Cosmological bounds of sterile neutrinos in a $SU(3)_C \otimes SU(3)_L \otimes SU(3)_R \otimes U(1)_N$ model as dark matter candidates[*]

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Abstract

We study sterile neutrinos in an extension of the standard model, based on the gauge group $SU(3)_C \otimes SU(3)_L \otimes SU(3)_R \otimes U(1)_N$, and use this model to illustrate how to apply cosmological limits to thermalized particles that decouple while relativistic. We analyse the cosmological limits imposed by N_{eff} and dark matter abundance on these neutrinos. Assuming that these neutrinos have roughly equal masses and are not Cold Dark Matter, we conclude that the N_{eff} experimental value can be satisfied in some cases and the abundance constraint implies that these neutrinos are hot dark matter.

INTRODUCTION

The existence of Dark Matter is one of the most important discoveries in Cosmology in the last century . The Standard Model of Particle Physics(SM) doesn't have a viable candidate for dark matter. We study one extension, proposed by Dias et al[1], is the so-called 3L3R extension, based on the gauge group $SU(3)_C \otimes SU(3)_L \otimes SU(3)_R \otimes U(1)_N$ and in it, 3 sterile - under $SU(2)_L$ - neutrinos appear, which seems to be good Warm Dark Matter candidates.

We try to impose cosmological constraints into these sterile neutrinos, with the determination of its abundance and impact on N_{eff} (the effective number of neutrino species). Our intent is to illustrate to particle physicists how to use cosmological limits in particle physics models.

THE 3L3R MODEL

The 3L3R model can be considered an extension of the 3-3-1 extensions, and the introduction of a SU(3)R group makes the seesaw mechanism for neutrino masses possible. The leptons in the 3L3R transforms in the following way:

$$\begin{aligned}\Psi_{aL} &= (\nu_{aL}, l_{aL}, N_{aL})^T \sim (\mathbf{1}, \mathbf{3}, \mathbf{1}, -1/3)\,,\\ \Psi_{aR} &= (\nu_{aR}, l_{aR}, N_{aR})^T \sim (\mathbf{1}, \mathbf{1}, \mathbf{3}, -1/3)\,,\end{aligned}$$

where $a = e, \mu, \tau$ are the three leptonic families, and $N_{a[L,R]}$ are new neutrinos that transforms as triplets of the $SU(3)_L$ and $SU(3)_R$ groups, respectively.

It's possible to apply the seesaw mechanism, which gives the following mass matrix for the left handed neutrinos:

$$M_{\nu'_L} = -\frac{\Lambda_M}{4\Lambda_D^2} \begin{pmatrix} y^D \left(y^M\right)^{-1} \left(y^D\right)^T \nu_{\eta_L}^2 & 0 \\ 0 & g^D \left(g^M\right)^{-1} \left(g^D\right)^T \nu_{\chi'_L}^2 \end{pmatrix}. \tag{1}$$

$M_{\nu'_L}$ is a 6×6 block diagonal matrix. The upper block gives the active neutrinos mass, and the lower the sterile neutrinos mass.

COSMOLOGICAL CONSTRAINTS

The prediction of the model of 3 new keV scale sterile neutrinos should have an impact in cosmological observables. We use two of them: N_{eff} (effective number of neutrinos) and abundance.

The N_{eff} constraint is a parameter related to the radiation energy density at a given temperature, and is defined as:

$$\rho_R = \rho_\gamma \left[1 + \frac{7}{8}\left(\frac{4}{11}\right)^{4/3} N_{eff}\right]. \tag{2}$$

Usually, N_{eff} is written as $N_{eff} = 3 + \Delta N_{eff}$, and ΔN_{eff} measures the excess of radiation ('Dark Radiation'), beyond active neutrinos. Suppose that the sterile neutrinos decouple at a temperature T_D with g_{si} entropic degrees of freedom. Right before the active neutrino decoupling, $g_s = 2+(7/8)(2.2+3.2) = 10.75$ (when e, e^+, photons and neutrinos are coupled). Then its possible to deduce that,

$$\Delta N_{eff} = \left(\frac{10.75}{g_{si}}\right)^{4/3} \text{(per sterile neutrino species)}, \tag{3}$$

Experimentally, we adopt the value $N_{eff} = 3.28 \pm 0.28$[2].

RESULTS

We analyse three different cases, with different N_{aL} decoupling temperatures: (1) $T_D \in [105, 140 MeV]$, (2) $T_D \in [140, 200 MeV]$, (3) $T_D \in [200, 220]$ MeV. We adopt $T_{Had} = 200 MeV$[3]. We have:

- Case 1: $g_{si} = 14.25 \Longrightarrow \Delta N_{eff} = 0.69$. (per neutrino species)

- Case 2: $g_{si} = 17.25 \Longrightarrow \Delta N_{eff} = 0.53$. (per neutrino species)
- Case 3: $g_{si} = 61.75 \Longrightarrow \Delta N_{eff} = 0.097$. (per neutrino species)

So at the 1σ level, case 1 is excluded, case 2 admits one sterile neutrino only, and in case 3 all three neutrinos are possible. The limits to the g_D and g_M are given in Figure 1.

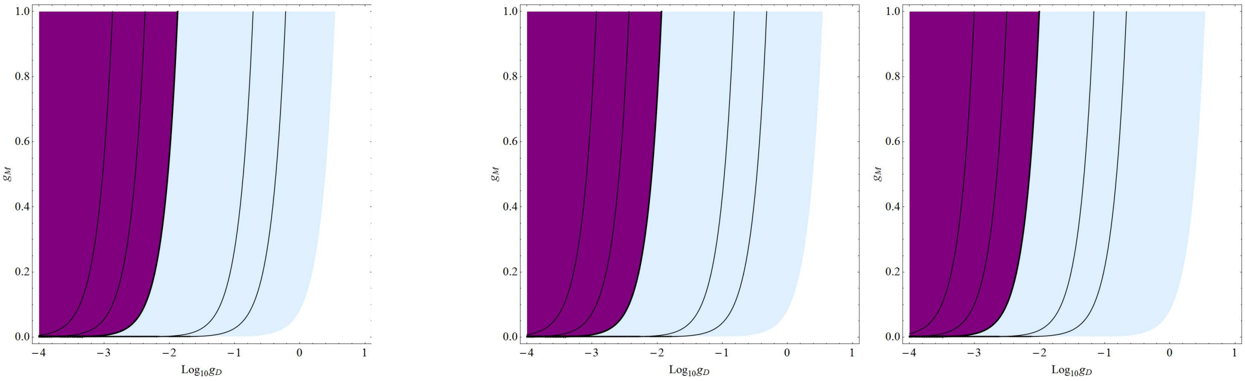

FIG. 1: Allowed regions of parameter space for g_D and g_M. Left: Case 1 ($\nu_{\chi'_L}$ = 5.7 TeV). Center: Case 2 ($\nu_{\chi'_L}$ = 7.2 TeV). Right: Case 3 ($\nu_{\chi'_L}$ = 9.3 TeV). Cases 1 and 2 have only one neutrino, and case 3 has three. In each graphic, from left to right, the first three isolines gives the values of g_D and g_M for $\xi = 0.01$, $\xi = 0.1$ and $\xi = 1$. The last two isolines gives values for which the sterile neutrino mass is $m_{N_{aL}} = 1$ keV and $m_{N_{aL}} = 10$ keV, respectively.

In tables 1 and 2 we give limits on the mass of these sterile neutrinos, and the maximum allowed value for g_D in each scenario. Since these candidates are Hot Dark Matter, another different limit can be imposed. It is possible to deduce that the sterile neutrinos affect the neutrino sum masses as $\sum_a (n_{N_{aL}}/n_\nu) m_{N_{aL}} \leq 0.17$ eV.

TABLE I: Values of the allowed neutrinos mass for each scenario and neutrino energy fraction of Dark Matter(ξ).

Cases					
Case 1 (one neutrino)		Case 2 (one neutrino)		Case 3 (three neutrinos)	
ξ	$m_{N_{aL}}$(eV)	ξ	$m_{N_{aL}}$(eV)	ξ	$m_{N_{aL}}$(eV)
0.01	0.14	0.01	0.17	0.01	0.21
0.1	1.45	0.1	1.76	0.1	2.1
1	14.56	1	17.62	1	21.03

For case 2, $(n_{N_{aL}}/n_\nu) = 0.62$ and allows only one neutrino, and case 3 has $(n_{N_{aL}}/n_\nu) = 0.17$ and 3 neutrinos. For $\xi = 0.01$, we have:

TABLE II: Maximum allowed value for g_D in each scenario, with $g_M = 1$ and $\nu_{\chi'_L} = 5.7$ TeV (case 1), $\nu_{\chi'_L} = 7.2$ TeV (case 2) and $\nu_{\chi'_L} = 9.3$ TeV (case 3).

	Cases		
ξ	Case 1 (1 neutrino)	Case 2 (1 neutrino)	Case 3 (3 neutrinos)
0.01	1.3×10^{-3}	1.1×10^{-3}	9.8×10^{-4}
0.1	4.2×10^{-3}	3.6×10^{-3}	3.1×10^{-3}

- Case 2: $\sum_a (n_{N_{aL}}/n_\nu) m_{N_{aL}} = 0.62 \times 0.17 \approx 0.11$ eV.
- Case 3: $\sum_a (n_{N_{aL}}/n_\nu) m_{N_{aL}} = 0.17 \times 3 \times 0.21 \approx 0.11$ eV.

So for both cases the bound given above is satisfied.

Both cases obey the cosmological bounds applied with $\xi = 0.01$ and, although unable to answer the DM problem, are not ruled out as HDM candidates.

CONCLUSIONS

We imposed the N_{eff} and abundance constraints on sterile neutrinos that arise in the 3L3R model. Altough we focused our analysis on this particular model, the results obtained are quite general and already known in cosmology: Stable thermalized keV particles overclose the Universe, and in this situation they are only possible if they are light (HDM) and constitutes only a small fraction of the Universe energy density.

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