Kaloper & AW '19

A Goldilocks Higgs

Two outstanding hierarchy problems in nature:

- c.c.:

$$\frac{\Lambda_0}{\Delta\Lambda_{loop}} \sim \frac{\Lambda_0}{M_p^4} \sim 10^{-122}$$

- EW hierarchy controlled by single dimensionful SM number, the Higgs VEV v_0:

$$\frac{v_0}{\delta v_{loop}} \sim \frac{v_0}{M_{GUT}} \sim 10^{-16}$$

observational situation !

- no new physics predicted by any known dynam. mech. stabilizing v_0 was found at scales up to $100 \times v_0$

- candidate theoretical explan. of c.c. from non-trivial p form vacuum structure + anthropics

$$\downarrow$$

can vacuum structure explain accommodation of small v_0 & lack of any new physics above v_0 ?

idea:

"monodromizing" an axion allows for radiatively stable axion mass by realizing broken shift symm. as SSB of dual gauge symm.

Kaloper & Sorbo '08

$$\mathcal{L} = \frac{1}{2}(\partial\phi)^2 + \frac{1}{48}(F_{\mu\nu\rho\sigma})^2 - \frac{\mu}{24}\phi\cdot\epsilon_{\mu\nu\rho\sigma}F^{\mu\nu\rho\sigma}$$

+ membranes of charge q under A_3

$$\Downarrow$$

$$\mathcal{L}_{\text{eff.}} = \frac{1}{2}(\partial\phi)^2 - \frac{1}{2}(q+\mu\phi)^2$$

dualizing & completing square:

$$\mathcal{L} = \frac{1}{2}\left|C_3 - dB_2\right|^2, \quad dB_2 = * d\phi$$

Dvali '05

$\leadsto$ can we monodromize the Higgs VEV ?

1st attempt by Herraez & Ibanez '16:

$$\mathcal{L} = \frac{1}{2}\left(F_a^2 + F_h^2\right) - \phi\left(\mu_a F_a + \mu_h F_h\right)$$
$$+ \xi |H|^2 \cdot F_h$$

SM Higgs

$\rightarrow$ creates landscape of vacua with differing Higgs VEVs $\checkmark$

Our observation:

one 4-form & no axion already does the job !

$$\mathcal{L} = \frac{1}{2}(\partial h)^2 - V(h) + \frac{1}{48}(F_{\mu\nu\rho\sigma})^2$$

$$\left\{ \begin{array}{l} - \dfrac{Q + c \cdot h^2}{24} \cdot \epsilon_{\mu\nu\rho\sigma} F^{\mu\nu\rho\sigma} \\[2ex] + \dfrac{1}{6} \epsilon_{\mu\nu\rho\sigma} (\partial^\mu Q) A^{\nu\rho\sigma} \end{array} \right.$$

$$Q = N \cdot q \quad \Big| \quad V(h) = \frac{\lambda}{4} h^4 - \frac{v^2}{2} h^2 + \Lambda$$

h : $U(1)$ Higgs for simplicity
(works with SM Higgs as well)

See also : Giudice, Kehagias & Riotto '19

again, completing the square & integrate out F :

$$V = \frac{\lambda}{4} h^4 - \frac{v^2}{2} h^2 + \frac{1}{2}(Q + c \cdot h^2)^2 + \Lambda$$

$$= \frac{\bar\lambda}{4} h^4 - \frac{\bar v^2}{2} h^2 + \frac{1}{2} Q^2 + \Lambda$$

$$\bar\lambda = \lambda + 2c^2$$

$$\bar v^2 = v^2 - 2c \cdot Q \ , \ Q = N \cdot q$$

as long as : $cq^2 \sim TeV^2$

$$\Rightarrow \exists \ N_* = \left[\frac{v^2}{cq} \right]$$

such that for :

$N = N_* + 1$ no EW SSB

$N = N_* - 1$

the c.c.

$$\Lambda_N = \frac{1}{2} N^2 q^2 + \Lambda + \frac{1}{4} \frac{(v^2 - 2Ncq)^2}{\bar\lambda}$$

is large & negative:

$$\Lambda_{N_*-1} << -\Lambda_{N_*} < 0$$

since:

$$\Delta\Lambda = \Lambda_{N_*} - \Lambda_{N_*-1} \simeq \frac{q v^2}{c} \cdot \left(1 - \frac{c}{\bar{\lambda}}\right)$$

and typically: $c/\bar{\lambda} << 1$

This EW hierarchy solution gives us a Christmas Tree like landscape, which also reduces the c.c. problem to MSSM levels:

$$\Delta\Lambda \simeq \frac{q v^2}{c} = c q \cdot \frac{v^2}{c^2} \sim TeV^2 \cdot M_p^2$$

Final comment:

the $h^2 \epsilon \cdot F$ coupling could arise in the UV from CP-even and CP-odd terms like:

UV $\xrightarrow{\text{integrate out } G_4}$ IR

$$h^2 \cdot G \cdot F \longrightarrow c \cdot h^2 \cdot \epsilon F$$

CP-even $\qquad$ CP-odd

$$h^2 \cdot G^2 \cdot \epsilon \cdot F \longrightarrow c \cdot h^2 \cdot \epsilon F$$

CP-odd $\qquad$ CP-even

$\Rightarrow$ expect Higgs at LHC to have significant CP-odd admixture!