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CFTP Centro de Física Teórica de Partículas

Axion paradigm with "coloured" neutrino masses

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PORTUGAL 2020

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COMPETE 2020

PROGRAMA OPERACIONAL CAPITAL HUMANO POCH

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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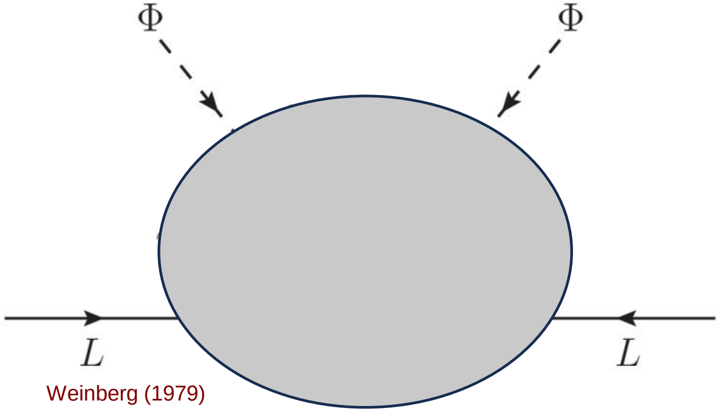

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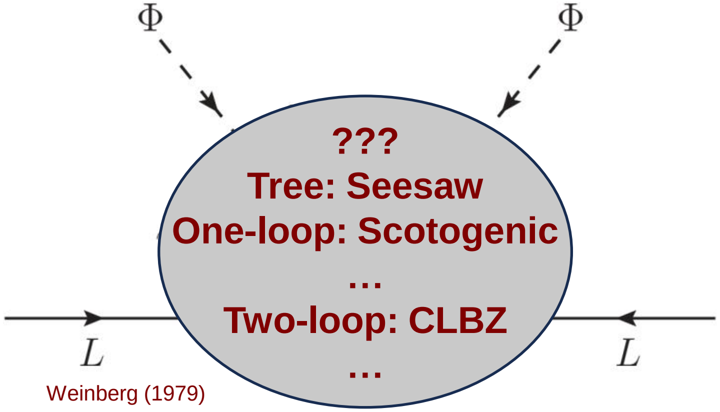

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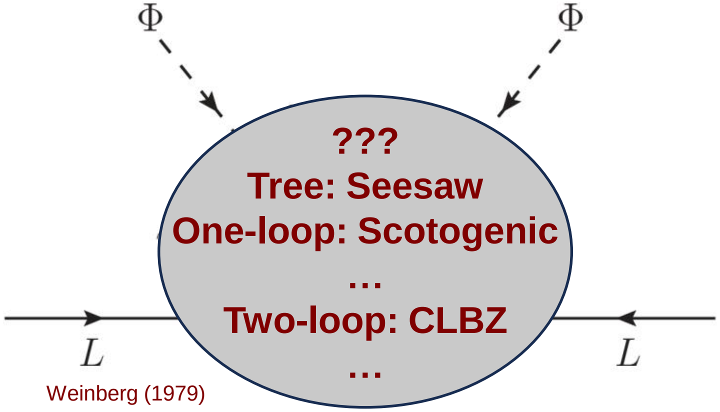

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Peccei,Quinn (1977),
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$$\mathrm{U}(1)_{\mathrm{PQ}}$$

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

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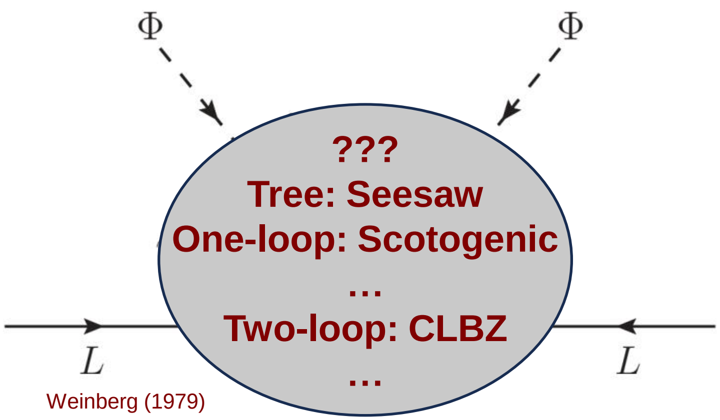

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$$\left(\frac{a}{f_a} - \bar{\theta} \right) \frac{\alpha_s}{8\pi} G\tilde{G}$$

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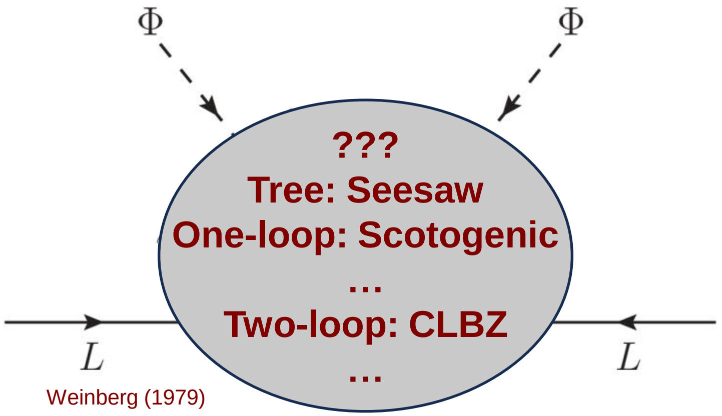

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Our approach:

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
Ψ_L	$[(p,q), 2n \pm 1, 0]$	ω	n_Ψ
Ψ_R	$[(p,q), 2n \pm 1, 0]$	0	n_Ψ
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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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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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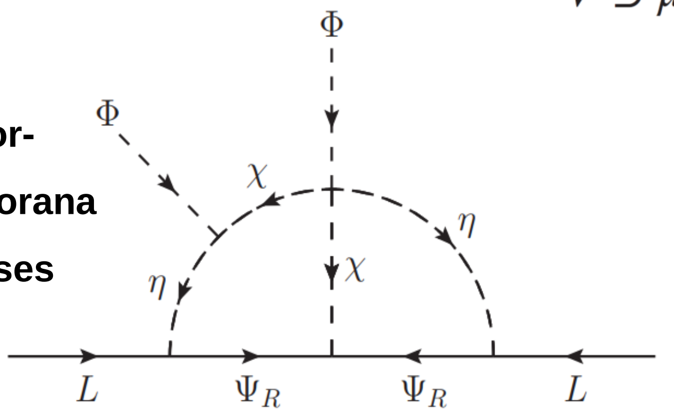
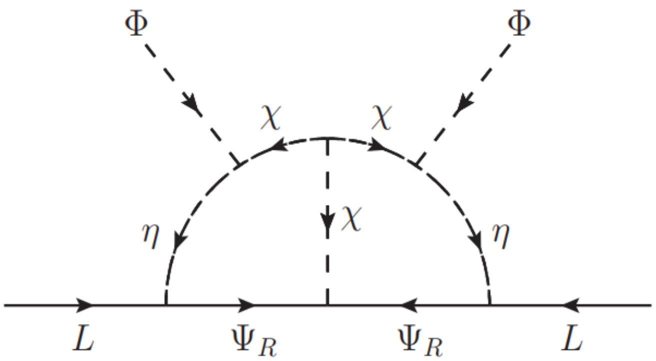
Two-loop color-mediated Majorana neutrino masses





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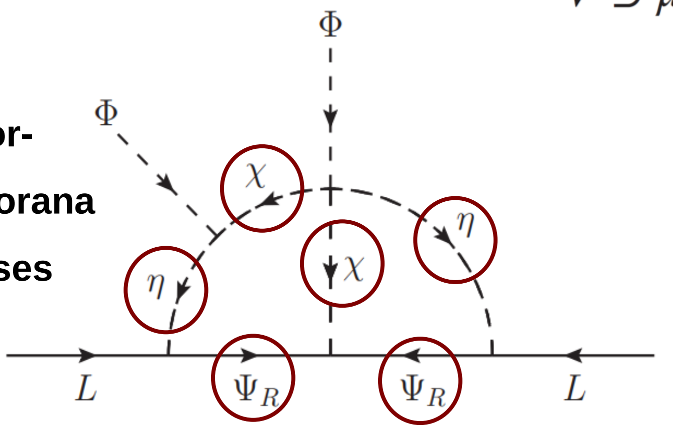

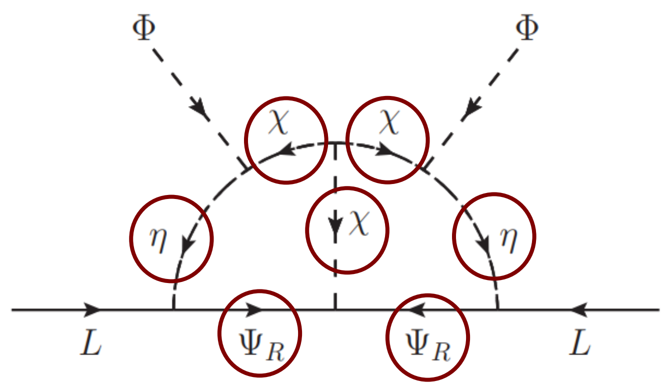

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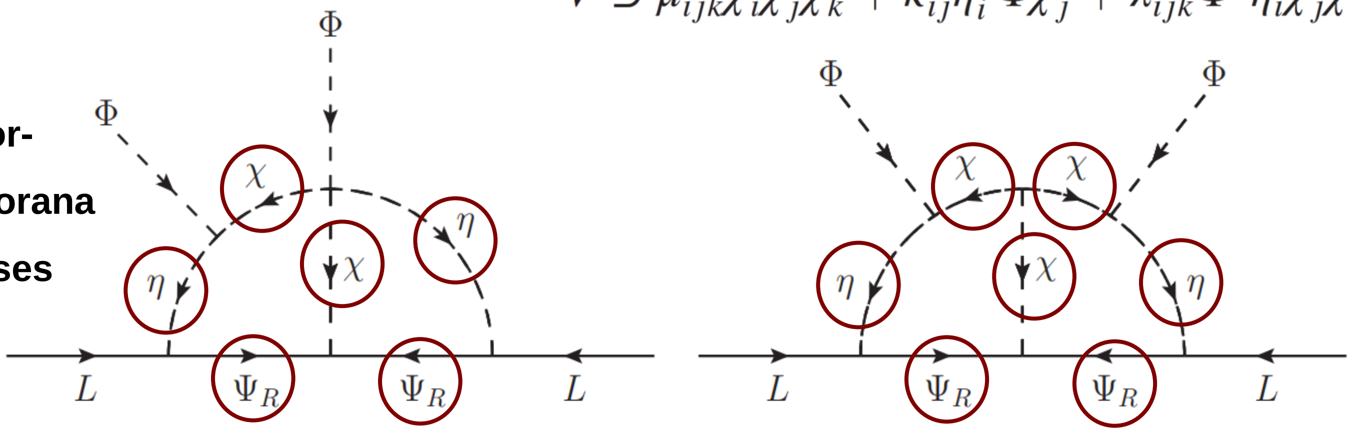

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$$(m_\nu)_{\alpha\beta} \sim 0.1 \text{ eV} \left(\frac{\tilde{Y}^j_{a\alpha} (\tilde{Y}_\chi)^k_{ab} \tilde{Y}^l_{b\beta}}{10^{-3}} \right) \left(\frac{\tilde{\mu}_{jkl}}{10^8 \text{ GeV}} \right) \left(\frac{v}{246 \text{ GeV}} \right)^2 \left(\frac{10^8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

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
	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	1	3	6	10	15
	15′	4/7	12/7	24/7	40/7	60/7

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

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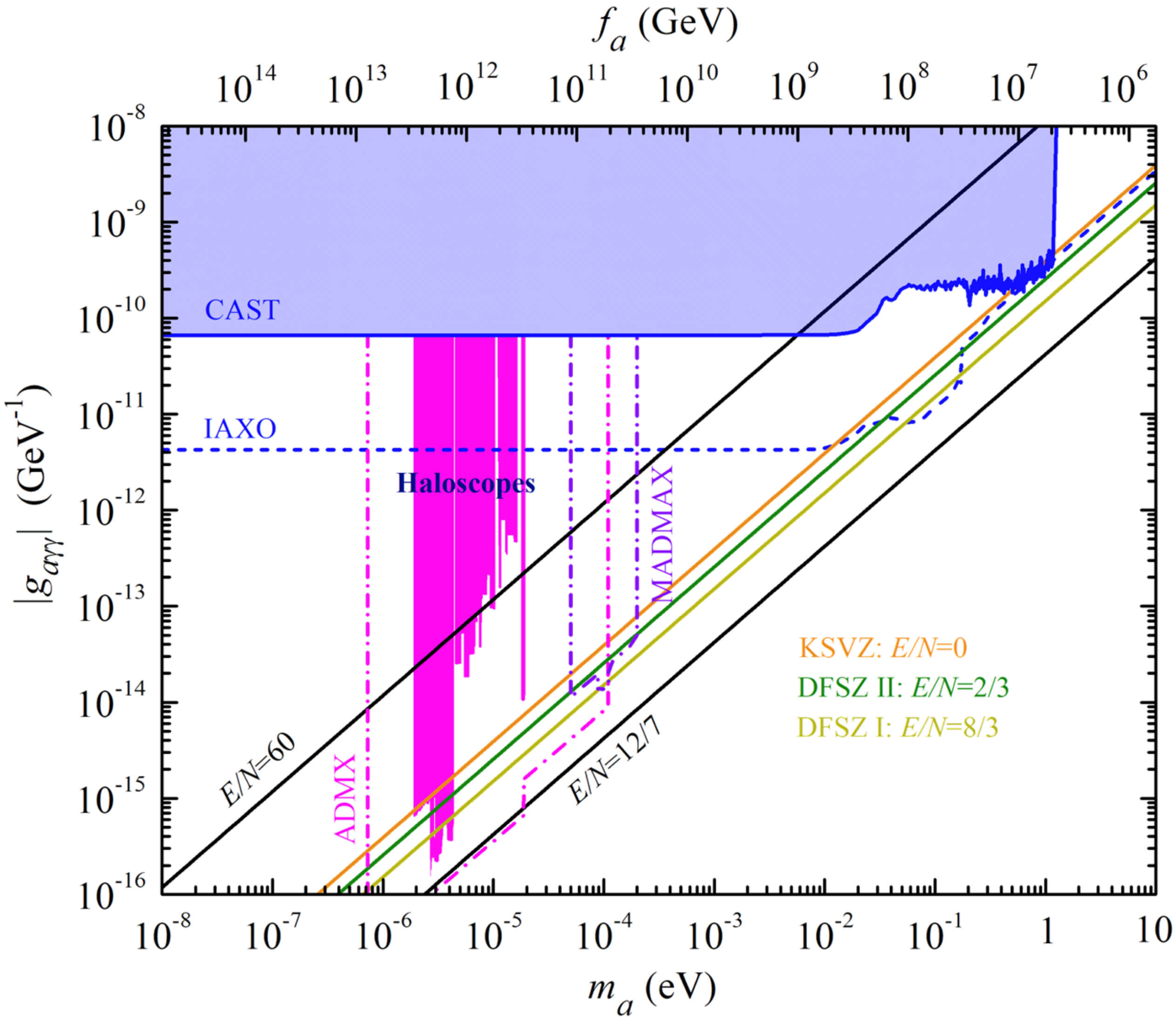

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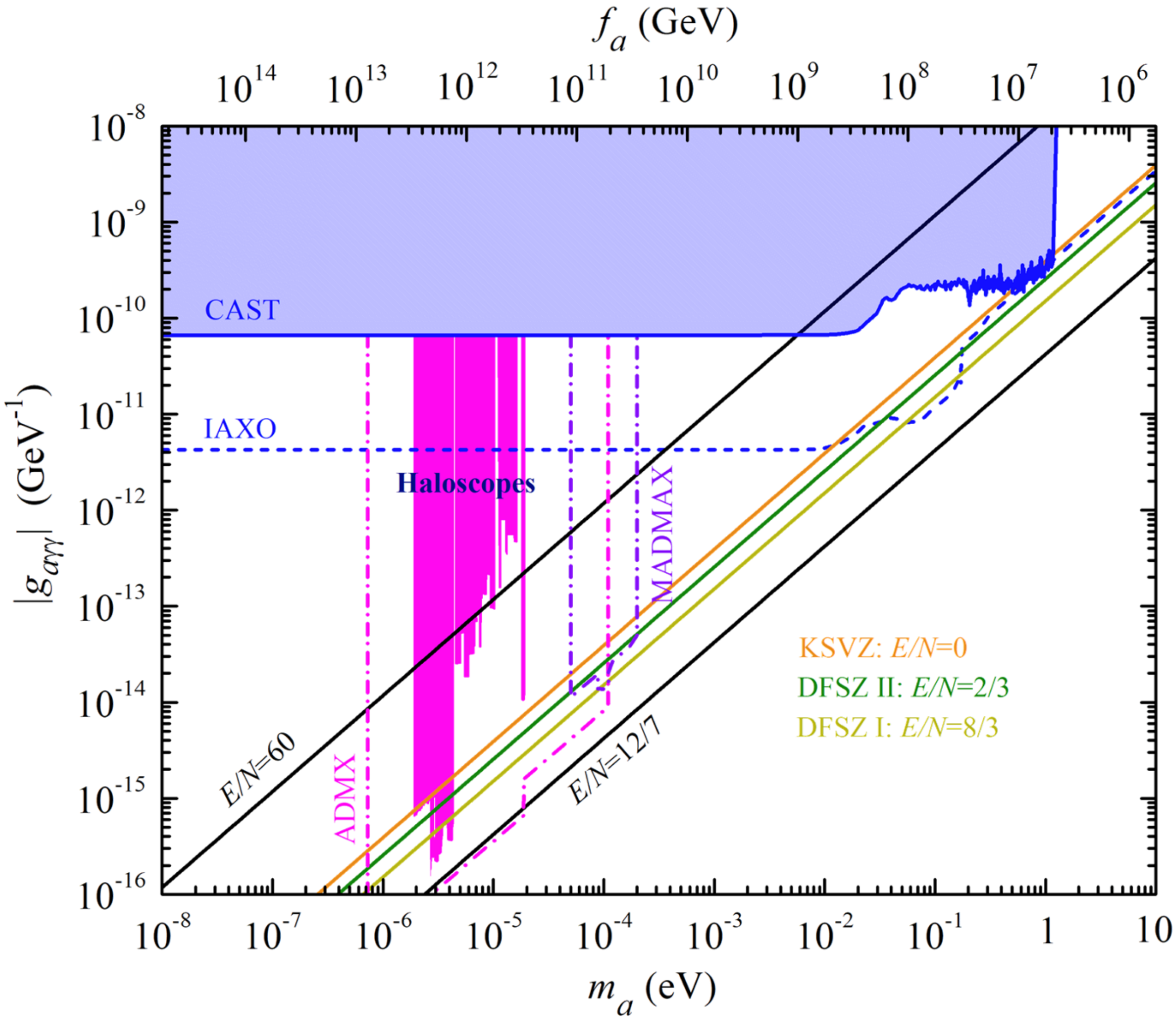

Axion-to-photon coupling allows to probe the different models at **helioscope** and **haloscope** experiments.

Axion dark matter and cosmology

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

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

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

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

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

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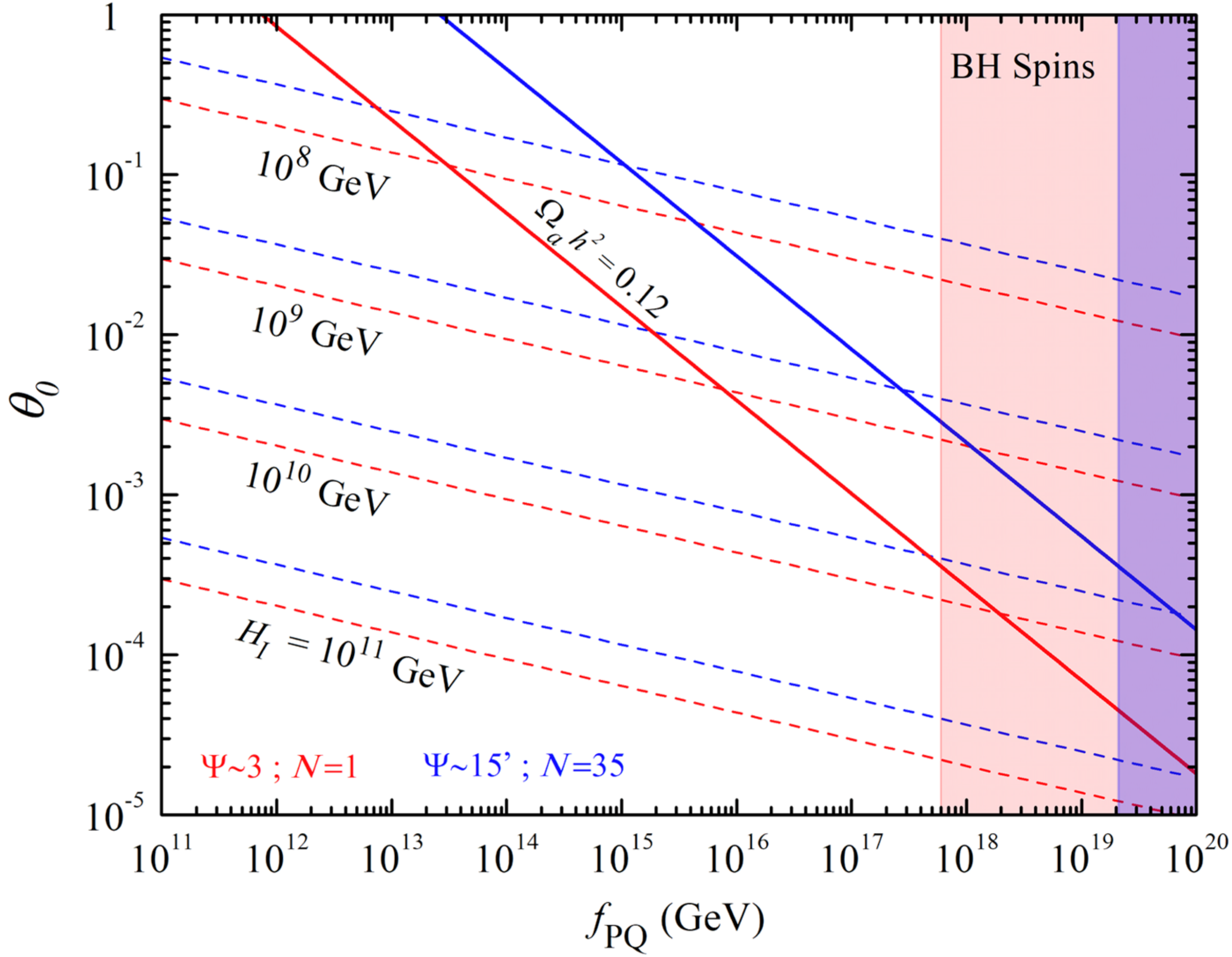
Isocurvature fluctuations are constrained by CMB data setting a bound on the inflationary scale

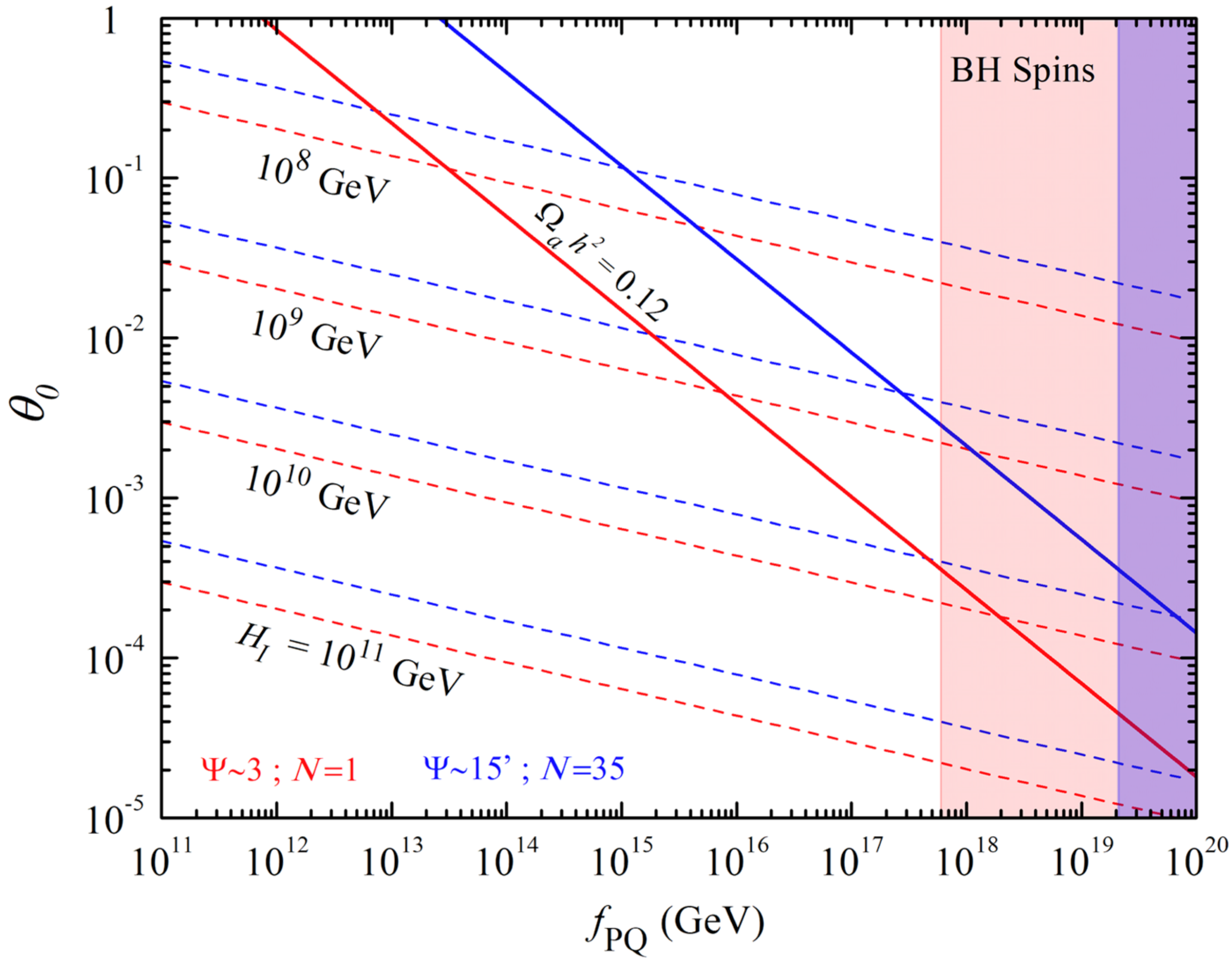
$$H_I \lesssim \frac{0.9 \times 10^7}{\Omega_a h^2 / \Omega_{\mathrm{CDM}} h^2} \left(\frac{\theta_0}{\pi} \frac{f_a}{10^{11}\ \mathrm{GeV}} \right) \mathrm{GeV}$$

Di Luzio et al. (2017)

Axion dark matter and cosmology



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 !