The geometrical destabilization of inflation: what? why? and how?

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Works with Krzysztof Turzynski & Vincent Vennin

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Project GEODESI

IAP

Apologies: (almost) no reference in this talk

Many many people investigated multi field inflation, including in this conference

Robert Brandenberger
Xingang Chen
Konstantinos Dimopoulos
Guillemet Domenech
Damien Easson
Tomohiro Fujita
Jinn-Ouk Gong
Robert Hardwick
David Langlois
Chunshan Lin
Tommi Markkanen
Tomohiro Matsuda
Shuntaro Mizuno
Ryo Namba
Carrilho Pedro

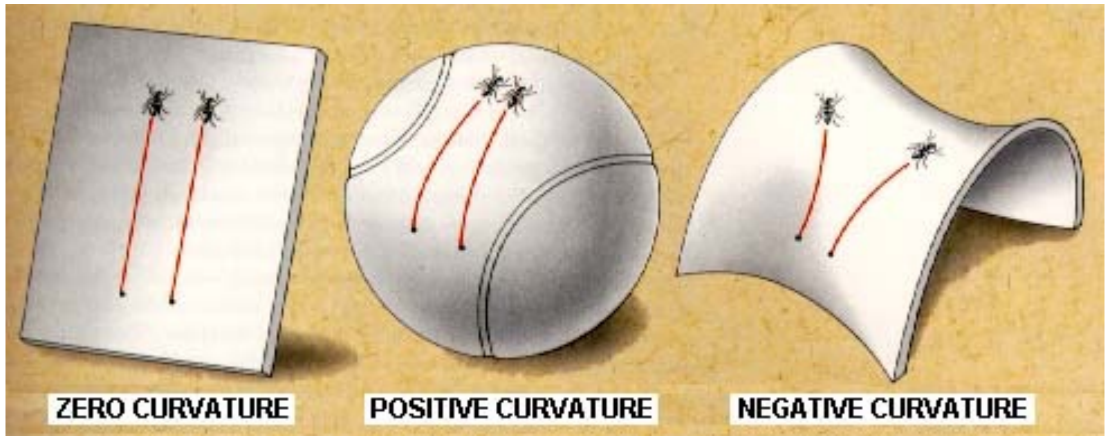
Gonzalo Palma
Antonio Riotto
Diederik Roest
John Ronayne
Maria Rozanska-Kaminska
Ryo Saito
Evangelos Sfakianakis
Yuichiro Tada
Krzysztof Turzynski
Vincent Vennin
Filippo Vernizzi
Nelson Videla
David Wands
Michal Wieczorek
…

Basic idea

Realistic inflationary models have fields which live in an internal space with curved geometry.

cf Diederik Roest's talk

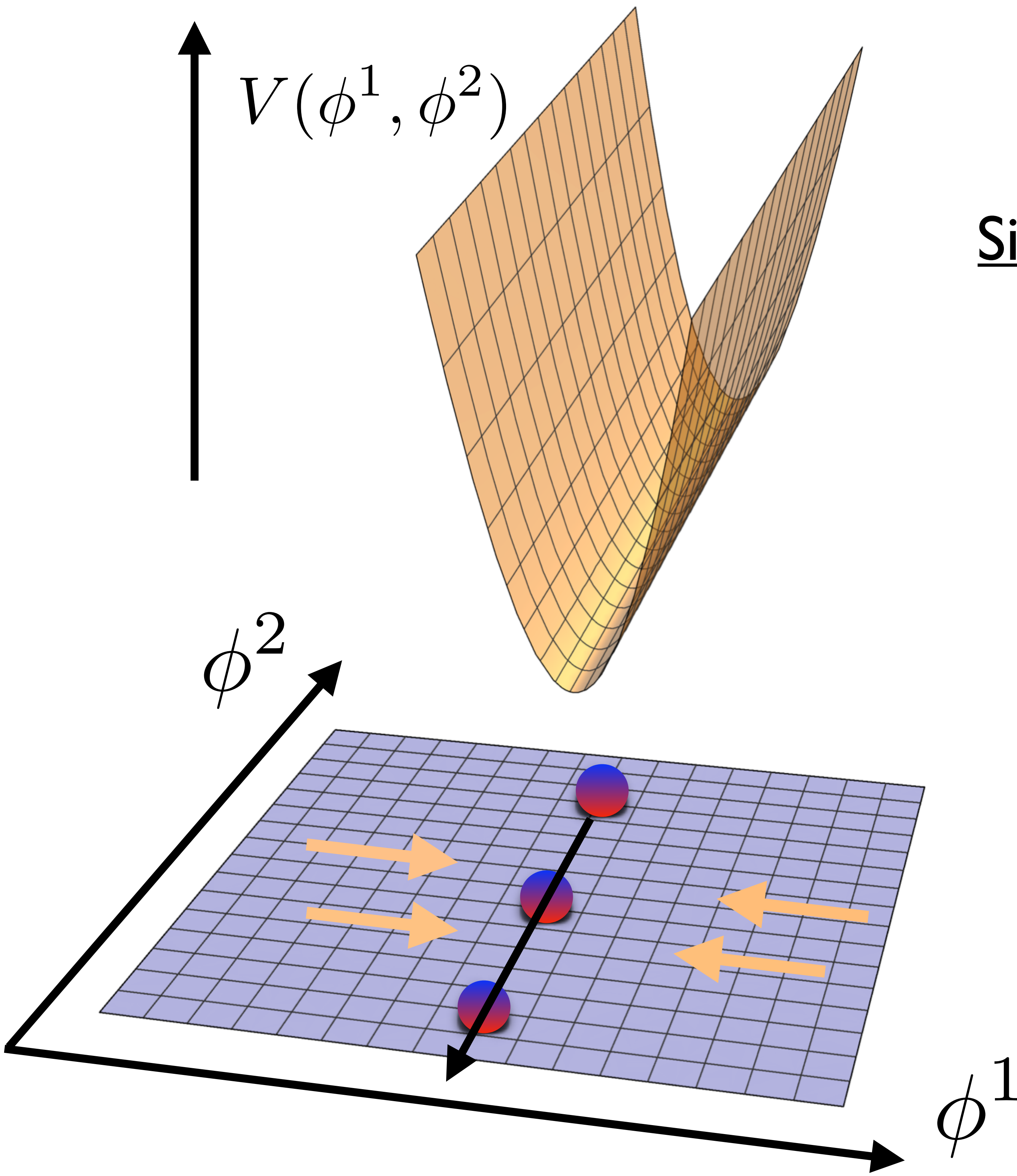
Initially neighboring geodesics tend to fall away from each other in the presence of negative curvature.



This effect applies during inflation,
it easily overcomes the effect of the potential,
and can destabilize inflationary trajectories.

Basic mechanism

Renaux-Petel, Turzynski, September 2016
PRL Editors' Highlight



Simplest 'realistic' models (hope):

Light inflaton
+
Extra heavy fields

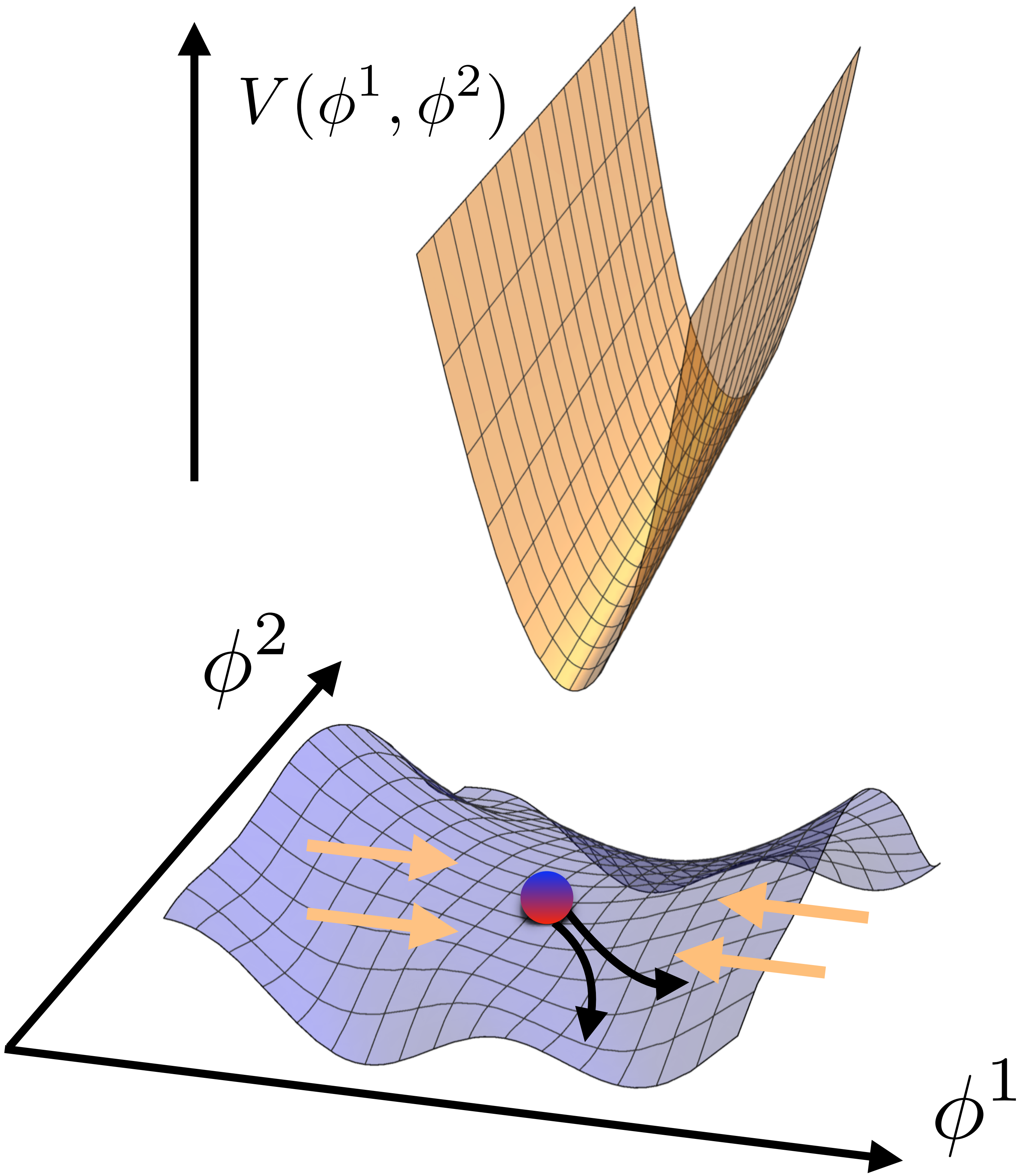
↳

Effective
single-field dynamics

(valley with steep walls)

Basic mechanism

Renaux-Petel, Turzynski, September 2016
PRL Editors' Highlight



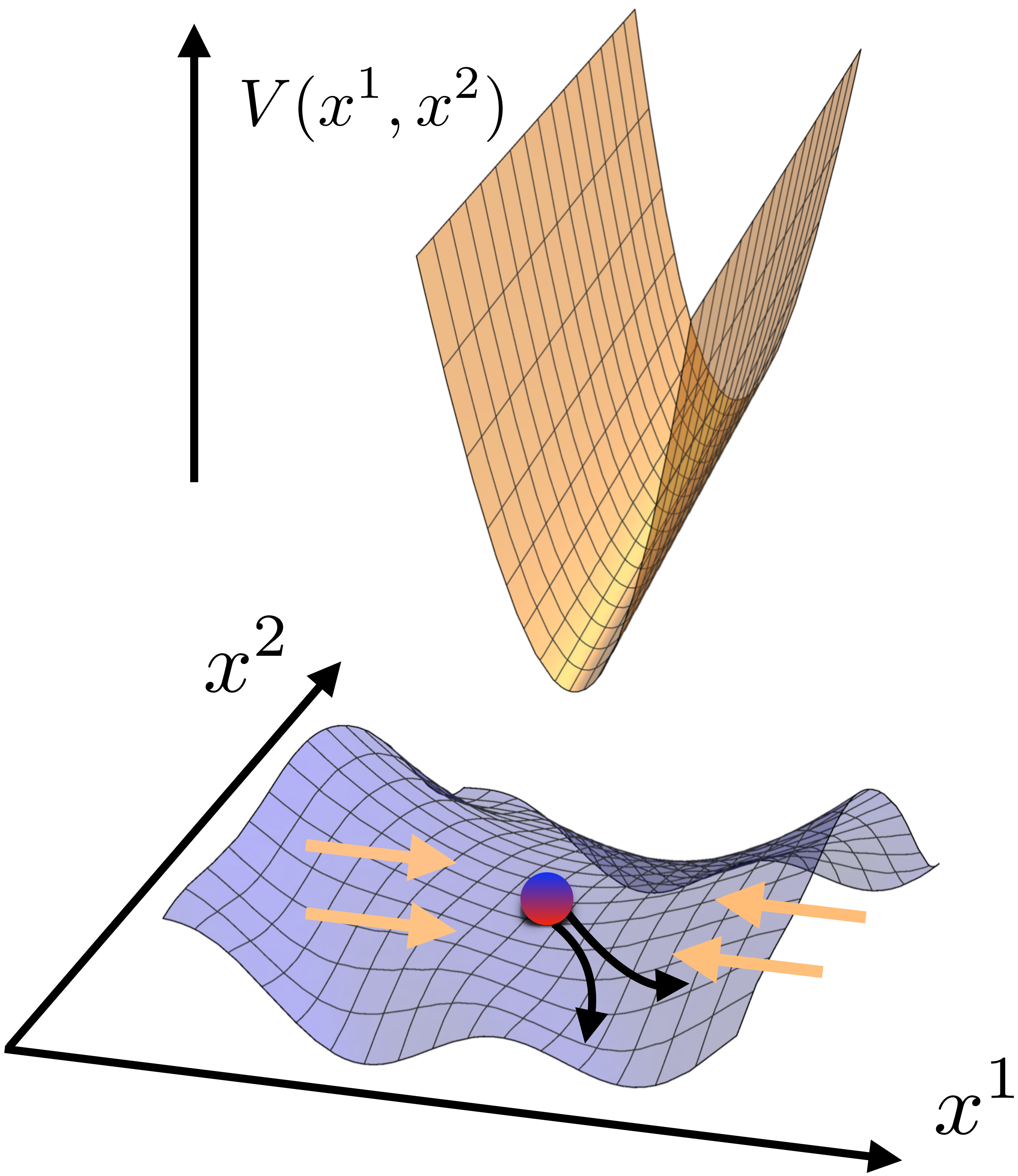
<u>More realistic:</u>

Light inflaton
+
Extra heavy fields
+
Curved field space

↳ Geometrical instability

Basic mechanism

Renaux-Petel, Turzynski, September 2016
PRL Editors' Highlight



Simple analogy:

- Position of a charged particle
- Electric force
- Surface geometry

↳ Geometrical instability

Multifield Lagrangian

$$S = \int \mathrm{d}^4x\sqrt{-g}\left(-\frac{1}{2}G_{IJ}(\phi^K)\partial_\mu\phi^I\partial^\mu\phi^J - V(\phi^I)\right)$$

1. A curved field space is generic

Top-down (e.g. supergravity), or bottom-up (EFT)

Field space curvature $\sim 1/M^2$

2. A priori, M can lie anywhere between H and Mp

Example: alpha-attractors $R^{\text{field space}} M_{\text{Pl}}^2 = -\frac{2}{3\alpha}$

Linear perturbation theory

$$\mathcal{D}_t\mathcal{D}_t Q^I + 3H\mathcal{D}_t Q^I + \frac{k^2}{a^2}Q^I + M^I_{\ J}Q^J = 0$$

Sasaki, Stewart, 95

$Q^I =$ fluctuations of field I in flat gauge

$$\mathcal{D}_t A^I = \dot{A}^I + \Gamma^I_{JK}\dot{\phi}^J A^K$$

Mass matrix:

$$M^I_{\ J} = V^I_{;J} - \mathcal{R}^I_{\ KLJ}\dot{\phi}^K\dot{\phi}^L - \frac{1}{a^3 M_{\rm Pl}^2}\mathcal{D}_t\left(\frac{a^3}{H}\dot{\phi}^I\dot{\phi}_J\right)$$

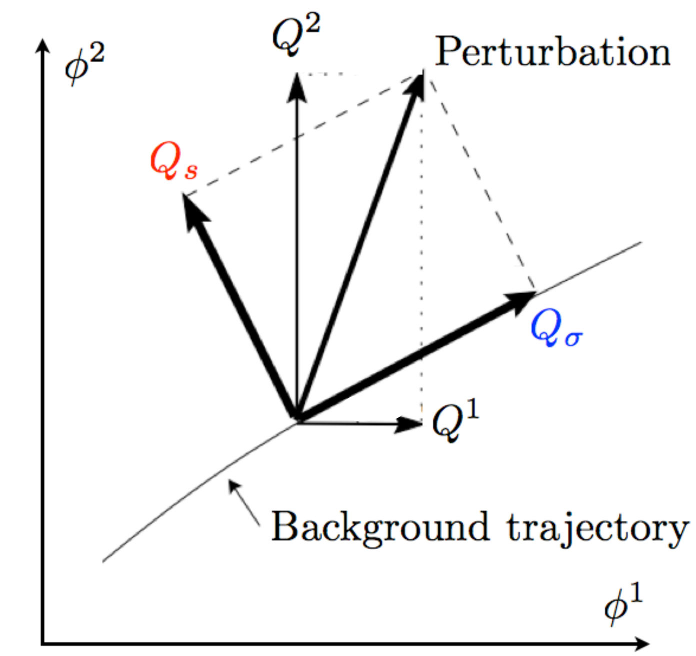
Riemann curvature tensor
of the field space metric

cf geodesic deviation equation

Two-field models (simplicity)

super-Hubble evolution
of the entropic field

$$\ddot{Q}_s + 3H\dot{Q}_s + m^2_{s(\mathrm{eff})} Q_s = 0$$



Gordon et al, 2000

Effective entropic mass squared:

$$\frac{m^2_{s(\mathrm{eff})}}{H^2} \equiv \frac{V_{;ss}}{H^2} + 3\eta_\perp^2 + \epsilon\, R^{\text{field space}} M^2_{\mathrm{Pl}}$$

Hessian
contribution

bending
contribution

'geometrical'
contribution

Geometrical destabilization

$$\frac{m^2_{s(\mathrm{eff})}}{H^2} \equiv \frac{V_{;ss}}{H^2} + 3\eta_\perp^2 + \epsilon\, R^{\mathrm{field\ space}} M_{\mathrm{Pl}}^2$$

Hessian contribution

bending contribution

'geometrical' contribution

When the geometrical contribution is negative and large enough, it can **render the entropic fluctuation tachyonic, even with a large mass in the static vacuum**, with potentially dramatic observational consequences.

Geometrical destabilization

Necessary condition (2-field): $R^{\text{field space}} < 0$

$$R^{\text{field space}} M_{\text{Pl}}^2 \sim (M_{\text{Pl}}/M)^2$$ generically $\gg 1$

→

Let us consider for instance $M = \mathcal{O}(10^{-2}, 10^{-3}) M_{\text{Pl}}$ (string scale, KK scale, GUT scale...)

Even for $\frac{V_{;ss}}{H^2} \sim 100$

The effective mass becomes tachyonic when:
$\epsilon \to \epsilon_c = 10^{-4}$ or 10^{-2}

Minimal realization

$$\mathcal{L} = -\frac{1}{2}(\partial\phi)^2\left(1 + 2\frac{\chi^2}{M^2}\right) - V(\phi) - \frac{1}{2}(\partial\chi)^2 - \frac{1}{2}m_h^2\chi^2$$

- Slow-roll model of inflation, with inflaton ϕ
- Heavy field χ with $m_h^2 \gg H^2$
- Simple dimension 6 operator suppressed by a **mass scale of new physics** $M \gg H$
- Generally expected from the effective theory point of view.

Minimal realization

$$\mathcal{L} = -\frac{1}{2}(\partial\phi)^2\left(1 + 2\frac{\chi^2}{M^2}\right) - V(\phi) - \frac{1}{2}(\partial\chi)^2 - \frac{1}{2}m_h^2\chi^2$$

• Terms linear in chi absent for consistency (or Z2 symmetry), and higher-orders in chi suppressed near the inflationary valley

• Does correspond to lots of models in the literature, in which it is sometimes said : «chi is stabilized by a large mass» so let us put chi=0 (consistently with the equations of motion)

Minimal realization

$$\mathcal{L} = -\frac{1}{2}(\partial\phi)^2\left(1 + 2\frac{\chi^2}{M^2}\right) - V(\phi) - \frac{1}{2}(\partial\chi)^2 - \frac{1}{2}m_h^2\chi^2$$

- Apparently benign high-energy correction (small correction to the kinetic term) but ...

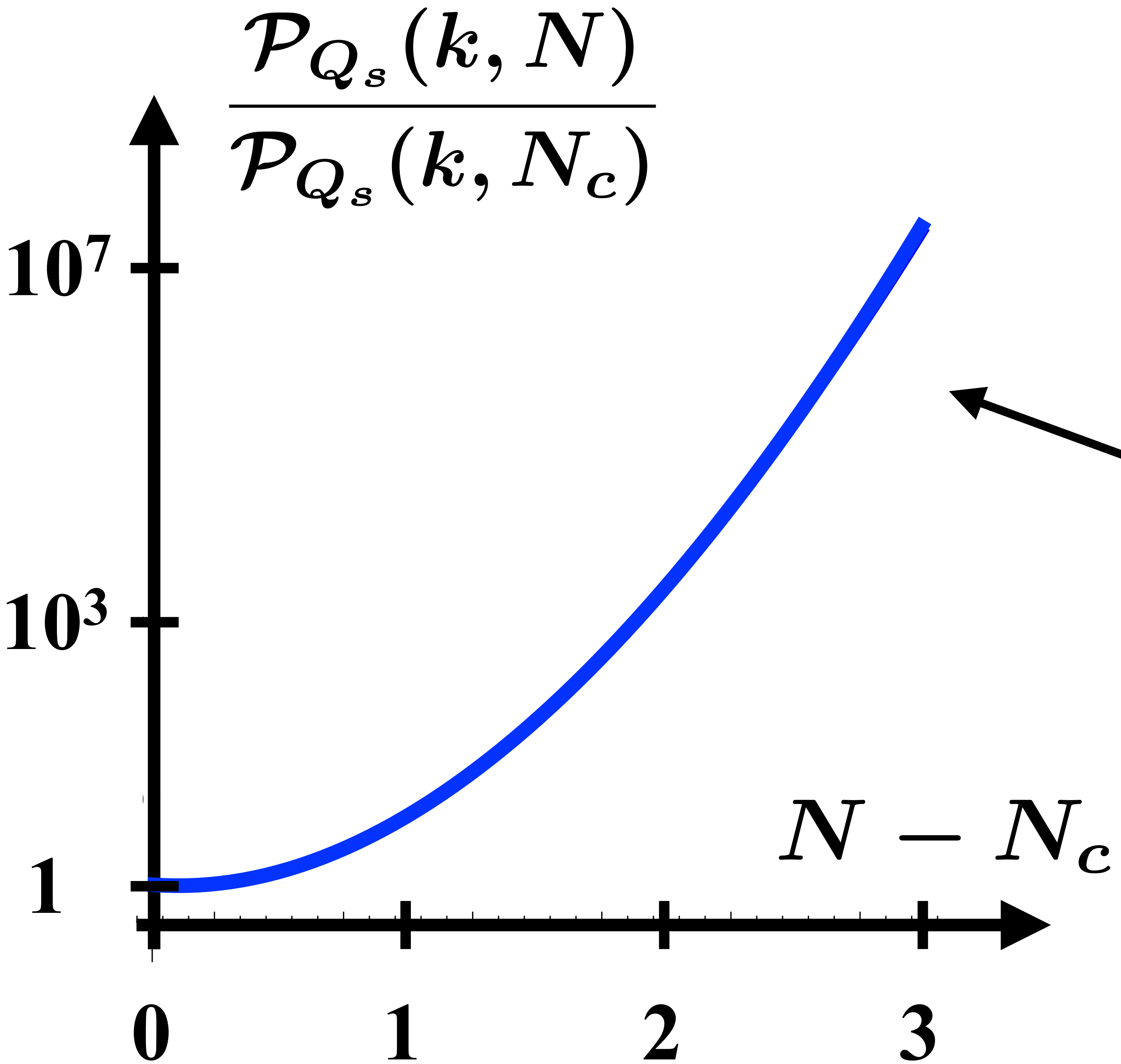
$$R^{\text{field space}} \simeq -\frac{4}{M^2} \quad \text{for} \quad \chi \ll M$$

$$\frac{m^2_{s(\text{eff})}}{H^2} = \frac{m_h^2}{H^2} - 4\,\epsilon(t)\left(\frac{M_{\text{Pl}}}{M}\right)^2 \quad \text{along} \quad \chi = 0$$

- The inflationary trajectory becomes unstable after $\epsilon \longrightarrow \epsilon_c$

Fate of the instability?

Rapid and efficient growth of super-Hubble entropic fluctuations



Example:

Starobinsky potential

$m_h = 10 H_c$

$M = 10^{-2} M_{\rm Pl}$

Numerical resolution (linear theory)

Theoretical modeling (early time):

$$\sim e^{\frac{1}{3}\frac{m_h^2}{H_c^2}\eta_c (N-N_c)^3}$$

Fate of the instability?

- Backreaction of fluctuations on background trajectory?
- Similar to hybrid inflation (but different kinetic origin and kinetic effects).
- Tachyonic preheating, possible production of primordial black holes, inflating topological defects …

Challenging!

possible tools

Stochastic inflation

Tada, RP, Pinol, in preparation

see Yuichiro Tada's talk

Lattice simulations

Wieczorek, RP, Turzynski, in progress

see Michal Wieczorek's talk

Fate of the instability?

Inhomogeneities dominate

↓

Premature end of inflation

↓

- **Universal bound on curvature scale**

RP, Turzynski, 1510.01281, PRL

- **Modified ranking of inflationary models**

1706.01835
RP, Turzynski, Vennin,
to appear in JCAP

OR

Inhomogeneities are shut off

↓

Second phase of inflation

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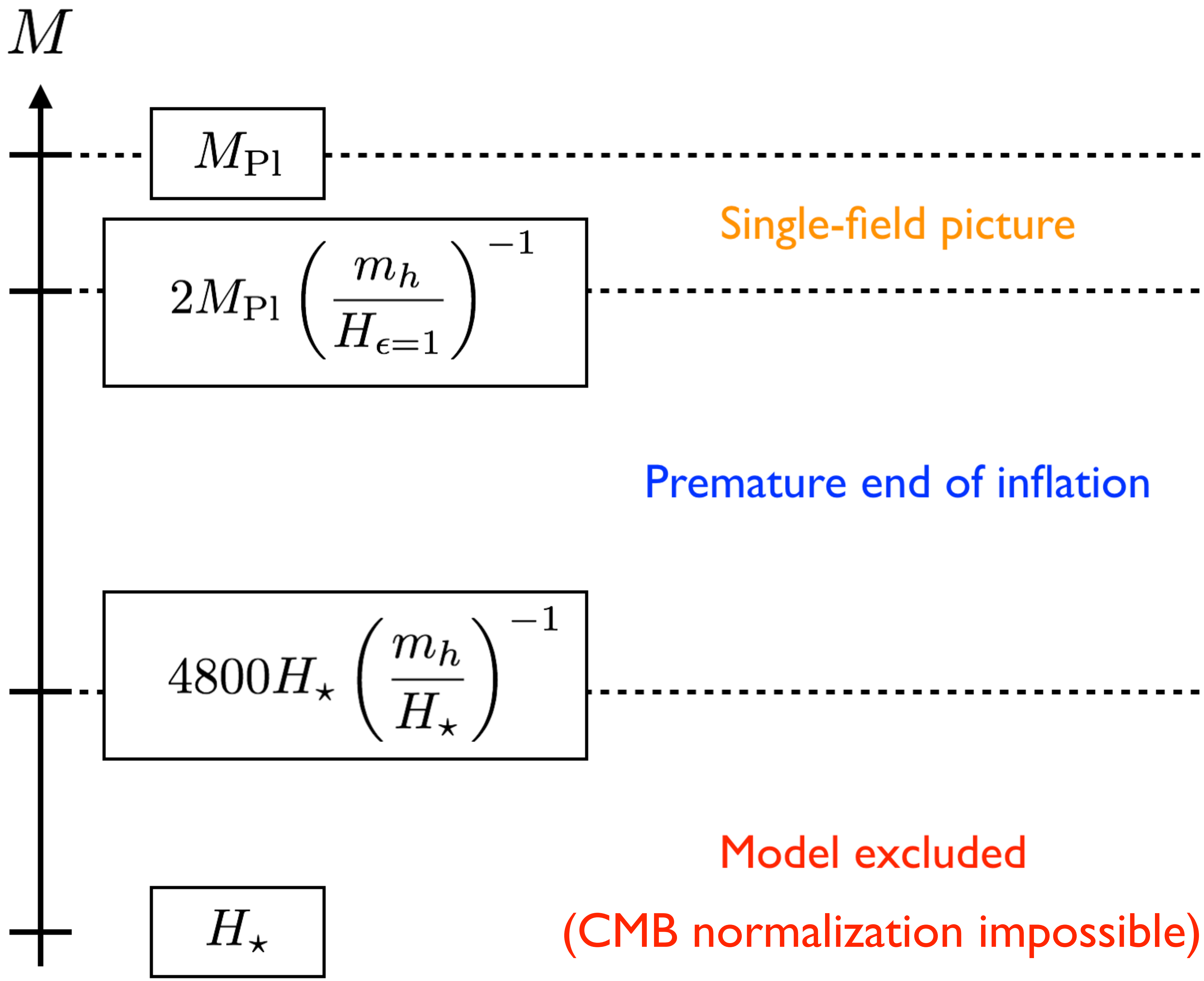
RP, Turzynski, 1510.01281

RP, Turzynski, to appear

RP, Tada, Garcia-Saenz, in preparation

(Non)-decoupling and the field space curvature scale



(Non)-decoupling and the field space curvature scale

M

Strong selection criterion on high-energy interactions above H!

Model-independent information about field space geometry, important in high-energy physics!

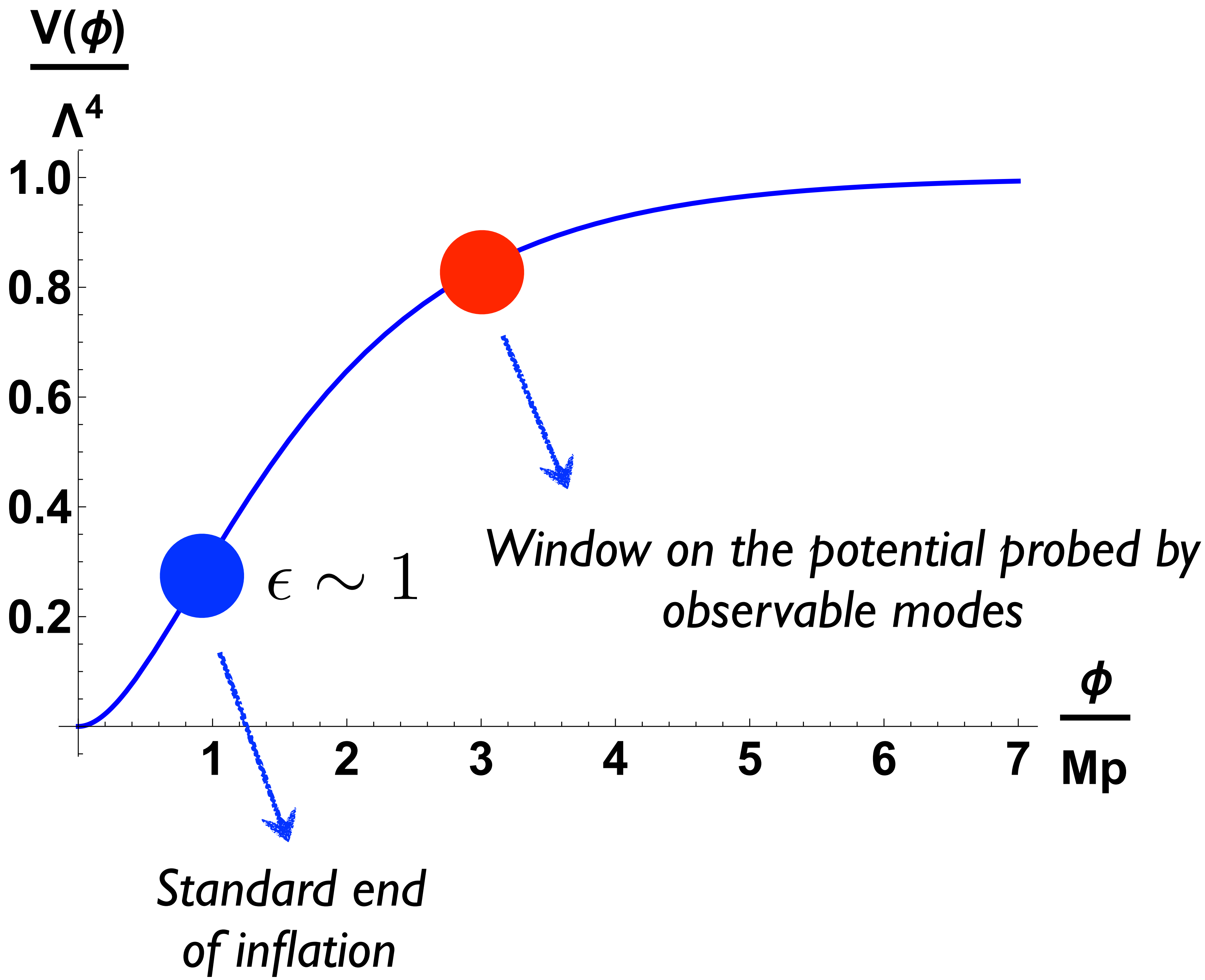
$$4800 H_\star \left(\frac{m_h}{H_\star} \right)^{-1}$$

Model excluded

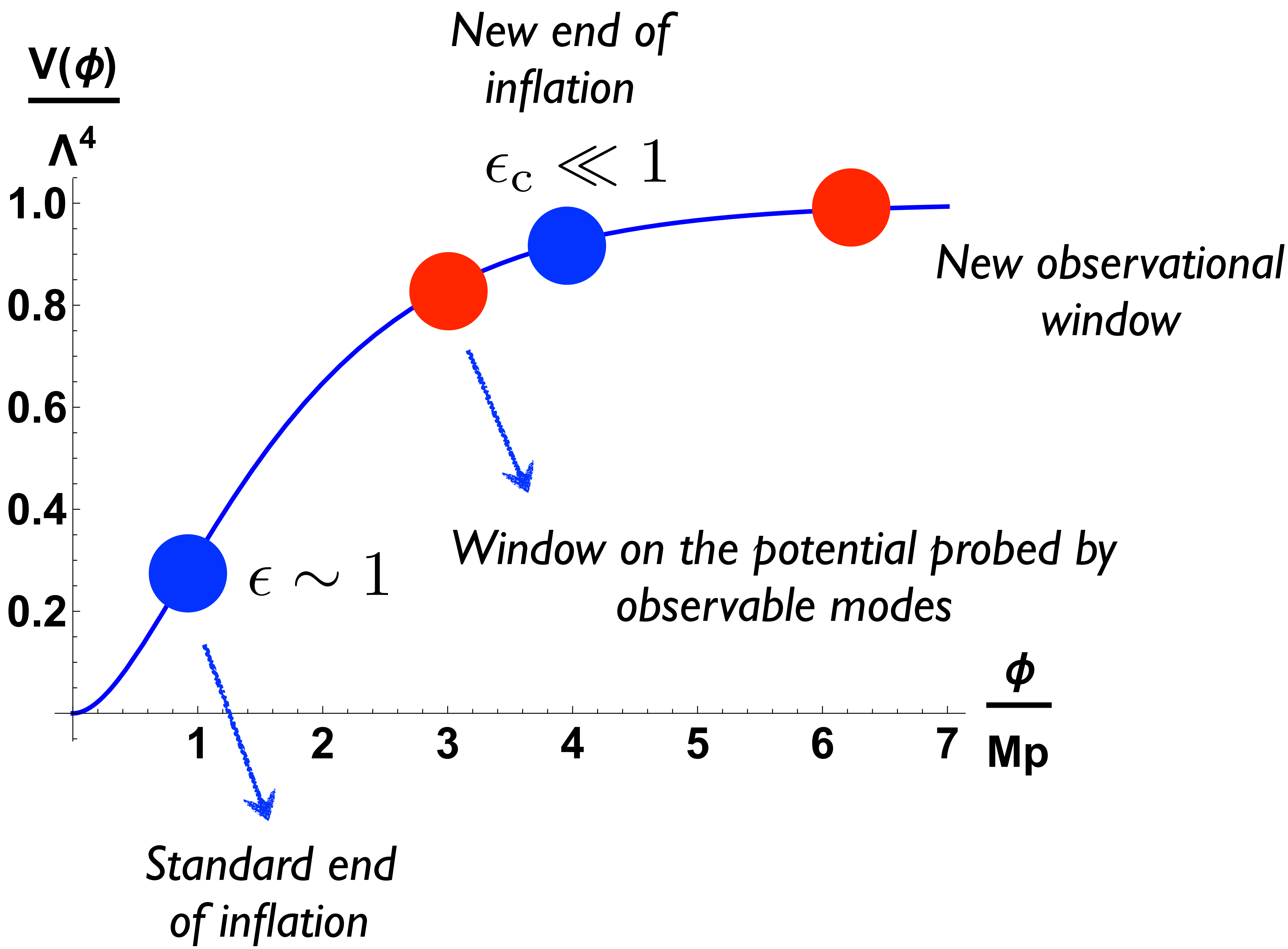
(CMB normalization impossible)

$H_\star$

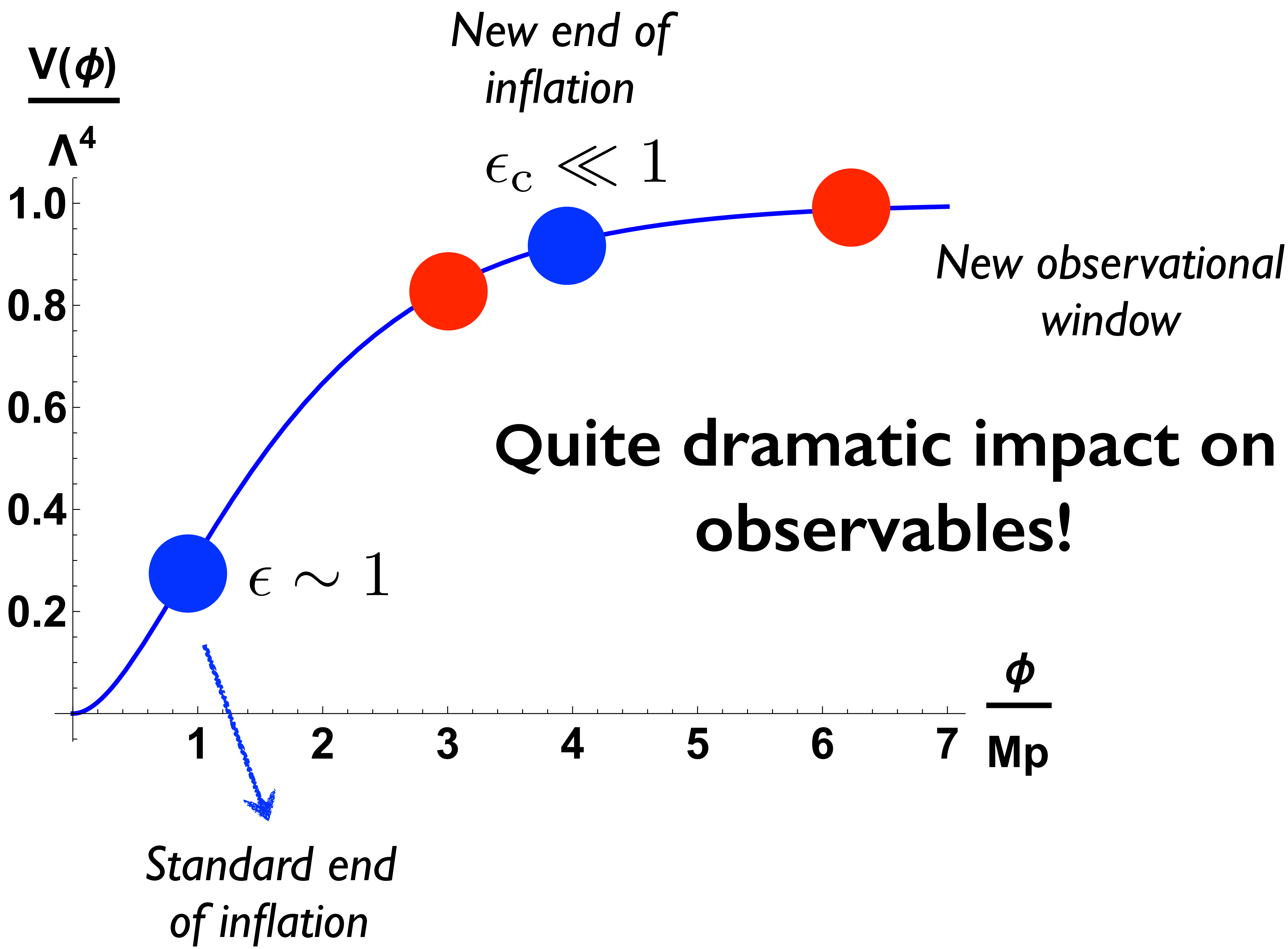
Premature end of inflation



Premature end of inflation

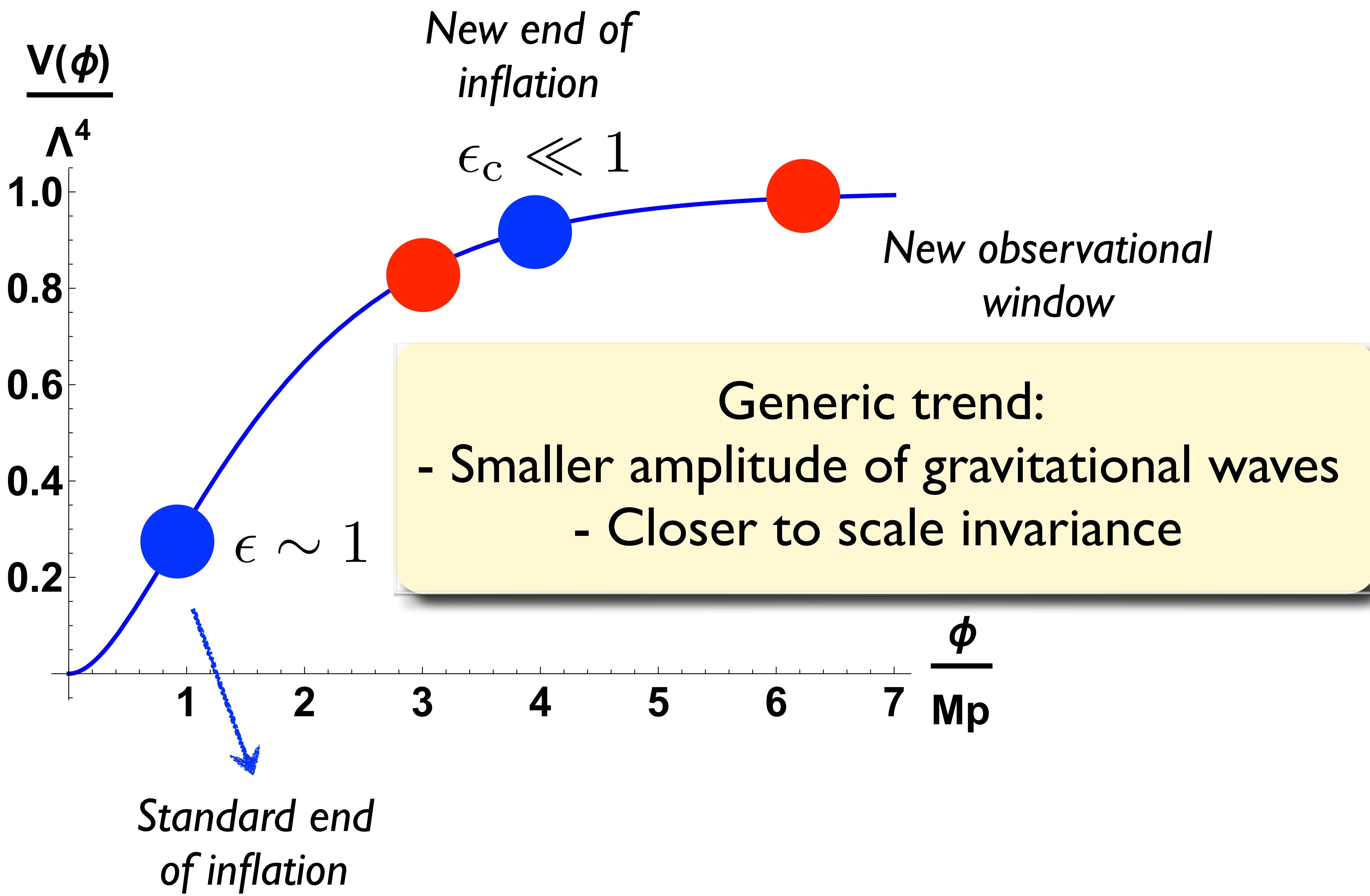


Premature end of inflation



Quite dramatic impact on observables!

Premature end of inflation

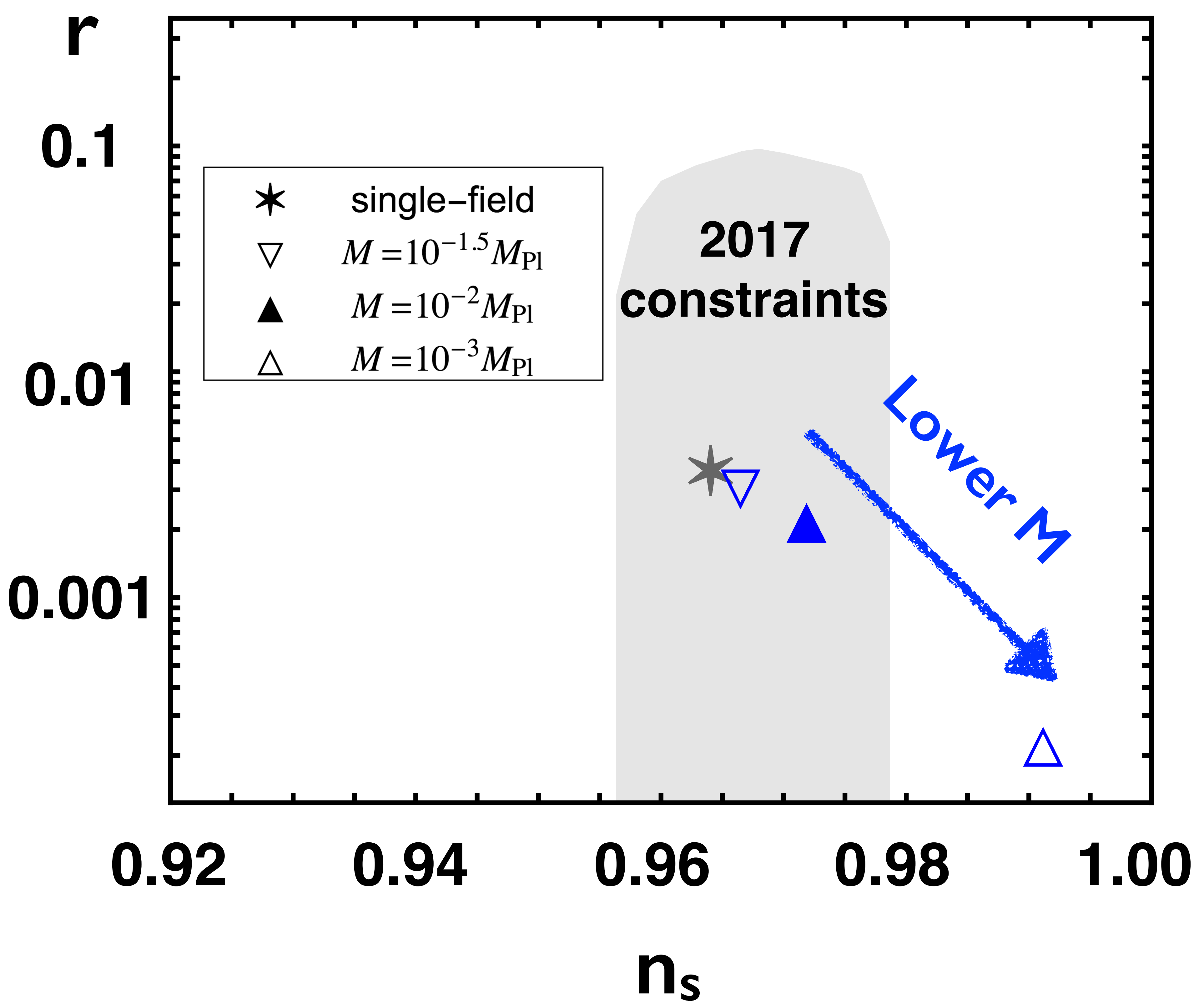


Observational predictions

Example:

Starobinsky potential

$m_h = 10 H_c$



Geometrical destabilization, premature end of inflation and Bayesian model selection

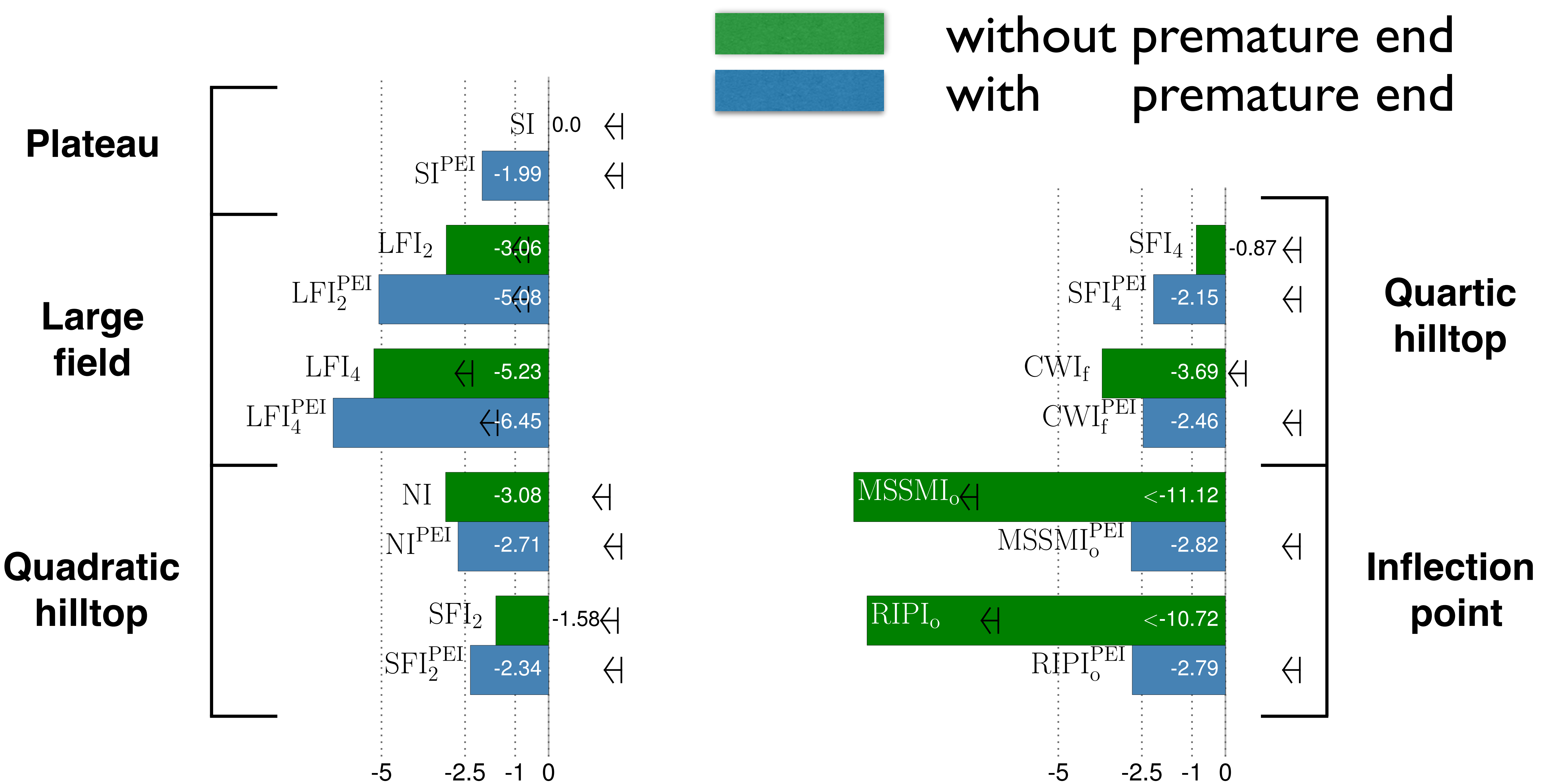
arXiv:1706.01835 RP, Turzynski, Vennin, JCAP

- Different classes of inflationary models are affected differently by a premature end of inflation (hilltop, inflection points, plateau, large-field…)

- Effects is degenerate with theoretical uncertainties about reheating

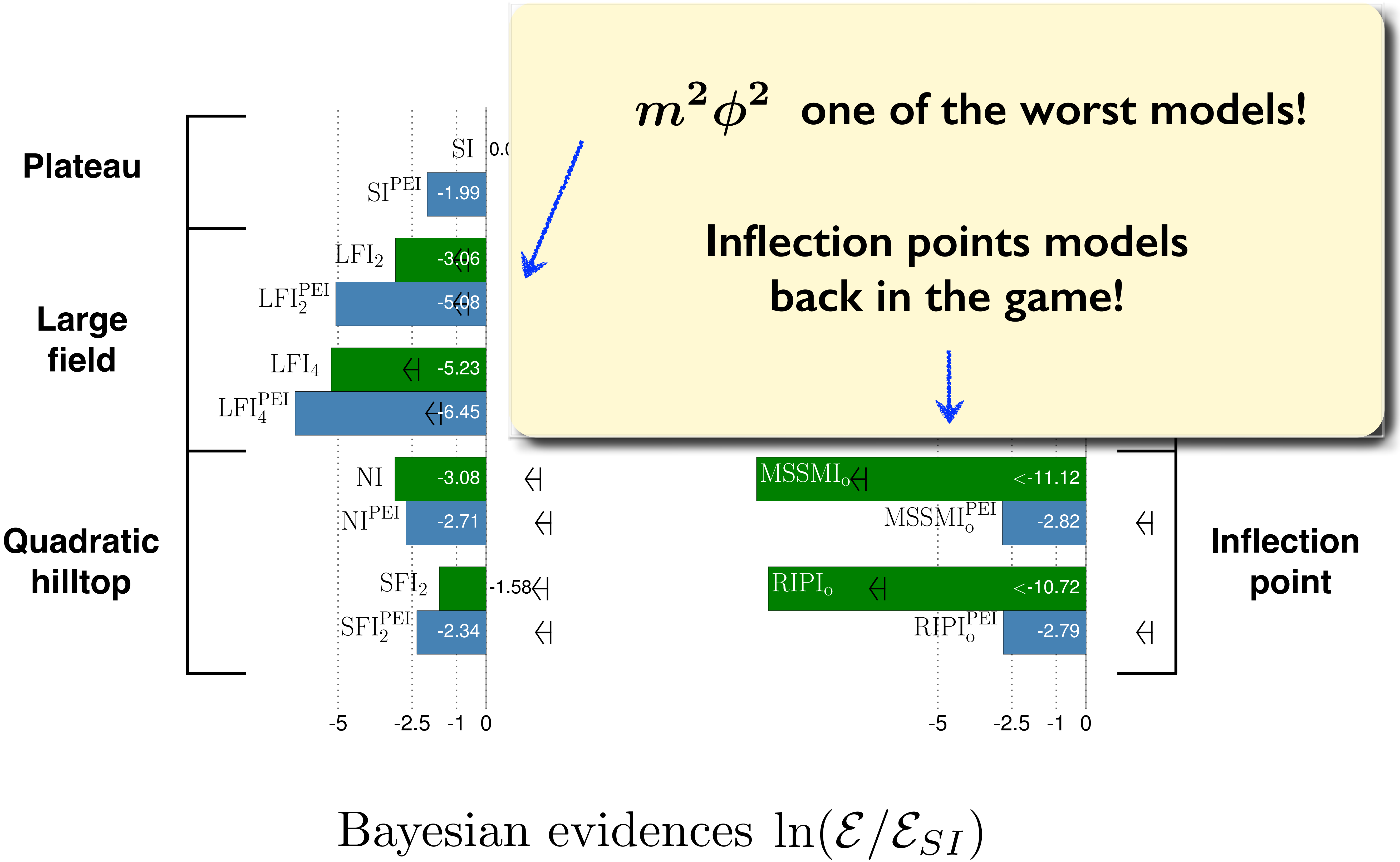
- Need for a full Bayesian analysis, consistently scanning over M >> H and reheating parameters

Reassessing the status of inflationary models



$$\text{Bayesian evidences } \ln(\mathcal{E}/\mathcal{E}_{SI})$$

Reassessing the status of inflationary models



Perspectives and generalizations

- Study of concrete models in the literature (alpha-attractors, others)

- Similar discussion in N-field models, with (N-1) threats of tachyonic instabilities, and the Ricci scalar replaced by relevant sectional curvatures

- Even more dramatic impact on models with masses of order the Hubble parameter (typical in susy)

- Features in the potential can trigger the instability

- Links with constraints on primordial non-Gaussianities

- Constraints on the internal geometry of HEP models, including string compactifications, rare!

Summary

In generic inflationary models in high-energy physics, there is the threat of an instability, so far overlooked, that:

- can prematurely end inflation (new mechanism)
- dramatically impacts observables
- modifies the interpretation of observations in terms of fundamental physics (and hence the observational status of models)
- constrain HEP in a unique manner

Conclusion

- The geometrical destabilization can qualitatively change our vision of inflation (e.g. landscapes 'with trivial field space geometry for simplicity' may not capture the correct physics)

- As important as the eta problem

- Exciting perspectives: new theoretical developments needed

- Recent ERC Starting Grant: opening of postdoc positions for next fall.