Bounds on Axions From Obscured Magnetars

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Light Dark World (LDW), KIT

19 Sep, 2023

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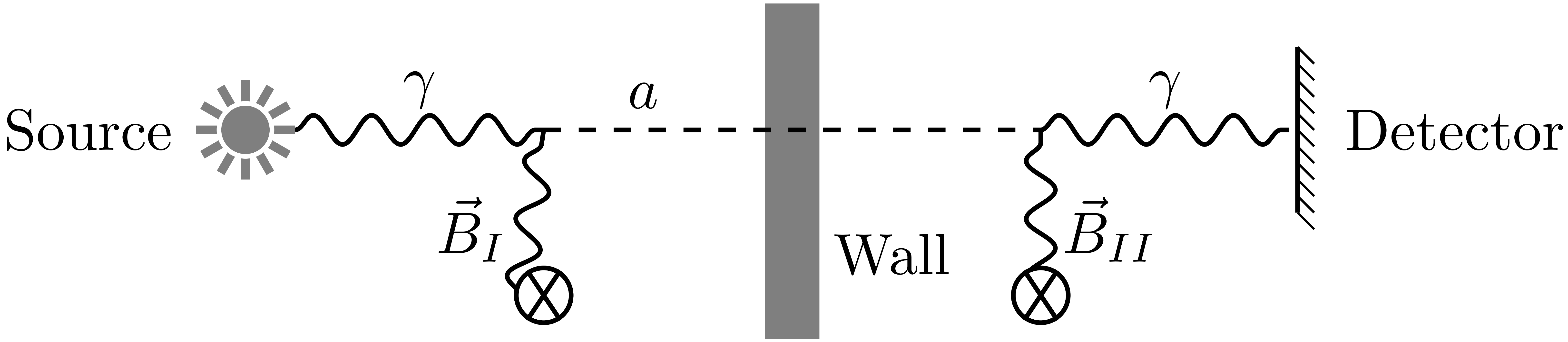
Recap…

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

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

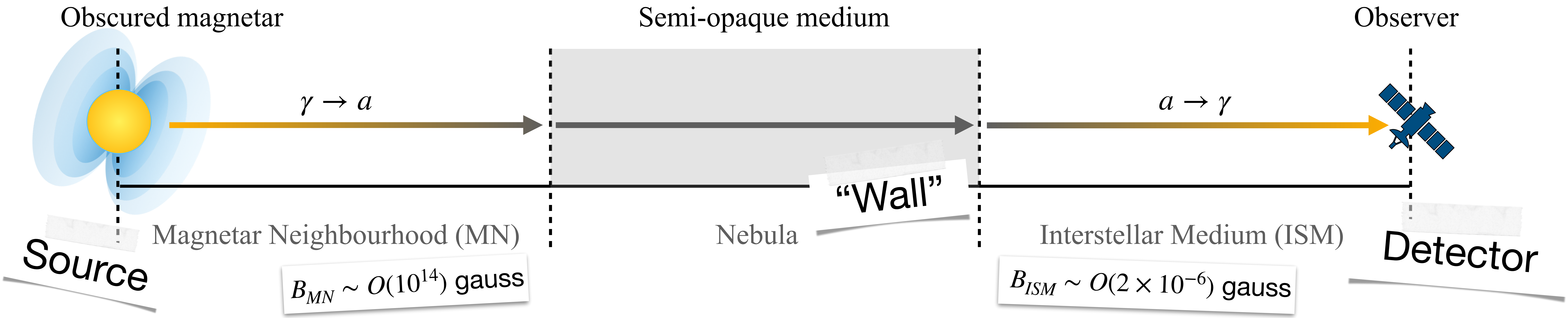
$$\mathcal{L}_{\rm ALP} \subset g_{a\gamma}\, \vec{E}\cdot\vec{B}\, a$$



- **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

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

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

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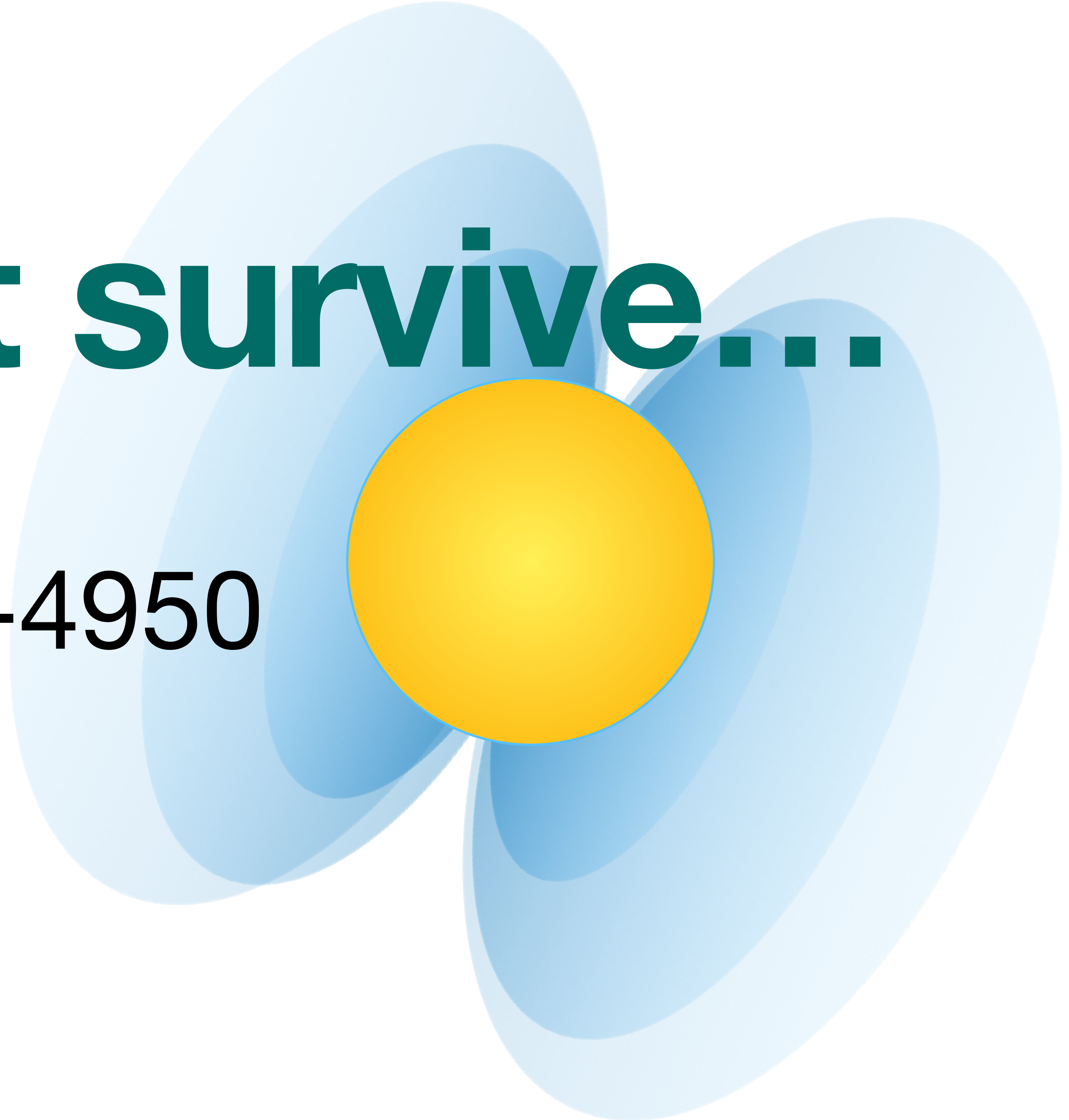
I. P_{sur} The fraction of photons that survive…



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

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

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

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

$(0.71 - 0.98)$ keV

- The ratio between the observed flux vs. the “expected” flux.

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

$F_{\rm obs}$(total) (erg cm^{-2} s^{-1})	F_0(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

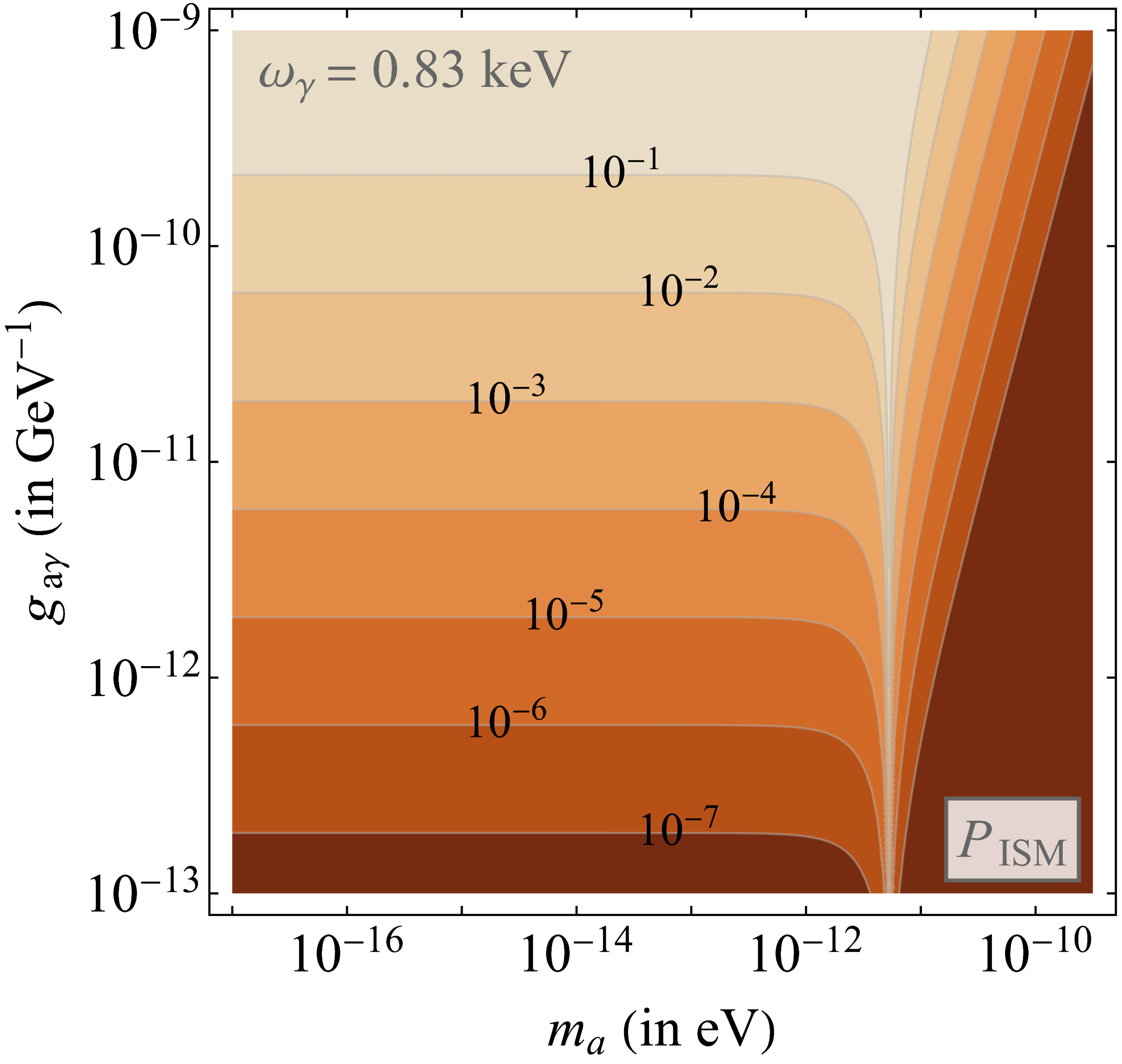
II. P_{ISM} Conversion probability in ISM

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

- We take:

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

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



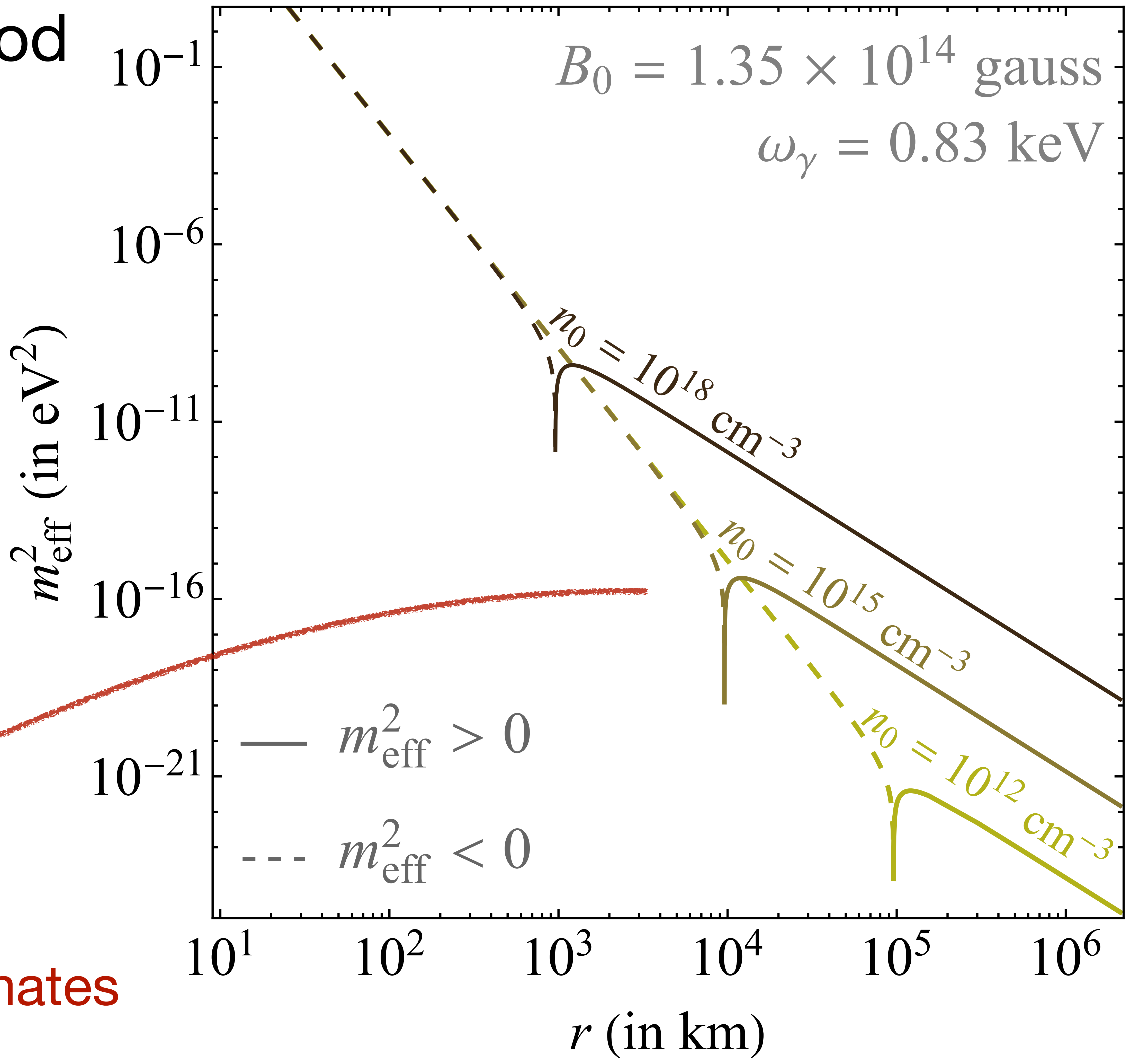
III. P_{MN} Conversion near the magnetar

- **Resonance** in the Magnetar Neighbourhood

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

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

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



Large uncertainties in charge density estimates

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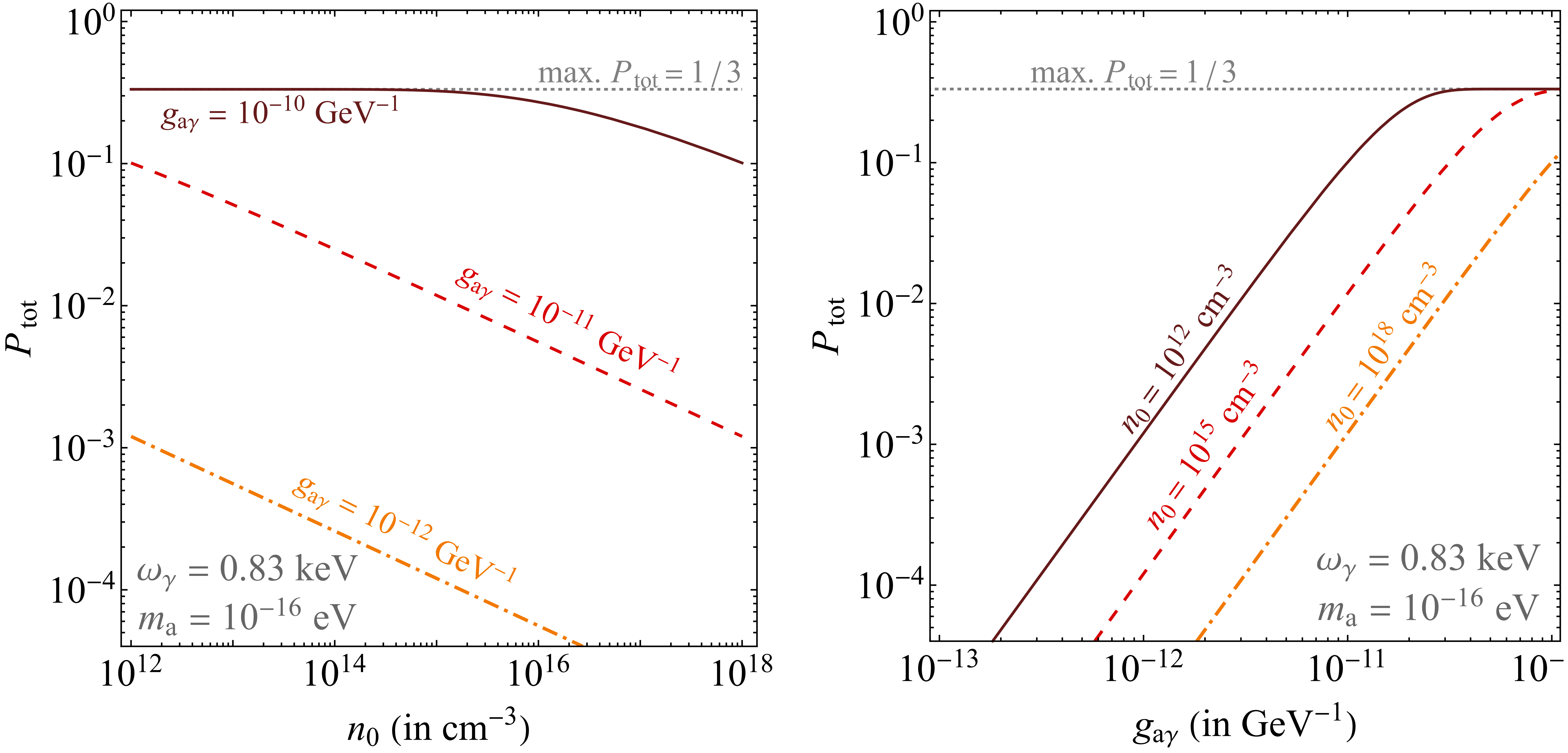
III. P_{MN} Conversion near the magnetar…

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

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

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

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



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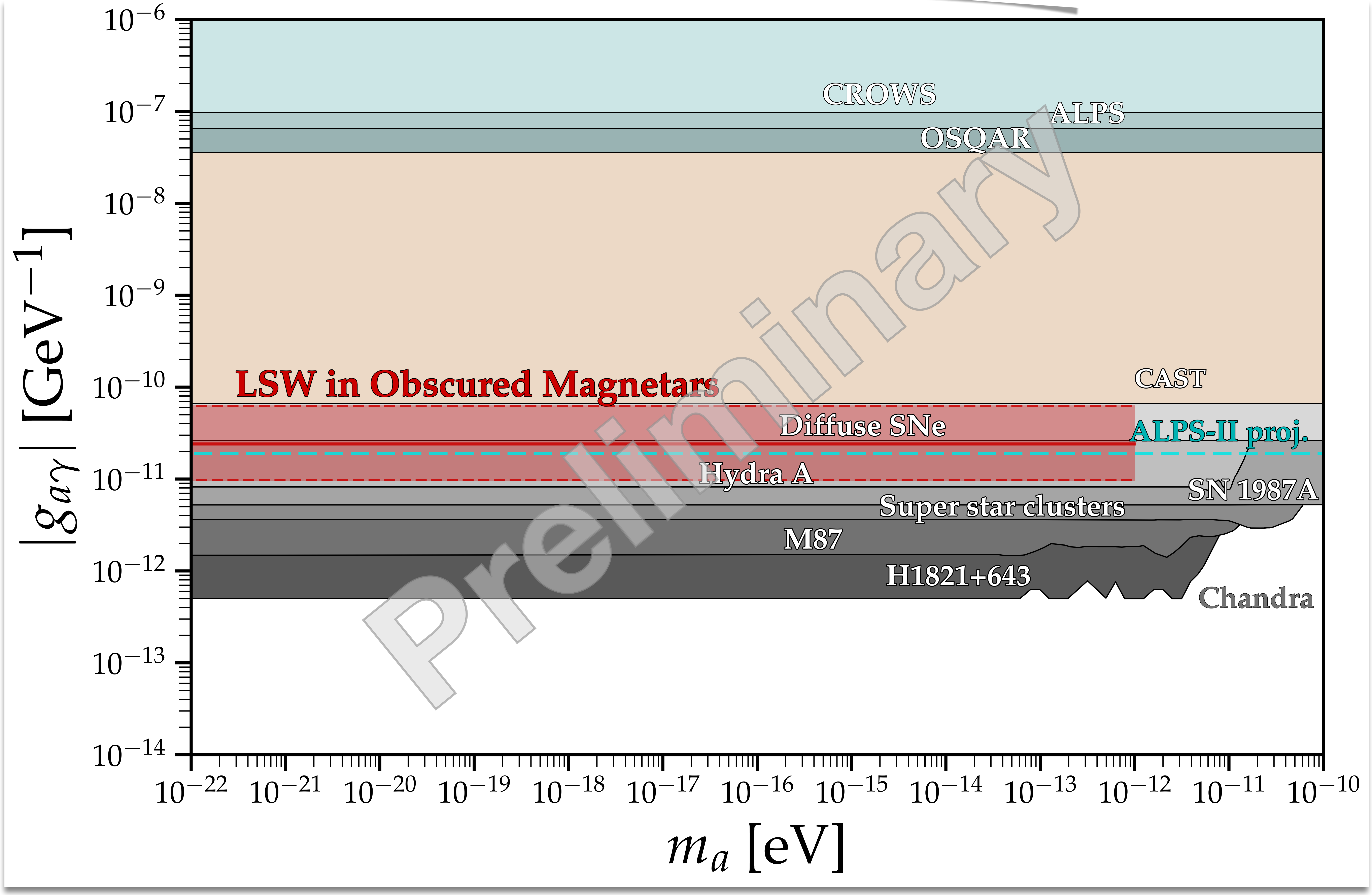
Results

- 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}



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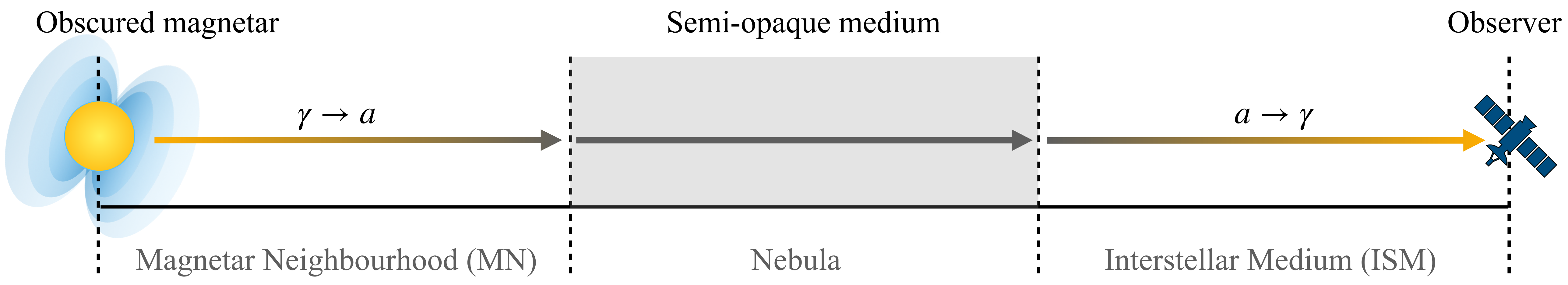
Take home message

- 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).



arXiv: 2310.#####
(In preparation)

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