Unstable Neutrinos Can Do It! ¹

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We present a cosmological scenario with unstable neutrinos which decay into a light neutrino and a relativistic boson. Theoretical and observational constraints severely narrow the values of mass and of lifetime of neutrinos. However, within this range, we can construct models with (i) \( \Omega = 1 \), (ii) age of the universe \( \gtrsim 13 \) billion years (b.y.) and (iii) \( h_0 \approx 0.5 \). The dynamical modeling shows that (a) the initial condensates of primordial \( v_t \) are disrupted by the decay, lowering their masses to acceptable values \( \sim 10^{12} M_\odot \), (b) the relativistic boson contributes nearly 0.25 to \( \Omega \), and (c) there emerge two prominent scales in dark matter distribution, one with a mass \( \sim 10^{12} M_\odot \) distributed over \( \sim 200 \) kpc around galaxies and another component with density \( \sim 10^{-27} \) g cm\(^{-3} \) distributed over \( \sim 1 \) Mpc. The model agrees with observations at all scales.

1. INTRODUCTION

Our universe seems to be made of mostly dark matter. The flat rotation curve of spirals, virial mass estimates of large clusters, and density determinations from virgo infall are all taken to indicate the existence of a large quantity of dark matter (see [1], for a recent review), suggesting

\[ \Omega_{\text{DM}} h_0^2 \gtrsim 0.2 \]  

(1)

It is unlikely that this dark matter is made of baryons [2]. Nonbaryonic dark matter can be conveniently classified [1] as "hot" or "cold." Detailed studies show that both the "hot" and "cold" dark matter candidates face problems of some kind.

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Hot dark matter (e.g., stable massive neutrinos with $m_v \sim 20$ eV) cannot cluster effectively at small scales. The first structures that form in this scenario [3] will have masses of the order of

$$M_j \simeq 3 \times 10^{16} \, M_\odot \left(\frac{m_v}{10 \, \text{eV}}\right)^{-2}$$  

Since collisionless neutrinos evolve without dissipation, it is difficult to explain galactic and subgalactic (e.g., dwarf spheroidal) halos in a neutrino scenario. Cold dark matter (with mass $m > 200$ keV) will form smaller structures ($M_j \sim 10^6 \, M_\odot$) first. This scenario, however, is overenthusiastic at small scales [4] and would lead to primordial fractions of dark and baryonic matter at small (e.g., galactic) scales. Since $\Omega$ at these scales is between (say) 0.1 and 0.5, cold dark matter is incompatible with an $\Omega = 1$ universe.

We show in this essay that a consistent dynamical scenario can be generated if one unstable neutrino (in addition to the stable neutrino) is present in the model. Such a model incorporates the good features of both cold dark matter (CDM) and hot dark matter (HDM) scenarios. An unstable component to the dark matter was considered—both in the context of neutrinos [5] as well as in the context of CDM [6]—by many authors. The present work differs from the previous analysis in the following significant aspects:

(i) We attempt to estimate the effect of heavy neutrino ($v_H$) decay on the structures already formed. It turns out that the decay disperses a sufficient amount of matter, lowering the mass of the surviving structures to acceptable levels.

(ii) The model is based on the decay mode $v_H \rightarrow v_L b$ where $v_L$ is a stable light neutrino and $b$ is a light (or massless) weakly interacting boson. This boson $b$ is relativistic even at the present epoch and helps in achieving $\Omega = 1$ (as far as we know this contribution was not taken into account in the previous discussions).

The kinematical details are discussed in Section 2 and the dynamics are described in Section 3.

2. KINEMATICS OF THE MODEL

Consider a scenario with (i) one unstable heavy neutrino $v_H$ with mass $m_H$ and lifetime $\tau$, and (ii) two species of light neutrinos $v_L$ each of mass $m_L$. In the very early universe ($T \gg m_H$), both $v_H$ and $v_L$ will be present in equilibrium concentrations. As the temperature drops to $T = T_{NR} = m_H$ the