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The Characters of Cosmic Background Neutrinos

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Abstract

From the measurement results of COBE satellite about the large angular anisotropy of the cosmic microwave background and the observations about the superstructures of the universe, we deduce that the mass of cosmic background neutrino is $\sim 0.2eV$, its chemical potential is $\sim -0.01eV$, and its magnetic moment is $\sim 10^{-10} - 10^{-11}\mu_B$.

1 Introduction

The measurement results [1]-[5] from COBE satellite about the large angular ($\sim 10^0$, i.e. $\sim 1000Mpc$) anisotropy ($\frac{\Delta T}{T} \sim 10^{-5}$) of the cosmic microwave background (CMB) give the theories of inflation and dark matter dominating in the universe a strong support, combining with the observations [6]-[10] of superstructures of the universe (SSU), people are taking further steps to explore what is actually happened that the universe is dominated by cold dark matter, or by hot dark matter, or by both at the same time [5],[11]-[15]. In this paper we inquire into the characters of cosmic background particles.

The scale of CMB anisotropy has reached $1000Mpc$, and the scale of SSU has also reached $1000Mpc$, and the SSU with flat form (great wall) or period structure [8],[9] had been observed as well. All of these imply that the aerodynamics effect in cosmic medium still affects cosmic structure on such so large scale, in this medium the sound velocity may reach $\sim 0.1c$[16]. We do not know what type of elementary particles can construct this medium, but from the known particles the sole rational candidate is neutrino. We shall use neutrino as a concrete example of cosmic background particles, and infer its mass m_ν, chemical potential μ_ν, and magnetic moment M_ν, on the basis of above stated results [1]-[10], and of $\Omega_\nu = 1$ ($\Omega_\nu = \frac{\rho_\nu}{\rho_c}$, in which ρ_ν is the average density of background neutrinos, $\rho_c = \frac{3H_0^2}{8\pi G}$ is the cosmic critical density).

2 Degenerate Neutrinos (Low Temperature Neutrinos)

Background Neutrinos(BN) At first we discuss the simplest situation: suppose BN are in a degenerate state, then

$$v_s = \sqrt{\gamma_0 \frac{\varepsilon_0}{m_\nu}}, \tag{1}$$

and $\gamma_0 = \frac{2}{3}$, in which ε_0 is the boundary energy [17], and

$$\varepsilon_0 = \mu_\nu = kT_0, \tag{2}$$

in which T_0 is the degenerate temperature [17]. For degenerate neutrinos, their density is

$$\rho_\nu = \epsilon_0 \mu_\nu^{\frac{3}{2}} m_\nu^{\frac{5}{2}}, \tag{3}$$

and $\epsilon_0 = (\frac{g_0}{2})\frac{2^{\frac{3}{2}}}{3\pi^2\hbar^3}$, in which g_0 is the number of helicity states of neutrino. From eqs(1)-(3), command $h = \frac{H_0}{100}$, get

$$m_\nu^4 = \frac{\rho_\nu h^2 \gamma_0^{\frac{3}{2}}}{\epsilon_0 v_s^3}, \tag{4}$$

$$\mu_\nu = \frac{1}{\gamma_0} m_\nu v_s^2, \tag{5}$$

$$T_0 = \frac{\mu_\nu}{k}. \tag{6}$$

Taking $g_0 = 6$, $H_0 = 100 km \cdot sec^{-1} \cdot Mpc$, substituting $v_s = 0.1c$ into, get $m_\nu \doteq 0.02 eV$, $\mu_\nu \doteq 3 \cdot 10^{-4} eV$, $T_0 \doteq 3.4^0 K$.

Clustering Neutrinos The existence of period superstructure [9] indicates that neutrinos may be presented in a clustering state, their density will become to $\tilde{\rho}_\nu$. According to the Jeans theory [18], the Jeans length λ_J is

$$\lambda_J = \frac{v_s}{\sqrt{4\pi G \tilde{\rho}_\nu}}. \tag{7}$$

From Ref[9], $\lambda_J = 128 Mpc$; from Eq(7), $\tilde{\rho}_\nu \doteq 6.9 \times 10^{-29} g \cdot cm^{-3}$, and Eq(4) becomes to

$$m_\nu^4 = \frac{\tilde{\rho}_\nu h^2 \gamma_0^{\frac{3}{2}}}{\epsilon_0 v_s^3}. \tag{8}$$

From eqs(8), (5), (6), get $m_\nu \doteq 0.03 eV$, $\mu_\nu \doteq 4 \cdot 10^{-4} eV$, $T_0 \doteq 4.8^0 K$. This results are near by that of BN, for simplicity, it will be only discussed the BN in next section.

3 High Temperature Neutrinos

Another extreme situation of BN is the high temperature state ($\frac{\mu_\nu}{kT_\nu} < -4$, T_ν is the temperature of BN)[19]. At this state

$$\rho_\nu = \epsilon|\mu_\nu|^{\frac{3}{2}} m_\nu^{\frac{5}{2}}, \tag{9}$$

and $\epsilon = (\frac{g}{2})\frac{2^{\frac{3}{2}}}{3\pi^2\hbar^3}$, $g = g_0 \cdot \frac{3\sqrt{\pi}}{4}|\xi|^{-\frac{3}{2}} \exp\xi$, in which $\xi \equiv \frac{\mu_\nu}{kT_\nu}$. Because of $v_s = \sqrt{\frac{5}{3}\frac{kT_\nu}{m_\nu}}$, command $\gamma_1 \equiv \frac{5}{3}\frac{1}{|\xi|}$, it will still have

$$|\mu_\nu| = \frac{1}{\gamma_1} m_\nu v_s^2, \tag{10}$$

and keep the form of eqs(9), (10) as that of eqs(3), (5), thus immediately obtain

$$m_\nu^4 = \frac{\rho_\nu h^2 \gamma_1^{\frac{3}{2}}}{\epsilon v_s^3}, \tag{11}$$

and

$$T_\nu = |\frac{\mu_\nu}{\xi k}|. \tag{12}$$

Taking $g_0 = 6$, $h = 1$, $\xi = -4$, from eqs(10)-(12), get $m_\nu \doteq 0.07eV$, $\mu_\nu \doteq -1.7 \cdot 10^{-3}eV$, $T_\nu \doteq 4.9^0K$. When ξ decreases from -4 to -22, m_ν and T_ν monotonically increase to 6.4 eV and 443^0K respectively, and μ_ν monotonically decreases to $-0.8eV$. From Eq(10) and Eq(12) it is thus clear that $T_\nu \propto m_\nu$, and $|\mu_\nu|$ approximately has a linear relation with m_ν.

4 Discussion

(1) We do not know what state that BN are situating in, it may be degenerate state, or high temperature state, or the state between them. However, the minimum value of m_ν is $0.02eV$ from the calculations above.

(2) From Refs[5]-[10], it is known that the clustering scale $R_C \sim 10^2 - 10^3 Mpc$, and the mass in this clustering region M_C ($M_C = \bar{\rho}_\nu \cdot \frac{4}{3}\pi R_C^3$) must be larger than the damping scale of free stream M_F ($M_F \sim \frac{m_{pl}^3}{m_\nu^2}$)[20], i.e.

$$\tilde{\rho}_\nu \cdot \frac{4}{3}\pi R_F^3 > \frac{m_{pl}^3}{m_\nu^2}, \tag{13}$$

in which m_{pl} is Plank mass. so,

$$m_\nu^2 > \frac{m_{pl}^3}{\frac{4}{3}\pi R_F^3 \tilde{\rho}_\nu}. \tag{14}$$

Taking $R_F = 1000Mpc$, then $m_\nu > 0.2eV$. This result means that BN is not in degenerate state. Using Eq(12), the neutrino temperature $T_\nu > 13^0K$, which is much larger than the microwave background temperature, it means that there exists a low energy phase transit after decoupling [16]; in the other hand, too large T_ν will also not be reasonable, therefore $m_\nu \sim 0.2eV$, $\mu_\nu \sim -0.01eV$. (From Ref[16], they are $m_\nu \sim 0.16eV$, $\mu_\nu \sim -0.007eV$).

(3) The essential condition for forming the halo of the galaxy or the cluster of galaxies from neutrinos is that the neutrino thermal velocity must be less than the escape velocity v_e of these celestial bodies, $v_e \sim 0.001c - 0.01c$. From the discussion above, we know BN are in a high temperature state, and the sound velocity or the thermal velocity is near by 0.1c, so, only the low velocity neutrinos can be captured into the halo regions, and the T_ν of them will decrease $4 - 6$ orders of magnitude, namely the neutrinos become to degenerate state. Taking $m_\nu \sim 0.2eV$ and $\rho_\nu \doteq 10^{-24} g \cdot cm^{-3}$, and substituting them into eqs(4), (5), get $\mu_\nu \sim 0.01eV$.

(4) If the twist break of cosmic proton spectrum at ultrahigh energy region is caused by the interaction between protons and BN [18] indeed, since $\mu_\nu \sim -0.01eV$, such break may locate at $\gamma \sim 10^8$.

(5) From the preliminary investigations about the structures at the scale of supercluster or up, such as filament, void, large scale stream, and etc.[20],[21], the results of that are not in contradiction with $m_\nu \sim 0.2eV$.

(6) From the discussion in Ref[22] about the relationship between cosmic magnetic field H (especially, galactic magnetic field) and neutrino magnetic moment M_ν, we have

$$H \sim n_\nu M_\nu, \tag{15}$$

in which n_ν is neutrino number density. Obviously, $M_\nu \propto m_\nu$. If $H \sim 10^{-5}G$, $M_\nu \sim 10^{-10}\mu_B$ (or $H \sim 10^{-6}G$, $M_\nu \sim 10^{-11}\mu_B$), then $n_\nu \sim 10^4$. From $\rho_\nu = \rho_c$, get $m_\nu \sim 0.2eV$. At this time the degenerate neutrinos constructing the halos of the galaxies or the clusters of galaxies do not affect the value of H.

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