Mérida, México

Neutrino Fluxes and Their Time Evolution of AGN Black Holes

G.TER-KAZARIAN[1], S.SHIDHANI[2].
[1] *Byurakan Astrophysical Observatory, Byurakan, 378433, Aragatsotn District, Armenia*
[2] *Phys. Dept./College of Science, SQU, POBox 36, Postal Code 123, Al-Khoud, OMAN*
gago@bao.sci.am, shidhani7@squ.edu.om

Abstract: We supplement a previous discussion of the neutrino 'pre-radiation times' (PRTs) of 234 black holes [1] by computing the neutrino fluxes. The microscopic approach [2]-[4] is of vital importance for two crucial elements required for the Z-burst scenario of air shower events of the extremely high energy cosmic rays (EHECRs) since: 1) it predicts the large fluxes of EHE neutrinos above $10^{21}\,eV$, even after the neutrino trapping in the superdense medium, produced by the predominant neutrino cooling of the AGN protomatter core via simple or nucleon-modified URCA processes, and the pionic reactions; 2) It also predicts an existence of the relic cosmic background neutrinos (CBN) of light mass $\sim 1\,eV$ originated in the hot primordial Big Bang phase, forming the hot dark matter (HDM). The considered 234 BHs are closely linked with the active galactic nuclei (AGNs), and have well-determined masses $M_{BH} \simeq (1.1\times10^{6}\div4.2\times10^{9})\,M_{\odot}$ and bolometric luminosities collected from the literature. The AGNs are favored as promising "pure neutrino sources" because the computed neutrino fluxes $F^{q}_{\varepsilon} \equiv \varepsilon_d\, F^{q}_{BH} \simeq (5.75\times10^{-9}\div2.69\times10^{-2})(eV\,cm^{-2}\,s^{-1}\,sr^{-1})$, $F^{\pi}_{\varepsilon} = 1.7\times10^{-4}\,F^{q}_{\varepsilon}$, and $F^{u}_{\varepsilon} = 2.5\times10^{-10}\,F^{q}_{\varepsilon}$ are highly beamed along the plane of accretion disk, and peaked at high energies and collimated in smaller opening angle $\theta \sim 1/\gamma$, with relativistic γ factor of emitting protomatter-plasma corresponding to $\varepsilon_d \sim 10^{-6}$ or even narrower cone.

Introduction

Almost four decades passed since the famous first detection of cosmic rays with huge energies above $10^{19}eV$ by the Volcano Ranch group led by John Linsley, but the solution to this outstanding puzzle had not been achieved yet. Even though there is a little doubt that the highest particles observed in cosmic rays up to energies $E \sim 10^{20}\,eV$ are produced outside of our Galaxy, nevertheless, the sites and relevant production mechanisms continue to be a mystery.

• *Rationale:* A definite pattern for the theoretical description of both the microscopic model of AGN and an origin of EHECR from a unified view point is recently emerged in the framework [1]-[4] (and references therein), the key objectives of which are the 'microscopic' extension of the phenomenological BH models. The microscopic theory of BH rather completes the phenomenological BH model by exploring the most important processes of rearrangement of vacuum state and a spontaneous breaking of gauge symmetry in gravity at huge energies. Hence a significant change of properties of space-time continuum is occurred simultaneously with a strong gravity. This, in turn, causes the matter-to-'proto-matter' phase transition, and the formation of the proto-matter core (SPC) inside the EH. It offers an advantageous way to avoid from overproduction of photons in cosmic rays at energies above $10^{19}\,eV$. In previous paper [1], on which the present article is based, we address the 'pre-radiation time' (PRT) of neutrinos from black holes, which implies the lapse of time from black hole's birth till radiation of an extremely high energy neutrinos. We have computed the PRTs of 234 AGN black holes, with the well-determined masses and bolometric luminosities, collected from the literature by [5]. The derived PRTs for the 60 AGN black holes are longer than the age of the universe ($\sim 13.7\,Gyr$) favored today. At present, some among remaining 174 BHs, therefore, may radiate neutrinos. Given all these necessary theoretical preparations, here we attempt to amplify and substantiate the assertions made in [1] and further, expose via a numerical calculations of the neutrino fluxes. While produced large flux of primary EHE neutrinos can still initiate the cascades of EHECRs via very complex chains of Z-burst interactions. This suggests that if EHE neutrino beam is sufficiently strong it can produce the observed EHECR within 100 Mpc by hitting local light relic neutrinos, by weak interactions, clustered in dark halos and form EHECR through the hadronic Z (s-channel production) and W- bosons (t-channel production) decays.

• *The cosmic background neutrinos:* The micropic approach also predicts the relic cosmic background neutrinos with light mass produced in hot primordial Big Bang phase. An expansion of the Universe cools the ultrarelativistic neutrino protomatter, and, as soon as it reaches the boundary of protomatter-ordinary matter, the neutrinos still have retained a residual mass at rest $\widetilde{m}^d_\nu c^2 \sim 1\,eV$ [2]. Such relic light neutrinos cluster into large galactic halos to form hot dark matter.

Neutrino fluxes

Both the quark- and the pion condensed protomatter core (PC) cool much more rapidly than n-p-e (proton-neutron-electron) PC, because the simple URCA process can occur in both cases, while in the n-p-e PC it is very inefficient for phase space reasons. In the last case the nucleon-modified URCA processes can occur only when the number of participating degenerate fermions is two larger than for simple URCA processes [2].

• *URCA reactions:* It is straightforward to show that nucleon modified URCA reactions can contribute efficiently only for extragalactic objects with enough small redshift $z << 1$:

$$F_\nu^{URCA} \simeq \frac{8.4\times10^{-43}}{\varepsilon_d}\frac{1+z}{\left(\sqrt{2.3+(1+z)^3}-\sqrt{3.3}\right)^2} \left(\frac{\widetilde{R}}{cm}\right)\left(\frac{T_e^{SPC}}{T_e^n}\right)^3 eV\,cm^{-2}\,s^{-1}\,sr^{-1}, \quad (1)$$

where F_ν^{URCA} is the total neutrino spectral flux of cooling of the PC by modified URCA reactions with no muons, T_e^{SPC} is the surface temperature of SPC: $T_e^{SPC} \sim 1.1 \times 10^{12} K \left(\frac{M}{M_\odot}\right)^{1/4}\left(\frac{10\,km}{\widetilde{R}}\right)^{1/2}$, $\widetilde{R}$ is the radius of SPC, $T_e^n \sim 2\times10^6\,K$ and $\varepsilon = \varepsilon_d\,\varepsilon_{trap}$, $\varepsilon_d = \frac{2\,\pi\,R_g\,\widetilde{d}}{4\,\pi\,R_g^2} = \frac{\widetilde{d}}{2R_g}$, $\widetilde{d}$ is the thickness of the protomatter disk at the edge of even horizon, R_g is the gravitational radius, ε_{trap} is the neutrino "trapping" coefficient, which is arisen due to the fact that as the neutrinos are formed in PC at super-high densities they experience greater difficulty escaping from the PC before being dragged along with the matter, namely the neutrinos are "trapped" comove with matter, and build up a semidegenerate Fermi sea.

• *Pionic reactions:* As in the modified URCA reactions, the total rate for all four processes: $\pi^-+n \rightarrow n+e^-+\bar{\nu}_e,\quad \pi^-+n \rightarrow n+\mu^-+\bar{\nu}_\mu$, and the two inverse processes, is essentially four times the rate of each reaction alone. Note that muons are already present when pions appear. A straightforward calculations give the EHE neutrino mean flux:

$$F_\nu^{\pi} \simeq \frac{5.8\times10^{-37}}{\varepsilon_d}\frac{1+z}{\left(\sqrt{2.3+(1+z)^3}-\sqrt{3.3}\right)^2} \left(\frac{\widetilde{R}}{cm}\right)\left(\frac{T_e^{SPC}}{T_e^n}\right)^3 eV\,cm^{-2}\,s^{-1}\,sr^{-1}. \quad (2)$$

However, the resulting total mean URCA energy-loss rate will then be dramatically larger due to the simple URCA process in the case of neutrino cooling of SPC located on much far ($z \sim 1$).

• *Quark reactions:* In the protomatter core the distorted quark Fermi energies are far below the charmed c-, t- , and b- quark production thresholds. Therefore, only 'up', 'down', and 'strange' quarks are present. The β equilibrium is maintained by reactions like (a) $d \rightarrow u+e^-+\bar{\nu}_e,\quad u+e^- \rightarrow d+\nu_e$, and (b) $s \rightarrow u+e^-+\bar{\nu}_e,\quad u+e^- \rightarrow s+\nu_e$, which are β decay and its inverse. These reactions constitute simple URCA processes in which there is a net loss of a $\nu_l\bar{\nu}_l$ pair at nonzero temperatures. Reactions (a) and (b) provide a cooling mechanism for the SPC. Note that in β equilibrium these reactions proceed at equal rates, thus, the total energy of flux due to the simple URCA processes is twice that due to reaction (a) or (b) alone. A sufficient accuracy is obtained by assuming β-equilibrium and that the neutrinos not to be retained in the medium of Λ-like protomatter. The URCA-energy-loss rate of the SPC due to the neutrino emission process $d \rightarrow u+e^-+\bar{\nu}_e$ can be written

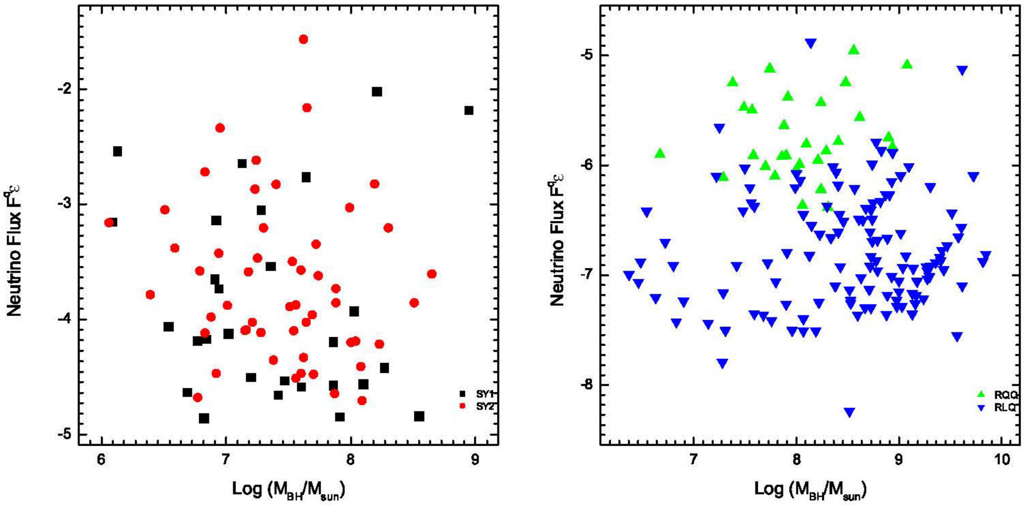

Figure 1: Flux-to-mass relation on logarithmic scales. Left panel: the SY1=Seyfert 1 and SY2=Seyfert 2. Right panel: the RQQ=radio-quiet and RLQ=radio-loud quasars.

$$\widetilde{\epsilon}^q_{\bar{\nu}\,\varepsilon} = 6V^{-1}\varepsilon\left(\prod_{i=1}^4 V\int \frac{d^3\widetilde{p}_i}{(2\pi)^3}\right)\widetilde{E}_{\bar{\nu}}V(2\pi)^4\times \delta^{(4)}(\widetilde{p}_d-\widetilde{p}_{\bar{\nu}_e}-\widetilde{p}_u-\widetilde{p}_e)\times \frac{|M|^2}{\prod_{i=1}^4 2\widetilde{E}_iV} f_d(1-f_u)(1-f_e). \quad (3)$$

where the momenta of particles of protomatter is denoted by wiggle. In this case, due to interaction, a rearrangement of vacuum state causes a shift of zero point energy and, thereby, the Poincaré generators of translations undergone the transformations. The four-vectors $\widetilde{p}_i$ in Eq. (3)are numbered as $i = 1,2,3,4 \equiv d,\bar{\nu}_e,u,e^-$, V is the normalization volume, $\mid M\mid^2$ is the squared invariant amplitude averaged over the initial d-quark spin and summed over the final spins of the u quark and the electron. Also, $f_\equiv \left[\exp\widetilde{\beta}(\widetilde{E}_i-\mu_i)+1\right]^{-1}$ is the fraction of phase space occupied at energy E_i (Fermi-Dirac distribution), the blocking factors $1-f_i$ accounting for the distribution of final states reduce the reaction rate, which ensure that the exclusion principle is obeyed; the factor 3 takes account of three color degrees of freedom, and 2 is the spin of the initial d quark. Since typical Fermi energies of quarks are high compared with the electron rest mass, a slight difference between μ_d and μ_e (or μ_s and μ_u) implies that the electrons will generally have a relativistic Fermi energy. In the framework of the model of standard electroweak interactions extended to semileptonic processes, for the processes with low distorted momentum transfer, the interaction Lagrangian density may be given in the form of a current-current interaction

$$\mathcal{L}^W_I = \frac{G}{2}\cos\theta_C\bar{u}\gamma^\mu(1-\gamma_5)d\,\bar{e}\gamma_\mu(1-\gamma_5)\nu_e, \quad (4)$$

where $G \simeq 1.435\times10^{-40} erg\,cm^3$ is the weak-coupling constant, θ_C is the Cabibbo angle ($\cos^2\theta \simeq 0.948$). The standard calculations give the resulting total mean EHE neutrino flux:

$$F^q_\nu \simeq \frac{3.4\times10^{-33}}{\varepsilon_d}\times \frac{1+z}{\left(\sqrt{2.3+(1+z)^3}-\sqrt{3.3}\right)^2}\times \left(\frac{\widetilde{R}}{cm}\right)\left(\frac{T_e^{SPC}}{T_e^n}\right)^3 eV\,cm^{-2}\,s^{-1}\,sr^{-1}. \quad (5)$$

Solving then the inverse problem we determine the radii and surface temperatures corresponding to these sources. The results of computations are summing up in the Fig. 1. As it is seen, the AGNs are favored as promising "pure neutrino sources" because the computed neutrino fluxes $F^q_\varepsilon \equiv \varepsilon_d F^q_{BH} \simeq (5.75\times10^{-9} \div 2,\dot{6}9\times10^{-2})(eV\,cm^{-2}\,s^{-1}\,sr^{-1})$, $F^\pi_\varepsilon = 1.7\times 10^{-4}F^q_\varepsilon$, and $F^u_\varepsilon = 2.5\times10^{-10}F^q_\varepsilon$ are highly beamed along the plane of accretion disk, and

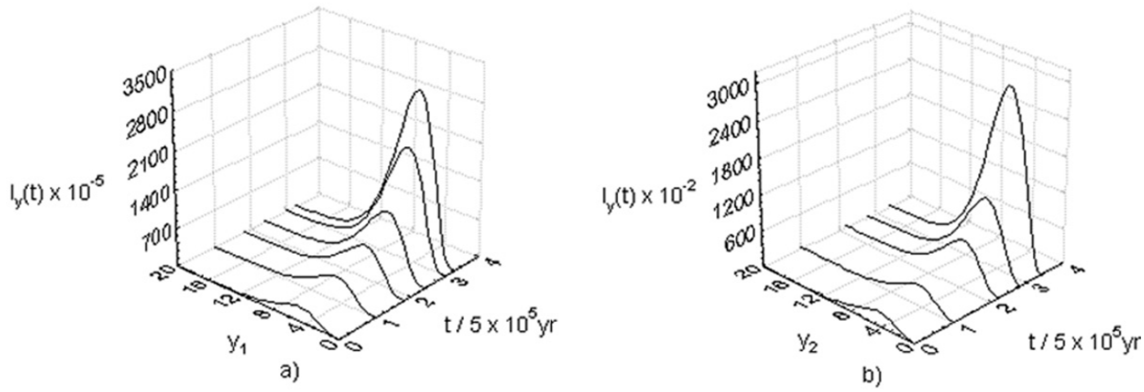

Figure 2: The mean EHE neutrino flaxes against the time for (a) "modified" URKA-processes, and (b) "simple" URKA-processes, in absence of muons and presence of SA.

peaked at high energies and collimated in smaller opening angle $\theta \sim 1/\gamma$, with relativistic γ factor of emitting protomatter-plasma corresponding to $\varepsilon_d \sim 10^{-6}$ or even narrower cone.

• *Self-Consistent Balance Problem of Neutrino Cooling of SPC:* Mean neutrino fluxes against the time can be determined from balance equation of the neutrino cooling of the SPC in presence of SA:

$$\frac{d\widetilde{U}}{dt} = -(\widetilde{L}_{\nu\,\varepsilon} + \widetilde{L}_{\gamma}) + \dot{\widetilde{M}}\,c^2, \qquad (6)$$

where thermal energy $\widetilde{U} = \widetilde{M}\,c^2$ resides exclusively in degenerate fermions of superdense protomatter of the core and disk. We assume the neutrino luminosity $\widetilde{L}_{\nu\,\varepsilon}$ dominates over the photon luminosity $\widetilde{L}_{\gamma}$, and use the expression $\dot{\widetilde{M}}$ for the ionized component of the interstellar medium. The results of numerical integrations of the equations describing the time evolution of AGN-neutrino flaxes are summed up in Fig. 2, where we inserted dimensionless intensities: $I_y(t_0) = d\,\widetilde{L}^{URCA}_{\nu\,\varepsilon}/A\,M_\odot\,c^2\,d\,y_1$, $I_y(t_0) = d\,\widetilde{L}^{q}_{\nu\,\varepsilon}/A\,M_\odot\,c^2\,d\,y_2$, where $y_1 \equiv \widetilde{E}_\nu/10^{21}\,eV$, $y_2 \equiv \widetilde{E}_{\bar{\nu}}/10^{21}\,eV$, $A^q \approx 2.6 \times 10^{-8}$ and $A^{URCA} \approx 5.2 \times 10^{-21}$. As it is seen the EHE neutrino fluxes increase with time for URKA-processes. The large flux of primary EHE neutrinos may initiate the cascades of EHECRs via very complex chains of interactions. This scenario supports the idea that AGNs can be a strong EHECR emitters.

Acknowledgements

(G.T.) gratefully thanks the Physics Dept. of SQU (Oman) for their hospitality, and for very friendly and scientifically exciting ambiance.

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