Ultra-High-Energy Cosmic Particles

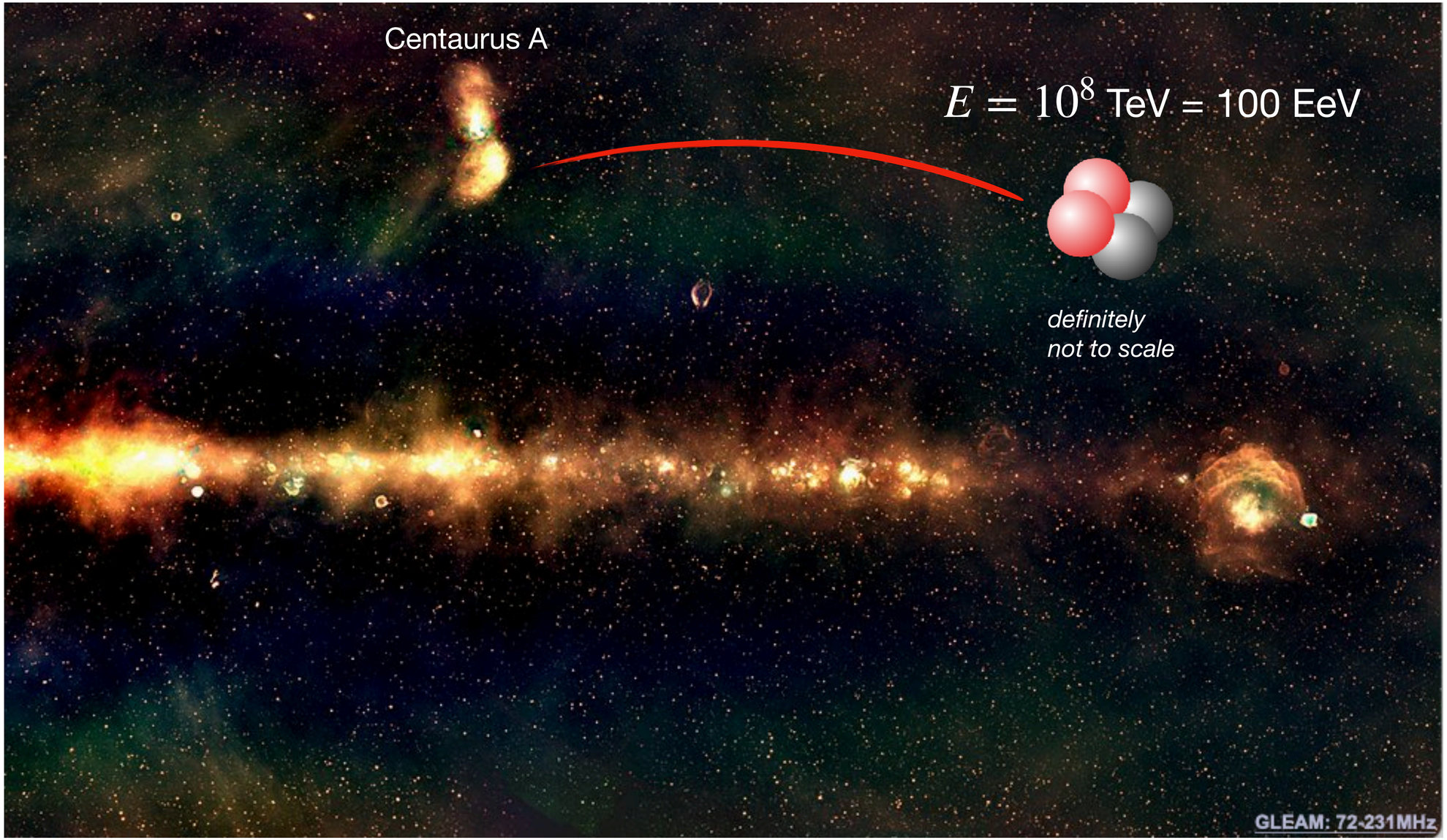
26th Symposium on Astroparticle physics in the Netherlands

Harm Schoorlemmer

Nikhef

Radboud University

The most extreme accelerators!

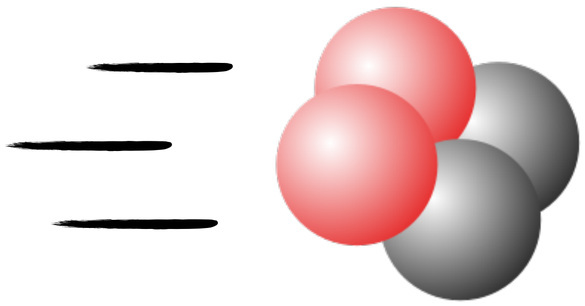


not to scale

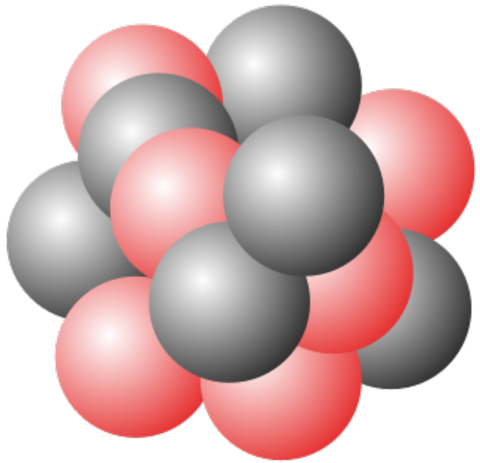
Earth

Extreme collisions!

Space



Atmosphere



$$\sqrt{s} \approx 300 \text{ TeV}$$

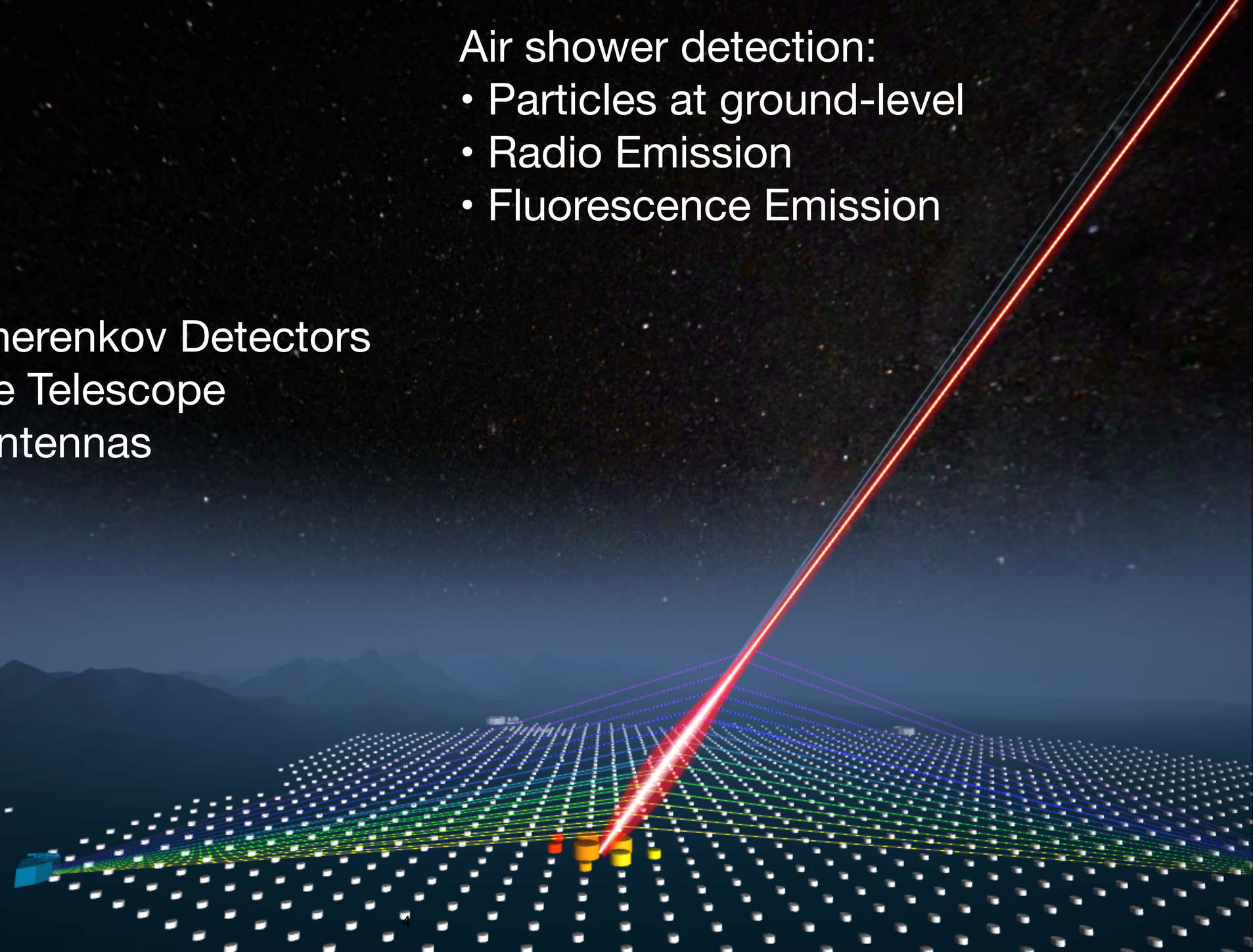
PIERRE AUGER OBSERVATORY

Air shower detection:

- Particles at ground-level
- Radio Emission
- Fluorescence Emission

Area: 3000 km^2

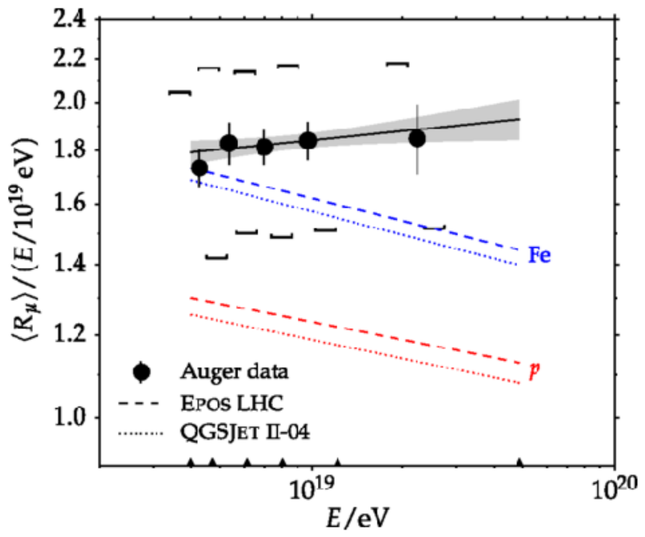
1600 + 60 Water-Cherenkov Detectors
24 + 3 Fluorescence Telescope
AERA: 153 Radio Antennas

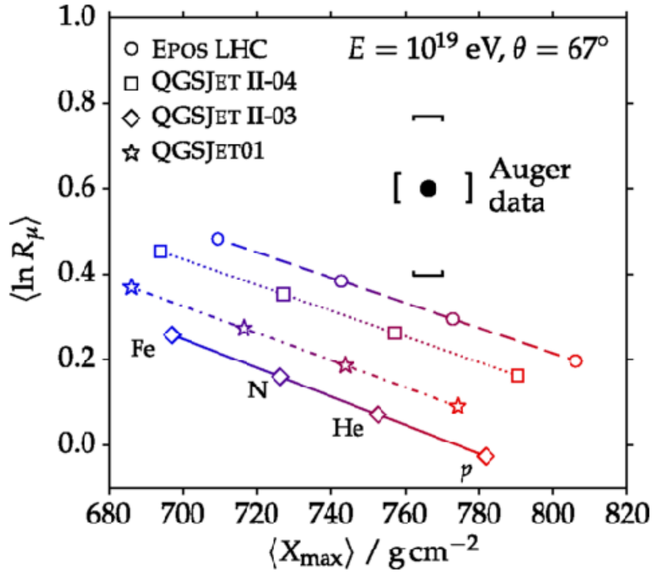


What is going on with the collisions?

On <u>average</u> more muons observed than in models*, but <u>fluctuations</u> in the muon number is not in tension.

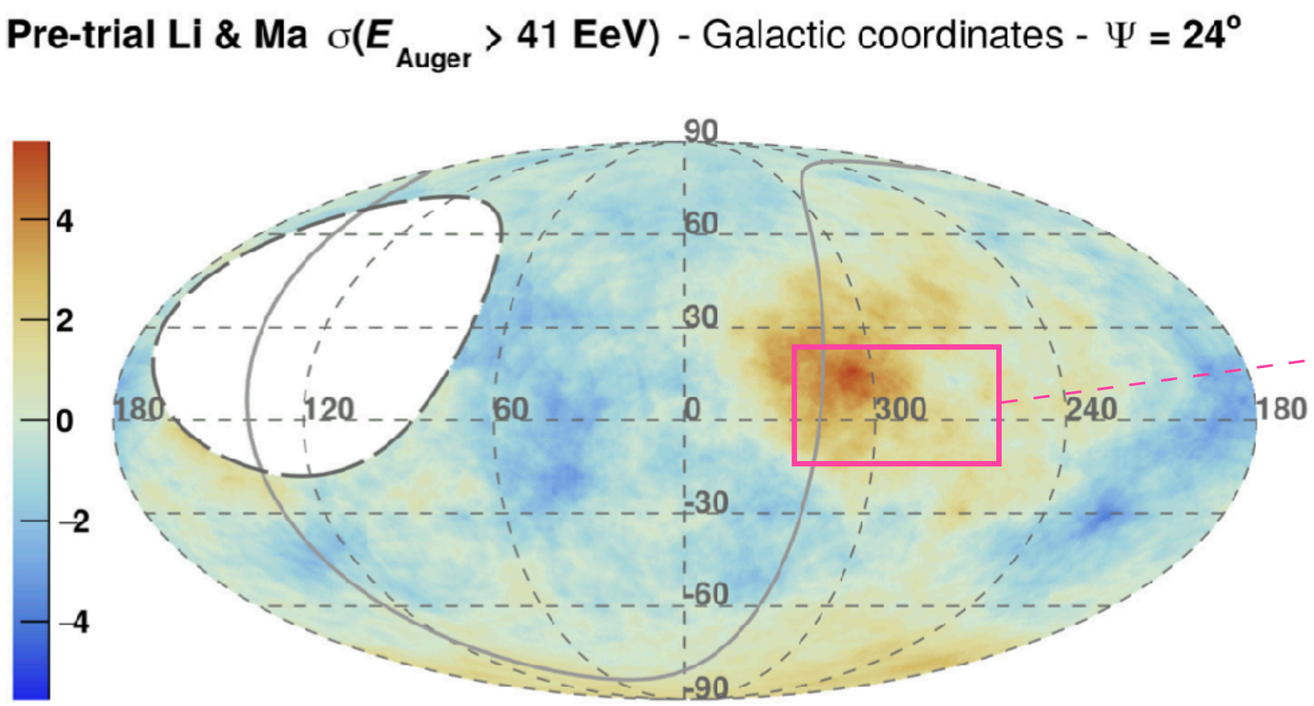
A. Aab et al. (Pierre Auger Collaboration)
Phys. Rev. Lett. 126, 152002 – Published 16 April 2021





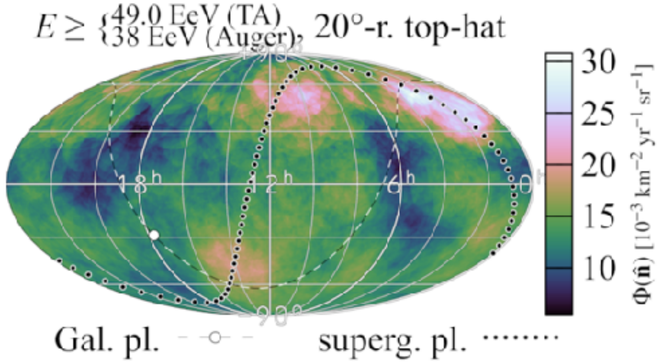
* *"Who ordered that?"*

What are these accelerators?



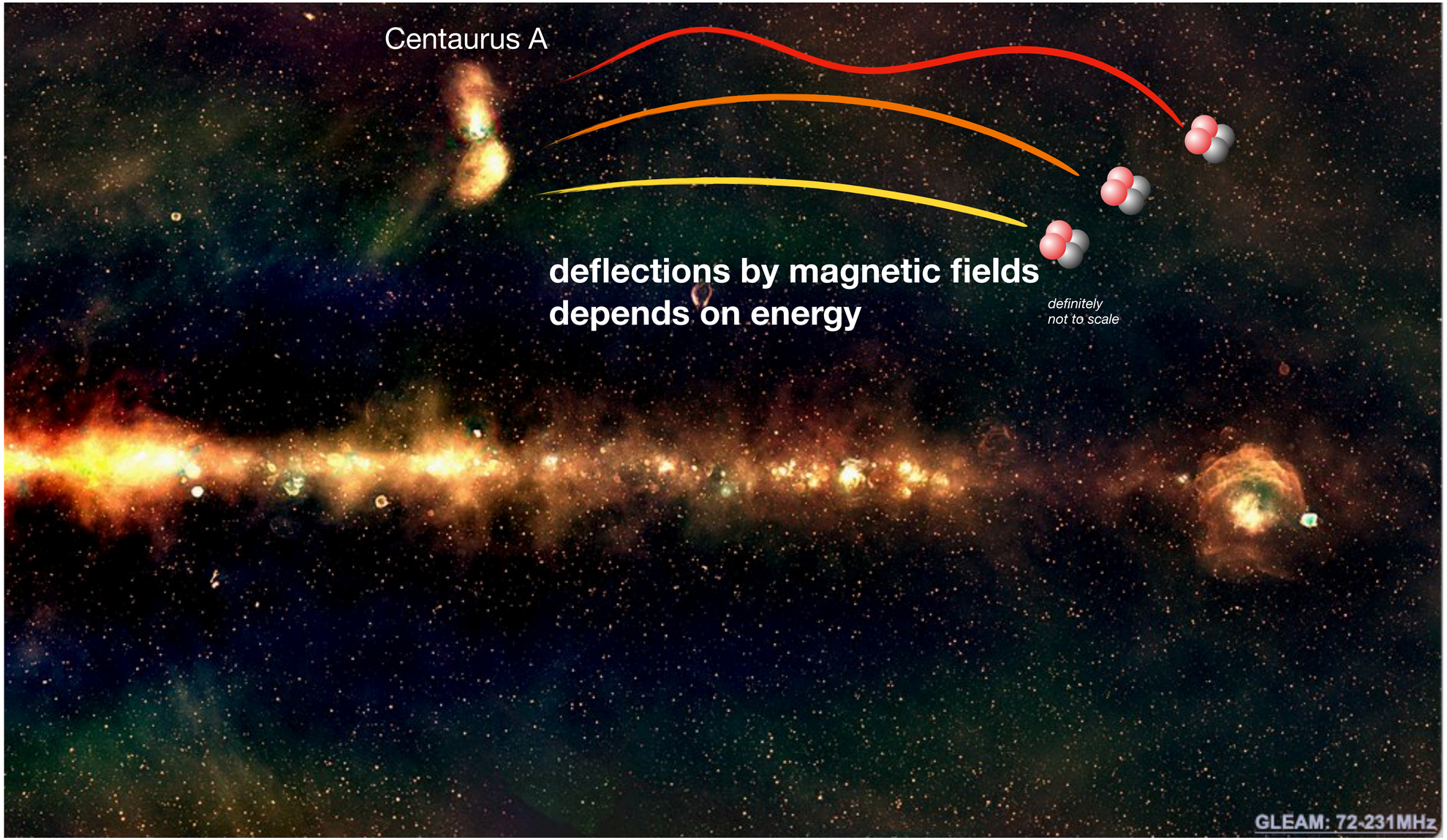
Pierre Auger Observatory, ICRC 2021 (Berlin)

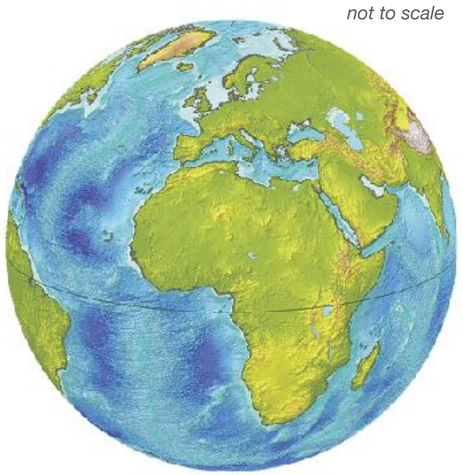
Auger + TA, ICRC 2021 (Berlin)



PIERRE AUGER OBSERVATORY

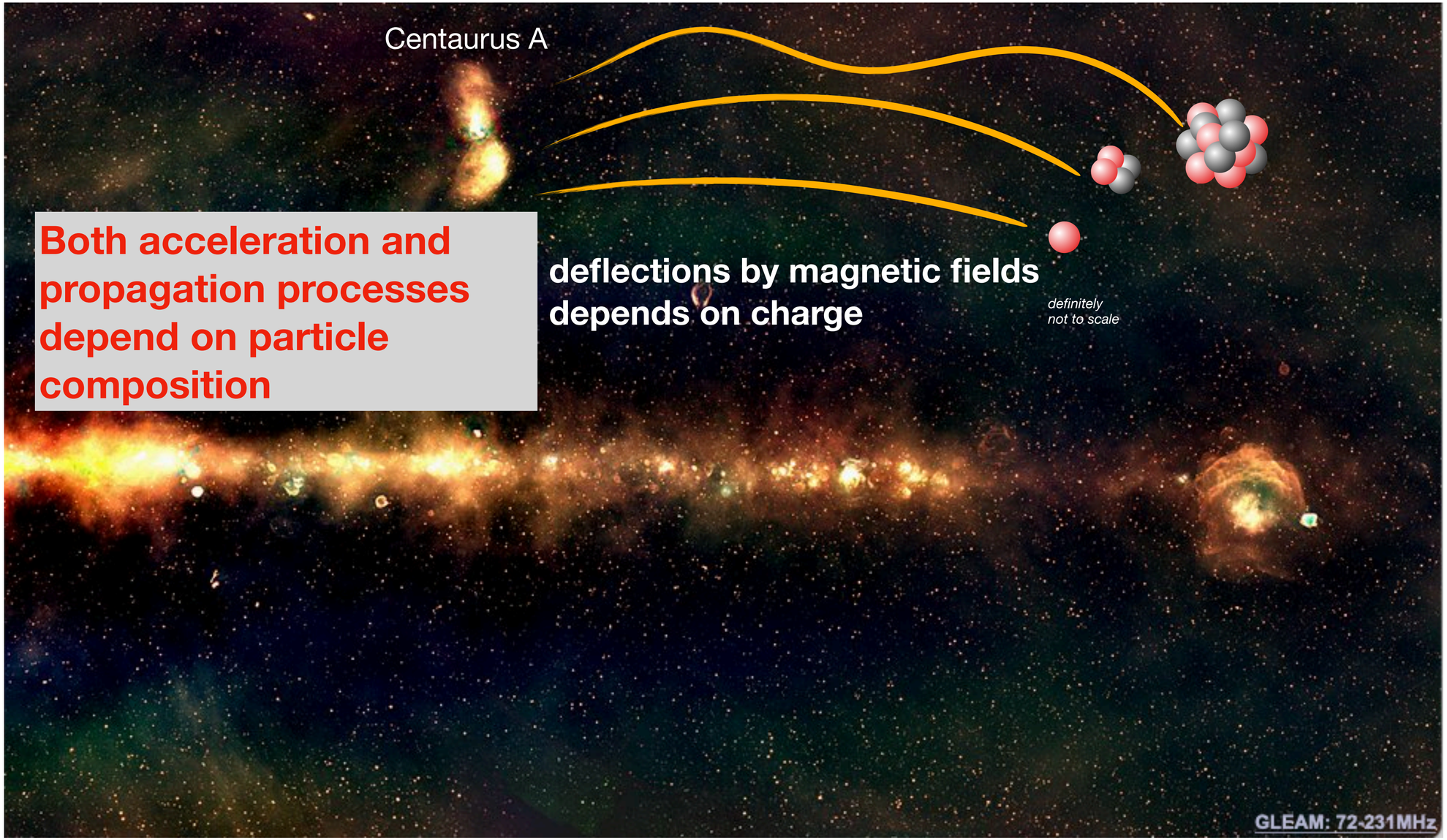
Why the fuzzy picture? Charged particle astronomy





Earth

Why the fuzzy picture? Charged particle astronomy

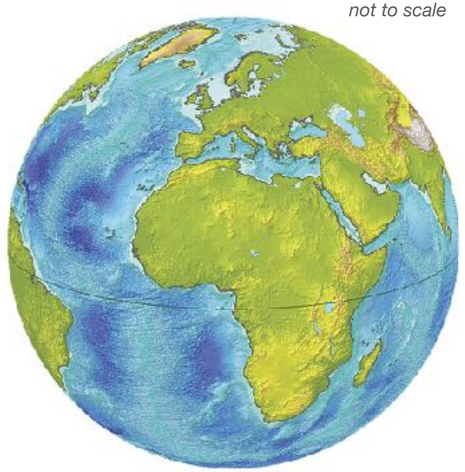


Both acceleration and propagation processes depend on particle composition

deflections by magnetic fields depends on charge

definitely not to scale

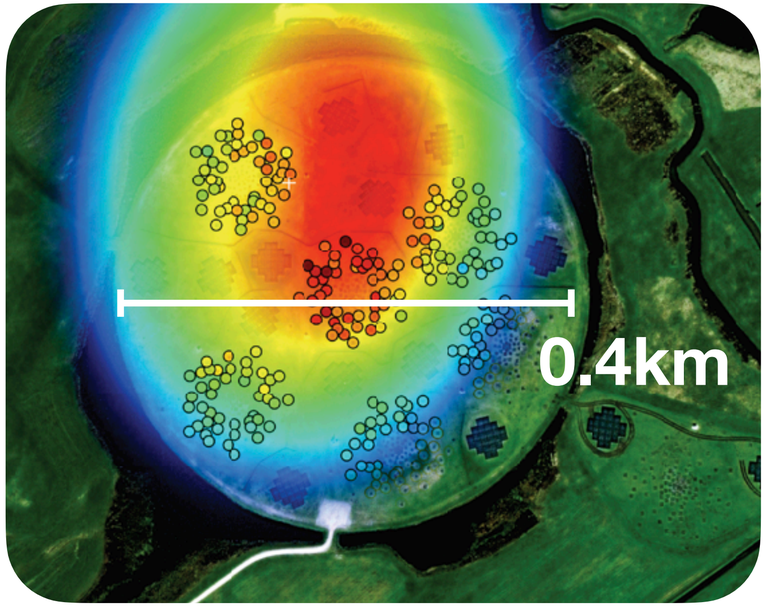
not to scale

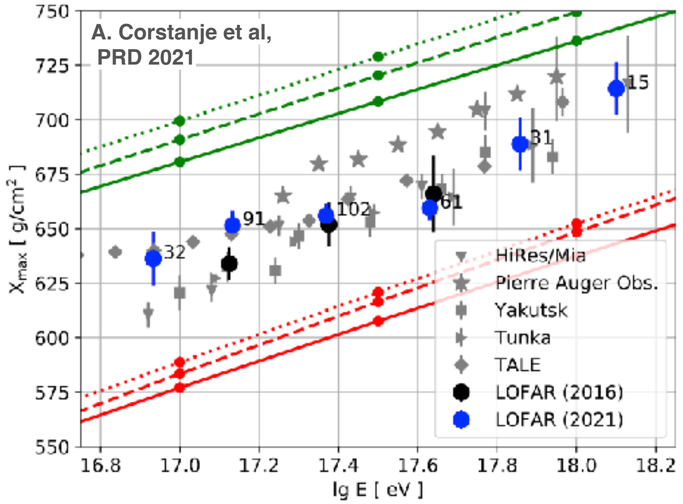


Earth

Radio detection of Air showers: Composition

LOFAR



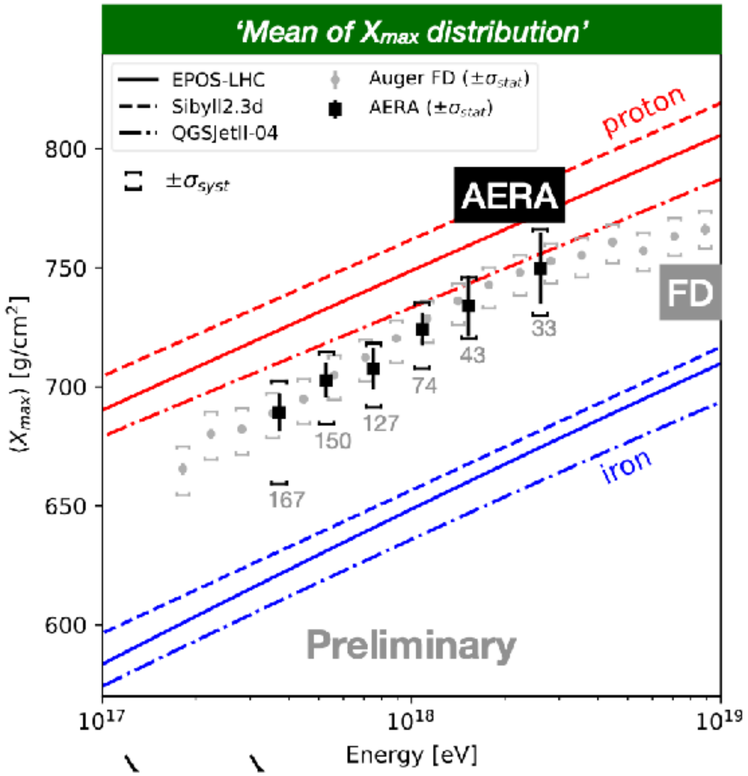


Sibyll-2.3d

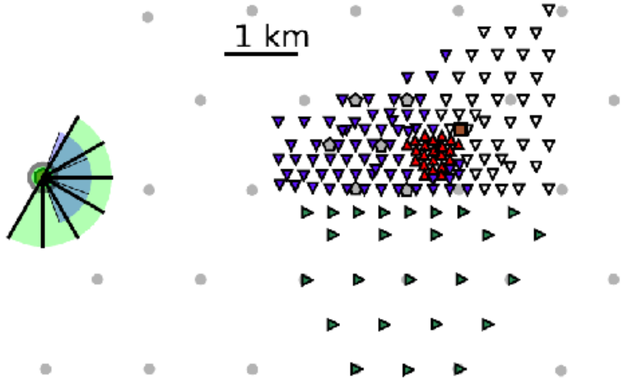
EPOS-LHC

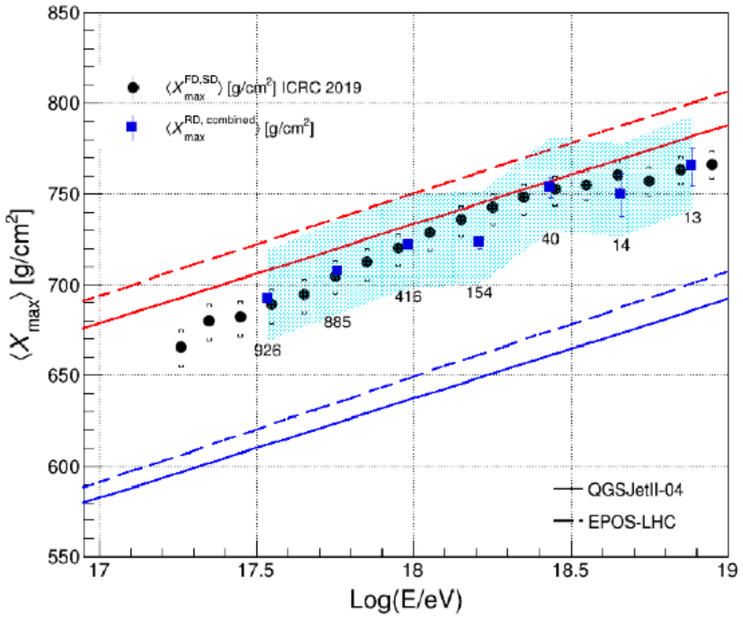
QGSJetII-04

AERA
Auger Engineering Radio Array



B. Pont
(ARENA 2022)





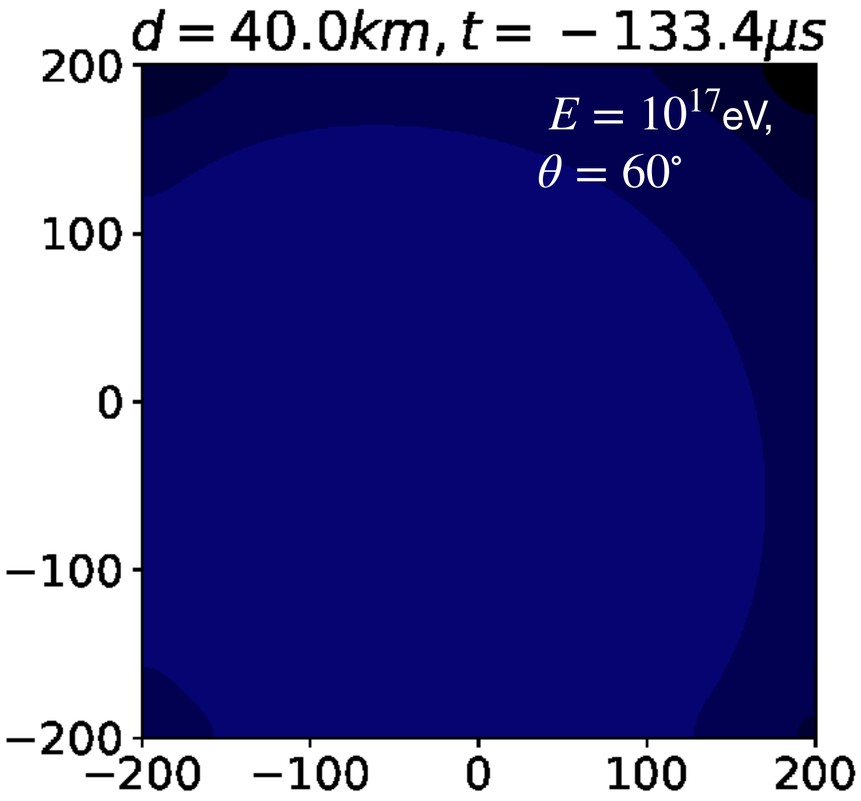
F. Canfora
(PhD Thesis 2021)

Radio detection of Air showers: Inteferometry

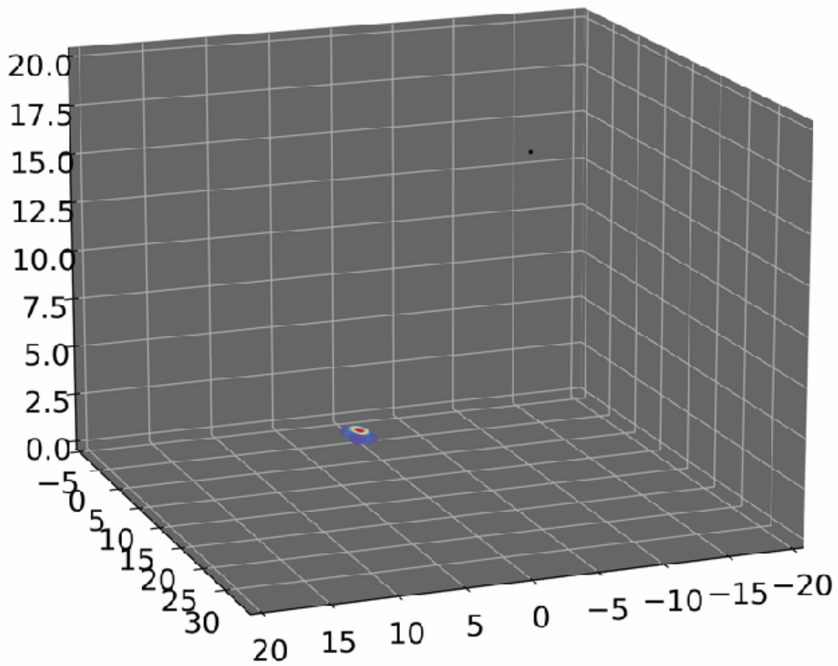
Accurate reconstruction of air shower geometry: Core, Direction & Shower depth.

Lower energy threshold in dense antenna arrays

Needs accurate (< 1ns) timing synchronisation between antennas



Shower plane (m)



Shower track (km)

HS & W. Carvalho et al,
EPJC 2021

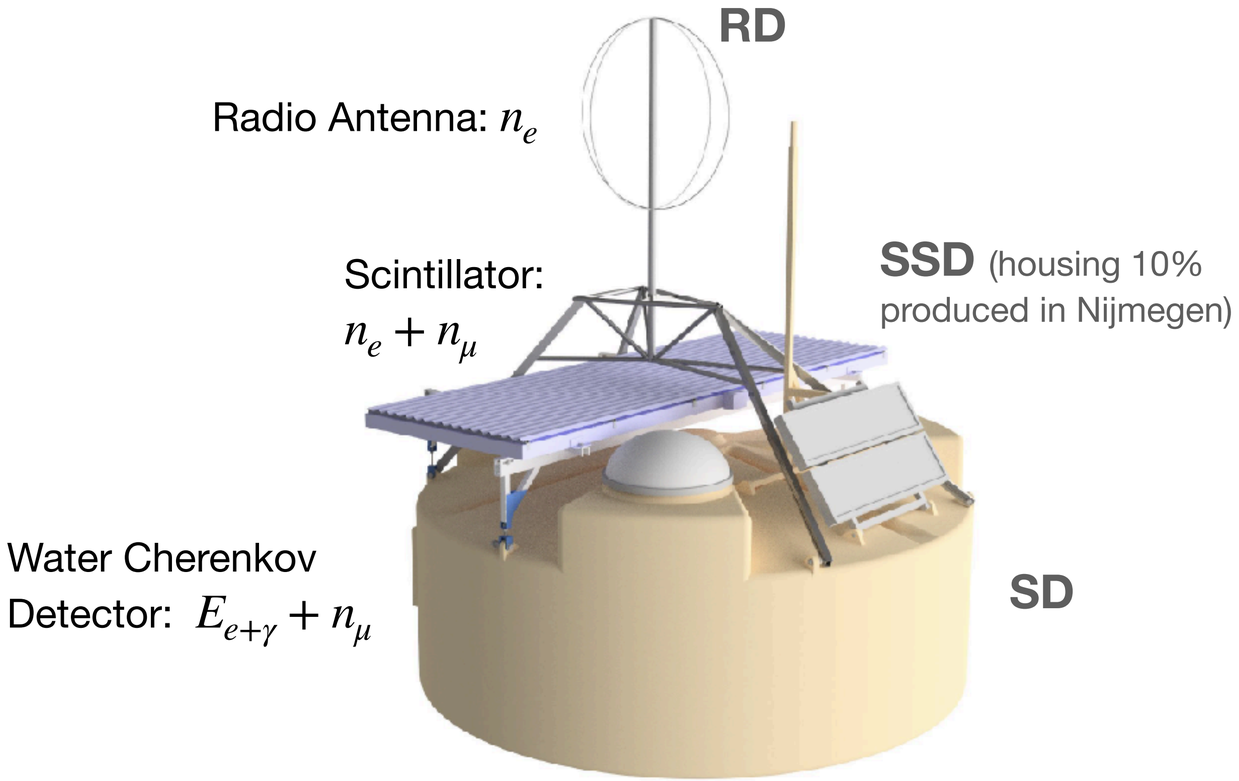
AugerPrime: Upgrade

Vertical $0^\circ < \theta < 60^\circ$

Combination of Scintillators + WCD to disentangle muonic and electromagnetic component

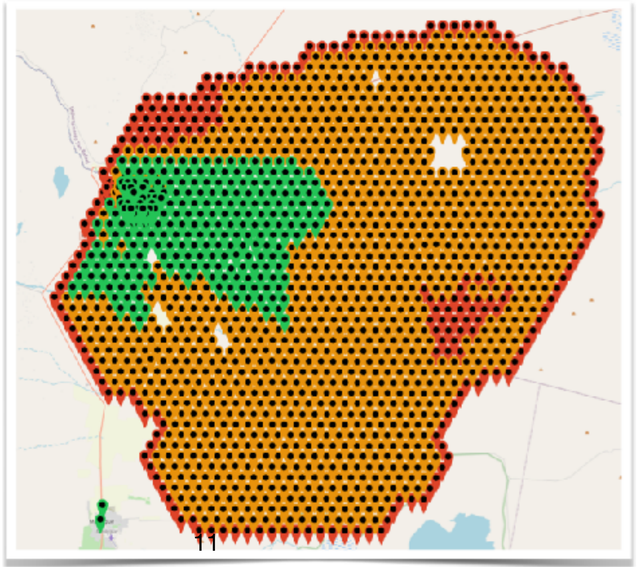
Horizontal $60^\circ < \theta < 85^\circ$

WCD "only" muons
Radio "only" electromagnetic



Status of deployment SSD:

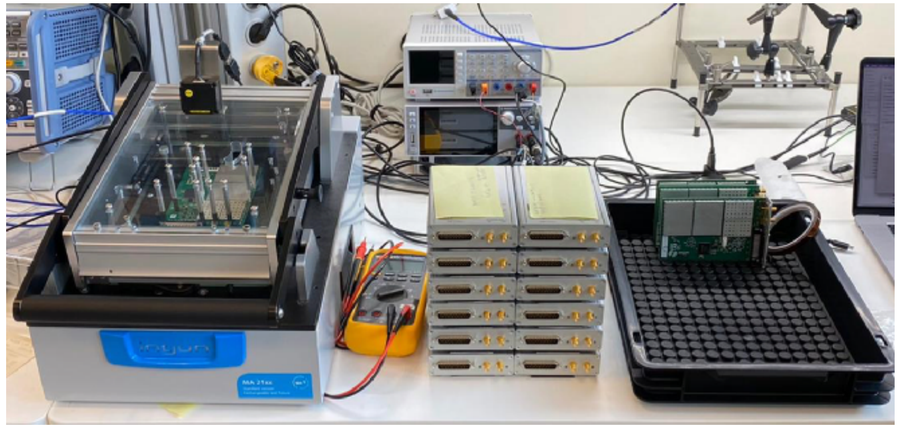
- SSD placed on >75% of stations
- >20% fully equipped
- Finalise installation this year
- In 2023 **only** AugerPrime



PIERRE AUGER OBSERVATORY

AugerPrime: Radio Detector

Digitisers developed by RadioLab @ Radboud University



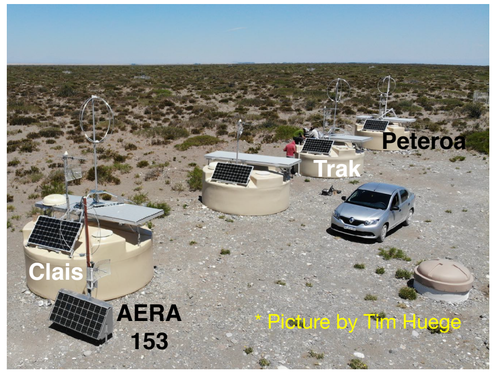
Schedule RD Deployment:

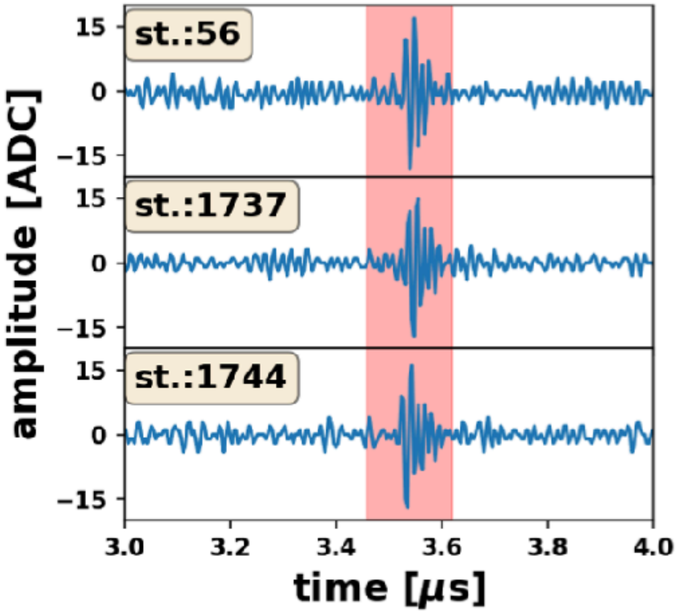
Phase 1
Antenna + Solar panels + Structure: June - November

Phase 2
Digitisers + Cables + Amplifiers: November - January

Full Array Early 2023

First events from 10 Stations



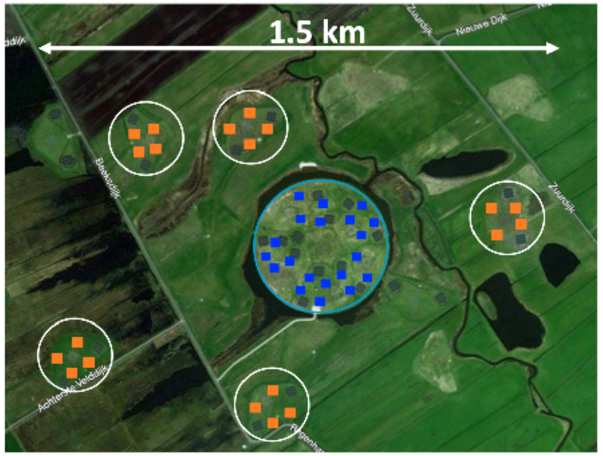


Radio trigger development

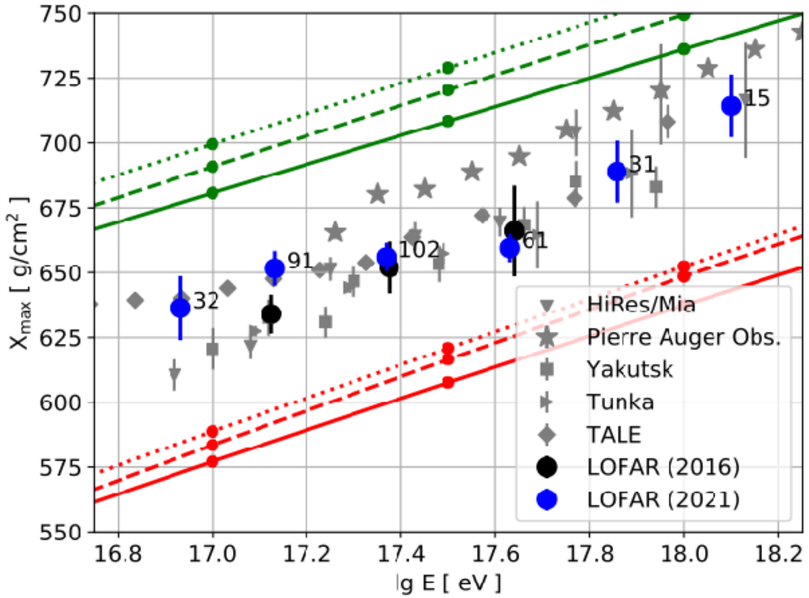
Dave Nitz (MTU)

LOFAR 2.0

Scint Array Extension

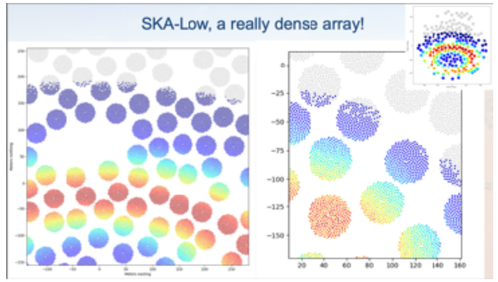


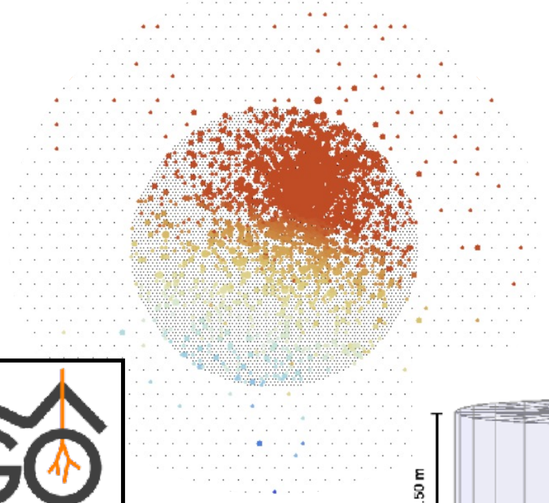
Radio-Scint Hybrid Triggering + More Observation Time

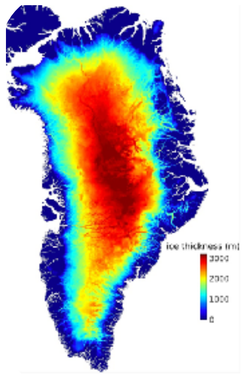


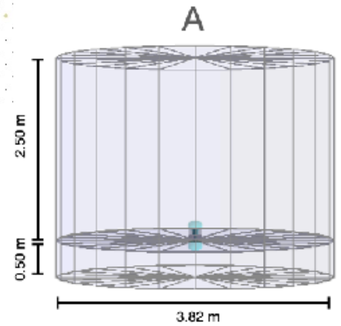
Larger Scint Array + More Observation Time

Further down the road



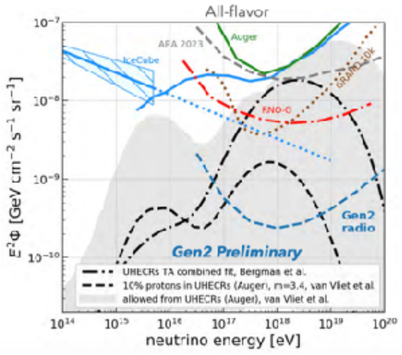


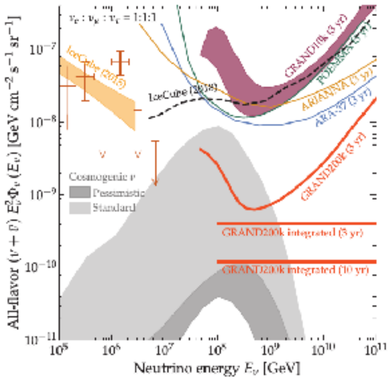


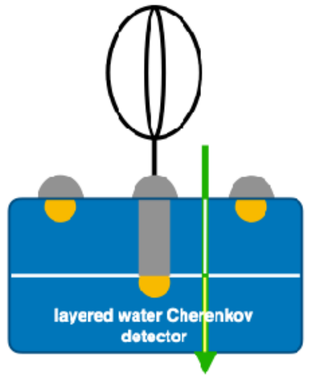


Multi-messenger observatories

G-COS:
The Global COSmic-ray Observatory







> 40000 km²,
X_{max} and N_e/N_μ

Summary

Cosmic ray puzzle(s) still open

- Challenging interplay between composition & energy
- Air shower physics not fully understood

Accuracy

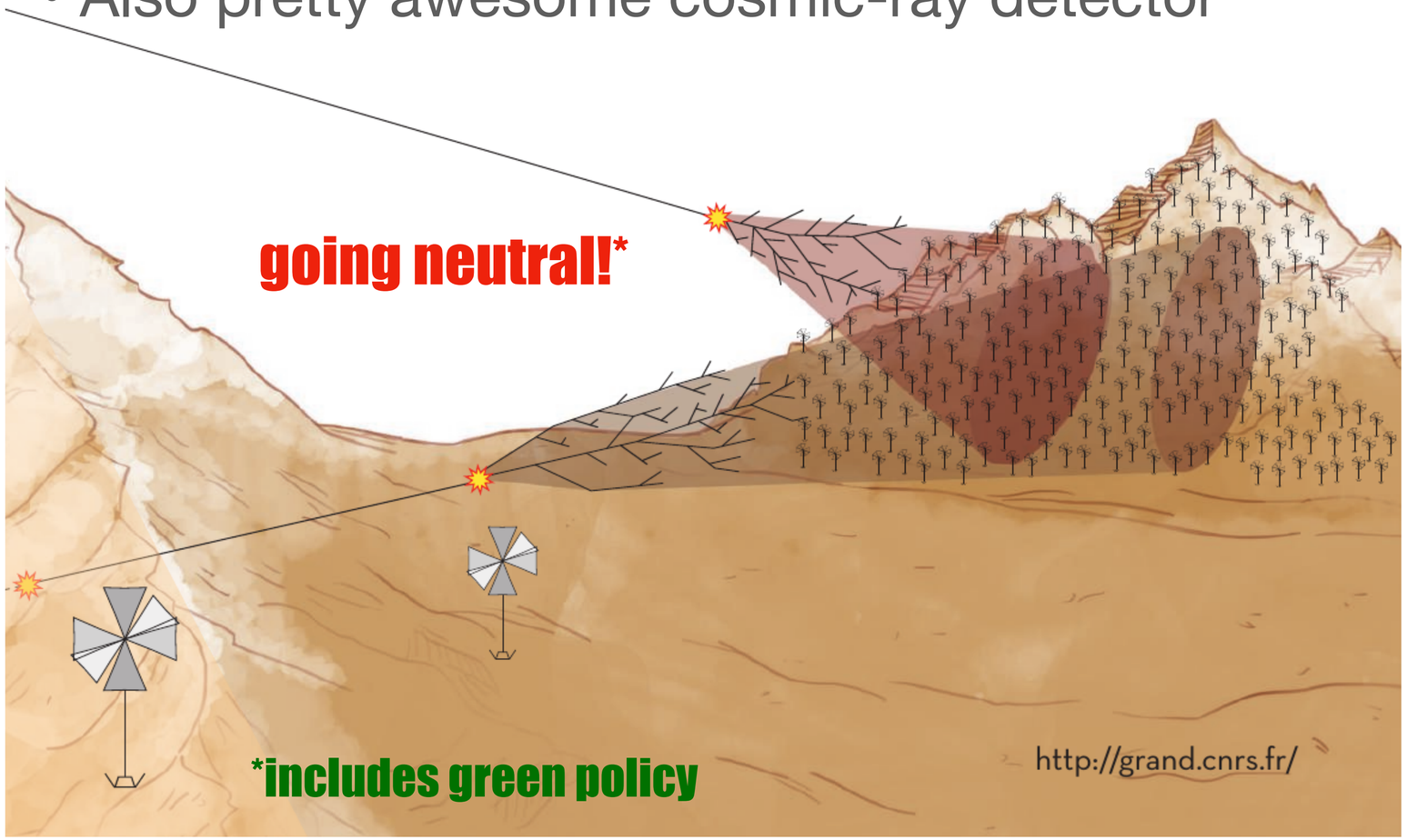
- Upgrade of Pierre Auger Observatory
- Upgrade of LOFAR
- Possibilities to “piggy back” on other experiments in the energy regime 10^{15}-10^{18} eV

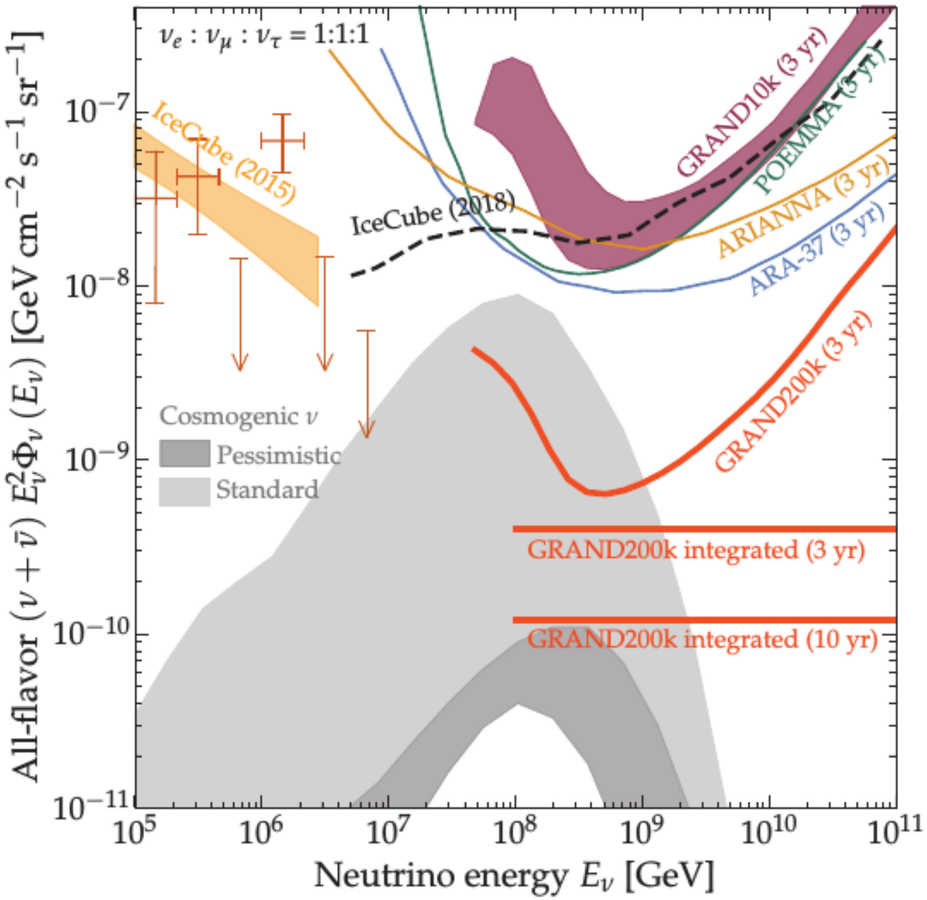
Scale-up

- GRAND
- G-COS

The Giant Radio Array for Neutrino Detection

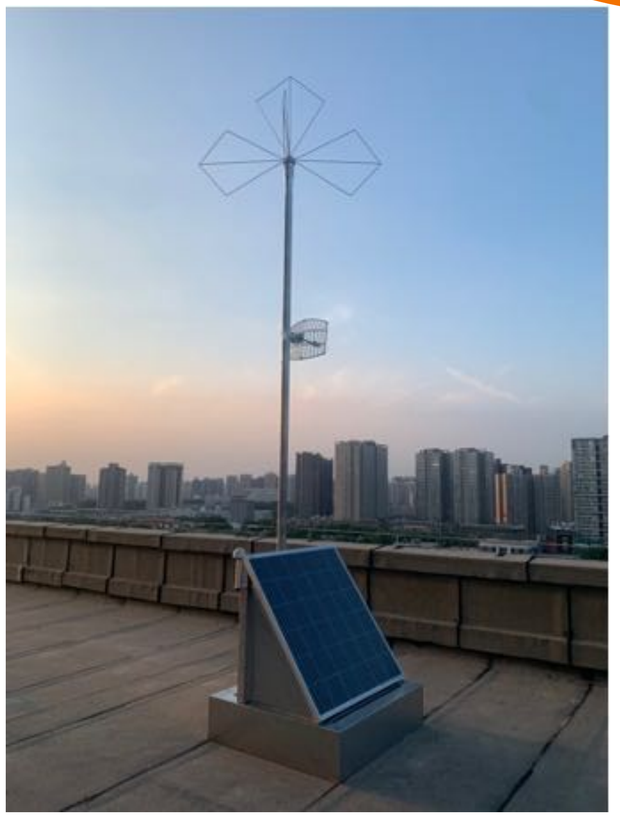
- Large radio array(s) focussing on “horizontal” air showers
- Hunt for Ultra-High-Energy neutrinos
- Also pretty awesome cosmic-ray detector

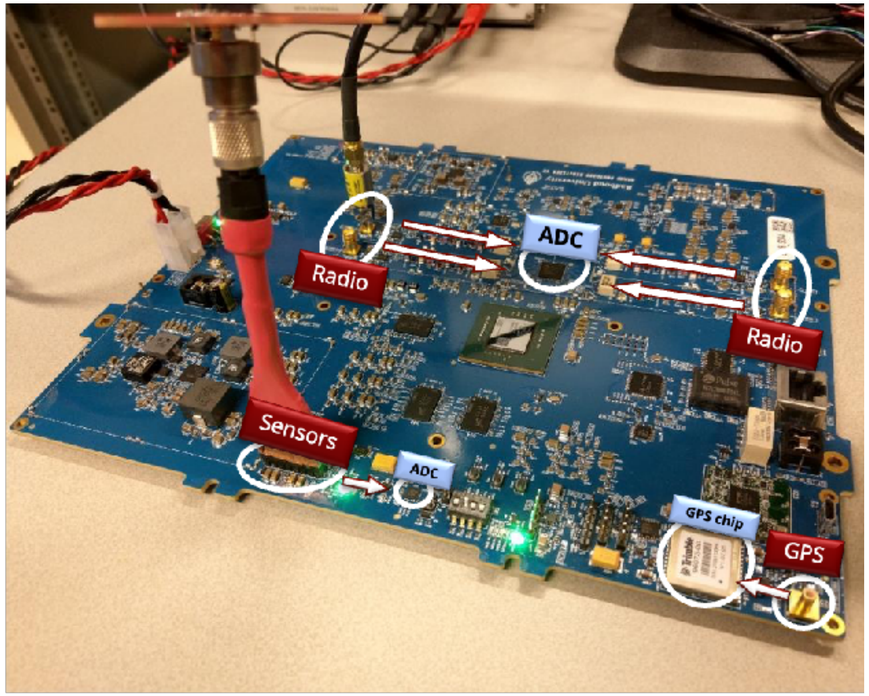




The Giant Radio Array for Neutrino Detection

GRANDProto → GRAND 10k → GRAND 200k





4 channels, 500 MHz, 14bit, 12 Watt

- Station mechanical design and electronics in Nijmegen
- 100 Stations ready for deployment (China)*
- 5 stations setup in Nançay Radio Observatory, France (coming months)

* delay due to COVID

The Team

new faces


Katey


Abha


Anthony


Mohamed


Rik

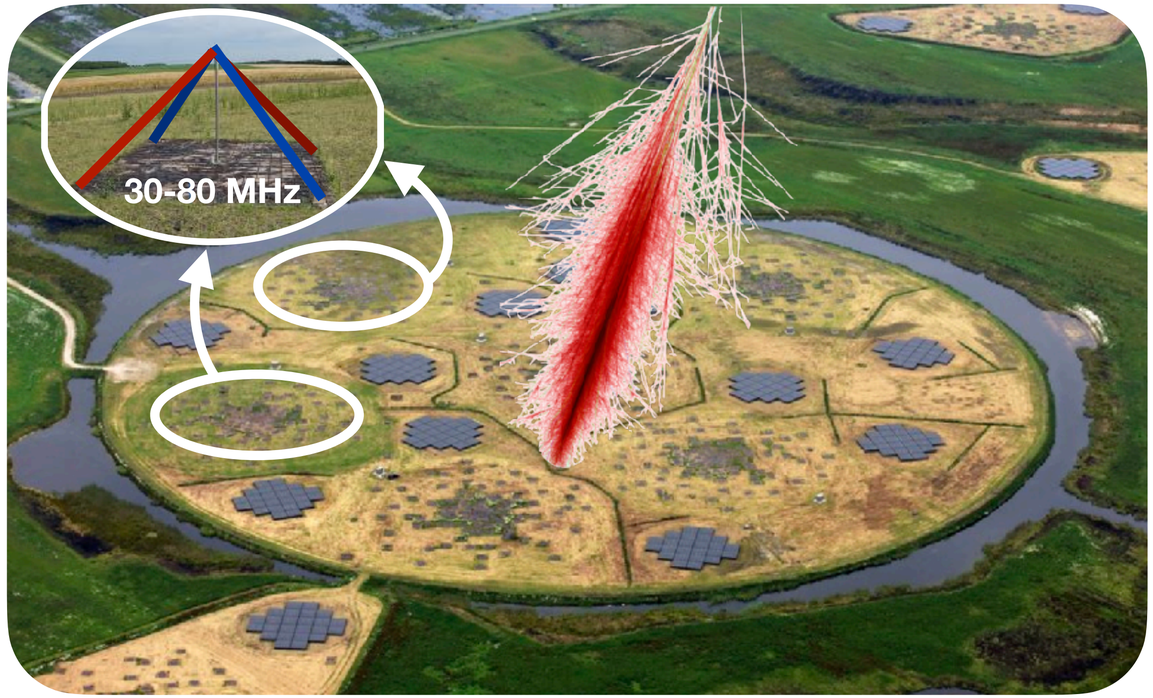

Nicoletta

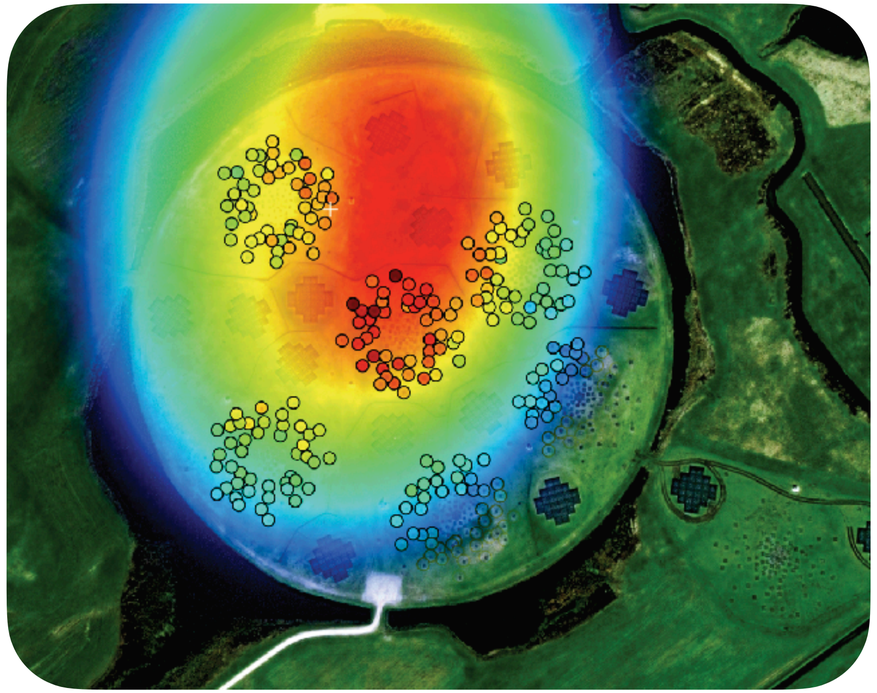
Pierre Auger Observatory:
Senior staff: Charles Timmermans, Sijbrand de Jong, Jörg Hörandel, Heino Falcke, Cristina Galea, **Harm Schoorlemmer, Katey Mulrey**
Post-doc: Washington Carvahlo jr., Bjarni Pont, Ugo Giaccari
PhD student: **Abha Khakuridikar**, **Anthony Bwembya**, **Mohamed Emam**, Mart Pothast, Mohit Saharan, Tomas Fodran
Bsc Student: Lotta Broekhoven
Visiting: Dave Nitz (MTU)

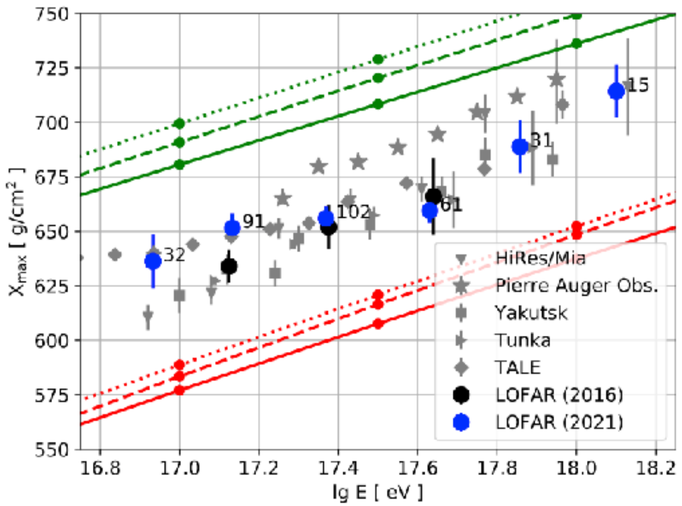
GRAND:
Senior staff: Charles Timmermans, Sijbrand de Jong, Cristina Galea, Harm Schoorlemmer
Msc Student: Eric Teunis de Boone, Inge Rens, Henk Brans
Bsc Student: Bram Ruijter

Techs: Peter Dolron, Roel Jordans, Daniel Szalas, Sjoerd Timmer, **Nicoletta Cucu Laurenciu**, **Rik van den Bosch**, Thei Wijnen

LOFAR: precision air shower measurements







Sibyll-2.3d

EPOS-LHC

QGSJetII-04

- Dense antenna array = unique way to probe the radio footprint
- Cosmic-ray composition measurements in the transition region
- Ongoing upgrades to prepare for LOFAR 2.0, next-gen experiments