Fibre Inflation

High-Fibre models
from regular potentials

String Pheno Workshop: CERN 2008

C.P. Burgess
with M. Cicoli and F.Quevedo

Outline

- String inflation
  - Why build models only a mother could love?
  - Gravity waves and stringy signals?
- Fibre Inflation and the LVS
  - Inflating with moduli
- Inflationary Observables
  - Correlations between r and ns; gravity waves;…

String Inflation

- What might one hope to learn?
  - about strings
  - about inflation

String Inflation

- *Wha*
  hope
  - *ab*
  - *ab*

String Theory: a theory in search of observational tests

Inflation: successful phenomenology seeking an underlying theory

String Inflation

- *Wha*
  hope
  - *ab*
  - *ab*

Happy Valentine's Day !

From *Physical Review D* Personal ads:

Mature paradigm with firm observational support seeks a fundamental theory in which to be embedded. No loop quantum gravity theories, please. Contact alan@mit.edu.

Elegant theory of everything desires to explore the landscape with a phenomenon in the hope that it will lead to a prediction. Let's get physical! Contact ed@ias.edu.

… Rocky Kolb

String Inflation

- *Wha*
  hope
  - *ab*
  - *ab*

Difficult to identify where we live within the string landscape. Seek ‘modules’ encoding low-energy features: standard model; dark energy; inflation; …

String Inflation

- *Wha*
  hope
  - *ab*
  - *ab*

Inflation provides a good description of primordial fluctuations as seen in the CMB: a rare observational window on physics at high energies?

Wish to know from string theory:

How hard is it to get flat enough potentials?

Does embedding into string theory carry observational implications?

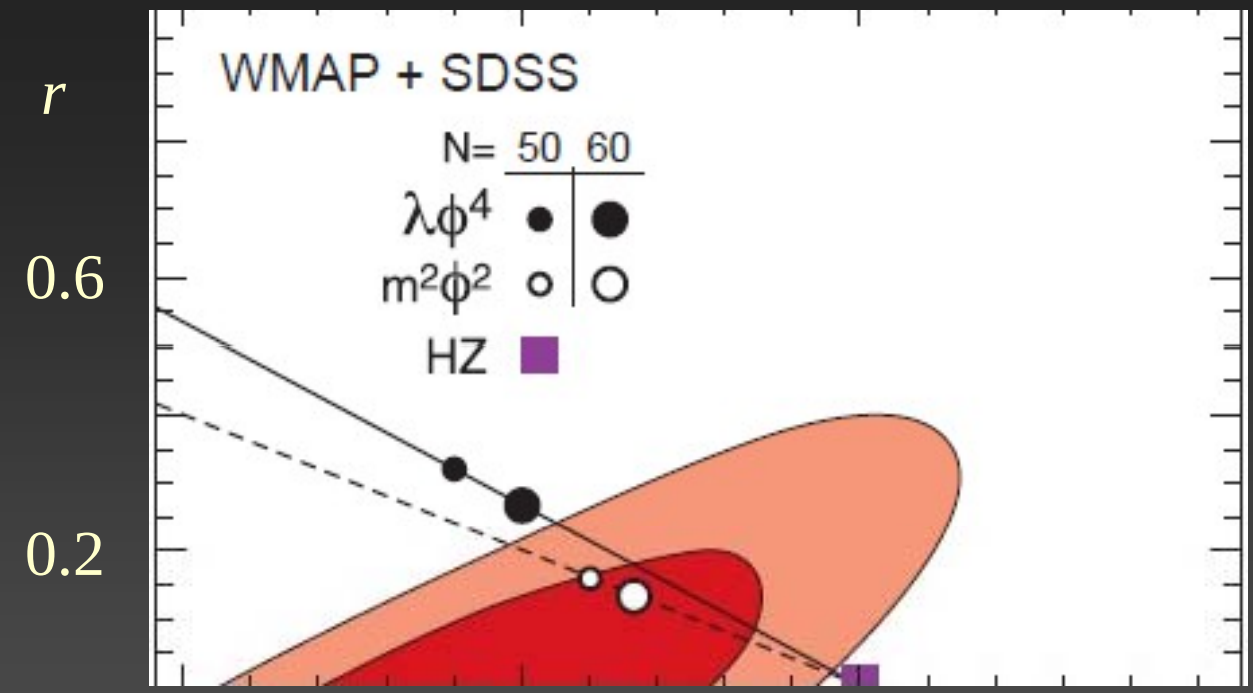
How does reheating work?

etc…

String Inflation

WMAP

- *Wha*
  hope
  - *ab*
  - *ab*



Seek: stringy inflationary signatures

Because inflation is found in 4D effective theory, predictions tend to follow 4D mechanisms

String Inflation

WMAP

- *Wha*
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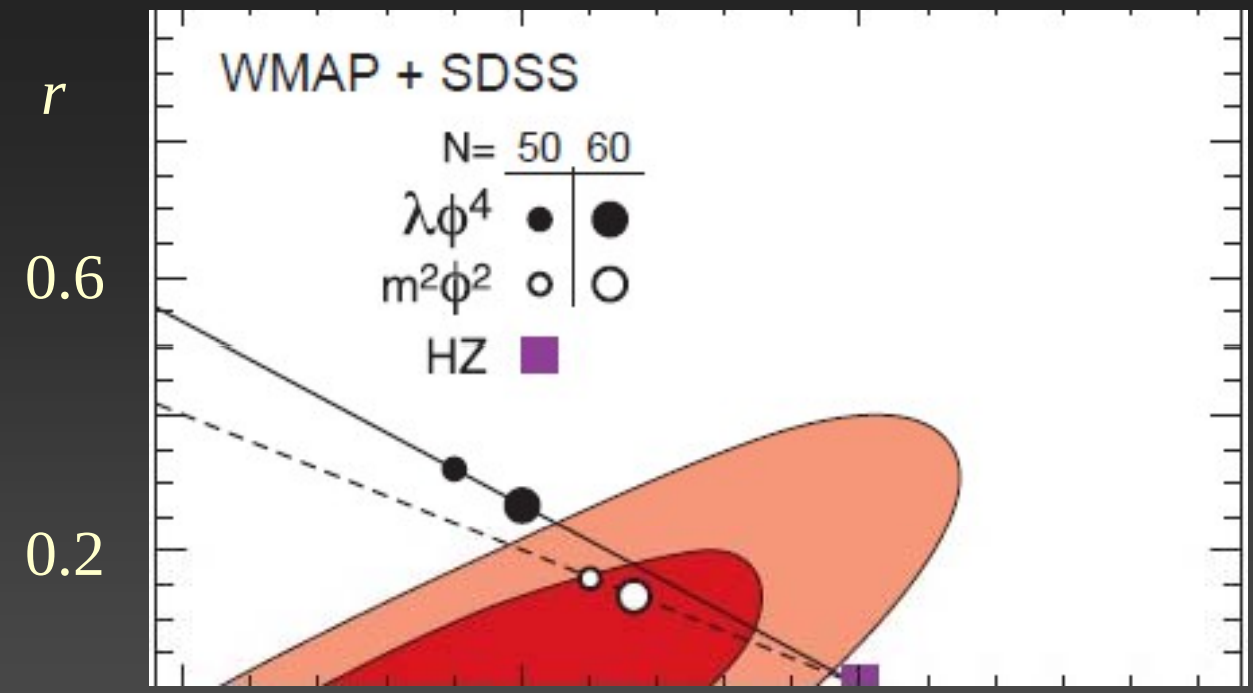

Seek: stringy inflationary signatures n_s

Could hope that string inflation provides only a subset of the possible 4D inflationary possibilities.

String Inflation

- *Wha*
  hope
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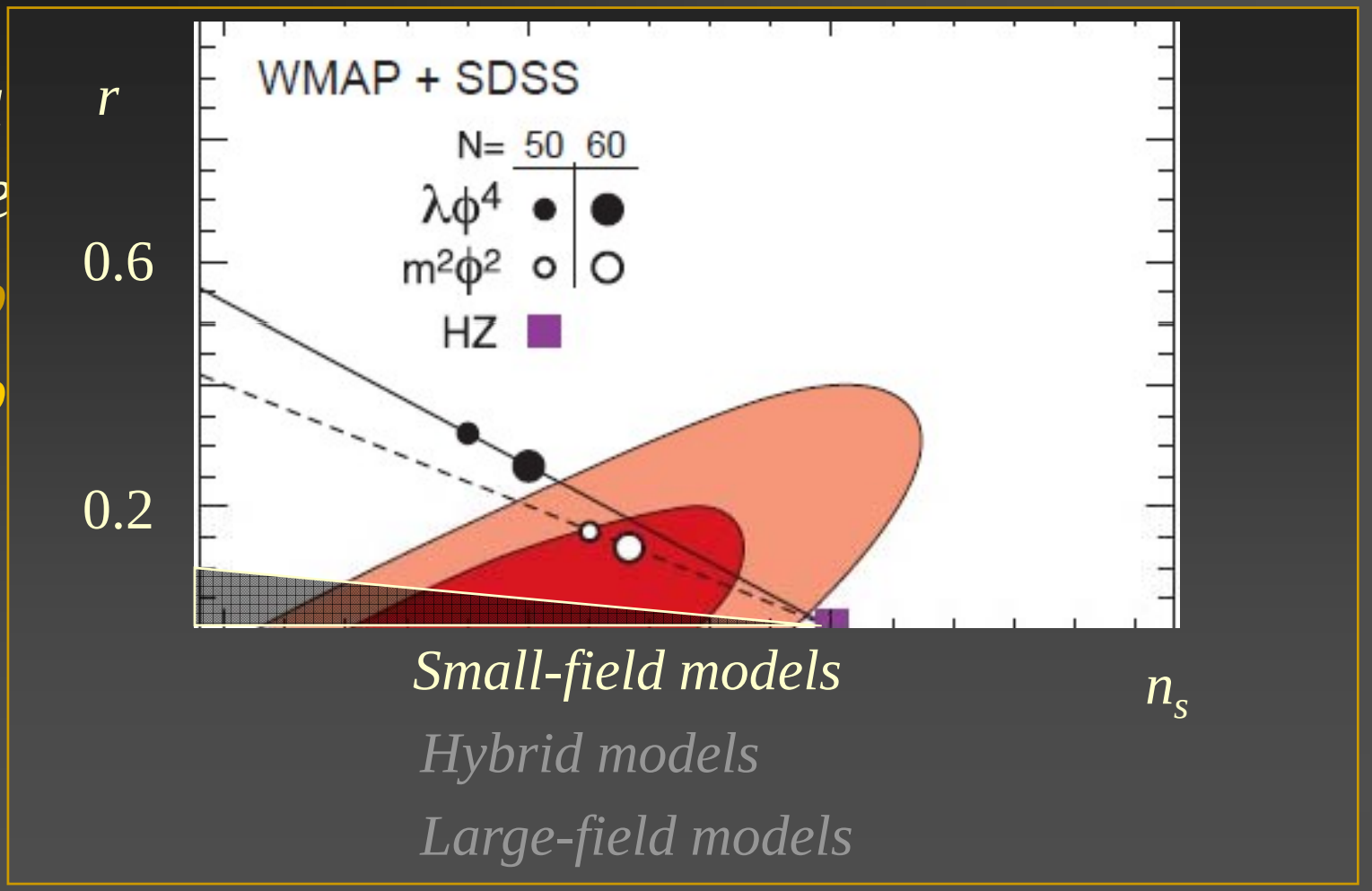
  - *ab*

WMAP



String Inflation

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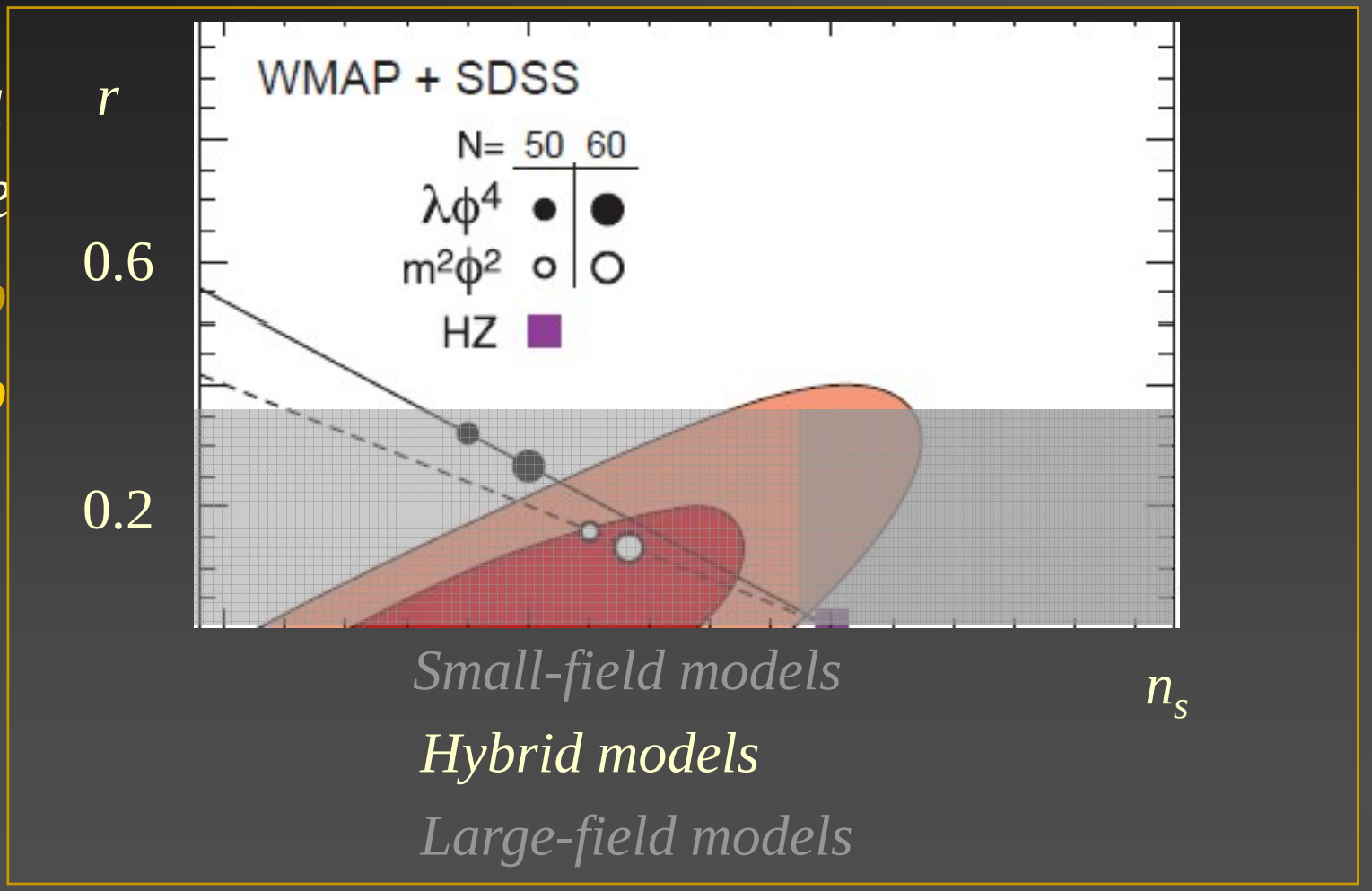
WMAP



String Inflation

WMAP

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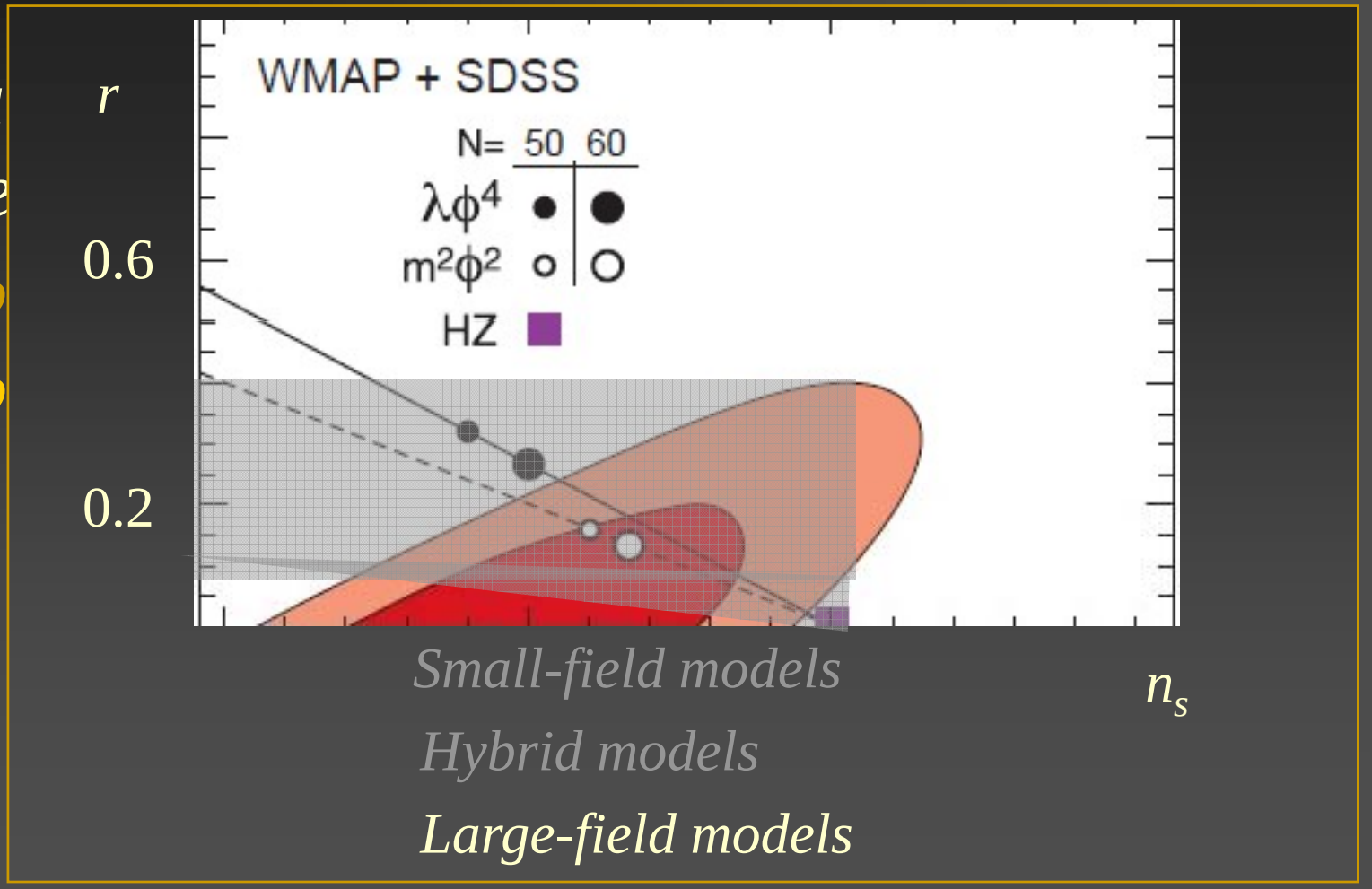
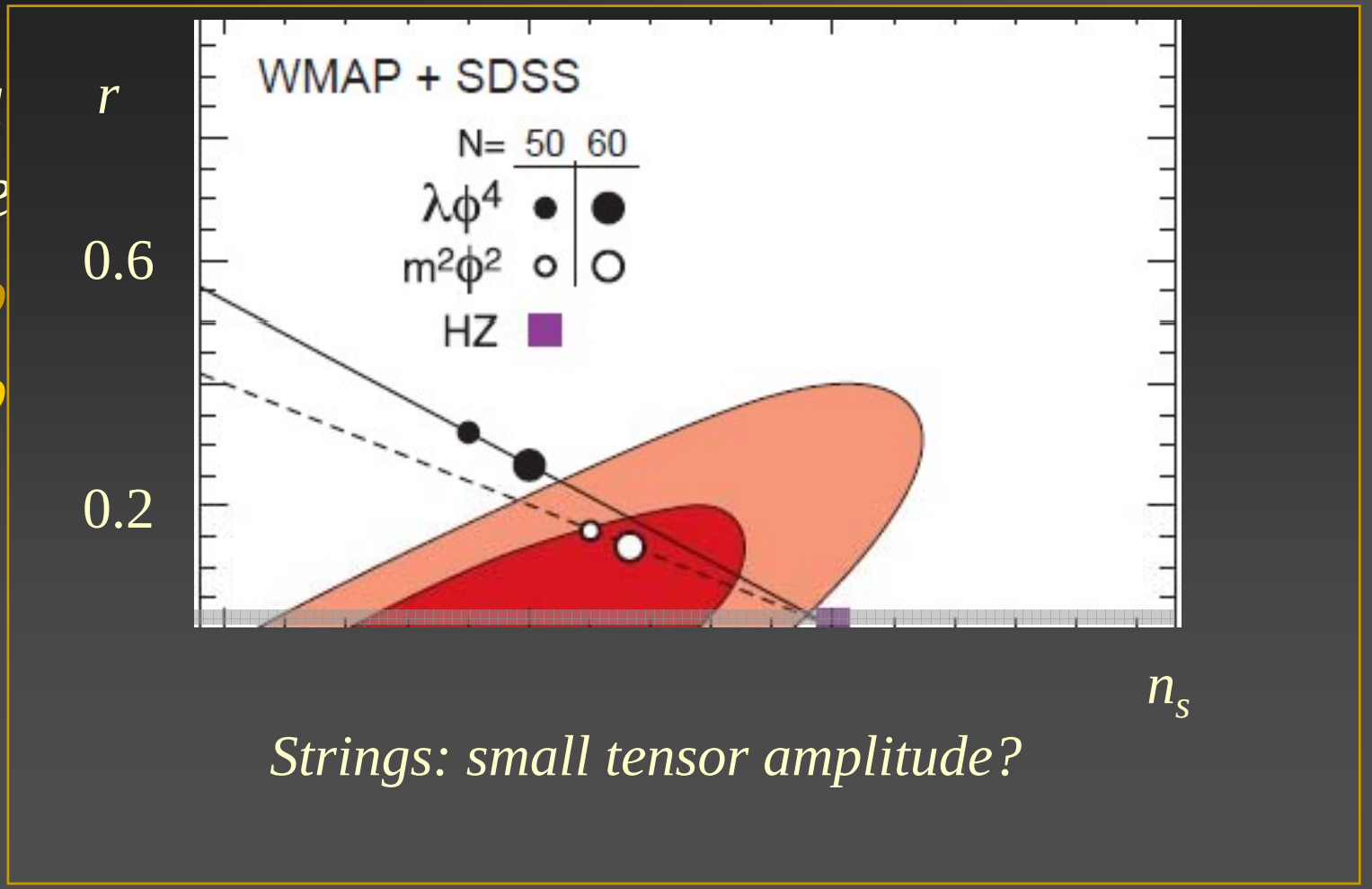


String Inflation

Linde & Kallosh
Baumann & McAllister

- *Wha*
  hope
  - *ab*
  - *ab*



Strings: small tensor amplitude?

String Inflation

Lyth

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$$r = 16\varepsilon = \frac{8}{N_{eff}^2}\left(\frac{\Delta\varphi}{M_p}\right)^2$$

$$N_{eff}^2 = \frac{8}{r}\int\left(\frac{\dot{\varphi}}{HM_p}\right)^2 Hdt \approx N_e^2$$

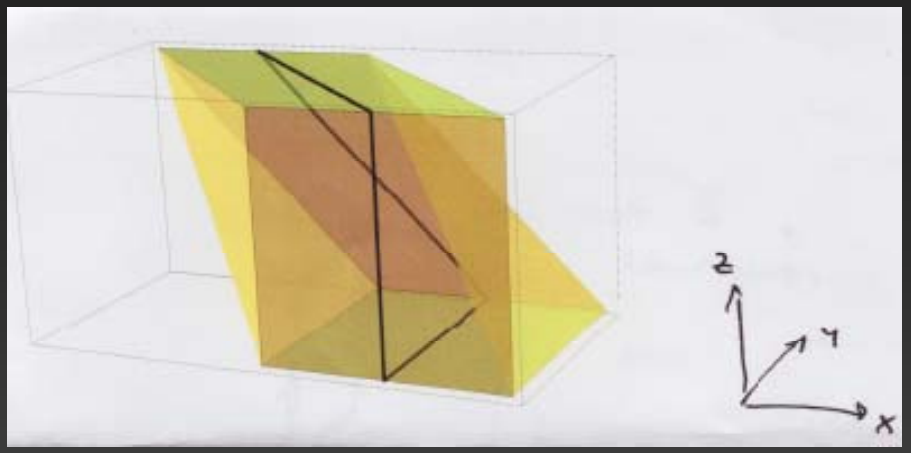
Appears difficult to obtain large $\Delta\varphi / M_p$

Strings: small tensor amplitude?

Emerging Picture

Silverstein & Westphal
McAllister, Silverstein & Westphal

- Mec
- *Robu*
- Min



First attempts to get large field range:

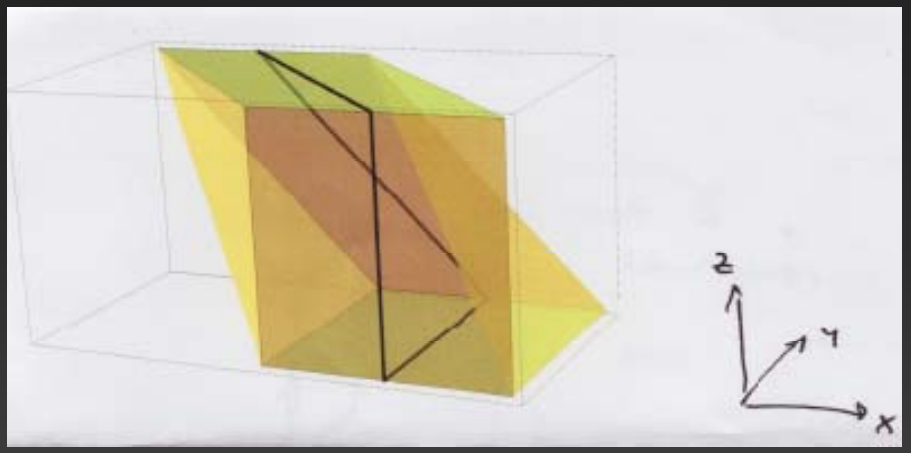
Type IIA: brane motion wrapped on a twisted torus.

Type IIB: aperiodic B_{mn} fields

Emerging Picture

Silverstein & Westphal
McAllister, Silverstein & Westphal

- Mec
- *Robu*
- M



Within the domain of low-energy effective theory?

$$\dot{\phi} \approx \sqrt{\varepsilon} M_s^2$$

Fibre Inflation

- The Large Volume Scenario

- Inflation in the LVS

Fibre Inflation

Covi, Gomez-Reino, Gross, Louis, Palma & Scrucca

- The
  Scen
- Infla

Searches over the years for accelerating cosmologies in 4D and extraD supergravities lead instead to strong no-go results.

Leading order in gs and a' often give no-scale models for moduli (eg Kahler moduli in Type IIB).

The flat potentials of no-scale models tend lie on the boundary of the no-go results; eg:

$$R(f^i) = \frac{2}{n} < \frac{2/3}{1 + H^2/m_{3/2}^2}$$ *(n=3 for no-scale models)*

Fibre Inflation

- The
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Suggests looking for inflation starting with no-scale moduli but including subleading g_s and α' terms.

Fibre Inflation

Becker, Becker, Haack & Louis

- The
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- Infla

In 4D string loops and α' corrections are suppressed (in Einstein frame) by powers of 6D volume, $V^{-1/3}$.

$$\frac{1}{g_s^2}\sqrt{-g}\,g^{\mu\nu}R_{\mu\nu}\left[1+\alpha'^3\left(g^{mn}R_{mn}\right)^3\right]+\cdots$$

$$\sqrt{-g}\,g^{\mu\nu}R_{\mu\nu}\left[1+\frac{\xi}{g_s^{3/2}V}\right]+\cdots$$

$$K\approx -2\ln\left(V+\frac{\xi}{2g_s^{3/2}}\right)+\cdots$$

Fibre Inflation

Balasubramanian, Berglund, Conlon & Quevedo

- The
  Scen
- Infla

Given several Kahler moduli, $\tau_b \gg \tau_s$, correction to K together with superpotential $W = W_0 + A\, e^{a\,\tau_s}$ can stabilize V at a very large volume minimum

$$\tau_s \approx \left(\frac{\xi}{g_s^{3/2}}\right)^{2/3} \propto \frac{1}{g_s}$$

$$V \approx W_0 \sqrt{\tau_s}\, e^{a\tau_s} \propto W_0 e^{a\xi^{2/3}/g_s}$$

Essentially any large volume is possible for a small range of τ_s.

Fibre Inflation

Conlon & Quevedo

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Potential has naturally weak dependence on any other large moduli $\tau_b \gg \tau_i \gg \tau_s$ with $V \sim V(\tau_b, \tau_i)$.

If

$$W \approx W_0 + Ae^{-a\tau_s}$$

then

$$U \approx \frac{\sqrt{\tau_s}}{V} e^{-2a\tau_s} - \frac{W_0 \tau_s}{V^2} e^{-a\tau_s} + \frac{\hat{\xi} W_0^2}{V^3}$$

up to 1/V and exp[-a τ_i] and exp[-a τ_b] terms

Fibre Inflation

Conlon & Quevedo

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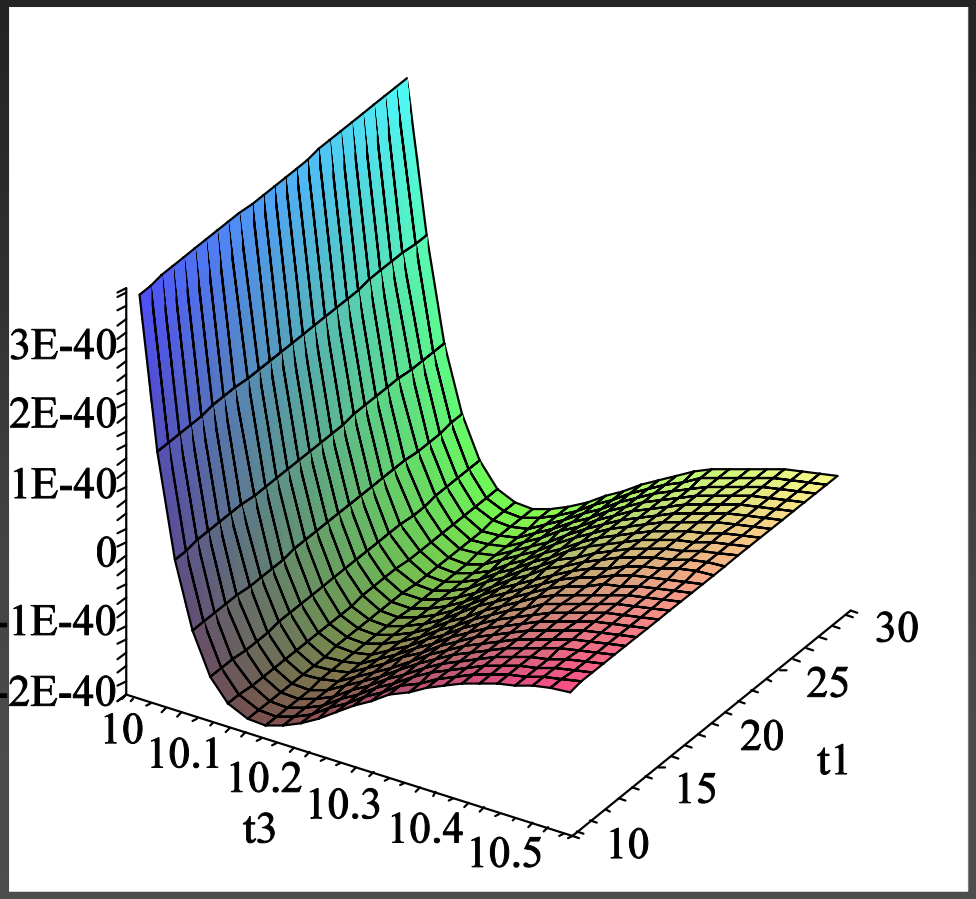

up to 1/V and exp[-a t_i] and exp[-a t_b] terms

Fibre Inflation

Conlon & Quevedo

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  Scen
- Infla

Kahler modulus inflation: *inflaton potential obtained by keeping terms that are of order exp[-a τ_i]*

$$\delta U \approx \frac{\sqrt{\tau_i}}{V} e^{-2a\tau_i} - \frac{W_0 \tau_i}{V^2} e^{-a\tau_i} + \frac{\hat{\xi} W_0^2}{V^3}$$

Slow roll naturally arises when τ_i is displaced to large values from its minimum.

$$\varphi \approx \tau_i^{3/4} V^{-1/2}$$

Fibre Inflation

Cicoli, Conlon & Quevedo
Cicoli, CB & Quevedo

- The
  Scen
- Infla

Fibre inflation: *inflaton potential dominated by subleading $1/V \sim \exp[-a\ \tau_s]$ corrections rather than by $\exp[-a\ \tau_i]$ corrections.*

Such corrections arise in the leading string loops, since $U_{tree} \sim V^{-3}$ while $U_{loop} \sim V^{-10/3}$.

It turns out that such loops can also compete with the $\exp[-a\ \tau_i]$ terms and so can ruin slow roll of Kahler Modulus Inflation.

Fibre Inflation

Berg, Haack & Pajer
Cicoli, Conlon & Quevedo

- The
  Scen
- Infla

String loop potential: *explicit 1-loop contributions have only been computed on orbifolded tori. Most of the potential's complication lies in its dependence on the complex structure moduli.*

Dependence on Kahler moduli can be inferred using educated guesses based on kinds of loops that enter (KK tree exchange, loops of winding states, etc).

$$\delta K \approx V^{-1}\left(\tau^{1/2} + \tau^{-1/2} + \cdots\right)$$

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$$\delta K \approx V^{-1}\left(\tau^{1/2} + \tau^{-1/2} + \cdots\right)$$

Potentially dangerous terms *drop from the potential!*

Fibre Inflation

Berg, Haack & Pajer
Cicoli, Conlon & Quevedo

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Kahler Modulus dependence of string loops:

KK tree exchange

$$\delta K \approx V^{-1} \sum_i \frac{C_i}{m_{KK}^2} \approx V^{-1} \sum_i C_i \; a_{ij} t^j$$

Loop of winding states

$$\delta K \approx V^{-1} \sum_i \frac{\tilde{C}_i}{m_W^2} \approx V^{-1} \sum_i \frac{\tilde{C}_i}{\tilde{a}_{ij} t^j}$$

Fibre Inflation

Berg, Haack & Pajer
Cicoli, Conlon & Quevedo

2-cycle transverse to D7

2-cycle of intersecting D7s

pendence of string loops:

$$\sum_i \frac{C_i}{m_{KK}^2} \approx V^{-1} \sum_i C_i \; a_{ij} t^j$$

tates

$$\delta K \approx V^{-1} \sum_i \frac{\tilde{C}_i}{m_W^2} \approx V^{-1} \sum_i \frac{\tilde{C}_i}{\tilde{a}_{ij} t^j}$$

Fibre Inflation

Cicoli, CB & Quevedo

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Scen

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A Specific Model: *Choose a Calabi-Yau that is a K3 fibration plus a blow-up modulus, with* $\tau_2 \gg \tau_1 \gg \tau_3$

$$V = (at_1 + bt_2)t_2^2 + ct_3^2 = \sqrt{\tau_1}(\tau_2 - \tau_1) + \tau_3^{3/2}$$

take leading corrections to W:

$$W \approx W_0 + Ae^{-a\tau_3}$$

add leading α' *and string loop corrections to K:*

$$K \approx -2\ln V - \frac{\hat{\xi}}{V} + \frac{C_1}{\tau_3^{1/2}} + \frac{C_1}{\tau_1^{1/2}} + \frac{C_1\tau_1^{1/2}}{\tau_2} + \tilde{C}_{12}\tau_1^{1/2}$$

Fibre Inflation

- The
  Scen
- Infla

Potential at leading order:

stabilizes $\tau_3 \sim g_s^{-1}$ *and* $V \sim exp[a\tau_3]$

Potential at next-to-leading order:

acquire potential in $\tau_1 \sim exp[2\,\varphi/\sqrt{3}]$

$$U \approx \frac{C}{V^{10/3}}\left(3 - 4e^{-\varphi/\sqrt{3}} + e^{-4\varphi/\sqrt{3}}\right)$$

Natural slow roll once $\varphi \gg 1$, *but boundary at* $\varphi \ll 6$.

Fibre Inflation

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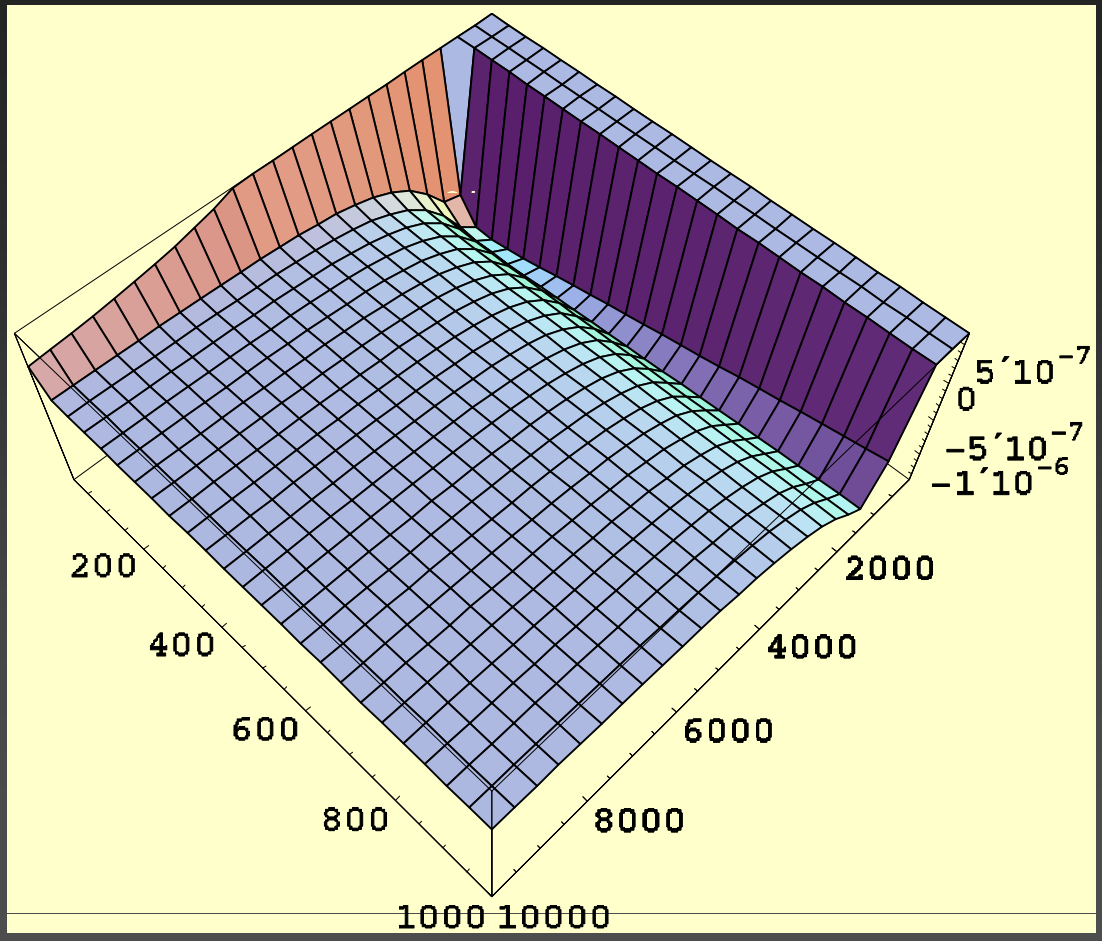

Fibre Inflation

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Potential at leading o

stabilizes $\tau_3 \sim g_s^{-1}$ *and* $V \sim exp[a\,\tau_3]$

only one free parameter!

Potential at next-to-leading order:

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Natural slow roll once $\varphi \gg 1$, *but boundary at* $\varphi \ll 6$.

Fibre Inflation

- The
  Scen
- Infla

Higher loops?

likely to introduce singularity at boundary $\varphi \sim 6$

guess: $$\delta K_{2loop} \approx \frac{\delta K_{1loop}}{t_1^2}$$

for O(1) coefficients, ratio of 2-loop to 1-loop terms is negligible when $\varphi \lesssim 5.9$

Fibre Inflation

Cicoli, CB & Quevedo

- The
  Scen
- Infla

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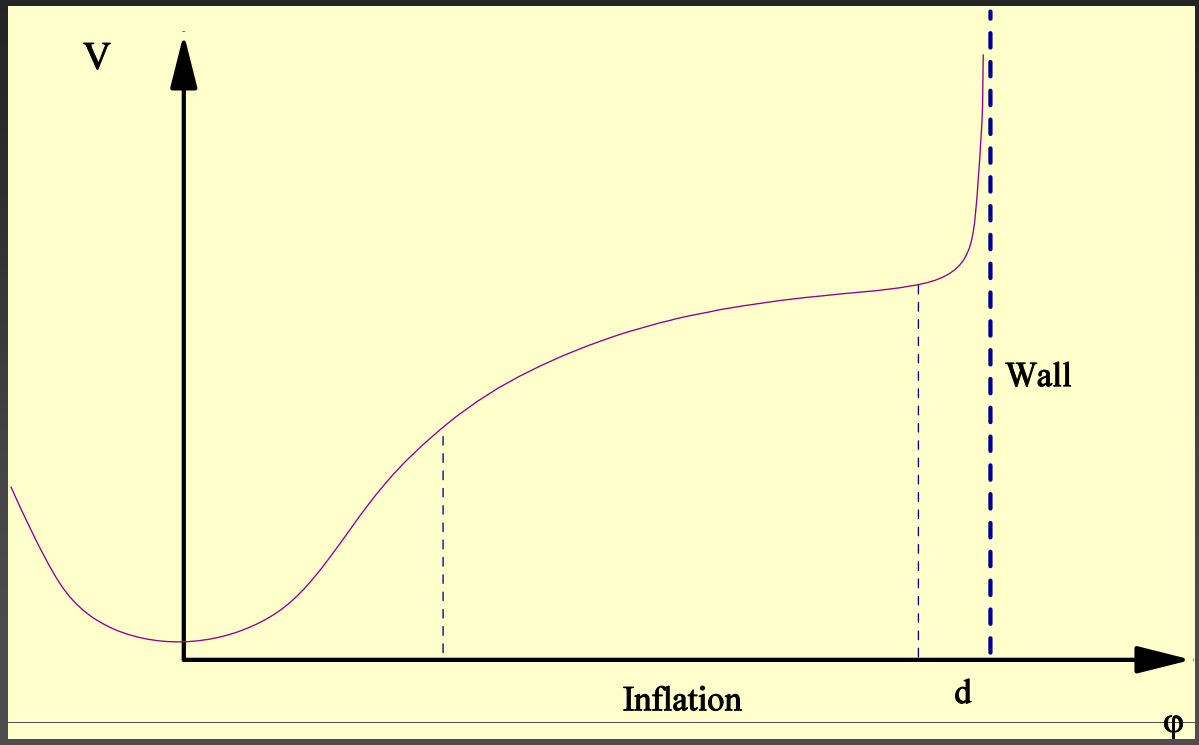
Higher loops?



Inflationary Observables

- Robust features

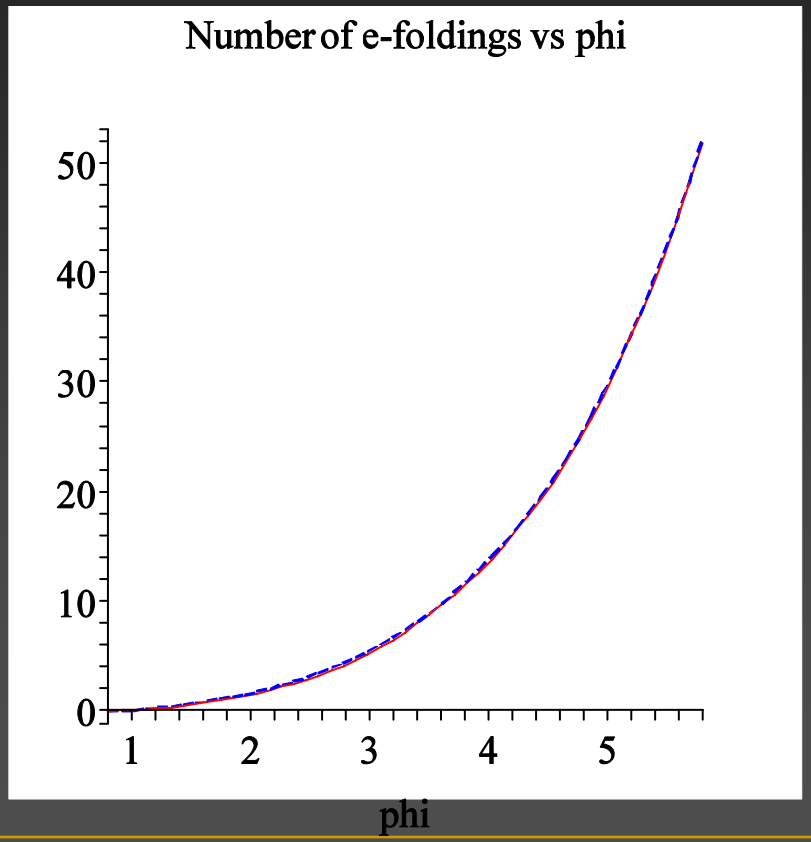
- More model dependent results

Inflationary Observables

- Robu

- Mor
  depe

Slow roll parameters depend only on N_e



Inflationary Observables

- Robu

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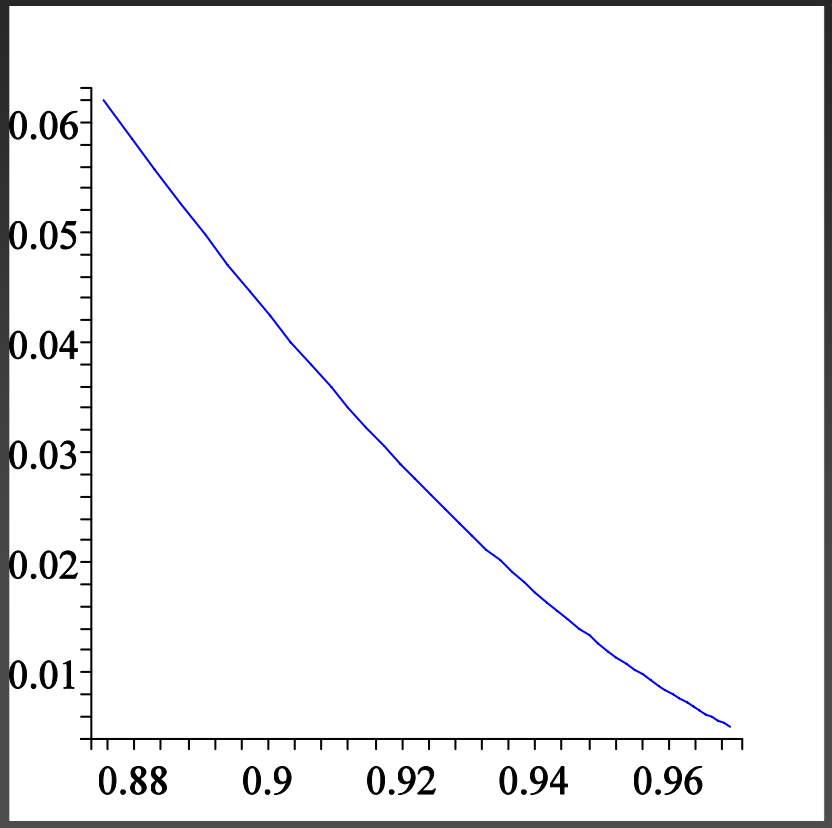
  depe

Correlates r and n_s like for large-field models.



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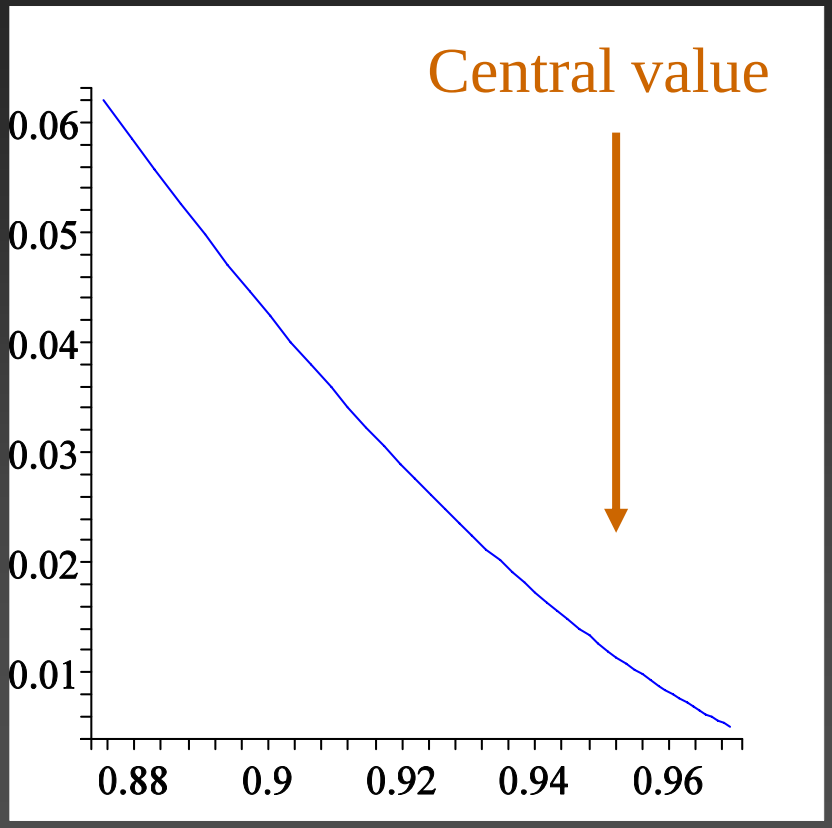

Inflationary Observables

- Robu
- More
  depe

Getting large enough scalar perturbations requires volumes of order $V \sim$ few thousand

Never get much more than 50-60 e-foldings, so might expect to see imprints of onset of inflation at horizone exit.

Slowness of roll does not require tuning of parameters in the potential, but does require initial conditions relatively near to the edge of the Kahler cone

Summary

- Systematic large volume expansions seem able to provide slow roll regimes with less tuning than most inflationary scenarios.
- Fibre inflation models can allow trans-Planckian excursions of the inflaton, and so can accommodate observably large r

Many thanks to the Organizers!!

- *Angel Uranga*
  - *The TH administrative staff (Nanie, Nadje & Jean)*

- Ignatio Antoniadis
- Elias Kiritsis
- Fernando Quevedo
- Herman Verlinde

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