Probing the dark universe through astrophysical and cosmic neutrinos

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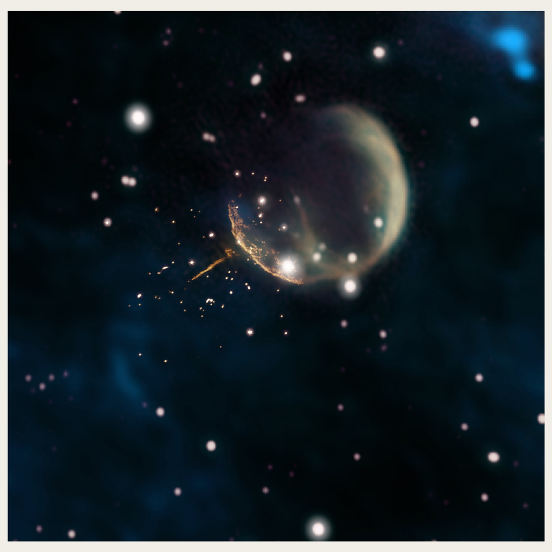
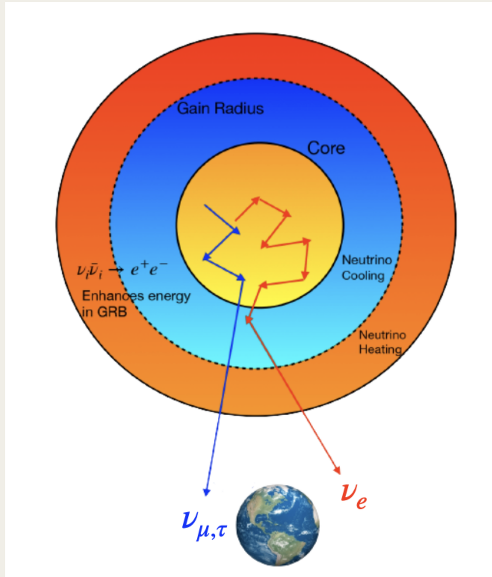
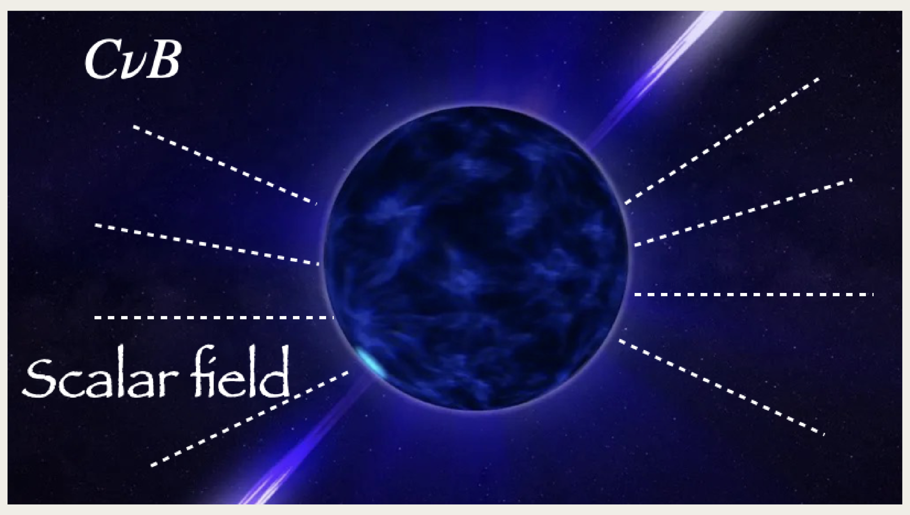
Sources of astrophysical and cosmic neutrinos



(a) Pulsar kick public.nrao.edu/news/cannonball-pulsar



(b) Neutrino emission from GRB



(c) Interaction of CνB with the scalar radiated from NS

Astrophysical and cosmic neutrinos can interact with the light BSM scalar and vector particles (can be DM) to explain cosmic phenomena.

Pulsar kick in ULDM background

Vector-neutrino interaction Lagrangian

$$-\mathcal{L}_{\rm int} = g'_{\alpha\beta}\bar{\nu}_\alpha\gamma^\mu\nu_\beta A'_\mu, \quad \alpha,\beta = e,\mu,\tau, \quad \xi_{\alpha\beta} = g'_{\alpha\beta}\hat{\mathbf{p}}\cdot\mathbf{A}' = g'_{\alpha\beta}\frac{\sqrt{2\rho_{\rm DM}}}{m_{A'}}\hat{\mathbf{p}}\cdot\hat{\boldsymbol{\Omega}} = \boldsymbol{\Omega}\cdot\hat{\mathbf{p}}$$

Scalar-neutrino interaction Lagrangian

$$-\mathcal{L}_{\rm int} = g'_{\alpha\beta}\partial_\mu\phi\bar{\nu}_\alpha\gamma^\mu\nu_\beta, \quad \alpha,\beta = e,\mu,\tau, \quad \xi_{\alpha\beta} = g'_{\alpha\beta}\hat{\mathbf{p}}\cdot\nabla\phi \simeq g'_{\alpha\beta}\sqrt{2\rho_{\rm DM}}\hat{\mathbf{p}}\cdot\mathbf{v}_\phi$$

Asymmetry of neutrino momentum

$$\frac{\Delta p}{p} = \frac{1}{6}\frac{\int_0^\pi \mathbf{F}_S(\varphi)\cdot\delta\hat{\boldsymbol{\Omega}}dS}{\int_0^\pi \mathbf{F}_S(\varphi)\cdot\hat{\mathbf{n}}dS} \simeq -\frac{1}{18}\frac{\varrho}{r_{\rm res}}$$

Resonance condition for active-sterile neutrino oscillation

$$\varrho = -\frac{g'_{ff}\frac{\sqrt{2\rho_{\rm DM}}}{m_{A'}}}{V_{\nu_f}(h_p^{-1}+h_{V_{\nu_f}}^{-1})} \ \text{(vector)}, \ \varrho = -\frac{g'_{ff}v_\phi\sqrt{2\rho_{\rm DM}}}{V_{\nu_f}(h_p^{-1}+h_{V_{\nu_f}}^{-1})} \ \text{(scalar)}$$

Memory signal from pulsar kick

$$|h(t)| \simeq \frac{2G}{r}\alpha L_\nu\mathcal{T} \lesssim 1.06\times10^{-19}\Big(\frac{|\alpha|}{0.01}\Big)\Big(\frac{E_{\rm tot}}{2\times10^{53}\ {\rm erg}}\Big)\Big(\frac{1\ {\rm kpc}}{r}\Big)$$

$$\alpha = \frac{S_+ - S_-}{S_+ + S_-} \simeq \frac{\Delta p}{p} = (1/18)(\varrho/r_{\rm res})$$

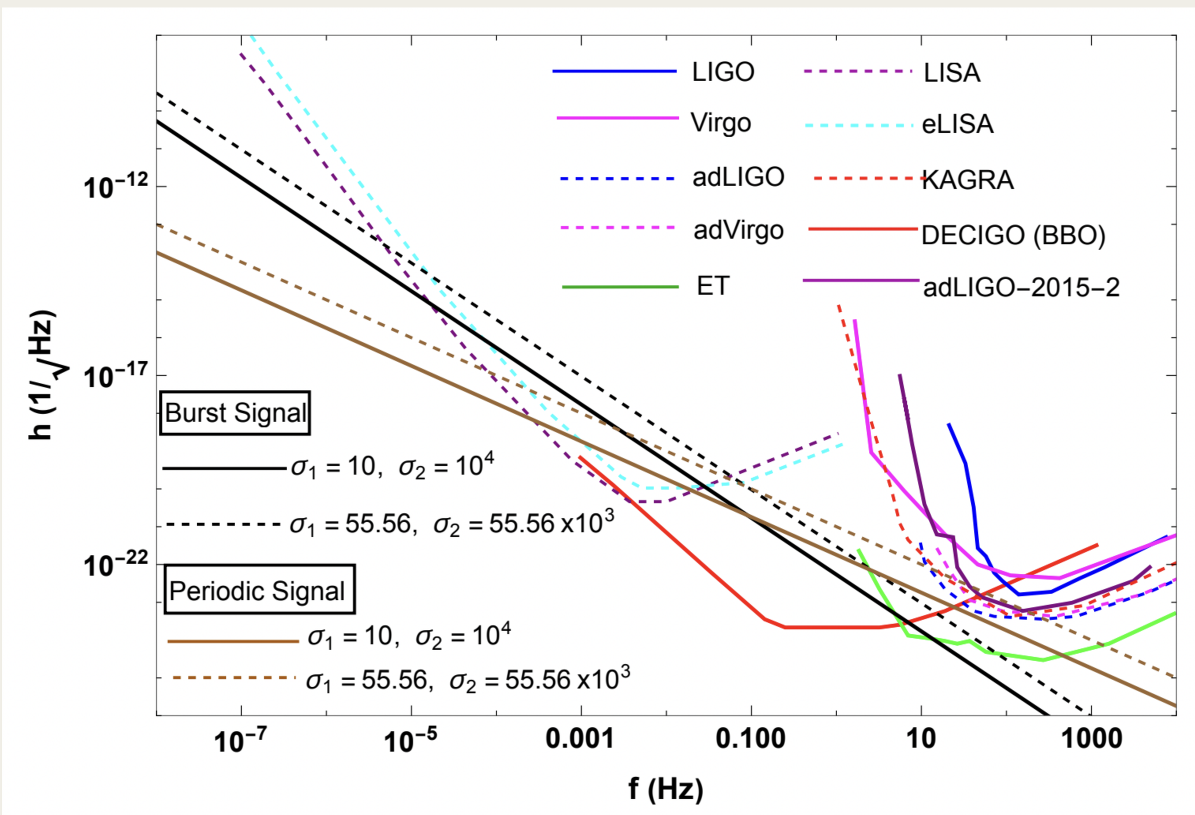


Figure 1. Variation of GW intensity with the frequency of radiation

$$\alpha = 1.8\times10^{-4}\sigma_1, \quad \sigma_1 = \frac{g_{ff'}/m_{A'}}{x_{\rm res}\eta} \ \text{(UVDM)}, \quad \alpha = 1.8\times10^{-7}\sigma_2, \quad \sigma_2 = \frac{g_{ff'}}{x_{\rm res}\eta} \ \text{(USDM)}$$

SME and pulsar kick

$$(i\Gamma^\nu_{lm}\partial_\nu - M_{lm})\nu_m = 0$$

$$\Gamma^\nu_{lm} \equiv \gamma^\nu\delta_{lm} + c^{\mu\nu}_{lm}\gamma_\mu + d^{\mu\nu}_{lm}\gamma_5\gamma_\mu + e^\nu_{lm} + if^\nu_{lm}\gamma_5 + \frac{1}{2}g^{\lambda\mu\nu}_{lm}\sigma_{\lambda\mu}$$

$$M_{lm} \equiv m_{lm} + im_{5lm}\gamma_5 + a^\mu_{lm}\gamma_\mu + b^\mu_{lm}\gamma_5\gamma_\mu + \frac{1}{2}H^{\mu\nu}_{lm}\sigma_{\mu\nu}$$

Leading order effective Hamiltonian

$$h_{\rm eff} = \frac{1}{E}(a^\mu_L p_\mu - c^{\mu\nu}_L p_\mu p_\nu)$$

$$a_L = g'_{ff}\frac{\sqrt{2\rho_{\rm DM}}}{m'_A} \lesssim 8.9\times10^{-13}\ {\rm eV}, \quad c_L = g'_{ff}\frac{\sqrt{2\rho_{\rm DM}}}{2pm'_A} \lesssim 5.2\times10^{-21}$$ **(JCAP 01 (2024) 069)**

Energizing GRBs via Z' mediated neutrino heating

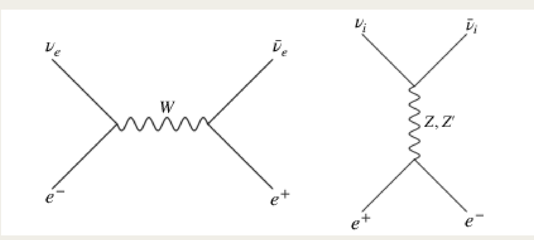


Figure 2. $\nu\bar{\nu} \to e^+e^-$ in energizing GRB

$$E^{\rm max}_{\rm GRB} \sim 10^{52}{\rm erg}, \quad \text{Observation}$$
$$E^{\rm Theory}_{GRB} \sim 1.5\times10^{50}{\rm erg}, \quad \text{Newtonian}$$
$$E^{\rm Theory}_{GRB} \sim 4.3\times10^{51}{\rm erg}, \quad \text{Schwarzschild}$$

Constraints on Z'

$$\dot{q}(r) = \int\int f_\nu(\mathbf{p}_\nu, r)f_{\bar{\nu}}(\mathbf{p}_{\bar{\nu}}, r)(\sigma|\mathbf{v}_\nu - \mathbf{v}_{\bar{\nu}}|E_\nu E_{\bar{\nu}}) \times \frac{E_\nu + E_{\bar{\nu}}}{E_\nu E_{\bar{\nu}}}d^3\mathbf{p}_\nu d^3\mathbf{p}_{\bar{\nu}}$$

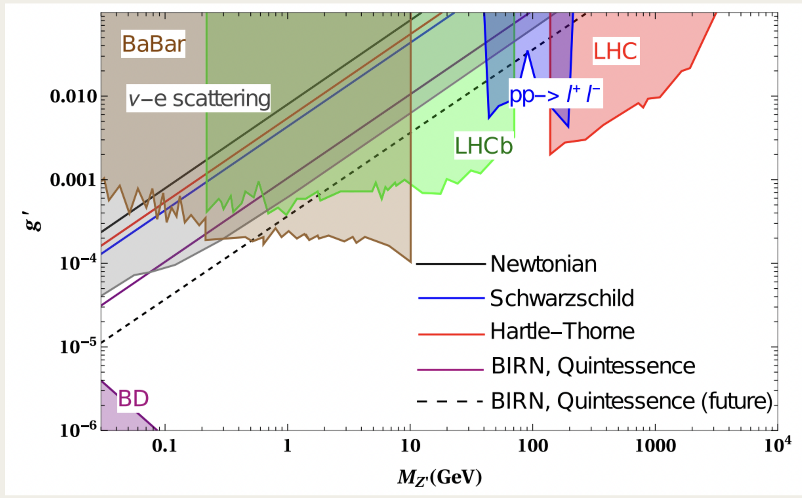


Figure 3. Constraints on Z' from GRB **(Eur.Phys.J.C 83 (2023) 3, 223)**

Scalar field interaction with CνB

$$\mathcal{L} = \frac{1}{2}\partial_\mu\phi\partial^\mu\phi - \frac{1}{2}m_\phi^2\phi^2 - g_e\phi\rho$$

$$\phi(r) = \frac{g_e}{m_\phi r}\Big[e^{-m_\phi r}\int_0^r r'\rho(r')\sinh(m_\phi r')dr' + \sinh(m_\phi r)\int_r^\infty r'\rho(r')e^{-m_\phi r'}dr'\Big]$$

Variation of electron mass

$$\Big(\frac{\Delta m_e}{m_e}\Big)_{net} = \frac{3g_e^2N}{4\pi R^3 m_\phi^2 m_e}\frac{e^{-m_\phi R}}{m_\phi R}(\sinh(m_\phi R) - m_\phi R\cosh(m_\phi R))$$

Scalar induced magnetic field

$$B^{net}_\phi(R) = \frac{3g_e^2N}{4\pi m_\phi^3 R^3\Omega}\Big(\frac{1}{R^3} + \frac{m_\phi}{R^2}\Big)e^{-m_\phi R}(\sinh(m_\phi R) - m_\phi R\cosh(m_\phi R)).$$

Pulsar spin-down

$$\frac{dE}{dt} = \frac{1}{8\pi^2}\Omega k^3\int\int d\Omega_n|\hat{\mathbf{n}}\cdot\mathbf{p}_\Omega|^2 = \frac{1}{12\pi}g_e^2R^2\Omega^4N^2\sin^2\theta_m\Big(1 - \frac{m_\phi^2}{\Omega^2}\Big)^{\frac{3}{2}}$$ **(arXiv: 2404.18309)**

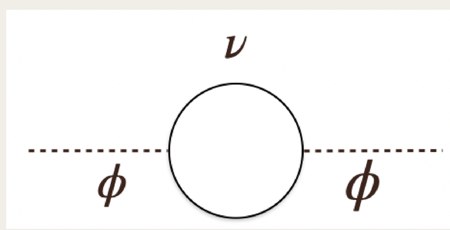


Figure 4. Scalar mass induced by CνB

The mass of the scalar modifies due to the CνB background

$$m_\phi^2 \to m_\phi^2 + y_\nu^2\frac{n_\nu}{m_\nu}$$

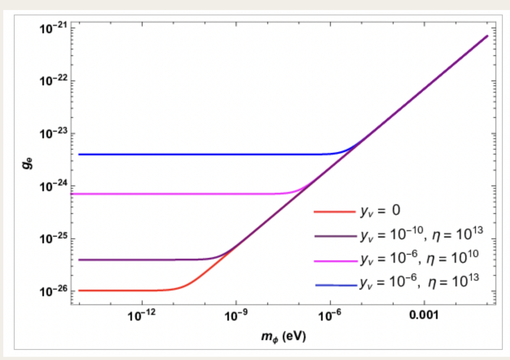


Figure 5. g_e vs. m_ϕ for different y_ν and η in search for scalar magnetic field

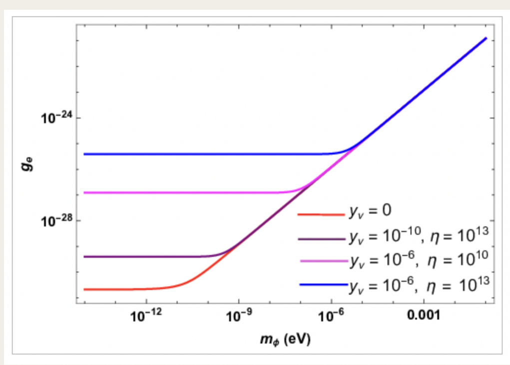


Figure 6. g_e vs. m_ϕ for different y_ν and η in search for electron mass variation

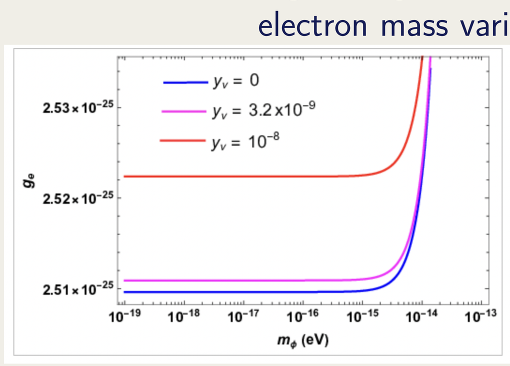


Figure 7. g_e vs. m_ϕ for different y_ν from pulsar spin-down

Acknowledgements

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