Tau Neutrino Astronomy by GZK UHE He

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Abstract. UHECR may be either nucleons or nuclei; in the latter case the Lightest Nuclei, as He^4 or He^3 , explains the absence of Virgo signals and the crowding of events around CenA bent by galactic magnetic fields. This model agrees with observed mass composition discovered in AUGER. However UHECR nucleons above GZK produce EeV neutrinos while Heavy Nuclei, as Fe UHECR do not produce much. Also UHECR He nuclei at few $10^{19}eV$ suffer nuclear fragmentation (producing low energetic neutrinos) once above one-few $10^{20}eV$. These UHE secondary neutrinos signals may influence expected (via GZK nucleon) Tau Neutrino Astronomy in significant and detectable way; the role of resonant antineutrino electron-electron leading to Tau air-shower may also rise.

1. UHECR Lightest Nuclei versus UHE ν

Astrophysical UHE neutrinos is being searched, since four decades, at TeV-PeV energy via neutrino muons in underground detectors. Their signal is greatly polluted from above (and below) by CR secondary muons (and atmospheric muon neutrinos into muons) and partially suppressed at PeVs, by Earth size opacity. Horizontal Muons at hundreds TeV, originated by astrophysical UHE neutrinos are also polluted by leading prompt atmospheric signals. However, since four decades, the rise of highest energy neutrino Astronomy is generally expected also by the cosmogenic EeV neutrinos, secondaries of GZK cut-off on Ultra High Cosmic Rays (UHECR). These ones are difficult to observe in km^3 detector. But since a decade [1] the UHE Tau Neutrino Astronomy have been foreseen and suggested in present and future detectors. Indeed Tau Air-shower Astronomy is an amplified Neutrino Astronomy observable in AUGER experiment via upward tau air-shower. The upward-horizontal EeV $\tau, \bar{\tau}$ appearance, via UHECR $p + \gamma_{CMB} \rightarrow \pi \rightarrow \nu$ has been predicted at rate 0.3 a year in AUGER. This rate, has only recently being confirmed by AUGER group estimates. Following the AUGER evidences (and Hires ones) of an UHECR GZK cut-off and the latest AUGER (possible) Super-Galactic anisotropy due to an eventual proton UHECR imply a secondary flux of UHE-GZK neutrino at EeVs energy within AUGER detection via $\tau, \bar{\tau}$ showering. In fact this occurs because the muon neutrino flavor mixing must feed also a tau neutrino component. Such UHE astrophysical tau neutrino (noise-free from any atmospheric background) may interact in and it may rises out the Earth as UHE τ ; these $\tau, \bar{\tau}$ decay in flight in atmosphere must lead to loud Tau Air-showers. Such a detectable flashes may rise in short times within Auger SD or FD arrays, namely once in a few years (2-4) from now. Nevertheless a recent alternative UHECR understanding [3], based on observed AUGER UHECR (nuclei) mass composition and with Cen-A rich clustering map, is in disagreement with UHECR proton understanding. This model is leading to different UHE neutrino predictions. It suggests that UHECR are made by Lightest Nuclei $(He^4, He^3, maybe also Be, B)$ mostly originated from Cen-A: their trajectories are bent and spread by galactic magnetic fields and they are incidentally clustered (by galactic fields) around Cen-A mostly along the same Super-Galactic Arm around farer Centaurs Cluster.

$$\delta_{rm} \gtrsim 11.3^{\circ} \cdot \frac{Z}{Z_{He^4}} \cdot \left(\frac{6 \cdot 10^{19} eV}{E_{CR}}\right) \left(\frac{B}{2 \cdot \mu G}\right) \sqrt{\frac{L}{20 kpc}} \sqrt{\frac{l_c}{kpc}} \tag{1}$$

This Lightest Nuclei for Highest Cosmic Rays model implies and foresees among the other, additional clustering of UHECR events around the nearest AGN Cen-A (the lightest UHECR the more correlated to the source, the heavier and with larger charges, the most bent and spread ones). The model explains the absence or a poor signal from Virgo (too far for the fragile nuclei to fly by). Such Lightest Nuclei for Highest Cosmic Rays are forced in a very confined cosmic volume (ten Mpc) due to a fragile light nuclear (few MeVs) binding energy. Usually heavy nuclei fragmentation pour energy only in UHE neutrino (at 0.1 - 0.01 EeV energy) spectra, less energetic than common



Figure 1. The first order bending for lightest UHECR, as He nuclei, is shown by the vertical arrow. The underline galactic magnetic fields almost vertical to Galactic Plane in Cen-A region, explain the longitudinal clustering of the events, overlapping by chance on Super Galactic Arm. It also explain the UHECR composition and the absence of Virgo. The heavier (Be,Li, B) will be bent more. The lighter He^3 less.

UHE EeV $p + \gamma_{CMB} \rightarrow \pi$ neutrino flux.

2. UHECR by Lightest Nuclei versus ν_{τ}

AUGER SD or FD are not able to reveal tens-hundreds PeV energy easily. However a less spaced sub-system, a more dense array AMIGA, nearest FD events and the additional telescope HEATS might lower the threshold accordingly. The 0.1 EeV mostly hadronic, inclined-upward, tau air-showers $\theta \leq 80$ occur at much lower altitudes than hadronic inclined *down*-going air-showers, at much nearer distances from telescopes than hadronic EeV air-showers, reducing the area and the rate. Nevertheless if rarest UHECR above $1 - 2 \cdot 10^{20} eV$, (a few in AUGER events), are made by He nuclei, they may still produce GZK photo-pions as well and EeV neutrinos too. Because of the limited He GZK interaction length their integral neutrino flux may be comparable or even more abundant than corresponding proton GZK ones at $6 \cdot 10^{19} eV$: therefore EeV tau Neutrino Astronomy, tails of the most energetic Lightest Nuclei GZK secondaries, may well rise at AUGER. EeV inclined tau decays, born nearly at sea level (versus inclined hadronic $\theta \geq 80$ ones developing at altitudes well above ten km) occur at air-density at least three times higher (than hadron horizontal ones); the Tau Air-shower hadron and electromagnetic and fluorescence size (and times) are three times faster (or their shower azimuth angular velocity). Such a brief $2-3\mu$ s and distinct up-ward lightening versus slow slow 10μ s diluted down-ward horizontal ones may be well disentangled within AUGER (and AMIGA SD) threshold and angular resolution; their strong curvature and their inclinations would rise within HEAT FD and AUGER FD, once every a couple of years. Possibly from the Ande side (West to East).



Figure 2. The AUGER Array and the inner area AMIGA and HEAT where lower energy air-showers might be revealed. The two different spacing (5.9 km^2 and the 23.5 km^2) offer the lower energy threshold respectively at 10¹⁶ and 10¹⁷ eV

Opening by their nearer distances and short timing, their inclined angles and low altitudes, a well defined new UHE Neutrino Astronomy. Able to disentangle the real UHECR nucleon or lightest nuclei UHECR nature. Indeed the appearence of the Resonant Glashow contribute in the upgoing Tau, while just doubling the signal at 0.01 EeV, it shine at horizontal angles as shown in differential angular spectra.

2.1. The resonant $\bar{\nu_e} + e \rightarrow W^- \rightarrow \nu_{\tau} + \tau$

The role of UHE neutrino interaction with matter is well understood: they also shape the neutrino survival across the Earth. Indeed the highest energy ν are opaque to Earth, but not to smallest cord. Therefore the harder events are the more tangent ones. The resonant $\bar{\nu_e} + e \rightarrow W^- \rightarrow \nu_{\tau} + \tau$ are very peculiar signals. Their opacity on Earth is extreme. They are as opaque as EeV energetic neutrinos. But their lower energy corresponds to higher flux (for constant energy fluence as Waxmann Bachall one). But their propagation in Earth is much smaller too. The compensated flux in 5-6 times higher than EeV one. Unfortunately this rate is (in AUGER) suppressed by detection threshold (nearly one hundred times smaller than EeV showers). Nevertheless the mini array AMIGA (of 6 km^2) and the HEAT telescopes may contribute to make detecable in a few year the same resonant $\bar{\nu}_e + e \rightarrow W^- \rightarrow \nu_\tau + \tau$: the distance will be ten times smaller and the showering azimuth angular velocity will appear *ten* times faster than already fast EeV Tau Airshower. Their curvature in AMIGA may leave a clear imprint.



Figure 3. The differential angular distribution of upgoing Tau assuming an usual Waxmann Bachall neutrino flux of $10eV \cdot cm^{-2}\dot{s}^{-1}$ Flux, for each neutrino flavor, derived from the observed UHECR GZK at $6 \cdot 10^{19}$ eV. Note the very peculiar bump due to the resonant antineutrino at 6.3 PeV; its strong inclination is due to the Earth opacity. The overall integral signal almost double the Tau skimming rate in the same energy band

3. Conclusions: UHE ν_{τ} Astronomy spectroscopy

The very exciting Neutrino Astronomy is beyond the corner. Either by EeV GZK [4],[5] secondaries or by tens PeV signals the detection via FD in AUGER is at the detection edge. The short and near air-shower from the telescope due to the lower energy makes the shower timing brief, sharp and at small zenith angle, and, upgoing. On the contrary the unique inclined horizontal down-going hadron shower are far away, diluted in air density and in time scale as well as at possible bifurcate (by geomagnetic field) structure. No way to be confused. Three or more times duration and morphology of *up or down* signature will disentangle any rare neutrino lights arriving from their unique but unusual sky: the Earth. Their rate, timing, energy and inclination may teach us



Figure 4. As above the integral rate of up going Tau including the resonant neutrino contribute. The small triangular The tiny bump nature of resonant antineutrinos is due to the energy spread of the tau at the tau-anti-neutrino tau birth. The rate are estimated for a total AUGER area at 10% efficiency for FD. The FD threshold is growing linearly with energy and it is respectively $300Km^2$, $30Km^2$, $3Km^2$ at the energy EeV, 0.1EeV, 0.01 EeV as shown by the arrows. Because of each rate at lower energies than EeV must be suppressed by corresponding factor (0.1, 0.01) making the expected event rate below unity in 3 years. The additional mini-array AMIGA at $27.5Km^2$, $6Km^2$ makes the detection in three years almost certain.

on the real nature (nucleon or lightes nuclei) of UHECR. In this hope we suggest (a) to implement the present AUGER array with additional array searching for shadows of inclined hadronic from Ande in AUGER; (b) To add Mini-Cherenkov telescope arrays facing Ande screen to reveal tau air-showers signals beyond the mountain chain also via direct Cherenkov flashes.(c) Locating a new telescope array few km distance to reduce the energy thresholds (d) Introducing novel trigger detection by fast horizontal track time signature.(e) Locating SD nearest to FD in order to enlarge their ability to discover the inclined events (blazing Cherenkov flashes) both in FD and in Cherenkov lights as well as in muon tracks in nearby SD array elements.

- Fargion D., 2002, ApJ, 570, 909; Fargion D.et.all. 1999, 26th ICRC, HE6.1.10,396-398; Fargion D., et all. 2004, ApJ, 613, 1285; Fargion D., et all. Adv. in Space Res.,37 (2006) 2132-2138; Fargion D. et al., Nuclear Physics B (Proc. Suppl.)2004,136,119
- [2] Fargion D. et al. arxiv:0708.3645v2; Nucl.Inst. Meth.A, 588;2008, 146-150.
- [3] Fargion D. Phys. Scr. 78 (2008) 045901, 1-4.
- [4] Greisen K 1966 Phys. Rev. Lett. 16 748
- [5] Zatsepin, G.T., Kuz'min, V.A.Zh. Eks. Teor. Fiz., Pis'ma Red.4 (1966)144