DETERMINATION OF "INOS" MASSES COMPOSING GALACTIC HALOS

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ABSTRACT. One of the most important discoveries in modern cosmology and astrophysics is that the dark matter dominates at every scale of the Universe (Rubin et al., 1978, Forman et al., 1985, Faber and Gallagher, 1979, Sancisi, 1987). The problem that follows is to understand the components of the dark matter and to determine the physical properties of these components.

In this talk we would like to establish the cosmological and astrophysical constraints on the physical properties of "inos" which are assumed to dominate substantially the dark matter making up the galactic halo and the Universe. In establishing constraints two different approaches, cosmological (Gershtein and Zel'dovich, 1966) and astrophysical (Malagoli and Ruffini, 1986), are usually followed, but, in this talk, we follow a new intermediate approach. We explicitly show that, in addition to the usual cosmological arguments, we have to impose some additional largely model independent constraints in order for "inos" to form the galactic halos at the necessary cosmological epoch.

The assumptions are (1) the galactic halos are virialized systems, either quantum or classical systems and that their mean mass density stays constant from the moment of formation until today, (2) the details of multi-fragmentation process in superclusters and clusters of galaxies are neglected. The galactic halos merge at $z \gtrsim z_F$ into a non-relativistic, homogeneous Friedmann Universe, in which the cosmological density as well as the momenta of the "inos" change with the well-known cosmological scaling law; $\rho_{nr} \propto a(t)^{-3}$ and $p(t) \propto a(t)^{-1}$, where $a(t)$ is the cosmological scale factor, (3) at $z \sim z_R$, the "inos" acquire relativistic velocities, correspondingly the density varies with the law $\rho_r \propto a(t)^{-4}$, (4) the decoupling between "inos" and the cosmological matter occurred at the time of the relativistic regime, when the "inos" were in thermal equilibrium, and (5) the cosmological density parameter is defined by $\Omega = \rho/\rho_{crit}$, where $\rho_{crit} = 1.88 \times 10^{-29}$ h^2 g cm^{-3} and $h = H_o/[100$ km/sec Mpc].

With these assumptions, the cosmological energy density of "inos" which were in thermal equilibrium before decoupling is given by (see Ruffini et al., 1983, Ruffini and Song, 1986b).

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$$\rho_r = [7/8 \sum_x g_x (T_x/T_e)^4 \; F_r(\xi_x)] \; a_B T_e^{\;4} \tag{1}$$

for $z \geq z_R$ and

$$\rho_{nr} = [3/4 \sum_x g_x m_x (T_x/T_e)^3 \; F_{nr}(\xi_x)] \; \lambda \; T_e^{\;3} \tag{2}$$

for $z < z_R$, where $\lambda = 3/4 \quad \zeta(3)/\zeta(4) \; a_B \; k$, $F_r(\xi_x) = [12\eta(4)]^{-1}$ $[1/4 \; \xi_x^{\;4} + 6 \; \eta(2) \; \xi_x^{\;2} + 12 \; \eta(4)]$, $F_{nr}(\xi_x) = [4\eta(3)]^{-1} \; [1/3 \; \xi_x^{\;3} + 4\eta(2)\xi_x$ $+ 4 \sum_{n=1}^{\infty} \; (-1)^{n+1} \; e^{-n\xi_x}/n^3]$, $\xi_x = \mu_D/kT_D$, $T_e = T_o \; (1+z)$, and $T_o = 2.7\emptyset^o$ K.

It is clear that the value T_x/T_e is dependent on the decoupling epochs of "inos" and clearly we must have $T_x/T_e \leq 1$ (Ruffini and Song, 1986a).

Assuming that at the epoch of halo formation the mean density of the Universe was equal to that of the galactic halo, we can then determine the redshift z_F, at the epoch of formation by using the present density of galactic halos (Ruffini and Song, 1986b);

$$1 + z_F = 11.98 \; (\Omega \; h^2)^{-1/3} \; \tilde{M}_H^{-1/3} \; \tilde{R}_H^{-1} \tag{3}$$

The flat rotation curves of galaxies give the epoch of the relativization of "inos";

$$1 + z_R = 1.22 \times 10^4 \quad (\Omega \; h^2)^{-1/3} \; \tilde{M}_H^{-1/6} \; \tilde{R}_H^{-1/2} \tag{4}$$

where $\tilde{M}_H$ and $\tilde{R}_H$ are mass and radius parameters of galactic halos in units of $M_H = 2 \times 10^{12} \; M_\odot$ and $R_H = 100$ kpc, respectively.

It is interesting to note that both the epoch z_R and z_F are only functions of Ωh^2 and of the macroscopic parameters, mass and radius, of the galactic halos. They are, however, not functions of the masses of the "inos" forming the galactic halo. Consequently we may express, in the different regimes, the mean mass density of the Universe in terms of the mass density of galactic halos, ρ_H, using the epochs of z_R and z_F;

$$\rho_r = \rho_H \; (1 + z_F)^{-3} \; (1 + z_R)^{-1} \; (1 + z)^4 \tag{5}$$

and $z > z_R$ and

$$\rho_{nr} = \rho_H \ (1 + z_F)^{-3} \ (1 + z)^3 \tag{6}$$

for $z < z_R$ and $\rho_H = 3.23 \times 10^{-26}$ g cm^{-3} $\tilde{M}_H \ \tilde{R}_H^{-3}$.

If we match expressions (5) and (6) with the cosmological "inos" energy density given in eqs. (1) and (2) by using eqs. (3) and (4), we obtain constraints on mass, T_x/T_e, g_x, and ξ_x of "inos" by the following equations:

$$\sum_x g_x m_x (T_x/T_e)^3 \ F_{nr} \ (\xi_x) = 36.24 \text{ ev } \Theta^3 \ \Omega h^2 \tag{7}$$

$$\sum_x g_x (T_x/T_e)^4 \ F_r \ (\xi_x) = 3.74 \ \Theta^{-4} \ (\Omega h^2)^{-4/3} \ \tilde{M}_H^{1/6} \ \tilde{R}_H^{1/2} \ . \tag{8}$$

It is very interesting to note that, if we define the effective number of degrees of freedom of "inos" by, (see eq. (1)),

$$N_x = 7/8 \ \sum_x g_x (T_x/T_e)^4 \ F_r \ (\xi_x) \tag{9}$$

the constraints on N_x, from the cosmological and galactic halo point of view, are then

$$N_x = 3.27 \ \Theta^{-4} \ (\Omega h^2)^{-4/3} \ \tilde{M}_H^{1/6} \ \tilde{R}_H^{1/2} \ . \tag{10}$$

This value is consistent with the one obtained by Yang et al. (1984).

For the most canonical case with $g_x = 2$, assuming the one "inos" dominating case we made a Figure 1 for the mass and temperature ratio with varying ξ_x, the degeneracy parameter. Knowing the condition $T_x/T_e \leq 1$, we may put constraints on mass and temperature. For this case, the governing equation for mass is

$$m_x = 11.3 \text{ ev } F_r^{3/4}(\xi_x) \ \ F_r^{-1} \ (\xi_x) \ \ \tilde{M}_H^{-1/8} \ \tilde{R}_H^{-3/8} . \tag{11}$$

Clearly the mass depends on the cosmological (F's in eq. (11)) and galactic halo ($\tilde{M}_H$ and $\tilde{R}_H$) components. For values of ξ_x, from zero to infinity, a very limited range of m_x is allowed and complimentary information can be obtained by the study of supercluster structure (Ruffini et al., 1986), and by the morphological study of galactic rotation (Malagoli and Ruffini, 1986, Arbolino and Ruffini, 1986).

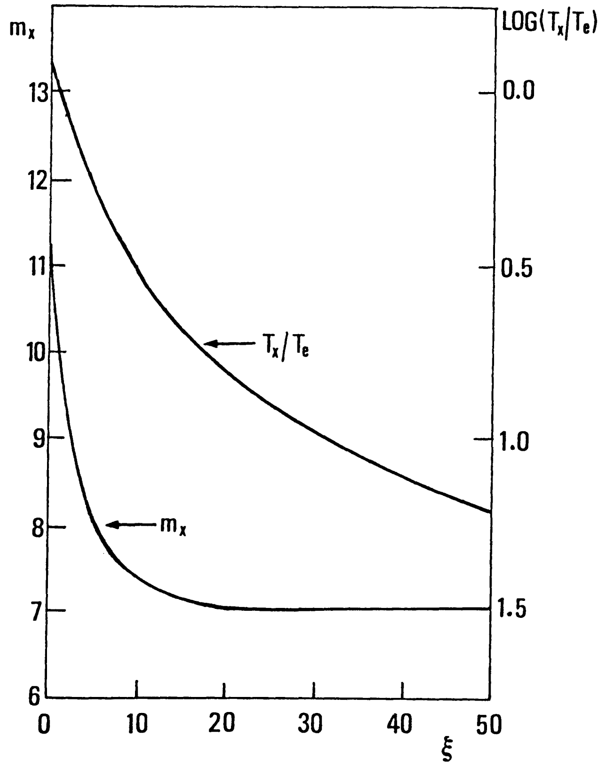

FIG. 1. The mass, m_x, and temperature ratio, T_x/T_e, are plotted by changing the degeneracy parameter ξ_x. Only the values of $T_x/T_e \leq 7.14 \times 10^{-1}$ is cosmologically allowed.

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