Upward and Horizontal τ Airshowers by UHE Neutrinos

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ABSTRACT: Upward and Horizontal τ Air-showers (UPTAUS and HORTAUS) emerging from the Earth crust , mountain chains or deep plate boundaries are the most powerful signals of Ultra High Energy UHE neutrinos $\bar{\nu}_e$ at PeV and ν_τ, $\bar{\nu}_\tau$ at energies near and above $10^{15} - 10^{19} eV$. The large τ Air-showers multiplicity N in secondaries $N_{opt} \simeq 10^{12}(E_\tau/PeV)$, $N_\gamma(< E_\gamma >\sim 10\,MeV) \simeq 10^8(E_\tau/PeV)$, $N_{e^-e^+} \simeq 2 \cdot 10^7(E_\tau/PeV)$, $N_\mu \simeq 3 \cdot 10^5(E_\tau/PeV)^{0.85}$ make easy their discovery. UHE ν_τ, ν_τ because of neutrino flavor mixing, ($\nu_\mu \leftrightarrow \nu_\tau$), should be as abundant as ν_μ, $\bar{\nu}_\mu$. Also $\bar{\nu}_e$, near the Glashow W resonance peak, $E_{\bar{\nu}_e} = M_W^2/2m_e \simeq 6.3 \cdot 10^{15}\,eV$ may generate τ Air-showers. The HORTAUS may test the UHE neutrino interactions leading to additional fine-tuned test of New TeV Physics in Mountain Valleys and Earth crust horizontal edges. UPTAUS or HORTAUS, beaming toward high mountains, air-planes, balloons and satellites should flash γ, μ, X and Cherenkov lights toward detectors. Such UPTAUS might already hit nearby most sensitive satellite as Gamma Ray Observatory (GRO) detectors flashing them by short (millisecond), hard, diluted $\gamma-$ burst at the edge of threshold. We claimed their identity with the observed Burst And Transient Source Experiment (BATSE) 78 Terrestrial Gamma Flashes (TGF). The TGF clustering toward Galactic Center and Plane, known galactic and extra-galactic sources strongly support their UHE ν_τ origin.

KEYWORDS: UHE neutrino -τ air shower-GZK.

Dedicated to Giorgio Perlasca heroic acts in Budapest, 1944

It is well known that Ultra High Energy UHE neutrino of astrophysical origin above tens TeV might overcome the nearby noise vertical of secondary atmospheric neutrinos. The latter, being secondaries of charged cosmic rays, smeared by galactic magnetic fields, have lost their interesting astrophysical source records. In cubic kilometer underground

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detectors, both ice or water, in order to avoid the noisy downward atmospheric muons and to overcome the Earth opacity for vertical upward tens-TeV neutrinos, one [1] should better neglect vertical signals and focus the attention mainly on Horizontal Underground detectors in kilometers wide disk-like or ring-like arrays finalized to trace horizontal UHE Muons and Taus ($10^{13} - 10^{18} eV$) born by UHE astrophysical ν_μ,ν_τ. Moreover because of τ amplified showering we prefer to suggest the UPTAUS and HORTAUS detection (after their parental UHE $(\nu_\tau, \bar{\nu}_\tau) + N$ interactions in rock, the τ ejection in air and their fast decay in flight) as the best tool for UHE neutrino discovery. Indeed UHE ν_τ and $\bar{\nu_\tau}$ may

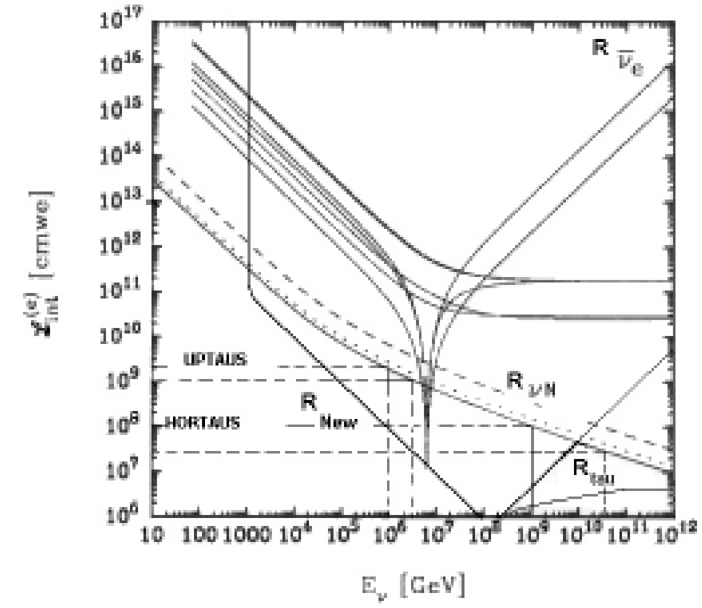

Figure 1: The UHE neutrino ranges as a function of the incoming UHE neutrino energy in Earth with overlapping the resonant $\bar{\nu}_e e$, $\nu_\tau N$ interactions; below in the corner the growing UHE τ boosted Lorentz range R_{tau} at the same energies and in water lowest curve bounded by photo-pion interactions. Finally the solid line R_{New} shows the interaction length due to New physics (extra dimension Gravity) at TeV for a matter density of rock $\rho = 3$.[1], [2]

be flavor converted from common pion secondaries: ν_μ and $\bar{\nu_\mu}$. The UHE neutrinos $\bar{\nu_e}$, ν_μ, $\bar{\nu}_\mu$, are expected Ultra High Energy Cosmic Rays (UHECR) ($\gtrsim 10^{16}$ eV) secondary products near Active Galactic Nuclei (AGN) or micro-quasars jets by common photo-pion decay relics by optical photons nearby the source, either pulsars (PSR) or AGNs $(p + \gamma \rightarrow n + \pi^+, \pi^+ \rightarrow \mu^+ \nu_\mu, \mu^+ \rightarrow e^+ \nu_e \bar{\nu}_\mu)$, or directly by proton proton scattering in interstellar matter. UHE neutrino flavor mix even at highest Greisen-Zatsepin-Kuzmin (GZK) energy ($> 4 \cdot 10^{19} eV$) because of the large galactic (Kpcs) and extreme cosmic (Mpcs) distances much longer than oscillation ones:

$$L_{\nu_\mu - \nu_\tau} = 4 \cdot 10^{-3}\, pc \left(\frac{E_\nu}{10^{16}\, eV}\right) \cdot \left(\frac{\Delta m_{ij}^2}{(10^{-2}\, eV)^2}\right)^{-1} \quad (1)$$

HORTAUS are better detectable in deep valleys or on front of large mountain chains like Alps, Rocky Mountains, Grand Canyons, Himalaya and Ande just near present AUGER project [3],[5]. Future Array Telescope may trace at best such EeV (10^{18} eV) HORTAUs in the Death Valley in USA by photoluminescent tracks [4]. The mountain chains screens undesirable horizontal ($> 70^o$) UHECR showers; HORTAUS may lead also to UHE horizontal muon bundle. The Mountain chains acts also as a characteristic $\bar{\nu_e}$ detector at Glashow energy peak ($6.3 PeV$). Present UPTAUS is analogous to the well-known [6] " τ double bang". The novelty lays in the explosive τ decay in air after its escape from the rock leading to amplified tau air-showers in flight. The UPTAUS-HORTAUS channels reflects the known τ decay modes (Fig.2).

Table 1
Tau Air Shower Channels

Decay	Secondaries	Probability	Air-shower
$\tau \to \mu^- \bar{\nu_\mu} \nu_\tau$	μ^-	$\sim 17.4\%$	Unobservable
$\tau \to e^- \bar{\nu_e} \nu_\tau$	e^-	$\sim 17.8\%$	1 Electromagnetic
$\tau \to \pi^- \nu_\tau$	π^-	$\sim 11.8\%$	1 Hadronic
$\tau \to \pi^- \pi^0 \nu_\tau$	π^-, $\pi^0 \to 2\gamma$	$\sim 25.8\%$	1 Hadronic, 2 Electromagnetic
$\tau \to \pi^- 2\pi^0 \nu_\tau$	π^-, $2\pi^0 \to 4\gamma$	$\sim 10.79\%$	1 Hadronic, 4 Electromagnetic
$\tau \to \pi^- 3\pi^0 \nu_\tau$	π^-, $3\pi^0 \to 6\gamma$	$\sim 1.23\%$	1 Hadronic, 6 Electromagnetic
$\tau \to \pi^- \pi^- \pi^+ \nu_\tau$	$2\pi^-$, π^+	$\sim 10\%$	3 Hadronic
$\tau \to \pi^- \pi^+ \pi^- \pi^0$	$2\pi^-$, π^+, $\pi^0 \to 2\gamma$	$\sim 5.18\%$	3 Hadronic, 2 Electromagnetic

Figure 2: The characteristic decay channels of UPTAUS and HORTAUS.

From the top of a mountain, a balloon or a satellite the Earth acts also as a huge target for UPTAUS or its wide corona crust for HORTAUS. Observing from a height h downward toward the Earth at any angle θ below the horizontal line,(θ $+\pi/2$ = zenith angle), the distances $d(\theta)$ toward the ground, (from where an UPTAUS or HORTAUS should arise) is:

$$d(\theta) = (R_\oplus + h) \cdot \sin\theta - \sqrt{(R_\oplus + h)^2 \cdot \sin^2\theta - (2hR_\oplus + h^2)} \tag{2}$$

The distance length at horizontal tangential angle θ_c where the square-root term above vanishes, simplify in:

$$d(\theta_c) = \sqrt{(2R_\oplus \cdot h) + h^2} \simeq 110\sqrt{\frac{h}{km}} \cdot km \tag{3}$$

Where $\theta_c = \arcsin\sqrt{(2h/R_\oplus)} \simeq 1.01^\circ\sqrt{(h/km)}$; the terrestrial cord distances $\triangle d(\theta)$ crossed by the primary UHE ν_τ (and partially by the consequent upcoming τ before its exit in air) is

$$\triangle d(\theta) = 2\sqrt{(R_\oplus + h)^2 \cdot \sin^2\theta - (2hR_\oplus + h^2)} \tag{4}$$

Such distances, which vanish for $\theta = \theta_c$, are not too long to suppress horizontal UHE neutrinos for small $\delta\theta$ $(= \theta - \theta_c)$ angles above θ_c, even at energies $E_{GZK} \simeq 4 \cdot 10^{19} eV$ energies. see Fig 1. The ν_τ+τ crossed distances are $\triangle d(\delta\theta)$:

$$\triangle d(\delta\theta) \simeq 2(R_\oplus + h)\sqrt{\delta\theta \sin 2\theta_c} \simeq 318 km\sqrt{\left(\frac{\delta\theta}{1^\circ}\right)\sqrt{\left(\frac{h}{km}\right)}} \tag{5}$$

The terrestrial surface below any high level observer covers huge areas A ($A = 2\pi R_{\oplus}(1 - cos(\theta_c)) \simeq 2\pi h R_{\oplus} \simeq 4 \cdot 10^4 \cdot km^2(h/km)$ for $h << R_{\oplus}$); however for too distant UPTAUS origination the shower signal might be bounded by the longer crossed slant depth atmosphere opacity. The effective area for UPTAUS observed from height h $> h_\circ$ ($h_\circ$ is the atmosphere exponential length $\simeq 8.55 km$) is smaller: $A_{eff} = \pi \cdot \cot^2(\theta) h^2 = 942 \cdot km^2(h/10 \cdot km)^2; (\theta = 60°)$. The Tau decay track (see the line R_τ in Fig.1), constrained by the characteristic distance horizons $d(\theta_c)$ defines a fine tuned HORTAU energy: $E_\tau = 2 \cdot 10^{18} eV \sqrt{(h/km)}$. This formulas cannot be extended to arbitrary energy (or any height h), because of the finite atmosphere size; see below. A too large tau lifetime may lead to τ decay in too empty atmosphere. Keeping care of the Earth opacity, at large nadir angle ($\gtrsim 60^0$) where an average Earth density may be assumed ($< \rho >\sim 5$) the transmission probability and creation of upward UHE τ is approximately:

$$P(\theta,\, E_\nu) = e^{\frac{-\triangle d(\theta)}{R_{\nu_\tau}(E_\nu)}} (1 - e^{-\frac{R_\tau(E_\tau)}{R_{\nu_\tau}(E_\nu)}})\,. \tag{6}$$

This expression should contain $\triangle d(\theta)$ from above equation and the ranges R_{ν_τ} and R_τ [1]are shown in Fig 1; for example at PeV the above probability is within a fraction of a million($\theta \approx 60^0$) to a tenth of thousands ($\theta \approx \theta_c$). At GZK energies only HORTAUS are allowed. The corresponding angular integral effective volume observable from a high mountain (or balloon) at height h (assuming a final target terrestrial density $\rho = 3$) for UPTAUS at 3 PeV (for any AGN neutrino flux model normalized within a flat spectra whose energy fluence $\phi_\nu \simeq 2\, 10^3 \frac{eV}{cm^2 \cdot s}$), is:

$$V_{eff} \approx 0.3\, km^3 \left(\frac{\rho}{3}\right) \left(\frac{h}{km}\right) e^{-(\frac{E}{3\, PeV})} \left(\frac{E}{3\, PeV}\right)^{1.363} \left(\frac{\phi_\nu}{2\, 10^3 \frac{eV}{cm^2 \cdot s}}\right) \tag{7}$$

Any AGN neutrino flux model normalized within such a flat spectra is leading, above 3 PeV, to ~ 10 UHE ν_τ upward event/km^3 year [2]. The consequent average upward effective event rate on a top of a mountain (h $\sim 2\, km$) is:

$$N_{eff} \simeq 8\, \frac{\text{events}}{\text{year}} \left(\frac{\rho}{3}\right) \left(\frac{h}{2\, km}\right) e^{-(\frac{E}{3\, PeV})} \left(\frac{E}{3\, PeV}\right)^{1.363} \left(\frac{\phi_\nu}{2\, 10^3 \frac{eV}{cm^2 \cdot s}}\right) \tag{8}$$

Their signals at ten kms distances should be $\phi_\gamma \simeq 10^{-4} \div 10^{-5} cm^{-2} s^{-1}$, $(\phi_{X \sim 10^5 eV}) \simeq 10^{-2} \div 10^{-3} cm^{-2} s^{-1}$). The optical Cherenkov flux is large $\Phi_{opt} \approx 1 cm^{-2}$. We claimed [1] that such UPTAUS or HORTAUS produce gamma bursts at the edge of GRO-BATSE originated from the Earth and named consequently as Terrestrial Gamma Flashes (TGF). The effective volume for UPTAUS and the event rate within an angle of view ($\theta > 60^o$) is, at 3 PeV, approximately to within 15 km^3 values and the expected UHE PeV rate is:

$$N_{ev} \sim 150 \cdot e^{-(\frac{E_\tau}{3\, PeV})} \left(\frac{E_\tau}{3\, PeV}\right)^{1.363} \left(\frac{h}{400 km}\right) \left(\frac{\phi_\nu}{2\, 10^3 \frac{eV}{cm^2 \cdot s}}\right) \frac{\text{events}}{\text{year}} \tag{9}$$

The TGF signals would be mainly γ at flux 10^{-2} cm^{-2} at X hundred keV energies. The correlations of these clustered TGFs directions toward GeV-MeV (EGRET), X sources, Milky Way Galactic Plane (Fig.3) support and make suggestive the TGF identification as UPTAUS and HORTAUS. The TGF location reflects the higher UPTAUS (and HORTAUS) interaction probability in the rock over the sea (and along the coastal plates). Highest magnetic field on Asia widely spreads UPTAUS making the TGF more observable. The present TGF-τ could not be produced by UHE $\bar{\nu}_e$ because of the severe Earth opacity and support the $\nu_\mu \leftrightarrow \nu_\tau$ flavor mixing. The new physics interaction at TeV while forbid upward UHE signals in underground km^3 detectors it will amplify the ν_τ signals beyond mountains, by two order of magnitude making extremely fruit-full UHE ν_τ astrophysics in near future. HORTAUS may develop nor at too dense low atmosphere (being absorbed),

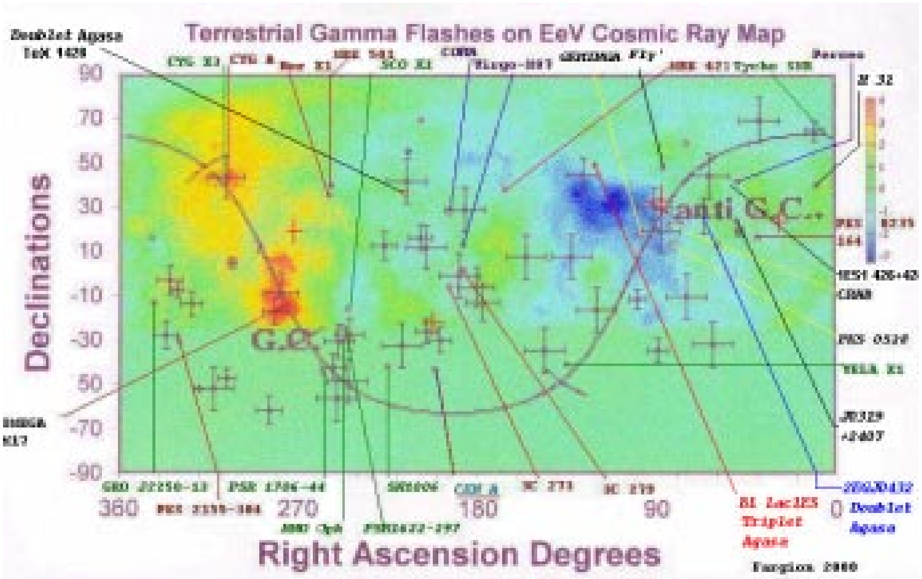

Figure 3: TGF events toward galactic center, disk and known sources on EeV AGASA map. Four red cross mark last TGF events. [1].

neither at too high, low atmosphere (where no shower may be amplified). HORTAUS charged secondaries may also turn upward by geo-magnetic fields into fan-thin- cone jets, appearing as UPTAUS. The maximal $c\tau$ distance is ruled by:

$$\int_0^{+\infty} n_0 e^{-\frac{\sqrt{(c\tau+x)^2+R_\oplus^2}-R_\oplus}{h_0}} dx \cong \int_0^{+\infty} n_0 e^{-\frac{(c\tau+x)^2}{2h_0 R_\oplus}} dx \cong n_0 h_0 A \tag{10}$$

$$c\tau = \sqrt{2R_\oplus h_0}\sqrt{ln\left(\frac{R_\oplus}{c\tau}\right) - lnA} \tag{11}$$

Where $A = A_{Had.}$ or $A = A_\gamma$ are parameters of order of unity, logarithmic function of energy, that calibrate the energy shower slant depth for both hadronic or electro-magnetic nature,[4]: $A_{Had.} = 0.792\left[1 + 0.02523\ln\left(\frac{E}{10^{19}eV}\right)\right]$; $A_\gamma = \left[1 + 0.04343\ln\left(\frac{E}{10^{19}eV}\right)\right]$. The solution of this equation leads to a characteristic UHE $c\tau_\tau = 546\ km$ decay distance at height $h = 23$ km where the HORTAUS start to shower. This imply a possibility to discover efficiently by satellite and balloons arrays UHE ν_τ, $\bar{\nu}_\tau$ up to 1.11 $10^{19} eV$. [4, 7]. From high satellite the arrival HORTAUS angle maybe confused ($\mp 1^\circ$) with most common Albedo Horizontal High Altitude Showers (HIAS) [4]. However from balloons heights and below, HIAS arrival angles split ($\geq 7^\circ$) from HORTAUS ones and are well distinguished. There is also the simplest possibility to observe UPTAUS and HORTAUS while they are hitting and lightening, via Cherenkov lights, upward mountain snow-walls. Such UPTAUS may also beam on lower boundary of high altitude clouds in the nights. These reflected flashing lights have a characteristic twin beam eight-shaped imprint that offers to Telescopes a new kind of signature for UHE Neutrino Astrophysics.

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