SMEFT Oscillon

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Z. Drogosz (Krakow), E. Sfakianakis (Harvard), K. Slawinska (Krakow), AW
"Standard Model Effective Field Theory and Oscillons", 2607.23616

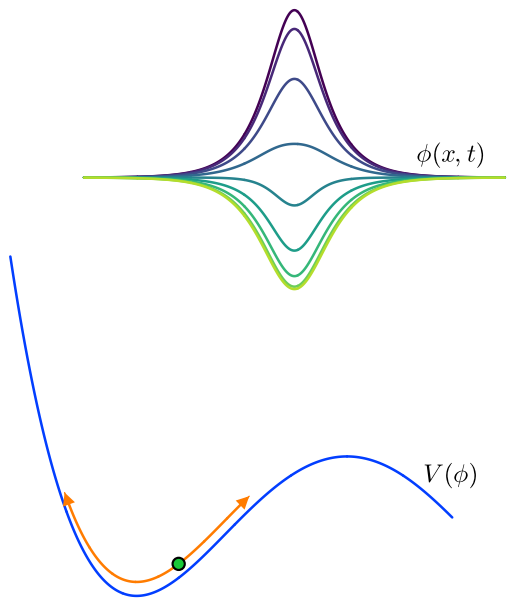
A. Alonso Izquierdo (Salamanca), A. Gonzalez-Parra (Salamanca), K. Slawinska (Krakow), AW, T. Winyard (Dundee)

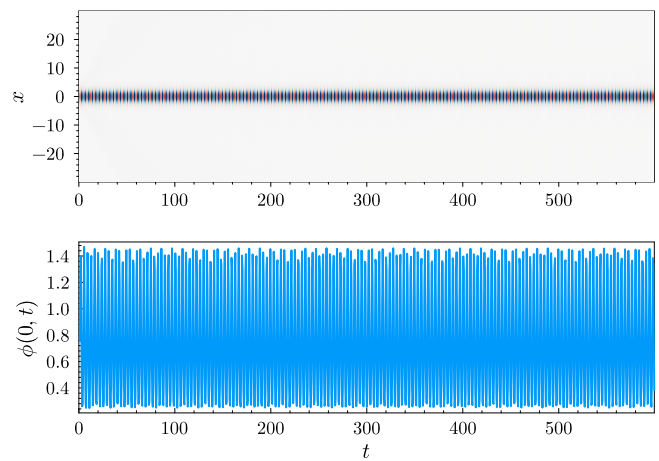
"Type I-II/II-I vortices from dimension-six self-interaction", 2610.17437

oscillons

oscillon - the most generic non-perturbative excitation in a non-linear field theory

- soliton-like excitation
  - non-perturbative, localized, particle-like
- quasi-periodic
  - permanent emission of radiation
  - but exponentially suppressed
- eventually unstable
  - but often **very long-lived** excitation
- generic
  - its existence does not rely on any topological argument or conserved Noether charges
  - nonlinearities $\rightarrow$ localized non-normalizable mode (e.g., threshold mode)





electroweak oscillons

- **no long-lived oscillon in the electroweak theory...**

  - long-lived oscillon requires $m_H = 2m_W$
  - $SU(2) \times U(1)$ and pure $SU(2)$ very similar
  - no long-lived oscillon beyond this point

  ...but the standard model is not the end of the story $\rightarrow$ New Physics

- **Standard Model Effective Field Theory**
  extends the Standard Model Lagrangian by higher-dimensional operators built from Standard Model fields and respecting the Standard Model gauge symmetries

$$\mathcal{L}_{\text{SMEFT}} = \mathcal{L}_{\text{SM}} + \sum_i \frac{c_i^{(6)}}{\Lambda^2} \mathcal{O}_i^{(6)} + \sum_i \frac{c_i^{(8)}}{\Lambda^4} \mathcal{O}_i^{(8)} + \cdots .$$

- ...so, can we find **long-lived oscillons in the SMEFT modified electroweak theory?**
  triggered by dimension-higher operators?

  here: (1) only one dimension-six operator

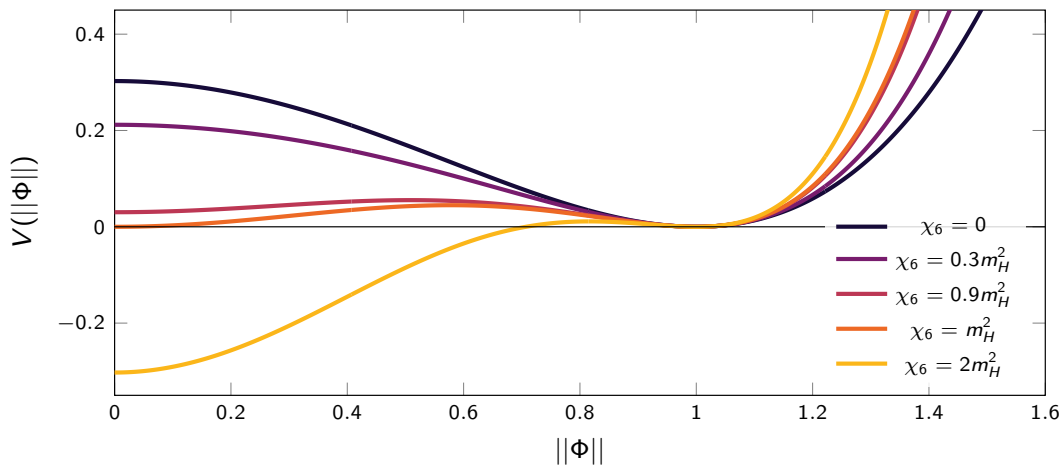
$$\mathcal{O}_6 = (\Phi^\dagger \Phi)^3,$$

  (2) only $SU(2)$ bosonic sector

the spherical $SU(2)$ SMEFT oscillons

- the operator $\mathcal{O}_6 = (\Phi^\dagger \Phi)^3$ changes the shape of the Higgs potential

$$V(\Phi^\dagger \Phi) = \frac{m_H^2}{8}(\Phi^\dagger \Phi - 1)^2 + \frac{\chi_6}{8}(\Phi^\dagger \Phi - 1)^3, \qquad m_W = 1,\ m_H = 1.556.$$



this can **affect non-perturbative field configurations in the electroweak sector.**

spherical oscillons

- the spherical ansatz parity odd / even contribution

$$W_0^a(\mathbf{x},t) = \frac{1}{g}G(r,t)\frac{x^a}{r} = 0 \quad \text{gauge choice}$$

$$W_j^a(\mathbf{x},t) = \frac{1}{g}\left[\frac{f_A(r,t)-1}{r^2}\epsilon_{jam}x^m + \frac{f_B(r,t)}{r^3}\left(r^2\delta_{ja} - x_j x_a\right) + \frac{f_C(r,t)}{r^2}x_j x_a\right],$$

$$\Phi(\mathbf{x},t) = \frac{v}{\sqrt{2}}\left[H(r,t) + iK(r,t)\frac{\tau\cdot\mathbf{x}}{r}\right]\begin{pmatrix}0\\1\end{pmatrix}.$$

- initial data

$$K(r,0) = 1 - 2e^{-r^2/R_0^2},$$

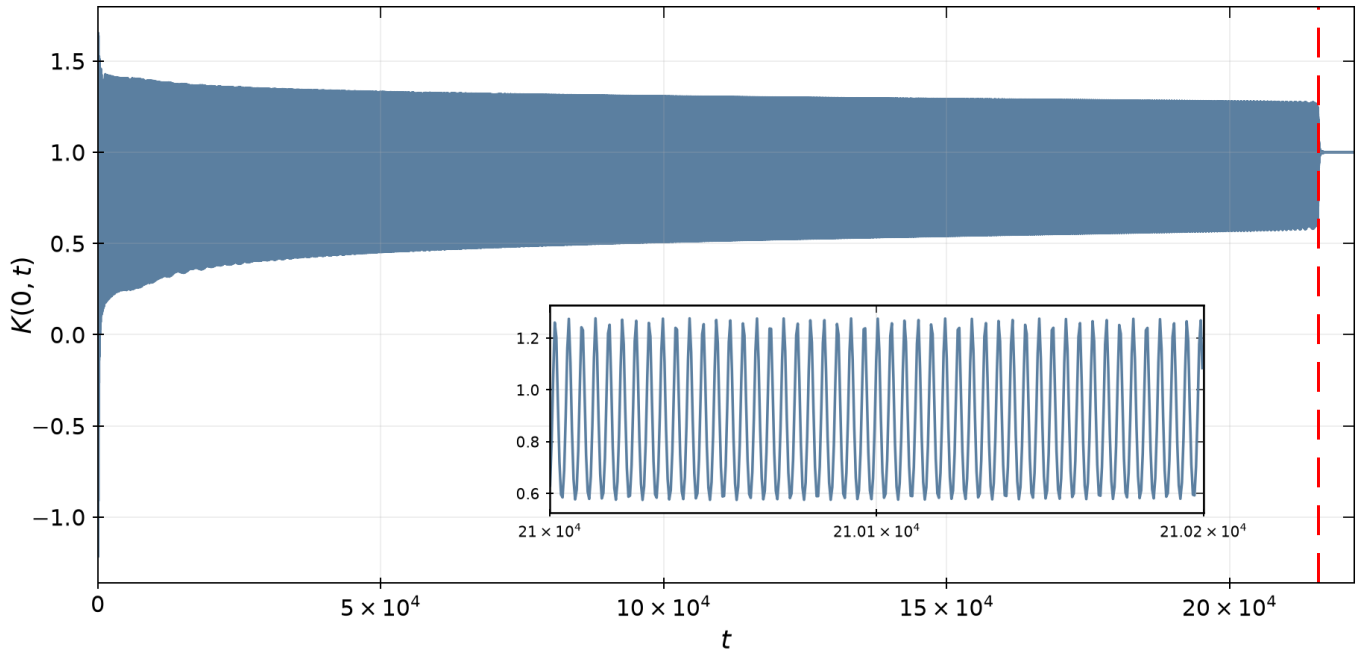
$$H(r,0) = -A_H\frac{r}{R_H}e^{-r^2/R_H^2}.$$

$\rightarrow$ through the coupled equations, this excites the remaining components of the spherical ansatz

$\rightarrow$ use the gauge symmetry to restore $G = 0$ via the Gauss law

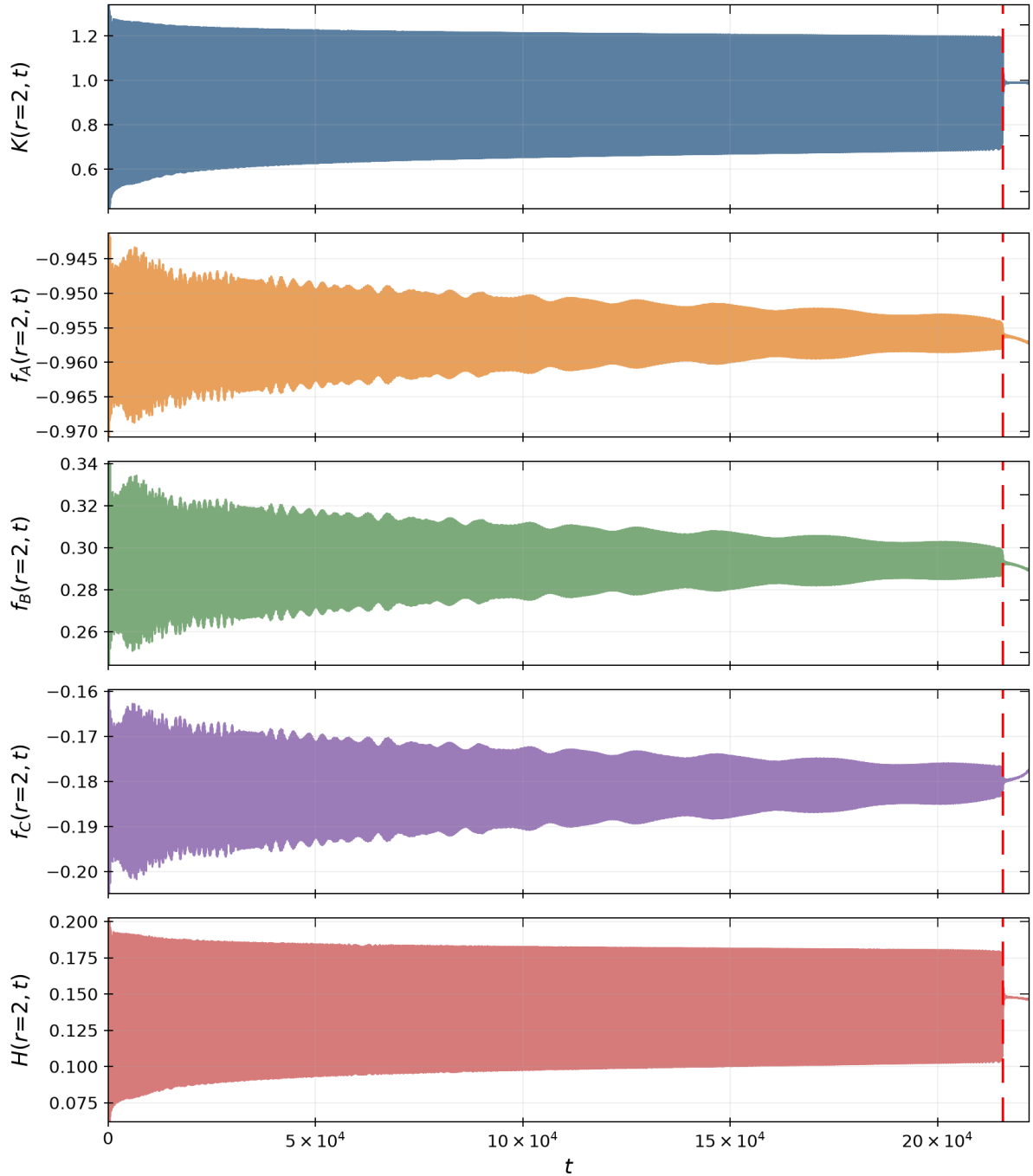
spherical oscillon

- **there are long-lived oscillons** e.g., $\chi_6/m_H^2 = 0.4$.

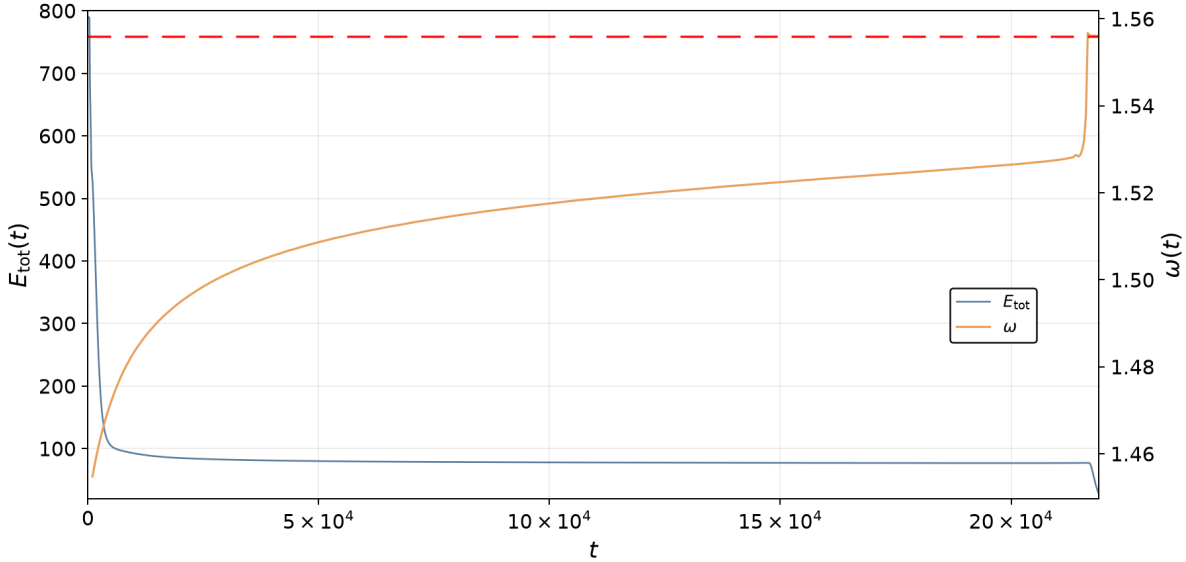


- **long-lived oscillons**
  all five fields evolve
  $\tau \approx 2.2 \times 10^5$

spherical oscillon



spherical oscillon



$m_H > \omega \approx 1.5 > m_W$

- energy of the oscillon $E_{osc} = 88 - 79$ i.e., $E_{osc} = 7.0 - 6.3$ TeV
  $E_{init} = 798$
- still **large basin of attraction for oscillon formation**
- **the oscillon lighter than sphaleron** $E_{sph} \approx 9$ TeV
- **long-lived oscillon in physically allowed regime** $\chi_6/m_H^2 < 0.5$

there is a long-lived oscillon for $m_H/m_W = 1.556$ in the SMEFT (minimal) extension of the SM

what is its impact on the phenomenology?

- **a new chanel in the sphaleron decay**

SMEFT sphaleron

- **the same EoM model**

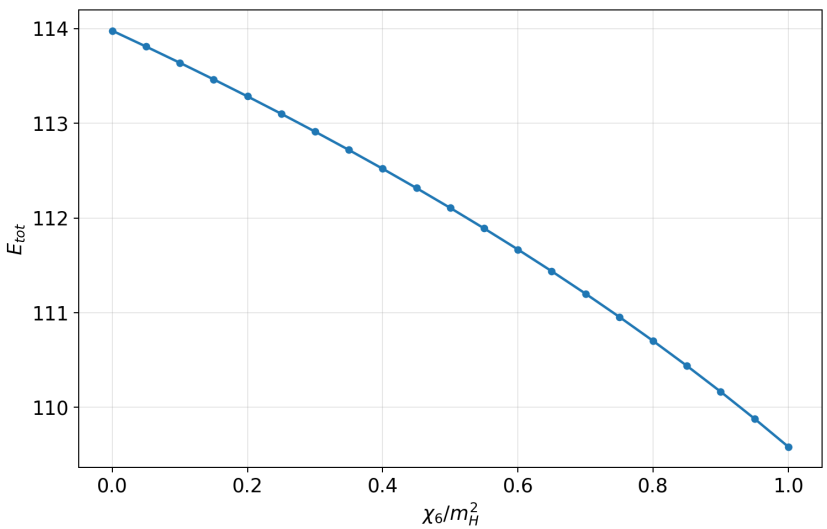
  to the ground state sphaleron: K, f_A fields

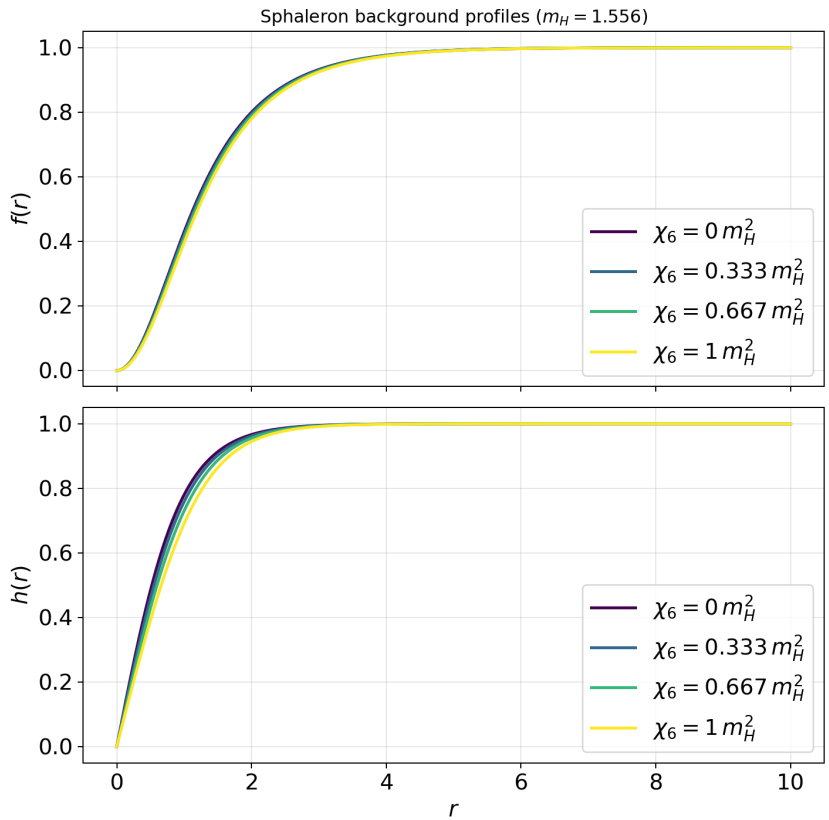
  $\rightarrow$ different boundary conditions to provide $N_{CS} = 1$

$$K(0) = 0 \quad K(\infty) = 1, \quad f_A(0) = 1, \quad f_A(\infty) = -1$$

- **very small change of static properties of the sphaleron**

  $\rightarrow$ shape and energy almost the same
  $(f = 1 - f_A,\ h = K)$



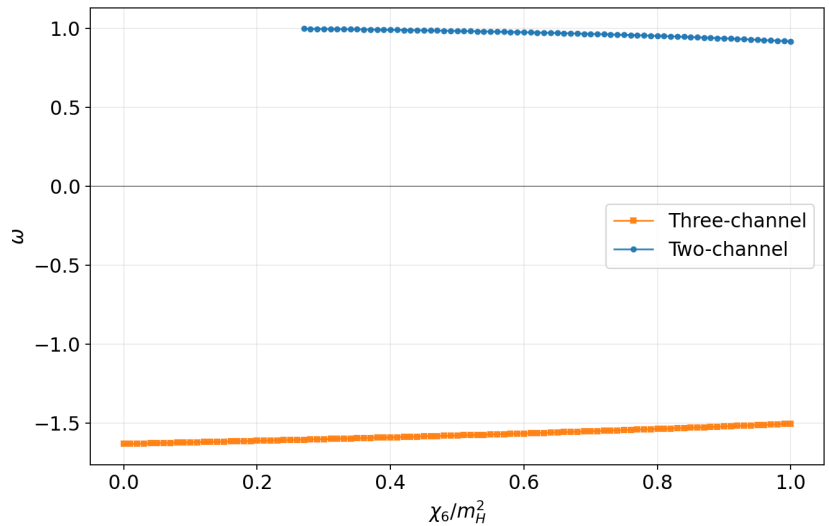


- **important modification of the spectral structure**

  $\rightarrow$ small perturbation of the sphaleron

$$a = \delta f_A, \qquad q = \sqrt{2}\, r\, \delta K, \qquad b = \delta f_B, \qquad c = \frac{r}{\sqrt{2}}\, \delta f_C, \qquad k = \sqrt{2}\, r\, \delta H$$

five-channel problem $\rightarrow$ odd 2-channel (K, f_A) $\times$ even 3-channel (H, f_B, f_C)



- small change in the negative mode flow
- **bound mode** $\chi_6 > 0.25 m_H^2$
- **a new decay channel decay into the oscillon**

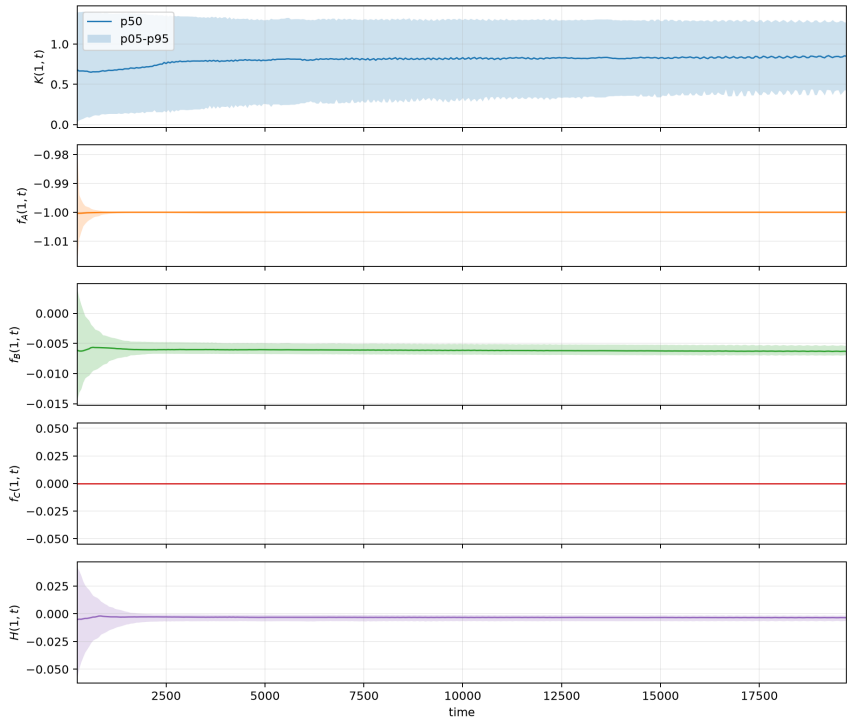
  $\rightarrow$ if there is the bound mode (preliminary result)

  $\rightarrow$ for rather strong perturbation (preliminary result)

- **decay into the oscillon**

  initial configuration

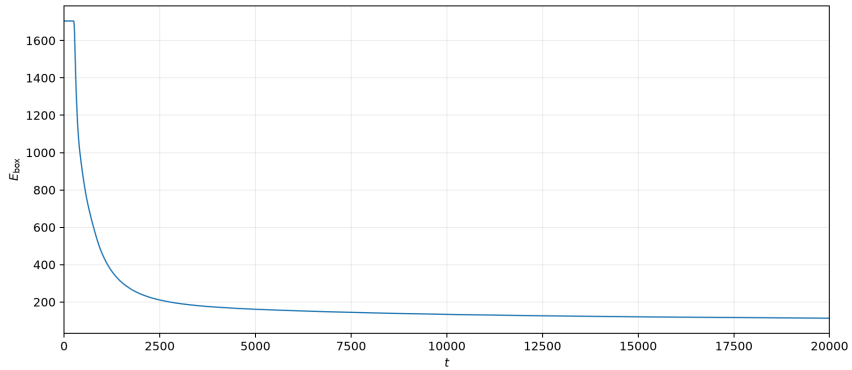
$$(f_A, K)(r,t) = \text{sphaleron} + \left(A_+ \cos(\omega t) + \frac{V}{\omega}\sin(\omega t)\right)\eta_{\text{shape}}, \quad (f_B, f_C, H) = A_-\,\eta_{\text{unstable}}$$



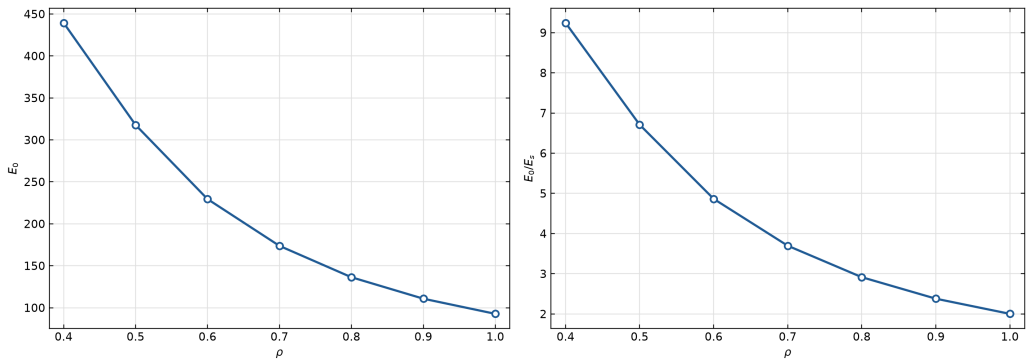
$\chi_6 = 0.3m_H^2, \quad A_- = -10^{-4}, A_+ = 6, V = -8$

- **rather strong perturbation**

energy evolution



lowest energy initial configuration that evolves to the oscillon $\rho = \chi_6 / m_H^2$



conclusions

- there is a long-lived oscillon for $m_H/m_W = 1.556$ in the SMEFT (minimal) extension of the SM

  $\rightarrow$ it exists in physically allowed regime $\chi_6/m_H^2 < 0.5$

  $\rightarrow$ large basin of attraction for oscillon formation

  $\rightarrow$ the oscillon lighter than sphaleron $Eosc \approx 7$ TeV vs. $E_{sph} \approx 9$ TeV

  $\rightarrow$ the sphaleron can decay into the oscillon....but it is a very energetic perturbation

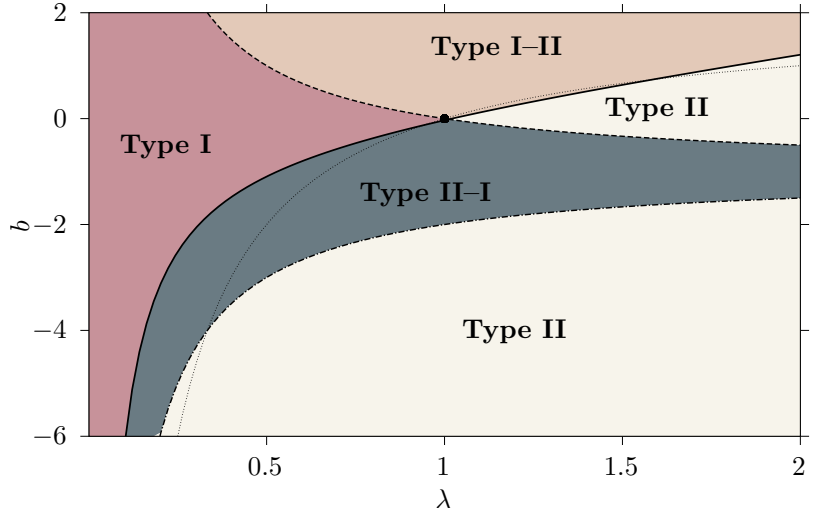
- $\mathcal{O}_6 = (\Phi^\dagger \Phi)^3$ can also changes the EW vacuum structure

  $\rightarrow$ new vortex phases in the Abelian-Higgs model with ϕ^6 interaction term

  $\rightarrow$ modification of the Ambjorn-Olesen vacuum at large $\vec{B}_{ext}$

new phases of AH vortices + ϕ^6

- **type I-II and II-I vortices** non-monotonic forces



- **vortices with nontrivial inner structure** type II-I

