



UAM

HIDDe

Hunting Invisibles: Dark sectors, Dark matter and Neutrinos

in collaboration with B. Gavela and M. Ramos (Madrid, IFT)

based on **2407.XXXX**
STAY TUNED!

Extra-Dimensional Maxion't

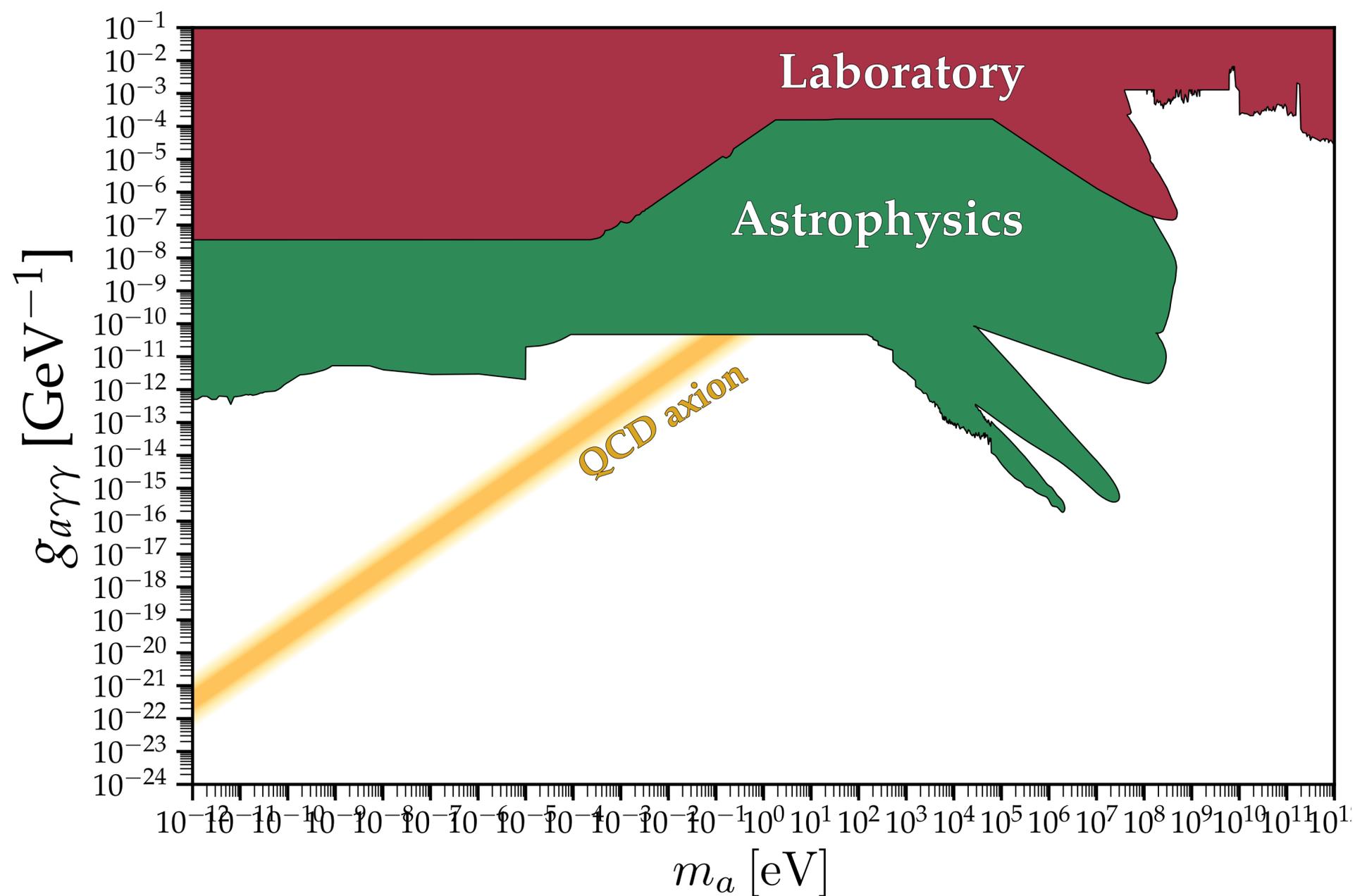
by Arturo de Giorgi (Madrid, IFT)

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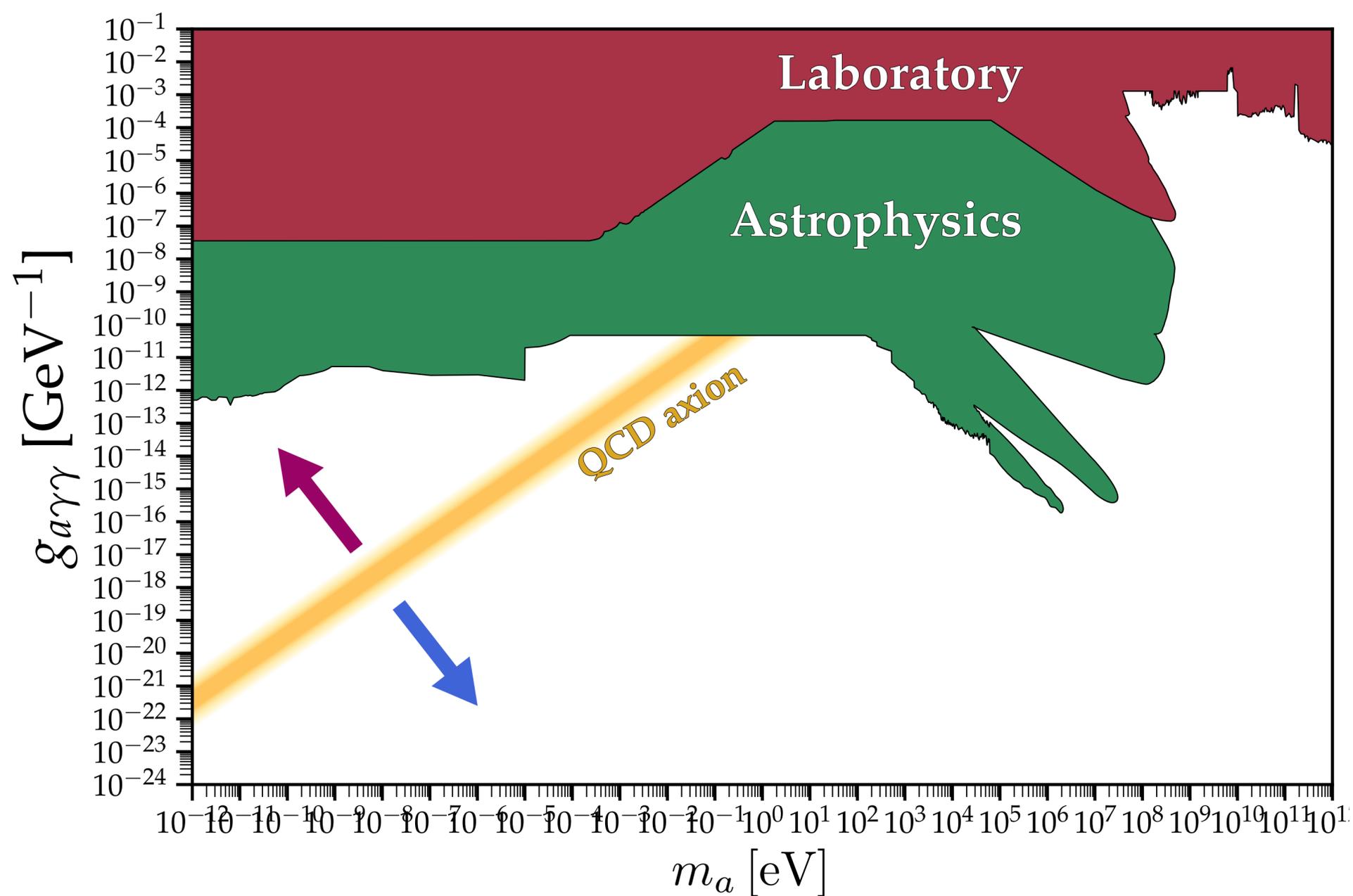
QCD Axion



$$\mathcal{L} \supset \frac{\alpha_s}{8\pi} \frac{a}{f_a} G\tilde{G}$$

$$\chi_{\text{QCD}} = m_a^2 f_a^2$$

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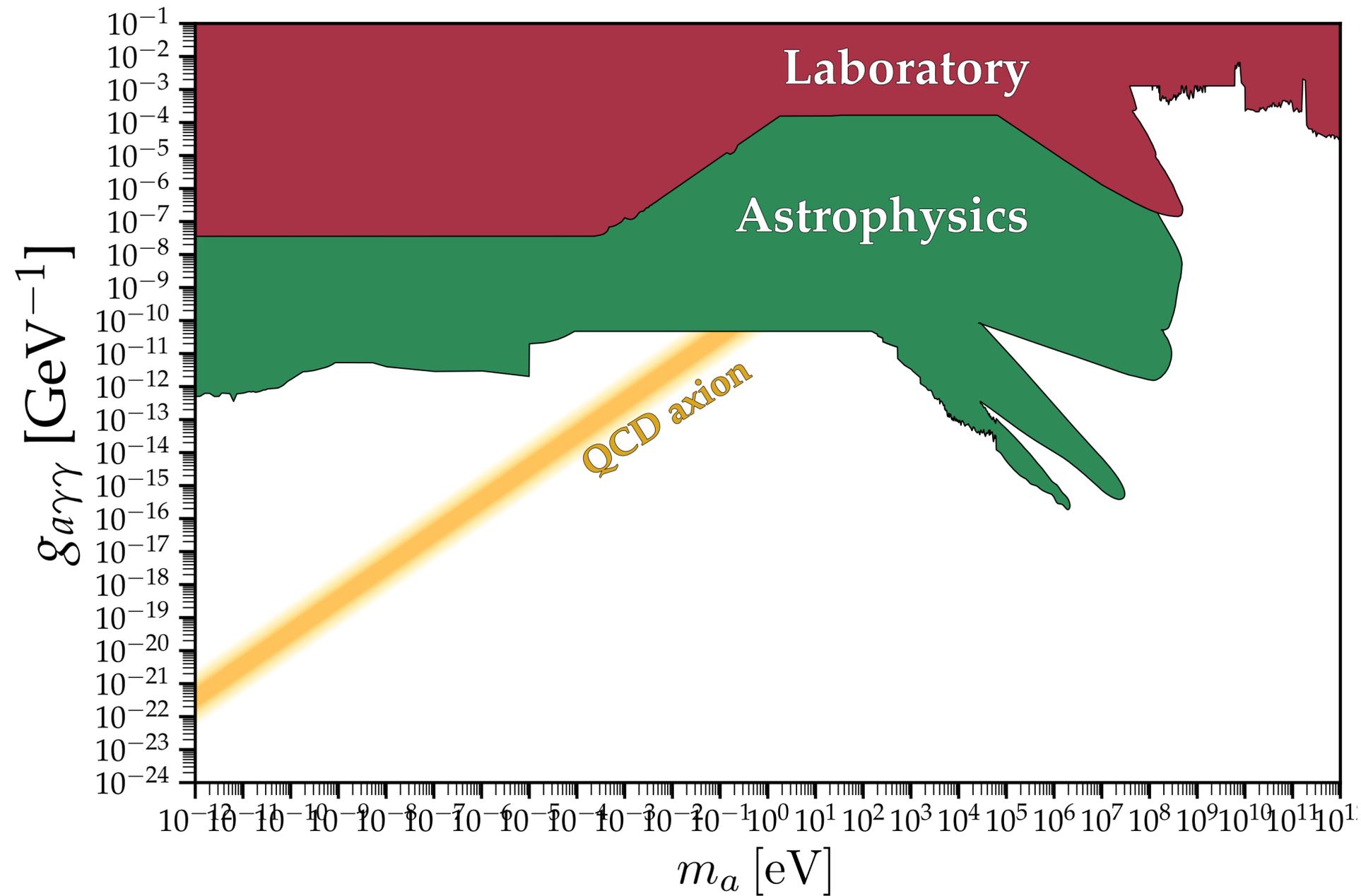
Lighter?

[Hook, 2018]
 [Di Luzio, Gavela, Quilez, Ringwald, 2021]
 ...

Heavier?

[Rubakov, 1997]
 [Bereziani, Gianfagna, Giannotti, 2001]
 [Gherghetta, Nagata, Shifman, 2016]
 [Dimopoulos, Hook, Huang, Marques-Tavares, 2016]
 ...

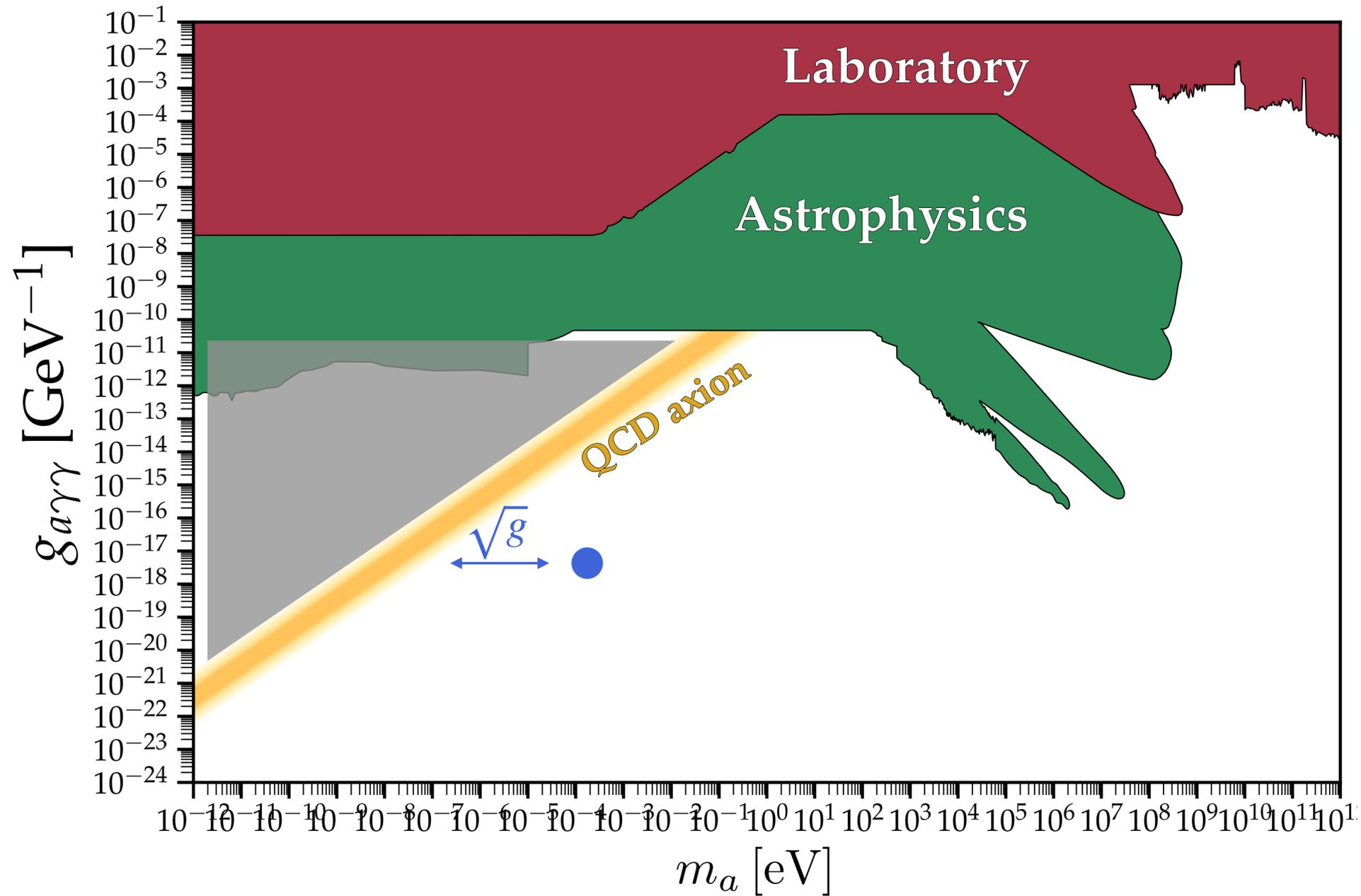
Multiple QCD Axions



$$\mathcal{L} = \frac{\alpha_s}{8\pi} \left(\sum_{k=1}^N \frac{\hat{a}_k}{\hat{f}_k} - \bar{\theta} \right) G\tilde{G} - V_B(\hat{a}_1, \hat{a}_2, \dots, \hat{a}_N)$$

[Gavela, Quilez, Ramos, 2023]

Multiple QCD Axions



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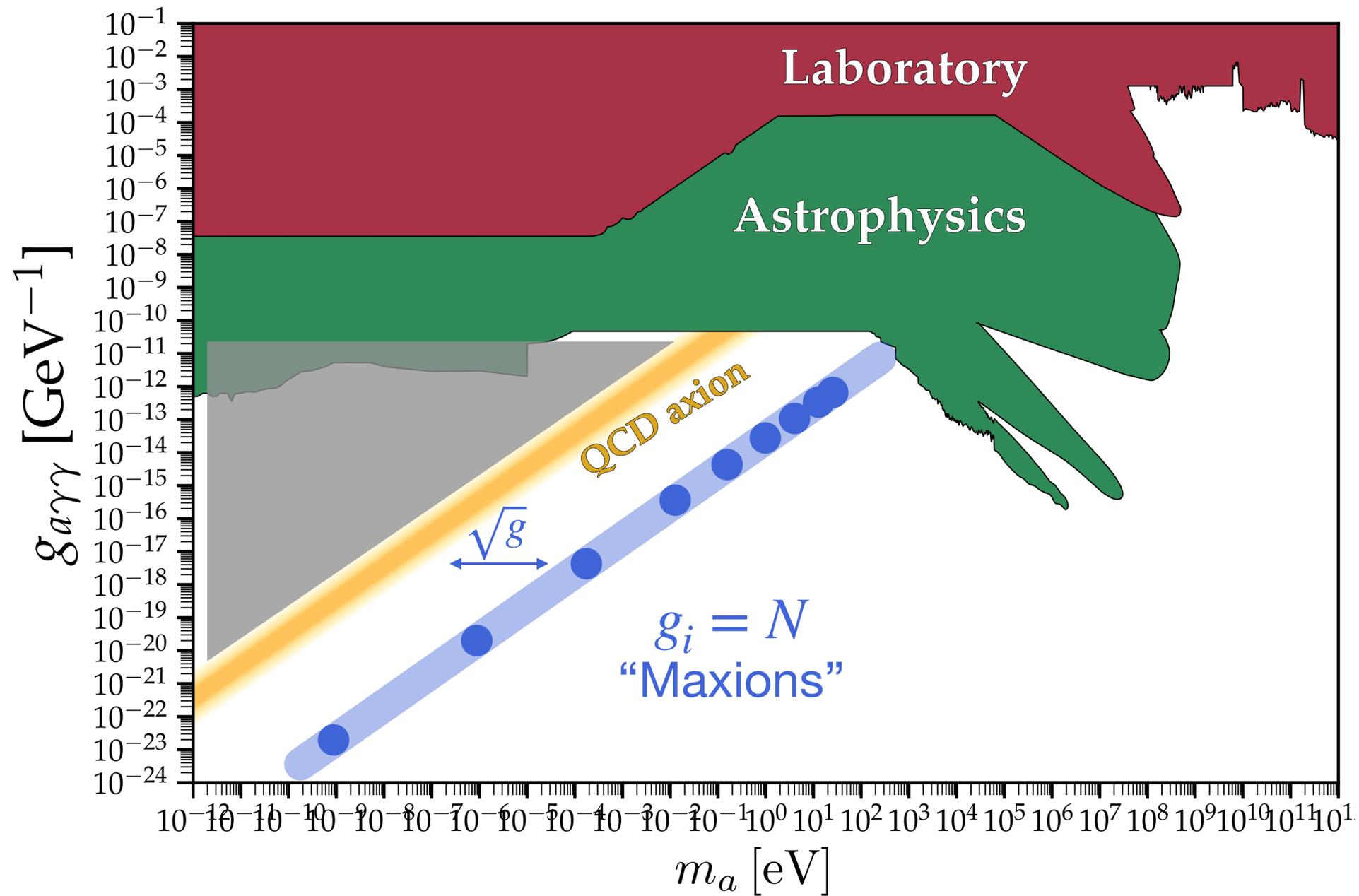
$$\chi_{\text{QCD}} = m_i^2 f_i^2 \times \frac{1}{g_i}$$

$$\sum_{i=1}^N \frac{1}{g_i} = 1$$

“QCD Axion Sum Rule”

[Gavela, Quilez, Ramos, 2023]

Multiple QCD Axions



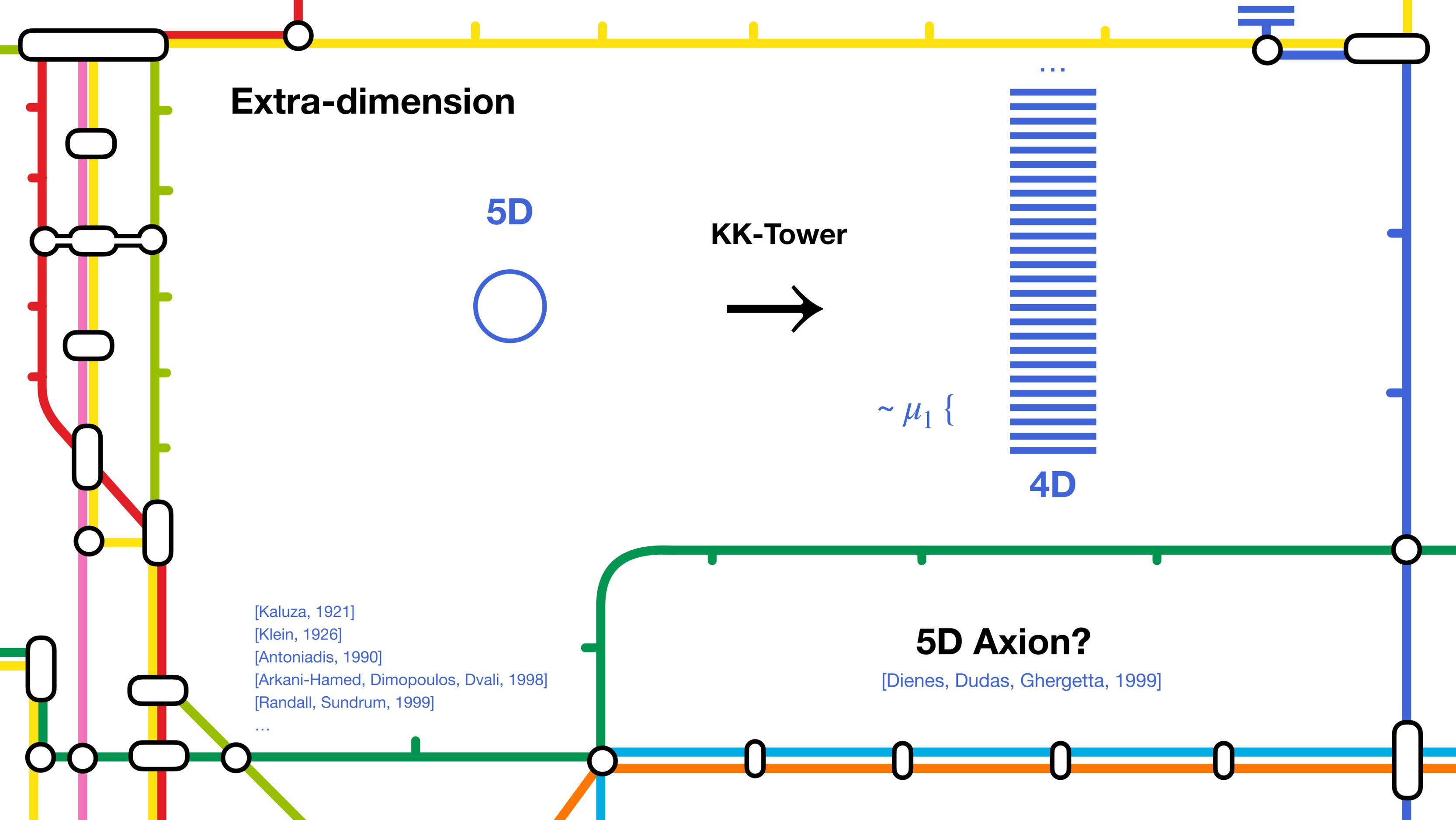
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“QCD Axion Sum Rule”

[Gavela, Quilez, Ramos, 2023]



Extra-dimension

5D

KK-Tower

$\sim \mu_1 \{$

4D

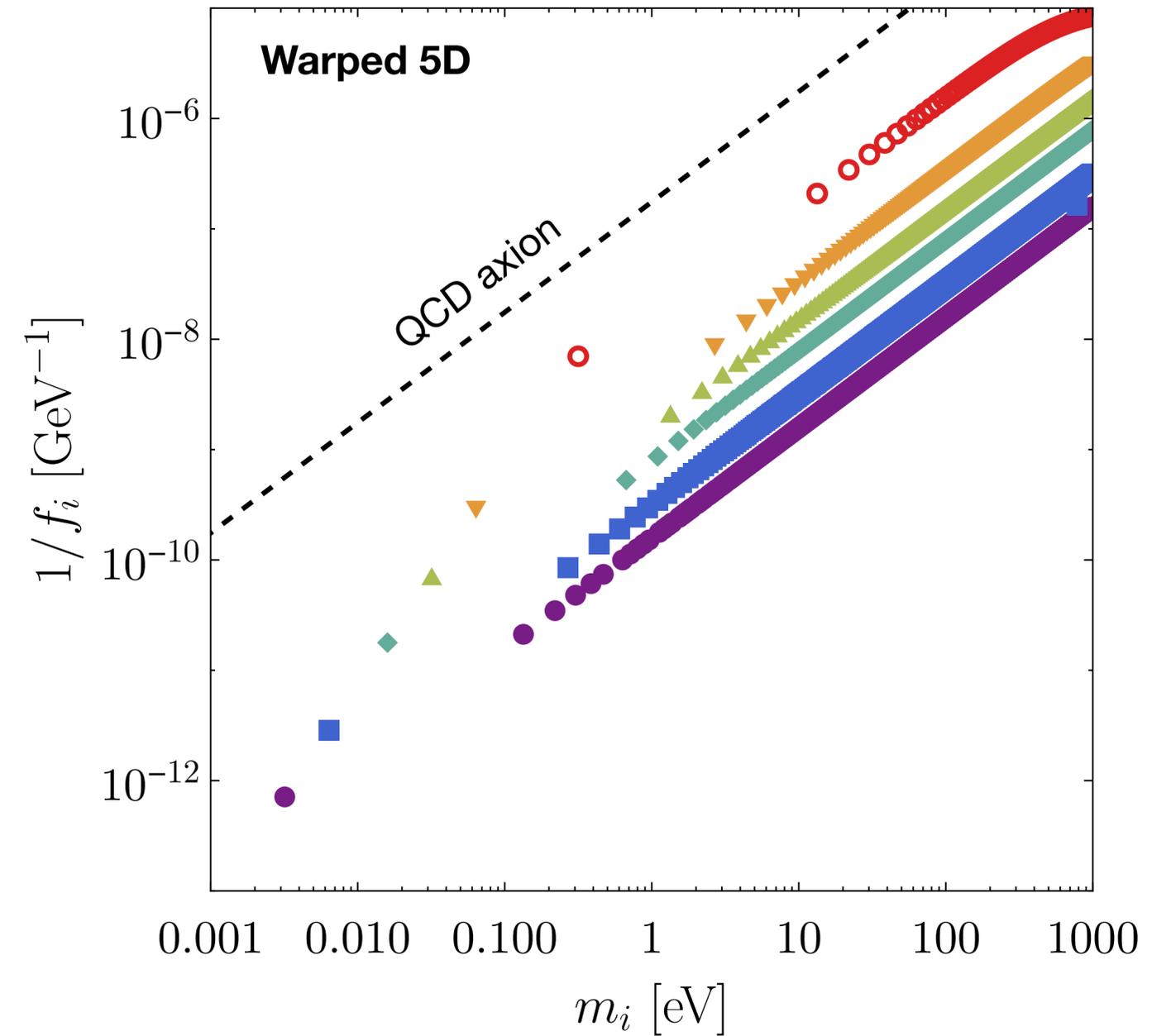
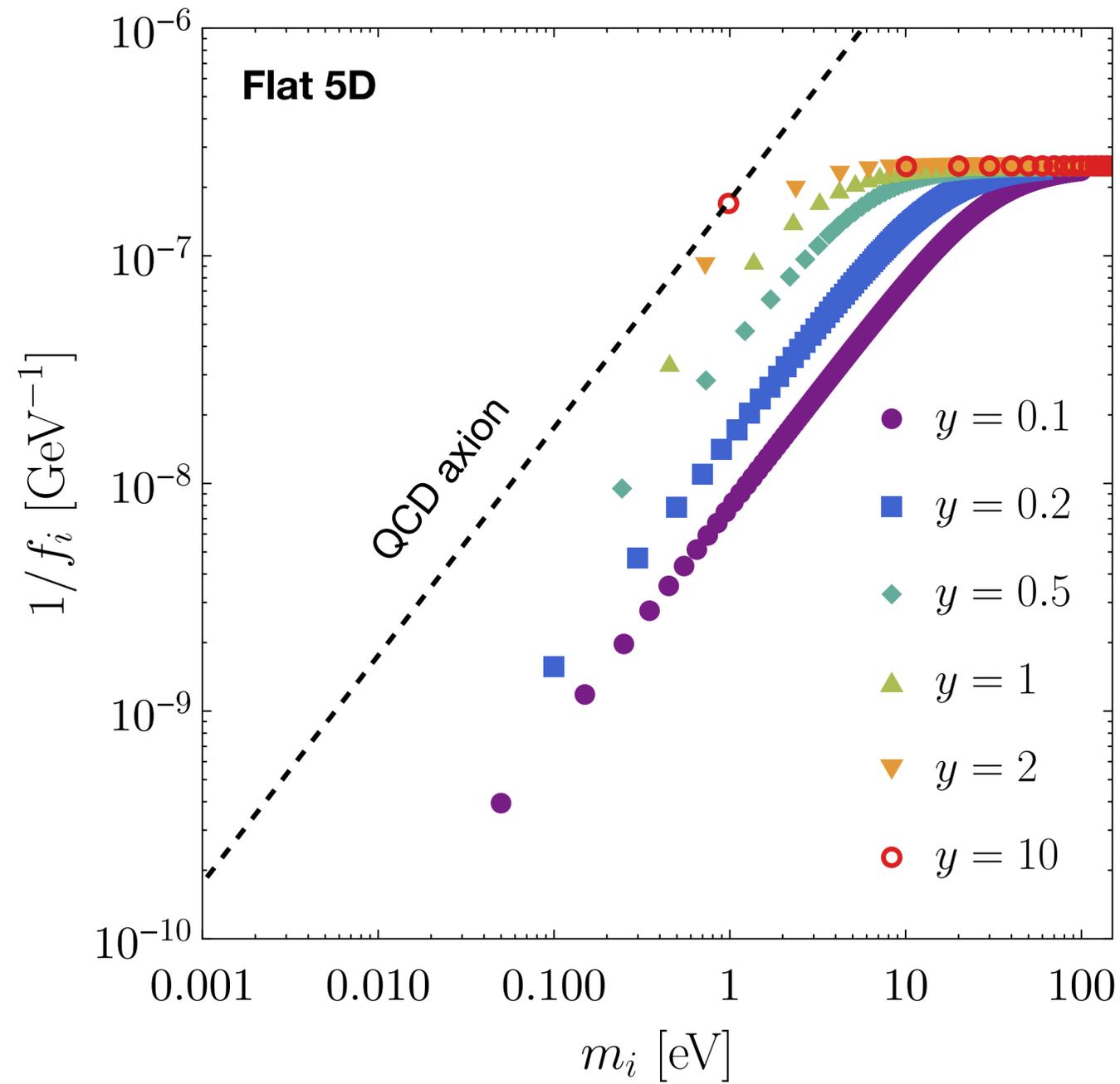
5D Axion?

[Dienes, Dudas, Ghergetta, 1999]

[Kaluza, 1921]
 [Klein, 1926]
 [Antoniadis, 1990]
 [Arkani-Hamed, Dimopoulos, Dvali, 1998]
 [Randall, Sundrum, 1999]
 ...

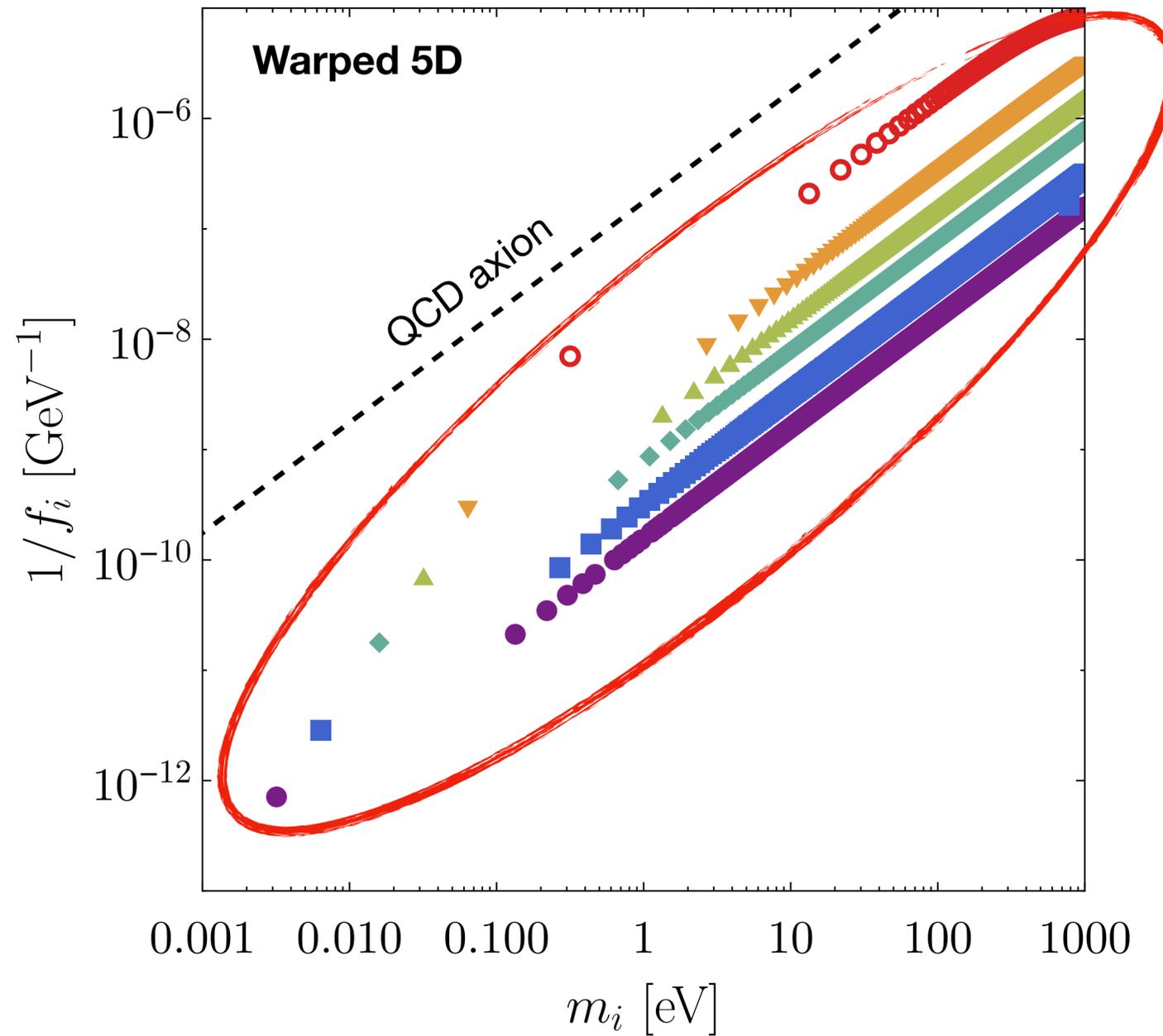
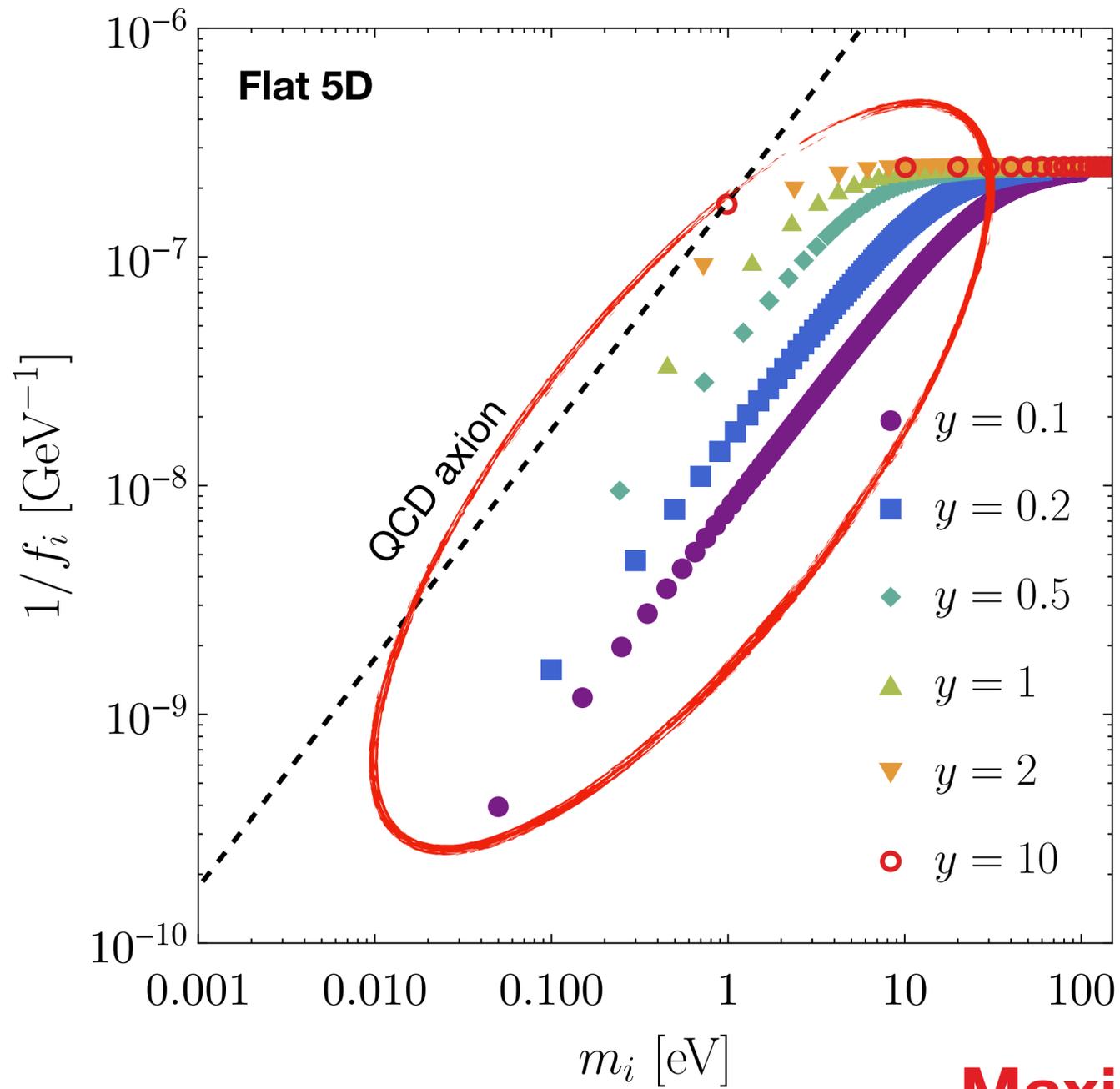
Extra-dimensional QCD Axions

$$y \equiv \frac{\mu_1}{m_{\text{PQ}}}$$



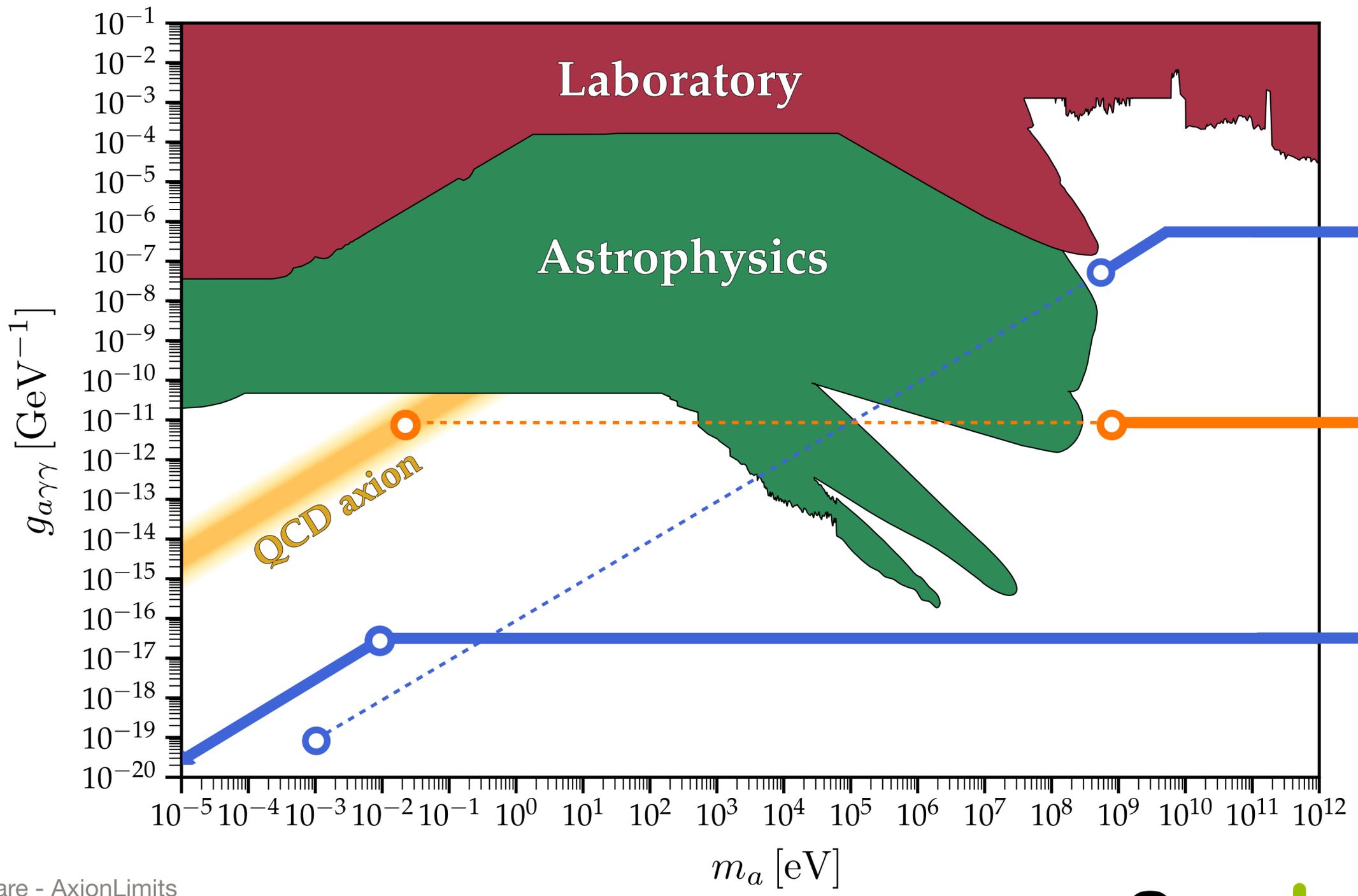
Extra-dimensional QCD Axions

$$y \equiv \frac{\mu_1}{m_{\text{PQ}}}$$



Maxion patterns

Where to look for?



credit: O'Hare - AxionLimits

Do you want to discuss and know more?

Come visit me!

Arturo de Giorgi (Madrid, IFT)



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Extra-Dimensional Maxion't

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Multiple QCD Axions

- The QCD Axion:

$$\mathcal{L} \supset \frac{\alpha_s}{8\pi} \frac{a}{f_a} G\tilde{G} \implies m_a^2 f_a^2 = \chi_{\text{QCD}}$$
- Multiple scalars?

$$\mathcal{L} = \frac{\alpha_s}{8\pi} \left(\sum_{k=1}^N \frac{a_k}{f_k} - \bar{\theta} \right) G\tilde{G} - V_B(a_1, a_2, \dots, a_N)$$

$$\implies m_i^2 f_i^2 = \chi_{\text{QCD}} \times g_i \quad \text{and} \quad \sum_{i=1}^N \frac{1}{g_i} = 1$$

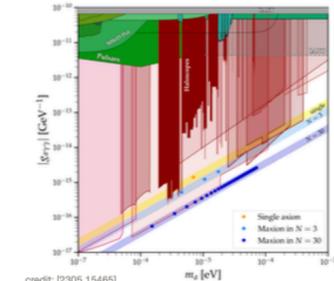
see: Gavela et al. (2305.15465)

Extra-dimension

- Compact extra-dimension:

$$S_g = \frac{M_s^3}{2} \int d^4x \int_{-\pi R}^{\pi R} dy \sqrt{g} (\mathcal{R} - 2\Lambda_B)$$


Maxions: $g_i = N, \forall i$



credit: [2305.15465]

5D Axion

- The QCD Axion propagates in an extra dimension:

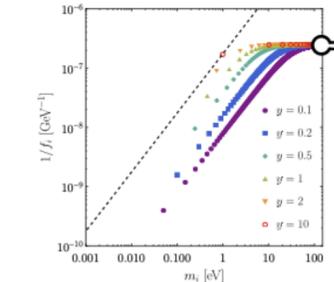
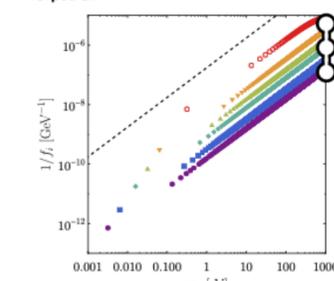
$$S \supset \int d^4x \int_{-\pi R}^{\pi R} dy \sqrt{g} \left(\frac{1}{2} M_s \partial^A a \partial_A a + \frac{\alpha_s}{8\pi} \frac{a}{f_5} G_{\mu\nu} \tilde{G}^{\mu\nu} \delta(y - \pi R) \right)$$
- Study 4D EFT via Kaluza-Klein decomposition:

$$a(x, y) = \frac{1}{(2\pi R M_s)^{1/2}} \sum_i a_i(x) \psi_i(y)$$

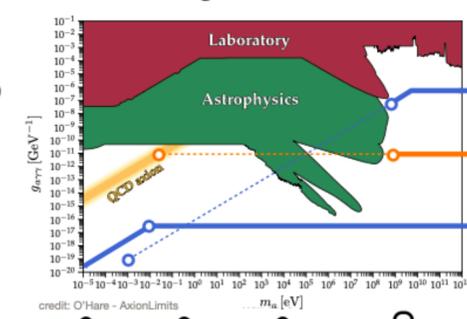
$$\mathcal{L} \supset \sum_n \left(\frac{1}{2} (\partial_\mu a_n)^2 - \frac{1}{2} \mu_n^2 a_n^2 \right) + \frac{1}{f_{\text{PQ}}} \frac{\alpha_s}{8\pi} \sum_n (a_n \psi_n^\pi) G_{\mu\nu} \tilde{G}^{\mu\nu}$$
- Infinite dimensional mass matrix! Maxions?

Extra-dimensional (M)axions

$y \equiv \frac{\mu_1}{m_{\text{PQ}}}, \quad N \sim \left(\frac{\psi_1}{y} \right)^2$

- Flat 5D:
 
- Warped 5D:
 

Too good to miss!



credit: O'Hare - AxionLimits

.. but something is missing!

- Collider reach? $\frac{\psi_1}{f_{\text{PQ}}} \lesssim \text{TeV}^{-1} \implies \mu_1 \lesssim 6 \text{ keV}$
- Below astro-bounds? $\frac{\psi_1}{f_{\text{PQ}}} \lesssim 10^{-14} \text{ GeV}^{-1} \implies \sqrt{g_0} \lesssim \frac{10^{-6} \text{ eV}}{\mu_1} \ll 1$

Take Home Message

- Extra dimensional axions? Decoupled or maxions!
- Maxions require extra mass sources besides 4D-QCD! String Theory?