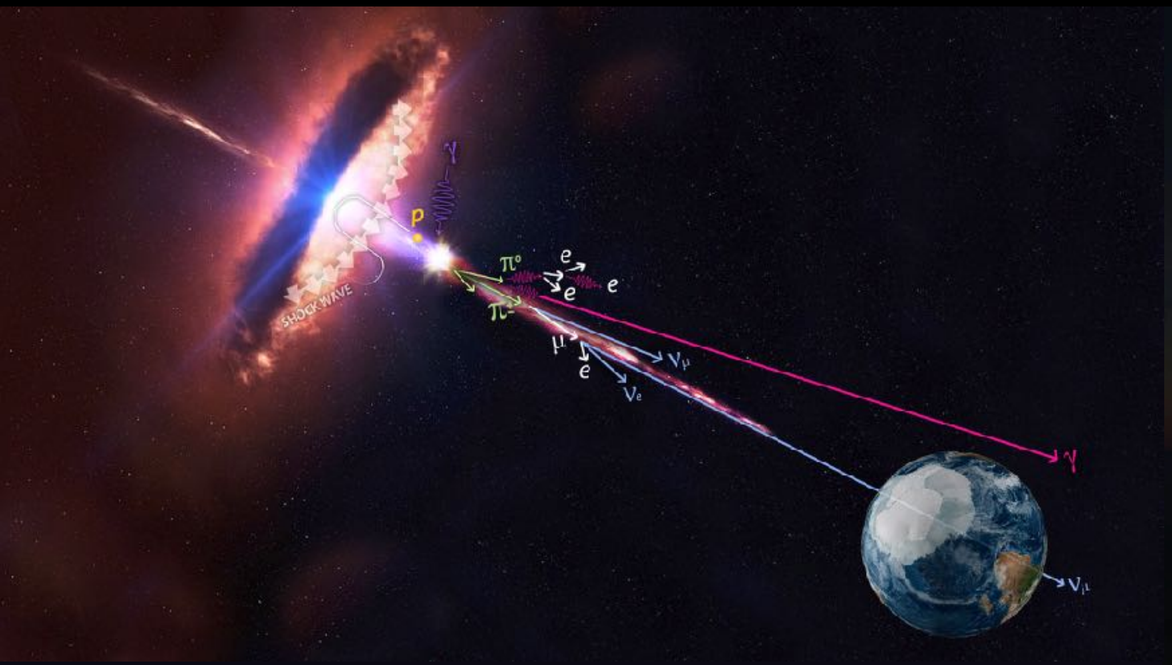
Cosmic Rays

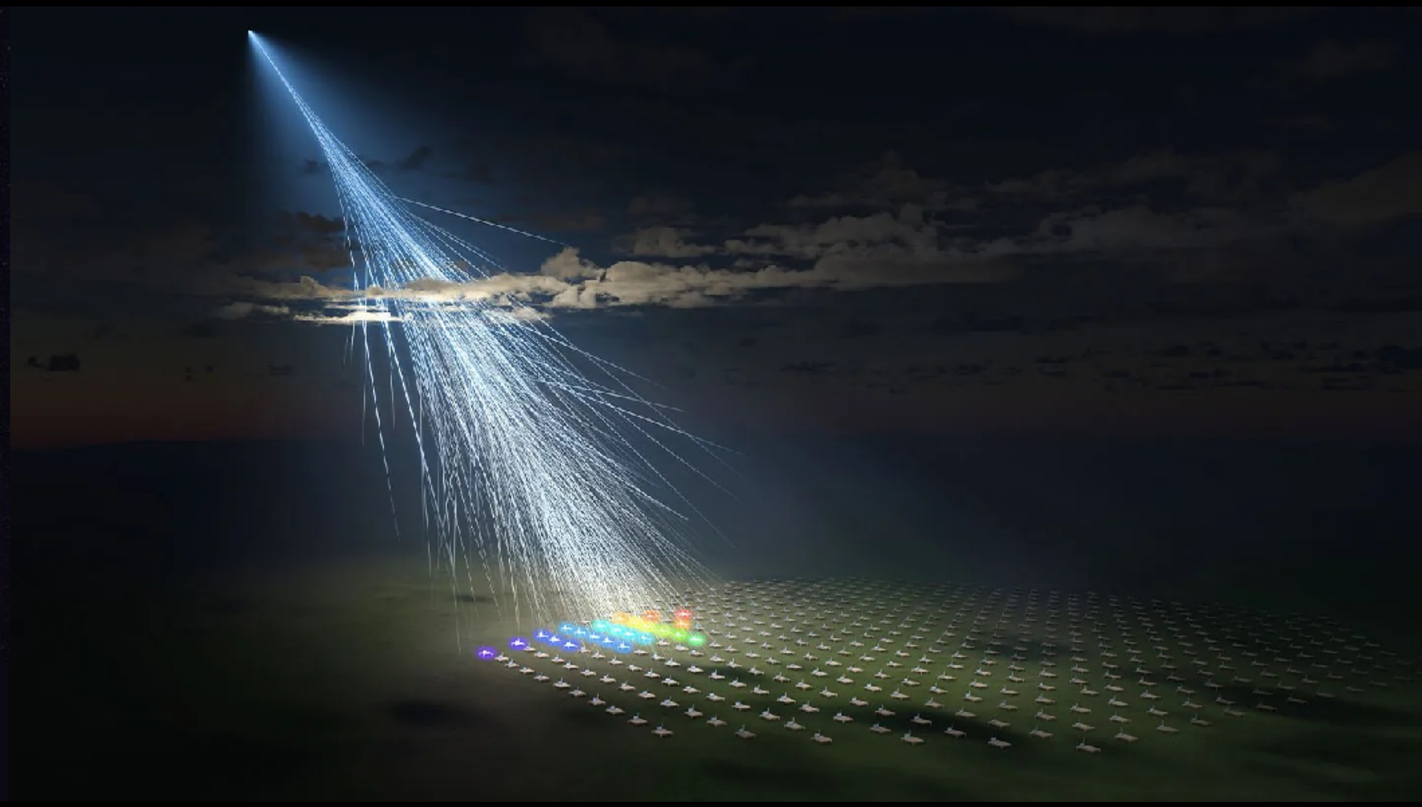
Astroparticle physics in the Netherlands

Soesterberg
12-13 June 2025

29th Symposium on Astroparticle Physics in the Netherlands

Physics and origin of the highest-energy particles in the Universe





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Radboud University - Nikhef - Vrije Universiteit Brussel

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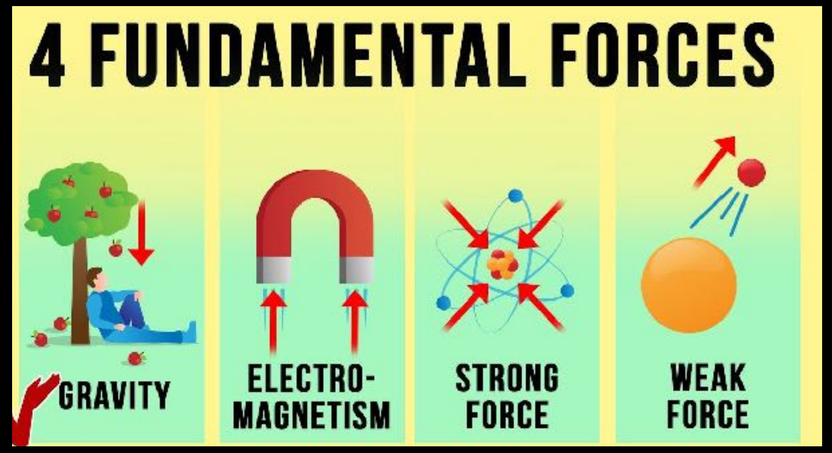
Multi-messenger astroparticle physics

nuclei, gamma rays, neutrinos, gravitational waves



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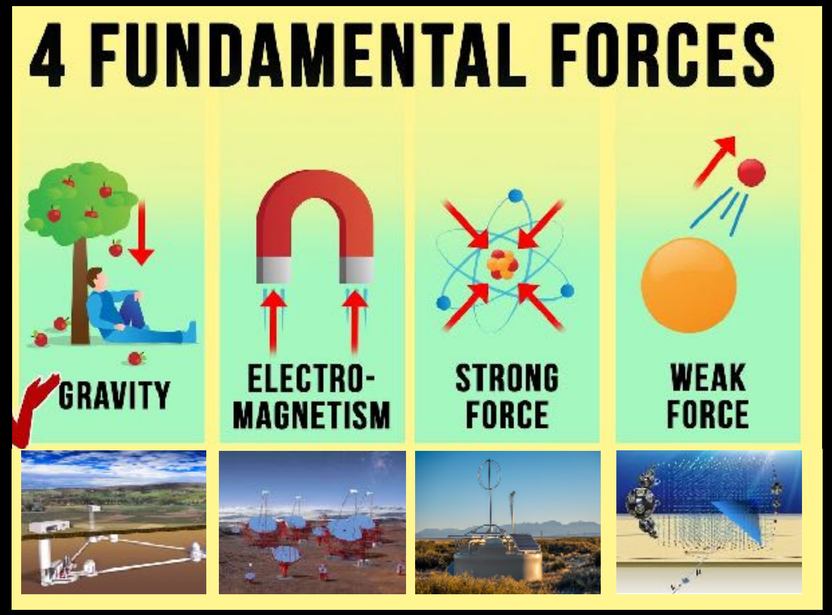

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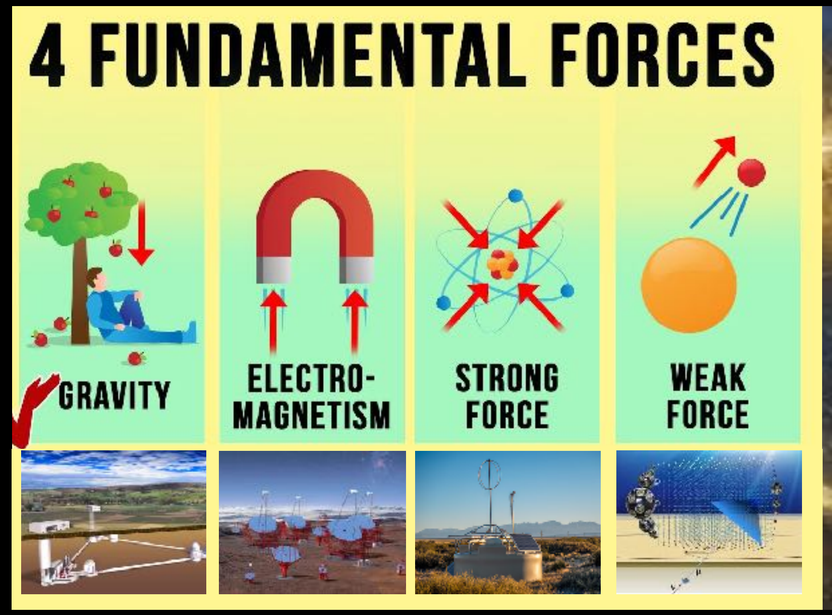

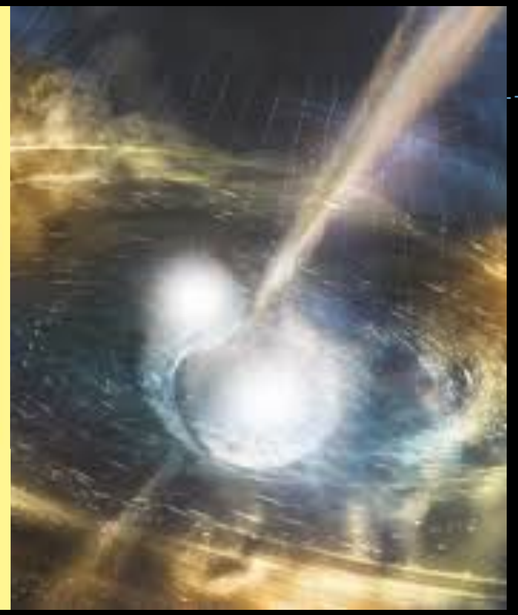

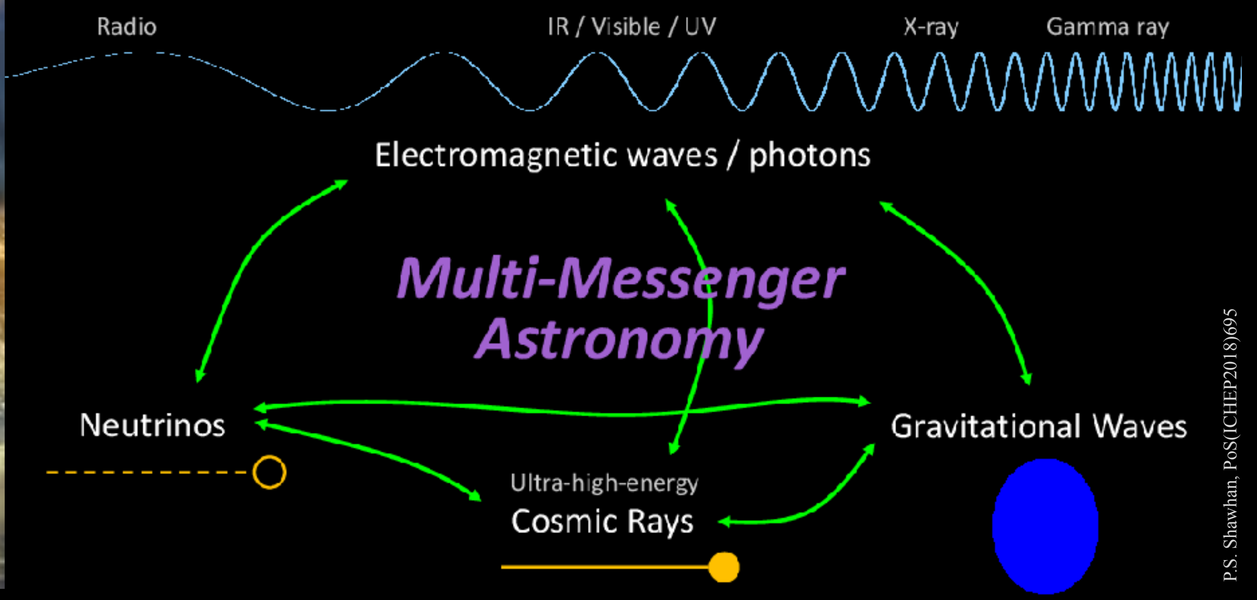

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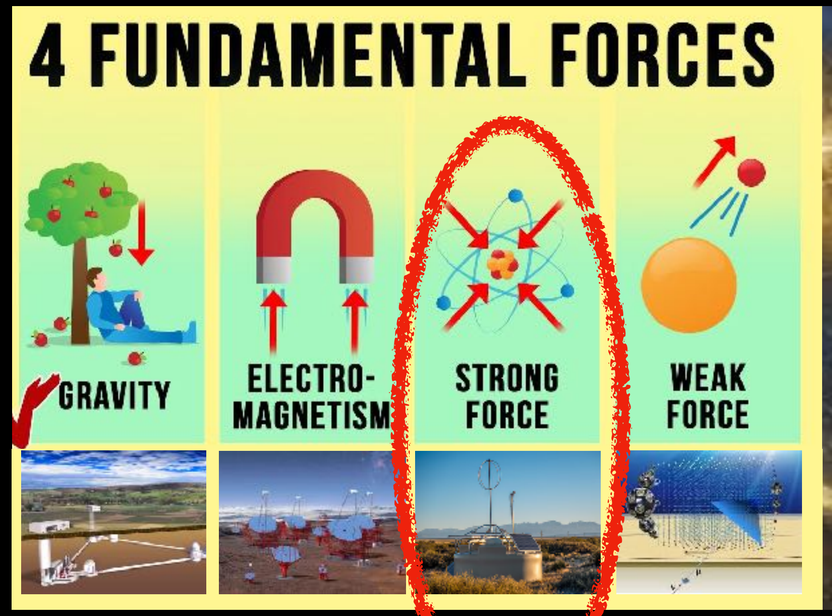

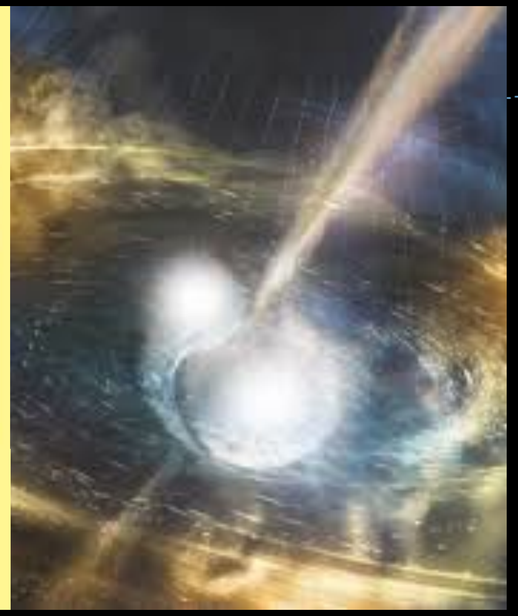

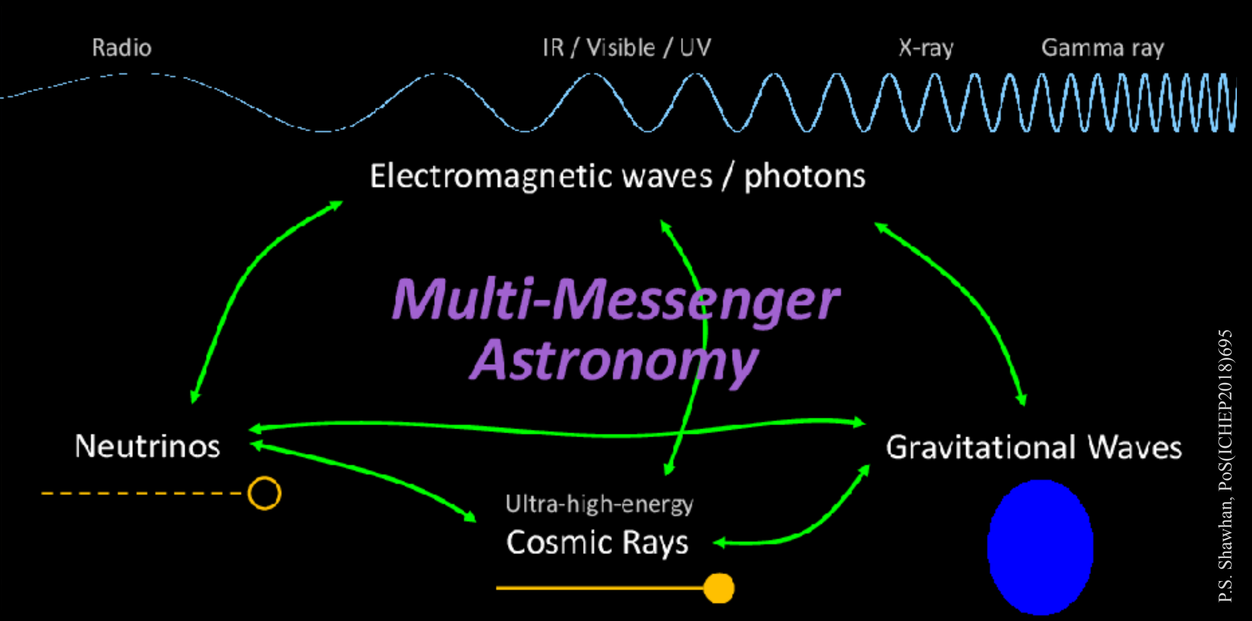

Jörg R. Hörandel

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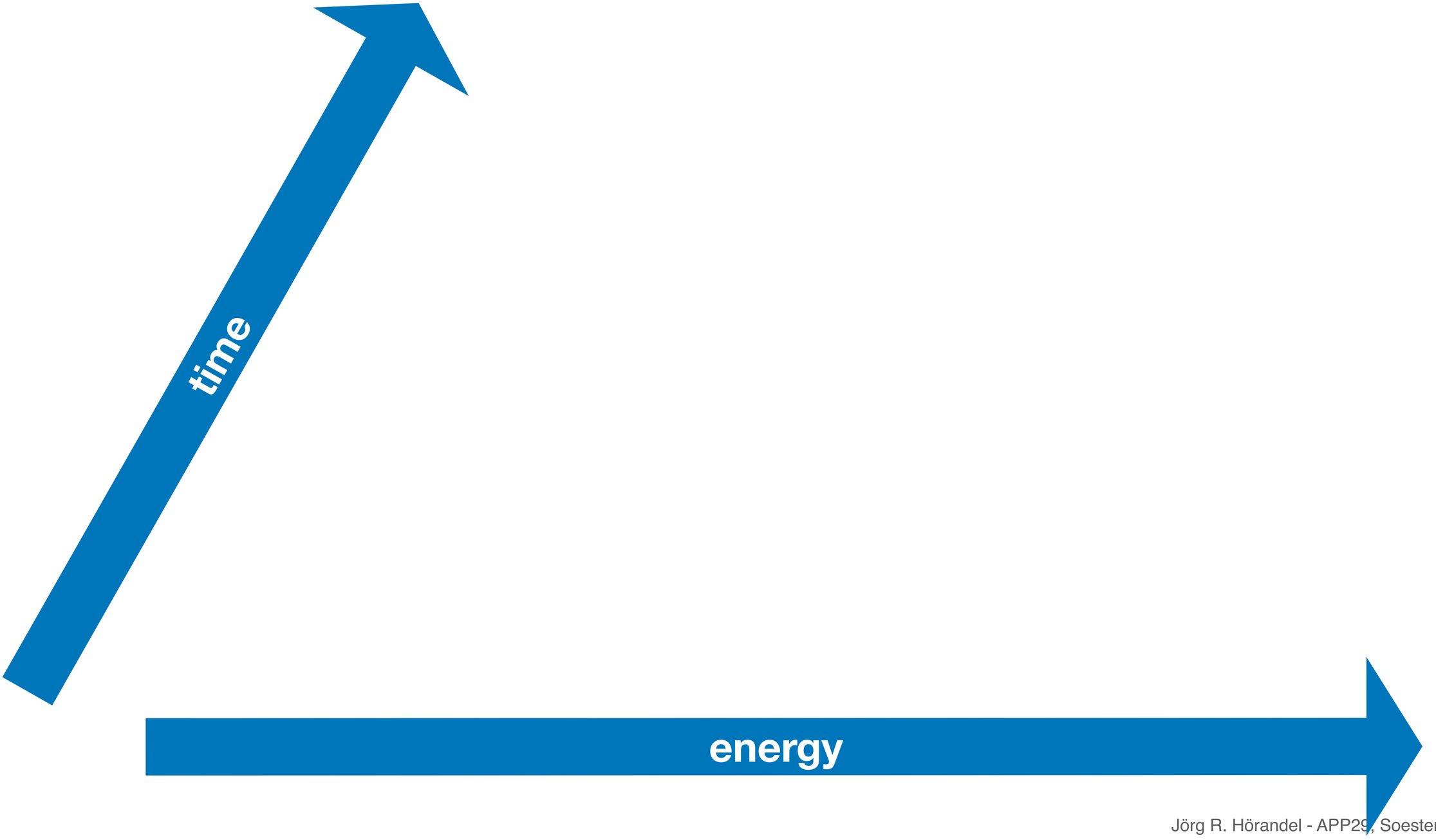
NL Cosmic-Ray landscape



NL Cosmic-Ray landscape

time

LOFAR CR

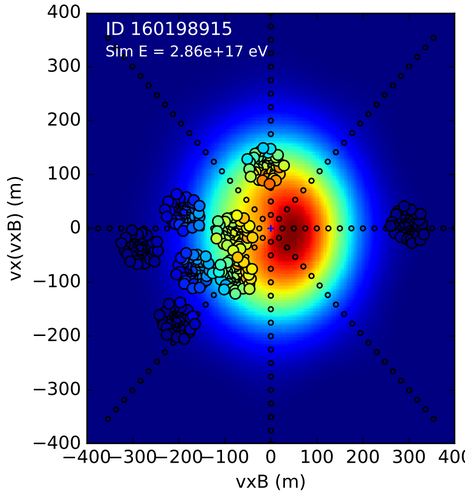
Pierre Auger Observatory

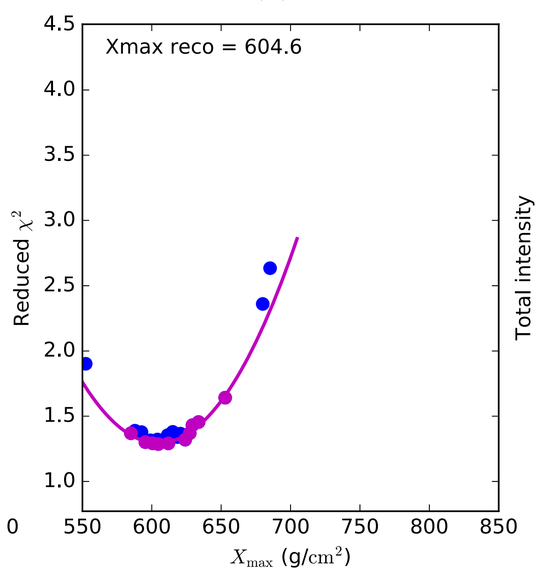
energy

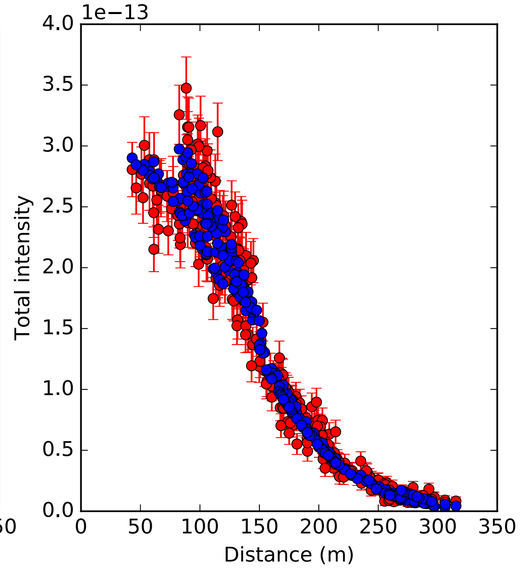
LOFAR

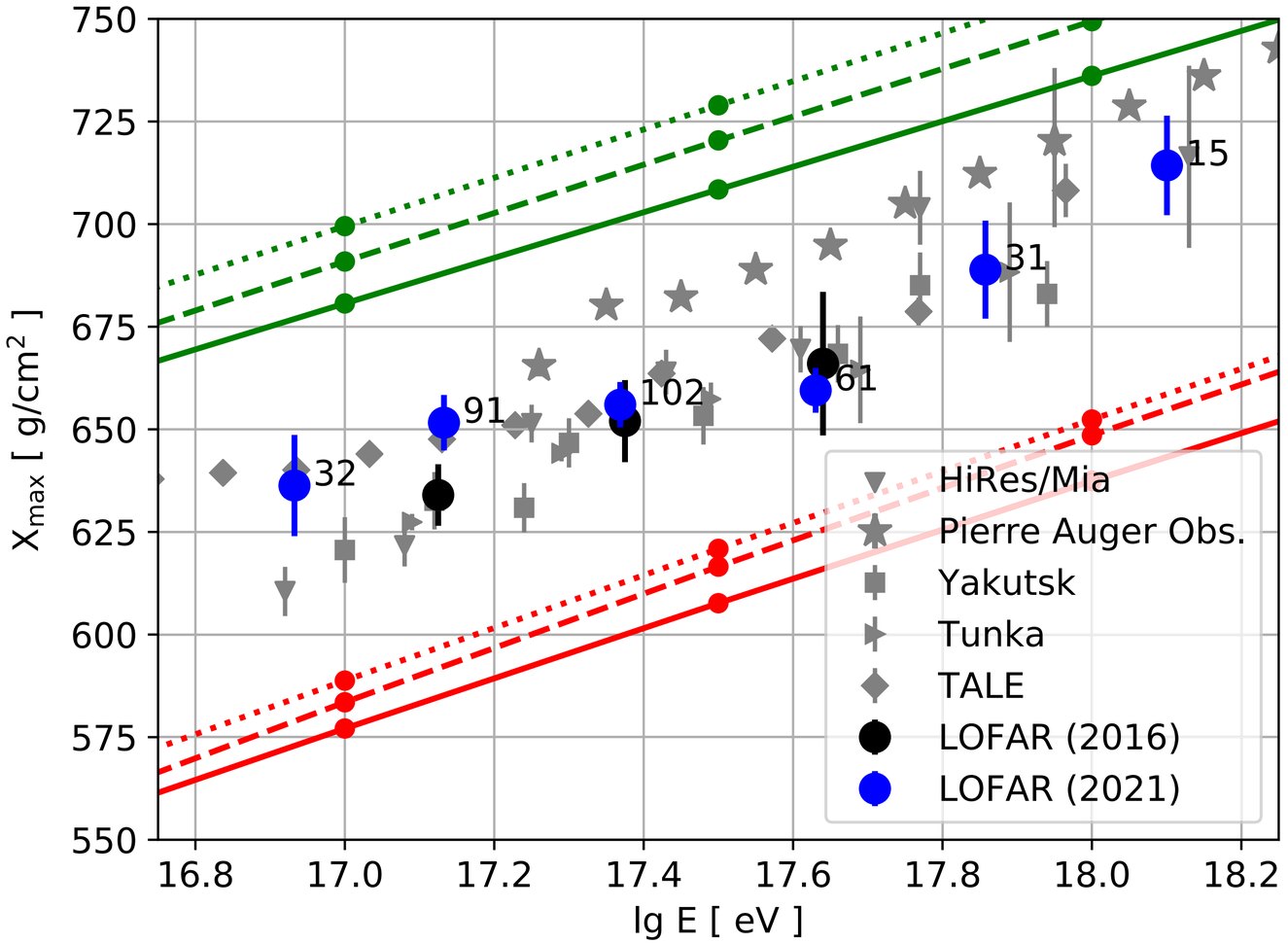
Depth of shower maximum and mass composition of cosmic rays from 50 PeV to 2 EeV measured with the LOFAR radio telescope

A. Corstanje,[1,2,*] S. Buitink,[1,2] H. Falcke,[2,3,4] B. M. Hare,[5] J. R. Hörandel,[2,4,1] T. Huege,[6,1] G. K. Krampah,[1] P. Mitra,[1] K. Mulrey,[1] A. Nelles,[7,9] H. Pandya,[1] J. P. Rachen,[1] O. Scholten,[8] S. ter Veen,[3] S. Thoudam,[10] G. Trinh,[11] and T. Winchen[12]









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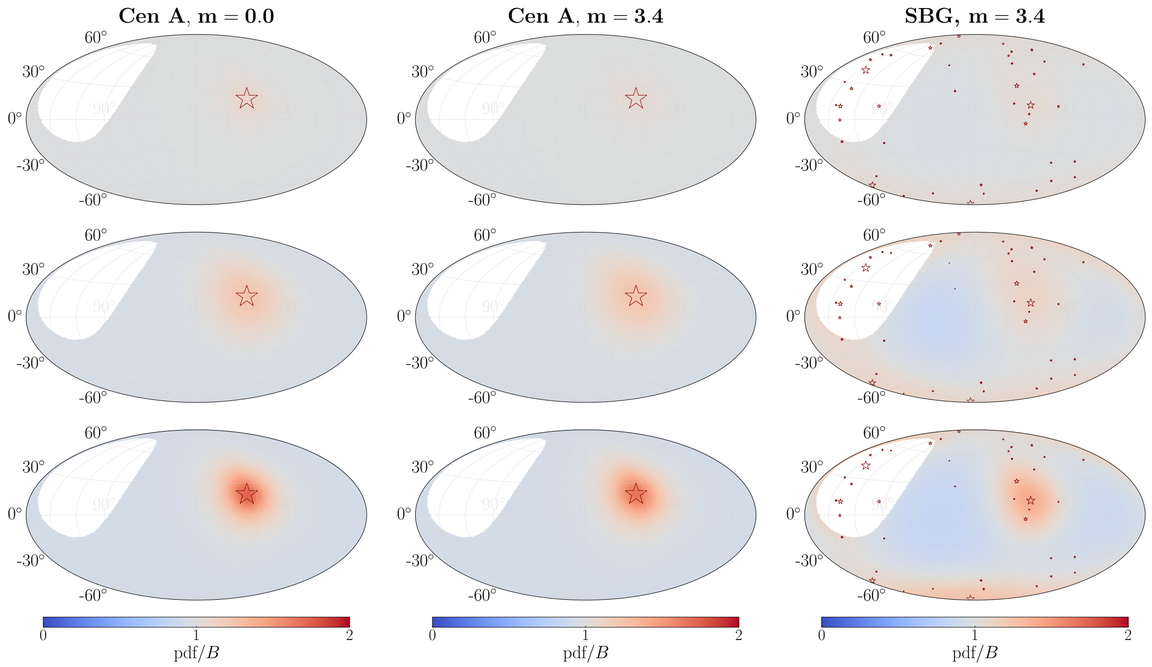
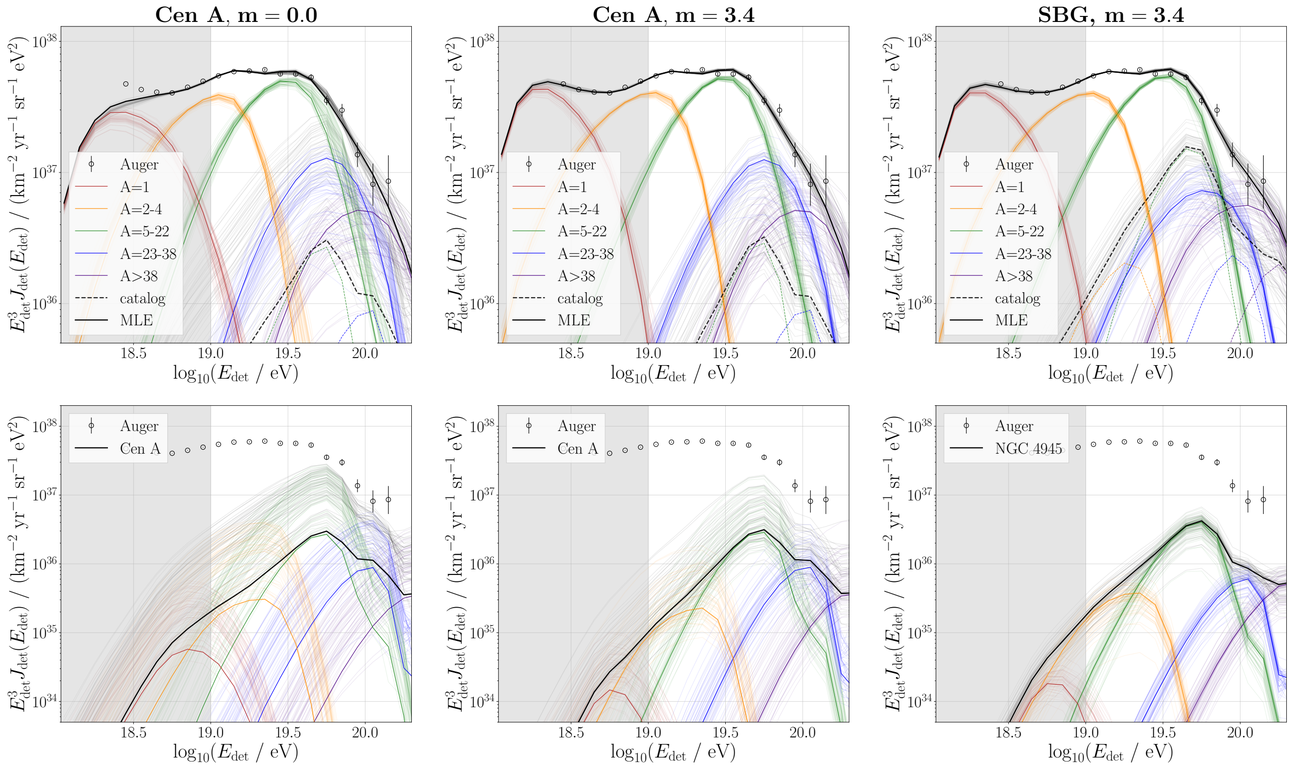
combining arrival direction, energy, and mass

Constraining models for the origin of ultra-high-energy cosmic rays with a novel combined analysis of arrival directions, spectrum, and composition data measured at the Pierre Auger Observatory

PIERRE AUGER OBSERVATORY





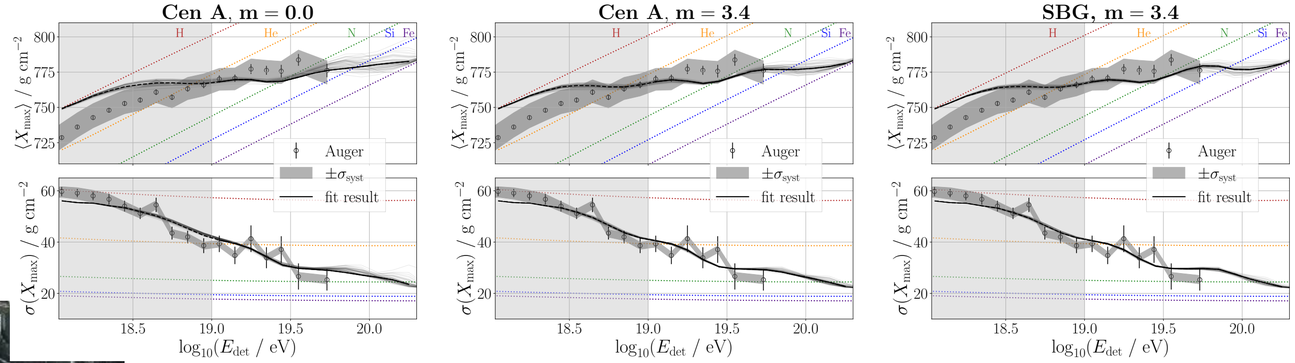
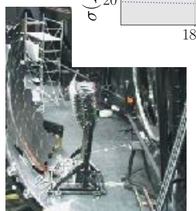


Figure 4. Modeled arrival directions pdf (eq. (2.17)), *left* for Centaurus A model with $m = 0$, *middle* for Centaurus A model with $m = 3.4$ and *right* for SBG model with $m = 3.4$. The energy bins $\log_{10}(E_{\rm det}/{\rm eV})$ =19.3 (*upper row*), $\log_{10}(E_{\rm det}/{\rm eV})$ =19.6 (*middle row*) and $\log_{10}(E_{\rm det}/{\rm eV})$ =19.9 (*lower row*) are shown as examples. The catalog contribution and with that the level of anisotropy rises with the energy, while the overall blurring decreases. Additionally, the contribution of individual sources depends on the energy through their distances and flux weights. The stars indicate the directions of the source candidates with the size scaling with the relative flux contribution before the observatory exposure is applied.



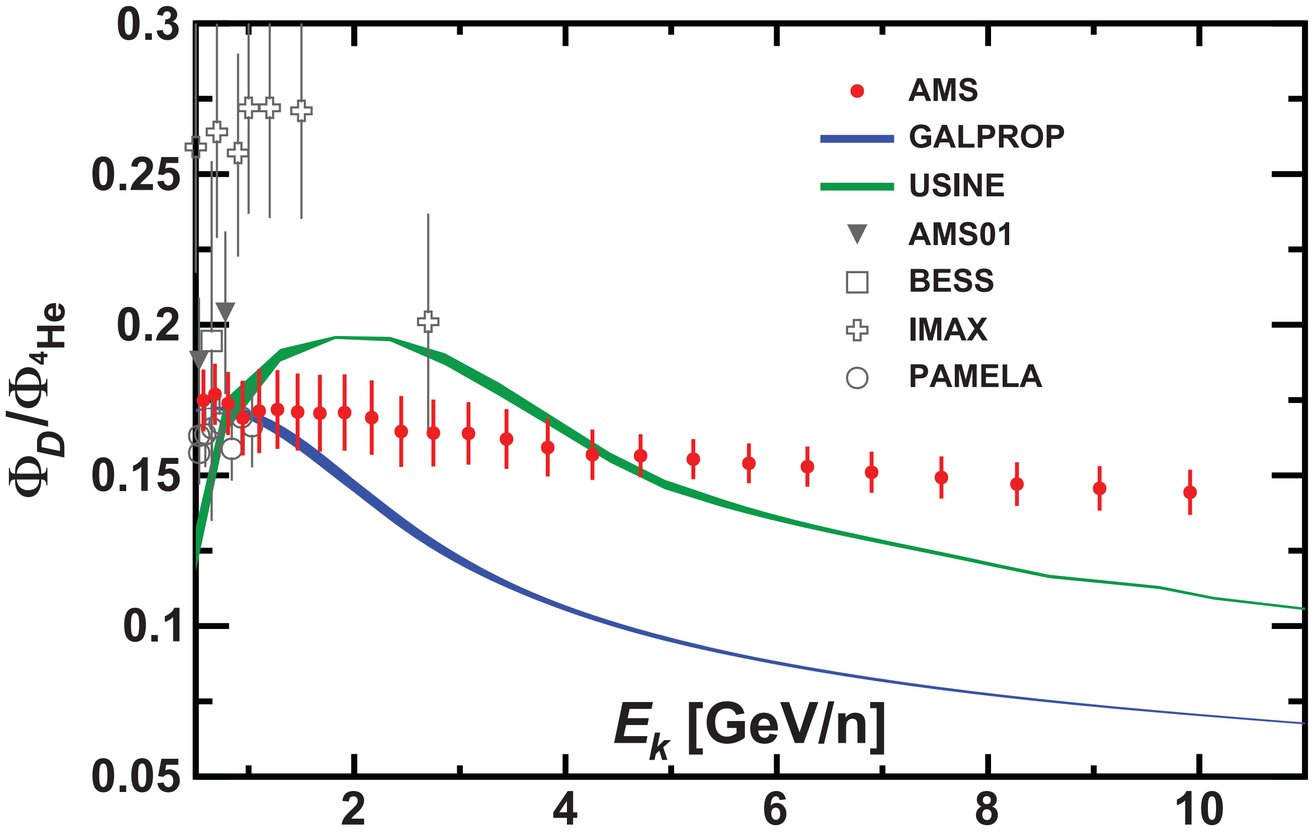
NL Cosmic-Ray landscape

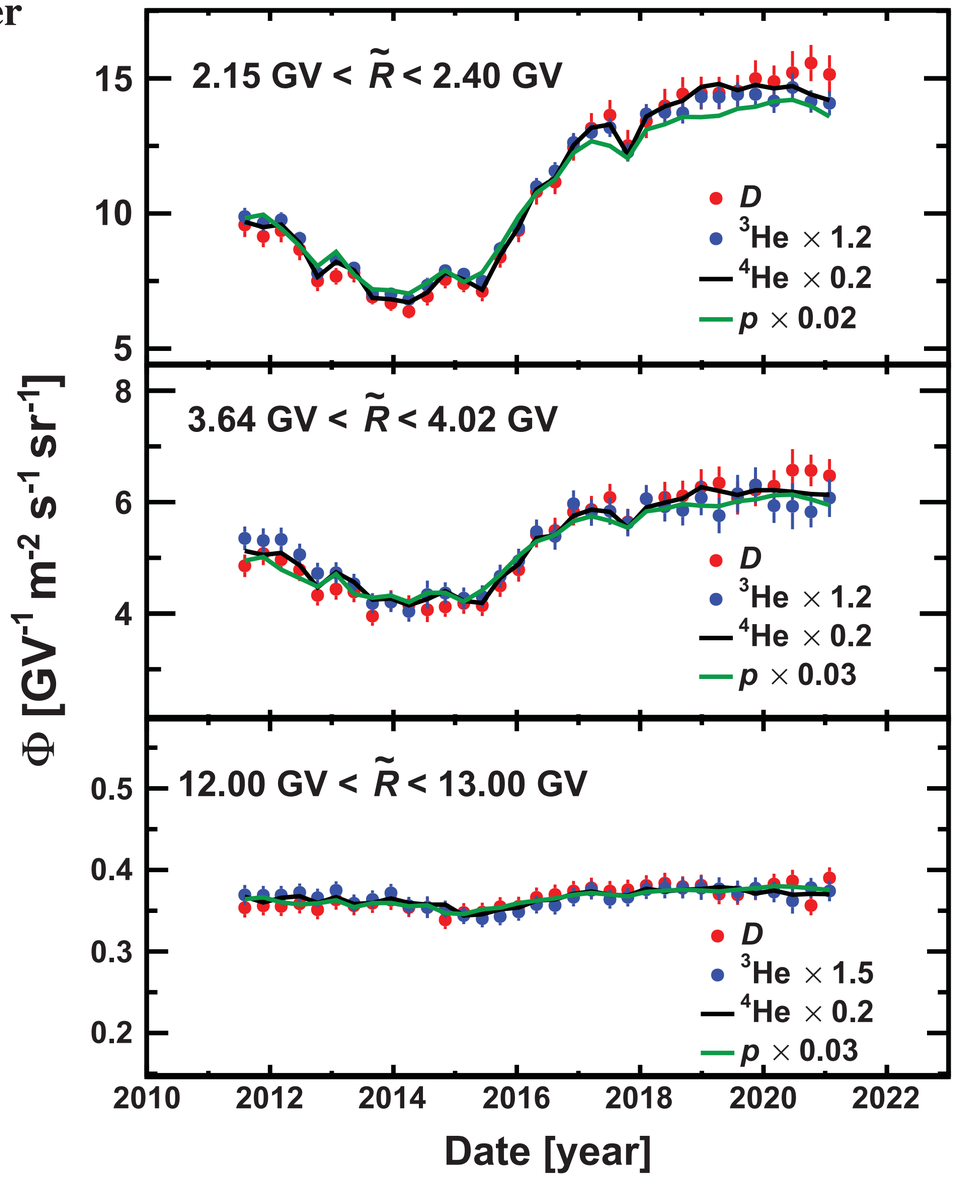
time

energy

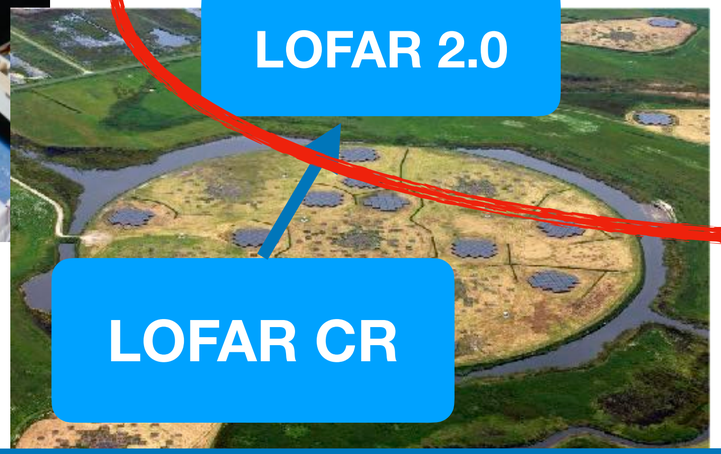
Editors' Suggestion | Featured in Physics

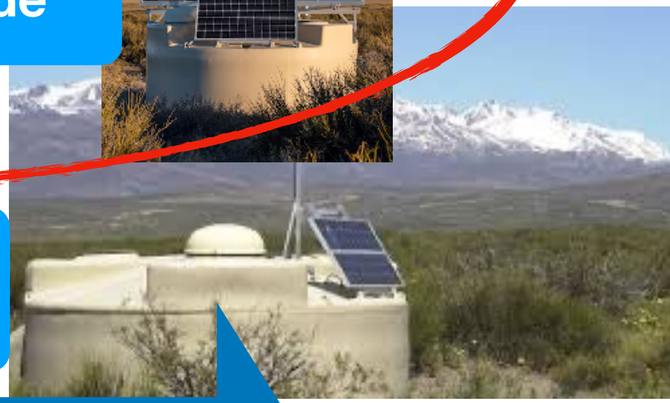
Properties of Cosmic Deuterons Measured by the Alpha Magnetic Spectrometer





NL Cosmic-Ray landscape





time

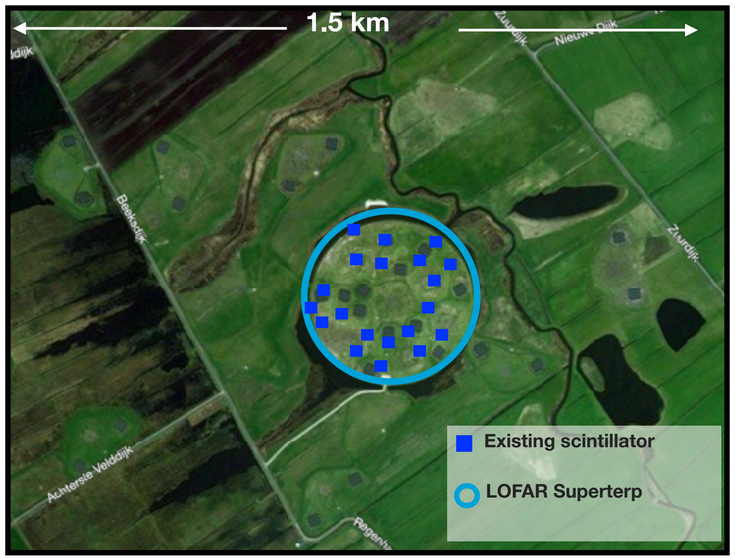
energy

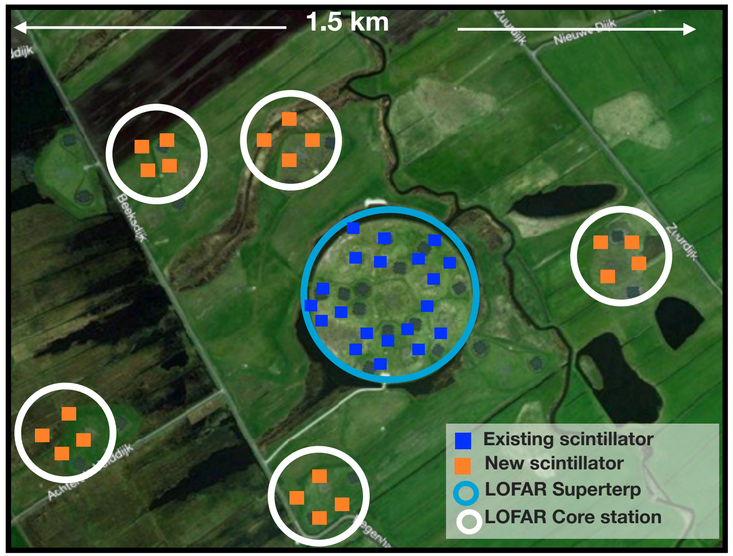
Upgrade of particle detector - LORA

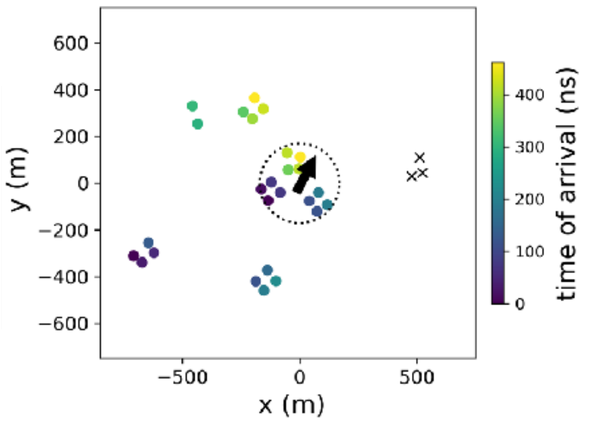
We doubled the size of the triggering array used at LOFAR.

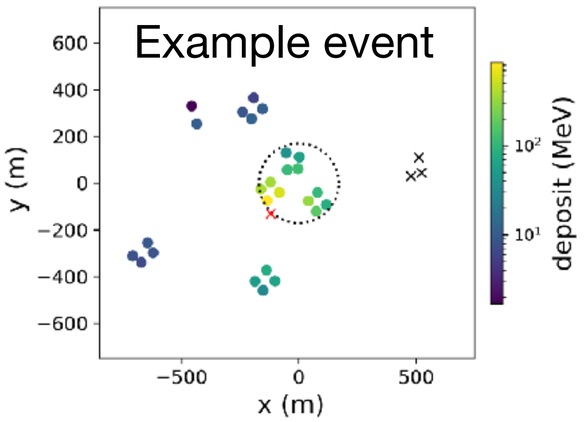
Key improvements:

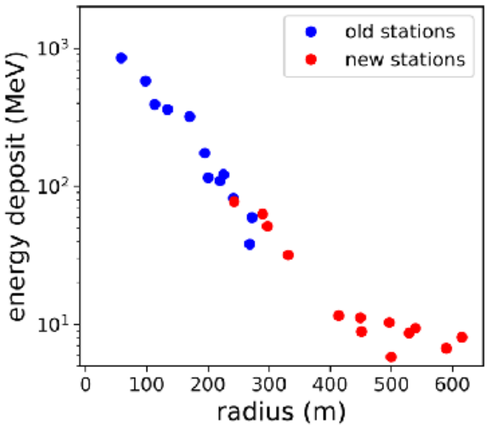
- **Larger effective area = higher energy events**
- **Better coverage = reduction in detection biases**
- **More detectors = more advanced triggering algorithms**





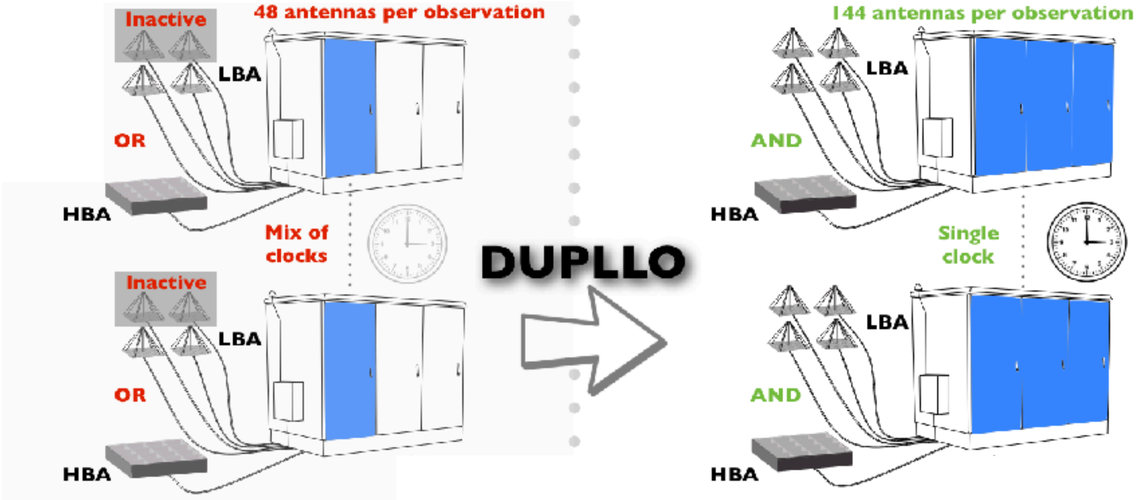






LOFAR 2.0

- LOFAR is getting an upgrade, primarily to serve astronomical observations - but is also highly beneficial for cosmic rays!

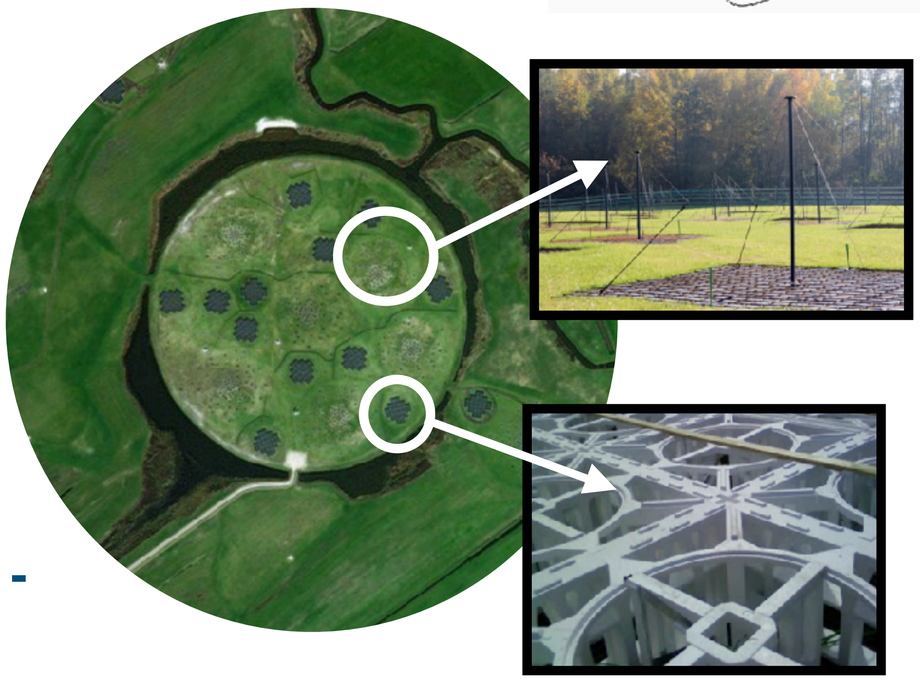


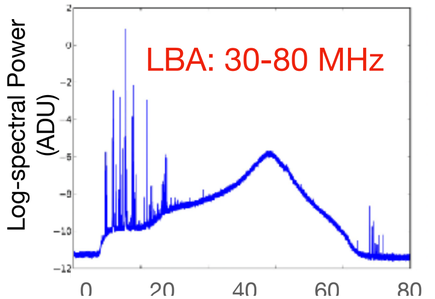
- Key improvements:

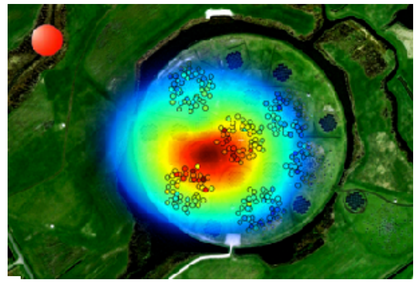
  - continuous observations for all antenna sets

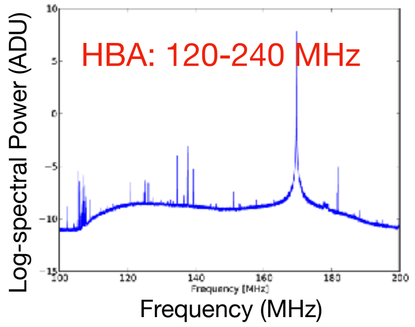
  - un-beamformed HBA antennas - much wider measurement range

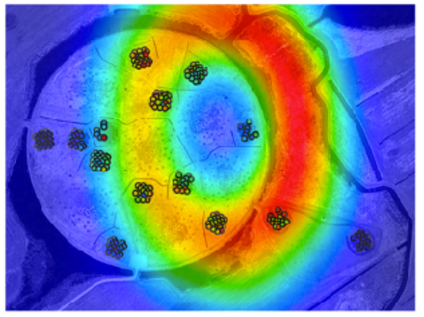
  - increased network speed - access to higher trigger rate, low energy events



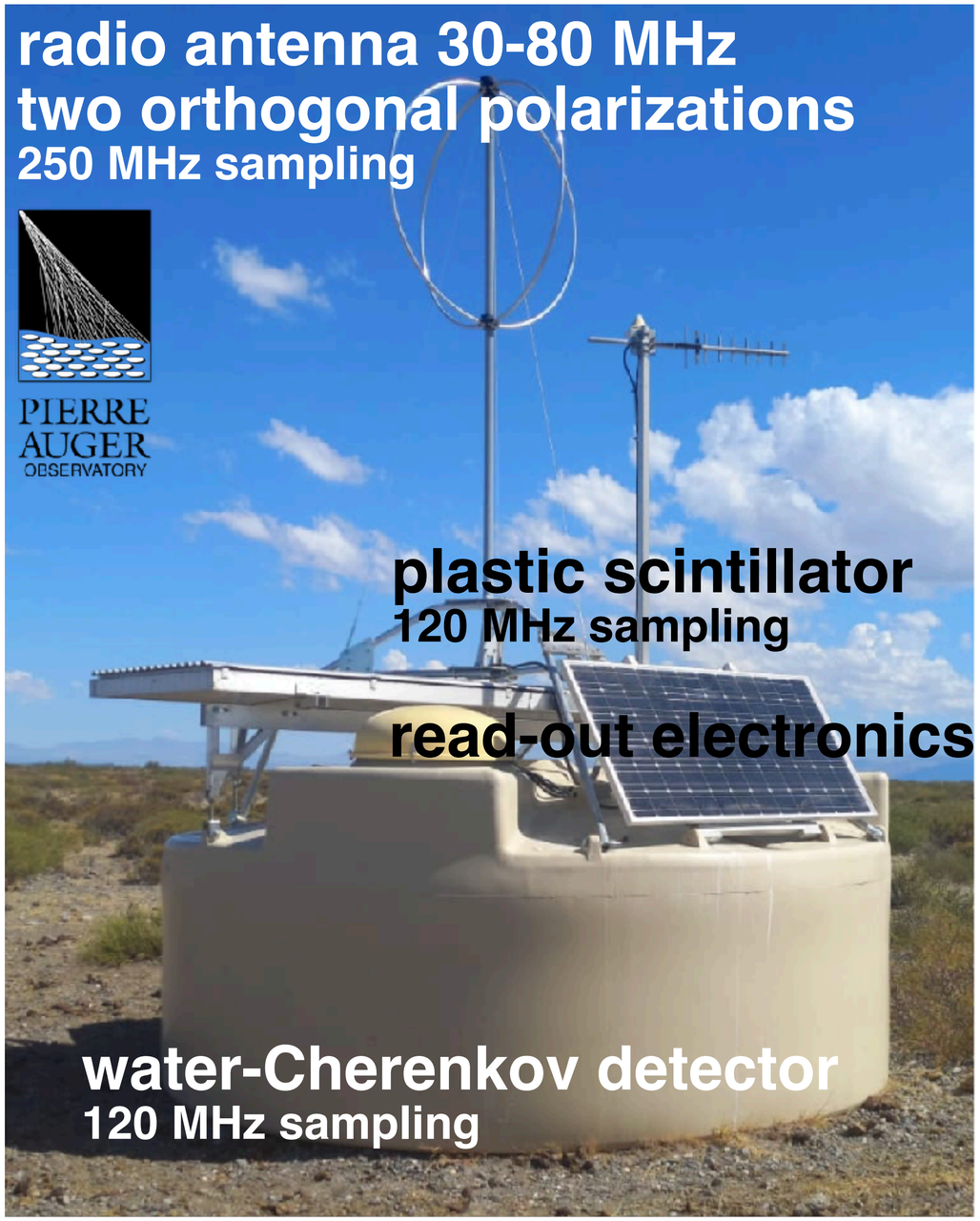








Upgrade of the Pierre Auger Observatory



Key science questions

- What are the sources and acceleration mechanisms of ultra-high-energy cosmic rays (UHECRs)?
- Do we understand particle acceleration and physics at energies well beyond the LHC (Large Hadron Collider) scale?
- What is the fraction of protons, photons, and neutrinos in cosmic rays at the highest energies?

extend mass sensitivity to inclined showers $\theta > 60^\circ$

NL signature contribution:

ERC Advanced Grant	3,5 M€
NWO subsidy	2,5 M€

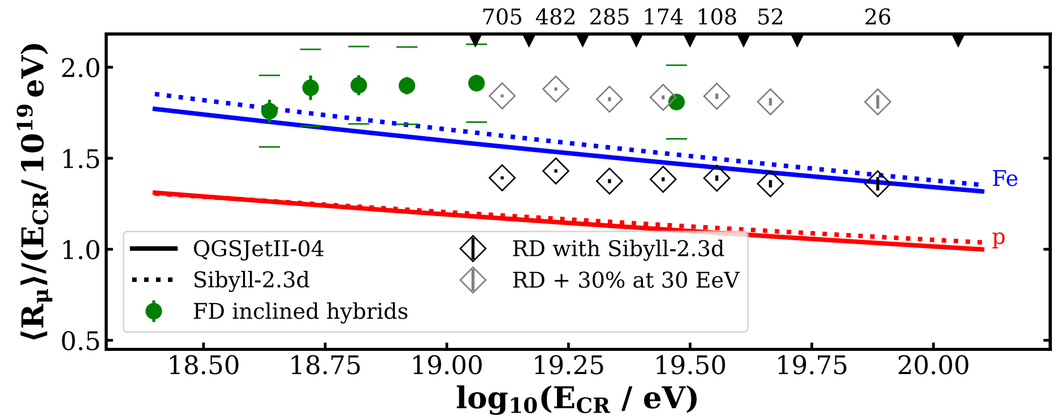
~25% of Auger Upgrade

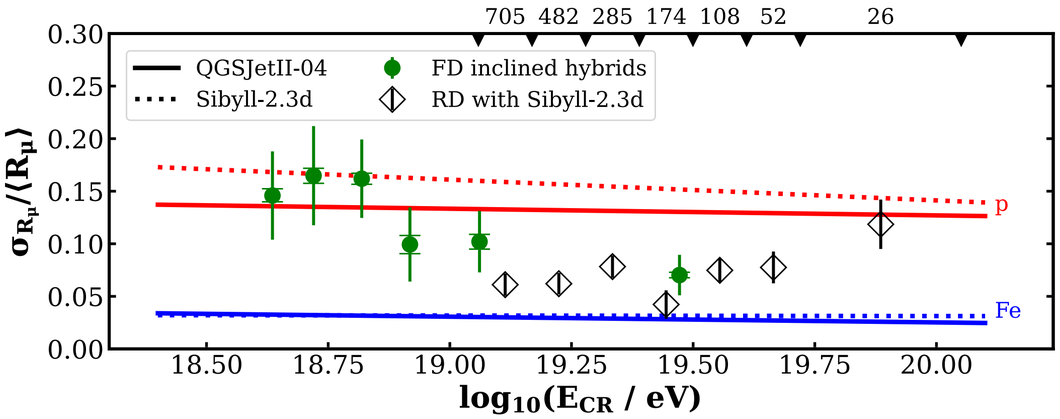
completed end of 2024!

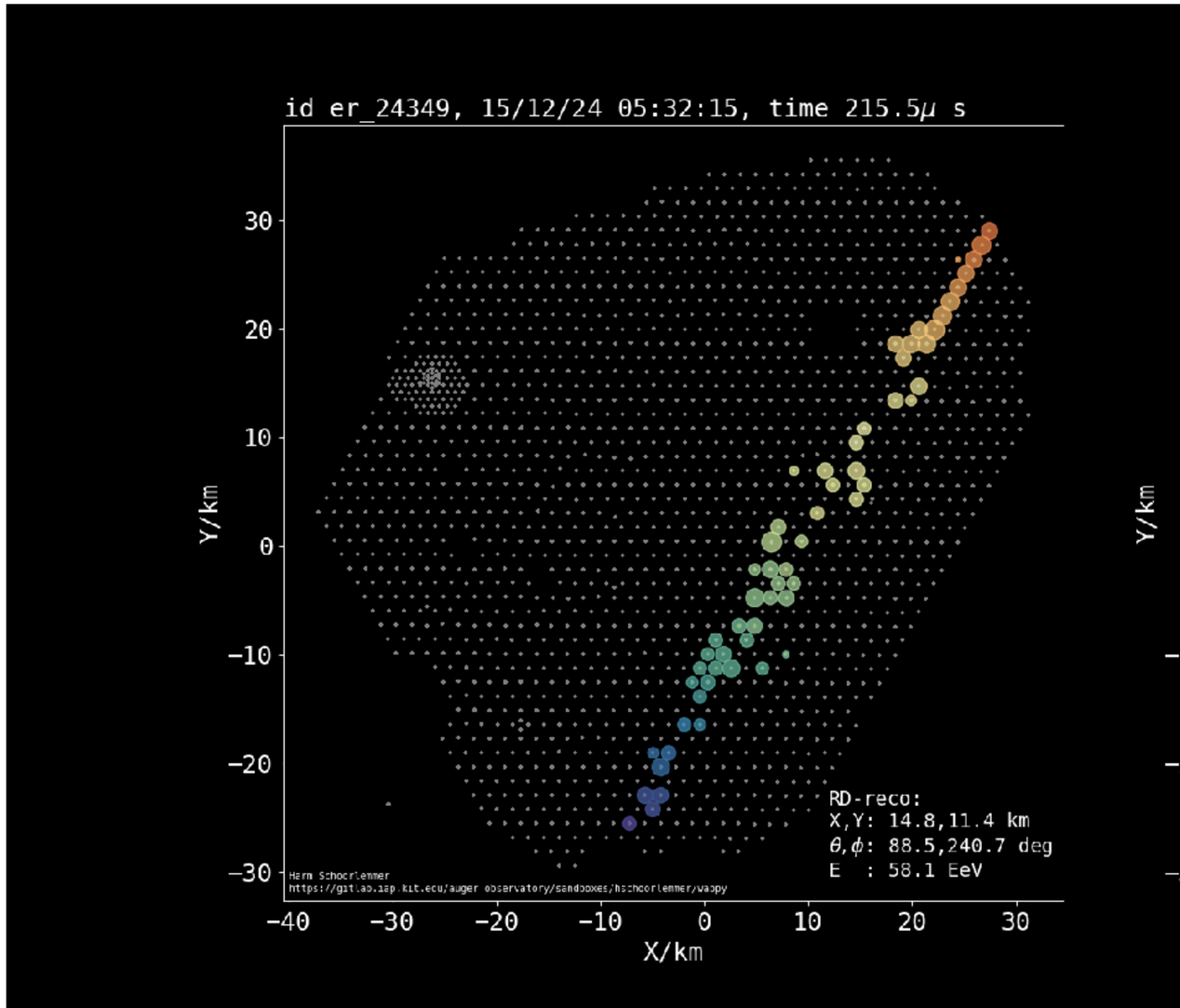
Radio Detector of the Pierre Auger Observatory

extend mass sensitivity to inclined showers $\theta > 60^\circ$

- **increasing measurements of *e*/m and *μ* components for inclined showers by an order of magnitude**
- **close to ideal p-Fe separation**





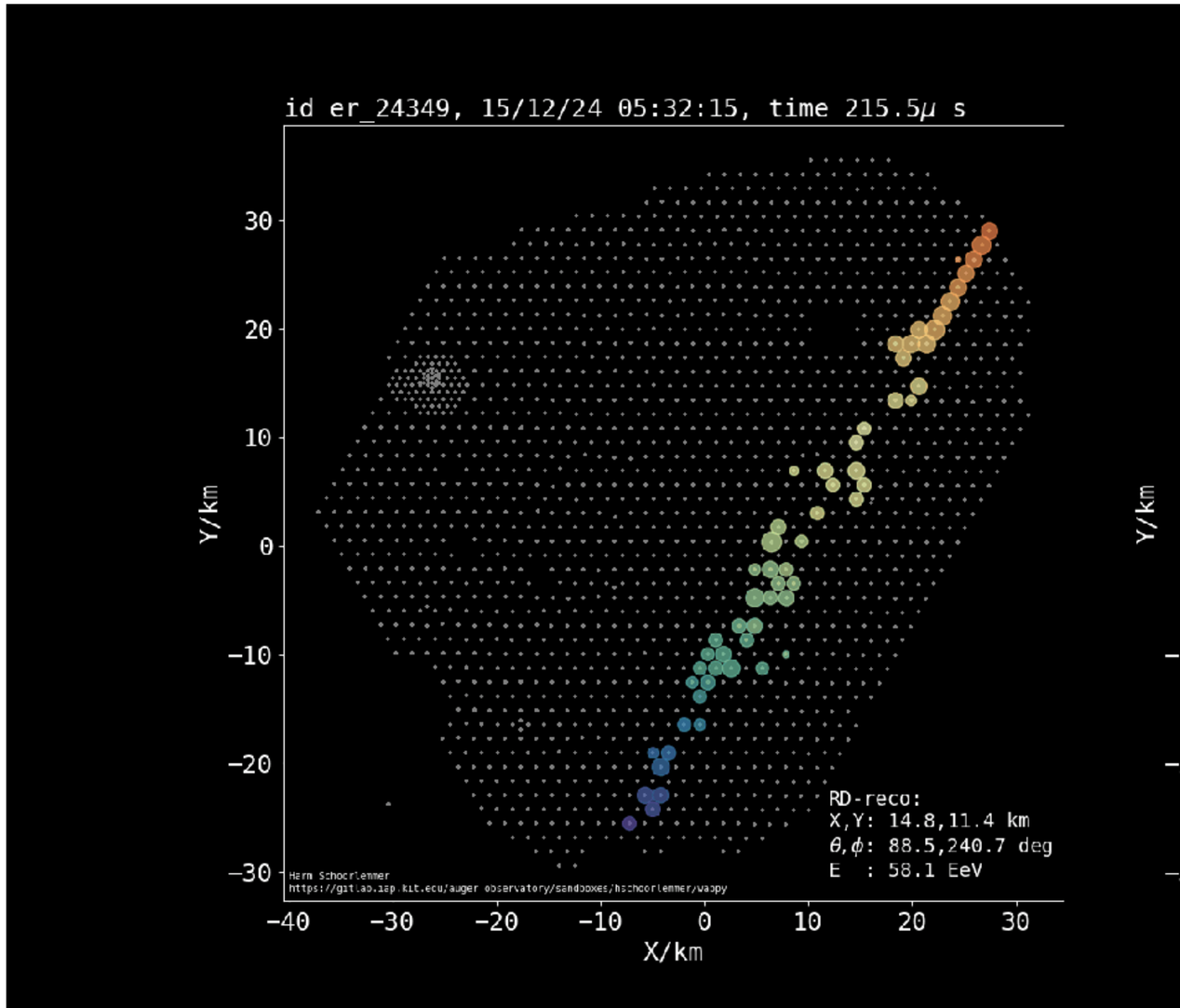


Radio Detector of the Pierre Auger Observatory

extend mass sensitivity to inclined showers $\theta > 60^\circ$

next 10 years:

- precise mass/type measurement of CRs
- isolate high-rigidity particles
  —> charged-particle astronomy
- measure 1st UHE neutrino
- measure 1st UHE gamma ray



Interferometry at the Pierre Auger Observatory

Basic idea: **add the capabilities to perform interferometry to the 3000 km² array**

This will enable for very horizontal air showers the determination of depth of shower maximum (X_{max})

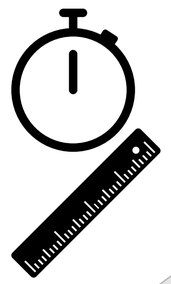
Cosmic ray composition at the highest energies

Air shower physics (studying energetic muons)

Deliverables:

Synchronisation system (~1ns)

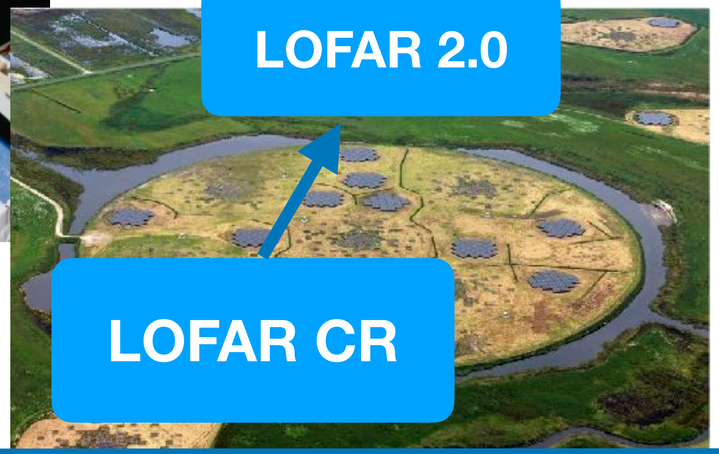
Localisation survey (< 30cm)



NL Cosmic-Ray landscape

AMS

SKA



LOFAR 2.0

LOFAR CR

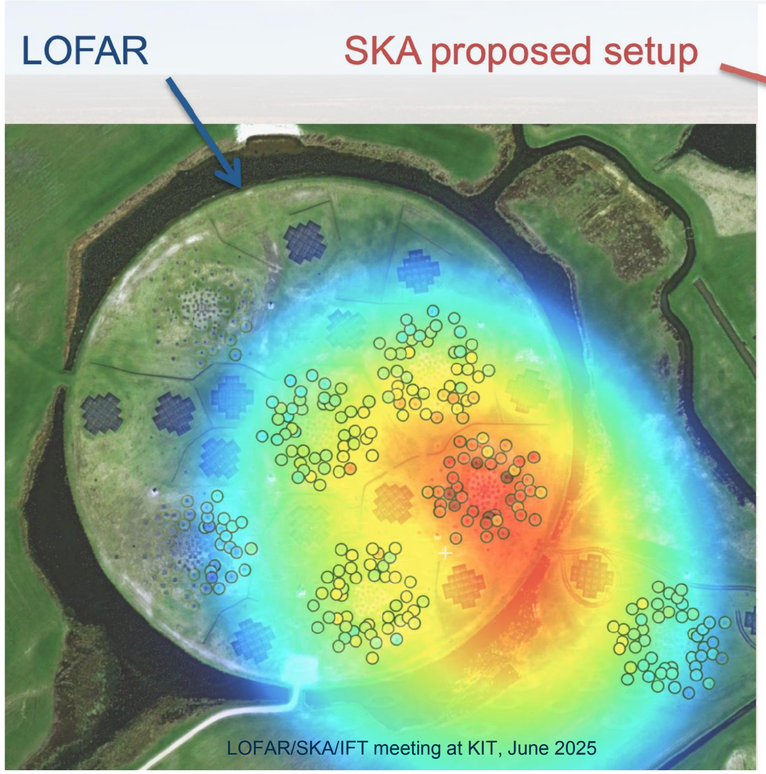
Upgrade

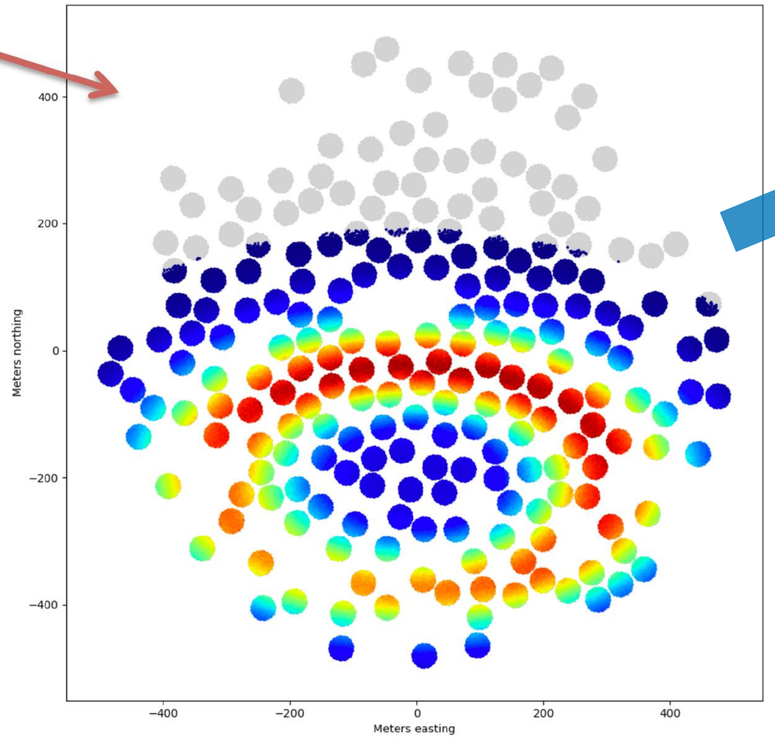
Pierre Auger Observatory

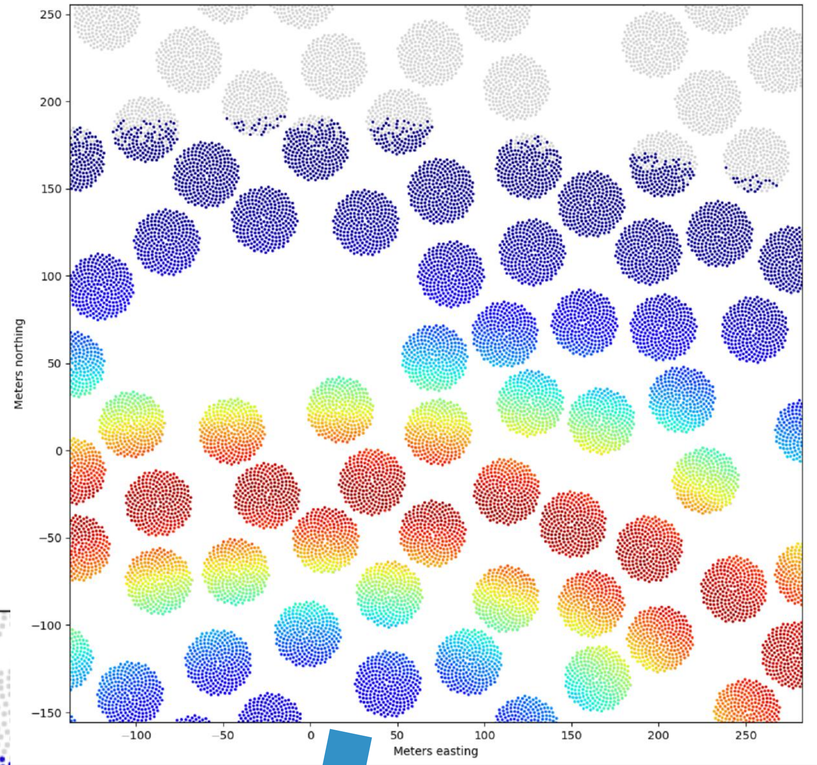
energy

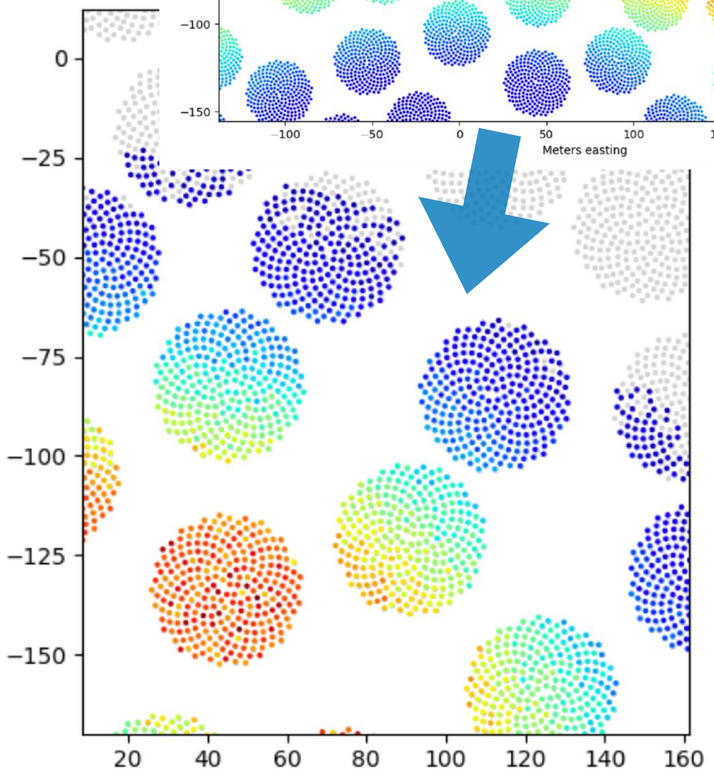
The Square Kilometer Array - SKA

Pierre Auger Observatory —> large detection area
LOFAR/SKA —> high antenna density









precision measurement of air showers in transition region

The Square Kilometer Array - SKA

Pierre Auger Observatory —> large detection area
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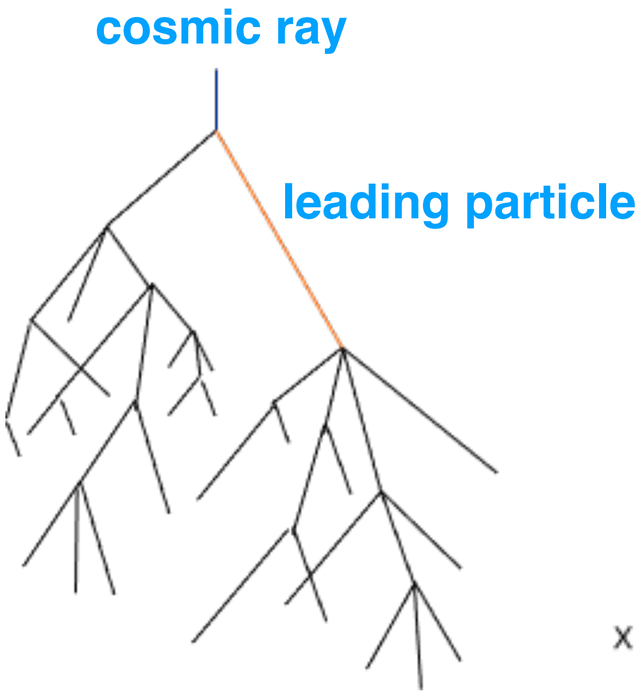
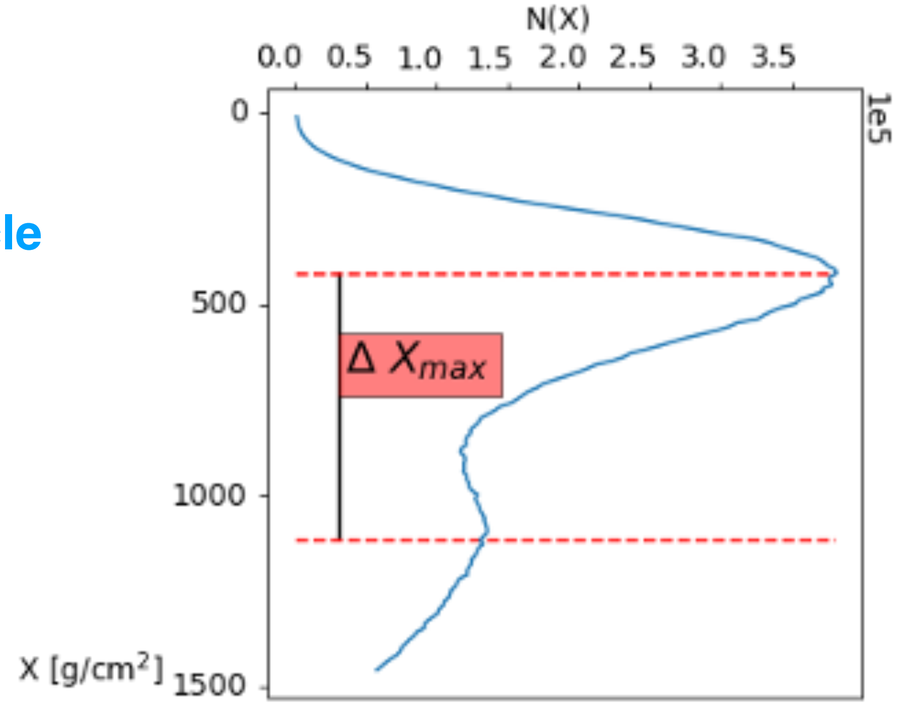
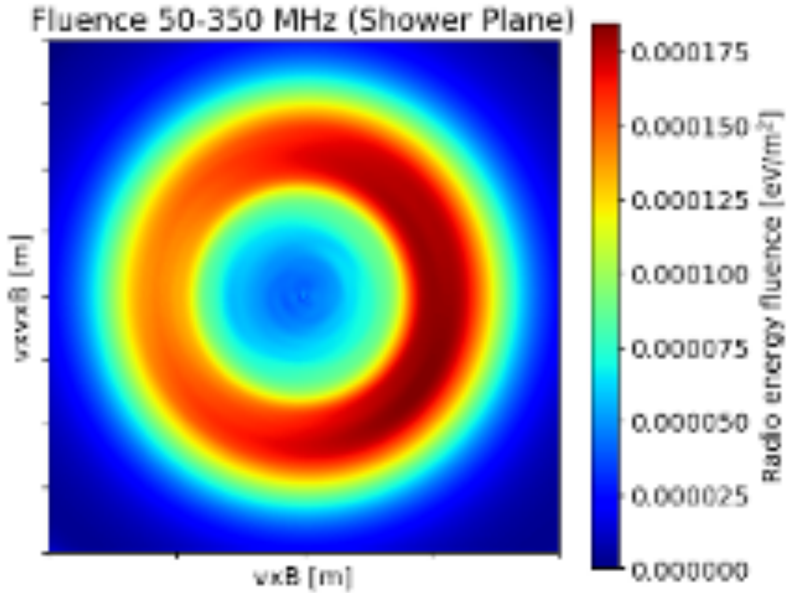
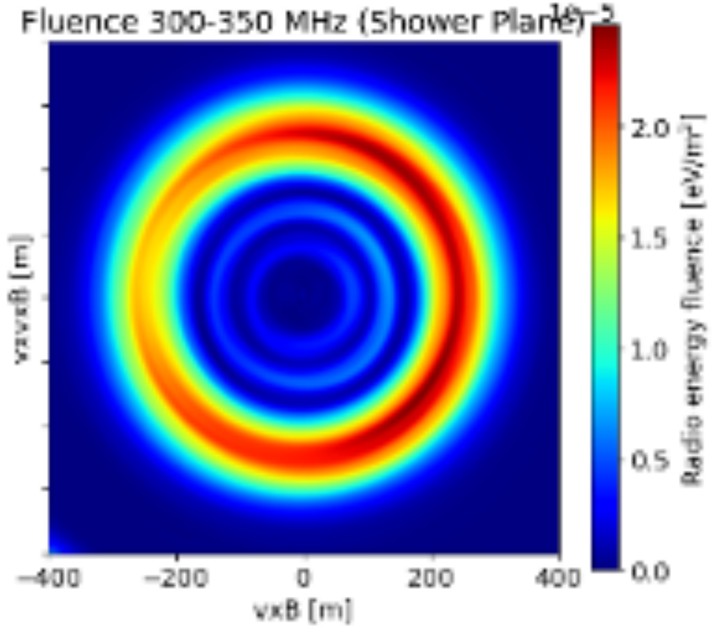






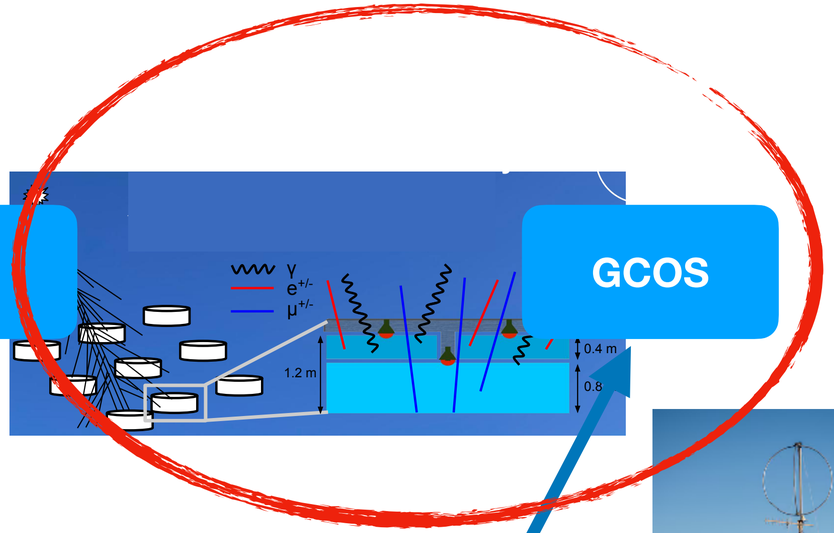


precision measurement of air showers in transition region

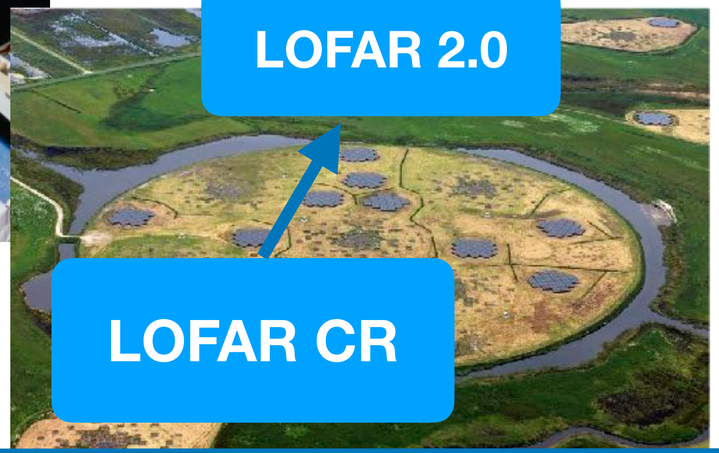
NL Cosmic-Ray landscape

AMS

SKA



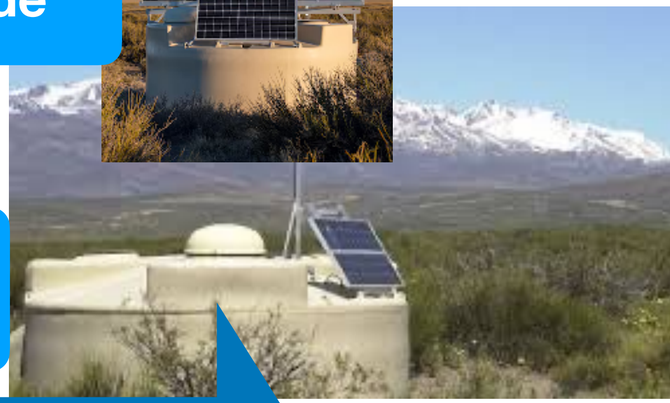
GCOS



LOFAR 2.0

LOFAR CR

Upgrade



Pierre Auger Observatory

energy

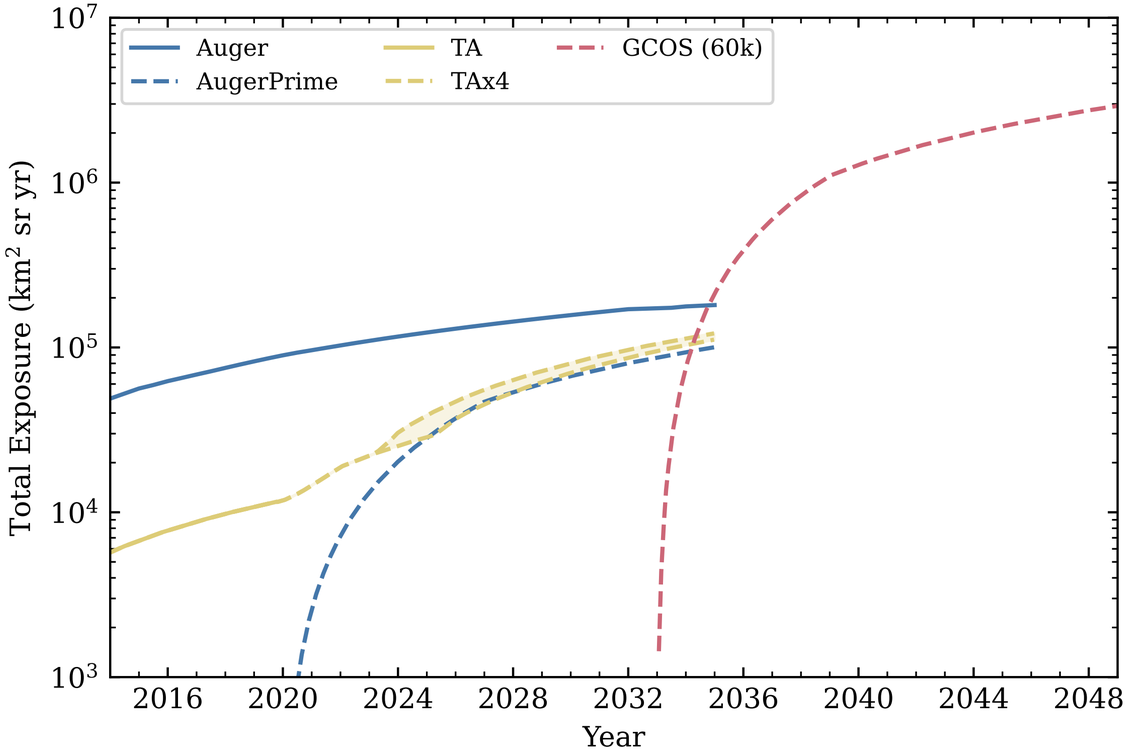
The Global Cosmic Ray Observatory - GCOS

preparing for the next-generation observatory after 2035

Could we extend Auger to build a 1st GCOS (R&D) site?

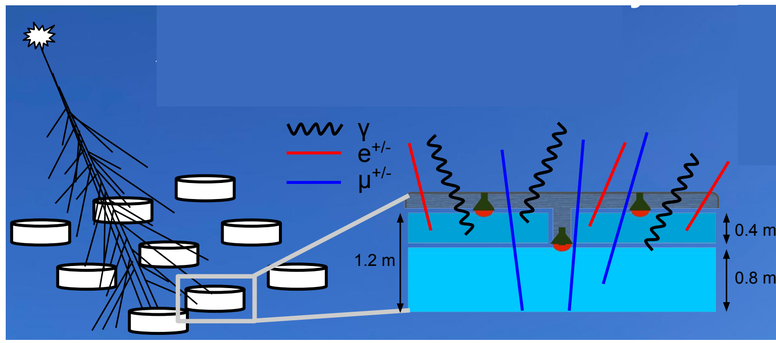
GCOS Requirements

- total area: 60 000 km^2
- number of sites ≥ 2
- trigger threshold: 10^{19} eV
- high-quality threshold: 3×10^{19} eV
- σ_E: 10%, $\sigma_{\ln A}$: 1, σ_θ: 1°
- high duty cycle, low maintenance



Particle Detector Design

- layered water Cherenkov detectors
- emag. and muonic EAS component
- detector spacing: 2.2 km
- number of stations: 18 000
- σ_S: 10%, σ_{N_μ}: 10%, $\sigma_{X_{\max}}$: 30 g/cm^2

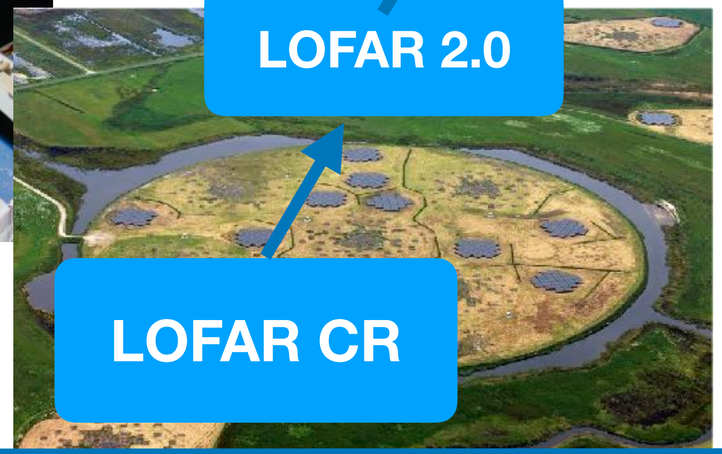


GCOS white paper
arXiv:2502.05657

NL Cosmic-Ray landscape

AMS

SKA



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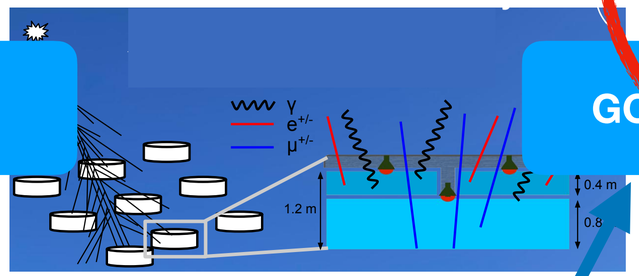

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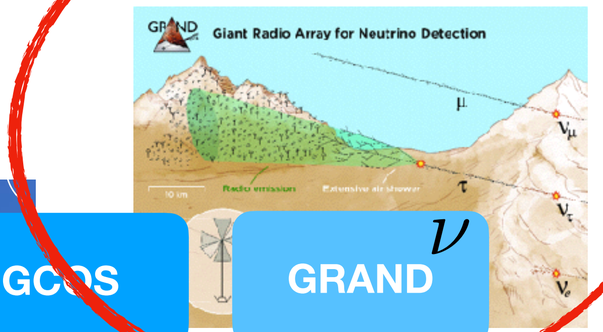
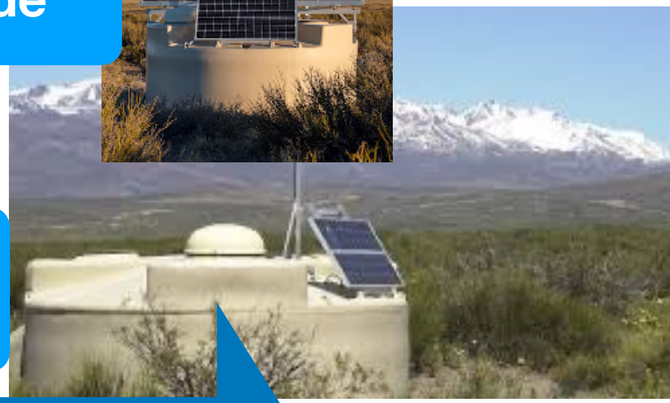


GRAND ν

Upgrade



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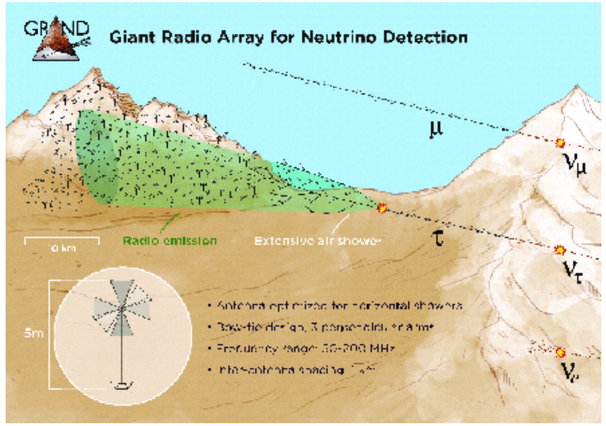
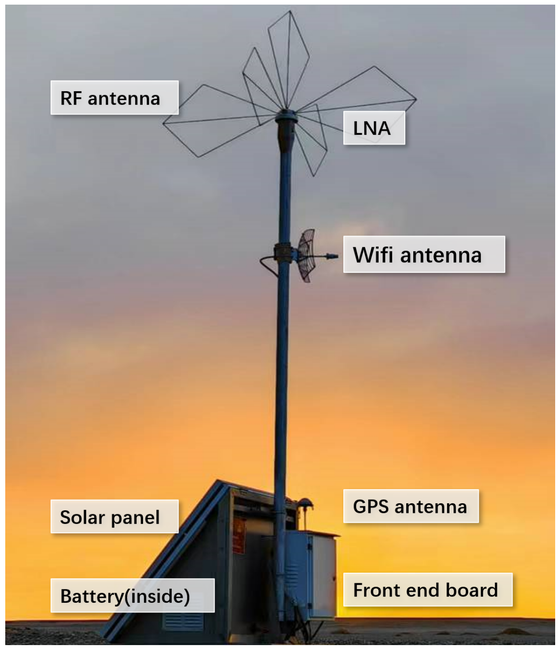
PROCEEDINGS OF SCIENCE

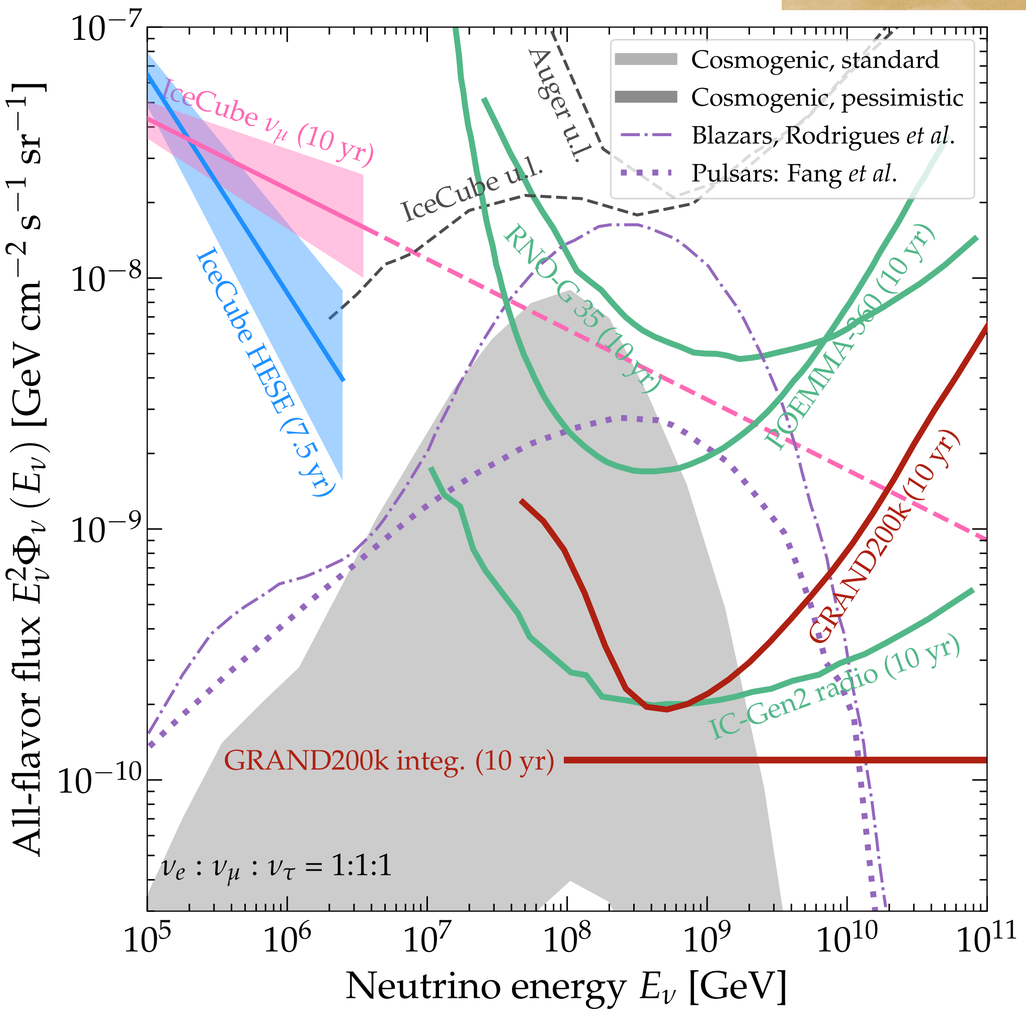
GRAND: status and perspectives

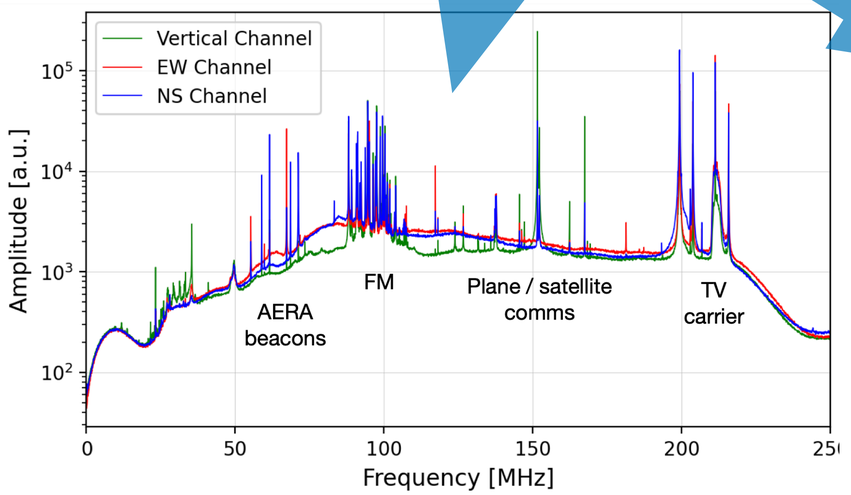
Kumiko Kotera[a,b,*] for the GRAND Collaboration

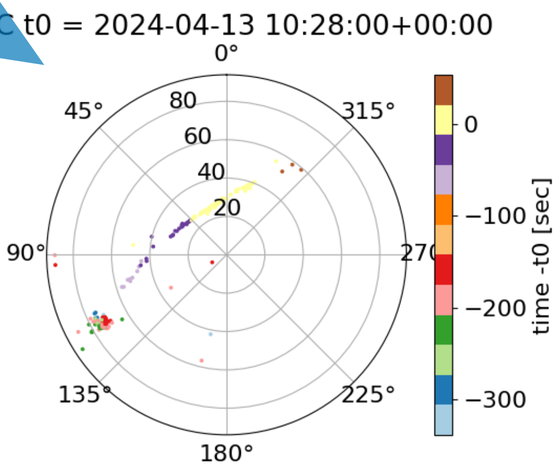


prototypes at Auger & China



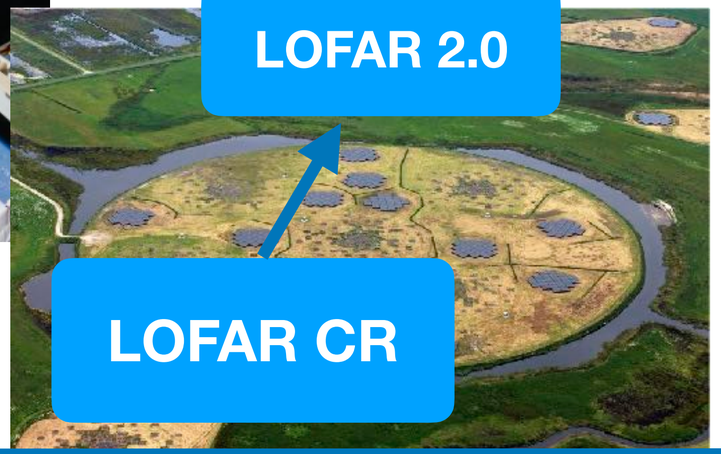






NL Cosmic-Ray landscape

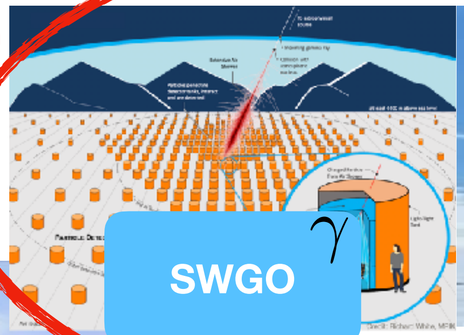
AMS



LOFAR CR

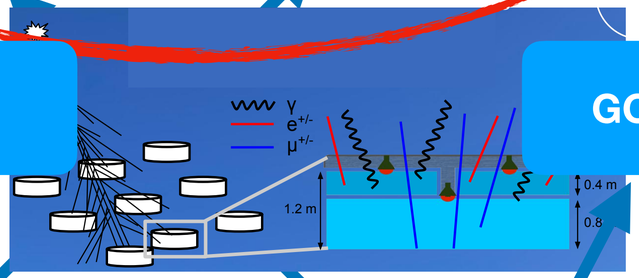
LOFAR 2.0

SKA

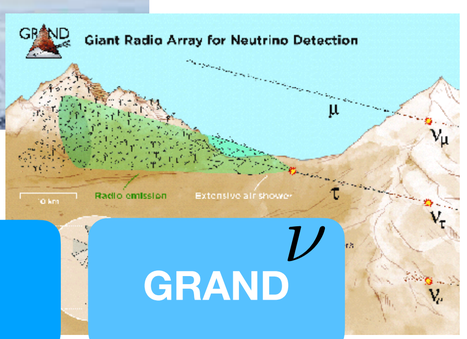


SWGO γ

RNO-G ν

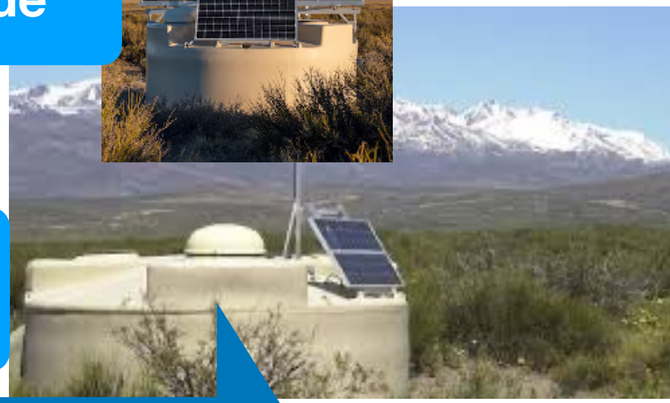


GCOS



GRAND ν

Upgrade



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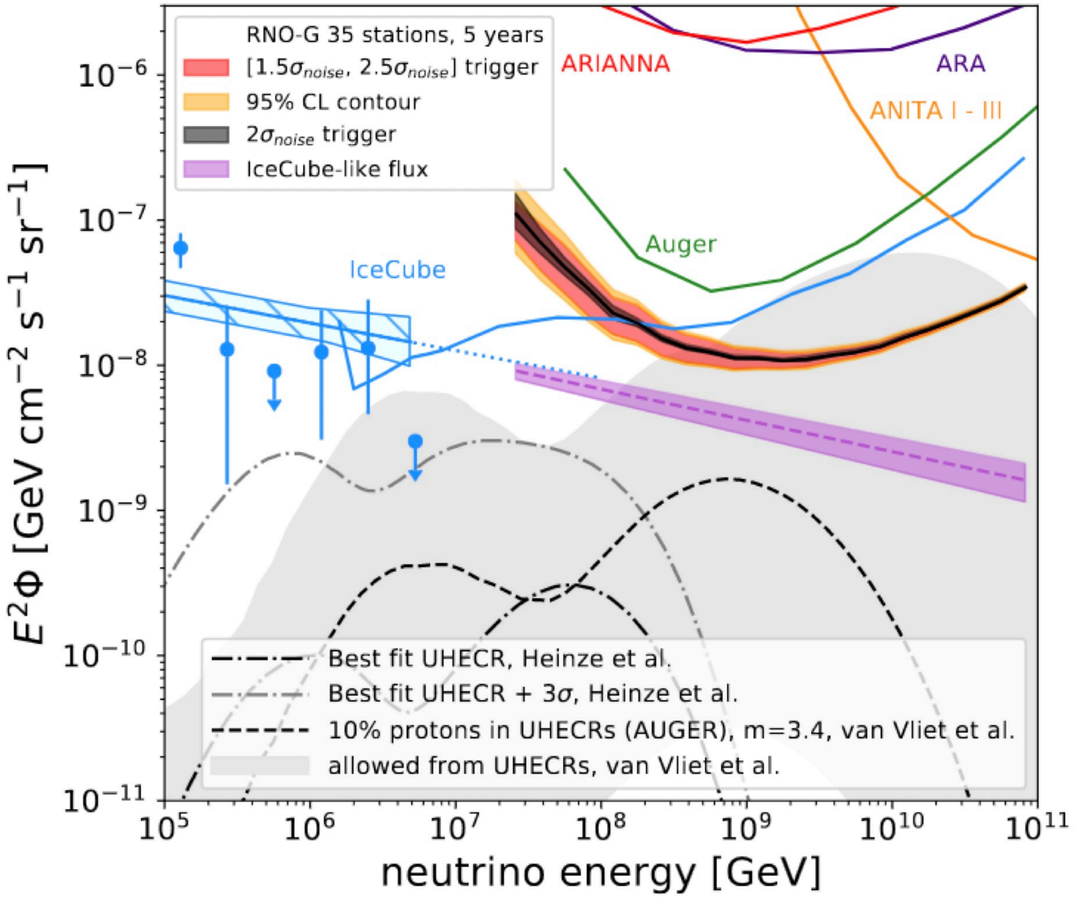
PROCEEDINGS OF SCIENCE

The Radio Neutrino Observatory in Greenland (RNO-G): Overview and Status

Kaeli Hughes[a,*] on behalf of the RNO-G Collaboration



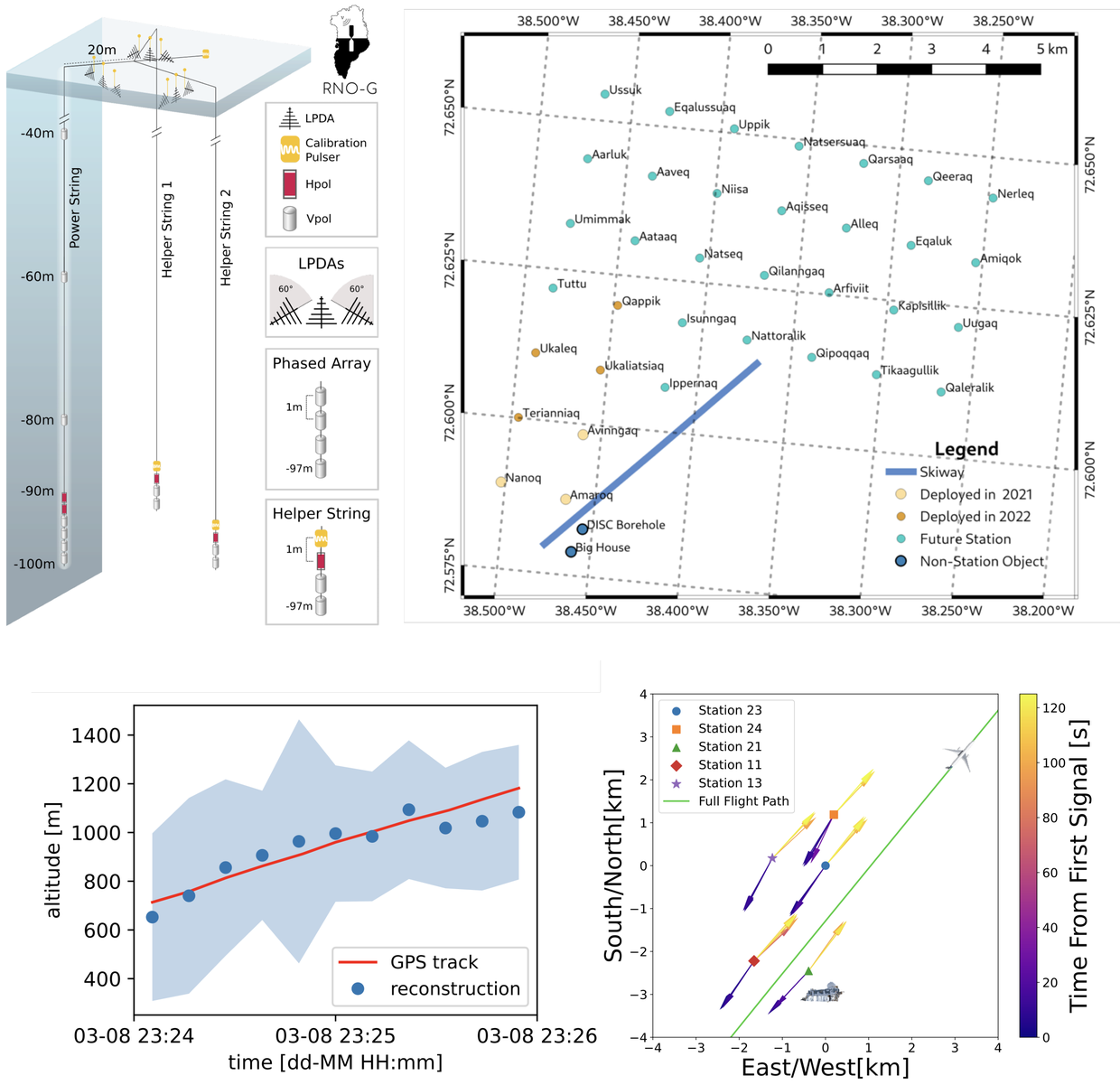


Figure 8: Left: the reconstruction of the local Radiosonde weather balloon, compared to the true reconstruction from the GPS file. Right: a set of reconstructed airplane events seen by five of the seven RNO-G stations.

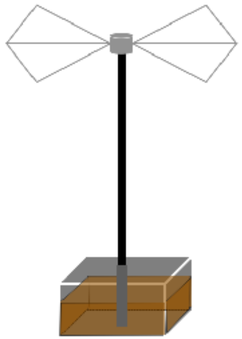
PoS(ARENA2024)001

Southern Wide-view Gamma-ray Observatory

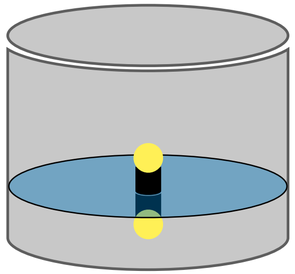
SWGO TURBO

And The Utility for Radio Beamformed Observations

Radio
800 x



Particles
>3500x



Array in a nutshell:
Altitude: 4,8 km
Area: 1 km²
Lattitude: -23 deg

Funded by the European Union
European Research Council
Established by the European Commission

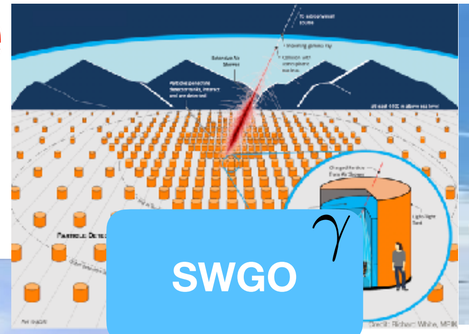
X_{max}, Energy, Direction *Muons, Energy, Direction* ***Unprecedented precision for air shower measurements***

Gamma-ray astronomy
Cosmic-ray composition
Air-shower physics

Radboud Universiteit

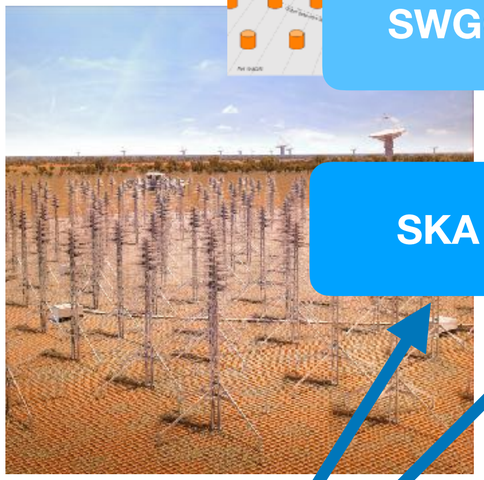
NL Cosmic-Ray landscape

activities for the next decade

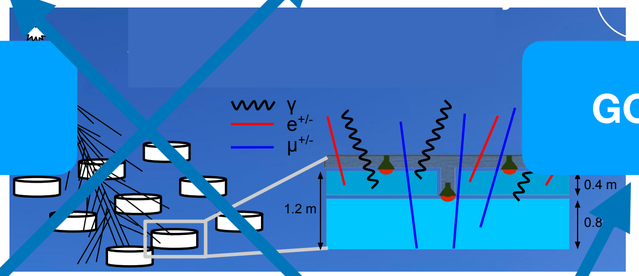


SWGO γ

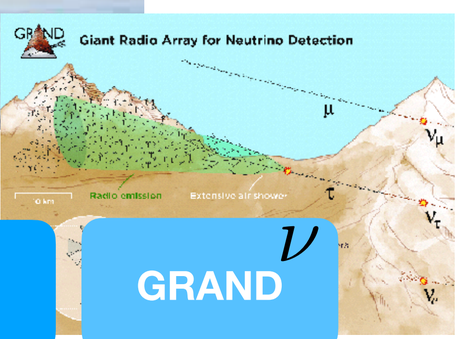
RNO-G ν



SKA

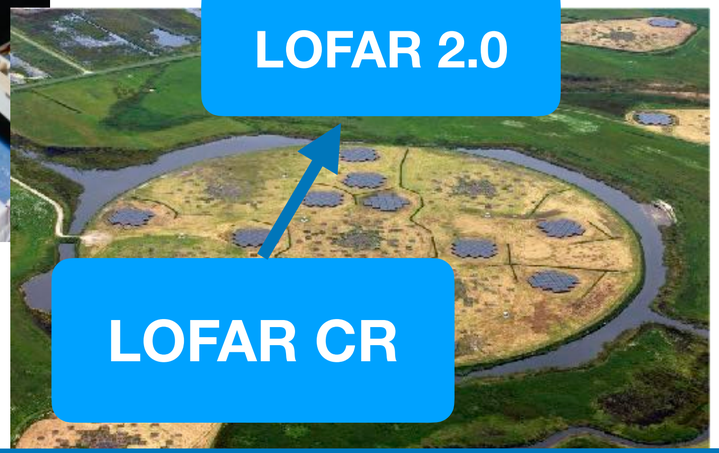


GCOS



GRAND ν

AMS



LOFAR 2.0

LOFAR CR

Upgrade

Pierre Auger Observatory

time

energy