Extra doublets and the dynamical relaxation

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Abstract

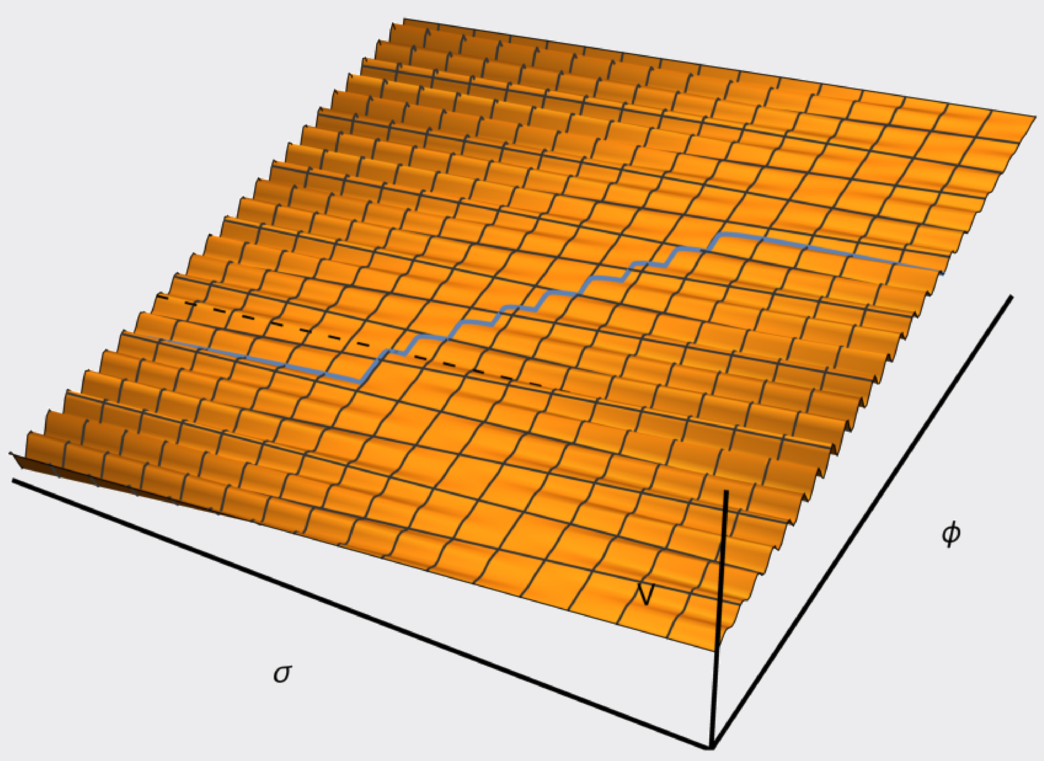
The dynamical relaxation provides an interesting solution to the hierarchy problem in face of the missing signatures of any new physics in recent experiments. Through a dynamical process involving a new axion-like particle (relaxion) it achieves a small electroweak scale without introducing new states observable in current experiments, all while maintaining technical naturalness. Poster presents relaxation in the case of a model with two Higgs doubles (2HDM) including the final values of vevs and explains the important role of global symmetries.

Dynamical relaxation [1, 2]

The dynamical relaxation is a novel solution to the hierarchy problem. It manages to naturally (only through $\mathcal{O}(1)$ parameters and small, symmetry-breaking couplings) generate a hierarchy between the electroweak scale an the model's cutoff. In its CHAIN variant, it extends the Standard Model with two scalar fields:

$$V(\phi,\sigma,H) = \Lambda^4\left(\frac{g\phi}{\Lambda}+\frac{g_\sigma\sigma}{\Lambda}\right) - \Lambda^2\left(\alpha-\frac{g\phi}{\Lambda}\right)|H|^2 + \lambda|H|^4 + A(\phi,\sigma,H)\cos\left(\frac{\phi}{f}\right),$$

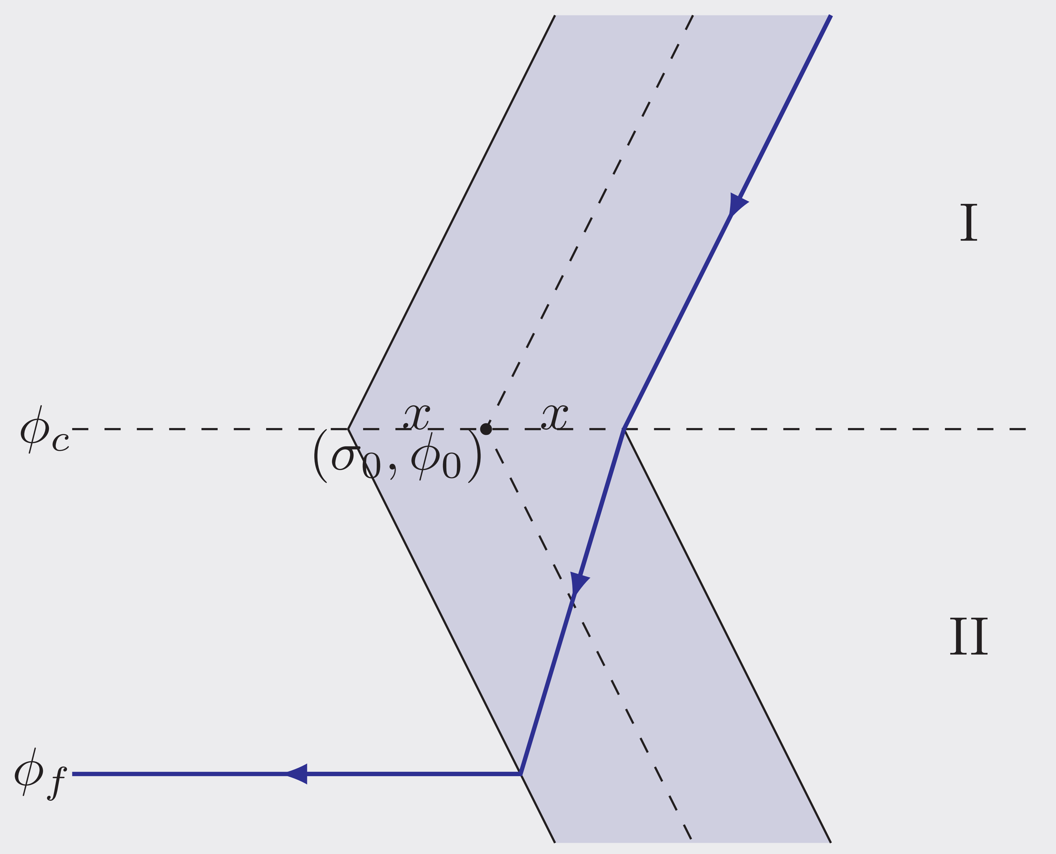
$$A(\phi,\sigma,H) = \epsilon\Lambda^4\left(\beta + c_\phi\frac{g\phi}{\Lambda} + c_\sigma\frac{g_\sigma\sigma}{\Lambda} + \frac{|H|^2}{\Lambda^2}\right).$$



The fields ϕ (the relaxion) and σ start from large values such that Higgs mass-squared is positive. Subsequently they roll down, with a friction provided by the onging inflation. They scan a range of Higgs masses until it changes sign and the EWSB occurs. At this point the amplitude of the periodic term starts to grow stopping the relaxation soon after, with the EW scale much smaller than the model's cutoff.

SM [3]

Geometrical analysis of the evolution allows to find a more robust formula for the electroweak scale after the relaxation, that includes $\mathcal{O}(1)$ parameters.



The first part gives the hierarchy between the model's cutoff Λ and the electroweak scale v, which is controlled by the ratio of the small couplings g/ϵ. The second shows the contribution from the $\mathcal{O}(1)$ parameters in the potential:

$$v^2 = \frac{g\Lambda f}{\epsilon}\frac{4}{\lambda\left(c_\sigma\frac{g_\sigma^2}{g^2}-c_\phi+\frac{1}{2\lambda}\right)}.$$

The effect of $\mathcal{O}(1)$ parameters will be significant when there is a cancellation in the denominator. This corresponds to a situation when the no-minima band gets aligned to the natural direction of evolution in the (ϕ,σ)-plane.

2HDM [3]

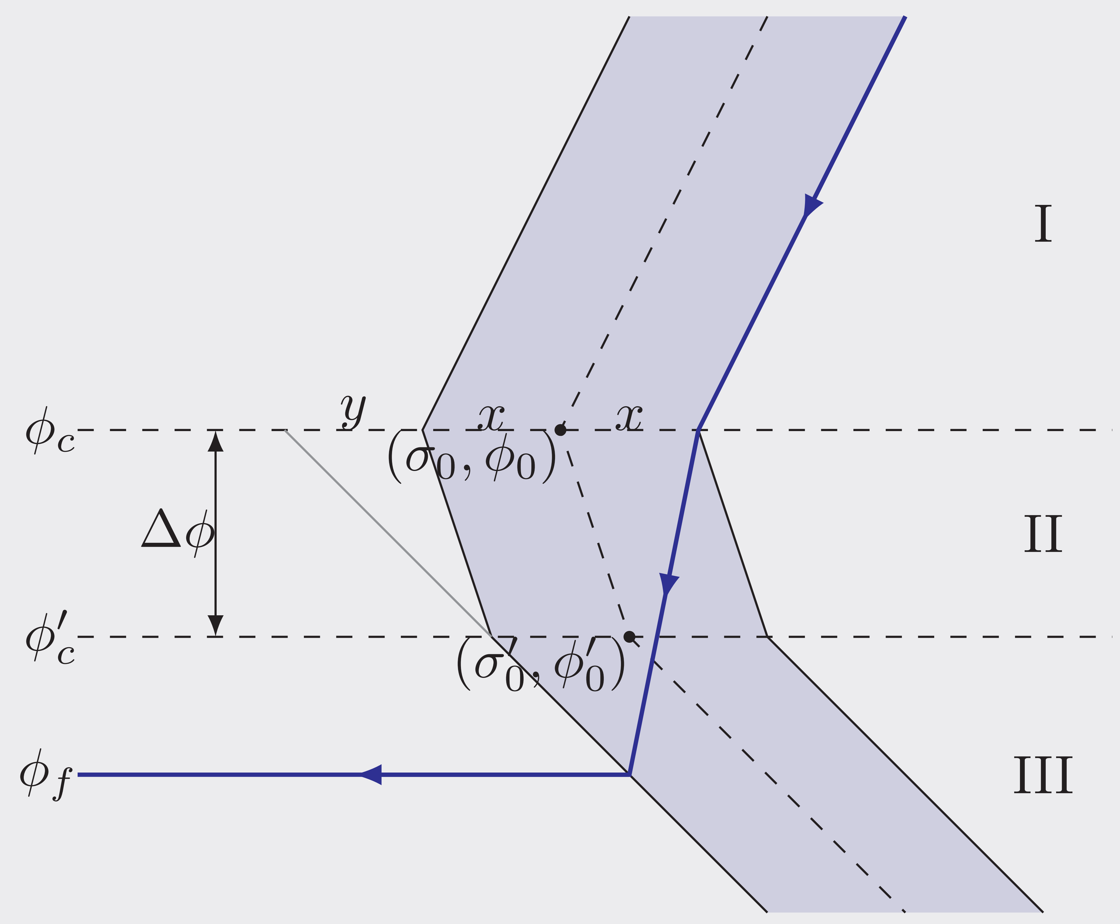
For the 2HDM the second Higgs doublet is assumed to couple to the relaxion in the same way the first one. Although the potential used is not the most general one, it allows for analytical solutions for the final vevs, and gives useful insight into the relaxation process:

$$V(\phi,\sigma,H_1,H_2) = \Lambda^4\left(\frac{g\phi}{\Lambda}+\frac{g_\sigma\sigma}{\Lambda}\right) - \Lambda^2\left(\alpha_1-\frac{g\phi}{\Lambda}\right)|H_1|^2 + \lambda_1|H_1|^4 - \Lambda^2\left(\alpha_2-\frac{g\phi}{\Lambda}\right)|H_2|^2 + \lambda_2|H_2|^4$$
$$+\lambda_3|H_1|^2|H_2|^2 + \epsilon\Lambda^4\left(\beta + c_\phi\frac{g\phi}{\Lambda} - c_\sigma\frac{g_\sigma\sigma}{\Lambda} + c_1\frac{|H_1|^2}{\Lambda^2} + c_2\frac{|H_2|^2}{\Lambda^2}\right)\cos\left(\frac{\phi}{f}\right).$$

With two Higgs doubles the no-minima band changes its slope twice. For the second doublet to contribute, both critical values of ϕ must be crossed, which is ensured by the condition:

$$\Delta\alpha = \alpha_1-\alpha_2 \lesssim \frac{g}{\epsilon} \sim \frac{v^2}{\Lambda^2}.$$

Otherwise only one doublet obtains a vev and stops the relaxation, leaving the other one vevless, with a mass of the order of Λ. This naturally fits the 2HDM with one doublet inert.
In 2HDM the final vevs have terms proportional to $\Delta\alpha$ that are not directly suppressed by the small coupling g. However, given the condition for inclusion of both doublets in the relaxation process those will be small as well:



$$v_1^2 = \frac{\Lambda^2}{\lambda_1}\left(1-\frac{\lambda_3^2}{4\lambda_1\lambda_2}\right)^{-1}\left[\frac{\lambda_3}{2\lambda_2}\Delta\alpha + 2\left(1-\frac{\lambda_3}{2\lambda_2}\right)\frac{\frac{gf}{\epsilon\Lambda}-c_2\frac{\lambda_1}{4\lambda_1\lambda_2-\lambda_3^2}\Delta\alpha}{c_\sigma\frac{g_\sigma^2}{g^2}-c_\phi+\frac{c_1}{2\lambda_1}+\frac{c_2}{2\lambda_2}}\right],$$

$$v_2^2 = \frac{\Lambda^2}{\lambda_2}\left(1-\frac{\lambda_3^2}{4\lambda_1\lambda_2}\right)^{-1}\left[-\Delta\alpha + \left(1-2\frac{\lambda_3}{2\lambda_1}\right)\frac{\frac{gf}{\epsilon\Lambda}-c_2\frac{\lambda_1}{4\lambda_1\lambda_2-\lambda_3^2}\Delta\alpha}{c_\sigma\frac{g_\sigma^2}{g^2}-c_\phi+\frac{c_1}{\lambda_1}+\frac{c_2}{\lambda_2}}\right].$$

Symmetry constrained models

Non-trivial dynamical relaxation in a model involving two Higgs doublets requires $\Delta\alpha$ to be smaller than v^2/Λ^2. This can be naturally achieved in 2HDM when additional symmetries are imposed. Out of six symmetry classes [4], three make sure that the required cancellation takes place. Physically viable models usually introduce soft breaking of those symmetries [5]. In such cases the relaxation would still work, and the potential would be technically natural.

	m_{11}^2	m_{22}^2	m_{12}^2	λ_1	λ_2	λ_3	λ_4	λ_5	λ_6	λ_7
U(2)		m_{11}^2	0		λ_1		$\lambda_1-\lambda_3$	0	0	0
CP3		m_{11}^2	0		λ_1			$\lambda_1-\lambda_3-\lambda_4$	0	0
CP2		m_{11}^2	0		λ_1					$-\lambda_6$
U(1)			0					0	0	0
Z_2			0						0	0
CP1			real					real	real	real

References

[1] P. W. Graham, D. E. Kaplan and S. Rajendran, *Cosmological Relaxation of the Electroweak Scale*, Phys. Rev. Lett. **115** (2015) 221801 [arXiv:1504.07551].

[2] J. R. Espinosa, C. Grojean, G. Panico, A. Pomarol, O. Pujolàs and G. Servant, *Cosmological Higgs-Axion Interplay for a Naturally Small Electroweak Scale*, Phys. Rev. Lett. **115** (2015) 251803 [arXiv:1506.09217].

[3] Z. Lalak and A. Markiewicz, *Dynamical relaxation in 2HDM models*, [arXiv:1612.09128].

[4] I. P. Ivanov, *"Minkowski space structure of the Higgs potential in 2HDM. II. Minima, symmetries, and topology*, Phys. Rev. D **77** (2008) 015017 [arXiv:0710.3490].

[5] P. S. Bhupal Dev and A. Pilaftsis, *Maximally Symmetric Two Higgs Doublet Model with Natural Standard Model Alignment*, JHEP **1412** (2014) 024 Erratum: [JHEP **1511** (2015) 147] [arXiv:1408.3405].