Section I. A. Cosmogenic Neutrinos in GRAND

- Unchartered territory and maybe top-selling argument of GRAND
- **Good**: cosmogenic neutrinos are guaranteed,
  and GRAND is the only experiment to guarantee its detection (down to most pessimistic)
- **Bad?**: large range of possible fluxes according to unknown UHECR source parameters
  so difficult to make a robust case? (for discovery or astronomy)

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A. Cosmogenic neutrinos in GRAND

Coordinators: MB, KK

The propagation of UHECRs in the intergalactic medium leads inevitably to the production of so-called *cosmogenic* neutrinos by photo-hadronic interactions on the cosmic radiation backgrounds. It depends mostly on parameters inherent to cosmic rays themselves that can be in principle observed (namely their chemical composition and overall flux), but also on the cosmic-ray injection spectral index and maximum acceleration energy at the source, and the source emissivity evolution history for diffuse fluxes.

1. Diffuse cosmogenic neutrino fluxes

The expected diffuse cosmogenic neutrino flux, *i.e.* integrated over the entire population of sources, can be calculated by requiring a fit to the observed total UHECR spectrum. Figure 1 summarizes the effects on this flux of different assumptions on the parameters listed above (Kotera *et al.*, 2010). It demonstrates that the parameter space is currently poorly constrained with uncertainties of several orders of magnitude in the predicted flux. There is however a guaranteed minimum flux, which corresponds to the case where UHECRs are composed of heavy nuclei, with low maximum cosmic-ray acceleration energies (typically $E_{Z,\rm max} < Z \times 100\,$EeV, with Z the charge number of nuclei), and no source evolution (gray dashed lines). Note that the largest spreads on the flux levels are due to the source emissivity history and the maximum cosmic-ray acceleration energies. In all scenarios, a prominent bump is present at energies $E_\nu \gtrsim 10^{17}\,$eV, that results from the photo-hadronic interactions of the highest energy cosmic rays with the cosmic microwave background.

The gray shaded region in Figure 1 corresponds to neutrino fluxes obtained for 'standard' parameters of UHECR models, that enable to fit the UHECR spectrum observed by the Auger Observatory and the Telescope Array. It includes UHECR models with pure proton, mixed (based on Galactic cosmic-ray abundances), and iron-rich (with 30% iron abundances) compositions, with maximum acceleration energies that range from $E_{Z,\rm max} \sim Z \times (10-300)\,$EeV. For $E_{Z,\rm max} \sim Z \times 10\,$EeV, mixed and iron-rich scenarios implies a proton-dominated composition below 10 EeV and an increasingly heavier composition above, possibly mimicking the composition measurements from Auger, depending on the spectral index assumed for the injection at the sources. In this 'realistic' range, source evolution models roughly follow the star formation history up to $z \sim 2$, beyond which the contribution of sources to the flux becomes mostly negligible.

The projected number of events in the EeV range for the 'standard' scenarios is of order with $0.6-2$ **[to calculate]** neutrinos per year for ARA/ARIANNA (Allison *et al.*, 2012; Barwick, 2011) and $50-500$ **[to calculate]** neutrinos per year for GRAND.

The sensitivity of GRAND reaches the lowest predicted limits: either a large number of cosmogenic neutrinos will be detected, under 'standard' assumptions on sources, or extremely severe constraints will be derived for the most pessimistic scenarios. The detection of a diffuse cosmogenic neutrino flux in the 'standard' range should thus allow the measurement of the cut-off energy in the spectrum, that would drastically constrain the maximum acceleration energy of cosmic rays at the source, leading to precious information on its nature and on the acceleration mechanisms at play. If an energy resolution of order *****% [recall ancient notes by Ke on spectra discrimination, maybe include her figures somewhere in the WP?]** over the energy span of GRAND ($\sim 10^{16}-3\times10^{20}$ eV) can be achieved to measure accurately the UHE cosmogenic neutrino peak energy, it will be possible to overcome most degeneracies in parameters and constrain the major cosmic-ray injection and source properties. If EeV neutrinos are detected, PeV neutrino information can also help select between competing models of UHECRs.

2. Cosmogenic fluxes from single sources

For single sources, (Decerprit and Allard, 2011) showed that the cosmogenic neutrino flux could be within reach of IceCube for powerful steady sources (see also (Essey *et al.*, 2010)) **[give precise numbers here for fluxes, luminosities, distances, and what it implies for GRAND, also given that because of the great angular resolution, these won't be point sources!]**. Only beamed sources (i.e., blazars) seem to satisfy the required luminosity condition to be observed by current instruments (otherwise, the required power exceeds the Eddington power), but the neutrino flux is then diluted by the deflection of cosmic rays (Murase *et al.*, 2011). In the case of transient sources, the total received flux should be diluted by the ratio of the emission time to the spread in the arrival times due to the magnetic fields, $\Delta t_s/\Sigma_t$, which could lower the flux of many orders of magnitude, preventing any detection.

References

Allison, P., J. Auffenberg, R. Bard, J. Beatty, D. Besson, *et al.*, 2012, Astropart.Phys. **35**, 457.

Barwick, S., 2011, International Cosmic Ray Conference **4**, 238.

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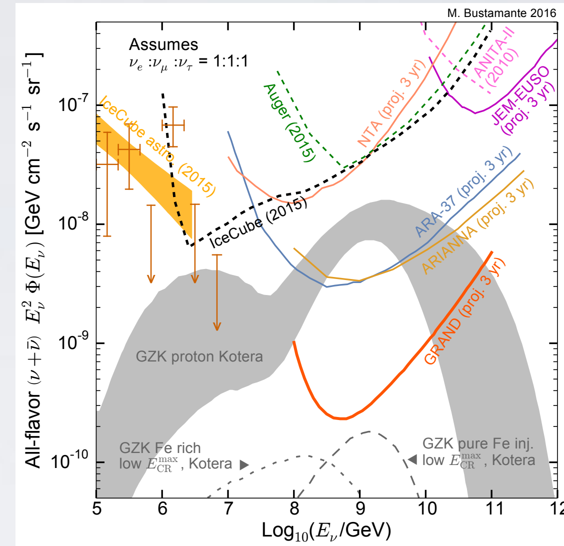

FIG. 1 **[plot to be updated]** Cosmogenic neutrino flux for all flavors, for different UHECR parameters compared to instrument sensitivities. Gray dashed lines: most pessimistic scenarios with no source evolution with: iron-rich (30%) composition and $E_{Z,\rm max} < Z$ 10 EeV (dotted line) and pure iron injection and $E_{Z,\rm max} = Z$ 100 EeV (solid), with Z the charge number of nuclei. Gray shaded range brackets all 'standard' parameters of UHECR models, that enable to fit the UHECR spectrum observed by the Auger Observatory and the Telescope Array, including pure proton, mixed (based on Galactic cosmic-ray abundances), and iron-rich (30%) compositions, with maximum acceleration energies that range from $E_{Z,\rm max} \sim Z \times (10-300)$ EeV. **[to be updated by Mauricio] Current experimental limits (solid lines) assume 90% confidence level and full mixing neutrino oscillation. The differential limit are presented for ANITA-II (green, ?) and Auger (red, ?), as well as the flux of neutrinos detected by IceCube (?). For future instruments, we present the projected instrument sensitivities (dashed lines) JEM-EUSO (?), ARA-37 for 3 years (Allison *et al.*, 2012), GRAND for 3 years.**

Murase, K., C. D. Dermer, H. Takami, and G. Migliori, 2011, ArXiv e-prints eprint 1107.5576.

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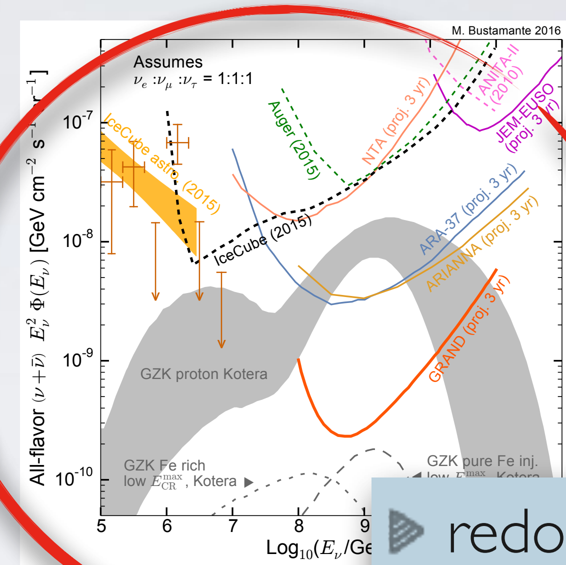

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▶ redo the figure, include Auger-compatible flux

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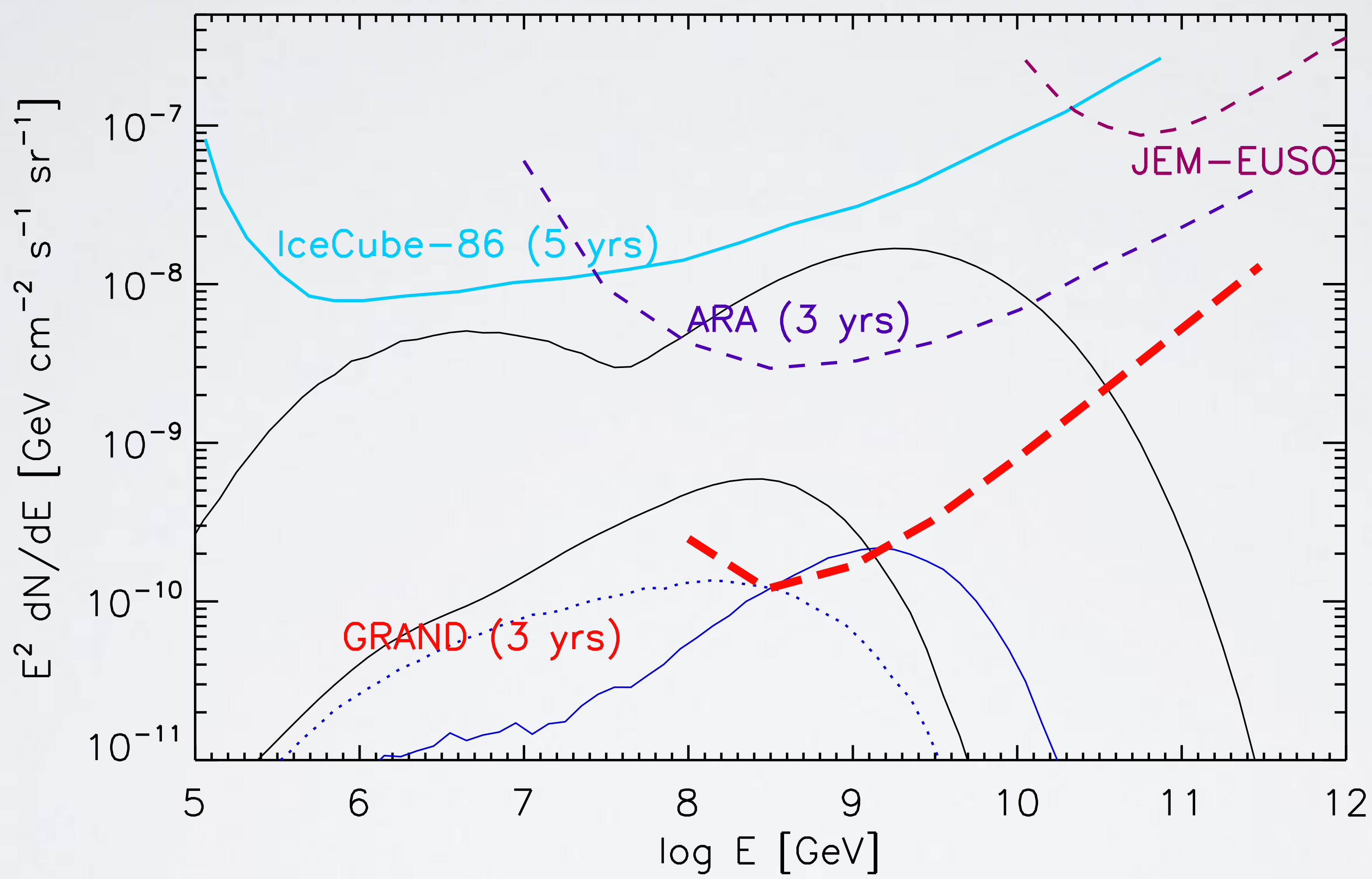
Expected flux of cosmogenic neutrinos - the allowed and "reasonable" ranges

- Parameters compatible with Auger observed composition (low proton max. energy) imply large range of uncertainties…



- A more precise calculation needed for Auger-compatible nu-flux
  Rafael Alves Batista will have results on Thursday

- How to turn this in the White Paper?

Computing expected numbers for these scenarios

- After Thursday (Rafael) + with input from sensitivity (updates?) calculate number of events expected
  Should be ready by Thursday PM/Friday AM

Spectral shape discrimination

- Not just for cosmogenic neutrinos but also applicable to nus directly from sources

- Preliminary work by Ke Fang

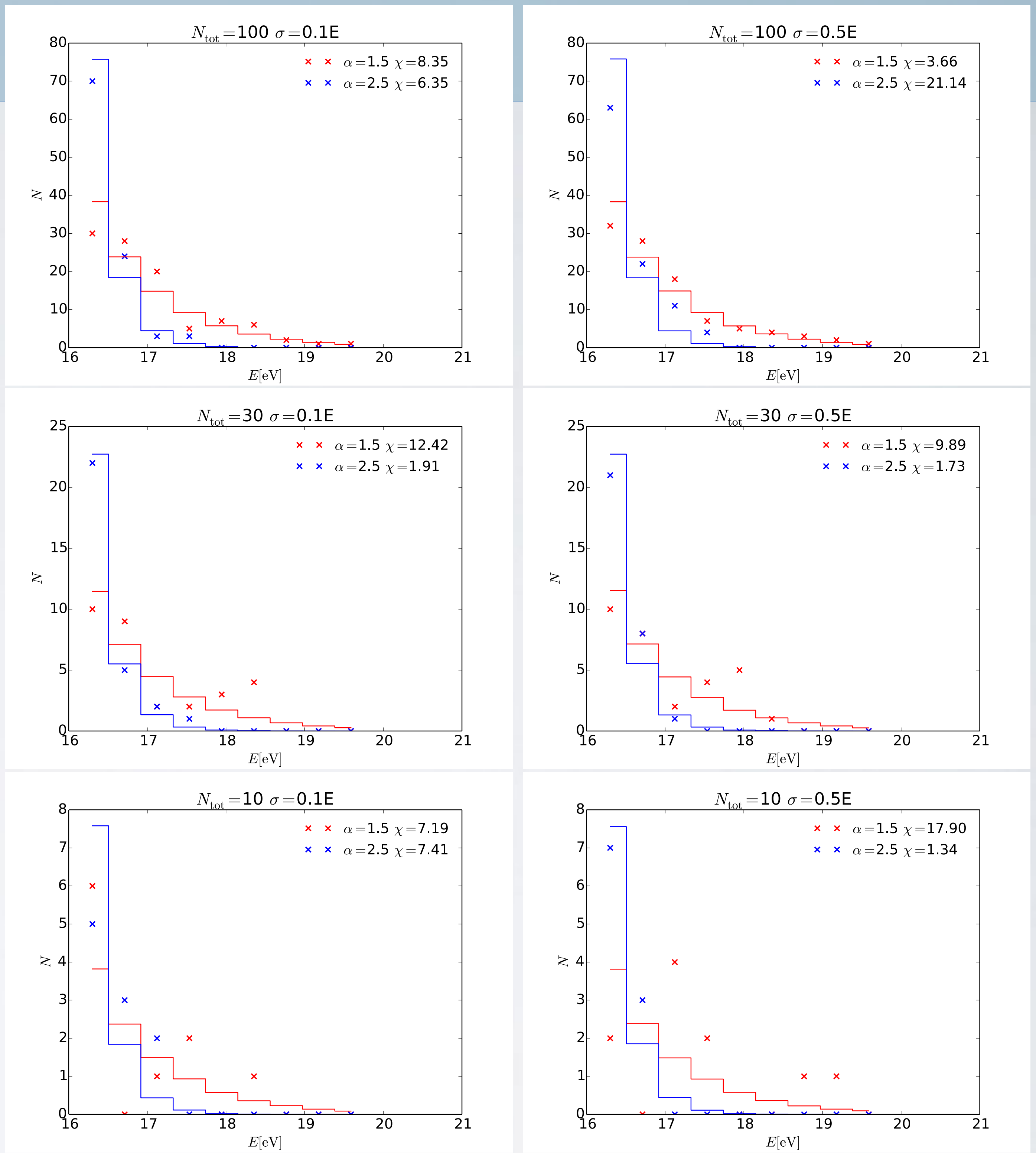


Figure 1: N events injected with $E_{\rm min} = 2 \times 10^{16}$ eV and $E_{\rm max} = 10^{20}$ eV following a power law spectrum $dN/dE \propto E^{-\alpha}$. For each event, the energy E is smoothed by a Gaussian distribution with a width of σ. The solid lines correspond to theoretical expectations and the markers are generated randomly.

- **Start discussion, but longer term work (maybe some hints in the WP)**

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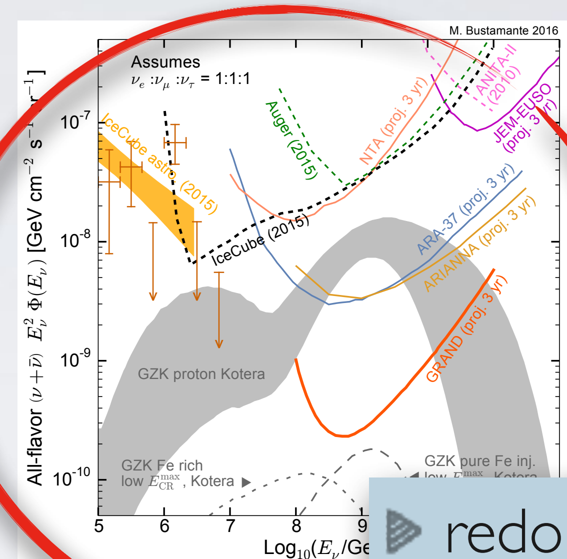

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