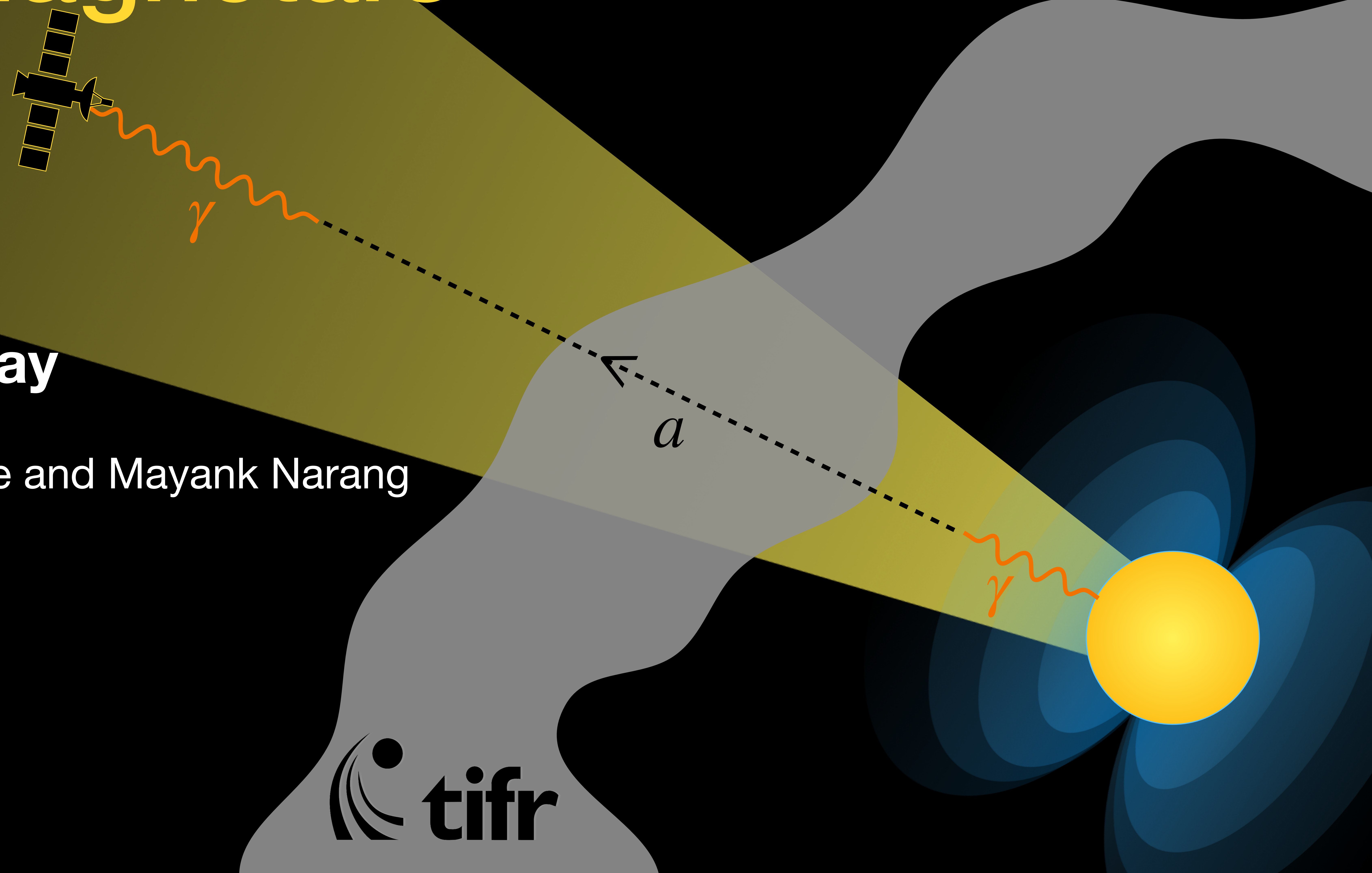
Shedding Light on Axions Through Obscured Magnetars



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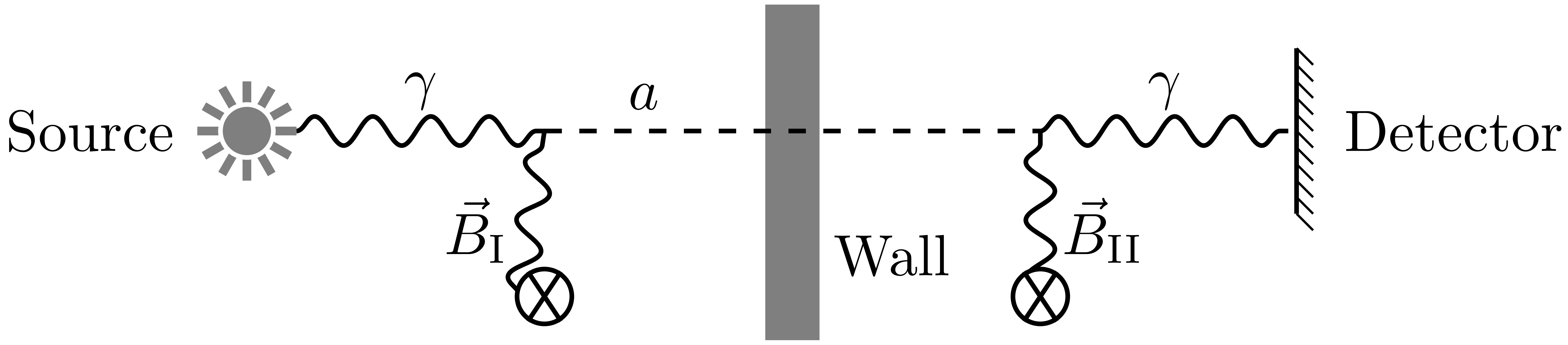
Recap…

- The **Light Shining through the Wall (LSW)** technique of looking for ALPs

$$\mathcal{L}_{\rm ALP} = \frac{1}{2}\partial^\mu a \partial_\mu a - \frac{1}{2}m_a^2 a^2 - \frac{1}{4}g_{a\gamma} a F_{\mu\nu}\tilde{F}^{\mu\nu}$$

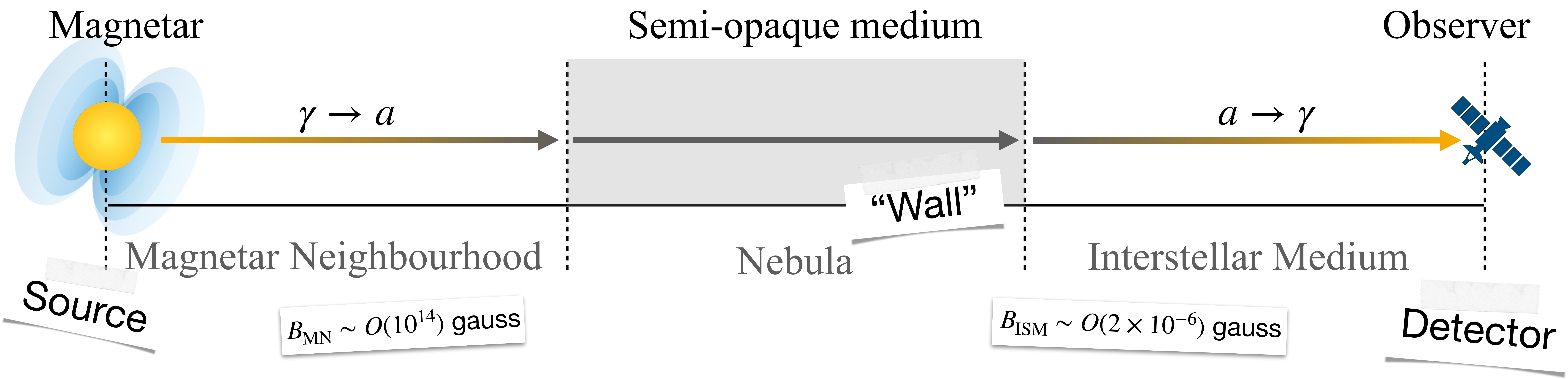
$$\mathcal{L}_{\rm ALP} \subset g_{a\gamma}\, \vec{E}\cdot\vec{B}\, a$$



- **Lab-based** experiments: OSQAR, CROWS, ALPS, ALPS - II (upcoming…)

Idea

- Applying the **LSW technique in astrophysics** by finding a suitable "laboratory".
- **Obscured Magnetars** are an excellent candidate.



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Obtaining the constraint on $g_{a\gamma}$

- The **fraction** of photons that are finally **observed** must always be **larger than** the **fraction** of photons **that may escape** through the $\gamma \to a \to \gamma$ **process.**

- Calculating $P(\gamma \to a \to \gamma)$ dependence on $g_{a\gamma}$ allows us to **constrain** the **ALP-photon coupling**.

- The **"escape probability"** is given by

$$P(\gamma \to a \to \gamma) = P_{\mathrm{MN}}(\gamma \to a) \times P_{\mathrm{ISM}}(a \to \gamma)$$

$$\boxed{P_{\mathrm{sur}} \gtrsim P_{\mathrm{MN}} P_{\mathrm{ISM}}}$$

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I. P_{sur} The fraction of photons that survive…

- A magnetar candidate for the **LSW technique**: PSR J1622-4950

$$P_{\text{sur}}(E, E+\delta E) = \frac{F_{\text{obs}}(E, E+\delta E)}{F_0(E, E+\delta E)}$$

$$F_{\text{obs}}(\text{bin}) \approx (0.68 - 2.01) \times 10^{-18}\ \text{erg cm}^{-2}\ \text{s}^{-1}$$

$$F_0(\text{bin}) = (0.44 - 2.72) \times 10^{-14}\ \text{erg cm}^{-2}\ \text{s}^{-1}$$

$(0.71 - 0.98)$ keV

- The ratio between the observed flux vs. the "expected" flux.

$$P_{\text{sur}} \approx (0.25 - 4.58) \times 10^{-4}$$

$F_{\text{obs}}(\text{total})$ (erg cm^{-2} s^{-1})	$F_0(\text{total})$ (erg cm^{-2} s^{-1})	kT (keV)	N_H (10^{22} cm^{-2})
$3.0^{+0.8}_{-0.6} \times 10^{-14}$	$11^{+9}_{-4} \times 10^{-14}$	0.5 ± 0.1	$5.4^{+1.6}_{-1.4}$

Anderson et al., MULTI-WAVELENGTH OBSERVATIONS OF THE RADIO MAGNETAR PSR J1622–4950 AND DISCOVERY OF ITS POSSIBLY ASSOCIATED SUPERNOVA REMNANT

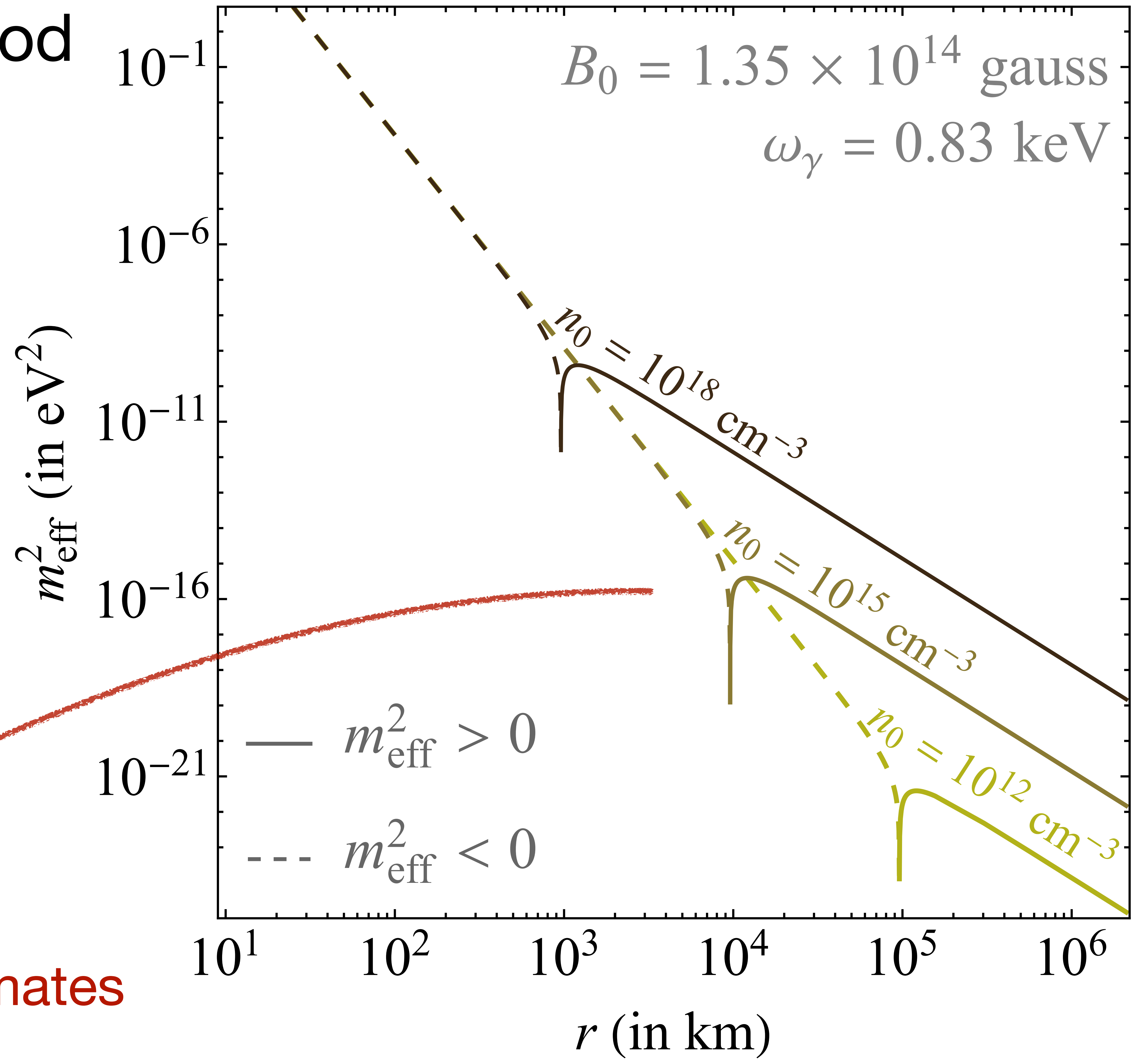
II. P_{MN} Conversion near the magnetar

- **Resonance** in the Magnetar Neighbourhood

$$m_{\rm eff}^2 = \frac{4\pi\alpha n_e}{m_e} - \frac{88\,\alpha^2\omega_\gamma^2}{135\,m_e^4}\frac{B^2}{2}$$

$$n_e \approx n_0\left(\frac{r}{r_0}\right)^{-3} \qquad B \approx B_0\left(\frac{r}{r_0}\right)^{-3}$$

- Resonance at $m_{\rm eff}^2 = m_a^2$
- Fluctuations may lead to multiple **pairs** of **resonances.**



Large uncertainties in charge density estimates

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II. $P_{\rm MN}$ Conversion near the magnetar…

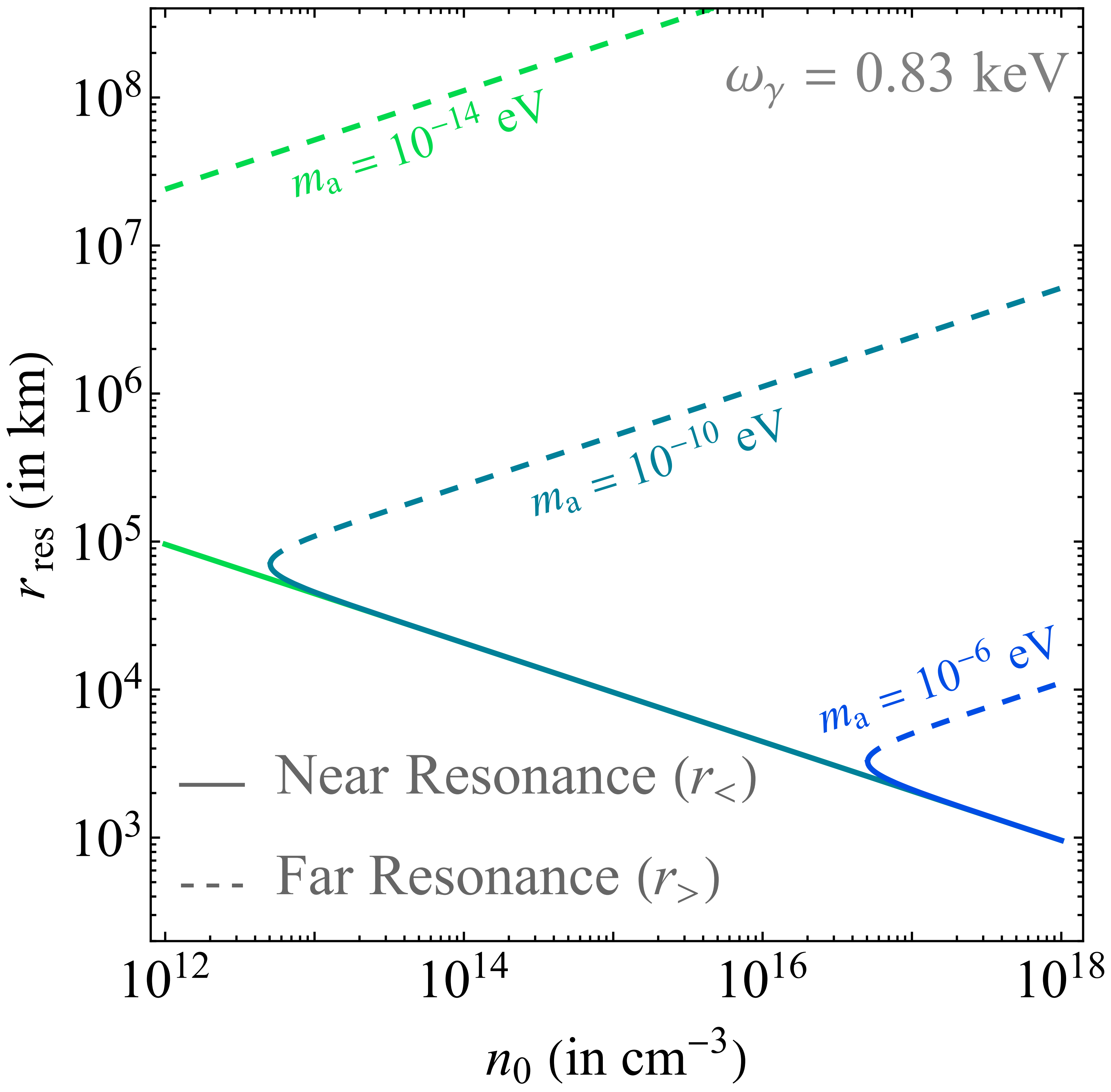
- Even in the simplified approximation: at least two resonances…

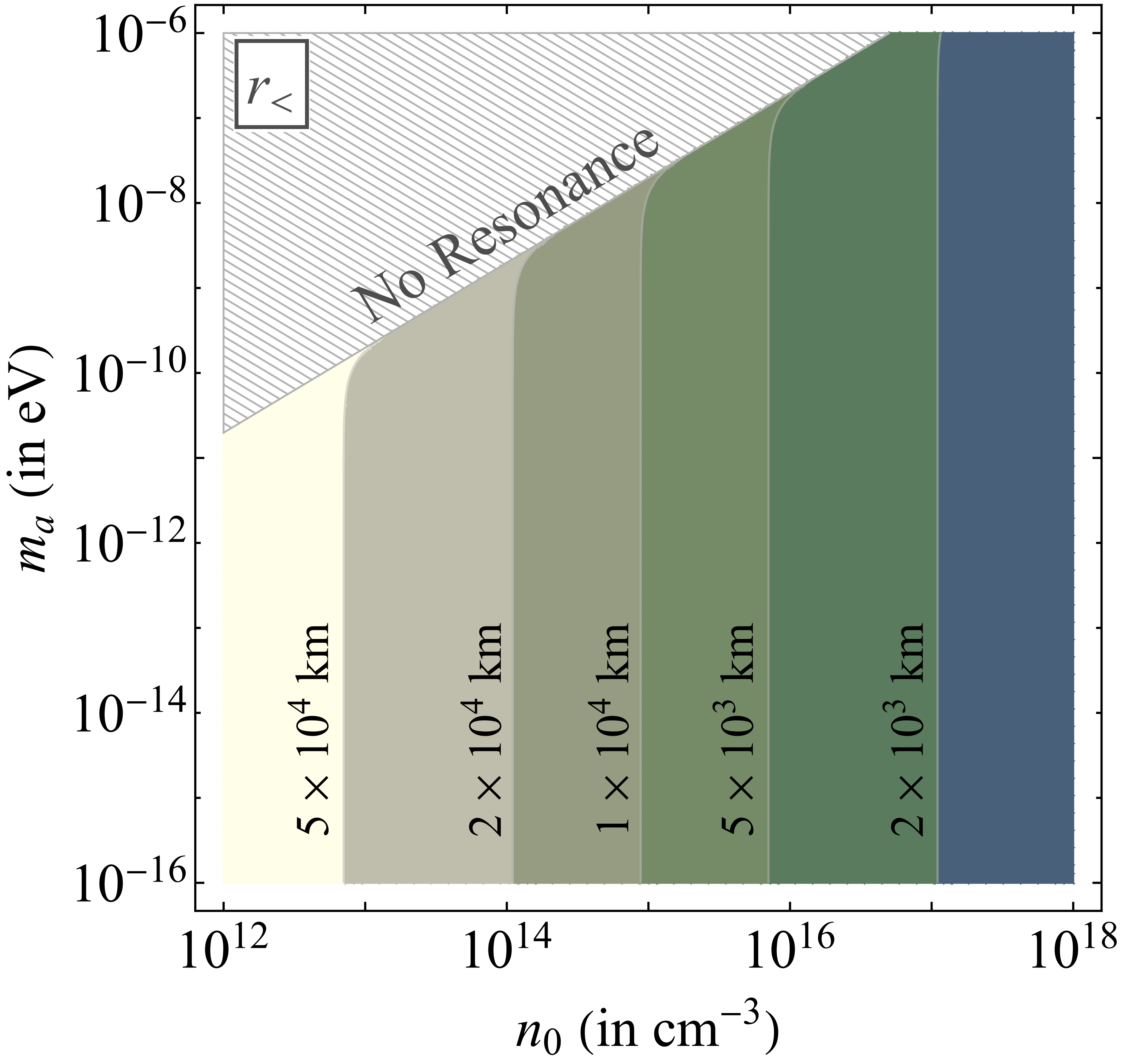
$$r_{\lessgtr} = r_0 \left[\frac{2\, c_B\, \omega_\gamma^2\, B_0^2}{c_n\, n_0 \pm \sqrt{c_n^2\, n_0^2 - 4\, c_B\, B_0^2\, \omega_\gamma^2\, m_a^2}} \right]^{1/3}$$

$$c_n \equiv \frac{4\pi\alpha}{m_e}\,, \qquad c_B \equiv \frac{88\,\alpha^2}{270\, m_e^4}$$

$$r_< \approx r_0 \left[\frac{c_B\, \omega_\gamma^2\, B_0^2}{c_n\, n_0} \right]^{1/3}$$

$$r_> \approx r_0 \left[\frac{c_n\, n_0}{m_a^2} \right]^{1/3}$$





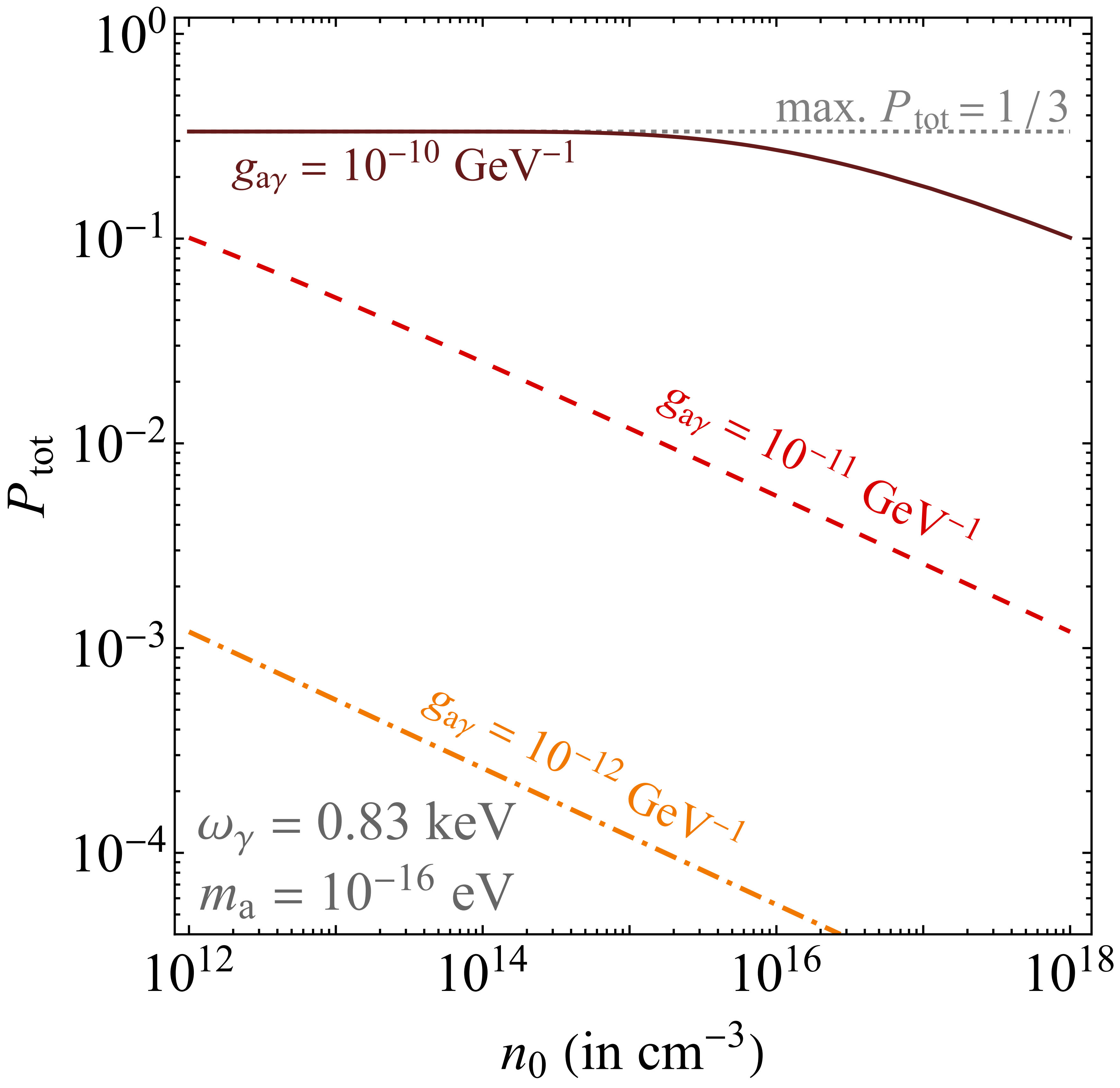
II. $P_{\rm MN}$ Conversion near the magnetar…

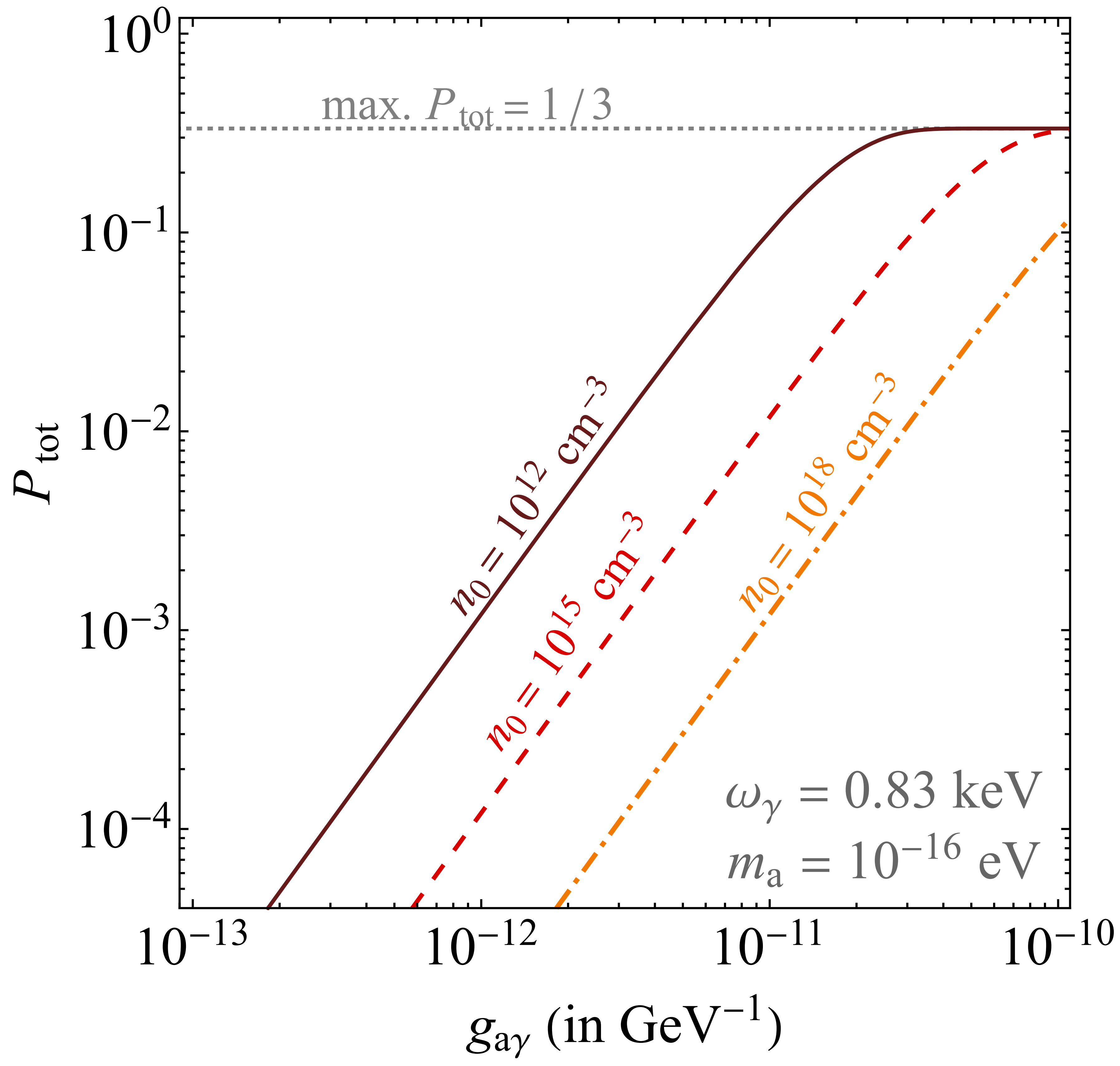
- We use conservative estimates for $P_{\rm MN} \equiv P_{\rm tot}$

$$P_{\rm tot} \approx \frac{1}{3}\left(1 - e^{-\frac{3\pi}{4}\Gamma_{tot}}\right)$$

$$\Gamma_{\rm tot} = \frac{2g_{a\gamma}^2\omega}{m_a^2}\sum_i^{n_r} B_{T,i}^2 \mathcal{R}_i$$

$$\mathcal{R}_i \equiv \left|\frac{d\ln m_{\rm eff}^2}{dl}\right|_{l=l_i}^{-1}$$





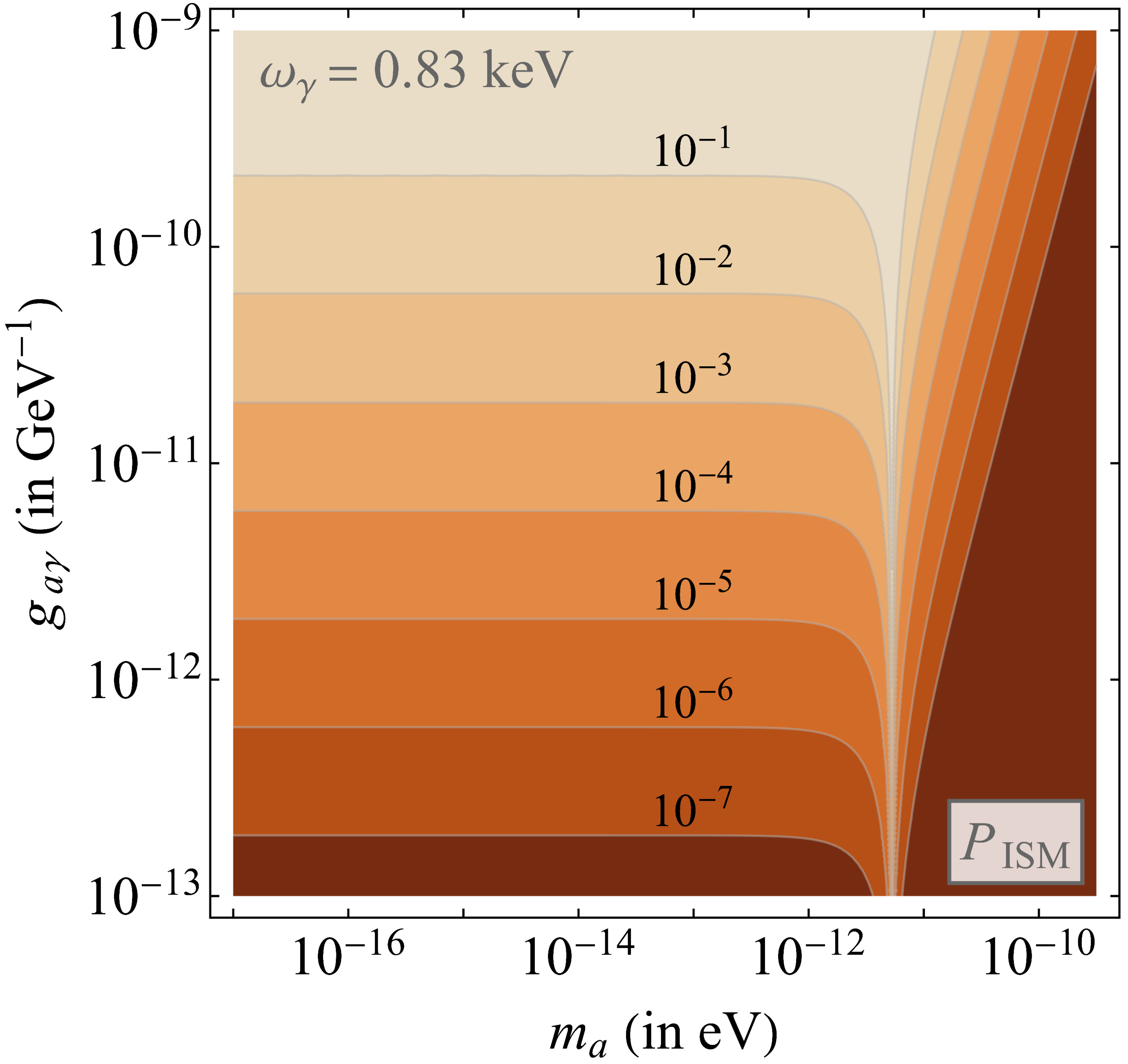
III. P_{ISM} Conversion probability in ISM

- The conversion probability in the ISM will be **averaged out.**

- We take the electron density and the magnetic field value to be:

$$n_{\text{ISM}} \approx 2 \times 10^{-2} \text{ cm}^{-3}$$

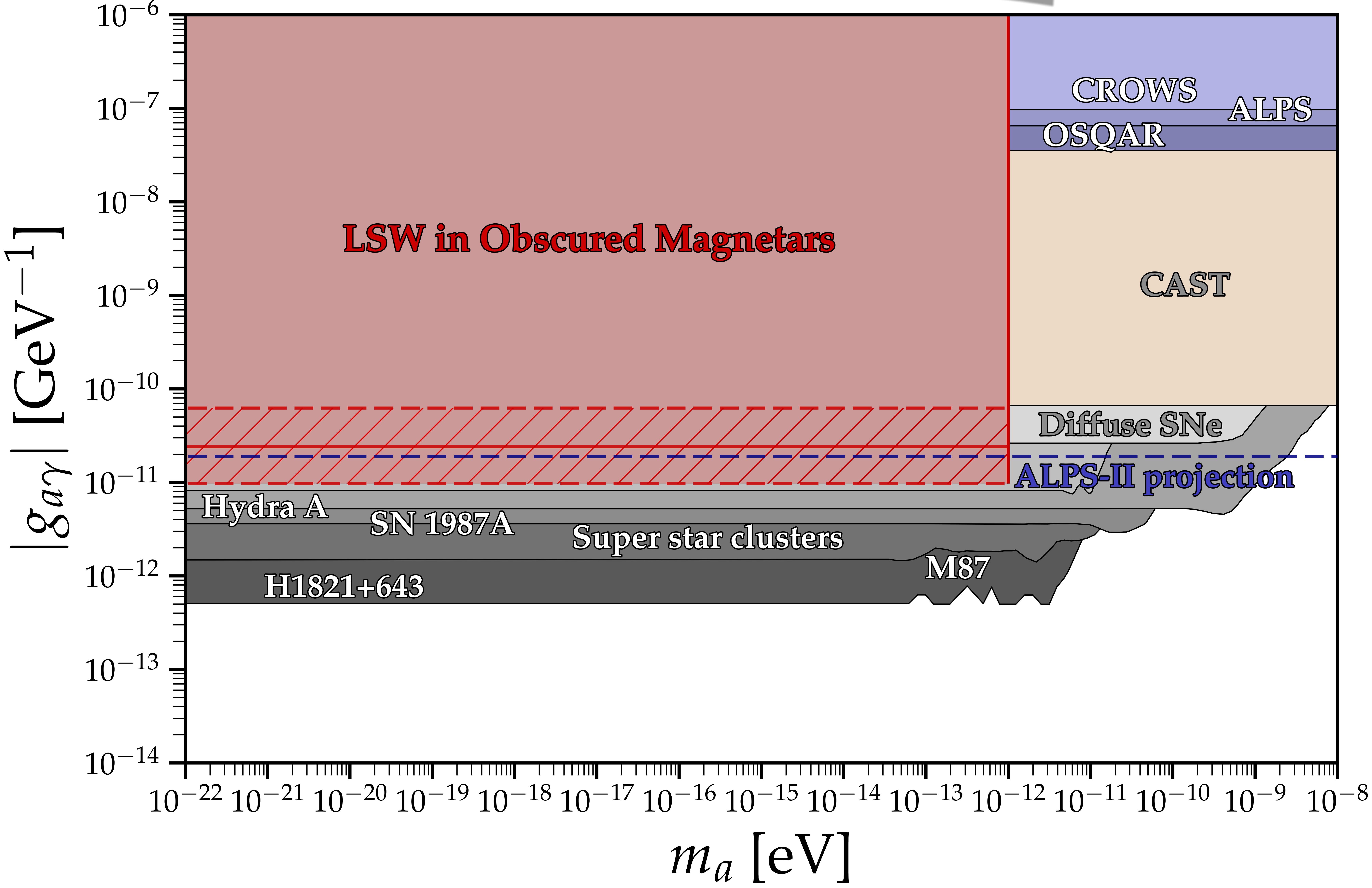
$$B_{\text{ISM}} \approx 2 \times 10^{-6} \text{ gauss}$$



Results

- Complementary to existing astrophysical bounds.
- Better than all current lab-based LSW bounds.
- Competitive even with ALPS-II projections for $m_a \lesssim 10^{-12}$ eV.

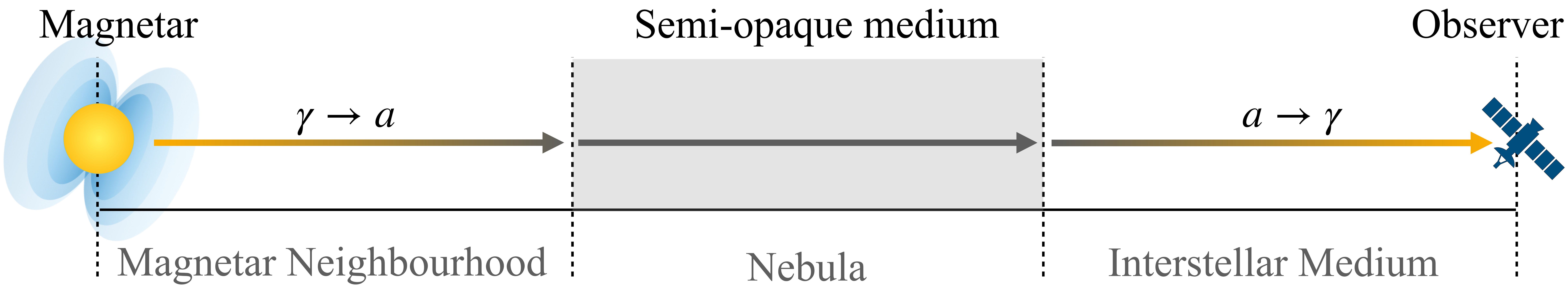
$g_{a\gamma} \lesssim (10^{-11} - 10^{-10})$ GeV^{-1}



Take home message

arXiv:2311.14298 [hep-ph]

- The idea: LSW + astrophysical systems
- The candidate: obscured magnetars
- The result: $g_{a\gamma} \lesssim (10^{-11} - 10^{-10})$ GeV^{-1} for low mass ALPs ($m_a \lesssim 10^{-12}$ eV).



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