

Ultra High Energy Neutrino-Relic Neutrino Interactions In Dark Halos to Solve Infrared-TeV And GZK Cut-Off

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Abstract. Ultra High Energy Neutrino scattering on Relic Light Neutrinos in Dark Galactic or Local Group lead to Z and WW,ZZ showering : the nucleon component of the shower may overcome the GZK cut-off while the electro-magnetic tail at TeVs up to EeVs energy may solve the Infrared-TeV cut-off in a natural way. Different Gamma TeV puzzles may find a solution within this scenario: new predictions on UHECR spectra in future data are derived.

1 Introduction: GZK and Infrared-TeV cut offs

The Ultra High Energy (UHE) neutrinos above GZK cut-off energies may interact with relic cosmic ones leading (via Z , W^+W^- , ZZ productions) to a rich and complex chain both in hadronic and electro-magnetic showers. The hadronic secondaries may be source of extra-galactic Ultra High Energy (UHE) cosmic rays (UHECR) originated at distances well above GZK ($\gtrsim 10 Mpc$) cut-off. The electro-magnetic secondaries either from gauge bosons' decays in flight but mainly by lepton pair productions ($\nu\nu \rightarrow e\tau, e\mu, \mu\tau$), may pollute by synchrotron radiation showering first EeV, and PeV as well as TeV gamma spectra. The survival TeV photons may break and overcome the severe infrared - TeV cut-offs as possibly observed in Mrk 501, in Mrk 421 and in possible GRB90417 TeV clustered photons. As a frame-work let us remind that modern astro-particle physics face the old standing problem of dark matter nature in galactic up to cosmic scales. Neutrino with a light mass may play a key role in solving at least partially the puzzle within a hot-cold dark matter (HCDM) scenario. Moreover, at the edge of highest energy astrophysics, the main open question regards the nature of highest (Ultra High Energy, UHE) cosmic rays above the Greisen Zatsepin Kuzmin cut-off ($\gtrsim 4 \cdot 10^{19} eV$). These rare events probably ejected by blazars AGN, or QSRs in standard scenario, should not come from large distances because of the electromagnetic "dragging friction" of cosmic 2.75 K BBR and of the diffused radio backgrounds. According to Greisen, Zatsepin and Kuzmin (1966) proton and nu-

cleon mean free path at $E > 5 \cdot 10^{19} eV$ is less than $30 Mpc$, while gamma rays at same energies have even shorter interaction length ($10 Mpc$) due to microwave and radio background (Prothoroe 1997). Nevertheless at nearby distances ($\lesssim 10 \div 20 Mpc$), these powerful sources (AGN, Quasars) suspected to be the unique source able to eject such UHECRs, are rare and in general absent in the few (tens) UHECR arrival directions. Strong and coherent magnetic fields, able to bend UHECR from nearer AGN sources the UHECR (proton, nuclei) have been proposed either by galactic and extragalactic origin. The needed magnetic coherent lengths and strength are not compatible with known data. Moreover the absence of any un-bent UHECR neutrons at GZK energies tracing the original source makes the galactic or extragalactic magnetic field solution less acceptable. Topological defects (TD) clustering in the dark halo were recently suggested to be the UHECR solution, but growing evidences for non homogeneous UHECR clustering in their arrival directions (in doublets and triplets), are standing in favor of compact UHECR sources (and not for any diffused dark TD clouds). Moreover recent identification of UHECR with nearest Blazars at redshift distances greater than allowable by GZK ones made more than ever necessary the UHECR propagation from cosmic distances (Tinyakov, Tkachev 2001). To escape this arguments there have been even recent suggestions and speculations (Blasi 2000) for an unexpected population of 500 compact dark clouds of $10^8 M_\odot$ each of TD clusters, nevertheless uncorrelated to visible galactic halo and disk. Therefore the solution of UHECR puzzle based on primary Extreme High Energy (EHE) neutrino beams (from far AGN) at $E_\nu > 10^{21} eV$ and their undisturbed propagation up to the interaction on relic light ν in dark galactic halo (Fargion, Salis 1997; Fargion, Mele, Salis 1999, Weiler 1999, Yoshida et al 1998) is still a favorite option. If relic neutrinos have a mass around few eVs to cluster in galactic halos, the collisions with EHE neutrinos determine high energy particle cascades which could contribute or dominate the observed UHECR flux above $5 \cdot 10^{19} eV$. Indeed the possibility that neutrino share a little mass has been reinforced by Super-

Kamiokande evidence for atmospheric neutrino anomaly via $\nu_\mu \leftrightarrow \nu_\tau$ oscillation. Consequently there are two extreme scenario for hot dark halos: either ν_μ, ν_τ are both extremely light ($m_{\nu_\mu} \sim m_{\nu_\tau} \sim \sqrt{\Delta m} \sim 0.07 \text{ eV}$) and therefore hot dark neutrino halo is very wide and spread out to local group clustering sizes (increasing the radius but loosing in the neutrino density clustering contrast), or ν_μ, ν_τ have degenerated (eVs - 10 eV masses) split by a very tiny different value.

In the first case the Z peak $\nu - \nu_r$ interaction (Fargion Salis 1997, Fargion, Mele Salis 1999, T. Weiler 1999, Yoshida et al 1998) will be the favorite one while in the second case a $\nu\nu$ interaction via $Z \rightarrow W^+W^-$ (Fargion, Mele, Salis 1999) and $\nu\nu \rightarrow ZZ$ (D. Fargion, M. Grossi, P. G. De Sanctis Lucentini, C. Di Troia, R. V. Konoplich 2001) will be the dominant one.

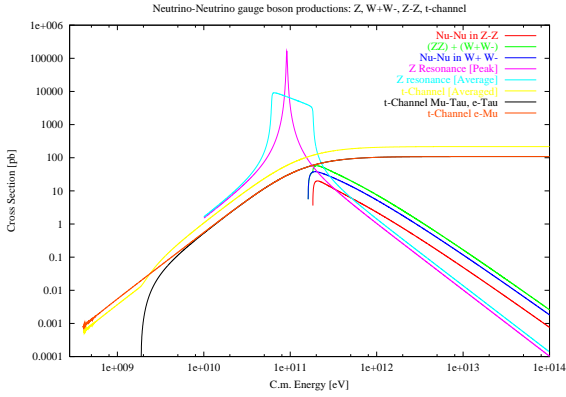


Fig. 1. The $\nu\bar{\nu} \rightarrow Z, W^+W^-, ZZ, T$ -channel, cross sections as a function of the center of mass energy in $\nu\nu$. These cross-sections are estimated also in average (Z) as well for each possible t-channel lepton pairs. The averaged Z-channel averaged the multiplicity of flavours pairs $\nu_i, \bar{\nu}_j$ respect to neutrino pair annihilations into Z neutral boson.

The hadronic tail of the Z or W^+W^- cascade might be the source of final p, \bar{p}, n, \bar{n} able to explain UHECR events observed by Fly's Eye and AGASA. However the same $\nu\nu_r$ interactions are source of Z and W decaying into pions as well as UHE lepton couples that are source of UHE gamma and electron pairs. Their average energy deposition for both gauge bosons decay is split as in short summary and detailed table below.

	Z	W^+W^-	t-channel
ν	58 %	55 %	47 %
γ	21 %	21 %	4 %
e^+e^-	16 %	19 %	49 %
p	5 %	5 %	-

Gamma photons at energies $E_\gamma \simeq 10^{20} - 10^{19} \text{ eV}$ freely propagate through galactic halo scales (hundreds of kpc) and could contribute to the extreme edge of cosmic ray spectrum (Yoshida et al 1998). The ratio of the final fluxes of nucleons, Φ_p over the corresponding electromagnetism flux Φ_{em}

Secondaries by $\nu\nu \rightarrow Z$ Interactions: $E_\nu = 10^{21} \text{ eV}$, Fluence $F_\nu = 20 \text{ eV}$, ($m_\nu = 0.4 \text{ eV}$)					
	Multiplicity	Energy (%)	$\sum E_{CM} (GeV)$	Peak Energy (EeV)	$\frac{E_{CM}}{E^2} (eV)$
p	2.7	6 %	5.4	$2.2 \cdot 10^6$	1.2
π^0	13	21.4 %	19.25	$1.9 \cdot 10^6$	4.25
γ_{ns}	26	21.4 %	19.25	95	4.25
π^\pm	26	42.8 %	38.5	$1.9 \cdot 10^6$	4.25
$(e^+e^-)_z$	26	12 %	11	50	2.3
$(e^+e^-)_{prompt}$	2	3.3 %	2.7	$5 \cdot 10^7$	1.32
$(e^+e^-)_\mu$	2	1.1 %	0.9	$1.6 \cdot 10^7$	0.45
$(e^+e^-)_\tau$	2	1.5 %	1.3	$1.2 \cdot 10^7$	0.6

Fig. 2. Total Energy percentage distribution into protons, neutral and charged pions and consequent gamma, electron pair particles both from hadronic and prompt leptonic Z, WW, ZZ productions and t-channels. We also calculated the electro-magnetic contribution due to the t-channel $\nu_i\nu_j$ interactions. We used LEP data for Z decay and considered W decay roughly in the same way as Z one. We assumed that an average number of 37 particles is produced during a Z(W) hadronic decay. The number of prompt pions both charged (18) and neutral (9), in the hadronic decay is increased by 8 and 4 respectively due to the decay of $K^0, K^\pm, \rho, \omega,$ and η particles. We assumed that the most energetic neutrinos produced in the hadronic decay mainly come from charged pion decay. Their number is roughly three times the number of π^0 's. UHE photons are mainly relics of neutral pions. Most of the γ radiation will be degraded around PeV energies by $\gamma\gamma$ pair production with cosmic 2.75 K BBR, or with cosmic radio background. The electron pairs instead, are mainly relics of charged pions and will rapidly lose energies into synchrotron radiation. Also prompt electron pairs (or leptonic secondaries) are considered. The consequent energy injection at each cosmic ray component and their showering spectra derived by boosted Z, WW decay in flight is shown in Figures below.

ratio is nearly $1/20$. Moreover if one considers the six pairs $\nu_e\bar{\nu}_e, \nu_\mu\bar{\nu}_\mu, \nu_\tau\bar{\nu}_\tau$ (and their hermite conjugate) t-channel interactions leading to discrete nearly monochromatic leptons at high energy, with no hadronic relics (as p, \bar{p}). This additional injection favors the electro-magnetic flux Φ_{em} over the corresponding nucleon one Φ_p by a factor 2 leading to $\frac{\Phi_p}{\Phi_{em}} \sim \frac{1}{40}$. We shall focus on Z, and WW, channels and their consequent electro-magnetic showering. These cascade will pile up into TeVs and later in GeVs while the previous one will double the electromagnetic shower mostly directly into the MeV band.

It is important to summarize the shower chain looking first to the EHE component and then following their consequent migration in lower energies.

2 The electromagnetic imprint of UHE neutrino scattering in the halo

Extra-galactic neutrino cosmic rays are free to move on cosmic distances up our galactic halo without constraint on their mean free path, because the interaction length with cosmic background neutrinos is greater than the actual Hubble distance. A Hot Dark Matter galactic halo model with relic light neutrinos (primarily the heaviest ν_τ or ν_μ), acts as a target for the high energy neutrino beams. The relic number density and the halo size are large enough to allow the $\nu\nu_{relic}$ interaction. As a consequence high energy parti-

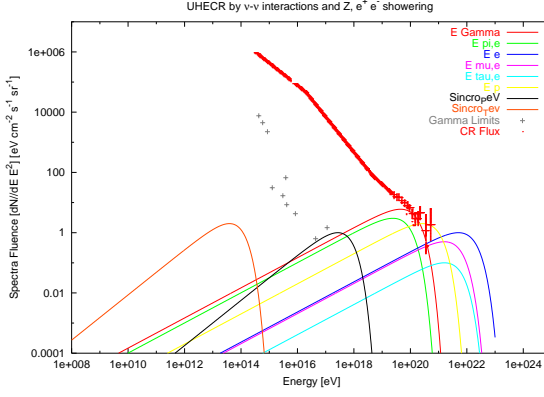


Fig. 3. Z decay Showering into nucleons, gamma and electron pairs over observed cosmic ray data and TeV gamma bounds. The sincro (T TeV, P PeV) gamma are degraded synchrotron radiation by UHE electron pairs secondaries in galactic magnetic fields. Here we assumed an incoming UHE neutrino at 10^{22} eV and a relic neutrino mass at 0.4 eV. The UHE Gamma are relics of neutral pions decay, E_p labels the nucleons, E_e the UHE prompt electron pairs, E_μ, E_τ by Z decay.

cle showers are produced in the galactic halo, overcoming the GZK cut-off. There are three main processes that can occur in the interaction of EHE and relic neutrinos. The $\nu\nu_r \rightarrow Z \rightarrow$ annihilation at the Z resonance; the second ($\nu_\mu \bar{\nu}_\mu \rightarrow W^+ W^- \rightarrow$ hadrons, electrons, photons) through W pair production. The third $\nu_e - \bar{\nu}_\mu, \nu_e - \bar{\nu}_\tau, \nu_\mu - \bar{\nu}_\tau$ and its hermite conjugate interactions of different flavor neutrinos mediated in the t -channel by the W exchange (i.e. $\nu_\mu \bar{\nu}_\tau \rightarrow \mu^- \tau^+$). These reactions are sources of prompt and secondary UHE electrons as well as photons resulting by hadronic τ decay. As we already noticed in the introduction, we'll assume that the nucleons, electrons and photons spectra (coming from W or Z decay) after $\nu\nu$ scattering in the halo, follow a power law that in the center of mass system is $\frac{dN^*}{dE^* dt^*} \simeq E^{*-\alpha}$ where $\alpha \sim 1.5$. This assumption is based on detailed Monte Carlo simulation of a heavy fourth generation neutrino annihilations (Golubkov, Konoplich 1998) (Fargion et al 1999, 2001) and with the model of quark - hadron fragmentation spectrum suggested by Hill (1983). In order to determine the shape of the particle spectrum in the laboratory frame, we have to introduce the Lorentz relativistic transformations from the center of mass system to the laboratory system. The number of particles is clearly a relativistic invariant $dN_{lab} = dN^*$, while the relation between the two time intervals is $dt_{lab} = \gamma dt^*$, the energy changes like $\epsilon_{lab} = \gamma \epsilon^* (1 + \beta \cos \theta^*) = \epsilon^* \gamma^{-1} (1 - \beta \cos \theta)^{-1}$, and finally the solid angle in the laboratory frame of reference becomes $d\Omega_{lab} = \gamma^2 d\Omega^* (1 - \beta \cos \theta)^2$. Substituting these relations one obtains

$$\left(\frac{dN}{d\epsilon dt d\Omega} \right)_{lab} = \frac{dN^*}{d\epsilon^* dt^* d\Omega^*} \gamma^{-2} (1 - \beta \cos \theta)^{-1} =$$

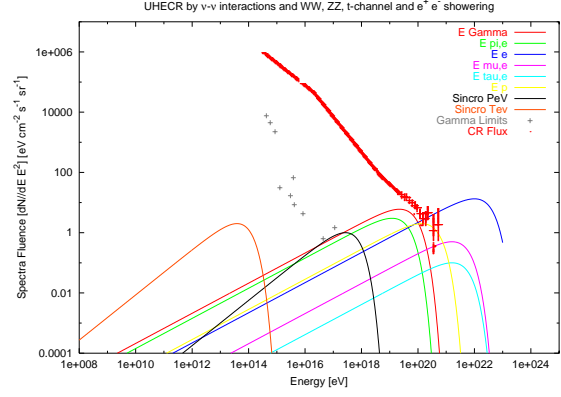


Fig. 4. WW and ZZ decay Showering as well as the t-channel UHE leptons decaying into nucleons, gamma and electron pairs over written on observed cosmic ray data and TeV gamma bounds. The sincro (T TeV, P PeV) gamma are degraded synchrotron radiation by UHE electron pairs secondaries in galactic magnetic fields. Note the electron pair excess at highest energies. Their presence due to t-channel showering should be masked by radio scattering and magnetic screening. Here we assumed an incoming UHE neutrino at 10^{22} eV and a relic neutrino mass at 0.4 eV. The UHE Gamma are relics of neutral pions decay, E_p labels the nucleons, E_e the UHE prompt electron pairs, E_μ, E_τ by Z decay.

$$\frac{\epsilon_*^{-\alpha} \gamma^{-2}}{4\pi} \cdot (1 - \beta \cos \theta)^{-1}$$

$$\left(\frac{dN}{d\epsilon dt d\Omega} \right)_{lab} = \frac{\epsilon^{-\alpha} \gamma^{-\alpha-2}}{4\pi} (1 - \beta \cos \theta)^{-\alpha-1} \quad (1)$$

and integrating on θ (omitting the lab notation) one loses the spectrum dependence on the angle.

The consequent fluence derived by the solid angle integral is:

$$\frac{dN}{d\epsilon dt} \epsilon^2 \simeq \frac{2^{\alpha-1} \epsilon^{-\alpha+2} \gamma^{\alpha-2}}{\alpha} \quad (2)$$

There are two extreme cases to be considered: the case where the interaction occurs at Z peak resonance and therefore the center of mass Lorentz factor γ is "frozen" at a given value (eq.1) and the case (WW, ZZ pair channel) where all energies are allowable and γ is proportional to $\epsilon^{1/2}$. Here we focus only on Z peak resonance. The consequent fluence spectra $\frac{dN}{d\epsilon dt} \epsilon^2$, as above, is proportional to $\epsilon^{-\alpha+2}$. Because α is nearly 1.5 all the consequent secondary particles will also show a spectra proportional to $\epsilon^{1/2}$ following a normalized energies shown in Tab.2, as shown in figures above. In the latter case (WW, ZZ pair channel), the relativistic boost reflects on the spectrum of the secondary particles, and the spectra power law becomes $\propto \epsilon^{\alpha/2+1} = \epsilon^{0.25}$. These channels will be studied in details elsewhere. In Fig. 1 we show the spectrum of protons, photons and electrons coming from Z hadronic and leptonic decay assuming a nominal primary CR energy flux $\sim 20 eV s^{-1} sr^{-1} cm^{-2}$, due to the total $\nu\bar{\nu}$ scattering at GZK energies. Let us remind that we assume an

interaction probability of $\sim 1\%$ and a corresponding UHE incoming neutrino energy $\sim 2000 eV s^{-1} sr^{-1} cm^{-2}$ near but below present UHE neutrino flux bound.

As it is shown in Table 2 and Figures above, the electron (positron) energies by π^\pm decays is around $E_e \sim 2 \cdot 10^{19} eV$ for an initial $E_Z \sim 10^{22} eV$ (and $E_\nu \sim 10^{22} eV$). Such electron pairs interacting with the galactic magnetic field ($B_G \simeq 10^{-6} G$) will lead, to direct TeV photons:

$$E_\gamma^{sync} \sim \gamma^2 \left(\frac{eB}{2\pi m_e} \right) \sim 27.2 \left(\frac{E_e}{2 \cdot 10^{19} eV} \right)^2 \left(\frac{m_\nu}{0.4 eV} \right)^{-2} \left(\frac{B}{\mu G} \right) TeV. \quad (3)$$

The spectrum of these photons is characterized by a power of law $dN/dEdT \sim E^{-(\alpha+1)/2} \sim E^{-1.25}$ where α is the power law of the electron spectrum, and it is showed in Figures above. As regards the prompt electrons at higher energy ($E_e \simeq 10^{21} eV$), their interactions with the galactic magnetic field is source of another kind of emission around tens of PeV energies, as is given by :

$$E_\gamma^{sync} \sim 6.8 \cdot 10^{16} \left(\frac{E_e}{10^{21} eV} \right)^2 \left(\frac{m_\nu}{0.4 eV} \right)^{-2} \left(\frac{B}{\mu G} \right) eV \quad (4)$$

The corresponding energy loss length instead is (Kuzmin 2000)

$$\left(\frac{1}{E} \frac{dE}{dt} \right)^{-1} = 3.8 \times \left(\frac{E}{10^{15}} \right)^{-1} \left(\frac{B}{10^{-6} G} \right)^{-2} kpc. \quad (5)$$

that for 10^{21} electron reduces to $\sim 10^{-3} pc$. Again one has the same power law characteristic of a synchrotron spectrum with index $E^{-(\alpha+1)/2} \sim E^{-1.25}$. Gammas at $10^{16} \div 10^{17} eV$ scatters onto low-energy photons from isotropic cosmic background ($\gamma + BBR \rightarrow e^+e^-$) converting their energy in electron pair. The expression of the pair production cross-section is is

$$\sigma(s) = \frac{1}{2} \pi r_0^2 (1 - v^2) [(3 - v^4) \ln \frac{1+v}{1-v} - 2v(2 - v^2)] \quad (6)$$

where $v = (1 - 4m_e^2/s)^{1/2}$, $s = 2E_\gamma \epsilon (1 - \cos \theta)$ is the square energy in the center of mass frame, ϵ is the target photon energy, r_0 is the classic electron radius, with a peak cross section value at

$$\frac{4}{137} \times \frac{3}{8\pi} \sigma_T \ln 183 = 1.2 \times 10^{-26} cm^2$$

Because the corresponding attenuation length due to the interactions with the microwave background is around ten kpc , the extension of the halo plays a fundamental role in order to make this mechanism efficient or not. As is shown in Fig.3-4, the contribution to tens of PeV gamma signals by Z (or W) hadronic decay, could be compatible with actual experimental limits fixed by CASA-MIA detector on such a range of energies. Considering a halo extension $l_{halo} \gtrsim 100 kpc$, the secondary electron pair creation becomes efficient, leading to a suppression of the tens of PeV signal. So electrons

at $E_e \sim 3.5 \cdot 10^{16} eV$ loose again energy through additional synchrotron radiation, with maximum around

$$E_\gamma^{sync} \sim 79 \left(\frac{E_e}{10^{21} eV} \right)^4 \left(\frac{m_\nu}{0.4 eV} \right)^{-4} \left(\frac{B}{\mu G} \right)^3 MeV. \quad (7)$$

Anyway this signal is not able to pollute sensibly the MeV-GeV background, and its intensity is restricted beneath EGRE detecting capacities. Gamma rays with energies up to 20 TeV have been observed by terrestrial detector only by nearby sources like Mrk 501 ($z = 0.033$) or very recently by MrK 421. This is puzzling because the extragalactic TeV spectrum should be, in principle, significantly suppressed by the γ -rays interactions with the extragalactic Infrared background, leading to electron pair production and TeVs cut-off. The recent calibration and determination of the infrared background by DIRBE and FIRAS on COBE have inferred severe constrains on TeV propagation. Indeed, as noticed by Kifune (2000), and Protheroe and Meyer (2000) we may face a severe infrared background - TeV gamma ray crisis. This crisis imply a distance cut-off, incidentally, comparable to the GZK one. Let us remind also an additional problem related to the possible discover of tens of TeV counterparts of BATSE GRB970417, observed by Milagrito (1999), being most GRBs very possibly at cosmic edges, at distances well above the IR-TeV cut-off ones. One may invoke unbelievable extreme hard intrinsic spectra or exotic explanation as gamma ray superposition of photons or sacrilegious Lorentz invariance violation (G.Amelino-Camelia 1998).

3 Conclusions

We suggest that the same UHE $\nu\nu_\nu$ interaction chain in dark halos, while being able to solve the UHECR GZK puzzle, may at the same time, solve the present IR-TeV paradox.

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