Galaxy Formation with Hot Dark Matter and Cosmic Strings

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Hot dark matter particles have large thermal velocities at t_{eq} and hence cannot be gravitationally bound on small scales (free streaming). In models of formation of structure based on linear adiabatic perturbations all inhomogeneities on scales smaller than the maximal free streaming length λ_J are washed out. The mass M_J inside a ball of radius λ_J exceeds the galaxy mass. Hence in the above models galaxies can only form by fragmentation of larger-scale objects. This is a severe problem.

The main result of recent work[1,2] is that cosmic string loops which seed galaxies survive neutrino free streaming. By the time the loops decay the free streaming length has fallen below the galactic scale, enabling galaxies to form independently of clusters.

We have studied the dissipationless clustering[3] of neutrinos (with a mass chosen to produce $\Omega = 1$) about a seed loop. Starting from the Liouville equation for the phase space density we derived an integral equation for the neutrino energy density perturbation in Fourier space[1]. After numerically solving this equation for a spectrum of Fourier modes we obtain the following mass profile about a seed loop of mass M_1. $\delta M(r)$ is the mass accreted inside a ball of radius r.

$$\delta M(r) = \frac{3}{2} M_1 z_{eq} \left\{ 1 - (1 + \frac{r}{L}) e^{-r/L} \right\} \quad \text{with} \quad L \cong 8 h_{50}^{-2} \text{Mpc} \qquad (1)$$

We note that L is significantly smaller than the maximal Jeans length λ_J in an adiabatic model. For $r \ll L$ we get

$$\delta M(r) \cong \frac{3}{4} M_1 z_{eq} \left(\frac{r}{L} \right)^2 \qquad (2)$$

The basic scenarios of structure formation are identical in cosmic string models with hot and cold dark matter. In both cases the largest loops at t_{eq} seed clusters, smaller ones galaxies. The radius of the seed of a cosmic structure is determined by requiring the correct number density. The number density of loops of radii R is given by a well determined distribution $n(R, t)$

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$$n(R,t) = \nu R^{-5/2} t_{eq}^{1/2} t^{-2} \quad , \quad R < t_{eq}, \quad t > t_{eq}, \quad \nu \sim 10^{-2}. \quad (3)$$

There are important differences in the detailed predictions of cosmic string models with hot versus those with cold dark matter. We obtain the following results[2]:

1. Cluster formation is unchanged (hence the value for the mass per unit length μ is the same).

2. The density profile (2) leads to flat galaxy halo rotation curves. With CDM we get $v(r) \sim r^{-1/8}$.

3. The mass function of galaxies is less steep with HDM than with CDM and is in good agreement with the Schechter luminosity function for $M < 10^{14} M_o$. We get $n(M) \sim M^{-3/2}$ compared to $n(M) \sim M^{-5/2}$ for CDM.

4. n(M) asymptotically approaches $n(M) \sim M^{-1/2}$ for $M \ll M_{cu}$ where $M_{cu} \simeq 10^7 M_o$. The corresponding cutoff mass for CDM is lower.

5. Galaxy masses are lower than with CDM. For objects with the mean separation of $10 h_{50}^{-1}$ Mpc we get a mass

$$M \simeq 5.10^{10} M_o h_{50}^6 \left[\frac{\sigma_c}{700}\right]^8 c \quad (4)$$

where σ_c is the cluster velocity dispersion in kms^{-1} and c is a constant of order 1 which depends on ν and on the time of formation of cluster loops. The above takes into account loop decay and baryon accretion (we assume $\Omega_B = 1/8$).

We conclude that a theory with hot dark matter and cosmic strings is a viable cosmological model. This conclusion has also been reached by Bertschinger and Watts[4].

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