The Anomalous Case of Axion EFTs and Massive Chiral Gauge Fields

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Anomalies and couplings: abelian case

Is the coupling between an ALP and vector gauge bosons always determined by mixed gauge-global anomalies?

$$\delta_{PQ}(\mathcal{L}) \propto D^{PQAA} \qquad \mathcal{A}(a \to AA) \propto \mathcal{C}$$

$$\mathcal{L}_{EFT} \supset -g^2 \frac{D^{PQAA}}{16\pi^2 f} a F_{\mu\nu}\widetilde{F}^{\mu\nu} + g^2 \frac{\mathcal{C}-D^{PQAA}}{8\pi^2 f} \partial_\mu a A_\nu \widetilde{F}^{\mu\nu}$$

Anomalous | Non anomalous

Can the amplitude be different to the anomaly coefficient?
If the UV fermions are (w.r.t. the gauge boson in the amp.):

Vector-like
$$\mathcal{C} = D^{PQAA}$$

Chiral
$$\mathcal{C} \neq D^{PQAA}$$

This is the well-known case of photons and gluons.

This discrepancy can not be seen with IR measurements. Can be removed with a redefinition of the PQ sym.

The abelian case is not relevant for phenomenology and the mismatch can not be seen from the IR.

Non-abelian case: a minimal model and sum rules

Take a DFSZ-like extension of the SM + chiral heavy leptons:

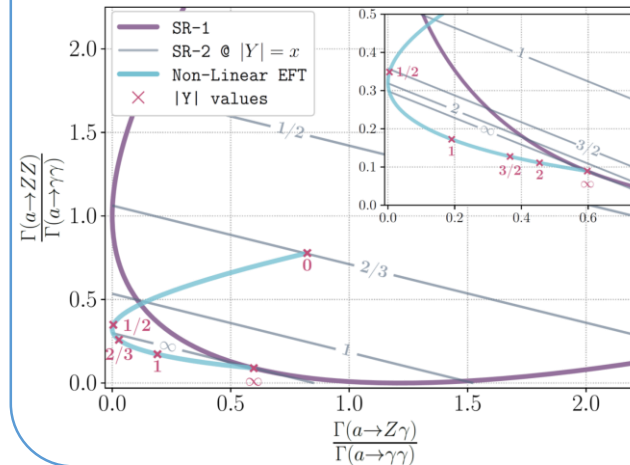$$L_{1,L} \sim (1,2,+Y), \quad E_{1,R} \sim (1,1,+Y-\tfrac{1}{2}), \quad N_{1,R} \sim (1,1,+Y+\tfrac{1}{2})$$
$$L_{2,L} \sim (1,2,-Y), \quad E_{2,R} \sim (1,1,-Y+\tfrac{1}{2}), \quad N_{2,R} \sim (1,1,-Y-\tfrac{1}{2})$$

If the ALP coupling to W and Z is related to UV mixed anomalies, the following sum rules should be respected:

SR-1: $\left[\dfrac{\Gamma(a \to ZZ)}{\Gamma(a \to \gamma\gamma)} - 1 - \dfrac{(t_W^2-1)^2}{2t_W^2}\dfrac{\Gamma(a \to Z\gamma)}{\Gamma(a \to \gamma\gamma)}\right]^2 - \dfrac{2(t_W^2-1)^2}{t_W^2}\dfrac{\Gamma(a \to Z\gamma)}{\Gamma(a \to \gamma\gamma)} = 0$

SR-2: $\Gamma(a \to \gamma\gamma) + \dfrac{1}{2}(t_W^{-2}-1)\Gamma(a \to WW) - t_W^{-2}\Gamma(a \to ZZ) + \dfrac{1}{2}(1-t_W^{-2})\Gamma(a \to Z\gamma) = 0$

But they are broken for generic Y (see plot below).

Left: Plot of the ratio of decay rates in the sum rules. If the model respected the sum rules, it would sit on the purple curve and the gray straight corresponding to its value of Y. But it does not and varying Y, one obtains the ratios along the cyan curve. Red crosses indicate the values for specific values of Y.

ALP couplings to massive chiral gauge bosons might not be related to anomalies. Relevant for W/Z bosons and distinguishable with IR obs.