Beyond the Standard Model BrainStorming Meeting:

Particle Physics and Cosmology interface

Vila do Conde, Portugal, 12-16 July, 2024

Axion paradigm with color-mediated neutrino masses

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Motivation

The Standard Model cannot explain:

- **Neutrino flavour oscillations** which imply massive neutrinos and lepton mixing;
- Observed **dark matter** abundance;
- **Strong CP problem:** Lack of a theoretical explanation for the non-observation of the neutron electric dipole moment which indicates that strong interactions preserve CP symmetry.

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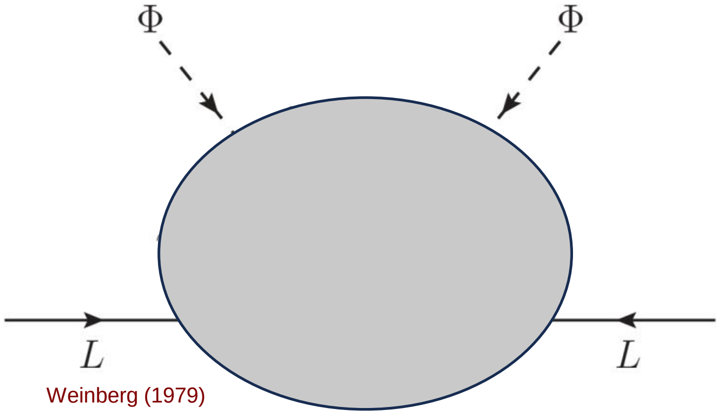

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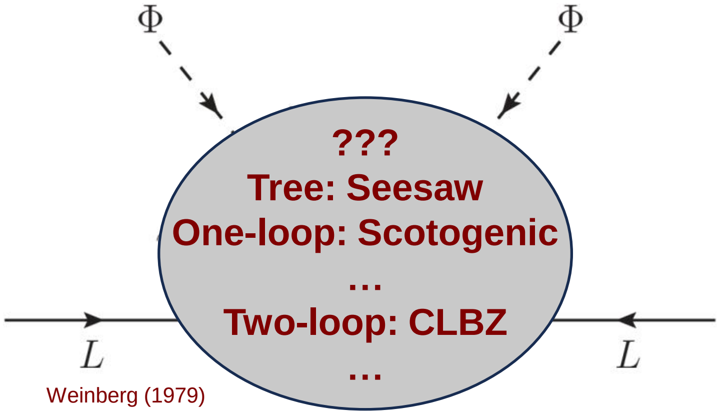

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One-loop: Scotogenic
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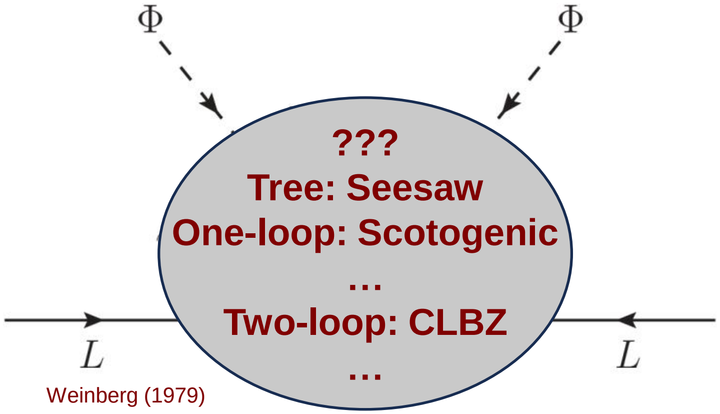

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Peccei,Quinn (1977),
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$$\sigma = \frac{v_\sigma + \rho}{\sqrt{2}} e^{i a_\sigma / v_\sigma}$$

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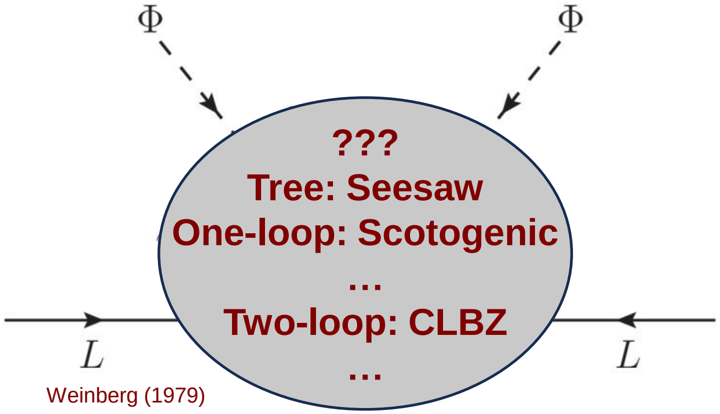

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Dynamical solution

$$\left(\frac{a}{f_a} - \bar{\theta} \right) \frac{\alpha_s}{8\pi} \, G\tilde{G}$$

$$\bar{\theta}_{\mathrm{eff}} = \bar{\theta} + \left\langle \frac{a}{f_a} \right\rangle = 0$$

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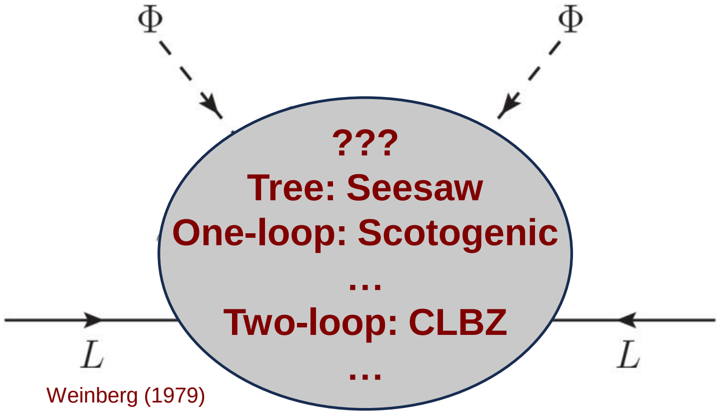

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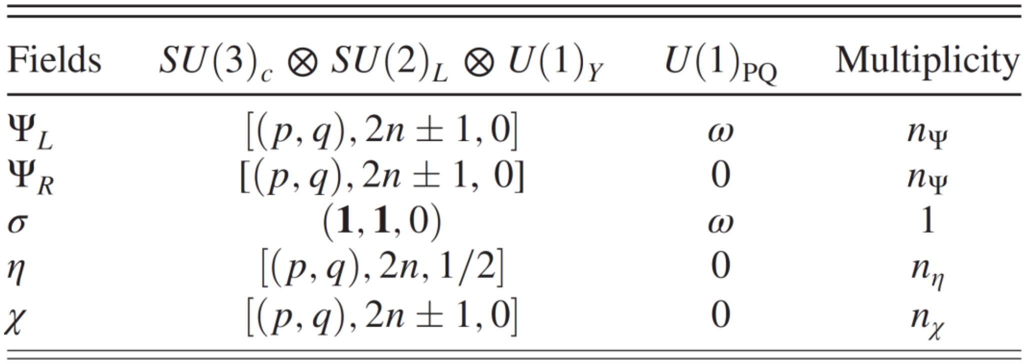
Our approach:

New class of models where **neutrino masses** are **radiatively generated by colored particles** which **simultaneously** solve through the PQ mechanism the **strong CP problem.** The predicted **axion** particle accounts for **dark matter**.

Axion paradigm with color-mediated neutrino masses



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$\boldsymbol{\Psi}_L$	$[(p,q), 2n \pm 1, 0]$	ω	n_Ψ
$\boldsymbol{\Psi}_R$	$[(p,q), 2n \pm 1,\ 0]$	0	n_Ψ
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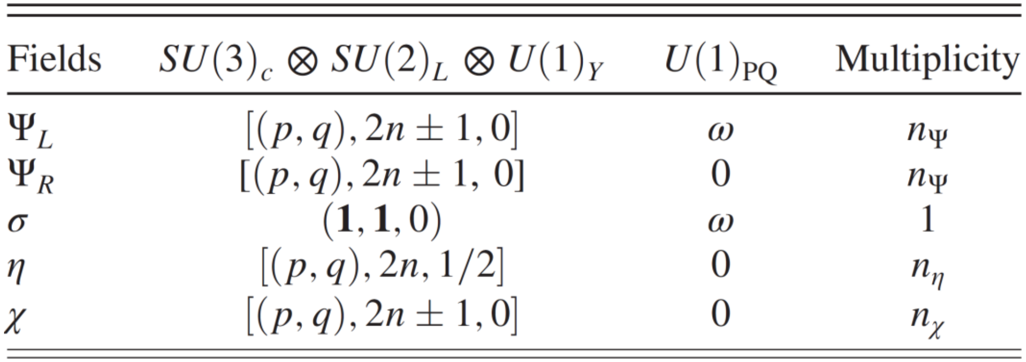

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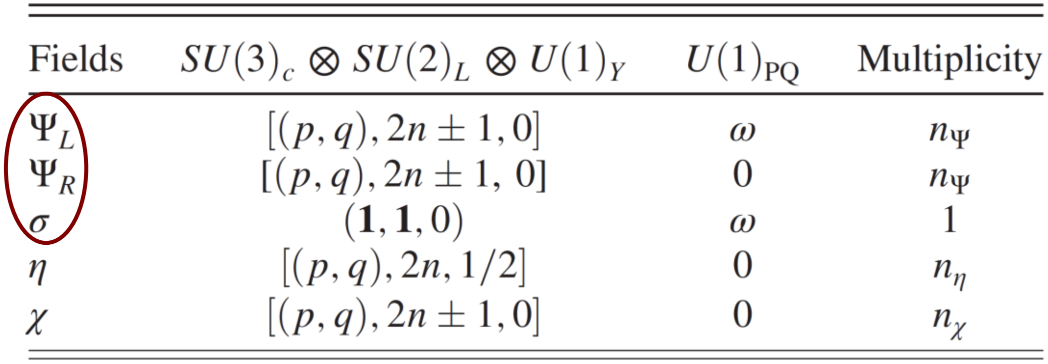

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$$N = 2 n_\Psi \omega (2n \pm 1) T(p,q)$$

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QCD axion mass relation

$$m_a = 5.70(7)\left(\frac{10^{12}\ \text{GeV}}{f_a}\right)\ \mu\text{eV}$$

Cortona et al.(2016)

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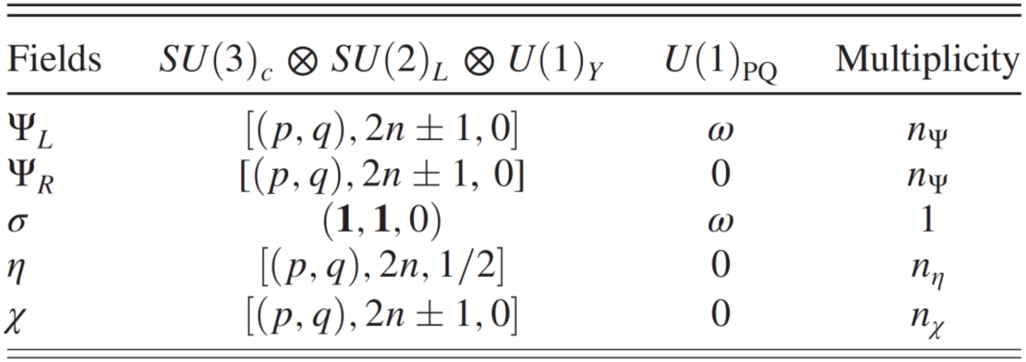

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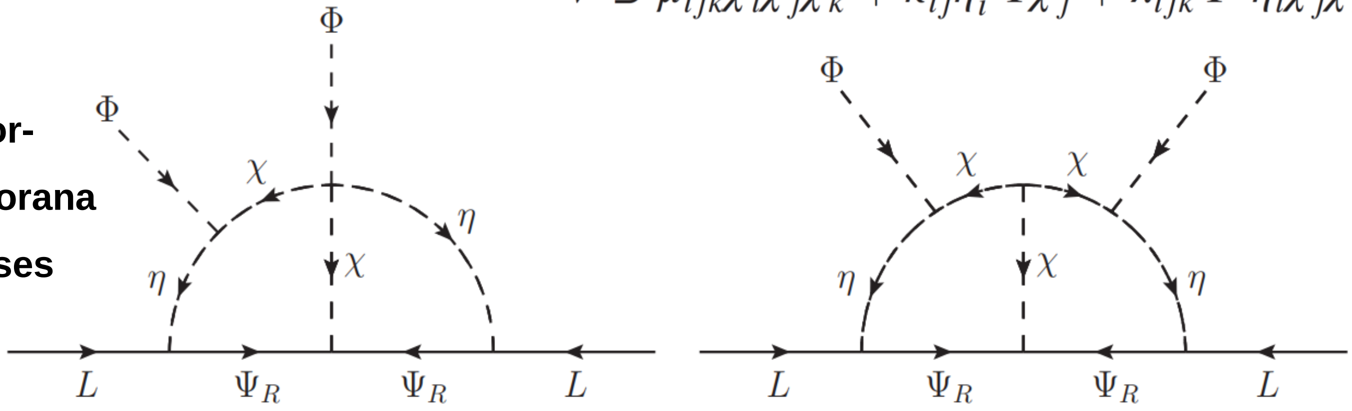

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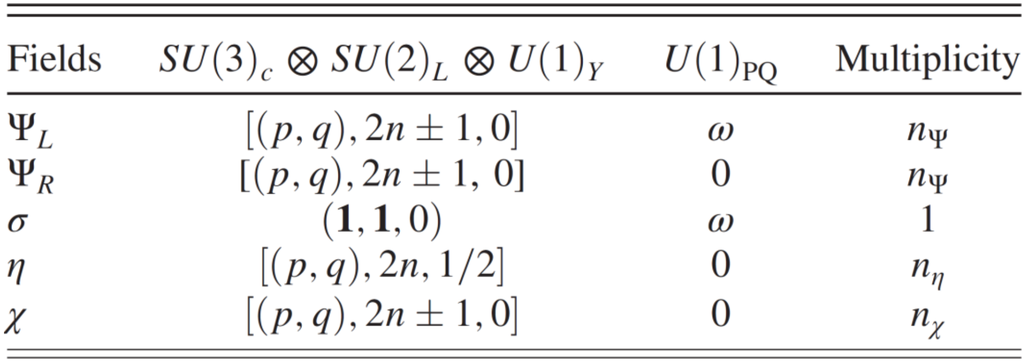

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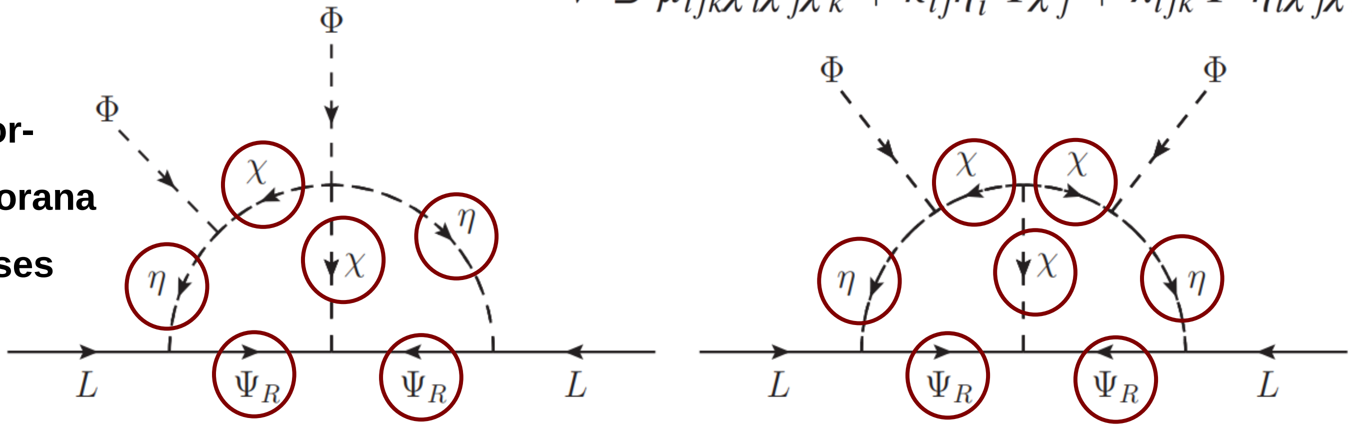

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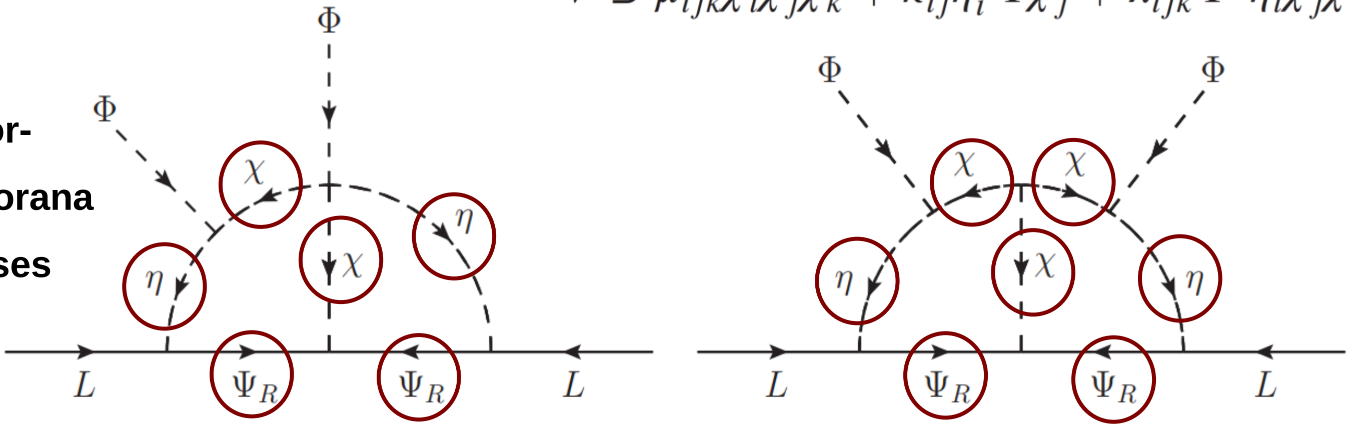

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$$(m_\nu)_{\alpha\beta} \sim 0.1\ \text{eV} \left(\frac{\tilde{Y}^j_{a\alpha} (\tilde{Y}_\chi)^k_{ab} \tilde{Y}^l_{b\beta}}{10^{-3}} \right) \left(\frac{\tilde{\mu}_{jkl}}{10^8\ \text{GeV}} \right) \left(\frac{v}{246\ \text{GeV}} \right)^2 \left(\frac{10^8\ \text{GeV}}{m_\zeta} \right)^2$$

Probing the axion-to-photon coupling

Axion-to-photon coupling

$$g_{a\gamma\gamma} = \frac{\alpha_e}{2\pi f_a}\left[\frac{E}{N} - 1.92(4)\right]$$

Cortona et al.(2016)

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E/N		**3**	**5**	**7**	**9**	**11**
$SU(3)_c$	**3**	4	12	24	40	60
	6	8/5	24/5	48/5	16	24
	10	8/9	8/3	16/3	80/9	40/3
	15	1	3	6	10	15
	15′	4/7	12/7	24/7	40/7	60/7

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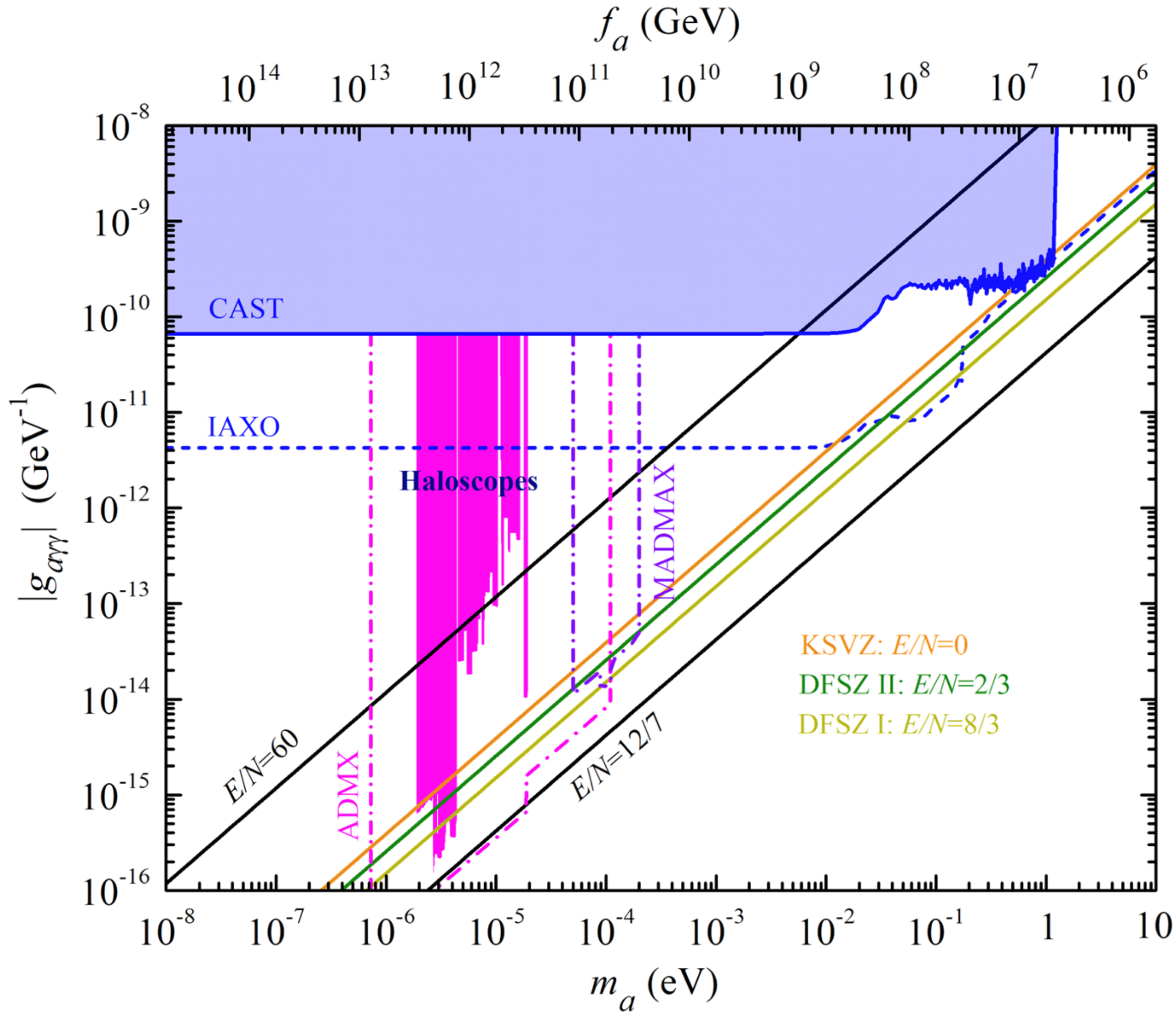
	15′	4/7	12/7	24/7	40/7	60/7

$$\boxed{\frac{E}{N} = \frac{d(p,q)}{(2n \pm 1)T(p,q)} \sum_{j=0}^{2n\pm1-1}\left(\frac{2n \pm 1 - 1}{2} - j\right)^2}$$

Probing the axion-to-photon coupling



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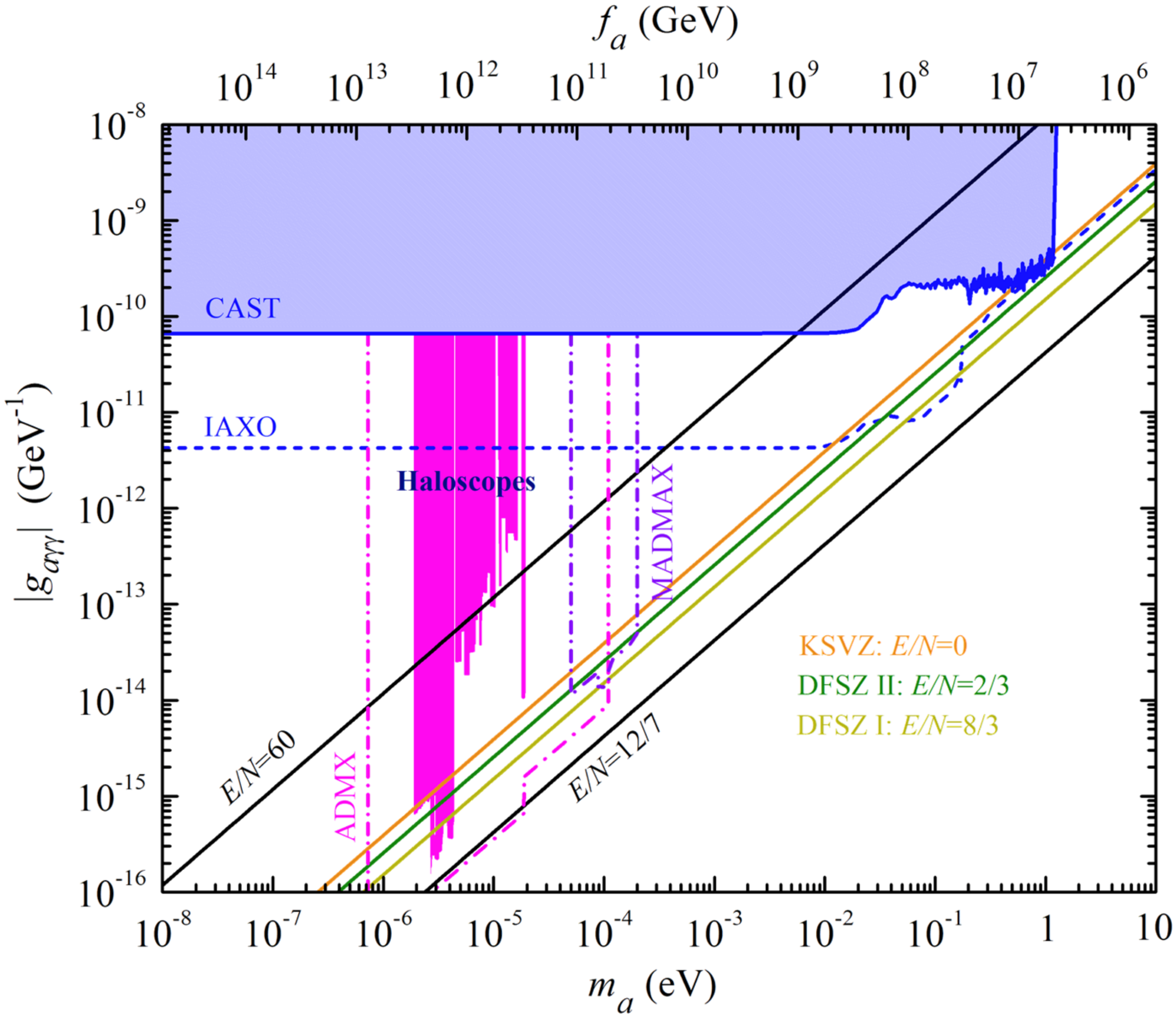

Axion-to-photon coupling allows to probe the different models at **helioscope** and **haloscope** experiments.

Axion dark matter and cosmology

Colored scalars

$\eta \quad ((p,q), 2n, 1/2)$

$\chi \quad ((p,q), 2n \pm 1, 0)$

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Axion dark matter via the misalignment mechanism in pre-inflationary scenario

Callan et al. (1978); Gross et al. (1981); Dimopoulos et al. (2008)

$$\Omega_a h^2 \simeq \Omega_{\mathrm{CDM}} h^2 \frac{\theta_0^2}{2.15^2} \left(\frac{f_a}{2 \times 10^{11}\ \mathrm{GeV}} \right)^{\frac{7}{6}}$$

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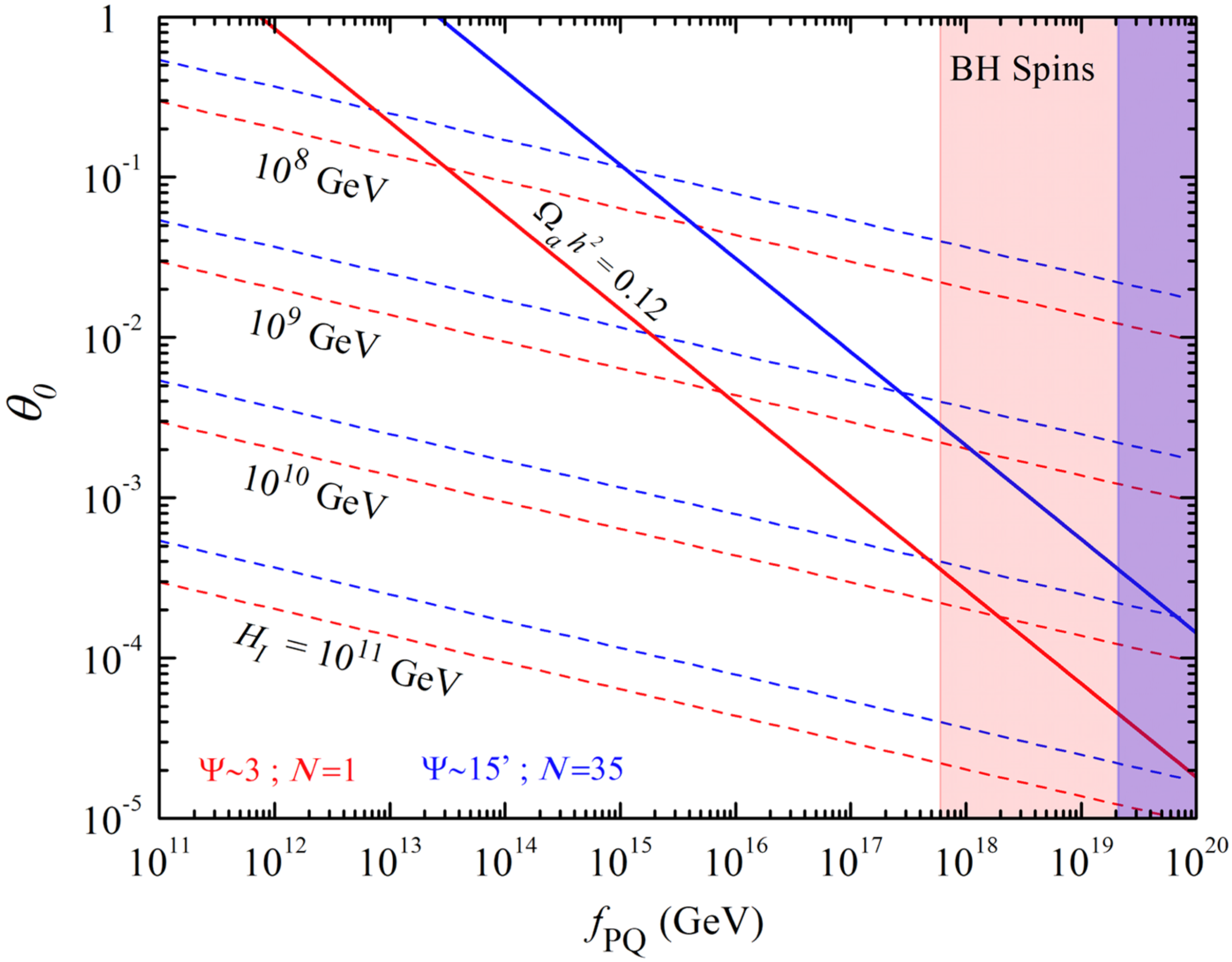
Isocurvature fluctuations are constrained by CMB data setting a bound on the inflationary scale

$$H_I \lesssim \frac{0.9 \times 10^7}{\Omega_a h^2 / \Omega_{\mathrm{CDM}} h^2} \left(\frac{\theta_0}{\pi} \frac{f_a}{10^{11}\ \mathrm{GeV}} \right) \mathrm{GeV}$$

Di Luzio et al. (2017)

Axion dark matter and cosmology



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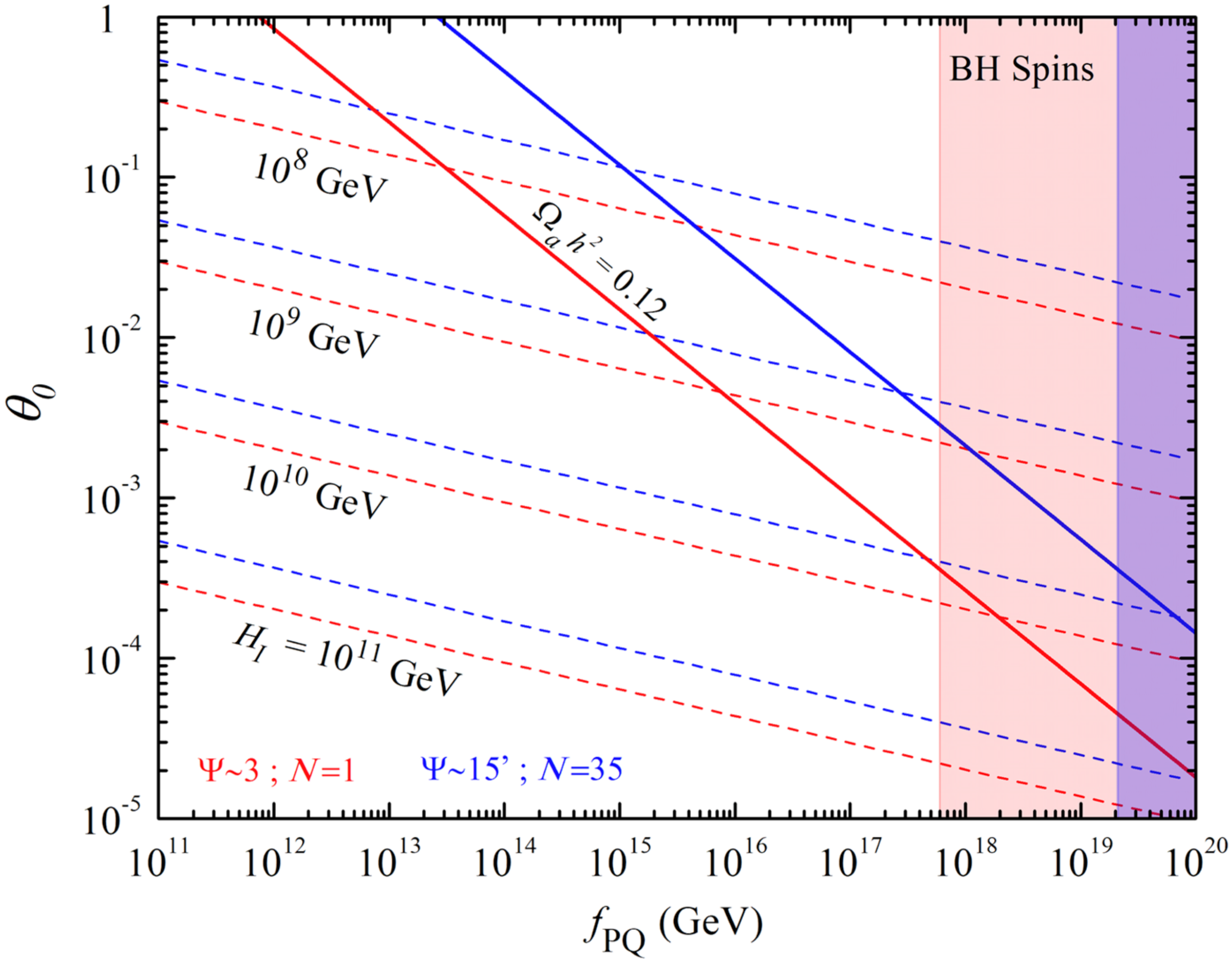

For **ϑ_0~O(1)**, axions can account for the **full CDM budget**, provided **$f_a \sim 10^{12}$ GeV**, a region currently under scrutiny at **haloscopes.**

Conclusion

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Thank you !