Inflation After Planck: An Issue

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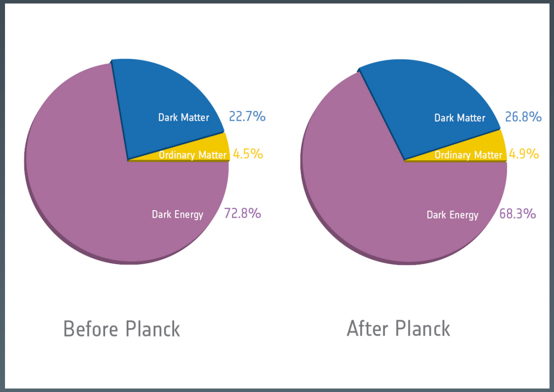
The Overshoot Problem in Inflation after Tunneling
Koushik Dutta, Pascal M. Vaudrevange, Alexander Westphal
JCAP 1201 (2012) 026

More Exact Tunneling Solutions in Scalar Field Theory
Koushik Dutta, Cecelie Hector, Pascal M. Vaudrevange, Alexander Westphal
Phys.Lett. B708 (2012) 309-313

An Exact Tunneling Solution in a Simple Realistic Landscape
Koushik Dutta, Pascal M. Vaudrevange, Alexander Westphal
Class.Quant.Grav. 29 (2012) 065011

Planck Results

“Simple but Challenging”

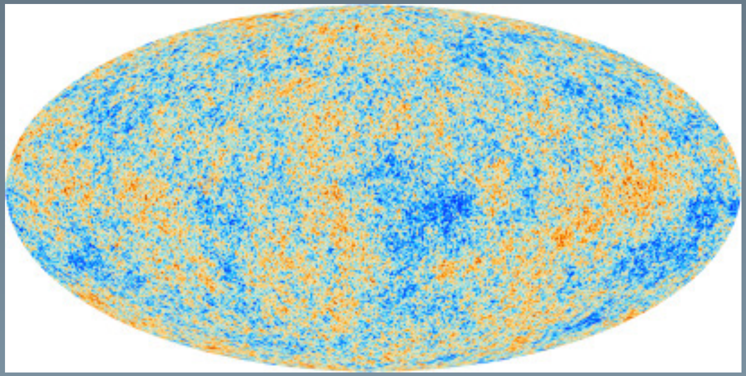


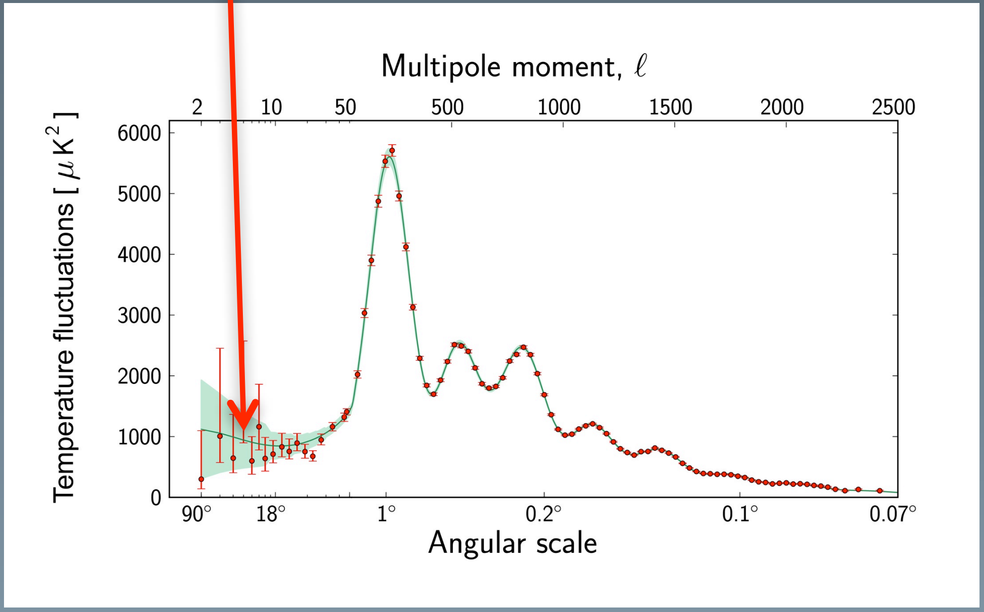
Consistent with ‘vanilla’ LCDM model

Nearly scale invariant spectrum: n_s = 0.96

Scale invariance ruled out over 5 sigma

Spatial curvature small





Dynamical mechanism: **Inflation**

- Starobinsky

- Guth

- Linde

- Steinhardt

Nearly exponential expansion: $a(t) \sim e^{\alpha t}$ H nearly constant

Condition for Inflation

$$\frac{\ddot{a}}{a} = -\frac{\rho + 3p}{6M_P^2} \Rightarrow p < -\rho/3$$

Scalar Fields

Canonical Kinetic energy and 'single' scalar field

$$p = \frac{1}{2}\dot{\phi}^2 - V(\phi)$$

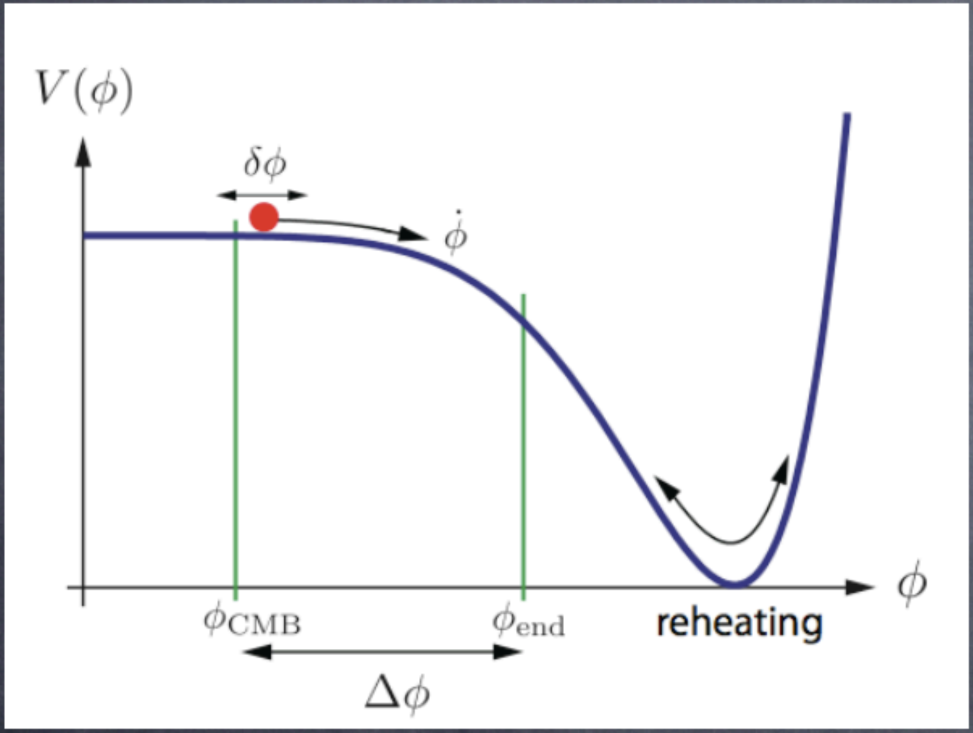
$$\rho = \frac{1}{2}\dot{\phi}^2 + V(\phi)$$

$$\frac{1}{2}\dot{\phi}^2 << V(\phi)$$

$$p \simeq -\rho$$

Classical Dynamics

$$\ddot{\phi} + 3H\dot{\phi} = -V''(\phi)$$



$$H^2 = \frac{1}{3}\left(V(\phi) + \frac{1}{2}\dot{\phi}^2\right)$$

Slow-roll parameters:

$$\epsilon = \frac{1}{2}(V'/V)^2$$

$$\eta = V''/V$$

You need to satisfy slow-roll conditions for a long time, typically N ~ 60

Generic Predictions

Nearly Gaussian fluctuations

Nearly scale-invariant spectrum

Adibatic perturbations

Generic Predictions

Nearly Gaussian fluctuations

$f_{NL}^{local}=2.7$ +/- 5.8, $f_{NL}^{equil}= -42$ +/- 75,
$f_{NL}^{ortho}= -25$ +/- 39

Nearly scale-invariant spectrum

$n_s = 0.96$ +/- 0 .0073

Adibatic perturbations

Isocurvature mode < few percent

Planck Observations

Intermediate Summary

Planck Results

ONE canonical dynamical 'light' degree of freedom:
INFLATON ("Simple")

Not 'natural' from the point of High Energy Physics

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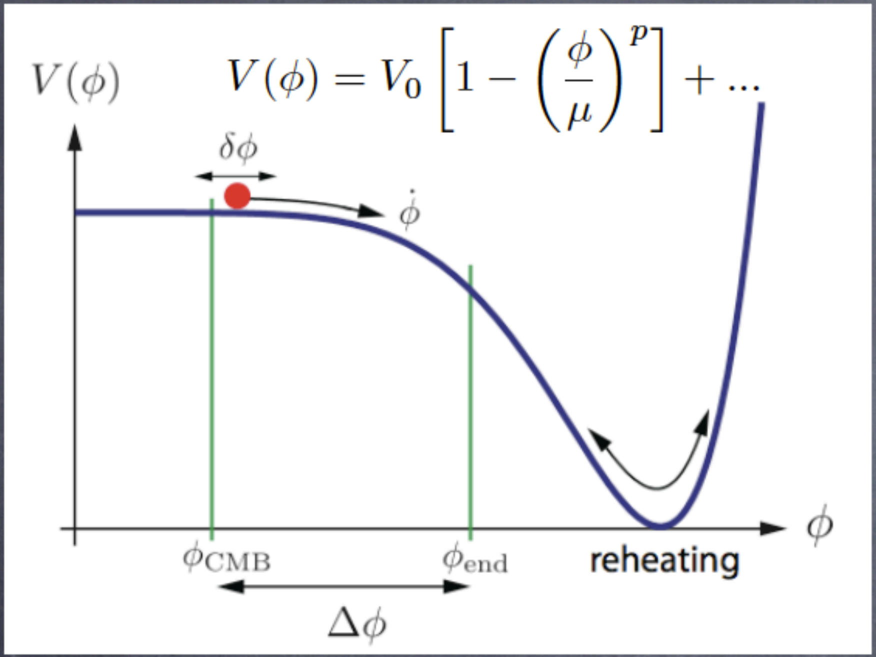
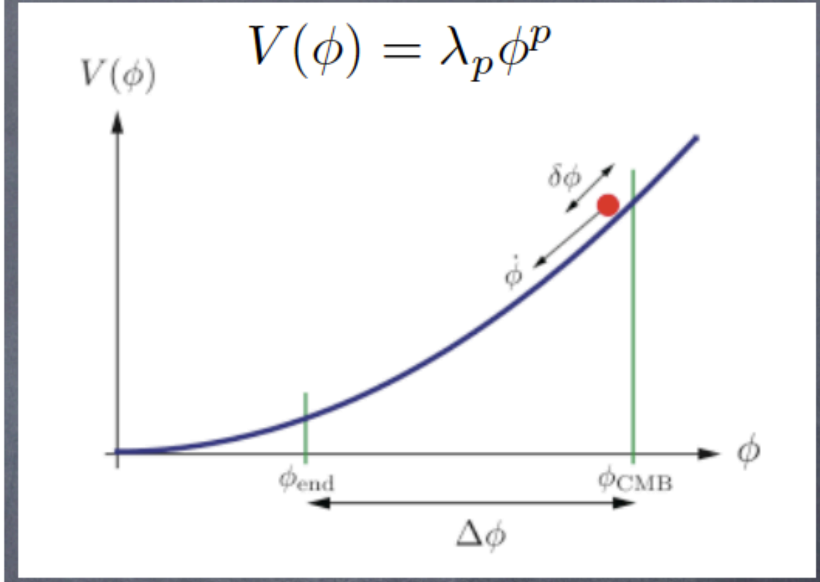
Who cares?

Many models e.g multi-fields, non-canonical K.E –
pretty much ruled out

Have a Closer Look





$\Delta\phi < M_P$

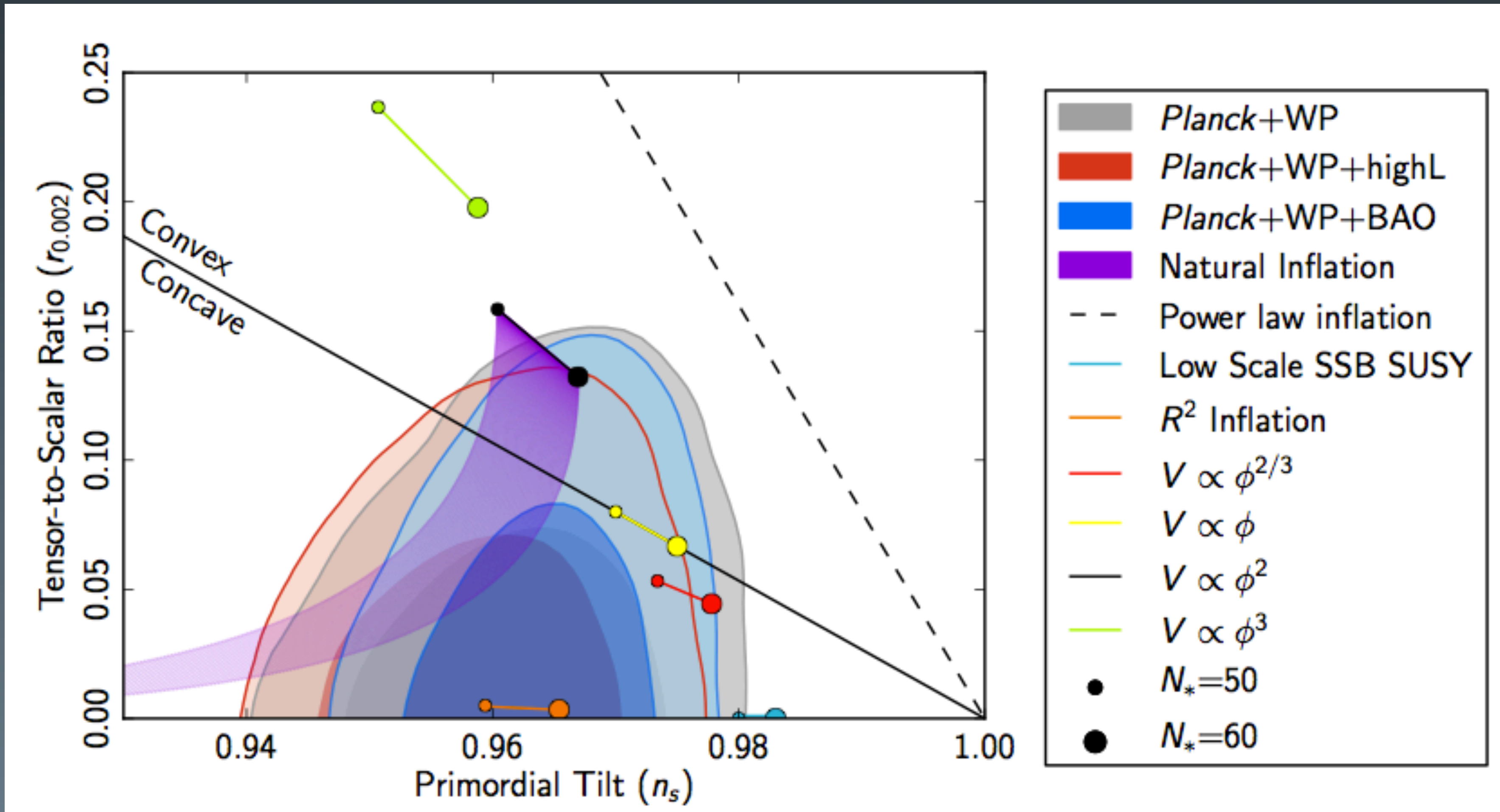
$\Delta\phi > M_P$

large tensor perturbations

$$\frac{\Delta\phi}{M_{Pl}} \sim \left(\frac{r}{0.01}\right)^{1/2}$$

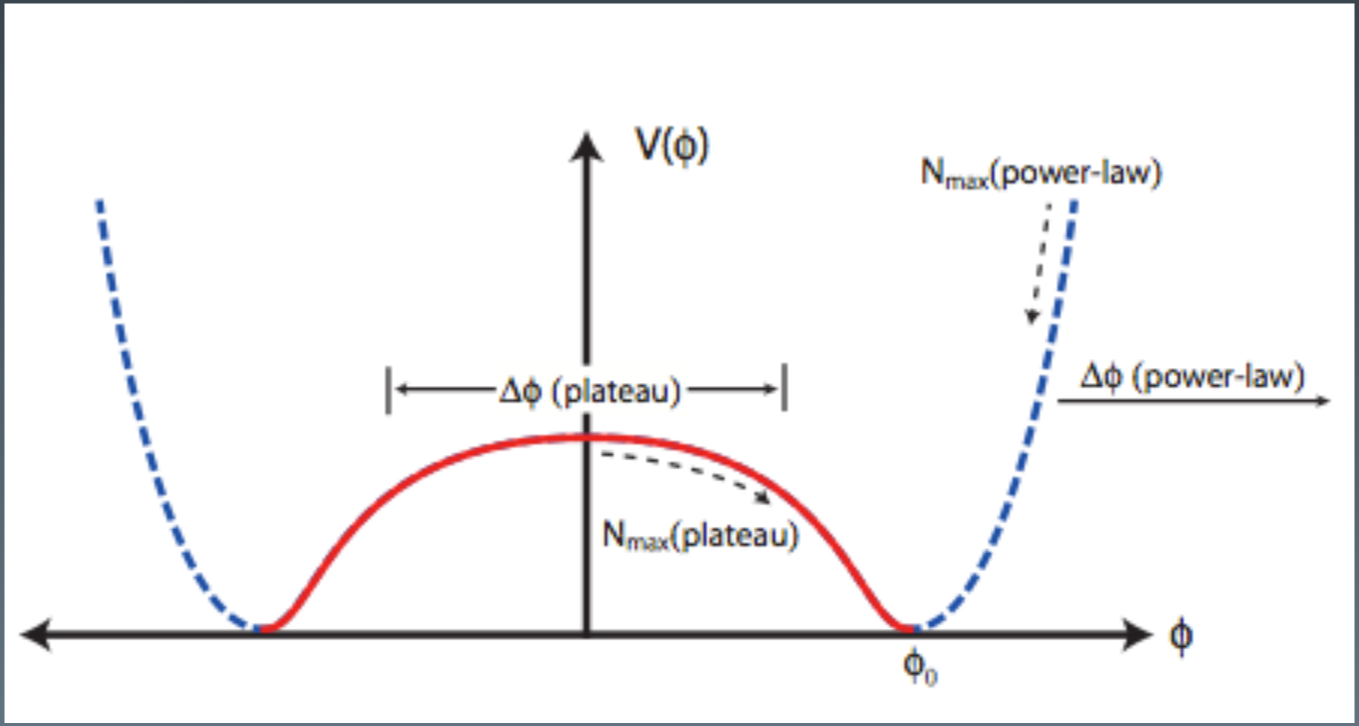
Lyth's bound

PLANCK r < 0.11



Exponential potential, **power-law potential**, inverse power-law potential excluded!

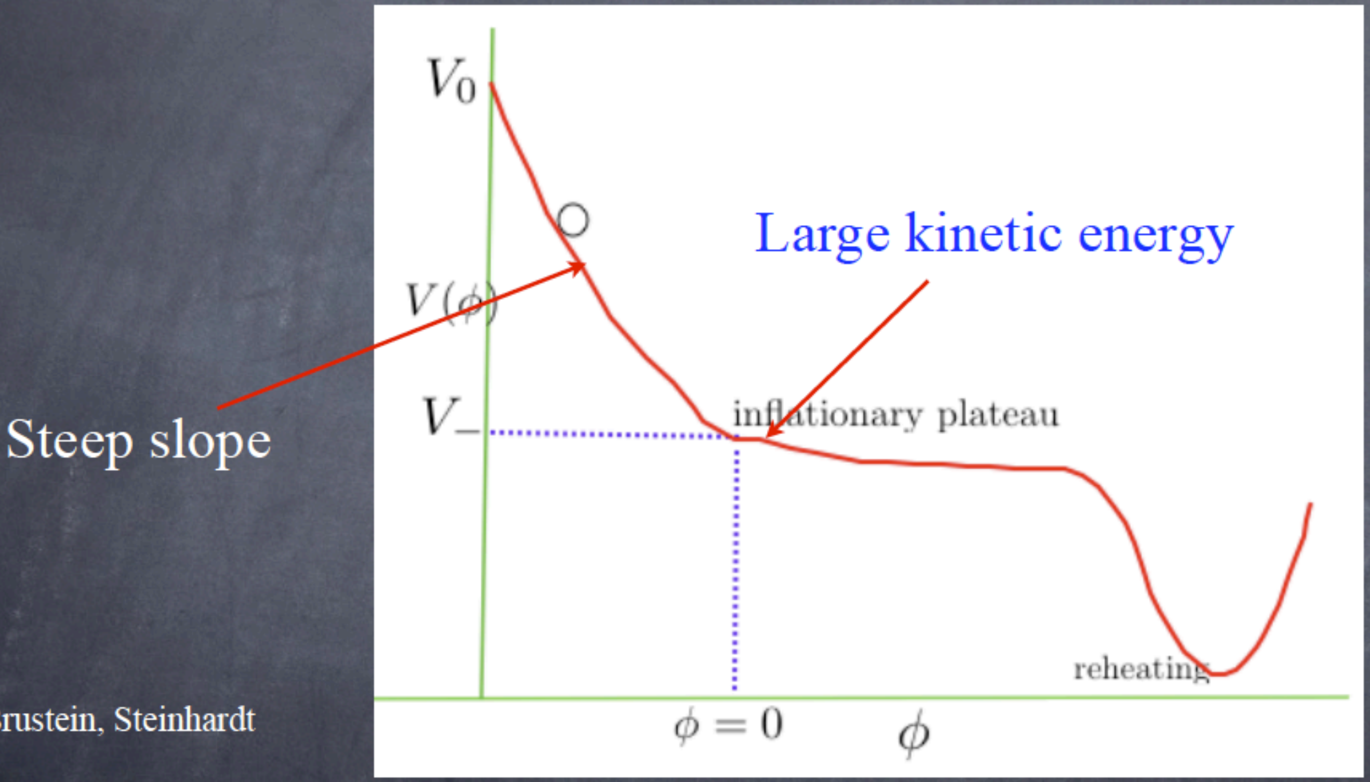
Symmetry breaking potential, axionic potential, hilltop, R^2 Potential doing well!



Data supports *plateau-like* potential

Ijjas, Steinhardt, Loeb - 2013

Overshoot Problem



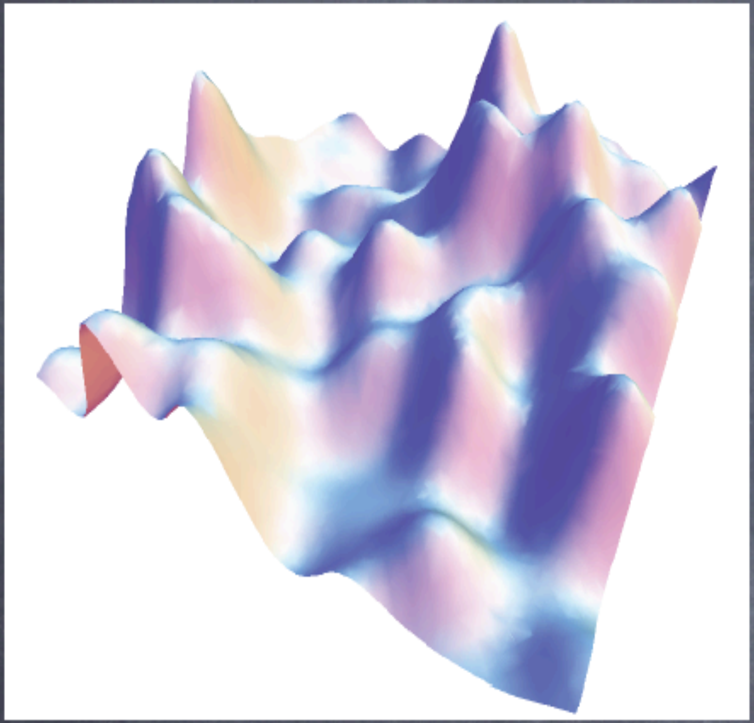
$\Delta\phi < M_P$

Brustein, Steinhardt

What determines the initial K.E, in general, the initial conditions and the subsequent dynamics?

UV Physics – Bubble Nucleation

String Theory   Landscape of vacuua



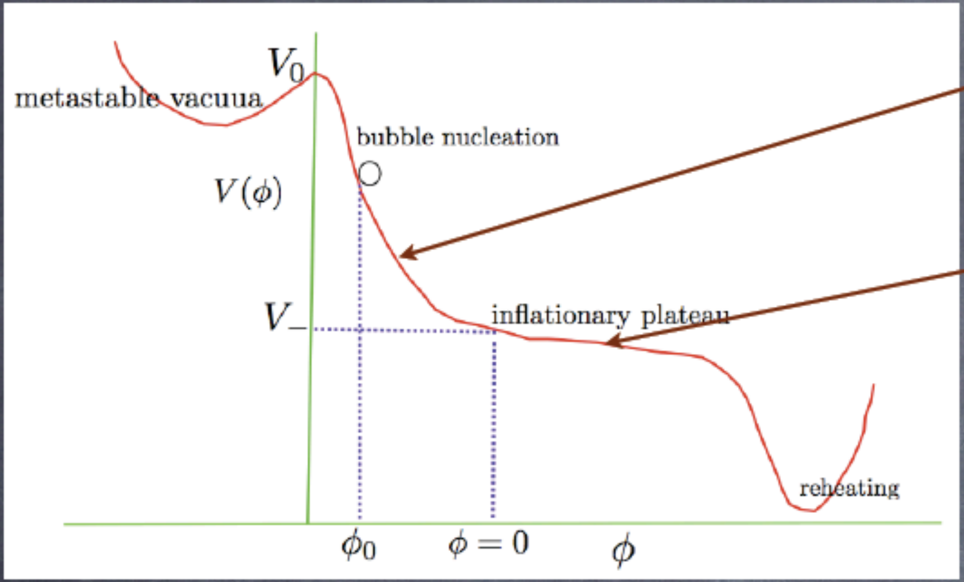
Tunneling from a close-by metastable vacuum

- Coleman de Luccia instanton
- Hawking-Moss instanton

bubble nucleation with negative curvature (k = -1)

very special initial condition $a(t) = t \quad \dot{\phi}_0 = \dot{\phi}(t=0) = 0$

Modeling the Problem



$$V_L(\phi) = (-1)^n \frac{\lambda_n}{n} \phi^n$$

$$V_R(\phi) = V_-(1 - \sqrt{2\epsilon}\phi)$$

$$H^2 = \frac{1}{3M_P^2}\left(\frac{\dot{\phi}^2}{2} + V(\phi)\right) + \frac{1}{a^2}$$

Thanks to CdL instanton

$\phi_0 < M_P$ $\quad$ $V_- << V_0$

$$\ddot{\phi} + 3H\dot{\phi} + \partial_\phi V = 0 \qquad H = 1/t$$

Large initial damping due to the nature of CdL solution

Example: Linear Case

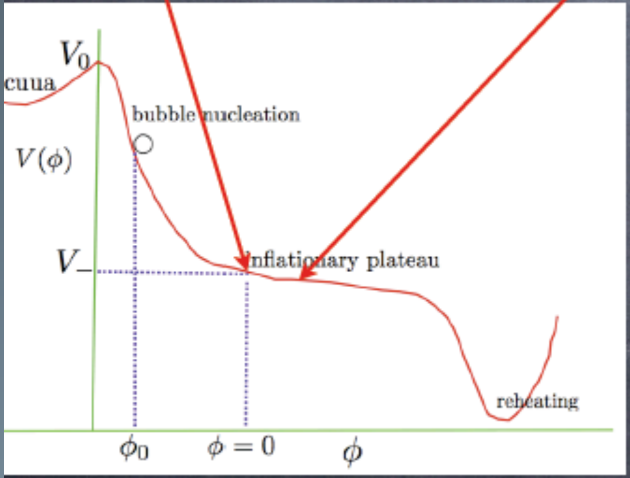
$$V(\phi) = V_-(1 - \lambda\phi) \qquad \phi(t) = \phi_0 + \frac{\lambda V_-}{8} t^2$$

$$t_f = 2\sqrt{\frac{-2\phi_0}{\lambda V_-}} \qquad \dot{\phi}(t_f) = \sqrt{-(\lambda V_- \phi_0)/2}$$

Curvature term = Potential energy

$$1/t_c^2 = 1/3V_-$$

$$\phi(t_c) = \frac{3}{4\sqrt{2}}\sqrt{\epsilon} - \phi_0$$



the amount of overshoot

$$\phi_{overshoot} = \frac{3}{4\sqrt{2}}\sqrt{\epsilon} + 2|\phi_0|$$

The assumption of curvature domination is consistent!

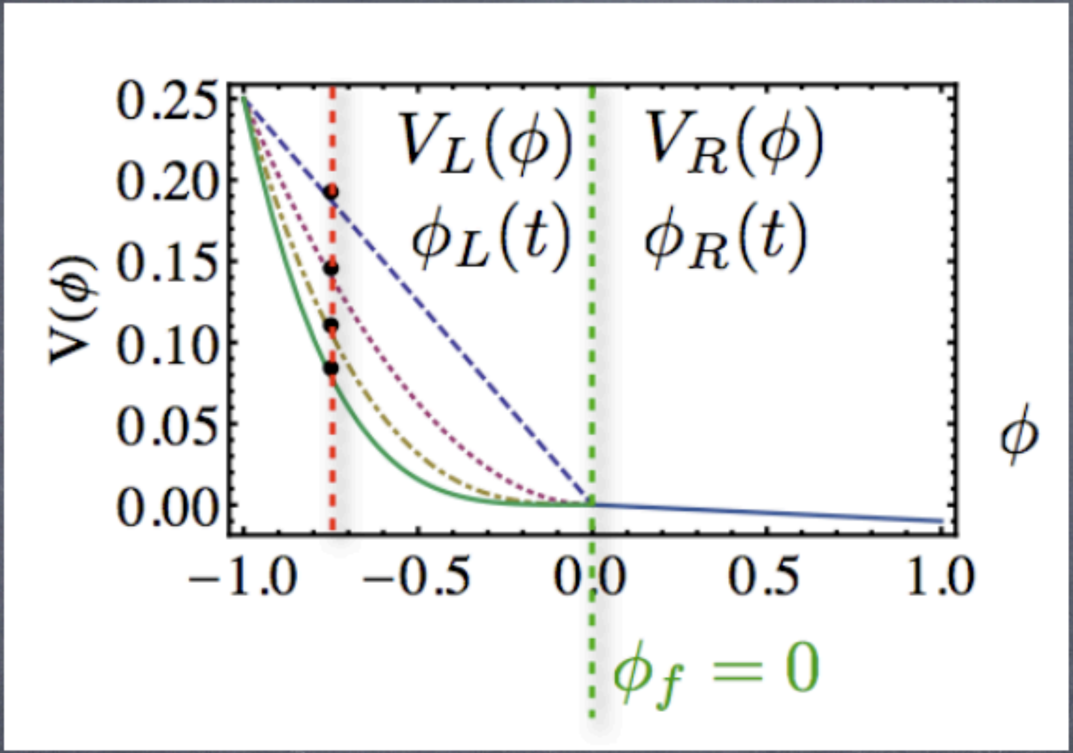
Freivogel, Kleban, Martinez, Susskind '05

An Universal behavior of the amount of overshooting for n < 4

$$\phi_{overshoot} = \frac{3}{4\sqrt{2}}\sqrt{\epsilon} + \mathcal{O}(1)|\phi_0|$$

No overshooting for quartic and higher order monomial

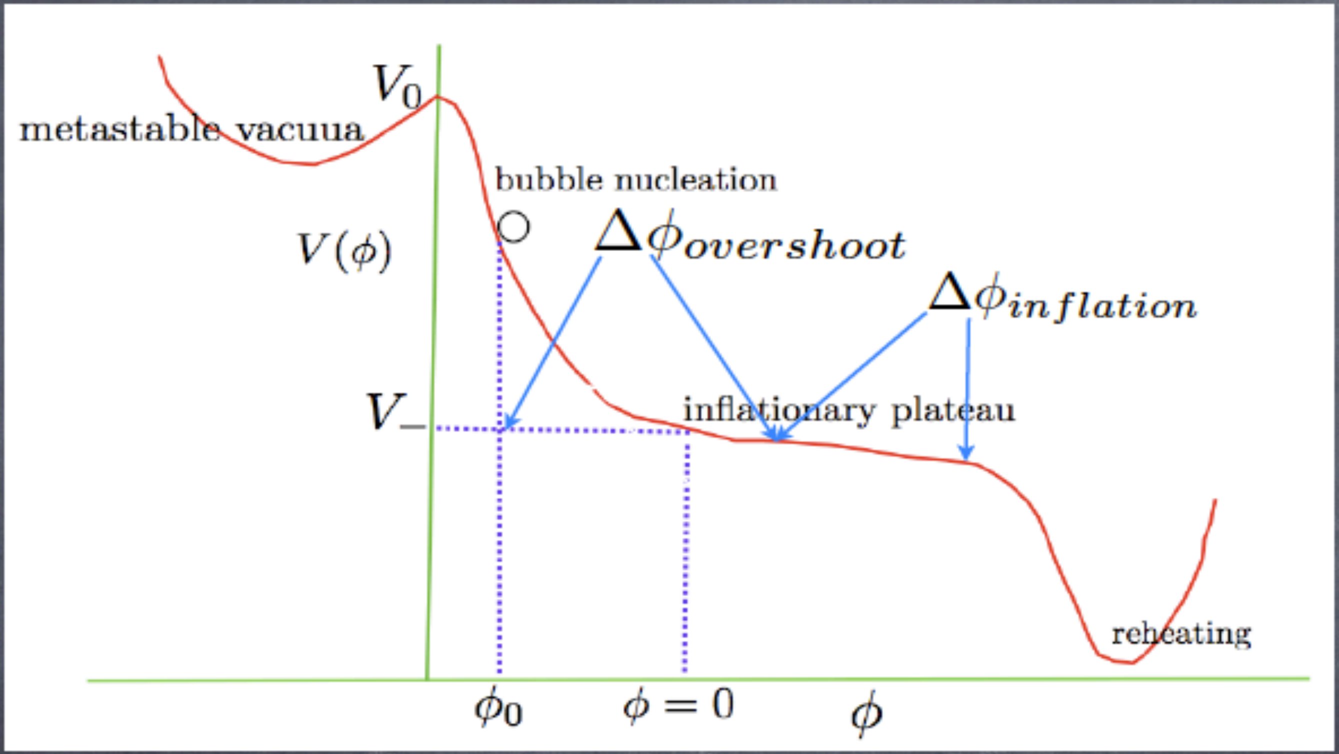
K D, Vaudrevange, Westphal



Higher monomial steeper at the beginning, but shallower at the end!

For steeper part 'time' is smaller, therefore friction is larger!

Final Point



$$\Delta\phi_{Tot} = \Delta\phi_{overshoot} + \Delta\phi_{inflation}(N = 60)$$

$$\phi_{overshoot} = \frac{3}{4\sqrt{2}}\sqrt{\epsilon} + \mathcal{O}(1)|\phi_0|$$

Conclusion

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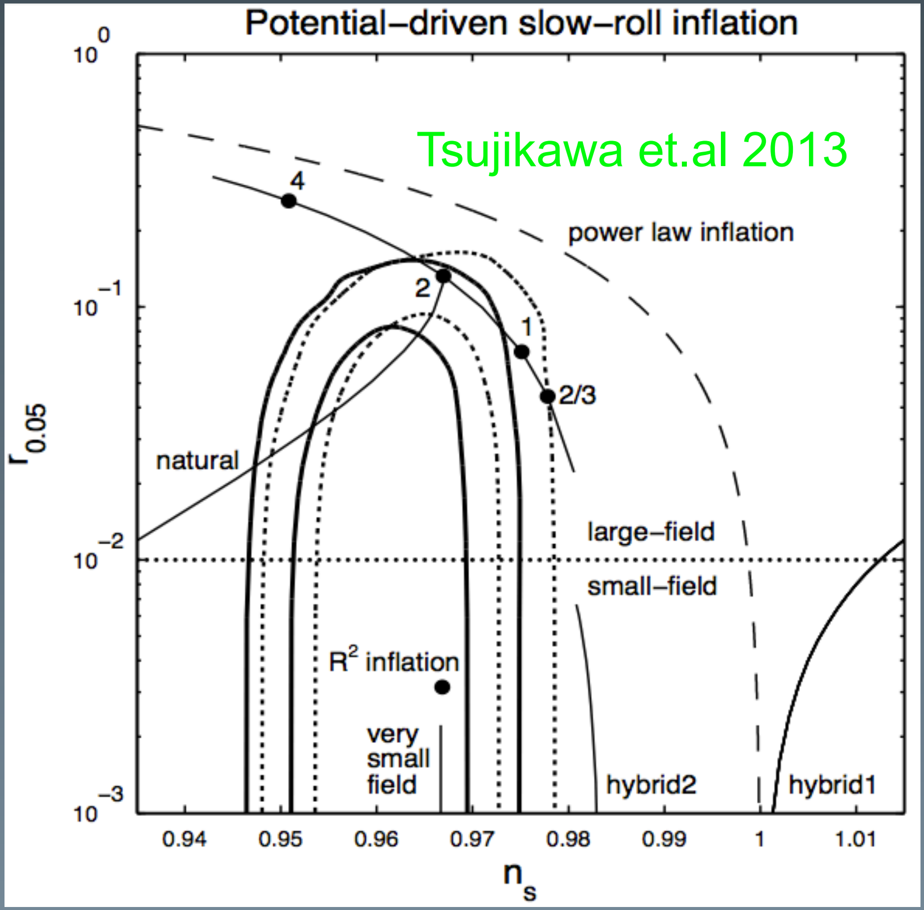
Plateau-like potentials preferred



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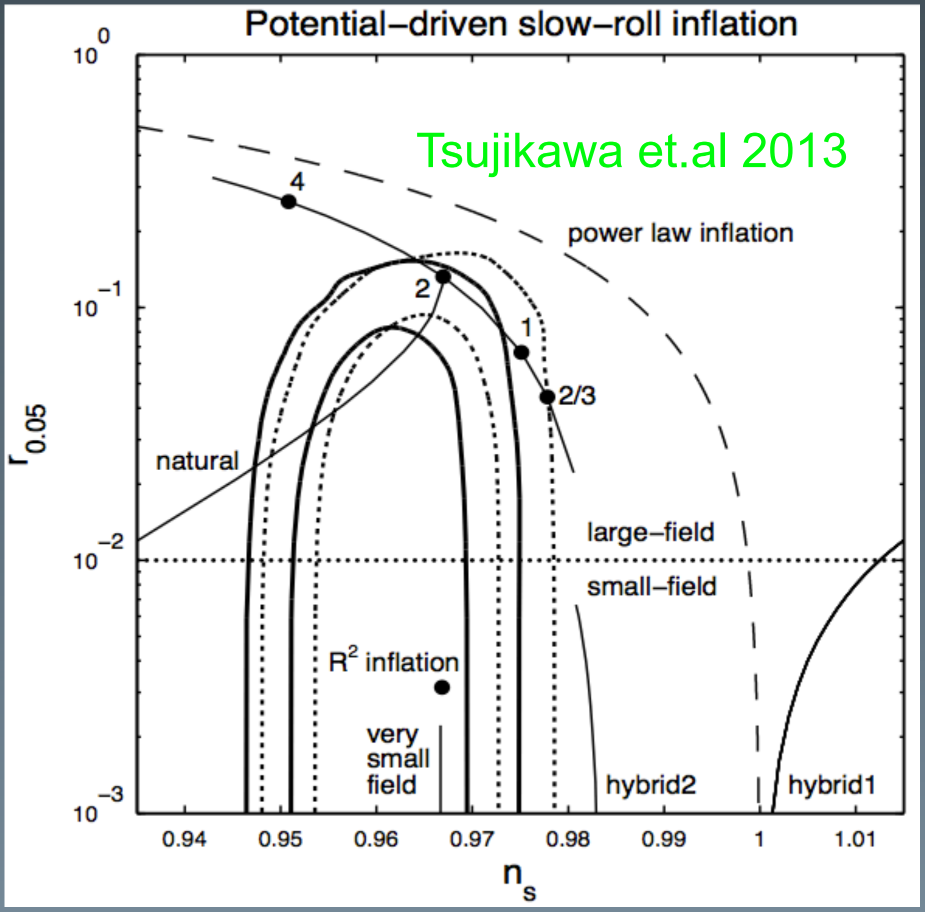
Overshoot issues related to the ‘small-field’ models

Solution: Bubble nucleation to seed inflation

K D, Vaudrevange, Westphal



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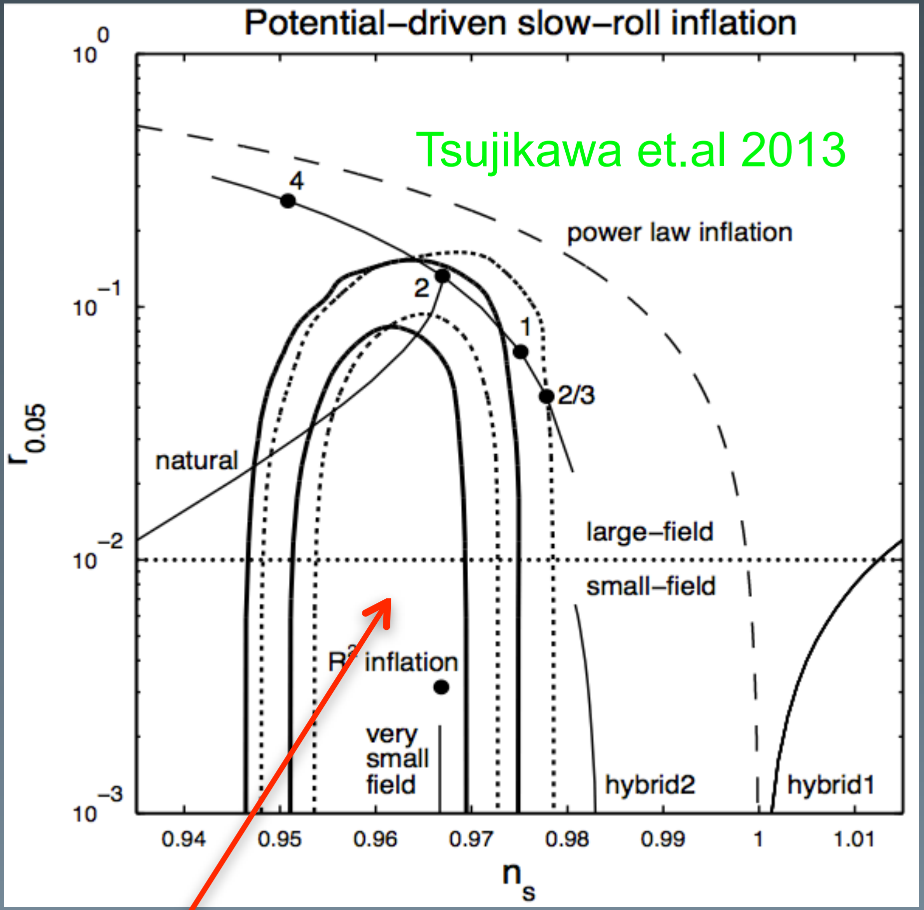

Stay tuned for Polarization data


Thank You