Neutrino Cooling and a Fueling at Disk Accretion Onto the SPC in AGN, and Origin of EHE G.R.s

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Abstract

Exploring the recent microscopic models of AGN [1] we investigate the stability of central, massive SPC and outline the main features of spherical accretion onto it. We solve the self-consistent balance problem of both the fueling at disk accretion onto SPC and its neutrino cooling via simple or nucleon-modified URCA processes and pionic reactions. We show that microscopic models are of vital importance for the crucial elements required for the GZK air shower events as far it predicts a large fluxes of EHE AGN-neutrinos above $10^{21}\, eV$. The part of neutrinos will be lost in the accretion disk and in a torus of hot gas surrounding the SPC to produce, further, the secondary EHE electrons, which, in turn, may give rise a secondary flux of the gamma-rays. This scenario supports the idea that AGNs can be a strong EHE G.R. emitters.

1. Introduction

Recently the microscopic generalization of the SBHA models of AGNs is developed [1] (and the references therein), wherein the particles have unique possibility to be accelerated up to the energy range above GZK cutoff [1-5]. This approach predicts a large flux of primary EHE extra-galactic AGN-neutrinos above $10^{21} eV$, even after the neutrino trapping in the superdense medium, produced by the predominant neutrino cooling of the SPC via simple or 'modified' URCA processes, and pionic reactions. This article is the continuation of [1], thus, tracing a complete resemblance with it we adopt its all ideas and notions.

- Primer on the Microscopic Models of AGNs

It is worth briefly reflecting upon the results far obtained in [1]. Discussed therein the gravitational theory explores a novel aspects expected from an assumed change of properties of space-time continuum (so-called, ID of the space-time continuum) in the central part of AGN in density range far above the nucleus. This manifests its virtues below the ID-threshold length, when the ID-mechanism acts. A matter located in the ID-region is undergone phase transition

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(a protomatter) of second kind, while the SPC is formed having the thermodynamic properties strongly differed from the thermodynamics of ordinary compressed matter. Therefore the equilibrium holds even for the maximum masses $M_{max} \simeq 3.48 \times 10^8 M_\odot$. After formation of the SPC, which accommodates the highest energy scale ($> 10^{21}\, eV$) in the central massive PC, it is located inside the EH sphere and could be observed only in presence of a matter to infall to the nucleus. At the early stage the compact SPC does work in the AGN absolutely in the same way as the central massive BH. But during the time $\leq 10^8\, yr$ this infalling matter has formed a PD around the PC tapering off faster at reaching out the edge of EH. The MSC effects acts then in the small region of intersection of PD with the EH, i.e.: the ID-field is switched on and a metric singularity disappeared, along with it a sharply increase of gravitational forces has ceased, and the particles may escape, in principle, through this vista to the outside world. The predominant cooling mechanism of the SPC is neutrino emission, namely the neutrino created leave the SPC carrying away energy and thus cooling of SPC. Both the quark- and the pion condensed PC cool much more rapidly than n-p-e-PC. In the latter the nucleon-modified URCA processes can occur only when the number of participating degenerate fermions is two larger than for simple URCA processes.

2. Prove of Stability of the SPC

Small radial deviations from equilibrium are governed by a Sturm-Liouville linear eigenvalue equation [6], with the imposition of suitable boundary conditions on normal modes with time dependence $\xi^i(\vec{x}, t) = \xi^i(\vec{x})\, e^{i\,\omega t}$. A necessary and sufficient condition for stability is that the potential energy be positive defined for all initial data of $\xi^i(\vec{x}, 0)$, namely if the frequency of normal mode of small perturbations is positive. A relativity tends to destabilize configurations. For the SPC one should note that the total mass M is located in the region of $r \leq \bar{r}$, $\bar{r}$-is the boundary of distribution of protomatter, thus, the ID-field $x(r) \neq 0$ (see [1]) gives an additional contribution $\left(\nabla \widetilde{P} - \nabla P\right)$ to the potential energy of interaction, where ∇P is the gradient of internal pressure, and hereinafter the quantities denoted by wiggles refer to SPC while the corresponding quantities of quark-star or neutron star are left without wiggles.. Therefore the condition for stability of SPC reads

$$\omega^2 \propto \bar{\Gamma}_1 - \frac{4}{3} - \frac{\beta}{3}\, \frac{|\widetilde{W}|}{M\, c^2} > 0, \qquad (1)$$

where $\beta \sim 1$ is the number dependent of internal structure of SPC, $\bar{\Gamma}_1$ is the pressure-averaged value of the adiabatic index $\Gamma_1 = \left(\partial\, \ln P / \partial\, \ln \rho\right)_s$, the generalized potential energy is written $\widetilde{W} = \int_0^{\bar{r}} \left[\left(\nabla \widetilde{P} - \nabla P\right) + (\widetilde{P} + \widetilde{\rho})F\right] d\,r$ and the gravitational acceleration reads $F = g^{00}\,\partial g_{00}/2\,\partial\,r$. According to [1], the condition eq.(1) yields $\bar{\Gamma}_1 > 1.671$. A numerical integrations of the equations eq.(2.31), eq.(4.1) and eq.(4.16)-eq.(4.22) in [1] gives $\bar{\Gamma}_1 \approx 2.216 \div 2.4$, which proves that the condition for stability of SPC holds.

3. Main Features of SA Onto SPC

We briefly outline the main features of spherical accretion onto SPC summed in the following three idealized models given below, that illustrate some of the physics associated with such a process.

- The Motion of Freely Moving Test Particles

Exploring the external geometry of SPC, with the given line element eq.(2.43) in [1], we consider the simplest model of the motion of freely moving test particle. Such particles move along geodesics, the equations of which being derivable from the variational principle that extremizes the distance along the wordline for the Lagrangian at hand

$$2L = (1 - x_0)^2\,\dot{t}^2 - (1 + x_0)^2\,\dot{r}^2 - r^2\sin^2\theta\dot{\varphi}^2 - r^2\dot{\theta}^2, \tag{2}$$

where $\dot{t} \equiv d\,t/d\,\lambda$ is the t-component of 4-momentum, and so on, λ is the affine parameter along the worldline, $x_0 = r_g/2r$ is the dimensionless gravitational potential. We are using the geometrized units and an affine parametrization such that $L = const$. The Euler-Lagrange equations show that if we orient the coordinate system so that initially the particle is moving in the equatorial plane (i.e. $\theta = \pi/2$, $\dot{\theta} = 0$), then the particle remains in this plane. There is two constant of the motion corresponding to the ignorable coordinates t and ϕ, namely the E-"energy-at-infinity", and the l angular momentum. The main features of free radial infall of particle from the infinity to EH ($x_0 = 1$) of SPC is absolutely the same as in the Schwarzschild geometry of BH. Namely, the particle may reach to EH for the infinite time measured by the distance observer, while its radial velocity equals zero at the points $r = r_g/4$ and $r = r_g/2$. However, the locally measured value of this time is finite, and the particle is observed by a local static observer at r to approach the EH along a radial geodesic at the speed of light, independent of l. Passing through the EH the particle continues in falling to reach the surface of the SPC. One can get a general picture of orbits just outside the EH ($r > r_g/4$) [1] by considering an "effective potential" $V(r) = (1 - x_0)^2\left(1 + \widetilde{l}^2/r^2\right)$, where $\widetilde{E} \equiv E/m$, $\widetilde{l} \equiv l/m$. There are no maxima or minima of V for $\widetilde{l} < 2\sqrt{2}\,M$. Circular orbits occur when $\widetilde{l} = Mr^2/(r - 2M)$ and $\widetilde{E}^2 = (r - M)^3/r^2(r - 2M)$.

Thus, circular orbits exist down to $r = 2M$, the limiting case corresponding to a photon. The circular orbits are stable if V is concave up, namely at $r > 4M$. The binding energy per unit mass of a particle in the last stable circular orbit at $r = 4M$, $\widetilde{E}_{binding} = (m - E)/M = 1 - (27/32)^{1/2}$.

- Collisionless SA Onto SPC

The distribution function f for a collisionless gas is determined by the collisionless Boltzmann equation or Vlasov equation, which is simply a statement of Liouville's theorem on a continuity for the flow of particles in phase space. In simplest case, for stationary, spherical distributions with isotropic velocities $f(E) = n_\infty \delta(E - E_\infty)/4\pi(2E_\infty)^{1/2}$, where far from the SPC the particle density is uniform and equal to n_∞ and the particle speed is $v_\infty << 1$, we get

$$n(r) = -\frac{n_\infty}{E_\infty v_\infty} \left\{ \left(E_\infty^2 - 1\right)^{1/2} - \left(E_\infty^2 - g_{00}(r)\right)^{1/2} + \right.$$
$$\left. \frac{1}{2} \ln \left| \frac{E_\infty^2 + \left(E_\infty^2 - g_{00}(r)\right)^{1/2}}{E_\infty^2 - \left(E_\infty^2 - g_{00}(r)\right)^{1/2}} \right| - \frac{1}{2} \ln \left| \frac{E_\infty^2 + \left(E_\infty^2 - 1\right)^{1/2}}{E_\infty^2 - \left(E_\infty^2 - 1\right)^{1/2}} \right| \right\}, \quad (3)$$

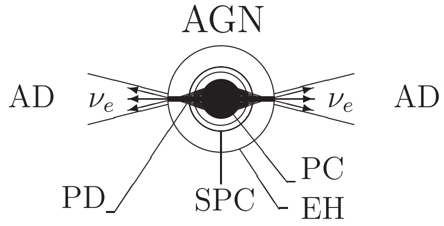
where g_{00} is given by the eq.(2.33) in [1]. Thus, approaching to EH the density of particles increases as $\left.\frac{n(r)}{n_\infty}\right|_{x_0 \to 1} \approx -\frac{1}{2\, v_\infty} \ln g_{00}$ up to the ID-field threshold value $n(r)^{-1/3} = 0.4 fm$, when the matter becomes protomatter (metric singularity vanishes - MSC effect) and it passes through EH forming the PD around the PC.

- Hydrodynamic SA Onto SPC

Here we discuss the analogue of Bondi equations for spherical, steady-state, adiabatic accretion onto SPC of mass M. The key equations then are baryon conservation, momentum conservation (relativistic Euler equation), and entropy equation. For any equation of state obeying the causality constraint $a^2 < 1$, where a is the sound speed, the flow must pass through a critical point r_s outside the EH. At large $r >> r_g/2$, where the inward radial velocity $u << 1$, one has $|v^{\hat{r}}| = u$; as $r \to \infty$, the proper flow velocity $v^{\hat{r}} \to 0$ and is subsonic. At $r = r_g/2$, $|v^{\hat{r}}| \equiv 1 > a$ and the proper velocity, which equals the speed of light, is supersonic. Note that this condition is independent of the magnitude of u. To calculate an explicit value for transonic accretion rate we need to adopt a polytropic equation of state. The critical accretion rate is determined by conditions at the same point r_s, which lies far outside the EH and, thus, uninfluenced by strong gravity. The approximate equality between the sound speed a_∞ and the mean particle speed v_∞ implies that the hydrodynamic accretion rate is larger than the collisionless accretion rate by the large factor $c/a_\infty \approx 10^9$. There exists, as well, the subsonic motion everywhere, when the flow is "choked off" by back pressure in subsonic regime. Thus, a total mass up to $2 \times 10^8\, M_\odot$ should be available inside of EH during the duty cycle of the AGN ($< 10^8\, yr$) [1]. For the mass to infall to the center, it must lose its large angular momentum which can be due to viscous torques in a geometrically thin AD.

4. 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:



$$\frac{d\widetilde{U}}{dt} = -(\widetilde{L}_{\nu\,\varepsilon} + \widetilde{L}_\gamma) + \dot{\widetilde{M}}\, c^2, \tag{4}$$

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 [1]. The results of numerical integrations of the equations describing the time evolution of AGN-neutrino flaxes are summed in figure 1. According to eq.(5.8) and eq.(5.14) in [1], we insert 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 part of neutrinos will be lost in the accretion disk and in a torus of hot gas surrounding the superdense core to produce, further, the secondary EHE electrons, which, in turn, may give rise a secondary flux of the gamma-rays. This scenario supports the idea that AGNs can be a strong EHE G.R. emitters. This is not a final report on a closed subject, but it is hoped that it will thereby add the knowledge on the role of detected EHE C.R.s as a signature of existence of protomatter sources in the Universe.

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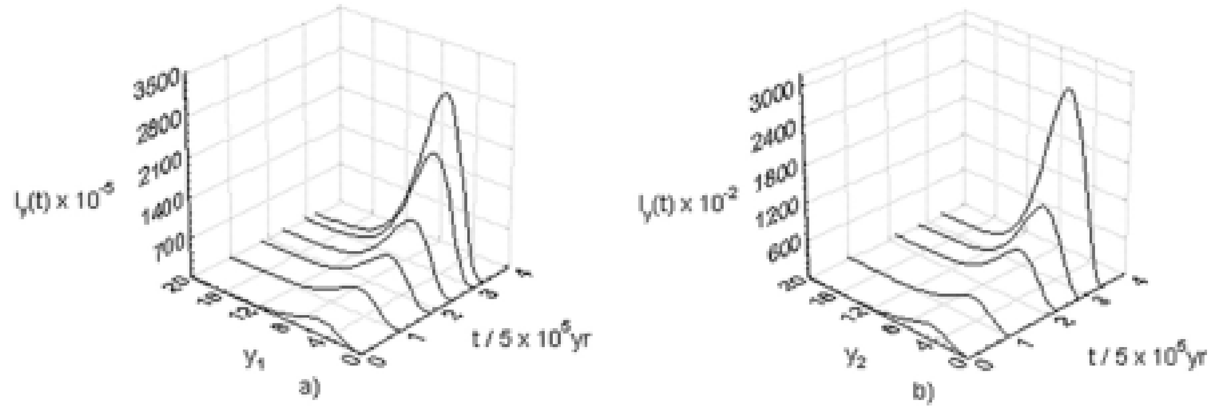

Fig. 1. The mean EHE AGN-neutrino flaxes against the time for (a) "modified" URKA-processes, and (b) "simple" URKA-processes, in absence of muons and presence of SA.

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5. List of Symbols/Nomenclature

EHE=Extremely High Energy
SPC=Superdense Protomatter Cores
PC=Protomatter Core
AD=Accretion Disk
SA=Spherical Accretion
C.R.=Cosmic Ray
SBHA=Standard Black Hole Accretion
BH=Black Hole
EH=Event Horizon
MSC=Metric Singularity Cutoff
G.R.=Gamma-Ray
GZK=Greisen-Zatsepin-Kuzmin

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