Particle physics models of inflation

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Based on DHL/Riotto 1999 Covi/DHL 2001 Alabidi/DHL 2005,2006

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- Assume inflaton perturbation generates structure.
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  - So that observation is sensitive to the inflation model.
- Don't ask much about what happened earlier, who cares?
- Focus on Einstein gravity with canonical kinetic term.
  - No need to be more exotic.
- Two well-motivated paradigms favoured by observation.
  - Further strong selection will come with better data.

Three tenacious myths

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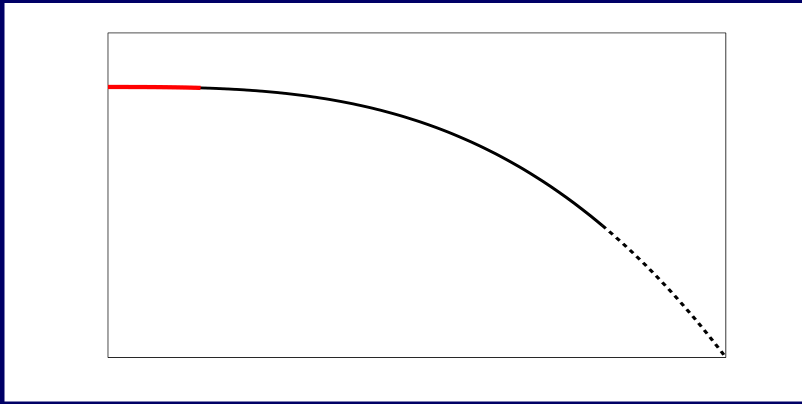
This is almost completely wrong

Fast-roll inflation

$$V = V_0 \left(1 - \frac{|\eta_0|}{2} \frac{\phi^2}{M_{\rm P}^2} \right) + \cdots$$

vev at $\phi \sim |\eta_0|^{-1/2} M_{\rm P}$



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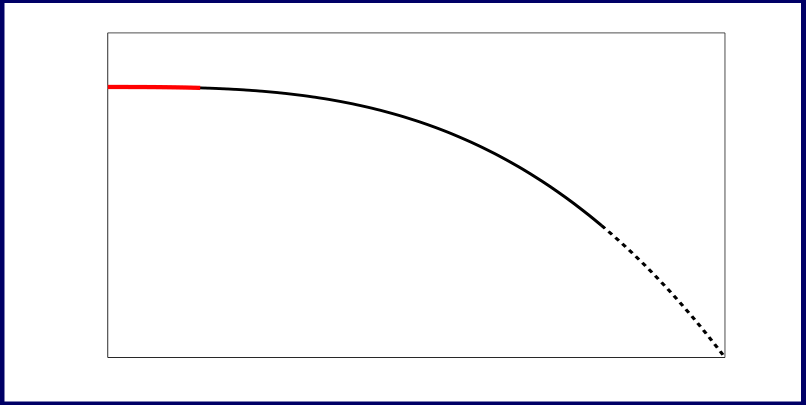

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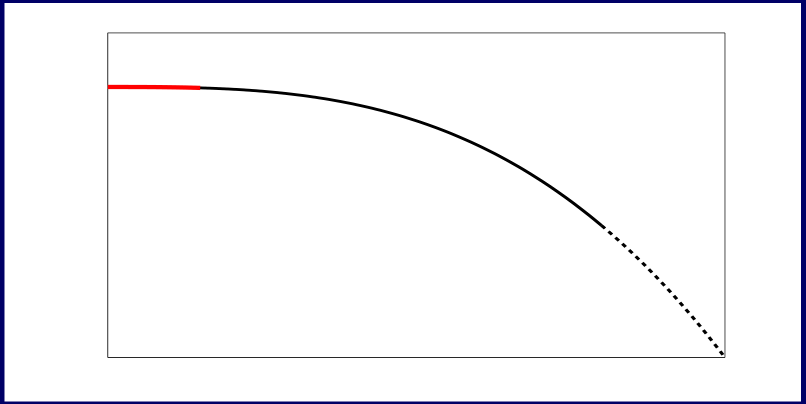

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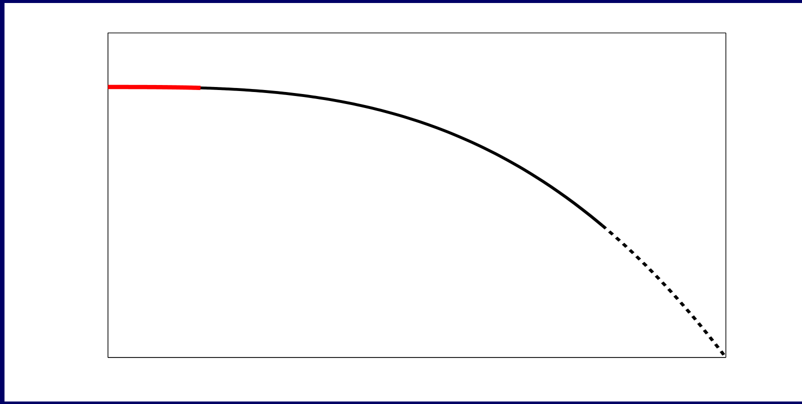

- Including quantum fluctuation: inflates if $|\eta_0| < 6$
- Eternal inflation first, then classical rolling
- Case $|\eta_0| \sim 1$ is 'fast-roll' inflation
  - The most natural value (from SUGRA or string theory)
  - Predicts $n - 1 \sim \pm 1$

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- and $d\phi/dN \simeq M_\mathrm{P}^2 V'/V \Longrightarrow \phi(N)$
- Slow-roll for convenience, can be marginally violated
  - But OBSERVATION needs it! (to get $|n-1| \ll 1$)

Slow-roll basics

Quantity	Prediction	Present observation	Eventual observation
$\mathcal{P}_\zeta$	$V/24\pi^2 M_{\rm P}^4\epsilon$	$(5\times 10^{-5})^2$	?
r	16ϵ	$\lesssim 1$	$\pm 10^{-4}$
$n-1$	$2\eta - 6\epsilon$	-0.05 ± 0.02 (setting $r=0$)	± 0.001
$\lvert f_{\rm NL}\rvert$	$\ll 1$	$\lesssim 100$	± 1

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- Observation needs ϵ and/or $\eta \sim 0.1$ to 0.01

Three waves, three paradigms

Three waves:

- 1980's: Non-hybrid
- 1990's: Hybrid
- 2000's: String theoretic
  - Non-hybrid (modular)
  - Hybrid (colliding branes)

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Three paradigms:

- Small-field $\Delta\phi \ll M_{\rm P}$
- Modular $\Delta\phi \sim M_{\rm P}$
- Large-field $\Delta\phi \gg M_{\rm P}$

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Motivation: string theory (SUSY **or not**, extra dimensions or not)

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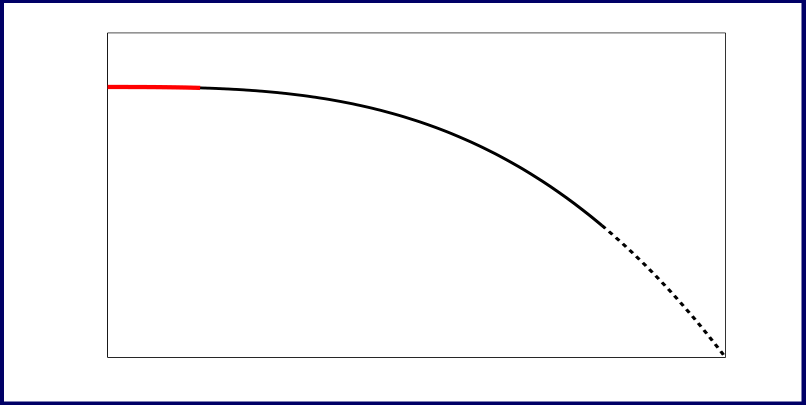

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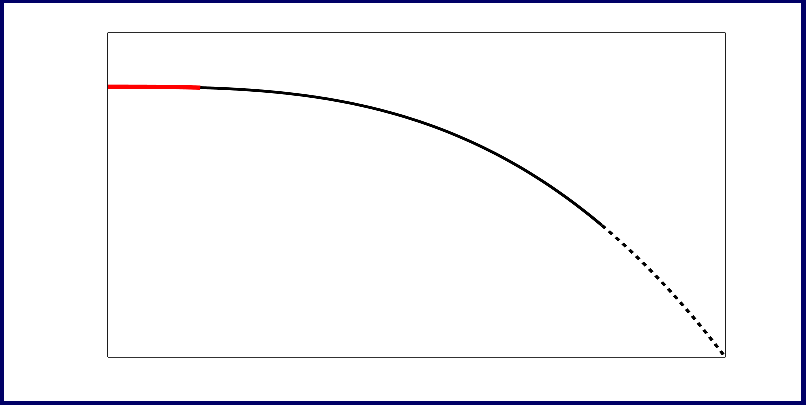

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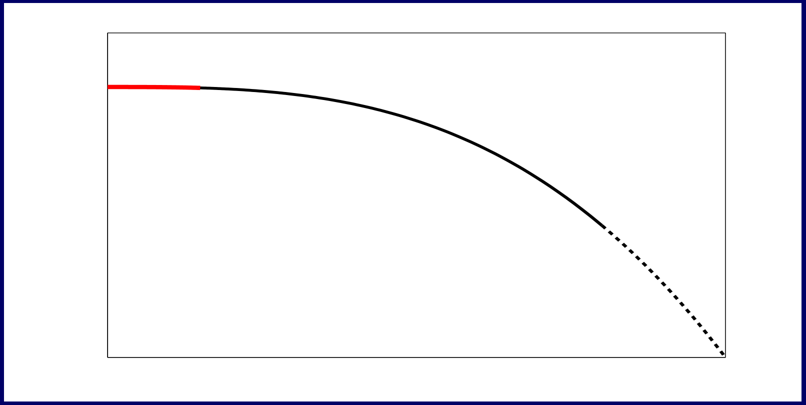

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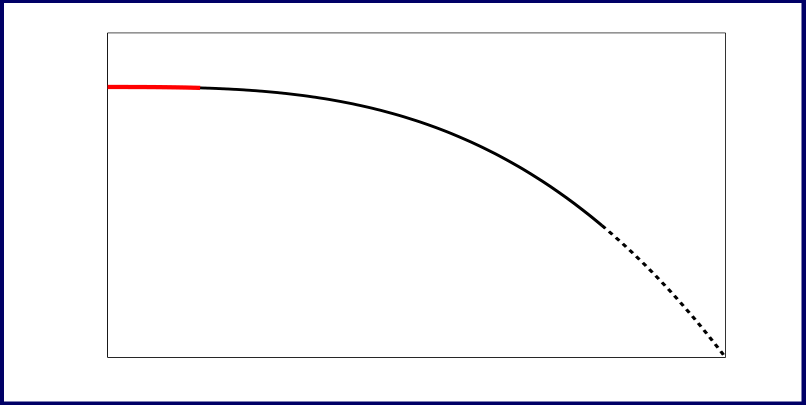

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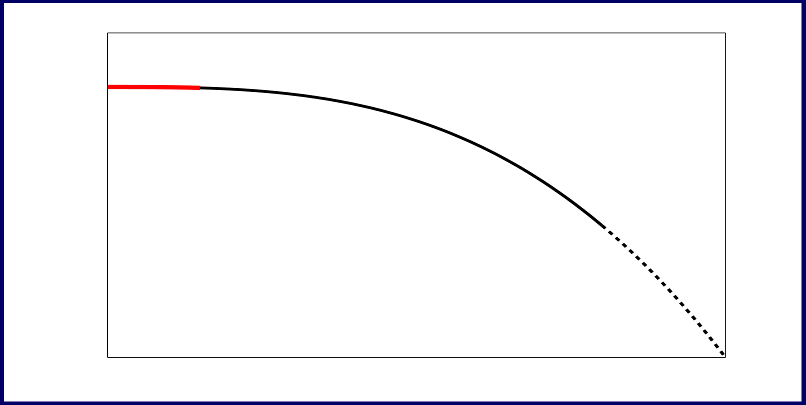


The strategy for inflation

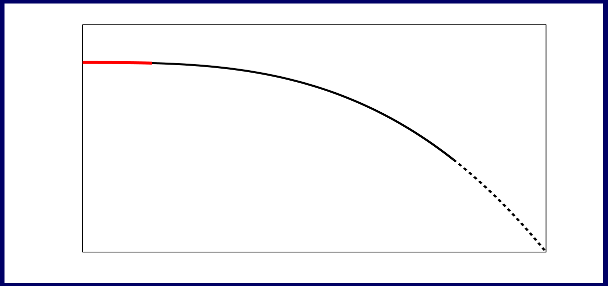
- Assume maximum at $\phi = 0$
- Begin with eternal inflation
- Tune to allow successful slow roll afterwards

Modular inflation: an approximation

Fast-roll unviable, so take

$V \simeq V_0[1 - (\phi/\mu)^p]$

with $\mu \sim M_{\rm P}$ and $p \gtrsim 3$



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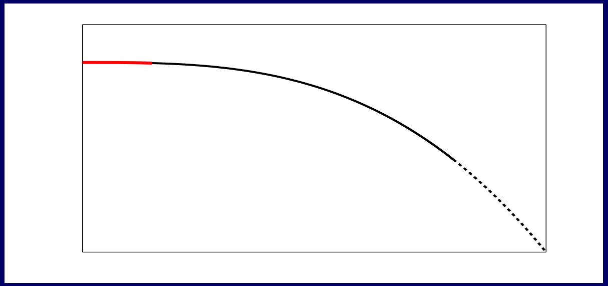

$$N = \frac{\mu^p}{M_\mathrm{P}^2} \int_{\phi_*}^{\phi_\mathrm{end}} \frac{d\phi}{\phi^{p-1}} \simeq \frac{1}{p(p-2)} \left(\frac{\mu}{M_\mathrm{P}}\right)^2 \left(\frac{\mu}{\phi_*}\right)^{p-2}$$

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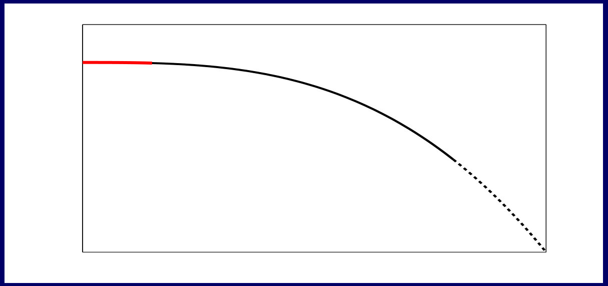

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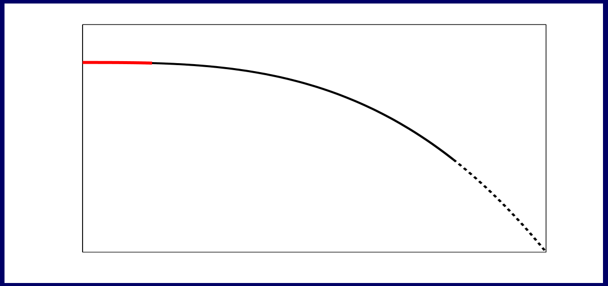

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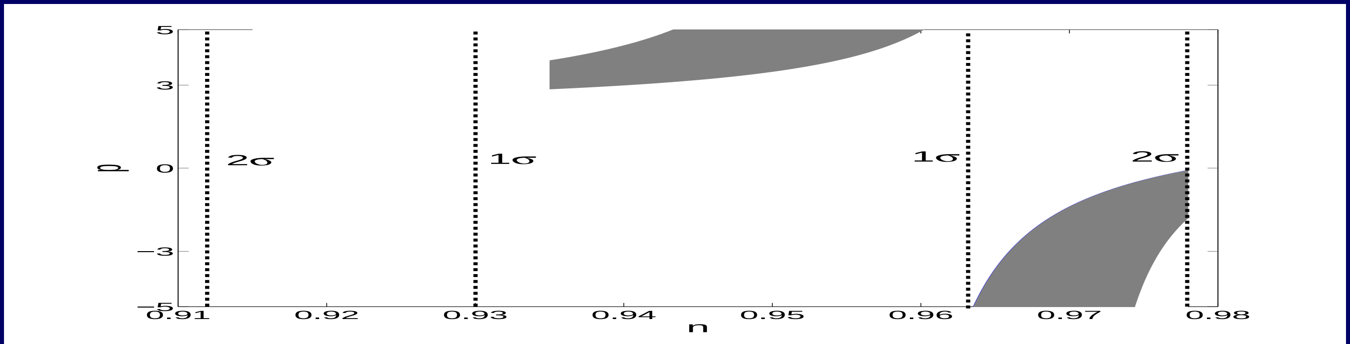
[With $\mu \ll M_{\rm P}$ this becomes a small-field inflation model]

Modular: prediction versus observation

Spectral index
$N = 54 \pm 7$



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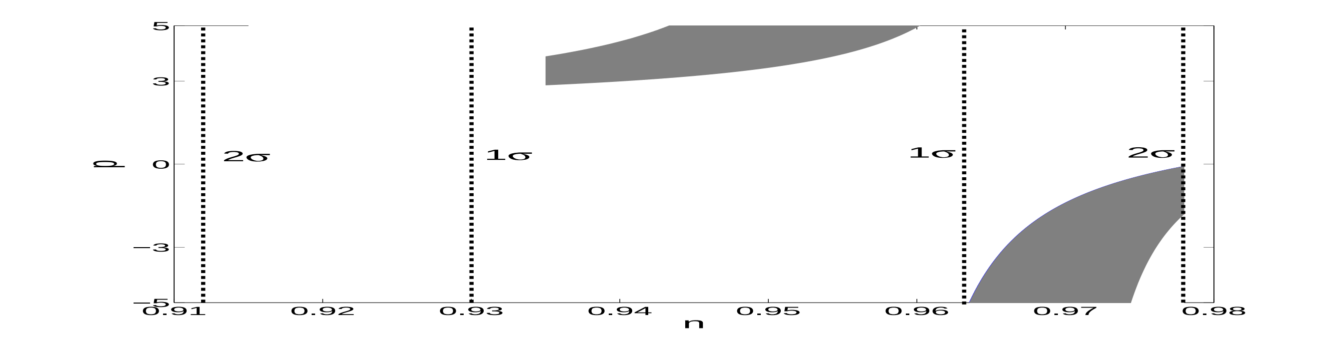
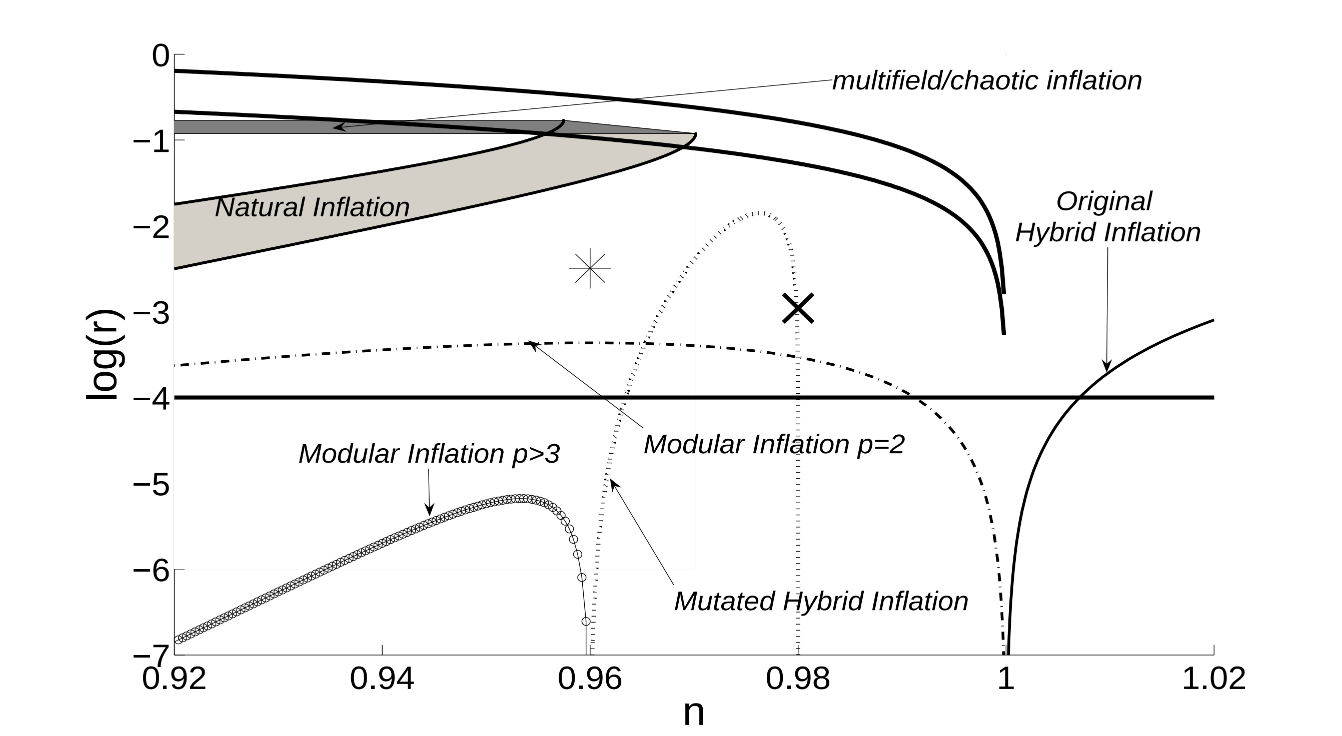


Tensor fraction
$N = 54$
$\mu = M_{\mathrm{P}}$



To be eventually observable need $r > 10^{-4}$

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- $n - 1 = 2\eta \Longrightarrow \eta \simeq -0.025$ **concave-down** potential

Small-field needs 'flat' direction

Assuming no strong cancellations, slow-roll conditions require†

†DHL/Riotto 1999

$$m^2 \ll V_0/M_{\rm P}^2 \simeq 3H^2 \qquad |\lambda| \ll 10^{-14}$$

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- Invoke a discrete R-symmetry (SUSY)

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- Strong modification of Eq. (1) is *likely*
- Soft SUSY-breaking can **dominate** V
  - eg. Supernatural inflation,etc. use vac. breaking scale.

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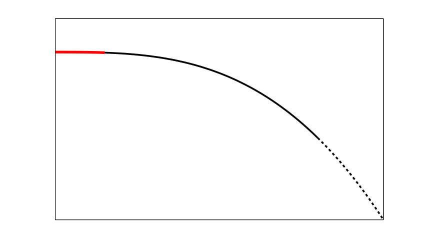

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Inverted hybrid $p = 2$

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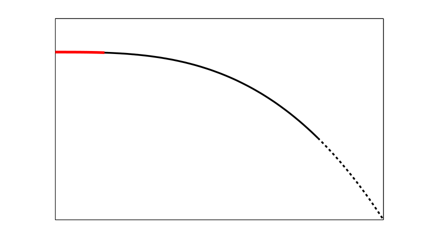

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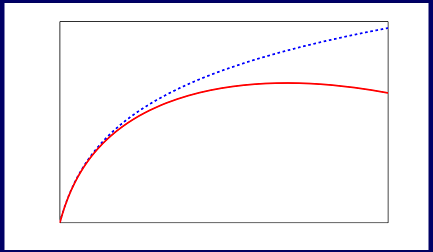

$V = V_0[1 - (\phi/\mu)^p]$ with $p \leq 0$

mutated, branes

$V = V_0[1 + \ln(\phi/Q)]$

F-, D-term

$V = V_0[1 - \exp(-q\phi/M_{\mathrm{P}})]$

R^2 gravity, branes

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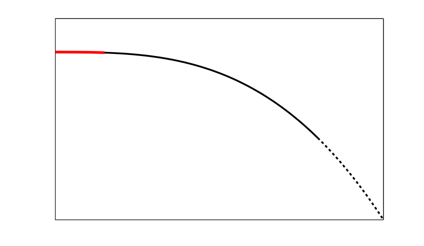

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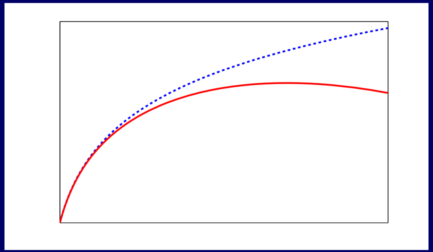

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mutated, branes

$V = V_0[1 + \ln(\phi/Q)]$

F-, D-term

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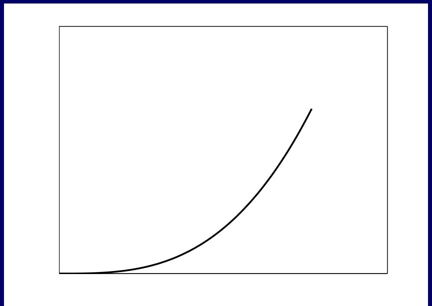

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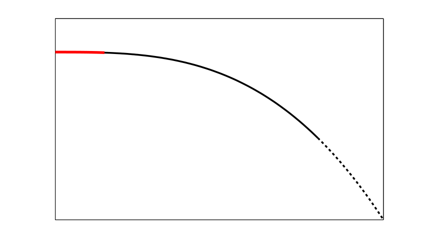
Tree-level hybrid eg. Supernatural

Small-field models



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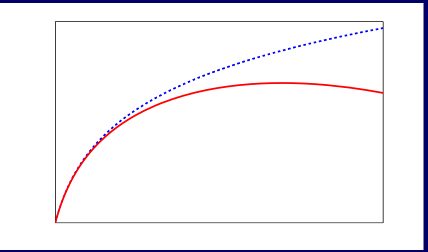
Non-hybrid ("New") $p \gtrsim 3$

Inverted hybrid $p = 2$



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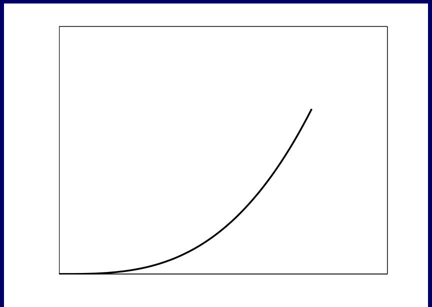

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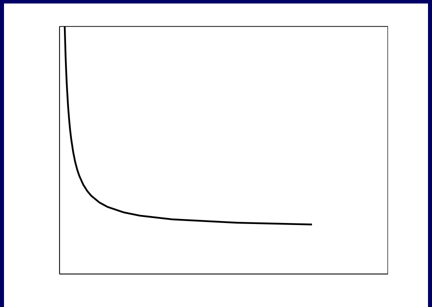
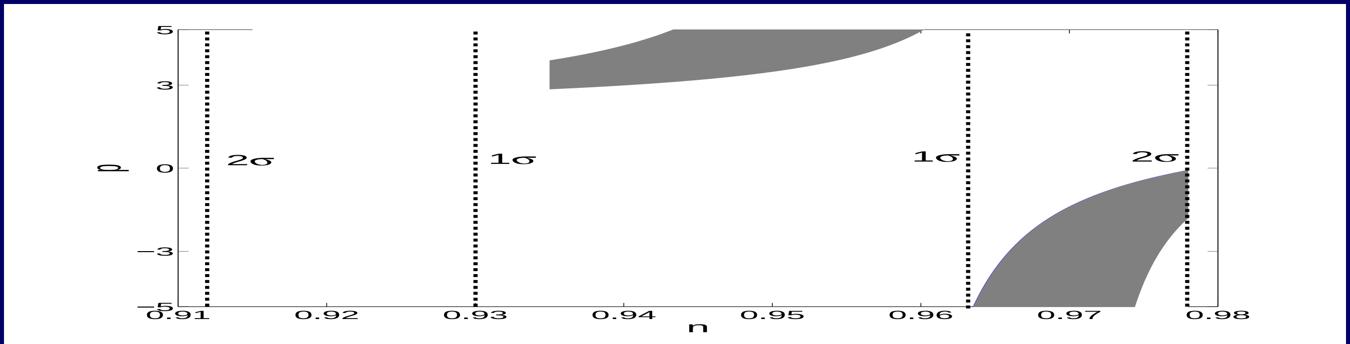


$V = V_0(1 + (\phi/\mu)^p]$ with $p < 0$

Dynamical susy breaking, branes

Small-field: prediction versus observation

Spectral index
$N = 54 \pm 7$



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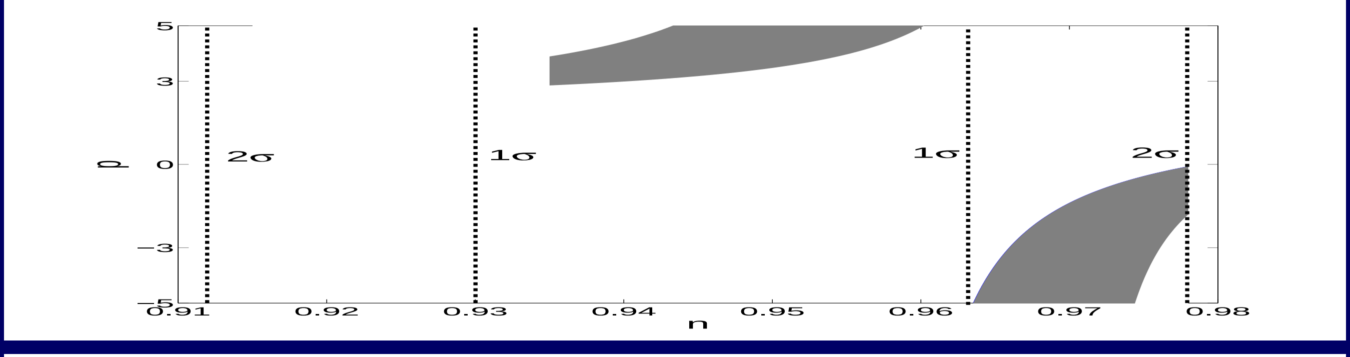

Tensor fraction
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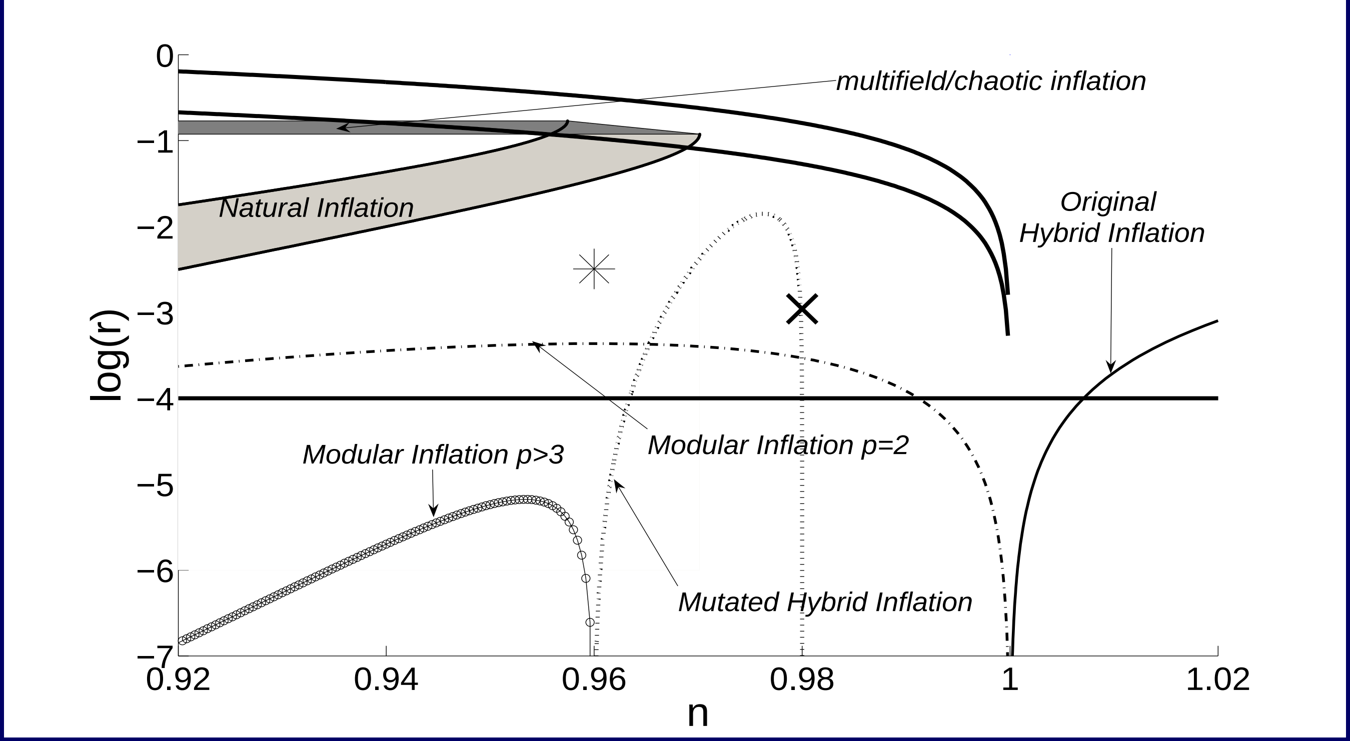
$\mu = M_{\mathrm{P}}$



Cross is D/F-term: $V = V_0(1 + \ln\phi)$

Star is $V = V_0(1 - \exp(-q\phi/M_{\mathrm{P}}))$.

A-term inflation

Allahverdi, Enqvist, Garcia-Bellido & Mazumdar hep-ph/0605035

DHL hep-ph/0605283

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- Not spoiled by SUGRA, extra non-renormalizable terms, loop corrections.

Large-field models: basics

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3. Not easy to connect with beyond-standard-model research.

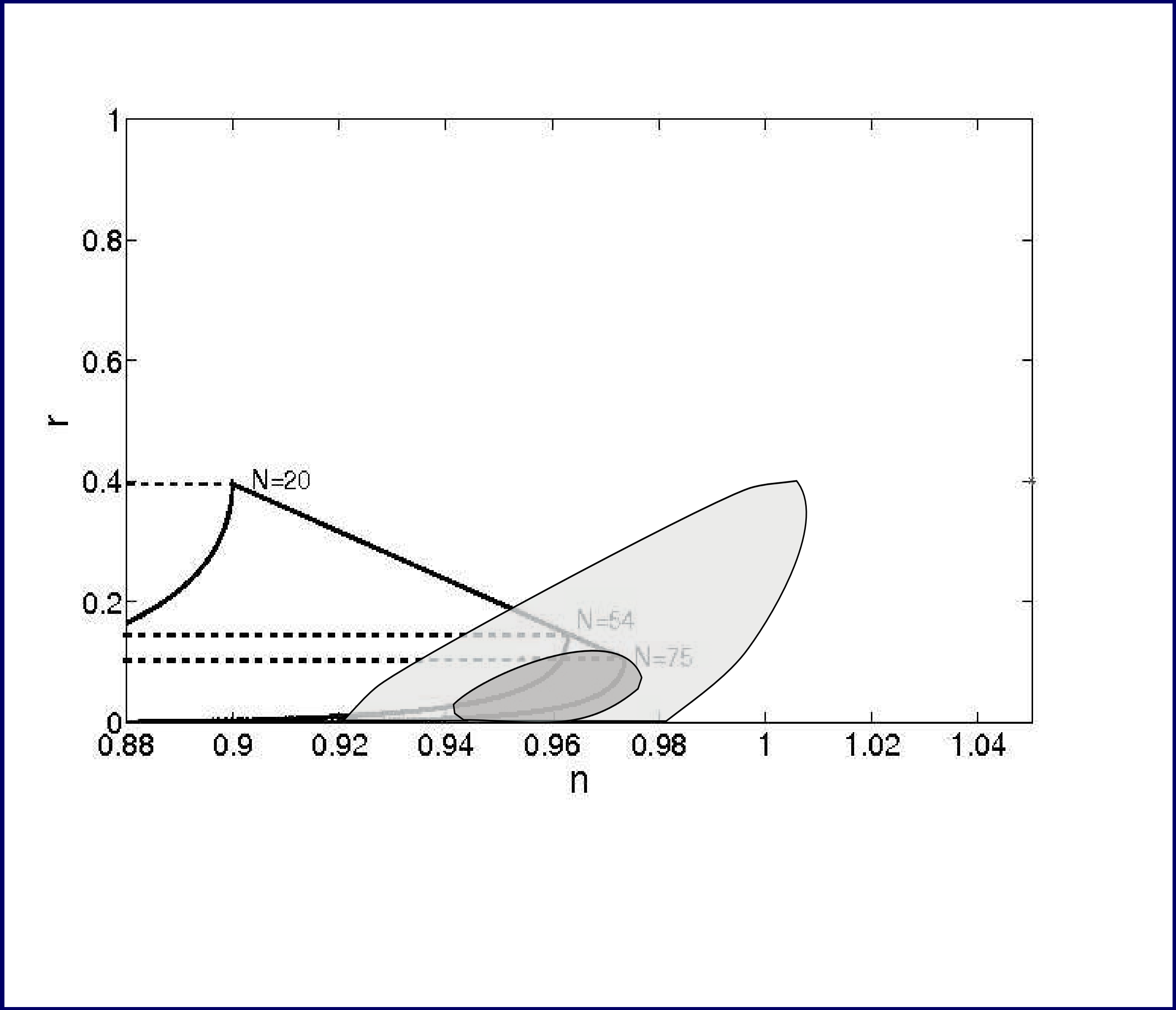
Large-field: disconnected approach

$V \propto \phi^p$

Predictions

$$n = 1 - \frac{2+p}{2N}$$
$$r = 4p/N$$

$p \simeq 2$ to 3 fits observation



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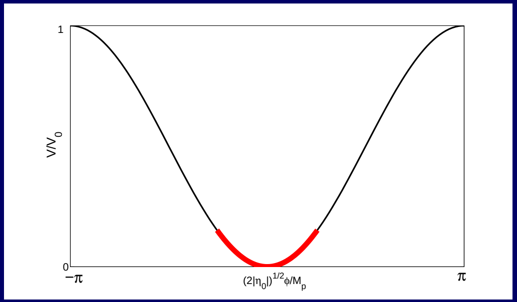

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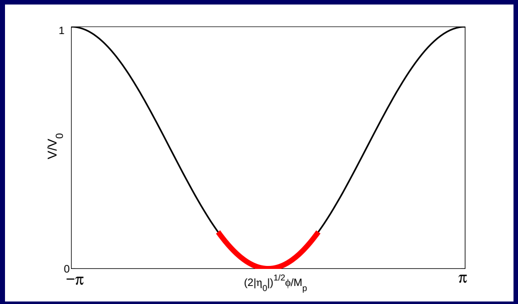

justifications:

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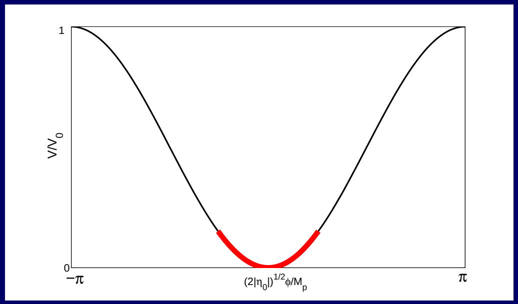

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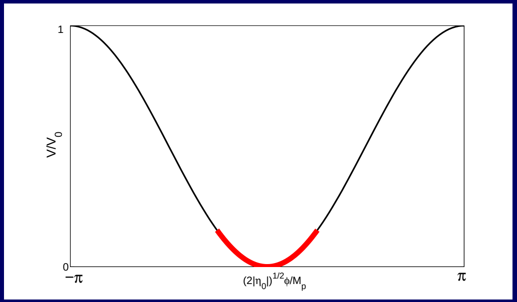

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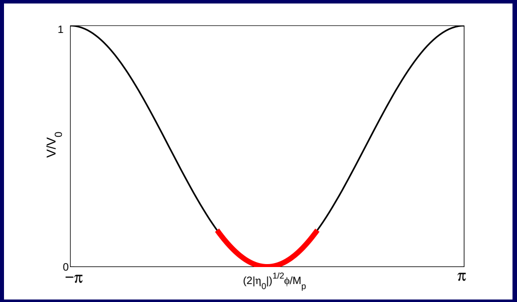

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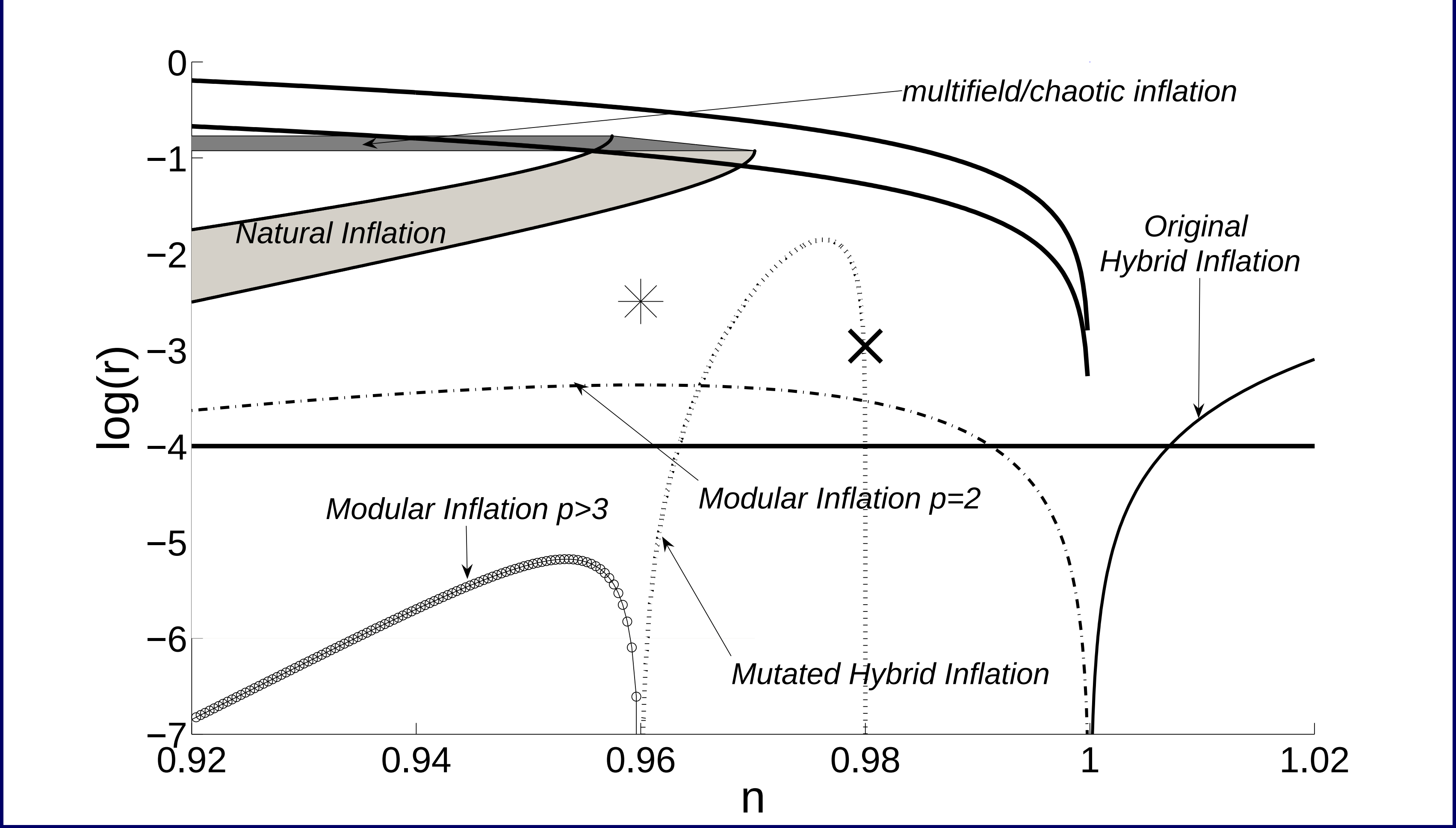
(iii) N-flation Dimopoulos/Kachru/McGreevy/Wacker 2005

($\Rightarrow$ mag. field? Anber/Sorbo 2006)

Large-field: predictions



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