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Neutrino mass and the Void structure of our Universe

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Recent neutrino oscillation experiments limit the range of the squared mass difference of two neutrino types with good accuracy. Combining the oscillation results with beta decay experimental result and the 2df result, the mass range of tau neutrino is constrained to be in the range $0.06 - 0.27\,\mathrm{eV}$. Using of this result, the author comes to the very interesting conclusion that if one kind of neutrino has a mass of $0.27\,\mathrm{eV}$, the void structure of our universe can be naturally explained.

1. Introduction

Muraki (1990) [1] discussed a relation between neutrino mass and dark matter of our Galaxy, noting that if one kind of neutrino had a mass of about $13\,\mathrm{eV}$, the dark matter of our Galaxy could be explained naturally by the neutrino mass. Since then, 15 years have passed and cosmic ray physicists have made great effort to limit the neutrino mass in a narrow range based on neutrino oscillation experiments. The experiments were either performed by using the long distance baseline between the Sun and the Earth or a short distance baseline in the atmosphere of the Earth [2, 3].

By this method, the difference of squared masses between two kinds of neutrinos is obtained in the form: $m_{\nu 2}^2 - m_{\nu 1}^2$ or $m_{\nu 3}^2 - m_{\nu 2}^2$. However by this method, the absolute mass of each neutrino type cannot be determined. Therefore we must use other data obtained by the beta decay experiment to determine the mass of the electron neutrino. According to current result obtained by the beta decay experiment, the upper limit of electron neutrino mass is less than $3\,\mathrm{eV}$ [4].

A further upper limit on the neutrino mass has been obtained by using cosmological data. By combining data obtained by WMAP (the microwave background fluctuation) and 2df (the measurement of the distribution of galaxies), the upper limit for the total mass of neutrinos is set at $\Sigma m_{\nu i} < 0.71\mathrm{eV}$ [5]. This provides the current upper limit on the absolute value of the neutrino mass. Taking account of these results, little freedom is now left on the range of the neutrino mass. So the hypothesis that the neutrino mass is the origin of the dark matter in our Galaxy must be abandoned. Therefore in this paper the author discusses another role of the neutrino mass in the universe. First we will fix the most plausible mass of neutrinos of each kind, i.e., for electron neutrino ($m_{\nu 1}$), muon neutrino ($m_{\nu 2}$) and tau neutrino ($m_{\nu 3}$). Then we will propose a possible scenario of the role of neutrino mass in our universe.

2. The neutrino mass and its role in our universe

The super Kamiokande experimental results show that the squared mass difference of neutrinos must be $0.0001\,\mathrm{eV/c^2}$ and $0.003\,\mathrm{eV/c^2}$ for $m_{\nu 2}^2 - m_{\nu 1}^2$ and $m_{\nu 3}^2 - m_{\nu 2}^2$ respectively. On the other hand we know from cosmological data that the total sum of neutrino mass. They must be less than $0.71\,\mathrm{eV/c^2}$. So the maximum masses of neutrinos must be less than $\leq 0.27\,\mathrm{eV}$ for $m_{\nu 3}$, for $m_{\nu 2} \leq 0.22\,\mathrm{eV}$, and for $m_{\nu 1} \leq 0.21\,\mathrm{eV}$. Let us call this possibility <u>case 1</u>.

In the other case, neutrinos should have a mass of at least $\geq 0.05\,\mathrm{eV}$. This conclusion results from the neutrino oscillation experiments [3]. Therefore in <u>case 2</u>, we can set the mass for each neutrino to be $m_{\nu 1} = 0.00005\,\mathrm{eV}$,

Figure 1. A pictorial presentation of the bubble void structure of our universe. On the surface of the bubble, matter galaxies are formed, while inside one bubble, neutrinos do exist.

$m_{\nu 2} = 0.01\,\mathrm{eV}$ and $m_{\nu 3} = 0.06\,\mathrm{eV}$. These masses are the lowest mass allowed for neutrinos. The mass of $m_{\nu 1}$ is not provided by the oscillation experiment itself, so I have assumed it by the analogy of the mass difference between charged leptons, $e : \mu = 1 : 200$.

In case 1, a dramatic thing is expected from the fact that neutrinos have the mass. Our scenario is as follows:

1. neutrinos have mass.
2. neutrinos are Dirac particles and they have a spin $1/2$.
3. for Dirac particles, the degeneracy force must be considered.
4. massive neutrinos are attracted by the gravitational force.
5. however because of the degeneracy force, they will not collapse to form a super black hall.
6. the Jeans mass of neutrinos grows and fluctuation of the baryonic matter will be erased.
7. the fluctuation of the baryonic matter can grow only at the border between neutrino bubbles.
8. the observed void structure of the universe [6] was formed by the neutrino degenerate force and growth of the density fluctuation at the border.

According above scenario we can estimate the size of condensed neutrino clouds. The method is the same as described in the paper of reference [1]. The radius of a neutron star can be obtained by the balance between the degenerate force of neutrons and the gravitational force: $r_n = 1.2(h^2/G)(1/M_n)^{1/3}(1/m_n)^{8/3} \approx 10\,\mathrm{km}$, where M_n corresponds to a 1.4 solar mass neutron star and h is Planck constant divided by 2π. As the

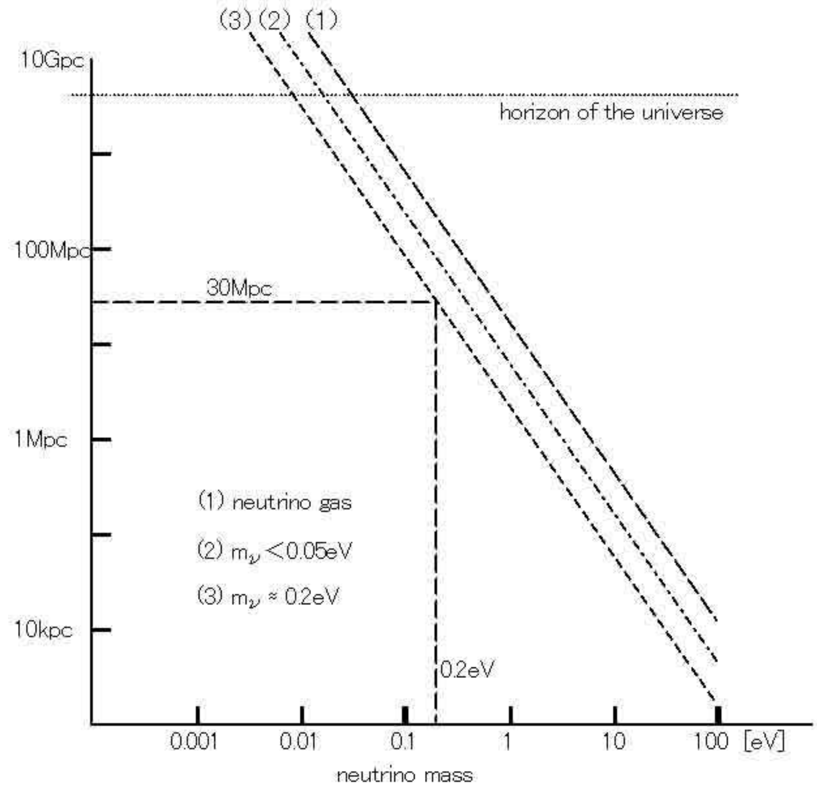

Figure 2. The relation between the radius of the neutrino cloud and the neutrino mass. In case the neutrino mass is 0.2 eV, the radius for the neutrino cloud is expected as 30 Mpc.

same way, we can obtain the radius of a neutrino cloud: $r_\nu = 1.2(h^2/G)(1/M_\nu)^{1/3}(1/m_\nu)^{8/3}$. Here M_ν corresponds to the mass of neutrino cloud or the total mass of neutrinos involved in a void. The M_ν may be expressed by $(4/3\pi r_\nu^3) \times 110 \times 10^6[\mathrm{m}^3] \times m_\nu[\mathrm{eV}] \times 1.7 \times 10^{-36}[\mathrm{kg}]$. By using those relations, we can obtain a radius of the neutrino cloud of $r_\nu = 3.8 \times 10^{23} \times m_\nu^{-3/2}[\mathrm{m}][\mathrm{eV}] = 13[\mathrm{Mpc}] \times m_\nu^{-3/2}[\mathrm{eV}]$. Here we must consider also the contribution to the gravitational mass from other neutrinos, m_2 and m_3. Therefore the above equation is modified to $r_\nu = 8[\mathrm{Mpc}] \times m_\nu^{-3/2}[\mathrm{eV}]$. If we put the neutrino mass 0.27 eV in this equation, we will get r_ν as 200 million light years, still twice as large as typical observed void structure [6] (note $0.27^{3/2} = 1/7$). The photo in Figure 1 represents the void structure of our universe described in $6 - 8$.

3. Application of our idea to actual phenomena of the universe

We are able to resolve the "factor two difference" above, because we did not take into account the effect of baryonic matter and cold dark matter in the scenario $1 - 8$. However in the universe, there is much more mass than is contained as neutrinos. According to the current analysis of the WMAP data [7], Ω_{matter} is 0.27 and Ω_ν is estimated to be 0.015. That means the mass of (dark matter + hydrogen gas) is 18 times heavier than the mass of neutrinos. Therefore if we replace the mass of $110m_\nu$ by $1980m_\nu$, we obtain a new relation

$r_\nu = 3.5[\mathrm{Mpc}] \times m_\nu^{-3/2}[\mathrm{eV}]$. The relation is presented in Figure 2. If we put the value of tau neutrino mass ($0.27\,\mathrm{eV}$) into the above equation, the radius the neutrino cloud is obtained as $25\,\mathrm{Mpc}$ or 80 million light years. This radius coincides well with the observed diameter of the void structure, 140 million light years [6]. Therefore if neutrinos have the masses as 0.21, 0.22 and $0.27\,\mathrm{eV}$ respectively, we can explain the void structure of our universe as resulting from the neutrino mass (case 1). This model is not so beautiful from the point of view of particle physics. We cannot account for the existence of the seesaw mechanism [8] nor explain the existence of flavors in nature. Of course there remains the possibility that the neutrino masses could be described by case 2. In the case 2, the neutrino cloud must have a typical diameter of $230\,\mathrm{Mpc}$ or 760 million light years. However it is not certain that we can define the concept of “the diameter of neutrino bubble” of such a large distance in an expanding universe. Further considerations are necessary. Various ideas concerning hot dark matter have been discussed frequently in the past [9].

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