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Axion Paradigm with Color-Mediated Neutrino Masses

Henrique Brito Câmara

henrique.b.camara@tecnico.ulisboa.pt

CFTP/IST, U. Lisbon

In collaboration with: A. Batra, F.R. Joaquim, R. Srivastava, J.W.F. Valle

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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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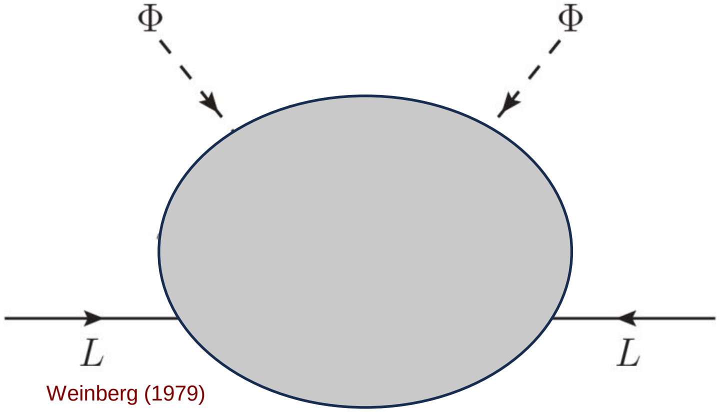

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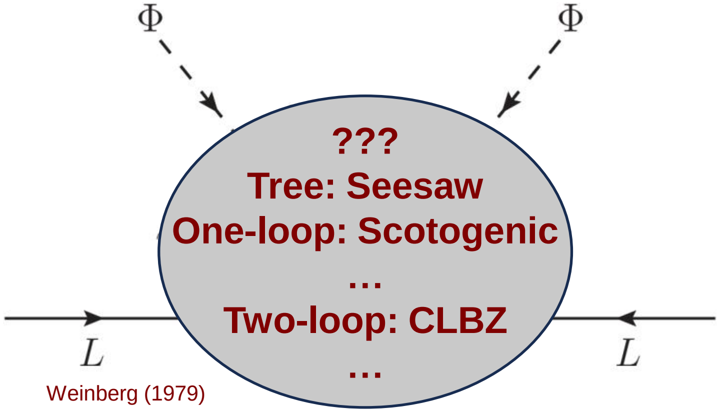

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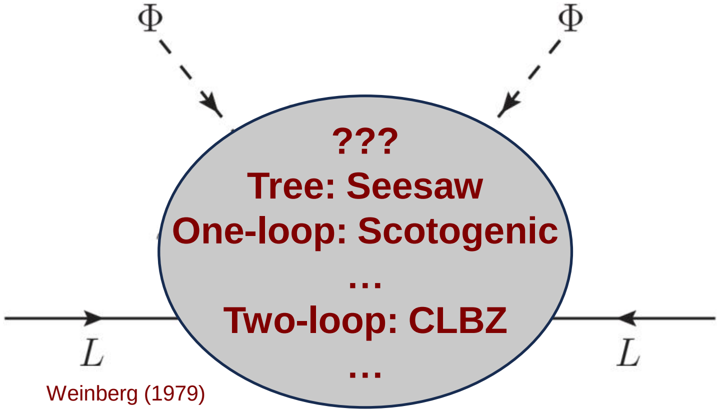

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$$\sigma = \frac{v_\sigma + \rho}{\sqrt{2}} e^{i a_\sigma / v_\sigma}$$

Vector-like quark

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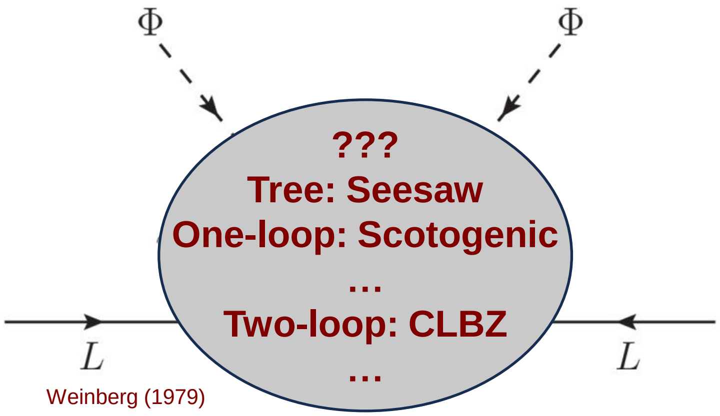

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Dynamical solution

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

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

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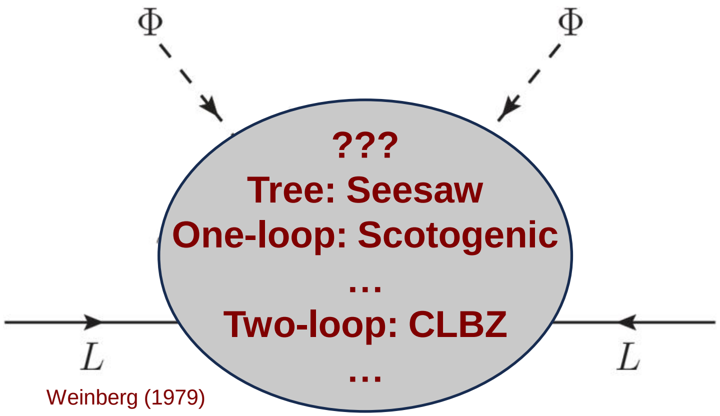

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Our approach:

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

Fields	$SU(3)_c \otimes SU(2)_L \otimes U(1)_Y$	$U(1)_{\text{PQ}}$	Multiplicity
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Ψ_R	$[(p,q), 2n \pm 1, 0]$	0	n_Ψ
σ	$(\mathbf{1}, \mathbf{1}, 0)$	ω	1
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Yukawa Lagrangian

$$-\mathcal{L}_{\text{Yuk.}} \supset \mathbf{Y}_\Psi \overline{\Psi_L} \Psi_R \sigma + \frac{1}{2} \mathbf{Y}_{\chi_j} \Psi_R^T C \chi_j \Psi_R + \mathbf{Y}_i \bar{L} \eta_i^* \Psi_R + \text{H.c.}$$

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Scalar Potential

$$V \supset \mu_{ijk} \chi_i \chi_j \chi_k + \kappa_{ij} \eta_i^\dagger \Phi \chi_j + \lambda_{ijk} \Phi^\dagger \eta_i \chi_j \chi_k + \text{H.c.}$$

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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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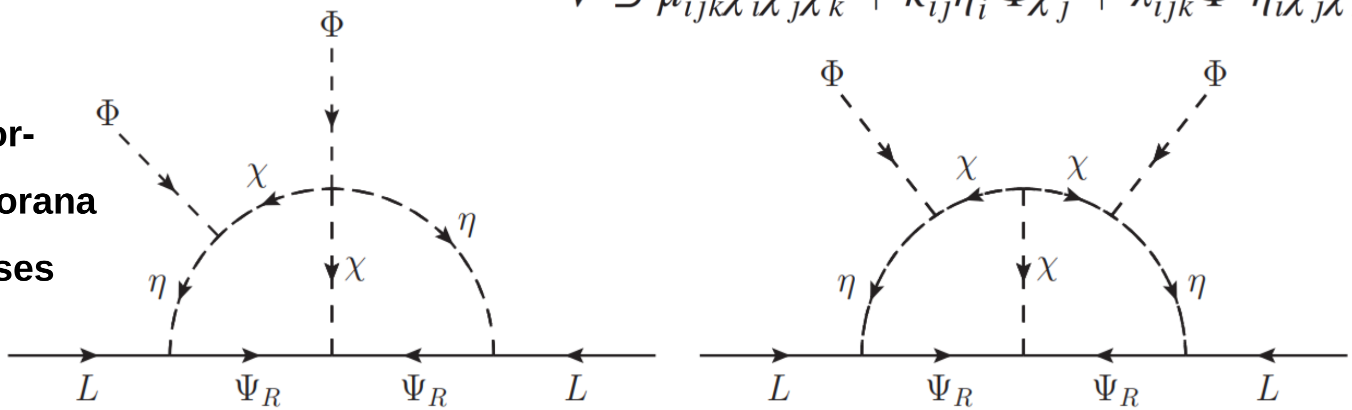

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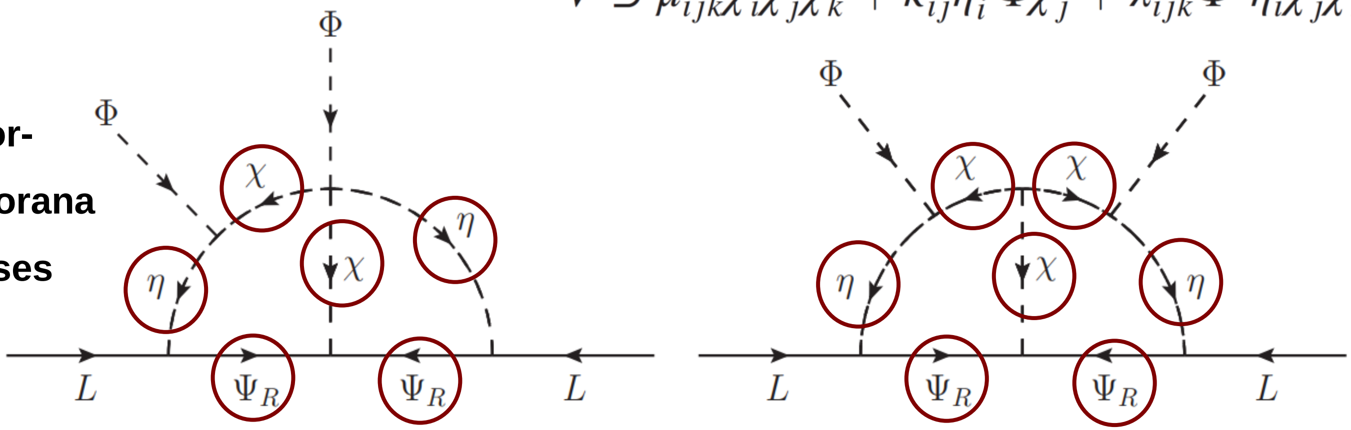

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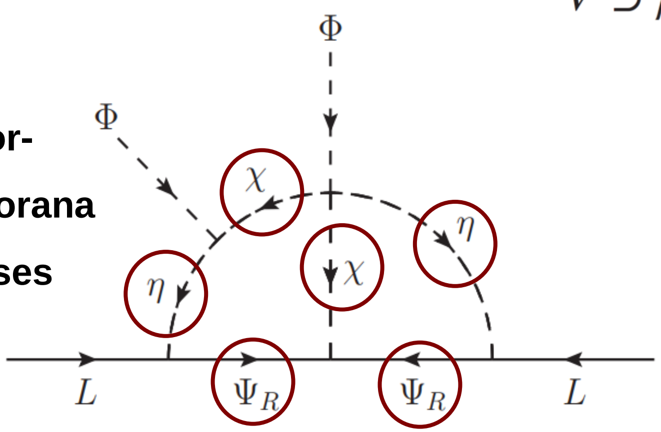

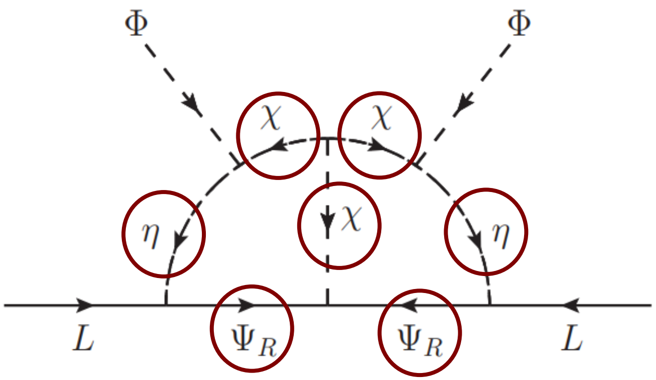

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$$(m_\nu)_{\alpha\beta} \sim 0.1 \text{ eV} \left(\frac{\tilde{Y}^j_{a\alpha} (\tilde{Y}_\chi)^k_{ab} \tilde{Y}^l_{b\beta}}{10^{-3}} \right) \left(\frac{\tilde{\mu}_{jkl}}{10^8 \text{ GeV}} \right) \left(\frac{v}{246 \text{ GeV}} \right)^2 \left(\frac{10^8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

Probing the axion-to-photon coupling

Axion-to-photon coupling

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

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	6	8/5	24/5	48/5	16	24
	10	8/9	8/3	16/3	80/9	40/3
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$$\frac{E}{N} = \frac{d(p,q)}{(2n\pm 1)T(p,q)} \sum_{j=0}^{2n\pm 1-1} \left(\frac{2n\pm 1-1}{2} - j\right)^2$$

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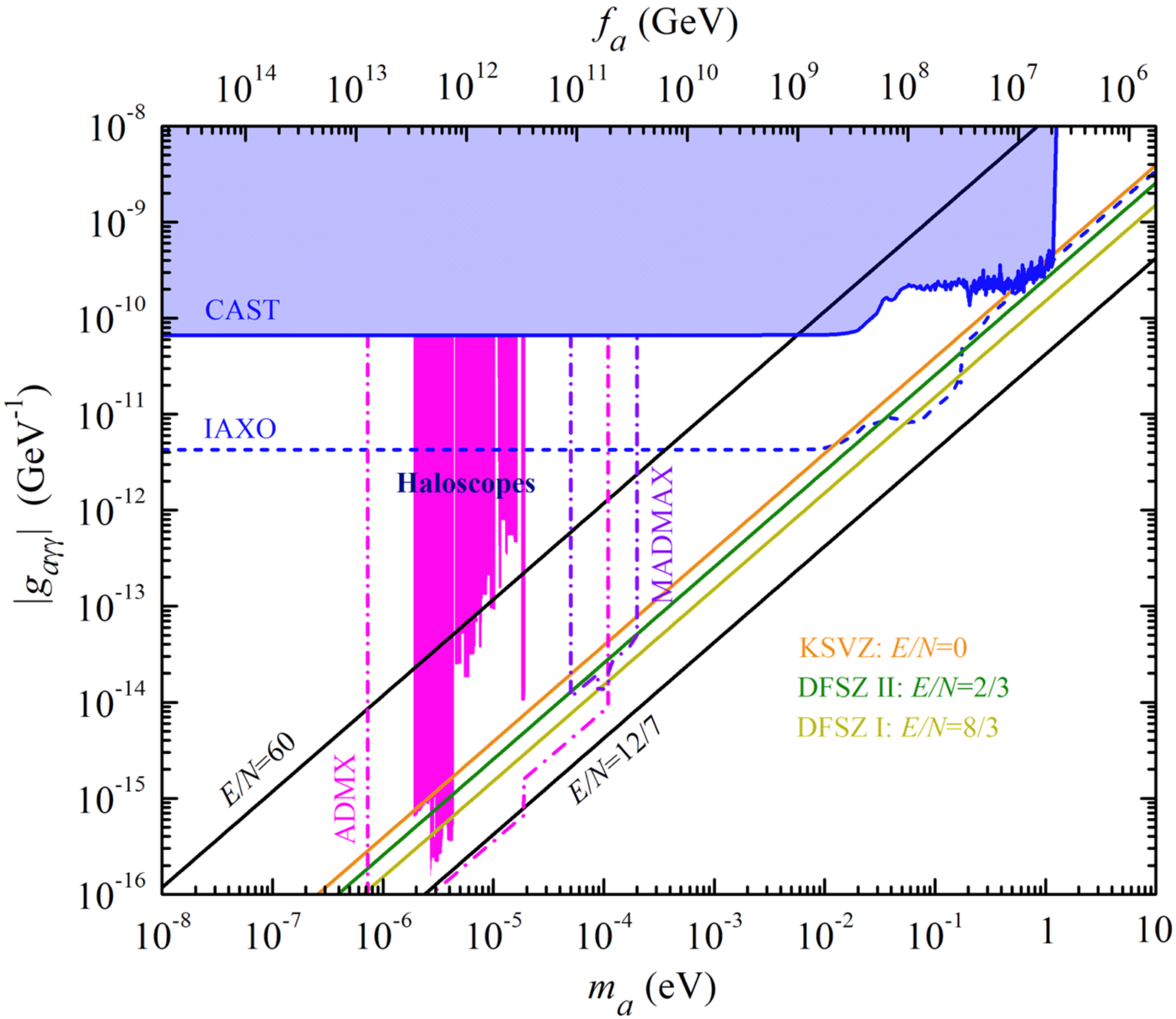

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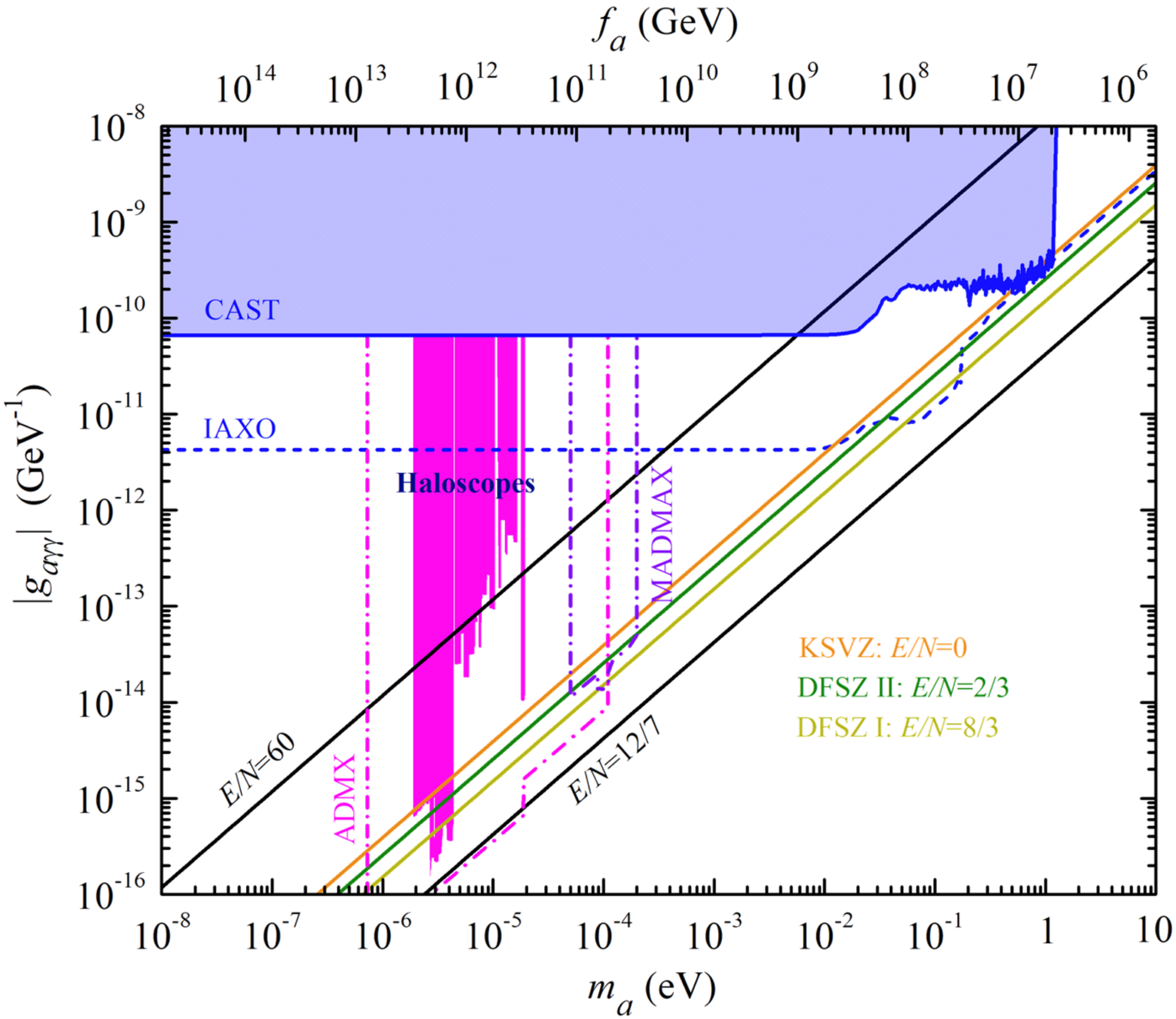

Axion-to-photon coupling allows to probe the different models at **helioscope** and **haloscope** experiments.

Axion dark matter and cosmology

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

Vector-like quarks

$\Psi_{L,R} \quad ((p,q), 2n \pm 1, 0)$

Lead to potentially dangerous stable couloured/baryonic and electrically charged relics …

Axions are naturally light, weakly coupled with ordinary matter, cosmologically stable, and can be nonthermally produced in the early Universe being an excellent DM candidate.

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

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

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

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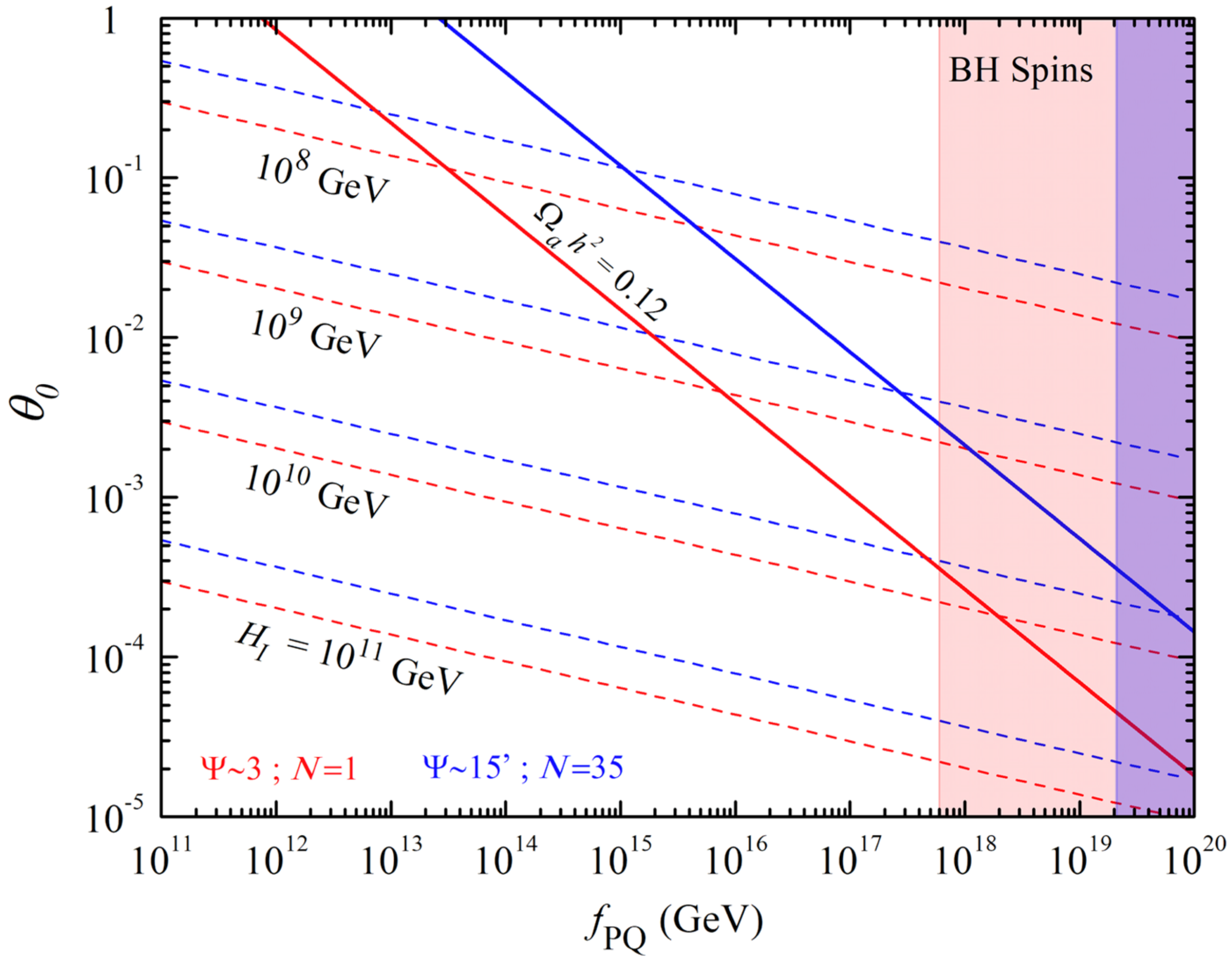
Isocurvature fluctuations are constrained by CMB data setting a bound on the inflationary scale

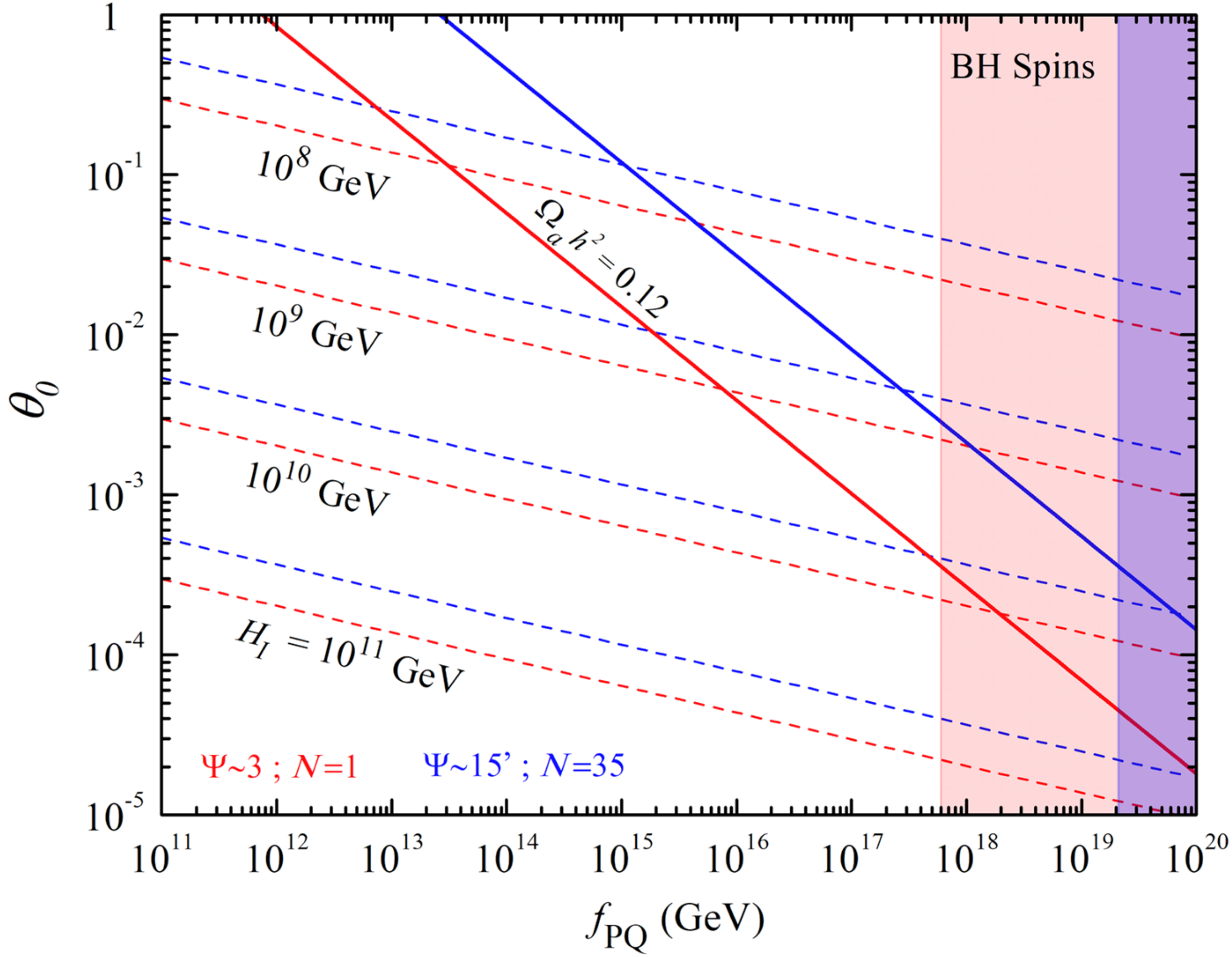
$$H_I \lesssim \frac{0.9 \times 10^7}{\Omega_a h^2 / \Omega_{\rm CDM} h^2} \left(\frac{\theta_0}{\pi} \frac{f_a}{10^{11}\ \rm GeV} \right)\ \rm GeV$$

Di Luzio et al. (2017)

Axion dark matter and cosmology



Axion dark matter and cosmology



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 !