

## Building non-vanilla QCD axion models

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In [1] and [2], my co-authors and I revisit the the field theory of axion model building from two separate perspectives. We first considered [1] the effects of small-size instantons arising from enlarged color gauge groups on the QCD axion mass, reaffirming earlier results that QCD axion masses can be parametrically heavier than vanilla models when the confinement effects of the extended color group symmetry contribute to the Peccei-Quinn (PQ) breaking. Notably, we discuss an improvement of the vanilla chiral Lagrangian that readily incorporates non-vanilla 't Hooft determinantal operators. In [2], we present the “Anarchic Axion” model where a possible soft-breaking of PQ symmetry is included in the scalar potential. Depending on the phase and magnitude of the soft-breaking term, an arbitrarily light QCD axion remains to solve the strong CP problem, albeit at the expense of increasing fine tuning. Besides expanding the axion parameter space beyond the vanilla QCD axion band, we have also discussed the phenomenology of axion-like particle effective field theories when the Standard Model is extended to include a gauged baryon number symmetry, offering new collider signatures for ALPs and  $Z'$  bosons [3].

[1] Kivel, Laux, FY, [JHEP 11(2022) 088, arXiv:2207.08740]

[2] Elahi, Elor, Kivel, Laux, Najjari, FY [arXiv:2301.08760]

[3] Kivel, Laux, FY [JHEP 03 (2023) 078, arXiv:2211.12155]

**Author:** YU, Felix (Johannes Gutenberg University Mainz)

**Presenter:** YU, Felix (Johannes Gutenberg University Mainz)

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