Neutrino masses and Hubble tension via a Majoron in MFV

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F. Arias-Aragón, E. Fernández-Martínez, **M. González-López**, L. Merlo

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manuel.gonzalezl@uam.es

Local and early Universe observations fail to agree in the determination of H_0. The tension stands curently a the 4-6σ level.[1,2]

Particle physics may provide a solution to this tension, and possibly link it to other open problems of the SM, such as neutrino masses.

A Majoron (ω) coupled to neutrinos may lower the tension to 2.5σ if its mass and coupling satisfy[3]

$m_\omega \in [0.1,1]$ eV

$\lambda_{\omega\nu\nu} \in [5\times10^{-14}, 10^{-12}]$

[1]Nature Astron. 3 (2019) 891 [1907.10625]
[2]Mon. Not. Roy. Astron. Soc. 498 (2020) 1, 1420 [1907.04689]
[3] Eur. Phys. J. C 80 (2020) 4, 294 [1909.04044]

The Majoron mechanism

We extend the SM with 3 right-handed neutrinos, N_R, and a complex scalar, χ. Their lepton number charges, $-L_N$ and L_χ, are a priori free.

$$-\mathscr{L}_\nu = \left(\frac{\chi}{\Lambda_\chi}\right)^{\frac{1+L_N}{L_\chi}} \bar{\ell}_L \tilde{H} \mathscr{Y}_\nu N_R + \frac{1}{2}\left(\frac{\chi}{\Lambda_\chi}\right)^{\frac{2L_N-L_\chi}{L_\chi}} \chi \bar{N}_R^c \mathscr{Y}_N N_R + \text{h.c.}$$

Locality: must $\in \mathbb{N}$

$$\chi = \frac{\sigma + v_\chi}{\sqrt{2}} e^{i\omega/v_\chi}$$

v_χ breaks lepton number

LN

$$\epsilon_\chi = \frac{v_\chi}{\sqrt{2}\Lambda_\chi}$$

- Light neutrino masses: $m_\nu = \frac{\epsilon_\chi^{\frac{2+L_\chi}{L_\chi}} v^2}{\sqrt{2} v_\chi} \mathscr{Y}_\nu \mathscr{Y}_N^{-1} \mathscr{Y}_\nu^T$
- Heavy neutrino masses: $M_N \simeq \epsilon_\chi^{\frac{2L_N-L_\chi}{L_\chi}} \frac{v_\chi}{\sqrt{2}} \mathscr{Y}_N$.
- Majoron-neutrino coupling: $\lambda_{\omega\nu\nu} = 2\frac{m_\nu}{L_\chi v_\chi}$

The features of the model depend crucially on the lepton number assignments. We consider two main (non-renormalizable) cases*:

	L_N	L_χ	v_χ	ϵ_χ	M_N	Λ_χ	Heavy neutrino mixing
Case NR1	1	1	0.1-2 TeV	(0.5-1.4)x10^{-4}	3.5-200 MeV	(1.4-11)x10^{3} TeV	2.5x10^{-10}-1.4x10^{-8}
Case NR2	1	2	0.05-1 TeV	(2.4-11)x10^{-7}	35-700 GeV	(1.4-6.5)x10^{5} TeV	7.1x10^{-14}-1.4x10^{-12}

*The renormalizable case ($L_N=-1$, $L_\chi=-2$) would need a fine-tuned neutrino Yukawa, $\mathscr{Y}_\nu^2/\mathscr{Y}_N \sim 10^{-13}$. The option $L_N = L_\chi = -1$ predicts $\epsilon_\chi \gg 1$ and is also disregarded.

Phenomenological signatures

1 Majoron couplings. Both cases NR1 and NR2 are allowed.

✓ Loop suppression in couplings to γ and e, escaping CAST and Red Giants bounds.

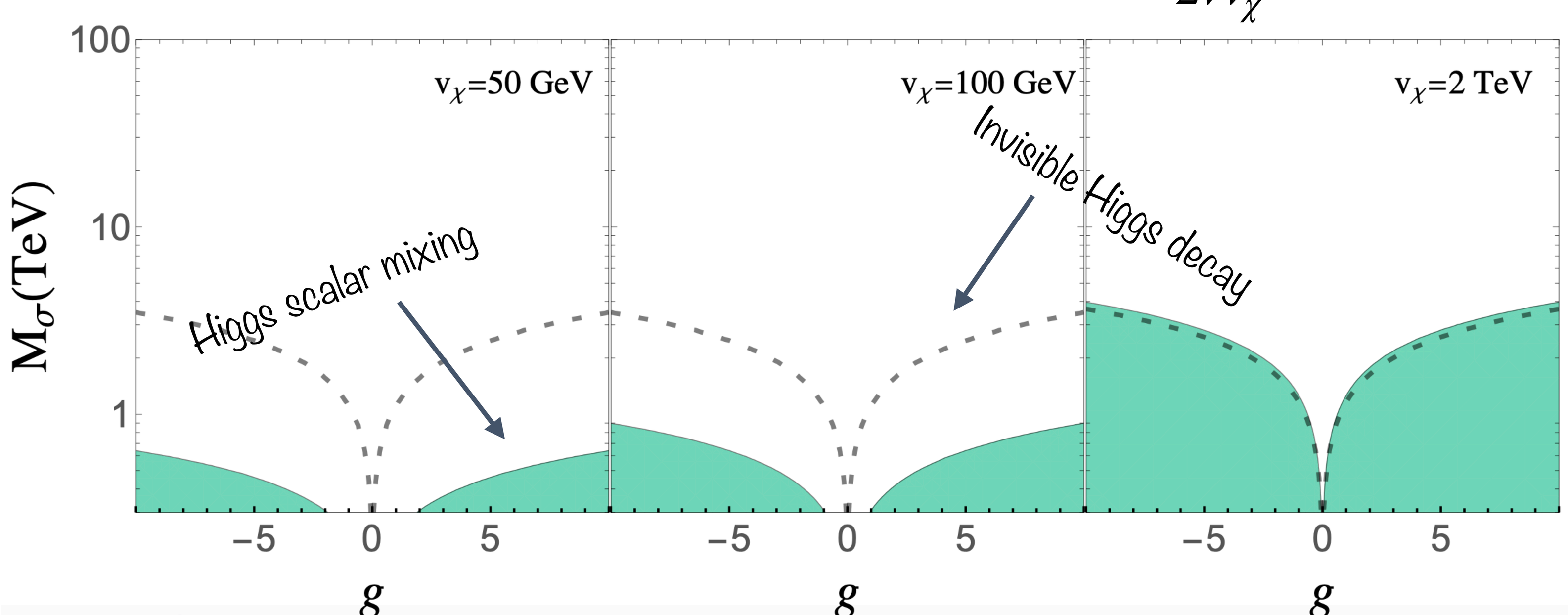
✓ Bounds from Majoron emission in $0\nu\beta\beta$ not strong enough.

2 Heavy neutrinos. Consequences in experiments and cosmology:

✓ Potentially testable in both cases NR1 (at beam dumps) and NR2 (at colliders, although small mixings hinder detection).

? Too long-lived in case NR1: its decay products would spoil BBN predictions.

3 Scalar sector. The radial part of χ and the Higgs mix with an angle θ. The quartic coupling is given by $g = \frac{M_\sigma^2 - M_h^2}{2vv_\chi}\sin 2\theta$.



✓ Room for interesting model features: no fine tuning in g needed for values of v_χ predicted by cases NR1 and NR2.

MFV embedding

An MFV framework, based on flavour symmetries, could offer solutions to several problems.[4,5]

$$\mathscr{G}_F = U(3)_{q_L} \times U(3)_{u_R} \times U(3)_{d_R} \times U(3)_{\ell_L} \times U(3)_{e_R} \times U(3)_{N_R}$$

$$\cup$$

$$\mathscr{G}_F^A = U(1)_B \times U(1)_L \times U(1)_{e_R} \times U(1)_{N_R} \times U(1)_{PQ} \times U(1)_Y$$

- $U(1)_L$ → Majoron → Hubble tension
- $U(1)_L$, $U(1)_{PQ}$ → Yukawa hierarchy → Flavour and neutrinos
- $U(1)_{PQ}$ → Axion → Strong CP

[4]JHEP 10 (2017) 168 [1709.07039]
[5]JHEP 06 (2011) 037 [1103.5461]

CONCLUSIONS

We have explored an SM extension consisting of 3 RHNs and a new scalar, that breaks lepton number symmetry. Two LN choices could provide an improvement of the Hubble tension, via a Majoron, and an explanation for neutrino masses. Both choices satisfy experimental constraints. This model can be included in an MFV framework that possibly solves other open problems of the SM, such as the flavour puzzle or strong CP.