# Curved spacetime Effective Field Theory (cEFT) as a tool to investigate vacuum stability

Łukasz A. Nakonieczny

**Based on the Ł. Nakonieczny, A. Nakonieczna, Z. Lalak arXiv:2004.12327.**

University of Warsaw, Faculty of Physics

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# Outline

1. Effective Field Theory – general overview
   - Why or when to use a EFT?
2. Curved spacetime Effective Field Theory – cEFT
   - Method of construction
   - cEFT and vacuum stability
3. Conclusions

# EFT in particle physics

Effective Field Theory as a way to look for either the new physics or better understanding of the old one.

Effective Field Theory is useful when:

- we do not have all the data
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Way of construction of EFT

- bottom-up
- top-down

The Standard Model of particle physics contains operators of the dimension up to four.

New physics may be encoded by operators with dimension higher than four.

# cEFT step by step

$S_{UV}(\phi, \Phi)$

$S_{UV}^{light}(\phi)$

$$S_{UV} = \int \sqrt{-g}\, d^4x \Big\{ -\frac{1}{2} d_\mu h d^\mu h - \frac{1}{2} m_H^2 h^2 - \frac{\lambda_H}{4!} h^4 - a_3 h^3 - \xi_H R h^2 + $$
$$ -\frac{1}{2} d_\mu X d^\mu X - \frac{1}{2} m_X^2 X^2 - \xi_X R X^2 - \frac{1}{2} \lambda_{HX} X^2 h^2 \Big\}$$

$S_{UV}^{heavy}(\Phi)$

$S_{UV}^{light,heavy}(\phi, \Phi)$

# cEFT step by step

$S_{cEFT}(\phi)$

$S^{light}(\phi)$

$$S_{cEFT} = \int \sqrt{-g}\, d^4x \Big\{ -\frac{1}{2} d_\mu h d^\mu h - \frac{1}{2} m_H^2 h^2 - \frac{\lambda_H}{4!} h^4 - a_3 h^3 - \xi_H R h^2 +$$

$$- \frac{1}{2} c_{dHdH} d_\mu h^2 d^\mu h^2 - c_{GHH} G^{\mu\nu} d_\mu h^2 d_\nu h^2 + - c_H h^2 - c_{HH} R h^4 - c_6 h^6 \Big\}$$

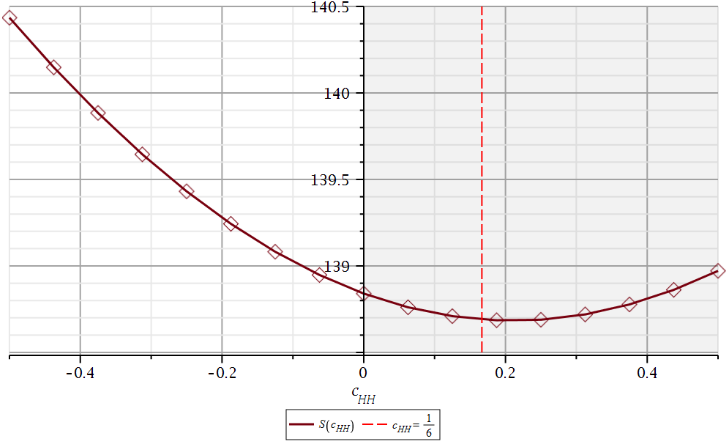
$$S^{light,heavy}(\phi, \Phi)_{|\Phi=\Phi_{cl}(\phi)} + \frac{i\hbar}{2} c_s \ln sdet \left(\mu^{-2} D_{ij}^2\right)_{|\Phi=\Phi_{cl}(\phi)}$$

$$\mathcal{S}^{Lorentzian} \xrightarrow{\text{Wick rotate}} \mathcal{S}^{Euc} \rightarrow EOM \rightarrow \mathcal{S}^{Euc}_{on-shell}$$

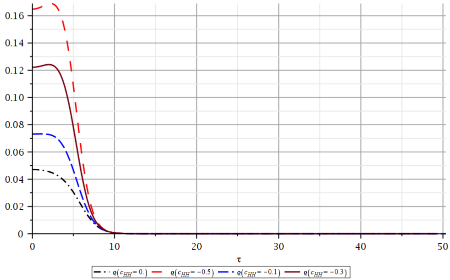
**Probability of the false vacuum decay in the instanton method**

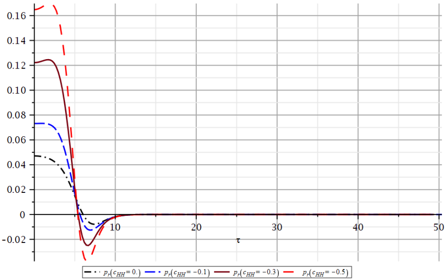
$$\Gamma = \mathcal{A} e^{-\mathcal{S}^{Euc}_{on-shell}}.$$

*S. R. Coleman, 'The Fate of the False Vacuum. 1. Semiclassical Theory', Phys. Rev. D 15 (1977) 2929–2936. [Erratum: Phys.Rev.D 16, 1248 (1977)].*
*S. Coleman and F. De Luccia, 'Gravitational effects on and of vacuum decay', Phys. Rev. D 21 (Jun, 1980) 3305–3315.*




The action calculated on solutions of EOM as functions of $c_{HH}$. The remaining parameters are
$\bar{M}_{Pl}^2 = 10^2, \lambda_H = 6.0, \xi_H = 0.0, m_H^2 = 0.2, a_3 = -0.4, c_6 = c_{dHdH} = 0.0, c_0 = 0.0.$




Energy densities (left) $\rho \equiv \dfrac{\overline{M}_{Pl}^2}{\kappa(h)} \overline{T}^{\tau}{}_{\tau}$ and pressure (right) $p_r \equiv \dfrac{\overline{M}_{Pl}^2}{\kappa(h)} \overline{T}^{\psi}{}_{\psi}$ for various $\xi_H$.
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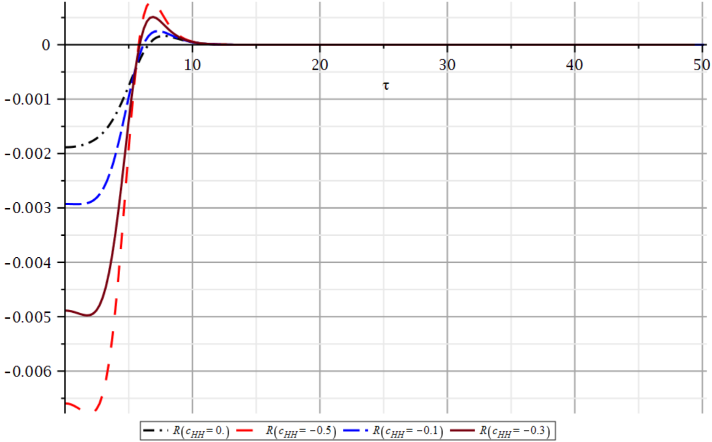
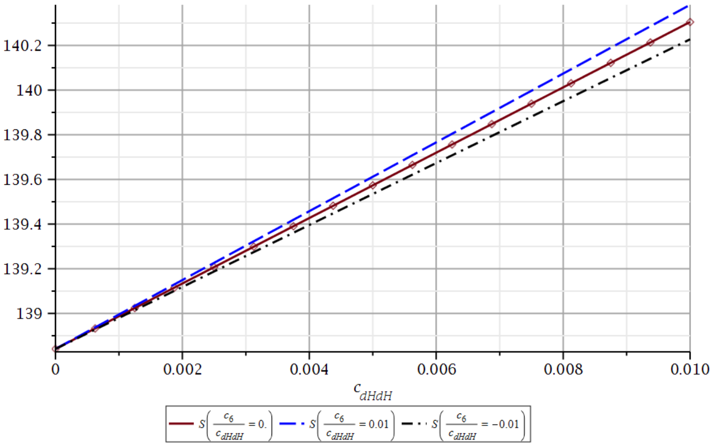



The Ricci scalar $R$ for various $\xi_H$. The remaining parameters are $\bar{M}_{Pl}^2 = 10^2, \lambda_H = 6.0, m_H^2 = 0.2, \xi_H = 0.0, a_3 = -0.4, c_6 = c_{dHdH} = 0.0, c_0 = 0.0$




The action calculated on EOM for various $c_{dHdH}$ and $c_6$. The remaining parameters are $\bar{M}_{Pl}^2 = 10^2, \lambda_H = 6.0, m_H^2 = 0.2, a_3 = -0.4, \xi_H = 0, c_0 = 0.0$.

# Conclusions

- The cEFT is a useful tool to capture the influence of gravity mediated operators on the false vacuum stability.
- Presence of the non-minimal coupling type operators may stabilize the false vacuum.
- Presence of dimension six operators contributing to the kinetic term of the light field leads to the false vacuum stabilization.

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Thank you for your attention.

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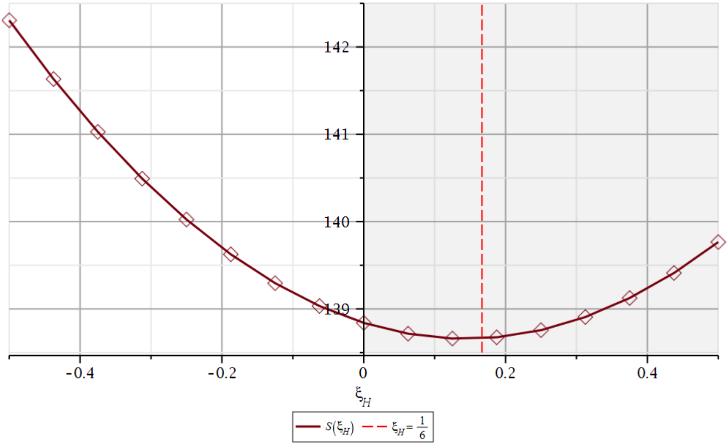
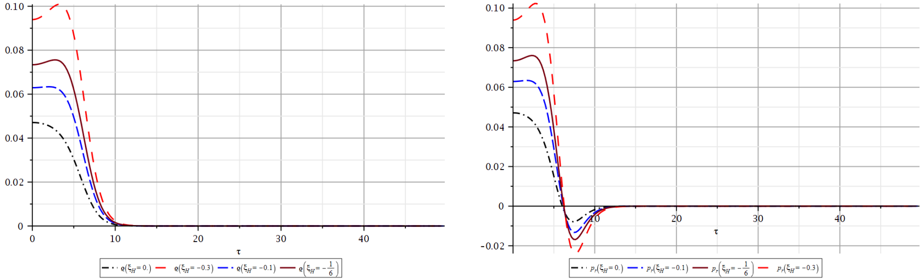



The action calculated on solutions of EOM as functions of $\xi_H$. The remaining parameters are $\bar{M}_{Pl}^2 = 10^2$, $\lambda_H = 6.0$, $m_H^2 = 0.2$, $a_3 = -0.4$, $c_{HH} = 0$, $c_6 = c_{dHdH} = 0.0$, $c_0 = 0.0$.

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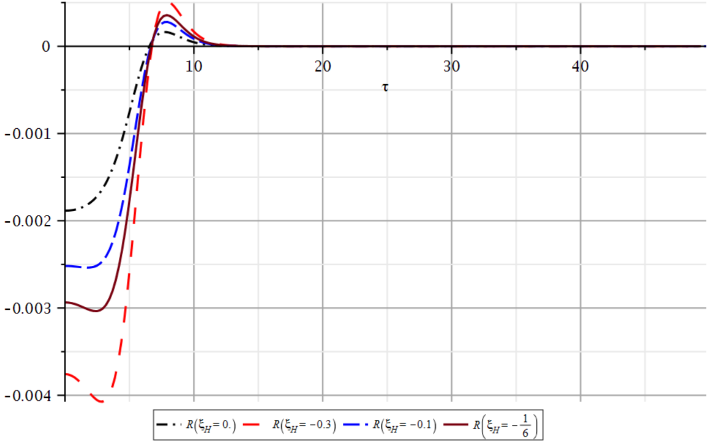


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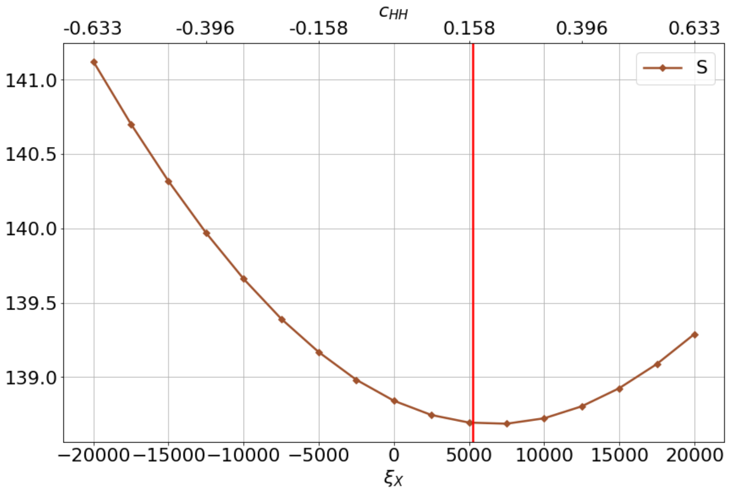
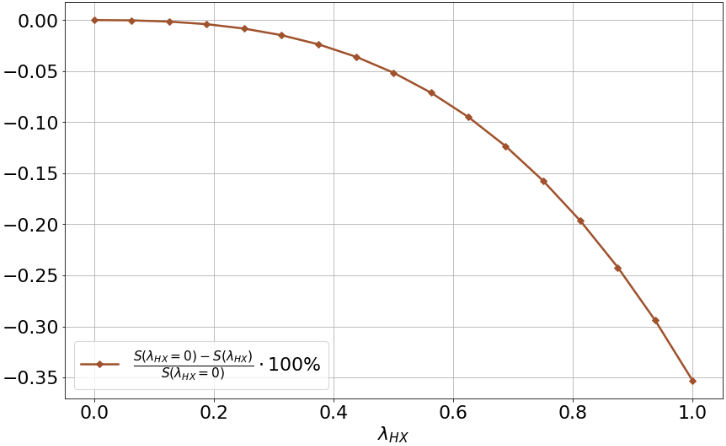



Influence of the $\xi_X$ on the false vacuum decay exponent. The remaining parameters are $\bar{M}_{Pl}^2 = 10^2$, $\lambda_H = 6.0$, $m_H^2 = 0.2$, $a_3 = -0.4$, $c_0 = 0.0$ and
$\lambda_{HX} = 0.1$, $c_{HH} = \frac{3\lambda_{HX}^2}{12(4\pi)^2}(2\xi_x - \frac{1}{6})$, $c_6 = \frac{\lambda_{HX}^3}{12(4\pi)^2}$, $c_{dHdH} = \frac{\lambda_{HX}^2}{12(4\pi)^2}$.




Influence of the $\lambda_{HX}$ on the false vacuum decay exponent. The remaining parameters are $\bar{M}_{Pl}^2 = 10^2$, $\lambda_H = 6.0$, $m_H^2 = 0.2$, $a_3 = -0.4$, $c_0 = 0.0$ and

$$\xi_X = -1,\ c_{HH} = \frac{3\lambda_{HX}^2}{12(4\pi)^2}(2\xi_x - \frac{1}{6}),\ c_6 = \frac{\lambda_{HX}^3}{12(4\pi)^2},\ c_{dHdH} = \frac{\lambda_{HX}^2}{12(4\pi)^2}.$$