Massive sterile neutrinos in the Early Universe: from thermal decoupling to cosmological constraints

Leonardo Mastrototaro (email: lmastrototaro@unisa.it) (Salerno University, Italy – INFN, Sez. di Napoli, Gruppo collegato di Salerno)

Based on L. Mastrototaro, P. D. Serpico, A. Mirizzi, N. Saviano ArXiv:2104.11752

WORK'S AIMS

In this work we focused on obtaining:

- a precise calculation of the sterile neutrino evolution in the Early Universe;
- bounds on the sterile neutrino parameters from the BBN and CMB measurement.

The existence of sterile neutrino emerges naturally in extensions of the Standard Model, like νMSM.

Interest in investigating their parameter space (m_s, τ_s)

From BBN and CMB one can obtain precise measurement to constraint ν_s parameters.

Expected improvement in the measurement from the future Stage 4 ground-based CMB experiments (CMB-S4)

HEAVY STERILE ν EVOLUTION

We investigate the possibility of the existence of heavy sterile neutrinos $(m < m_\pi)$ might be thermally produced in the Early Universe.

We numerically solved the exact Boltzmann equation for sterile and active neutrino population

$$x = m_0 a(t) \qquad y = m_0 p \qquad z = Ta(t)$$

$$\partial_x f = \frac{I}{xH}$$

$$I = \frac{(2\pi)^4}{2E_1}\int d^3\widehat{p_2} d^3\widehat{p_3}\, d^3\widehat{p_4} \mathrm{F}(f_1, f_2, f_3, f_4) S |M|^2 \delta^4(p_1 + p_2 - p_3 - p_4)$$

$|M|^2$ sum of scattering and decay processes for ν_s and

$$F(f_1, f_2, f_3, f_4) = -\prod_i f_i \prod_f (1 \pm f_f) + \prod_i (1 \pm f_i) \prod_f f_f$$

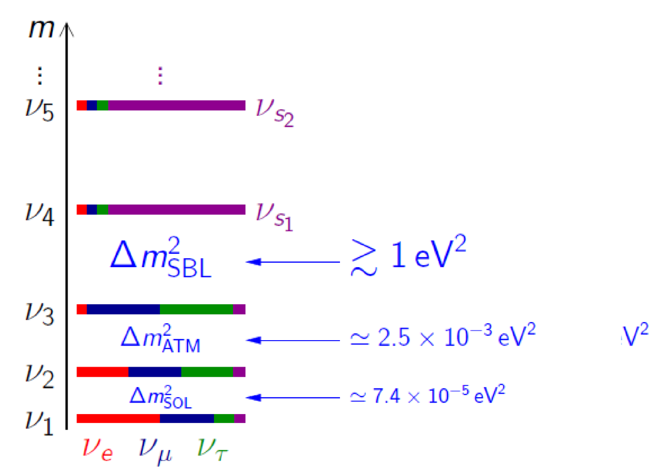
I is a 9-dimensional integral that we reduce to a 3-dimensional integral to solve numerically using the technique developed by *[Hannestad et al, arXiv:astro-ph/9506015]*

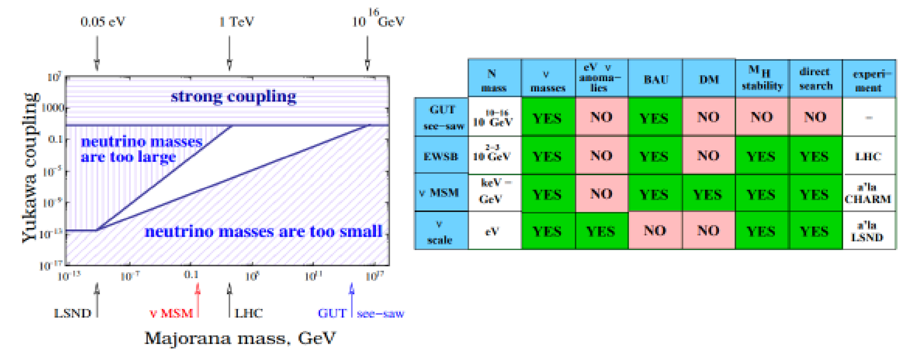
For active neutrinos, we include the neutrino oscillation:

$$I_\alpha \to \sum_\beta P_{\beta\alpha} I_\beta$$

$P_{\beta\alpha}$ is the time-average transition probability from flavour β to α

HEAVY STERILE NEUTRINOS





$$\begin{pmatrix} \nu_e \\ \nu_\mu \\ \nu_\tau \\ \nu_s \end{pmatrix} = \begin{pmatrix} U_{e1} & U_{e2} & U_{e3} & U_{e4} \\ U_{\mu 1} & U_{\mu 2} & U_{\mu 3} & U_{\mu 4} \\ U_{\tau 1} & U_{\tau 2} & U_{\tau 3} & U_{\tau 4} \\ U_{s1} & U_{s2} & U_{s3} & U_{s4} \end{pmatrix} \begin{pmatrix} \nu_1 \\ \nu_2 \\ \nu_3 \\ \nu_4 \end{pmatrix}.$$

Extra sterile neutrinos with masses $m_s \gg m_a$ and mixed with the active ones through a mixing angle θ_s are predicted in different extensions of the Standard Model

RESULTS AND CONSTRAINTS

m_s [MeV]	$\sin^2\theta_{\tau 4}$	τ [s]	T_D^n [MeV]
20.0	2.6×10^{-2}	3.0×10^{-1}	4.35
40.0	2.8×10^{-3}	8.8×10^{-2}	9.24
60.0	5.5×10^{-4}	6.0×10^{-2}	16.83
80.0	1.5×10^{-4}	5.0×10^{-2}	26.53
100.0	5.8×10^{-5}	4.4×10^{-2}	37.10
130.0	1.6×10^{-5}	4.2×10^{-2}	59.13

Heavy ν_s affect N_{eff} and Y_p due to active spectral distortion and H

$$N_{eff} = \left(\frac{z_0}{z}\right)^4 \left(3 + \sum_{\alpha=e}^{\tau} \frac{\Delta\rho_{\nu_\alpha}}{\rho_{\nu_0}} + \frac{\rho_{\nu_s}}{\rho_{\nu_0}}\right)$$

$$Y_p = Y_{p,SM}^{prec} \frac{Y_{p,\nu_s}^{Born}}{Y_{p,SM}^{Born}}$$

$$Y_p = 2X_n e^{-\frac{180}{\tau_n}} \qquad X_n = \frac{n_n}{n_n + n_p}$$

$$\frac{dX_n}{dx} = \frac{\omega_B(p \to n)(1 - X_n) - \omega_b(n \to p)X_n}{xH}$$

Planck results: $N_{eff} = 2.99 \pm 0.17$ and $Y_p = 0.245 \pm 0.003$

Sterile neutrinos affect N_{eff} and Y_p that are both relevant for CMB. We used a likehood analysis

$$\chi^2_{CMB} = (\Theta - \Theta_{obs})\Sigma^{-1}_{CMB}(\Theta - \Theta_{obs})^T$$

$$\Theta = (N_{eff}, Y_p) \qquad \Theta_{obs}(2.97, 0.246)$$

$$\Sigma_{CMB} = \begin{pmatrix} \sigma_1^2 & \sigma_1\sigma_2\rho \\ \sigma_1\sigma_2\rho & \sigma_2^2 \end{pmatrix}$$

$$\sigma_1 = 0.2650 \qquad \sigma_2 = 0.0177 \qquad \rho = -0.845$$