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Improved limits on cosmogenic fluxes from Ultra-High Energy Cosmic Rays

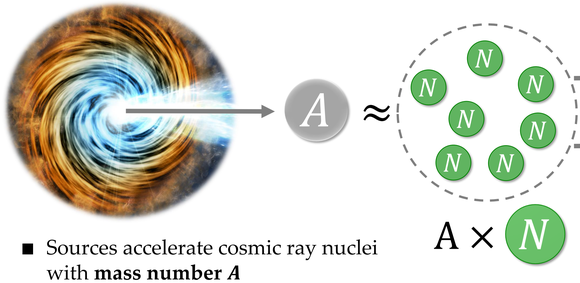
VILLUM FONDEN

Abstract

- The sources of Ultra-High Energy Cosmic Rays (UHE CRs) are **still unknown** – observations of cosmogenic neutrinos and γ-rays would allow us to tests models for UHE CRs
- For next-generation neutrino/CR detectors, we want **lower limits** on the cosmogenic fluxes of neutrinos and γ-rays consistent with the observed UHE CR spectra and composition [1]
- We show that next-generation neutrino/CR experiments are **capable of observing EeV cosmogenic neutrinos** if the observed proton contribution is **above 2-10%**
- Our flux predictions can be considered as **lower limits of the cosmogenic emission**, that **only depend on the observed average mass** composition above $E_{\rm GZK} \simeq 50$ EeV

UHE CR spectrum from source to observation

Source



- Sources accelerate cosmic ray nuclei with **mass number *A***
- We consider UHE CRs with $E_{\rm CR} \gtrsim A \times 50$ EeV

What if we consider the UHE CRs as a **nucleon spectrum**, e.g. A individual nucleons instead of 1 nucleus?

Pion production

- UHE CRs above $E_{\rm GZK}$ interact with Cosmic Microwave Background photons via delta resonance
- Produces cosmogenic neutrinos and γ-rays in the EeV energy range

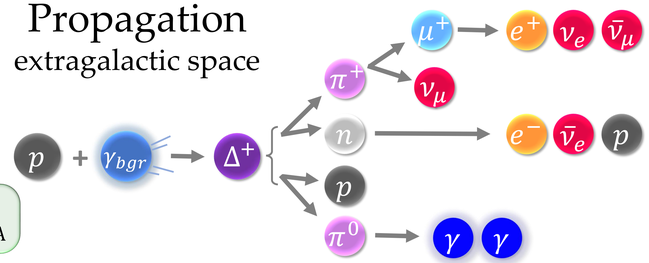
Works for nucleon spectrum: as scattering of A nucleons with $E = E_{\rm CR}/{\rm A}$

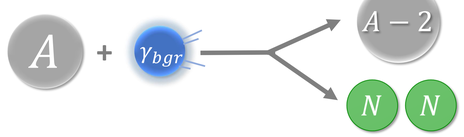
Photodisintegration

- UHE CRs photo-dissociated via the Giant Dipole Resonance → lead to nucleon losses

Works for nucleon spectrum: Conserves the energy per nucleon

Propagation
extragalactic space

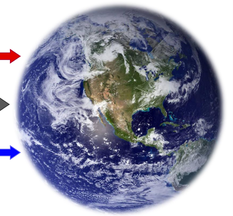




Flux observations

- Hence for the fluxes that reach Earth, neutrino and γ-ray energy in the EeV range will only depend on nucleon energy

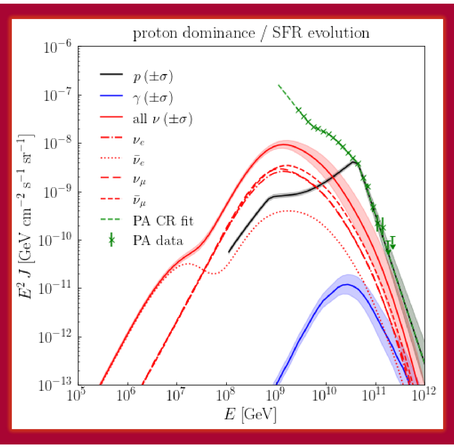
We can treat the UHE CR emission spectrum as a **nucleon spectrum**



- We can estimate UHE CR nucleon spectrum from Pierre Auger data [3]:

$$J_{\rm N}(E_{\rm N}) \simeq A_{\rm o}^{2-\gamma} J_{\rm CR}(50\ {\rm EeV}) \left(\frac{E_{\rm N}}{50\ {\rm EeV}}\right)^{-\gamma}$$

Cosmogenic fluxes



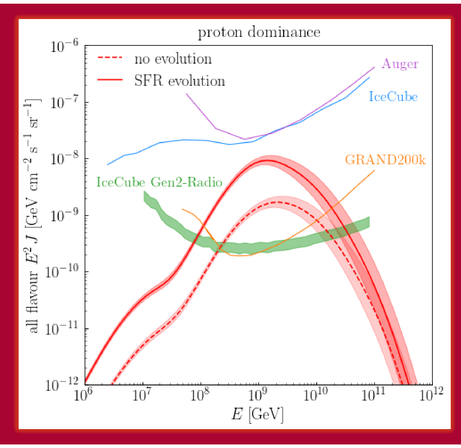
- We use CRPropa3 [2] Monte Carlo propagation simulation and **fit the observed UHE CR nucleon spectrum** to recent observations of UHE CRs above 50 EeV from the Pierre Auger Collab. [3]
- We get the resulting **cosmogenic neutrinos and γ-rays**, with the γ-rays attenuated by the CMB
- We use either **no source evolution** or **Star-Formation Rate** (SFR) redshift evolution [4]:

$$\mathcal{H}_{SFR}(z) \propto \begin{cases} (1+z)^{3.4} & z < 1, \\ (1+z)^{-0.3} & 1 < z < 4 \end{cases}$$

- We get cosmogenic fluxes **factor 5 higher** for SFR evol.

Minimal flux prediction

- We get cosmogenic neutrino flux predictions that **only depend** on the observed average **mass composition** above 50 EeV:
  - ***Minimal* fluxes** since extending UHE CR emission spectrum to lower energies will increase fluxes
- Depends strongly on mass composition of UHE CRs above 50 EeV:
  - Limits **scale as $J \propto A_o^{-3.2}$** for heavier nuclei spectrum
- Observatories [5, 6] are **capable of detecting** cosmogenic neutrinos if the observed contribution of protons is **2% ("SFR evolution")** or **10% ("no evolution")**



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[3] A. Aab et al., (Pierre Auger Collab.), Phys. Rev. Lett. 125 no. 12, (2020) 121106, arXiv:2008.06488
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[5] M. G. Aartsen et al., (IceCube-Gen2 Collab.), J. Phys. G 48 no. 6, (2021) 060501, arXiv:2008.04323
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[7] M. G. Aartsen et al., (IceCube Collab.), Phys. Rev. D 98 no. 6, (2018) 062003, arXiv:1807.01820
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