

Poster prizes

Congratulations to all!

The jury had a very hard time...

Suspense...

Third prize: Fabio Bernardo & Philipp Schicho


UNIVERSITÉ DE GENÈVE


Swiss National Foundation

Limits of EFTs at finite temperatures

strong EFTs phase transitions

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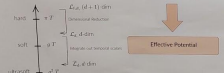
Introduction

Phase transitions are vibrant and interesting phenomena that could have occurred in the early stage of the Universe, interesting a great natural-world quest. The main parameters from which we can reconstruct the gravitational signal of these phenomena are a transition strength, $\Delta\epsilon$, a transition scale, Λ , a critical temperature and μ_c , bubble wall velocity. One of the main ingredients to determine these is the **Effective Potential** built as an energy density, of a scale field background.

$$m_{eff}^2 = -\frac{\partial^2 V_{eff}}{\partial \phi^2} = \int_{\mathcal{D}_d} d^d x \left(-\partial_\mu \phi - \partial_\mu (\phi + \delta) \right) \quad (1)$$

When the temperature is close to its critical value T_c , at which the phase transition occurs, it is possible to identify a hierarchy of scales, which allows the construction of Effective Field Theories (EFTs) by integrating out the larger scales.

Figure 1: An example of a **perturbative** **renormalization group** (RG) flow, which consists of two steps: the **renormalization** **decomposition** into the different components of a **3-dimensional EFT**, as they provide to construct the **Effective Potential** (EFTs) by integrating out scale heavy modes. The **renormalized** **beta function** of the **renormalized** **coupling** is then used to determine the scale of the **renormalized** **coupling**, which is then used to determine the scale of the **renormalized** **coupling**.



The limits of the EFT approach

The EFT provides valuable insights as long as the main parameters are included in the tracing steps. However, when the construction of **higher-dimensional operators** is required, these operators are not included in the EFT. Therefore, when the construction of **higher-dimensional operators** is required, these operators are not included in the EFT. Therefore, when the construction of **higher-dimensional operators** is required, these operators are not included in the EFT.

Figure 2: An example of the EFT approach for the following effective potential:

$$V_{eff}(\phi) = \frac{1}{2} m^2 \phi^2 + \frac{1}{4} \lambda \phi^4 + \frac{1}{6} \lambda' \phi^6 + \dots$$

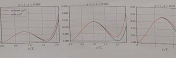


Figure 2: An example of the EFT approach for the following effective potential:

It is clear from Figure 2 that the EFT approach is not valid for the large values of the coupling λ . The effective potential $V_{eff}(\phi)$ is not bounded from below, and the effective potential $V_{eff}(\phi)$ is not bounded from below. The effective potential $V_{eff}(\phi)$ is not bounded from below, and the effective potential $V_{eff}(\phi)$ is not bounded from below. The effective potential $V_{eff}(\phi)$ is not bounded from below, and the effective potential $V_{eff}(\phi)$ is not bounded from below.

Figure 3: An example of the EFT approach for the following effective potential:

It is clear from Figure 3 that the EFT approach is not valid for the large values of the coupling λ . The effective potential $V_{eff}(\phi)$ is not bounded from below, and the effective potential $V_{eff}(\phi)$ is not bounded from below. The effective potential $V_{eff}(\phi)$ is not bounded from below, and the effective potential $V_{eff}(\phi)$ is not bounded from below.

Figure 4: An example of the EFT approach for the following effective potential:

It is clear from Figure 4 that the EFT approach is not valid for the large values of the coupling λ . The effective potential $V_{eff}(\phi)$ is not bounded from below, and the effective potential $V_{eff}(\phi)$ is not bounded from below. The effective potential $V_{eff}(\phi)$ is not bounded from below, and the effective potential $V_{eff}(\phi)$ is not bounded from below.

Figure 5: An example of the EFT approach for the following effective potential:

It is clear from Figure 5 that the EFT approach is not valid for the large values of the coupling λ . The effective potential $V_{eff}(\phi)$ is not bounded from below, and the effective potential $V_{eff}(\phi)$ is not bounded from below. The effective potential $V_{eff}(\phi)$ is not bounded from below, and the effective potential $V_{eff}(\phi)$ is not bounded from below.

Figure 6: An example of the EFT approach for the following effective potential:

It is clear from Figure 6 that the EFT approach is not valid for the large values of the coupling λ . The effective potential $V_{eff}(\phi)$ is not bounded from below, and the effective potential $V_{eff}(\phi)$ is not bounded from below. The effective potential $V_{eff}(\phi)$ is not bounded from below, and the effective potential $V_{eff}(\phi)$ is not bounded from below.

Figure 7: An example of the EFT approach for the following effective potential:

It is clear from Figure 7 that the EFT approach is not valid for the large values of the coupling λ . The effective potential $V_{eff}(\phi)$ is not bounded from below, and the effective potential $V_{eff}(\phi)$ is not bounded from below. The effective potential $V_{eff}(\phi)$ is not bounded from below, and the effective potential $V_{eff}(\phi)$ is not bounded from below.

Figure 8: An example of the EFT approach for the following effective potential:

It is clear from Figure 8 that the EFT approach is not valid for the large values of the coupling λ . The effective potential $V_{eff}(\phi)$ is not bounded from below, and the effective potential $V_{eff}(\phi)$ is not bounded from below. The effective potential $V_{eff}(\phi)$ is not bounded from below, and the effective potential $V_{eff}(\phi)$ is not bounded from below.

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- [1] F. Bernardi, P. Klotz, P. Schicho, T. Vi. Tenkanen, *Journal of High Energy Physics*, 2023.
- [2] F. Bernardi, P. Klotz, P. Schicho, T. Vi. Tenkanen, *Journal of High Energy Physics*, 2023.
- [3] F. Bernardi, P. Klotz, P. Schicho, T. Vi. Tenkanen, *Journal of High Energy Physics*, 2023.
- [4] F. Bernardi, P. Klotz, P. Schicho, T. Vi. Tenkanen, *Journal of High Energy Physics*, 2023.
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Abelian Higgs model

To test the validity of the EFT approach, we consider the case of a lightest Abelian Higgs model. This simple model shares features with many other, often more complex, models.

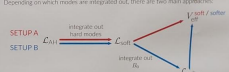
$$L = \frac{1}{2} (\partial_\mu \phi)^2 - \frac{1}{2} m^2 \phi^2 - \frac{1}{4} \lambda \phi^4 - \frac{1}{6} \lambda' \phi^6 - \dots$$

For a fixed coupling λ , we have:

- For $\lambda < 0$: $\phi = 0$ (trivial mode)
- For $\lambda > 0$: $\phi = \sqrt{m^2/\lambda}$ (non-trivial mode)
- For $\lambda < 0$: $\phi = 0$ (trivial mode)
- For $\lambda > 0$: $\phi = \sqrt{m^2/\lambda}$ (non-trivial mode)

Close to the critical point, the following hierarchy of scales emerges

Depending on which modes are integrated out, there are two main approaches:



Effects of higher-dimensional operators

By considering the effect of higher-dimensional operators,

$$V_{eff}(\phi) = \frac{1}{2} m^2 \phi^2 + \frac{1}{4} \lambda \phi^4 + \frac{1}{6} \lambda' \phi^6 + \dots$$

Figure 5 shows the effect of the ϕ^6 operator being relevant for small values of λ . The ϕ^6 operator is the dominant transition.

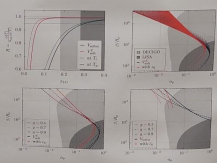


Figure 5: Plots of the effective potential

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Finite-temperature bubble nucleation with shifting scale hierarchies



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Classical scale invariant models

exhibit large interdependence with strong phase transitions since bare
reninist and low temperature

$$w(T) = [-\epsilon] \frac{1}{T} \quad (1)$$

and the field ϕ is trapped in the false vacuum ϕ_f for a long time until
perturbation with the temperature $T_c \ll T_c^*$

The new scale invariant exponential scalar (see) is much larger than
the Higgs v . Need RG improvement to find out what happens




Figure 1. RG improved potential for fermions $\psi = 0$. $M = (T - T_c)/T_c$

Split temperature into high- and low temperature regimes

- High- T : Small field regime $M(T) \propto T$
- Low- T : Large field regime $M(T) \propto T^2$

ISM exponents will explain mass term. Example: $SU(2)_C \otimes M$.

$$V(\phi) = \frac{1}{2} \phi^2 + \frac{1}{4} \phi^4 + \frac{1}{6} \phi^6 + \dots \quad (2)$$

Scale shifting

in the last ~ 100 years by computing the full 1-loop statistical part

$$A_{\text{eff}} = -\frac{1}{2} \text{Tr} \ln \left(\frac{\partial^2 V(\phi)}{\partial \phi^2} \right) \times \frac{1}{2} \text{Tr} \ln \left(\frac{\partial^2 V(\phi)}{\partial \phi^2} \right) \quad (3)$$

with $\partial^2 V(\phi) = \frac{\partial^2 V(\phi)}{\partial \phi^2}$. The gauge scale fluctuation determinant
only should be computed on the leading order lattice solution ϕ_f

The Fluctuation determinants

can be determined by expanding in spherical harmonics

$$\frac{\partial^2 V(\phi)}{\partial \phi^2} = \frac{\partial^2 V(\phi)}{\partial \phi^2} \quad (4)$$

GeTand-Yaglom theorem: holomorphic nature of functional determinant
leads to natural scale invariance. Implications in Bubble nucleation
statistical scale invariance

$A_{\text{eff}} \propto \text{det} \Delta \propto \text{det} \Delta \propto \text{det} \Delta \propto \text{det} \Delta$

long for scaling system N^d and the cross to leading potential $V(\phi)$

Comparison of approximations to Γ

MD approximation between N^d and N^d with dimensionless
mass and N^d (GeV), driven by spatial gauge modes

Figure 3. Relative difference of exact value R_{rel} and Γ prediction Γ_{pred}




To determine the bubble nucleation rate Γ

the action is evaluated in the Ansatz ϕ_f with 4-loop temperature
factors into dynamical and statistical parts

$$\Gamma = A_{\text{eff}} + A_{\text{eff}} \quad (5)$$

with the naive estimates $A_{\text{eff}} \propto T^4$ and $A_{\text{eff}} \propto T^4 \ln T$

Since the escape point is at the high temperature regime T_c , there
Bubble-nucleation can be determined on 1D for nucleation Γ

Bubble tails causing trouble.

the effect of contribution to $\Delta \phi$ from scale shifters $\Gamma(M) \propto \phi^2$
in the form after EFT is modified. The nucleation EFT prescription [6]

- integrate over vector modes to obtain, their former contribution,
- include their contribution to the coefficient of ϕ^2 ,
- effective double-constant from the exponential of Γ .




Figure 4. The bubble for $M = 1$ (red)

Higher-order terms in the $\Delta \phi$ expansion are mandatory for
stable predictions for the exponential scale transitions

Derivative expansion and other important results

Full matrix contribution to $\Delta \phi$ explicitly requires results

Jacobian prefactor performs worse than a single Γ matrix

References:

- [1] G. 't Hooft, Nucl. Phys. B 190, 455 (1981)
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- [3] M. Kiekrlik, B. Świąteżewska, P. Schicho, T. V. I. Tankeev, J. van de Vlis, V. Waznev, U. Genciev, P. Hentski, C.ERN
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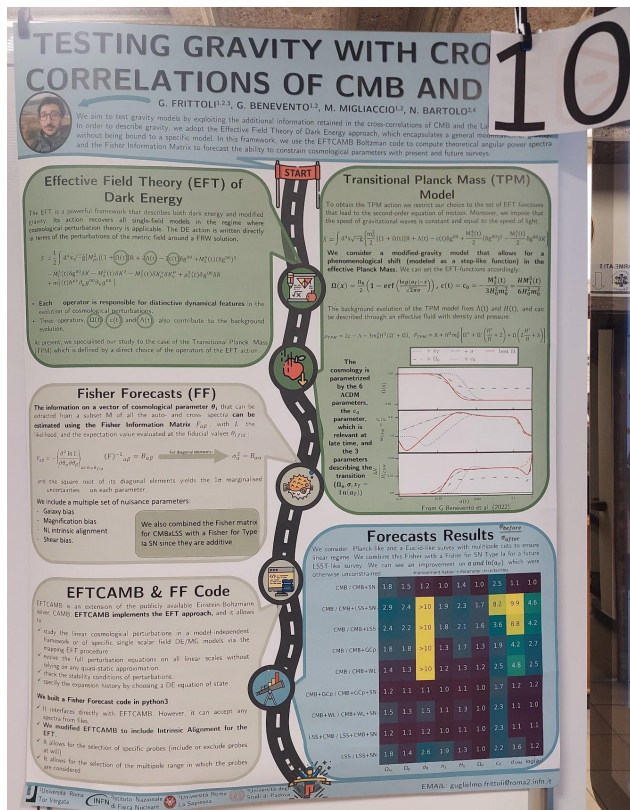
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Congratulations

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Second prize: Guglielmo Frittoli



Congratulations!

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Thank you for participating!



**Thank you for all the amazing
contributions!**

A big thank you to all!

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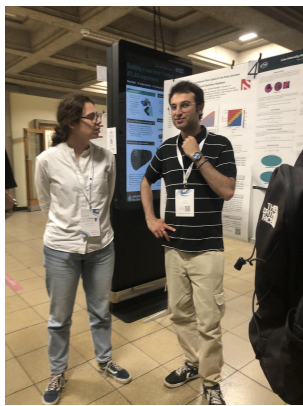
Corinne,
Angela

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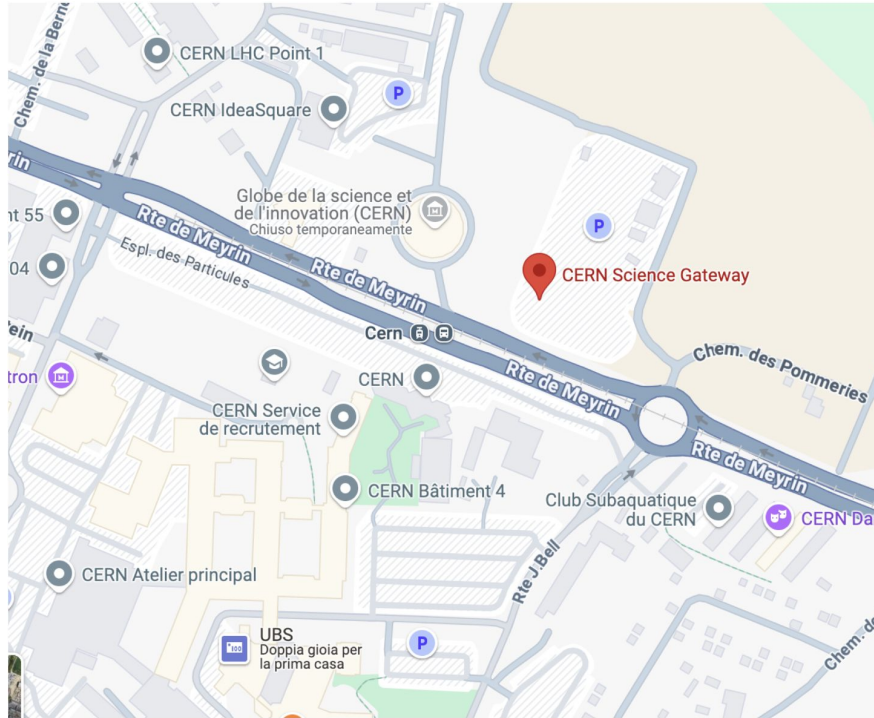






CERN tour

Meeting point at the CERN Science Gateway at 2:30pm



14:30 - 15:30 visit of the museum
15:30 - 16:00 collection of visitor badges
16:00 - 18:00 visit of the experimental sites