Cosmic Neutrino Detection from the International Space Station

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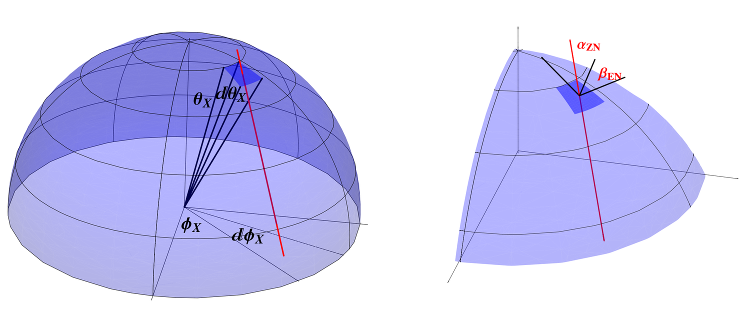
Space Based Observatories and Upgoing Extensive Air Showers

- UHECR detectors will soon be operational onboard the International Space Station (ISS). Space-based observatories (aside from detecting EAS) will be able detect up going showers generated by the decay of τ leptons produced in CC interactions of ν_τ with the Earth's crust.
- Each charged particle of the shower has ability to emit Cherenkov light if $\beta^{-2} < \epsilon(\omega, h)$ is satisfied, where β is the velocity of the particle in natural units, ω is the wavelength of Cherenkov light, h is the altitude of the light emitting particle, and ϵ is the dielectric constant of the atmosphere.
- How many of these τ initialed events would be potentially be recordable per year?

Simple Calculation of EAS from Upgoing τ

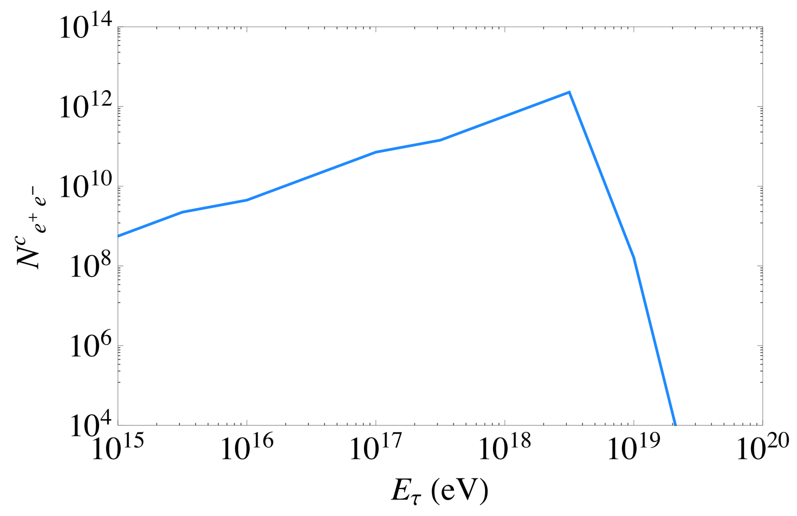
- Assume uniform density spherical Earth. Generate τ exiting surface with $(E_\tau, E_\tau + dE_\tau)$ at coordinates $(\theta_X, \theta_X + d\theta_X)$ and $(\phi_X, \phi_X + d\phi_X)$, see Fig. 1
  τ exits Earth in some direction specified by local spherical coordinates $(\alpha_{ZE}, \beta_{EN})$, see Fig 1.

Fig. 1: τ Exits Earth Along Red Line Path



- EAS development modeled using simplistic Heitler model [1], which may overestimate signal.
- Figure 2 shows maximum number of charged particles (per shower) that can emit Cherenkov light in atmosphere.

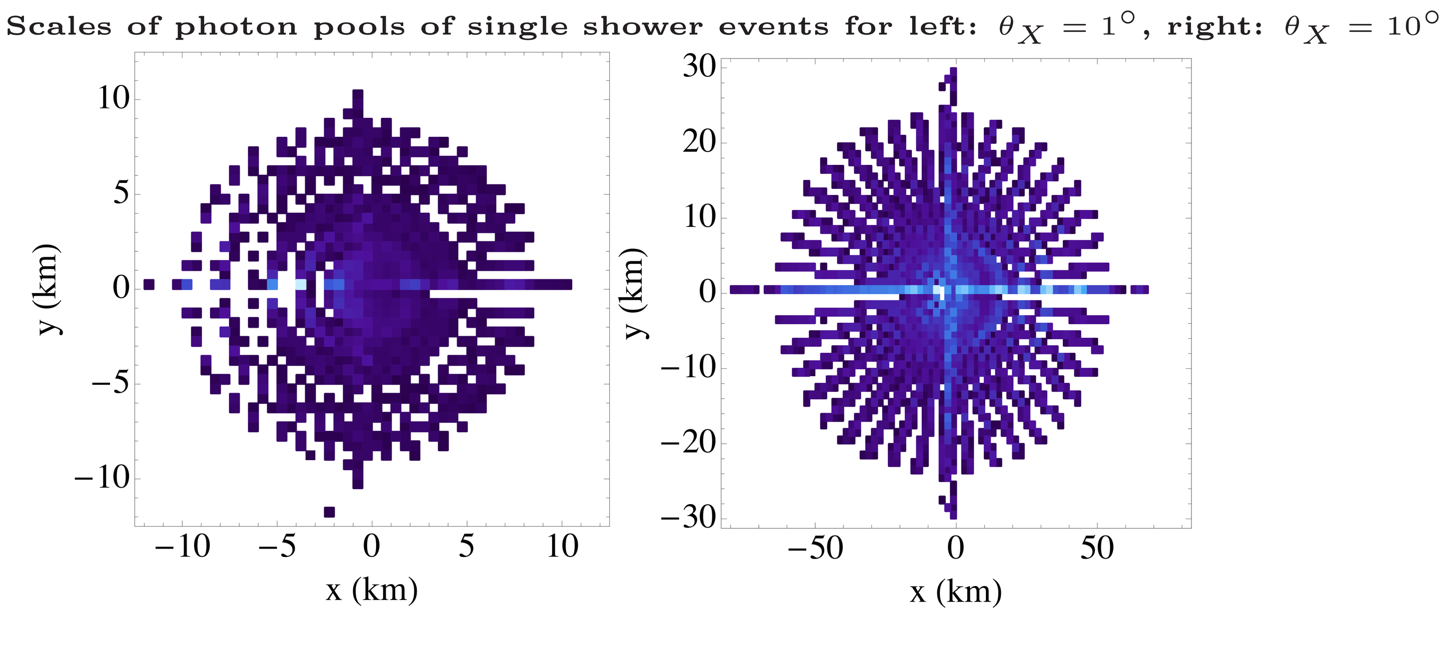
Fig. 2, Number of charged particles that emit Cherenkov light vs. τ energy



Cherenkov Light at Aperture Calculation

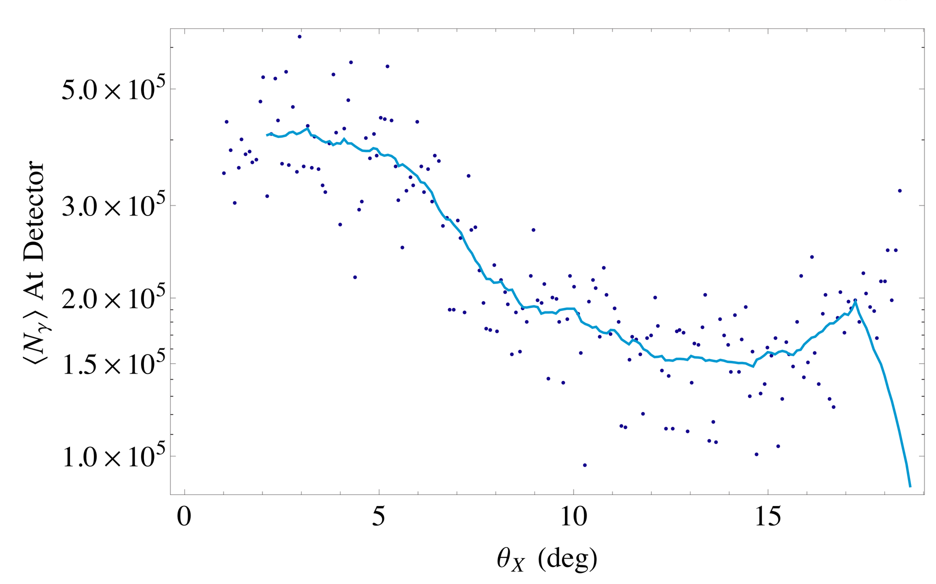
- Generate 25 different initial tau directions at exit point on Earth surface (θ_X, ϕ_X) to sample space $(\alpha_0, \alpha_0 \pm 1.45^\circ)$ and $(\beta_0, \beta_0 \pm 1.45^\circ)$, with (α_0, β_0) local coordinates of ISS direction and1.4° is maximum Cherenkov opening angle.
- After Δt, light reaches ISS altitude ($h \approx 400$ km).
  Fit Cherenkov rings (radius $= c\Delta t \sin\theta_c$) to ellipse.
  Consider reduction of photon density as Chernekov ring has expanded $\rho_\gamma = \rho^0_\gamma / 2\pi c \Delta t \sin(\theta_c)$, where ρ^0_γ is the initial photon density of the ring, with an opening angle θ_c.
- Photon bath has a scale of $10 - 100$ km depending on Earth exit location.
  Figure 3 displays representative photon distribution at ISS altitude.
  Detector aperture is taken to be circle of 1 m radius.

Fig. 3, Scales of photon pools of single shower events for left: $\theta_X = 1^\circ$, right: $\theta_X = 10^\circ$



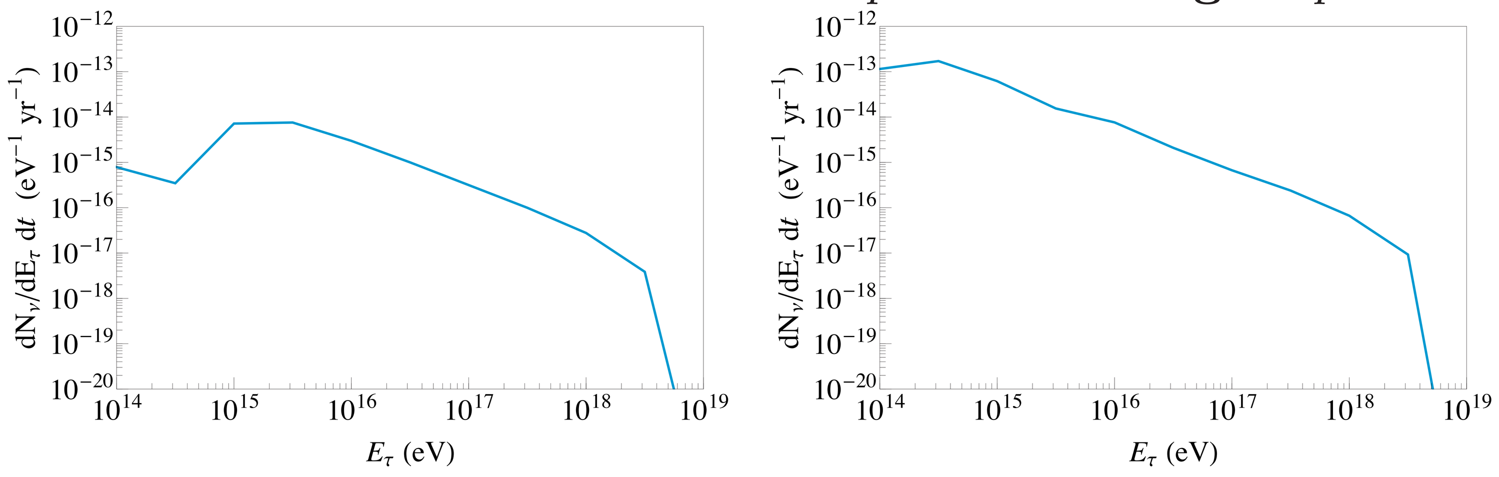
- Figure 4 shows representative count of photons for aperture at $E_\tau = 10^{15}$ eV

Fig. 4, Average number of photons across the aperture vs. θ_X, for $E_\tau = 10^{15}$ eV



Event Rate for Detectablity of Upgoing Showers

Differential τ Event Rate for left: $p = 2.3$ and right: $p = 2.15$



$p = 2.3 \;\rightarrow 9.28$ **Events/year :** $p = 2.15 \;\rightarrow 26$ **Events/year**

Event Rate Calculation

- For triggering shower we set threshold $N_\gamma = 400$ photons per GTU per pixel across entire E_ν. Trigger requires coincident detection at two telescopes separated by ISS length.
- Assume isotropic cosmic neutrino flux

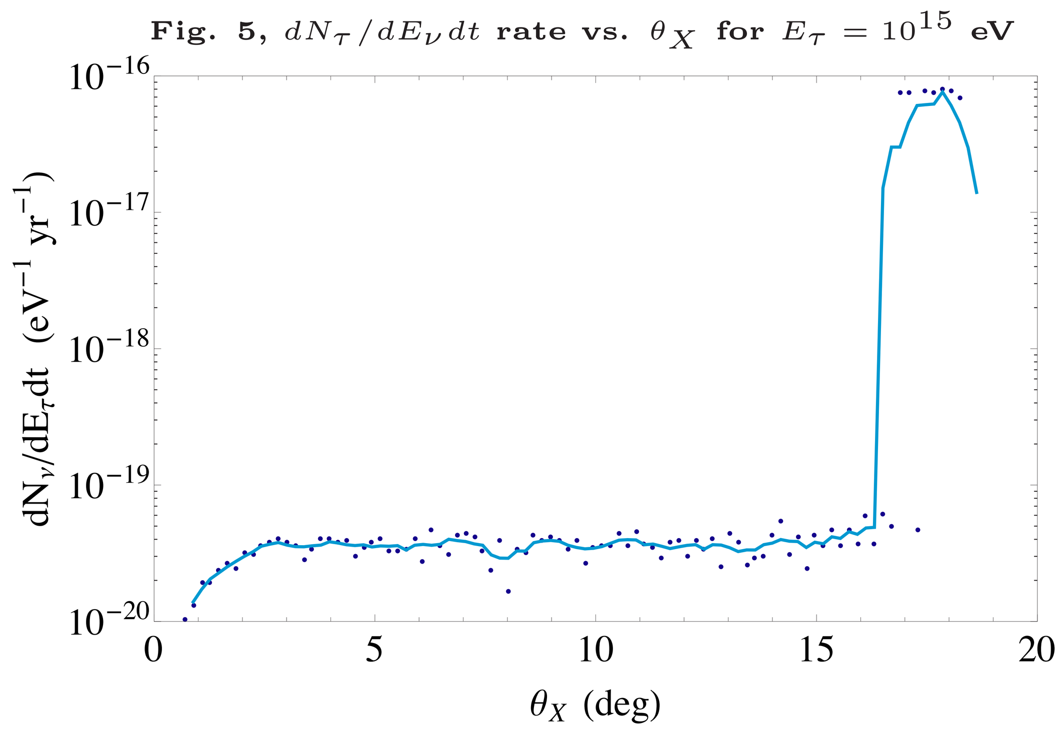
$$\frac{dN_\nu}{dE_\nu \, d\Omega_{\rm source} \, dA \, dt} = \Phi E_\nu^{-p} \tag{1}$$

  using unbroken power-law $p = 2.3$, $\phi = 2.0 \times 10^{-6}$ GeV cm^{-2} s^{-1} sr^{-1} [2] and LW [3] flux $p = 2.15$ with $\Phi = 10^{-7}$GeV cm^{-2} s^{-1} sr^{-1} steepening to $p = -3.75$ at 3 PeV [4].
- For showers above threshold, we backtrace through Earth along direction of initiating τ to find projection of exiting area $R_E^2 \sin(\theta_X) d\theta_X d\phi_X$ on incident side of Earth dA_E.
- Source solid angle that would create the τ is $d\Omega_{\alpha\beta} = \sin(\alpha) d\alpha d\beta$.
- Using the number of incident neutrinos on dA_E from $d\Omega_{\alpha\beta}$ we propagate them through the Earth. This is done via the approximation that the Earth is essentially a gas for neutrinos given their small interaction cross section, $\sigma = (6.04 \text{ pb})(E_\nu/\text{GeV})^{0.385}$ [5]. That is the number of neutrinos per time with $(E_\nu, E_\nu + dE_\nu)$ that convert to τ between $(l, l + dl)$ is

$$dN_{\nu \to \tau} = P(E_\nu, l) \Phi E_\nu^{-p} dE_\nu \, dl \, d\Omega_{\alpha\beta} \, dA_E \; , \;\; P(E_\nu, l) = (n_E \sigma) e^{-l n_E \sigma} \; , \tag{2}$$

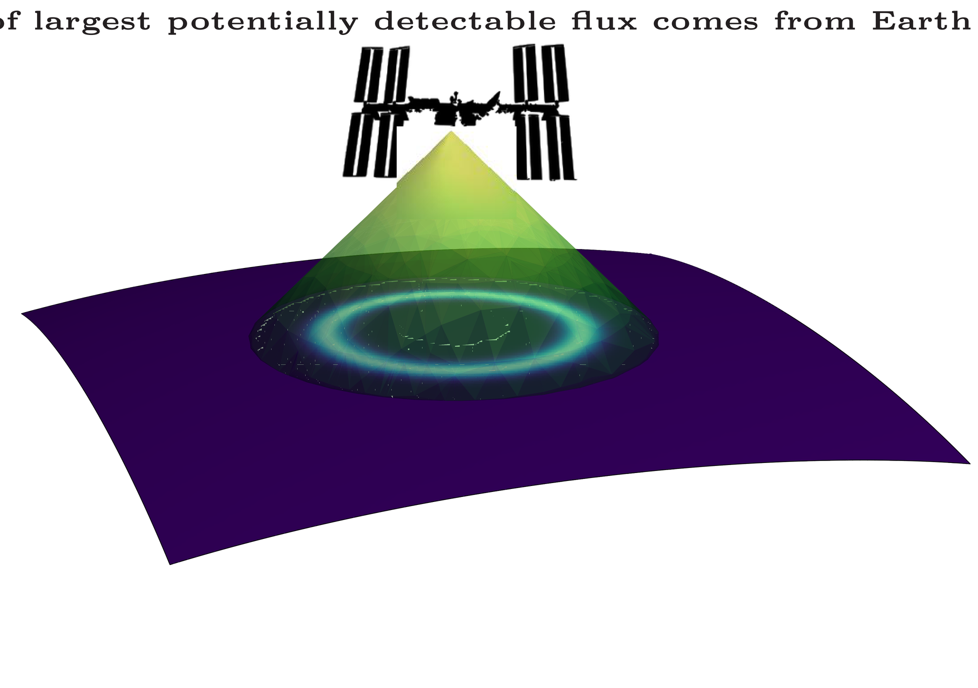
  with $n_E \approx 4.43 \times 10^{37}$ km^{-3} the average number density of the Earth.
- We take the energy of the τ to be 80% of the ν_τ energy across the entire energy range.
  We model τ energy loses by $dE_\tau/dX = -a - bE_\tau$,
  with $a = 0.2$ eV km^2 kg^{-1} and $b = 8.0 \times 10^{-14}$ km^2 kg^{-1} [6].
- We numerically integrate over all energies of exiting tau and over all locations on Earth within the horizon distance to the ISS.
  The differential event rate per year as a function of the exit location θ_X is given in Fig. 5

Fig. 5, $dN_\tau/dE_\nu dt$ rate vs. θ_X for $E_\tau = 10^{15}$ eV



- Most of the detectable neutrinos are Earth skimmers/at the edge of the FOV see Fig. 6

Fig. 6, Region of largest potentially detectable flux comes from Earth skimming events



- Taking into account $\sim 10\%$ duty cycle we find for :

$$p = 2.3 \rightarrow 9.28 \text{ events/yr} \quad \text{and} \quad p = 2.15 \rightarrow \; 26.3 \text{ events/yr} \tag{3}$$

References and Acknowledgement

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