FERMILAB
APR
IBRAR
Fermilab Library
0 1160 0041628 3
BIHEP-CR-95-01

BIHEP-CR-95-01

ON THE MASS AND THE MATTER STATE OF COSMIC DARK MATTER PARTICLES (II)

Huang Wuliang

Institute of High Energy Physics, Academia Sinica, Beijing, China

Abstract

According to the restraint condition: $v_s \sim 0.1c - 0.01c$ (v_s is the sound velocity in dark matter medium), the bosons can be the candidate of dark matter only in a universe with a low energy phase transition (LEPT) during the evolution, and the mass of bosons is still near by $10^{-1} - 10^{-2} eV$, and the chemical potential of bosons is still near by $10^{-5} - 10^{-4} eV$ as that of fermions in Ref[1].

NAME	I D No.	M.S.

RETURN TO FERMILAB LIBRARY

1 Fermions as the dark matter

2 Bosons as the dark matter

2.1 Bosons are relativistic as their decoupling

At this condition the equations in Ref[1] can still be used, but in all of these equations the foot sign f (fermions) must be substituted by b (bosons), and the term $[exp(Z-\gamma)+1]$ must be substituted by $[exp(Z-\gamma)-1]$; besides, there are three points to be explained: (1) The values of g for bosons usually are 1 or 2, and the value of Ω_b usually is near 1 [2], so we shall be discussing in a range of $w = 1 - 10$. (2) The chemical potential of bosons is negative, i.e. $\gamma \leq 0$. (3) When the bosons isoentropically evolute from relativistic particles to non-relativistic particles, their value of γ will translate from $\gamma = 0$ to $\gamma = -1.245$.

2.1.1 the calculated results without LEPT

Since $\gamma \leq 0$, it is well known that $m_b = m_{bmin}$, $T_b = T_{bmax}$, $v_s = v_{smax}$, when $\gamma = 0$. Taking $T_{b0} = 1.9^oK$, for $\gamma = 0, -1.245, -20$, we obtain the calculated results as follows:

w	v_s/c	$m_b(eV)$	$T_b(^oK)$	$\mu_b(eV)$	γ
1	2.7×10^{-6}	65.7	6.7×10^{-6}	0	0
10	2.7×10^{-5}	6.57	6.7×10^{-5}	0	0
1	4.6×10^{-7}	531	8.3×10^{-7}	-8.9×10^{-11}	-1.245
10	4.6×10^{-6}	53.1	8.3×10^{-6}	-8.9×10^{-10}	-1.245
1	3.0×10^{-15}	8.3×10^{10}	5.3×10^{-15}	-9.2×10^{-18}	-20
10	3.0×10^{-14}	8.3×10^{9}	5.3×10^{-14}	-9.2×10^{-17}	-20

It is obviously that the sound velocity in b medium is too low, so, without LEPT, for the formation of the superstructure in the universe (FSU) no direct influence is from bosons, this is not like the influence from fermions in Ref[1], because the value of γ of fermions can be larger than zero.

2.1.2 the calculated results with LEPT

Taking $\gamma = -1.245$, $v_s/c = 0.01, 0.1$, get

w	v_s/c	$m_b(eV)$	$T_b(^oK)$	$\mu_b(eV)$	$T_{bo}(^oK)$
1	0.01	0.29	0.22	-2.4×10^{-5}	23.4
1	0.1	0.052	4.0	-4.3×10^{-4}	41.5
10	0.01	0.17	0.13	-1.3×10^{-5}	13.2
10	0.1	0.029	2.3	-2.4×10^{-4}	23.4

In such condition for FSU the effect from bosons is like that from fermions, and the mass and the chemical potential of bosons are all like that of fermions.

2.2 Bosons are non-relativistic as their decoupling

At this time, the temperature of bosons is not related to that of microwave background. For convenience' sake Eq(5) can be rewritten in a form

$$T_b \doteq \frac{kT_{bo}T_{\gamma o}}{Km_bc^2}, \tag{1}$$

where $K > 1$, from which eqs(9),(10) become to

$$m_b = K^{\frac{3}{2}} \cdot \frac{\Omega_b h^2}{J_{\frac{1}{2}} g} \cdot \frac{2^{\frac{1}{2}}\pi^2\hbar^3c^3\rho_c}{k^3(T_{bo}T_{\gamma o})^{\frac{3}{2}}}; \tag{2}$$

$$m_bv_s = \sqrt{\frac{10}{9}\frac{T_{bo}T_{\gamma o}J_{\frac{3}{2}}}{K \cdot J_{\frac{1}{2}}}} \cdot \frac{k}{c}. \tag{3}$$

For K=100, the results are as follows:

w	v_s/c	$m_b(eV)$	$T_b(^oK)$	$\mu_b(eV)$	γ
1	2.7×10^{-10}	6.6×10^4	6.7×10^{-11}	0	0
10	2.7×10^{-9}	6.6×10^3	6.7×10^{-10}	0	0
1	4.6×10^{-11}	5.3×10^5	8.3×10^{-12}	-8.9×10^{-16}	-1.245
10	4.6×10^{-10}	5.3×10^4	8.3×10^{-11}	-8.9×10^{-15}	-1.245
1	3.0×10^{-19}	8.3×10^{13}	5.3×10^{-20}	-9.2×10^{-23}	-20
10	3.0×10^{-18}	8.3×10^{12}	5.3×10^{-19}	-9.2×10^{-22}	-20

Comparing these results with that in section 2.1.1, we can see that $m_b \uparrow$, $T_b \downarrow$, $\mu_b \downarrow$, $v_s/c \downarrow$, so, for FSU the influence of such particles is far less.

2.3 Boson Condensation

Under a giving number density of bosons ($n_b = const.$), when the chemical potential of bosons tends to zero, the temperature of bosons will tend to T_o. From Ref[3],

$$T_o = \frac{3.31}{w^{\frac{2}{3}}} \cdot \frac{\hbar^2}{m_b^{\frac{5}{3}} k} \cdot \rho_c^{\frac{2}{3}}, \qquad (4)$$

From eqs(1) and (4), get

$$\frac{T_b}{T_o} \doteq (\frac{k}{\hbar c})^2 \cdot \frac{T_{bo} T_{\gamma o}}{3.31 \cdot K} \cdot (\frac{m_b w}{\rho_c})^{\frac{2}{3}}. \qquad (5)$$

If $\frac{T_b}{T_o} = 1, w = 1, K = 1, T_{bo} = 1.9^o K$, then $m_b = 65.6eV$;
if $w = 1, K = 1, T_{bo} = 1.9^o K, m_b = 0.1eV$, then $\frac{T_b}{T_o} = 1.3 \times 10^{-2}$;
if $w = 1, K = 1, T_{bo} = 1.9^o K, m_b = 10^{-5}eV$, then $\frac{T_b}{T_o} = 2.9 \times 10^{-5}$.

It is clearly that without LEPT for bosons with mass $m_b < 65.6eV$ there can appear boson condensation. Under this state, in b medium the sound velocity v_s is zero, so they will be no influence on FSU.

3 Discussion

(1) The main clues in this paper is the restraint condition: $v_s \sim 0.1c - 0.01c$ (condition A) deduced from FSU, since then we can solve the mass and the matter state of the dark matter particles.

(2) If there does not exist LETP, only the fermions near by a degenerate state and with $m_f \sim 10^{-1} - 10^{-2}eV$, $\mu_f \sim 10^{-5} - 10^{-4}eV$ can obey condition A.

(3) If there exists LEPT and the dark matter particles are relativistic as their decoupling, either fermions or bosons are the candidate of dark matter, and the ranges of their mass and chemical potential are much the same, which are $\sim 10^{-1} - 10^{-2}eV$ and $\sim 10^{-5} - 10^{-4}eV$ respectively.

(4)In summary, starting from FSU, we can infer that there at least exists one type of dark matter composed of weakly interacting particles with mass $\sim 10^{-1} - 10^{-2}eV$.

References

[1] W.L.Huang, BIHEP-CR-94-04.

[2] G.F.Smoot et al, Astrophys.J.Lett, 396(1992), L1.

[3] L.D.Landau et al, "Statistical Physics", Pergamm Press, London, 1958.