Gamma-ray spectral modulations induced by photon-ALP-dark photon oscillations

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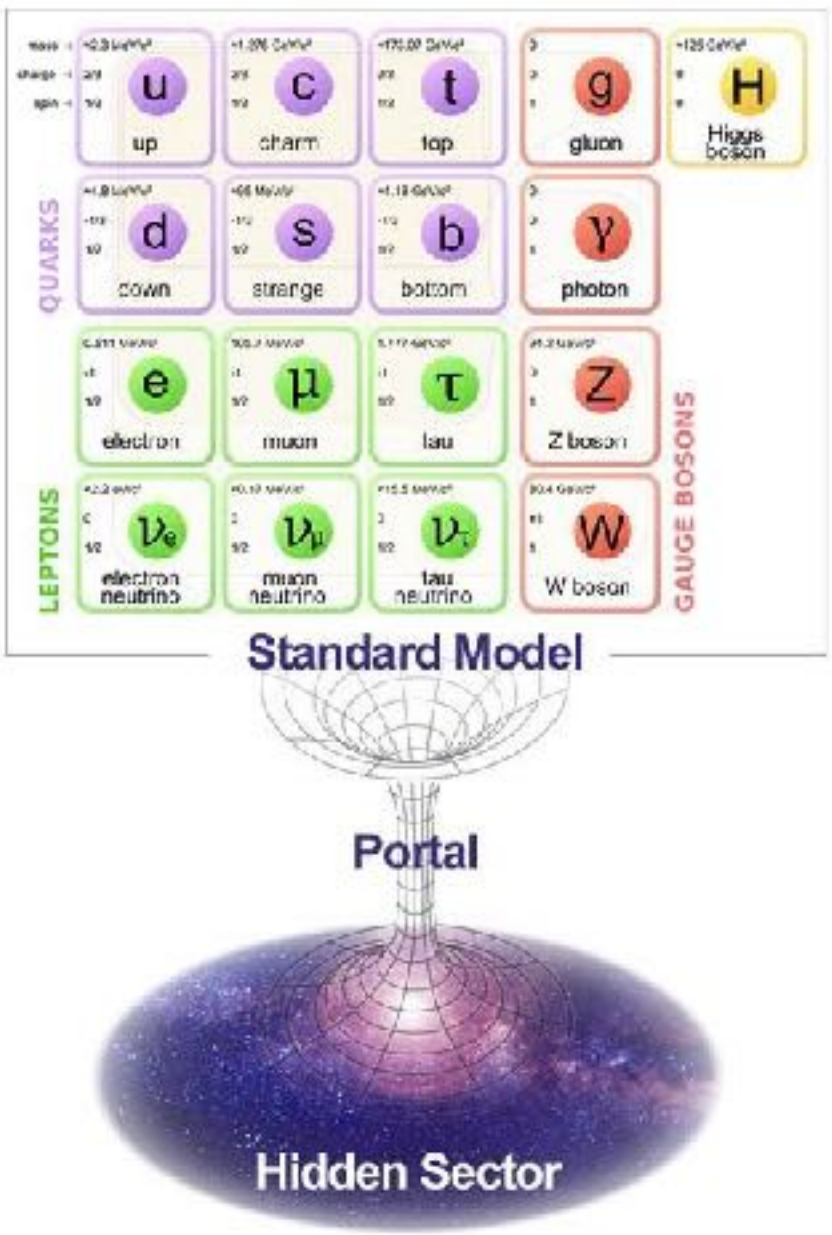
Outline

Portal physics



- ‘door’, ‘gate’, or ‘entrance’
- 4 well-known portals

Portal physics

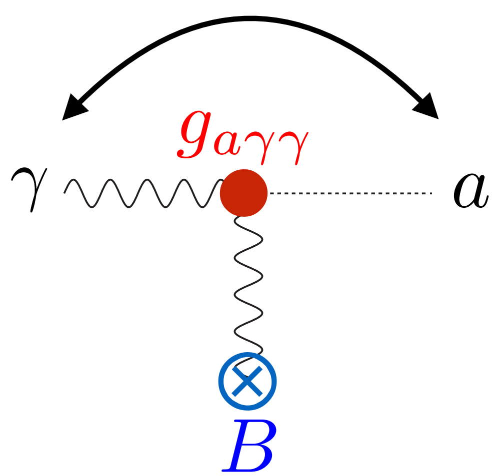
01	02	03	04
Higgs portal	**Axion portal**	**Vector portal**	**Neutrino portal**
spin-0 scalar	spin-0 pseudoscalar	spin-1 vector	spin-1/2 fermion
$\|S\|^2 H^\dagger H$	$a/f_a F_{\mu\nu}\tilde{F}^{\mu\nu}$	$F_{\mu\nu}Z'^{\mu\nu}$	LHN
	$(\partial_\mu a/f_a)\,\bar{\psi}\gamma^\mu\psi$		

Dark axion portal

$a/f_a F_{\mu\nu}\tilde{F}'^{\mu\nu}$

Photon-ALP oscillation

- In the presence of background magnetic field, Photon and ALP are oscillated through the Axion-portal



$$\left[\overbrace{\omega + i\partial_z}^{\text{relativistic } v \approx c} - \begin{pmatrix} \omega_{\mathrm{pl}}^2/2\omega & g_{a\gamma\gamma}B/2 \\ g_{a\gamma\gamma}B/2 & m_a^2/2\omega \end{pmatrix}\right]\begin{pmatrix} A_{\|} \\ a \end{pmatrix} = 0$$

$\vec{A}_{\|} \| \vec{B}$

$$-g_{a\gamma\gamma} aF\tilde{F}/4 = a\vec{E}\cdot\vec{B}$$

Photon-ALP oscillation

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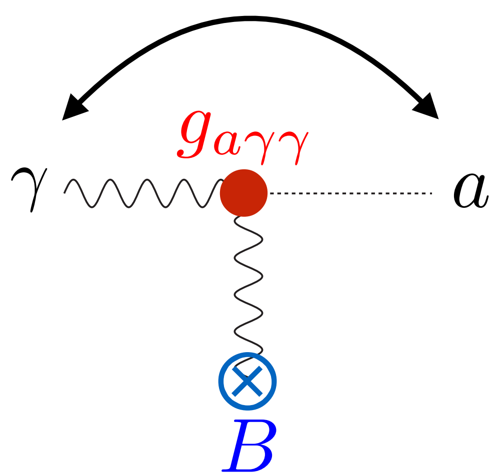


$$\triangle^2_{\rm osc} = (g_{a\gamma\gamma}B)^2 + \left(m_a^2 - \omega_{\rm pl}^2\right)^2/4\omega^2$$

$$P_{a\leftrightarrow\gamma} = \underbrace{\sin^2 2\theta}_{\text{mixing angle}} \sin^2 \frac{\overbrace{\triangle_{\rm osc} l}^{\text{phase retardation}}}{2}$$

$$\frac{1}{2}\tan 2\theta = \frac{\omega g_{a\gamma\gamma} B}{m_a^2 - w_{\rm pl}^2}$$

at large mixing, $\simeq \sin^2 \dfrac{\triangle_{\rm osc} l}{2} \propto (g_{a\gamma\gamma} B_{\rm ext} l)^2$

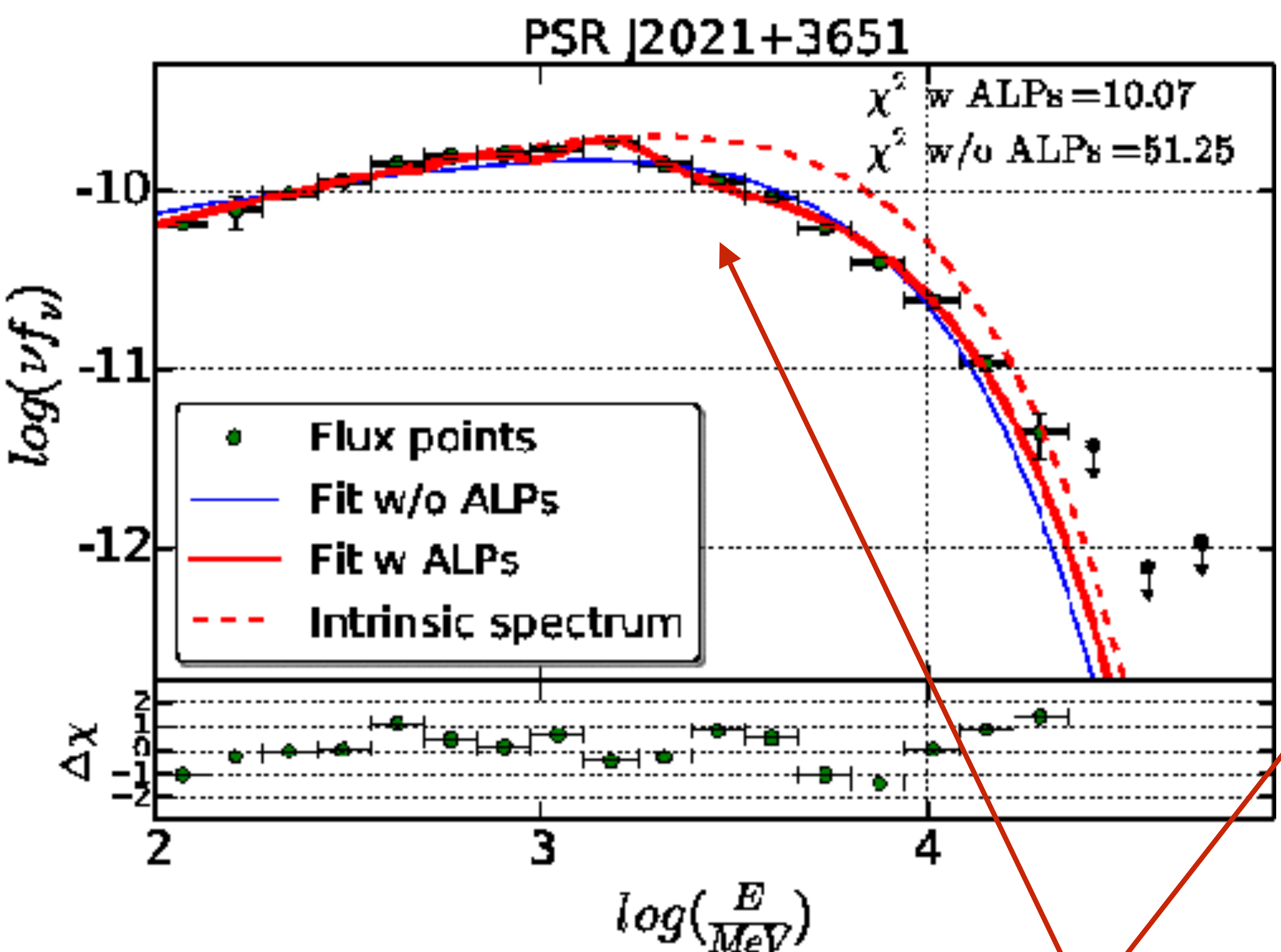
$\theta \approx \pi/4$

$\omega > \omega_c = |m_a^2 - \omega_{\rm pl}^2|/2g_{a\gamma\gamma}B$

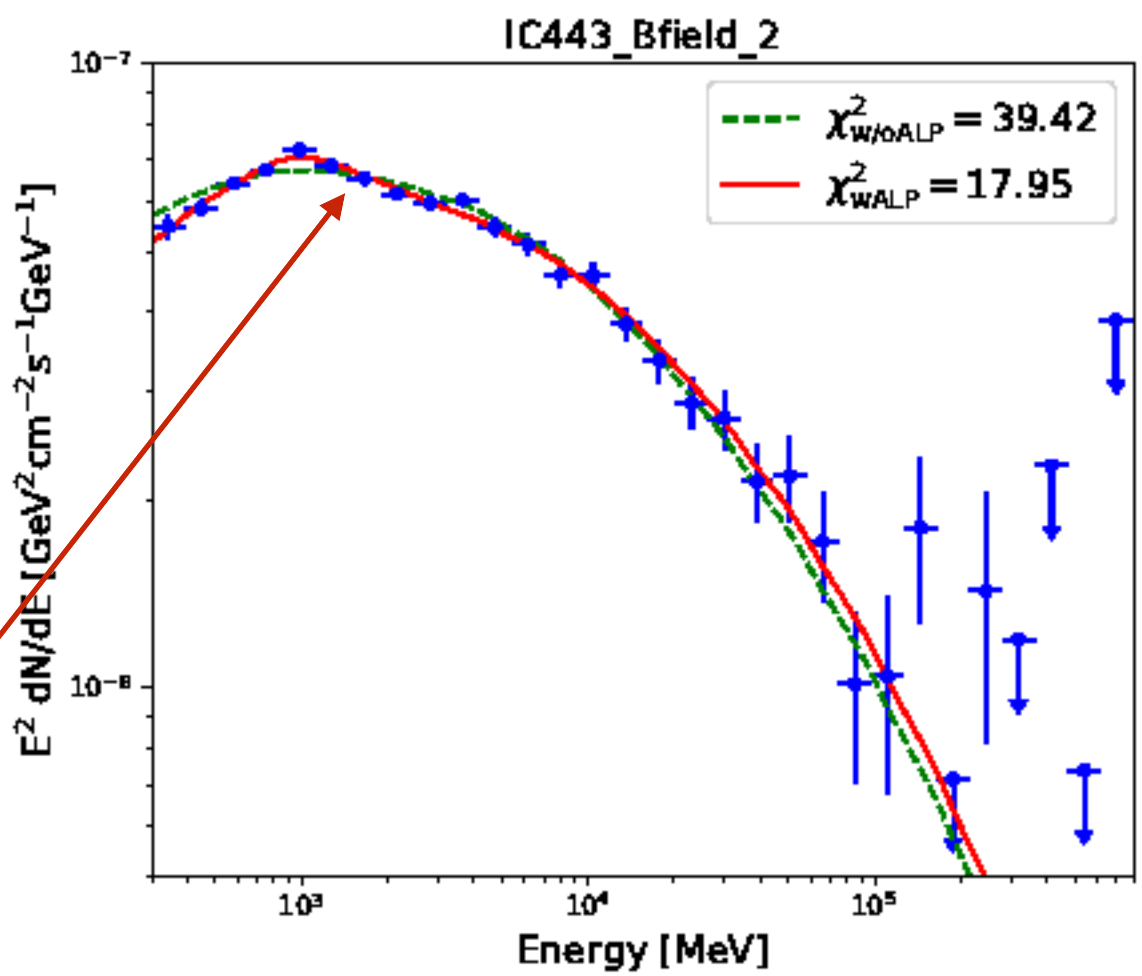
Gamma-ray spectral modulations

Photon-ALP conversion

[J. Majumdar et al., 18]



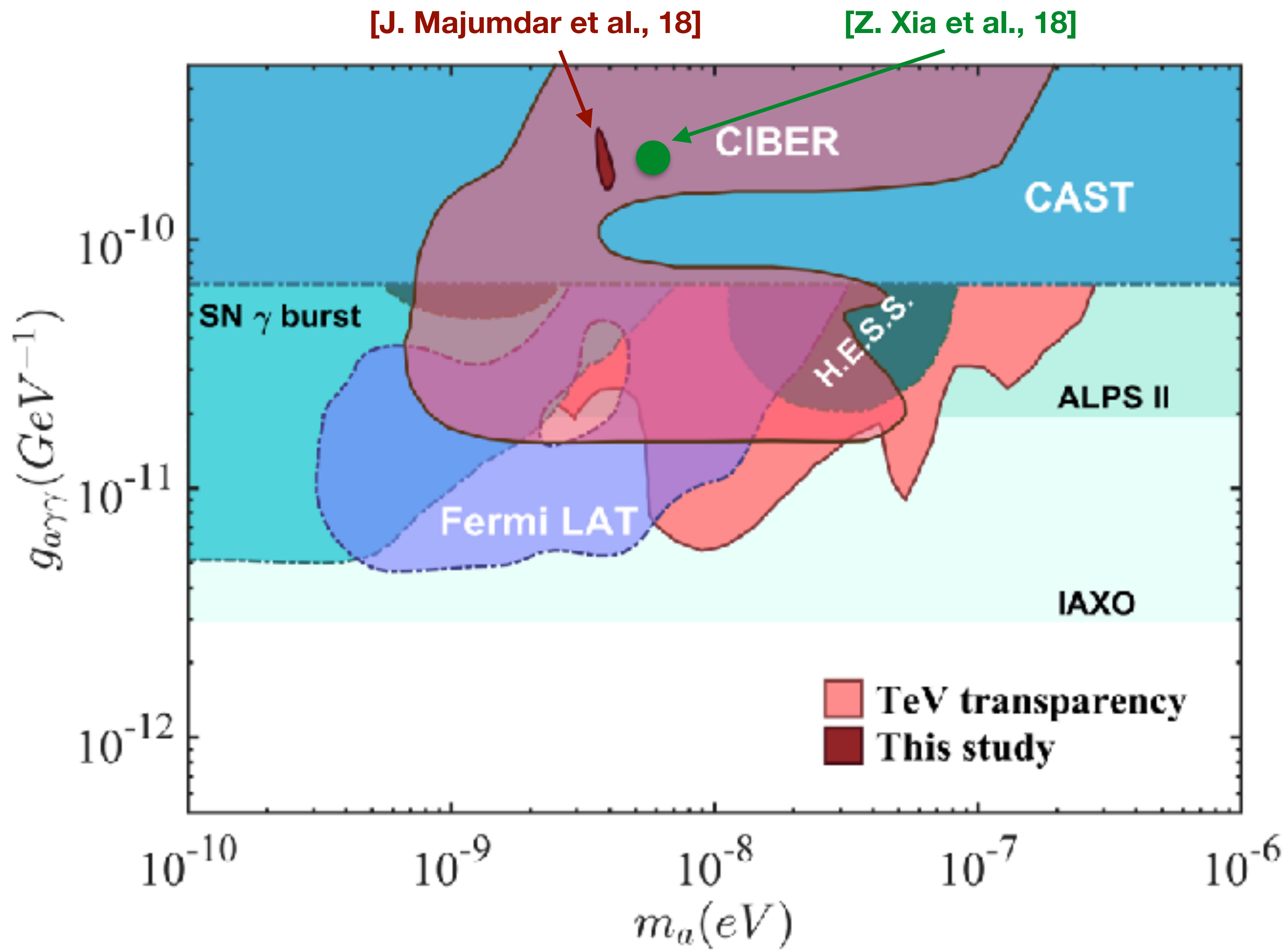
[Z. Xia et al., 18]



$$\omega \simeq \omega_c = 250\,\mathrm{MeV}\left(\frac{m_a}{\mathrm{neV}}\right)^2\left(\frac{10^{-10}\,\mathrm{GeV}^{-1}}{g_{a\gamma\gamma}}\right)\left(\frac{1\,\mu\mathrm{G}}{B}\right)$$

Gamma-ray spectral modulations

Photon-ALP conversion

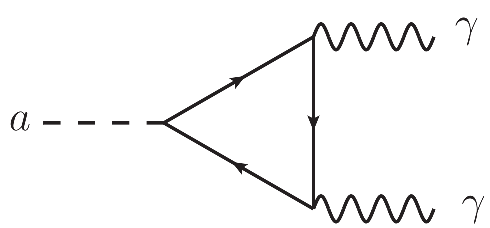


Dark axion portal

- Portal connecting Dark photons (Vector-portal) and Axions or ALPs (Axion-portal) at the same time

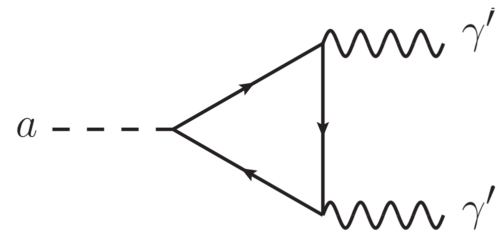
- Not just from a product of two individual portals, but rather new

$U(1)_{\mathrm{PQ}} \otimes U(1)_{\mathrm{em}} \otimes U(1)_{\mathrm{em}}$



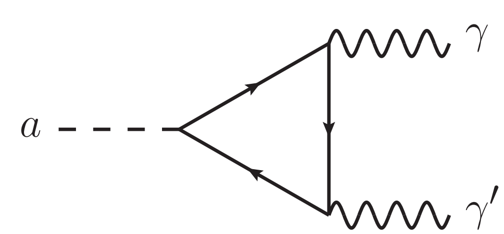
$g_{a\gamma\gamma}$

$U(1)_{\mathrm{PQ}} \otimes U(1)_{\mathrm{D}} \otimes U(1)_{\mathrm{D}}$



$g_{a\gamma'\gamma'}$

$U(1)_{\mathrm{PQ}} \otimes U(1)_{\mathrm{em}} \otimes U(1)_{\mathrm{D}}$



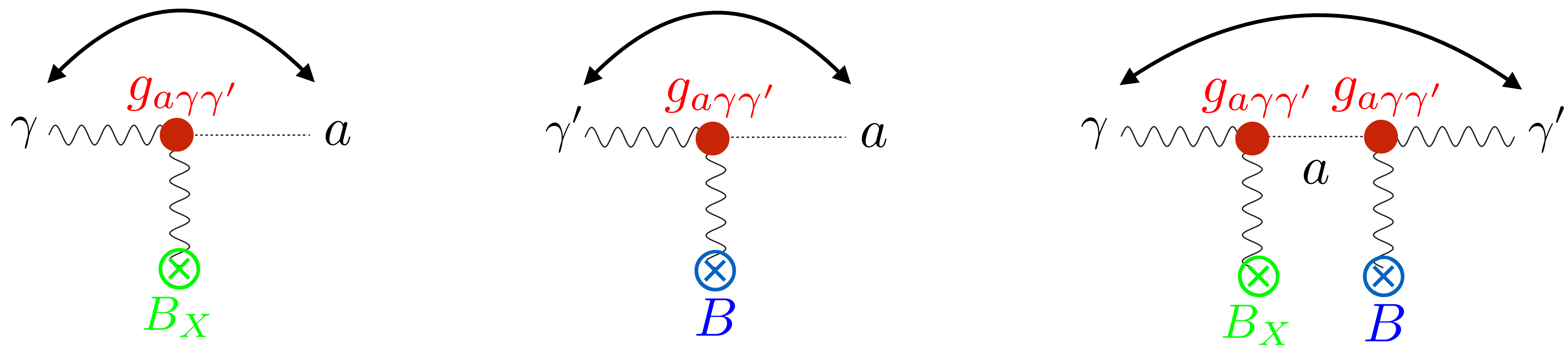
$g_{a\gamma\gamma'}$

- Can be sizable?

[K. Choi, S. Lee, H. Seong, SY, 18]

Photon-ALP-Dark photon oscillation

- In the presence of background dark photon field as well as magnetic field, **<u>Photon, ALP, and Dark photon</u>** are oscillated through the **Dark axion-portal**



$$\left[\omega + i\partial_z - \begin{pmatrix} \omega_{\rm pl}^2/2\omega & 0 & g_{a\gamma\gamma'}B_X/2 \\ 0 & 0 & g_{a\gamma\gamma'}B/2 \\ g_{a\gamma\gamma'}B_X/2 & g_{a\gamma\gamma'}B/2 & m_a^2/2\omega \end{pmatrix}\right]\begin{pmatrix} A_\parallel \\ X_\parallel \\ a \end{pmatrix} = 0$$

[K. Choi, S. Lee, H. Seong, SY, 18]

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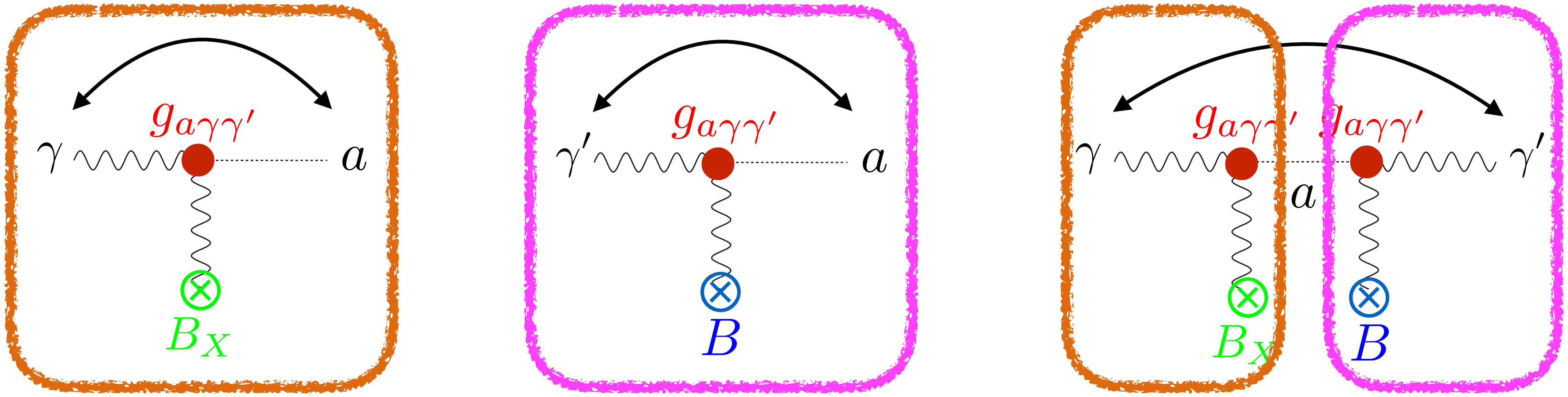


$$P_{\gamma\leftrightarrow a} \simeq \left(\frac{B_X^2}{B_{\rm eff}^2}\right) \sin^2 \frac{\triangle_{\rm osc} l}{2}$$

at large mixing,

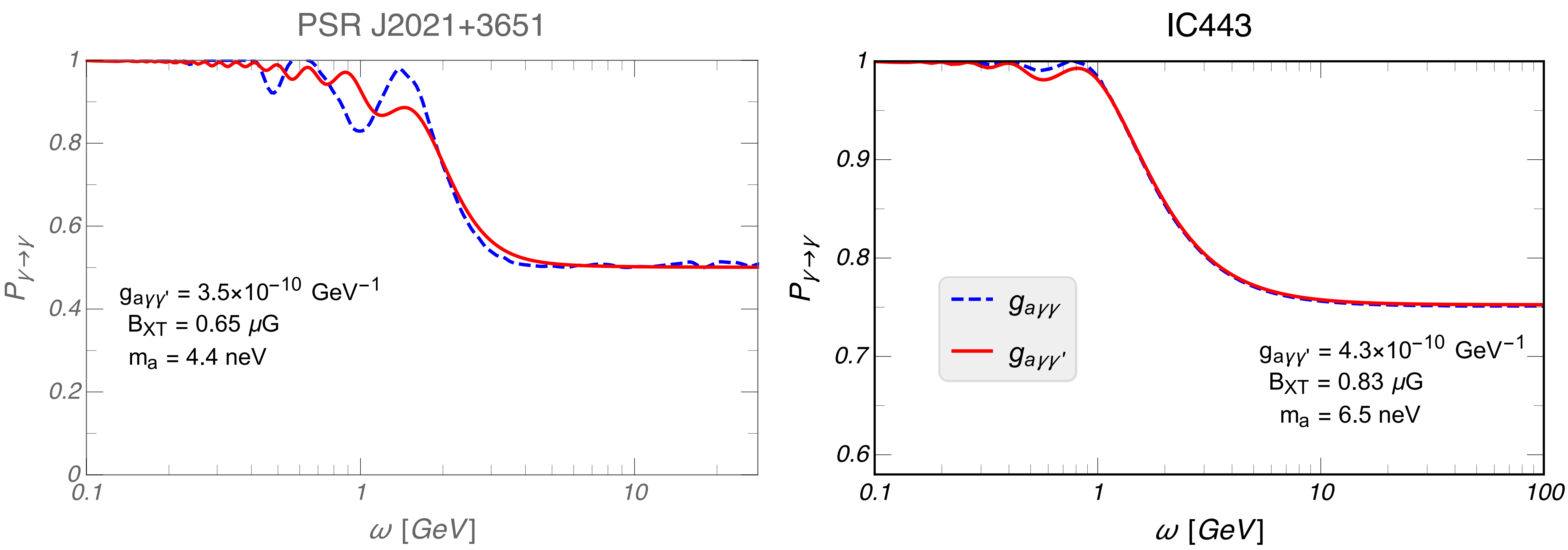
$\omega > \omega_c$

$$P_{\gamma\leftrightarrow \gamma'} \simeq 4\left(\frac{B_X^2}{B_{\rm eff}^2}\right)\left(\frac{B^2}{B_{\rm eff}^2}\right) \sin^4 \frac{\triangle_{\rm osc} l}{4}$$

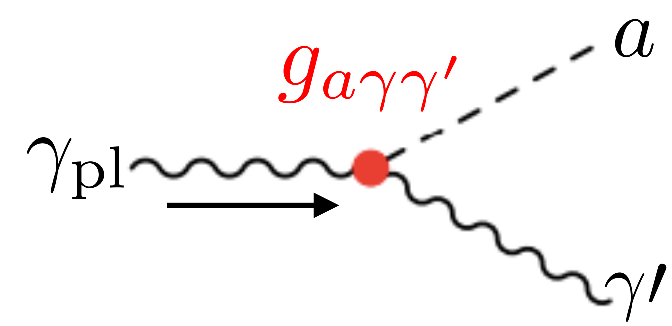
Gamma-ray spectral modulations

Photon-ALP-Dark photon conversion

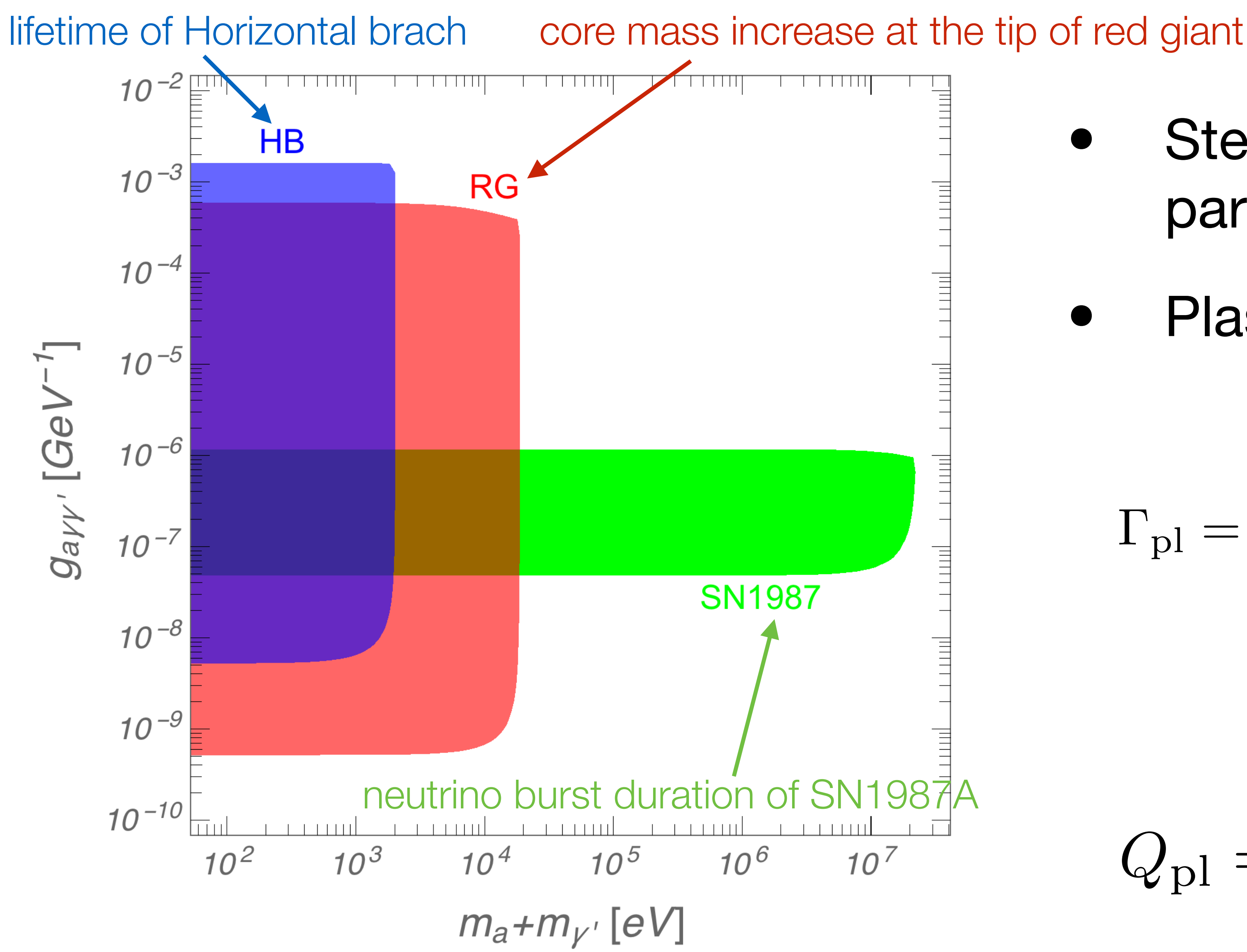
see **[K. Choi, H. Kim, T. Sekiguchi, 18]** $B_X \sim \mathcal{O}(100)\mathrm{nG},\ l \sim \mathcal{O}(10)\mathrm{kpc}$



[SY, in preparation]



Astrophysical constraints



- Stellar cooling via novel particles emission
- Plasmon decay

plasmon mass $\propto n_e$

$$\Gamma_{\rm pl} = \frac{g_{a\gamma\gamma}^2}{96\pi}\frac{w_{\rm pl}^4}{\omega}\left[\beta\left(1, \frac{m_a}{w_{\rm pl}}, \frac{m_a}{w_{\rm pl}}\right)\right]^{3/2}$$

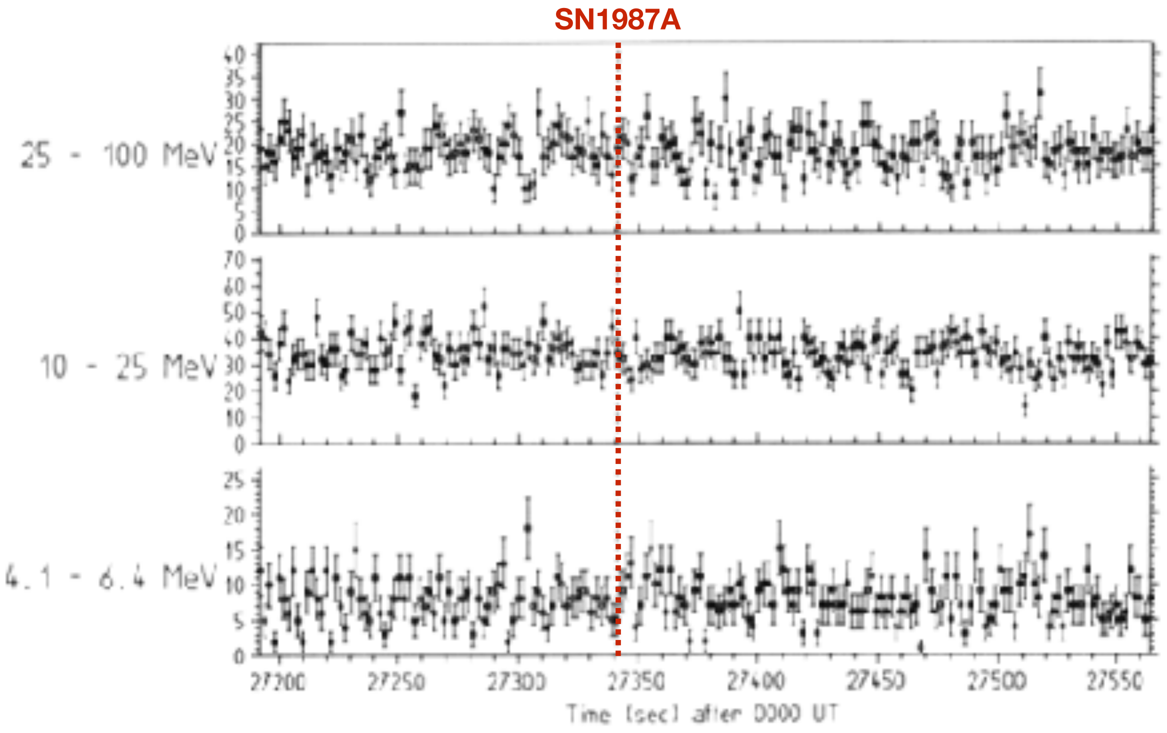
$$Q_{\rm pl} = \frac{2}{2\pi^2}\int_0^\infty dk k^2 \frac{\omega\Gamma_{\rm pl}}{e^{\omega/T}-1}$$

Observational constraints

SN1987A gamma-ray burst

- At the time when the neutrino bursts from SN1987A were observed, the Gamma-Ray Spectrometer of the Solar Maximum Mission were operative and could have potentially detected the ALP signal converted into the gamma-ray.

- The lack of a gamma-ray signal coincidence with the neutrino emission from SN1987A provides a strong bound on ALP parameters.



γ fluence limit for 10s

$< 0.6\,\mathrm{cm}^{-2}$

$< 0.4\,\mathrm{cm}^{-2}$

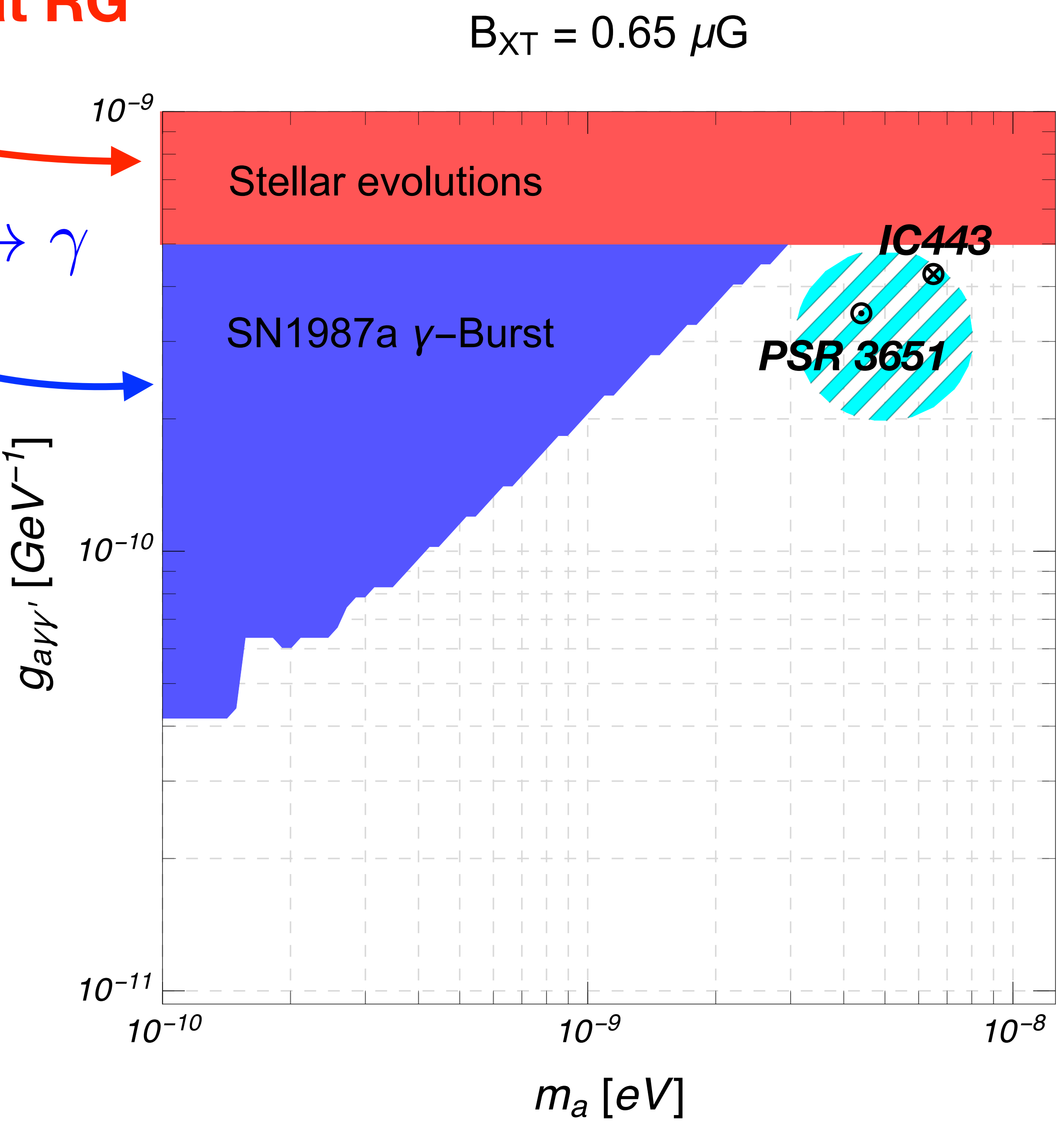
$< 0.9\,\mathrm{cm}^{-2}$

[K. Choi, S. Lee, H. Seong, SY, 18]

Observational constraints

Core mass increase at RG

γ-burst from $a, \gamma' \to \gamma$



Conclusion

- We discussed the phenomenology implications on the Axion-portal and the dark axion portal physics associated with gamma-ray spectral irregularities of point-like sources
- The required parameter value in the Axion portal scenario is in conflict with the present phenomenological constraints, but it would be not in the dark Axion portal scenario.
- The new portal might open up new avenues to search for the beyond Standard Model.