

QCD Axion Dark Matter with Enhanced Abundance via Level Crossing

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Misalignment mechanism

[Preskill, Wise, Wilczek 1983;](#)

[Abbot, Sikivie 1983; Flschler 1983](#)

QCD axion would be matter when it oscillates in its potential.

Through the misalignment mechanism, the QCD axion abundance is given by

$$\Omega_a \equiv \frac{\rho_{a,0}}{\rho_{\text{crit}}} \simeq 0.24 \theta_i^2 \left(\frac{f_a}{10^{11} \text{GeV}} \right)^{1.17} \left(\theta_i = \frac{a_i}{f_a} \right),$$

[Bae, Huh, Kim 0806.0497; Visinelli, Gondolo 0903.4377; Ballesteros, Redondo, Ringwald, Tamarit 1610.01639](#)

without fine-tuning θ_i ($\theta_i = \mathcal{O}(1)$).

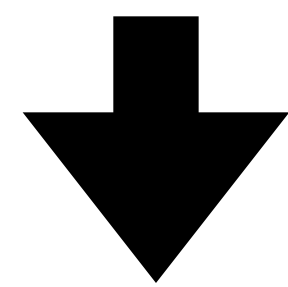
If $f_a = 10^{11-12} \text{GeV}$, the QCD axion can be all of the observed DM, $\Omega_a \simeq 0.24$.

From the relationship, $m_a \approx \frac{m_\pi f_\pi}{f_a}$, we expect $m_a = \mathcal{O}(10^{-5}) \text{eV}$.

Mixing phenomena

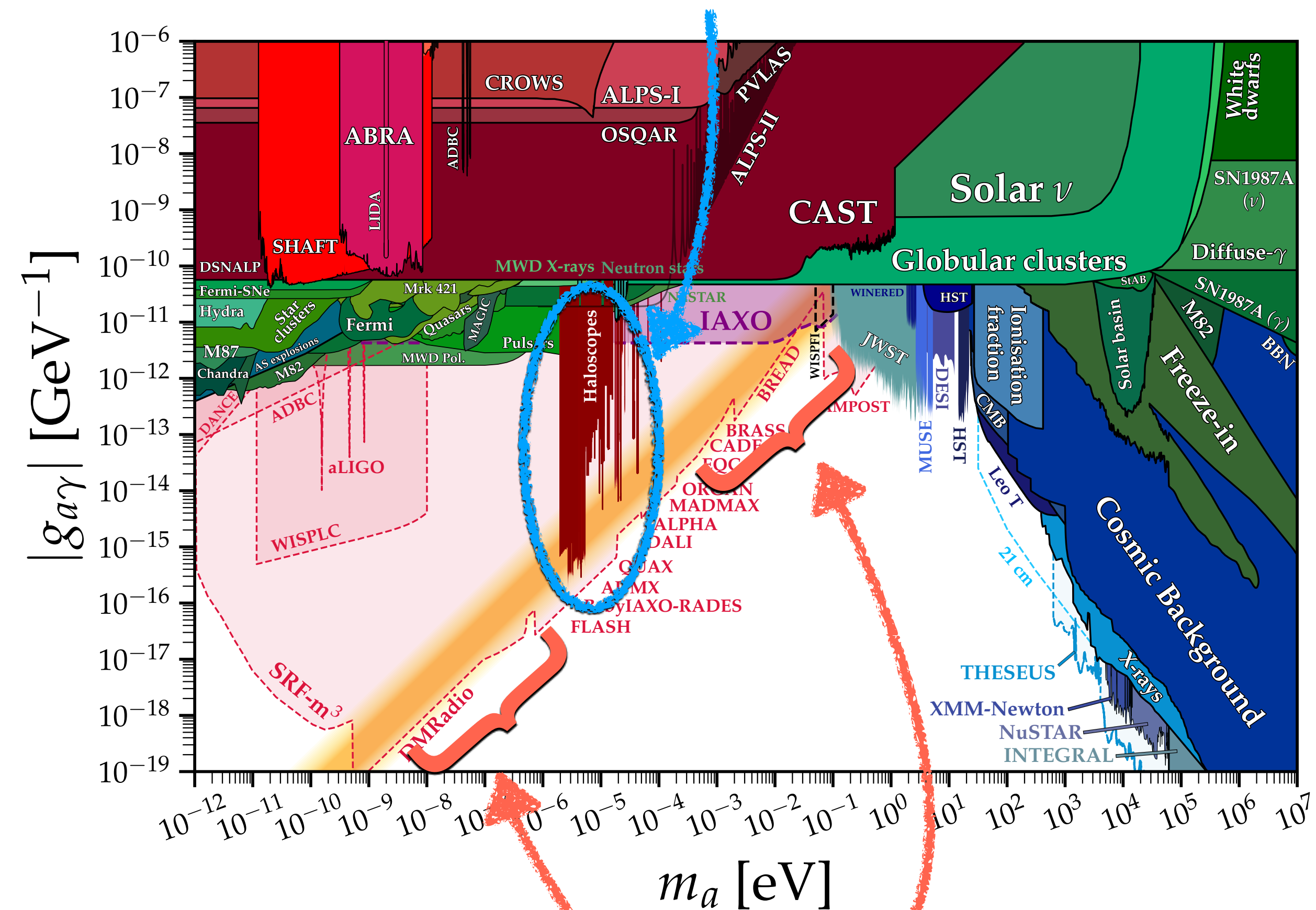
The misalignment mechanism predicts $m_a = \mathcal{O}(10^{-5})$ eV.

However, it is plausible for the QCD axion to **mix** with another axion, like neutrinos (level crossing).



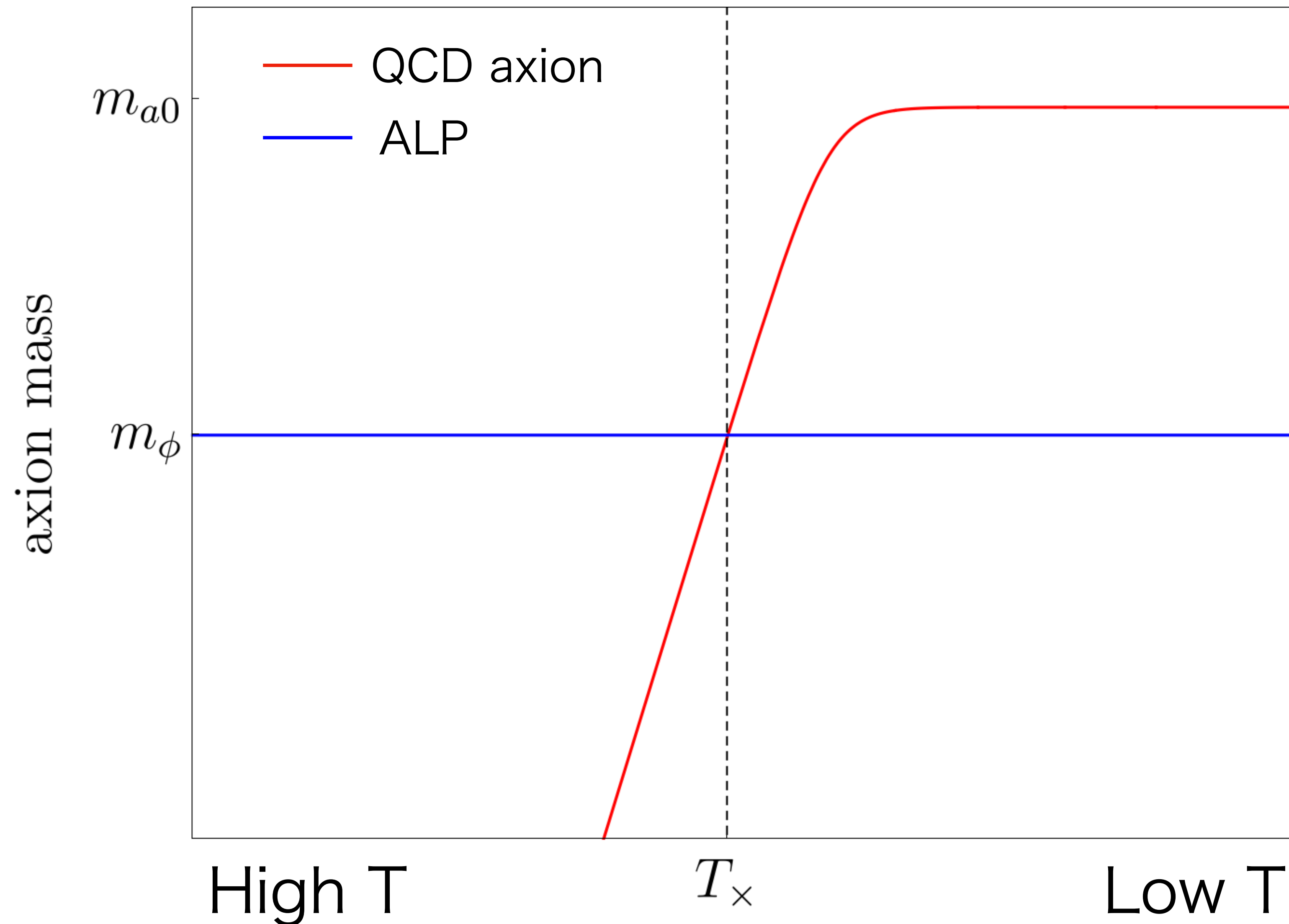
The prediction for QCD axion dark matter changes significantly.

This mass region is well-motivated as a candidate for dark matter.



QCD axion would be dark matter in these region with mixing.

Level crossing between axions



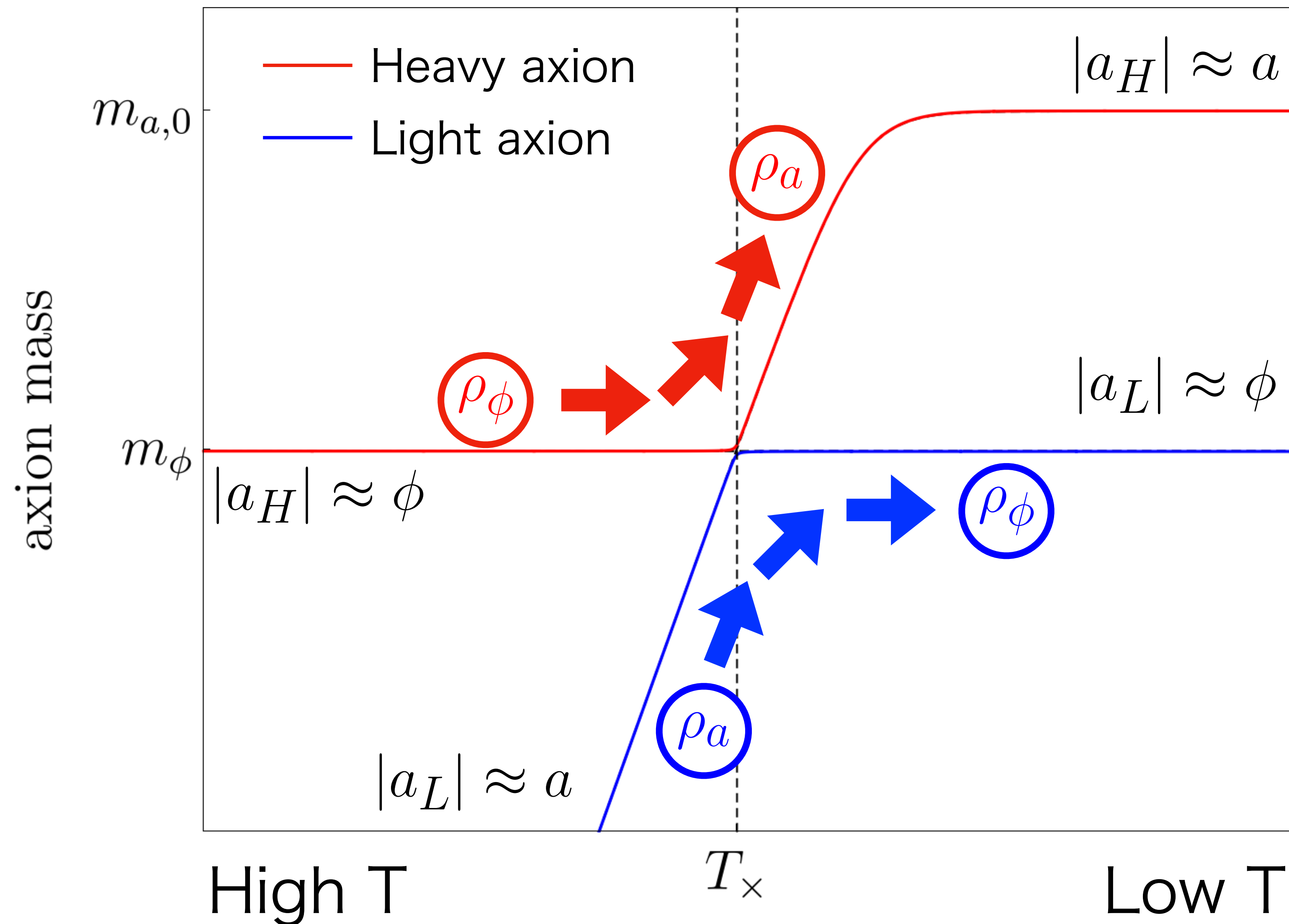
QCD axion

+

ALP with

$$m_{\phi} < m_{a,0}$$

Level crossing between axions



QCD axion

+

ALP with

$$m_\phi < m_{a,0}$$

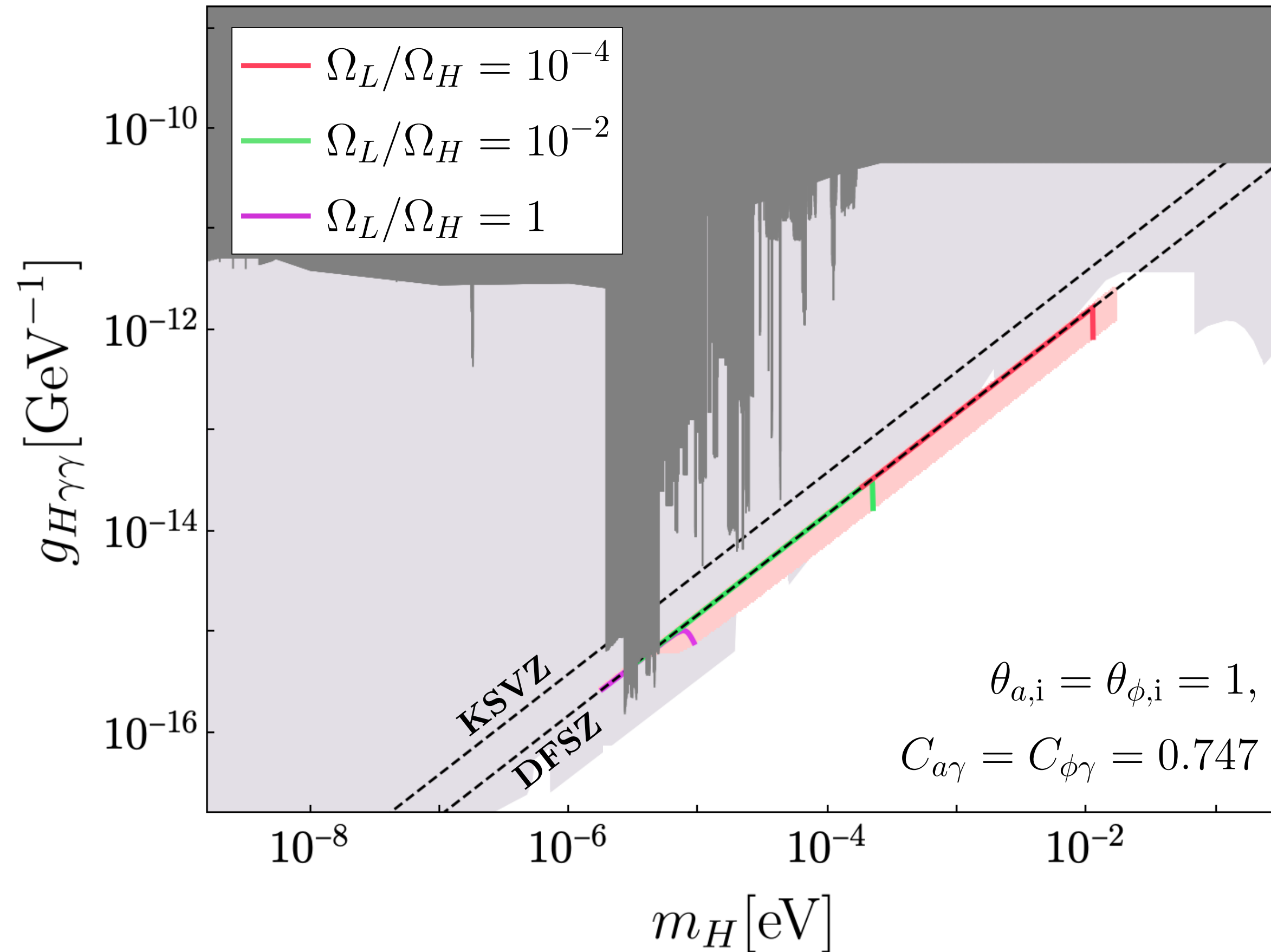
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mass mixing

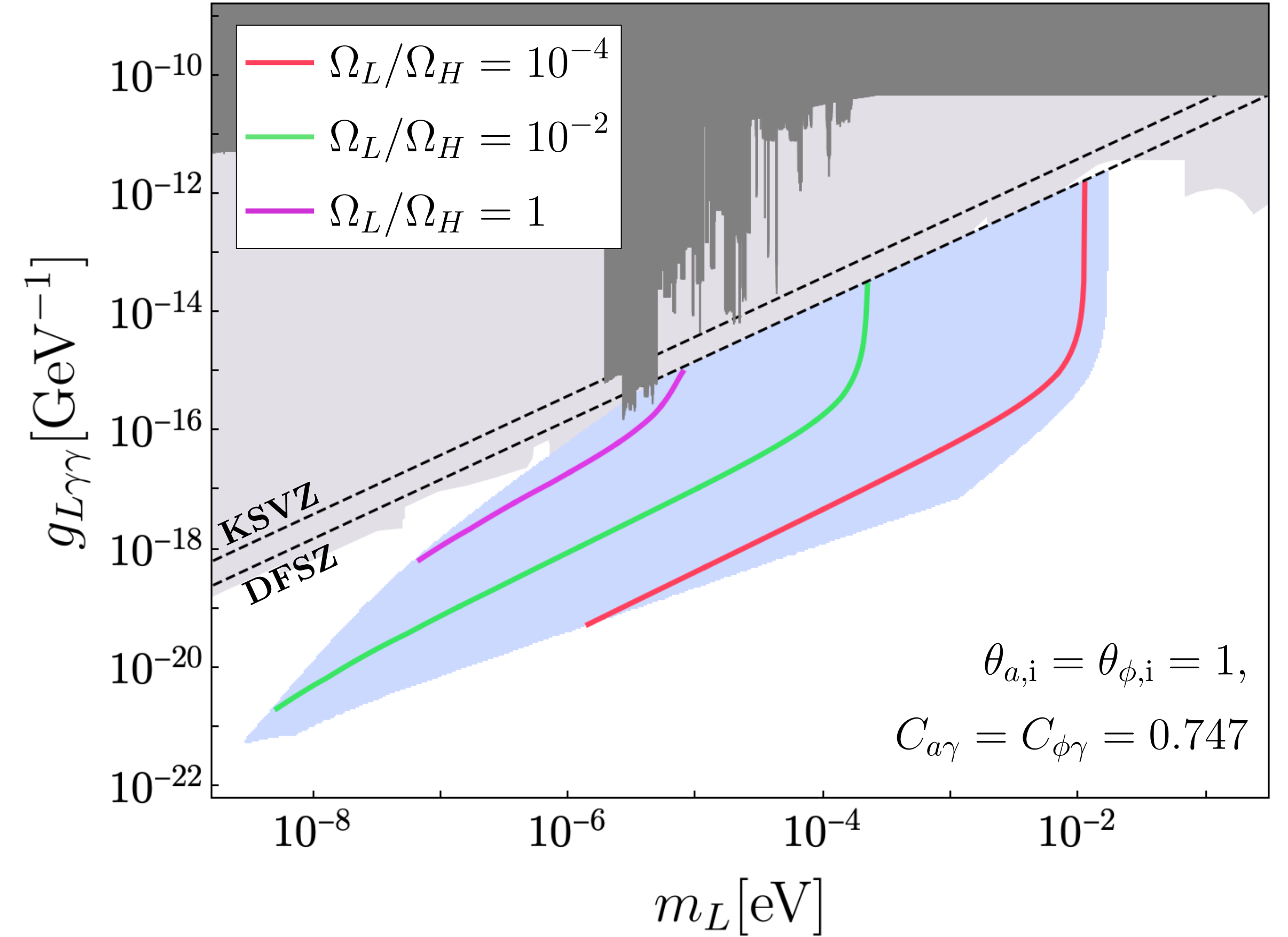
ALP and QCD axion numbers can be exchanged through the mixing.

Final Results

Heavy axion



Light axion



Various limits taken from <https://cajohare.github.io/AxionLimits/>.

Summary

- We have researched the scenario in which the QCD axion is possible to mix another axion.
- Through the mixing, the dynamics of the current model undergoes significant changes.
- Then, QCD axion DM can be relatively heavy.
- These scenario can be probed by the axion direct search experiments such as TOORAD and BREAD.