Axion–neutrino interactions in seesaw models and astrophysical probes

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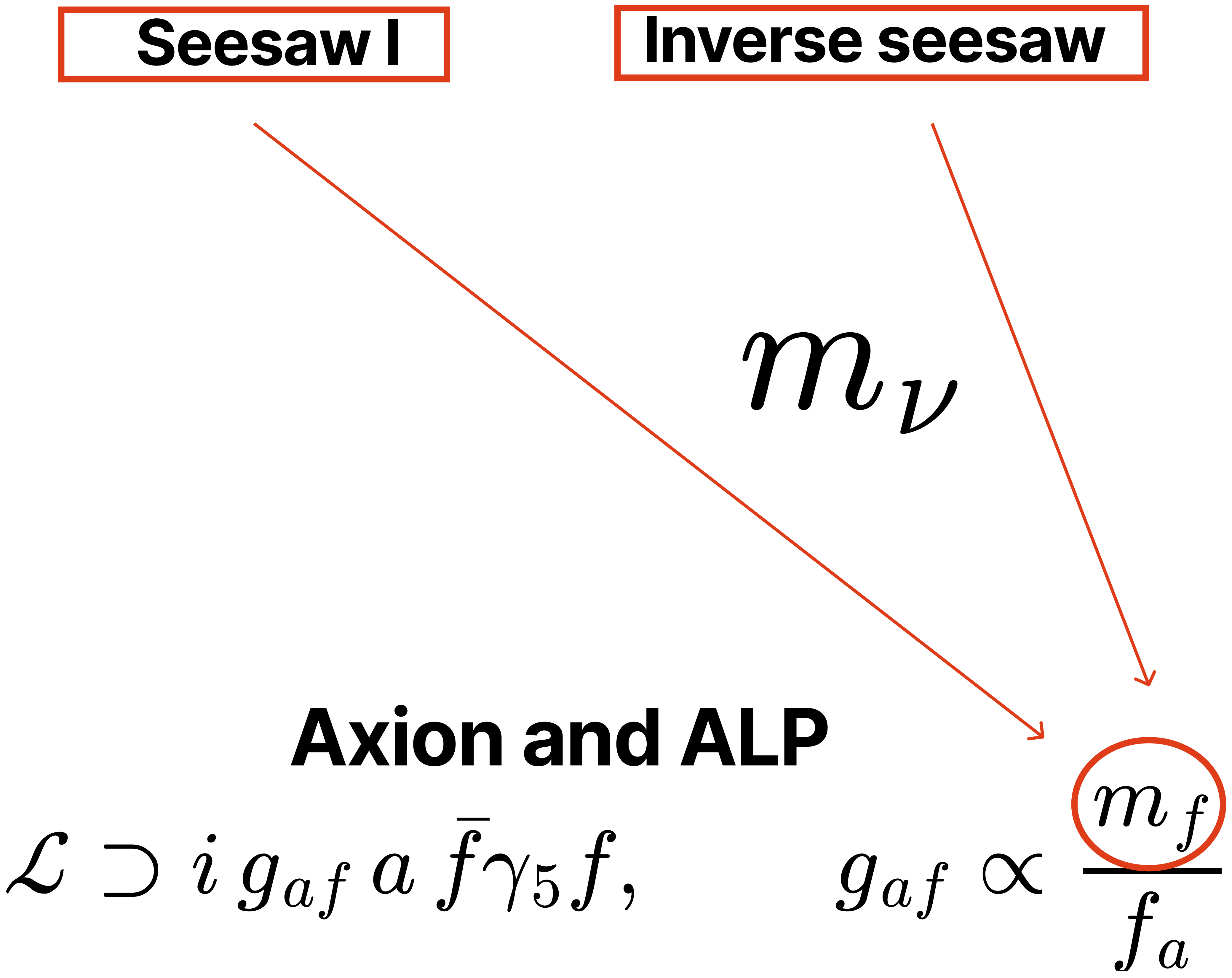
May 22, Quarks 2026

Axion and ALP

Hypothetical pseudo-Nambu–Goldstone bosons that arise in a variety of extensions of the Standard Model, most famously in the Peccei–Quinn solution to the strong-CP problem.

Extentions of Standart Model

Massive neutrinos



Seesaw I

Inverse seesaw

$$m_\nu$$

Axion and ALP

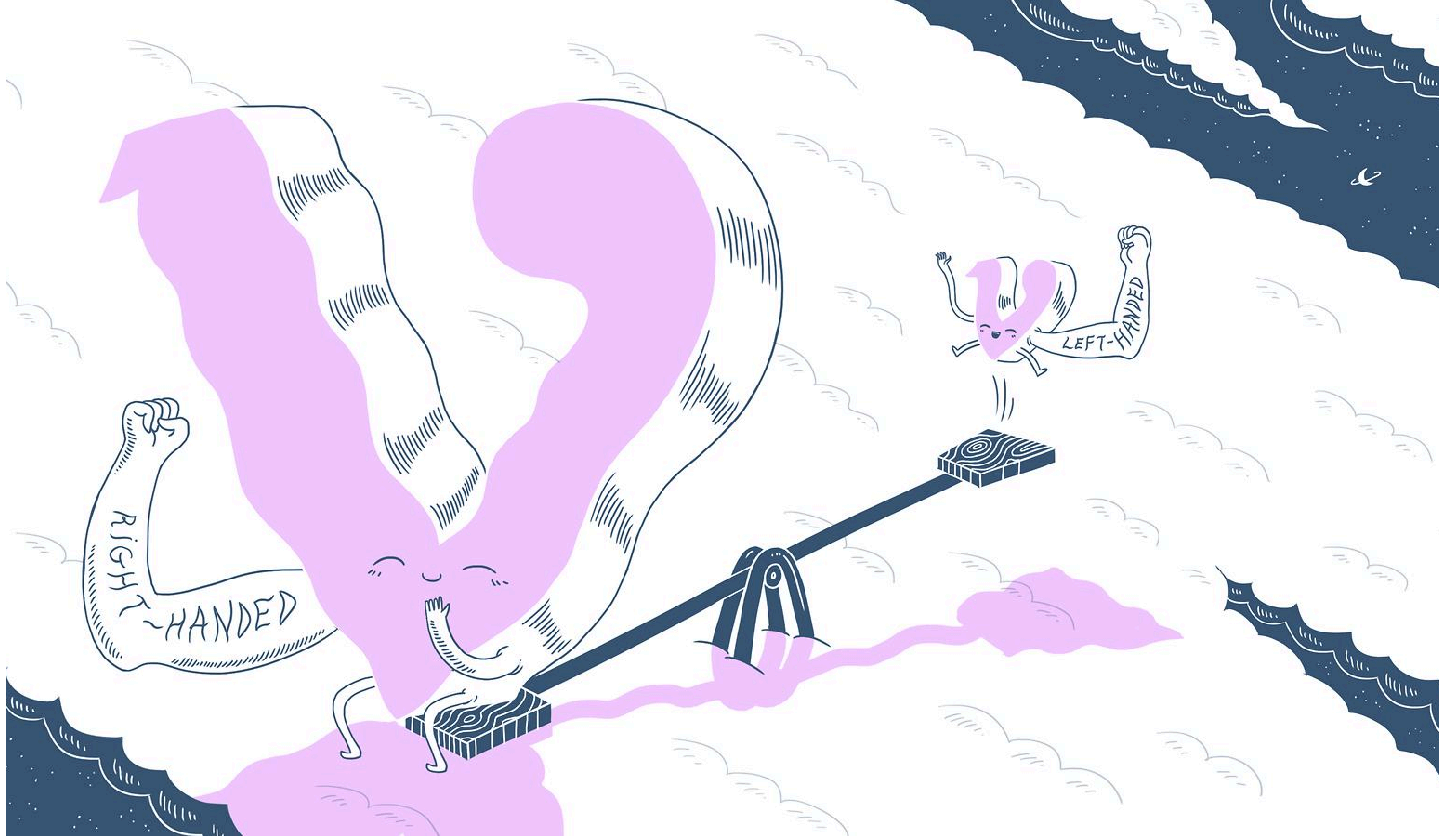
$$\mathcal{L} \supset i\, g_{af}\, a\, \bar{f}\gamma_5 f, \qquad g_{af} \propto \frac{m_f}{f_a}$$

Neutrino oscillations demonstrate that neutrinos are massive, implying that an axion–neutrino coupling is generically allowed in mass-proportional frameworks.

Can we detect the result of such interaction in different astrophysical scenarios ?

Seesaw I

$$\mathcal{L} = \mathcal{L}_{\text{SM}} + i\bar{N}_R\partial N_R - (Y_\nu)_\alpha \bar{L}_\alpha \tilde{H} N_R$$
$$-\frac{1}{2}(\mathcal{M}_R)\overline{N_R^c}N_R + \mathcal{L}_{aNN} + \mathcal{L}_{ae} + \text{h.c.}.$$



$$\mathcal{L}_{aNN} = \frac{C_\nu}{f_a}(\partial_\mu a)\bar{N}_R\gamma^\mu\gamma_5 N_R = -\frac{2iC_\nu}{f_a} m_{N_R} a \bar{N}_R \gamma_5 N_R$$

$$\mathcal{M}_\nu = \begin{pmatrix} 0 & \mathcal{M}_D \\ \mathcal{M}_D^\top & \mathcal{M}_R \end{pmatrix}$$

$$\Gamma(a \to \nu\nu) = \frac{m_N^2 m_a |U_{\nu N}|^4}{2\pi f_a^2}\sqrt{1 - \frac{4m_\nu^2}{m_a^2}}$$

$$U_{N\nu} \simeq \mathcal{M}_D \mathcal{M}_R^{-1}$$

Inverse Seesaw

$$\mathcal{L}_{\mathrm{mass}} = -\overline{N_R} m_D \nu_L - \overline{S_R} M N_R^c - \tfrac{1}{2} \overline{S_R} \mu S_R^c + \mathrm{h.c.}$$

$$\mathcal{M}_\nu = \begin{pmatrix} 0 & m_D^\top & 0 \\ m_D & 0 & M^\top \\ 0 & M & \mu \end{pmatrix}$$

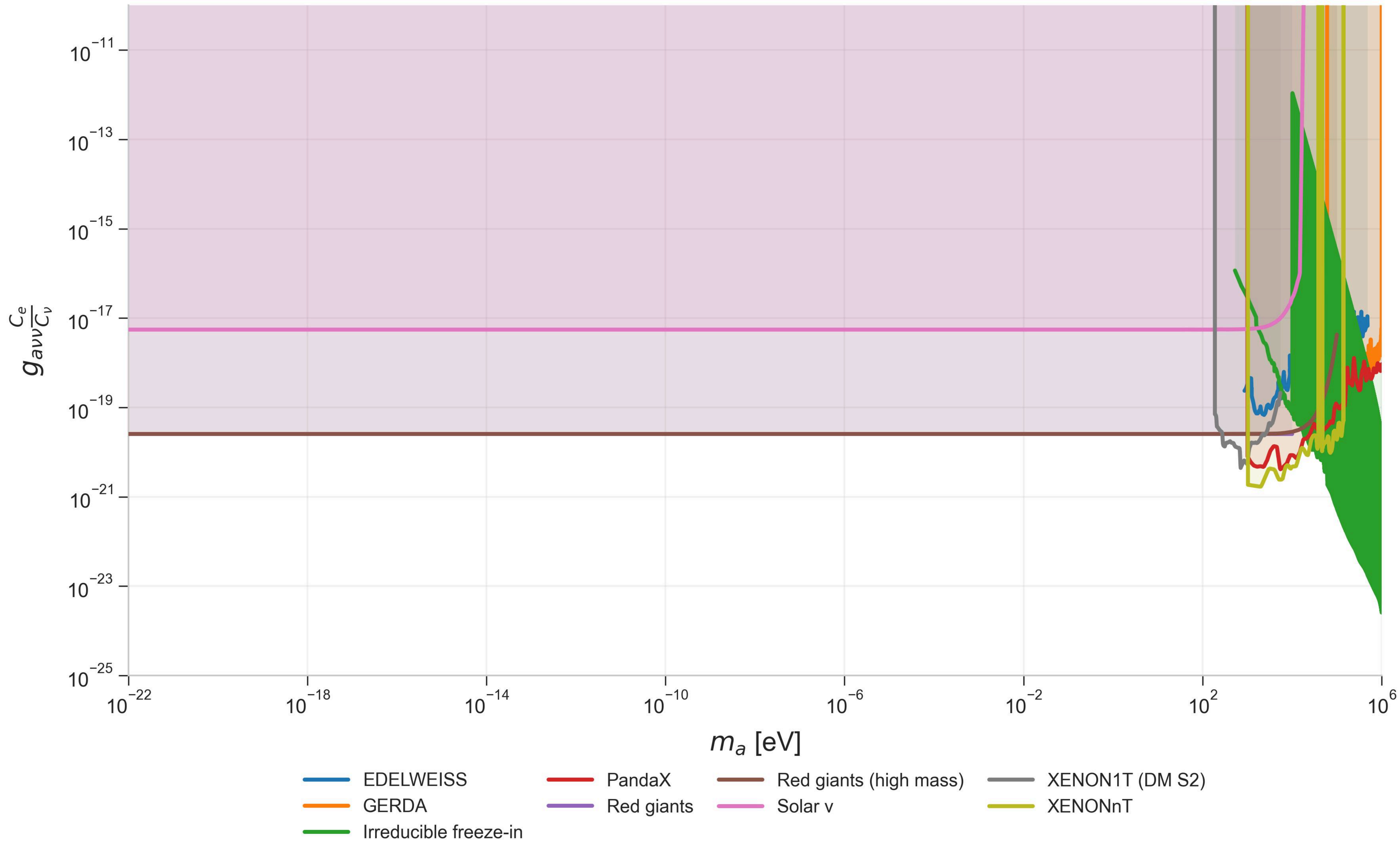
$$m_\nu \simeq \mu \frac{m_D^2}{M^2},$$

$$m_\pm \simeq \pm\sqrt{M^2 + m_D^2} + \mu \frac{M^2}{2\left(M^2 + m_D^2\right)}.$$

$$\mathcal{L}_{a\psi\psi} = \frac{1}{f_a}(\partial_\mu a)\bar{\psi}\gamma^\mu\gamma_5 Q\psi = \frac{1}{f_a}(\partial_\mu a)\bar{\nu}\gamma^\mu\gamma_5 G\nu$$

ALP constraints

$$g_{a\nu} = g_{aee} \frac{C_\nu}{C_e} \frac{m_\nu}{m_e}$$



Time delay

$$\tau = n\,\sigma_{\nu\nu}\,D \qquad \tau \approx 10^{-53}$$

The probability for a neutrino to scatter on a CνB neutrino along the line of sight is $1 - e^{-\tau}$

Axion flux

$$\rho_{\rm DM} = 0.4\,{\rm GeV/cm^3}$$

$$\tau = n\,\sigma_{\nu\nu}\,D$$

$$\tau \approx 10^{-15}$$

Conclusions

- **Within minimal and phenomenologically viable Type-I and inverse-seesaw models,none of our benchmark scenarios can yield an observable effect**

- **Detectable signals would require either non-minimal model-building that decouples $g_{a\nu}$ from charged-lepton constraints and astrophysical settings with drastically enhanced effective target densities**

Thank you!

This work is supported by the Russian Science Foundation, grant 22-12-00253-P.