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Neutrino Majorana Mass from Black Hole

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Abstract

We propose a new mechanism to generate the neutrino Majorana mass in TeV-scale gravity models. The black hole violates all non-gauged symmetries and can become the origin of lepton number violating processes. The fluctuation of higher-dimensional spacetime can result in the production of a black hole, which emits 2 neutrinos. If neutrinos are Majorana particles, this process is equivalent to the free propagation of a neutrino with the insertion of the black hole. From this fact, we derive the neutrino Majorana mass. The result is completely consistent with the recently observed evidence of neutrinoless double beta decay. And the obtained neutrino Majorana mass satisfies the constraint from the density of the neutrino dark matter, which affects the cosmic structure formation. Furthermore, we can explain the ultrahigh energy cosmic rays by the Z-burst scenario with it.

TeV-scale gravity models propose that the true fundamental scale is O(TeV), and thus many effects of the quantum gravity will appear in future experiments. The most appealing phenomenon is the production of TeV-scale black holes. TeV-scale colliders or high-energy cosmic ray detectors can be the candidates of black hole factories. The black hole is considered to break all non-gauged symmetries. So we can expect the lepton number violating processes occur in the decay of black holes [1].

In this letter, we consider a new mechanism to generate the neutrino Majorana mass from a black hole. The existence of the neutrino Majorana mass implies that the lepton number is violated in nature. [2] announced that the HEIDELBERG-MOSCOW double beta decay experiment observed the evidence for neutrinoless double beta decay. It will be the first evidence of the lepton number violation in the world, if confirmed. Our mechanism naturally explains the result of [2]. The obtained Majorana mass is consistent with the expected density of the neutrino dark matter in the universe. Furthermore its value enables the Z-burst scenario to explain cosmic rays above the GZK cutoff.

In TeV-scale gravity models, we have to identify the number of extra dimensions n, and the true fundamental scale M_D. Since superstring theory or M-theory suggest 10-dimensional or 11-dimensional spacetime, we consider the cases of $n = 6, 7$ in this letter.

As is pointed out in [3, 4], the decay of black holes do not discriminate any of the Standard Model (SM) particles. The possibility that a certain particle being emitted from a black hole depends on the degree of freedom of the particle. That of the SM is about 120, of a neutrino is 2, and of a Higgs boson is 1.

Since we do not know the fundamental theory of the quantum gravity, we have to depend on the semiclassical approximation. To validate this description, the entropy of a black hole must be large enough [5]. From this requirement, we have $M_{BH} \gtrsim 5M_D$, where M_{BH} is the black hole mass. And as we raise the black hole mass, the production rate of the black hole is reduced drastically. So we consider a black hole with mass $M_{BH} \sim 5M_D$.

From figure 1, we observe that the number of particles emitted from a black

hole is about 4 if $M_{BH} \sim 5M_D$. So we can consider the production of 2 neutrinos and 2 Higgs bosons from a black hole which is produced by the fluctuation of (n+4)-dimensional spacetime.

Let us assume that neutrinos are Majorana particles. Then this process leads to the Majorana mass term of neutrinos, as can be seen in figure 2. Since ν^c is the antiparticle of ν, figure 2 can be interpreted as the propagation of ν, with the insertion of a black hole and 2 Higgs bosons. This insertion leads to the neutrino Majorana mass.

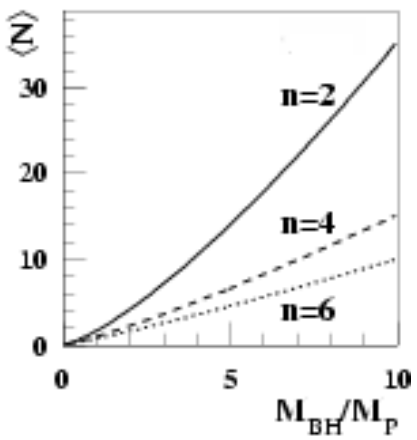

Figure 1: The average decay multiplicity for a Schwarzschild black hole [4]. Here $M_P = M_D$.

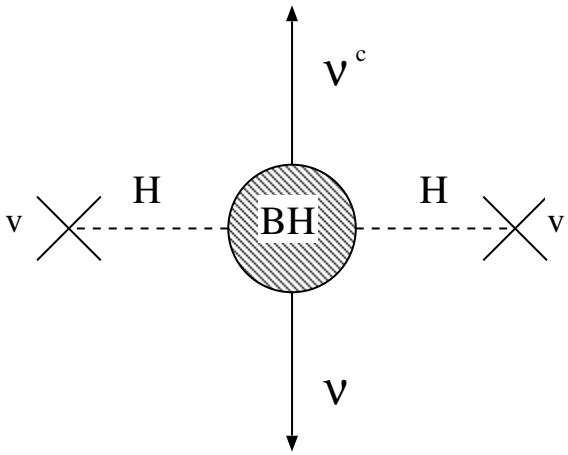

Figure 2: The Feynman diagram responsible for the Majorana mass term of neutrinos.

Now we estimate the neutrino Majorana mass obtained in the process figure 2.

Firstly, the black hole must survive until they decay into 2 neutrinos. The Planck time of $(n+4)$-dimensional spacetime is given by [6]:

$$t_{pl} = \left[\frac{(2\pi)^{n-1}}{4M_D^{n+2}}\right]^{1/(n+2)}, \tag{1}$$

and from the uncertainty principle, we can violate the conservation low of energy during Δt. It is:

$$\Delta t = \frac{1}{\Delta E} = \frac{1}{5M_D}. \tag{2}$$

So the suppression factor arises from the time instability of the black hole is:

$$\frac{\Delta t}{t_{pl}} \sim \frac{1}{15}. \tag{3}$$

Secondly, the black hole should hold the energy $M_{BH} \sim 5M_D$ inside the $(n+4)$-dimensional Schwarzshild black hole, whose radius is R_S. This fact leads to the suppression factor:

$$\left(\frac{1}{5M_D R_S}\right)^3 \sim (\frac{1}{5})^3, \tag{4}$$

where R_S is given by [7]:

$$R_S = \frac{1}{\sqrt{\pi} M_D}\left[\frac{M_{BH}}{M_D}\left(\frac{8\Gamma(\frac{n+3}{2})}{n+2}\right)\right]^{1/(n+1)}. \tag{5}$$

Thirdly, the black hole must emit 2 neutrinos (since these neutrinos form the Majorana mass term, their degree of freedom is 2.) and 2 Higgs bosons which acquire the vacuum expectation values (VEV). The probability of this decay mode being realized is given by:

$$\frac{2 \cdot 1^2}{121^4} \sim 9.3 \times 10^{-9}. \tag{6}$$

Finally the VEV of Higgs bosons v is suppressed by the true fundamental scale M_D. So the existence of 2 Higgs bosons results in the suppression factor:

$$(\frac{v}{M_D})^2 = (\frac{0.174 \text{ TeV}}{M_D})^2. \tag{7}$$

Including all of the results, the neutrino Majorana mass becomes:

$$\begin{aligned} m &= M_{BH} \ (\frac{1}{15}) \ (\frac{1}{5})^3 \ (9.3 \times 10^{-9}) \ (\frac{0.174 \text{ TeV}}{M_D})^2 \\ &= 0.75 \text{ eV } (\frac{1 \text{ TeV}}{M_D}). \end{aligned} \tag{8}$$

Here we obtain the tiny neutrino Majorana mass using the arguments about the TeV-scale black hole only. From now we discuss the obtained neutrino Majorana mass with experimental results.

Consider about neutrinoless double beta decay. [2] searched the decay mode $^{76}Ge \rightarrow ^{76} Se + 2e^{-}$, and reported the half life to be:

$$T_{1/2}^{0\nu} = (0.8 - 18.3) \times 10^{25} \text{ yr.} \tag{9}$$

This result can be interpreted as the existence of neutrino effective mass:

$$\langle m \rangle = (0.11 - 0.56) \text{ eV with best fit } 0.39 \text{ eV}, \tag{10}$$

which is defined by $\langle m \rangle \equiv |m_1|U_{e1}|^2 + m_2|U_{e2}|^2 + m_3|U_{e3}|^2|$. Here $U_{\alpha i}$ are the MNS matrix elements [8], and for the simplicity we do not consider about CP-violation in the lepton sector now. We justify this neglectfulness later.

In our setup, neutrinoless double beta decay is induced by a black hole. Its explicit process is shown in figure 3.

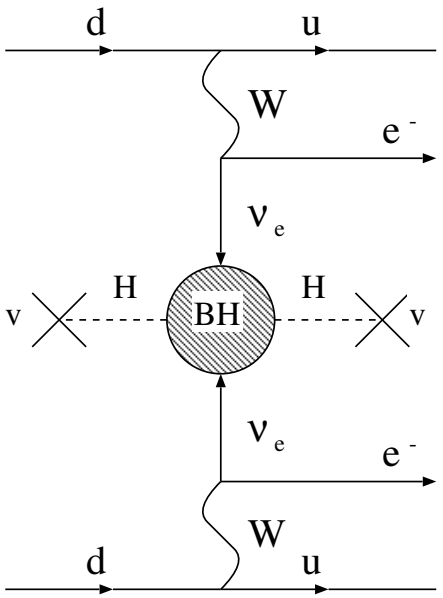

Figure 3: The explicit example of neutrinoless double beta decay induced by a black hole.

The neutrino Majorana mass is generated by a black hole, resulting in $m = (0.75 \text{ eV})\ (1 \text{ TeV})/(M_D)$. So 3 generation neutrinos are almost degenerate, and radiative corrections split their masses. From CHOOZ experiment [9] we have $|U_{e3}|^2 < 0.03$ and we neglect this term. Then $\langle m \rangle$ is roughly given by $2m$. From

equation (10), in order to explain the observed neutrinoless double beta decay by our mechanism, we obtain:

$$0.11 \leq 1.5 \frac{1 \text{ TeV}}{M_D} \leq 0.56, \text{ with best fit } 0.39 \tag{11}$$

This result can be interpreted as a constraint on M_D. It becomes:

$$2.7\text{TeV} \ \leq M_D \ \leq 14\text{TeV}, \text{ with best fit } 3.8 \text{ TeV}. \tag{12}$$

From naturalness of TeV-scale gravity models, M_D should not exceed 1TeV too much. But as you can see from equation (12), we can explain the result of [2] without spoiling it. If we take into account the effects of CP-violation, $\langle m \rangle$ becomes smaller because a CP-violating phase cancels the contribution between m_1 and m_2. As a result, the value of M_D is also reduced and naturalness improves. So the neglectfulness of CP-violation do not affect our discussions.

So we arrive at an interesting result. **The TeV-scale black hole can be a very natural origin of the observed neutrinoless double beta decay.** If a CP-violating phase modifies the allowed region of M_D, There exists a possibility that the LHC can observe semiclassical TeV-scale black holes. In that case we can compare the value of M_D obtained from neutrinoless double beta decay experiments and at the LHC, and verify whether the neutrino Majorana mass is generated by a black hole or not.

Hereafter we consider about the astrophysical constraints on the masses of neutrinos, and show you that our results are consistent with them.

First consider about the dark matter in the universe. Neutrinos can be the candidates of the hot dark matter, and their masses affect the evolution of the universe. The most stringent constraint in the case of three degenerate neutrinos is obtained by the considerations on the cosmic structure formation in the low-matter density universe. It becomes [10]:

$$\sum_{i=1}^{3} \leq 1.8 \text{ eV}, \tag{13}$$

where i denotes the generation of neutrino. To satisfy this constraint, the true fundamental scale M_D should be:

$$M_D \geq 1.3 \text{ TeV}. \tag{14}$$

This is consistent with equation (12). And from the identity: $\Omega_\nu h^2 = \sum_{i=1}^{3} m_i/(93.8\text{ eV})$, we obtain:

$$\Omega_\nu h^2 = 0.024 \frac{1\text{ TeV}}{M_D} \leq 0.018. \tag{15}$$

So the neutrino component can contribute to the matter density of the universe less than about 13%. (Here we assumed that $h = 0.7$ [11] and $\Omega_m = 0.28$ [12, 13].)

Next consider about the ultrahigh energy cosmic rays. After the measurement of the cosmic microwave background (CMB) radiation, it was claimed that the spectra of cosmic rays suddenly dump at the energy $E \sim 4 \times 10^{19}$ eV (the GZK cutoff), since at the energy cosmic rays result in the interaction with the CMB photons and lose their energies [14]. But some experiments like AGASA [15] found cosmic rays above the cutoff. This is a serious challange not only for astrophysicists but also for particle physicists.

Many scenarios are proposed to explain such cosmic rays, but here we consider about the Z-burst scenario. It is based on the Z boson production resulting from the resonant annihilation of ultrahigh energy cosmic neutrinos with relic neutrinos into Z bosons. Since neutrinos do not interact with the CMB photon even if their energies are very high, they can travel a very long distance. So we can explain cosmic rays above the GZK cutoff if they annihilate into Z boson near our galaxy, escaping from the short attenuation length of ultrahigh energy cosmic rays.

[16] showed that in the case ordinary cosmic rays are protons of extragalactic origin, the required neutrino mass to explain current experiments is given by:

$$0.08\text{eV} \leq m_\nu \leq 1.3\text{eV}. \tag{16}$$

Our results can satisfy this condition if:

$$0.58\text{TeV} \leq M_D \leq 9.4\text{TeV}. \tag{17}$$

From equation (14), we cannot explain some region of this constraint. But most of the region are consistent with the previous results.

Now we show you the three obtained constraints on the true fundamental scale M_D in our model, namely the neutrino Majorana mass is generated by the TeV-

scale black hole.

$2.7 \text{ TeV} \leq M_D \leq 14 \text{ TeV}$ with best fit $M_D = 3.8$ TeV,

in order to explain the observed neutrinoless double beta decay. (18a)

$M_D \geq 1.3$ TeV,

from the considerations about the density of the neutrino dark matter. (18b)

$0.58 \text{ TeV} \leq M_D \leq 9.4 \text{ TeV}$,

in order to explain cosmic rays above the GZK cutoff by the Z-burst scenario. (18c)

So we can explain three experimental results stated above by assuming:

$$2.7 \text{ TeV} \leq M_D \leq 9.4 \text{ TeV}. \tag{19}$$

To summarize, we propose a new mechanism to generate the neutrino Majorana mass in the context of TeV-scale gravity models. The TeV-scale black hole can generate the neutrino Majorana mass, and the observed neutrinoless double beta decay is naturally explained by the mechanism. If it is correct, the true fundamental scale M_D measured by neutrinoless double beta decay experiments and at the future colliders should agree. This can be a definite test of the results shown in this letter. The obtained neutrino Majorana mass is consistent with the astrophysical constraint on the density of the neutrino dark matter, which affects the cosmic structure formation. And it enables us to explain cosmic rays above the GZK cutoff by the Z-burst scenario.

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