Composite Inflation

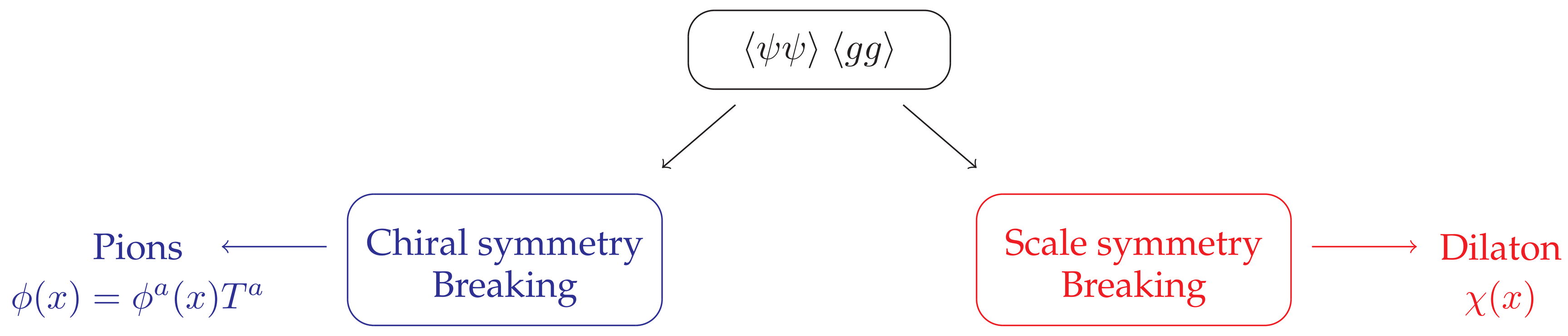
G. Cacciapaglia*, D. Cheong°, A. Deandrea*, W. Isnard*, S. Park°
* IP2I, Université Lyon 1, France
° Yonsei University, Seoul, Republic of Korea

Introduction

We consider the idea of a composite origin for inflation based on a fundamental gauge theories. Such theories are known to confine at low scales, leading to the spontaneous breaking of the chiral and scale symmetry. As a result, we get Nambu-Goldstone bosons in the form of pions and a light dilaton. The scale anomaly constrains the dilaton potential leading to specific features. We show that it naturally offers a flat direction useful to generate inflation in the early universe. Pions play a role in determining the effective potential for the dilaton and are necessary to ensure a timely end of inflation through a waterfall mechanism.

The Model

For concreteness, we consider a SU(N_c) gauge theory coupled to N_f Dirac fermions. In the IR, a fermion or gluon condensate can form $\langle\psi\psi\rangle\ \langle gg\rangle$, leading to the breaking of two global symmetries: the **chiral** and **scale** symmetry. Such models also exhibit a **walking dynamics**, which means that the gauge coupling α remains constant between the fermion mass scale m_f and the condensation scale Λ. This feature allows us to compute the scale anomaly and determine the dilaton potential.



The pions are usually parameterized in a non-linear form $U(x) = \exp\left(\frac{i\phi}{f_\phi}\right)$. The expansion of the chiral Lagrangian leads to the full expression :

$$\frac{\mathcal{L}}{\sqrt{-g}} \supset \frac{1}{2}R - \frac{1}{2}\partial_\mu\chi\partial^\mu\chi - \frac{f_\phi^2}{2}\left(\frac{\chi}{f_\chi}\right)^2 \mathrm{Tr}\left[\partial_\mu U^\dagger\partial^\mu U\right] - \frac{\lambda_\chi}{4}\chi^4\left(\log\frac{\chi}{f_\chi} - A\right) + \frac{\lambda_\chi\delta_1 f_\chi^4}{2}\left(\frac{\chi}{f_\chi}\right)^{3-\gamma_m}\mathrm{Tr}\left[U + U^\dagger\right] + \frac{\lambda_\chi\delta_2 f_\chi^4}{4}\left(\frac{\chi}{f_\chi}\right)^{2(3-\gamma_{4f})}\mathrm{Tr}\left[(U - U^\dagger)^2\right] - V_0.$$

Kinetic terms — Dilaton Potential — Pion mass — 4 Fermi interaction

We can set a few constraints on those parameters:

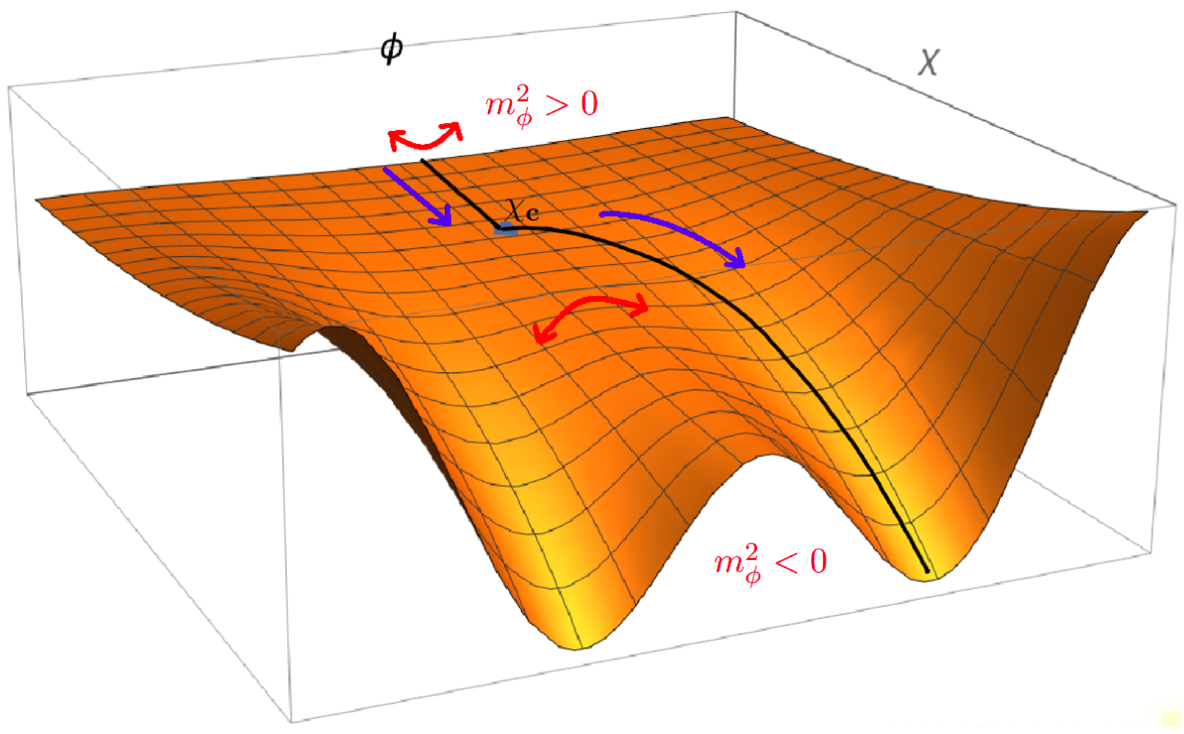
— **Lattice studies**: $0 < \gamma_m \leq 1$ and we also suppose $0 < \gamma_{4f} \leq 1$

— **Composite consistency**: $\max(\delta_1, \delta_2) \lesssim f_\phi^4/f_\chi^4\lambda_\chi$

Waterfall mechanism

From the previous Lagrangian we can derive the potential for inflation. For small χ values, we notice that the pions are kept in their minimum, reproducing a **single small-field inflation** for the dilaton χ. The inflaton rolls down the pion valley until a **critical value** χ_c where the pions develop a tachyonic mass. Due to the tachyonic instability, they act as waterfall fields and terminate inflation while the pion perturbations grow exponentially. In order to terminate inflation rapidely, this exponential growth must be compensated by the Hubble expansion, leading to:

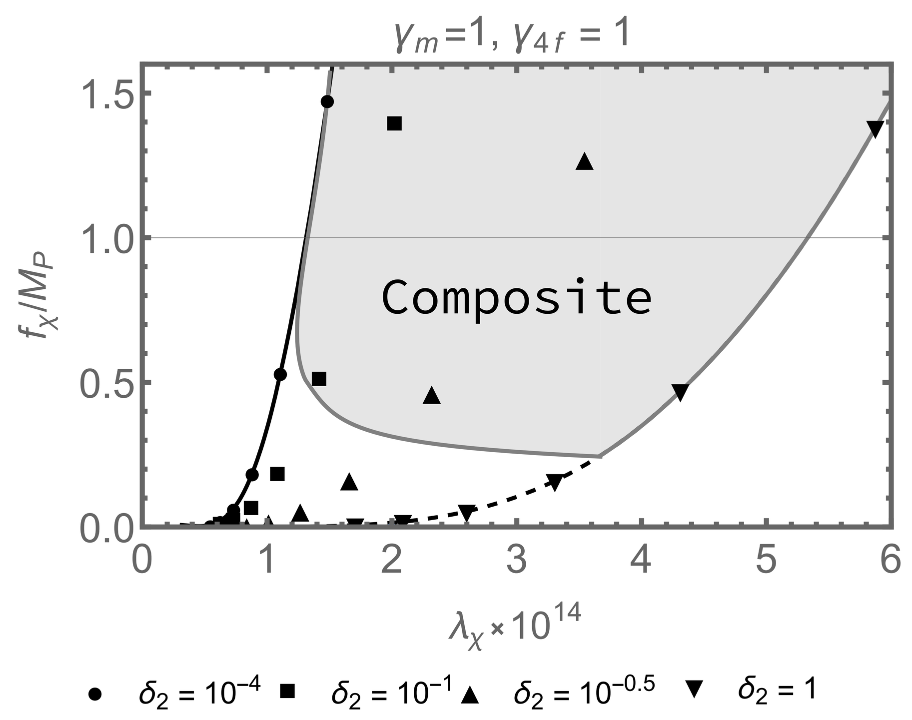
$$\left|m_\phi^2\right|_{\phi=0,\ \chi=\chi_c+\Delta\chi} \gg H^2$$

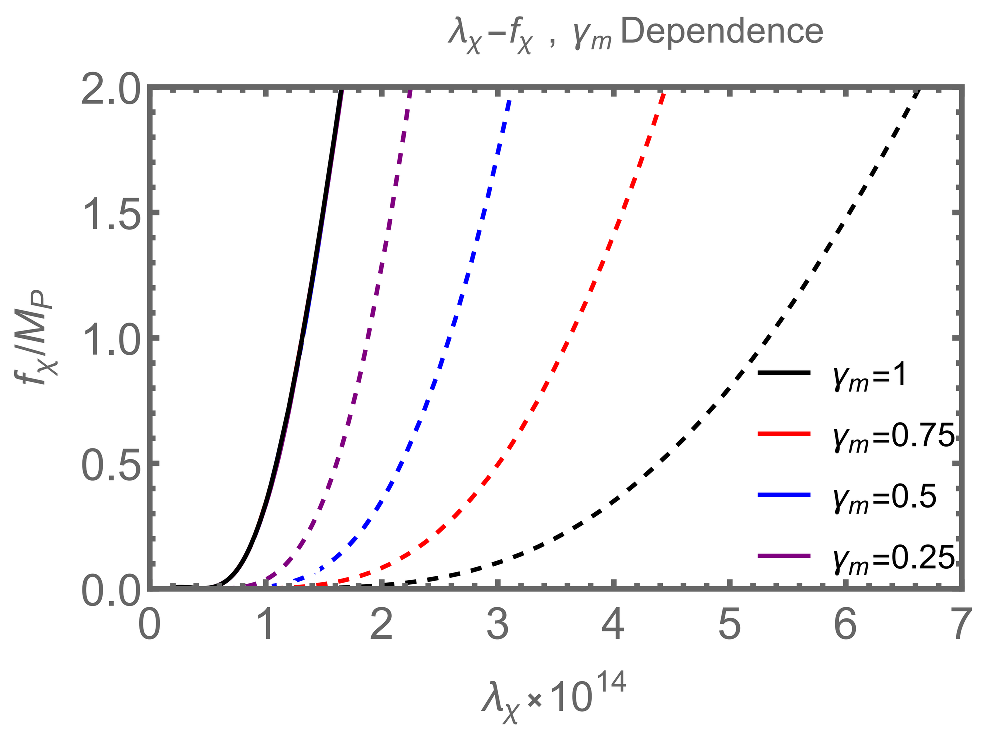


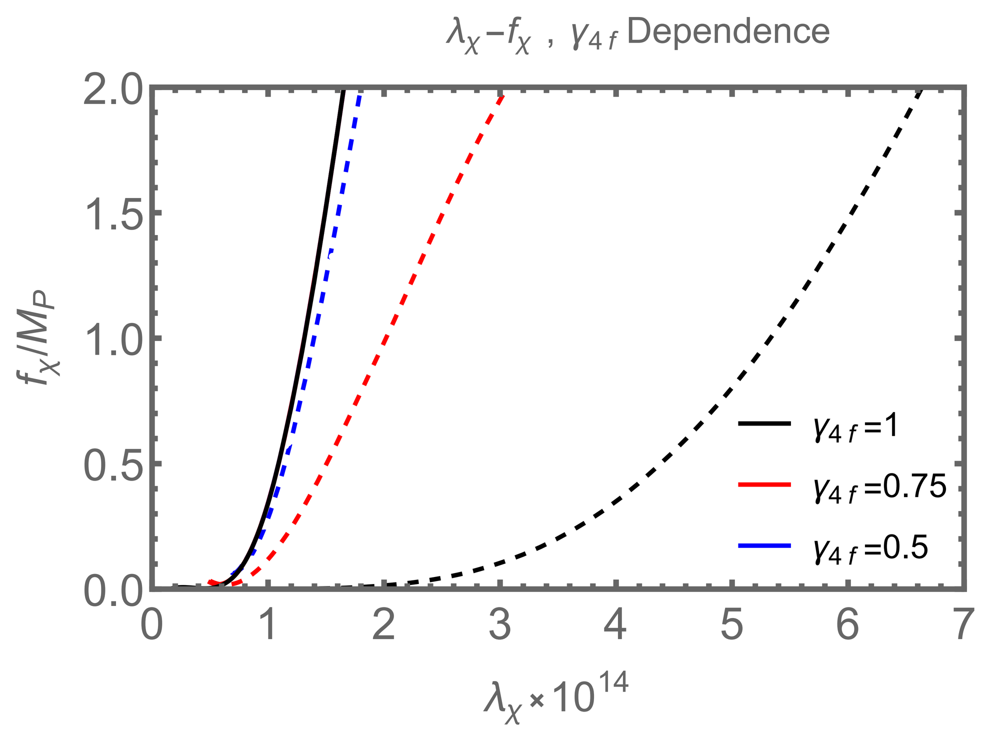
Parameter space

In the following χ^* corresponds to the pivot scale for the dilaton field. We have 5 parameters (δ_1, δ_2, λ_χ, f_χ, χ^*) and we can impose 3 constraints to satisfy the cosmological observations, leading to the following parameter space available to realize inflation:

$$\mathcal{P}_\zeta(k^*) = 2.1\times10^{-9}, \quad n_s = 0.965, \quad N_e = 50.$$







— Prediction for the inflationary scale: $m_\chi \sim 10^{11}$ GeV $m_\phi \sim 10^{14}$ GeV $H_{\rm inf} \sim 10^{10}$ GeV

References

[1] Giacomo Cacciapaglia, Dhong Yeon Cheong, Aldo Deandrea, Wanda Isnard, and Seong Chan Park. Composite hybrid inflation: Dilaton and waterfall pions, 2023.

[2] Giacomo Cacciapaglia, Claudio Pica, and Francesco Sannino. Fundamental Composite Dynamics: A Review. *Phys. Rept.*, 877:1–70, 2020.

[3] Hiroyuki Ishida and Shinya Matsuzaki. A Walking Dilaton Inflation. *Phys. Lett. B*, 804:135390, 2020.

Future work

— Reheating phase and couplings to the Standard Model

— Pions as Dark Matter

— Primordial Black Holes and Gravitational Waves production