Searching for axion-like particles through the photon disappearance channel

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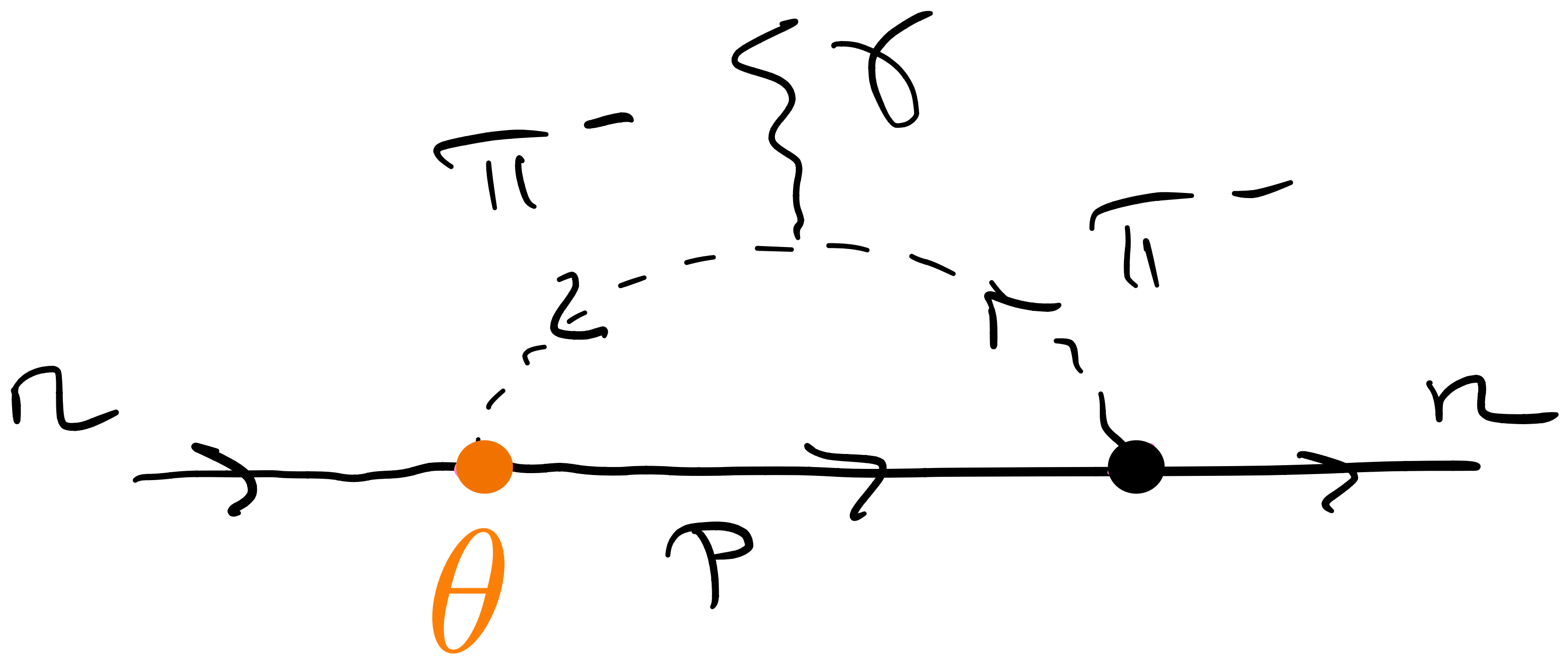
Axion physics is booming

Swedish
Research Council

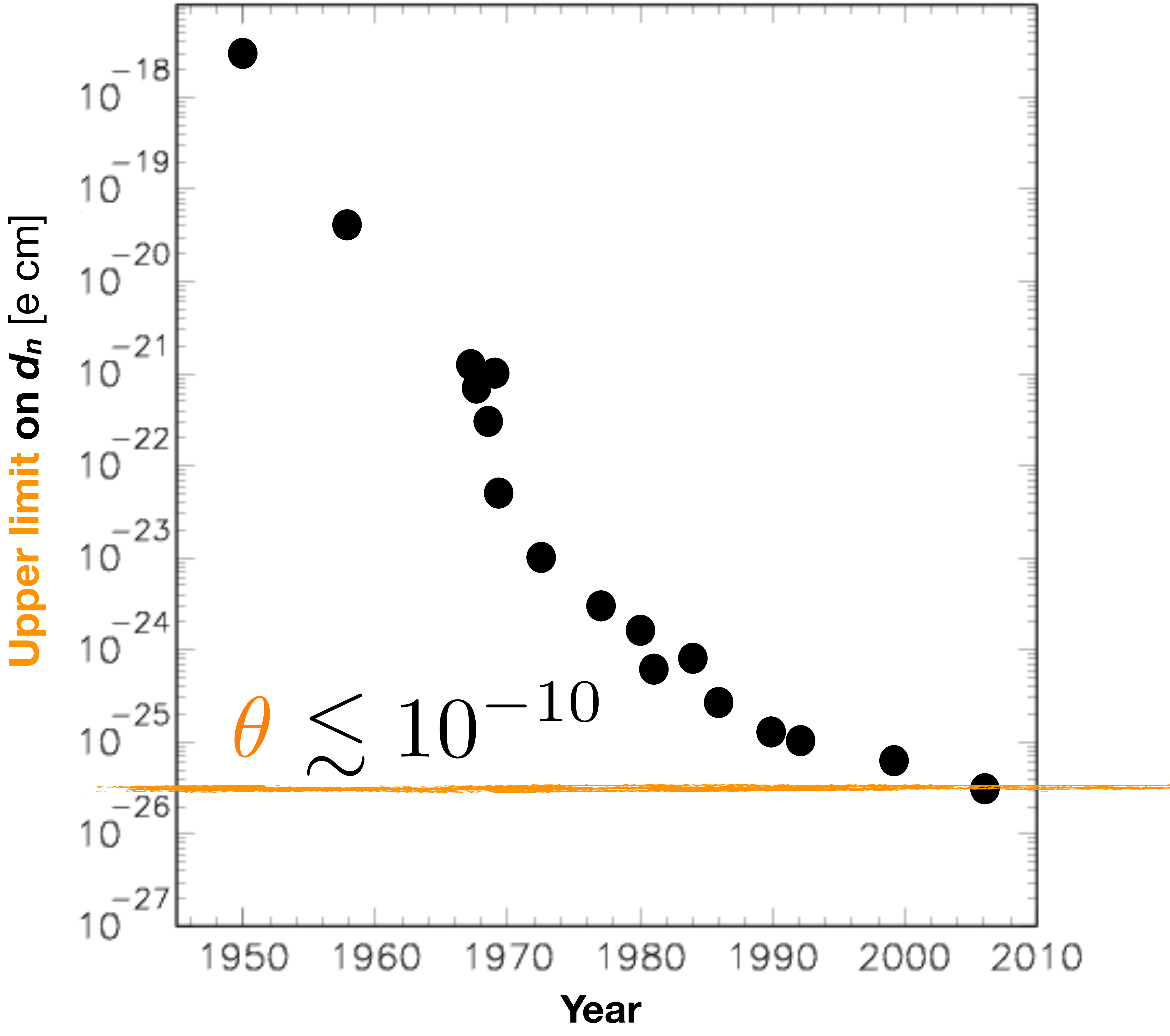
Example: AxionDM@SU

Neutron electric dipole moment



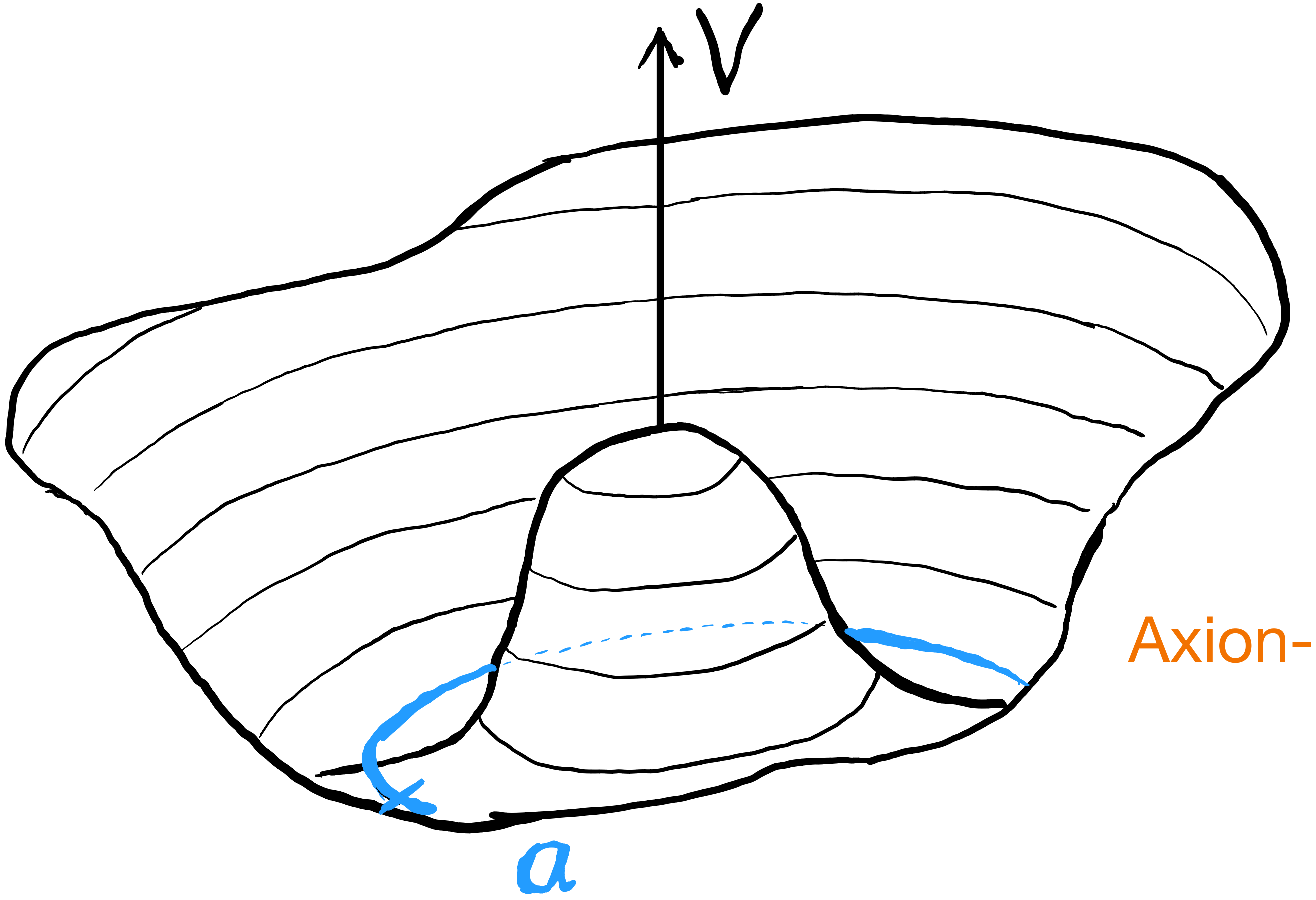
Parameter of SM,
angle

$$d_N = \left(5.2\times10^{-16}\, e\cdot\mathrm{cm}\right)\theta$$



$\theta \lesssim 10^{-10}$

Axions: remnants of broken symmetries



QCD axion:

$$\theta \longrightarrow a \longrightarrow 0$$

Axion-like particles (ALPs):

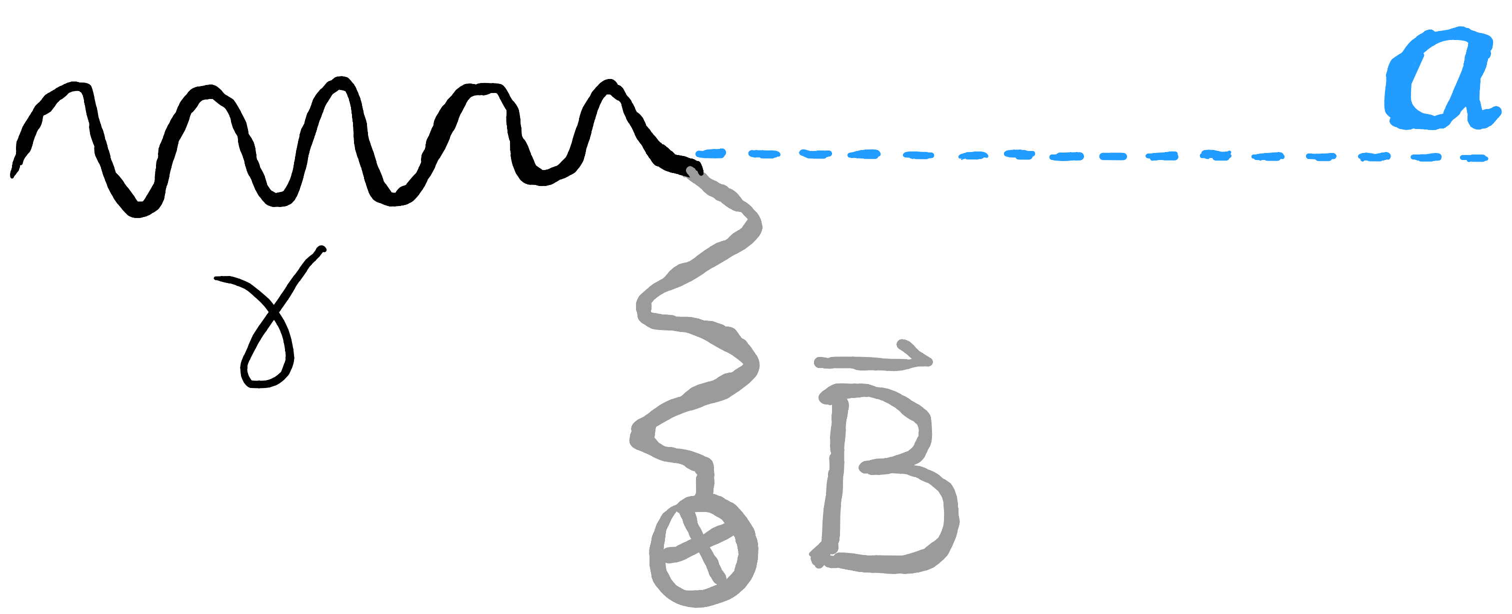
Ubiquitous in BSM theories

Parameters

$$\mathcal{L} \supset \frac{1}{2} m_a^2\, a^2 + \frac{g_{a\gamma}}{4}\, a\, \mathbf{E} \cdot \mathbf{B}$$

QCD axion:

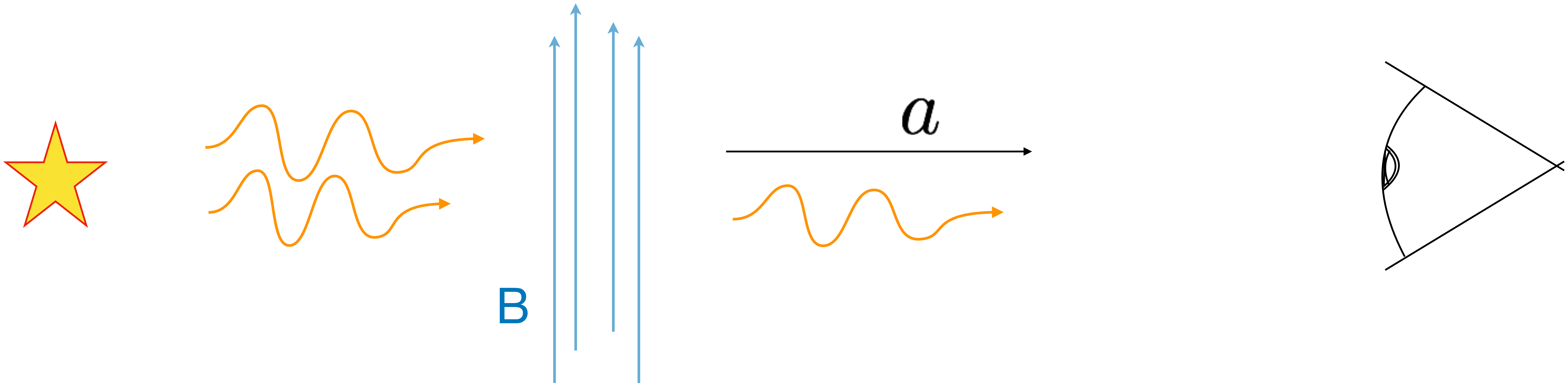
One independent parameter, two scales



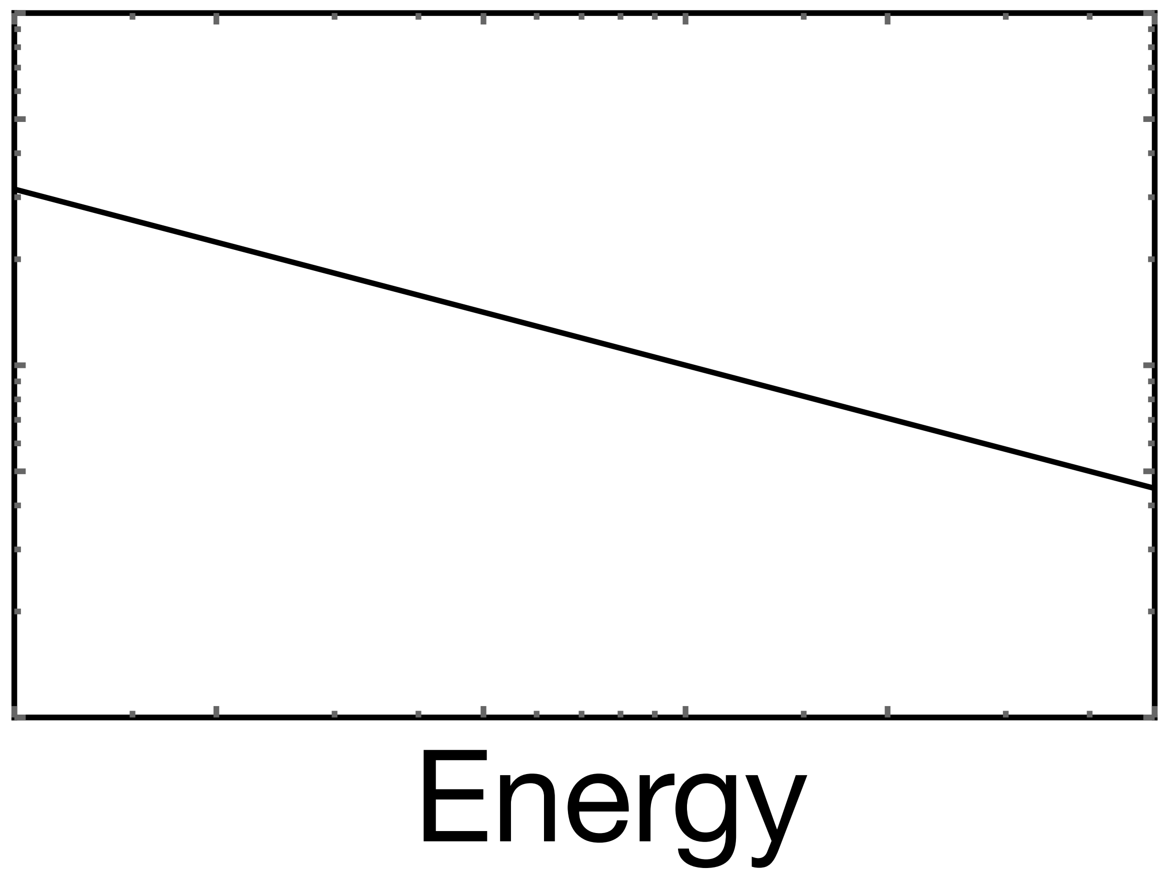
Axion-like particles:

Two independent parameters

The photon disappearance channel



Initial photon spectrum



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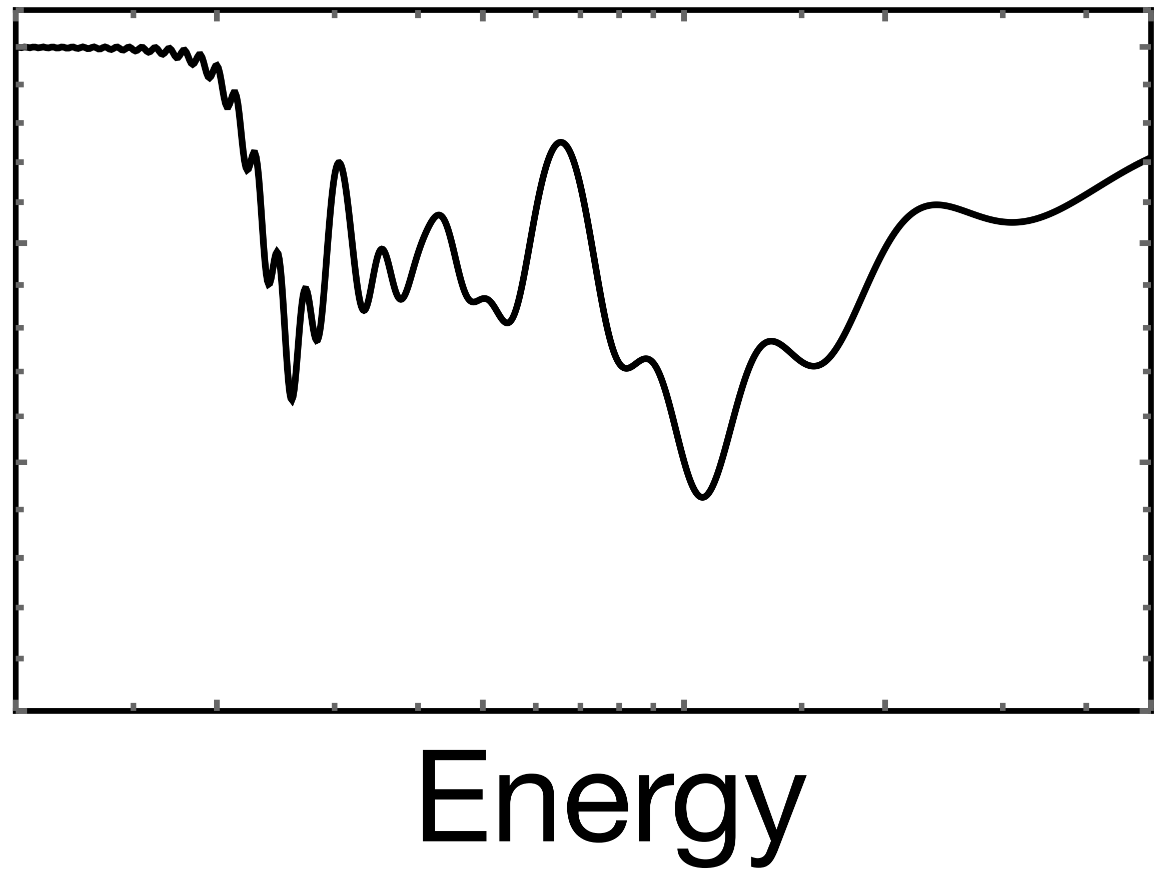
Survival probability



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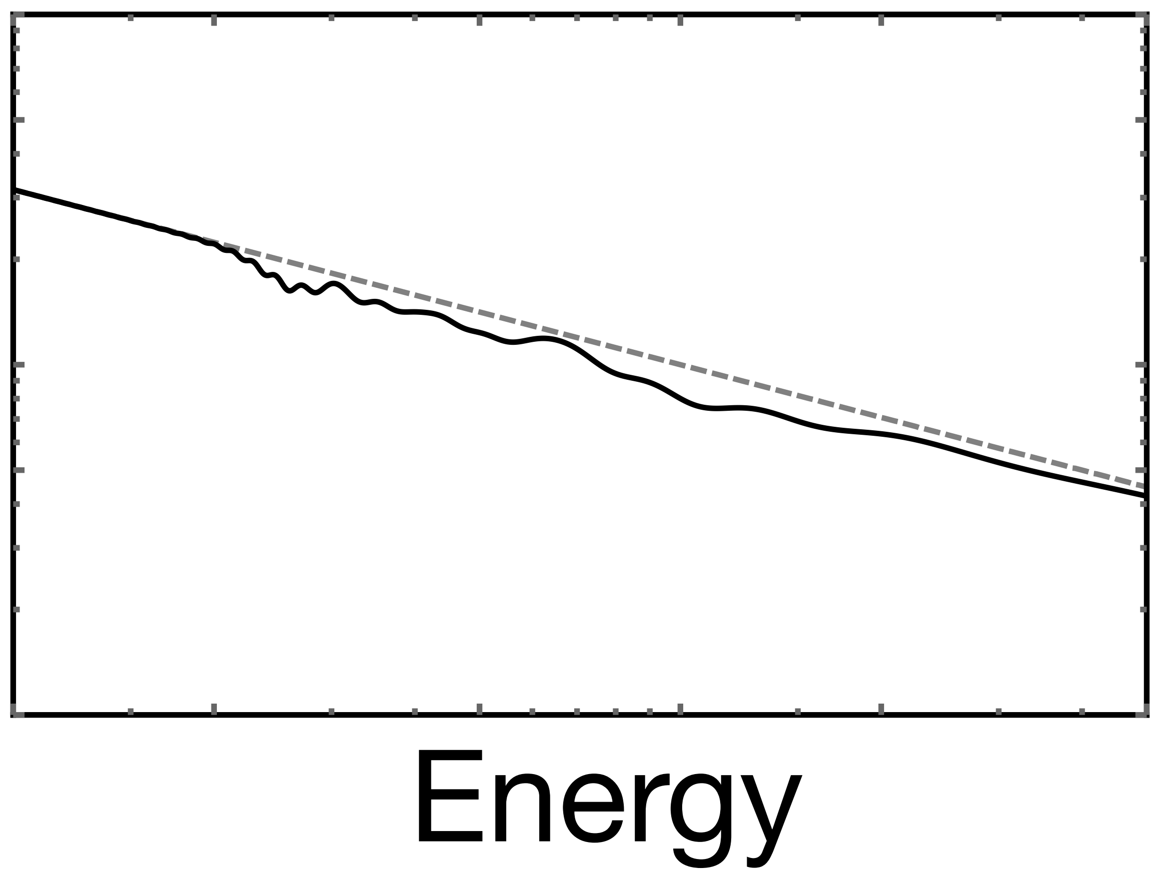
Final photon spectrum



‘Axion electrodynamics’

in a magnetic plasma

Classical field theory:

$$(\Box + m_a^2)a = -g_{a\gamma}\dot{\mathbf{A}} \cdot \mathbf{B}_0 \; ,$$

$$(\Box + \omega_{pl}^2)\mathbf{A} = g_{a\gamma}\dot{a}\,\mathbf{B}_0 \; ;$$

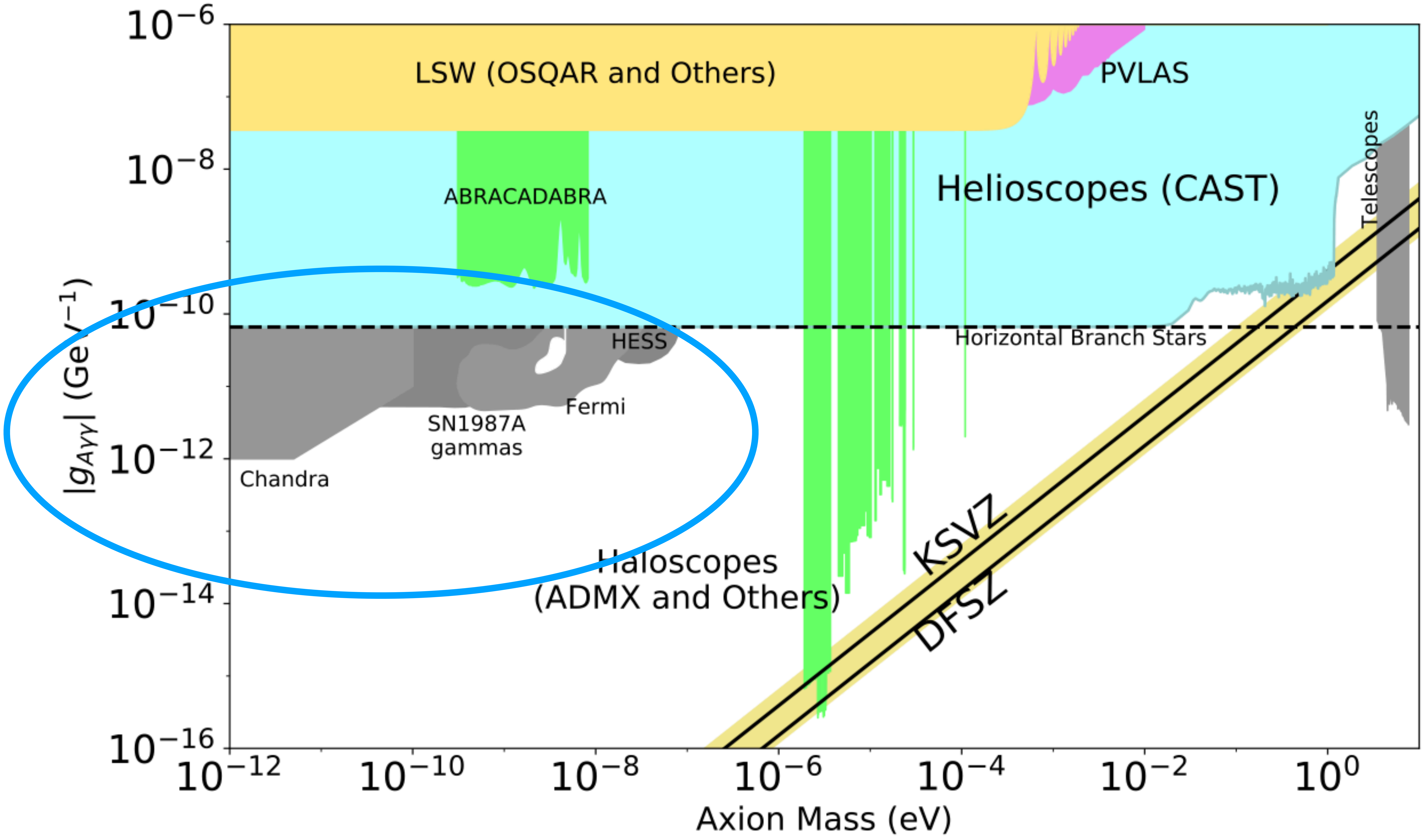
Schrödinger-like equation:

$$i\frac{d}{dz}\Psi(z) = (H_0 + H_I)\Psi(z)\,;$$

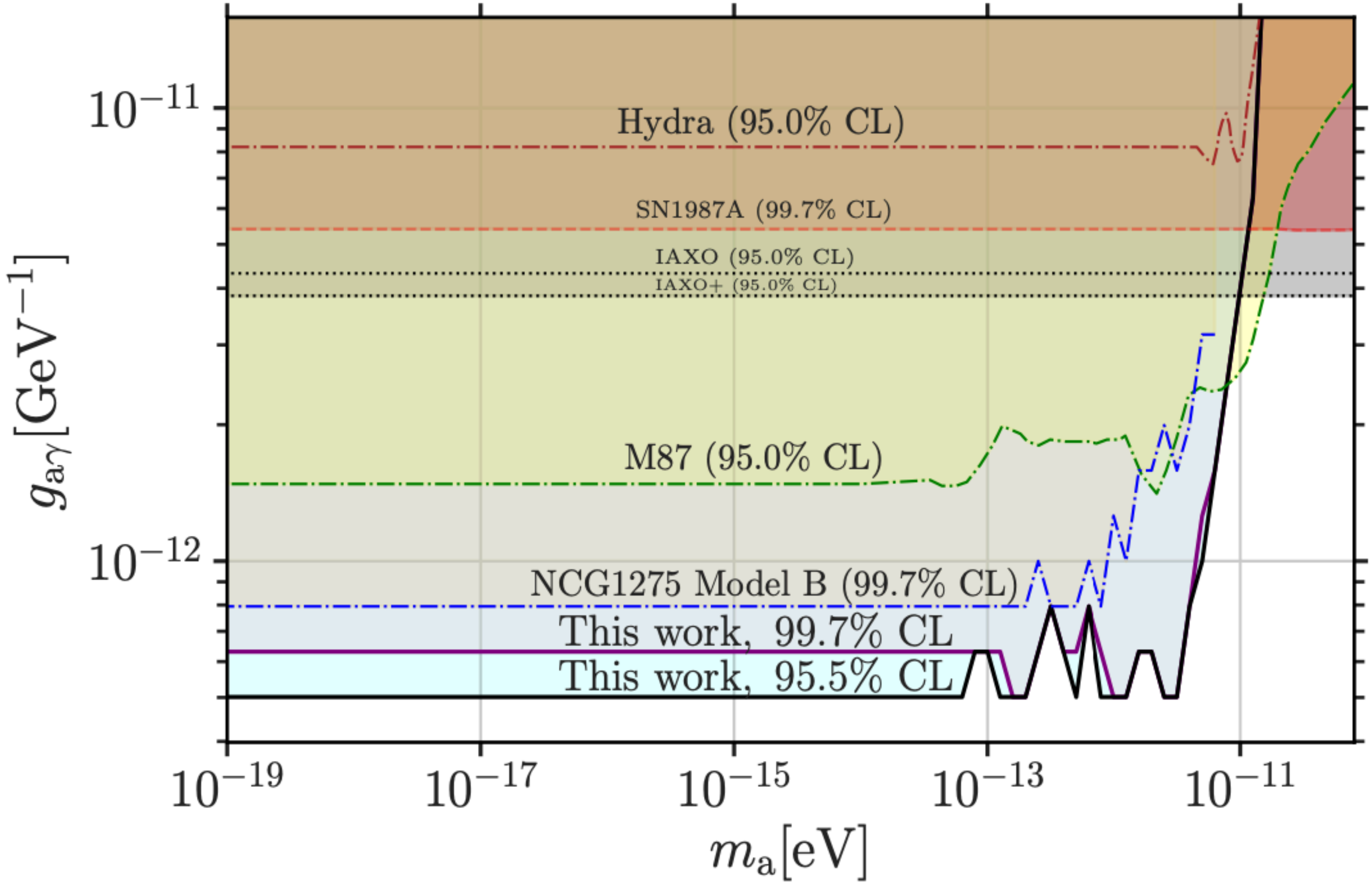
$$\Psi(z) = \begin{pmatrix} A_x \\ A_y \\ a \end{pmatrix} \qquad H_0 = -\frac{1}{2\omega}\begin{pmatrix} \omega_{pl}(z)^2 & 0 & 0 \\ 0 & \omega_{pl}(z)^2 & 0 \\ 0 & 0 & m_a^2 \end{pmatrix} \qquad H_I = \frac{g_{a\gamma}}{2}\begin{pmatrix} 0 & 0 & B_x \\ 0 & 0 & B_y \\ B_x & B_y & 0 \end{pmatrix} \; ;$$

Chandra observation of NGC 1275 in the Perseus cluster

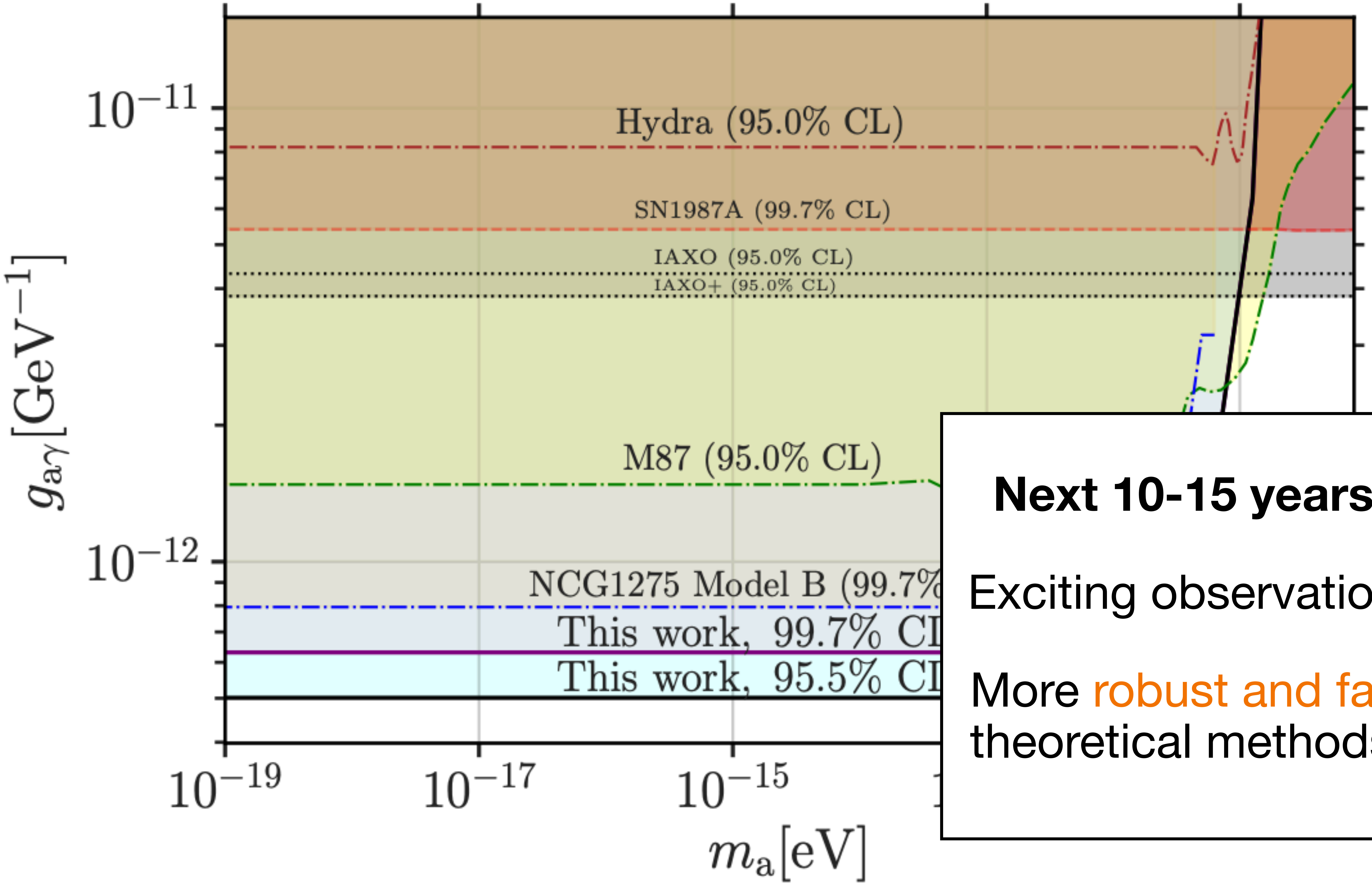
[Reynolds, Marsh, et al.]



[Particle Data Group: axion review 2019]



[Sisk Reynes et al.]



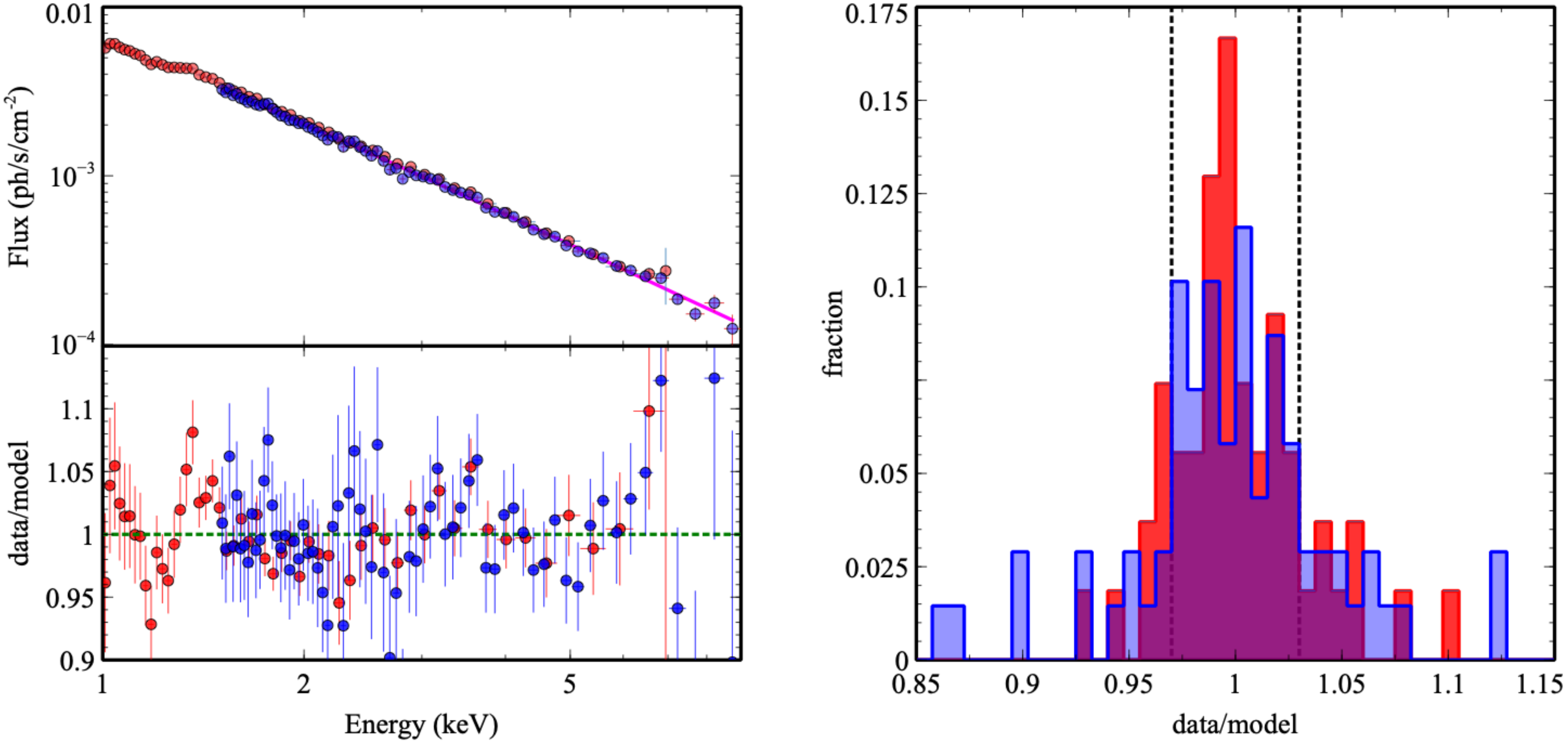
Next 10-15 years:

Exciting observational prospects

More robust and faster theoretical methods needed

[Sisk Reynes et al.]

Small residuals



[Reynolds, Marsh, et al.]

“Quantum” perturbation theory for classical mixing

Useful for current & future high-quality spectra

Transition amplitude:

$$\mathcal{A}_{\gamma_x \to a} = -i\frac{g_{a\gamma}}{2}\int_0^z dz' B_x(z') e^{-i\Phi(z')}$$

Can be expressed as certain Fourier transforms

Conversion probability:

$$P_{\gamma_x \to a}(\eta) = \frac{g_{a\gamma}}{2}\left[\mathcal{F}_s(B_x)^2 + \mathcal{F}_c(B_x)^2\right]$$

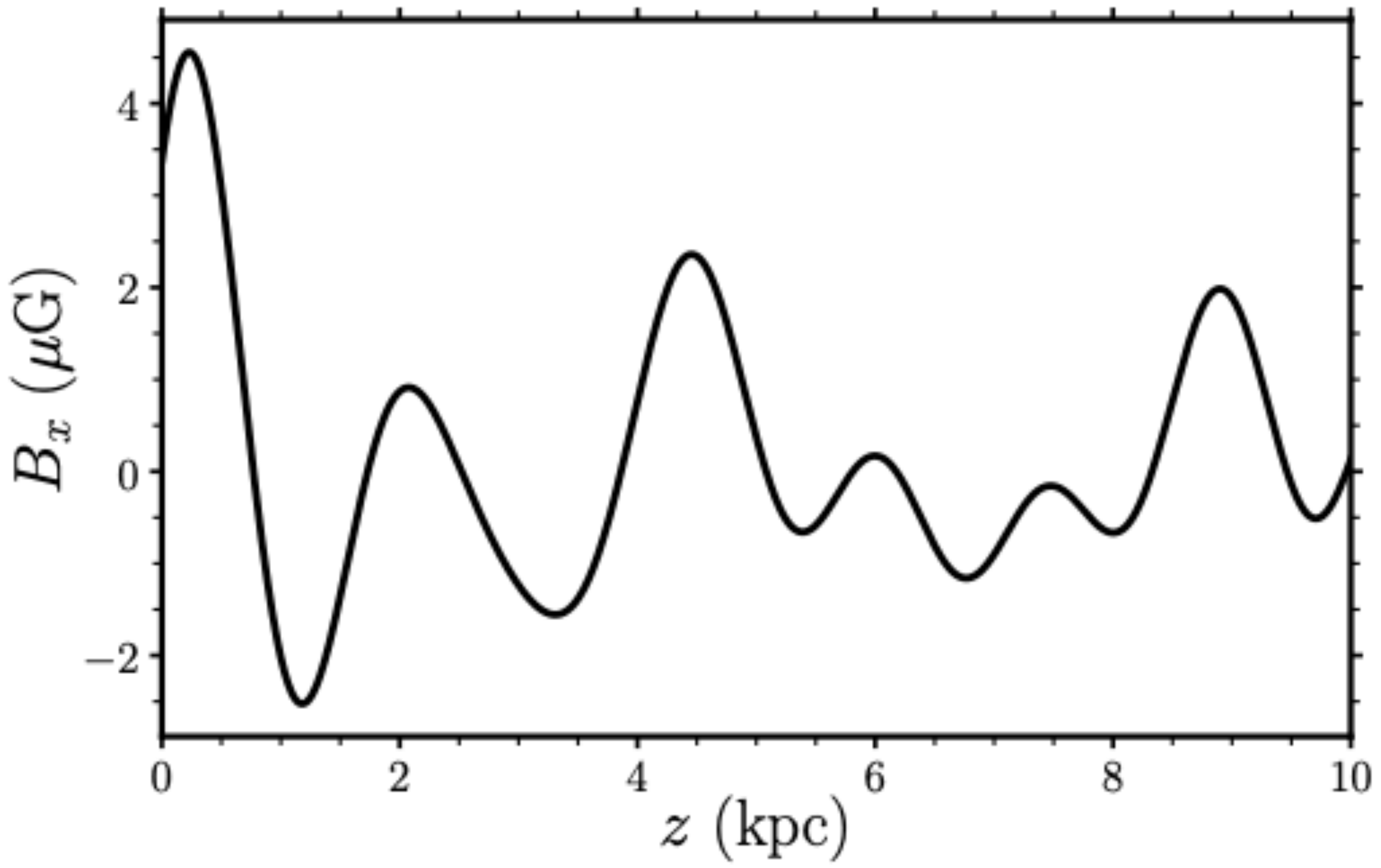
Power spectrum of B

$$= \frac{g_{a\gamma}^2}{2}\mathcal{F}_c\Big(c_{B_x}(L)\Big)$$

Fourier transform of the magnetic autocorrelation function

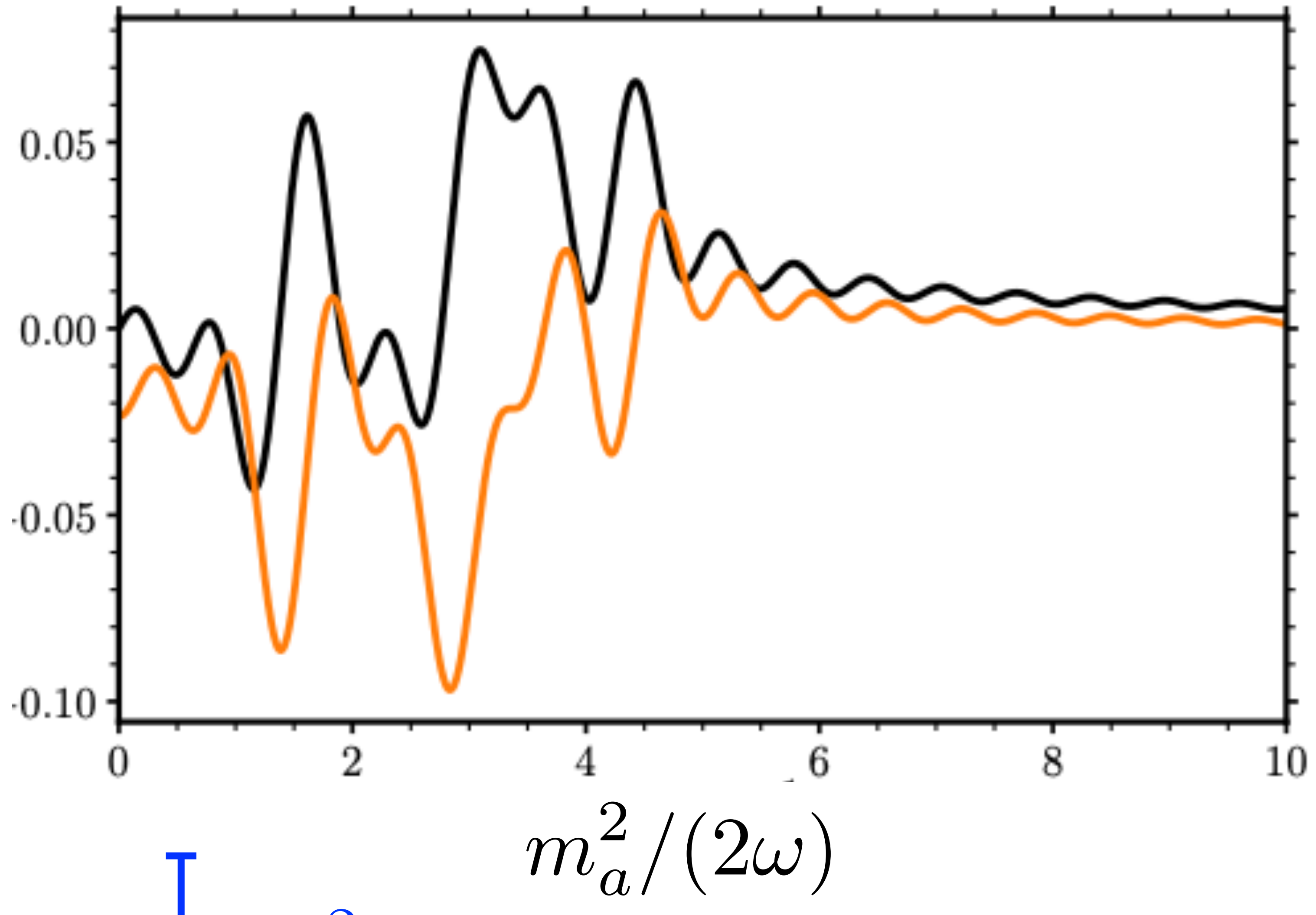
[Marsh, Matthews et al.]

Magnetic field



$\mathcal{F}_c$, $\mathcal{F}_s$

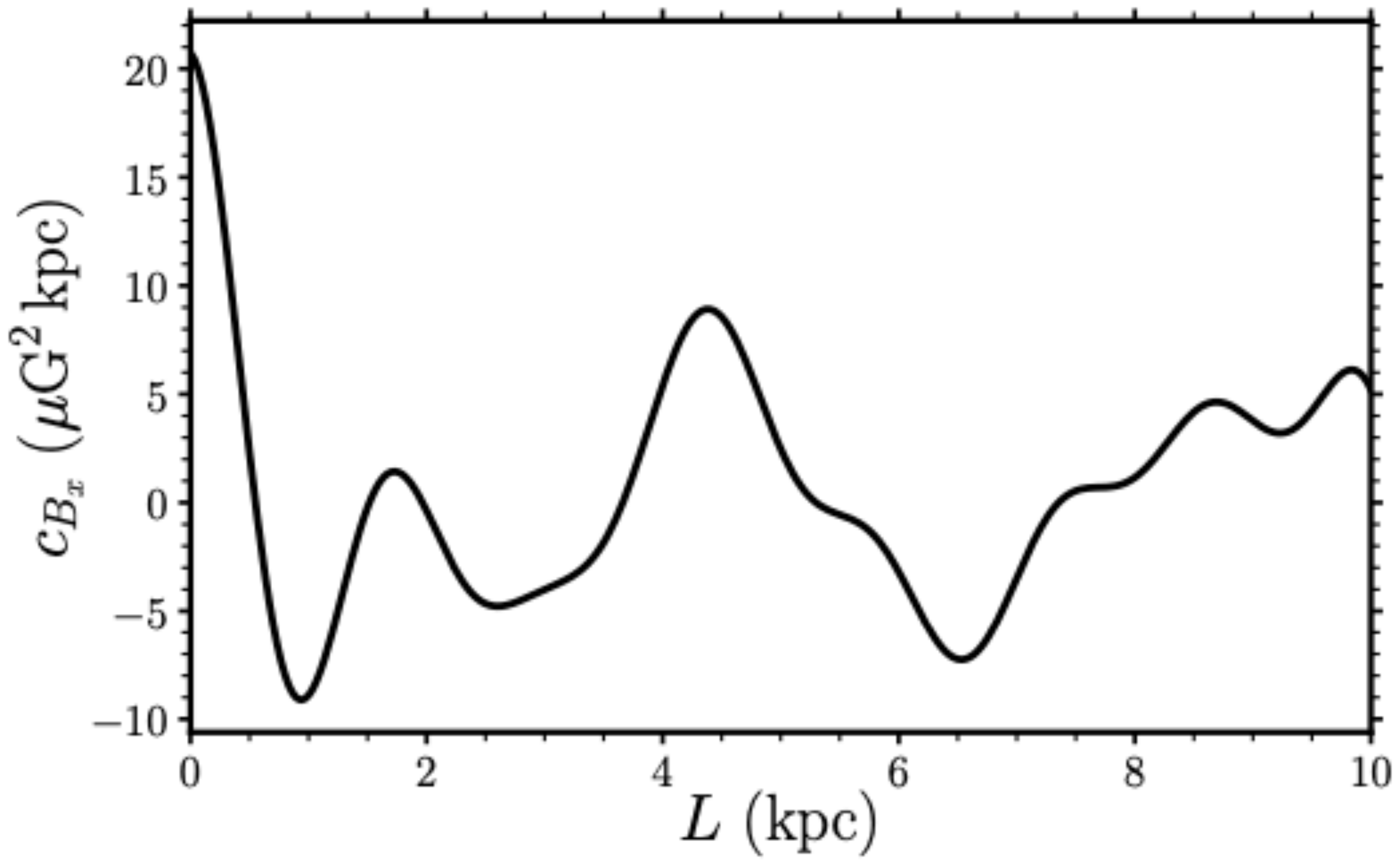
Amplitude



c_B

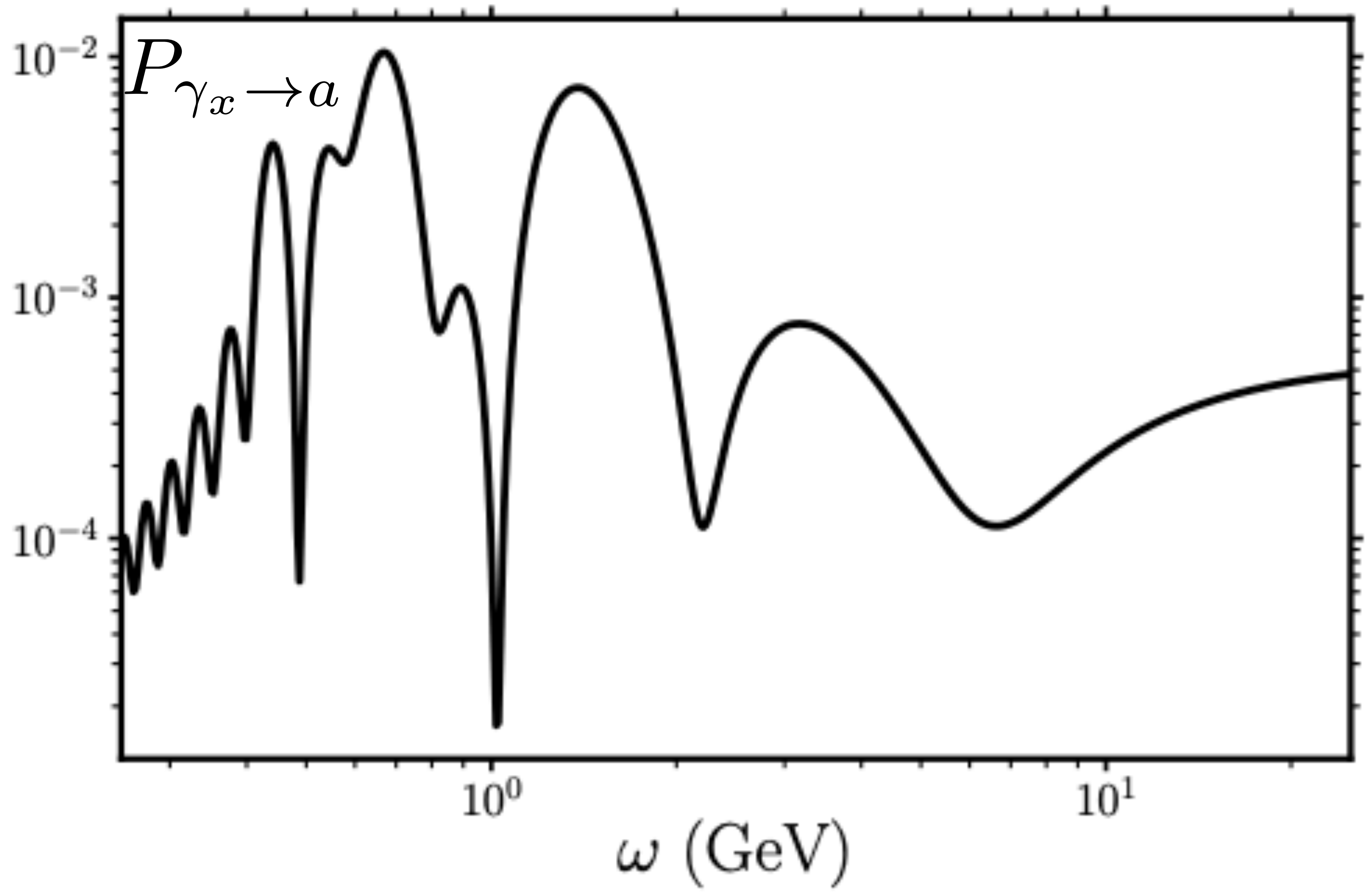
$|\mathcal{A}|^2$

Autocorrelation



$\mathcal{F}_c$

Probability



Extensions:

Method works for relativistic axions, for arbitrary $\omega_{\rm pl}(z)/m_a$

Conceptual insight:

Questions about spectrum of $P_{\gamma\to a}$ =
Questions about real-space magnetic autocorrelation

New analytical solutions:

- Cell models vs. turbulent magnetic fields
- Regular magnetic fields
- General magnetic fields

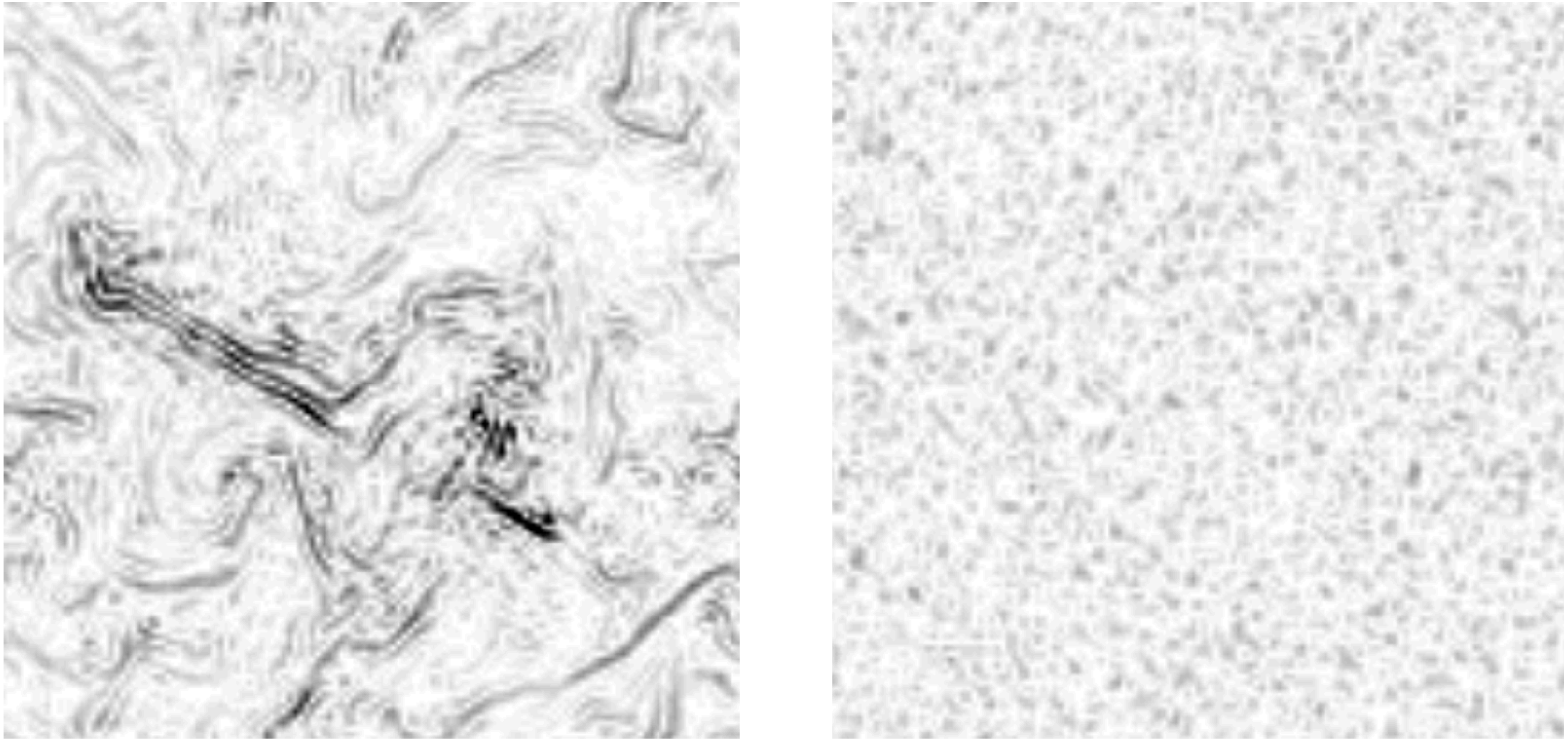
Fast numerics:

The FFT is really very fast.

New methods?

Stop modelling the magnetic field, instead just use the power spectrum?

What really matters for axion-photon conversion?



[Maron, Goldreich]

Thanks!