

Stopping the dynamical relaxation by particle production

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Outline

- ▶ Dynamical relaxation: what it is all about?
- ▶ Particle production as an energy dissipation mechanism
 - ▶ Vector case
 - ▶ Scalar case

Motivation

- ▶ Quantum corrections to the Higgs' mass are quadratically divergent. If there is no new physics Higgs mass should be of the order of the Planck scale
- ▶ Most protection mechanisms (SUSY, extra dimensions) predict new physics close to the electroweak scale, but we don't see one in experiments
- ▶ Can we devise a model that predicts a hierarchy of scales, but is natural (no fine tuning)?

How relaxation works?

Graham, Kaplan, Rajendran, 2015

Drives relaxion
towards smaller
values

Higgs-
relaxion
interaction

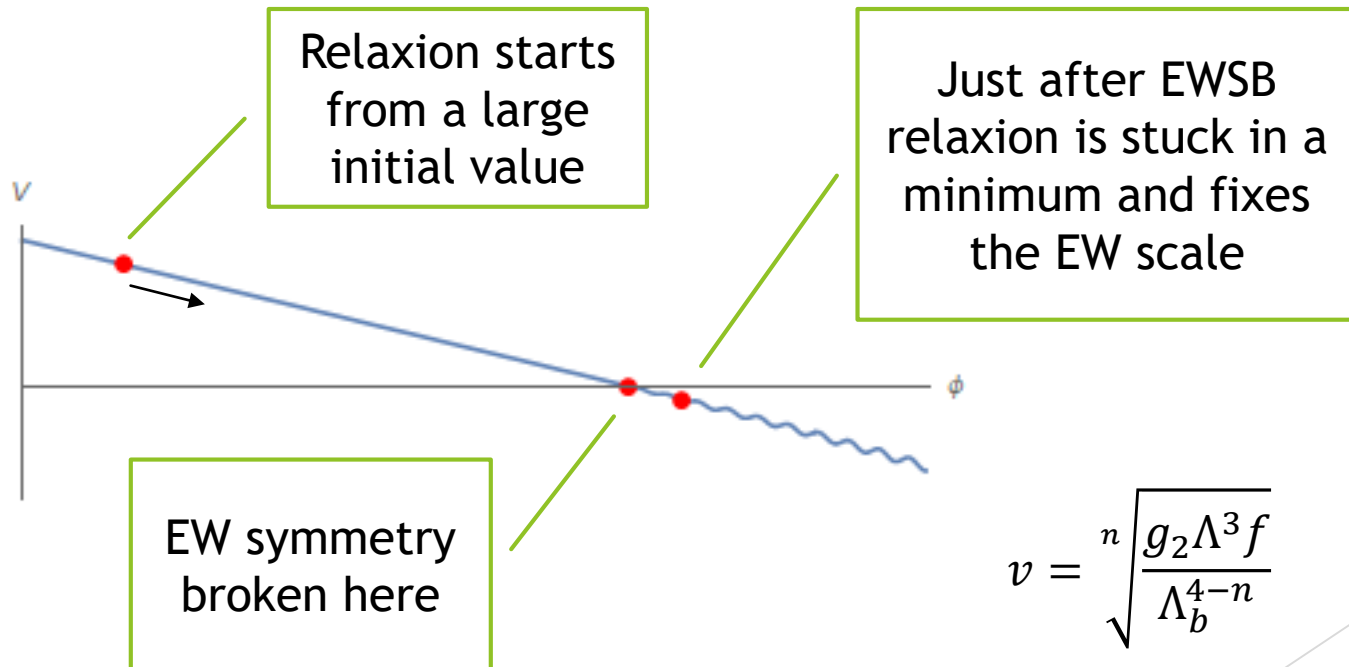
Higgs quartic
interaction

$$V(\phi, h) = g_1 \Lambda^3 \phi + (\Lambda^2 - g_2 \Lambda \phi) h^2 + \frac{\lambda}{4} h^4 + v^n \Lambda_b^{4-n} \cos\left(\frac{\phi}{f}\right)$$

Quantum-
corrected Higgs
mass term

Effective potential
from relaxion's
anomalous coupling

How relaxation works?



Problems

- Quantum corrections can spoil the relaxation process

$$\Lambda_b^4 \cos\left(\frac{\phi}{f}\right) \quad g_2 \phi \Lambda_b^3 \cos\left(\frac{\phi}{f}\right)$$

Solution: CHAIN [Espinosa et al., 2015]

- Requires an ongoing inflation to dissipate relaxion's energy
- Inflation must be very slow and very long

$$H_I^3 < g_1 \Lambda^3 \quad N_e > \frac{H_I^2}{g_1^2 \Lambda^2}$$

- Are transplanckian field excursions possible?

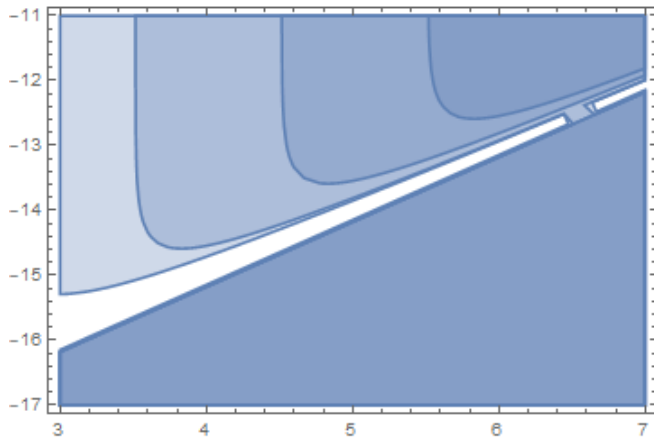
Energy dissipation by particle production

- ▶ Relaxation starts in a broken phase. Higgs and all particles coupled to it are heavy
- ▶ Periodic barriers independent from the EW scale and always present. Initial relaxion's kinetic energy sufficient to cross the barriers
- ▶ Relaxion rolls towards higher values
- ▶ Close the EW symmetry recovery massive states coupled to relaxion would become light and would be produced in abundance ($\dot{\omega}_k/\omega_k^2 \gg 1$)
- ▶ Produced light states take away relaxion's kinetic Energy, causing it to stop in one of the minima

Benefits

- ▶ Relaxation independent from inflation,
- ▶ Relaxation is fast ($\dot{\phi} \approx \Lambda^2$) and requires no transplanckian field excursions
- ▶ Rich phenomenological consequences which can be used to constrain the model

Generic constraints



- ▶ Not to many e-folds ($N_e < 20$) to ensure that the primordial fluctuations are not washed out
- ▶ Temperature must be controlled, to make sure EW symmetry is not recovered before relaxation is complete
- ▶ It is best to start in a cold Universe (e.g. inflation decays into a hidden sector)

Production of vector bosons

[Hook, Marques-Tavares, 2016]

$$V(\phi, h) = -g_1 \Lambda \phi + (-\Lambda^2 + g_2 \Lambda \phi) h^2 + \frac{\lambda}{4} h^4 \\ + \frac{\phi}{f} V_{\mu\nu} \tilde{V}^{\mu\nu} + \Lambda_b^4 \cos\left(\frac{\phi}{f'}\right)$$

- ▶ No new states required beyond the SM and the relaxion
- ▶ Consistent with experimental constraints
[Fonseca, Morgante, Servant, 2018]
- ▶ Requires very specific coupling to exclude relaxion-photon interaction

$$V_{\mu\nu} \tilde{V}^{\mu\nu} = g_W^2 W_{\mu\nu}^a \tilde{W}^{a\mu\nu} - g_B^2 B_{\mu\nu} \tilde{B}^{\mu\nu}$$

Higgs production

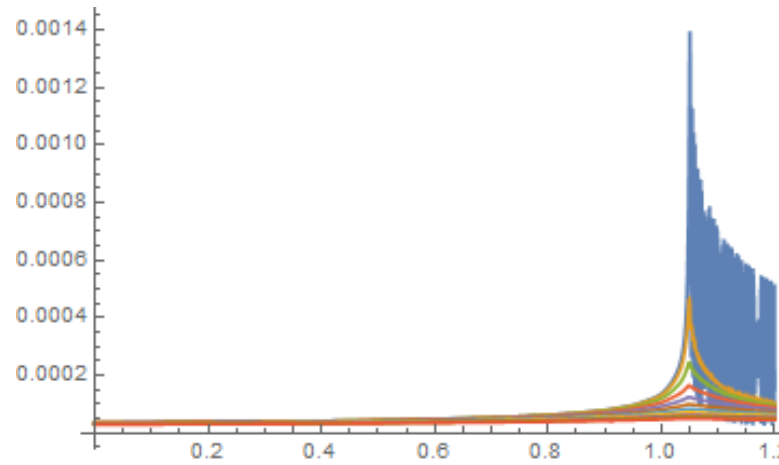
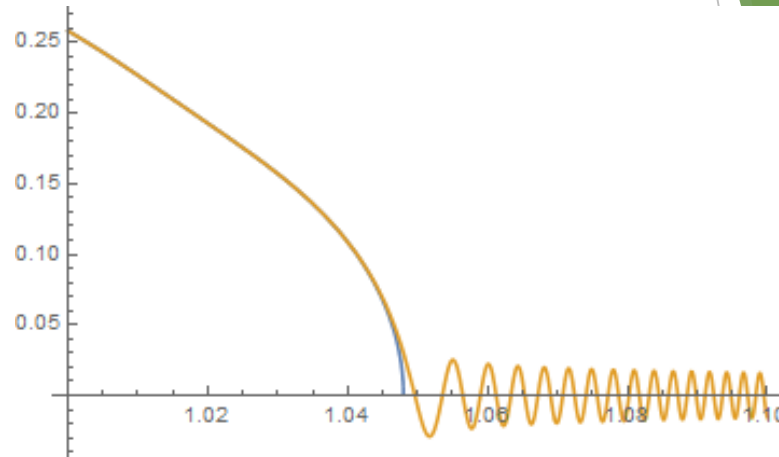
$$V(\phi, h) = -g_1 \Lambda \phi + (-\Lambda^2 + g_2 \Lambda \phi) h^2 + \frac{\lambda}{4} h^4 + \Lambda_b^4 \cos\left(\frac{\phi}{f}\right)$$

- Higgs follows its minimum if

$$\dot{\phi} < (g_2 \Lambda)^{1/2} \left| \phi - \frac{\Lambda}{g_2} \right|^{3/2}$$

- Effective production if

$$\dot{\phi} > 2\sqrt{2}(g_2 \Lambda)^{1/2} \left| \phi - \frac{\Lambda}{g_2} \right|^{3/2}$$

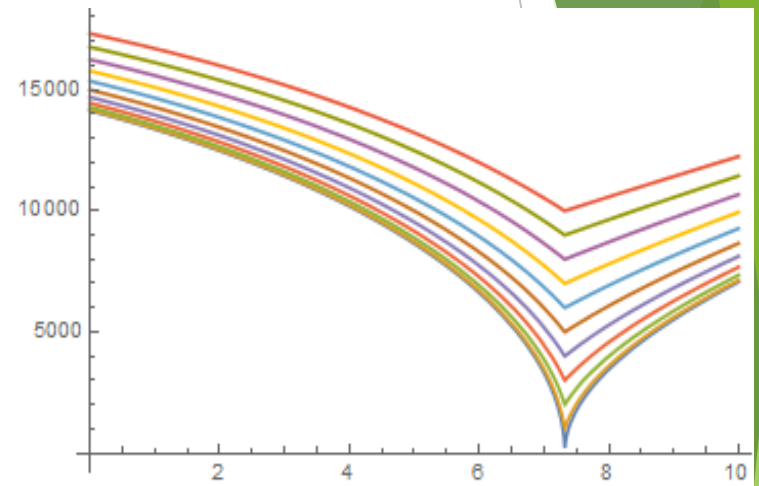


Higgs production

- ▶ Production rate surprisingly independent from model's parameters
- ▶ Particle production is never effective enough to stop the relaxation

$$\frac{\dot{\omega}_0}{\omega_0^2} < 0.7$$

- ▶ Interesting possibility: inverse Higgs relaxation



Scalars vs vectors

- ▶ Higgs case

$$\omega_k = \sqrt{k^2 + (g_2 \Lambda \phi - \Lambda^2 + 3\lambda h_0^2)}$$

- ▶ Vector case

$$\omega_k = \sqrt{k^2 + g_V^2 h^2 - \frac{\dot{\phi}}{f} k}$$

- ▶ Mass of vector bosons depends on $\dot{\phi}$. Production is self-reinforcing
- ▶ Derivative coupling necessary (?)

Conclusions

- ▶ Relaxation provides an interesting solution to the hierarchy problem, where a hierarchy of scales is generated naturally
- ▶ Using particle production as an energy dissipation mechanism avoids major issues of the original proposal
- ▶ Production of vector bosons works, and is consistent with experimental constraints
- ▶ Production of scalar particles is insufficient to stop the relaxation