Neutrino masses from simple scoto-seesaw model with spontaneous CP violation

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invisibles
neutrinos, dark matter & dark energy physics

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Motivation

The **Standard Model** (SM) of particle physics describes electroweak interactions at low energies with remarkable precision but cannot provide an explanation for:

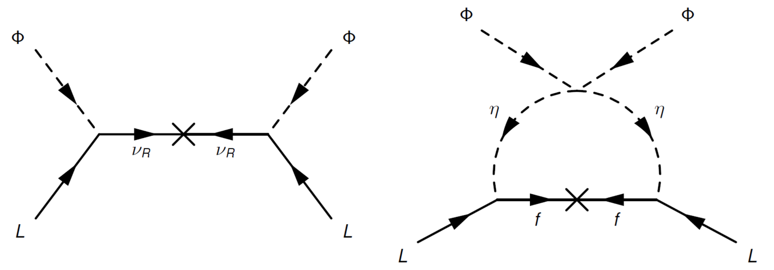
- **neutrino flavour oscillations** which imply nonvanishing neutrino masses and lepton mixing;
- observed **dark matter** abundance.

Straightforward and **elegant** solution:

Minimal scoto-seesaw mechanism

Atmospheric mass scale arises at tree level from the **type-I seesaw mechanism** while the **solar mass scale** emerges radiatively through a **scotogenic loop** [1]

$$\mathcal{L}_{\text{new}} = -\bar{L}\mathbf{Y}_\nu^*\tilde{\Phi}\nu_R - \frac{1}{2}M_R\overline{\nu_R}\nu_R^c - \bar{L}\mathbf{Y}_f^*\tilde{\eta}f - \frac{1}{2}M_f\bar{f}f^c$$



At the effective level: $\mathbf{M}_\nu = -v^2\dfrac{\mathbf{Y}_\nu\mathbf{Y}_\nu^T}{M_R} + \mathcal{F}(M_f, m_{\eta_R}, m_{\eta_I})M_f\mathbf{Y}_f\mathbf{Y}_f^T$

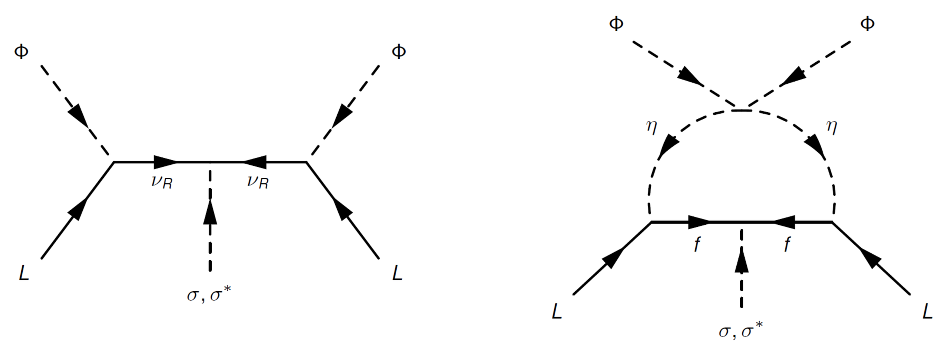
Predicts one massless neutrino, accommodates neutrino oscillation and LFV data, provides a viable WIMP dark matter candidate, **but lacks in predictivity**!

Can we reduce the number of parameters in the Lagrangian and, simultaneously, accommodate **neutrino oscillation data**, **dark matter stability** and **spontaneous CP violation** using a **single discrete flavour symmetry?**

Adding spontaneous CP violation

The number of parameters can be reduced by requiring the **Lagrangian to be CP symmetric** and invoking a **spontaneous origin for leptonic CP violation**. For that we introduce a **new scalar singlet** with **complex VEV**, $\langle\sigma\rangle = ue^{i\theta}$.

$$\frac{1}{2}(y_R\sigma + \tilde{y}_R\sigma^*)\overline{\nu_R}\nu_R^c + \frac{1}{2}(y_f\sigma + \tilde{y}_f\sigma^*)\bar{f}f^c + \text{H.c.} \xrightarrow{\text{SSB}} |M_R|e^{i\theta_R}\overline{\nu_R}\nu_R^c + |M_f|e^{i\theta_f}\bar{f}f^c + \text{H.c.}$$



At the effective level: $\mathbf{M}_\nu = -v^2 e^{i(\theta_f-\theta_R)}\dfrac{\mathbf{Y}_\nu\mathbf{Y}_\nu^T}{|M_R|} + \mathcal{F}(|M_f|, m_{\eta_R}, m_{\eta_I})|M_f|\mathbf{Y}_f\mathbf{Y}_f^T$

- **CPV is successfully transmitted to the neutrino sector** provided that $\theta \neq k\pi$ ($k \in \mathbb{Z}$) and $y_{R,f} \neq \tilde{y}_{R,f}$
- A minimal potential which allows to implement SCPV must contain a phase sensitive term of the type $\sigma^4 + \text{H.c.}$

Adding a discrete flavour symmetry

Consider the **most restrictive textures** for $\mathbf{Y}_\nu$, $\mathbf{Y}_f$ and $\mathbf{Y}_\ell$ realizable by **minimal discrete flavour symmetry** in order to maximize predictivity.

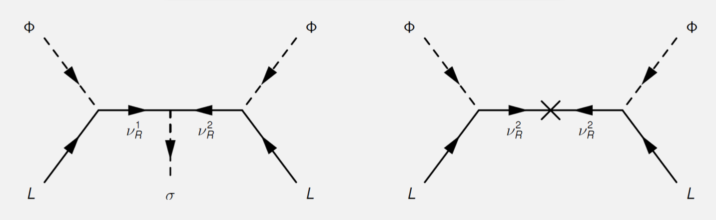
Particle content:

	Fields	$SU(2)_L \otimes U(1)_Y$	$\mathcal{Z}_8^{e-\tau *} \to \mathcal{Z}_2$
Fermions	L_e	$(\mathbf{2}, -1/2)$	$\omega^6 \equiv -i \to +1$
	L_μ	$(\mathbf{2}, -1/2)$	$\omega^0 \equiv 1 \to +1$
	L_τ	$(\mathbf{2}, -1/2)$	$\omega^6 \equiv -i \to +1$
	ν_R^1	$(\mathbf{1}, 0)$	$\omega^6 \equiv -i \to +1$
	ν_R^2	$(\mathbf{1}, 0)$	$\omega^0 \equiv 1 \to +1$
	f	$(\mathbf{1}, 0)$	$\omega^3 \to -1$
Scalars	Φ	$(\mathbf{2}, 1/2)$	$\omega^0 \equiv 1 \to +1$
	σ	$(\mathbf{1}, 0)$	$\omega^2 \equiv i \to +1$
	η	$(\mathbf{2}, 1/2)$	$\omega^5 \to -1$
	χ	$(\mathbf{1}, 0)$	$\omega^3 \to -1$

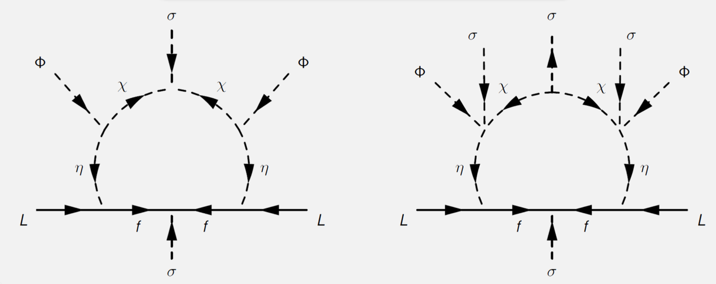
$\langle\Phi\rangle = v$, $\langle\sigma\rangle = ue^{i\theta}$, $\langle\eta\rangle = \langle\chi\rangle = 0$

*$\mathcal{Z}_8^{e-\mu}$ and $\mathcal{Z}_8^{\mu-\tau}$ are other possible charge assignments, with decoupled τ and e, respectively

Tree level



Radiative level



Allowed Yukawa and mass matrices by discrete symmetry $\mathcal{Z}_8^{e-\tau}$:

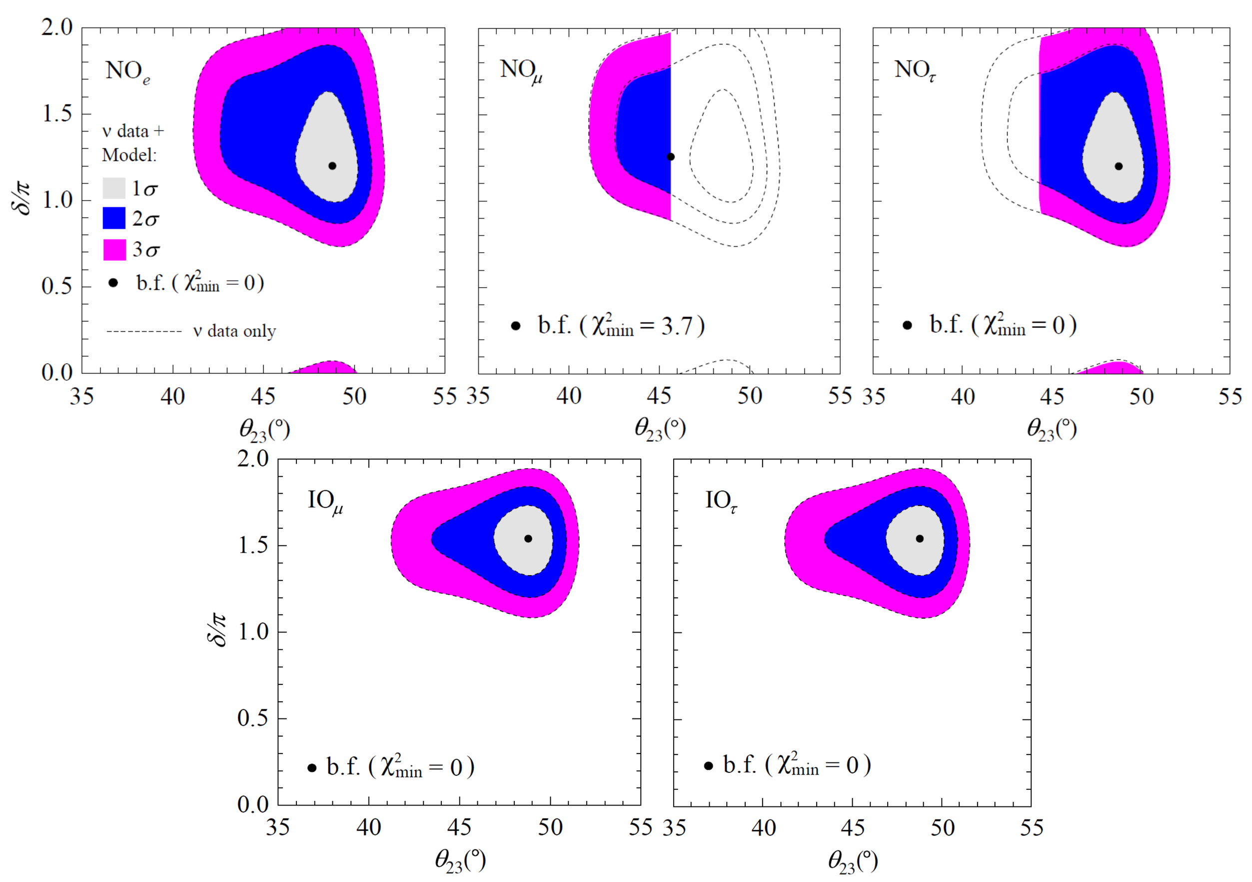
$$\mathbf{Y}_\nu = \begin{pmatrix} x_1 & 0 \\ 0 & x_2 \\ x_3 & 0 \end{pmatrix} \mathbf{M}_R = \begin{pmatrix} 0 & M_{12}\,e^{-i\theta} \\ M_{12}\,e^{-i\theta} & M_{22} \end{pmatrix} \mathbf{Y}_f = \begin{pmatrix} y_1 \\ 0 \\ y_2 \end{pmatrix} \mathbf{Y}_\ell = \begin{pmatrix} w_1 & 0 & w_2 \\ 0 & w_3 & 0 \\ w_4 & 0 & w_5 \end{pmatrix}$$

At the effective level:

$$\mathbf{M}_\nu = -v^2\mathbf{Y}_\nu\mathbf{M}_R^{-1}\mathbf{Y}_\nu^T + \mathcal{F}(M_f, m_{S_i})M_f\mathbf{Y}_f\mathbf{Y}_f^T$$
$$\mathbf{M}'_\nu = \mathbf{U}_\ell^T\mathbf{M}_\nu\mathbf{U}_\ell = \mathbf{U}^*\text{diag}(m_1, m_2, m_3)\mathbf{U}^\dagger$$

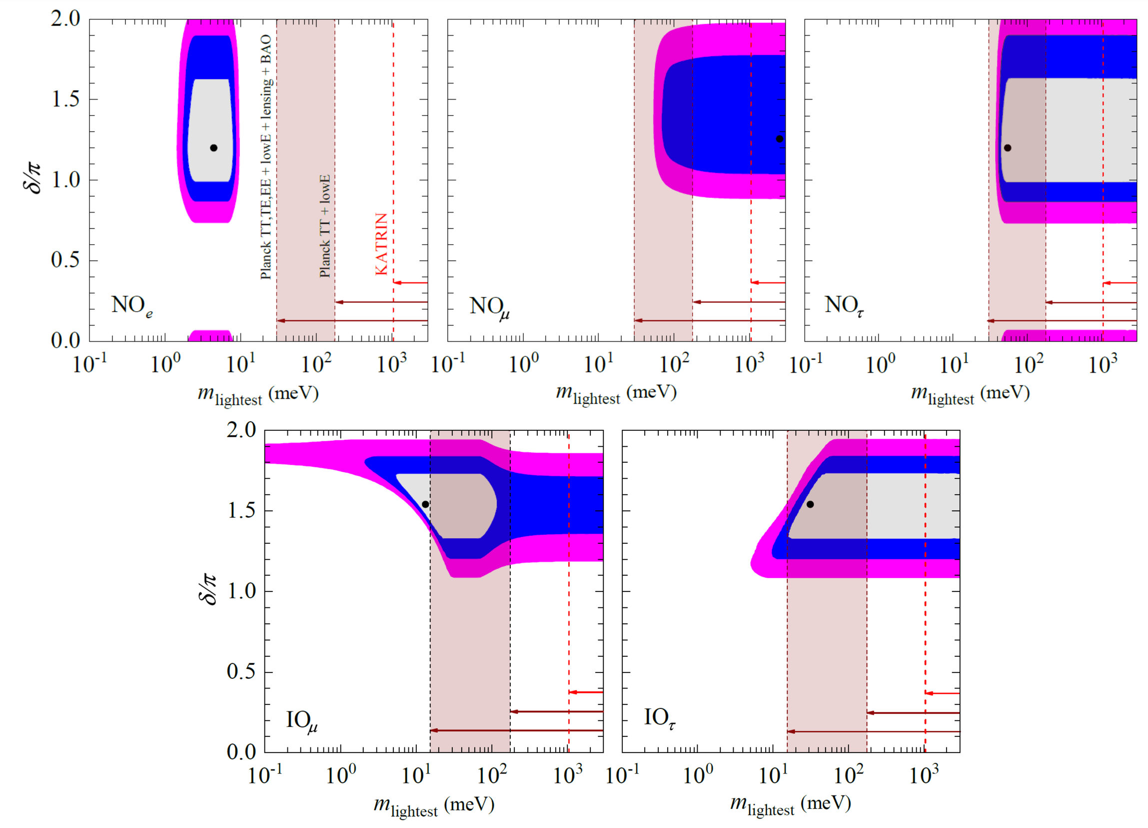
- decoupled e: $(\mathbf{M}'_\nu)_{11} = 0$ for $\mathcal{Z}_8^{\mu-\tau}$
- decoupled μ: $(\mathbf{M}'_\nu)_{22} = 0$ for $\mathcal{Z}_8^{e-\tau}$
- decoupled τ: $(\mathbf{M}'_\nu)_{33} = 0$ for $\mathcal{Z}_8^{e-\mu}$

δ and θ_{23} predictions



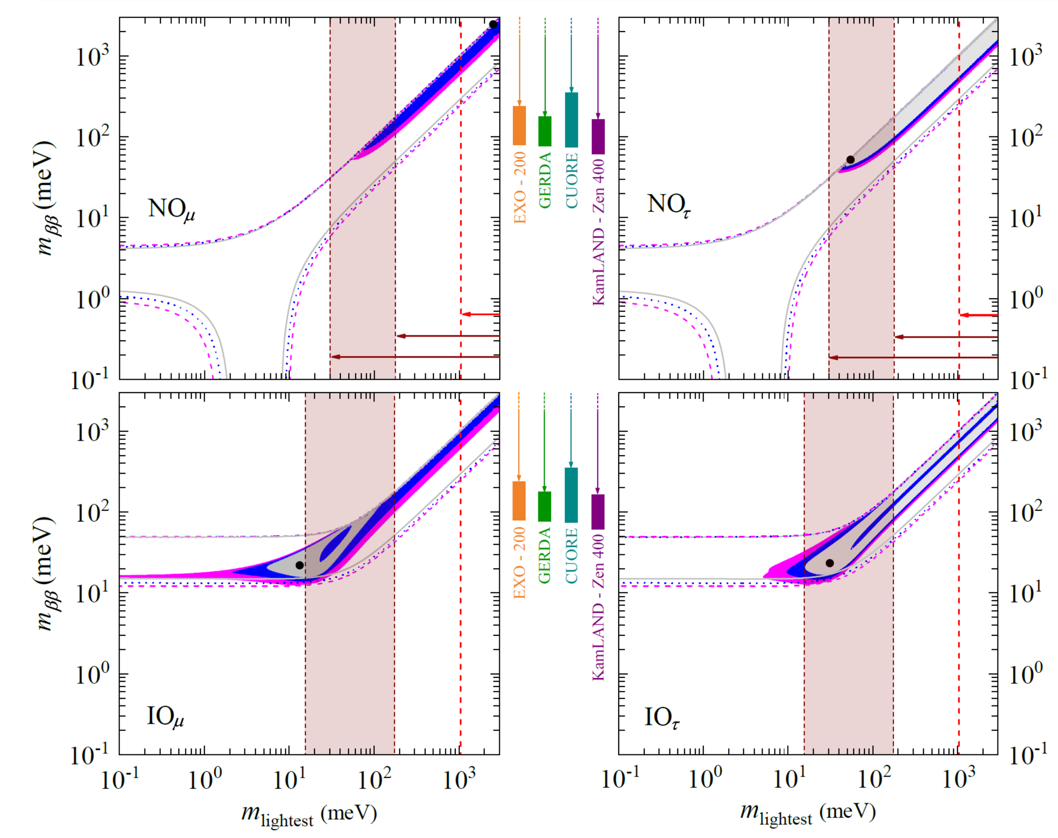
- IO$_e$ is incompatible with data since it leads to vanishing 0υββ decay rate
- For NO$_e$, IO$_\mu$ and IO$_\tau$, the model allowed regions coincide with the experimental ones
- NO$_\mu$ (NO$_\tau$) selects the first (second) octant for θ_{23}

Constraints on the lightest neutrino mass



- For NO$_e$ upper and lower limits for m_{lightest} are established
- NO$_\mu$, NO$_\tau$ and IO$_\tau$ we get lower bounds for m_{lightest} which are very close to the cosmological and KATRIN bounds

Constraints on $m_{\beta\beta}$



- NO$_e$ predicts $m_{\beta\beta} = 0$, allowed by neutrino oscillation data and current $m_{\beta\beta}$ experimental limits
- In all remaining cases the model establishes a lower bound on $m_{\beta\beta}$
- Current KamLAND bound nearly excludes the NO cases

Conclusions

- We propose a **simple scoto-seesaw model** where **neutrino masses**, **dark matter stability** and **SCPV** are accommodated with a **single $\mathcal{Z}_8$ symmetry**, which is broken down to a dark $\mathcal{Z}_2$ by the VEV of a **new complex scalar singlet σ**. This VEV is the **unique source of SCPV** being transmitted to the leptonic sector via the couplings of σ to ν_R and f.
- The **$\mathcal{Z}_8$ symmetry leads to low-energy constraints** that can be tested against neutrino data. For **NO**, the predicted **ranges on m_{lightest} will be fully tested** by **near-future 0υββ-decay experiments**. For **IO**, better determination of δ and further sensitivity improvement from upcoming 0υββ-decay experiments are required to test the model.

References

[1] N. Rojas, R. Srivastava and J. W. F. Valle, Phys.Lett.B 789 (2019) 132-136

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