Search for ultralight particles from compact stars through gravitational wave telescopes

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Fundamental Physics and Gravitational Wave Detectors, Pollica

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COST EUROPEAN COOPERATION IN SCIENCE & TECHNOLOGY

COSMIC WISPERS CA21106

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About Me !

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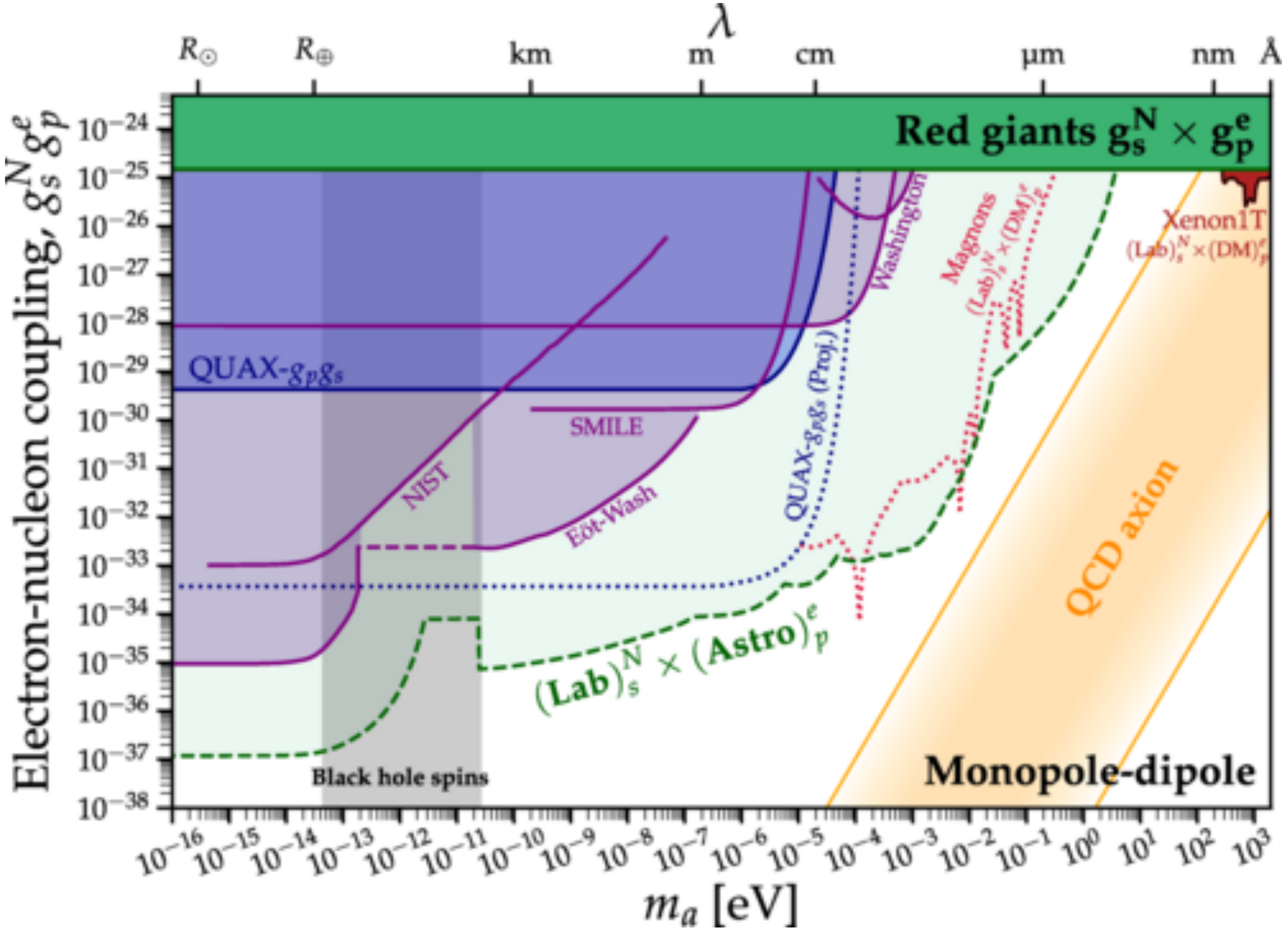
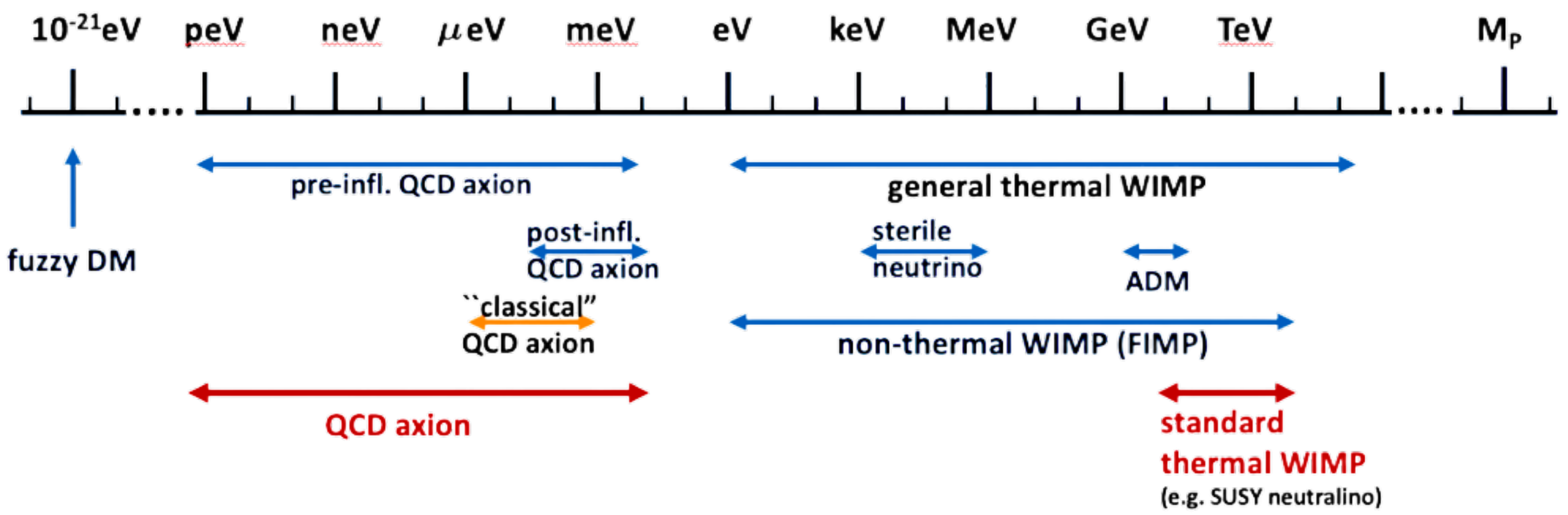
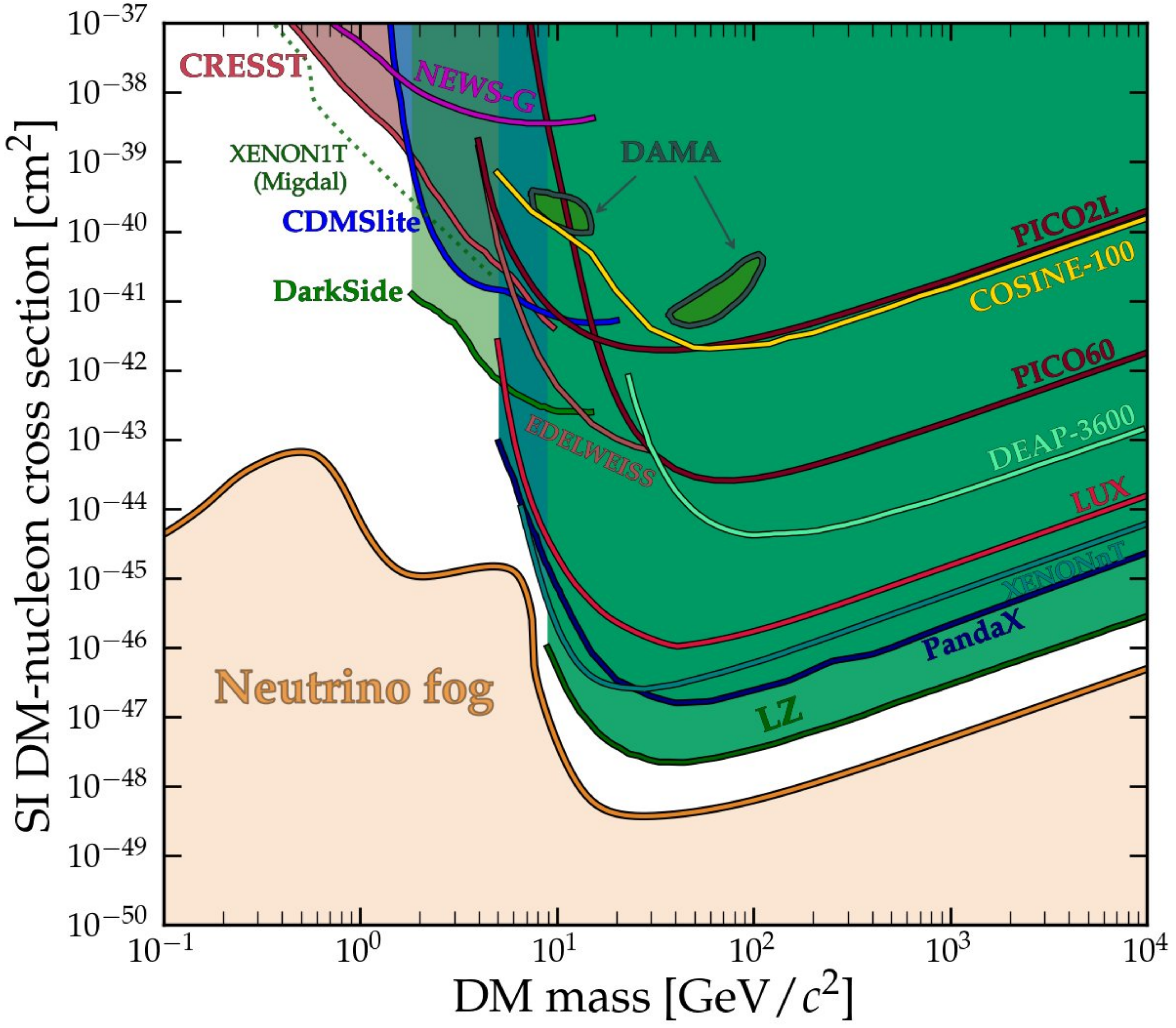
Associated with QUAX gs-gp collaboration



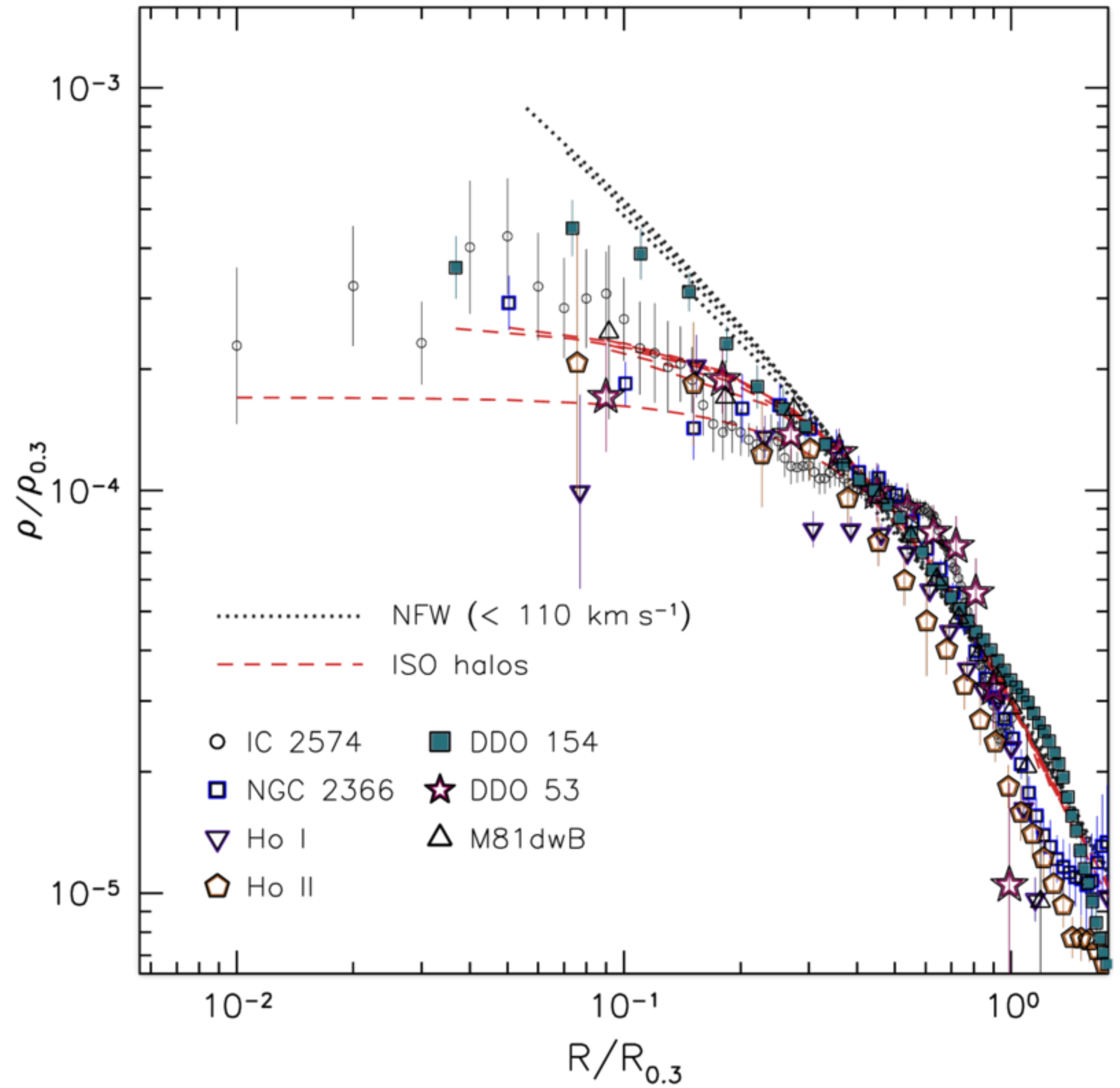
DM: Motivations



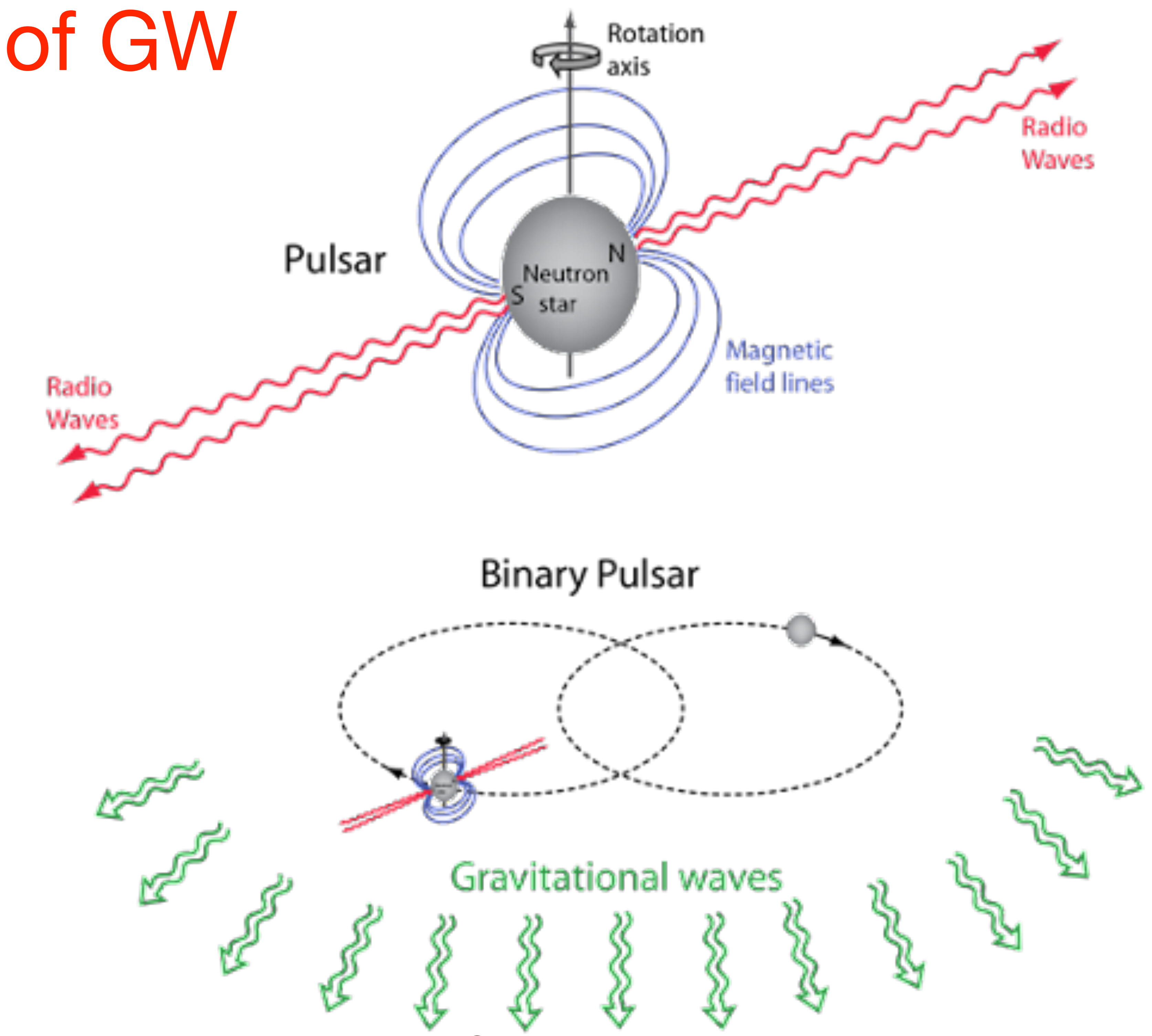
LZ collaboration, 2024



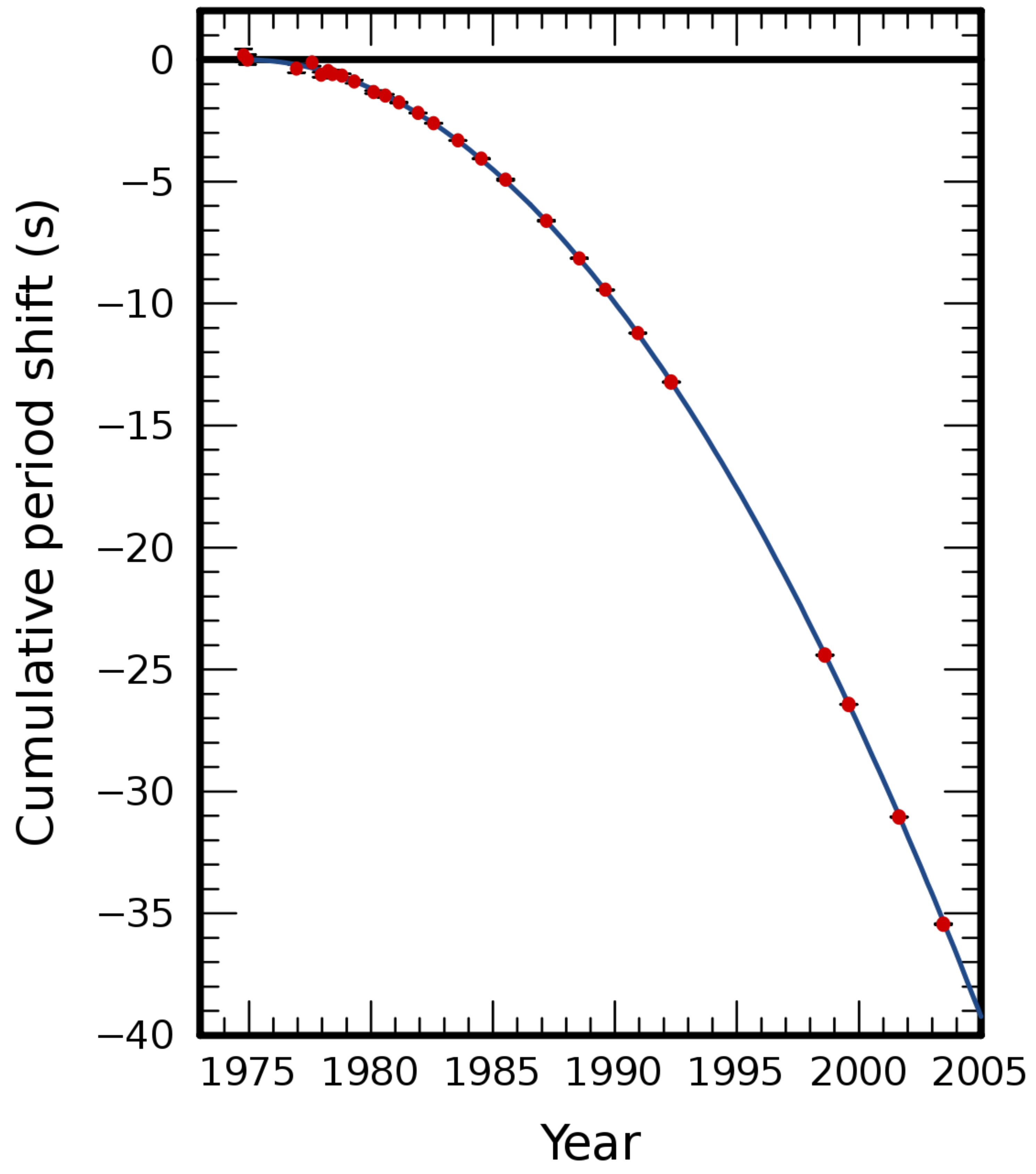
Astron J, 2011



Indirect dectection of GW



Weisberg, Taylor, ASP conference series , vol 328, 2005



$$P = \frac{G}{5}\left(\frac{d^3Q_{ij}}{dt^3}\frac{d^3Q_{ij}}{dt^3} - \frac{1}{3}\frac{d^3Q_{ii}}{dt^3}\frac{d^3Q_{jj}}{dt^3}\right)$$

$$\frac{dE_{GW}}{dt} = \frac{32G}{5}\Omega^6\left(\frac{m_1m_2}{m_1+m_2}\right)^2 a^4(1-e^2)^{-7/2}\left(1+\frac{73}{24}e^2+\frac{37}{96}e^4\right)$$

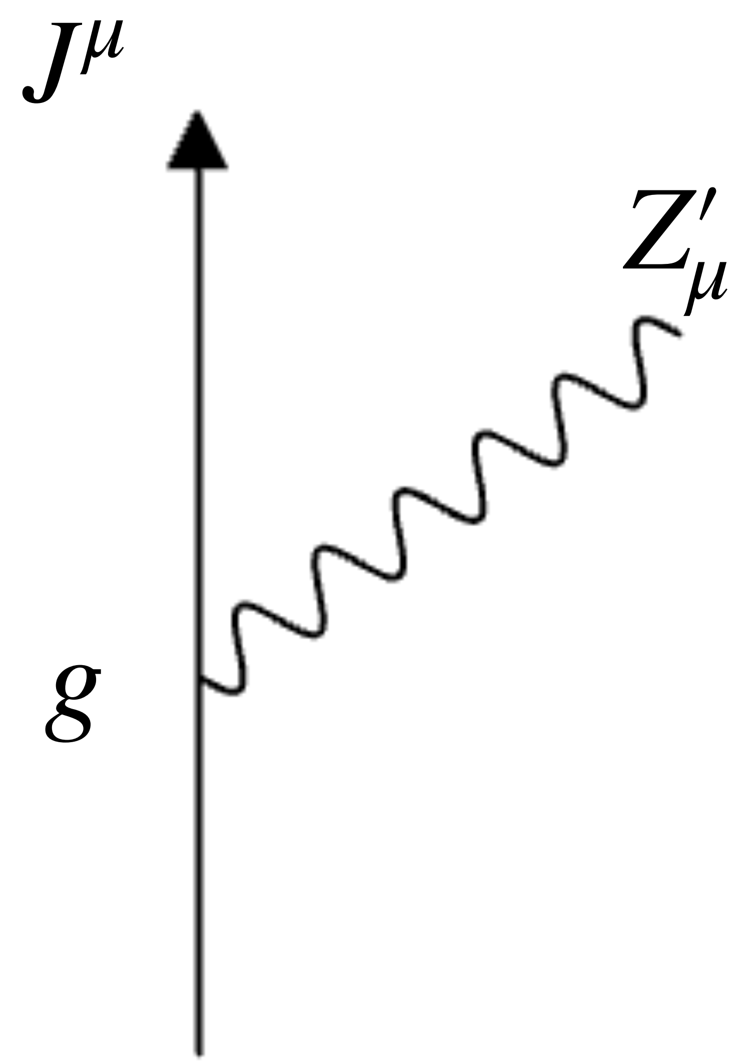
Peters, Mathews, Phys. Rev, 1963

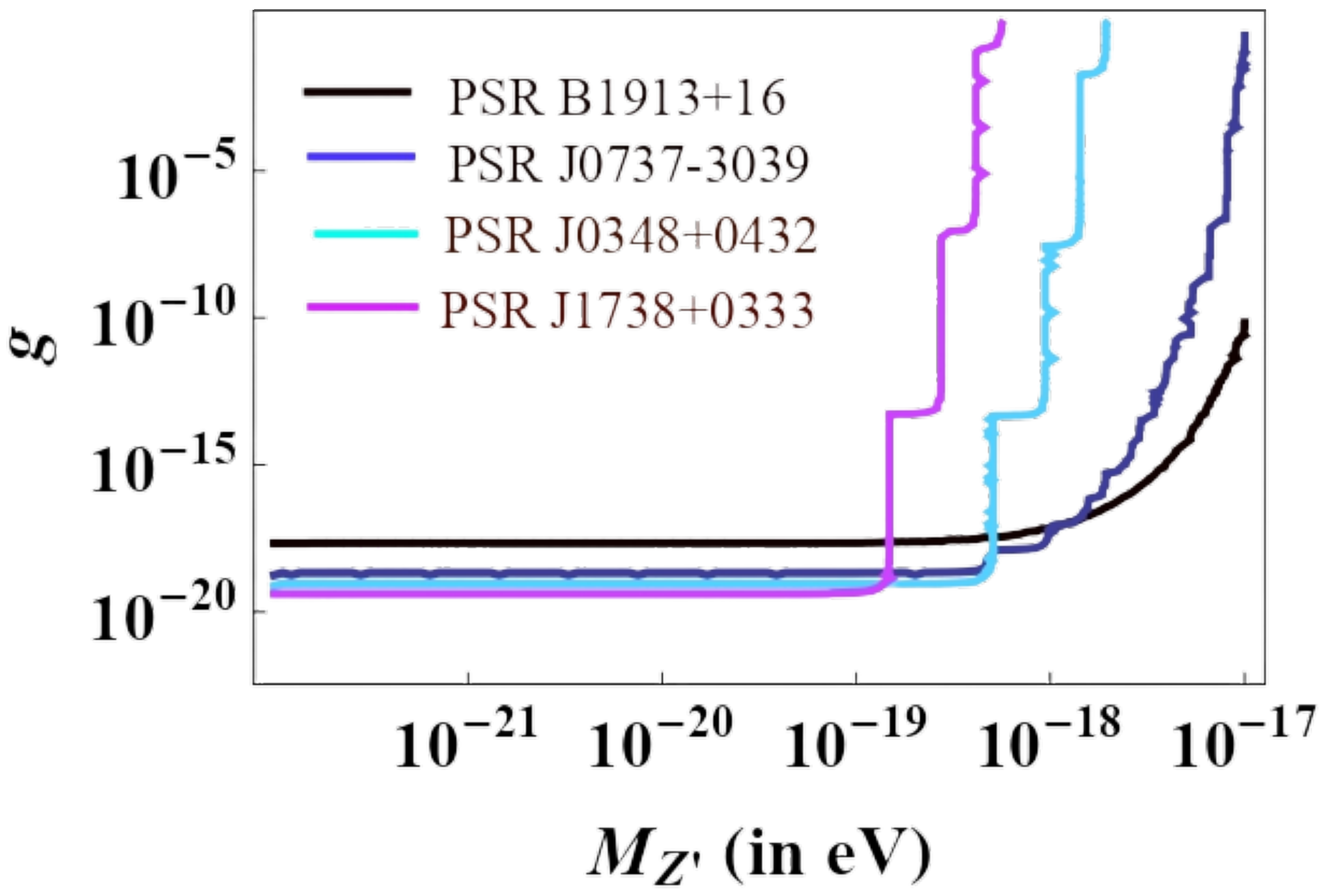
$$\dot{P}_b = 6\pi G^{-\frac{3}{2}}(m_1m_2)^{-1}(m_1+m_2)^{-\frac{1}{2}}a^{\frac{5}{2}}\left(\frac{dE}{dt}\right)$$

Spin-1

Ultralight $L_\mu - L_\tau$ vector

Constraining particle physics models





HT: $P \sim 8$ h $\rightarrow \Omega \sim 10^{-19}$ eV

$Q_\mu \approx 10^{55}$

Garani, Heeck, Phys. Rev. D, 2019

$$\mathscr{L} \supset g' Z'_\mu (\bar{\mu}\gamma^\mu \mu - \bar{\tau}\gamma^\mu \tau + \bar{\nu}_\mu \gamma^\mu L \nu_\mu - \bar{\nu}_\tau \gamma^\mu L \nu_\tau)$$

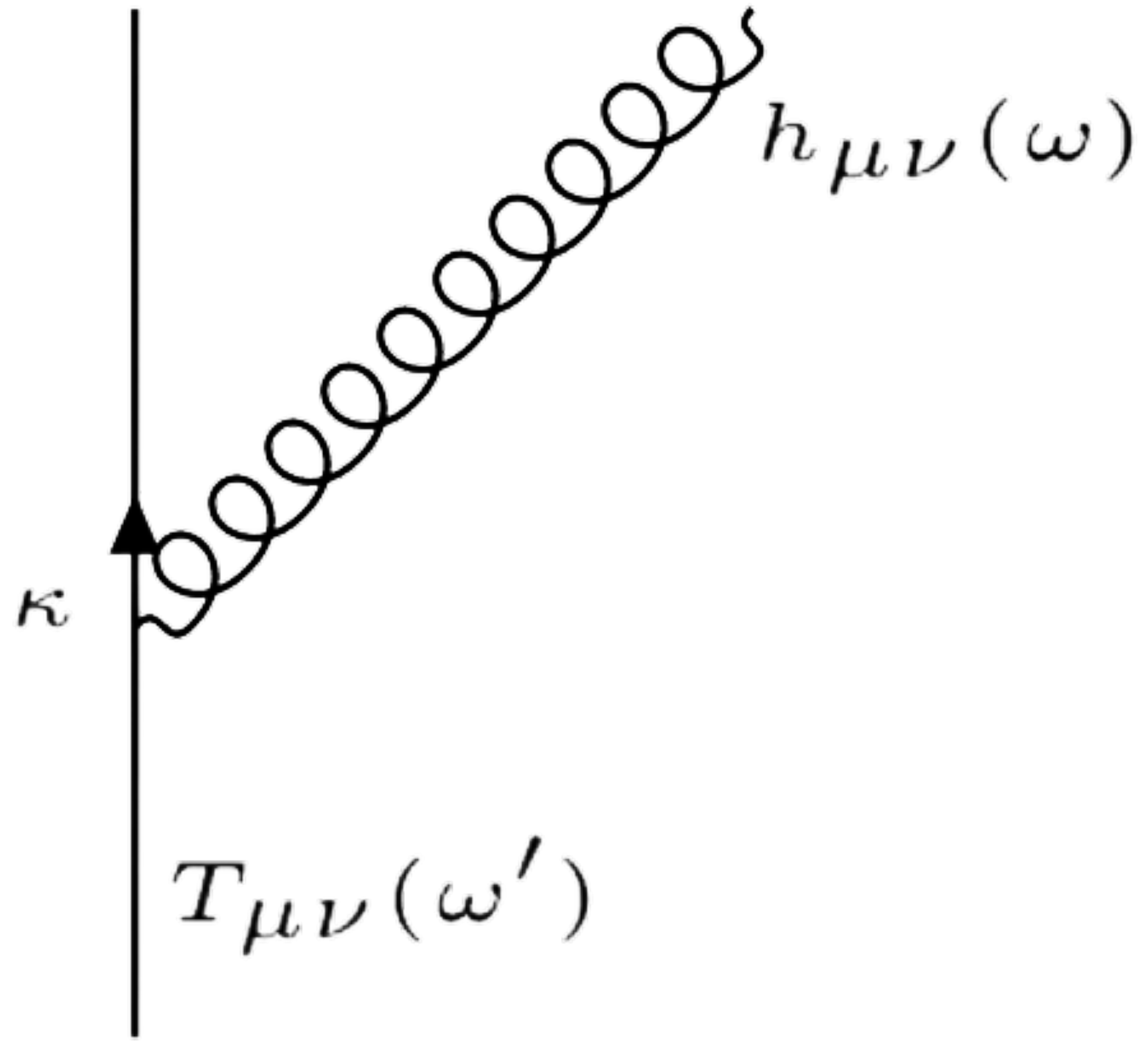
$$\frac{dE_V}{dt} = \frac{g^2}{6\pi} a^2 M^2 \left(\frac{Q_1}{m_1} - \frac{Q_2}{m_2}\right)^2 \Omega^4 \sum_{n>n_0} 2n^2 \left[J_n'^2(ne) + \frac{(1-e^2)}{e^2} J_n^2(ne)\right] \left(1 - \frac{n_0^2}{n^2}\right)^{\frac{1}{2}} \left(1 + \frac{1}{2}\frac{n_0^2}{n^2}\right) \qquad n_0 = \frac{M_{Z'}}{\Omega}$$

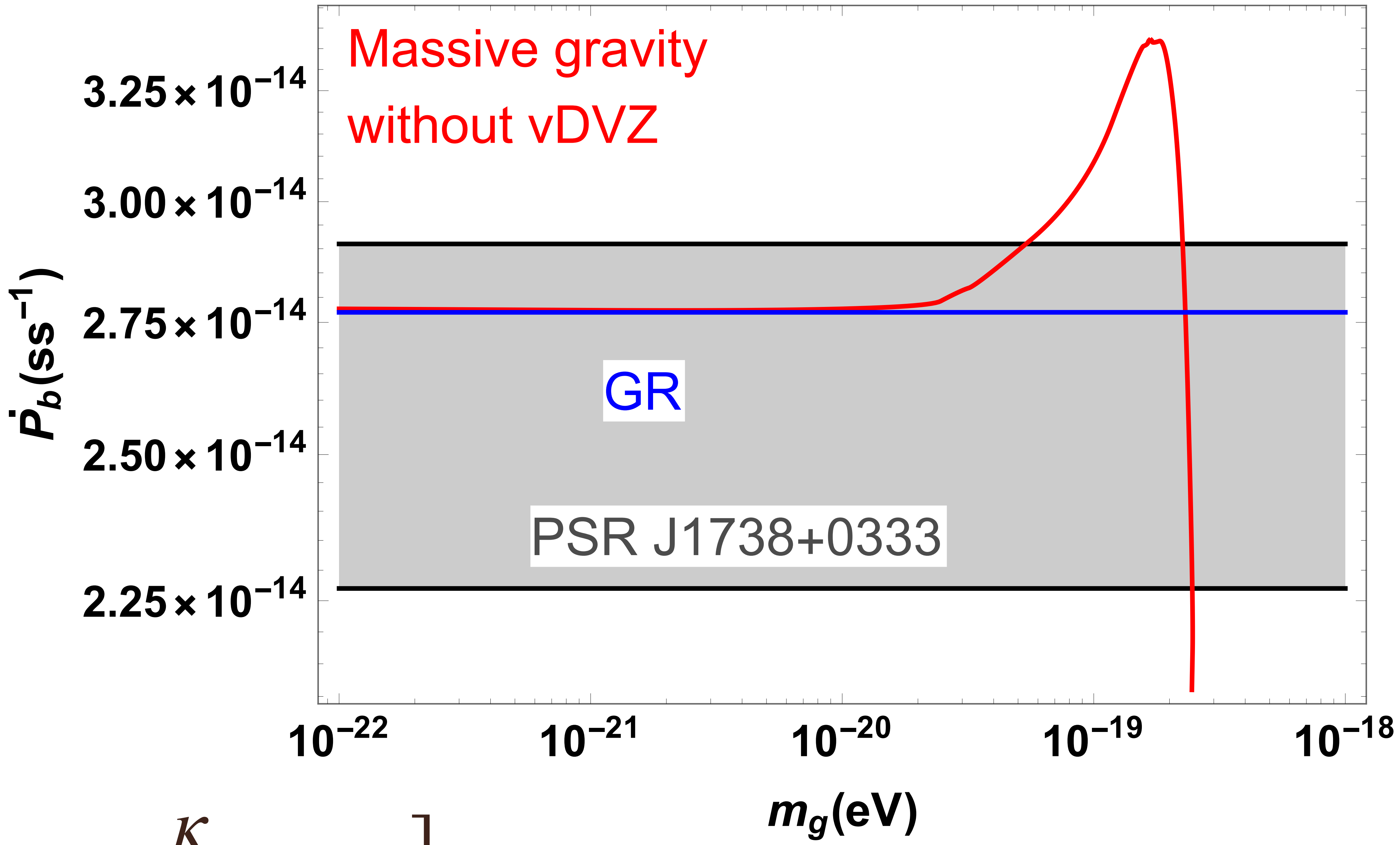
T.K.P, S. Mohanty, S. Jana, Phys. Rev. D, 2019

Spin-2

Massive graviton

$$V^{(1/2)}(r) = \frac{GM_1M_2}{r} e^{-m_g r}$$





$$S = \int d^4x \left[\frac{1}{2}h_{\mu\nu}\epsilon^{\mu\nu\alpha\beta}h_{\alpha\beta} + \frac{1}{2}m_g^2 h_{\mu\nu}(\eta^{\mu(\alpha}\eta^{\beta)\nu} - (1-a)\eta^{\mu\nu}\eta^{\alpha\beta})h_{\alpha\beta} + \frac{\kappa}{2}h_{\mu\nu}T^{\mu\nu}\right]$$

$$a = \frac{1}{2}$$

$$D^{1/2}_{\alpha\beta\mu\nu}(k) = \frac{1}{-k^2+m_g^2}\left(\frac{1}{2}(\eta_{\alpha\mu}\eta_{\beta\nu} + \eta_{\alpha\nu}\eta_{\beta\mu} - \frac{1}{2}\eta_{\alpha\beta}\eta_{\mu\nu}\right) + (k - \text{dependent terms})$$

$$\frac{dE}{dt} = \frac{32G}{5}\mu^2 a^4 \Omega^6 \sum_{n=1}^{\infty} n^6 \sqrt{1-\frac{n_0^2}{n^2}}\left[f(n,e)\left(1+\frac{4}{3}\frac{n_0^2}{n^2}+\frac{1}{6}\frac{n_0^4}{n^4}\right) - \frac{5J_n^2(ne)}{36n^4}\frac{n_0^2}{n^2}\left(1-\frac{n_0^2}{4n^2}\right)\right]$$

$$m_g < 1.81 \times 10^{-20}\ \text{eV}$$

T.K.P, S. Mohanty, S. Jana, JCAP, 2022

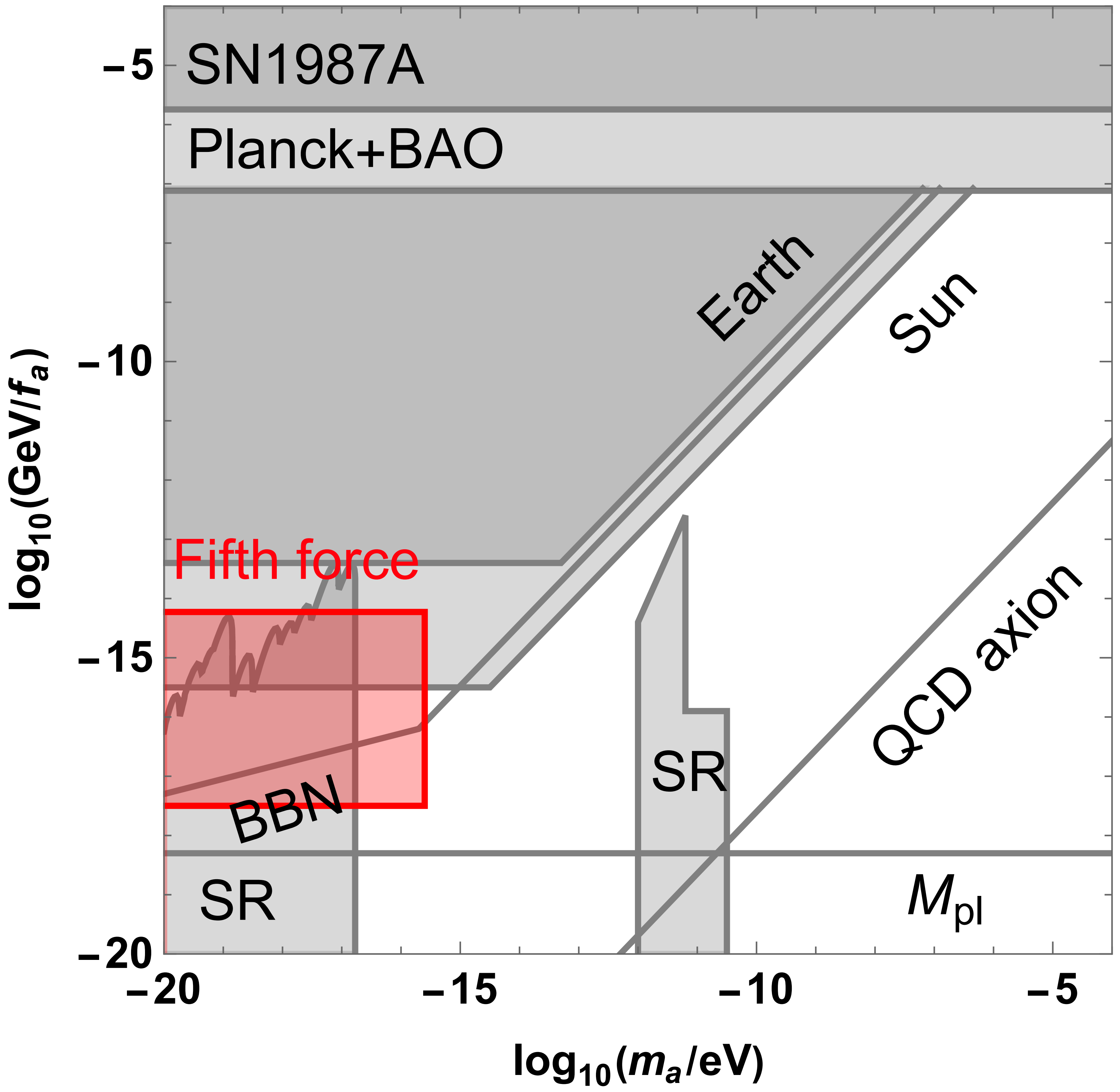
Spin-0

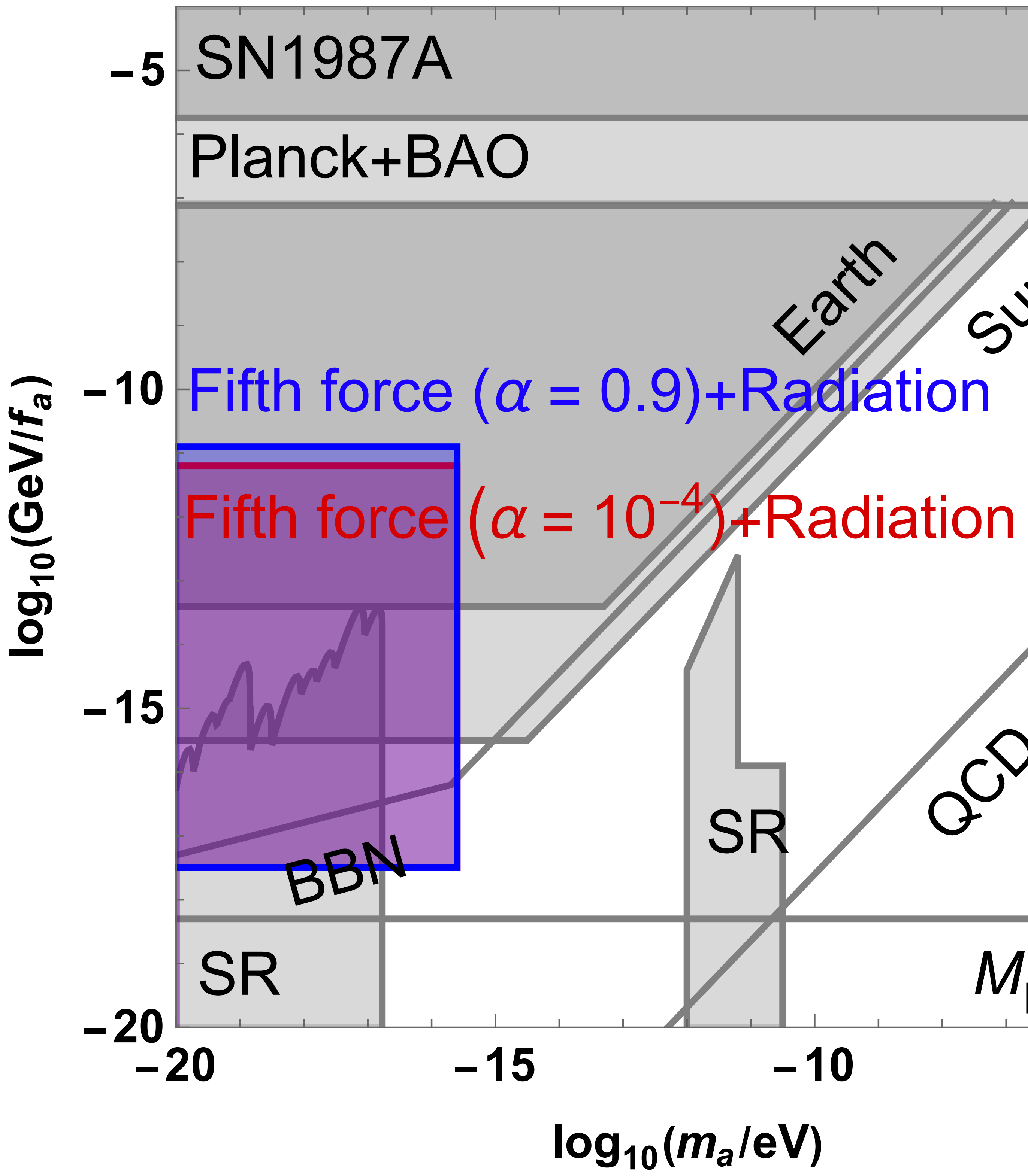
Axions

Hook, Huang, JHEP, 2018

$$q_{eff} = -\frac{8\pi G M f_a}{\ln\left(1-\frac{2GM}{r_{NS}}\right)} \qquad p = 8\pi G f_a \mu a\left[\frac{1}{\ln\left(1-\frac{2Gm_2}{r_{NS}}\right)} - \frac{1}{\ln\left(1-\frac{2Gm_1}{r_{NS}}\right)}\right] \qquad F_5 = \frac{q_1 q_2}{4\pi a^2}$$

$$\frac{dE}{dt} = -\frac{32}{5}G\mu^2 a^4\omega^6(1-e^2)^{-\frac{7}{2}}\left(1+\frac{73}{24}e^2+\frac{37}{96}e^4\right) - \frac{\omega^4 p^2}{24\pi}\frac{(1+e^2/2)}{(1-e^2)^{\frac{5}{2}}}$$





T.K.P, A.Ghoshal, G. Lambiase,Phys. Dark. Universe, 2024

Direct detection: GW170817

See talk by Costantino pacilio

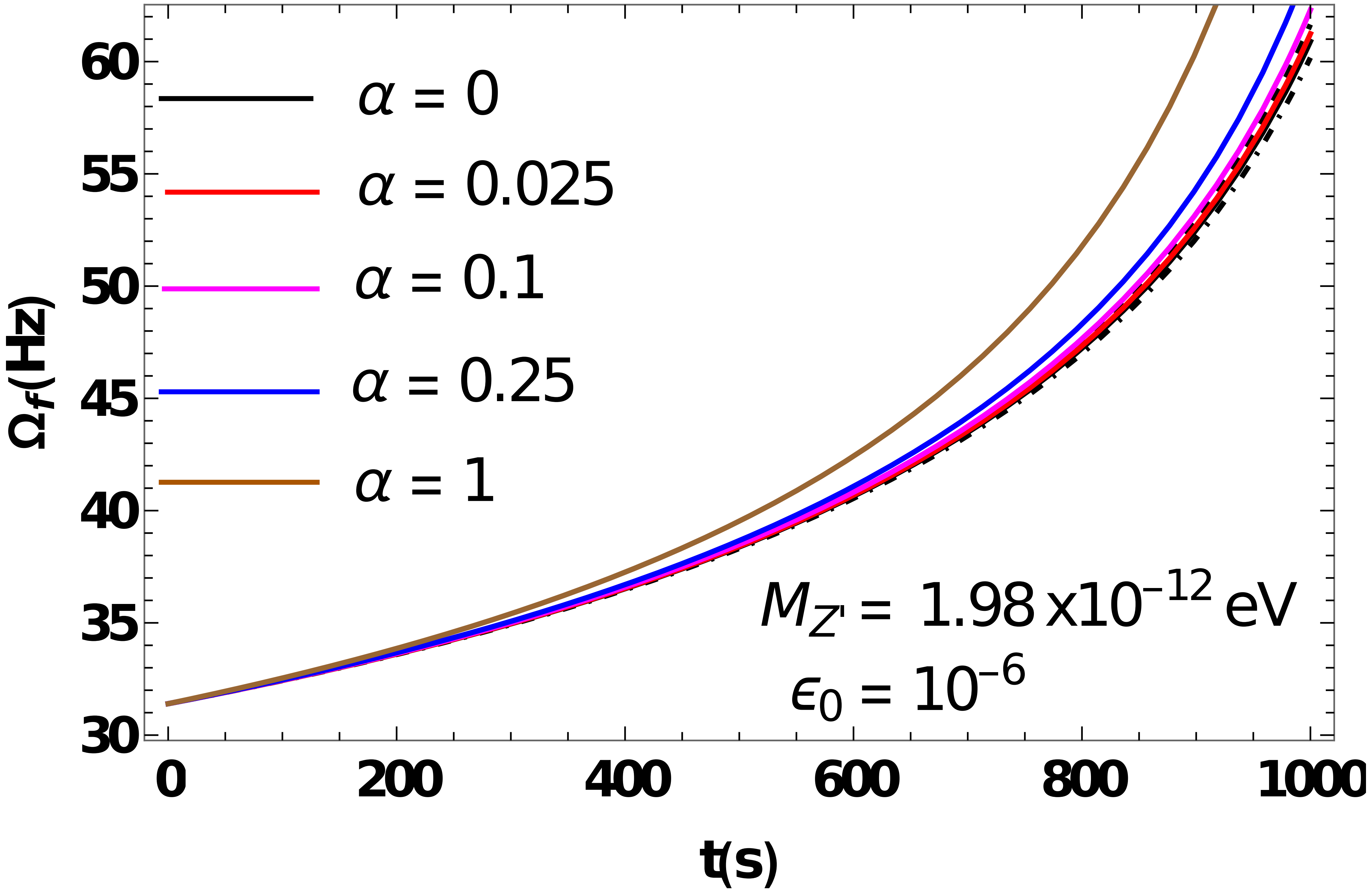
$$\dot{\Omega}_f = L_1 + L_2^{S/V} + L_3 + L_4 + L_5$$

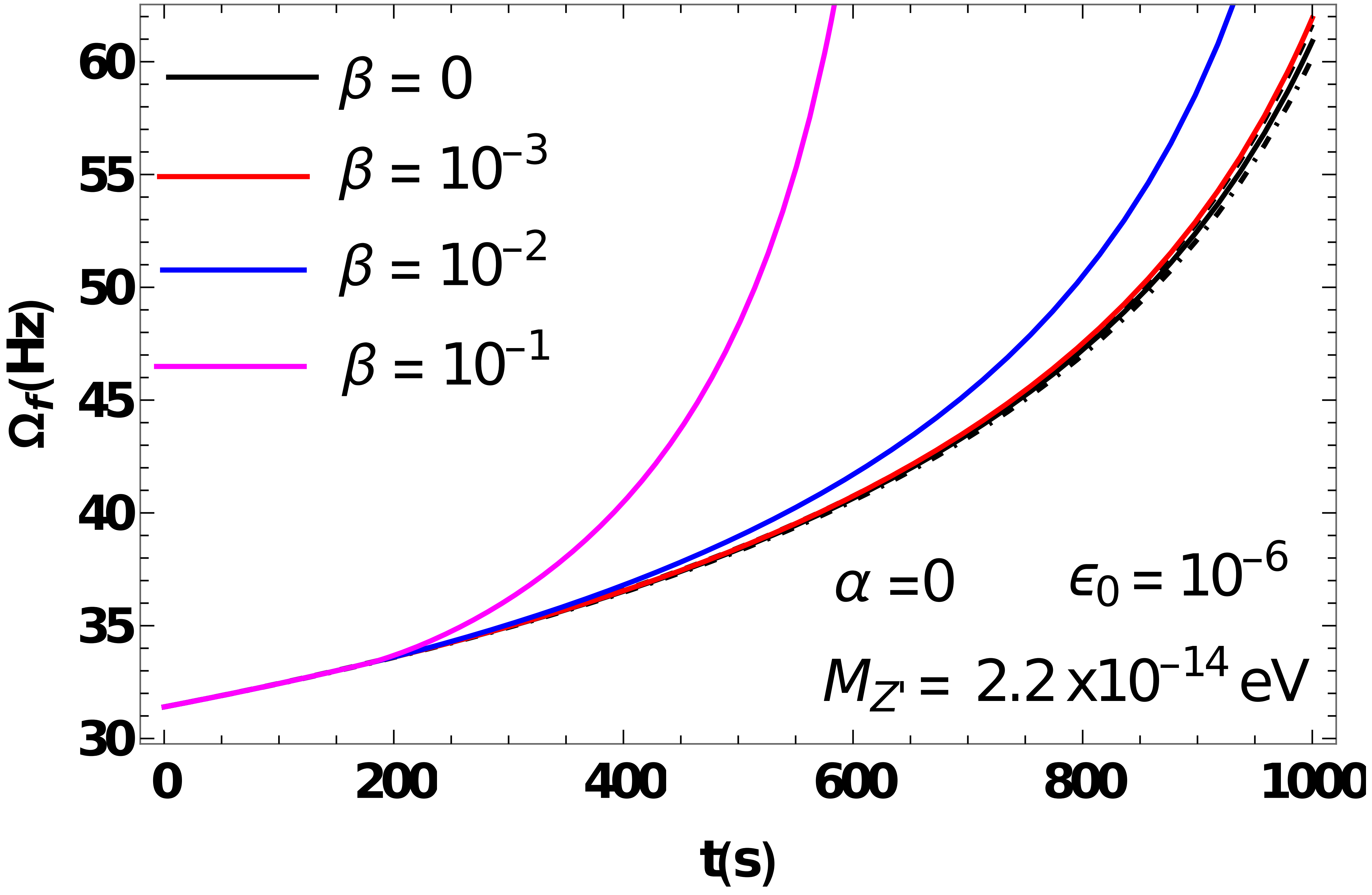
$$\frac{dr}{dt} = -\frac{64}{5}\frac{G^3 Mm(M+m)}{r^3}(1-\epsilon^2)^{-7/2}\left(1+\frac{73}{24}\epsilon^2+\frac{37}{96}\epsilon^4\right)$$

$$L_1 = \frac{96}{5}(G\mathscr{M}_{\rm ch})^{\frac{5}{3}}\Omega_f^{\frac{11}{3}}(1-\epsilon^2)^{-\frac{7}{2}}\left(1+\frac{73}{24}\epsilon^2+\frac{37}{96}\epsilon^4\right)(1+\alpha)^{\frac{2}{3}}$$

$$\beta = \frac{g_V^2 Mm\left(\frac{Q}{M}-\frac{q}{m}\right)^2}{\pi G(M+m)^2} \qquad \delta = \left(\frac{Q}{M}-\frac{q}{m}\right)^2$$

$$\dot{\Omega} = \frac{96}{5}G^{5/3}\mathscr{M}_{\rm ch}^{5/3}\Omega^{11/3}(1-\epsilon^2)^{-7/2}\left(1+\frac{73}{24}\epsilon^2+\frac{37}{96}\epsilon^4\right) + \frac{g^2}{2\pi}\frac{\Omega^3\mathscr{M}_{\rm ch}^{5/3}}{(M+m)^{2/3}}\delta \times \sum_{n>n_0^V} 2n^2\left[J_n'^2(n\epsilon)+\left(\frac{1-\epsilon^2}{\epsilon^2}\right)J_n^2(n\epsilon)\right]\sqrt{1-\frac{n_0^{V2}}{n^2}}\left(1+\frac{n_0^{V2}}{2n^2}\right)$$





T.K.P, A.Ghoshal, G. Lambiase, Phys. Dark. Universe, 2024

Memory signal from pulsar kick

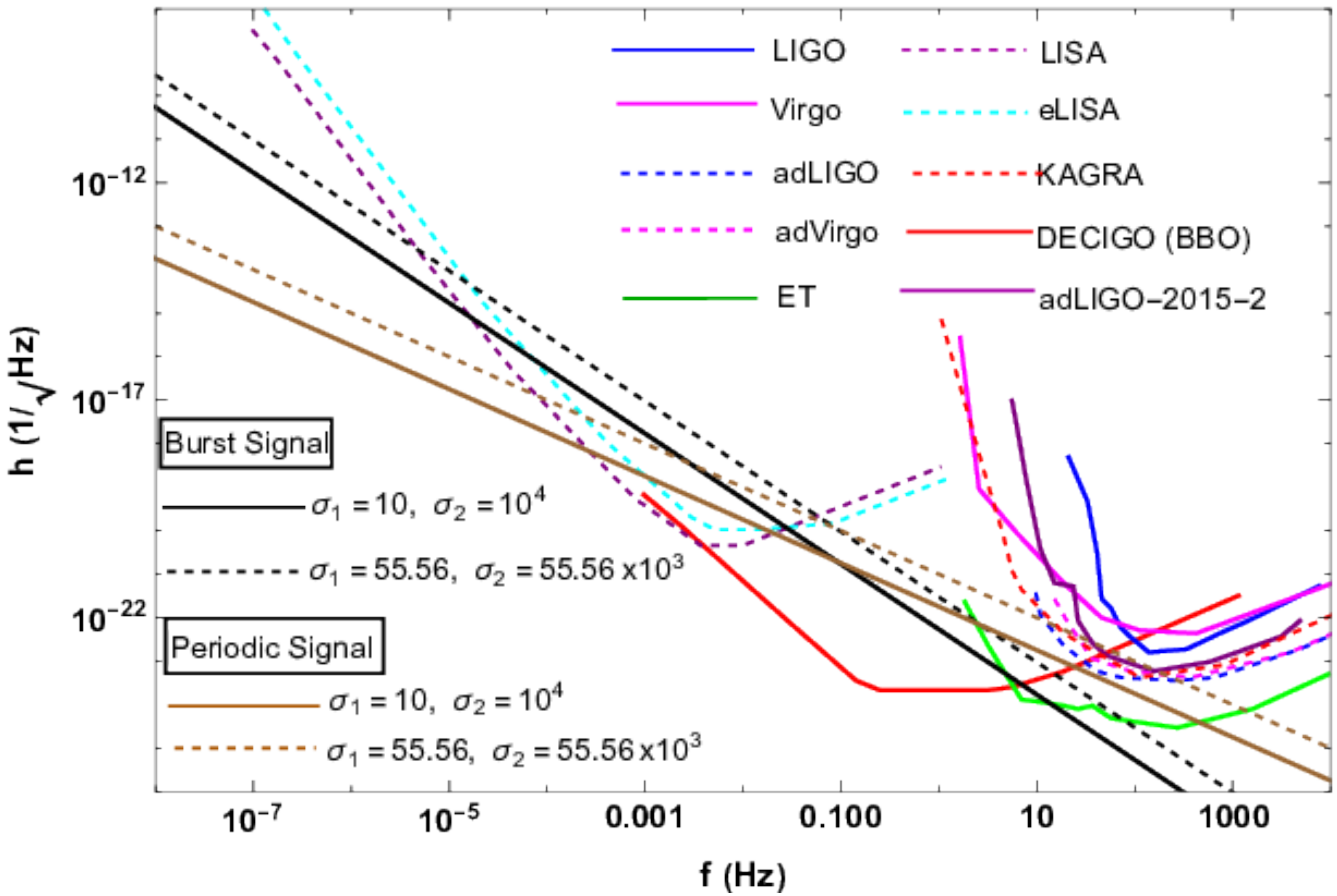
Kusenko, Segre PRL, 1996

Barkovich et al, Phys. Rev. D, 2002

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

$$|h(t)| \simeq \frac{2G}{r}\alpha L_\nu \mathscr{T} \lesssim 1.06 \times 10^{-19}\left(\frac{|\alpha|}{0.01}\right)\left(\frac{E_{\rm tot}}{2\times 10^{53}\ {\rm erg}}\right)\left(\frac{1\ {\rm kpc}}{r}\right)$$

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



For UVDM

$$\alpha = 1.8 \times 10^{-4}\sigma_1, \quad \sigma_1 = \frac{g_{ff'}/m_{A'}}{x_{\rm res}\eta}$$

For USDM

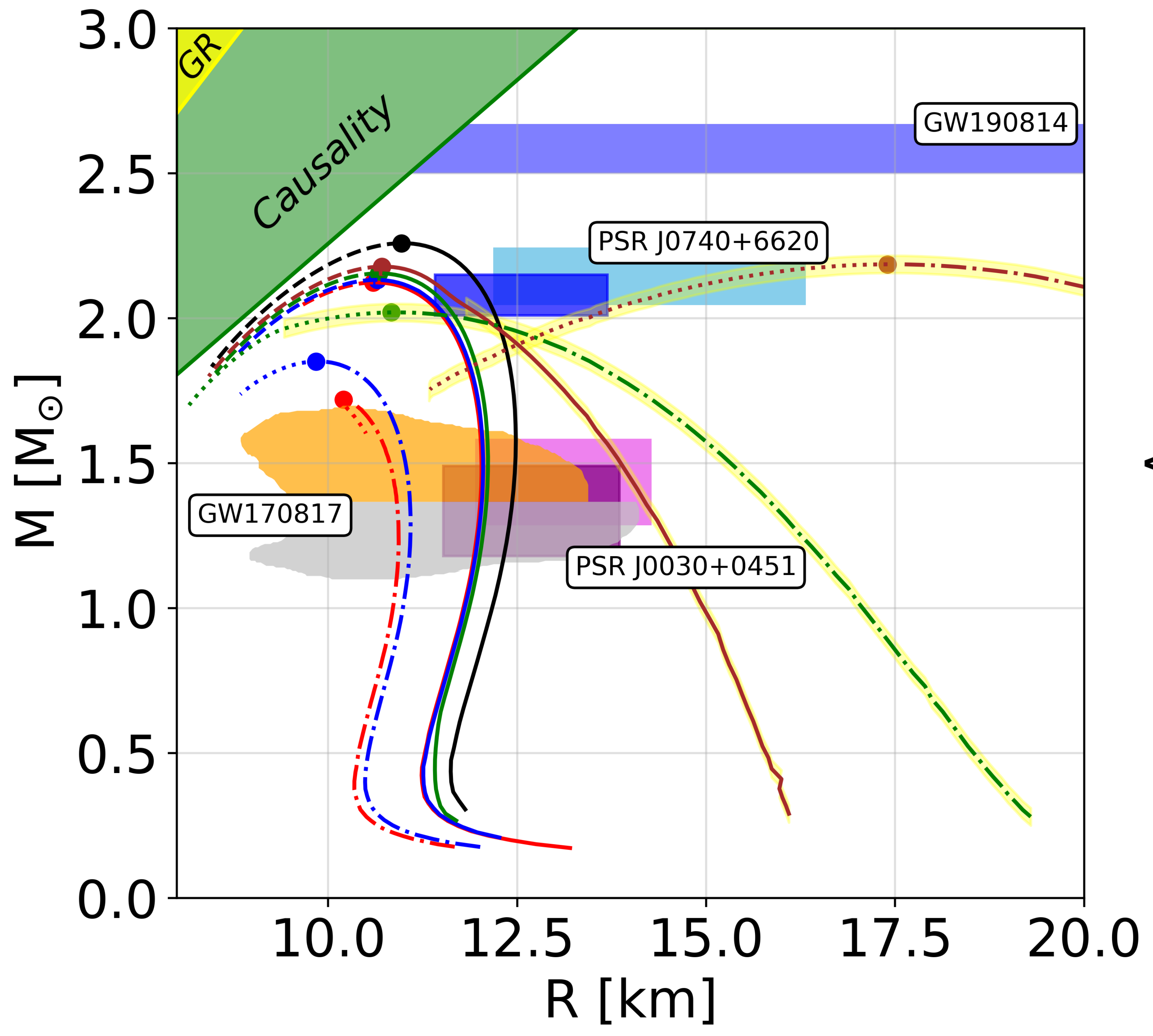
$$\alpha = 1.8 \times 10^{-7}\sigma_2, \quad \sigma_2 = \frac{g_{ff'}}{x_{\rm res}\eta}$$

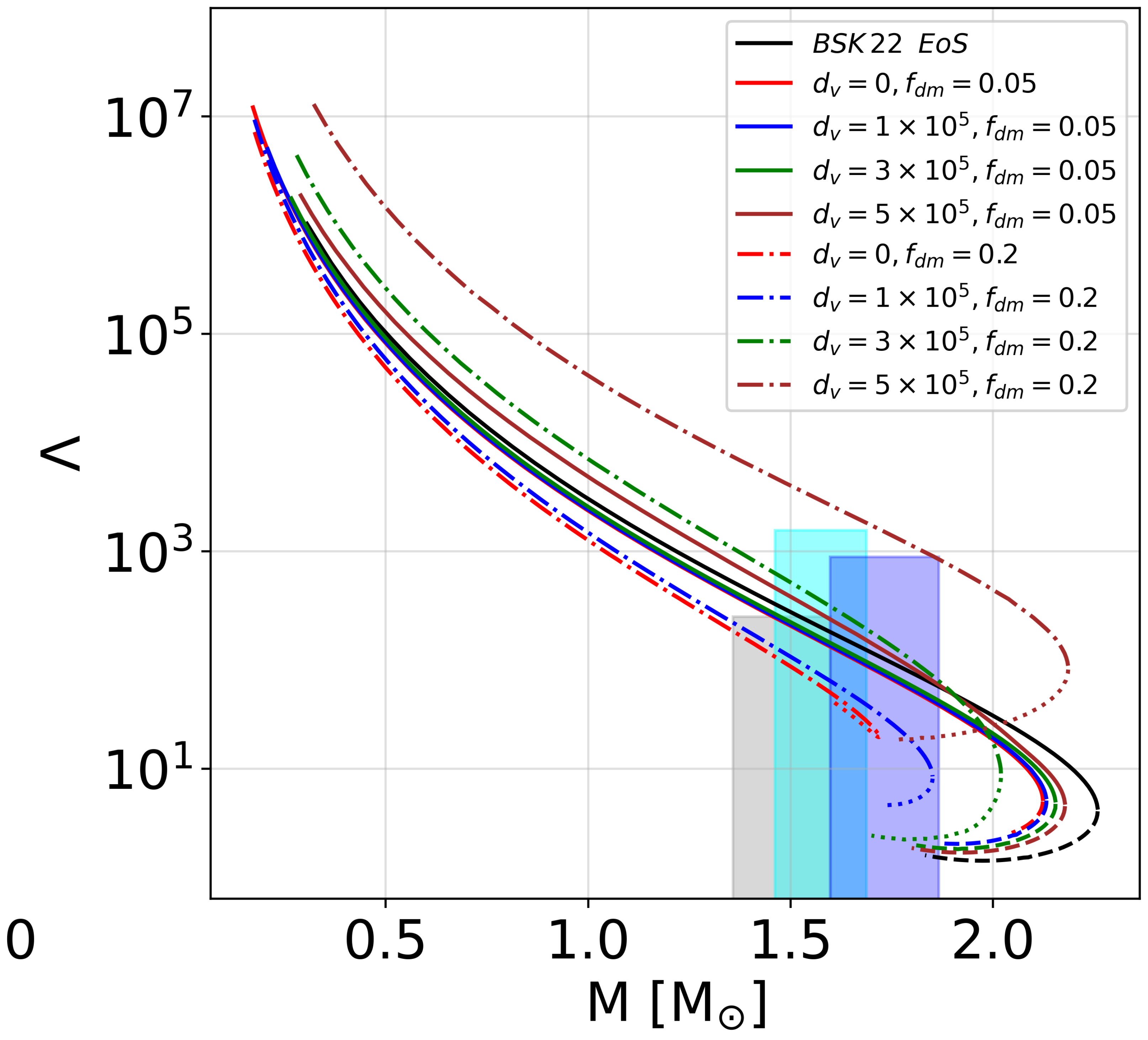
G. Lambiase, T.K.P, JCAP, 2024

DM admixed NS

See talk by Reed Essick

$$\mathscr{L} = \bar{\Psi}(x)\left[\gamma_\mu\left(i\partial^\mu - g_v V^\mu(x)\right) - \left(M_D - g_{s_1}\phi(x)\right)\right]\Psi(x) + \frac{1}{2}\left(\partial_\mu\phi(x)\partial^\mu\phi(x) - m_{s_1}^2\phi^2(x)\right) - \frac{1}{4}V_{\mu\nu}V^{\mu\nu} + \frac{1}{2}m_v^2 V_\mu(x)V^\mu(x)$$





BM: BSK 22

F. Grippa, G. Lambiase, T.K.P, arXiv: 2407.16386


Thank You !