Backreaction in the dynamical relaxation

Adam Markiewicz

Institute of Theoretical Physics
Faculty of Physics
University of Warsaw

PLANCK 2018

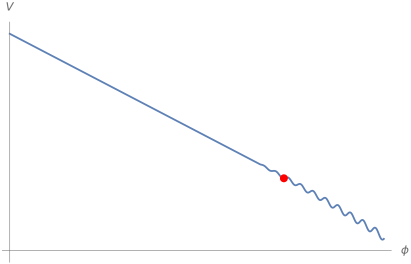
in collaboration with Z. Lalak

Outline

Dynamical relaxation

Graham, Kaplan, and Rajendran 2015

$$V(\phi, v) = g\Lambda^3\phi - \Lambda^2\left(\alpha - \frac{g\phi}{\Lambda}\right)|H|^2 + \epsilon v^n \Lambda_c^{4-n}\cos\left(\frac{\phi}{f}\right)$$



- Quantum corrections are canceled by a large value of the relaxion field
- Selection mechanism ensures that we end up in a vacuum, where EW scale is small

Properties

- Technically natural. Only $\mathcal{O}(1)$ parameters and small, symmetry-breaking couplings
- Natural range of the order of Λ/g, which means transplanckian field excursion
- Final electroweak much smaller than the cutoff Λ, which can be as large as $10^9\,\mathrm{GeV}$ Espinosa et al. 2015

$$v = \left(\frac{gf\Lambda^3}{\epsilon\Lambda_c^{4-n}}\right)^{1/n}$$

- Requires some form of an energy dissipation mechanism, eg. inflation or particle production Hook and Marques-Tavares 2016

Axion from a bulk gauge symmetry

- Start from a $U(1)$ gauge field in the bulk

$$A_M(x,y) \to A_M(x,y) + \partial_M \alpha(x,y)$$

- Enforce boundary conditions on the branes

$$A_\mu(x,y)\Big|_{y=\text{const}} = 0 \qquad \partial_5\left(a(x,y)A_5(x,y)\right)\Big|_{y=\text{const}} = 0$$

- Extradimensional on a brane gives a scalar with a shift symmetry

$$A_5(x,y) = \phi(x)h(y) \qquad \phi(x) \to \phi(x) + \text{const}$$

- Example: can be used to obtain the QCD axion Choi 2004

The backreaction term

- Relaxion couples to a non-abelian gauge field

$$\frac{1}{32\pi^2}\frac{\phi}{f}\epsilon_{\mu\nu\rho\sigma}F_a^{\mu\nu}F_a^{\rho\sigma}$$

- Non-perturbative instanton effects result in an effective potential below confinement scale Λ_c

- For QCD we get

$$V \supset y_u v \Lambda_{QCD}^3 \cos\left(\frac{\phi}{f}\right)$$

- Can the relaxion influence the backreaction term beyond being an argument of the cosine? McAllister et al. 2018

The confinement scale

- The confinement scale originates from the RGE running

$$\beta = -\left(\frac{g_{YM}^3}{16\pi^2}\right)\left(\frac{11}{3}T(Ad) - \frac{2}{3}\sum_{i=1}^{n_F} T(R_i) - \frac{1}{3}\sum_{a=1}^{n_S} T(R_a)\right)$$

- Theory strongly coupled below Λ_c

$$g_{YM}(\Lambda_c) \sim 1 \qquad\qquad \Lambda_c \sim \exp\left(-\frac{8\pi^2}{\xi g_{YM}^2}\right)$$

- For a bulk gauge field the effective coupling on the brane would be suppressed by the volume of the extra dimensions

$$\Lambda_c \sim \exp\left(-\frac{8\pi^2 V_n}{\xi g_{YM}^2}\right)$$

- Possible problem if the size of the extra dimensions increase during (or because of) the relaxation

Compactification

$$\beta = -\left(\frac{g_{YM}^3}{16\pi^2}\right)\left(\frac{11}{3}T(Ad) - \frac{2}{3}\sum_{i=1}^{n_F} T(R_i) - \frac{1}{3}\sum_{a=1}^{n_S} T(R_a)\right)$$

- Kaluza-Klein modes enter the β function and modify the confinement scale
- For a fixed cutoff increasing the size of the extra dimension compresses the KK towers pushing new states below it

  $$m = m_0 + \frac{n}{2\pi R}$$

  This leads to an exponential effect of the confinement scale
- Can it cancel the suppression of the gauge coupling?

Compactification

Novales-Sánchez and Toscano 2010

- Interesting gauge structure of the compactified theory with two kinds of gauge transformations
- Standard gauge transformations

$$
\begin{aligned}
\delta A_\mu^{(0)a} &= \mathcal{D}_\mu^{(0)ab}\alpha^{(0)b} \\
\delta A_\mu^{(m)a} &= gf^{abc}A_\mu^{(m)b}\alpha^{(0)c} \\
\delta A_5^{(m)a} &= gf^{abc}A_5^{(m)b}\alpha^{(0)c}
\end{aligned}
$$

- Non-standard gauge transformations

$$
\begin{aligned}
\delta A_\mu^{(0)a} &= gf^{abc}A_\mu^{(n)b}\alpha^{(n)c} \\
\delta A_\mu^{(m)a} &= \mathcal{D}_\mu^{(mn)ab}\alpha^{(n)b} \\
\delta A_5^{(m)a} &= \mathcal{D}_5^{(mn)ab}\alpha^{(n)b}
\end{aligned}
$$

Compactification

García-Jiménez et al. 2016; Granados-González et al. 2017

- In the zero mass limit summing up contributions from all KK modes produces a finite result

$$\beta(g) = -\frac{g^3}{(4\pi)^2}\left\{\frac{11}{3}N - \frac{2}{3}n_f + \left(\frac{1-2^n}{2^n}\right)\left[\frac{11-\left(\frac{n}{2}\right)}{3}N - 2^{\frac{n}{2}}\left(\frac{2}{3}\right)n_f\right]\right\}$$

- Asymptotic freedom is preserved

- Contribution from the KK modes is not proportional to the volume of the extra dimensions so the exponential suppression of confinement scale (and the backreaction term) will be there

Monodromy example

$$V(\phi, v) = g\Lambda^3\phi - \Lambda^2\left(\alpha - \frac{g\phi}{\Lambda}\right)|H|^2 + \epsilon v^n \Lambda_c^{4-n}\cos\left(\frac{\phi}{f}\right)$$

- The discrete symmetry $\phi \to \phi + 2\pi f$ is gauged, so it cannot be broken explicitly Gupta et al. 2016
- Solution: monodromy Ibáñez et al. 2016

Monodromy example

Axion monodromy arising from a Stueckelberg massive $U(1)$ gauge field
Furuuchi 2016

$$S_{5D} = \int \mathrm{d}^4x \int_{S_1} \mathrm{d}y \, \sqrt{-g} \left(-\frac{1}{4} F_{MN} F^{MN} - \frac{1}{2} m_2 \mathcal{A}_M \mathcal{A}^M - (D_M \Phi)^\dagger (D^M \Phi) \right)$$

$$D_M = \partial_M - iqA_M \qquad\qquad \mathcal{A}_M = A_M - ie^{i\theta} \partial_M e^{-i\theta}$$

$$\Phi(x, y) = \frac{1}{\sqrt{2\pi R}} \sum_{n \in \mathbb{Z}} \Phi_n(x) \exp\left(\frac{iny}{R} \right)$$

$$S_{5D} \supset \int \mathrm{d}^4x \left(\frac{1}{2} m^2 \phi^2 + \sum_{n \in \mathbb{Z}} \left(\frac{n}{R} - q\phi \right)^2 |\Phi_n|^2 \right) \qquad \phi \sim A_5^{(0)}$$

Conclusions

- Dynamical relaxation is an interesting possibility of controlling quantum corrections to the Higgs field
- Extra dimensions are an interesting source of shift-symmetric fields, but they can introduce unwanted side-effects
- If the size of an extra dimension varies during relaxation, gauge coupling suppression and KK tower squeezing can create an exponential suppression of the backreaction term