IPMU INSTITUTE FOR THE PHYSICS AND MATHEMATICS OF THE UNIVERSE

Running Kinetic Inflation

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@Summer Insitute

Fuminobu Takahashi

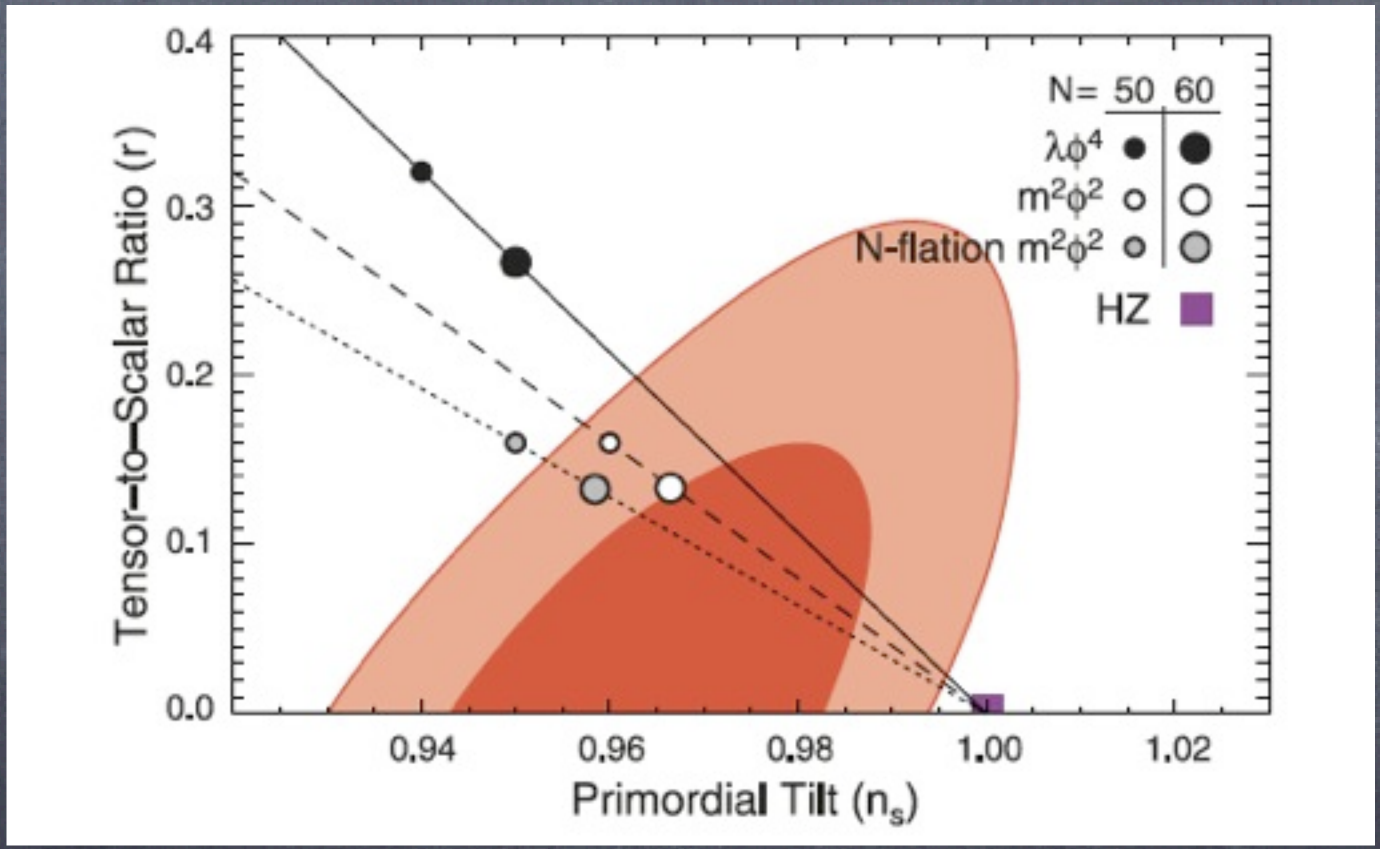
(IPMU, Univ. of Tokyo)

FT, arXiv:1006.2801, to appear in PLB.

Nakayama and FT, in preparation.

1. Introduction

Inflation has been strongly supported by observation.



Komatsu et al (2010)

However, the inflation model is not yet determined.

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Perhaps, it is useful to have another class of inflation models.

Goal:

Build a new inflation model which predicts the tensor-to-scalar ratio within the reach of observations.

It would be nicer if

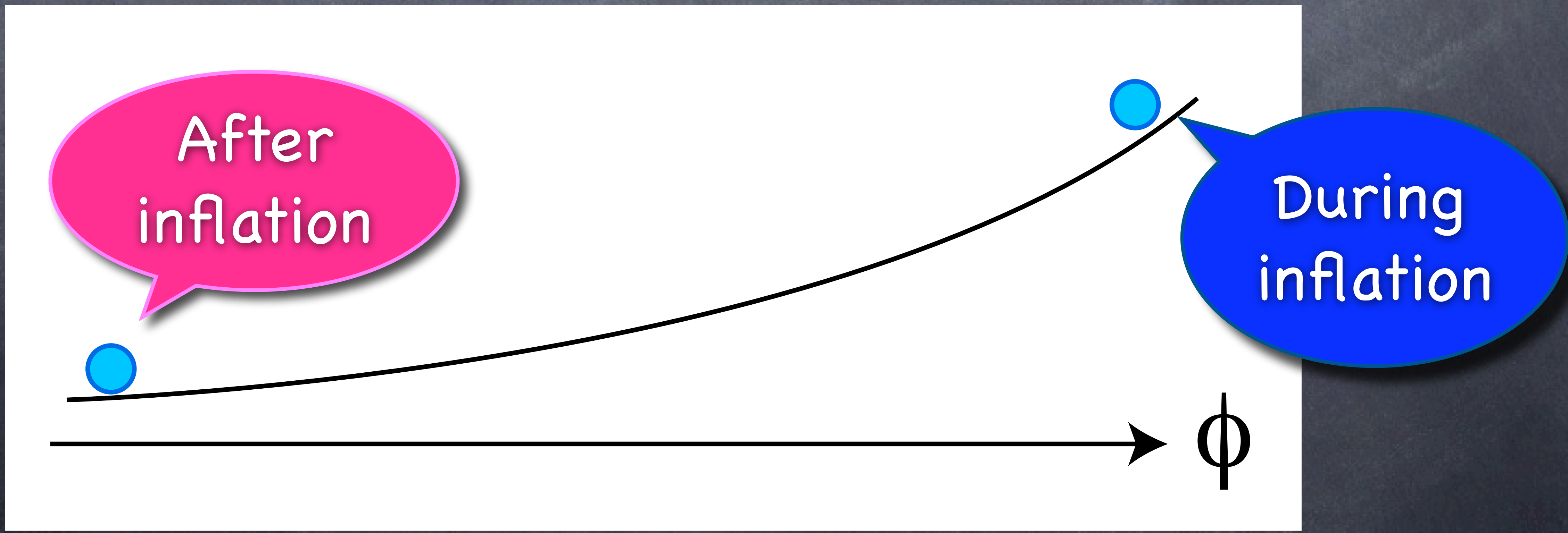
the model has implications for other probes such as the direct GW detection experiment and/or LHC.

2. Basic Idea

The inflaton moves over a long distance during inflation, especially if r > 0.01.

$$\frac{\Delta\phi}{M_p} \gtrsim \sqrt{\frac{r}{0.01}}$$

Lyth `96



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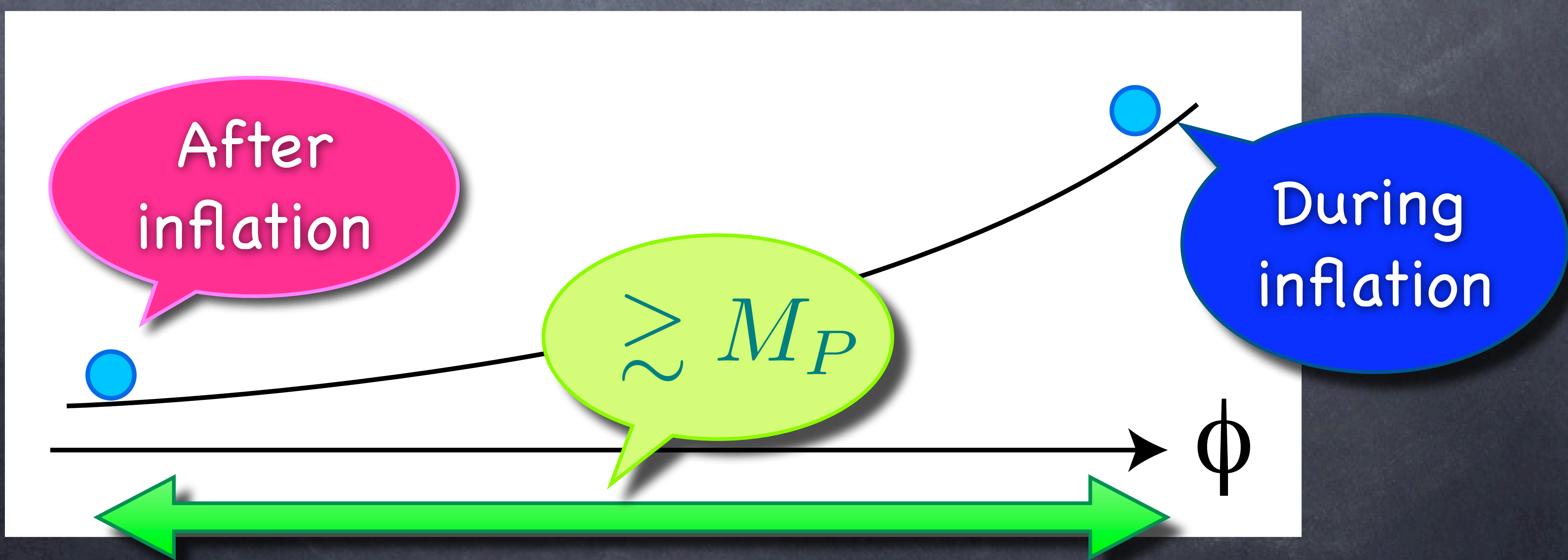
The physics during inflation may be different from after inflation.



- For instance let us consider a kinetic term:

$$\mathcal{L}_K = \frac{1}{2}(1+\phi^2)(\partial\phi)^2$$

Planck unit

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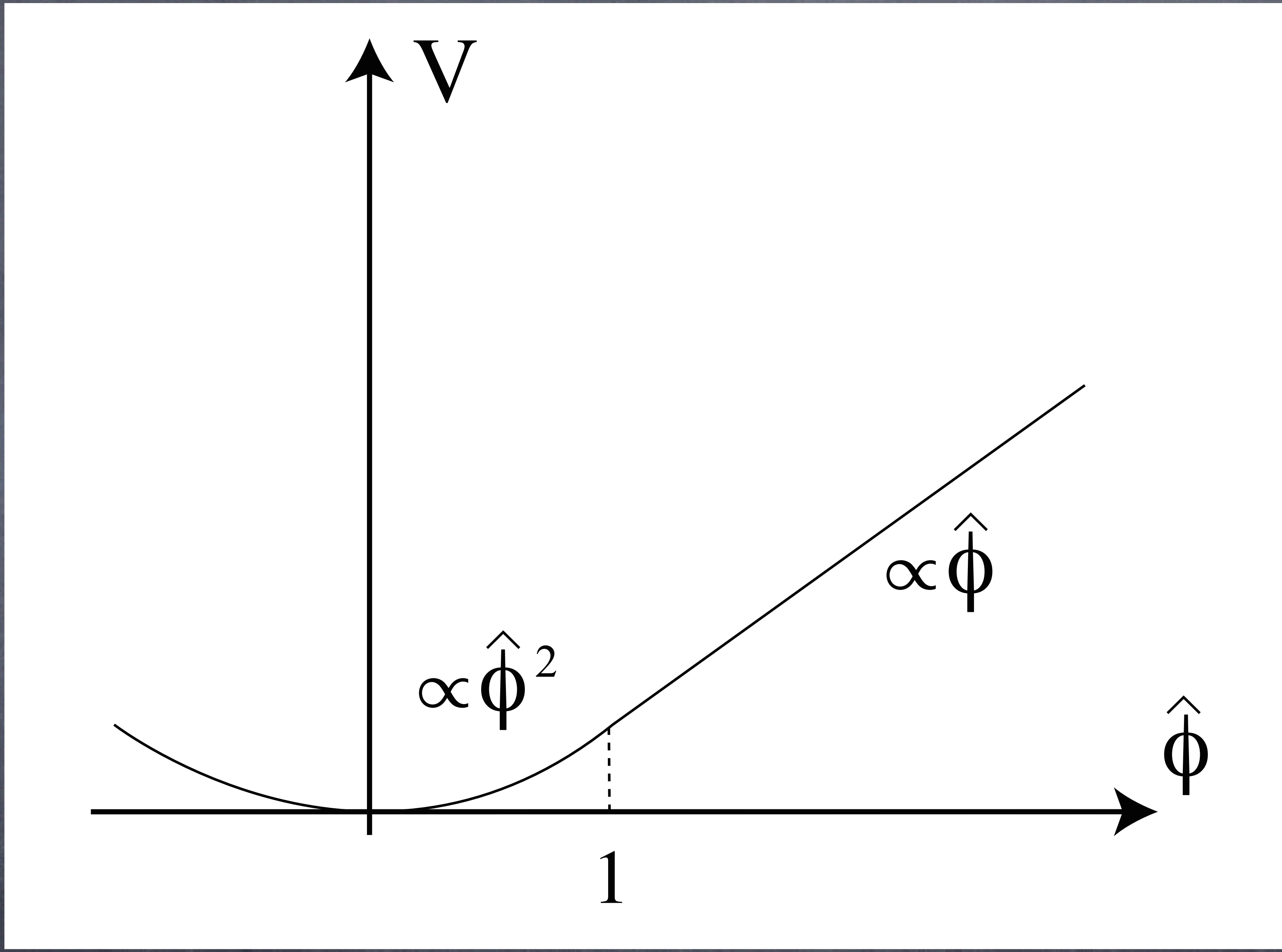
So, the effective potential is changed!

$$\frac{1}{2}m^2\phi^2 \Rightarrow m^2\hat{\phi} \quad \text{for } \phi \gg 1$$

The form of the scalar potential changes due to the kinetic term.



$$\frac{1}{2}m^2\phi^2 \Rightarrow m^2\hat{\phi} \quad \text{for } \phi \gg 1$$

☑ It seems generic that the form of the kinetic term changes during and after inflation, which modifies the inflaton dynamics.

☑ This is the case especially if the inflaton moves over a large scale as in the chaotic inflation.

☑ A large kinetic term is advantageous for the inflation to occur, because the potential becomes flatter!

3. Running kinetic inflation in sugra

Some sort of shift symmetry is needed to prevent the inflaton from appearing in the exponential pre-factor.

$$V = e^K \left(D_i W g^{i\bar{j}} (D_j W)^* - 3|W|^2) \right)$$

For instance, $\phi \longrightarrow \phi + \alpha \qquad \alpha \in \mathbf{R}$

$$K = ic_1(\phi - \phi^\dagger) - \frac{1}{2}(\phi - \phi^\dagger)^2 + \cdots$$

The inflaton is ϕ_R in this case.

Kawasaki, Yamaguchi, Yanagida, `00

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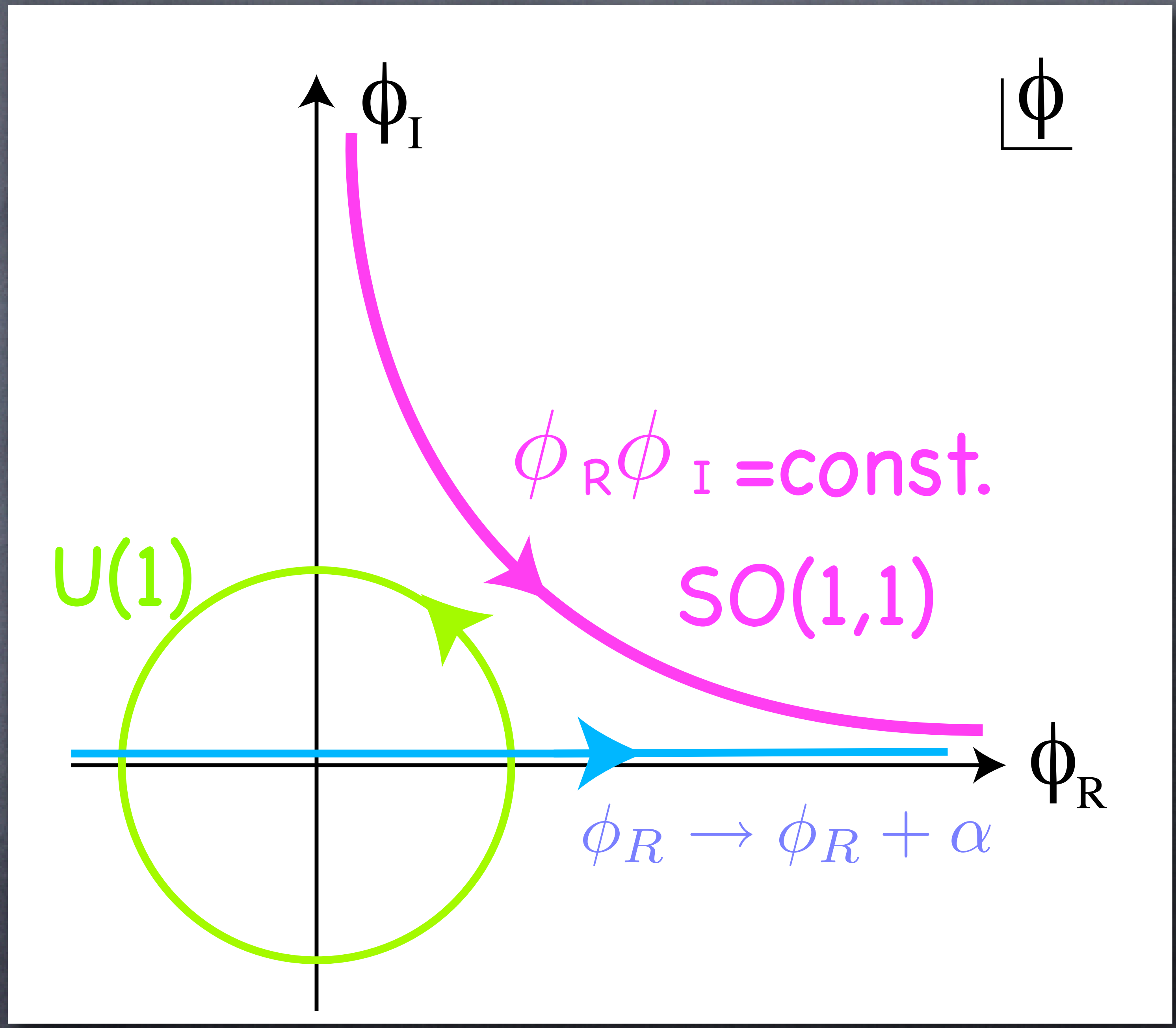
There are in general other possibilities.
We consider a SO(1,1) symmetry.



$$\phi_R\phi_I = \text{const.} \Rightarrow \phi^2 \to \phi^2 + \alpha$$

We assume that the Kahler potential respects the shift symmetry at large scales.

$$K = ic(\phi^2 - \phi^{\dagger 2}) - \frac{1}{4}(\phi^2 - \phi^{\dagger 2})^2 + \cdots ,$$

$$\Delta K = \kappa|\phi|^2$$

$$\Rightarrow \boxed{\mathcal{L}_K = \left(\kappa + (2 + \cdots)|\phi|^2\right) \partial^\mu \phi^\dagger \partial_\mu \phi,}$$

The kinetic term grows at large field values, in a controlled way thanks to the shift symmetry.

Note: $\phi^2 - \phi^{2\dagger} = \mathrm{const.}$ along the inflation trajectory.

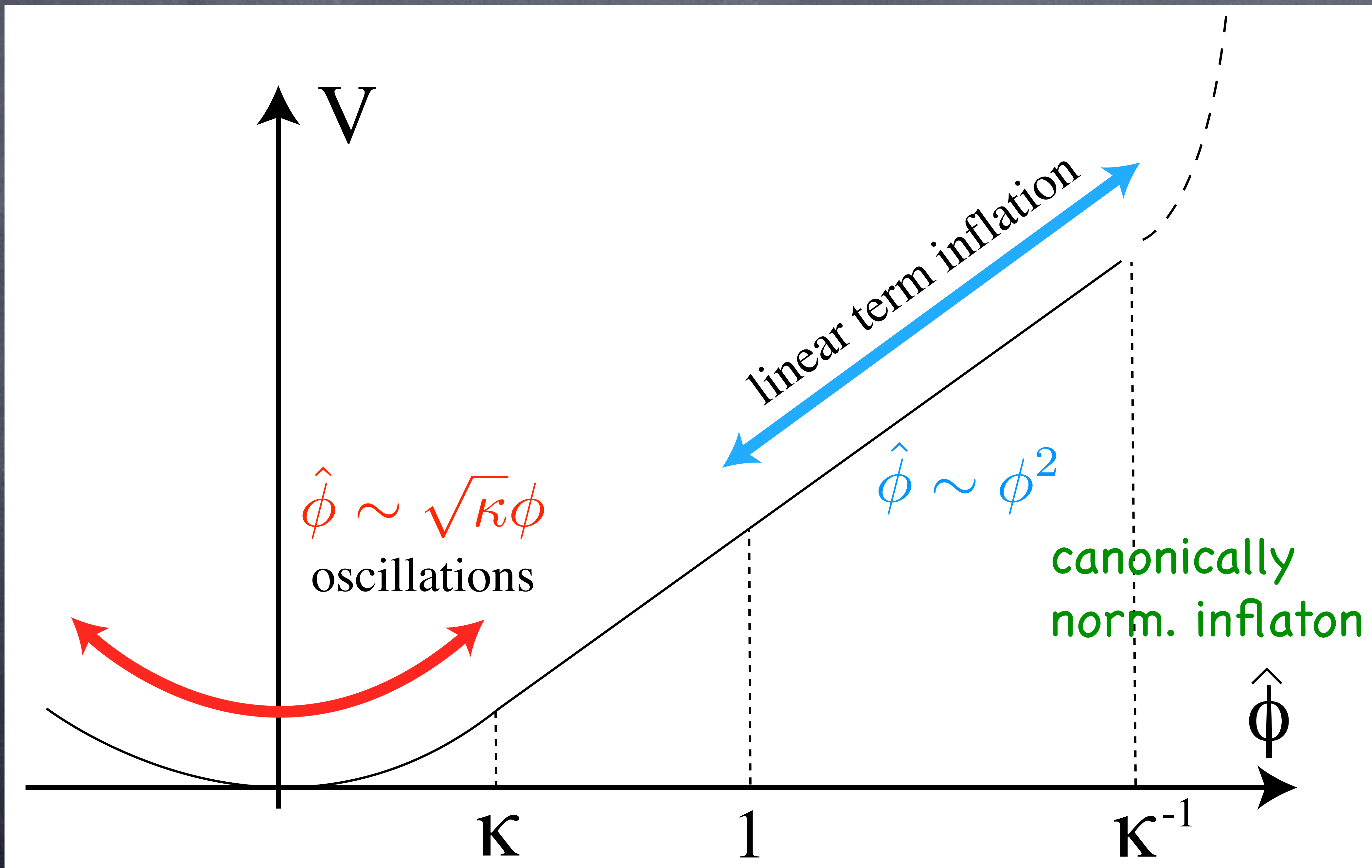
A linear chaotic inflation model

FT, arXiv:1006.2801

$$K = \kappa|\phi|^2 + ic(\phi^2 - \phi^{\dagger 2}) - \frac{1}{4}(\phi^2 - \phi^{\dagger 2})^2 + |X|^2$$

$$W = mX\phi,$$

We impose Z_2 and $U(1)_R$ symmetries.



See Silverstein et al for construction in string theory.

The inflaton potential

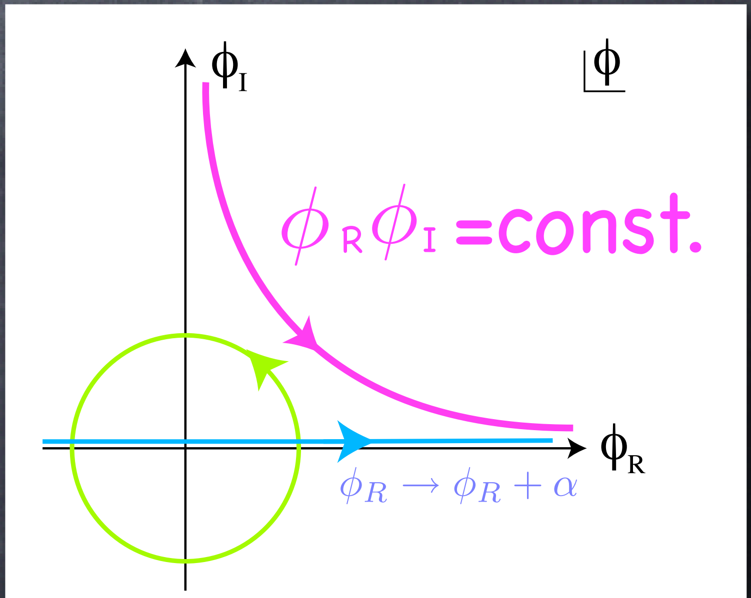
- X is stabilized at the origin during and after inflation.

$$V \approx \frac{1}{2} e^{\frac{\kappa}{2}(\phi_R^2+\phi_I^2)-4c\phi_R\phi_I+2\phi_R^2\phi_I^2} m^2 \left(\phi_R^2+\phi_I^2\right).$$

- ϕ_I is stabilized at $\phi_I \approx \frac{c}{\phi_R}.$ during inflation.

$$\mathcal{L} \approx \frac{1}{2}\phi_R^2(\partial\phi_R)^2 - \frac{1}{2}m^2\phi_R^2,$$

for ϕ_R >> 1.



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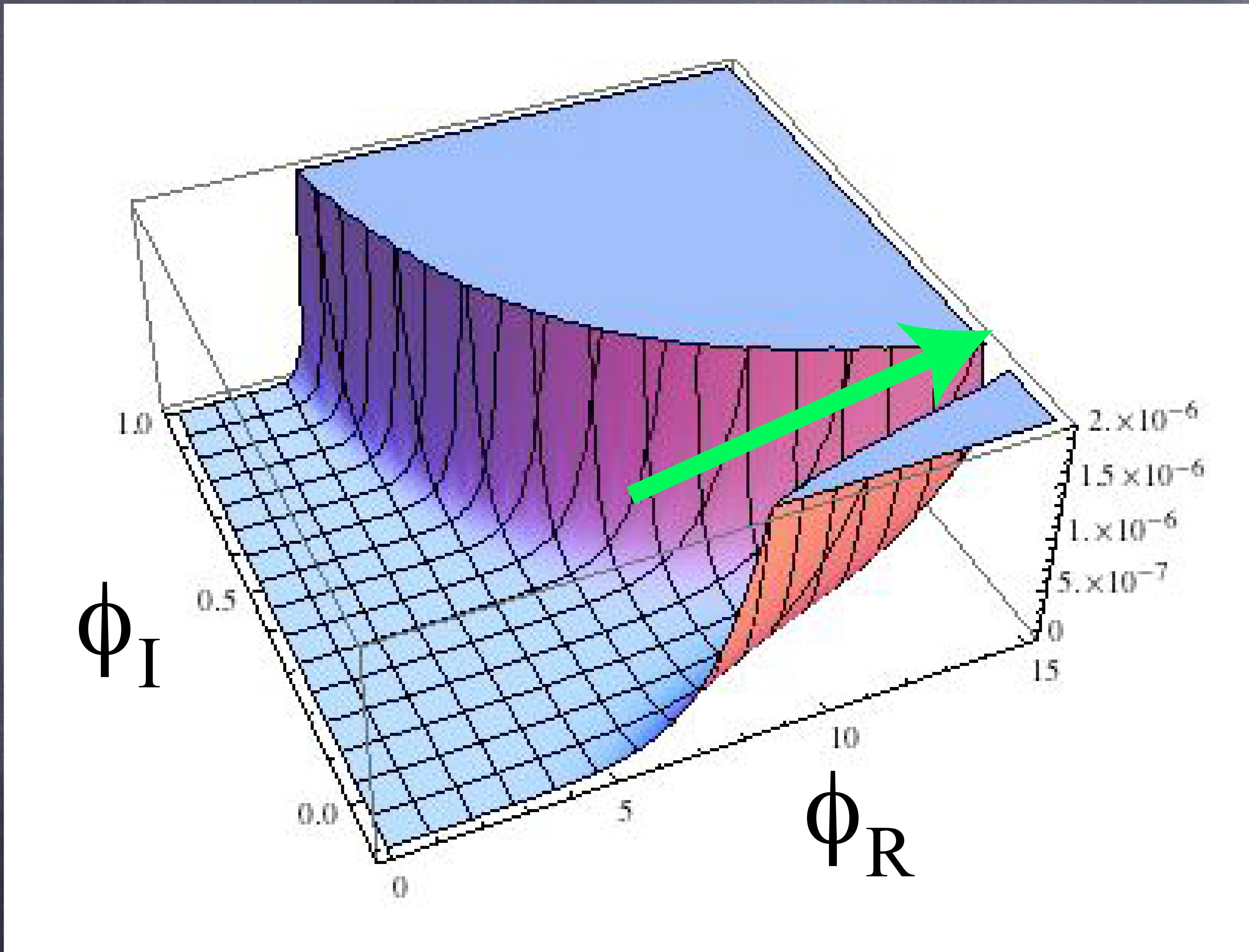


1.0
0.5
0.0
ϕ_I
0
5
10
15
ϕ_R
2.×10⁻⁶
1.5×10⁻⁶
1.×10⁻⁶
5.×10⁻⁷
0

The WMAP normalization:

$$\Delta_{\mathcal{R}}^2 \simeq \left(\frac{H}{\dot{\varphi}}\frac{H}{2\pi}\right)^2 \simeq \frac{m^2\varphi_N^3}{12\pi^2} \approx (2.43 \pm 0.11) \times 10^{-9}$$

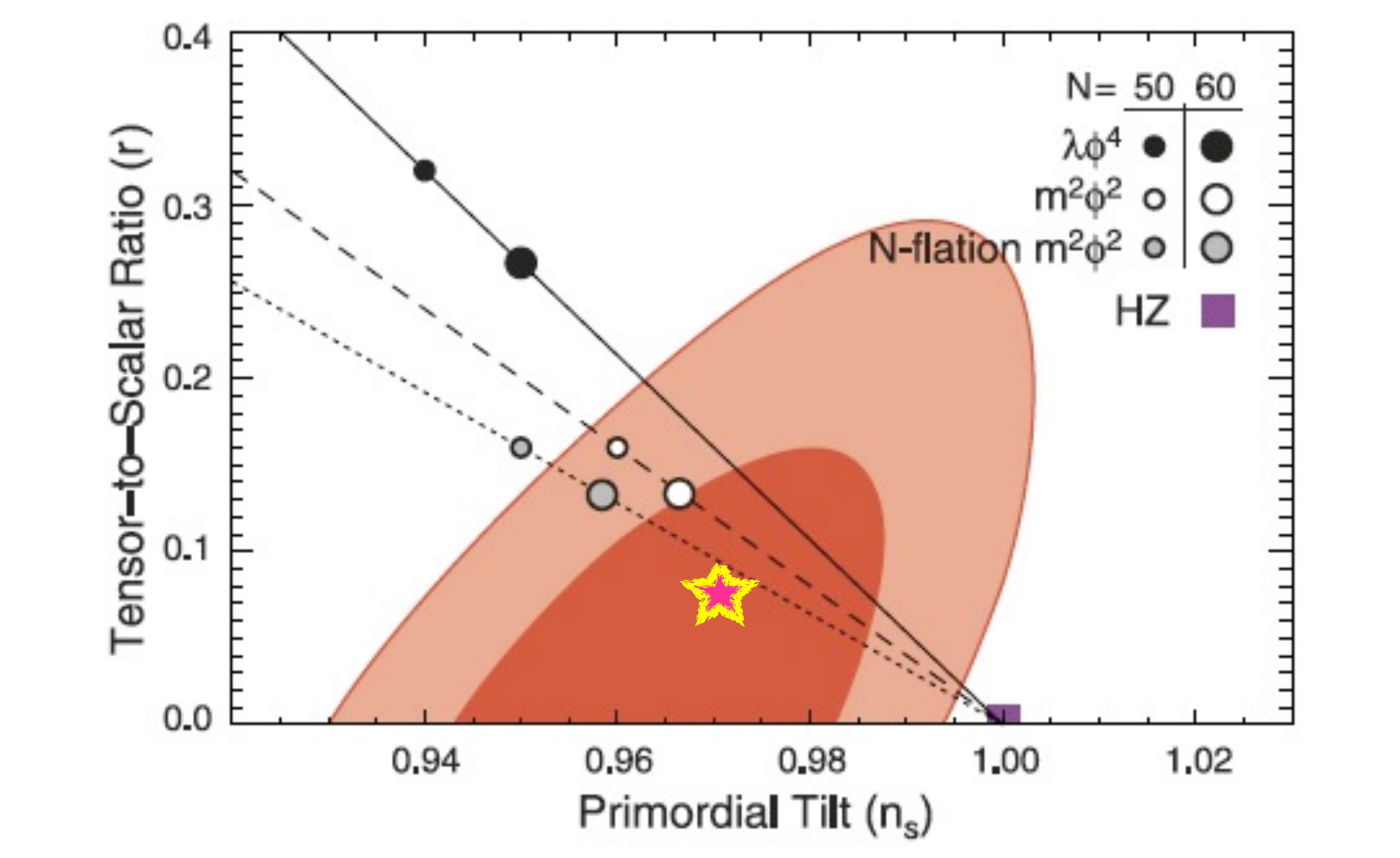
$$m \simeq 3.6 \times 10^{13}\,\mathrm{GeV}$$

$$\hat{\phi}_{60} \sim 11 M_p$$

$$V \sim m^2 \hat{\phi}$$

The inflaton mass at the origin: $m_\phi = \frac{m}{\sqrt{\kappa}}$

$$m_\phi = 4 \times 10^{14}\,\mathrm{GeV}\left(\frac{\kappa}{10^{-2}}\right)^{-1/2}\left(\frac{m}{4 \times 10^{13}\,\mathrm{GeV}}\right).$$



N= 50 60
λφ4
m2φ2
N-flation m2φ2
HZ
Tensor-to-Scalar Ratio (r)
0.0
0.1
0.2
0.3
0.4
0.94
0.96
0.98
1.00
1.02
Primordial Tilt (ns)

Reheating processes:

1) Introduce a coupling such as

$$W = \lambda X H_u H_d,$$

$$T_R \sim 10^{10}\,\mathrm{GeV}\left(\frac{\lambda}{10^{-5}}\right)^2\left(\frac{m_\phi}{10^{14}\,\mathrm{GeV}}\right)^{1/2}.$$

2) Through sugra couplings:

$$\Delta K = \delta(\phi + \phi^\dagger)$$

Endo, Kasawaki, FT, Yanagida, `06
Endo, FT, Yanagida, `07

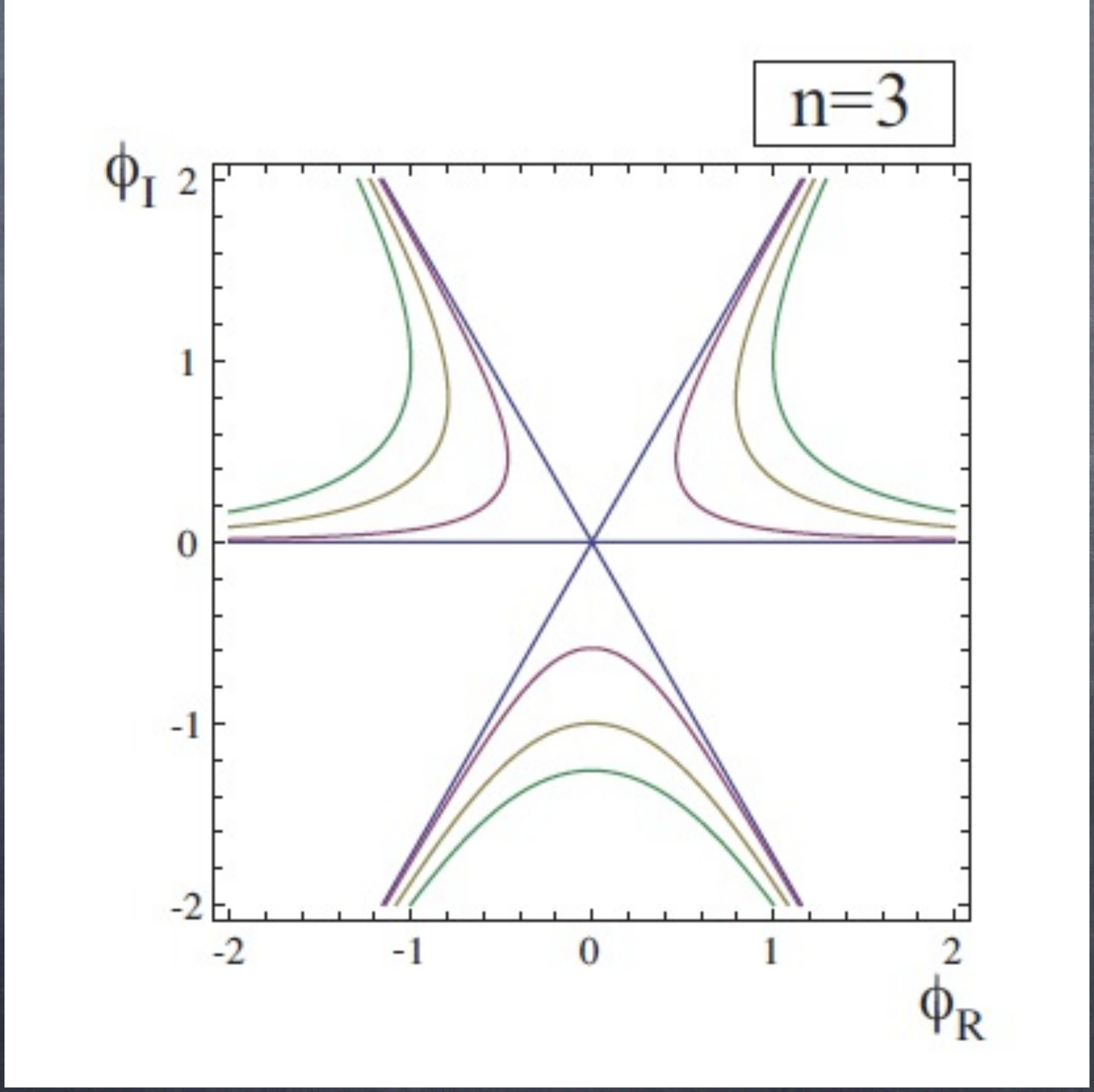
Decays into the top quarks and gluons.

$$T_R \sim 5\times 10^6\,\mathrm{GeV}\left(\frac{\delta/\sqrt{\kappa}}{10^{-3}}\right)\left(\frac{m_\phi}{10^{14}\,\mathrm{GeV}}\right)^{3/2}.$$

Generalization is straightforward.

The shift symmetry can be generalized to ϕ^n.

$$\phi^n \to \phi^n + \alpha$$



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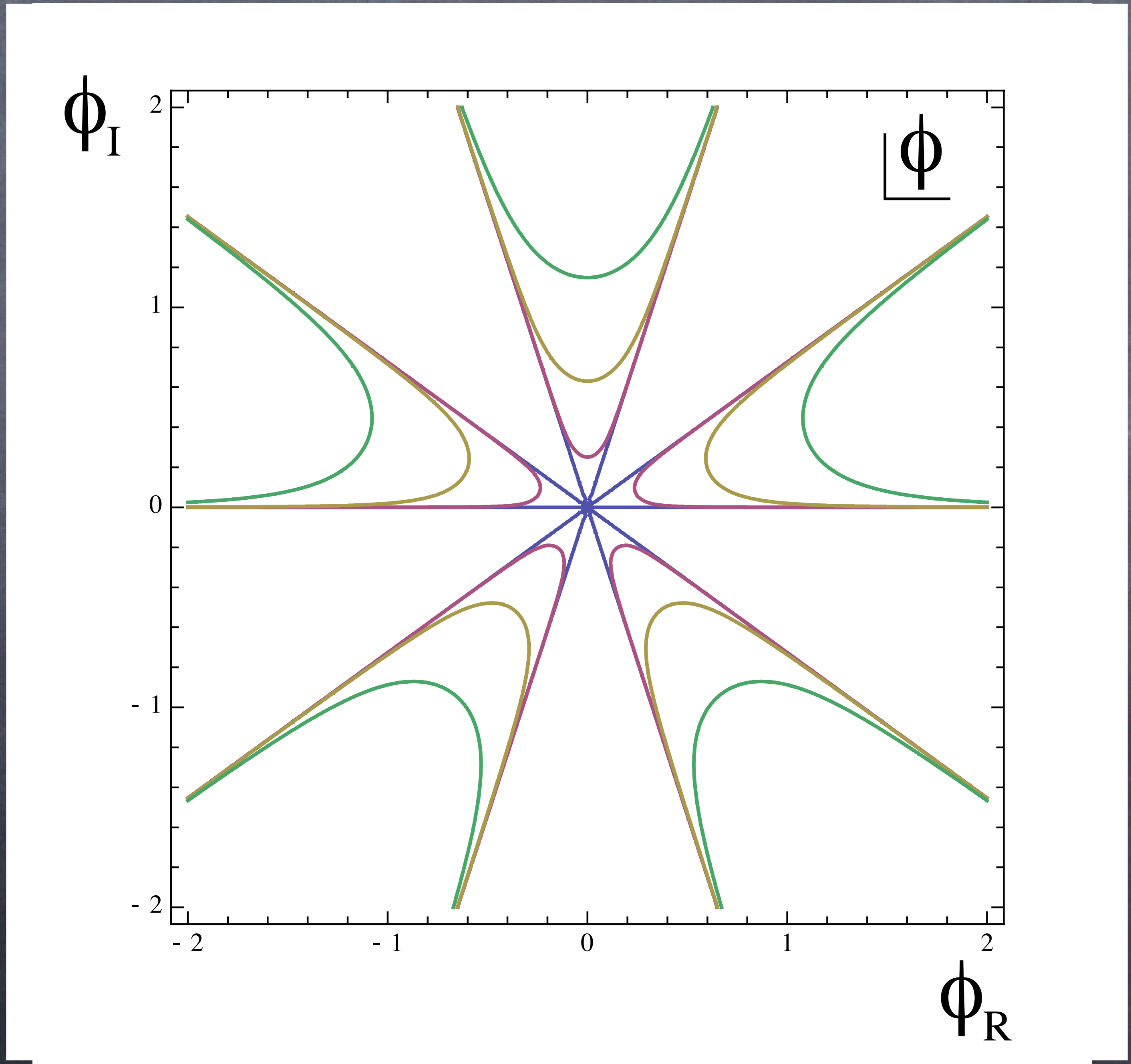


Thus, we can have a variety of chaotic inflation models along the same line.

$$\phi^n \to \phi^n + \alpha$$

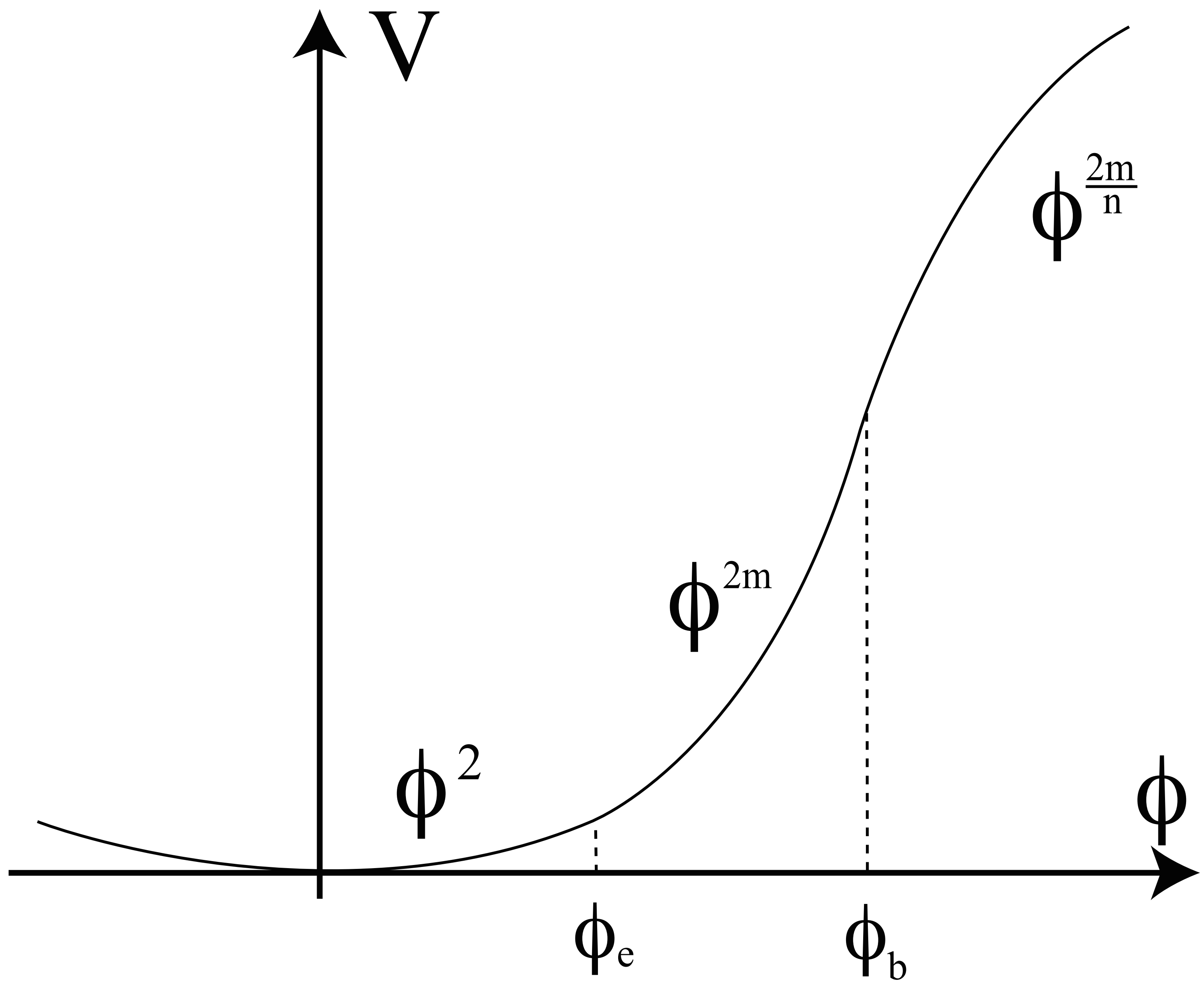
$$W = \lambda X \phi^m$$

	ϕ	X
$U(1)_R$	0	2
Z_k	1	$-m$

$$V \propto \begin{cases} \phi^{\frac{2m}{n}} & \text{during inflation} \\ \phi^{2m} & \text{after inflation} \end{cases}$$

$$n_s = 1 - (1 + m/n)/N_e \qquad r = 8m/(nN_e)$$

Linear inflation is for (n,m) = (2,1).



V
$\phi^{\frac{2m}{n}}$
ϕ^{2m}
ϕ^2
ϕ
ϕ_e
ϕ_b

4. Applications

We focus on the case of m>=2.

Then the inflaton is massless in the SUSY limit.

4.1 Solution to the non-thermal gravitino problem

Gravitino Pair-Production

Kawasaki, F.T. and Yanagida, hep-ph/0603265, 0605297
Asaka, Nakamura and Yamaguchi, hep-ph/0604132
Endo, Hamaguchi and F.T., hep-ph/0602061
Nakamura and Yamaguchi, hep-ph/0602081

- Relevant interactions:

$$e^{-1}\mathcal{L} = -\frac{1}{8}\epsilon^{\mu\nu\rho\sigma}\left(G_\phi \partial_\rho \hat{\phi} + G_z \partial_\rho z - \text{h.c.}\right)\bar{\psi}_\mu \gamma_\nu \psi_\sigma$$

$$-\frac{1}{8}e^{G/2}\left(G_\phi \hat{\phi} + G_z z + \text{h.c.}\right)\bar{\psi}_\mu \left[\gamma^\mu, \gamma^\nu\right]\psi_\nu,$$

ϕ : inflaton field

$$G \equiv K + \ln|W|^2$$

z : SUSY breaking field, w/ $G^z G_z \simeq 3$

Taking account of the mixings,

$$G_\phi \sim \langle \phi \rangle \frac{m_{3/2}}{m_\phi} \quad \text{for} \quad m_\phi < m_z$$

Gravitino Pair Production Rate:

$$\Gamma_{3/2} \simeq \frac{|G_\phi|^2}{288\pi} \frac{m_\phi^5}{m_{3/2}^2 M_P^2} \simeq \frac{1}{32\pi} \left(\frac{\langle \phi \rangle}{M_P} \right)^2 \frac{m_\phi^3}{M_P^2}$$

Endo, Hamaguchi and F.T., hep-ph/0602061
Nakamura and Yamaguchi, hep-ph/0602081

for $m_\phi < m_z$

- Gravitino pair production is effective especially for low-scale inflation models.
- Gravitino abundance is inversely proportional to the reheating temperature!

Gravitino Abundance:

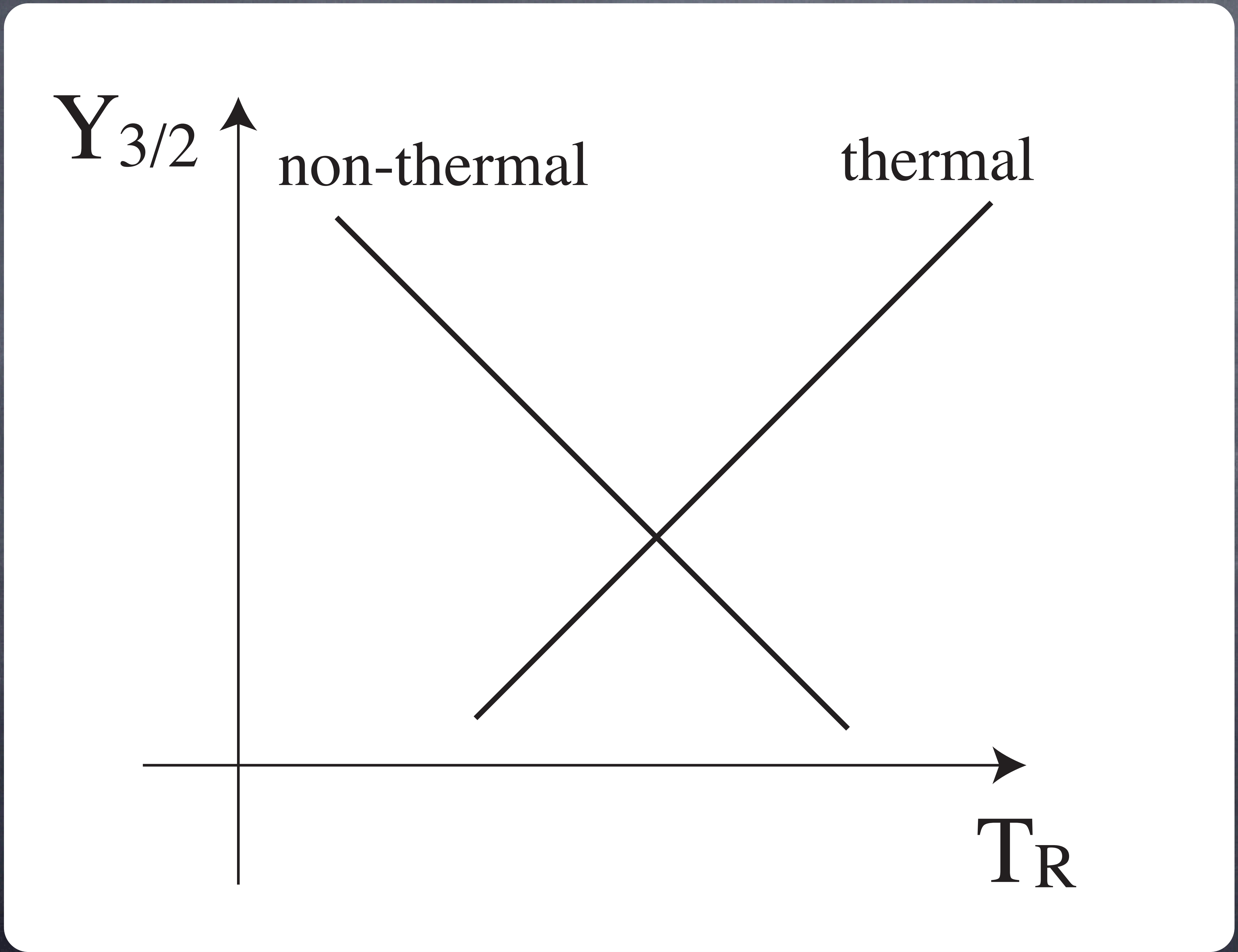
$$Y_{3/2} \simeq 2\,\frac{\Gamma_{3/2}}{\Gamma_{\rm total}}\frac{3}{4}\frac{T_R}{m_\phi},$$

$$\sim 10^{-14}\left(\frac{g_*}{200}\right)^{-\frac{1}{2}}\left(\frac{T_R}{10^6\,{\rm GeV}}\right)^{-1}$$

$$\times\left(\frac{\langle\phi\rangle}{10^{15}\,{\rm GeV}}\right)^2\left(\frac{m_\phi}{10^{10}\,{\rm GeV}}\right)^2$$

Note: $\Gamma_{\rm total} \sim \frac{T_R^2}{M_P}$

Gravitino Abundance



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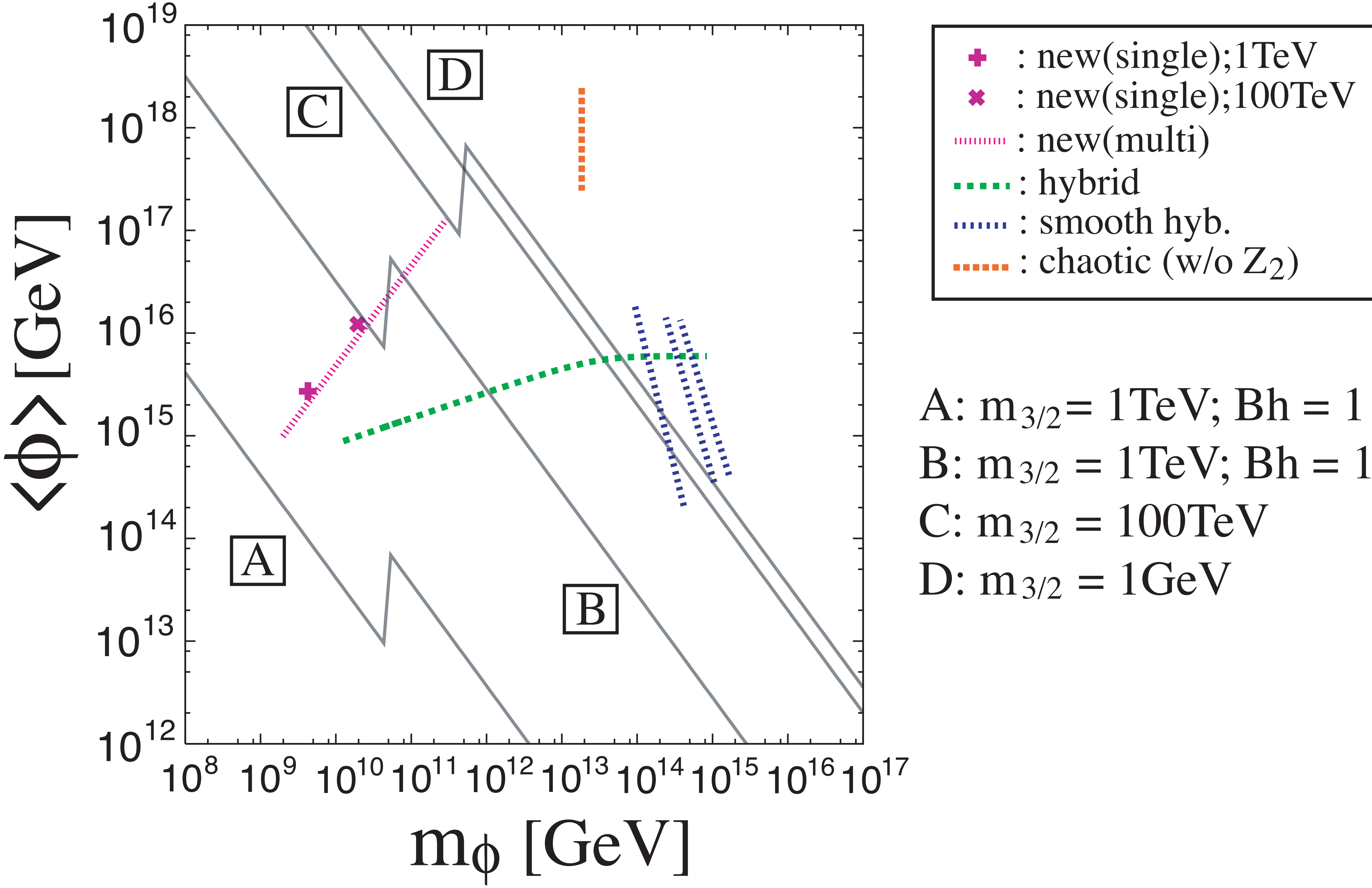
Conservative

Constraints on the inflation models;



A: $m_{3/2} = 1\text{TeV}$; $Bh = 1$

B: $m_{3/2} = 1\text{TeV}$; $Bh = 10^{-3}$

C: $m_{3/2} = 100\text{TeV}$

D: $m_{3/2} = 1\text{GeV}$

Solutions:

(i) Postulate a symmetry on the inflaton.

e.g.) chaotic inflation

$$V = \frac{1}{2}m^2\phi^2 \text{ w/ } \phi \leftrightarrow -\phi$$

(ii) AMSB, GMSB

cosmological constraints are relaxed.

(iii) late-time entropy production

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$$m_\phi = O(m_{3/2})$$

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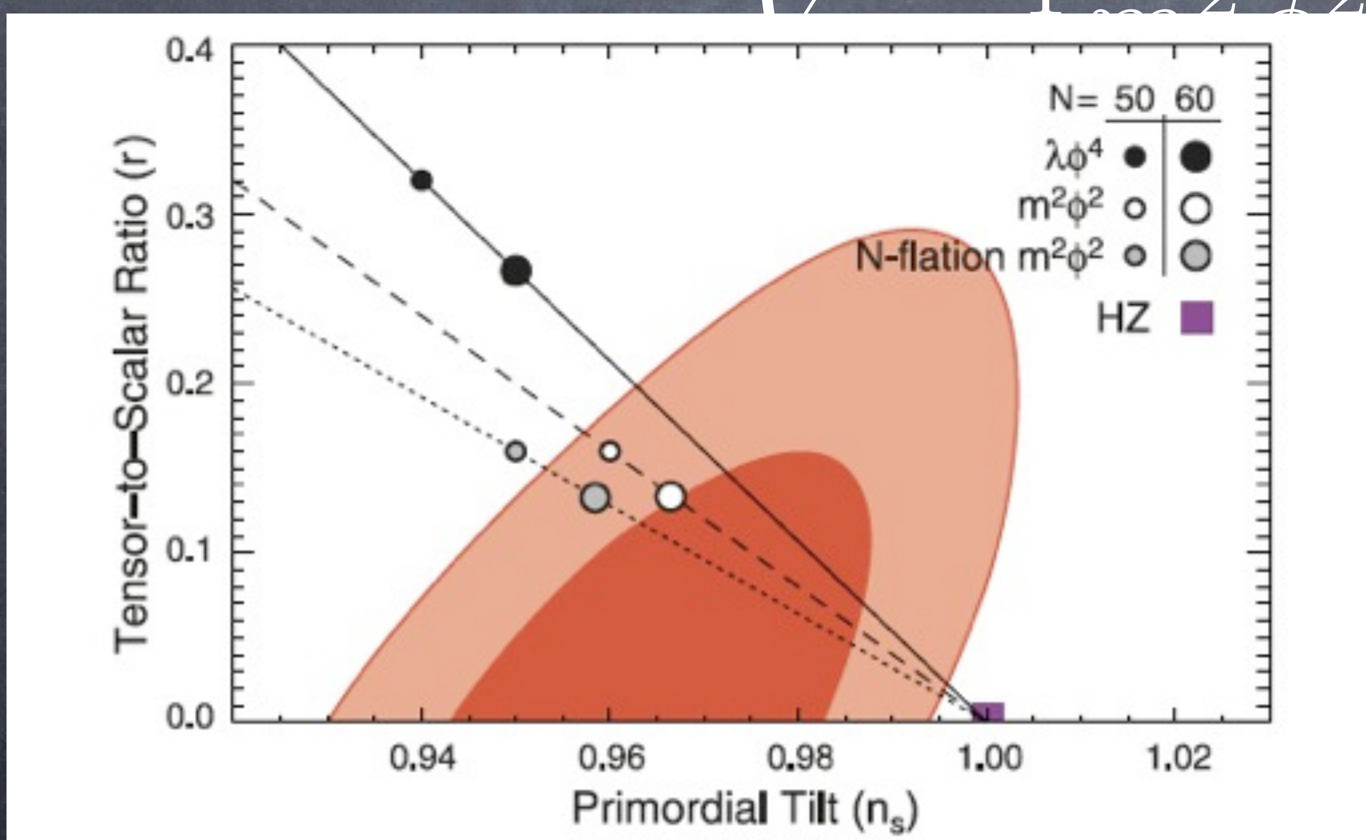

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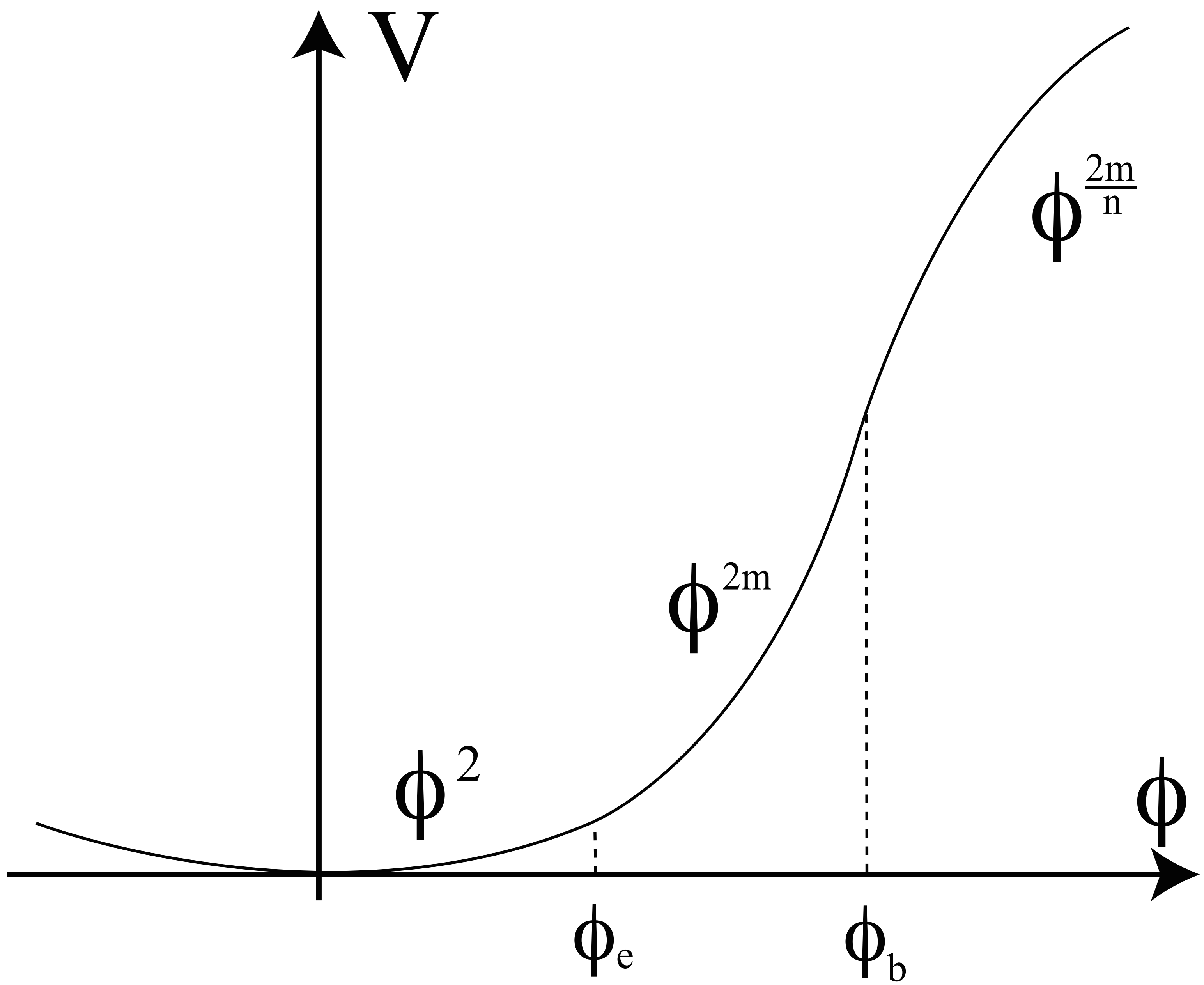
4.2 Enhancement of gravity waves

There are a kination epoch after inflation, during which the inflaton energy decreases faster than radiation.



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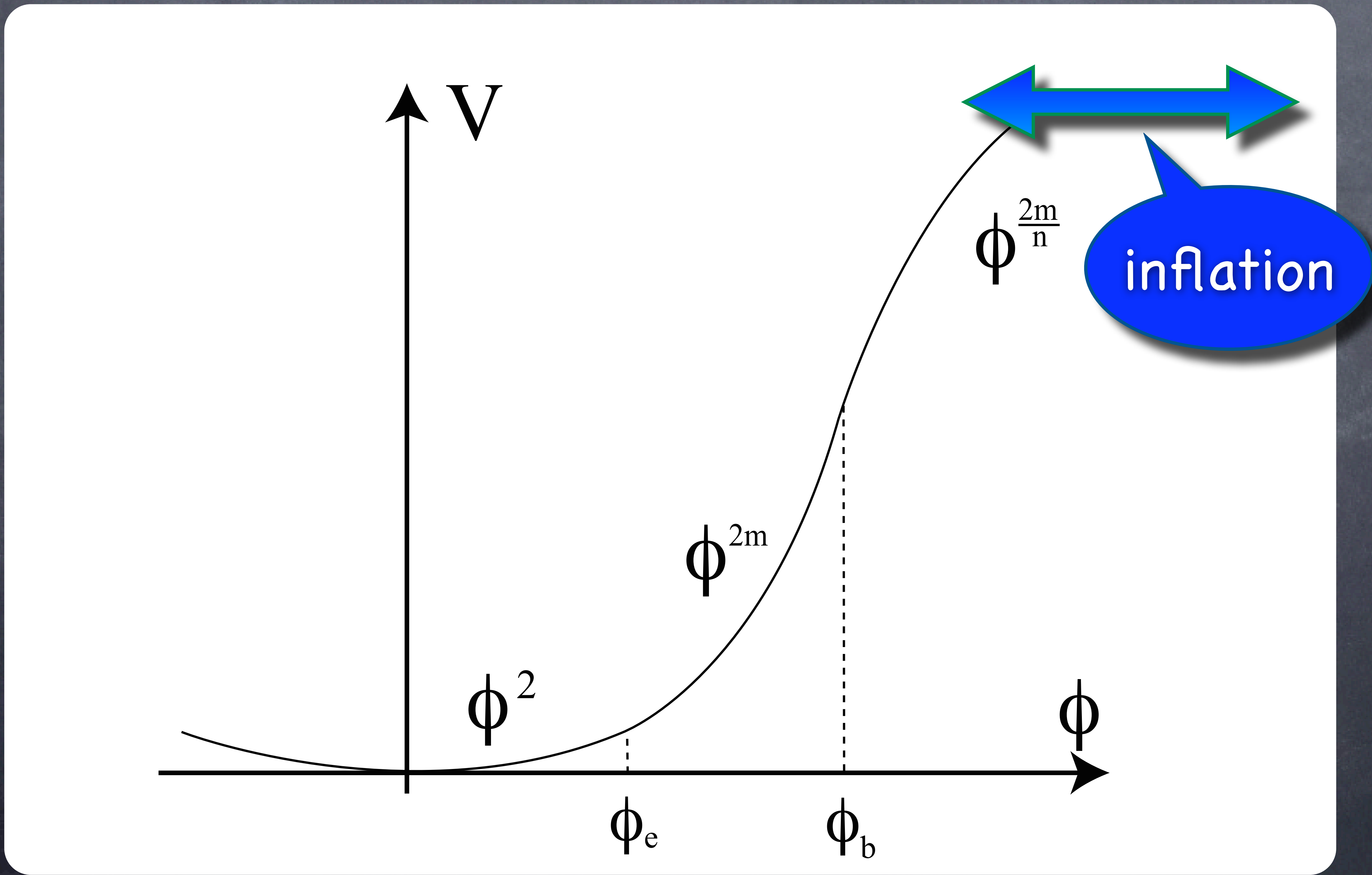

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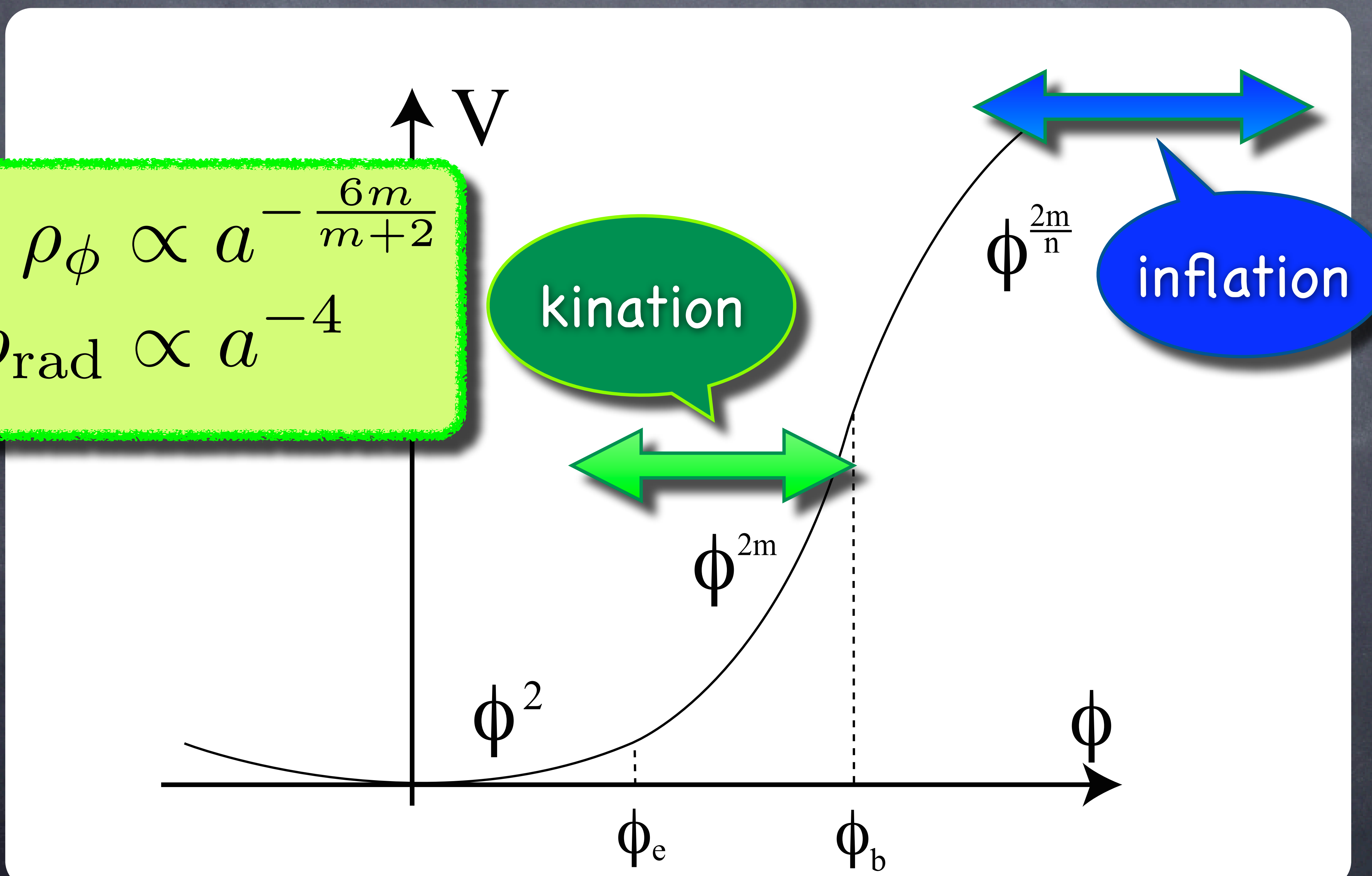
$$\rho_\phi \propto a^{-\frac{6m}{m+2}}$$

$$\rho_{\rm rad} \propto a^{-4}$$



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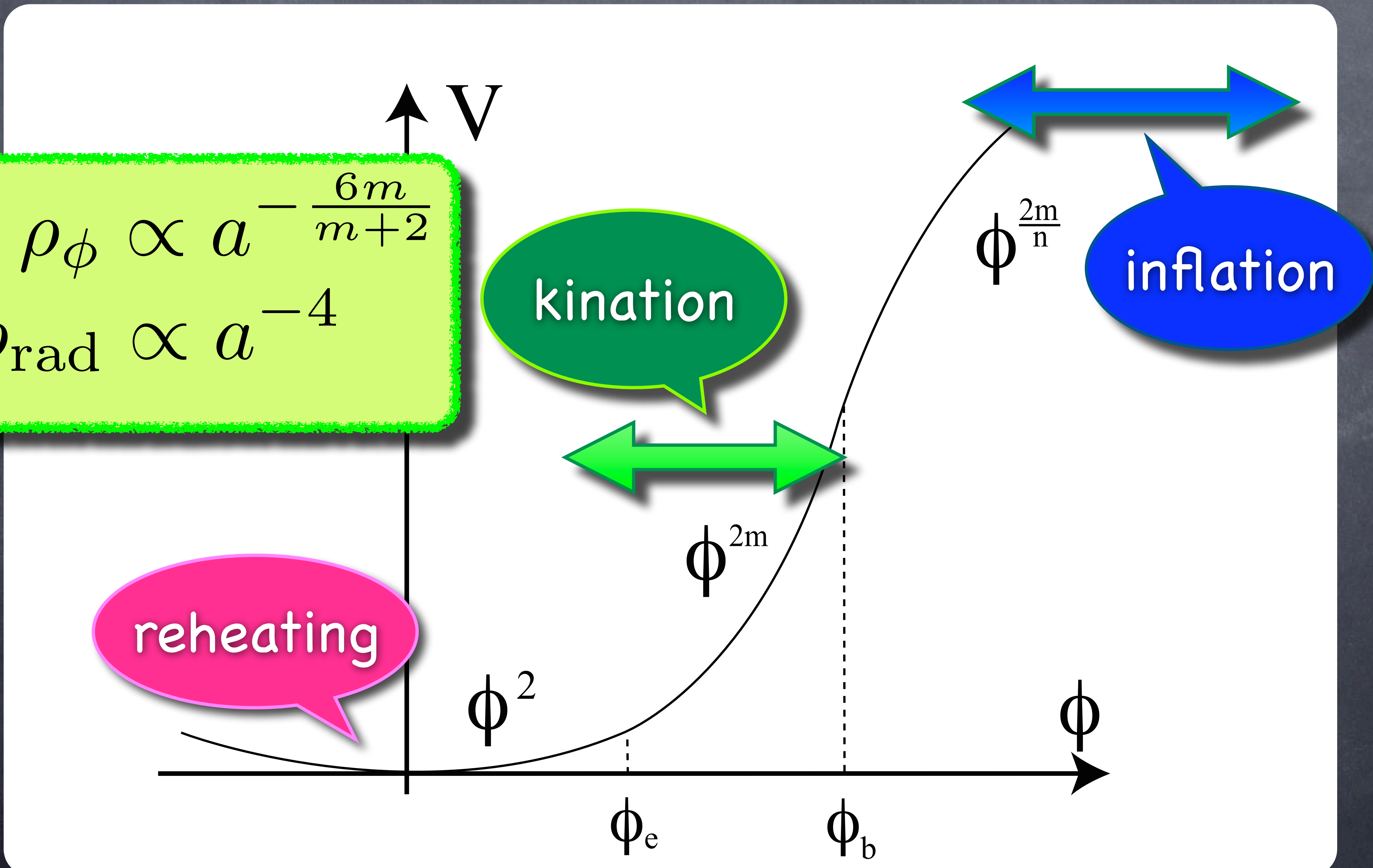
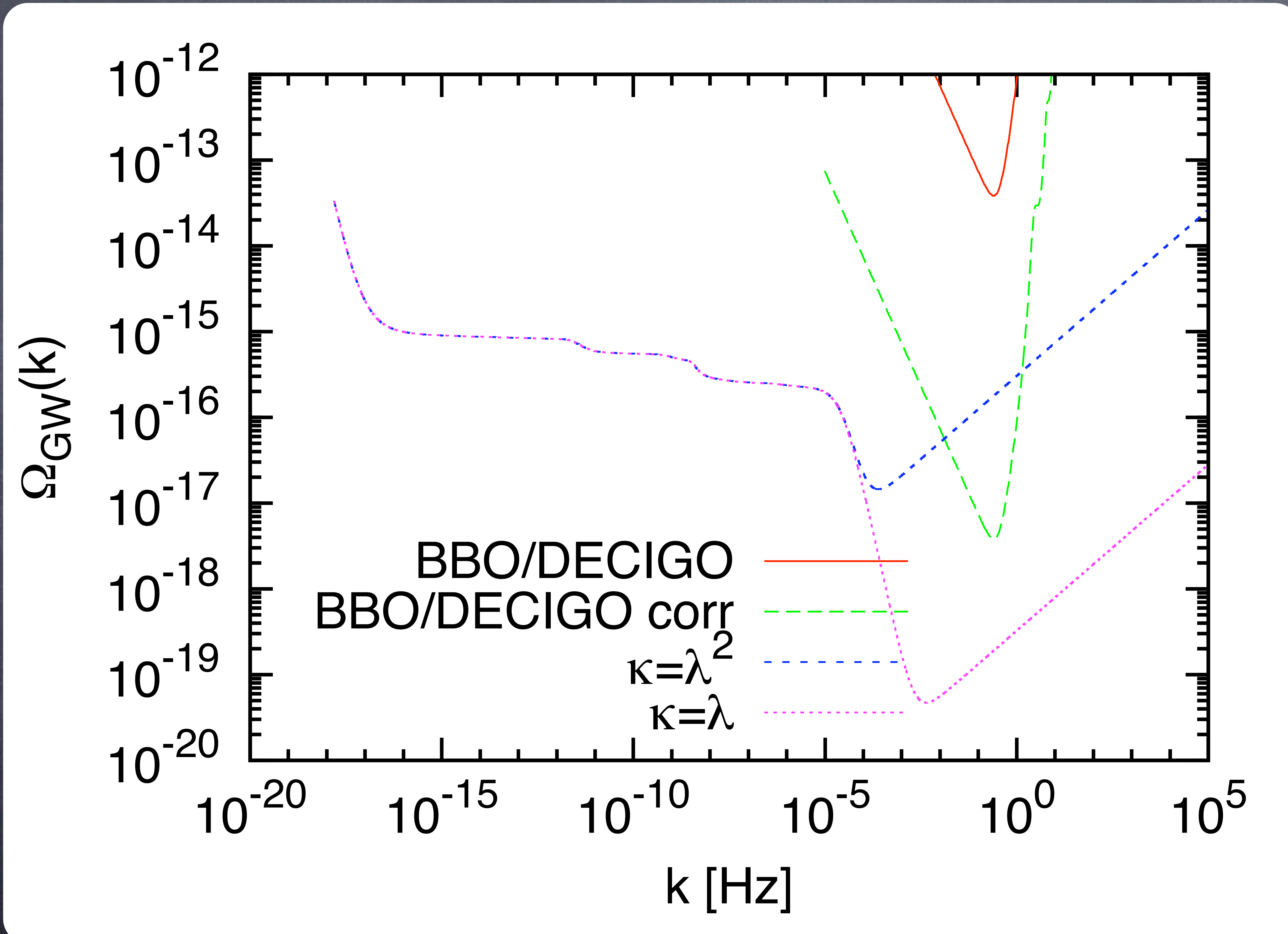


Example: n=4 and m=3



Nakayama and FT, in preparation

4.3 Inflatino dark matter

Nakayama and FT, in preparation

The inflaton is massless in the SUSY limit, if $m \geq 2$.

$$m_\phi = O(m_{3/2})$$

For successful reheating, the inflaton should have unsuppressed couplings with the SM sector.

$$\Rightarrow \int d^2\theta \, \lambda_\phi \phi H_u H_d$$

The set-up resembles nMSSM, where the singlino becomes DM. The discrete Z_{nR} symmetry in nMSSM can be consistent with the shift symmetry;

$$\phi^n \to \phi^n + \alpha$$

5. Conclusions

- Proposed an inflation model with a running kinetic term. As a concrete example we constructed a variety of the chaotic inflation model.
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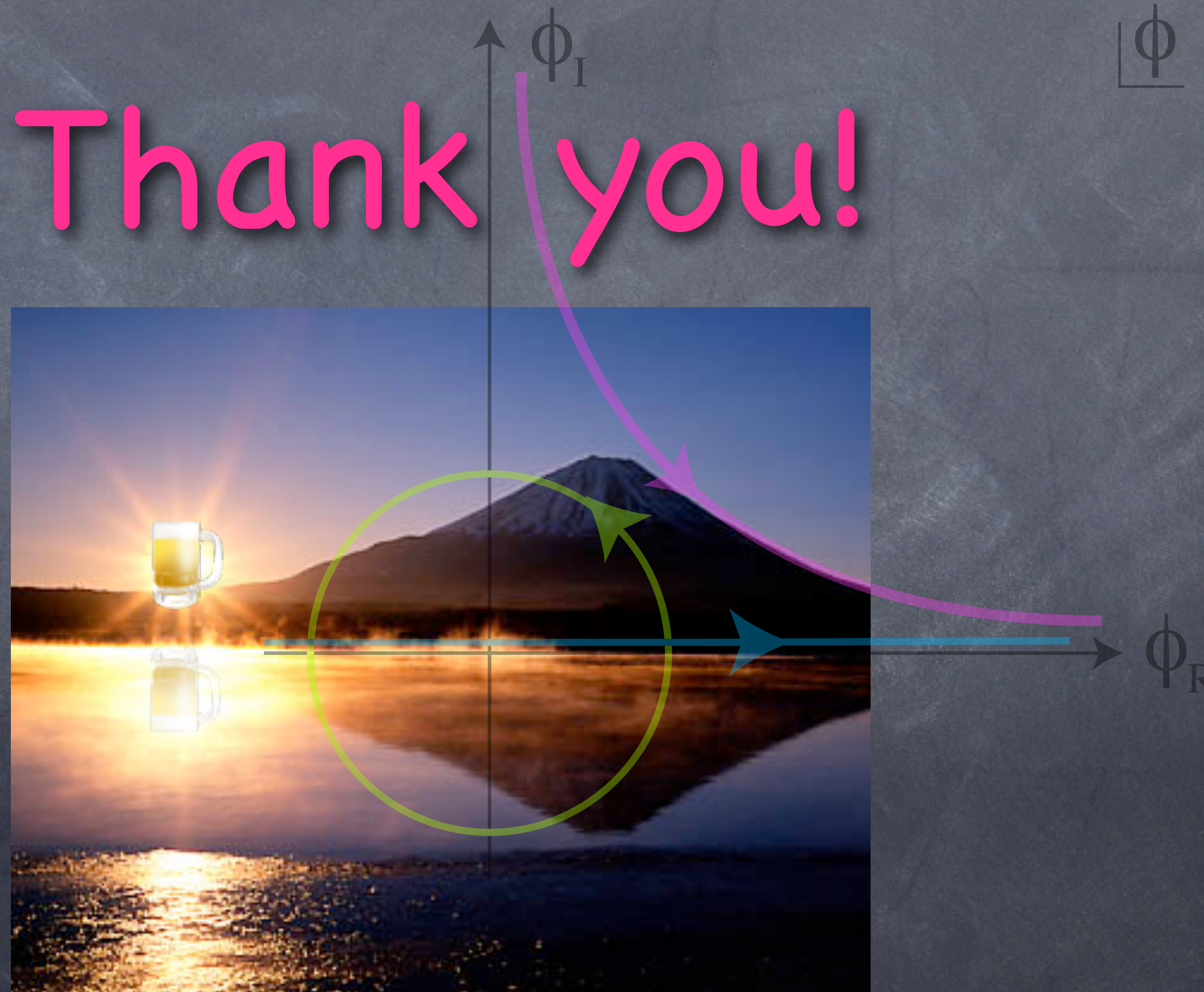
- Proposed an inflation model with a running kinetic term. As a concrete example we constructed a variety of the chaotic inflation model.
- The potential becomes steeper after inflation.
- The non-thermal gravitino problem can be avoided.
- The gravity waves can be enhanced.
- The inflaton and inflatino may be produced at LHC. In particular, the inflatino may be DM!

Thank you!



Preheating is suppressed because the inflaton does not pass the origin.