Comment on the paper Neutrino lighthouse at Sagittarius A*: Interior of a black hole as the birthplace of cosmic rays and neutrinos

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Interior of a black hole as the birthplace of cosmic rays and neutrinos

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Abstract

Apparently a quarter of very-high-energy neutrinos detected so far at the IceCube [1, 2] come from the center of the Milky Way, i.e. *the supermassive black hole in the center of our galaxy behaves as a neutrino (or antineutrino?) factory* [3]. A few years ago [4, 5, 6] it was argued that if particles and antiparticles have gravitational charge of the opposite sign, the interior of a black hole must be the birthplace of cosmic rays including neutrinos; hence, generally speaking, each black hole *must be a point-like source of antineutrinos*. Now, we show that, in the case of the Milky Way's supermassive black hole, our theoretical predictions are compatible with the observed range (30 TeV to 2 PeV) of energies.

So far the IceCube experiment [1, 2] has observed 36 very-high-energy neutrino events with energies in the 30 TeV to 2 PeV range. A recent paper [3] *Neutrino lighthouse at Sagittarius A** has revealed the first observational hints that 9 of these 36 neutrinos come from the center of our Galaxy; apparently the Milky Way's supermassive black hole acts as a "factory" of high-energy neutrinos. As underlined in the aforementioned paper "the origins of ultra-high-energy and very-high-energy cosmic rays and ultra- and very-high-energy astrophysical neutrinos are major unknowns". If confirmed that Sagittarius A* is a point-like source of neutrinos, black holes will be established as major origins of cosmic rays and neutrinos; however the physical mechanism of their creation will remain an open question. The eventual understanding of the mechanism will presumably demand huge scientific efforts and the study of many different ideas including the "wild" ones. In the present Comment we focus on that topic and suggest one possible mechanism for creation; the proposed mechanism distinguishes from all mechanisms proposed so far in that the birthplace of cosmic rays and neutrinos is deep inside the horizon of a black hole.

Let us start by noting that the gravitational properties of antimatter are not known. Hopefully, before the end of this decade, three competing experiments at CERN (AEGIS [4], ALPHA [5] and GBAR [6]) will reveal if atoms of antihydrogen fall down or fall up in the gravitational field of the Earth, i.e. if particles and antiparticles have the gravitational charge of the same or opposite sign.

The eventual gravitational repulsion between matter and antimatter inevitably leads to the conclusion that the interior of a black hole can be the birthplace of cosmic rays and in particular neutrinos. Simply, in the case of a black hole made from matter, a fraction of antiparticles created within the horizon will be violently ejected outside the horizon. As we will argue in the case of a supermassive black hole the ejected antiparticles might have ultra-high-energy.

A black hole can absorb material from its neighborhood. It is obvious that, as the result of the collisions of the infalling material (analogous to collisions in our accelerators), different kinds of antiparticles can be created *inside the horizon* and (assuming the gravitational repulsion between matter and antimatter) some of them will be violently ejected outside the horizon. Of course, the ejection rate should be greater if the quantity of the infalling material is greater; hence the black hole behaves as an *irregular source* of cosmic rays and neutrinos.

In addition to this irregular creation and emission of antiparticles there is a second mechanism of creation of particle-antiparticle pairs, mainly neutrino-antineutrino pairs as described [7, 8, 9] a few years ago. Namely, virtual particle-antiparticle pairs from the quantum vacuum might be converted into real ones by a sufficiently strong gravitational field deep inside the horizon of a black hole (this is the gravitational analog of the Schwinger mechanism in quantum electrodynamics). However, for the supermassive black hole in the center of the Milky Way, the energy of emitted antineutrinos (resulting from a *direct* creation of neutrino-antineutrino pairs) is estimated to be less than a few tens GeV [7, 8] which is incompatible with the observed range (30 TeV to 2 PeV) and roughly one order of magnitude less than is needed for the detection at the best available neutrino telescope Ice Cube at the South Pole. It is unfortunate that only a small region of the IceCube array (called Deep Core [10]) is enabled to detect neutrinos (antineutrinos) with energies as low as about 10 GeV. Hopefully, the next generation of neutrino telescopes will be designed to lower the IceCube neutrino energy threshold by over an order of magnitude making it possible to test predictions of reference [7] for both Milky Way and Andromeda Galaxy.

According to the above discussion we are forced to try to explain the observed energy range (30 TeV to 2 PeV) as result of creation of particle-antiparticles pairs in collisions of the infalling matter with matter of the black hole. One of major previous results [7, 8, 9] is that matter of a black hole is not collapsed to a singularity but rather compressed in a "ball" of small, but still macroscopic size, with "radius" which (in the simplest case of a Schwarzschild black hole) is well approximated by $r_H \approx \sqrt{\lambdabar_e R_S}$,where $\lambdabar_e$ and R_S are respectively the reduced Compton wavelength of an electron and the Schwarzschild radius of the black hole. A simplified picture is that the accelerated infalling matter hits the black hole considered as a fixed target in the same way as we do it in our accelerators and leads to production of particle-antiparticle pairs. As argued in the previous work [7, 8] the energy ε_m with which an infalling particle of mass m hits the target (and consequently the upper limit for energy of products of collision) is

$$\varepsilon_m \approx \sqrt{\frac{R_S}{\lambdabar_e}} mc^2 \tag{1}$$

Consequently, in the case of Milky Way's supermassive black hole (with a mass of about four million solar masses), an infalling proton or neutron, might hit the "surface" of the black hole (determined by r_H) with an energy of about $10^{11} GeV$; such a maximum of collision energy makes possible the observed range (30 TeV to 2 PeV) of antineutrino energies. In the case of the largest known black holes (about ten billion solar masses) the energy of infalling protons and neutrons may be of the order of $10^{13} GeV$; incidentally, this energy is comfortably larger than the energy of the most energetic cosmic rays, which opens the possibility that supermassive black holes are origin of ultra-high-energy cosmic rays.

For the black hole in the center of our galaxy the accretion rate is very low (see for instance a recent review [11]); roughly only about a few billionths of the solar mass per year (see Table 7.1 in [11]) falls inside the horizon. This infalling mass expressed in the number of protons is about a few times $10^{48}\ p/year$. As noticed in [11], larger accretion rates probably occur from time to time when large, low angular momentum gas clouds fall into the center, or when a star is scattered to within the tidal disruption radius at a rate of once every 40,000 years; however for illustrative purpose we use the standard accretion rate of a few times $10^{48}\ p/year$. Collisions of the infalling material (mainly protons) will produce a huge number of antineutrinos, but the expected number of antineutrinos should be smaller than the number of infalling protons. For example, possible scenarios of proton-proton collisions include

$$p + p \to p + p + \pi^0 \quad and \quad p + p \to p + p + \pi^+ \tag{2}$$

Consequently, neutrinos and antineutrinos are result of decay of π^0 and π^+; however the majority of decay modes leads to creation of neutrinos [13] and only a tiny fraction of decays (like $\pi^0 \to \gamma\nu\bar{\nu}$) produces antineutrinos which can be ejected outside of the horizon. Hence, the number $N_{\bar{\nu}MW}$ of the created antineutrinos (within the horizon of Milky Way's supermassive black hole) must be much smaller than the number of infalling protons.

The probability to detect an antineutrino within the IceCube can be approximated by

$$P \approx 1.3 \times 10^{-6} E^{0.8} \quad for \quad E = 1 - 10^{3}\, TeV \tag{3}$$

which is essentially the formula (10) from Halzen [12].

Taking into account the size of the IceCube and its distance from the black hole, the number of antineutrinos that can hit the IceCube is $\approx 1.27 \times 10^{-36} N_{\bar{\nu}MW}$. Together with the approximation (3) this leads to the following estimate of the expected number of detections

$$N_{\det} \approx 1.65 \times 10^{-42} E^{0.8} N_{\bar{\nu}MW} \quad for \quad E = 1 - 10^{3}\, TeV \tag{4}$$

For *illustration* let us take the mean value of energies of detected (anti)neutrinos (see Table 1 in [3]) which is about 224 TeV; consequently $E^{0.8} \approx 75$ and $N_{\det} \approx 1.2 \times 10^{-40} N_{\bar{\nu}MW}$. If $N_{\bar{\nu}MW} \approx 10^{41} / year$ (which is quite plausible according to the above discussion and accretion rate) we must detect a few antineutrinos per year in good agreement with [3], i.e. apparently 9 detections within a 3 year period!

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