Memory Burden in Locked Inflation

Lukas Komisel
Supervisor: Prof. Dr. Gia Dvali

IMPRS Recruiting Workshop, 12.07.2023

lukas.komisel@physik.lmu.de

Systems with Enhanced Information Storage

Dvali, 2018; Dvali et al., 2018; Dvali et al. 2021

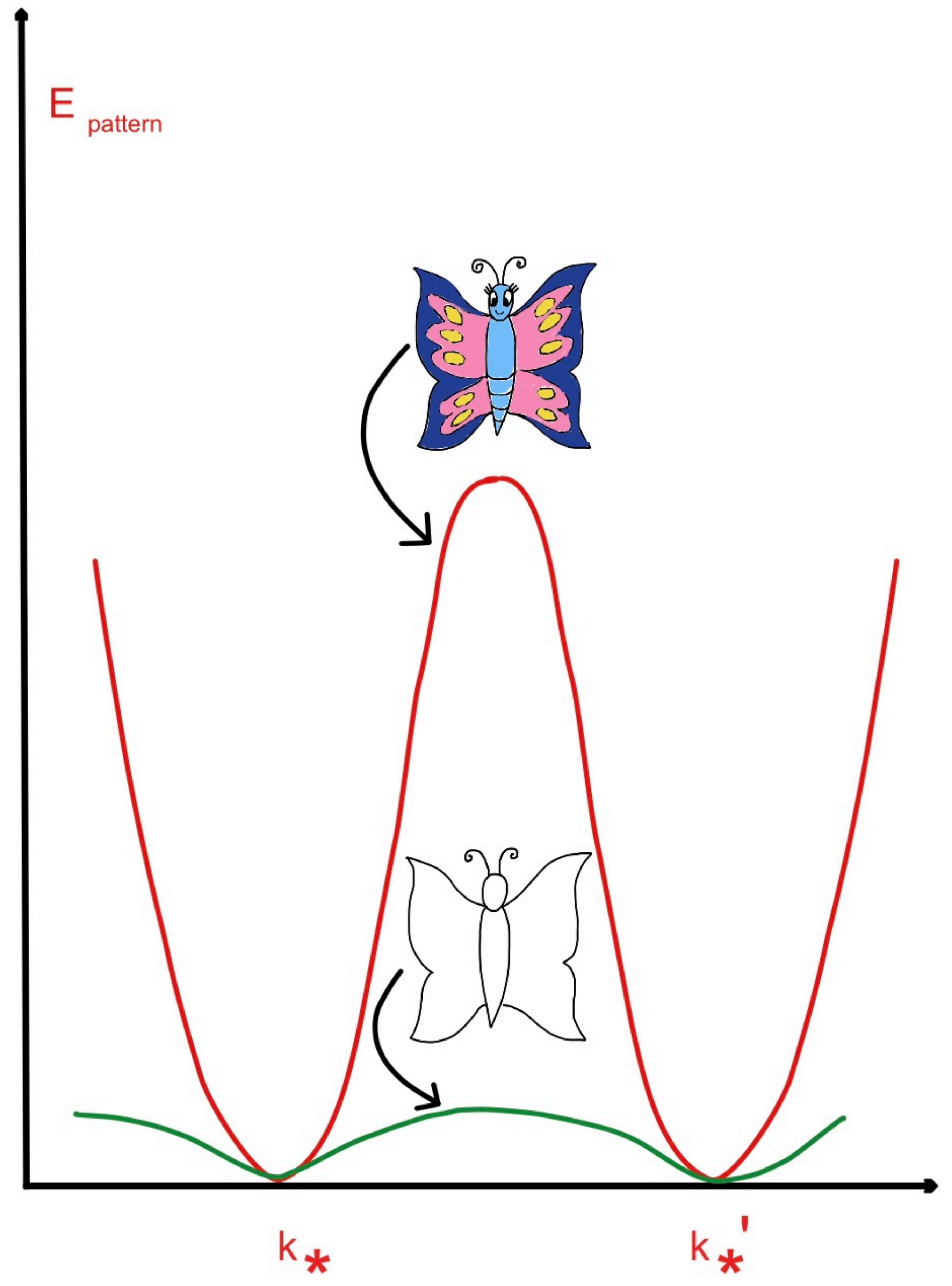
- Systems with critical states + large number of modes
  - In critical state: energy gap of modes very small

⇒*Memory Modes* store Information with little energy cost.

  - Outside critical state: information very energy expensive

⇒ Stored information hinders decay of critical state

→ ***Memory Burden Effect***



Dvali, 2018, arXiv:1810.02336 **[hep-th]**

Toy Model Example

Dvali, 2018; Dvali et al., 2018; Dvali et al. 2021

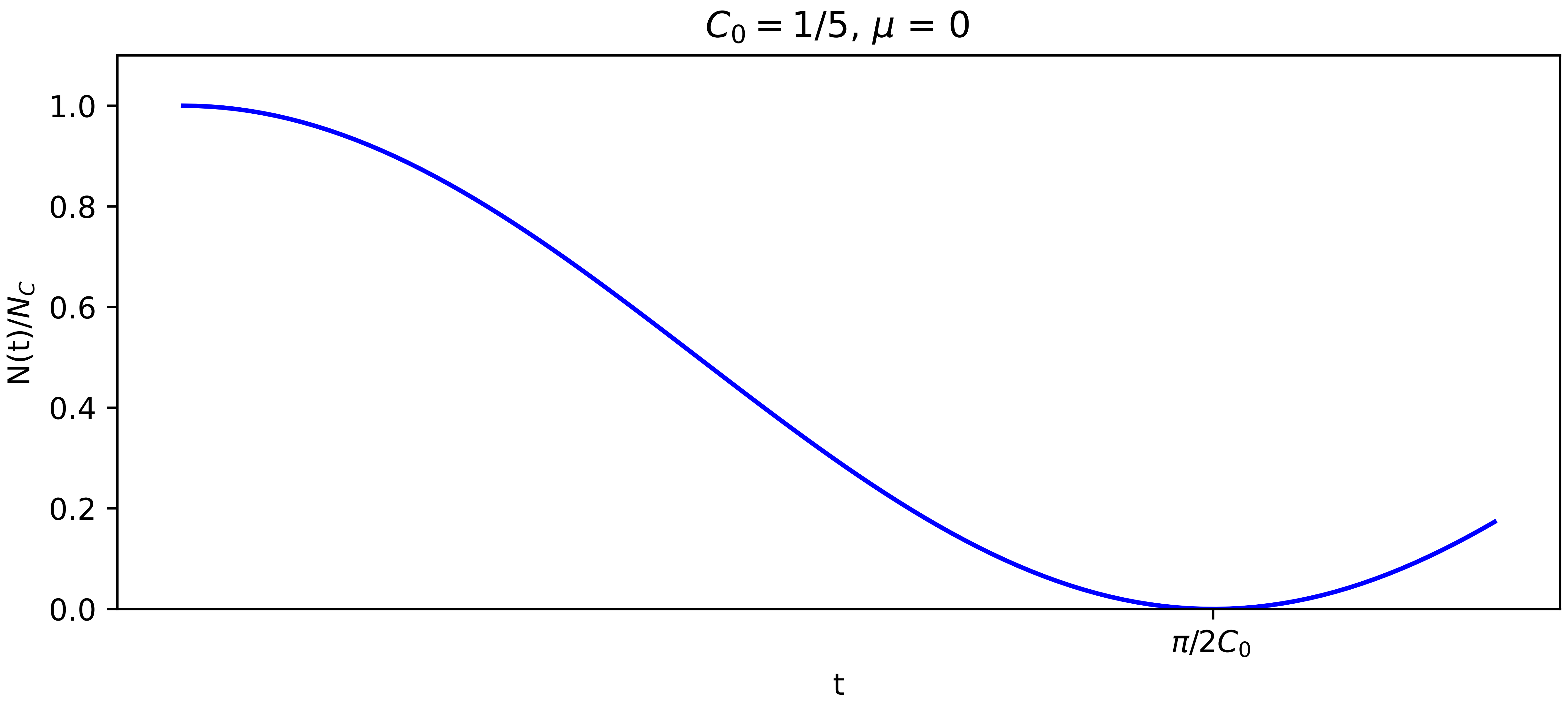
$$H = \epsilon_0 \hat{n}_0 + \epsilon_0 \hat{m}_0 + \left(1 - \frac{\hat{n}_0}{N_C}\right) \sum_{k=1}^{K} \epsilon_k \hat{n}_k + C_0 \left(\hat{a}_0^\dagger \hat{b}_0 + \hat{b}_0^\dagger \hat{a}_0\right), \; |\text{in}\rangle = |N_C, 0, n_1, \ldots, n_k\rangle$$

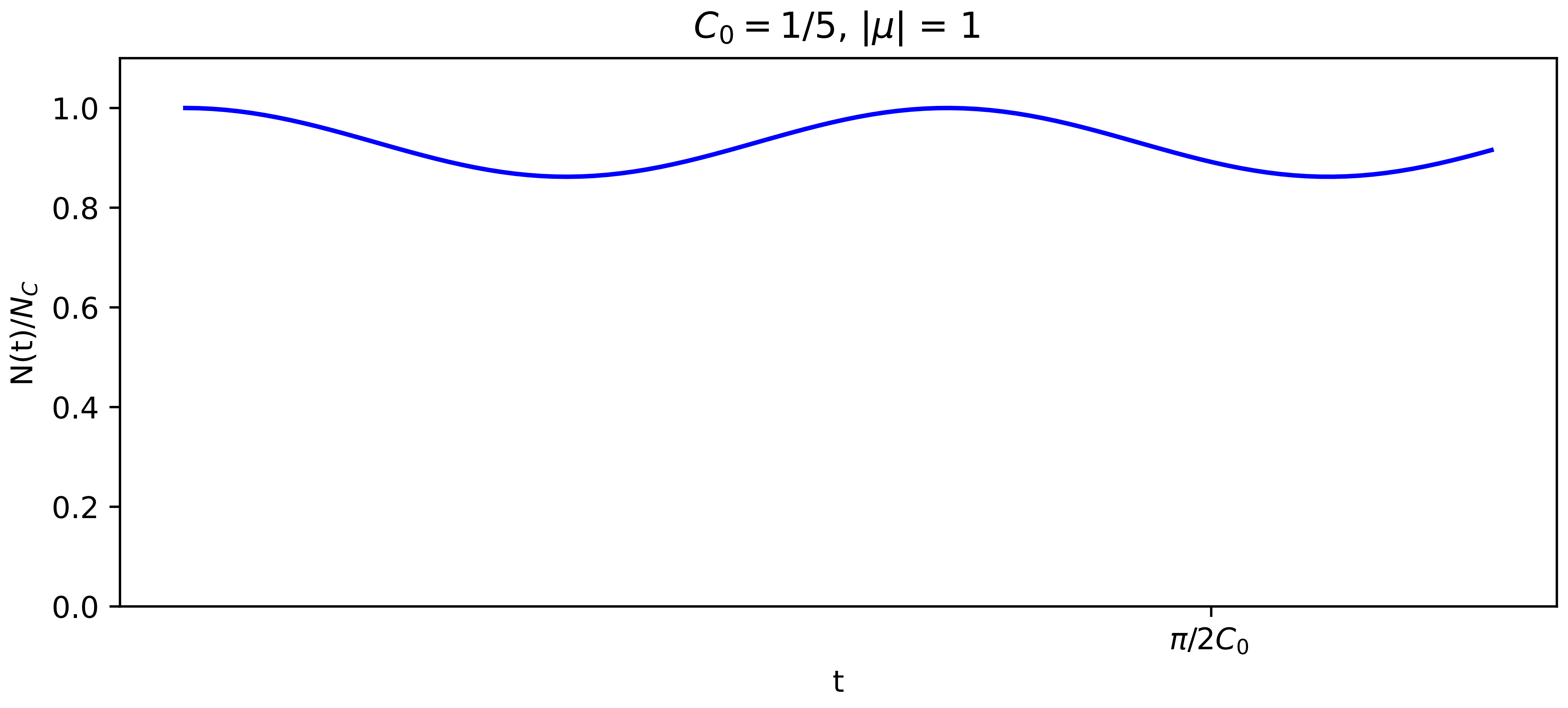
- $\hat{n}_0 = \hat{a}_0^\dagger \hat{a}_0 \leftrightarrow$ *Master Mode*, $\hat{n}_k = \hat{a}_k^\dagger \hat{a}_k \leftrightarrow$ *Memory Modes*, $n_k = \langle \hat{n}_k \rangle \leftrightarrow$ *Information*
- $\mu = -\sum_{k=1}^{K} \epsilon_k n_k / N_C$ quantifies Memory Burden
- No change in pattern between $|\hat{n}_0 = N_C, \hat{m}_0 = 0\rangle$ and $|\hat{n}_0 = 0, \hat{m}_0 = N_C\rangle$: $\Delta E = -N_C \mu$

Toy Model Example

Dvali, 2018; Dvali et al., 2018; Dvali et al. 2021

Time-evolution of $n_0 = \langle \hat{n}_0 \rangle$: $n_0(t) = N_C \left(1 - \frac{4C_0^2}{4C_0^2 + \mu^2} \sin^2 \left(\sqrt{C_0^2 + \mu^2/4}\, t \right) \right)$

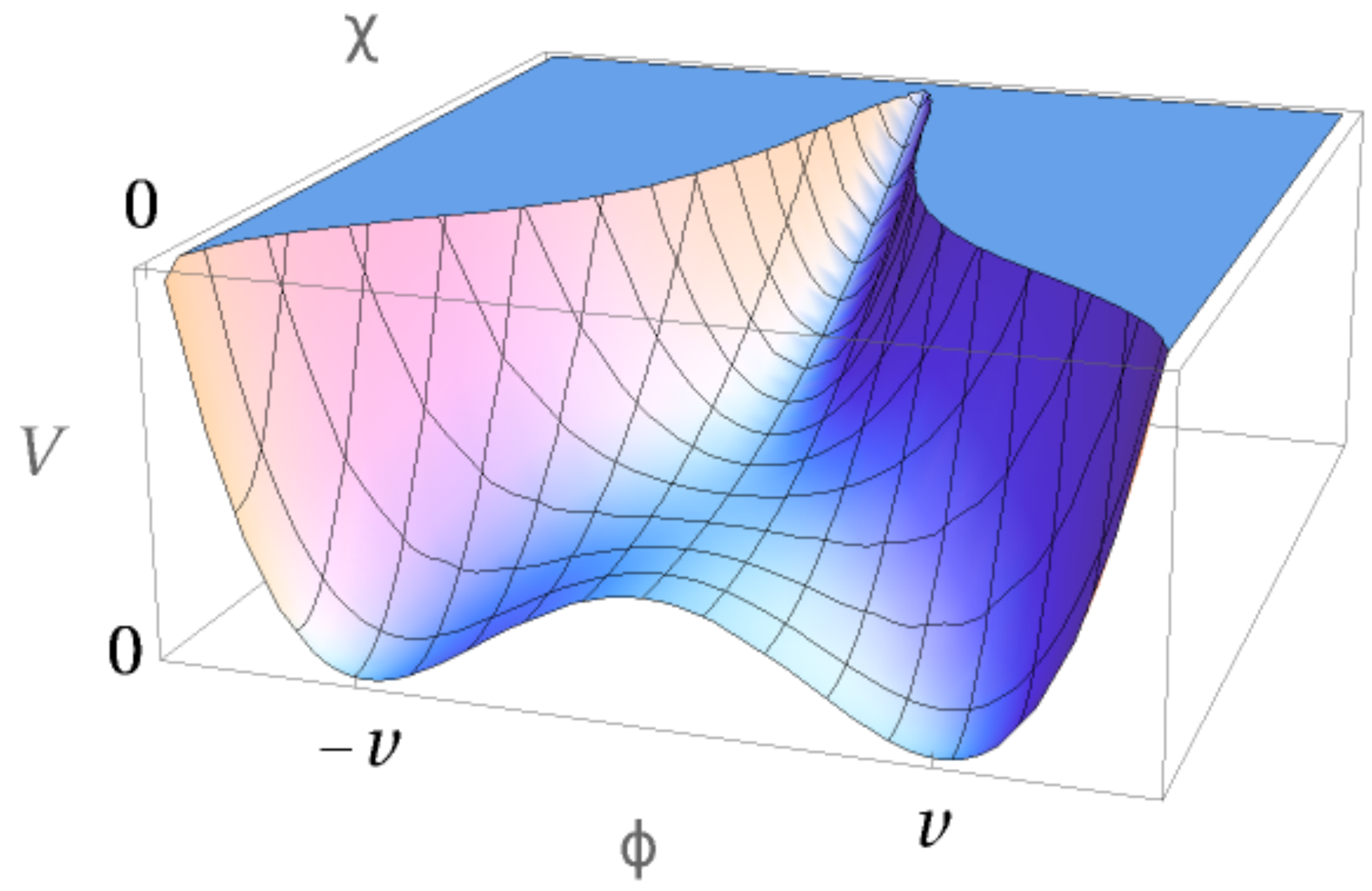




Double Field Approach

Locked Inflation

Dvali, Kachru, 2003

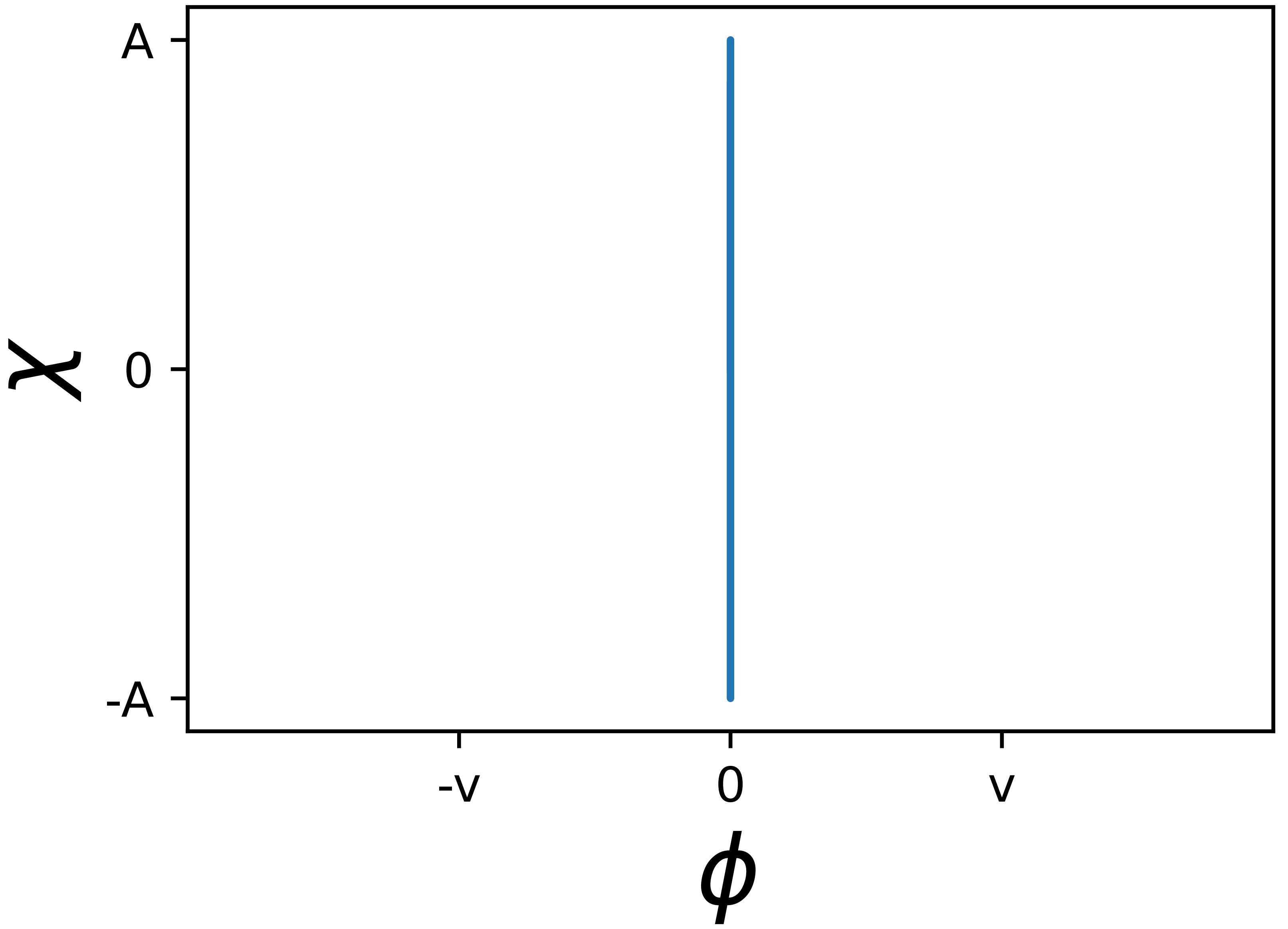


- 2 fields ϕ, χ, $V = \frac{g^2}{4}\left(\phi^2 - v^2\right)^2 + \frac{m^2}{2}\chi^2 + \lambda^2\phi^2\chi^2$
- Background $\phi_B = 0$, $\chi_B = A\cos(mt)$
- Fluctuations φ around ϕ_B, Eom.:

$$\Box\,\varphi + (\lambda^2 A^2 - g^2 v^2)\varphi + \lambda^2 A^2 \cos(2mt)\varphi = 0,\; m_0^2 \equiv \lambda^2 A^2 - g^2 v^2$$

- Expand φ in momentum modes

$$\Rightarrow \ddot{\varphi}_k + (k^2 + m_0^2)\varphi_k + \lambda^2 A^2 \cos(2mt)\varphi_k = 0$$ (*Mathieu equation)*

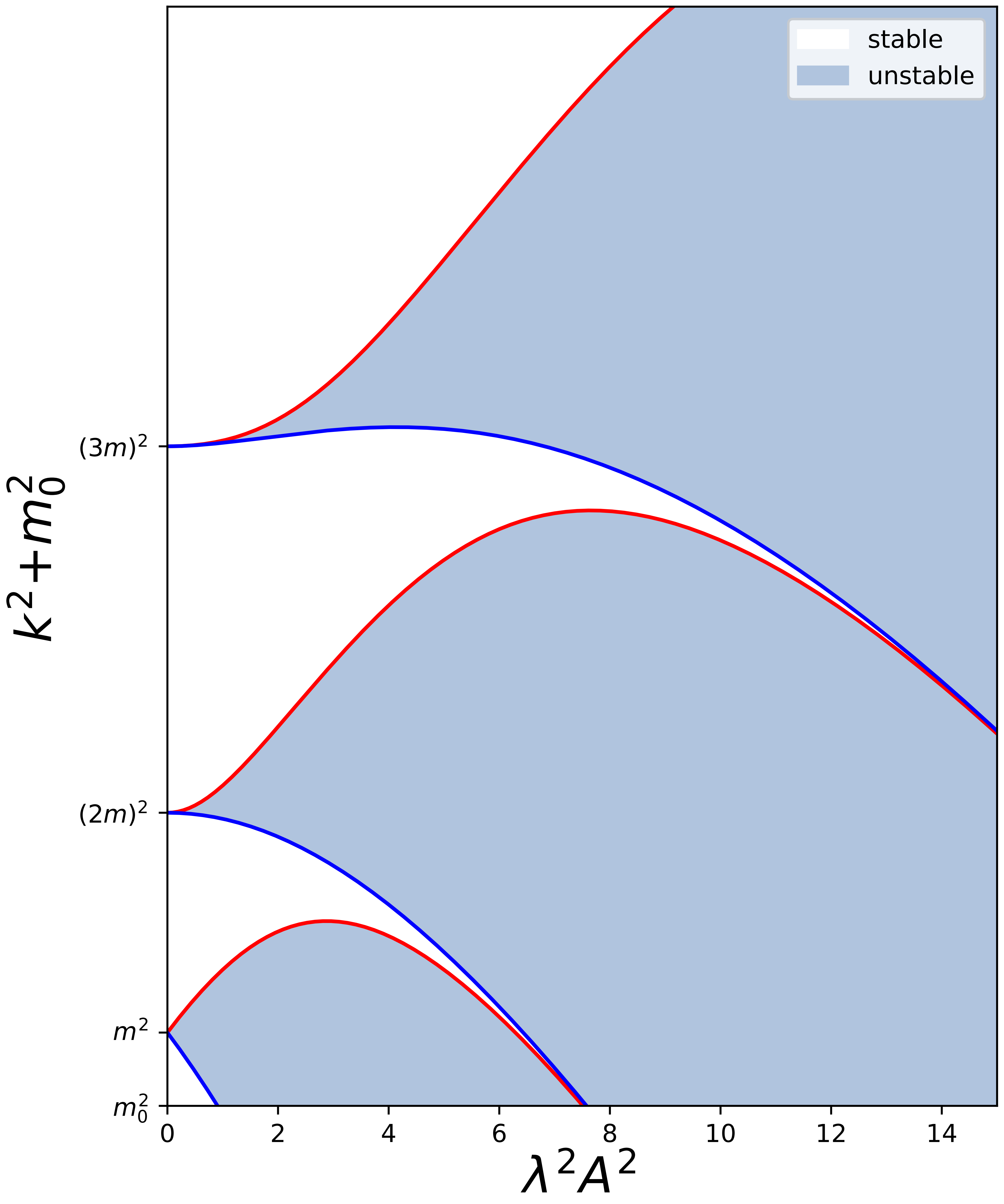


Stability of the Background

$$\ddot{\varphi}_k + (k^2 + m_0^2)\varphi_k + \lambda^2 A^2 \cos(2mt)\varphi_k = 0$$

- Parametric resonance at $k^2 + m_0^2 = (nm)^2$, $n \in \mathbb{N}$
- Stable solutions exist for $\dfrac{\lambda^2 A^2}{k^2 + m_0^2} \ll 1$
- For low momentum most modes are unstable

$\Rightarrow$ Stabilization of $\phi_B = 0$ not possible



Multi Field Approach

Adding symmetries

- Modify the potential: N copies of χ + $SO(N)$ symmetry:

$$V = \frac{g^2}{4}\left(\phi^2 - v^2\right)^2 + \frac{m^2}{2}\sum_i^N \chi_i^2 + \lambda^2 \sum_i^N \phi^2 \chi_i^2$$

- Background $\phi_B = 0$, $\chi_{iB} = A\cos(mt + \theta_i)$, $i = 1,\ldots,N$

- ϕ $\leftrightarrow$ *Master Mode*, $\chi_i \leftrightarrow$ *Memory Modes*, $\theta_i \leftrightarrow$ *Information*

- Eom. for momentum modes of φ:

$$\ddot{\varphi}_k + (k^2 + m_0^2)\varphi_k + \lambda^2 A^2 \sum_{i=1}^N \cos(2mt + 2\theta_i)\varphi_k = 0,\ m_0^2 \equiv N\lambda^2 A^2 - g^2 v^2$$

Multi Field Approach

Stabilization through Memory Burden

- Use: $\sum_{i=1}^{N} \cos(2mt + 2\theta_i) = N\delta \cos(2mt + \Theta)$, with $N^2\delta^2 = \sum_{i,j} \cos 2(\theta_i - \theta_j)$

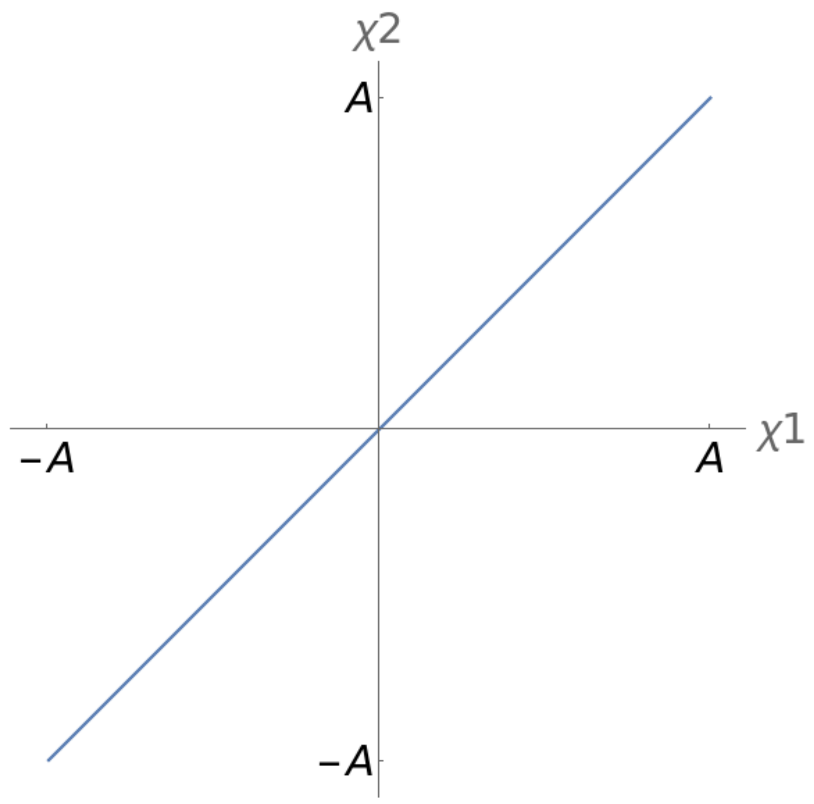
$$\Rightarrow \ddot{\varphi}_k + (k^2 + m_0^2)\varphi_k + \delta N \lambda^2 A^2 \cos(2mt + \Theta)\varphi_k = 0$$

- δ *quantifies Memory Burden*, maximal burden for $\delta = 0$

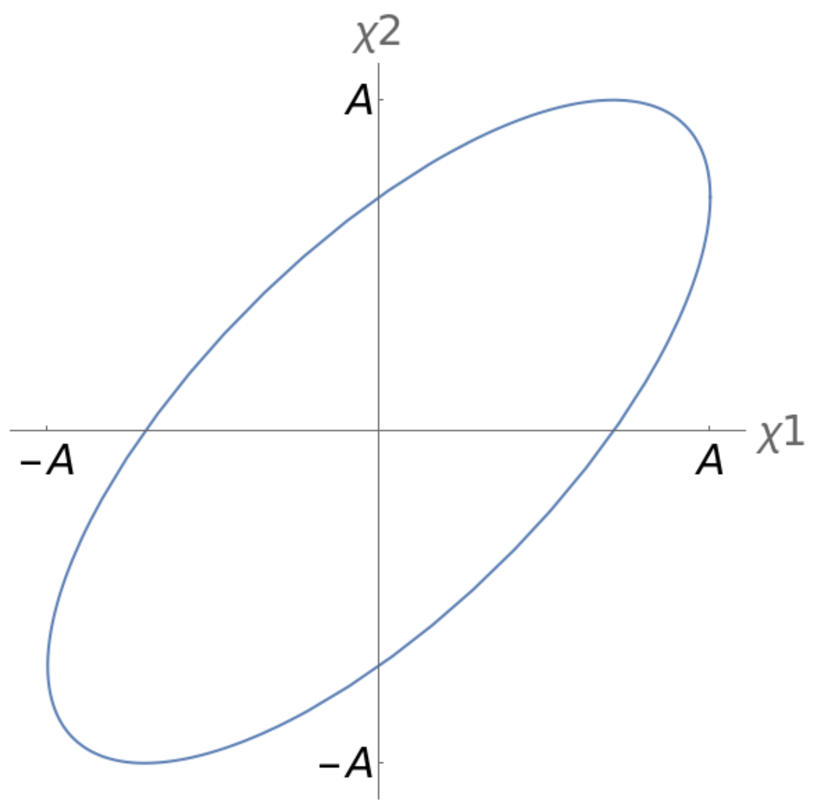
$\Rightarrow$ ***Memory Burden causes suppression of oscillations***

$\Rightarrow$ Low momentum modes can be stabilized

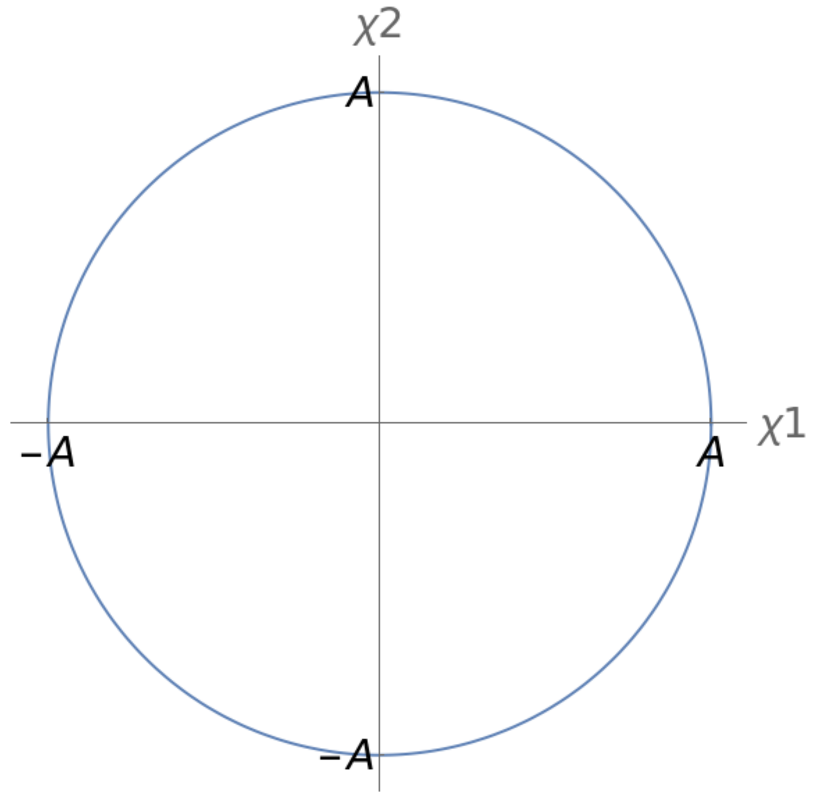
$\Rightarrow \phi_B = 0$ ***metastable vacuum***



$\delta = 1$



$\delta = 1/2$



$\delta = 0$

Double Scaling Limits

- Mathieu equation only valid to lowest order in perturbation theory
- Double scaling limit, minimize corrections from cross-interaction:
  $N \to \infty,\ \lambda^2 \to 0,\ N\lambda^2$ const .

$\Rightarrow$ Corrections only in powers of $N\lambda^2$

- Minimize corrections from self-coupling: $v^2/m^2 \sim N,\ g^2 \sim 1/N$

$\Rightarrow$ No self-coupling for $N \to \infty$

- Memory Burden $\delta \sim 1/N$ for random phases

$\Rightarrow$ $\phi_B = 0$ ***stable vacuum*** for $N \to \infty$

Quantum Corrections

Dvali, Eisemann, 2022

- After double scaling, few contributions survive
- Effective description: Coleman-Weinberg term
  - Correction to the χ_i:

$$V_C(\chi_i) \simeq \frac{\lambda^4}{16\pi^2} \sum_{i,j} \chi_i^2 \chi_j^2 \left(\ln\left(\frac{2\lambda^2 \sum_i \chi_i^2 - g^2 v^2}{\mu^2} \right) + \frac{3}{2} \right)$$

  - Correction to ϕ:

$$V_C(\phi) \simeq \frac{N\lambda^2 m^2}{16\pi^2} \phi^2 \left(\ln\left(\frac{m^2}{\mu^2} \right) + \frac{3}{2} \right)$$

- Suppress Corrections to guarantee stability

Parameter Regimes

Dvali, Eisemann, 2022

$$V_C(\chi_i) \simeq \frac{\lambda^4}{16\pi^2} \sum_{i,j} \chi_i^2 \chi_j^2 \left(\ln\left(\frac{2\lambda^2 \sum_i \chi_i^2 - g^2 v^2}{\mu^2} \right) + \frac{3}{2} \right) \qquad V_C(\phi) \simeq \frac{N\lambda^2 m^2}{16\pi^2} \phi^2 \left(\ln\left(\frac{m^2}{\mu^2} \right) + \frac{3}{2} \right)$$

- Oscillations important for $\mu \sim m$
- Suppress cross-interactions of χ_i: $A^2 \sim g^2 v^2 / N\lambda^2$
- Supress mass correction to ϕ: $\sqrt{N} \ll 1/\lambda$ and $m/gv \ll 1/\sqrt{N}\lambda$

Summary

- Memory Burden stabilizes systems in critical states
- Enhancing Locked inflation by N fields can cause Memory Burden
- Large N limit can completely stabilize the false vacuum