Cosmological Relaxation of the EW Scale & Broken dS Symmetry

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based on arXiv:1507.08649, w/ Pedro Schwaller

Naturalness and the EW hierarchy problem

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- Novel (technically) natural solutions to EW hierarchy problem probably need no further justification.

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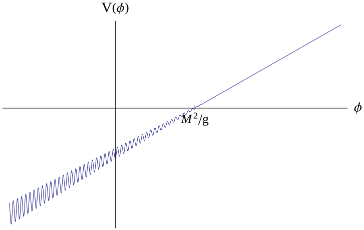
Cosmological relaxation of the EW scale

Recent proposal: hierarchy between EW scale and putative cutoff M paraphrased into parametrically large field excursion for some new field ϕ that couples to the Higgs. Graham, Kaplan, Rajendran arXiv:1504.07551



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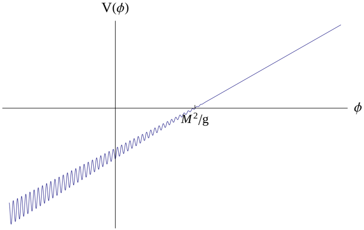

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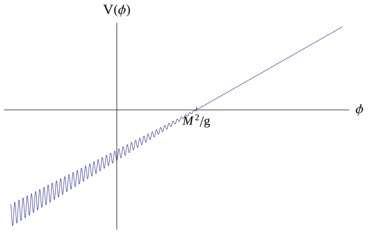

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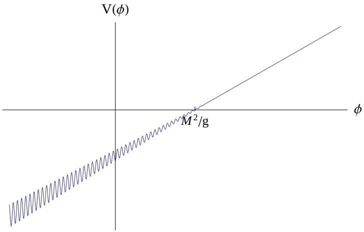

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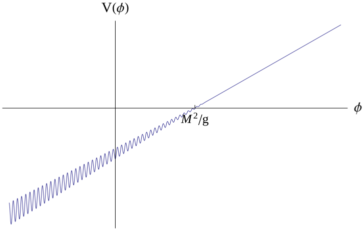

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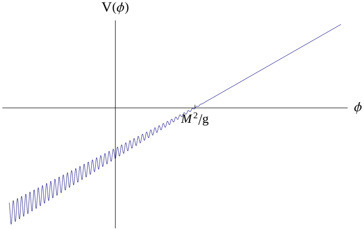
- EW symmetry breaking when $\phi = M^2/g$.
- Inflation provides a natural context for this field excursion.

Cosmological relaxation of the EW scale

(Cf. Abbot's 'solution' to the cosmological constant problem). Hierarchy problem now expresses as requiring a very large i.e. super cut-off field excursion during inflation (since we don't want to tune initial conditions either) $\Delta\phi \gtrsim M^2/g$.



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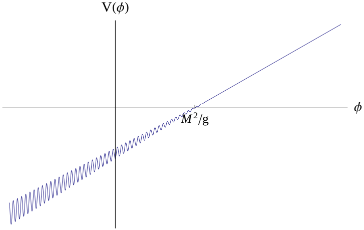

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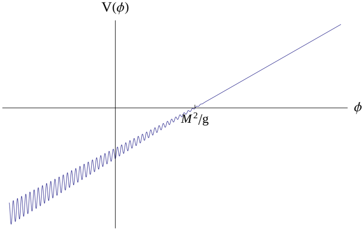

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- $\Lambda^4(\langle h\rangle) = \Lambda^4\langle h\rangle/v$, $v := 246GeV$ hence $\frac{\langle h\rangle}{v} = \frac{gM^2 f}{f_\pi^2 m_\pi^2}$ can be made order one for small enough g for very large values of the cutoff $M \gg v$.

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  $M \sim 10^{10} GeV, \Lambda \sim 100 GeV, g \sim 10^{-22} GeV$
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- Have we just merely shuffled all tuning issues into the inflaton sector?

Other recent work

- Espinosa, Grojean, Panico, Pomarol, Pujolas, Servant; arXiv:1506.09217
- Hardy; arXiv:1507.07525
- Antipin, Redi; arXiv:1508.01112
- Jaekel, Mehta, Witkowski; arXiv:1508.03321
- Gupta, Komaragodksi, Perez, Ulbaldi; arXiv:1509.00047
- Batell, Giudice, McCullough; arXiv:1509.00834

The role of broken dS symmetry

In neglecting changes to quantities over many Hubble times, GKR were implicitly working in the dS limit. Let us re-examine the field excursion required.

- Spectator field on an arbitrary background:
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- $|\Delta\phi| = \phi_0 - \phi \gtrsim M^2/g$ implies $\Delta\mathcal{N}_{\rm min} \gtrsim \log\left(1 + 2\epsilon_0 \frac{3H_0^2}{g^2}\right)^{\frac{1}{2\epsilon_0}}$

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- Stopping condition w/ $f \sim \Lambda$ is $\Lambda^4 = gM^3$, which puts a bound on the cutoff: $M \lesssim \epsilon_0^{-1/10}\left(\Lambda^4 M_{\rm pl}\right)^{1/5}$.

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- One can recast minimum number of e-folds required into a bound on the Hubble scale at the end of inflation: $H_f = H_0 e^{-\epsilon_0 \mathcal{N}} \to H_f \lesssim \frac{g}{\sqrt{6\epsilon_0}}$ when $\epsilon_0 \gg g^2/H_0^2$.
- Also require: $H_0 \lesssim \Lambda$.
- $\rho_\phi = \frac{g^2 M^4}{2H_0^2(3+\epsilon_0)^2}\left[1 + \frac{3}{\epsilon_0}\left(1 - e^{2\mathcal{N}\epsilon_0}\right)\right] + \phi_0 M^2 g$
- Requiring $\phi_0 \gtrsim 2M^2/g$, it follows that $\rho_\phi \lesssim 3H^2 M_{pl}^2$ will always be true if: $M^2\left(\frac{g^2}{2H_0^2\epsilon_0(3+\epsilon_0)} + 2\right) \lesssim \frac{6gM_{pl}}{\sqrt{2\epsilon_0}(3+\epsilon_0)}$.
- In the limit $g^2/H_0^2 \ll \epsilon_0$, we find this implies $M^2 \lesssim \frac{3}{\sqrt{2}(3+\epsilon_0)}\frac{gM_{\rm pl}}{\sqrt{\epsilon_0}}$
- Stopping condition w/ $f \sim \Lambda$ is $\Lambda^4 = gM^3$, which puts a bound on the cutoff: $M \lesssim \epsilon_0^{-1/10}\left(\Lambda^4 M_{\rm pl}\right)^{1/5}$.
- For $\epsilon_0 \sim 10^{-2}$, this implies $M \lesssim 250$ TeV for $\Lambda = 100$ GeV with $\Delta\mathcal{N} \gtrsim 50 \log\left(\frac{M^6}{\Lambda^6}\right) \approx 3 \times 10^3$. Far more reasonable.

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- Gaussian perturbations if $H_* \ll \phi_*$
- $\Delta_{\mathcal{R}} \approx \kappa^2 \frac{H_*^2}{\pi^2 \sigma_*^2} \simeq 2.2 \times 10^{-9}$, $n_s - 1 = -2\epsilon_* + 2\frac{(V_{\sigma\sigma})_*}{3H_*^2}$.

Cosmological relaxation of the EW scale

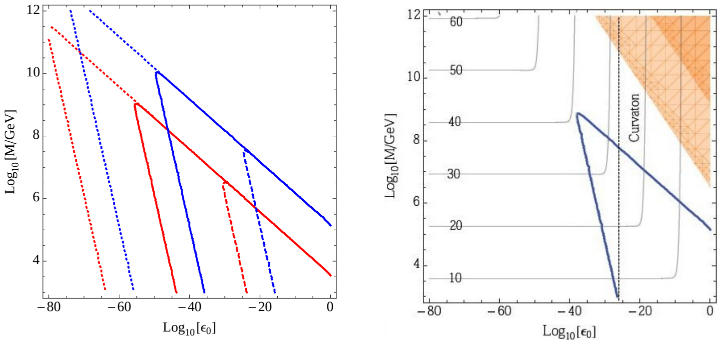

Figure: Left: Upper bounds on M as function of ϵ_0. The solid red (blue) contours correspond to $H_0 = \Lambda = 1$ GeV (100 GeV) respectively. Dashed (dotted) lines correspond to $H_0 = 10^{-5}\Lambda$ ($H_0 = 10^5\Lambda$). Right: Allowed region for $\Lambda = 100$ GeV, with grey lines showing $\log_{10}\mathcal{N}_{\rm min}$. The light (darker) orange shaded region has $T_{RH} < $ TeV ($T_{RH} < 100$ MeV), and we choose H_0 such that $H_0 \leq \sqrt[3]{\Lambda^4/M}$ is satisfied for $M \leq 10^9$ GeV. The parameter g is set everywhere by $gM^3 = \Lambda^4$. In the region to the right of the vertical dashed line, a curvaton field is needed.

Open Questions

So far, there are a LOT of questions that remain to be answered about this mechanism from the cosmology side.

- Could the relaxion also be the inflaton?
- Are there any observable (resonant?) signatures of the relaxion/ curvaton in the CMB/ LSS?
- In this scenario, the EW phase transition can happen before or after the end of inflation. Consequences for/ constraints from reheating?
- Can the relaxion settle in neighbouring valleys within the same Hubble patch? Would that lead to interesting new defects? Is this already ruled out/ severly constraining of the scenario as a whole?
- ...