NEUTRINO MASSES AND HUBBLE TENSION VIA A MAJORON IN MFV

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Based on: FAA, E. Fernández-Martínez, M. González-López, L. Merlo. Eur. Phys. J. C 81, 28 (2021), 2009.01848

Motivation

- Early Universe vs local $\boldsymbol{H_0}$ in $\mathbf{4-6\sigma}$ **tension** [1,2]
- **Majoron** with $m_\omega \in [0.1,1]$ eV, $\lambda_{\omega\nu\nu} \in [5\times10^{-14}, 10^{-12}]$ **helps** [3]
- **Compatibility with** other BSM physics: Type-I **Seesaw**, **flavour** continuous **symmetries**, **axion**
- Pheno in **colliders** (N_R, H invisible decay, new scalar), **Astrophysics** (CAST and Red Giants) and **majoron in** $\boldsymbol{0\nu\beta\beta}$

The Majoron Mechanism

- **3RH**$\boldsymbol{\nu}(\boldsymbol{N_R})$+**Singlet complex scalar**$(\boldsymbol{\chi})$, **Lepton #** $\boldsymbol{-L_N}$ and $\boldsymbol{L_\chi}$

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

$$\chi = \frac{\sigma+v_\chi}{\sqrt{2}}e^{i\frac{\omega}{v_\chi}}, \qquad \varepsilon_\chi = \frac{v_\chi}{\sqrt{2}\Lambda_\chi}$$

- Neutrino **masses and** $\omega-\nu$ **coupling generated** after **SSB** of **LN**

$$m_\nu = \frac{\varepsilon_\chi^{\frac{2+L_\chi}{L_\chi}}v^2}{\sqrt{2}v_\chi}\mathcal{Y}_\nu\mathcal{Y}_N^{-1}\mathcal{Y}_\nu^T, \qquad m_N = \varepsilon_\chi^{\frac{2L_N-L_\chi}{L_\chi}}\frac{v_\chi}{\sqrt{2}}\mathcal{Y}_N$$

$$\mathcal{L}_\omega^{low-energy} \supset i\frac{\lambda_{\omega\nu\nu}}{2}\omega\bar{\nu}_L\nu_L^c,\ \lambda_{\omega\nu\nu} = 2\frac{m_\nu}{L_\chi v_\chi}$$

	L_N	L_χ	v_χ	ε_χ	$\langle M_N\rangle$	Λ_χ
CASE NR1	1	1	$[0.1,2]$ TeV	$[0.49,1.4]\times10^{-4}$	$[3.5,200]$ MeV	$[1.4-11]\times10^3$ TeV
CASE NR2	1	2	$[0.05,1]$ TeV	$[2.4,11]\times10^{-7}$	$[35.4,707]$ GeV	$[1.4-6.5]\times10^5$ TeV

The Majoron and Axion from a MFV Setup

- Yukawas→ 0 ⇒ One $U(3)$ for each Field = MFV Symmetry group $\mathcal{G}_F$[4-5]

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

- **PQ**, broken by new scalar Φ, **explains** $\boldsymbol{m_b/m_t}$ **and** $\boldsymbol{m_\tau/m_t}$ [6]

$$x_{q_L} = x_{l_L} = x_{u_R} = x_{N_R} = 0, x_{d_R} = x_{e_R} = 3, \mathrm{x}_\Phi = -1, \Phi = \frac{\rho+v_\Phi}{\sqrt{2}}e^{i\frac{a}{v_\Phi}}$$

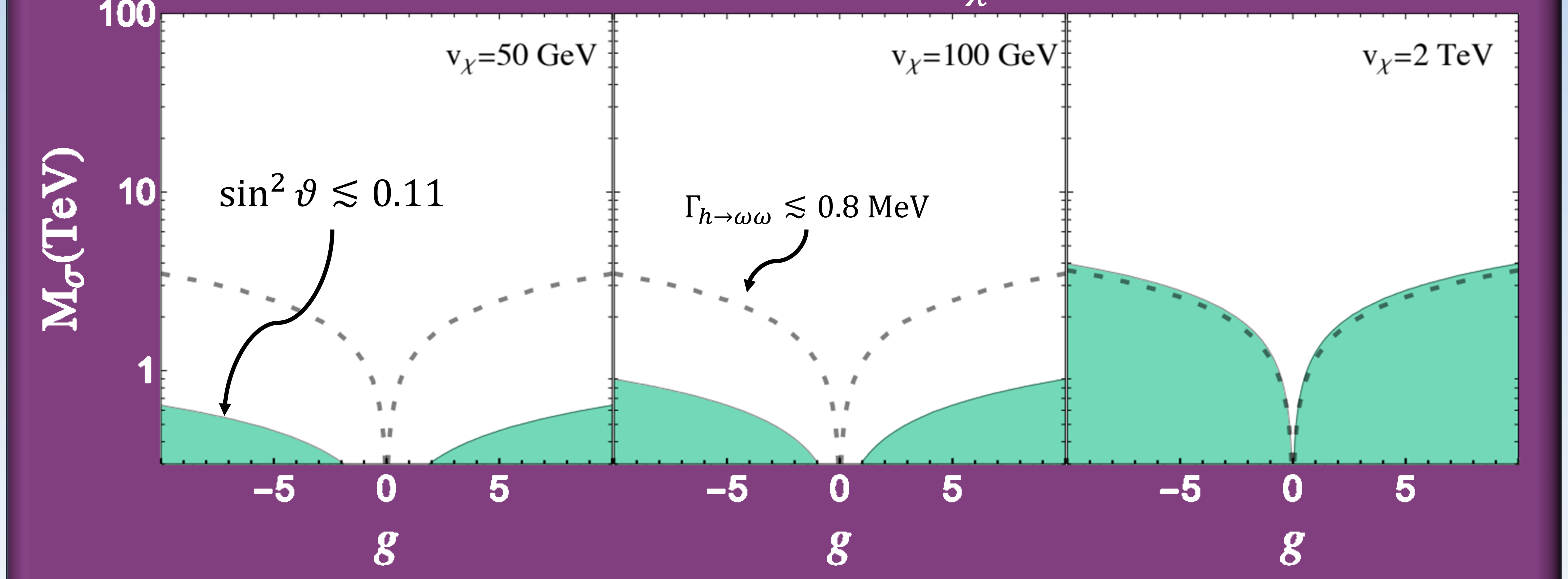
- Lepton MFV requires assumptions: $\mathcal{Y}_N \propto \mathbb{1}$ &$\mathcal{Y}_N \in \mathbb{R}$ [5,7] or $\mathcal{Y}_\nu \propto \mathbb{1}$ [8]
- Majoron+axion+low flavour NP scale $\Lambda_\mathrm{F} \sim 1-10$ TeV naturally form MFV

Phenomenological Signatures

	$\lambda_{\omega\gamma\gamma}$	λ_{wee}	$\lambda_{\omega\nu\nu}$
CASE NR1	$[10^{-39},10^{-36}]$ GeV^{-1}	$[10^{-25},10^{-24}]$	$[10^{-14},10^{-12}]$
CASE NR2	$[10^{-34},10^{-32}]$ GeV^{-1}	10^{-20}	
Exp. Upper bounds	10^{-10} GeV^{-1}	10^{-13}	10^{-5}

Low scalar masses!

$$gH^\dagger H\chi^*\chi \to g = \frac{M_\sigma^2-M_h^2}{2vv_\chi}\sin 2\vartheta$$



- Case NR1 has N testable at experiments like DUNE or SHiP
- Case NR2 may allow N production at LHC or future colliders
- $N \to 3\nu$ decay before BBN bounds light-heavy neutrino mixing θ_s

$$\sin^2\theta_s \lesssim 10^{-15}-10^{-17}$$

- Light N in case NR1 may be disfavoured
- Case NR2 can escape the bound decaying before BBN thanks to heavier M_N

	$\langle M_N\rangle$	$\sin^2\theta_s$	$\Gamma^Z_{N\to3\nu}$	$\Gamma^\omega_{N\to3\nu}$
CASE NR1	$[3.5,200]$ MeV	$[2.5\times10^{-10},\ 1.4\times10^{-8}]$	$\mathcal{O}(10^{-38})$	$\mathcal{O}(10^{-68})$
CASE NR2	$[35.4,707]$ GeV	$[7.1\times10^{-14},\ 1.4\times10^{-12}]$	$\mathcal{O}(10^{-27})$	$\mathcal{O}(10^{-66})$

References: [1] L. Verde, T. Treu, and A. Riess, 1907.10625 [2] K. C. Wong et. al., H0LiCOW XIII, 1907.04869 [3] M. Escudero and S. J. Witte, 1909.04044 [4] D'Ambrosio et al., 020736 [5] Cirigliano et al., 0507001 [6] FAA and L. Merlo, 1709,07039 [7] S. Davidson and F Palorini, hep-ph/0607329, [8] R. Alonso et al., 1103,5461