Giant Radio Array for Neutrino Detection: Present and Perspectives

Ke Fang
UHEAP Workshop, Chicago, IL, Mar 1, 2016
Take-home messages
What is GRAND?

Giant Radio Array for Neutrino Detection

Let’s not be shy... and go for a GIANT array!
How do GRAND detect neutrinos?
Radio detection of horizontal extensive air showers of neutrino-induced tau decay

$\nu_\tau \rightarrow \tau$
Why do we need GRAND?
Current: non-detection of EeV neutrinos

Direct probe of the highest energy sources in the Universe!

Plot by M. Bustamante
Why do we need GRAND?
Future: sensitivity for pessimistic scenarios
+ statistics, statistics, statistics!

Plot by M. Bustamante
Why do we need GRAND?
Future: sensitivity for pessimistic scenarios + statistics, statistics, statistics!

Plot by M. Bustamante
Detector details
From Neutrino to Lepton

\[ \nu_\tau \rightarrow \tau \rightarrow \text{decay} \]

<table>
<thead>
<tr>
<th>Air</th>
<th>Rock</th>
<th>Air</th>
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<tbody>
<tr>
<td>( \nu_\tau )</td>
<td>CC</td>
<td>( \tau )</td>
</tr>
<tr>
<td>( \text{Rock depth} )</td>
<td>Flight distance</td>
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From Neutrino to Lepton

Conversion efficiency from neutrino to tau lepton decaying in the air

Prob. Distribution of flight distance

Grand ICRC 1508.01919
Extensive Air Shower

$\nu_\tau$
Extensive Air Shower

30-80MHz Efield computation
ZHAireS simulation code

$2 \times 10^{17}$ eV tau decay @ origin
Subsequent shower:
$E = 1.4 \times 10^{17}$ eV
$\theta = 89.5^\circ$

Shower axis
Atmosphere transparent to radio waves. Short waves prevent detection below 25MHz. Extension of antenna to 200-300MHz possible.

EAS radio detection: 30-100 MHz

- Sky noise level: rms 15μV/m
- Efield emitted by horizontal EAS still in detection range after 100 km

A large array of radio antennas well suited for neutrino-induced EAS!
Sensitivity Study

ν Propagation→τ Decay→EAS Development(→Radio Emission)

Ev = 1 EeV

Simulation array: 90,000 antennas over 60,000 km² with 800 m step size in Tianshan Mountain

Earth-skimming only: ±4° around the horizon

Antenna triggers if In direct view of shower + Inside a light cone of a few degrees (0.5–3°) + τ decay vertex is 14–120 km away

Showers detected if at least 8 antennas fired
Effective Area & Sensitivity

- Earth opaque for $>\pm 4^\circ$ around horizontal
- Mountains are sizable targets ($\sim 40\%$ of total)
GRAND field of view — at 1 EeV

3-year average:

Field Of View at 1 EeV

Figure by Foteini Oikonomou

Mauricio Bustamante (CCAPP OSU)
Angular Resolution

- Computed analytically for all detected showers following simulation by Ardouin et al. [1007.4359]
- Assumes 3 ns trigger timing precision
- High resolution due to extended trigger zone

Median = 0.02°
Mean = 0.05°
f(Δθ>1°) = 0.2%
... thanks to mountains!
Challenges
Background Rejection

Background radio signals of cosmic origin:
- **muons**: very unlikely due to longer decay time
- **atmospheric neutrinos**: none above 10 PeV
- **UHECRs**: 5-sigma cut by rejection > 1°

Terrestrial backgrounds: human activities, natural electric discharge in the air, thunderstorms etc: $10^{8.5}$ events/year requires rejection factor > $10^9$ → Major Challenge!
Background Rejection

EAS signatures:

• **Trigger pattern at ground** (started inside array + beamed emission with flat wavefront + reconstructed source below horizon)
• **Polarization pattern** (perpendicular both to geomagnetic field & direction of propagation of shower)
• **Cherenkov cone**
Science Objectives

- Discovery of cosmogenic neutrinos
- Testing Source Models
- Pinpoint Neutrino Sources
- UHECR detection
- Flavor composition at EeV
- New physics
- ......
Grande would be able to break the degeneracy!
Detecting A Source On Top of the Background

Pinpointing Neutrino Sources

\[
\bar{N} = 4.8 \times 10^{-3} \left( \frac{N_{\text{tot}}}{1000} \right) \left( \frac{(0.1^\circ)^2}{5\% \times 4\pi} \right)
\]

With 0.1 deg resolution, a doublet has a p-value $1 \times 10^{-5}$ to be from different sources $\Rightarrow$ 4.2 sigma detection

✓ Doublet events $\rightarrow$ Pinpointing the source!
✓ With $> 10^{-6}$ Mpc$^{-3}$ source number density, doublets are guaranteed with $\sim 1000$ events
Tentative timeline
GRAND tentative timeline

07/07: meeting with Wu XP
02/15: GRAND workshop

TREND: EAS autonomous radiodetection
GRANDproto: study of EAS bckgd rejection
GRAND: giant array for neutrinos

TREND15
TREND50 run
Data analysis
GRANDproto development
GRANDproto run
GRAND preliminar study
GRAND design study
GRAND engineering array
GRAND

O. MARTINEAU
TREND: TREND 50 (2011-2014)
TIANSHAN Radio Experiment for Neutrino Detection
Achieved autonomous EAS detection & identification with radio antennas
Experiment by NAOC, IHEP & V. Niess, O. Martineau

50 butterfly antennas, 1.5km²

TREND Pioneers @ Ulastai
GRANDproto

EXPLORATORY setup to investigate on the potential of polarization measurement for air shower identification

• Array fully funded by NAOC & IHEP.

• Hybrid setup: 35 3-polar antennas + 24 scintillators

• 6 antennas & 6 scintillators deployed in summer 2015 to test hardware, DAQ and reconstructions to be completed in summer 2016

• Radio array electronics developed at LPNHE, to be validated on site March 2016.

Scintillateur GRANDproto
Antenne 3D GRANDproto
Carte analogique GRANDproto (test été 2015)
Carte numérique GRANDproto (novembre 2015)
Giant radio array to detect cosmogenic neutrinos even in the most pessimistic case.

Possible timeline:

2016: GRANDproto + proposal

2018: engineering array of ~1000km²

2021: start building full array
GRAND team

France:
- Olivier Martineau-Huynh (LPNHE, CNRS-IN2P3, Universités Paris VI & VII)
- Kumiko Kotera (Institut d’Astrophysique de Paris)
- Didier Charrier (SUBATECH, CNRS-IN2P3, Université de Nantes)
- Valentin Niess (Clermont Université, Université Blaise Pascal, CNRS-IN2P3)
- Nicolas Renault-Tinacci (Institut d’Astrophysique de Paris)
- Julia Schmid (Laboratoire AIM, Université Paris Diderot/CEA-IRFU/CNRS)
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- Xiangping Wu (National Astronomical Observatory)
- Jianli Zhang (National Astronomical Observatory)
- Yi Zhang (Key Laboratory of Particle Astrophysics, Institute of High Energy Physics)

23 people
Expertise from TREND and theory

Join us!
GRAND sensitivity study – simulation

3 $10^{20}$ eV neutrino
2.4 $10^{20}$ eV shower
$\theta = 88^\circ$
2114 antennas triggered

3D view (shower referential)

Radio emission cone
(4.5° for $E > 30 \mu$V/m
@ $E_{sh} = 2.4 \times 10^{20}$ eV)

Top view (Earth referential)

Cut view (Earth referential)

Neutrino interaction

Longitudinal axis (km)

Northing [km]

Easting [km]

Lateral axis (km)

Vertical axis (km)

Antenna field
(trig’ed antennas)

Shower axis

Neutrino interaction

O. MARTINEAU

Slide by M. Bustamante