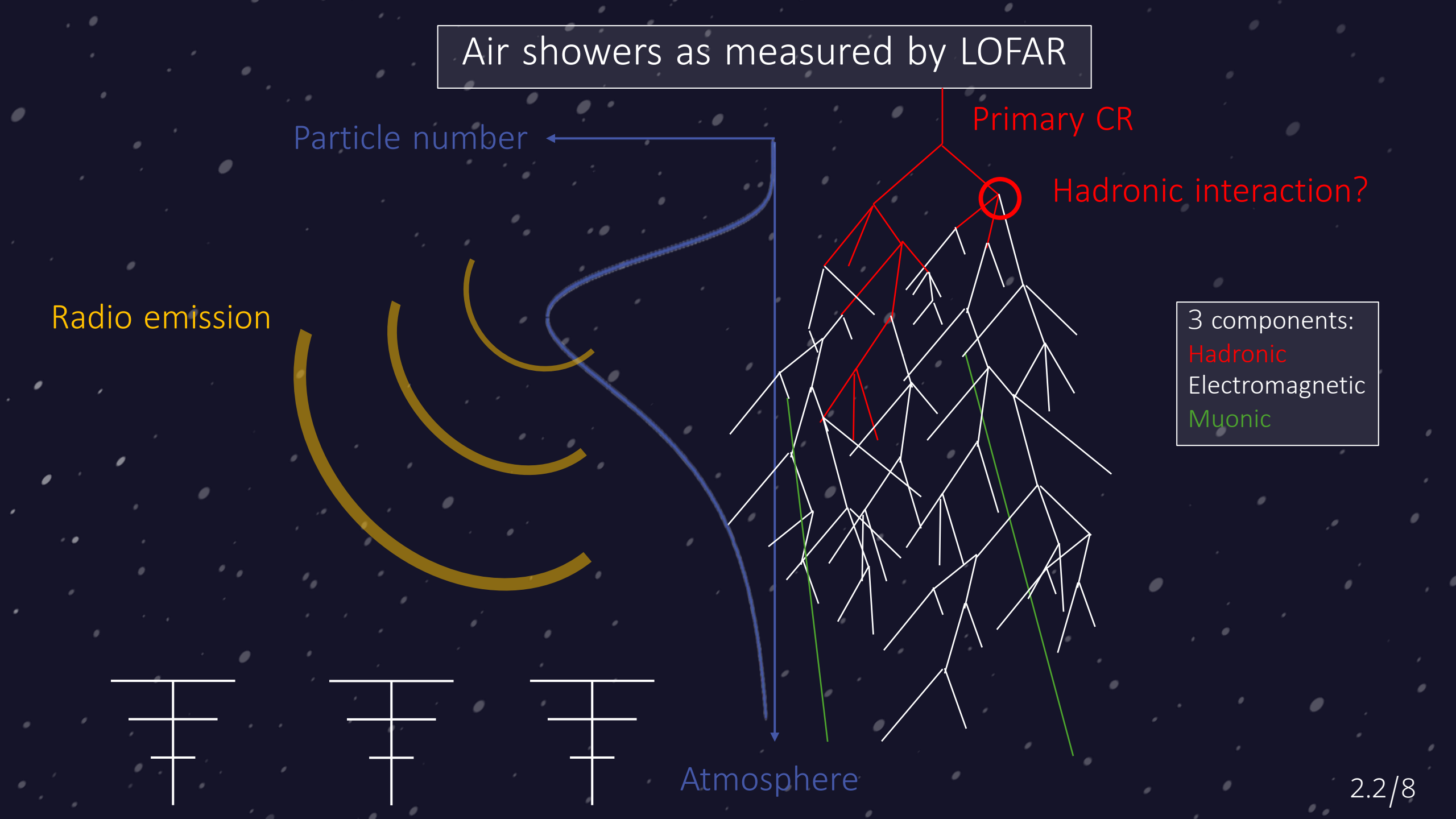
A cosmic ray collides with the atmosphere causing an extensive air shower which emits coherent radio.

Drawing credit: Karen Terveer

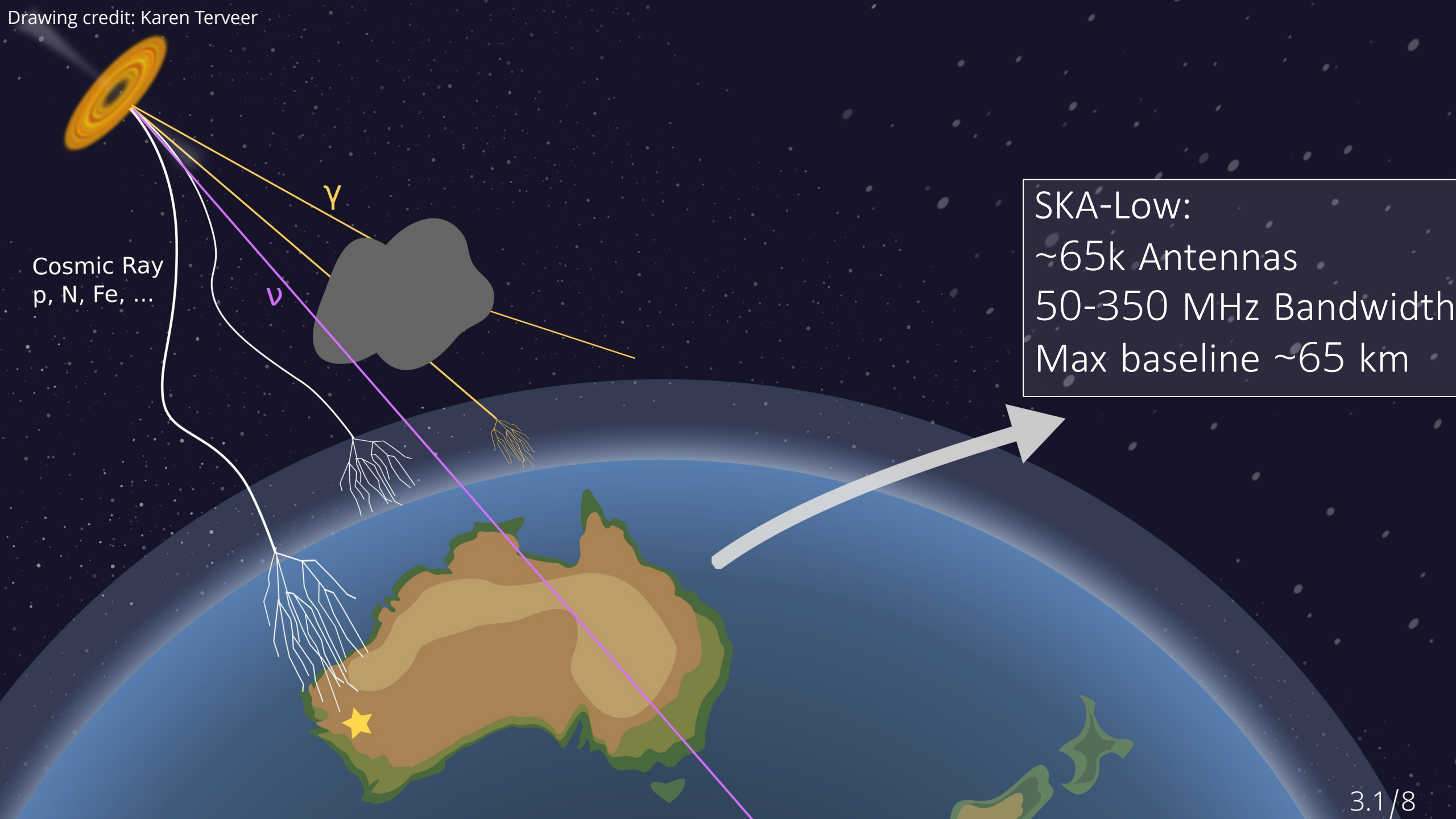


Using LOFAR:
Understand radio emission
&
Measure mass composition*
*Small statistics limited energy range

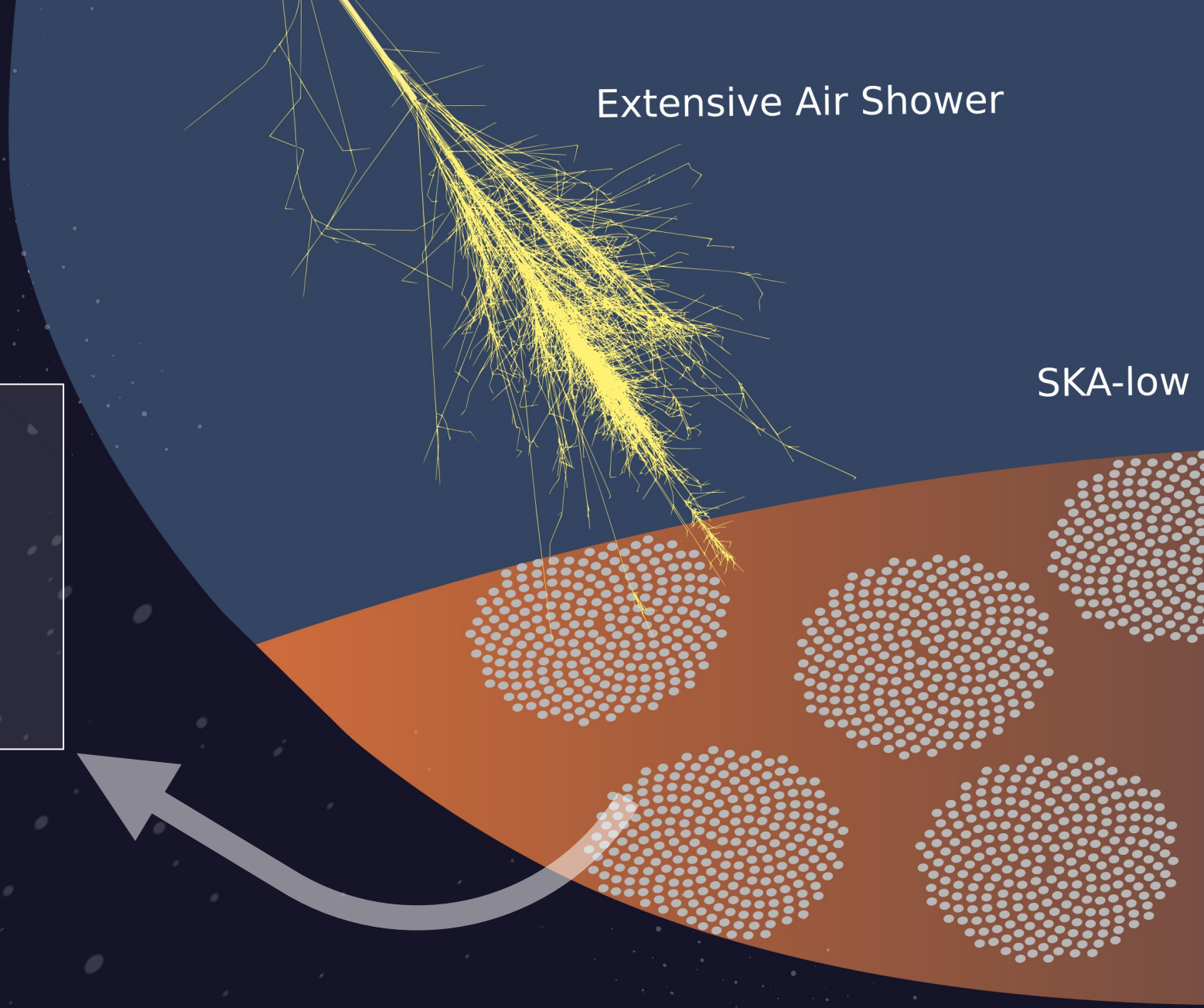
Air showers as measured by LOFAR



Towards the future


Drawing credit: Karen Terveer
γ
Cosmic Ray
p, N, Fe, ...
ν
SKA-Low:
~65k Antennas
50-350 MHz Bandwidth
Max baseline ~65 km

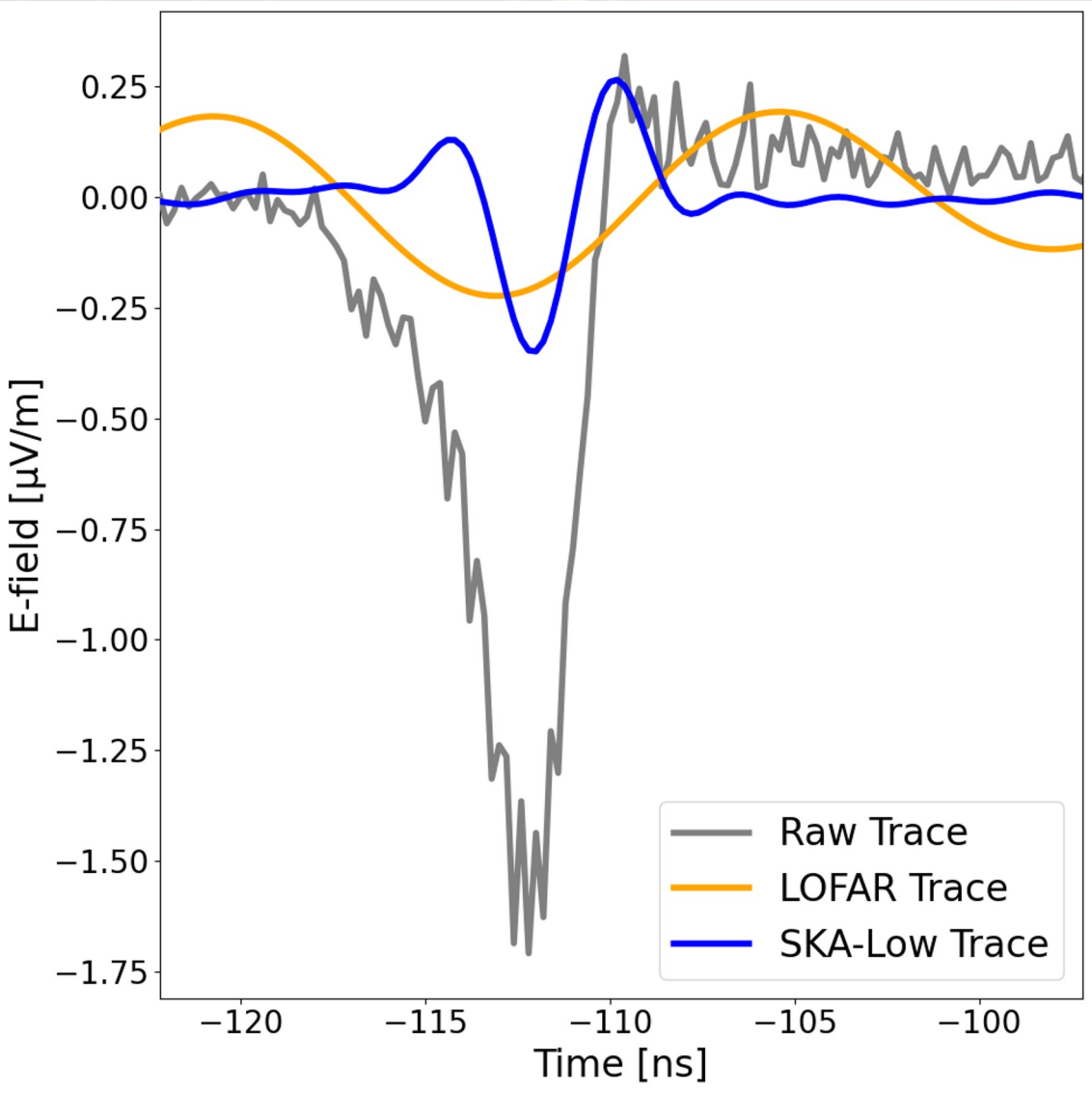
Drawing credit: Karen Terveer

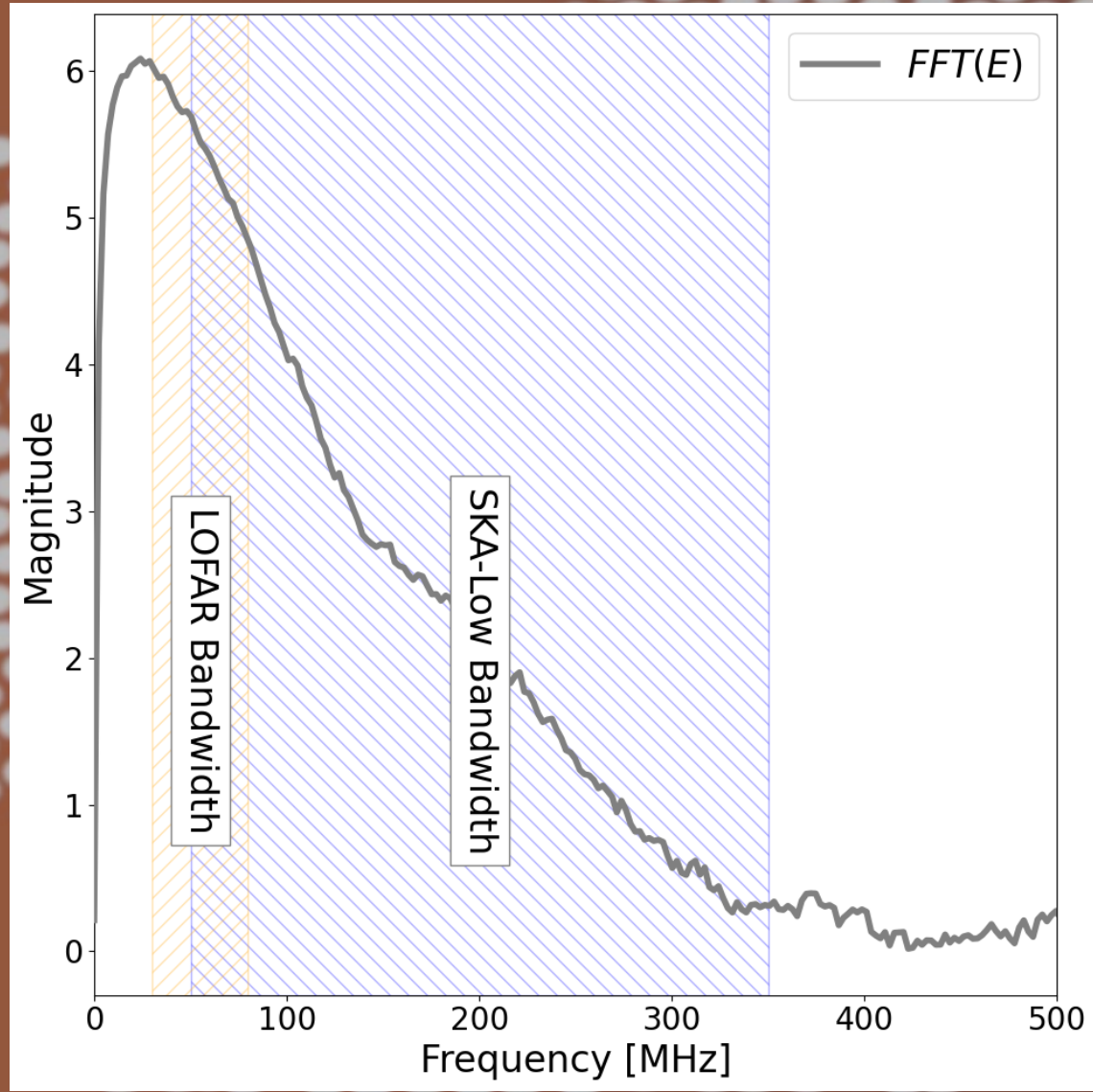


Compared to LOFAR:
Antenna density up by ~100
Bandwidth from 30-80 MHz to 50-350 MHz
Lower energies possible*

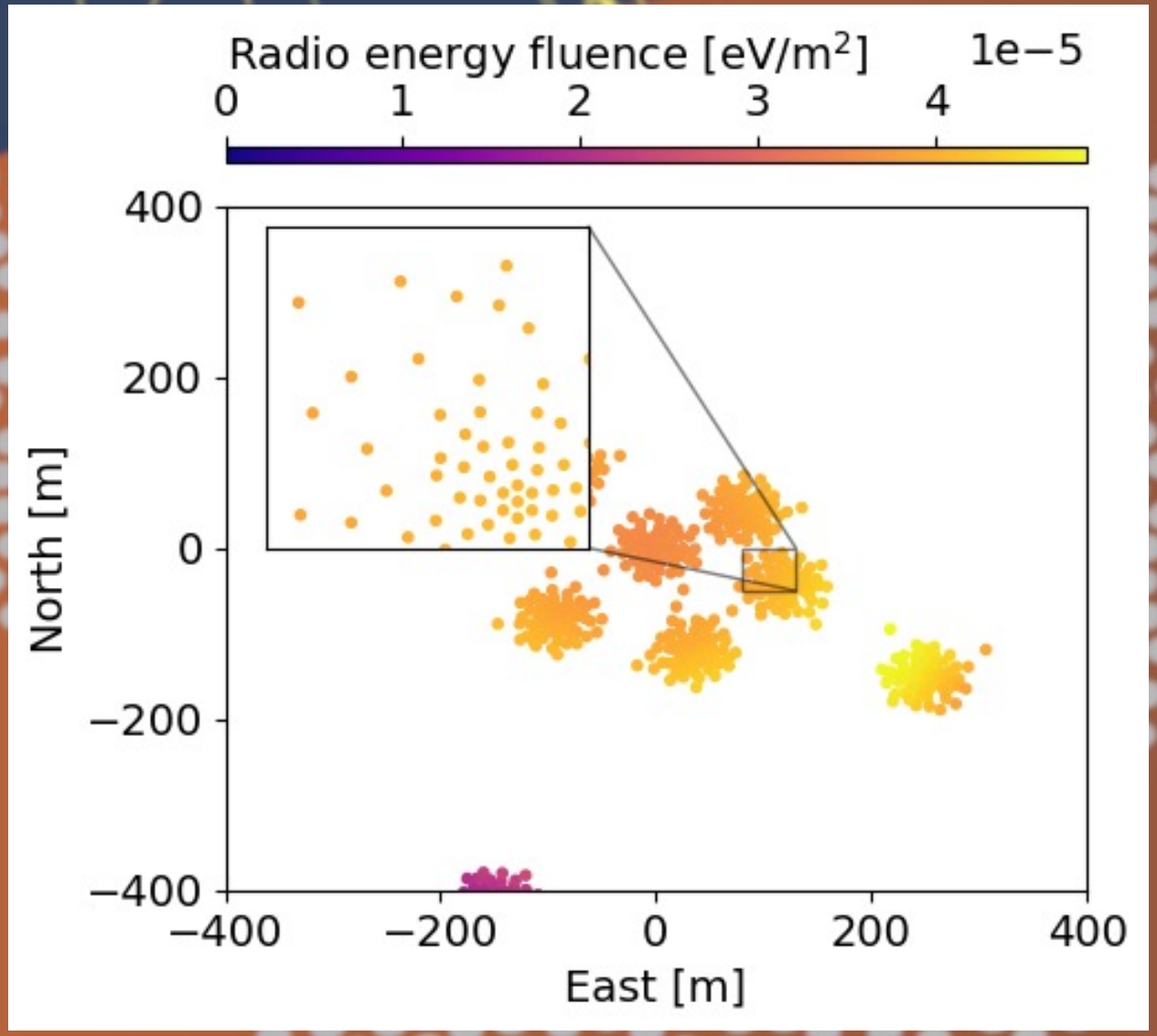
Paper: radio-interferometric technique
By . Schlüter in JINST 16 2021

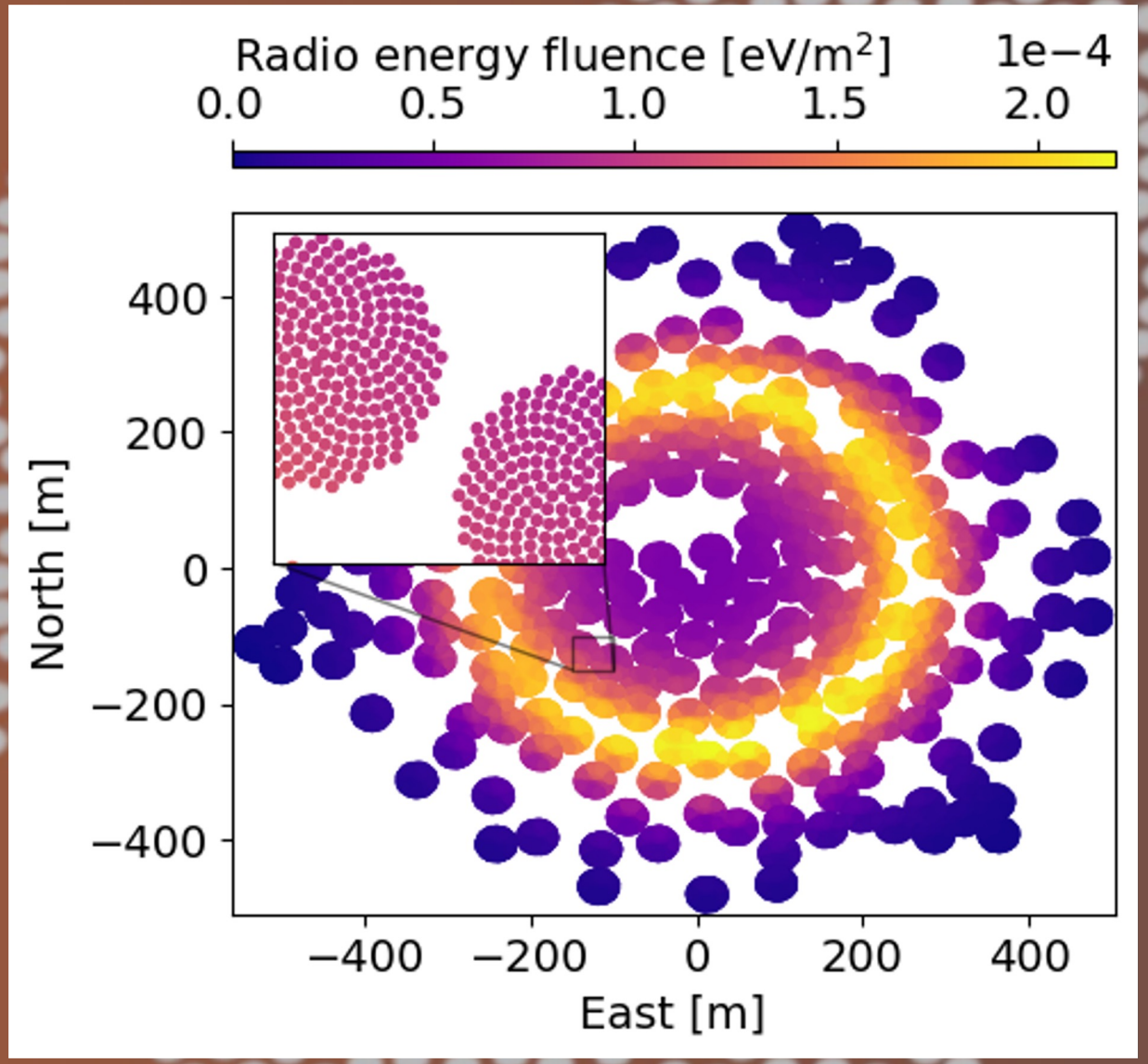
On an individual antenna level
SKA-low's bandwidth opens a new measurement window





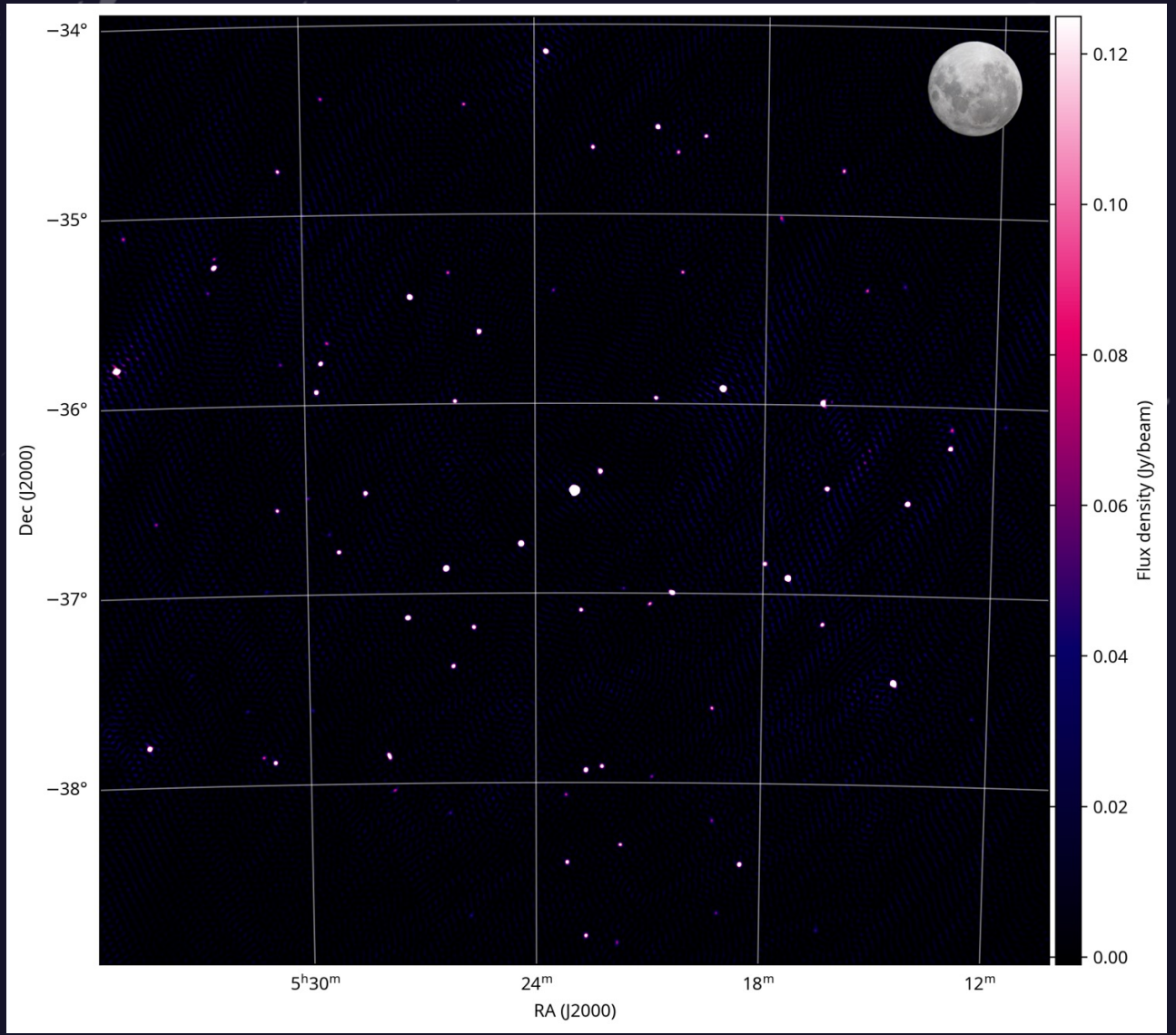
Just so many antennas...





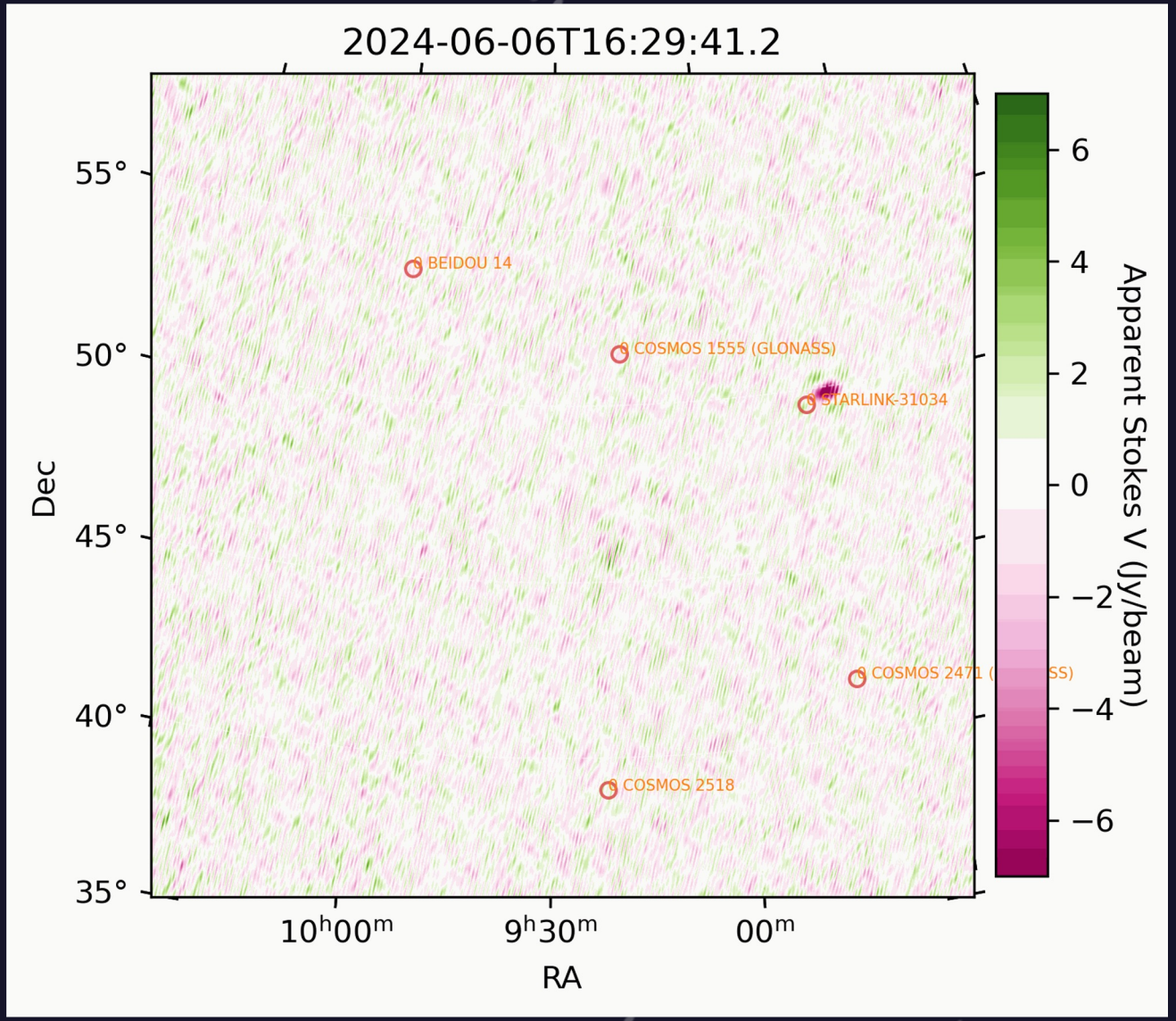

What is going on now?
The first 1.024 antennas have been deployed.
The first image has been made!

First image:
In an area of 100 moons,
~85 brightest known galaxies
in that region.



Article: SKA-Low's first glimpse of the Universe

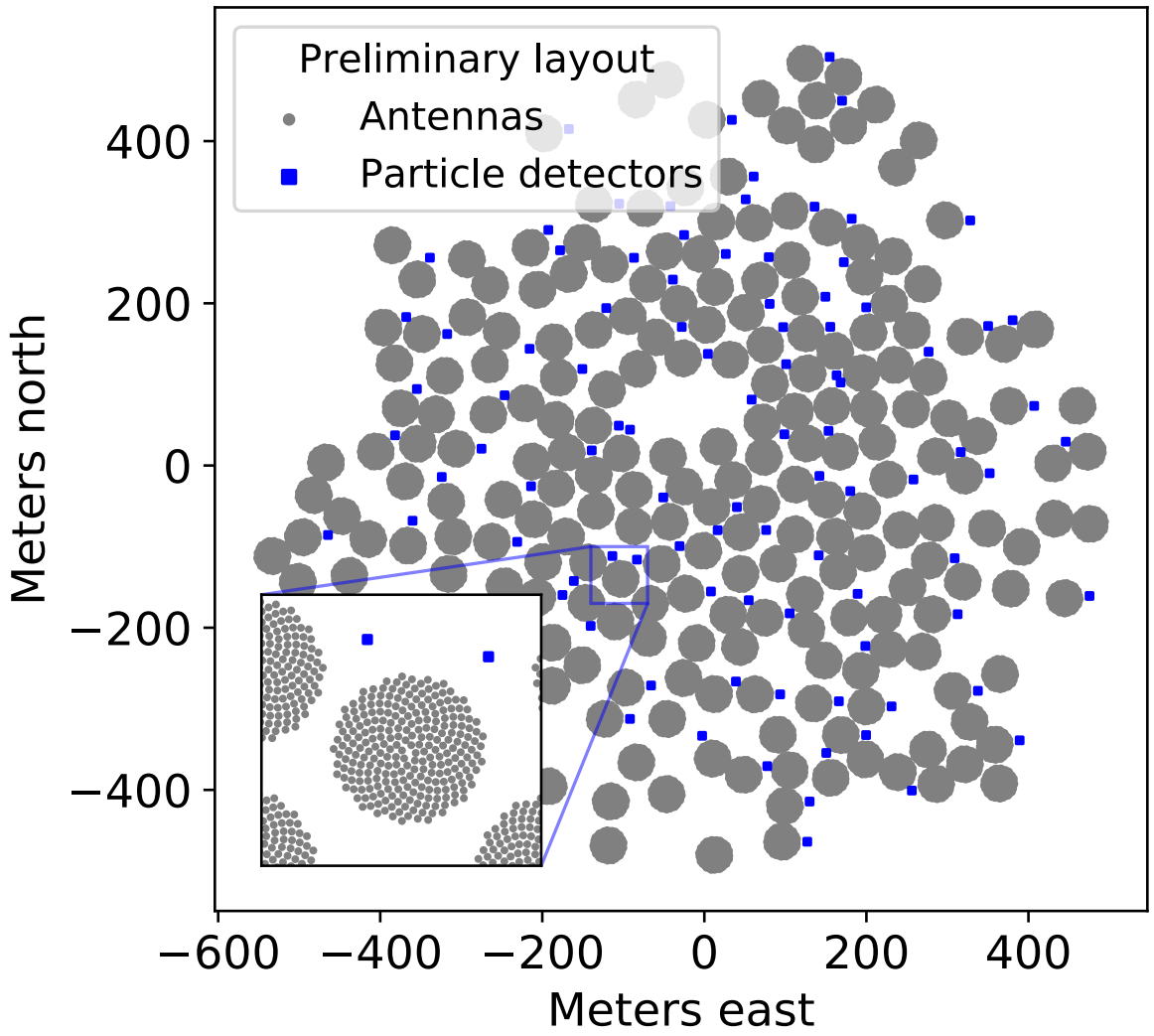
We aren’t alone in the sky…



Presentation: When Satellites Speak Loudly
By X. Zhang at the LOFAR Family meeting 2025

What about cosmic ray events?

To do cosmic ray physics we need particle detectors for triggering.



Paper: The SKA Particle Array Prototype
By J.D. Bray in Nuclear Instruments and Methods in Physics Research 2020

Scintillators made at KIT, in collaboration with VUB and Radboud

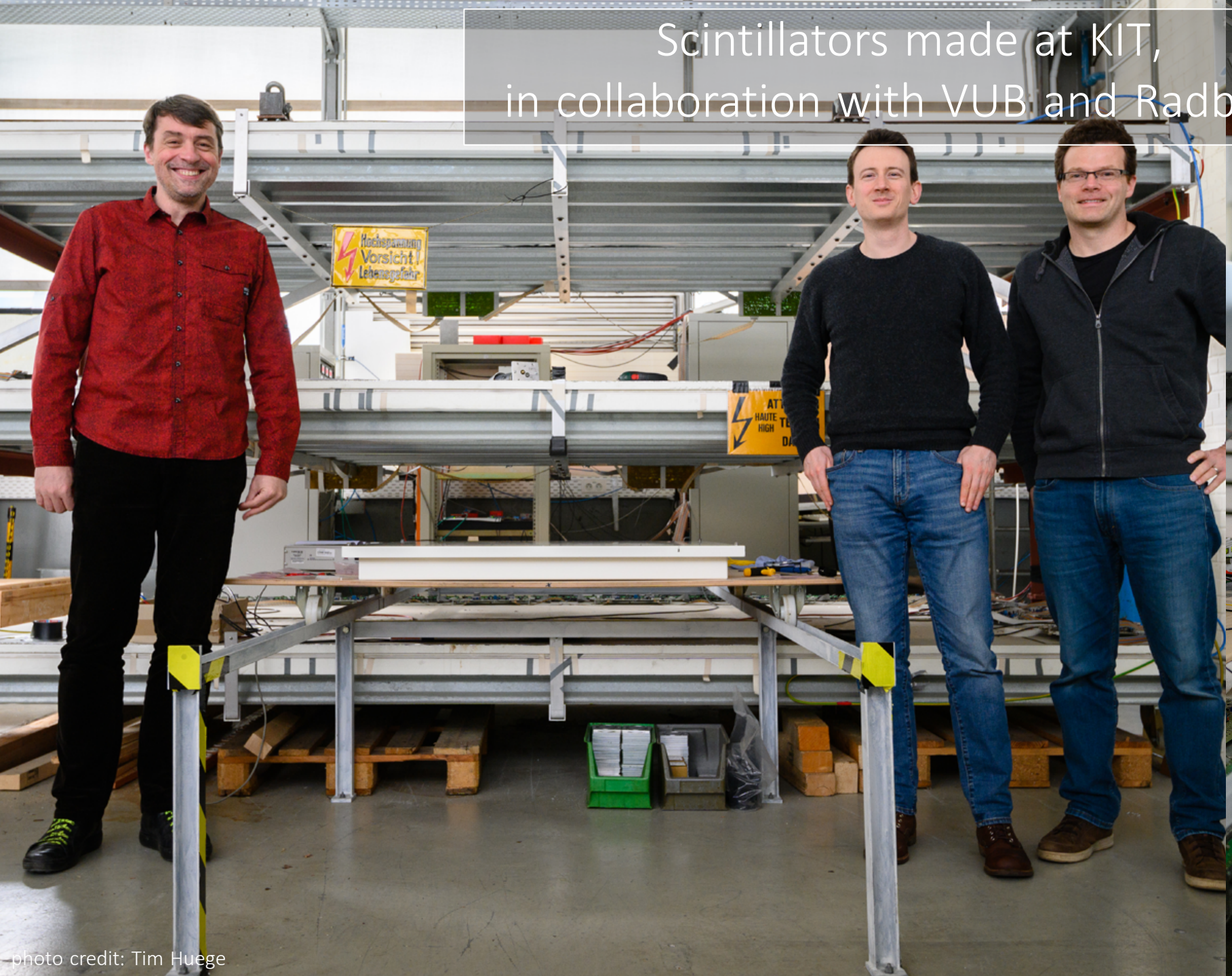
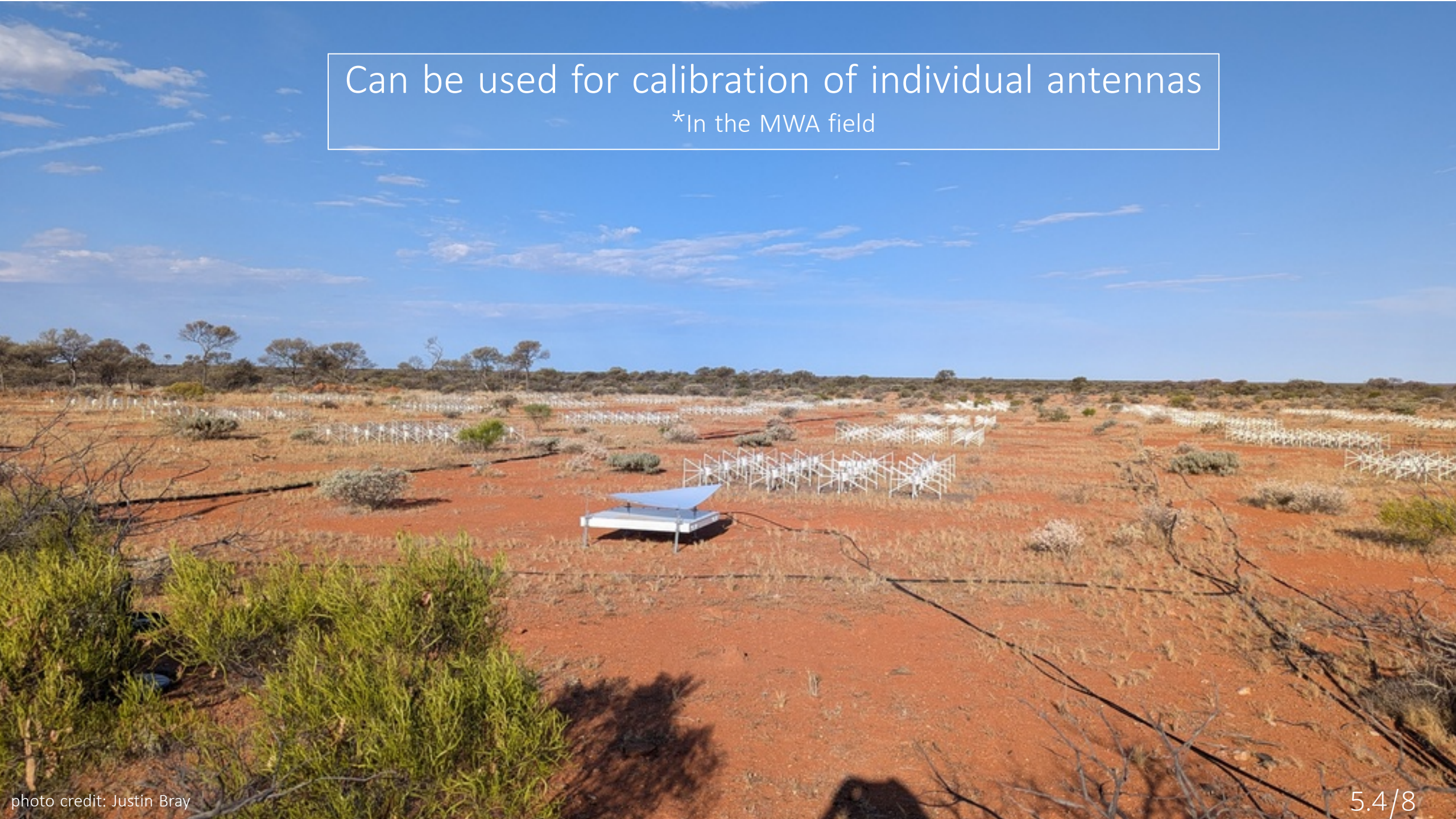


photo credit: Tim Huege

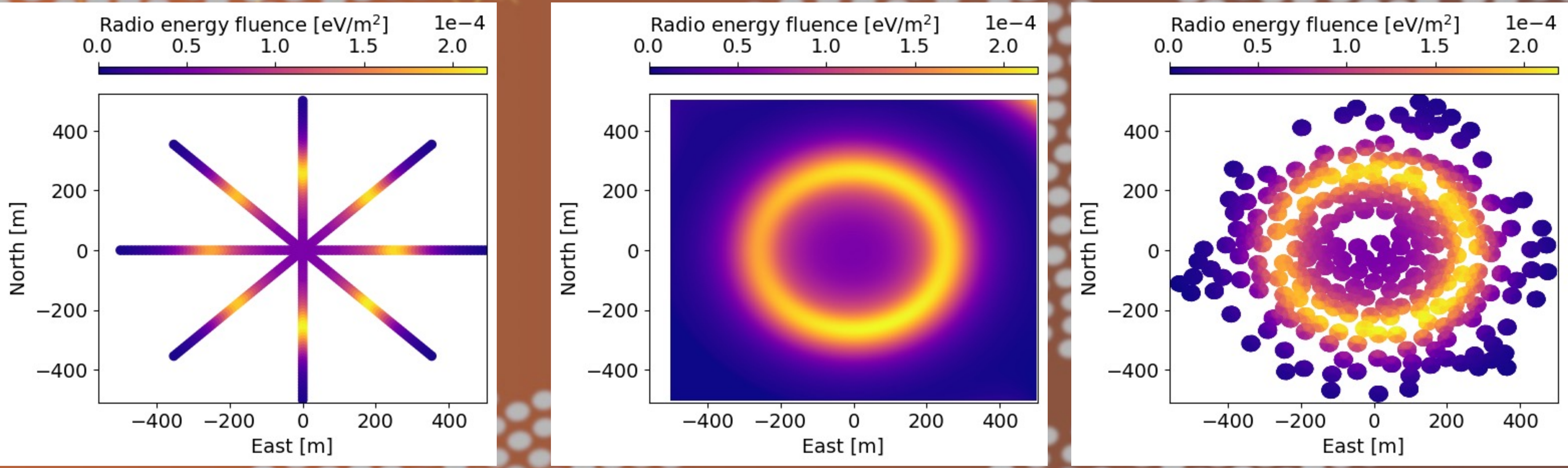
One went on a field trip.

photo credit: Justin Bray


Can be used for calibration of individual antennas
*In the MWA field
photo credit: Justin Bray

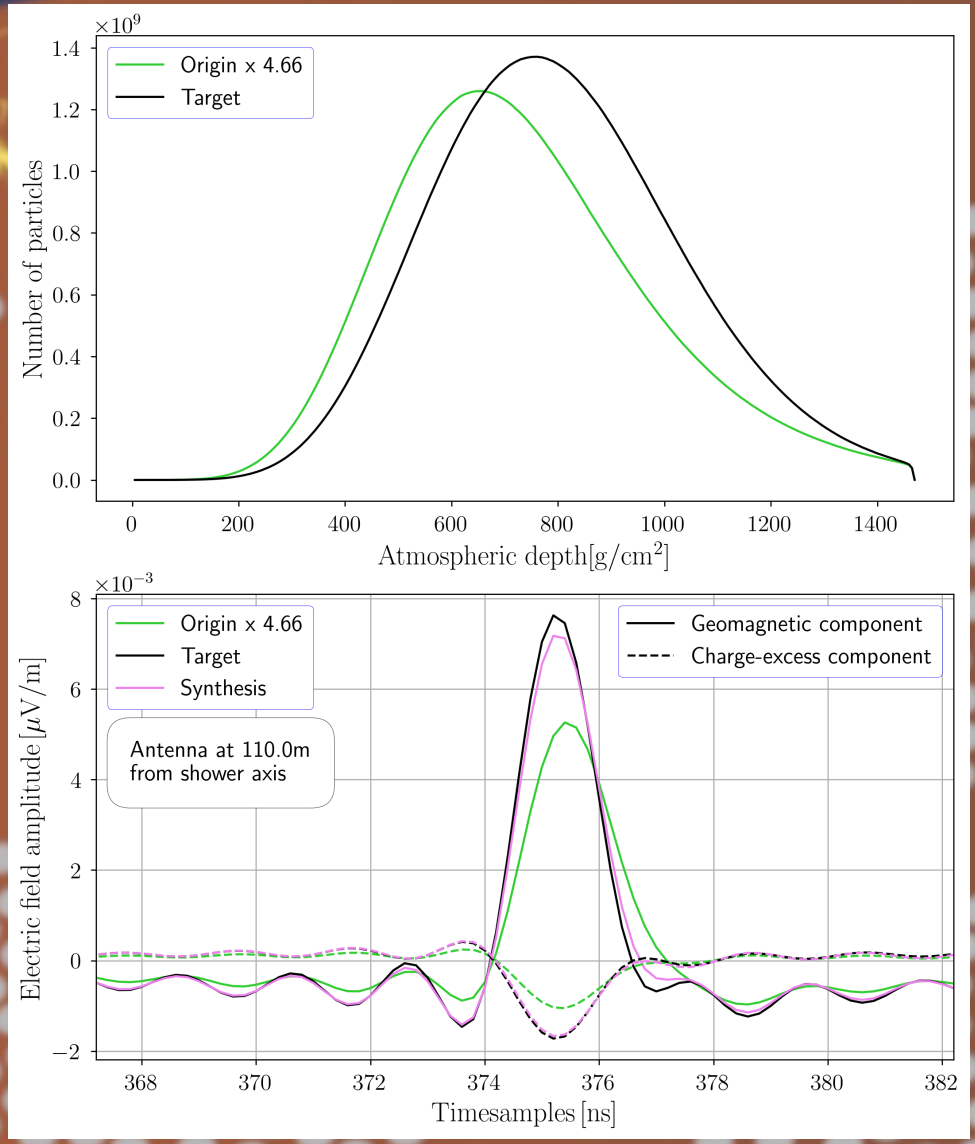
So many antennas…
Slow simulations, like really slow

Using an electric-field based interpolator we can simulate ~200 antennas instead of ~60k.



Paper: A high-precision interpolation method for pulsed radio signals from cosmic-ray air showers
By A. Corstanje in JINST 18 P09005, 2023

Using SMIET simulations go from weeks to minutes.



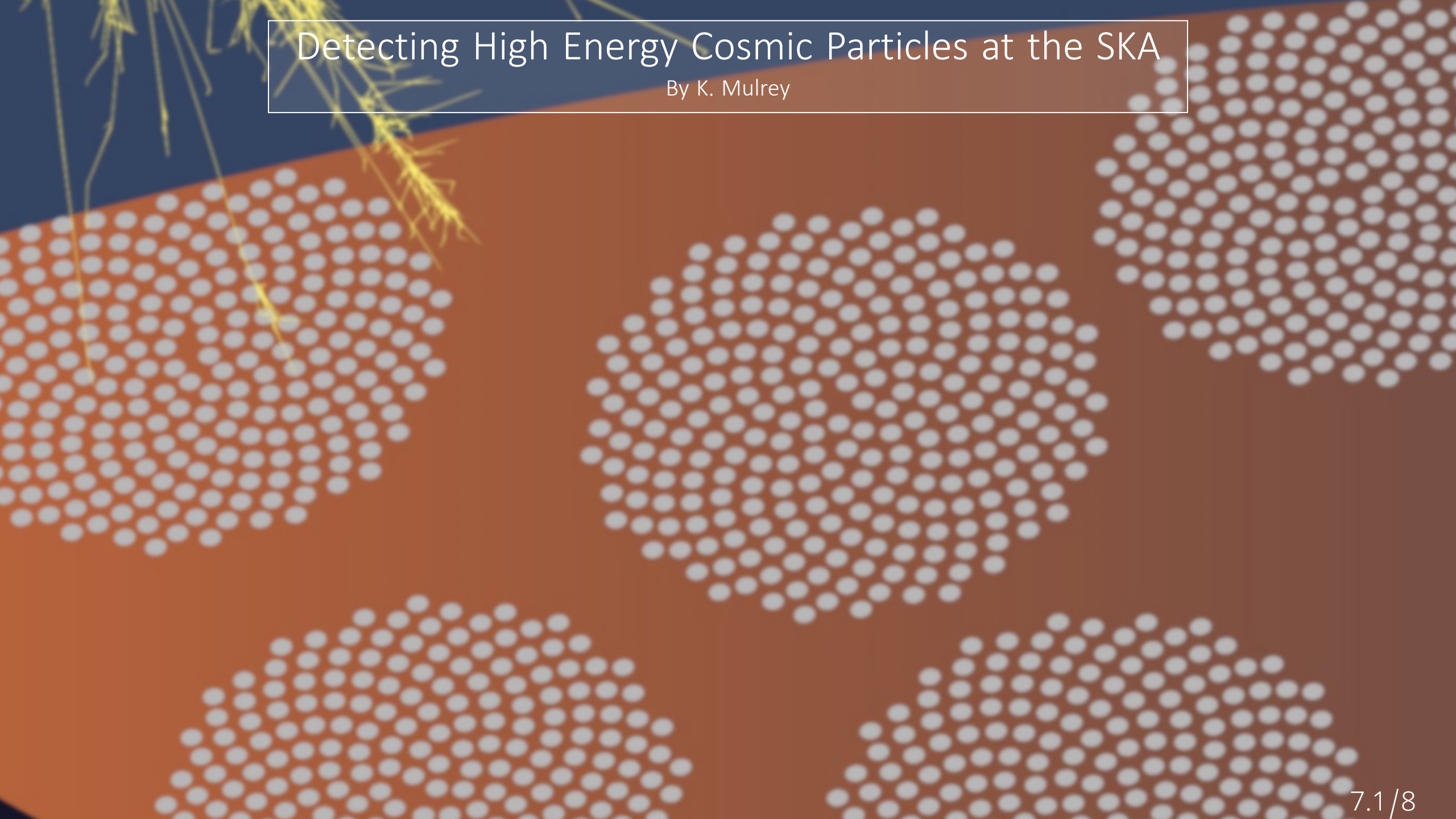
Open source software, that is one pip install away!

Papers:
SMIET by Mitja Desmet in Astroparticle Physics 2025
Proof of principle for template synthesis by M. Desmet in Astroparticle Physics 2023


Want to know what SKA-Low will allow us to do?
SKA-Low science chapters are on the way.

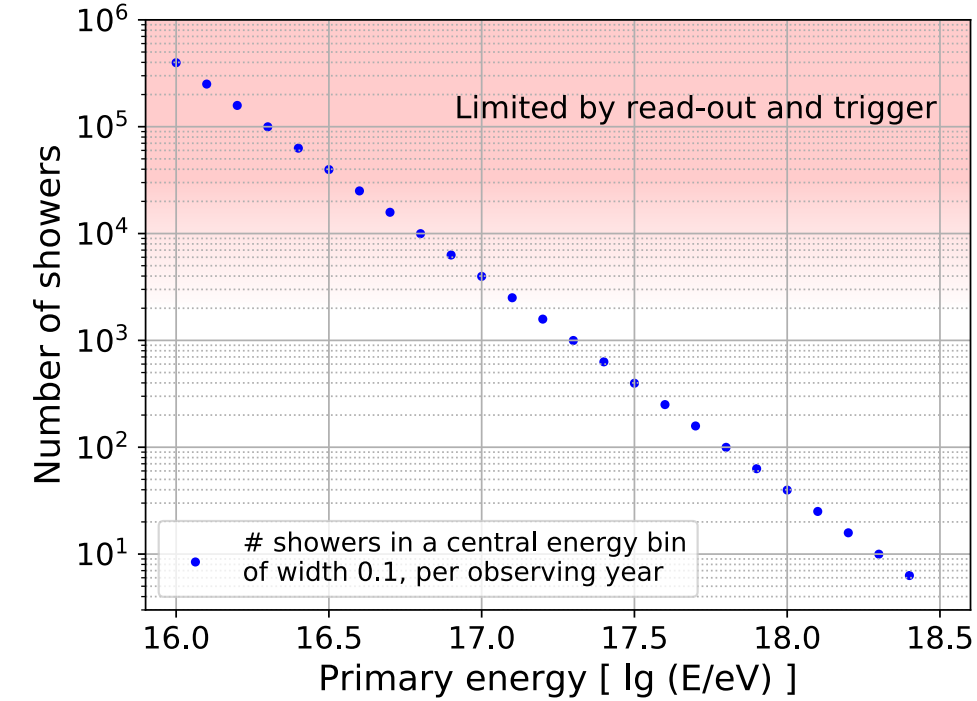
Detecting High Energy Cosmic Particles at the SKA

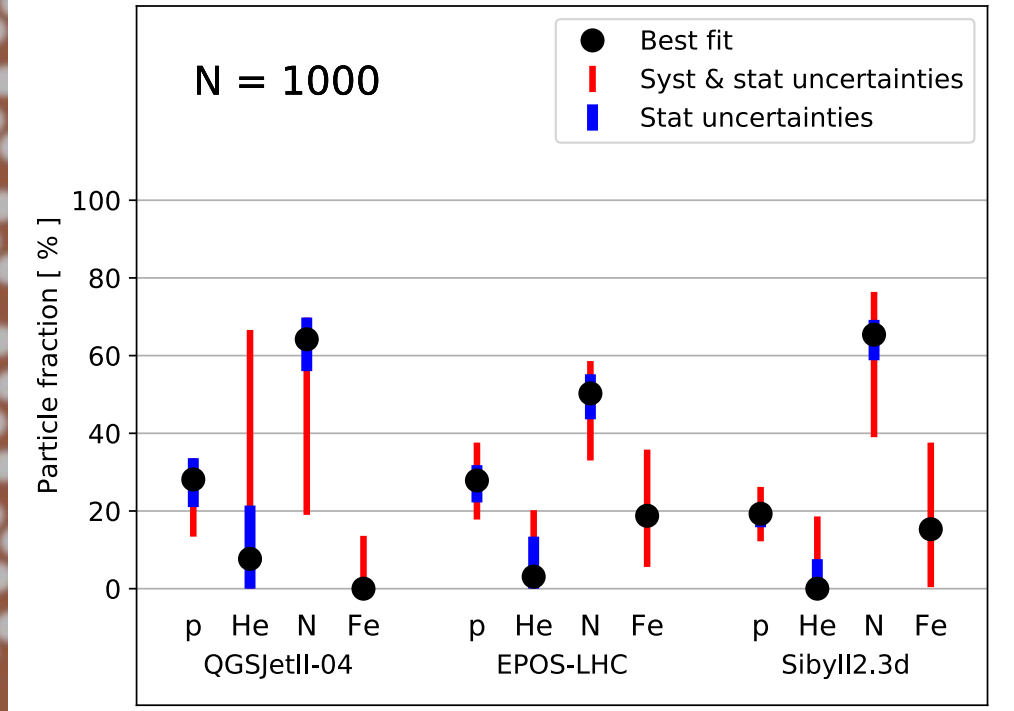
By K. Mulrey



Origins of cosmic rays in the Galactic-extragalactic transition energy range

By A. Corstanje & S. Saha

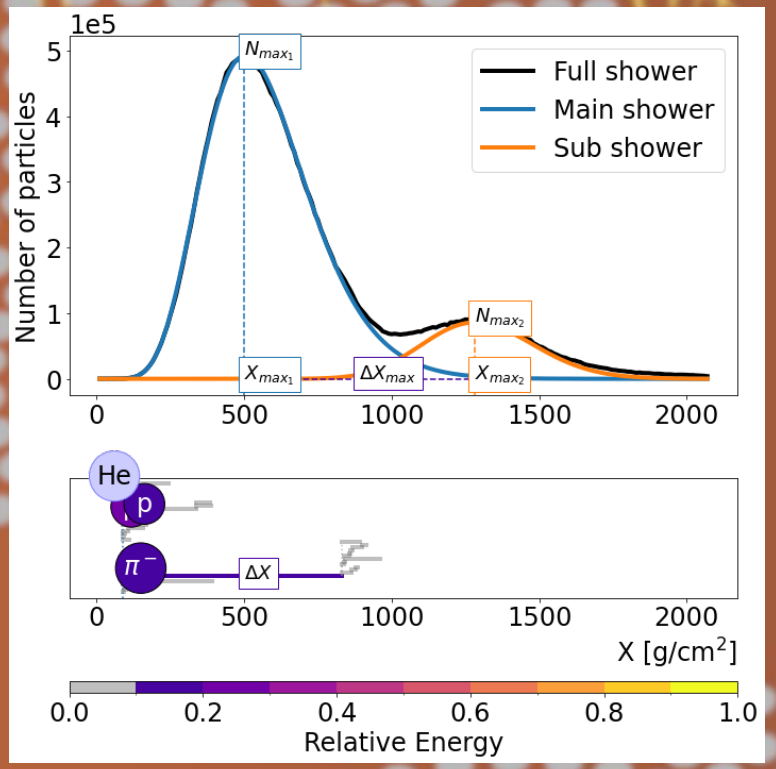


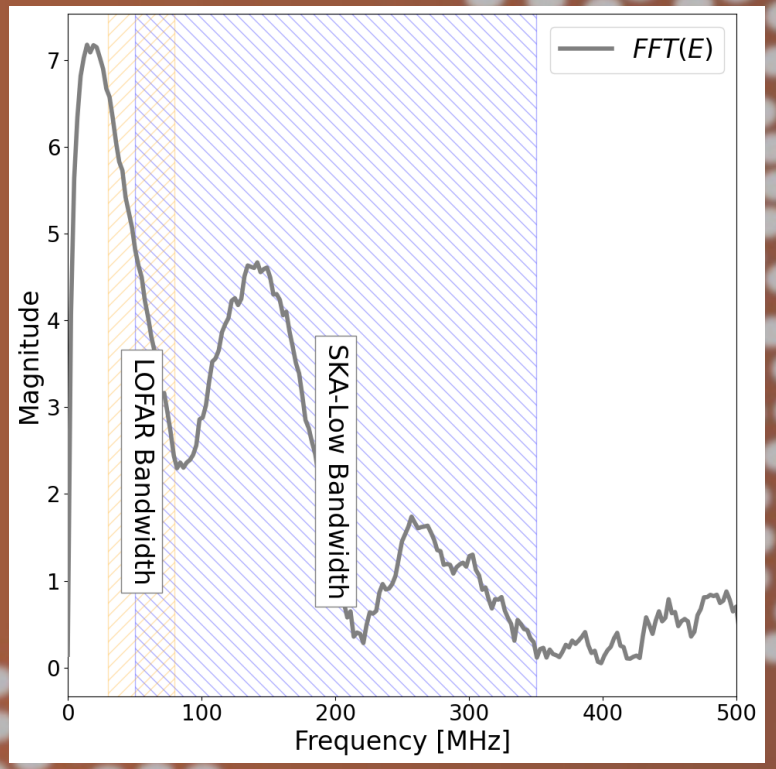


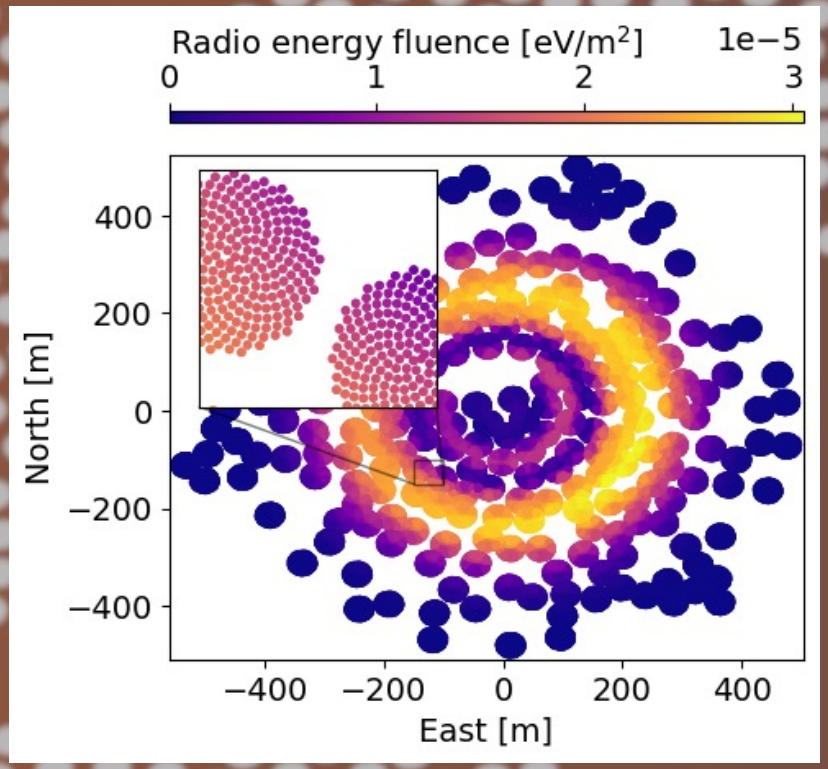
Paper: A LOFAR-style reconstruction of cosmic-ray air showers with SKA-Low
By A. Corstanje in Phys. Rev. D

Studying high-energy hadronic physics from observations of anomalous air showers

By S. Buitink & V. De Henau



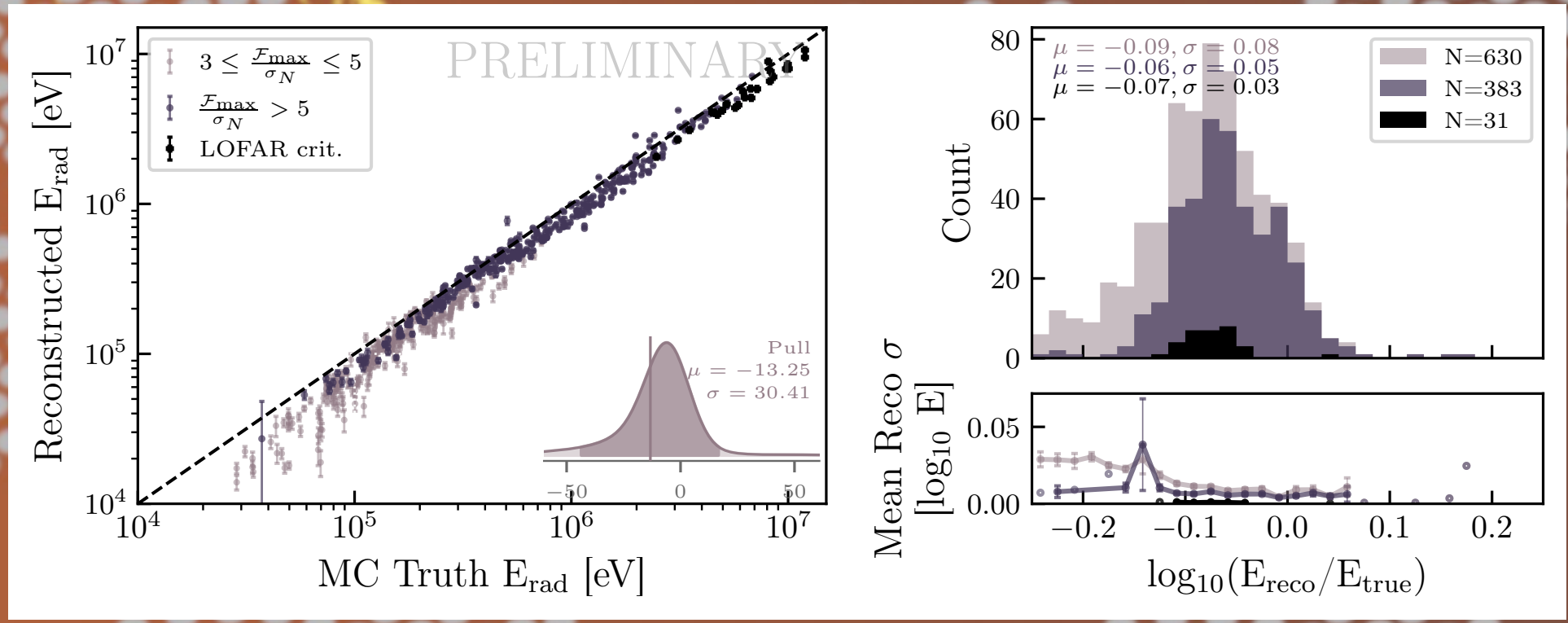




Proceedings: Investigating double bump air showers with the SKA
By V. De Henau ICRC 2025

Interferometric analysis of air-shower radio emission in the near field with an information field theory approach

By K. Watanabe & K. Terveer



Proceedings:

Reconstructing air showers using probabilistic forward modelling for LOFAR

By K. Terveer ICRC 2025

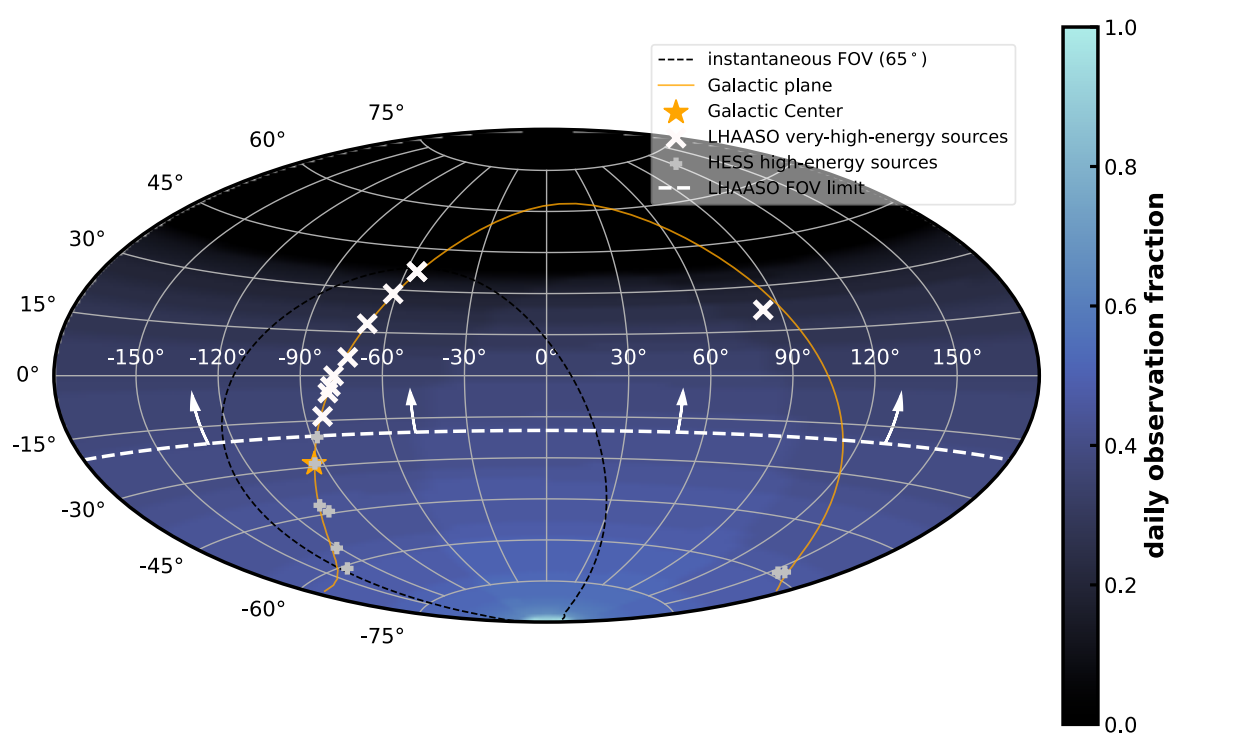
A novel approach for air shower profile reconstruction with dense radio antenna arrays using Information Field Theory

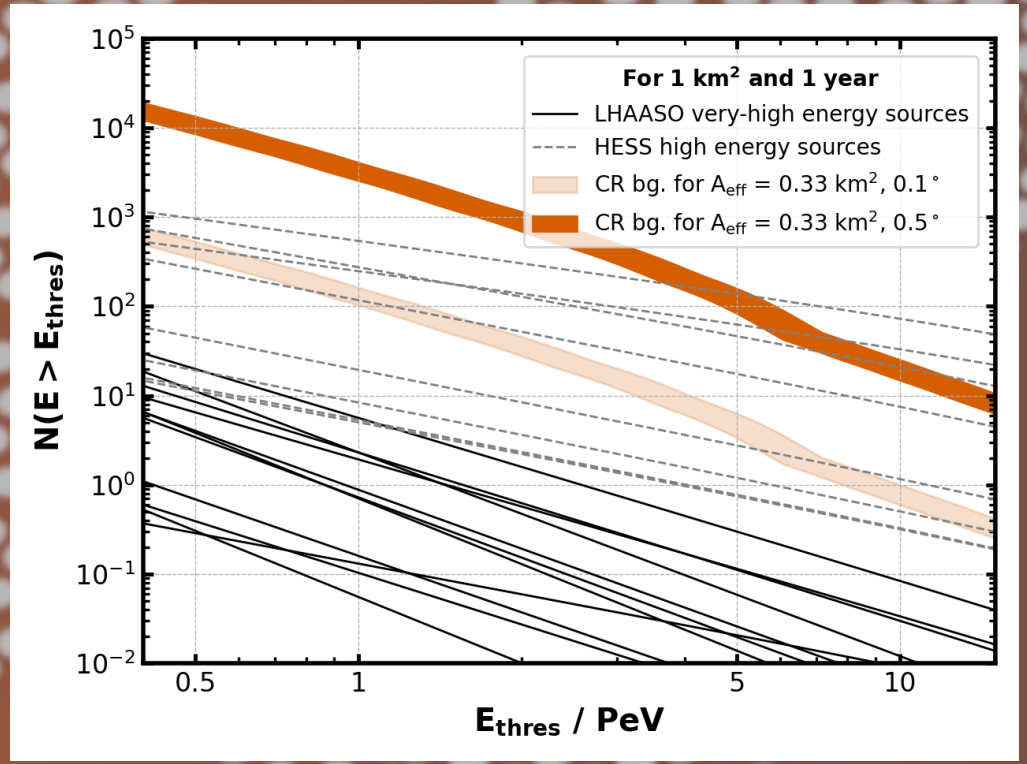
By K. Watanabe

Using SKA-Low to detect PeV gamma-rays from Galactic Sources

By A. Nelles, P. Laub & H. He

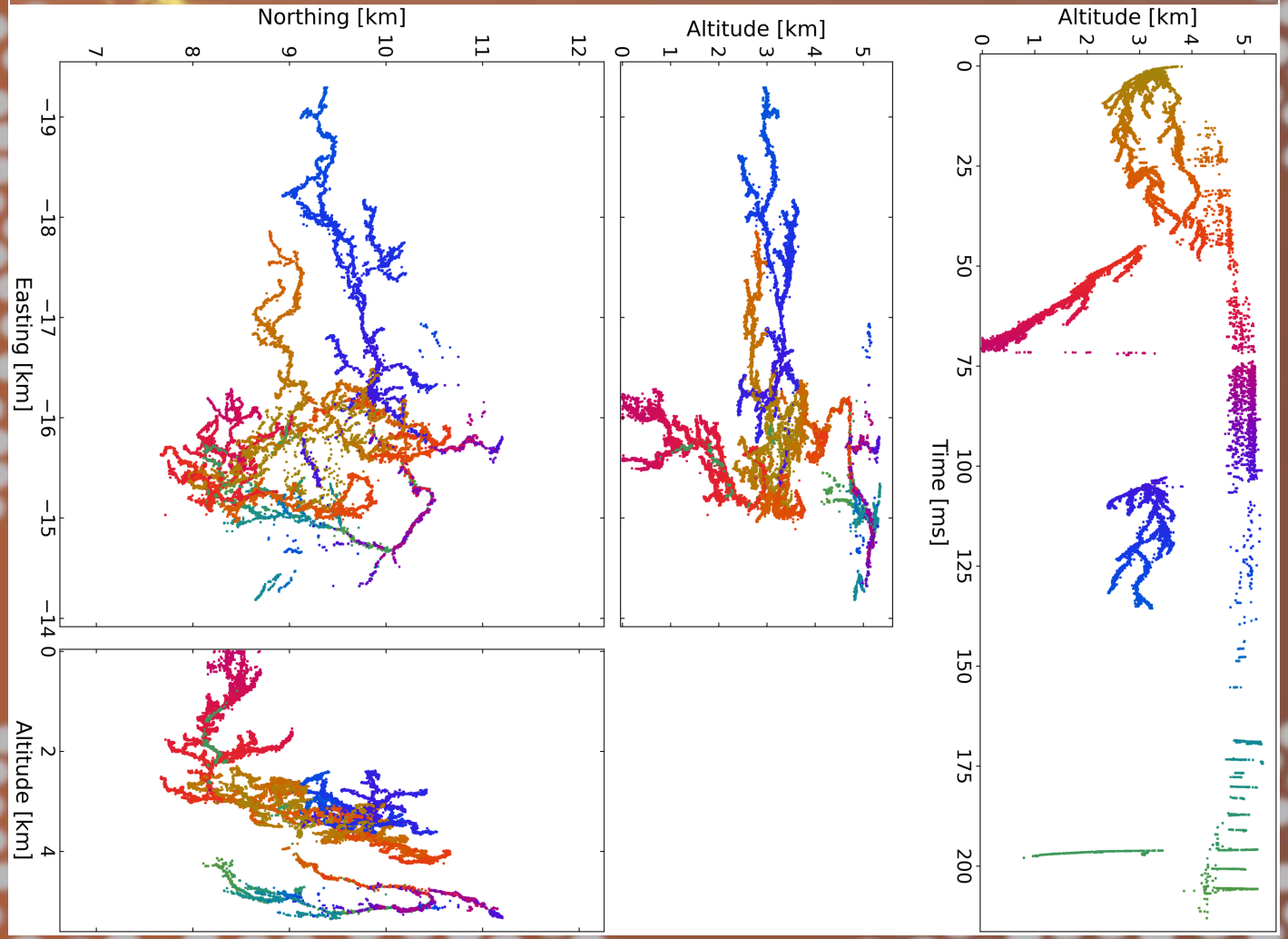
*disclaimer this is very hard
High risk, high reward





Proceedings: Using SKA-low to detect PeV gamma-rays from Galactic Sources
By F. Schlüter and P. Laub ICRC 2025

Unveiling the Mysteries of Lightning: Exploring its fundamental Physical Processes with SKA-LOW



Paper: Radio emission from negative lightning leader steps reveals inner meter-scale structure
By B. Hare in Phys. Rev. Lett. 124 2020


Question?