Automatic Peccei-Quinn symmetry

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Motivation

Do we have to impose the PQ symmetry to solve the strong CP problem? Can it arise automatically/accidentally?
We construct a dynamical (composite) axion model where the PQ symmetry arises automatically as a consequence of chirality and gauge symmetry. The theory is protected from quantum gravitational corrections until dimension nine operators.

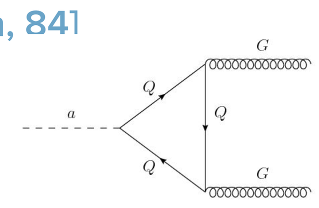
Peccei-Quinn solution

Strong CP problem: Why is it so small?

$$\mathcal{L} \supset \bar{\theta}\frac{\alpha_s}{8\pi}G\tilde{G} \qquad \bar{\theta} \lesssim 10^{-10}$$

→ If $\bar{\theta}$ were a scalar field, its vev would be zero [Vafa+Witten, 84]

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



→ Introduce a $U(1)_{PQ}$ symmetry (classically exact): [Peccei+Quinn 77]

- Spontaneously broken ⇒ pseudo-Goldstone Boson: AXION
- Anomalous: explicitly broken by QCD instantons ⇒ massive

Massless quark solution

→ Under a axial rotation: $U(1)_A: \quad q \to e^{\frac{\alpha}{2}i\gamma_5}q$

$$\mathcal{L} \supset -\cancel{m_q}\bar{q}q - \theta\frac{\alpha_s}{8\pi}G\tilde{G} \longrightarrow -\cancel{m_q}\bar{q}e^{i\alpha\gamma_5}q - (\theta-\alpha)\frac{\alpha_s}{8\pi}G\tilde{G}$$

→ Massless up quark, disfavored by lattice, Can it be exotic?

Massless quark solution and dynamical axion

	$SU(3)_c$	$SU(\tilde{N})$
ψ	□	□
χ	1	□

→ Two massless quarks absorb the two $\bar{\theta}$
→ $SU(\tilde{N})$ confines at a high scale

→ $SU(\tilde{N})$ Confines + Chiral Symmetry Breaking: $U(4)_L \times U(4)_R \xrightarrow[\langle\bar{\psi}\psi\rangle]{\langle\bar{\chi}\chi\rangle} U(4)_V$

pseudo-Goldstone Bosons (pGB): $16 = 8 + 3 + \bar{3} + 1 + 1$

The η' becomes the dynamical axion

Invisible axion drawbacks

→ The $U(1)_{PQ}$ symmetry is imposed: $\mathcal{L} \supset -\cancel{m}\bar{\psi}\psi - \cancel{m}\bar{\chi}\chi$

→ PQ quality: Quantum Gravity operators can spoil nEDM $\quad g_5\dfrac{|\Phi|^4(\Phi+\Phi^*)}{M_{\text{Planck}}}$

Solution: Accidental axions

Automatic PQ: Chiral SU(5)

		$SU(5)$	$SU(3)_c$	$U(1)_{PQ}$
LH	$\psi_{\bar{5}}$	$\bar{\mathbf{5}}$	**8**	-3
LH	ψ_{10}	**10**	**8**	$+1$

→ Free from gauge anomalies
- Analogous to usual SU(5) GUT: **5*** + **10**
- **8** is a pseudoreal representation

→ Automatically we get a $U(1)_{PQ}$:
- Mass terms are automatically forbidden!
- Analogous to usual B-L in SU(5) GUT

Is the global chiral SSB upon SU(5) confinement?

$$\boxed{SU(8)_{5^*} \times SU(8)_{10}} \times \boxed{U(1)_{PQ=B-L}}$$

Impossible to match 't Hooft anomalies: It has to be spontaneously broken

$$\langle \mathbf{10\,10\,10\,\bar{5}}\rangle \sim \Lambda_5^6$$

$$SU(8)_{5^*} \times SU(8)_{10} \longrightarrow G \supset SU(3)_c$$

Possible to match anomalies. Two options:
1. No chiral SB ⇒ Massless coloured baryon phenomenologically excluded χ = 10 5* 5*
2. Chiral SB ⇒ pGB, AXION

$$\langle \mathbf{\bar{5}\,\bar{5}\,10\,\bar{5}\,\bar{5}\,10}\rangle \sim \Lambda_5^9\,, \quad \mathbf{\bar{5}\,\bar{5}\,10\,\bar{5}\,\bar{5}\,10} \sim \Lambda_5^9 e^{-i\,10\,a/f_{PQ}}$$

A simple UV completion of the invisible axion model

$$m_a^2 f_a^2 = m_\pi^2 f_\pi^2 \frac{m_u m_d}{(m_u+m_d)^2}$$

But automatic, and protected...

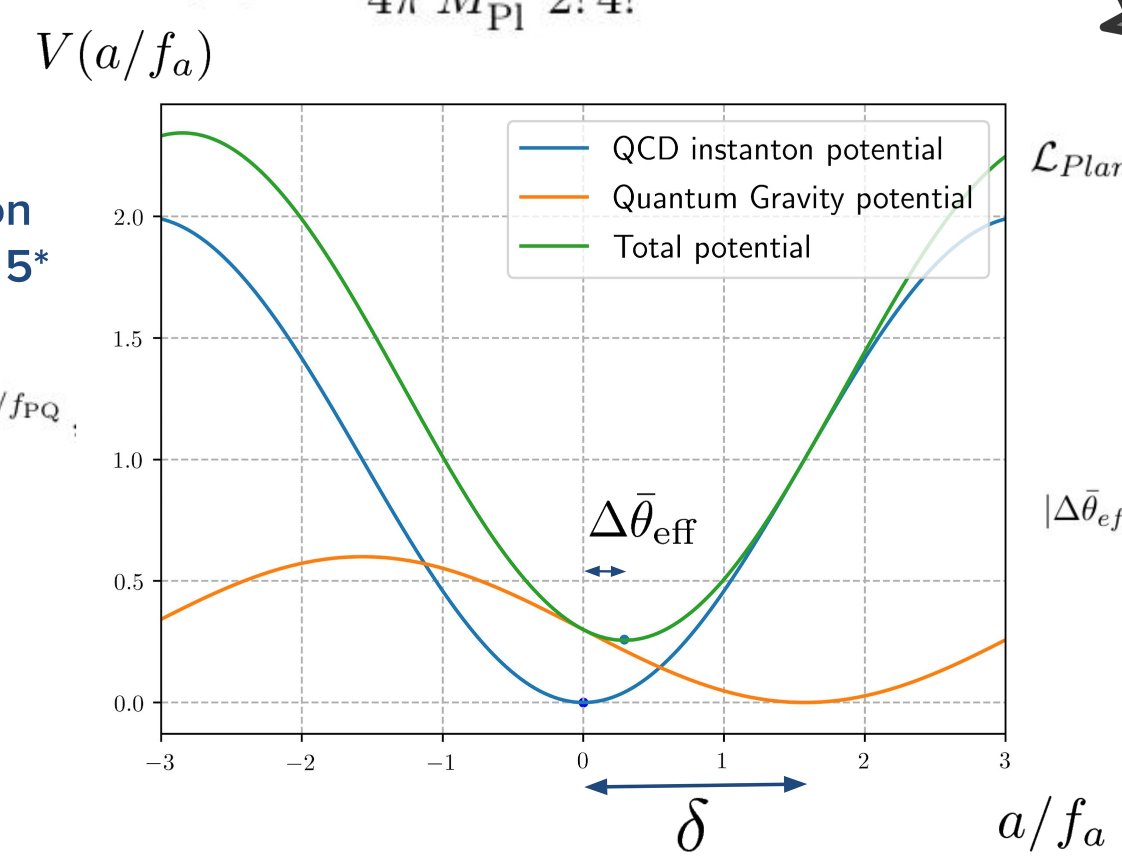
PQ quality: Quantum Gravity operators

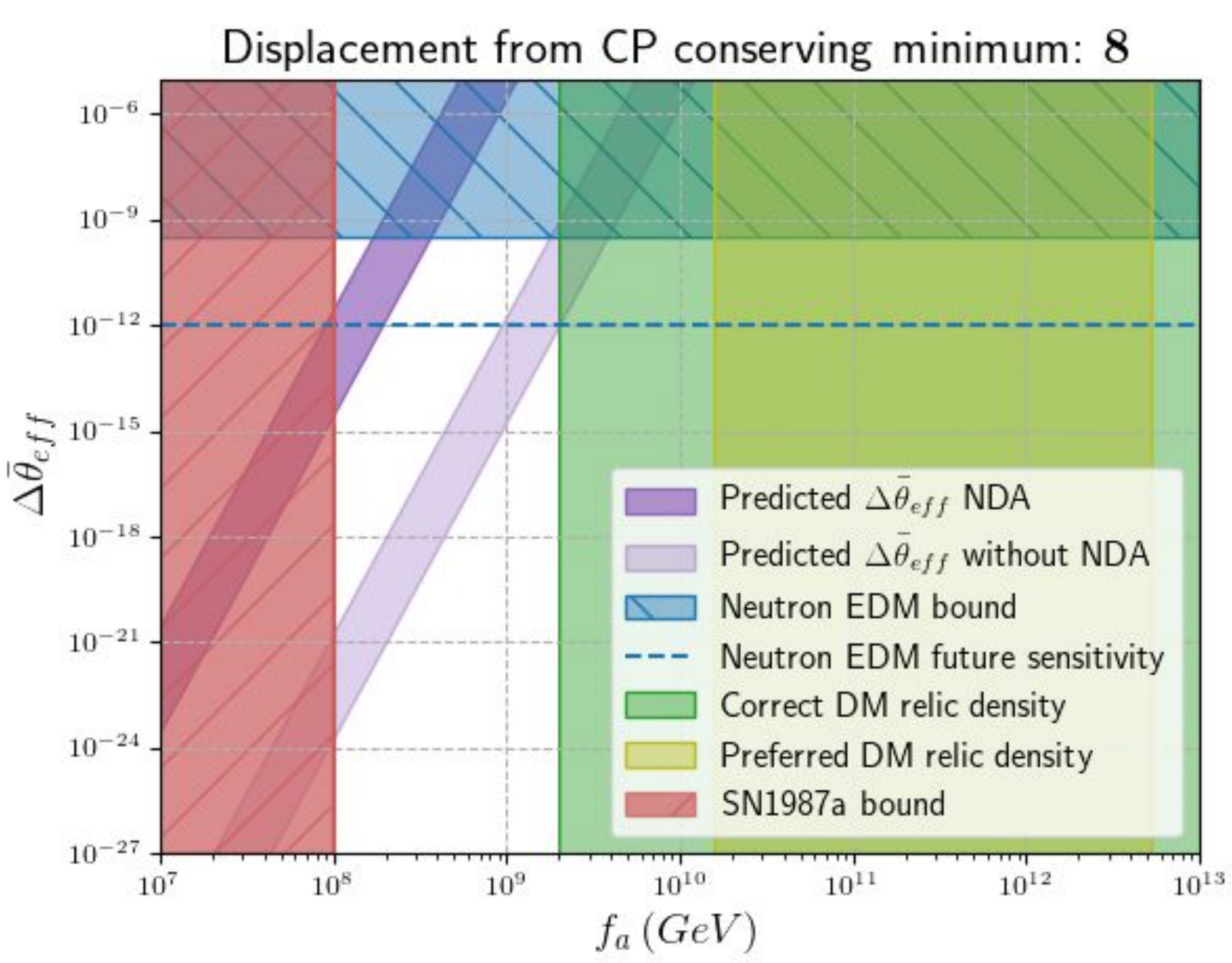
$$\mathcal{L}_{\cancel{PQ}} = c\,\frac{1}{4\pi}\frac{1}{M_{\text{Pl}}^5}\frac{1}{2!\,4!}\,\mathbf{\bar{5}\,\bar{5}\,10\,\bar{5}\,\bar{5}\,10}$$

NDA

$$\mathcal{L}_{Planck} = c\,\frac{(4\pi)^2}{2!\,4!}\left(\frac{N}{5}\right)^9\frac{f_a^9}{M_{Pl}^5}e^{-i\frac{10}{N}a/f_a}$$

$$|\Delta\bar{\theta}_{eff}| = |c\sin(\delta)|\,\frac{2\,(4\pi)^2}{4!}\left(\frac{N}{5}\right)^8\frac{f_a^9}{M_{Pl}^5\Lambda_{\text{QCD}}^4}$$





Conclusions

- A dynamical (composite) axion model where the PQ symmetry arises **automatically** is constructed.
- Based on a confining group SU(5) with **chiral** fermions in pseudoreal representations of colour.
- Presents an inherent **protection** from dangerous quantum non-perturbative gravitational effects.