UHECR AND GRB NEUTRINOS: AN INCOMPLETE REVOLUTION?

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Abstract

At highest energy edges Ultra High Energy Cosmic Ray, (UHECR) and PeVs neutrino (UHE\(\nu\)), should soon offer new exciting astronomy. The fast and somehow contradictory growth of hundred of antagonist models shows the explosive vitality of those new astronomy frontiers. No conclusive understanding on the UHECR and UHE neutrino source are at hand. The earliest expectation of GRBs (as a one shoot Fireball model) as the main (UHE\(\nu\)) sources has been rejected. The source of UHECR as the expected GZK ones within our Super-Galactic Plane (within few tens Mpc) it has been quite disproved. However alternative models on GRB (as the long life precessing Jets) and the new updated records by AUGER, TA, ICECUBE are offering nevertheless partial understanding and early hint for point source correlations along our galaxy and toward Cen A, the nearest extragalactic AGN.
1 The Cosmic Ray Century

A century ago radioactivity was used to probe atomic nature. The same radioactivity was discovered around us made by electrons (beta), alfa (Helium nuclei) and gamma (photons). Radioactivity was apparently mainly made by terrestrial matter; indeed as one rise far from the soil radioactivity start to decline. However Victor Hess, a century ago, discovered that at highest altitude while in balloons the radioactivity first decrease, but soon, (a few km above the sea level), it grows to tens or even hundred times more than sea level: a cosmic radioactivity rules at highest sky, consequently the cosmic rays (CR) nature was born. To day we do know that CR are mixed up but they are mostly charged particles as proton, Helium and other nuclei; CR are well representative of our solar system element composition; electron and positron are also present in CR. Photons and Neutrinos are shining too. Photons (gamma from X to TeVs energy) are well observed. Neutrinos not, mainly because CR atmospheric neutrino secondary pollution and because extreme neutrino weak interaction. Cosmic Ray energies ranges in an almost steady power law for nearly eleven order of magnitude from GeV to ZeV energy. Cosmic rays are mostly stop at twenty km. altitude (ten meter water equivalent) by our safe protective terrestrial atmosphere. Moreover Charged CR are smeared by terrestrial, solar and galactic magnetic fields leading to confused homogeneous rain with no apparent source imprint. We are blind within such a smooth CR rain. No source, no astronomy at sight. In some sense the existence of large scale galactic magnetic fields (smearing CR) are testimony of the (mysterious) cosmic magnetic monopole absence (the celebrated Parker monopole bound). To be more accurate here on sea level we feel only a part of such smooth CR secondaries, traces made by scattering fragments of nucleons-nuclei that are raining in high altitude atmosphere, fragments known as muons or gamma and electron pairs, as well as secondary neutrino, called because of it, atmospheric neutrinos. These are the neutrino noises hiding a more rare underline neutrino astronomy. Most power-full CR (TeVs-PeVs-EeVs-ZeVs) are observed on sea level by their catastrophic pair-production chain, leading to a tree-like air-shower whose top vertex is the primary CR event and whose late ramification are the million or thousand of billion secondaries pairs leptons (and few hadrons). To observe such UHECR there are both water Cherenkov array detector (surface detectors in $km^2$ array) or Fluorescence Telescope array tracking
air-shower lightening in the dark nights (in AUGER,HIRES,TA) experiments. At TeVs-PeVs energies CR air showering might blaze by Cherenkov flash, large optical telescope arrays (as Hess, Veritas, Magic) or large scintillator and water arrays as ARGO and Milagro as well as ice (ICECUBE). These telescope experiments found in last decade a large number of TeVs point sources (partially coincident with $\gamma$ GeVs Fermi satellite signals); the array ones, ARGO and Milagro and ICECUBE CR, found a remarkable (tens degree size) anisotropy in the TeVs sky whose source is puzzling; we suggested an UHECR radioactive beamed imprint (mostly galactic) and its decay in flight as a possible source [21]. We also try to find here UHECR and UHE neutrino correlation as discussed and summarized in Fig1. Charged particles in CR at higher and higher energies maybe accelerated on star flare, Supernova explosion shells, jets either in micro (as GRBs, SGRs) and-or in macro sites (as AGN nuclei, Quasars), in brightest Radio Galaxies or even along more candidate places [29]. We are all hunting for the CR sources nature since a century with no definitive success (yet). UHECR and UHE neutrino might point to them. Two main UHE neutrino models rise in last a few years: a Galactic and an Extragalactic origination, each of the two defending the UHECR and UHE neutrino traces within different arguments. Indeed in last decade we all hoped to reveal soon their origination by their extreme UHECR (possibly un-deflected) component, hundred billions times more energetic than lower GeV-TeV CR. UHECR if nucleon while crossing in random walk in our $\mu$ Gauss magnetic fields, have to fly within narrow angle $\delta_{rm-p} \simeq 2.5^\circ$. No such a clustering multiplet, out of a remarkable a triplet to be discussed, has been found see Fig1. UHECR, following AUGER composition data might be nuclei, light ones (He-like); in that case the incoherent random angle bending along the galactic plane and arms, crossing along the whole Galactic disk of 20 kpc arriving in different (alternating) spiral arm fields and within a characteristic coherent length of 2kpc for He nuclei becomes $\delta_{rm-He} \simeq 16^\circ$ [21], well consistent with observed UHECR Cen A clustering, see Fig1. On the contrary UHECR might be heavy (Fe,Ni..) ones, explaining the extreme spread of UHECR events along Vela that is the nearest and brightest Gamma pulsar in the sky, see Fig1.
The one shoot Fireball failure versus GRB precessing jet

The UHE $\nu$ signature was expected to be associated in time with several GRB (Gamma Ray Burst) sources or with BL Lac flaring sources; other source candidate are the Star-Burst galaxy and the Radio Galaxies. The most popular Fire-ball model of GRB (one huge shoot event, within or without a fountain jet) has been disproved. It should be noted that if GRB are not one shoot event but a long (decaying in hours-day scale time($\frac{1}{t_{\text{life}}}^{-1}$) life) jet [9] than its precessing blazing time (for neutrinos) should not be longer correlated with the short gamma-X blazing time (a constraint assumed of second-minute in Fireball times). Indeed in precessing GRBs Jet model it has been assumed since long ago a wider time scale to embrace also (otherwise mysterious) GRBs (as well as SGRs) precursors and statistical Jet solid angle [9] [11]. These observed precursor may be both gamma and neutrino events; such precursor neutrinos are indeed observed in a few GRB events: a 109 TeV neutrino, within 0.2$^{\circ}$ of GRB091230A, with a localization uncertainty of 0.2$^{\circ}$, and detected time some 14 hours before the gamma GRB091230A trigger; a 1.3 TeV neutrino 1.9$^{\circ}$ off GRB090417B, with localization uncertainty of 1.6$^{\circ}$, and detection time 2249 seconds before the trigger of GRB090417B; a 3.3 TeV neutrino 6.1$^{\circ}$ off GRB0909219, with a localization uncertainty of 6.1$^{\circ}$, and detection time 3594 seconds before the GRB090219 trigger. These three observed GRB-neutrino precursor neutrino event (unexplained in fireball one-shoot model) may be, at a few percent of all the UHE neutrino events in ICECUBE. Additional GRBs might be at higher redshift and they may be part of the ICECUBE UHE neutrino sources if one enlarge the GRB-neutrino time windows; however also AGN jet and local galactic UHE $\nu$ may play a role. As we shall show a few correlated UHE neutrino and UHECR may be present inside galactic plane as well as few smeared clustering in tens TeV $\gamma$ CR anisotropy and spread multiplet in tens EeV UHECR around Cen-A may trace the UHECR astronomy, see details in Fig[11]. It should be noted that if UHE neutrino will cluster in a spread tail group of events one might advocate either UHECR scattering along galactic gas (as for the Fermi bubble traced by its observed $\gamma$ fountain), or one may suggest the radioactive (light and heavy) UHECR decay in flight, offering a possible correlation to UHECR $10^{18} - 10^{20}$ eV clustering and the large scale Milagro-Argo-ICECUBE TeVs-PeVs $\gamma$ anisotropy [20] [21].
The UHE neutrino flavor metamorphosis

Let us remind that neutrinos are neutral and always un-deflected; (to be more precise in cosmology and for neutrinos with mass in expanding universe once they became non-relativistic neutrinos might be bent by gravity too; this may play a minor role in largest scale dark matter density growth and large scale formation). Therefore the UHE neutrino may offer a new Astronomy. However, as we mentioned, at low (less than tens TeV) energies, neutrinos are polluted by abundant (CRs fragments), a smeared atmospheric neutrino noise that are hiding any underlying astrophysical neutrino point-source. Let us remind that atmospheric GeV neutrinos while being mostly born at a ratio ($\nu_e : \nu_\mu : \nu_\tau = 1 : 2 : 0$) by proton-proton scattering interactions chain in atmosphere, once at hundred GeV-TeV, they become ruled, at sea level, by muons neutrinos ($\nu_e : \nu_\mu : \nu_\tau \simeq 0.1 : 1 : 0$); this occurs because the relativistic pion (and Kaon) still decay, feeding muons and anti-muons neutrinos while their muon decay, the main road to electron flavor birth, is inhibited by a longer muon lifetime. Therefore electron (and rarest charmed born tau flavor) presence at hundred GeV-TeV are rare (less than 10%); most signals (at hundred GeV-TeV) are muon neutrino tracks as observed by inner ICECUBE experiment, the Deep Core, in the last years. Here we don’t discuss the atmospheric muon neutrino conversion and partial suppression by flavor mixing that is tuned at GeV energies and led to the PontecorvoMakiNakagawaSakata in last two decades. To consider the flavor mixing and possible experiment along the Earth see [23]

However at higher energies (above tens TeV-PeV) the extraterrestrial signals might (and indeed do) overcome the softer atmospheric neutrino noise (mainly because the astrophysical hardest spectra). Indeed those extraterrestrial signals, while being expected to be born, in general, by $p + p$ or $p + \gamma$ in flux ratio,($\nu_e : \nu_\mu : \nu_\tau \simeq 1 : 2 : 0$), because of the mixing and because of the large galactic distances, may oscillate and converted into electron and tau neutrino flavor component. The outcome in a first approximation lead to a final equipartition flavor flux: ($\nu_e : \nu_\mu : \nu_\tau = 1 : 1 : 1$), because of the complete flavor de-coherence mixing in flight. These ruling shower signals have been observed by last 3 years ICECUBE event data. The dominant $\nu_e$ and $\nu_\tau$ interaction are mainly electromagnetic leading to Cherenkov spherical shower in ice. These majority of spherical shower events (28) are four times more abundant than muon tracks (7). This may sound contradictory keeping in mind that a third of
these 35 events should be atmospheric muon or neutrino noise\textsuperscript{18} (in principle all of them noise signals should mainly show up as muons, too many respect 7 observed ones); however because a very different detector flavor acceptance it maybe still consistent with ($\nu_\tau : \nu_\mu : \nu_e = 1 : 1 : 1$) \textsuperscript{26, 6}; once considering also the Neutral Current contribute. Therefore the best hope and probe of a new UHE $\nu$ astronomy is the recent neutrino sudden flavor change at tens TeV-PeV energy \textsuperscript{6}. But all showering cascades are smeared in their arrival direction ($\pm 15^\circ$) and they are making inconclusive any map correlation. Therefore a more directional astronomy is needed, as the one made by muon tracks. Additional such signals are able to open an UHE neutrino astronomy: they are in-written into few tens TeV energy (crossing in ICECUBE) muons at horizons \textsuperscript{24}; the first estimate of nearly 40 of such events offer hope for soon novel astronomy. Unfortunately the recent published (TeV-PeV)\textsuperscript{18} (not only those above tens-TeV-PeV) muon crossing inside the ICECUBE were painting a puzzling random map, not favoring any known or expected $\gamma$ X source, \textsuperscript{18}. A more restrictive filtering of those events (muon crossing above few Tens TeV) may be more telling for extraterrestrial nature, but such a selection has not been done yet \textsuperscript{24}. We must remind that an anti-neutrino electron $\bar{\nu}_e + e$ peak resonance may tag and reveal a different neutrino sky volume. Indeed a Glashow resonance peak may rise by $\bar{\nu}_e + e \rightarrow W^-$ at $E_{\bar{\nu}_e} = 6.3$ PeV \textsuperscript{27}, but it has not been observed (yet), while observing 2 PeV cascade shower. This is suggesting either a sudden softening in the PeV neutrino spectra \textsuperscript{6} or a smooth interchange (around ten TeV energy) between a soft power law in atmospheric neutrino with a harder extraterrestrial neutrino power law within a fine-tuned parameters (apt to avoid the expected Glashow signal as well as its ideal $\tau$ double bang signature) \textsuperscript{28}. The powerful $\nu_\tau$ discover via its first bang inside a rock (mountain, or Earth) and its consequent $\tau$ escape outside in air, decaying in an amplified $\tau$ airshower, is a very promising adjoint neutrino astronomy at highest energy range PeVs-EeV, first foreseen more than 15 years ago \textsuperscript{12} and to day widely searched in different large experimental array today \textsuperscript{4, 9, 11}, (the so called Earth skimming neutrinos, \textsuperscript{13}).

4 The UHECR fly undeflected: an UHECR Astronomy?

We expected that UHECR might flight straight because of their energetic rigidity, at best for UHECR proton. They survive the Lorentz bending and
smoothing occurring for lower (up to EeV) CR. Such UHECR, well above EeV, are extremely rare, but their interaction at high altitude in atmosphere makes their explosive pair-production tree air-shower along their fall, proliferous and amplified into extended wide area (tens km square size). Their detection may be tested by wide spread km distance array, each detector even of minor volume (few square meter swimming-pool for Cherenkov detection) on the ground. Such experiments like Flys’ Eye, AGASA, Hires, Auger, TA, were located in last two decades over hundreds or several thousands km square area. These UHECR (if nucleon or even nuclei) might exhibit a cut off (within nearly 2% of cosmic radius) because of the ”Cosmic Back Ground Radiation” opacity, mostly by $p + \gamma \rightarrow \Delta \rightarrow \pi + \text{nucleon}$ interaction, the so-called photon-pion GZK cut off \[^{30}\]. Their consequent GZK neutrinos (at EeV energies) are not observed yet and cannot feed the mentioned ICECUBE events. A more severe distance cut occur to UHECR nuclei propagation because of their fragility by photon-nuclei dissociation; moreover light and heavy nuclei are partially or totally bent while crossing the galaxy. Therefore their maps might trace only nearby local Universe well within $1 - 2\%$ percent of cosmic size. To escape the near Universe size (GZK size bounded, in case of UHECR clustering at far extragalactic edges) one may consider the UHE neutrinos at ZGeV hitting the relic cosmic ones via Z-resonance (in analogy to Glashow W resonance) \[^{10}\]: the Z UHE decay into nucleons or antinucleons might be the final trace explaining UHECR correlation well above GZK bounded universe; this proposal found much interest and it will be actual if UHECR are correlated with guaranteed AGN above GZK distances. UHECR neutron are also expected but well confined within one Mpc ($E_n \simeq 10^{20}$ eV) size while UHE photons ($E_\gamma \simeq 10^{18} - 10^{20}$ eV) are bounded within a few tens Mpc. No such UHECR neutron or photon source or clustering has been found (yet). UHE neutrino might test most of the far and secret Universe edges, but they may observe also nearby galactic sources. The simplest solution of UHECR (nearby Local Super-galactic plane) and of UHE neutrino (expected to be traces of GRBs) have been in a very recent years fallen away. New galactic and extragalactic candidate source have been considered, somehow with much dispute and disagreement in the scientific arena. Therefore UHECR either nucleon or nuclei must arise in a small (tens Mpc) or even narrow (few Mpc) Universe, possibly in sharp astronomy (for proton) or in a smeared clustering map (for light nuclei
or nearest galactic heavy nuclei). The last AUGER maps showed only marginal smeared clustering and a rarest remarkable triplet \(^{31}\), see Fig. 1.

## 5 Conclusions

The difficult puzzle of UHECR astronomy and the UHE neutrino maps may soon be matched by cooperative test and overlapping. There are often unexplainable delay in UHECR (AUGER) data release. Nevertheless the sources as nearest AGN Cen A, rise as a remarkable smeared clustering of UHECR events in AUGER \((E_{\text{UHECR}} > 6 \cdot 10^{19} \text{ eV})\) as well in rare overlapping tens EeV long chain events foreseen \(^{20}\), and observed, \(^{22} \text{ } 21\), may be well understood if they are mostly made by He nuclei and its fragments. The nearest brightest \(\gamma\) pulsar Vela is also suspected to correlate a train of UHECR events (if heavy Fe,Ni,Co nuclei), and a doublet of ICECUBE neutrinos (see Fig. 1 event n. 3 (a muon) and 6 (a shower) in ICECUBE \(^{17}\)) as well as a remarkable TeVs ICECUBE CR anisotropy \(^{21}\), Cen-X3 and Cygnus region is also rising in ARGO TeVs anisotropy \(^{21}\) and in a very rich (7) recent UHECR multiplet clustering containing also new TA and old Hires events. The most surprising narrow triplet is the newest rarest highest energy doublet \(^{31}\), by an additional third event (by last TA UHECR data); other triplet and quadruplet point to unknown sources not far from galactic plane; they are possibly showing a cooperative galactic and extragalactic source role; we offered here first attempts in this difficult map understanding (see Fig. 1). We believe that with care and with needed time we are going to disentangle (within the fog of such noisy high energy sky) the first sources shining from our near and far Universe; we believe that most are related to precessing jet beaming, galactic and extragalactic in tuned and equiparable ratio (see also \(^{25}\)), and UHECR as well as UHE neutrino are not found along contemporaneous explosive or flaring event, because of a different timing of the jet blazing beam. UHE neutrinos are by most distant GRB and AGN blazing whose timing maybe often delayed or precursor respect gamma flaring or burst. On the contrary UHECR are mostly galactic or in nearest Universe. Few sources (UHECR-UHE \(\nu\)) overlap within nearest galaxy and AGN sky.
6 In memory

This article is devoted to Daniele Habib greatest linguist and translator, who disappeared in these days half a century ago.

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Figure 1: The UHECR map in equatorial coordinate following AUGER detector (South) and TA (in North). There are few clustering tagged by five arrows: the most left and north one point toward a TA-Hires multiplet along Cen-3X, one of the location of gamma anisotropy at TeV by Milagro-Argo detectors; the next arrow point toward the remarkable UHECR made by highest doublet (TA-AUGER) UHECR found recently where a new third UHECR has been just found this year by TA; the probability to occur such an event is well below $10^{-4}$; a third arrow on the center-right side point on to a clustering along a nearest AGN, Cen-a not far from the largest energetic 2 PeV event number n.35 in ICECUBE over a doublet around the Cen A cluster, where an additional twin overlapping multi-plet occurs at 20 EeV energy see; the fourth arrow point to the nearest and brightest Gamma Pulsar, Vela, related to an aligned AUGER triplet event; the fifth arrow point to a doublet by TA and a singlet by AUGER, an additional single by Hires UHECR events nearby a well collimated UHE neutrino muon found by ICECUBE event n.5; all these five region are candidate of UHECR and possibly UHE neutrino sources, mostly galactic.