



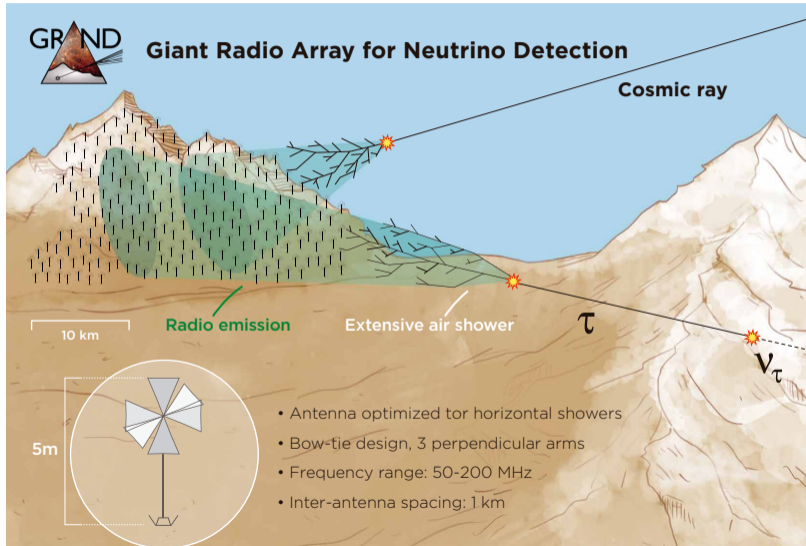
GRAND: Giant Radio Array for Neutrino Detection

RAMESH KOIRALA
(ON BEHALF OF THE GRAND COLLABORATION)
NANJING UNIVERSITY, CHINA

WIN 2023
ZHUHAI, CHINA
JULY 07, 2023

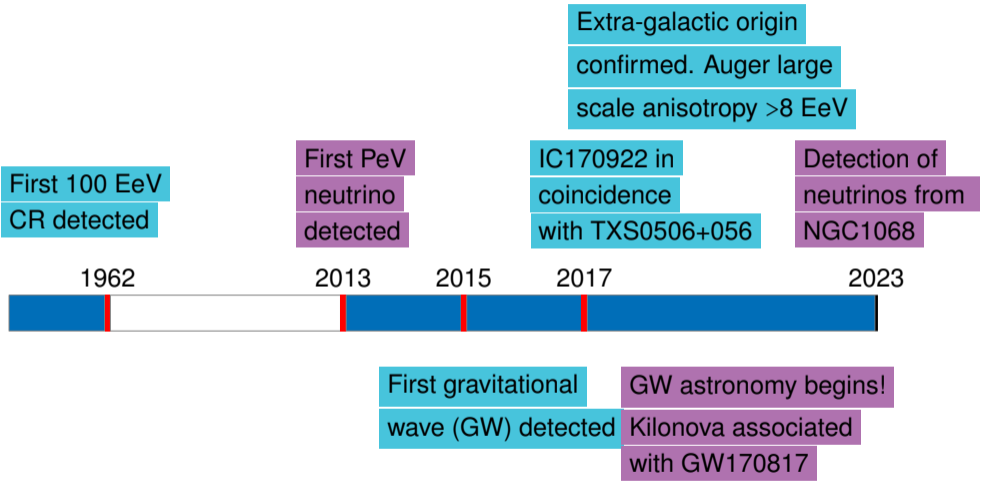
Detection Principle

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- GRAND@Auger
- GRAND@Nancay
- Collaboration
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Timeline

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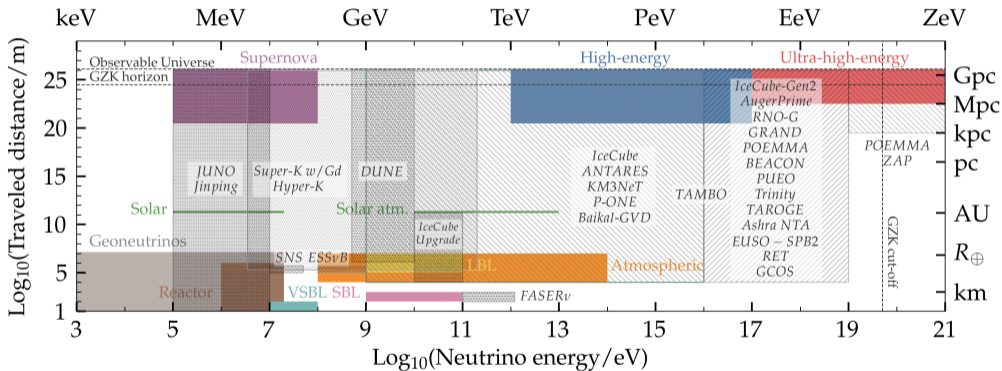
We still don't know the origin of UHECRs.



Neutrino Astronomy

Plot by Mauricio Bustamante

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M. Ackermann et al., *JHEAp* (arXiv:2203.08096)

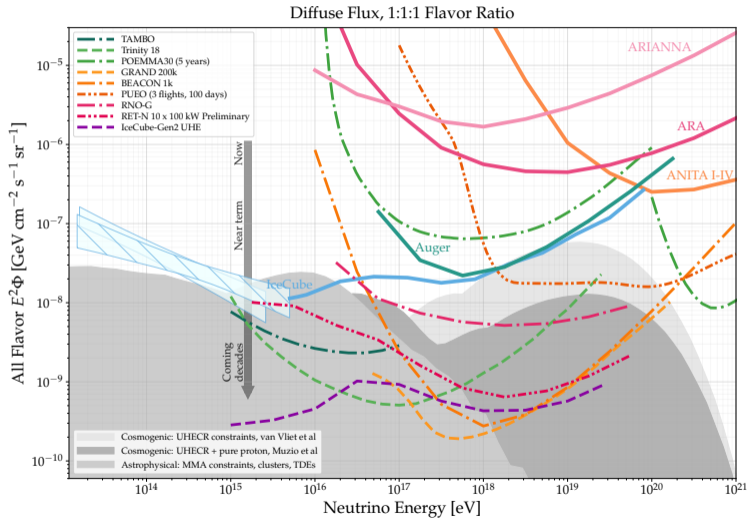
M. Ackermann et al., *Bull. Am. Astron. Soc.*, (arXiv:1903.04333)



Neutrino Sensitivity

M. Ackermann et al., JHEAp (arXiv:2203.08096)

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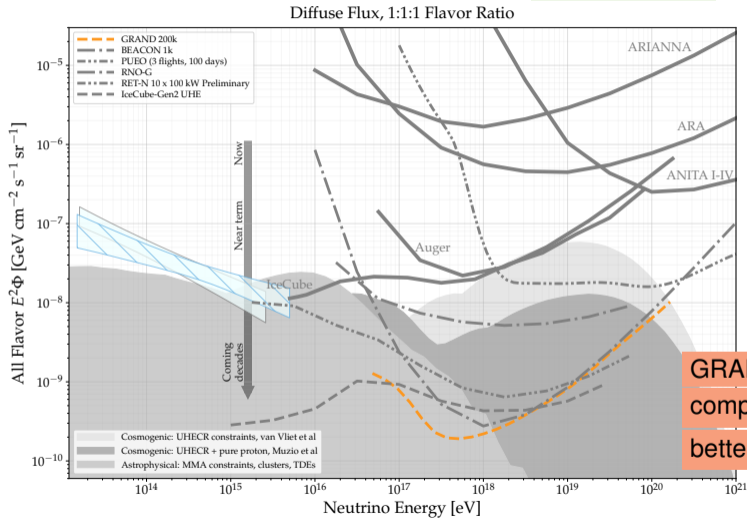


Neutrino Sensitivity

M. Ackermann et al., JHEAp (arXiv:2203.08096)

Plot by Stephanie Wissel

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GRAND200k has comparable or better sensitivity



Introduction

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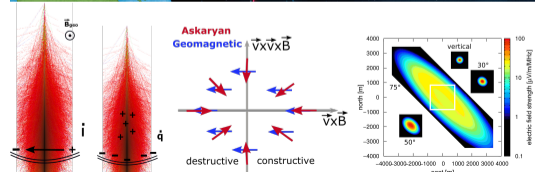
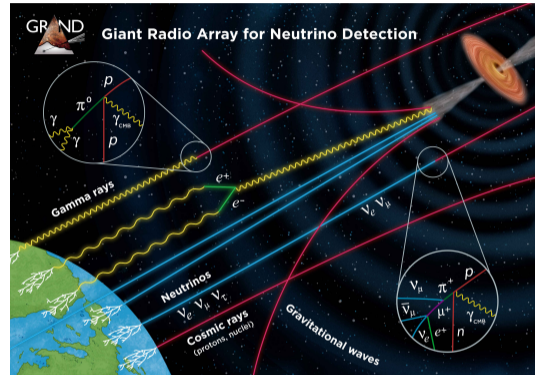
GRAND@Auger

GRAND@Nancy

Collaboration

Summary

- GRAND is a radio detector.
- CRs, γ -rays, and neutrinos produce extensive air showers.
- Radio waves are emitted mainly due to the geomagnetic and Askaryan effects.
- Radio detection is a mature technique: AERA, LOFAR, CODALEMA, Tunka-Rex, TREND, etc.
- Radio antennas: cheap, scalable, robust, ideal for giant arrays.



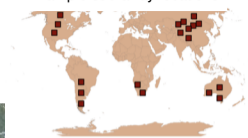
The GRAND Concept

200,000 radio antennas over 200,000 km²

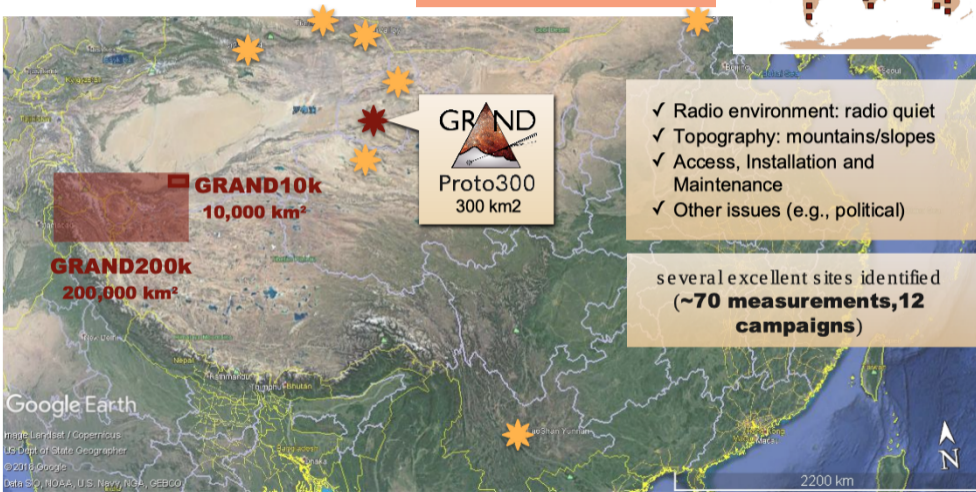
20 sub-arrays of 10,000 antennas over

favorable sites in China and worldwide.

Example sub-array locations



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- ✓ Radio environment: radio quiet
- ✓ Topography: mountains/slopes
- ✓ Access, Installation and Maintenance
- ✓ Other issues (e.g., political)

several excellent sites identified
(~70 measurements, 12 campaigns)



Deployment Timetable

Before 2023

- Site search and development of detectors
- Deployment of antennas in 3 different locations

2023 - 2028

- Deployment and operation of prototype arrays
- Characterize background and features of autonomous detection of inclined EAS

- Optimize array design, deployment strategy, and operation for later stages of GRAND
- Scout and select sites for two GRAND10k
- Securing funding for GRAND10k arrays

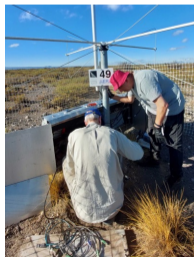
After 2028

- Construct GRAND10k arrays

Dunhuang, China



Malargüe, Argentina



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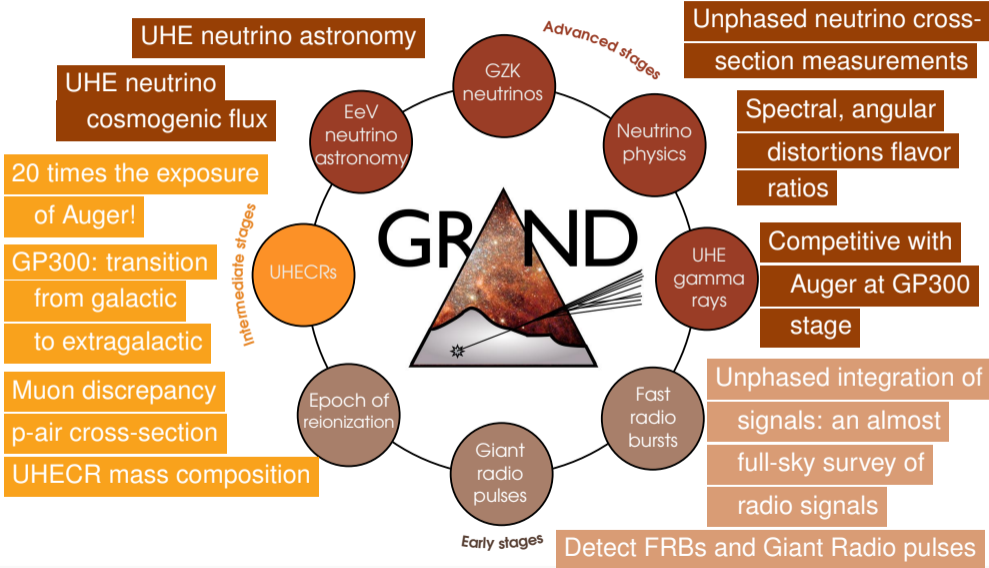
Collaboration

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Rich Science Case

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New Physics

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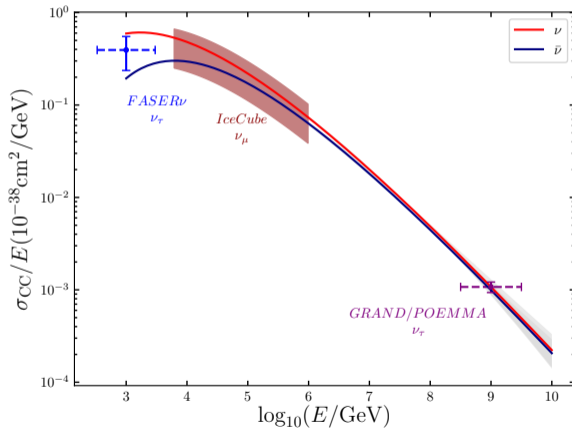
Collaboration

Summary

Study for New Physics

- Neutrino-nucleon cross-section at UHE
- Neutrino decay
- Lorentz-invariance violation
- Active-sterile neutrino mixing
- Pseudo-Dirac neutrinos
- Indirect detection of dark matter or energy
- etc.

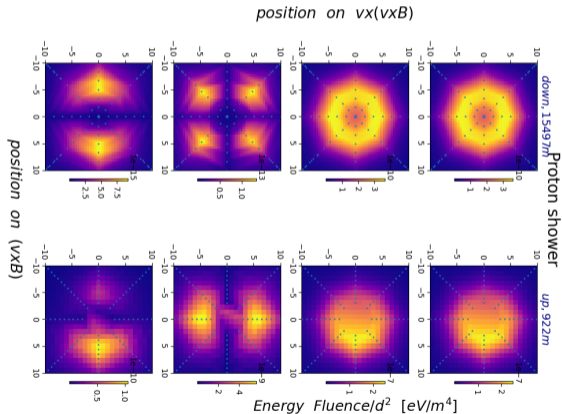
P. Denton & Y. Kini, PRD (arXiv:2007.10334)



New Mechanism

New Radio Emission Mechanism

- geosynchrotron: clover leaf pattern



C. Zhang, S. Chiche, et al., 2023 (under review)

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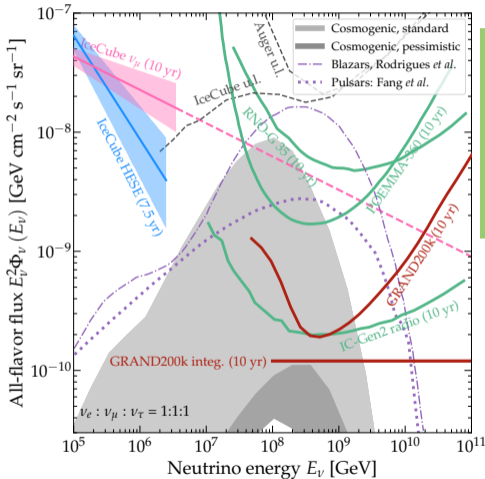
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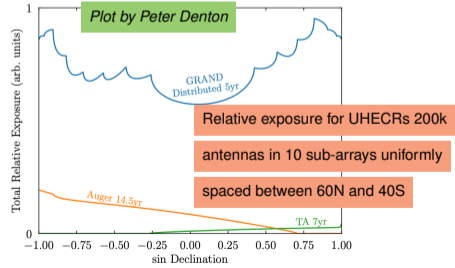
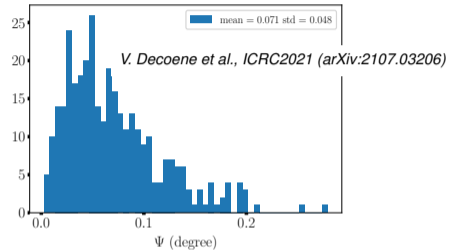
Simulation Performance

K. Kotera, ICRC2021 (arXiv:2108.00032)



Plot by Mauricio Bustamante

GRAND full sensitivity to neutrinos ($E > 10^{17}$ eV) $\sim 4 \times 10^{-10}$ $\text{GeV cm}^{-2} \text{s}^{-1} \text{sr}^{-1}$
 Angular resolution $\sim 0.1^\circ$ (V. Decoene Ph.D 2020)
 Energy resolution $< 10\%$ (B. Lago & Rio GRAND team)
 Xmax resolution $< 40 \text{gcm}^{-2}$ for $E > 10^{19}$ eV (C. Guepin Ph.D 2019)



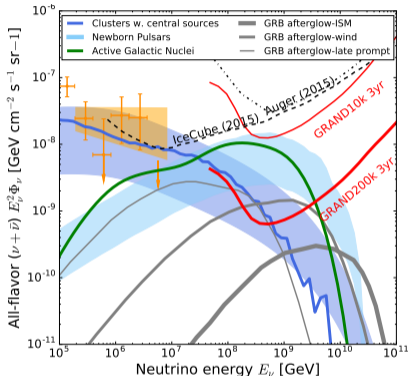
Guaranteed to detect UHE cosmogenic neutrino

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Astrophysical Point Source?

GRAND, *Sci. China Phys. Mech. Astron* (arXiv:1810.09994)



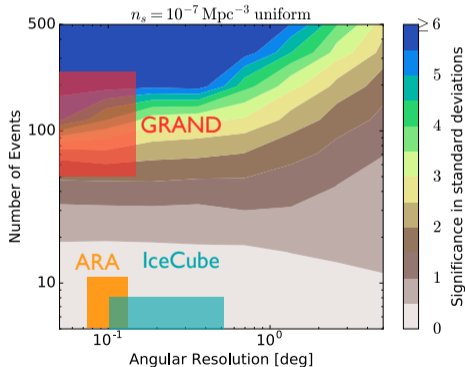
Possible to detect the first EeV neutrino ... with GRAND10k.

Possible to detect EeV neutrino source ... with GRAND200k.

Significance of point source detection

100s of UHE neutrinos in 3 years

~ 0.1° angular resolution



K. Fang et al., *JCAP* (arxiv:1609.08027)

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GRAND End-to-End Simulation Chain

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DANTON

$\nu \rightarrow \tau$ decay

backward MC over

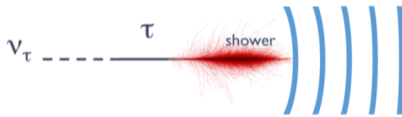
...realistic topography

GRAND, *Sci. China Phys.* (arxiv:1810.01978)

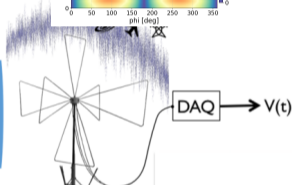
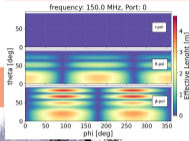
ZHAireS

CoREAS

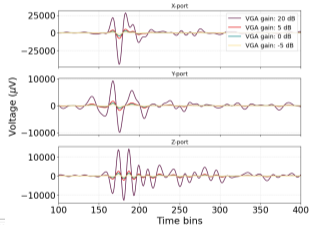
Radio Morphing



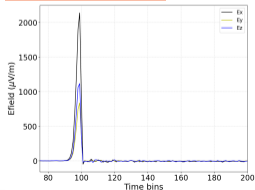
Antenna Response



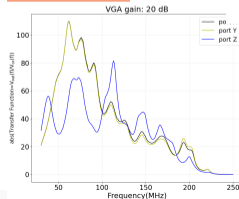
Output Voltage



Electric Field



RF Chain



Plots by Ramesh Koirala (GRANDlib)



GRANDlib - Software Package

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GRAND@Auger

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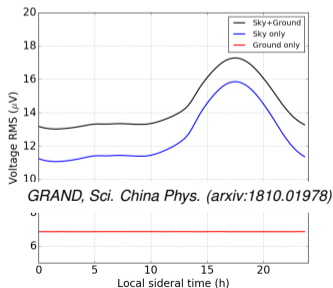
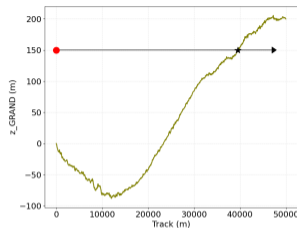
Summary

- python3 offline software package for the GRAND that runs on docker.
- Has classes to manage and analyze data.
- Computes voltage from an electric field.
- Deals with terrestrial coordinate systems, topography (TURTLE), and geomagnet (GULL).
- Deals with data input/output in ROOT files.
- Computes galactic noise (LFmap) and radio-frequency (RF) chain.

<https://github.com/grand-mother/grand>



Plot by Ramesh Koirala (GRANDlib)



GRAND Prototypes

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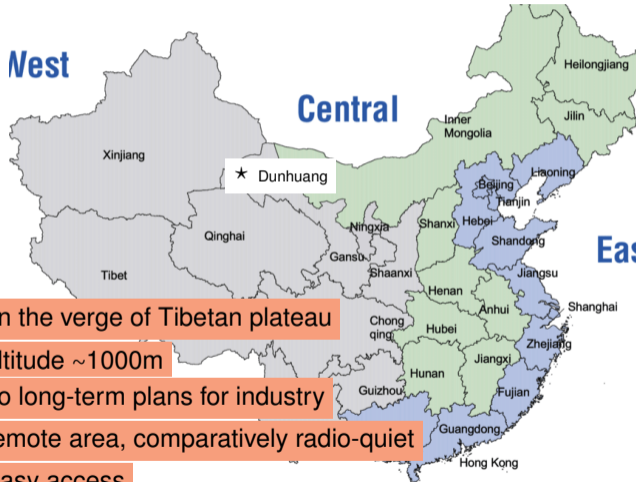
Summary

- There are 3 prototypes of GRAND currently being deployed.
 - GRANDProto300 (China, major): Pathfinder for GRAND10k
 - GRAND@Nancay (France, test): Testing hardware and trigger
 - GRAND@Auger (Argentina, test): Cross-calibration with Auger data

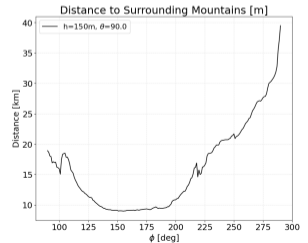
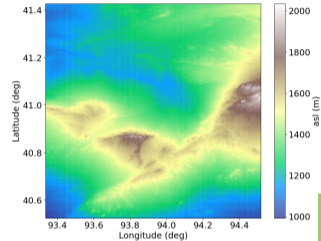


GRANDProto300 - Location

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Topography

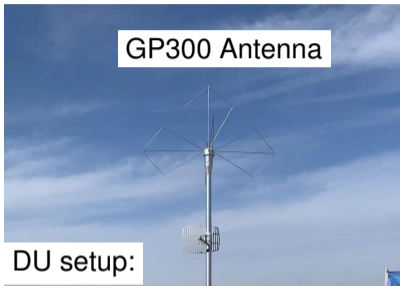


Plots by Ramesh Koirala (GRANDlib)



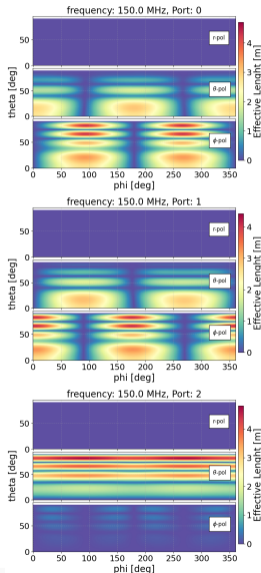
GRANDProto300 - Experimental Setup

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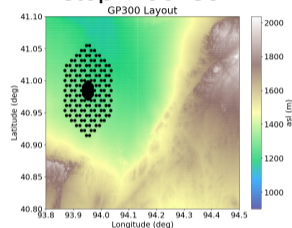


DU setup:

antenna, nut, 3.5m pole, DAQ,
wifi, solar panel, battery, etc



300 antennas, 200 km²
1km step + denser infill.



500 MSPS FPGA+CPU
Bullet wifi data transfer

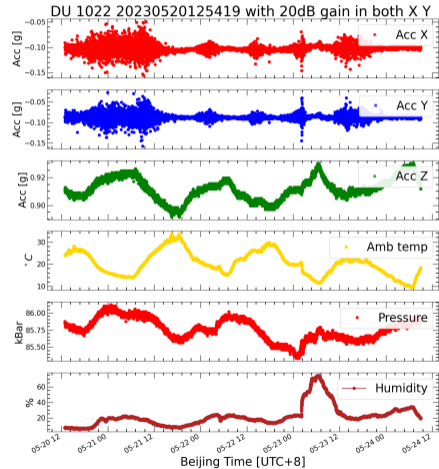


GRANDProto300 - Initial Performance

Plot by PengXiong Ma

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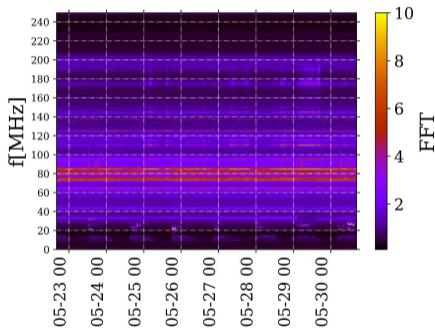
- 13 antennas (+1 reference antenna) deployed in Dunhuang, Gansu, China.
- Test bench for further GRAND stages.
- Test on the detection unit's performance is ongoing.
- Initial study confirms a reasonable performance.
- More work is required before full deployment.



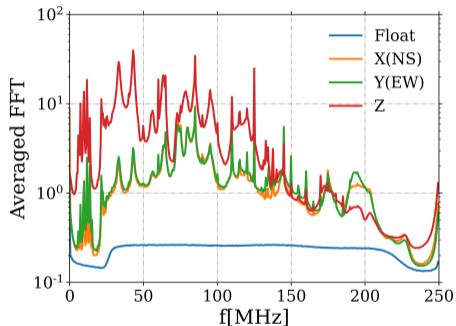
GRANDProto300 - Initial Performance

Plots by Xishui Tian

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Signals detected by DU35 over time



Time averaged signals detected by DU35



GRANDProto300 - Science Goals

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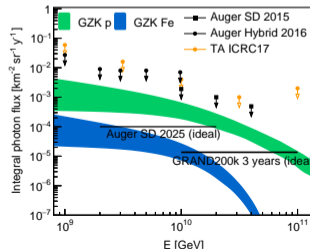
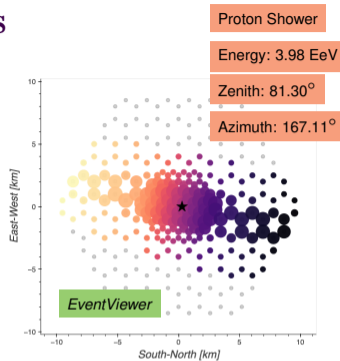
GRAND@Auger

GRAND@Nancay

Collaboration

Summary

- Test bench for GRAND10k.
- Autonomous radio detection of extensive air showers.
- Validation via comparison to known results.
- Galactic/Extra-galactic transition.
- Cosmic-ray physics (energy spectrum and composition, X_{\max} reconstruction, muon content in EAS, etc).
- Detect UHE gamma-rays.
- Detect transient sources like fast radio bursts.



arXiv:1810.09994



GRAND@Auger

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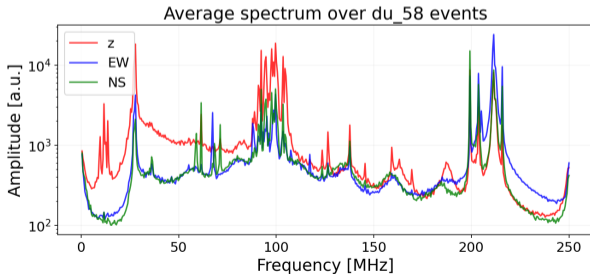
GRAND@Nancay

Collaboration

Summary

- Agreement to deploy 10 GRAND antennas in the site of Pierre Auger Observatory in Argentina.
- Goal is to perform an event-by-event comparison of the data with Auger.
- Four antennas already deployed. Testing at the Auger site is currently ongoing.

Plot by Beatriz de Errico



GRAND@Nancay

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GRAND@Nancay

Collaboration

Summary

- Four antennas were installed in 2022 at the Nancay Radio Observatory, France.
- The antennas were shipped to France from their production site in China.
- Joint effort of LPNHE, IAP (Paris), and KIT (Karlsruhe).
- These antennas are used for hardware and trigger tests.



GRAND Collaboration

Argentina

Belgium

Brazil

China (15)

Denmark

France (9)

Germany

Greece

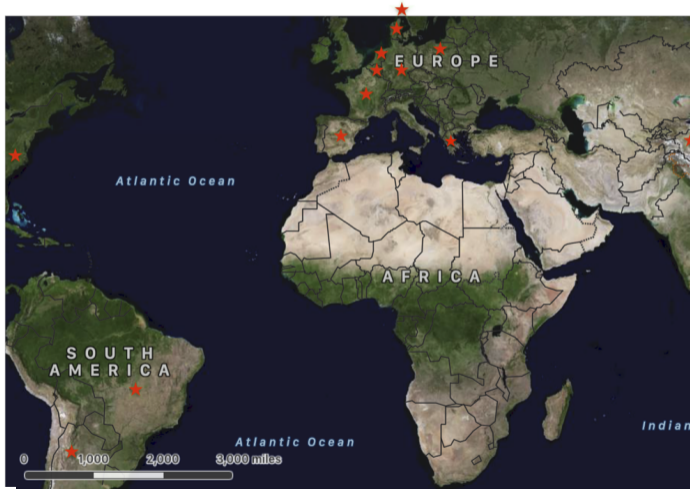
Netherlands

Norway

Poland

Spain

USA (6)



Asia
Europe
North America
South America
4 Continents

13 countries

and is growing ...

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GRAND Collaboration

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44 Institutions

95 Members

and is growing ...



极高能宇宙线和中微子射电探测研讨会



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GRAND@Auger

GRAND@Nancay

Collaboration

Summary

- GRAND is an international collaboration with members from 13 countries across 4 continents.
- First phase of GRANDProto300 is under construction and will be the pathfinder for GRAND10k.
- Calibration and testing with 13 antennas (+1 reference antenna) is currently ongoing.
- Deployment of more antennas for GRANDProto300 will soon follow.
- Two sites for GRAND10k are planned, one in each hemisphere for better sky coverage.
- Exciting time ahead!



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website: <http://grand.cnrs.fr>

white paper: <https://arxiv.org/abs/1810.09994>

Github: <https://github.com/grand-mother>

Join us and share your ideas!

Kumiko Kotera, IAP France (kotera@iap.fr)

Olivier Martineau, LPNHE France (martineau@lpnhe.in2p3.fr)

Xiang-Ping Wu, NAOC China (wxp@bao.ac.cn)

Ruoyu Liu, Nanjing University (ryliu@nju.edu.cn) → Postdoc position at NJU!!

Ramesh Koirala, Nanjing University (rkoirala@nju.edu.cn)

