PROCEEDINGS OF SCIENCE

GRAND: A Giant Radio Array for Neutrino Detection*

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The detection of ultra-high-energy (UHE) neutrinos, with energy in excess of 10^8 GeV, is an important key to solving the mystery of the origin of UHE cosmic rays. The detection of UHE cosmogenic neutrinos will confirm the photo-dissociation of UHE cosmic rays and the identification of the sources of UHE neutrinos will help to identify the sources of UHE cosmic rays. The flux of these UHE neutrinos is expected to be low and their detection is a challenge. We present the Giant Radio Array for Neutrino Detection, GRAND, that is based on proven methods of radio frequency detection of extensive air-showers, which will allow for a huge exposure at a relatively modest price. On top of discovering UHE neutrinos, GRAND will be able to investigate many other science topics, including neutrino physics, UHE gamma-ray detection, UHE cosmic ray science with very large statistics, the detection of fast radio bursts and giant radio pulses, and a measurement of the epoch of re-ionisation. The R&D and different initial phases of development of GRAND, and the physics reach for these research topics will be discussed.

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*This paper reflects the GRAND status at the talk, the status at the time of writing can be found in [1]
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1. Science Case for a giant neutrino detector

Ultra-high-energy (UHE) cosmic rays, charged particles with an energy in excess of an EeV, still lead to many questions: Where are they produced, how are they produced, how do they propagate through the universe and why can't we properly describe their interactions in the atmosphere? Knowing the sources of UHE cosmic rays will address many of these questions. The most promising probes of the sources of UHE cosmic rays are neutral stable particles: photons and neutrinos. In the energy range of interest for UHE cosmic rays, the range of photons is mostly limited to about 10 Mpc.UHE neutrinos on the other hand may travel unimpeded from extremely far away. Two mechanisms of UHE neutrino production can be distinguished: production at *point sources* of UHE cosmic rays in hadronic interactions, via the decay of charged pions, or cosmogenic neutrinos produced by the decay of pions resulting from interaction of UHE cosmic rays with the cosmic photon background.

The rates for UHE neutrinos can be estimated by extrapolating the IceCube observation [2] assuming an E^{-2} spectrum, but it is uncertain where this spectrum will be cut off. Predictions of cosmogenic neutrinos are on firmer ground, but rates span more than one and a half order of magnitude due to the uncertainty in the particle type composition of the UHE cosmic rays. Nevertheless, a minimum sensitivity may be defined for cosmogenic neutrinos that guarantees an observation in all possible scenarios. Prediction for the UHE neutrino flux, a measurement of HE neutrinos and prediction for sensitivities for future experiments are plotted in Fig. 1.

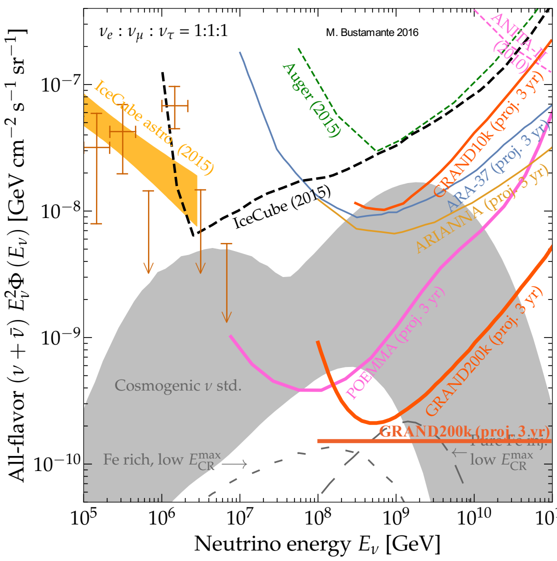

Figure 1: *Neutrino flux versus energy. Predicted cosmogenic neutrino flux is gray-shaded. IceCube measurement in yellow band and points. Dashed lines: 90% C.L. upper limits of IceCube (black), Auger (green) and ANITA (purple). Full lines: estimated 3-year sensitivities for ARA-37, ARIANNA, POEMMA, GRAND10k, and GRAND200k. References in [2, 3].*

The aim of Giant Radio Array for Neutrino Detection (GRAND) is to create am observatory with a sensitivity to always measure some UHE neutrinos. The number and energy spectrum of the detected events will allow to distinguish between different UHE cosmic ray particle type scenarios and the angular distribution will reveal the point sources, if there are any. When point sources are identified it will be much easier to relate observed UHE cosmic rays to these sources especially for ultra-high-rigidity cosmic rays. This will enable to better estimate the cosmic magnetic fields and in turn to relate lower rigidity cosmic rays also to these sources.

2. Ultra-High-Energy Neutrino Detection

The neutrino cross section with matter increases with the neutrino energy and for UHE neutrino this cross section reaches the several nanobarn level. While this leaves the Universe still transparent to these neutrinos, it corresponds to a considerable conversion probability from a neutrino to a charged lepton when skimming the Earth's surface, as shown in Fig. 2. Given that some

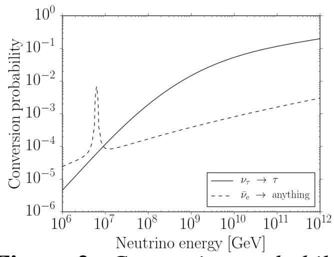

Figure 2: *Conversion probability for neutrinos that skim the Earth's surface with the lepton emerging at 1° elevation as a function of energy [4].*

km of rock is a good target and the practically uniform interaction probability along the depth of the target, a conversion into an electron nearly always leaves so much rock in the way that the electromagnetic shower is being fully absorbed. Conversion into a muon may will likely cause the muon to escape the rock, but it is subsequently hard to detect it efficiently. If a neutrino converts into a tau lepton, the tau lepton will traverse many km of rock without leaving much more than a minimum ionising trace. However, after about 10^{-12} s the tau will decay, which is typically after tens of km in the relevant range. The tau will decay for about 70% hadronically and start an extensive air shower in the atmosphere, which can be detected.

In the GRAND proposal, the horizontal showers are detected by the radio frequency radiation they emit in the 30 MHz to 200 MHz. This beamed signal travels unhindered through the atmosphere and is detectable by radio detector stations at large distances from the air shower. The principle of detection is schematically shown in Fig. 3. Detection of horizontal air shower with the radio detection technique has been demonstrated in [5]. In GRAND, the optimal distance between the antenna stations will be about 1 km. Given the optimal sensitivity in an area with high mountains, the detector will be split in about 20 hot spots in several mountain areas, each with a size of about 10 000 km^2.

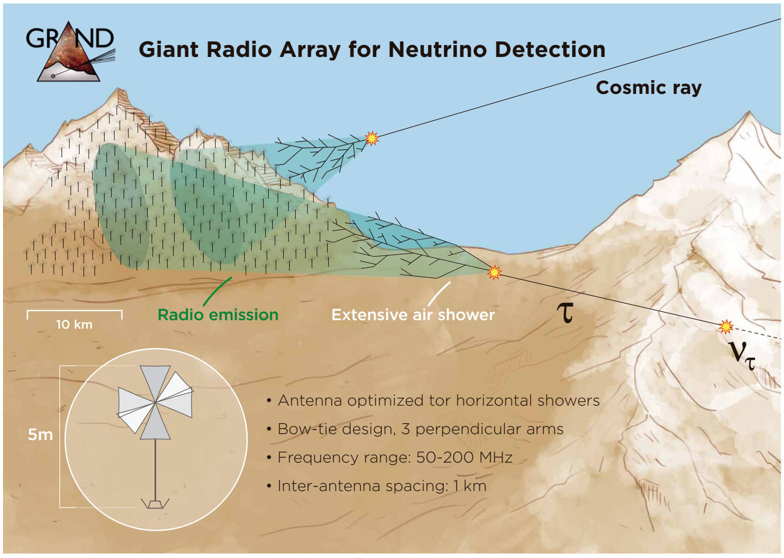

Figure 3: *GRAND detection principle.*

3. GRAND Science

The sensitivity of a 10 000 km^2 GRAND hot spot on a realistic location has been simulated in detail. The full GRAND observatory with 200 000 km^2 has been extrapolated from the results of this hot spot. The sensitivity curves that are obtained are plotted in Fig. 1, showing that indeed with such an array in three years time the lowest estimated UHE neutrino flux is accessible.

The detection of UHE neutrinos will allow for studies of their sources, but also particle physics research, such as cross section measurements at ultra-high-energy, where searches can be done for new physics. In addition to UHE neutrino detection, GRAND offers a wide palette of science opportunities, collecting about 6400 cosmic rays with $E > 10^{10.5}$ GeV, allowing proton astronomy, even with a small proton fraction at UHE. Sensitivity to UHE photons opens the possibility to look for UHE axions in the universe that may convert in the omnipresent magnetic fields into UHE photons. When detecting UHE photons the Landau-Pomeranchuk-Migdal effect can be studied for the first time. Besides particle detection a large radio array such as GRAND can also be used for the detection of fast radio bursts and giant radio pulses and for detecting the red-shifted 21 cm line, where the epoch of re-ionisation may be observed.

4. GRAND: Summary and Timeline

The proposed GRAND observatory consists of several arrays of radio frequency detectors for extensive air showers, in total covering an area of 200 000 km^2. It will address the enigmas of the UHE cosmic rays by detecting UHE neutrinos and it will do neutrino physics in an energy regime that cannot accessed at present. In addition, GRAND will be a very versatile multi-messenger observatory, able to detect heavy nuclei, protons, photons neutrinos, and who knows will be able to detect new particles beyond the Standard Model. GRAND also provides bonuses in cosmology and astronomy with the possibility to detect fast radio bursts, giant radio pulses and the dip in the red-shifted 21 cm line due to the epoch or re-ionisation.

In 2018 a 35 radio, 21 scintillator detector station test array GRANDProto35 is being deployed in Ulustai, China. The prototype array GRANDProto300, with 300 autonomous radio detector stations covering 300 km^2 has been funded and will be deployed in 2020 in China at a location that is presently being selected. The next step for a 10 000 radio detector station array, GRAND 10k, the first of about 20m hot spots, is planned for deployment in 2025. The aim for that array is to produce the radio detector stations for 1500 € per unit. The full observatory covering about 20 hot spots is planned to become operational in stages and to be completed in the mid-2030s.

References

[1] J. Àlvarez-Muñiz *at al.*, *Giant Radio Array for Neutrino Detection: Science and Design*, arXiv:1810.09994.

[2] M.G. Aartsen *et al.* (IceCube Collab.), *A combined maximum-likelihood analysis of the high-energy astrophysical neutrino flux measured with IceCube*, Astrophys.J. 809 (2015) 98;

[3] K. Kotera, D. Allard, A.V. Olinto, *Cosmogenic Neutrinos: parameter space and detectabilty from PeV to ZeV*, JCAP 1010 (2010) 013; M.G. Aartsen *et al.* (IceCube Collab.), *Constraints on Ultrahigh-Energy Cosmic-Ray Sources from a Search for Neutrinos above 10 PeV with IceCube*, Phys. Rev. Lett. 117 (2016) 241101 and Phys. Rev. Lett. 119 (2017) 259902 (Erratum); A. Aab, *et al.* (Pierre Auger Collab.), *Improved limit to the diffuse flux of ultrahigh energy neutrinos from the Pierre Auger Observatory*, Phys. Rev. D91 (2015) 092008; P.W. Gorham, *et al.*, *Observational Constraints on the Ultra-high Energy Cosmic Neutrino Flux from the Second Flight of the ANITA Experiment, Phys. Rev. D82 (2010) 022004 and Phys. Rev. D85 (2012) 049901 (Erratum); P. Allison ém et al.,* Design and Initial Performance of the Askaryan Radio Array Prototype EeV Neutrino Detector at the South Pole, Astropart. Phys. 35 (2012) 457; PS.W. Barwick ém et al., *A First Search for Cosmogenic Neutrinos with the ARIANNA Hexagonal Radio Array*, Astropart. Phys. 70 (2015) 12; A. Neronov, D.V. Semikoz, L.A. Anchordoqui, J. Adams, A.V. Olinto, *Sensitivity of a proposed space-based Cherenkov astrophysical-neutrino telescope*, Phys. Rev. D95 (2017) 023004.

[4] Figure prepared by Valentin Niess, using NuTauSim, described in: J. Alvarez-Muñiz, W. R. Carvalho Jr, K. Payet, A. Romero-Wolf, H. Schoorlemmer, E. Zas, *A Comprehensive Approach to Tau-Lepton Production by High-Energy Tau Neutrinos Propagating Through Earth*, Phys. Rev. D97 (2018) 023021.

[5] A. Aab *et al.*, *Observation of inclined EeV air showers with the radio detector of the Pierre Auger Observatory*, JCAP10 (2018) 026.