ISAPP 2024: Particle Candidates for Dark Matter

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Axion paradigm with "coloured" 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;
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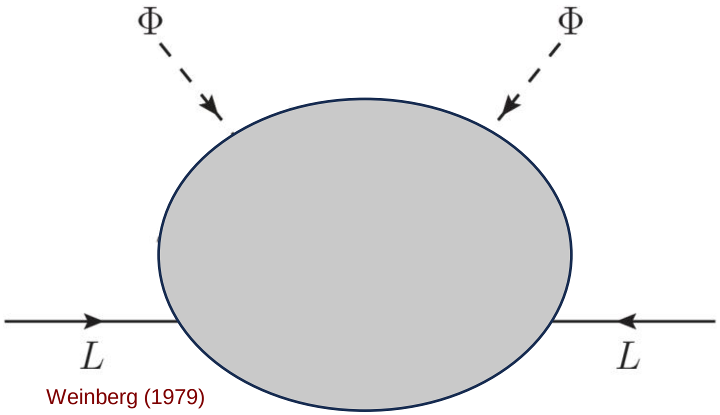

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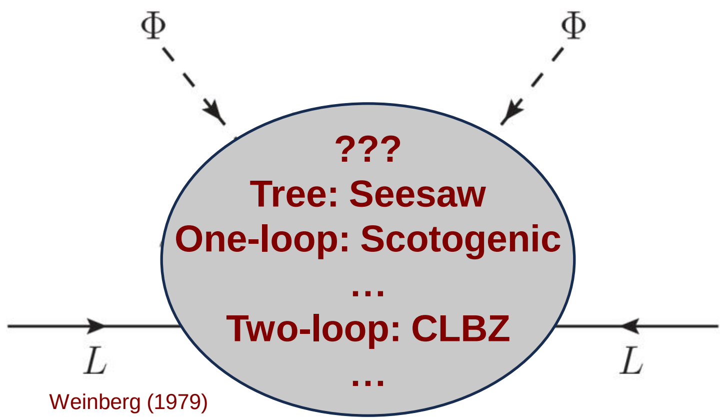

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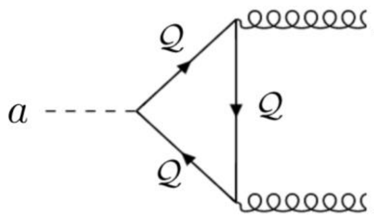

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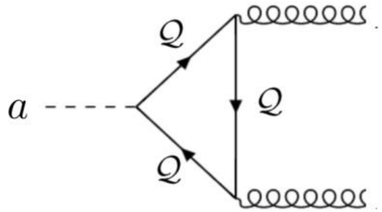

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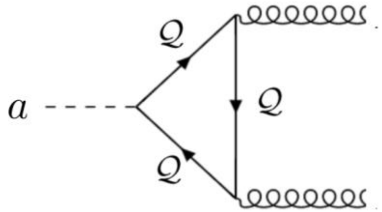

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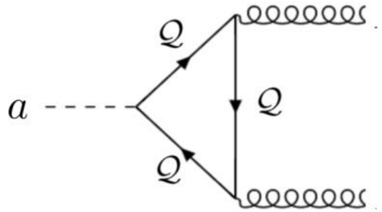

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Our approach:

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

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

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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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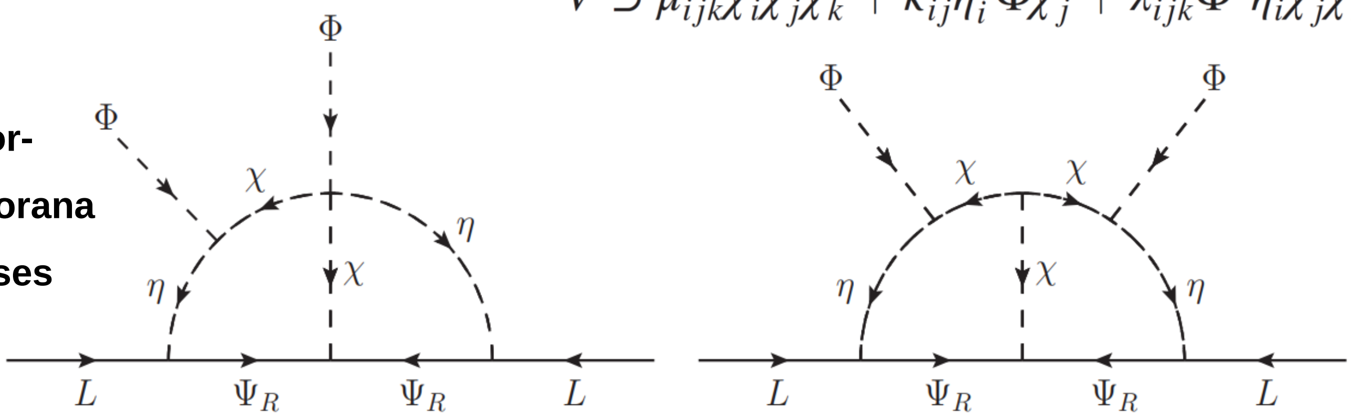

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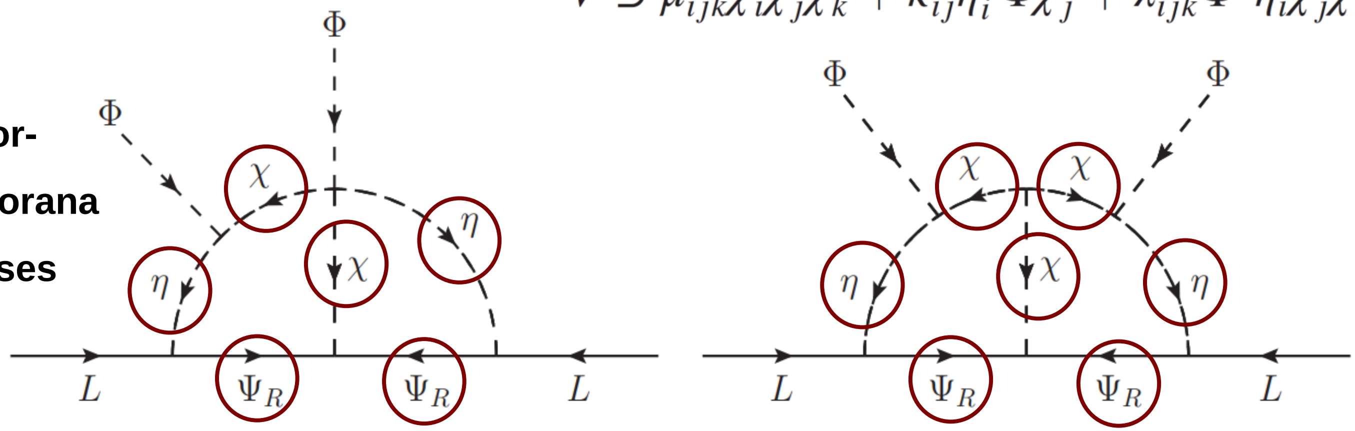

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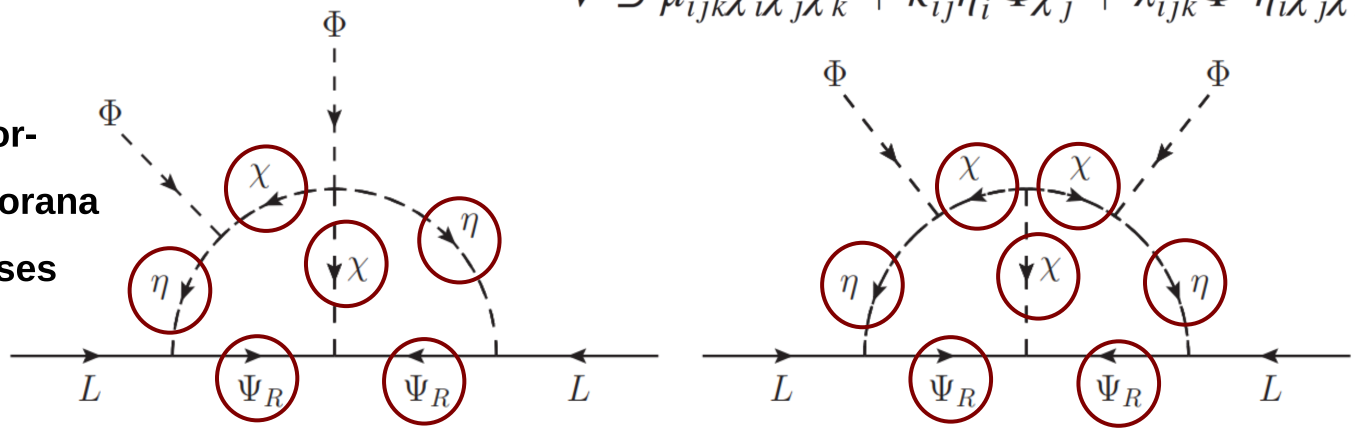

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$$(m_\nu)_{\alpha\beta} \sim 0.1 \text{ eV} \left(\frac{\tilde{Y}^j_{a\alpha} (\tilde{Y}_\chi)^k_{ab} \tilde{Y}^l_{b\beta}}{10^{-3}} \right) \left(\frac{\tilde{\mu}_{jkl}}{10^8 \text{ GeV}} \right) \left(\frac{v}{246 \text{ GeV}} \right)^2 \left(\frac{10^8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

Probing the axion-to-photon coupling

Axion-to-photon coupling

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

Cortona et al.(2016)

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E/N		$SU(2)_L$				
		3	**5**	**7**	**9**	**11**
$SU(3)_c$	**3**	4	12	24	40	60
	6	8/5	24/5	48/5	16	24
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	15′	4/7	12/7	24/7	40/7	60/7

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

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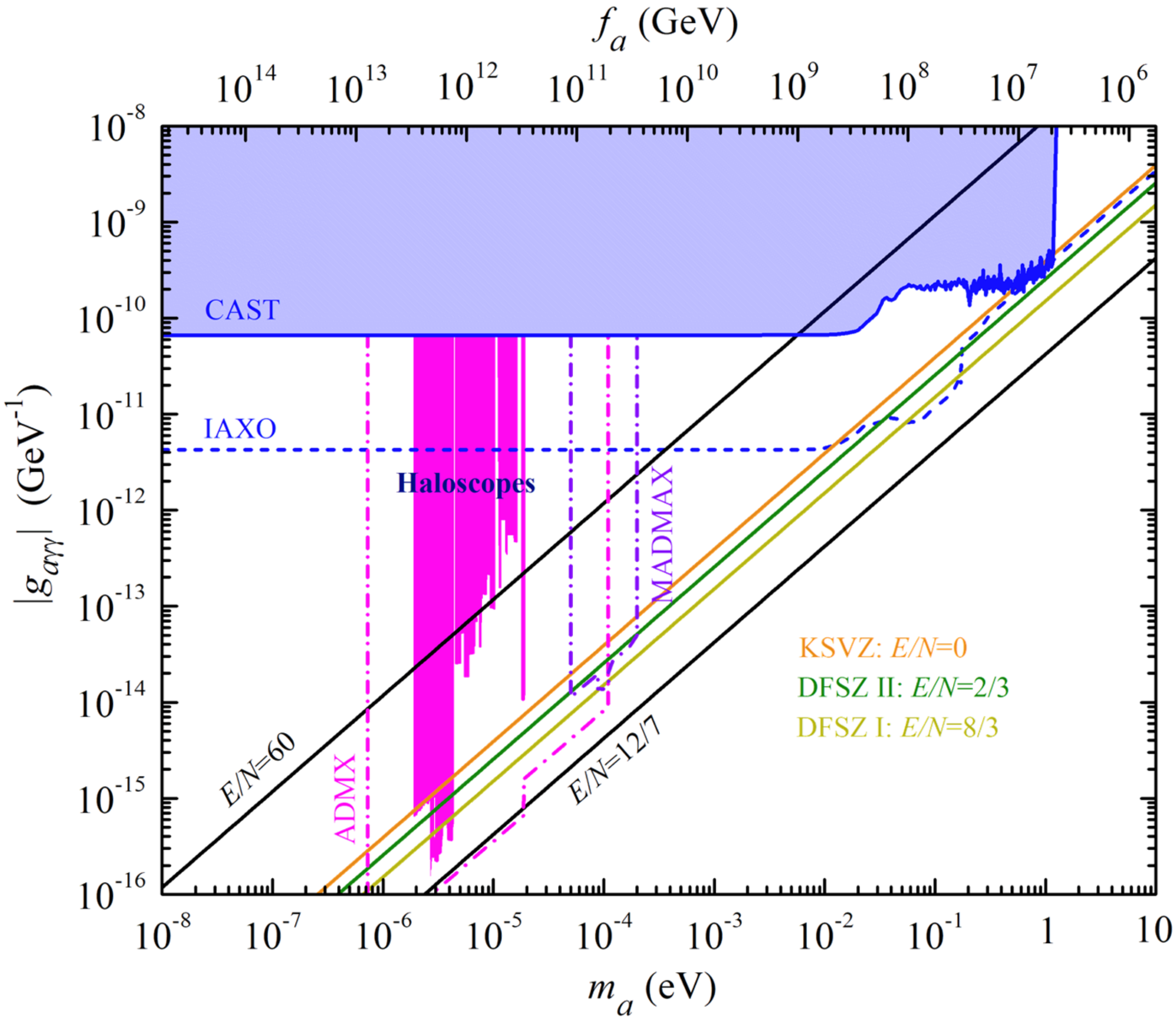

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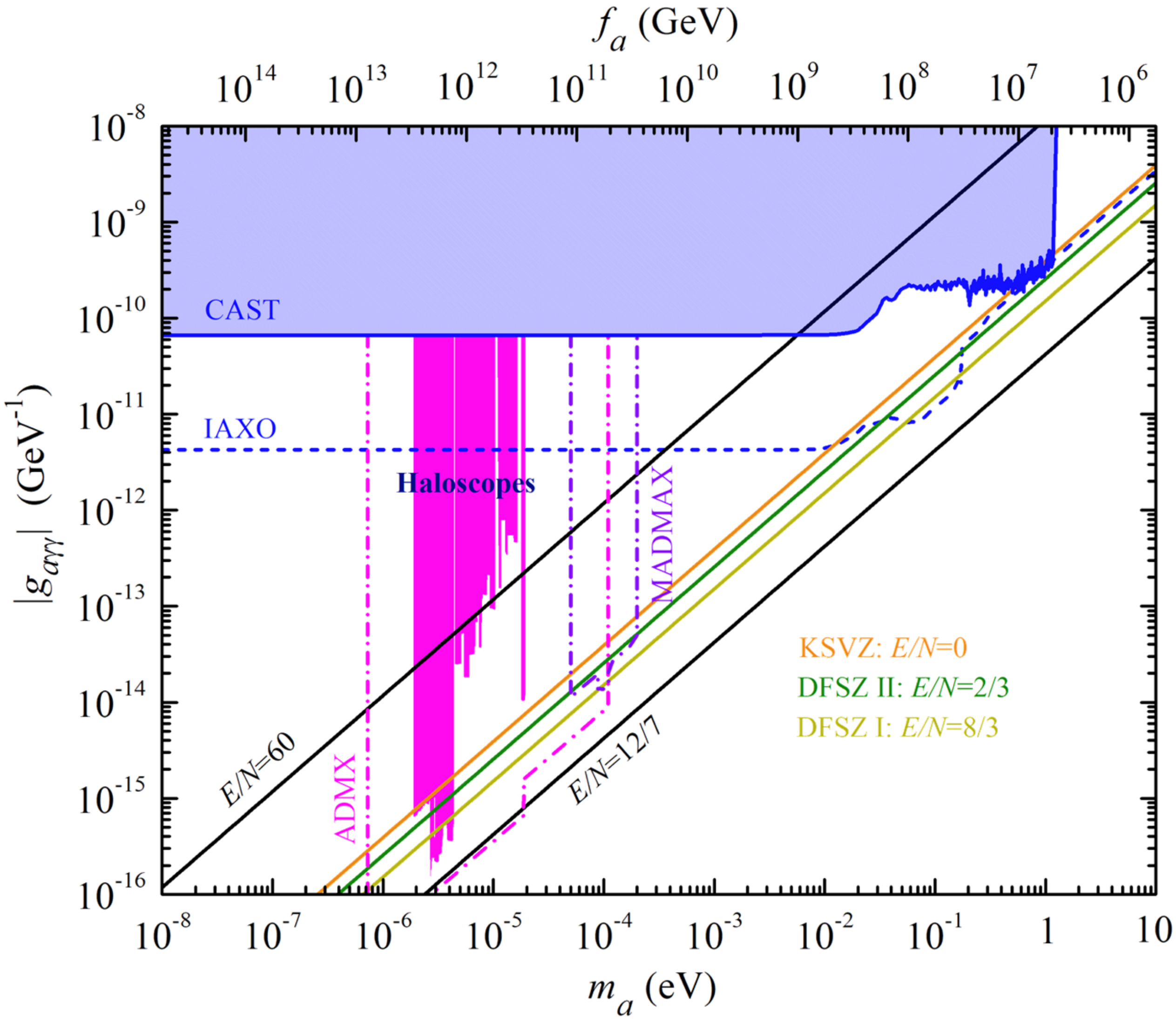

Axion-to-photon coupling allows to probe the different models at **helioscope** and **haloscope** experiments.

Axion dark matter and cosmology

Colored scalars

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

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

Vector-like quarks

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

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

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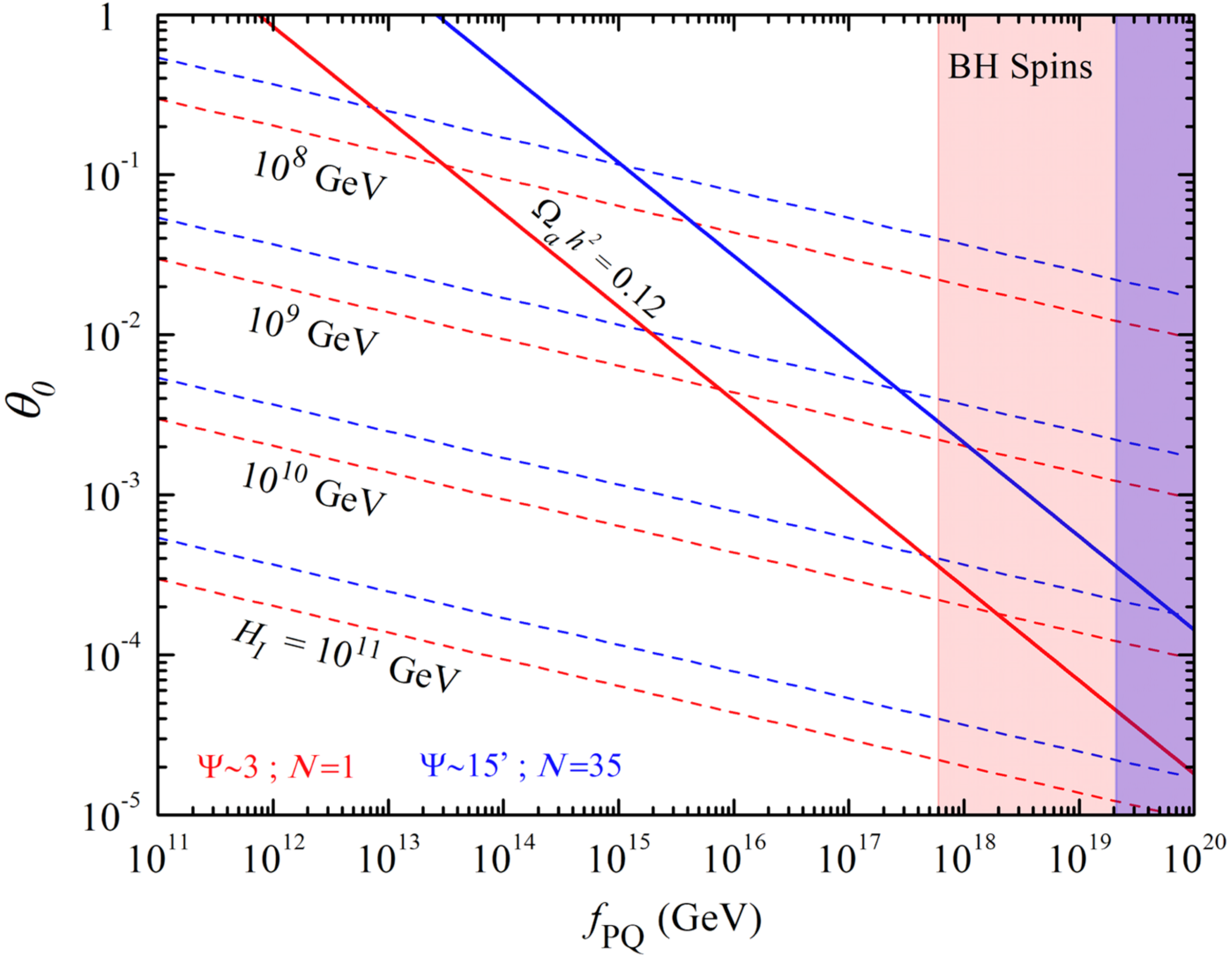
Isocurvature fluctuations are constrained by CMB data setting a bound on the inflationary scale

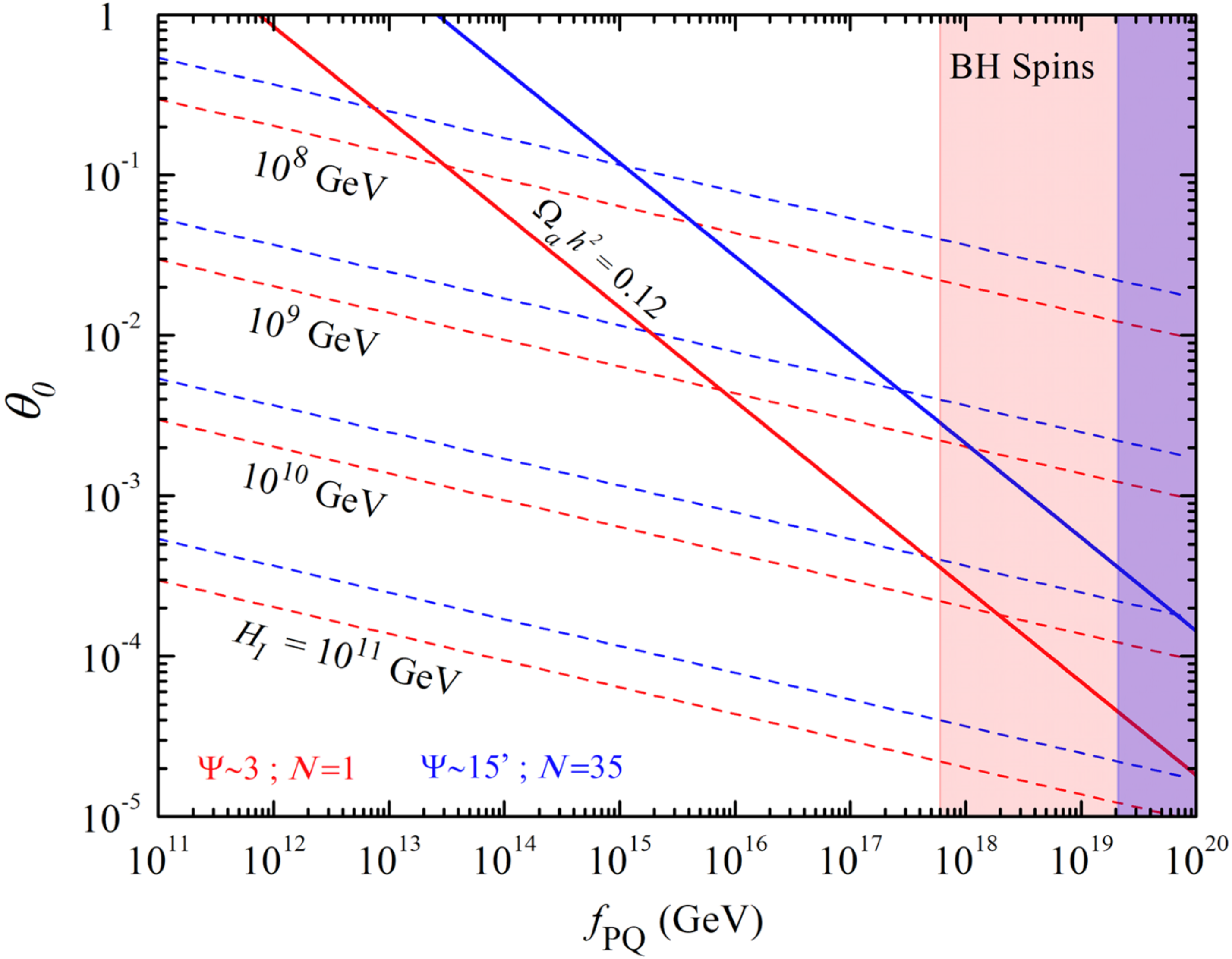
$$H_I \lesssim \frac{0.9 \times 10^7}{\Omega_a h^2 / \Omega_{\rm CDM} h^2} \left(\frac{\theta_0}{\pi} \frac{f_a}{10^{11}\ \rm GeV} \right) \rm GeV$$

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

- We proposed a **connection between** two seemingly unrelated facts: **small neutrino masses and the strong CP problem**. This was achieved within a **novel class** of KSVZ axion schemes, containing **exotic colored fermions and scalars** that act as **Majorana neutrino mass mediators** at the two-loop level.

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Thank you !