BLAZING CERENKOV FLASHES AT THE HORIZONS BY COSMIC RAYS AND NEUTRINOS INDUCED AIR-SHOWERS

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Abstract

High Energy Cosmic Rays (C.R.) versus Neutrino and Neutralino induced Air-Shower maybe tested at Horizons by their muons, gamma and Cerenkov blazing signals. Inclined and Horizontal C.R. Showers (70° - 90° zenith angle) produce secondary (γ,e±) mostly suppressed by high column atmosphere depth. The air column depth suppresses low energy Showers (TeV-PeV) and it dilutes higher energy (PeV-EeVs) ones. Indeed also earliest shower Cerenkov photons are diluted by large distances and by air opacity, while secondary penetrating, μ± and their successive decay into e±,γ, may revive additional Cerenkov lights. The larger horizontal distances widen the shower’s cone while the geo-magnetic field open it in a very characteristic fan-like shape polarized by local field vector, making these
elongated showers spread, fork-shaped diluted and more frequent, up to three order of magnitude (respect to vertical showers). GeVs $\gamma$ telescopes at the top of the mountains or in Space may detect at horizons PeVs up to EeV and more energetic hadronic cosmic rays secondaries. Details on arrival angle and column depth, shower shape, timing signature of photon flash intensity, may inform us on the altitude interaction and primary UHECR composition. Below the horizons, at zenith angle (90° – 99°) among copious single albedo muons, rare up-going showers traced by muon ($e^\pm, \gamma$) bundles would give evidence of rare Earth-Skimming neutrinos, $\nu_{\tau}$, at PeVs energies. They are arising by Tau Air-Shower (HorTaus) ($\nu_{\tau} + N \rightarrow \tau + X$, $\tau \rightarrow$ hadrons and/or electromagnetic shower). Their rate may be comparable with 6.3 PeVs $\nu_e$ neutrino induced air-shower (mostly hadronic) originated above and also below horizons, in interposed atmosphere by $W^-$ resonance at Glashow peak. Additional and complementary UHE SUSY $\chi^0 + e \rightarrow \hat{e} \rightarrow \chi^0 + e$ at tens PeVs-EeV energy may blaze, as $\nu_e - e \rightarrow W^-$ shower, by its characteristic electromagnetic signature. (These UHE $\chi^0$ are expected in topological defect scenarios for UHECRs). Their secondary shower blazing Cerenkov lights and distances might be disentangled from UHECR by Stereoscopic Telescopes such as Magic ones or Hess array experiment. The horizontal detection sensitivity of Magic in the present set up (if totally devoted to the Horizons Shower search) maybe already be comparable to AMANDA underground neutrino detector at PeVs energies.

1 UHECR Cerenkov Lights, Muons and Bundles at Horizons

Ultra High Energy Cosmic Rays (UHECR) Showers (from PeVs up to EeVs and above, mainly of hadronic nature) born at the high altitude in the atmosphere, may blaze (from the far edge) above the horizon toward Telescopes such as Magic one. The earliest gamma and Cerenkov lights produced while they propagate through the atmosphere are severely absorbed because of the deep horizontal atmosphere column depth ($10^4 - 5 \cdot 10^4 \ g \cdot cm^{-2}$ ), must anyway survive and also revive: indeed additional diluted but penetrating muon bundles (from the same by C.R. shower) are decaying not far from the Telescope into electrons which are source themselves of small Cerenkov lights. Also the same muon while hitting the Telescope may blaze a ring or arc of Cerenkov lights. These suppressed muon bundle secondaries, (about $10^{-3}$ times less abundant than the peak of the gamma shower photons) are arising at high altitude, at an horizontal distances 100 – 500 km far from the observer (for a zenith angle 85° – 91.5° while at 2.2km. height); therefore these hard (tens-hundred GeV) muon shower bundles (from ten to
millions muons from TeVs-EeVs C.R. primary) might spread in huge areas (tens- hundred \( km^2 \)); they are partially bent by geo-magnetic fields and they are randomly scattered, often decaying at tens-hundred GeV energies, into electrons and consequent mini electromagnetic-showers traced by their optical Cerenkov flashes. These diluted (but spread and therefore better detectable) brief (nanosecond-microsecond) optical signals may be captured as a cluster by largest telescope on ground as recent Stereoscopic Magic or Hess, Veritas arrays. Their Cerenkov flashes, single or clustered, must take place, at detection threshold, at least tens or hundreds times a night for Magic-like Telescope facing toward horizons \( 85^\circ - 90^\circ \). Their "guaranteed" discover may offer a new tool in CR and UHECR detection. Their primary hadronic signature might be hidden by the distance but its tail may arise in a new form by its secondary muon-electron-Cerenkov of electromagnetic nature. On the same time below the horizons a more rare (three-four order of magnitude) but more exciting PeV-EeVs Neutrino \( \nu_{\tau} \) Astronomy may arise by the Earth-Skimming Horizontal Tau Air-Showers (HorTaus); these UHE Taus are produced inside the Earth Crust by the primary UHE incoming neutrino \( \nu_{\tau}, \overline{\nu}_{\tau} \), generated mainly by their muon-tau neutrino oscillations from galactic or cosmic sources.\[6\],[7],[8]. Finally just above or below the horizon edge, within a few hundred of km distances, it might also be observable the guaranteed and well tuned \( \overline{\nu}_{\tau}+e \rightarrow W^- \rightarrow X \) air-showers at 6.3PeV Glashow resonant peak energy; the W main hadronic (2/3) or leptonic and electromagnetic (1/3) signatures may be well observed and their rate might calibrate a new horizontal neutrino-multi-flavour Astronomy \[6\]. The \( \overline{\nu}_{\tau}+e \rightarrow W^- \rightarrow X \) of nearby nature (respect to most far away ones at same zenith angle of hadronic nature) would be better revealed by a Stereoscopic Magic twin telescope or a Telescope array like Hess, Veritas. Additional Horizontal flashes might arise by Cosmic UHE \( \chi_o+e \rightarrow \overline{e} \rightarrow \chi_o+e \) electromagnetic showers within most SUSY models, if UHECR are born in topological defect decay or in their annihilation, containing a relevant component of SUSY particles. The UHE \( \chi_o+e \rightarrow \overline{e} \rightarrow \chi_o+e \) behaves (for light \( \overline{e} \) masses around Z boson ones) as the Glashow resonant case \[1\]. Finally similar signals might be abundantly and better observed if UHE neutrinos share new extra-dimension (TeV gravity) interactions: in this case also neutrino-nucleons interaction may be an abundant source of PeVs-EeVs Horizontal Showers originated in Air \[6\]. The total amount of air inspected within the solid angle \( 2^\circ \cdot 2^\circ \) by MAGIC height at Horizons (360 km.) exceed 44km\(^3\) but their consequent detectable beamed volume are corresponding to an isotropic narrower volume: \( V= 1.36 \cdot 10^{-2} \ km^3 \), nevertheless comparable (for Pevs \( \overline{\nu}_{\tau} \rightarrow W^- \rightarrow X \) and EeVs \( \nu_{\tau}, \overline{\nu}_{\tau}+N \rightarrow \tau \rightarrow X \) showers) to the present AMANDA confident volume.
Figure 1: Schematic Picture of an Horizontal Cosmic Ray Air-Shower (superior track) (HAS), and an up-going Tau Air-Shower induced by EeV Earth-Skimming $\nu_\tau$ HORTAU and their muons and Cerenkov lights blazing a Telescope as the Magic one. Also UHE $\bar{\nu}_e - e$ and $\chi^0 - e$ Scattering in terrestrial horizontal atmosphere at tens PeVs energy may simulate HAS, but mostly at nearer distances respect largest EeV ones of hadron nature at horizon’s edges.

Figure 2: Observed Flux of Muons as a function of the zenith angle above (left \[13\],\[12\]) the horizons; for the muons below the horizons their flux at 91° zenith angle is two order of magnitude below $\simeq 10^{-7} cm^{-2} s^{-1} sr^{-1}$, as observed by NEVOD and Decor detectors in recent years. As the zenith angle increases the upward muons flux reduces further; at 94° and ten GeV energy it is just four order below: $\simeq 10^{-9} cm^{-2} s^{-1} sr^{-1}$ \[16\],\[17\]; at higher energies (hundred GeVs) and larger zenith angle only muons induced by atmospheric neutrinos arises at $\simeq 2 - 3 \cdot 10^{-13} cm^{-2} s^{-1} sr^{-1}$ as well as Neutrino Tau induced Air-Shower (muon secondaries).
2 Blazing Cerenkov Flashes by Horizons Showers and Muons

The ultrahigh energy cosmic rays (UHECR) have been studied in the past mainly versus their secondaries ($\gamma$, $e^\pm$, $\mu^\pm$) collected vertically in large array detectors on the ground. This is due to the rare event rate of the UHECR in the atmosphere and due to the high altitude where the shower takes place, expand and amplify downward. On the contrary at the horizons the UHECR are hardly observable (but also rarely looked for). They are diluted both by the larger distances as well as by the exponential atmosphere opacity suppressing the electromagnetic (electron pairs and gamma) secondaries; also their rich optical Cerenkov signal is partially suppressed by the horizontal air opacity. However this suppression acts also as a useful filter leading to the choose of higher CR events; their Cerenkov lights will be scatter and partially transmitted ($1.8\cdot10^{-2}$ at 551 nm, $6.6\cdot10^{-4}$ at 445 nm) depending on the exact zenith angle and seeing: assuming a suppression on average $5\cdot10^{-3}$ and the nominal Magic threshold at 30 GeV gamma energy, it does corresponds to a hadronic shower at far horizons (diluted by nearly three order of magnitude by larger distances) at an energy above $E_{CR} \simeq 6$ PeV. Their primary flux maybe estimated considering the known cosmic ray fluxes at same energy on the top of the atmosphere (both protons or helium) (see DICE Experiment referred in[12]):

$$\phi_{CR}(E = 6 \cdot 10^{15}eV) \simeq 9 \cdot 10^{-12}cm^{-2}s^{-1};$$

at a distance $d = 167km \cdot \sqrt{\frac{h}{2.2km}}$ (zenith angle $\theta \simeq 87^\circ - 88^\circ$) corresponding to a wide shower area [$A = \pi \cdot (\Delta \theta \cdot d)^2 \simeq 2.7 \cdot 10^{11}cm^2(\frac{d}{10km})^2$, observed by a opening angle [$\Delta \Omega = (2^\circ \cdot 2^\circ)\pi \simeq 3.82 \cdot 10^{-3}sr.$] is for a night of record ($[\Delta(t) = 4.32 \cdot 10^4s]$):

$$N_{ev} = \phi_{CR}(E = 6 \cdot 10^{15}eV) \cdot A \cdot \Delta \Omega \cdot \Delta(t) \simeq 401/12h$$

Therefore one may foresee nearly every two minutes a far hadronic Cerenkov lightening Shower in Magic facing at the far horizons at zenith angle $87^\circ - 88^\circ$. Increasing the observer altitude $h$, the horizon zenith angle also grows: $\theta \simeq [90^\circ + 1.5^\circ \sqrt{\frac{h}{2.2km}}]$ In analogy at a more distant horizontal edges (standing at height 2.2km as for Magic, while observing at zenith angle $\theta \simeq 89^\circ - 91^\circ$ still above the horizons) the observation range $d$ increases:

$$d = 167\sqrt{\frac{h}{2.2km}} + 360km = 527km;$$

the consequent shower area widen by more than an order of magnitude (and more than three order respect to vertical showers) and the foreseen event number, now for much harder C.R. at $E_{CR} \geq 3 \cdot 10^{17}eV$, becomes:

$$N_{ev} = \phi_{CR}(E = 3 \cdot 10^{17}eV) \cdot A \cdot \Delta \Omega \cdot \Delta(t) \simeq 1.6/12h$$
Therefore at the far edges of the horizons $\theta \simeq 91.5^\circ$, once a night, an UHECR around $E_{eV}$ energies, blazes to the Magic (or Hess, Veritas, telescopes). At each of these far primary Cherenkov flash is associated a long trail of secondary muons in a very huge area; these muons eventually are also hitting inside the Telescope disk; their nearby showering, while decaying into electrons in flight, (source of tens-hundred GeVs mini-gamma showers) is also detectable at a rate discussed below.

### 3 Single-Multi muons: Arcs, Rings and Gamma by $\mu^\pm \rightarrow \gamma, e^\pm$

As already noted the main shower blazing photons from a CR may be also reborn or overlap with its secondary tens-hundred GeVs muons, either decaying in flight as a gamma flashes, or by direct Cerenkov muons lights painting arcs or rings while hitting the telescope. Indeed these secondary very penetrating muon bundles may reach hundreds km far distances ($\simeq 600km \cdot \frac{E_{\mu}}{100\, GeV}$) away from the shower origin. To be more precise a part of the muon primary energy will dissipate along 360 km air-flight (nearly a hundred GeV energy), but a primary $130 - 150$ GeV muon will reach a final $30 - 50$ GeV energy, just at minimal Magic threshold value. Let us remind the characteristic secondary abundance in a shower: $N_\mu \simeq 3 \cdot 10^5 \left( \frac{E\, CR}{P\, eV} \right)^{0.85}$

These multiplicity are just at a minimal (GeV) energies [4]; for the harder (a hundred GeV) muons their number is (almost inversely proportionally to energy) reduced: $N_\mu(10^2 \cdot GeV) \simeq 1.3 \cdot 10^4 \left( \frac{E\, CR}{P\, eV} \right)^{0.85}$

These values must be compared with the larger peak multiplicity (but much lower energy) of electro-magnetic shower nature: $N_{e^+e^-} \simeq 2 \cdot 10^7 \left( \frac{E\, CR}{P\, eV} \right); N_\gamma \simeq 10^8 \left( \frac{E\, CR}{P\, eV} \right)$. As mentioned most of these electromagnetic tail is lost (exponentially) at horizons (above slant depth of a few hundreds of $g \cdot cm^{-2}$)(out of the case of re-born, upgoing $\tau$ air-showers [8],[9]); therefore gamma-electron pairs are only partially regenerated by the penetrating muon decay in flight, $\mu^\pm \rightarrow \gamma, e^\pm$ as a parasite electromagnetic showering [3]. Indeed $\mu^\pm$ may decay in flight (let say at 100 GeV energy, at 2–3% level within a 12–18 km distances) and they may inject more and more lights, to their primary (far born) shower beam.

These tens-hundred GeVs horizontal muons and their associated mini-Cerenkov $\gamma$ Showers have two main origin: (1) either a single muon mostly produced at hundreds km distance by a single (hundreds GeV-TeV parental) C.R. hadron primary (a very dominant component) or (2) rarer muon, part of a wider and spread horizontal muon bundle of large multiplicity born at TeVs-PeV or higher energies, as secondary of horizontal shower. Between the two cases there is a smooth link. A whole continuous spectrum of multiplicity begins from an unique muon up to a multi muon shower production. The dominant noisy ”single” muons at hundred-GeV energies
will lose memory of their primary low energy and hidden mini-shower, (a
hundreds GeV or TeVs hadrons); a single muon will blaze just alone. The
muon "single" rings or arcs frequency is larger (than muon bundles ones)
and it is based on solid observational data ([13] ; [12], as shown in fig.2 and
references on MUTRON experiment therein); these "noise" event number
is:

\[ N_{ev} = \phi_{\mu}(E \approx 10^2 eV) \cdot A_{Magic} \cdot \Delta \Omega \cdot \Delta(t) \approx 120/12h \]

The additional gamma mini-showers around the telescope due to a decay
(at a probability \( p \approx 0.02 \)) of those muons in flight, recorded within a larger
collecting Area \( A_{\gamma} \geq 10^9 \text{cm}^2 \) is even a more frequent (by a factor \( \geq 8 \)) noisy
signal:

\[ N_{ev} \geq \phi_{\mu}(E \approx 10^2 eV) \cdot p \cdot A_{\gamma} \cdot \Delta \Omega \cdot \Delta(t) \approx 960/12h \]

These single background gamma-showers must take place nearly once a
minute (in an silent hadronic background) and they are an useful tool to be
used as a prompt meter of the Horizontal C.R. verification.

On the contrary PeVs (or higher energy) CR shower Cerenkov lights
maybe observed, more rarely, in coincidence both by their primary and by
their later secondary arc and gamma mini-shower. Their 30 – 100 GeV
energetic muons are flying nearly undeflected \( \Delta \theta \leq 1.6^o \cdot \frac{100 \text{GeV}}{E_{\mu} \cdot 300 \text{km}} \)
for a characteristic horizons distances \( d \), partially bent by geo-magnetic
0.3 Gauss fields; as mentioned, to flight through the whole horizontal air
column depth (360 km equivalent to 360 water depth) the muon lose nearly
100 GeV; consequently the origination muon energy should be a little above
this threshold to be observed by Magic: (at least 130 – 150 GeV along
most of the flights). The deflection angle is therefore a small one: \( \Delta \theta \leq 1^o \cdot \frac{150 \text{GeV}}{E_{\mu} \cdot 300 \text{km}} \). Magic telescope area \( (A = 2.5 \cdot 10^6 \text{cm}^2) \) may record at
first approximation the following event number of direct muon hitting the
Telescope, flashing as rings and arcs, each night:

\[ N_{ev} = \phi_{CR}(E = 6 \cdot 10^{15} \text{eV}) \cdot N_{\mu}(2 \cdot \text{GeV}) \cdot A_{Magic} \cdot \Delta \Omega \cdot \Delta(t) \approx 45/12h \]

to be correlated (at 11% probability) with the above results of 401 primary
Cerenkov flashes at the far distances. As already mentioned before, in
addition the same muons are decaying in flight at a minimal probability
2\% leading to a mini-gamma-shower event number in a quite wider area
\( (A_{\gamma} = 10^9 \text{cm}) \):

\[ N_{ev} = \phi_{CR}(E = 6 \cdot 10^{15} \text{eV}) \cdot N_{\mu}(2 \cdot \text{GeV}) \cdot p \cdot A_{\gamma} \cdot \Delta \Omega \cdot \Delta(t) \approx 360/12h \]

Therefore, in conclusion, at 87° – 88° zenith angle, there are a flow of
primary \( E_{CR} \approx 6 \cdot 10^{16} \text{eV} \) C.R. whose earliest showers and consequent
secondary muon-arcs as well as nearby muon-electron mini-shower take
place at comparable (one every 120 s.) rate. These certain clustered signals offer an unique tool for gauging and calibrating Magic (as well as Hess, Cangaroo, Veritas Cerenkov Telescope Arrays) for Horizontal High Energy Cosmic Ray Showers. Some more rare event may contain at once both Rings, Arcs and tail of gamma shower and Cerenkov of far primary shower. It is possible to estimate also the observable muons-electron-Cerenkov photons from up-going Albedo muons observed by recent ground experiments\cite{16, 17}: their flux is already suppressed at zenith angle 91° by at least two order of magnitude and by four order for up-going zenith angles 94°. Pairs or bundles are nevertheless more rare (up to $\phi_\mu \leq 3 \cdot 10^{-13} cm^{-2} s^{-1} sr^{-1}$ \cite{16, 17}). They are never associated to up-going shower out of the case of tau air-showers or by nearby Glashow $\bar{\nu}_e - e \rightarrow W^-$ and comparable $\chi^0 + e \rightarrow \tilde{e}$ detectable by stereoscopic Magic or Hess array telescopes, selecting and evaluating their column depth origination, just discussed below.

4 UHE $\bar{\nu}_e - e \rightarrow W^-$ and $\chi^0 + e \rightarrow \tilde{e}$ resonances versus $\tau$ air-showers

The appearance of horizontal UHE $\bar{\nu}_e, \nu_\tau \rightarrow \tau$ air-showers (Hortaus or Earth-Skimming neutrinos) has been widely studied \cite{5, 6, 2, 10, 7, 8, 14, 18, 15, 9}; their rise from the Earth is source of rare clear signals for neutrino UHE astronomy (see fig.3). However also horizontal events by UHE 6.3 PeV, Glashow $\bar{\nu}_e - e \rightarrow W^-$ and a possible comparable SUSY $\chi^0 + e \rightarrow \tilde{e}$ hitting and showering in air have non negligible event number:

$$N_{ev} = \phi_{\bar{\nu}_e} (E = 6 \cdot 10^{15} eV) \cdot A \cdot \Delta \Omega \cdot \Delta (t) \simeq 5.2 \cdot 10^{-4}/12h$$

assuming the minimal GZK neutrino flux : $\phi_{\bar{\nu}_e} (E = 6 \cdot 10^{15} eV) \simeq 5 \cdot 10^{-15} eV cm^{-2} s^{-1} sr^{-1}$. Therefore during a year of night records and such a minimal GZK flux, a crown array of a 90 Magic-like telescopes on 2 • $\pi = 360^\circ$ circle facing the horizons, would discover an event number comparable to a $Km^3$ detector, ( nearly a dozen events a year). Indeed Magic facing at the Horizons as it is, offer a detection comparable to present AMANDA $\simeq 1\%Km^3$ effective volume. In conclusion while Magic looking up see Gamma GeV Astronomy, Magic looking at Horizons may well see UHE (PeVs-EeVs) CR, and rarely along the edge, GZK $\bar{\nu}_e - e \rightarrow W^-$ neutrinos, $\nu_\tau \rightarrow \tau$ air-showers and, surprisingly even SUSY $\tilde{e}$ lights in the sky (with showers).

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Figure 3: Tau Air-Showers (left) rates, by Earth Skimming Neutrino $\tau$ and their consequent (right) Muons Secondary rate angular distribution at different observer height, at $10^{17}$ eV energy, exceeding even the atmospheric neutrino induced muon flux $\phi_\mu \simeq 3 \cdot 10^{-13} \cdot \text{cm}^{-2} \text{s}^{-1} \text{sr}^{-1}$.

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