Composite Inflation

"Walking Dilaton and Waterfall Pion"

Dhong Yeon Cheong (Yonsei University)

with Giacomo Cacciapaglia, Aldo Deandrea, Wanda Isnard, Seong Chan Park

G. Cacciapaglia, **DYC**, A. Deandrea, W. Isnard, S.C.Park (arXiv : 2306.xxxxx)

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연세대학교
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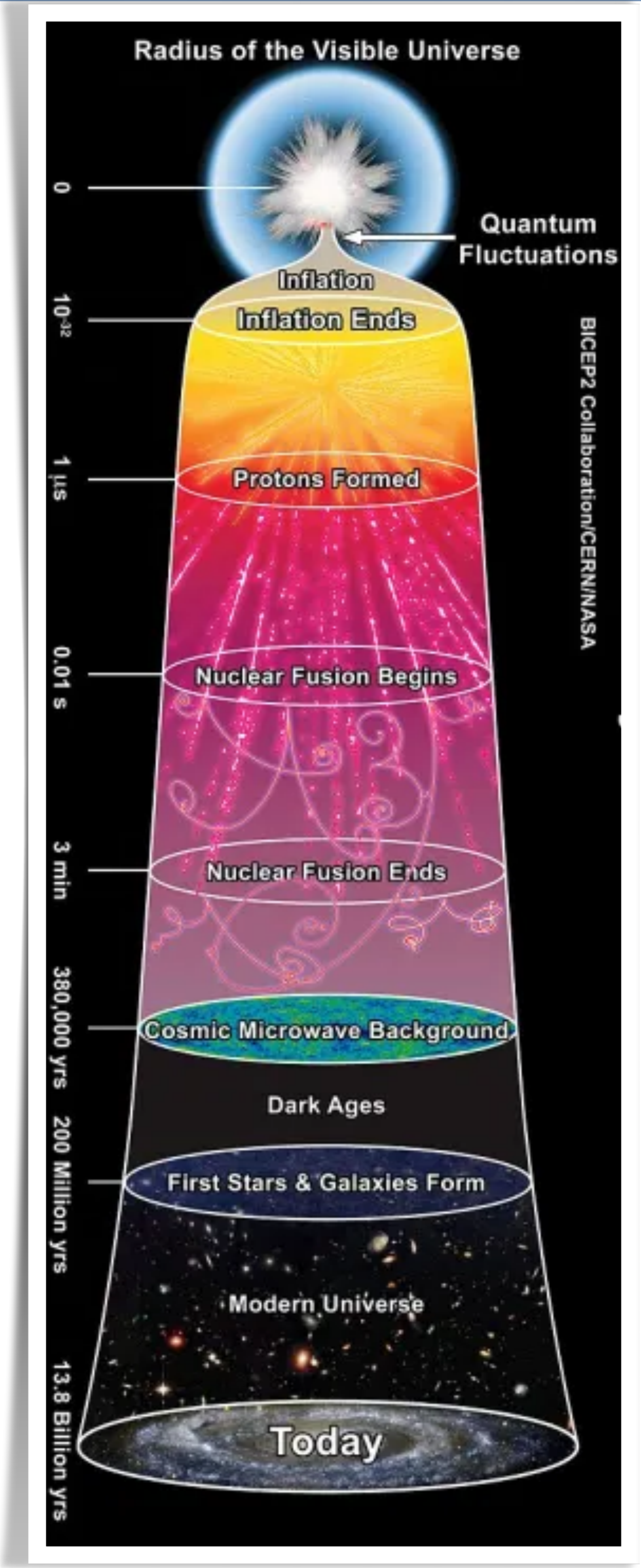
Content

Introduction



Initial Conditions for our Hot Big Bang

Horizon Problem

Flatness Problem

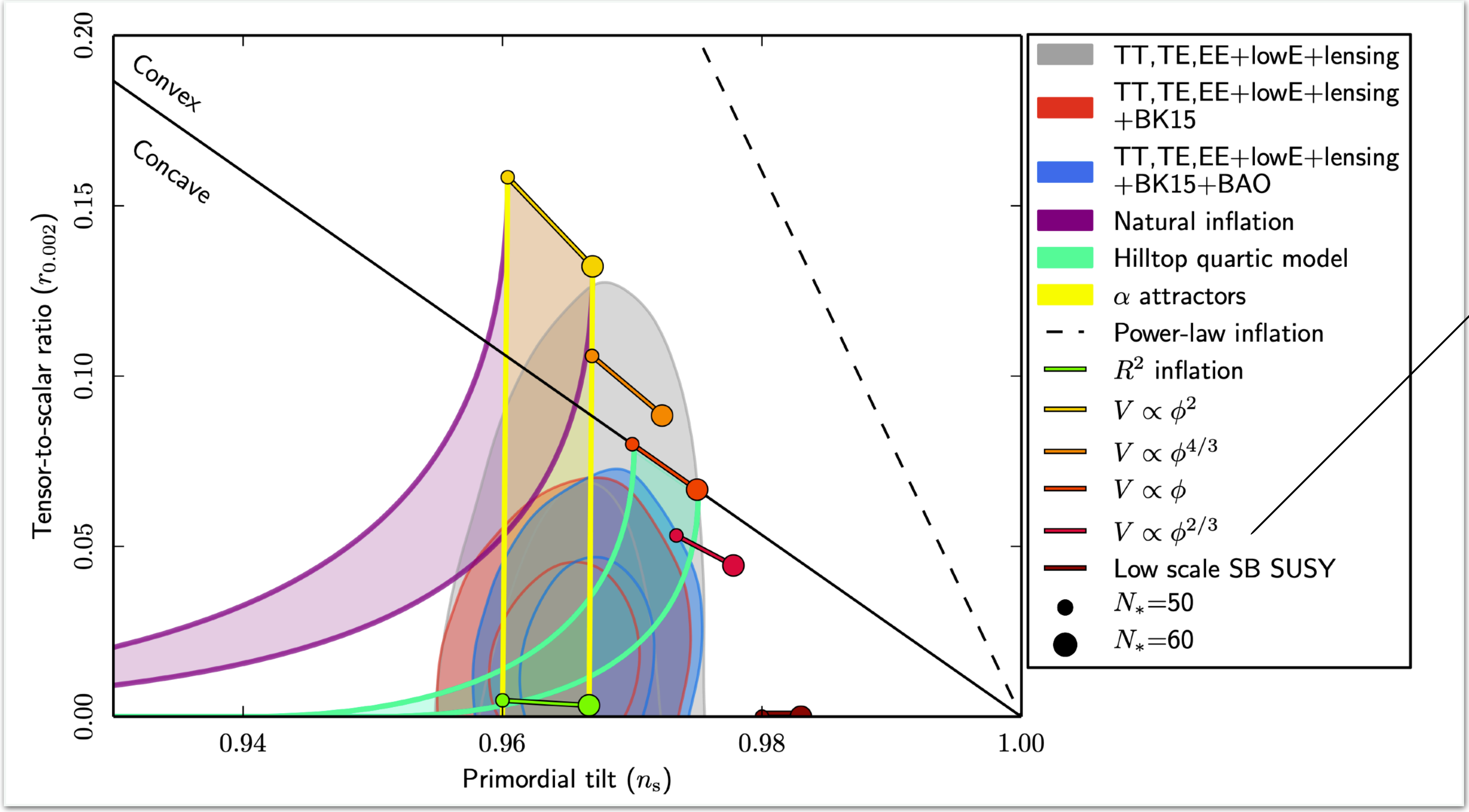
Inflation, "*Exponential Expansion*"

Duration : $N_e = \ln(a_e/a_*) \sim 60$

Quantum Fluctuations in CMB

Introduction

- CMB observations allow precision tests to inflationary models



[Planck Collaboration., arXiv:1807.06211]

Characterized by *slow-roll parameters*

$$\epsilon \equiv -\frac{\dot{H}}{H^2} = \frac{\dot{\phi}^2}{2H^2}$$

$$\eta \equiv -\frac{\ddot{\phi}}{\dot{\phi}H}$$

$$\mathscr{P}_{\mathscr{R}} \simeq \frac{V}{24\pi^2 M_P^4 \epsilon}$$

$$n_s \simeq 1 - 6\epsilon + 2\eta$$

$$r \simeq 16\epsilon$$

Introduction

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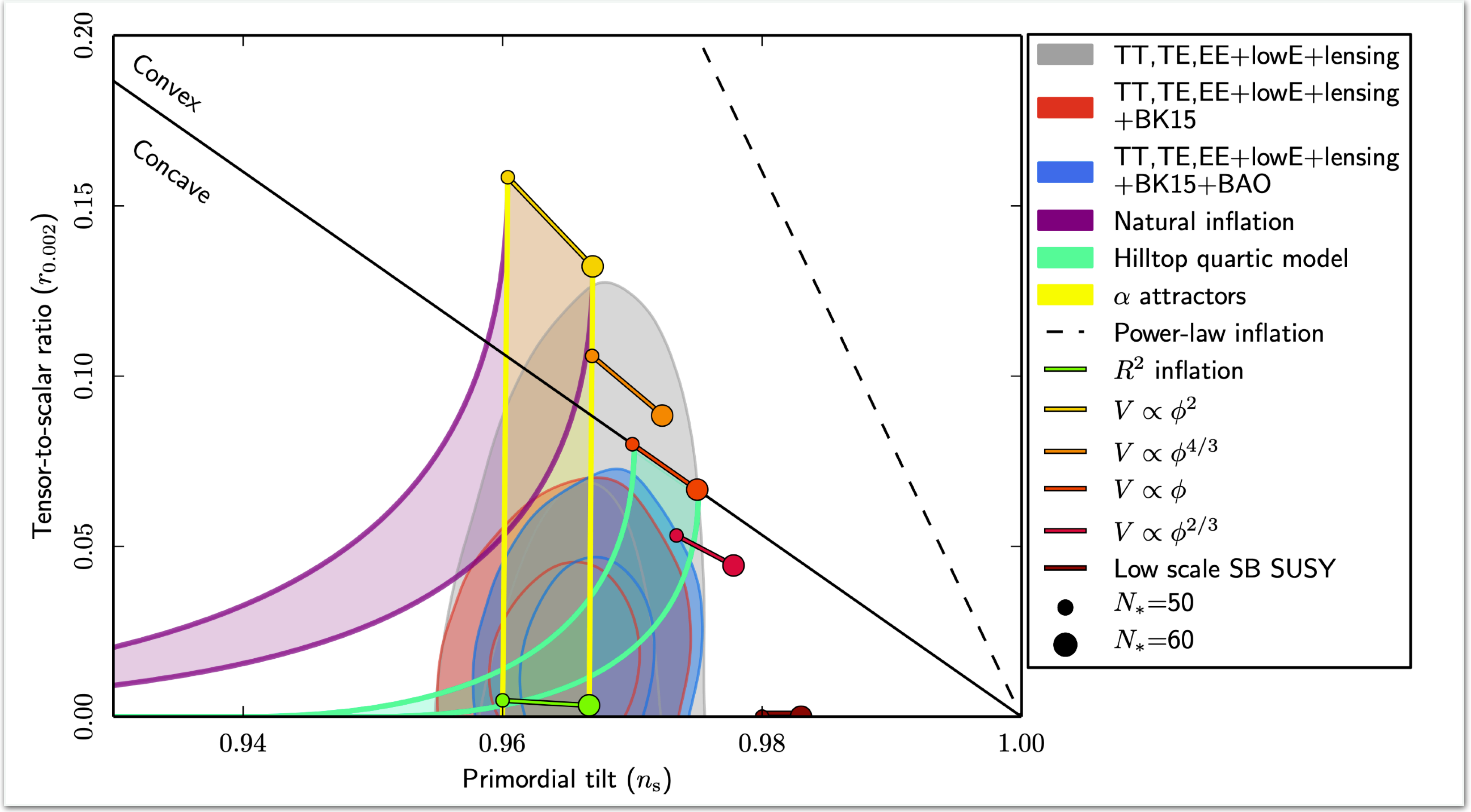

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Q) What is our inflaton?

Q) Phenomenology induced by inflation?

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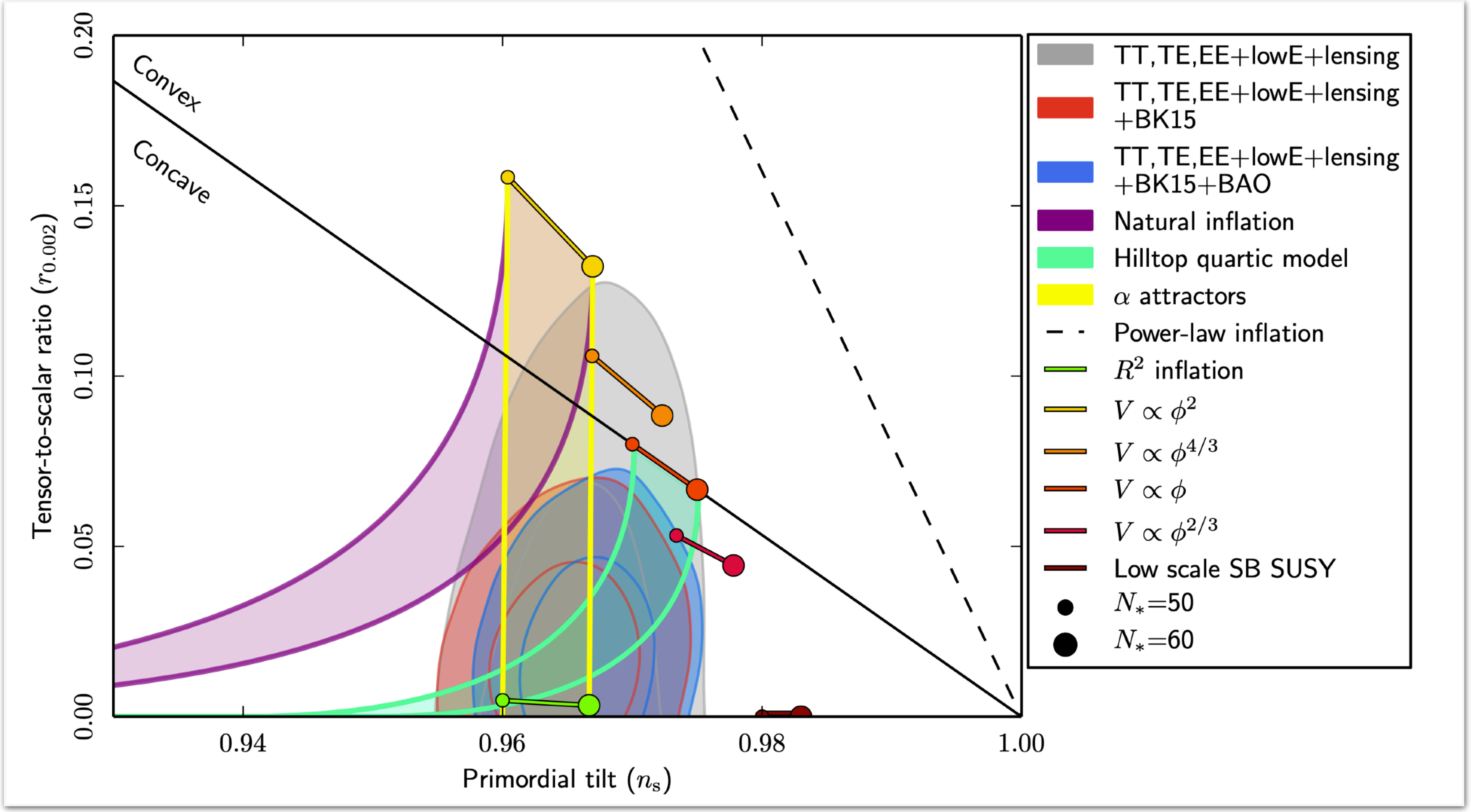

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Today's talk!

Q) What is our inflaton?

Q) Phenomenology induced by inflation?

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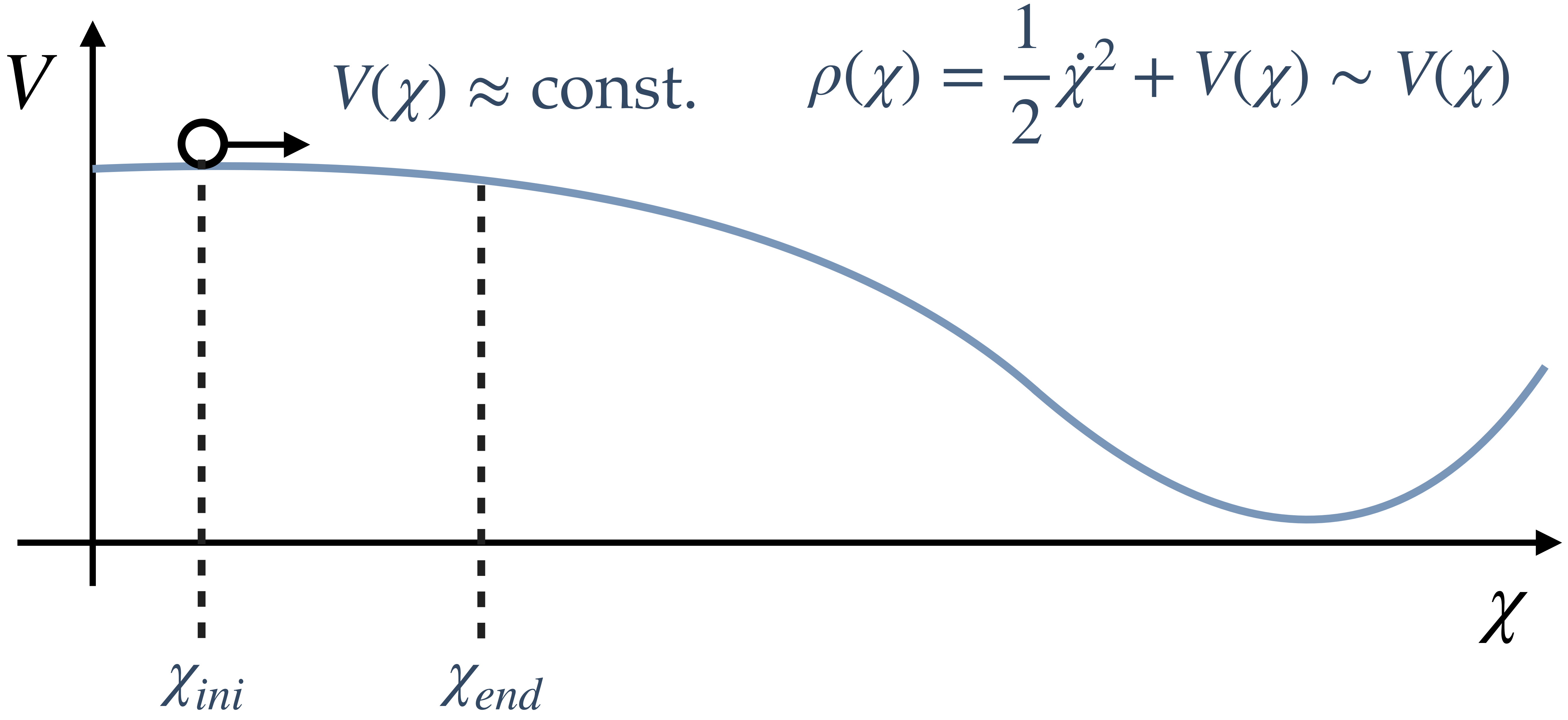
Inflation in a particle physics language



$$\rho(\chi) = \frac{1}{2}\dot{\chi}^2 + V(\chi) \sim V(\chi)$$

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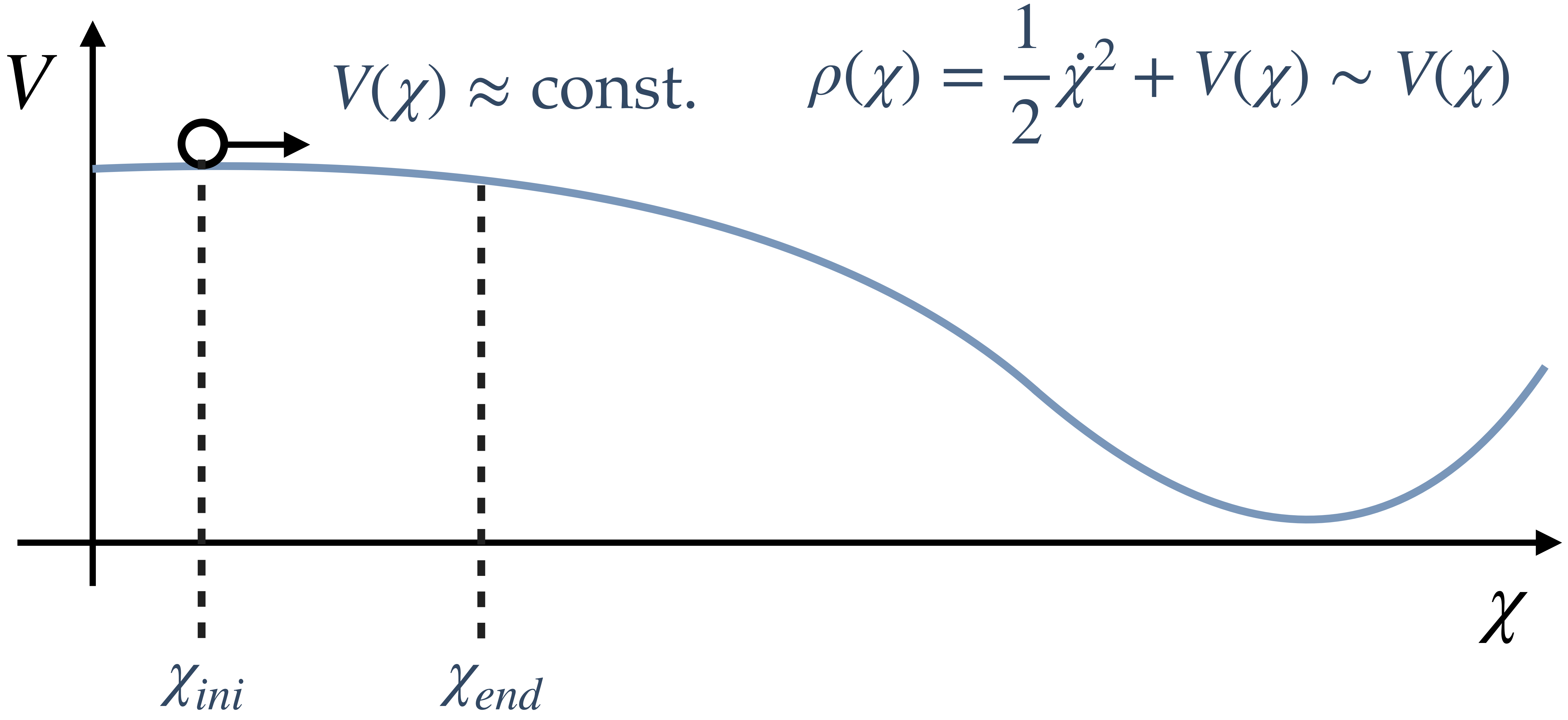
$V(\chi) \approx \text{const.}$ $\quad \rho(\chi) = \frac{1}{2}\dot{\chi}^2 + V(\chi) \sim V(\chi)$



$$\epsilon \simeq \epsilon_V = \frac{M_P^2}{2}\left(\frac{V'}{V}\right)^2$$

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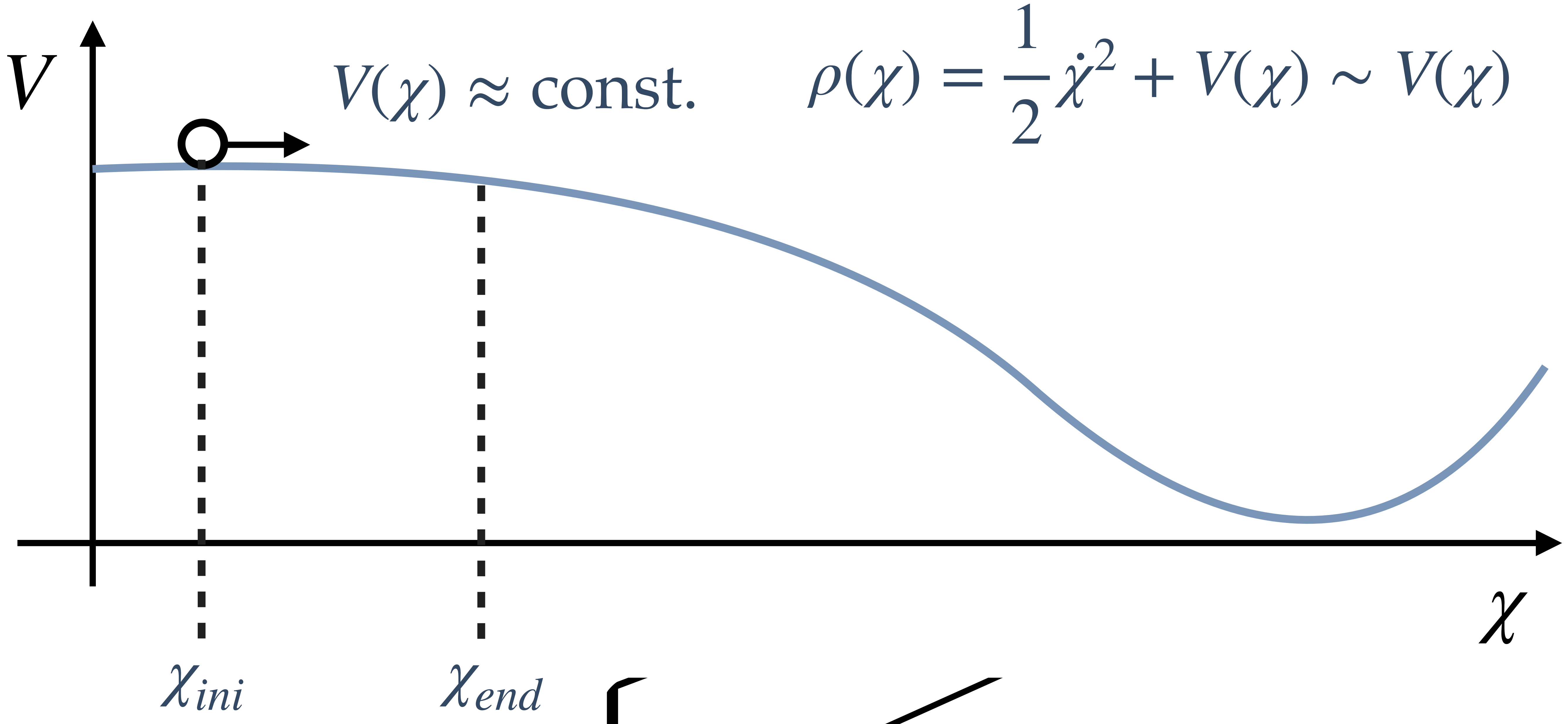

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$$(\mathscr{P}_R(k_*),\ n_s,\ r) \rightarrow (2 \times 10^{-9},\ 0.965,\ \lesssim 0.05)$$

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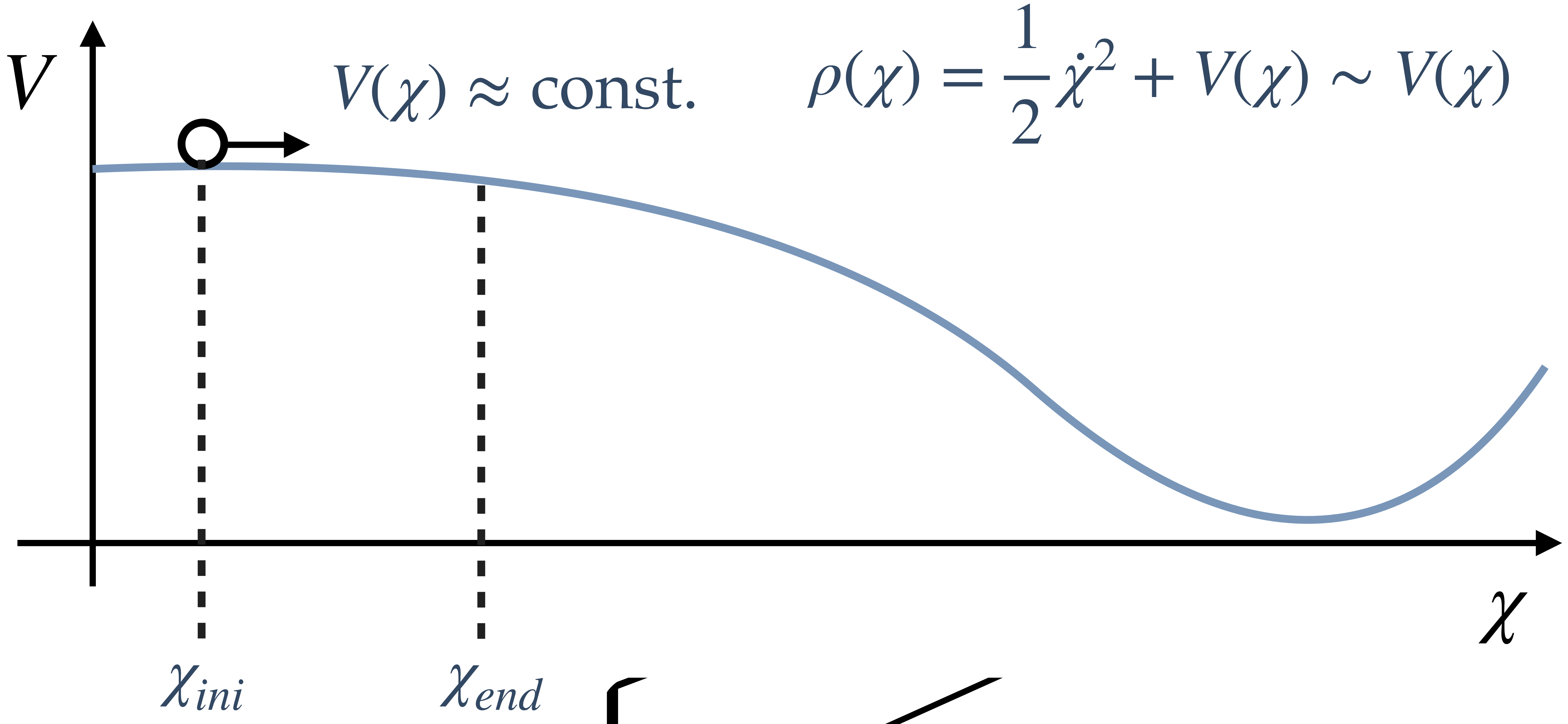

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Flat Potential : "Extremely flat, but not perfectly flat"! $V' \ll V \quad \& \quad V' \neq 0$

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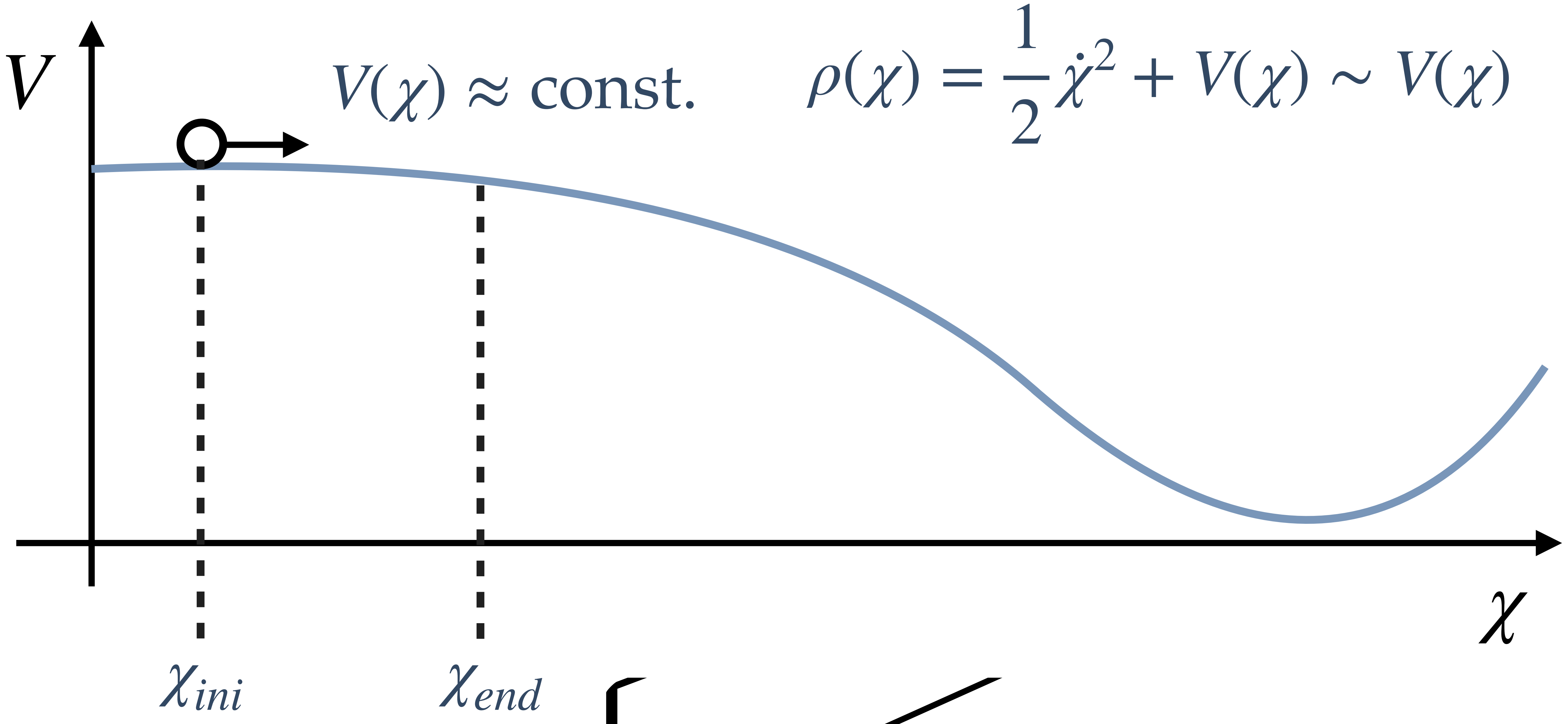

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$\longrightarrow$ Q) Natural Explanation for this flatness?

Introduction

Q) Flatness?

Introduction

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Composite Theories

Introduction

Q) Flatness?

Composite Theories

$SU(N_c)$ Gauge theory, N_f Dirac Fermions ψ_j

For a review, see e.g

[G. Cacciapaglia, C. Pica, F. Sannino, Phys. Rept. (2020)]

$$\mathscr{L} = -\frac{1}{4}F^a_{\mu\nu}F^{a\mu\nu} + \bar{\psi}_j(i\sigma^\mu D_\mu)\psi_j$$

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Chiral Symmetry

Scale Invariance

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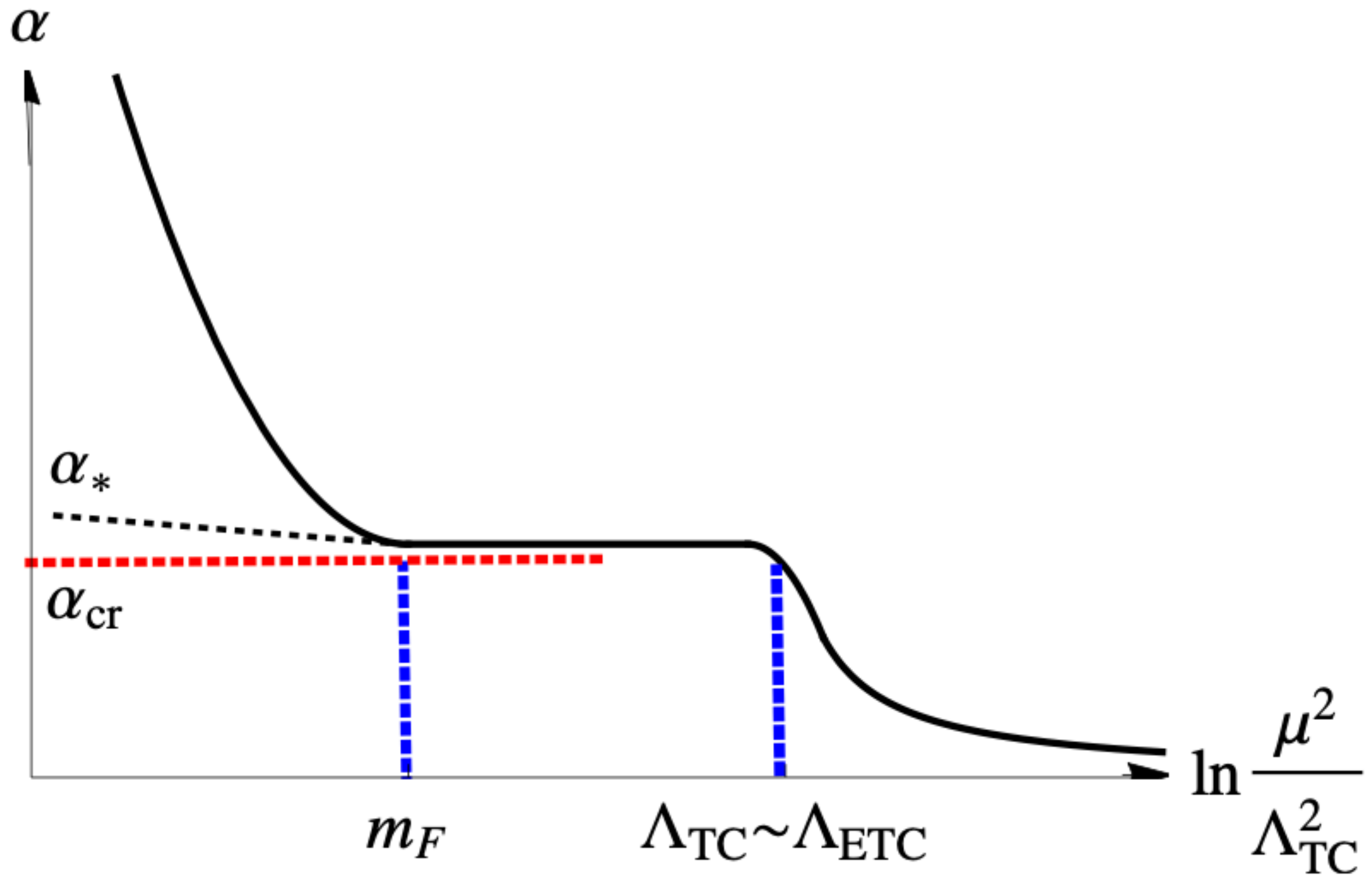

Fig. from [S. Matsuzaki, K. Yamawaki, JHEP (2015)]

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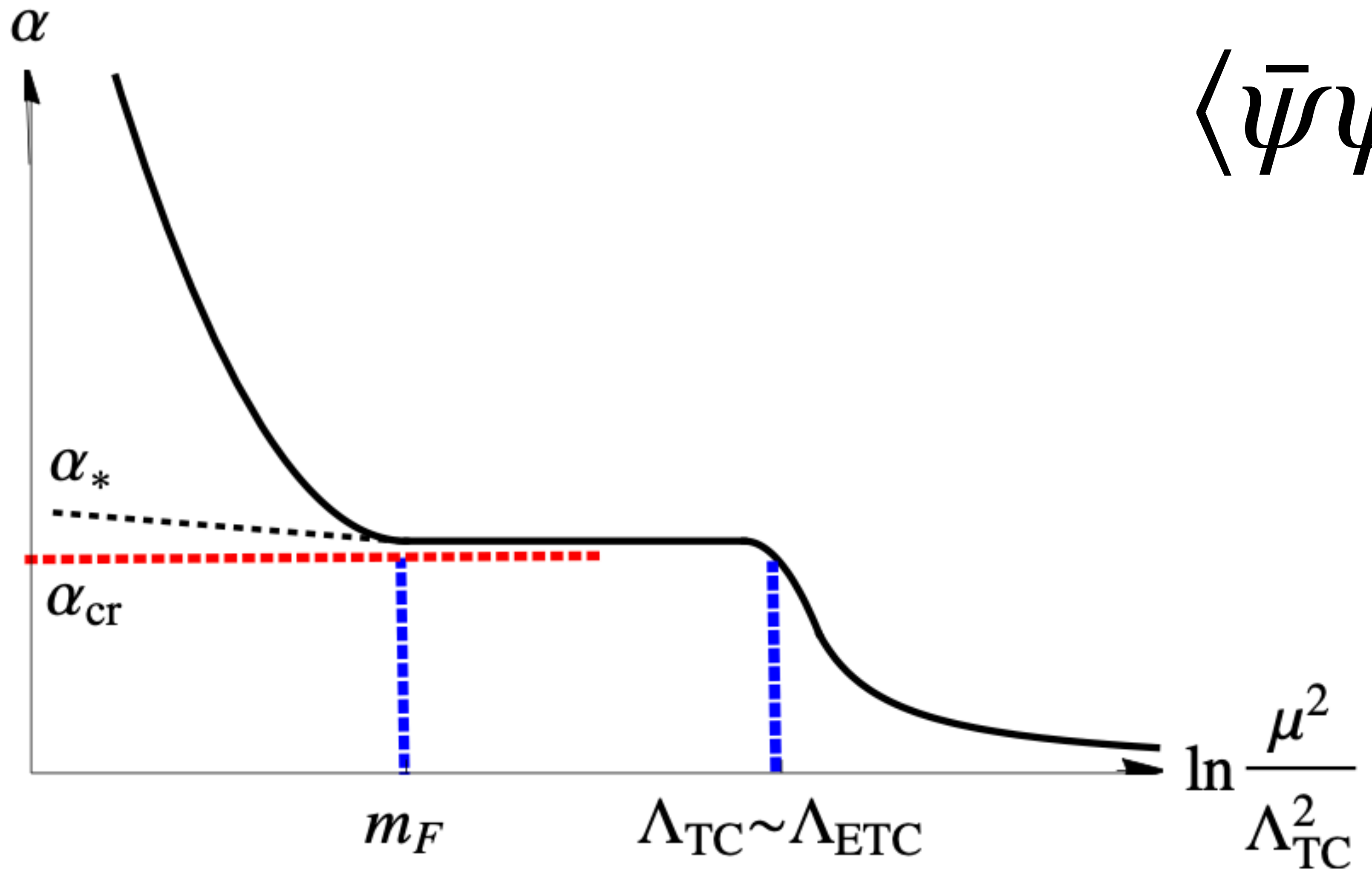

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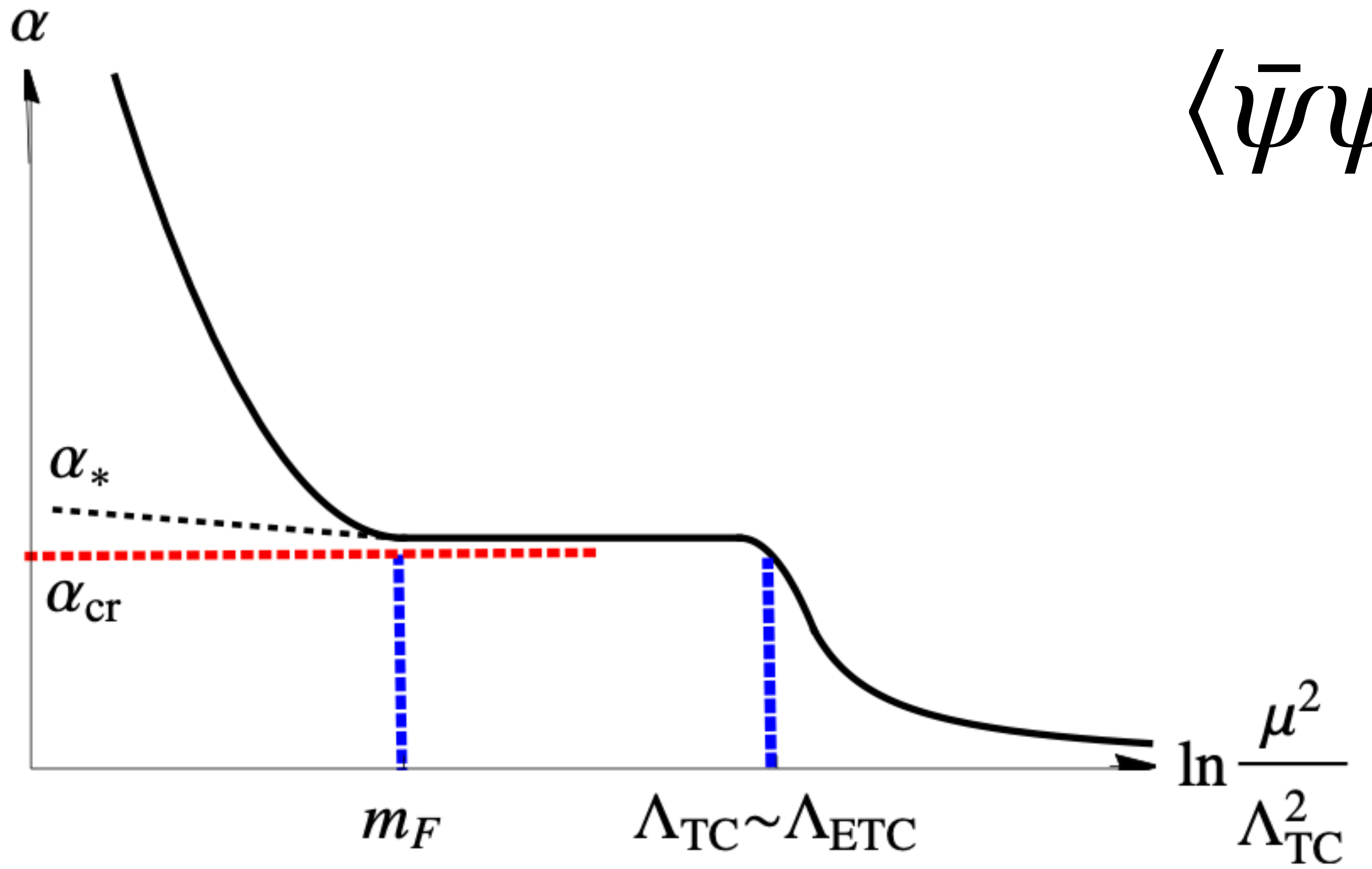

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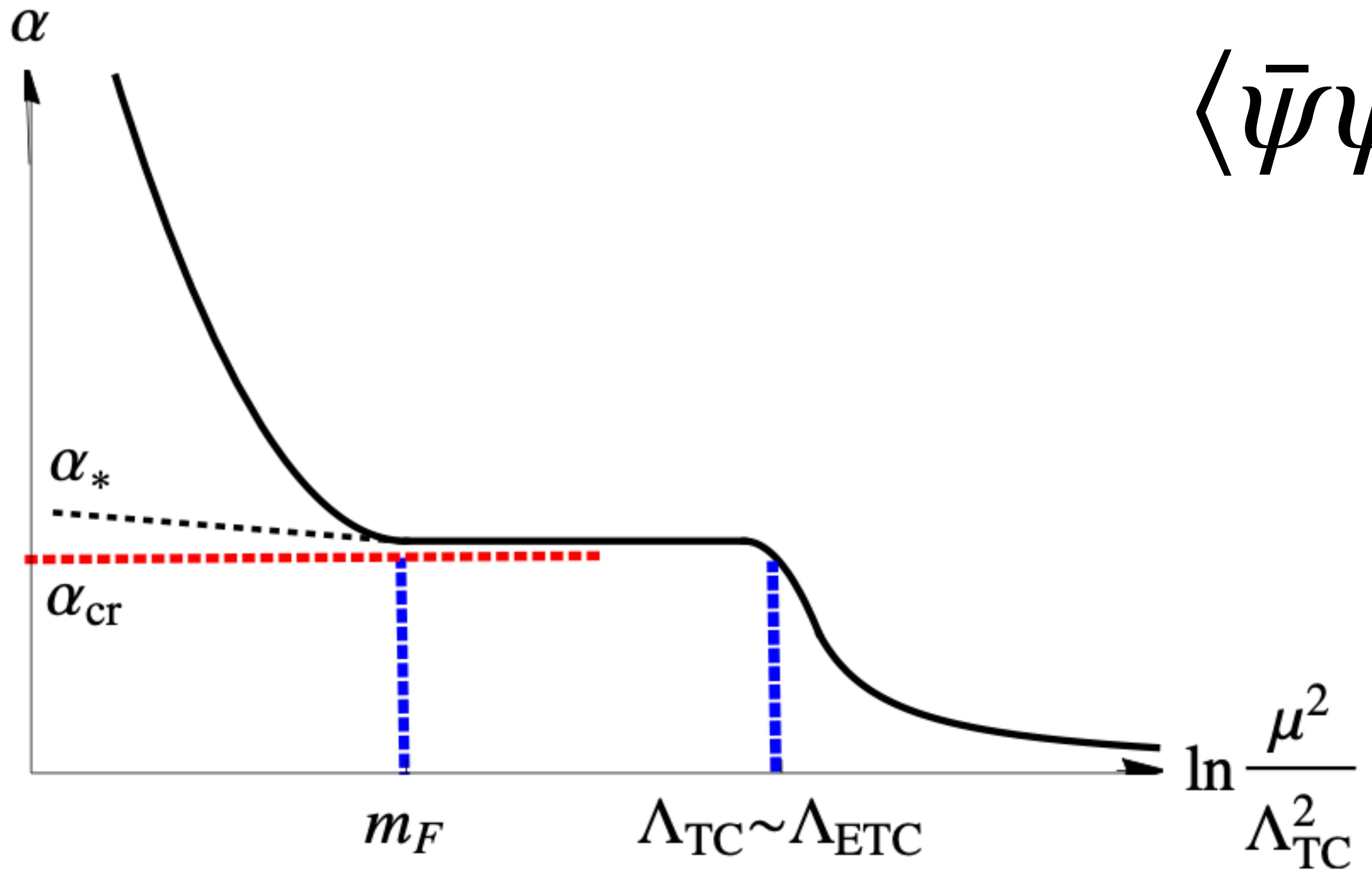
pNGB : $\phi^a(x)$



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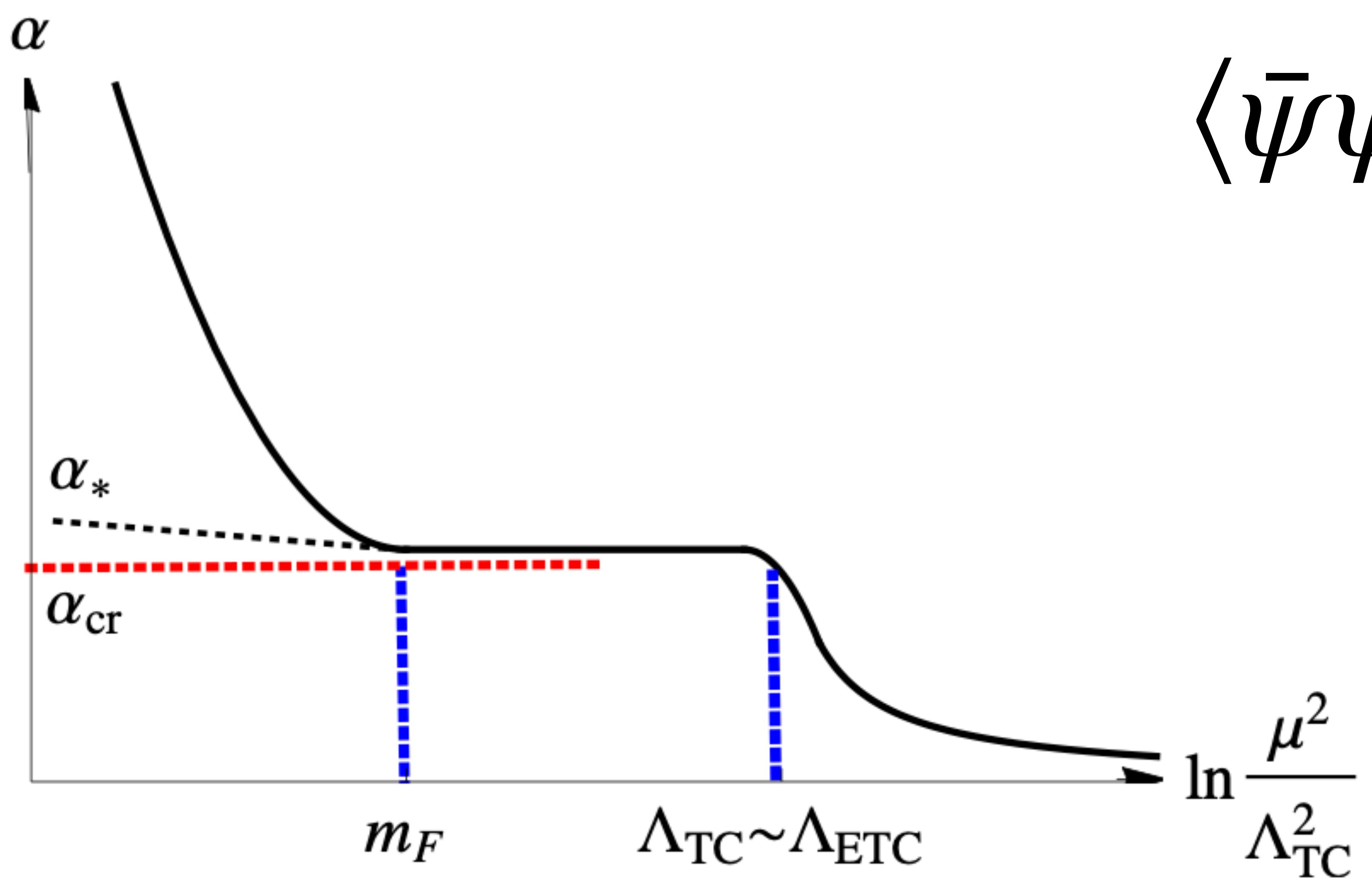

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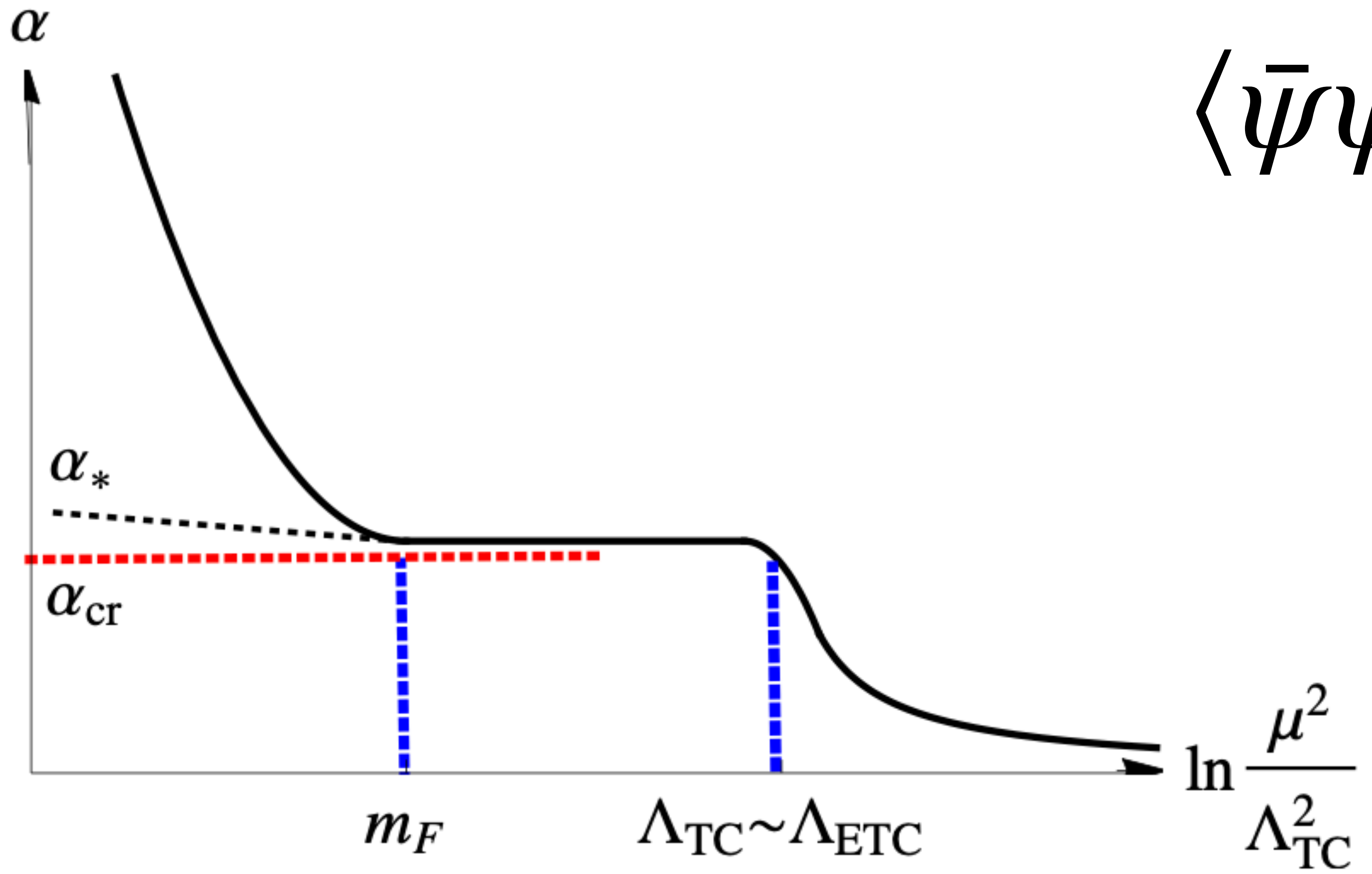
pNGB : $\chi(x)$



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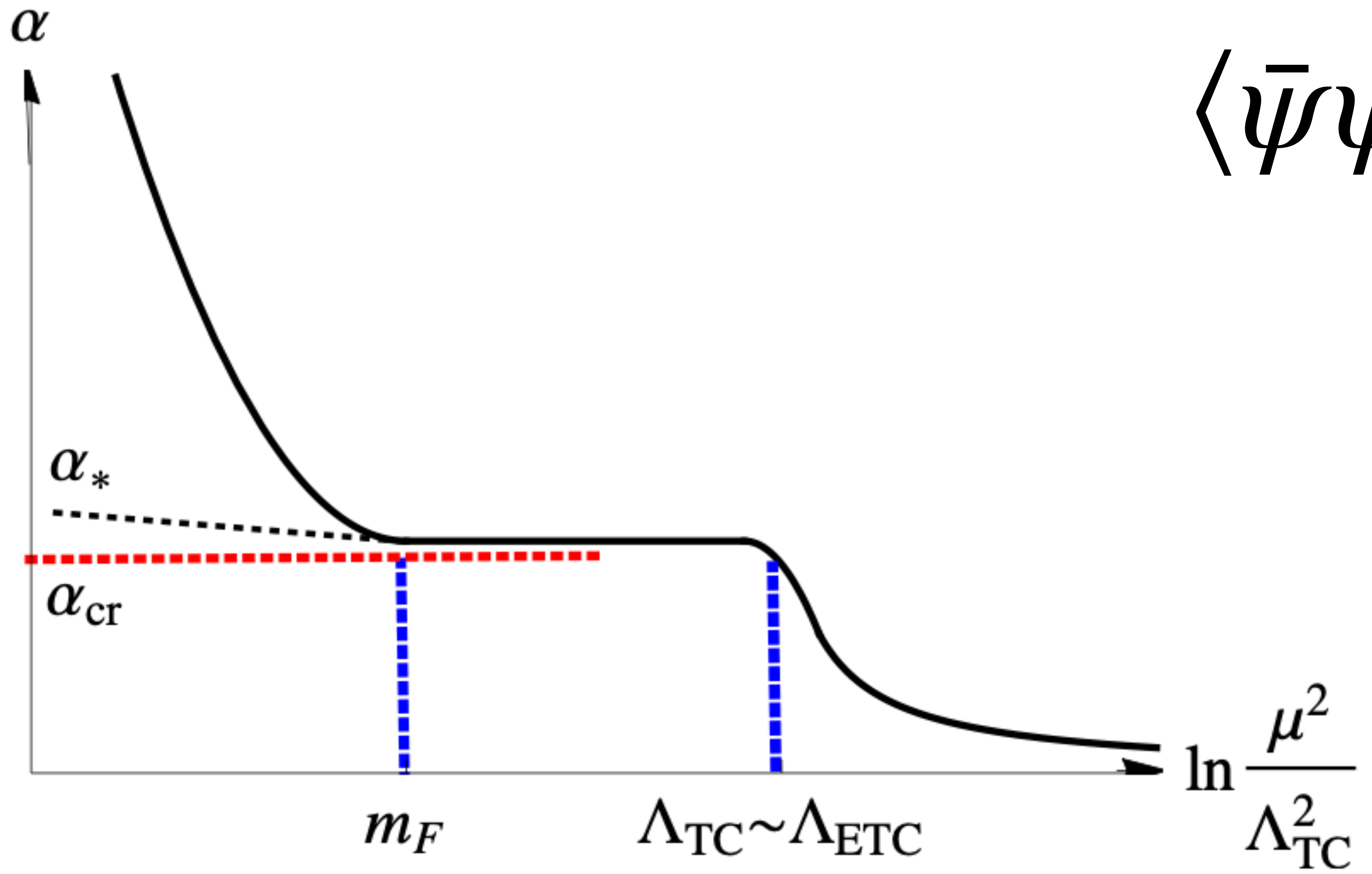

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Analytic and Lattice Studies support $\gamma_i \sim \mathcal{O}(1)$

[C.N. Leung, S. T. Love, W. A. Bardeen, (1989)]
[LatKMI Collaboration, (2014)][LatKMI Collaboration, (2017)], and more

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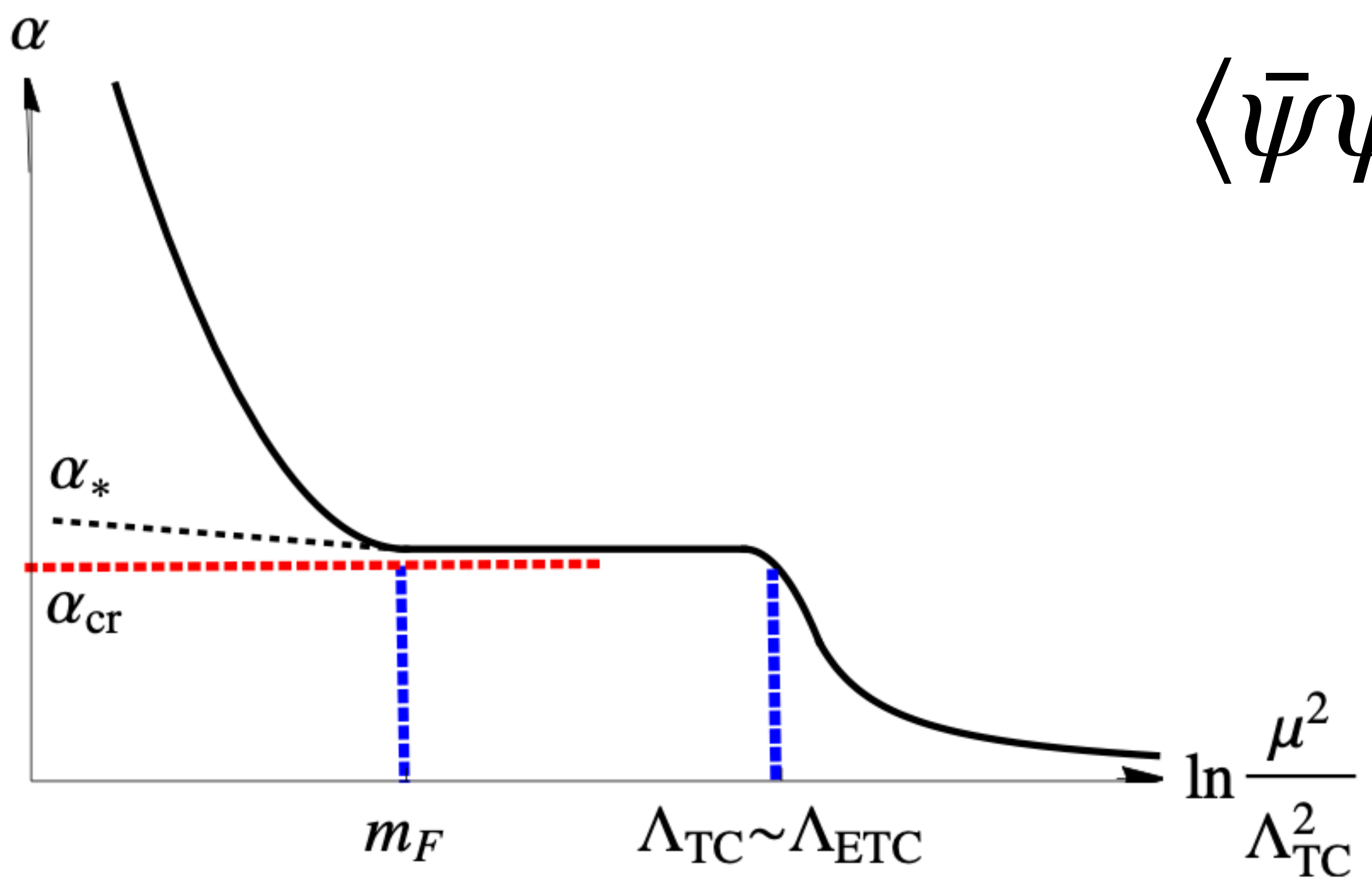

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Light composite pNGBs arise, $\mathscr{L}_{\rm dChPT}$

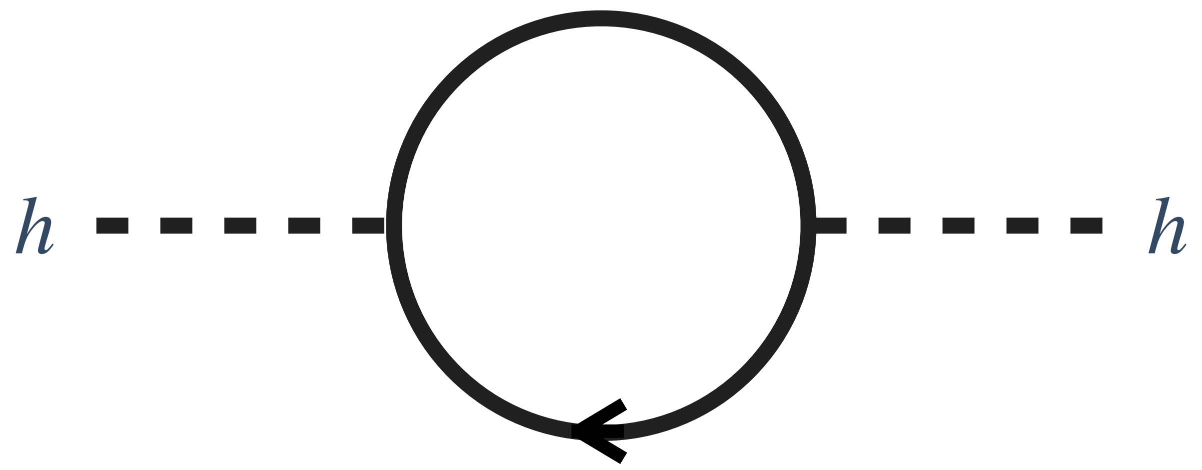
[S. Matsuzaki, K. Yamawaki, (2014)] [T. Appelquist, J. Ingoldby, M. Piai, (2017)] ...

Introduction

(Composite) Higgs

Higgs : hierarchy problem

$m_h \ll M_P$: Large Quadratic Divergence

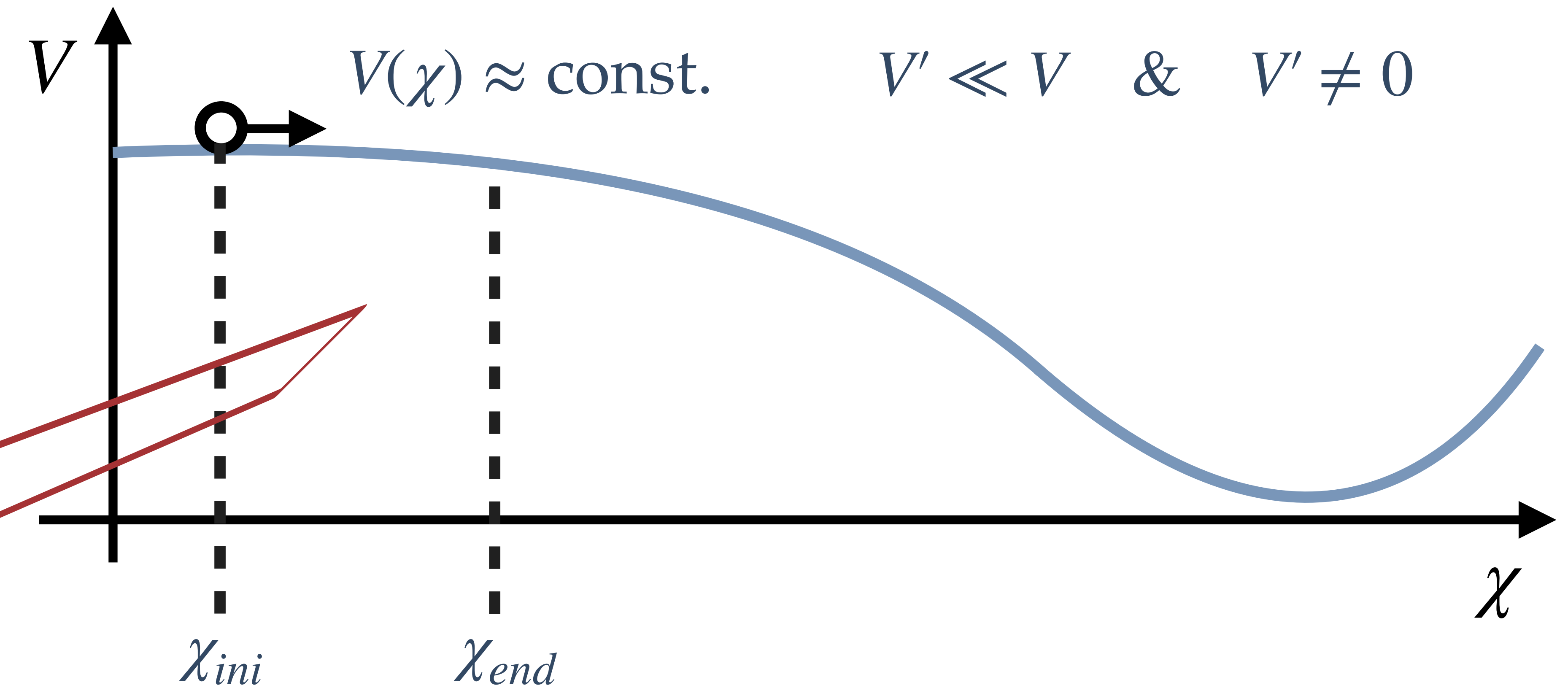


Composite Higgs : Remove Fundamental Scalar

Protect Higgs mass

~~(Composite)~~ Inflation

Inflation : Potential "Flatness"



Composite Inflation : Remove Fundamental Scalar

Protect inflaton potential

Composite Models can tackle each problem given their scale!

Light composite pNGBs, can inflation occur?

The Model

$SU(N_c)$ Gauge theory, N_f Dirac Fermions in the Fundamental Rep. $\chi(x)$

$\phi(x) = \phi^a(x)T^a$ $\quad U(x) = \exp\left(\frac{i\phi}{f_\phi}\right)$

$M_P = 1$

$$\frac{\mathscr{L}}{\sqrt{-g}} \supset \frac{1}{2}R - \frac{1}{2}\partial_\mu\chi\partial^\mu\chi - \frac{f_\phi^2}{2}\left(\frac{\chi}{f_\chi}\right)^2 \mathrm{Tr}\partial_\mu U^\dagger\partial^\mu U$$

$$+\frac{\lambda_\chi}{4}\chi^4\left(\log\frac{\chi}{f_\chi} - A\right) + \frac{\lambda_\chi\delta_1 f_\chi^4}{2}\left(\frac{\chi}{f_\chi}\right)^{3-\gamma_m} \mathrm{Tr}\left(U + U^\dagger\right)$$

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Dilaton - Pion Kinetic Terms

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Pion mass term

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4-Fermi interaction term

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4-Fermi interaction term

The Model

$$V(\phi,\chi) = -\lambda_\chi \delta_1 f_\chi^4 \left(\frac{\chi}{f_\chi}\right)^{3-\gamma_m} \cos\frac{\phi}{f_\phi} - \lambda_\chi \delta_2 f_\chi^4 \left(\frac{\chi}{f_\chi}\right)^{2(3-\gamma_{4f})} \sin^2\frac{\phi}{f_\phi} + \underbrace{\frac{\lambda_\chi}{4}\chi^4\left(\log\frac{\chi}{f_\chi} - A\right)}_{V_{CW}} + V_0 \,.$$

$$\text{Vev requirement}: V(\phi_0,\chi_0) = 0 \quad \text{and} \quad V_\chi(\phi_0,\chi_0) = 0$$

$$V_0 = \frac{\lambda_\chi f_\chi^4}{16}\left[1 + \frac{2\delta_1^2}{\delta_2}(2 - \gamma_{4f} + \gamma_m) + 8\delta_2(\gamma_{4f} - 1)\right] \qquad A = \frac{2\delta_1^2(\gamma_m - \gamma_{4f}) + \delta_2(8\delta_2(\gamma_{4f} - 3) + 1)}{4\delta_2}$$

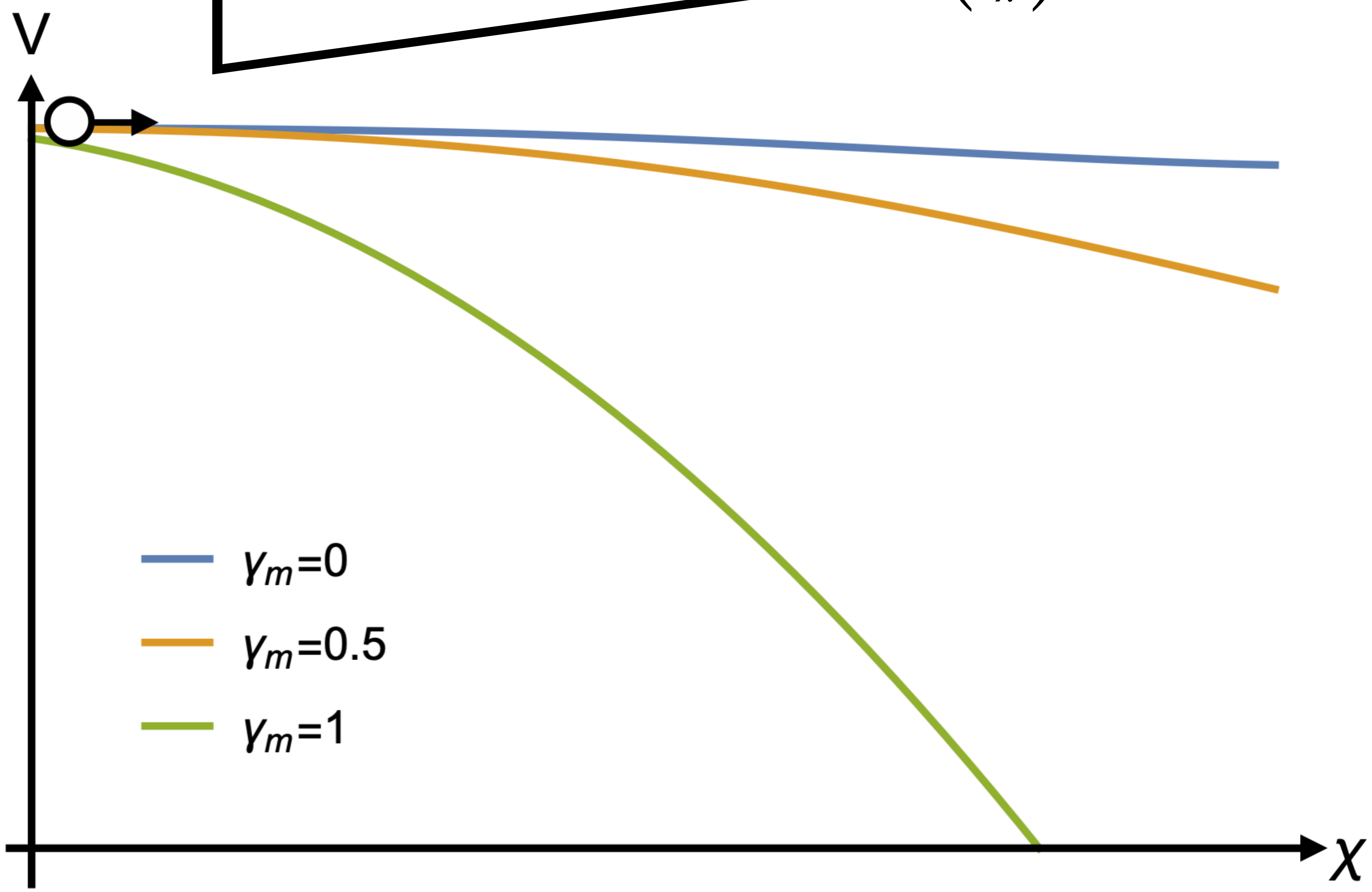
Explicit anomalous dimension dependence! Inflationary predictions alter

Inflationary Dynamics

1) $\delta_2 = 0$, Single Field Dynamics

Inflation occurs at $\chi \ll f_\chi$

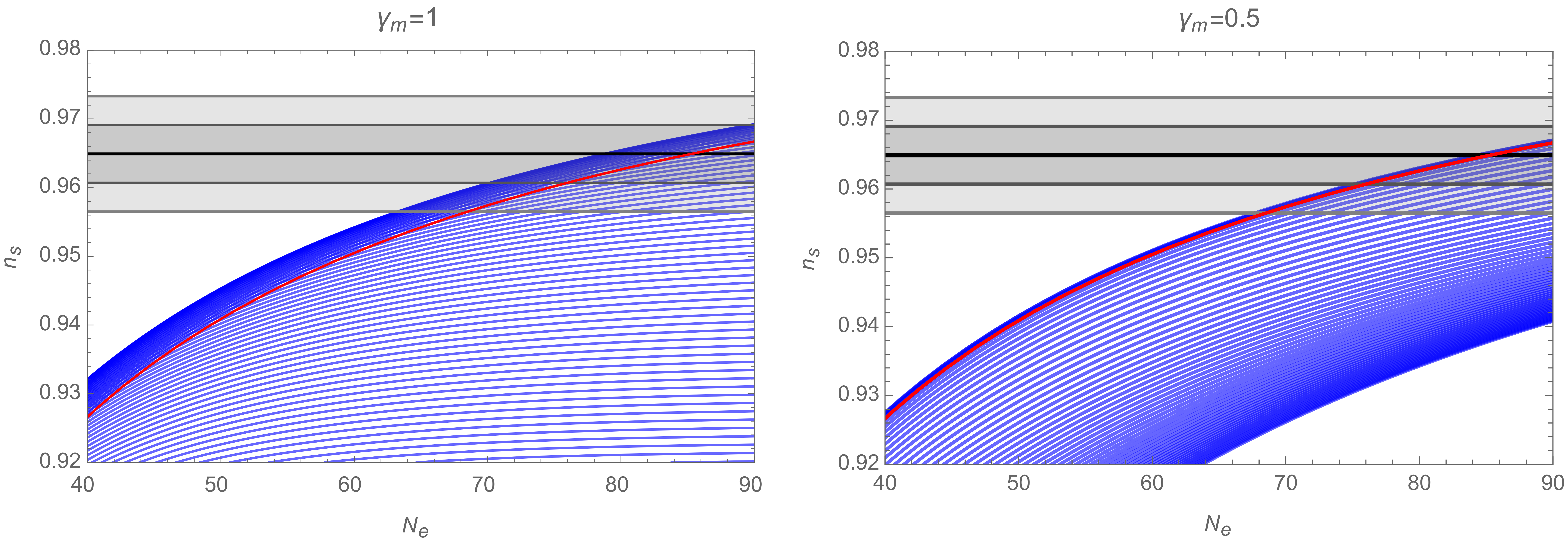
$$V(\phi = 0, \chi) = -\lambda_\chi \delta_1 f_\chi^4 \left(\frac{\chi}{f_\chi}\right)^{3-\gamma_m} + \frac{\lambda_\chi}{4}\chi^4 \left(\log\frac{\chi}{f_\chi} - A_{\text{single}}\right) + V_0^{\text{single}}.$$



- V_{CW} + corrections
- γ_m alters corrections
- $(\epsilon, \eta) \to (\mathscr{P}_{\mathscr{R}}, n_s, \ldots)$ γ_m dependence

Inflationary Dynamics

1) $\delta_2 = 0$, Single Field Dynamics

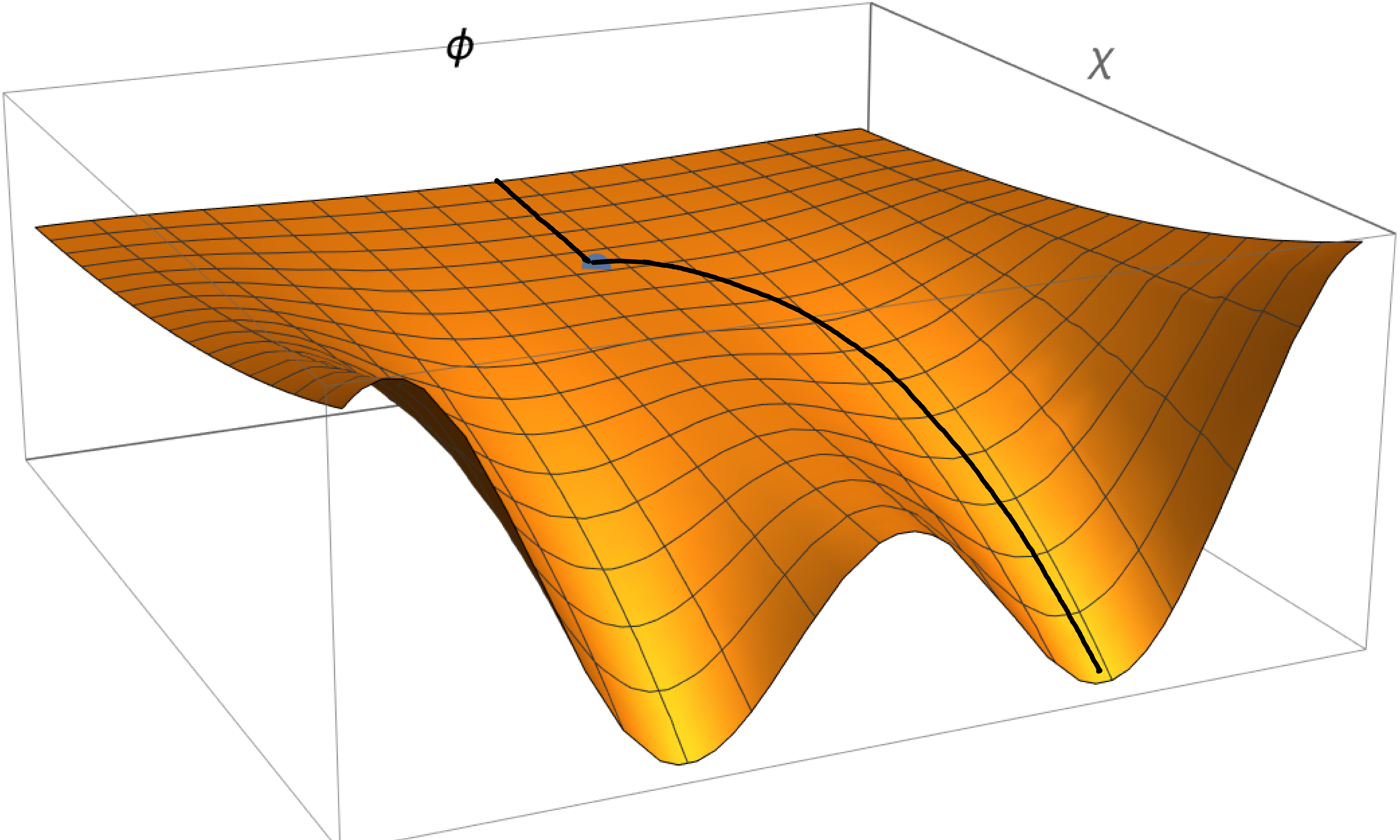


$N_e \sim 70$ for CMB compatibility

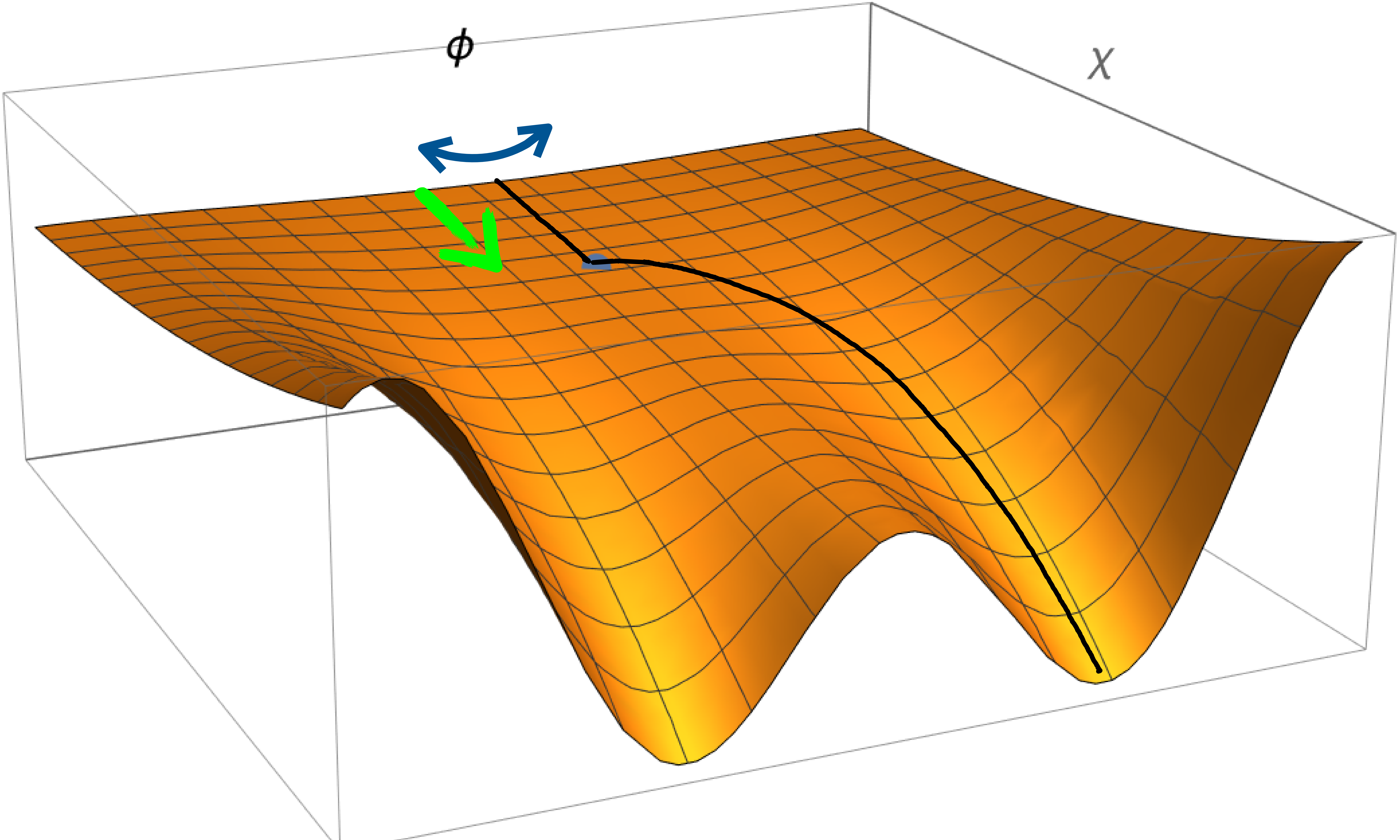
$$N_e \simeq 61 + \frac{2}{3} \ln \frac{V_0^{1/4}}{10^{16}\ \mathrm{GeV}} + \frac{1}{3} \ln \frac{T_{reh}}{10^{16}\ \mathrm{GeV}}$$

Not favored from CMB observations

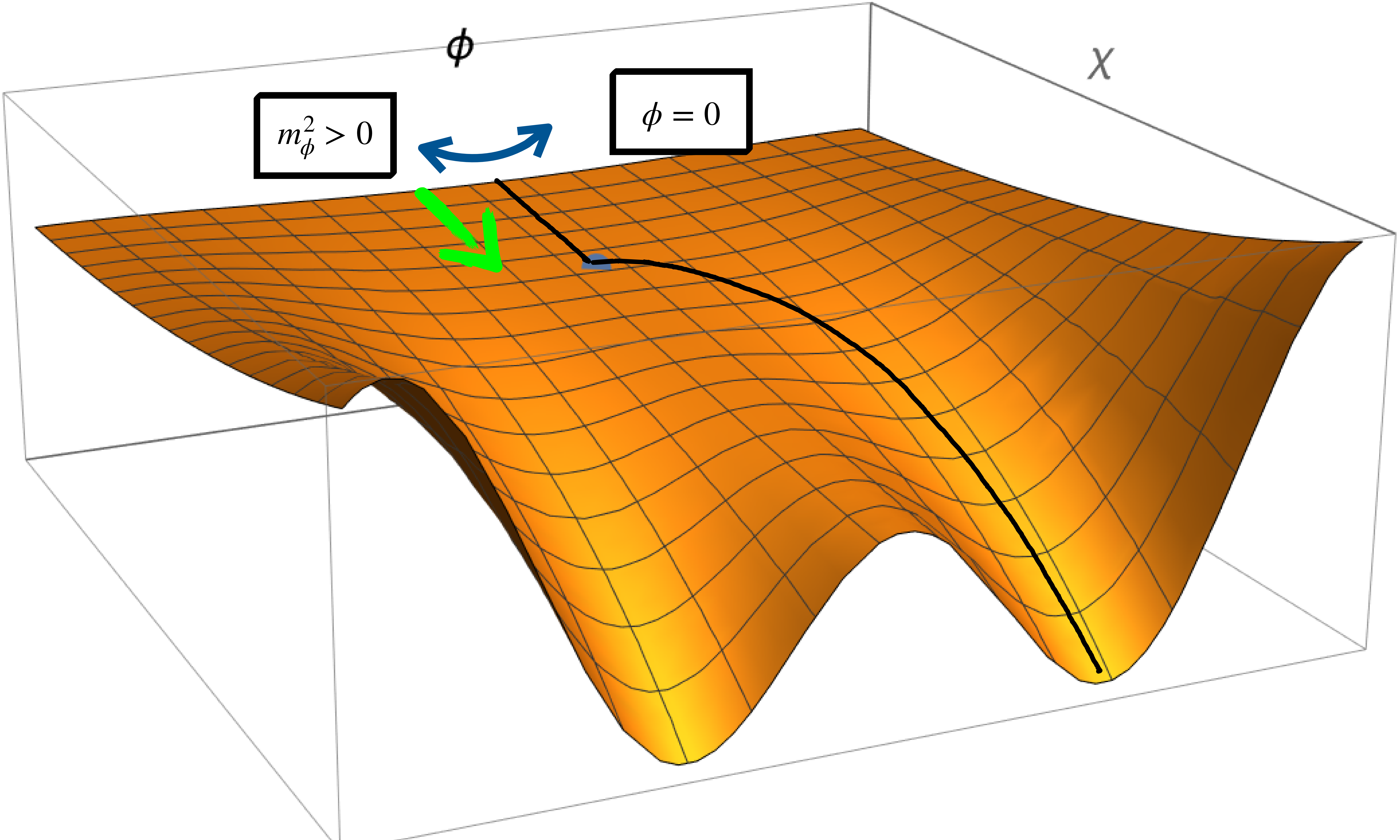
Inflationary Dynamics



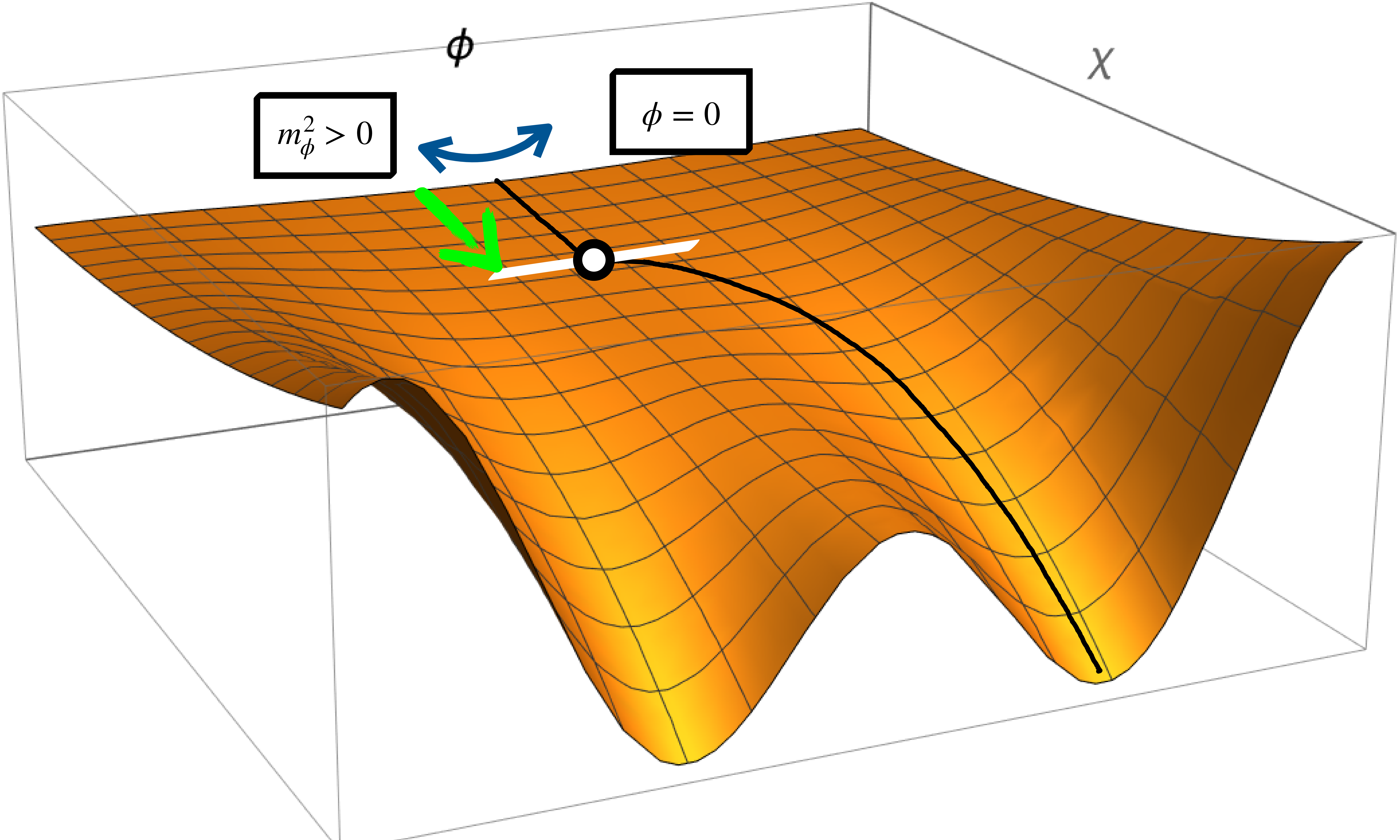
Inflationary Dynamics



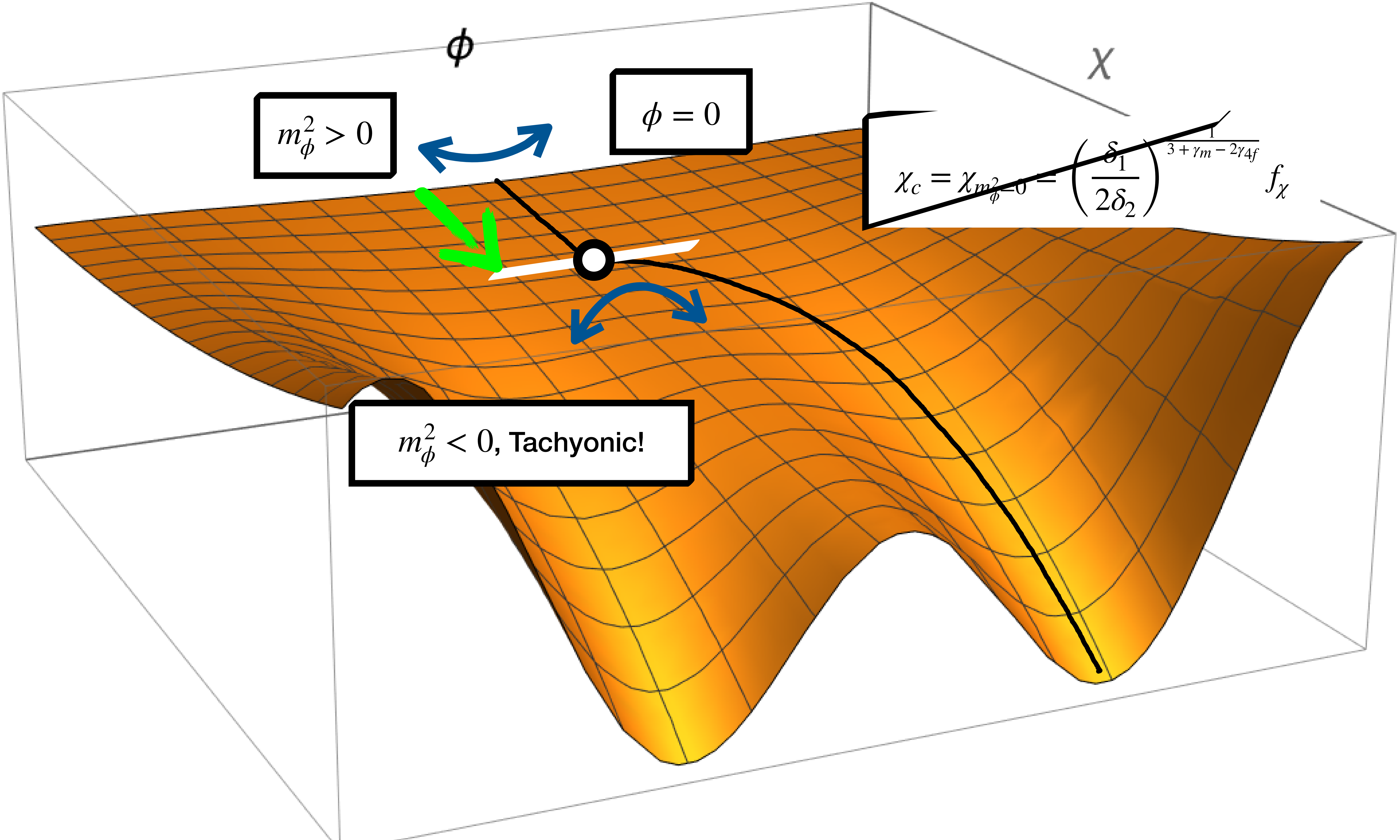
Inflationary Dynamics



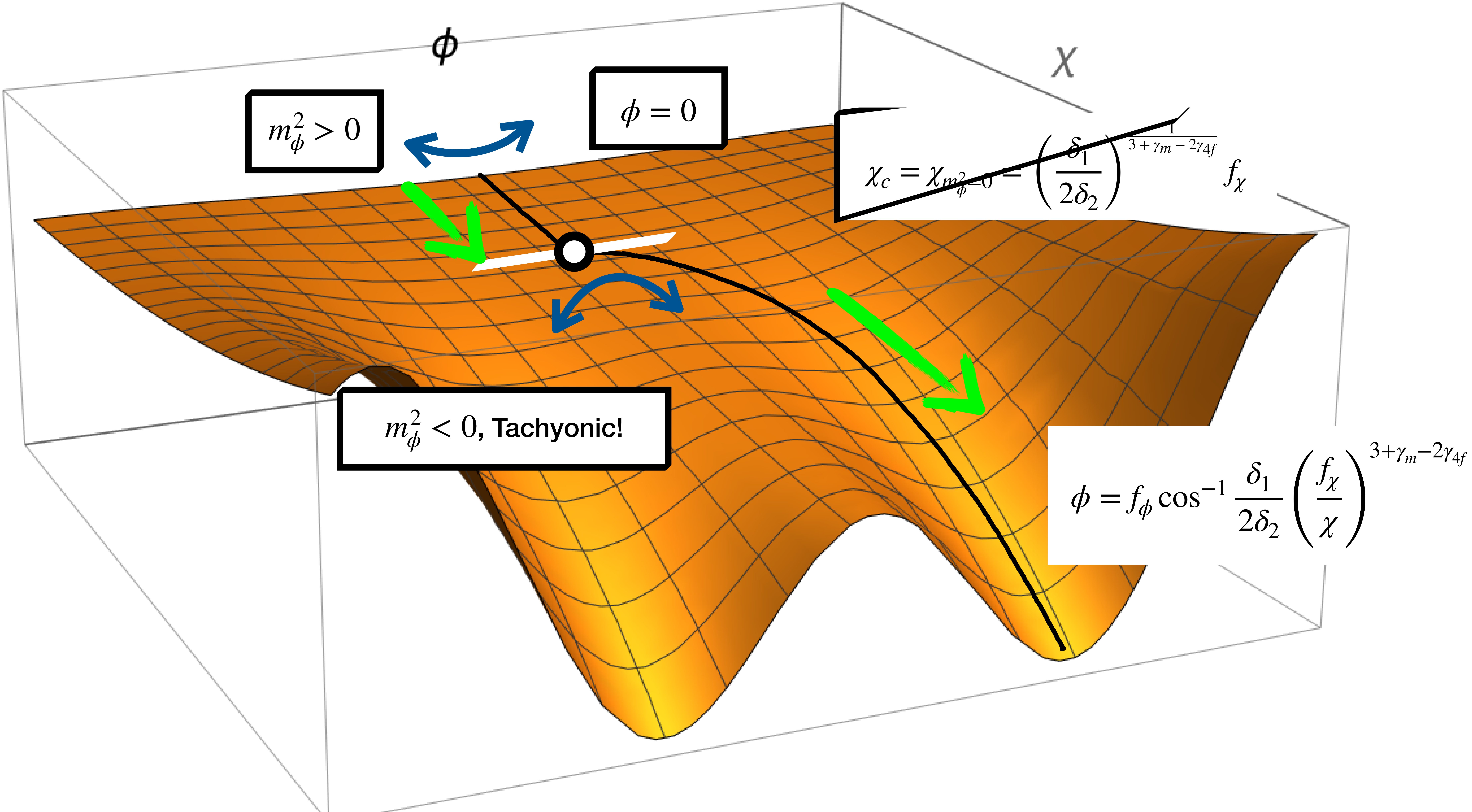
Inflationary Dynamics



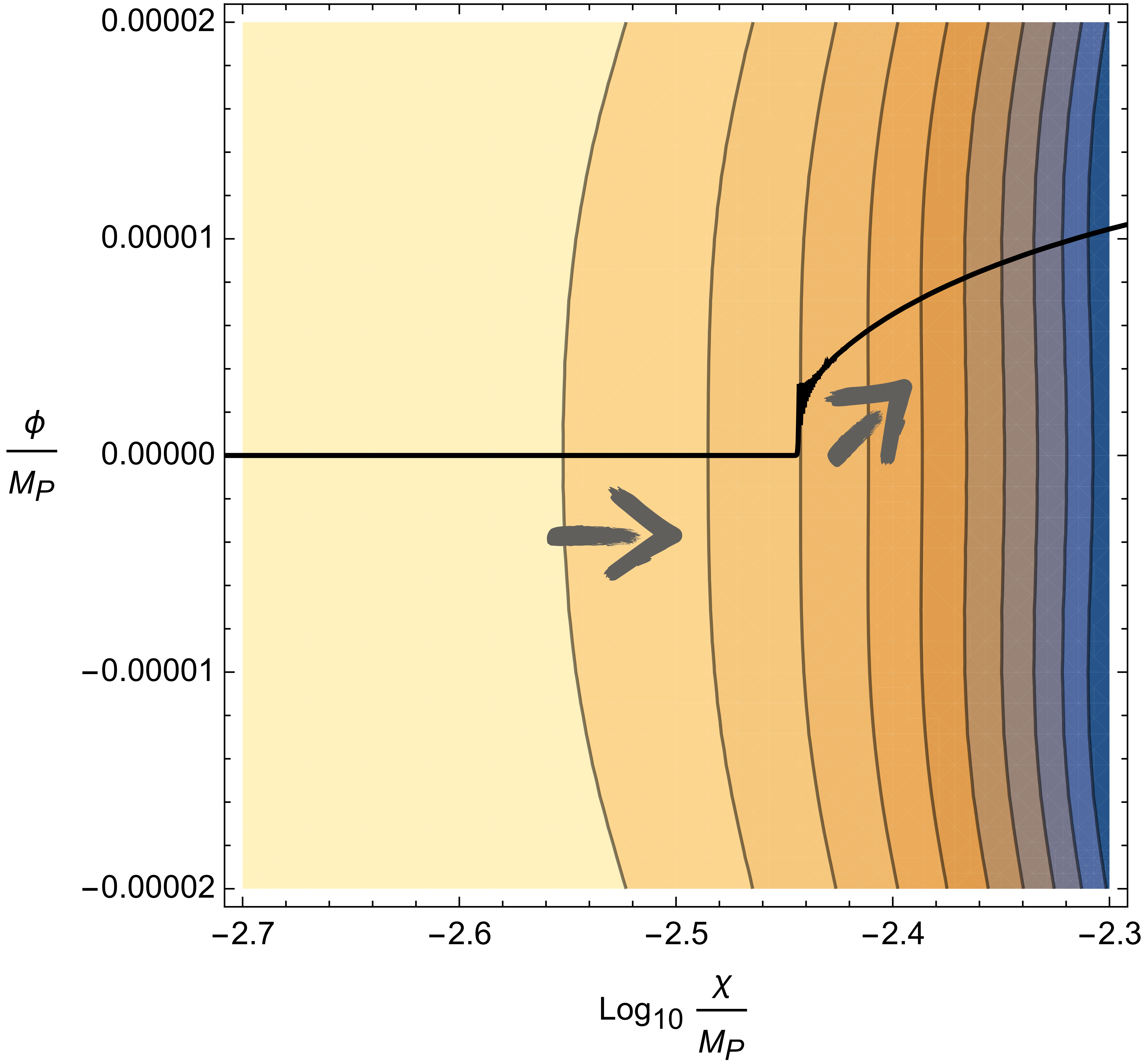
Inflationary Dynamics



Inflationary Dynamics

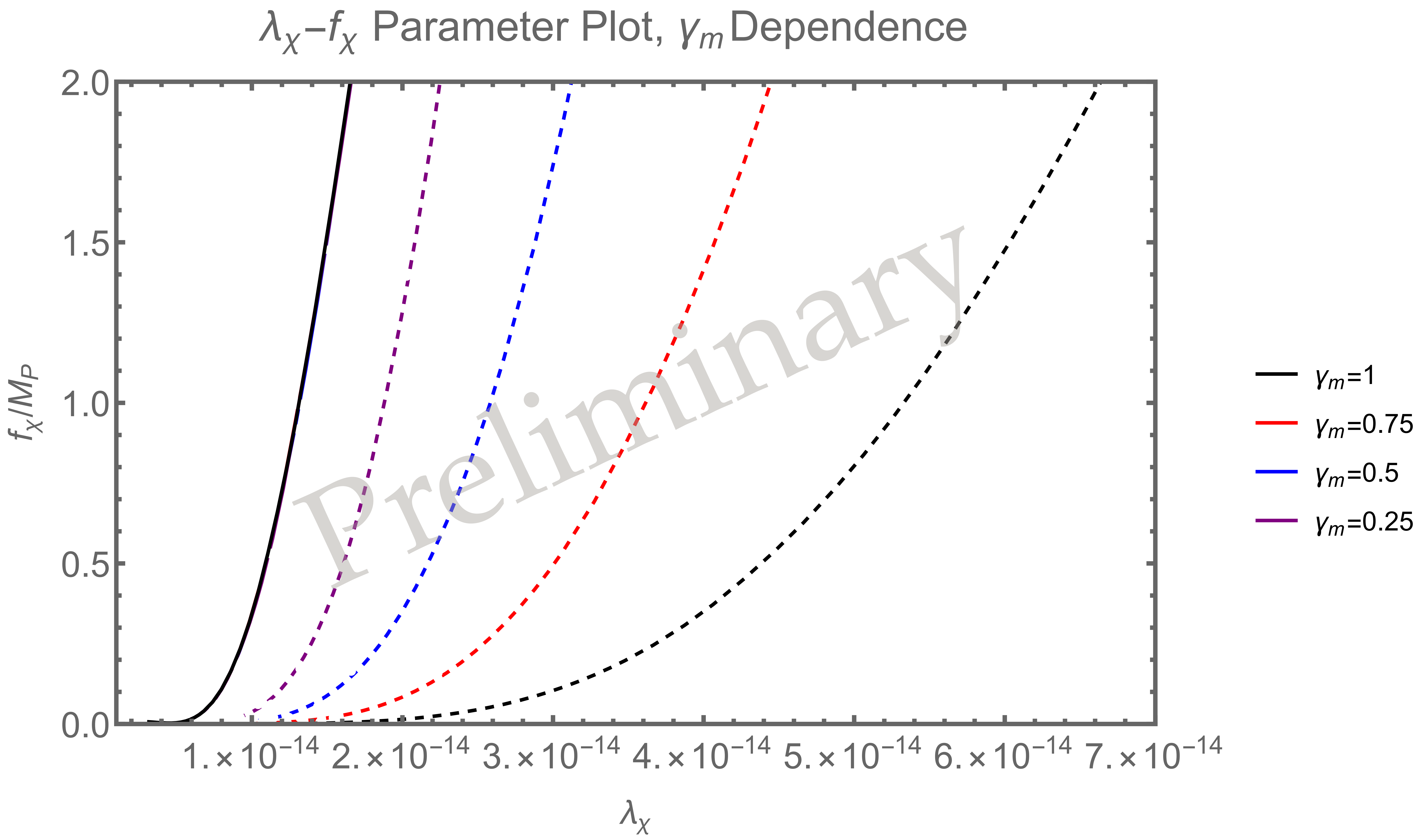


Inflationary Dynamics - Waterfall

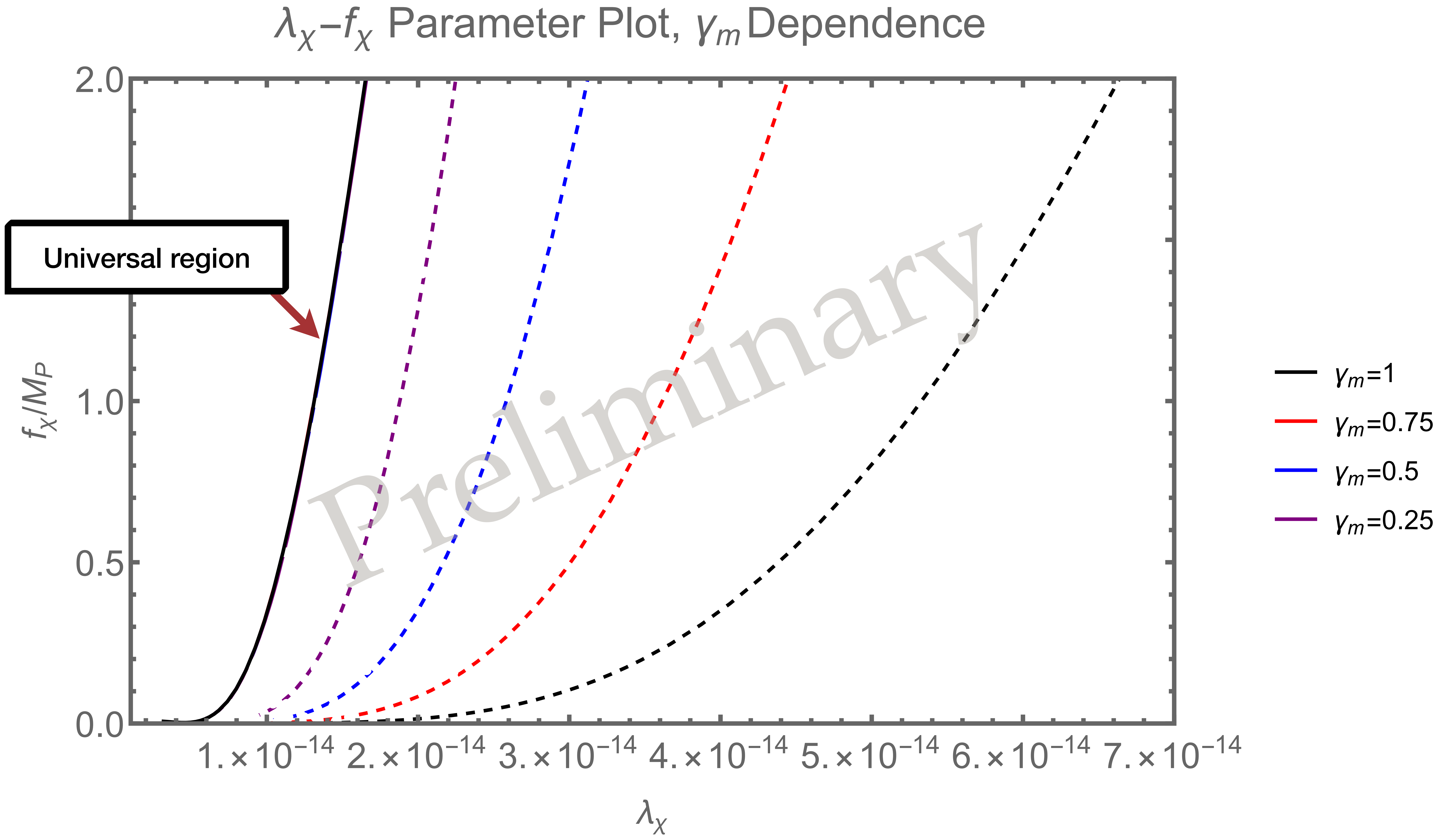


- Dynamical Pions trigger a "waterfall transition"
- Premature termination in inflation, shortens efold
- Co-existence of χ and ϕ, observation compatible inflation

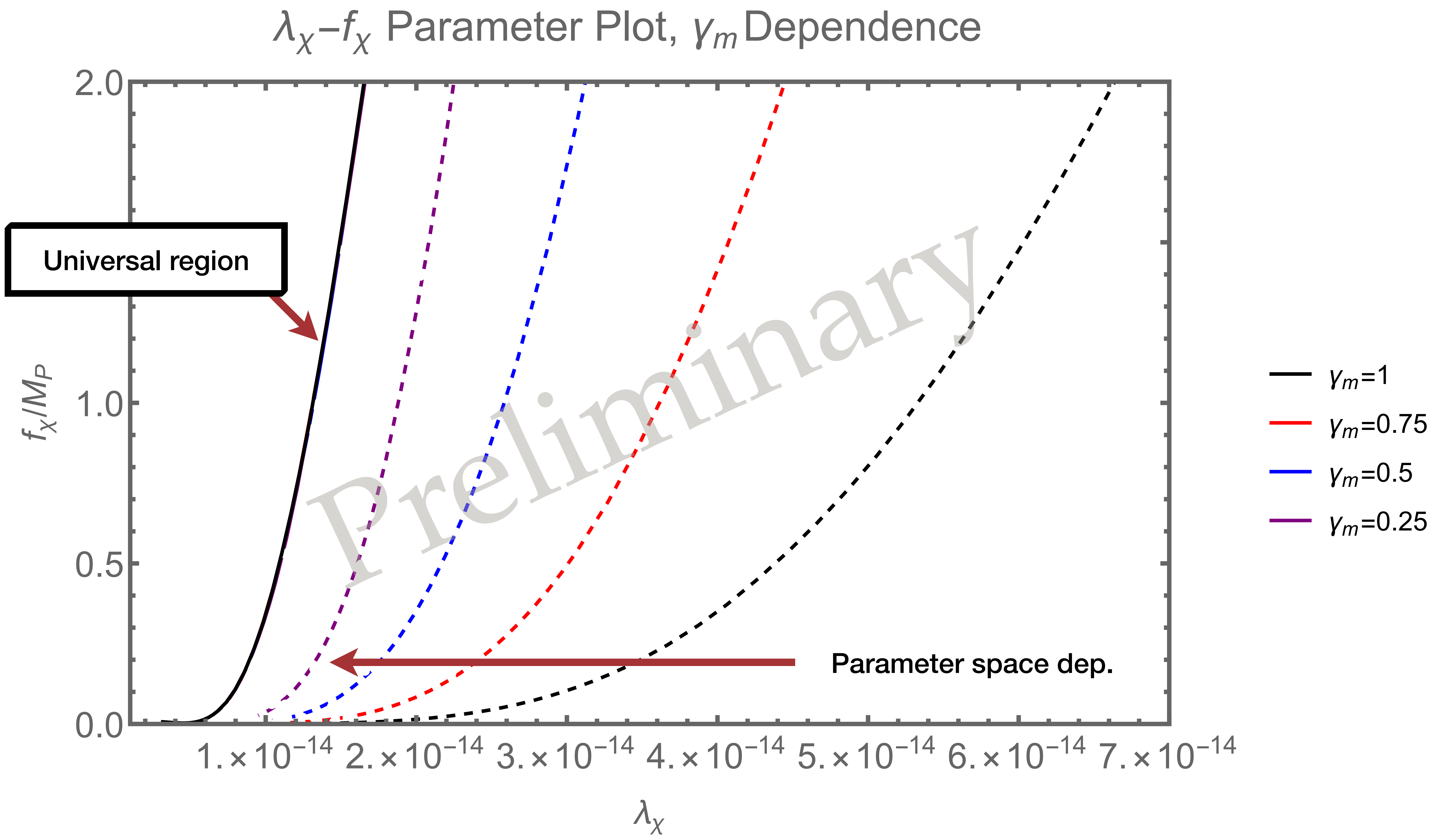
Observational Consequences



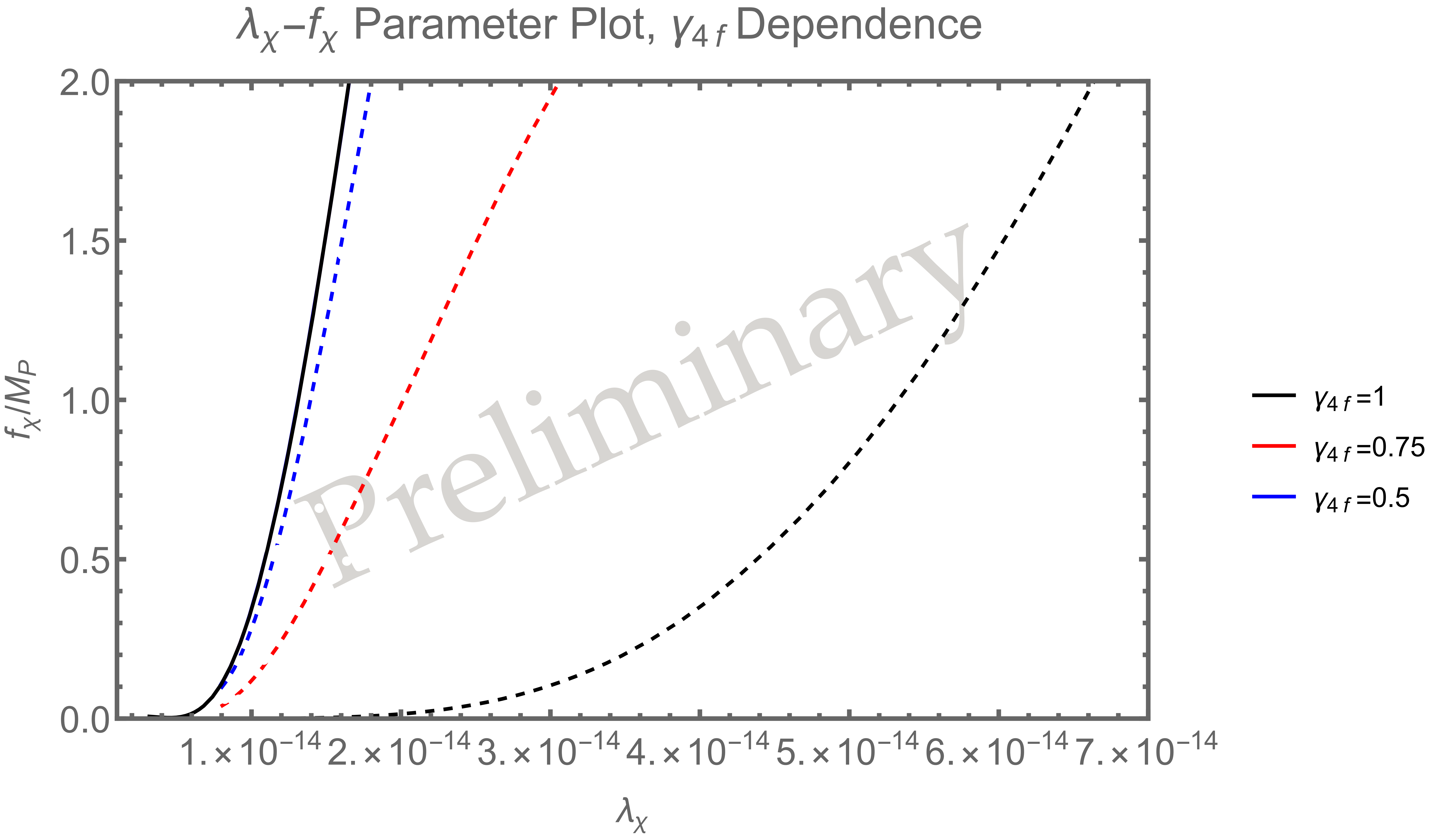
Observational Consequences



Observational Consequences



Observational Consequences



Summary & Outlooks

- Inflation provides initial conditions for our Hot Big Bang, successful paradigm.
- Particle physics origin still unknown, requires “flatness”
- In analogy to composite Higgs, composite inflation can protect inflaton “hierarchy”
- Interplay of composite pNGBs can lead to dilaton inflation and waterfall pions, fully compatible with CMB
- Phenomenology associated? (UV completion, experimental constraints, GWs)
- Much more to study, stay tuned if interested!

“Thank you!”