Hillclimbing inflation

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Based on

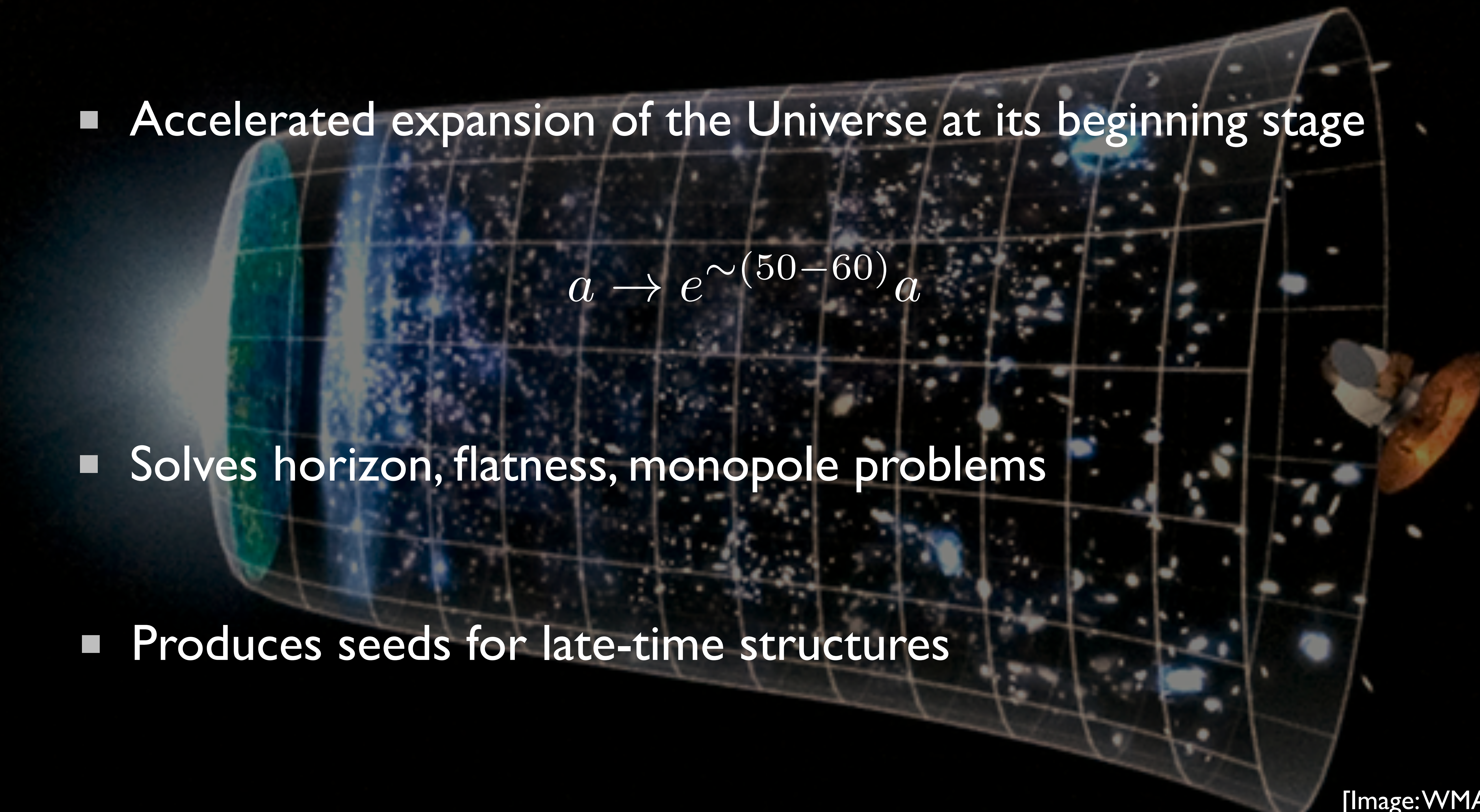
1703.09020 & 1705.03696 with **Kunio Kaneta & Kin-ya Oda**

Dec.12, 2017, CosPA

Introduction & Summary

INFLATION

[Starobinsky ’80, Sato ’81, Guth ’80, ...]
[Mukhanov & Chibisov ’81]



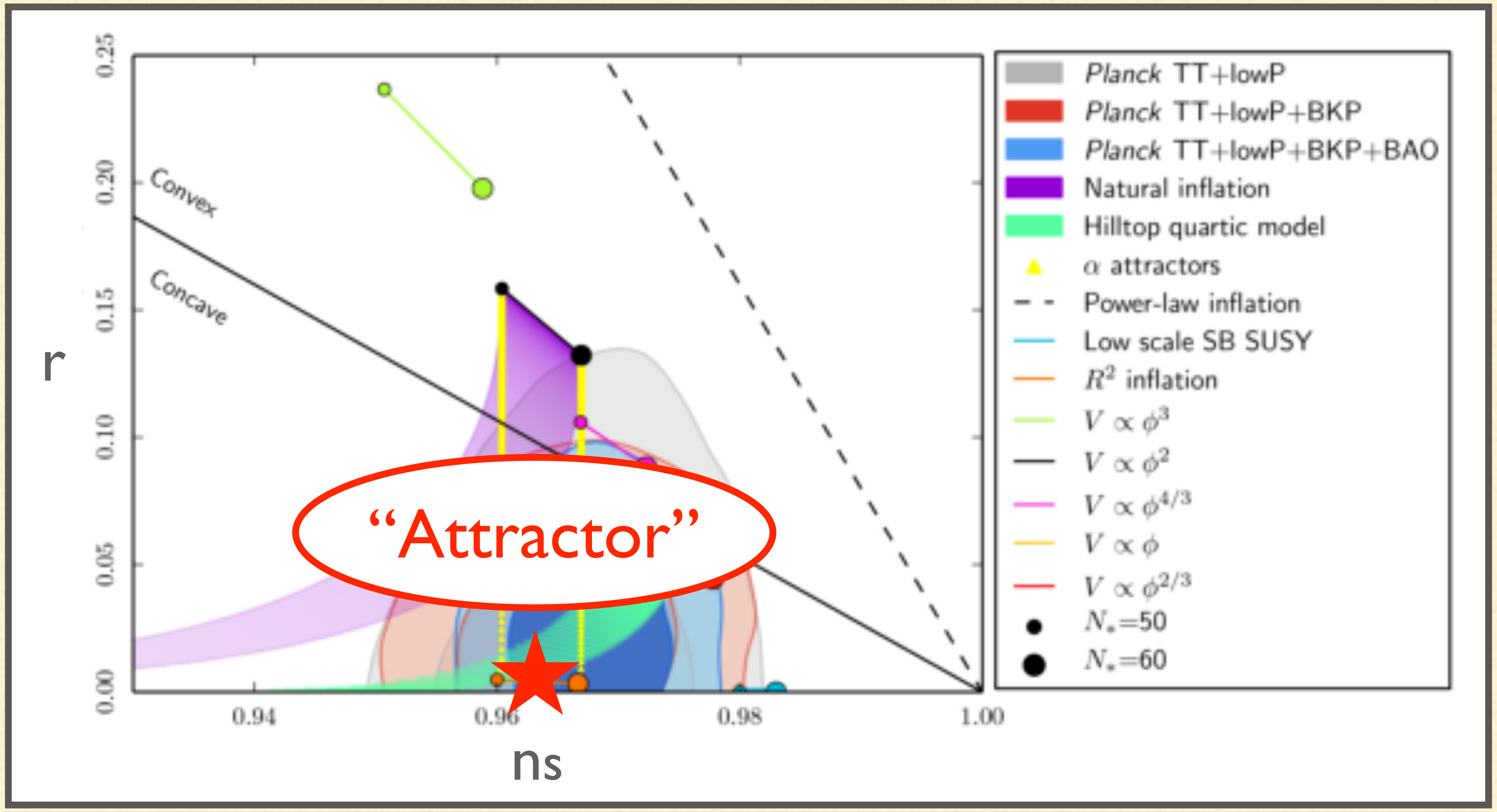
- Accelerated expansion of the Universe at its beginning stage

$$a \to e^{\sim(50-60)} a$$

- Solves horizon, flatness, monopole problems
- Produces seeds for late-time structures

[Image: WMAP]

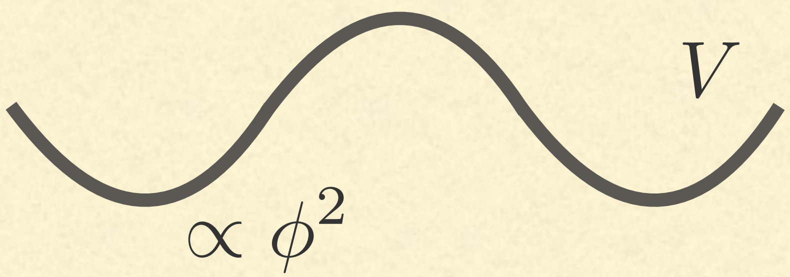
FOCUS IN THIS TALK: ATTRACTORS

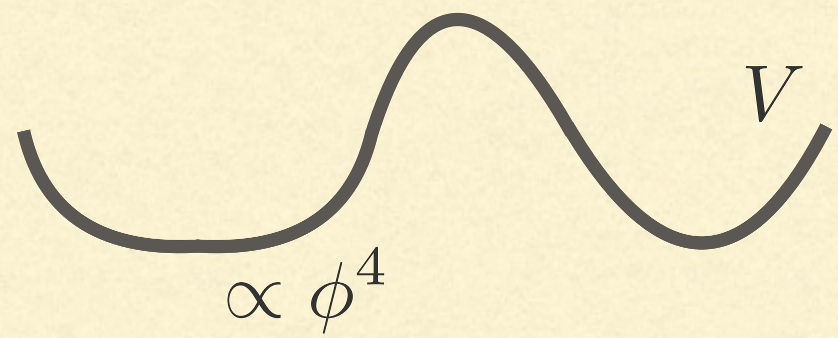


$$\mathcal{P}_\zeta(k) = \mathcal{P}_\zeta(k_*) \left(\frac{k}{k_*}\right)^{n_s - 1 + \cdots} \quad \& \quad r = \frac{\mathcal{P}_T(k_*)}{\mathcal{P}_\zeta(k_*)} = \frac{\text{Tensor amplitude}}{\text{Scalar amplitude}}$$

SUMMARY

- Consider the following inflationary setup:





- Potential $V(\phi)$ with multi-minima

SUMMARY

- Consider the following inflationary setup:

- Potential $V(\phi)$ with multi-minima & Conformal factor $\Omega(\phi)$ (s.t. $\mathcal{L} \supset \Omega(\phi)R$)

- They behave like $V \propto \Omega^2$ arond one minimum

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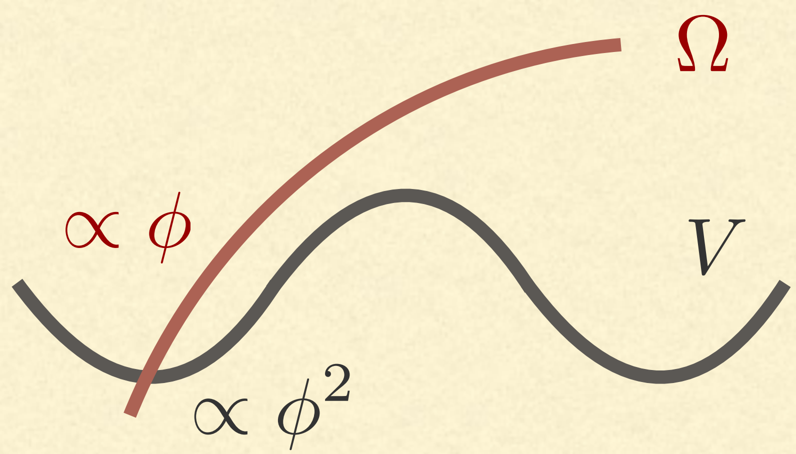
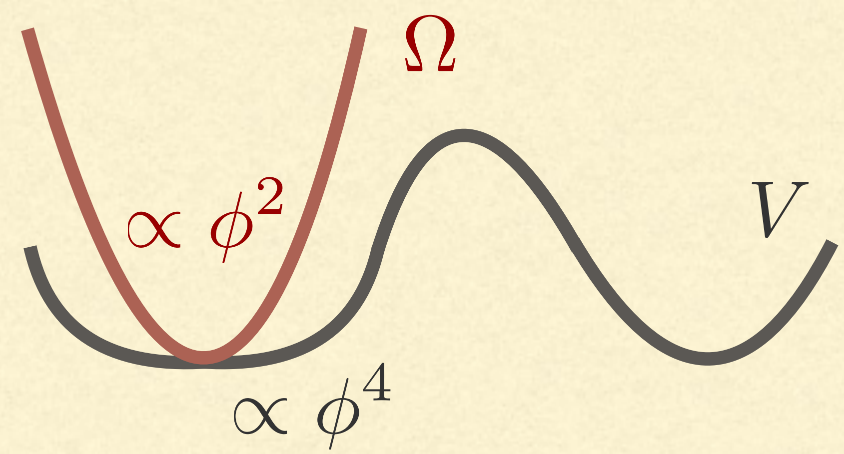


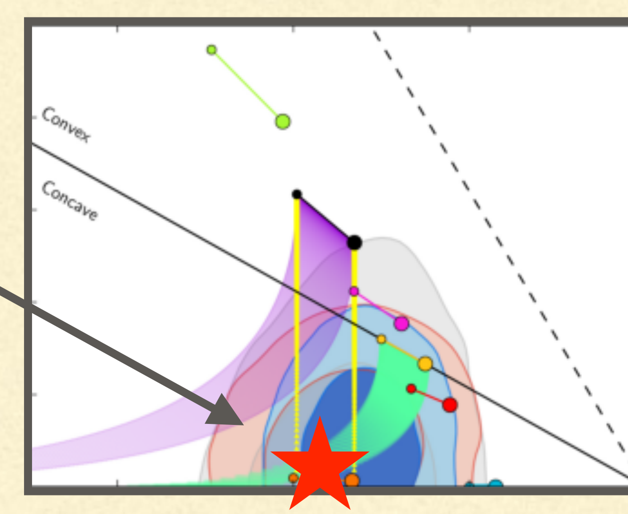


- Potential $V(\phi)$ with multi-minima & Conformal factor $\Omega(\phi)$ (s.t. $\mathcal{L} \supset \Omega(\phi)R$)

- They behave like $V \propto \Omega^2$ arond one minimum

- Then inflationary predictions come here

regardless of model details



TALK PLAN

1. Hillclimbing inflation
2. Relation to other attractors
3. Summary

HILLCLIMBING INFLATION

- Consider single-field inflation

$$S = \int \sqrt{-g} \left[\frac{1}{2}\Omega(\phi)R - \frac{1}{2}(\partial\phi)^2 - V(\phi) \right]$$

ϕ : Inflaton / Ω : Conformal factor / $M_P = 1$ unit

CONFORMAL TRANSFORMATION

- Einstein-frame description

  - Redefinition of metric (Conformal transformation) : $g_{\mu\nu} \to \Omega^{-1} g_{\mu\nu}$

  - Many Ω's show up to cancel out original Ω

$$S = \int \sqrt{-g} \left[\frac{1}{2} \Omega R - \frac{1}{2} (\partial \phi)^2 - V \right]$$

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$$\sqrt{-g} \downarrow \Omega^{-2} \sqrt{-g} \qquad R \downarrow \Omega \left[R - \frac{3}{2} (\partial \ln \Omega)^2 + \cdots \right]$$

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$$S = \int \sqrt{-g} \left[\frac{1}{2} \Omega R - \frac{1}{2} (\partial\phi)^2 - V \right]$$

$$\downarrow \qquad\qquad \downarrow$$

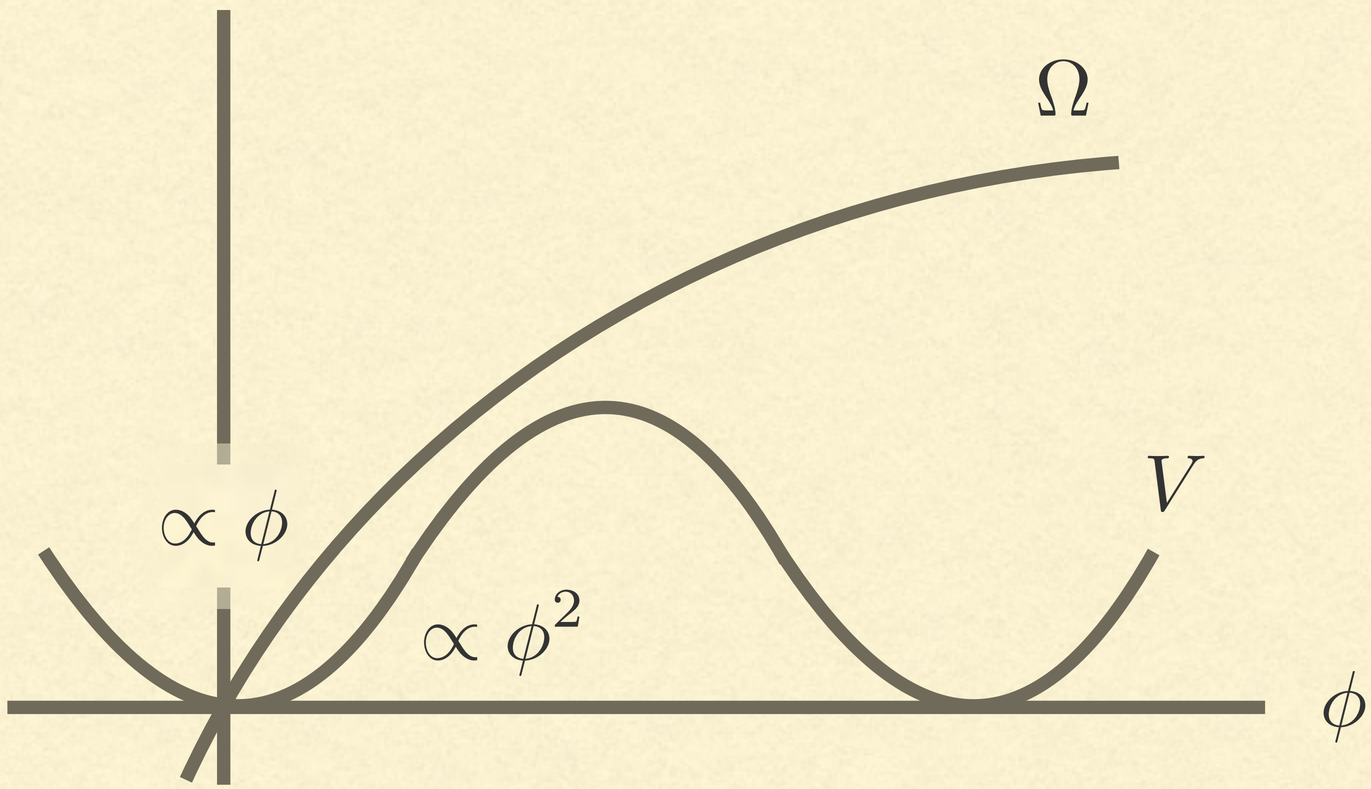
$$\Omega^{-2}\sqrt{-g} \qquad \Omega\left[R - \frac{3}{2} (\partial \ln \Omega)^2 + \cdots \right]$$

  - Remaining $\ln \Omega$ works as inflaton, moving in the potential V/Ω^2

FLAT POTENTIAL

- Einstein-frame potential becomes flat

because of vertical lifting up & horizontal stretching



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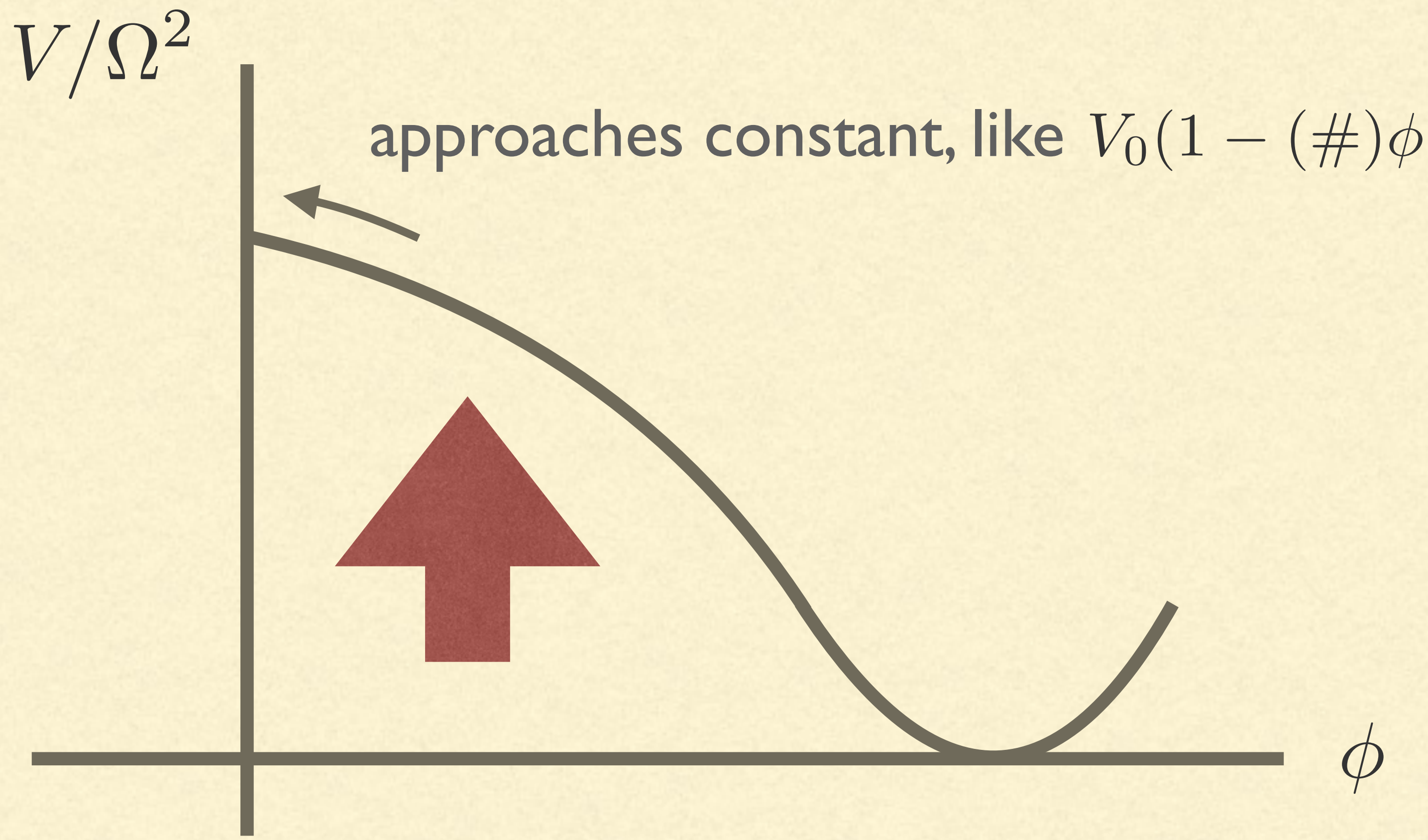

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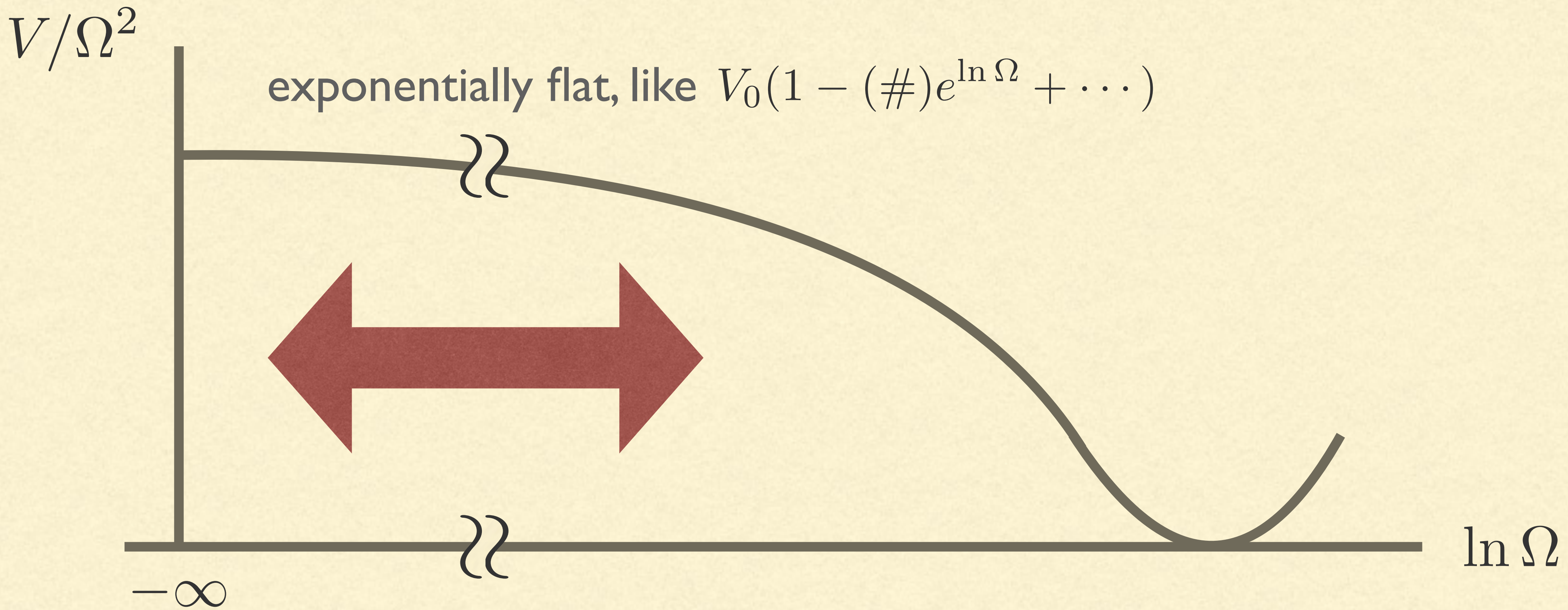

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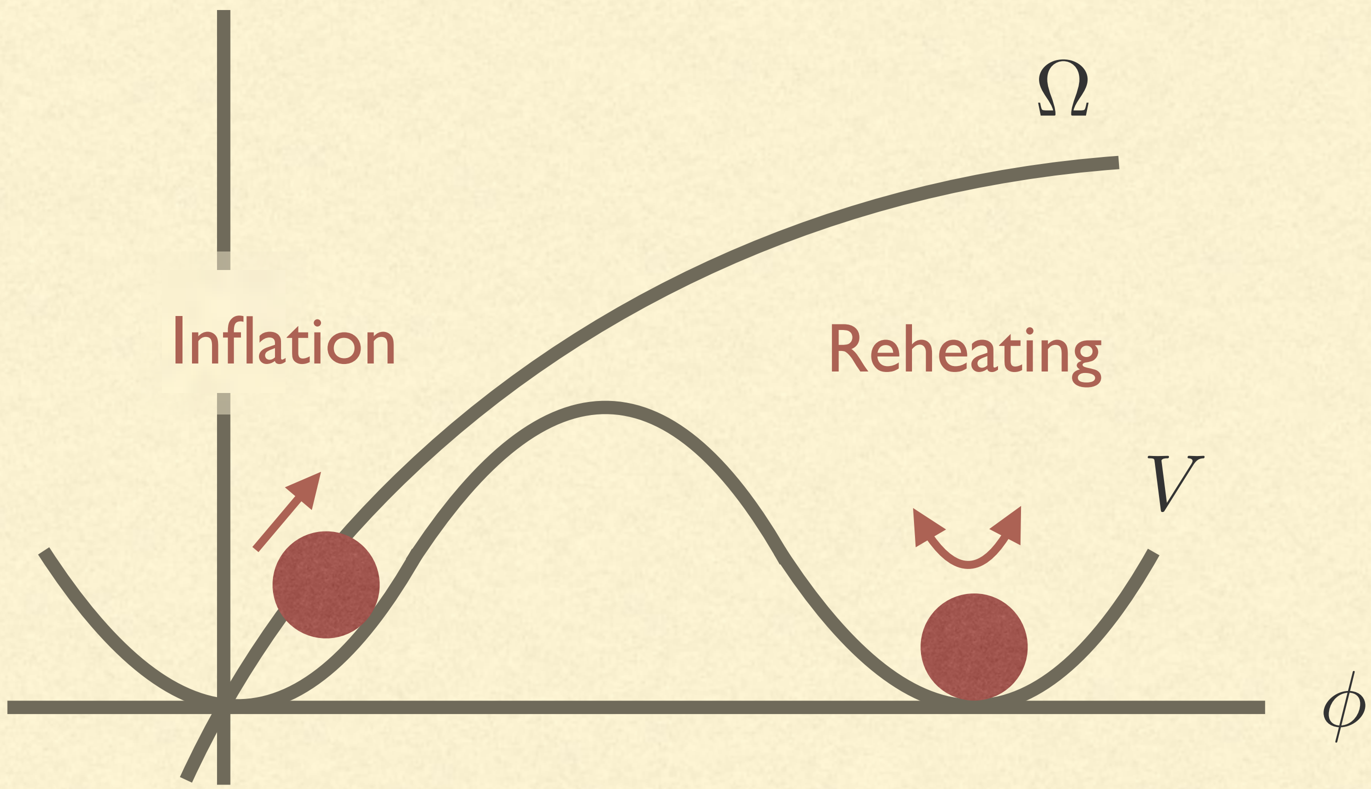


INFLATIONARY PREDICTIONS

- Exponentially flat potentials give sweet spot of CMB

$$n_s \simeq 1 - \frac{2}{N}, \qquad r \simeq \frac{12}{n^2 N^2}$$

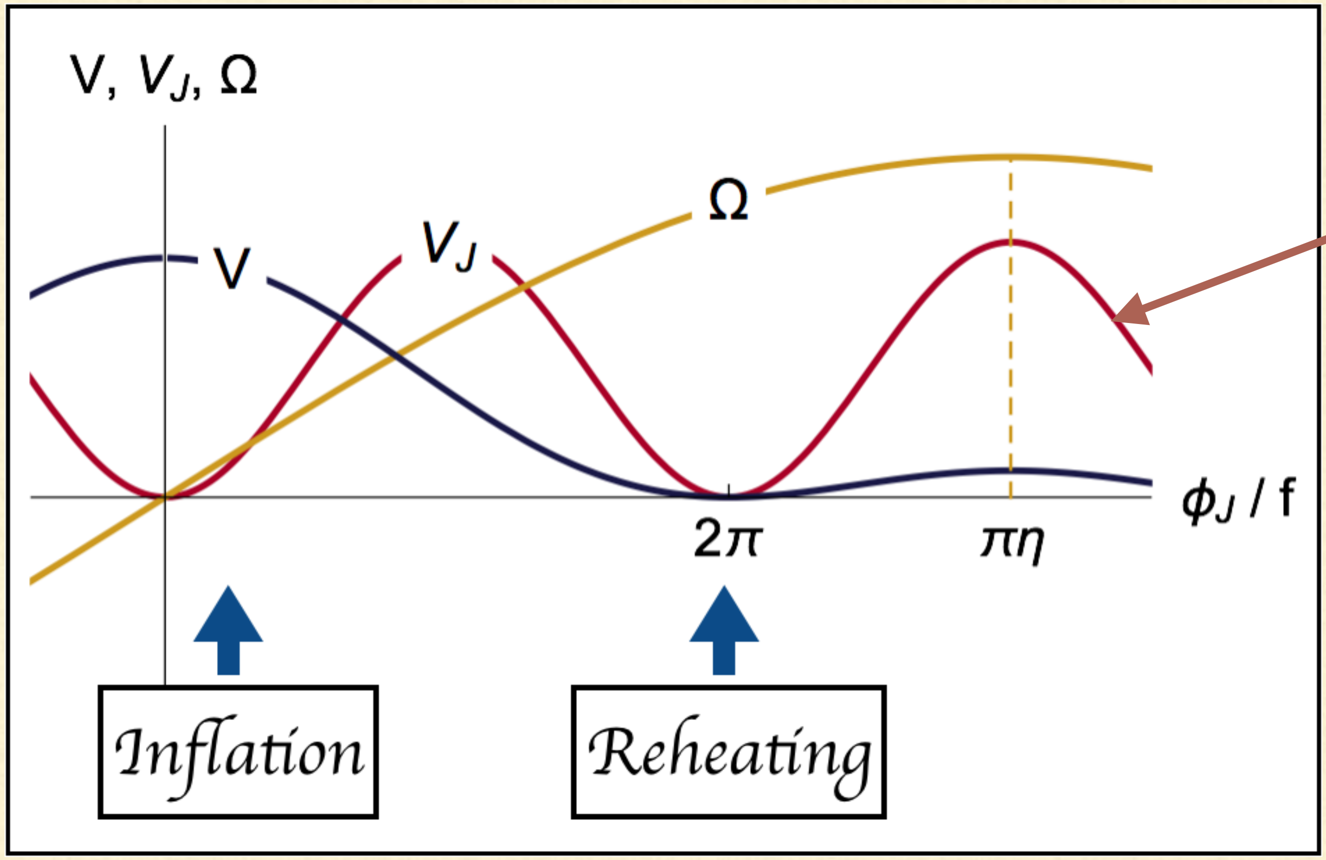
N : e-folding / n : "leading exponent" $V/\Omega^2 = V_0(1 - (\#)\phi^n + \cdots)$

- Actual values of r differ by O(10)% among models (next slide)

→ observationally interesting

HILLCLIMBING NATURAL INFLATION

- Setup : $S = \int \sqrt{-g}\left[\frac{1}{2}\Omega R - \frac{1}{2}(\partial\phi)^2 - V\right]$



$V = \Lambda^4\left[1 - \cos(\phi/f)\right]$

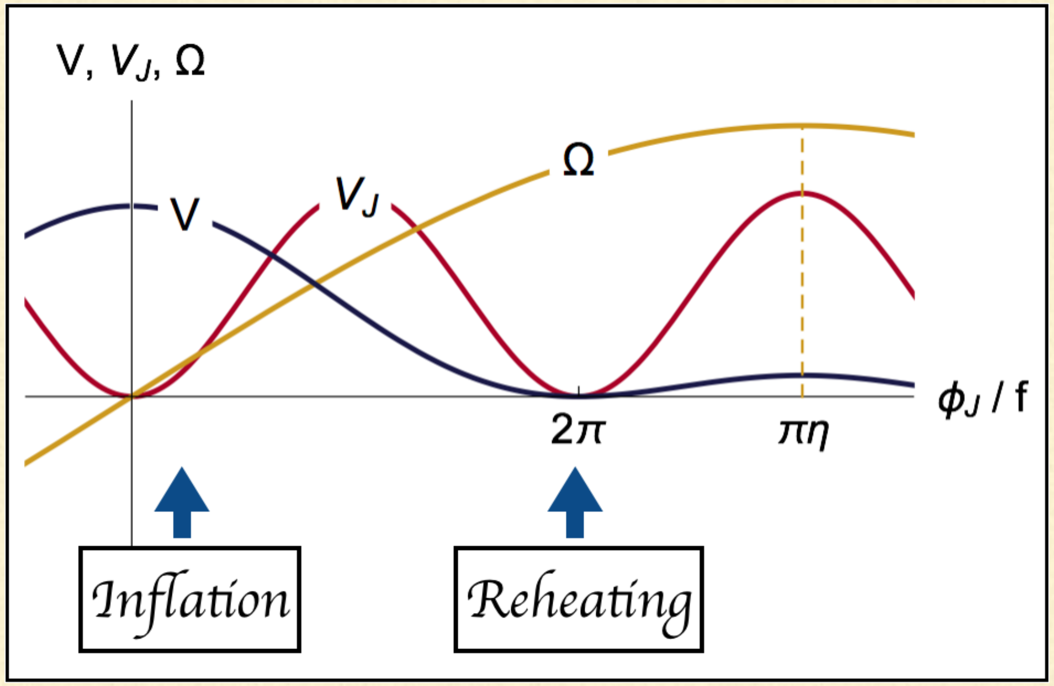
: quadratic in ϕ around $\phi \sim 0$

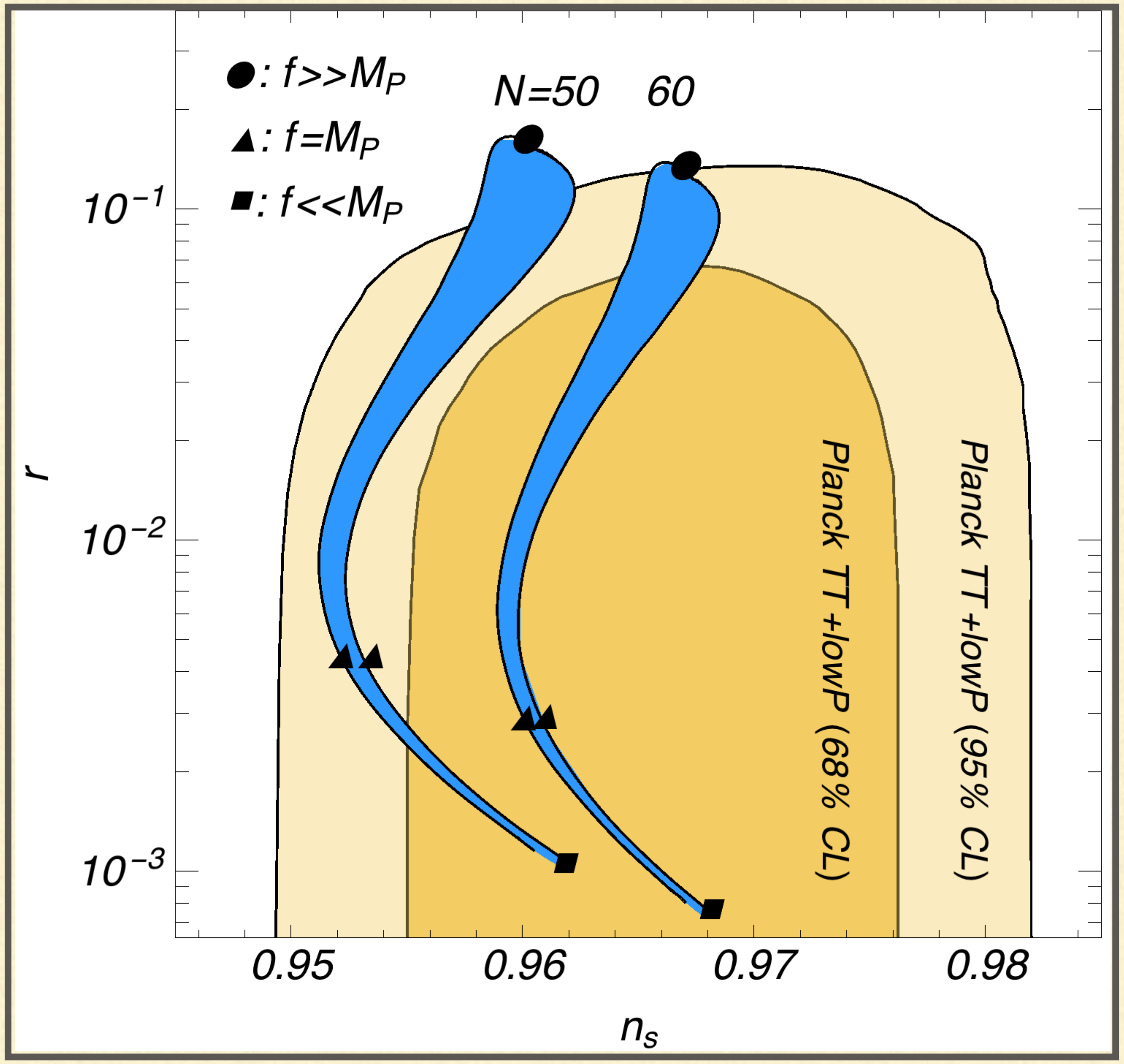
$\Omega = \omega \sin(\phi/2\eta f)$

: linear in ϕ around $\phi \sim 0$

HILLCLIMBING NATURAL INFLATION

- Inflationary predictions



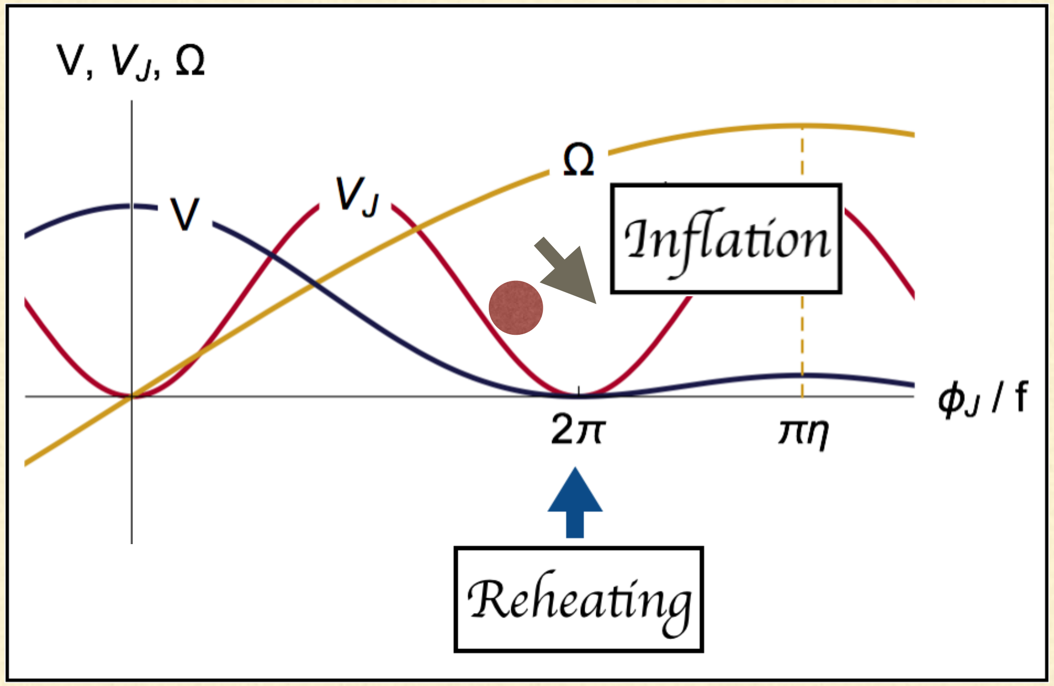


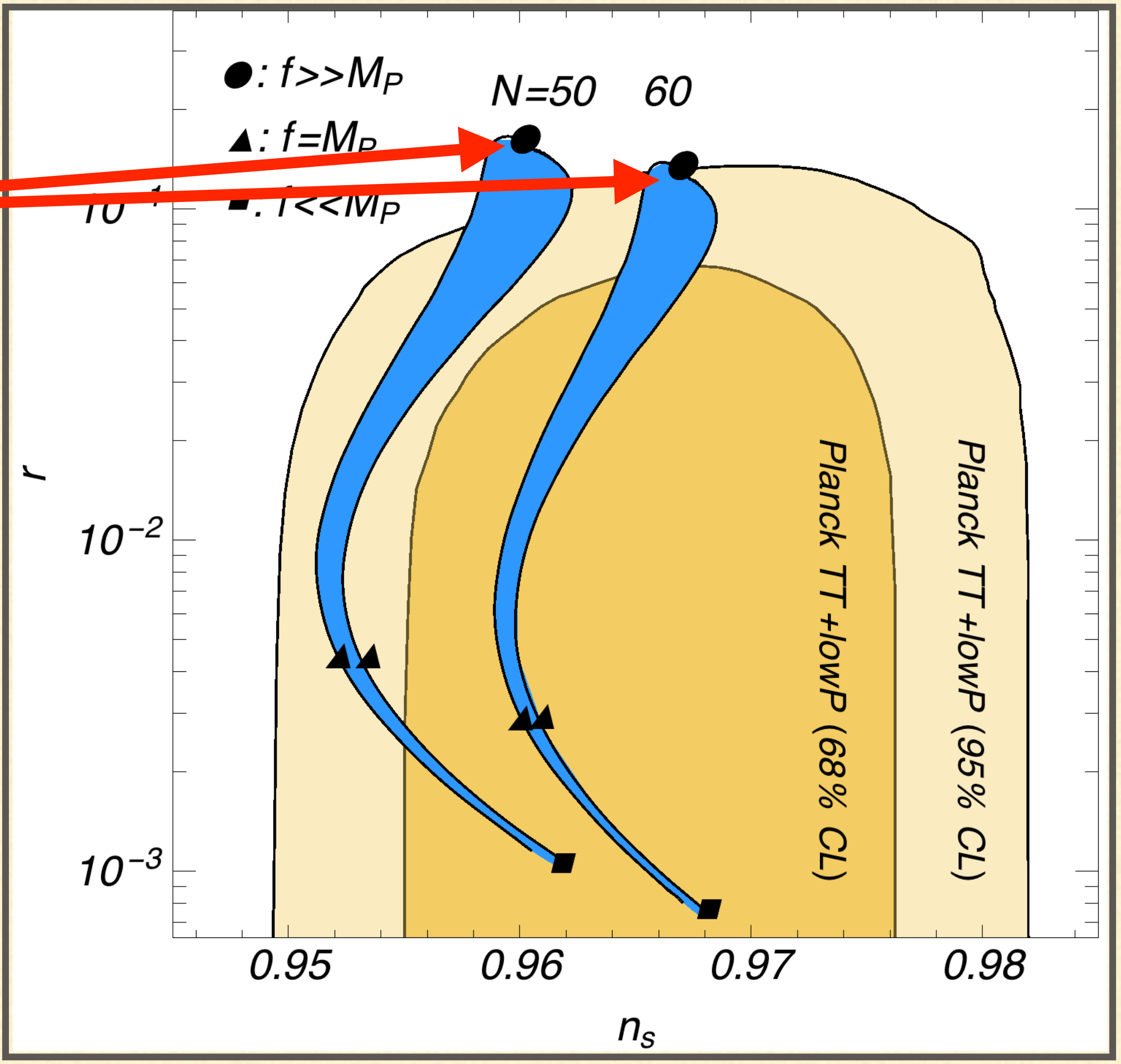
HILLCLIMBING NATURAL INFLATION

- Inflationary predictions

Large f ($\gg M_P$)

: quadratic chaotic



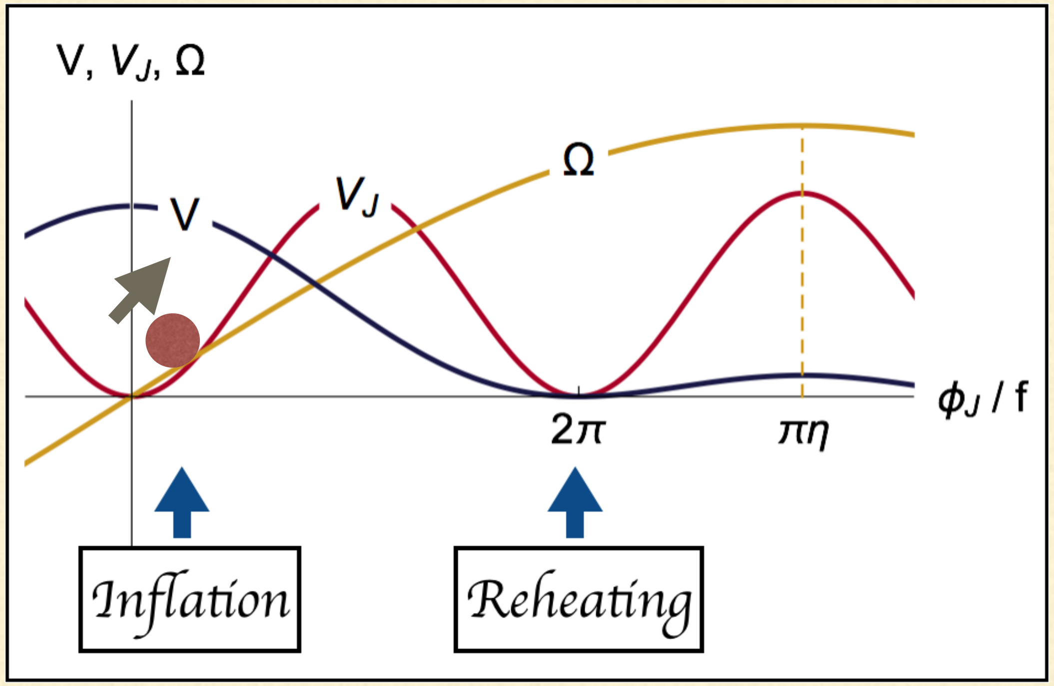


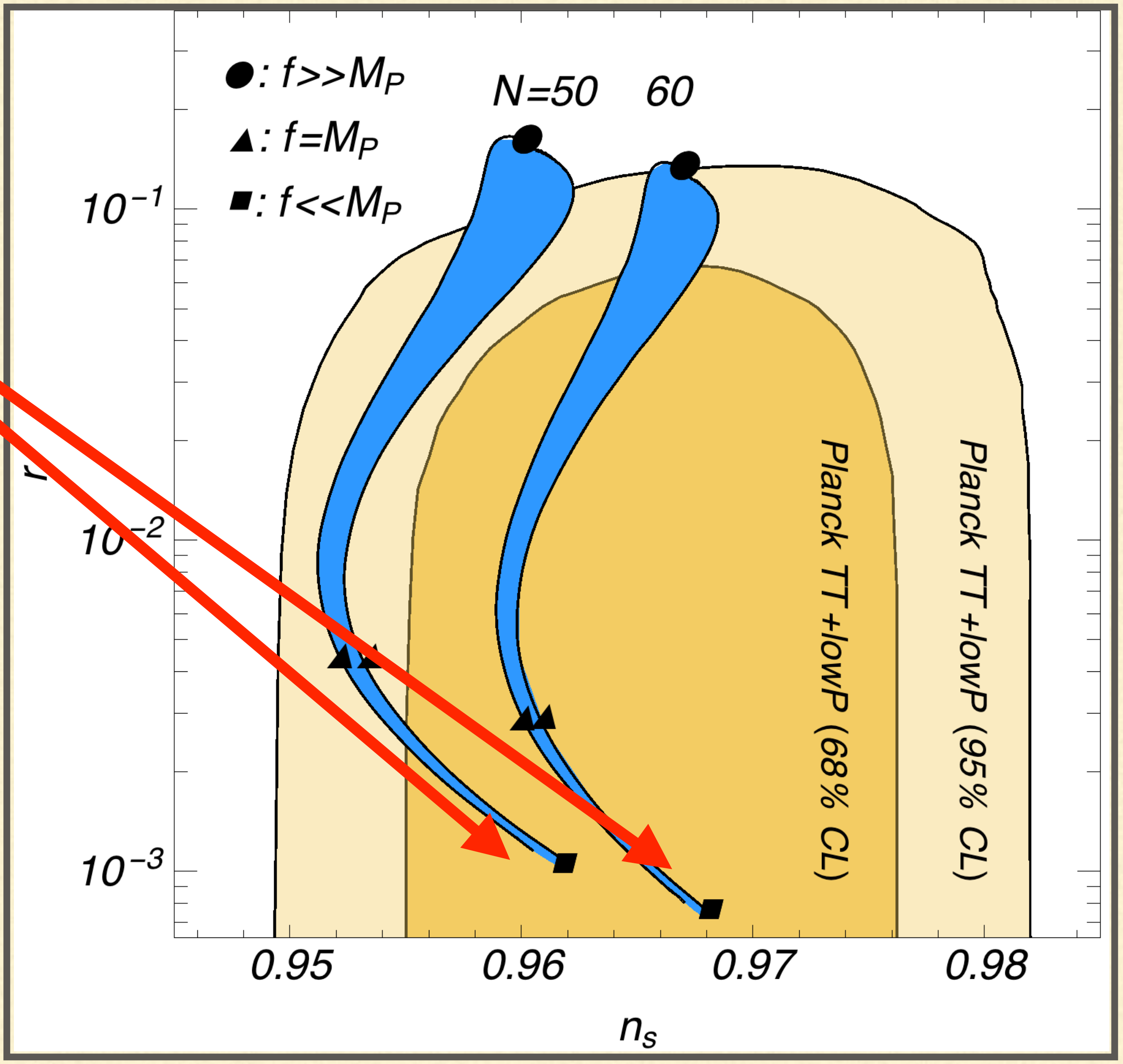
HILLCLIMBING NATURAL INFLATION

- Inflationary predictions

Small f $(\ll M_P)$

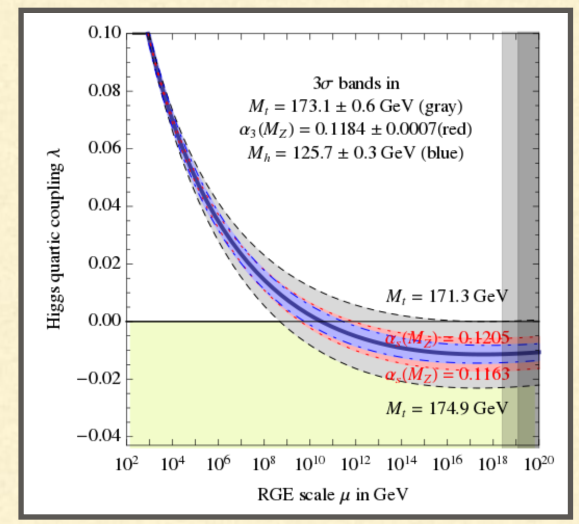
: attractor behavior

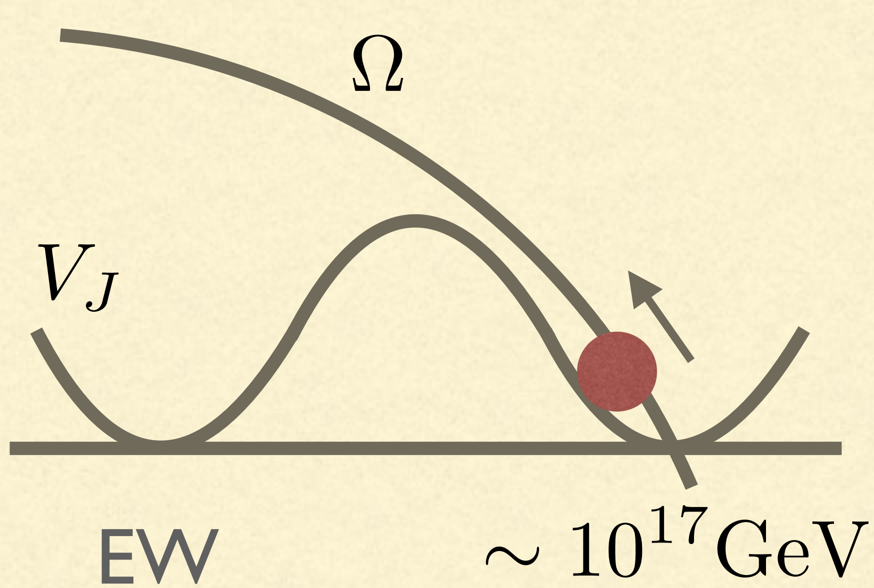


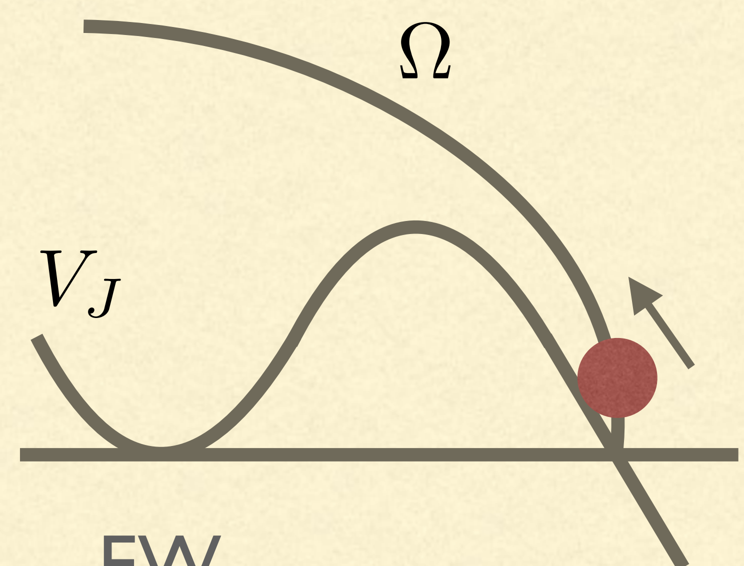


HILLCLIMBING HIGGS INFLATION

- Hillclimbing with Higgs potential
  - Suppose that Higgs quartic hits 0 at some point
  - Suppose that conformal factor vanishes there
    (Generalized Multi Point Principle?)

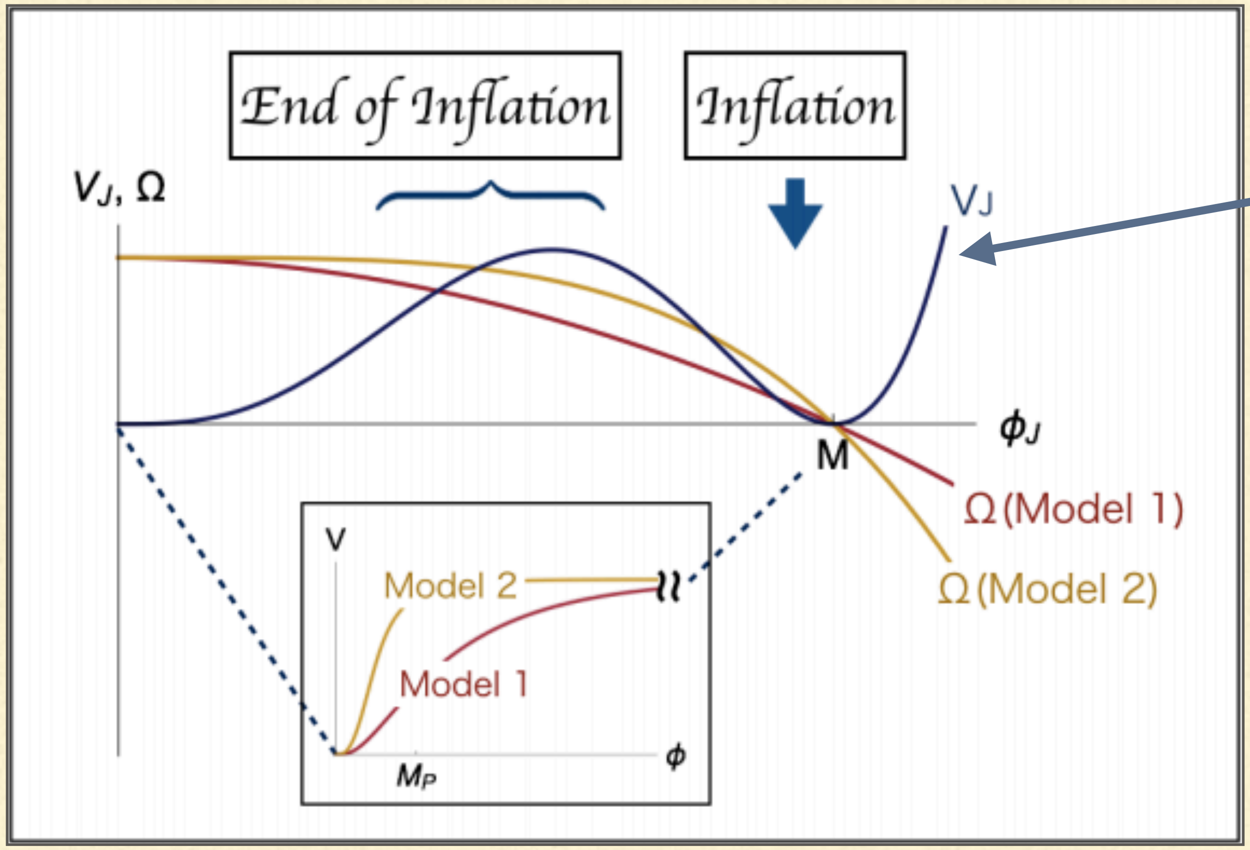






HILLCLIMBING HIGGS INFLATION

- Setup : $S = \int \sqrt{-g}\left[\frac{1}{2}\Omega R - \frac{1}{2}(\partial\phi)^2 - V\right]$



Potential $V = \lambda(\phi)\phi^4/4$

$$\lambda(\phi) = \beta(\ln(\phi/M))^2 + \cdots$$

Conformal factor

$\Omega = 1 - (\phi/M)^2$ (Model 1)

$\Omega = 1 - (\phi/M)^4$ (Model 2)

HILLCLIMBING HIGGS INFLATION

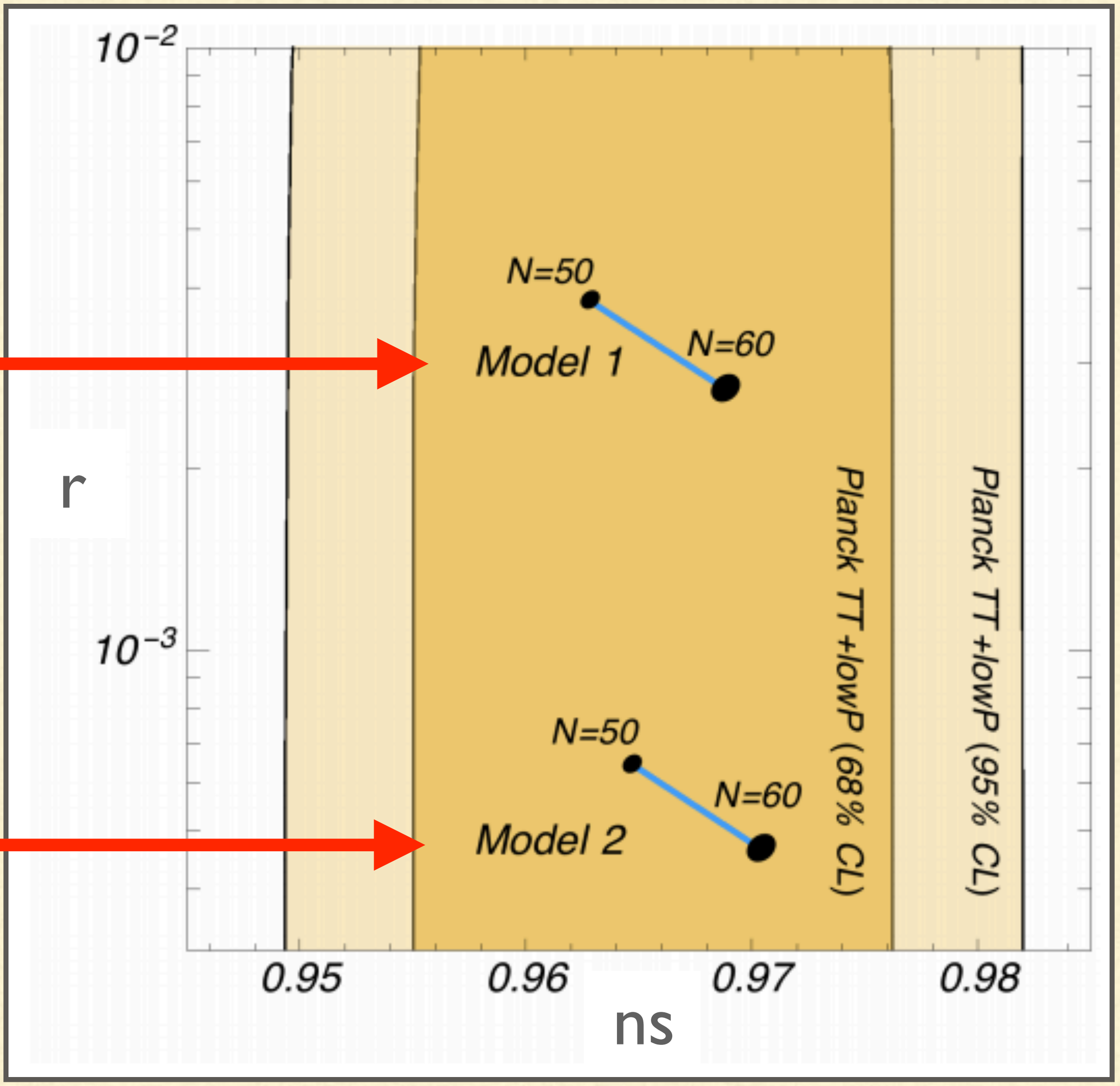
- Inflationary predictions

Model 1

- Leading exponent n = 1
- O(10)% difference from "ordinary" Higgs inflation

Model 2

- Leading exponent n = 2



TALK PLAN

✔ Hillclimbing inflation
2. Relation to other attractors
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RELATION TO OTHER ATTRACTORS

- Difference in how to realize exponentially flat potential
- ξ-attractor [Linde et. al. '14] [Salopek et. al. '89, Luccin et al. '86, Futamase & Maeda '89, ...]

  - Higgs inflation ($\Omega = 1 + \xi\phi^2$ & $V = \lambda\phi^4/4$) and its generalization

  - Uses $\Omega \gg 1$ for inflation, and $\Omega \leftrightarrow 1/\Omega$ correspondence to Hillclimbing inflation

- α-attractor [Kallosh et. al. '13, '14]

  - Pole-type attractor in modern context

  - Actually, its original construction in Jordan frame (+ in a certain gauge) falls within Hillclimbing scheme

TALK PLAN

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SUMMARY

- We propose a class of models

  where ***the inflaton climbs up the potential hill***

- These models show attractor behavior to **CMB sweet spot**

- This mechanism is **applicable to multi-vacuum potentials**

  such as natural-inflation potential or Higgs potential

COLLABORATOR

- Kunio Kaneta

IBS-CTPU → Minnesota

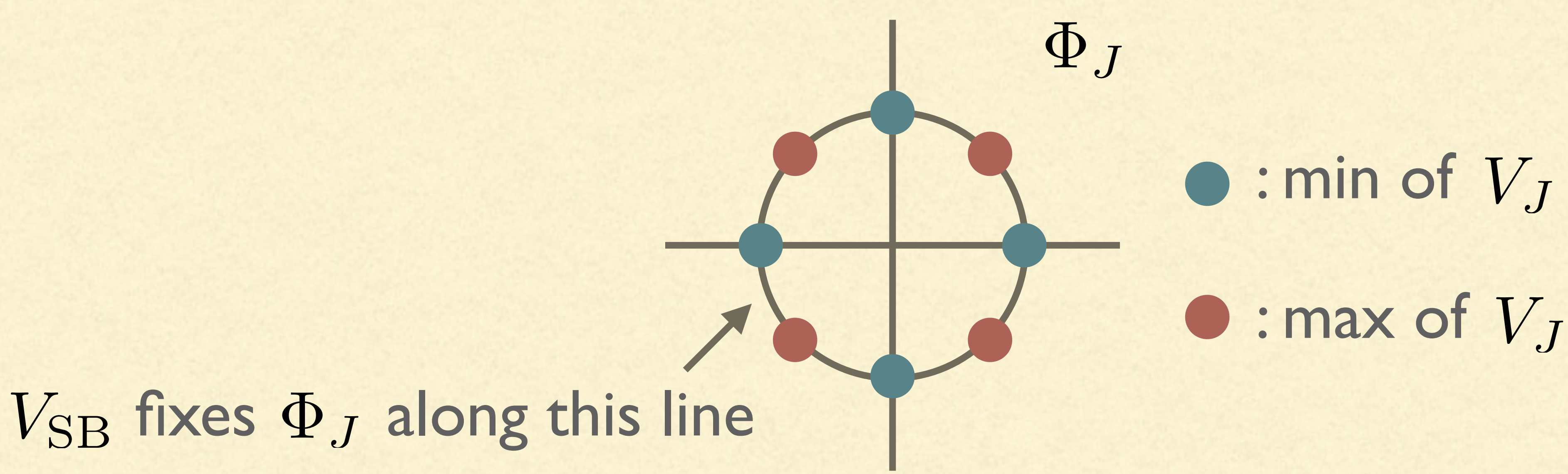
Backup

HILLCLIMBING NATURAL INFLATION

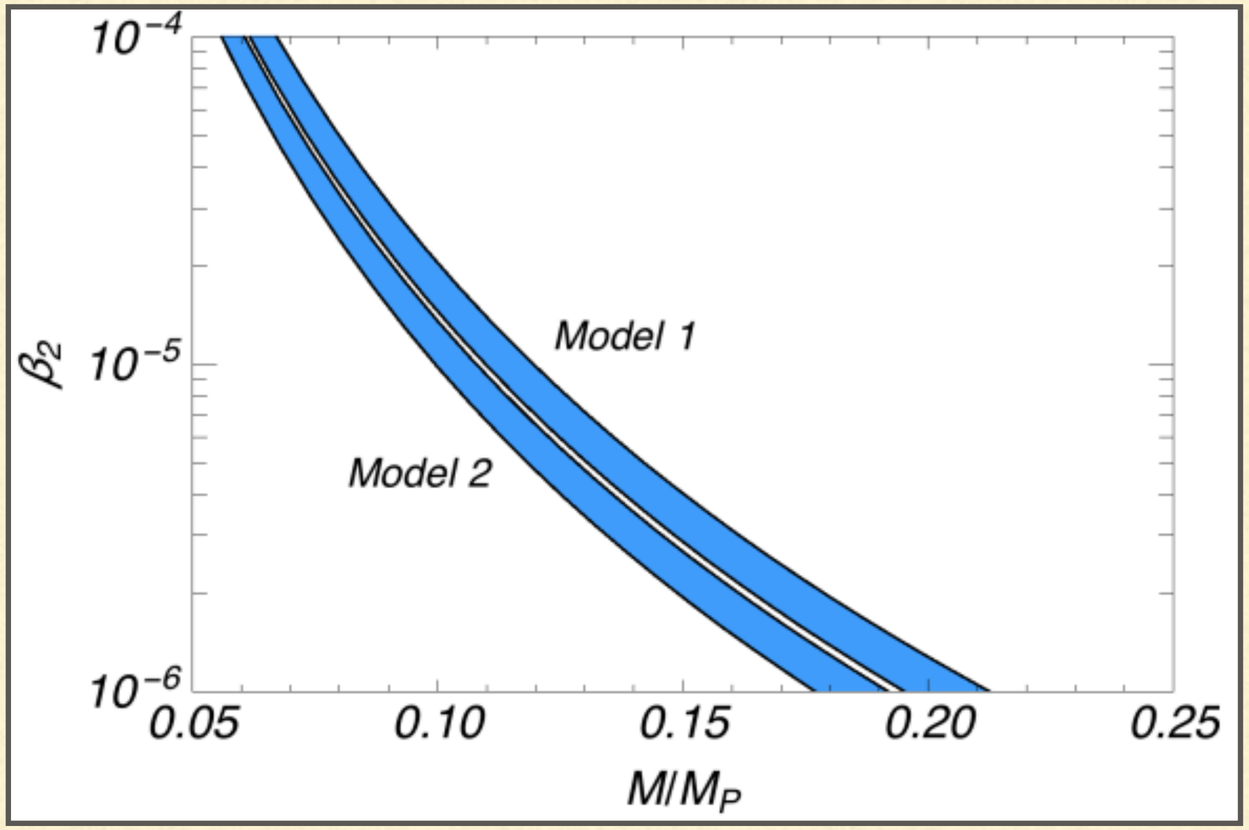
- Origin of the action? Difficult to justify this action by symmetry argument ...

$$S = \int \sqrt{-g_J}\left[-iM(\Phi_J - \Phi_J^\dagger)R_J - |\partial\Phi_J|^2 - V_J\right]$$

$$V_J = \lambda\left[|\Phi_J|^4 - \frac{1}{2}(\Phi_J^4 + \Phi_J^{\dagger 4})\right] + V_{\rm SB}$$



HILLCLIMBING HIGGS INFLATION



Ω	Model 1	Model 2
$M/M_{\rm P}$	$[0.1005, 0.0923]$	$[0.0907, 0.0837]$
$\phi_{\rm J,end}/M_{\rm P}$	$[0.0635, 0.0583]$	$[0.0562, 0.0519]$
$\phi_{\rm J,CMB}/M_{\rm P}$	$[0.0991, 0.0912]$	$[0.0854, 0.0791]$
n_s	$[0.9628, 0.9688]$	$[0.9647, 0.9703]$
r	$[0.00381, 0.00272]$	$[0.000646, 0.000468]$

ATTRACTORS

- Classification