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Superheavy dark matter particles and right-handed neutrinos

In this talk, "Bottom-up"and "top-down"approaches are presented for the formation and evolution of the nonlinear dark matter structures in different eras. Results strongly suggest a superheavy dark matter scenario with a critical particle mass of 10^{12}GeV. Superheavy right-handed neutrinos of this mass can be a very promising candidate. The sterile neutrinos of mass 10^{12}GeV can account for neutrino oscillations, dark matter, and baryon asymmetry at the same time and potentially stabilize the electroweak vacuum. Particles of this mass can have a free streaming mass comparable to the particle mass and form the smallest structure among all particles of any mass. In the "bottom-up" approach, particles of this critical mass can form the smallest haloes as early as 10^{-6}s with a density ratio of $32\pi^2$ from the spherical collapse model. The halo mass increases rapidly to $10^8 M_\odot$ at the matter-radiation equality to allow for an early and rapid galaxy formation and to $10^{13} M_\odot$ that matches observations at $z = 0$. In the "top-down" approach, the mass and energy cascades are identified for hierarchical structure formation with a scale-independent constant rate of the energy cascade $\varepsilon_u \approx 10^{-7} m^2/s^3$. This leads to universal scaling laws on relevant scales r, that is, a two-thirds law for the kinetic energy ($v_r^2 \propto \varepsilon_u^{2/3} r^{2/3}$) and a four-thirds law for the halo inner density ($\rho_r \propto \varepsilon_u^{2/3} G^{-1} r^{-4/3}$). These scaling laws can be confirmed by both Illustris simulations and rotation curves. By extending these scaling down to the smallest structure scale, we can estimate a particle mass $m_X = (\varepsilon_u \hbar^5 G^{-4})^{1/9} = 10^{12}$GeV (consistent with the critical mass in the "bottom-up"approach), size $l_X = (\varepsilon_u^{-1} \hbar G)^{1/3} = 10^{-13}$m, and a characteristic time $\tau_X = c^2/\varepsilon_u = 10^{16}$ years. Here, $\hbar$ is the Planck constant, and c is the speed of light. The binding energy $E_X = (\varepsilon_u^5 \hbar^7 G^{-2})^{1/9} = 10^{-9}$eV suggests a dark radiation field associated with the formation and evolution of haloes. If exists, axion-like dark radiation should be produced around $t_X = (\varepsilon_u^{-5} \hbar^2 G^2)^{1/9} = 10^{-6}$s (QCD phase transition) with a mass of $E_X = 10^{-9}$eV, a GUT scale decay constant 10^{16} GeV, or an effective axion-photon coupling 10^{-18}GeV^{-1}. The energy density of dark radiation is estimated to be about 1\% of the CMB photons. This work suggests a heavy dark matter scenario along with a light axion-like dark radiation. Superheavy right-handed neutrinos can be a very promising candidate. More details can be found in arXiv:2202.07240.

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