The Signature of Neutrinos on the Lyman-α Forest

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We quantify the impact that massive neutrinos have on the distribution of low density and high redshift regions of the Intergalactc Medium as probed by the Lyman-α forest. We run hydrodynamic simulations that include dark matter, baryons and neutrino particles and extract mock quasar (QSO) spectra. We find that the distribution of the low baryon density regions is strongly affected by the Ω_ν value, once the amplitude of the matter power spectrum is fixed at large scales. Based on our findings, we propose a new sensitive method to measure neutrino masses by using QSO spectra.

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Introduction. Neutrino oscillation experiments pointed out that neutrinos are not massless particles. Since then a huge effort has been made to measure and constraint neutrino masses over the last years.

Current experimental bounds constraint the electron neutrino mass to be below $m_\nu < 2.05-2.3$ eV [1, 2], while cosmology bounds for the sum of all neutrino masses are still significantly stronger. Constraints from WMAP7 alone yield to $m_\nu < 1.3$ eV [3], while combinations of these results with LSS studies put limits on $m_\nu < 0.3$ eV [4, 5, 6, 7]. The current tightest constraint in the form of a 2σ upper limit is $m_\nu < 0.17$ eV, comes by combining CMB, Large Scale Structure (LSS) and the Lyman-α[8]. Among all the different observables the Lyman-α forest is particularly constraining since it probes structures over a wide range of redshift, in a mildly non-linear regime and at small scales, where the neutrino signature is present [9].

As an additional mass contribution neutrinos play an important role for structure formation. Their large velocity dispersion make them behave in a very different way from the common cold dark matter (CDM) particles like neutralinos. These velocities produce a suppression in the small scale matter power spectrum, making the shape of the total mass power spectrum a potential probe for neutrino masses. On scales much smaller than the free-streaming length of neutrinos, the relative suppression is given by [9] $\left|\frac{\Delta P(k)}{P(k)}\right| \simeq 8\frac{\Omega_\nu}{\Omega_m}$, where $\Omega_\nu h^2 = (\Sigma m_\nu)/(93.14 \text{ eV})$.

Some previous works have studied the role of neutrinos in dark matter halos [10, 11, 12], cosmology [13, 14, 15] and intracluster medium [16], using both linear approaches and N-body/hydrodynamic techniques, to properly model the non-linear regime. Indeed it has been shown that at scales 1-10 h^{-1} Mpc the non-linear suppression is redshift and mass dependent in a way that is different from a naive extrapolation of linear theory. At these scales also baryons are expected to impact significantly on the matter power spectrum and thereby this regime has to be addressed with simulations that do include baryonic physics.

In this paper we study the effect that neutrinos produce in hydrogen low density regions, that we label as *voids*. The impact that neutrinos have in dark matter halos is not large, as previous studies have demonstrated [10, 11, 12]. The reason is that large neutrino thermal velocities prevent them to cluster significantly in halos, making their contribution there very small. In contrast, the impact of neutrinos in void properties can be expected to be stronger. In this paper we define voids as under dense regions with overdensities $\delta = \rho_m/\bar{\rho}_m - 1 < 0$ and sizes ranging from few to ~ 30 Mpc/h [17].

Here we aim to study the effect of neutrinos on the low density hydrogen gas populating the voids. We probe this regime by looking at the Lyman-α forest. The Lyman-α forest is a powerful tool used to constraint cosmological parameters and probe the nature of dark matter among others (for a Lyα review see [18, 24]). Lyman-α voids and their dependence on cosmological parameters have been studied in [19]. In this paper, we focus on the dependence of void properties on the sum neutrino masses. By introducing a new and simple statistical tool, we restrict ourself to the study of low density regions, that sample most of the IGM volume, and demonstrate that neutrino masses have a significant impact on the Lyman-α signature of these regions.

Numerical Method. We run cosmological simulations using the Tree-SPH code GADGET-3 [20], which has been extended to include neutrinos in two different ways: either by solving their potential on the mesh or by representing them as discrete particles [15]. Here, we use the first implementation and we refer to [13, 14, 15] for a critical comparison of the two methods. Our simulations consist of 2×512^3 CDM plus gas particles sampling a periodic box of 512 $h^{-1} Mpc$. We use the flat ΛCDM model with cosmological parameters $\Omega_{CDM} + \Omega_\nu = 0.25$, $\Omega_\Lambda = 0.7$, $\Omega_b = 0.05$, $h = 0.7$ and $n_s = 1$. We consider three degenerates neutrino species with total mass $\Sigma m_\nu = 0.0$ eV, $\Sigma m_\nu = 0.3$ eV and $\Sigma m_\nu = 0.6$ eV.