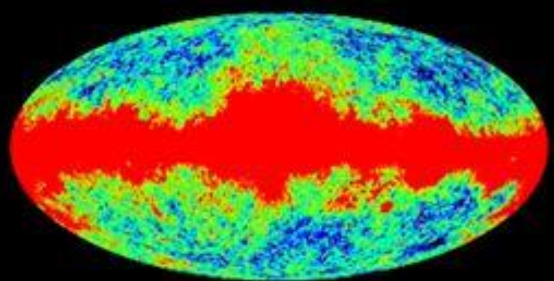
String Inflation: Why?



Convoluted models

walk the Planck

C.P. Burgess

Outline

- Context: *Occam vs Wilson*
  - Why build models only a mother could love?
- Some UV – sensitive issues
  - Naturalness;
  - Large field excursions and tensor modes;
  - Robustness
  - Reheating vs insulation; mind broadening; initial conditions; …
- A tentative scorecard

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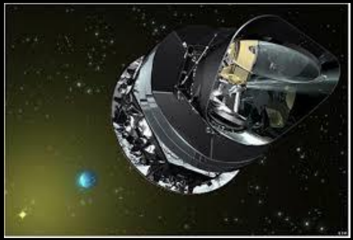
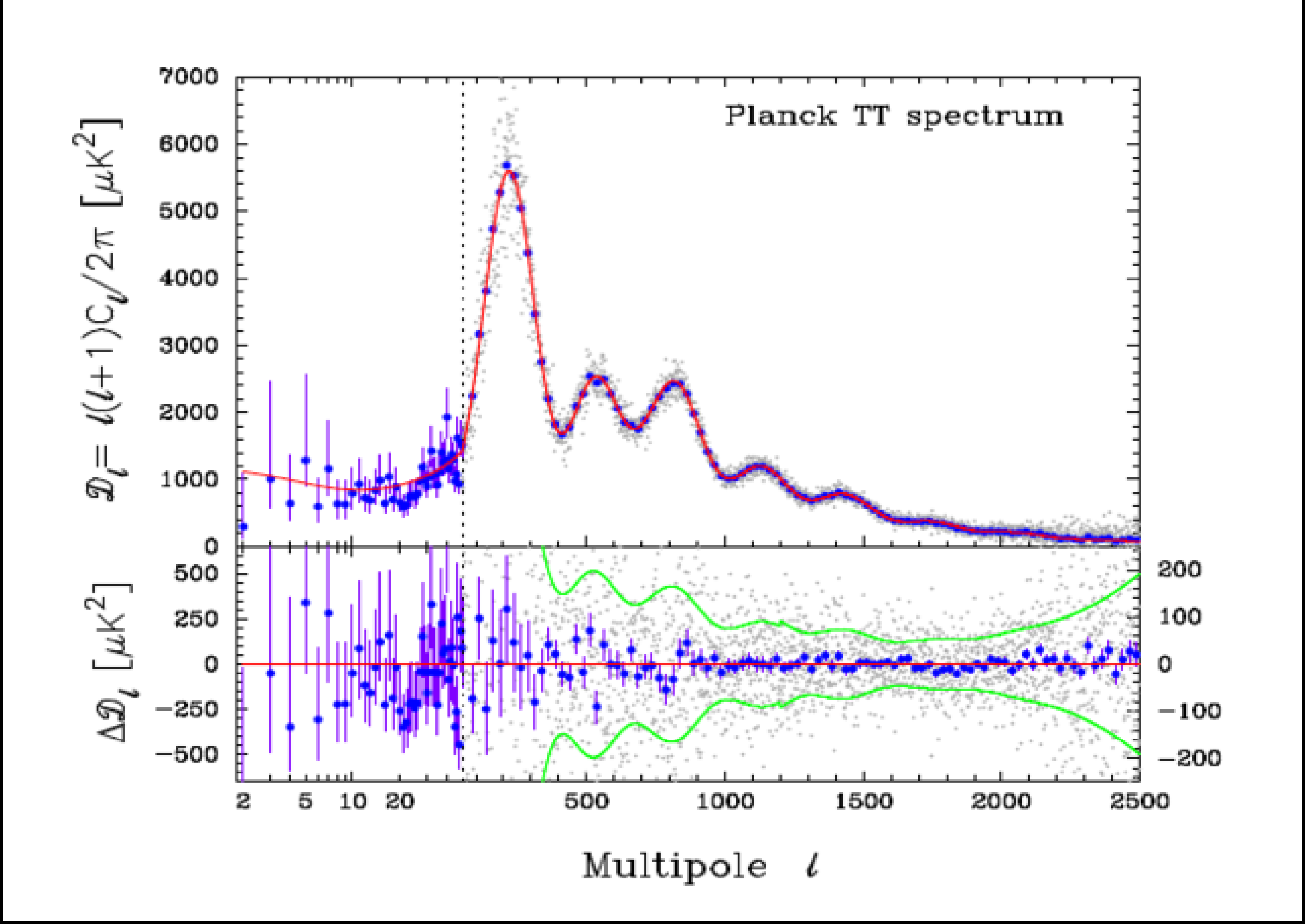


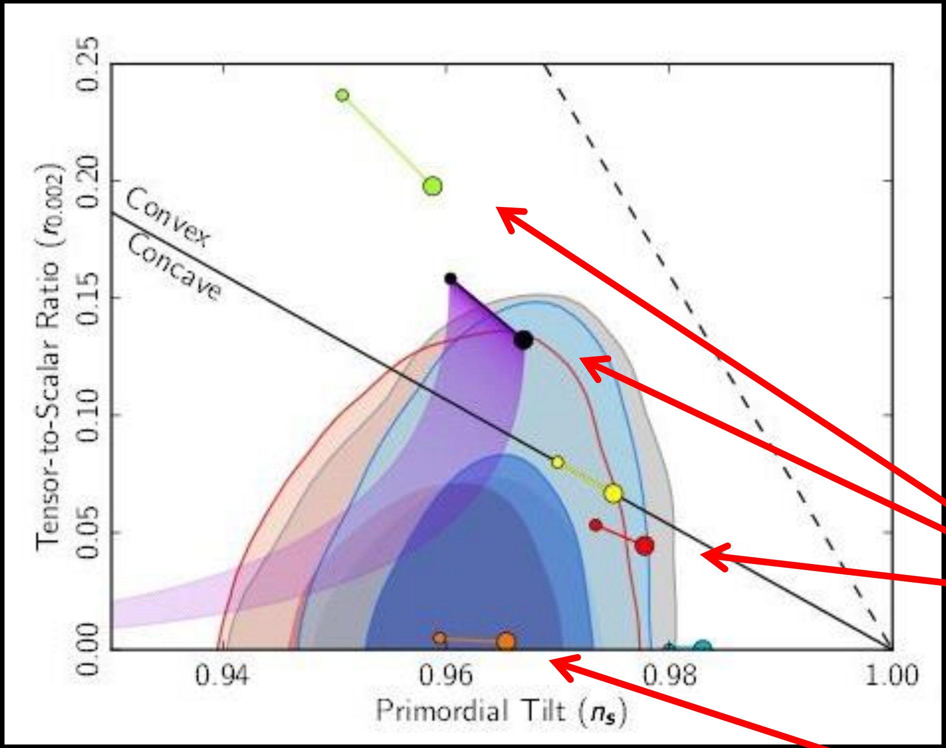


Planck TT spectrum
$\mathcal{D}_\ell = \ell(\ell+1)C_\ell/2\pi$ [μK^2]
$\Delta\mathcal{D}_\ell$ [μK^2]
Multipole ℓ
7000
6000
5000
4000
3000
2000
1000
0
500
250
0
−250
−500
200
100
0
−100
−200
2
5
10
20
500
1000
1500
2000
2500

Context

Context

Planck 2013



$$P_s(k) = A_s k^{n_s - 1}$$

$$r = \frac{A_T}{A_S}$$

$$V(\varphi) \propto \varphi^p$$

$$L = M^2 R + \gamma R^2$$

Simple models work well

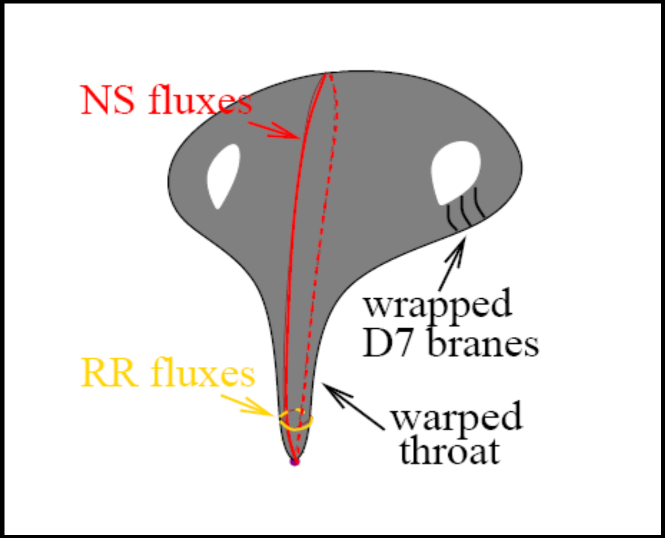
Context

String cosmology involves complicated constructions (extra dimensions, wrapped branes, fluxes, gaugino condensation, supersymmetry, …)

eg:

$$K = -2\ln V = -2\ln\left(\tau_1^{3/2} - \tau_2^{3/2}\right)$$

$$W = W_0 + A_1 e^{a_1 T_1} + A_2 e^{a_2 T_2}$$



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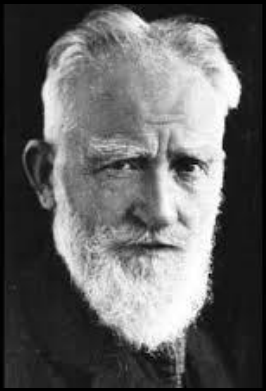


Divided by a common language

Context

Divided by a common language

Context

- Occam:
- Wilson:

Context

- Occam: *What is the simplest possible model that the data requires?*

- Wilson:

Context

- Occam: *What is the simplest possible model that the data requires?*
- Wilson: *Low energy limit is often messy. What is generic and stable?*

  eg SUSY vs simple dark matter model

Context

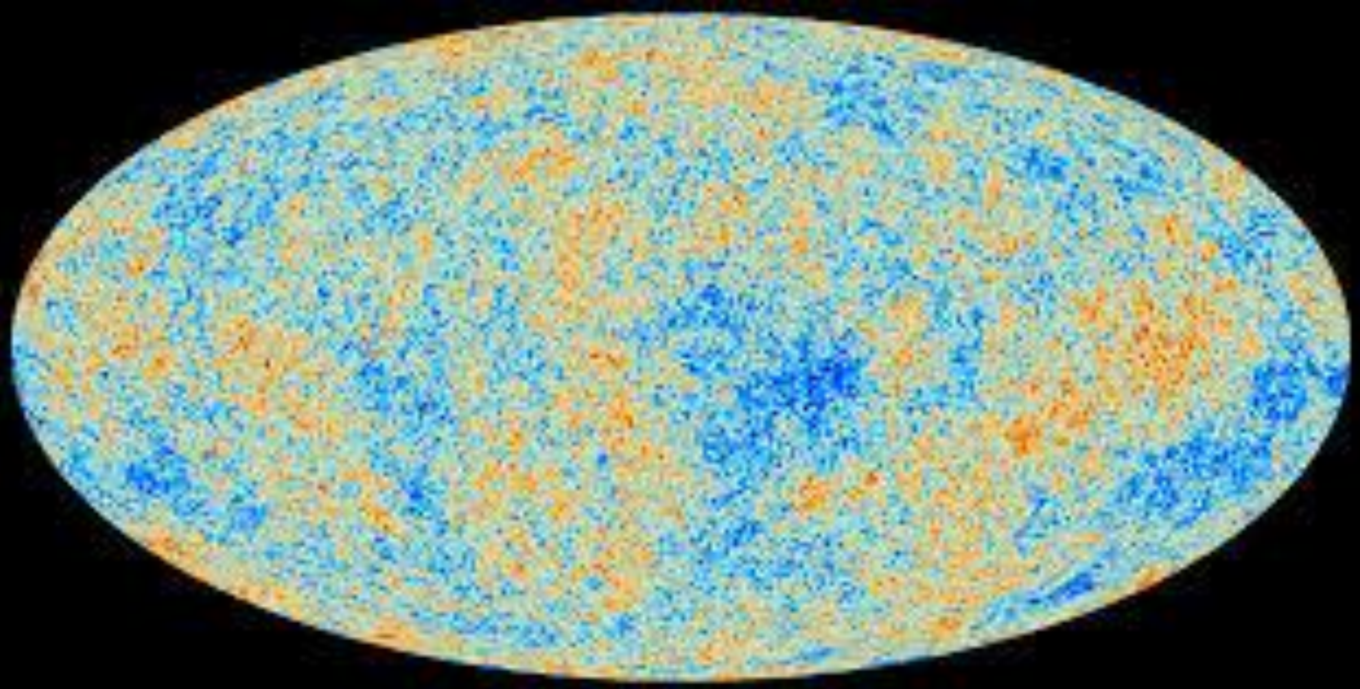
- Occam: *What is the simplest possible model that the data requires?*

- Wilson: *Low energy limit is often messy. What is generic and stable?*

Why embed into UV theory? *Conceptual problems of simple models often require it…*

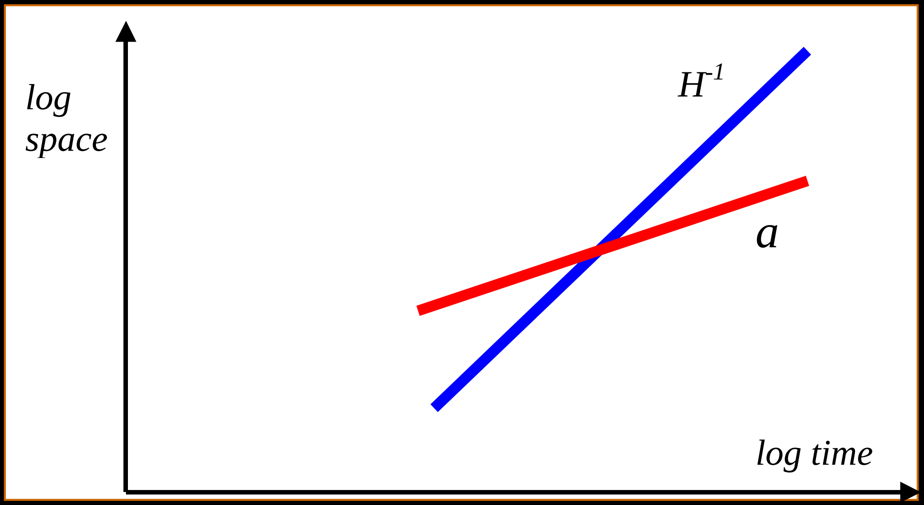
Context

Planck 2013



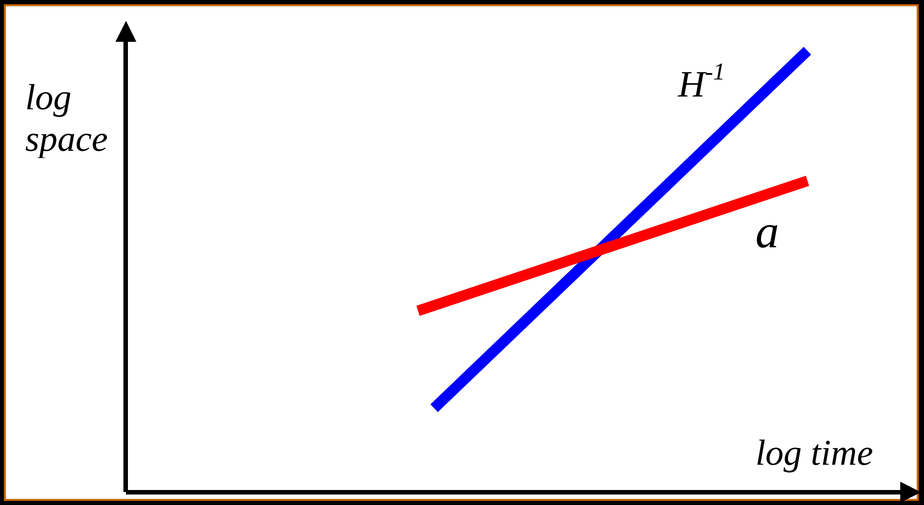
Primordial fluctuations

Context



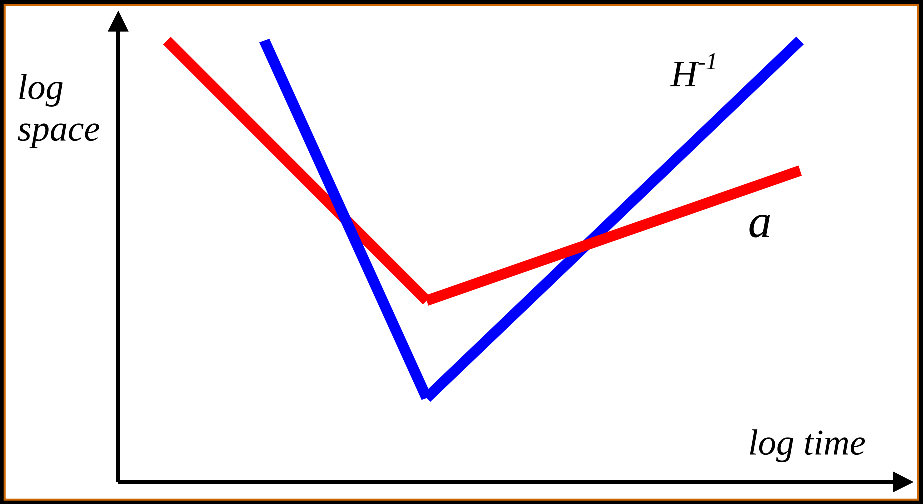
The problem: *how to generate correlations over scales that were super-Hubble in size?*

Context



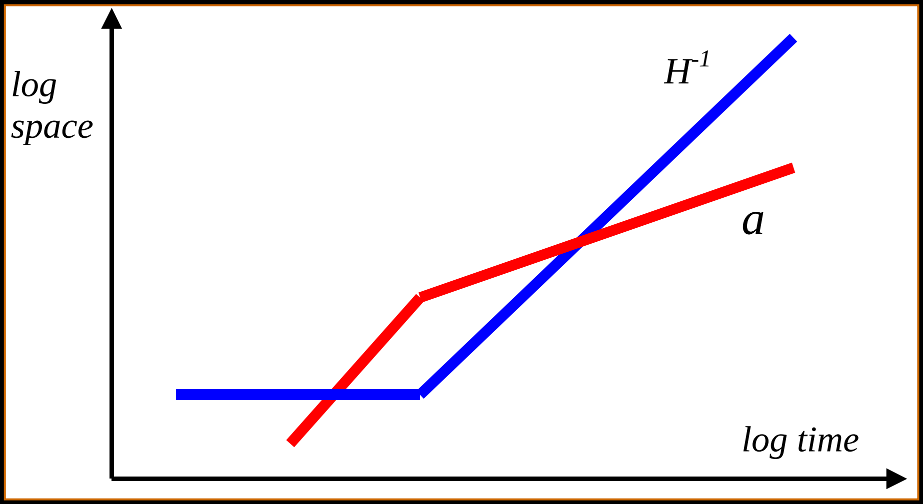
Usual way out: *is the extrapolation wrong?*

Context



Possible solution: *the expansion could have accelerated…eg a bounce*

Context



Possible solution: *the expansion could have accelerated…eg inflation*

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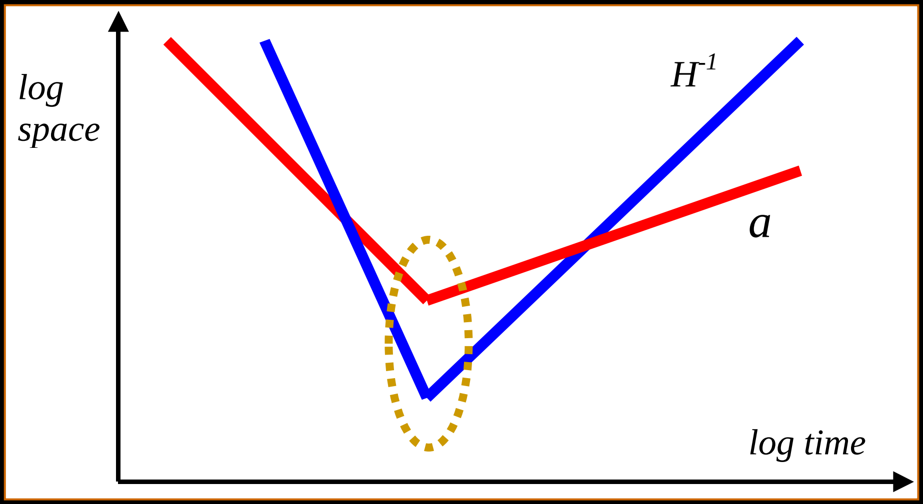
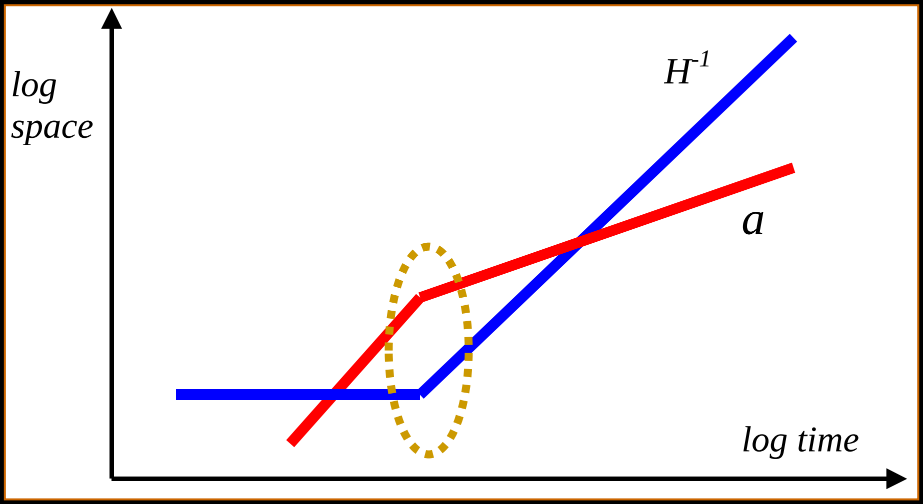


But: *can and why should it bounce?*

Context



But: *can and why should inflation start or end?*

Context

Some problems best addressed with a UV completion:

If a bounce, why is the bounce semi-classical?

Why does inflation start or end?

Why are scalars light (why scale invariant)?

What does one do with a landscape/multiverse?

Why doesn't trans-Planckian physics intrude?

Why doesn't energy dissipate?

Why aren't initial conditions important?

and so on…..

Context

Inflation: *impressive phenomenology seeking a fundamental theory (on the edge of the quantum gravity regime) within which to sit;*

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String Theory: *an impressive fundamental theory seeking experimental consequences to test*

Context

Rocky Kolb

Happy Valentine's Day!

Inflation and strings were made for each other. – *Cliff Burgess*

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.

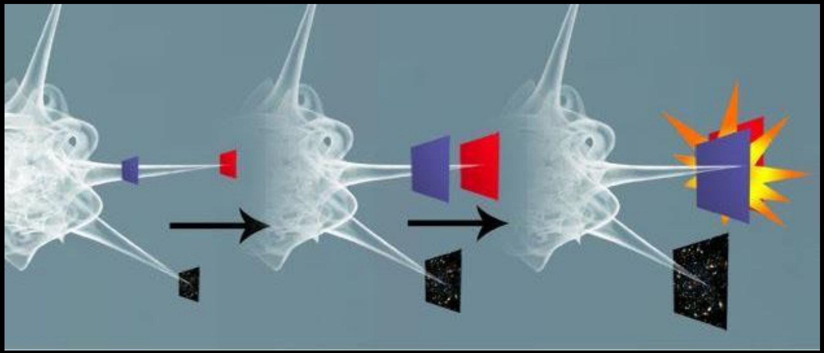
Elegant theory of everything desires to explore the landscape with a phenomenon in the hope that it will lead to a prediction. Let's get physical! Contact ed@ias.edu.

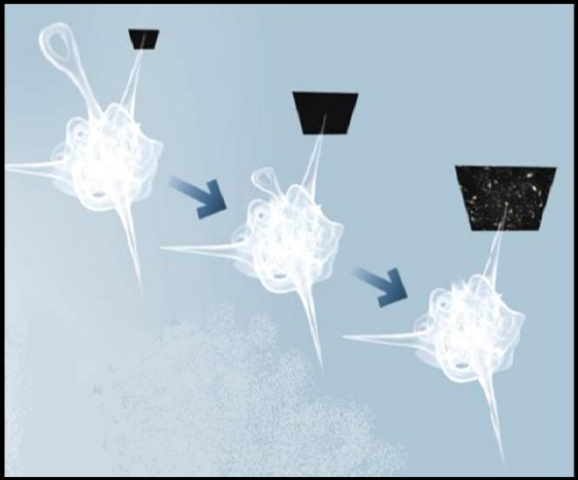
Context

Superficially easy to find inflation in string theory:

It has many 4D scalars. (eg: brane positions; moduli)

$$g_{mn}(x) = g_{mn}(\alpha^i; x)$$





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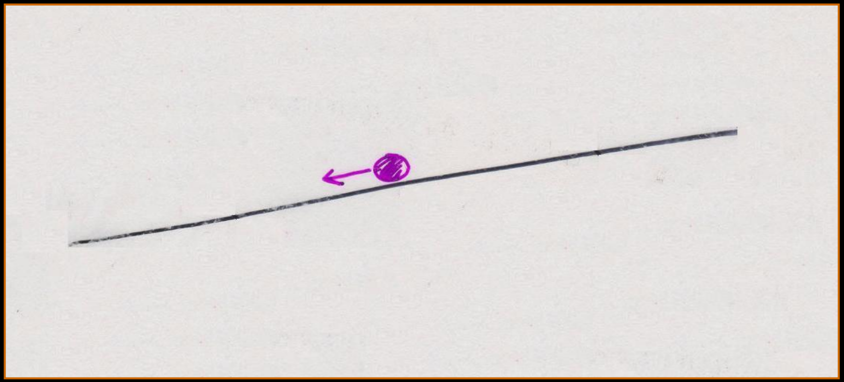
Superficially easy to find inflation in string theory:

It has many 4D scalars; supersymmetry can give these very flat potentials



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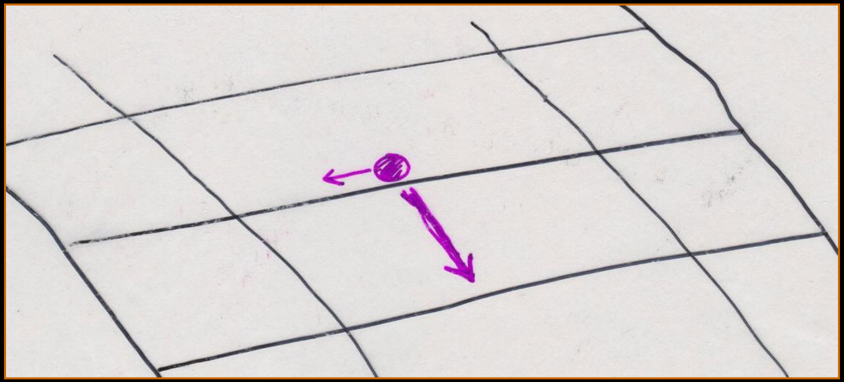
Superficially easy to find inflation in string theory:

It has many 4D scalars; supersymmetry can give these very flat potentials;

BUT: a convincing case for inflation requires reliably knowing the potential that stabilizes *all* moduli



Context

Giddings, Kachru & Polchinski
Kachru, Kallosh, Linde & Trivedi

It has become possible to compute the low-energy potential for *all* moduli for some string constructions since around 2000.

Context

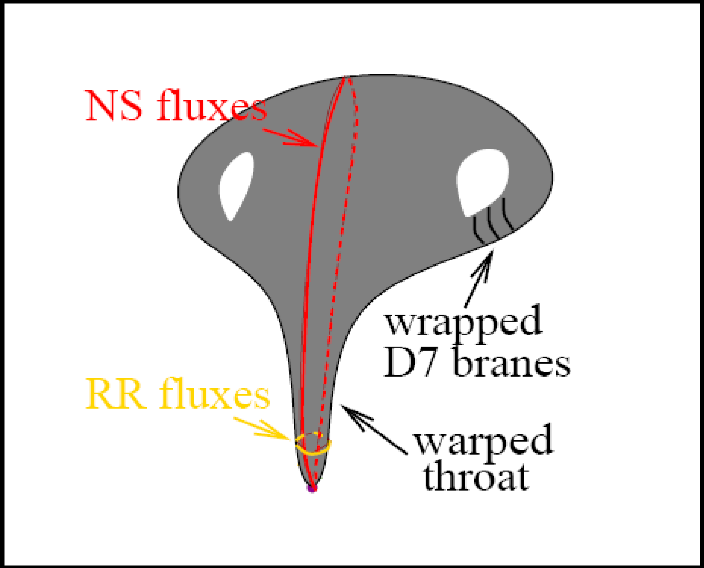
Giddings, Kachru & Polchinski
Kachru, Kallosh, Linde & Trivedi

It has become possible to compute the low-energy potential for *all* moduli for some string constructions since around 2000. First done for Type IIB vacua

Key ingredients:

D3 and D7 branes & orientifolds

Fluxes sourced by these branes, wrapping extra dimensions



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UV Issues

- Naturalness (why are scalars light?)
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UV Issues: naturalness

It is unusual to find scalars that are systematically lighter than the other scales in the problem:

ways out: supersymmetry, goldstone symmetry

UV Issues: naturalness

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ways out: supersymmetry, goldstone symmetry

Slow-roll condition $M^2V'' \ll V \sim \mu^4$ means inflation requires scalar is *extremely* light: $m \ll H \sim \mu^2/M$

Unusually: sensitive even to ‘Planck slop’:

if $L \supset V_0$ then what forbids $L \supset V_0\, \varphi^2/M^2 \sim H^2\varphi^2$?

UV Issues: naturalness

So far as we can tell inflation seems no easier to get in string theory than for generic field theories

But we also tend only to seek inflation in a regime with strings well-described by a field theory anyway.

UV Issues: naturalness

Brandenberger & Vafa

So far as we can tell inflation seems no easier to get in string theory than for generic field theories

But we also tend or
with strings well-de

Some exceptions, like string-gas cosmology, but the good news *(you leave the field theory limit)* is also the bad news *(hard to calculate reliably because have left the field theory limit)*

UV Issues: naturalness

So far as we can tell inflation seems no easier to get in string theory than for generic field theories

Scalars can be light, usually by exploiting known mechanisms (like super- or Goldstone-symmetries)

de Sitter space tends to ruin supersymmetry, so often find inflaton as pseudo-Goldstone bosons

UV Issues: naturalness

So fa
strin

Scal
these

de Si
find

SUSY often combines two types of pGB:

$$X = e^{\varphi} + ia$$

where:

- a *is an axion: in G/H with G compact*

$$V(a) = V_0 + V_1 \cos(a/f) + \cdots$$

with $f \sim M_s \ll M_p$

UV Issues: naturalness

Freese, Frieman & Olinto

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Inflation requires $f \gg M_p$

UV Issues: naturalness

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- *ϕ is a modulus: in G/H with G noncompact*

  $$V(\varphi) = V_0 + V_1 e^{-\varphi/f} + \cdots$$

  with $f \sim M_p$

UV Issues: naturalness

BMQRZ th/0111025

Arises, eg, as radius of extra-dimensional cycle: $r = \ell \, e^{\varphi/f}$ *with energy given as series in* $1/r$ *given a kinetic term* $L = M^2[R + (\partial r/r)^2]$

Calculable regime: $r \gg \ell$ *and so* $\varphi \gg f$

s of pGB:

compact

$) + \cdots$

with $f \sim M_s \ll M_p$

de Si

find

- ϕ *is a modulus: in G/H with G noncompact*

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UV Issues: naturalness

Goncharov & Linde

Inflation requires $\varphi \gg f$ which is the same as the calculable regime; with no condition on size of f.

BUT inflation also requires $V_0 \neq 0$

s of pGB:

compact

$) + \cdots$

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de Si

find

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UV Issues: naturalness

Should take pGB potentials very seriously!!

In particular exponential potentials:

$$V(\varphi) = V_0\left(1 - e^{-k\,\varphi} + \cdots\right)$$

so

$$\epsilon = e^{-2k\,\varphi} \quad \textit{and} \quad \eta = e^{-k\,\varphi}$$

so slow roll is same as large field

UV Issues: naturalness

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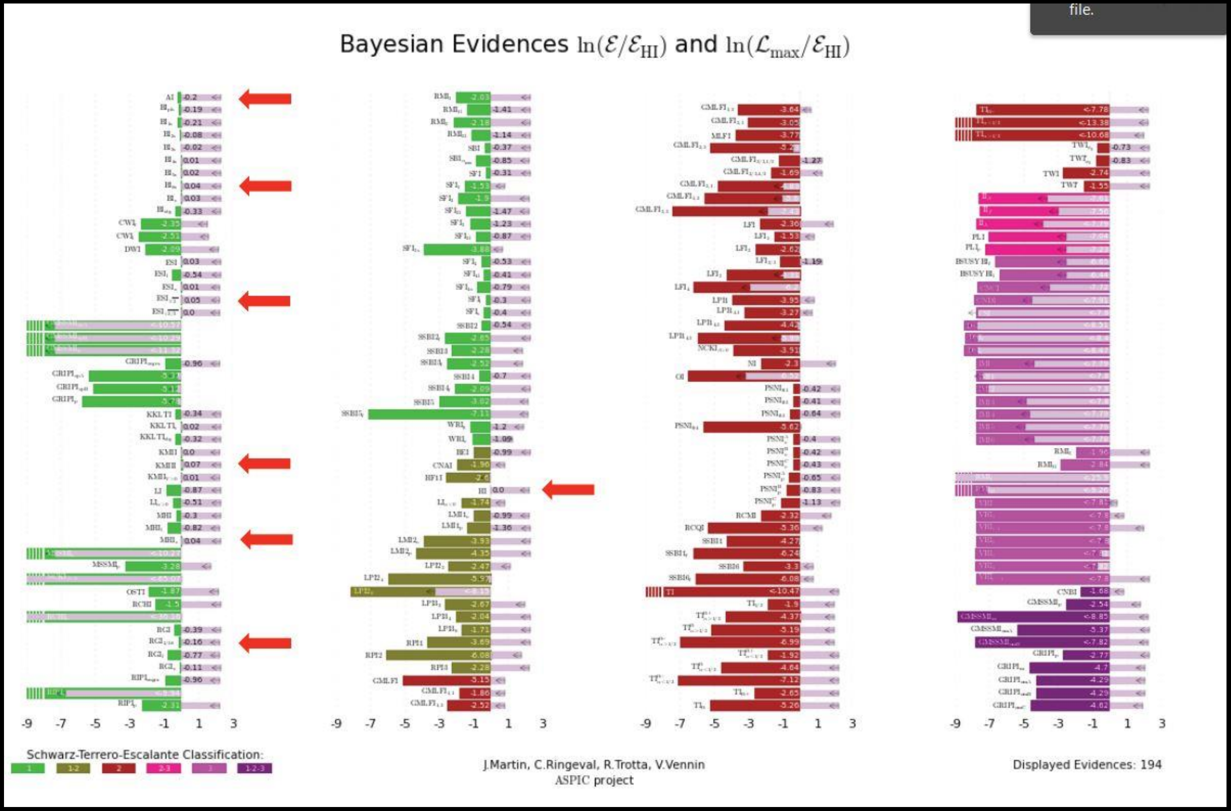
so

$$\epsilon = e^{-2k\,\varphi} \quad \text{and} \quad \eta = e^{-k\,\varphi}$$

since $\varepsilon \sim \eta^2$ get prediction $r \sim (n_s\text{-}1)^2$

UV Issues: naturalness

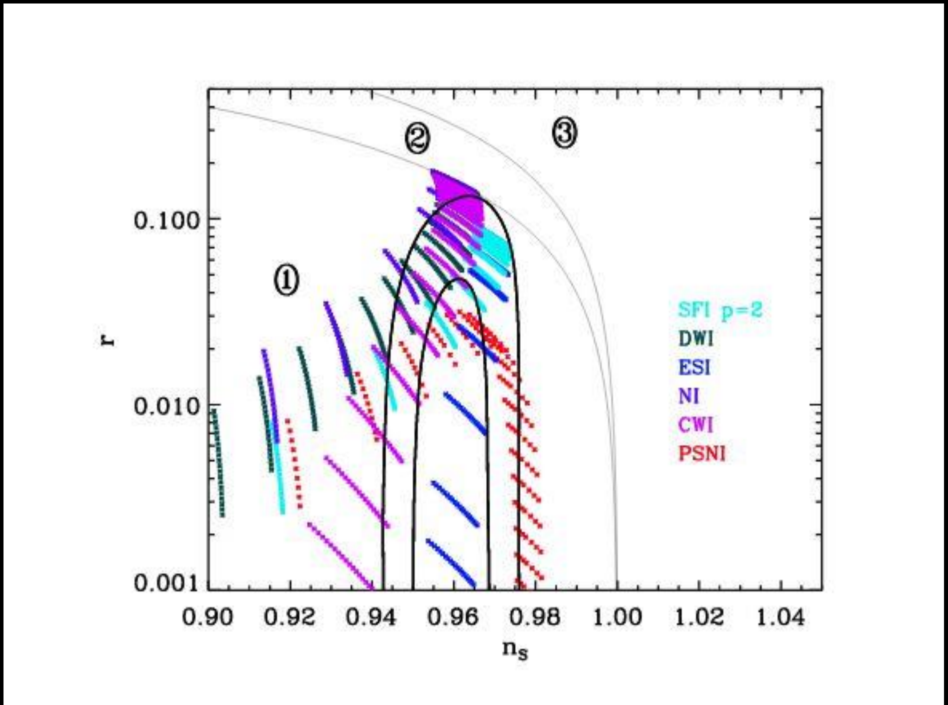
Martin, Ringeval & Vennin 2013



Exponentials do well in comparison of models

UV Issues: naturalness

Martin, Ringeval & Vennin 2013



Why some do better than others

UV Issues: naturalness

Starobinsky
Bezrukov & Shaposhnikov

Do string vacua also give R^2 or Higgs-type inflation?

$$L = M^2 R + \gamma R^2 + \frac{R^3}{M^2} + \cdots$$

with $M = M_p$ and $\gamma \gg 1$?

UV Issues: naturalness

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Actually do *get curvature expansions, but usually with M_s everywhere, so do not get unusually large R^2 term.*

UV Issues: naturalness

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with $M = M_p$ and $\gamma \gg 1$?

Actually do *get curvature expansions, but usually with M_s everywhere, so do not get unusually large R^2 term.*

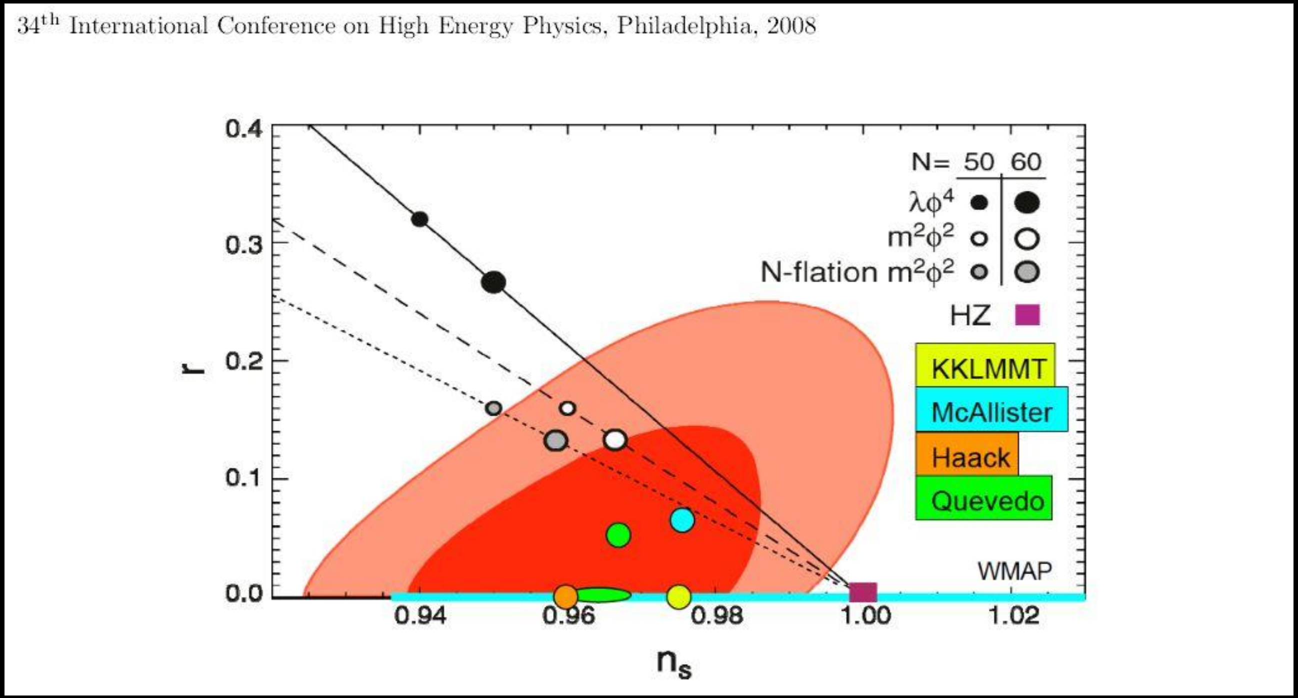
But Higgs and R^2 inflation can also be regarded as exponential potentials, which seem easier to get.

UV Issues

- Naturalness (why are scalars light?)
- Trans-Planckian fields and tensor modes?
- Robustness
  - Multiple scalars and non-Gaussianity
  - Decoupling vs trans-Planckianism?
- Reheating
- Mind broadening

UV Issues: large fields and tensors

Early models tend to share a preference for small *r*



J. Polchinski ICHEP 08 summary talk

UV Issues: large fields and tensors

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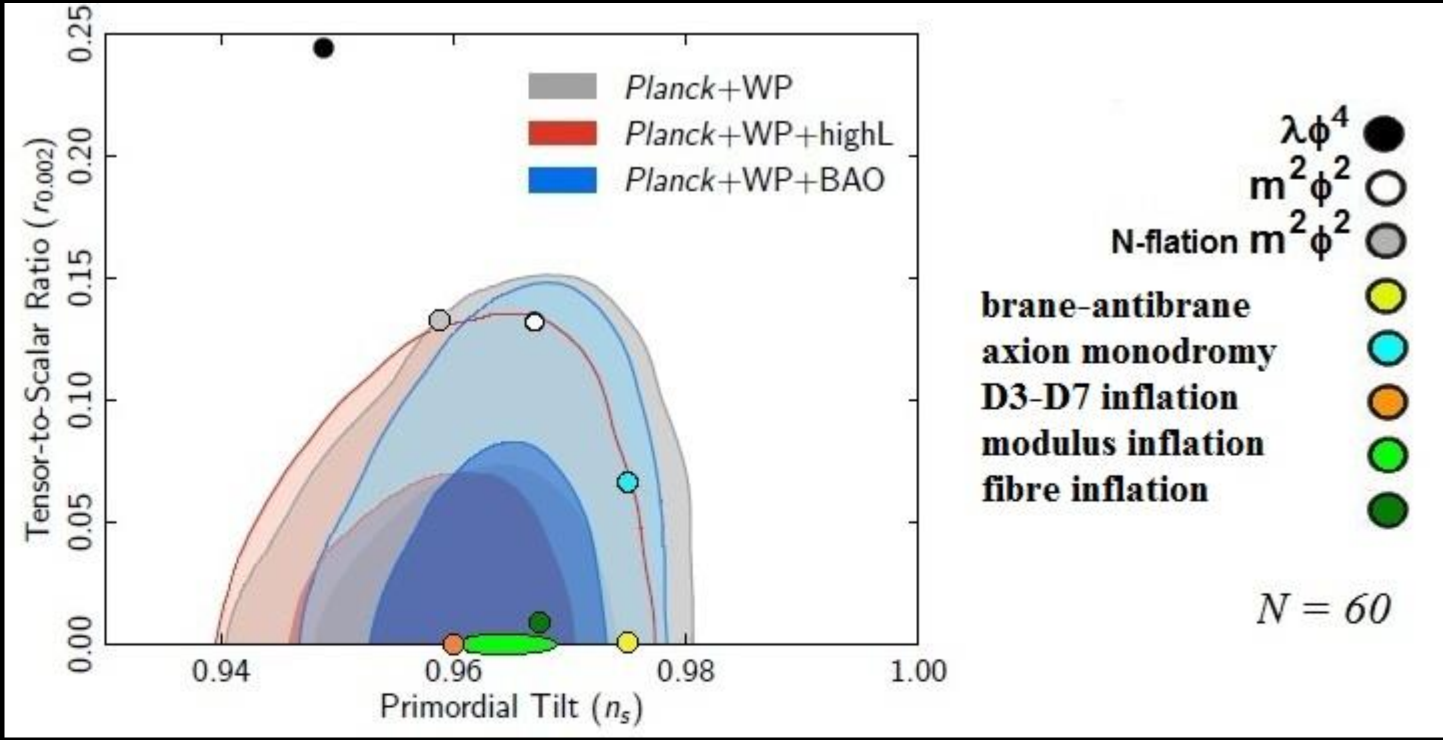

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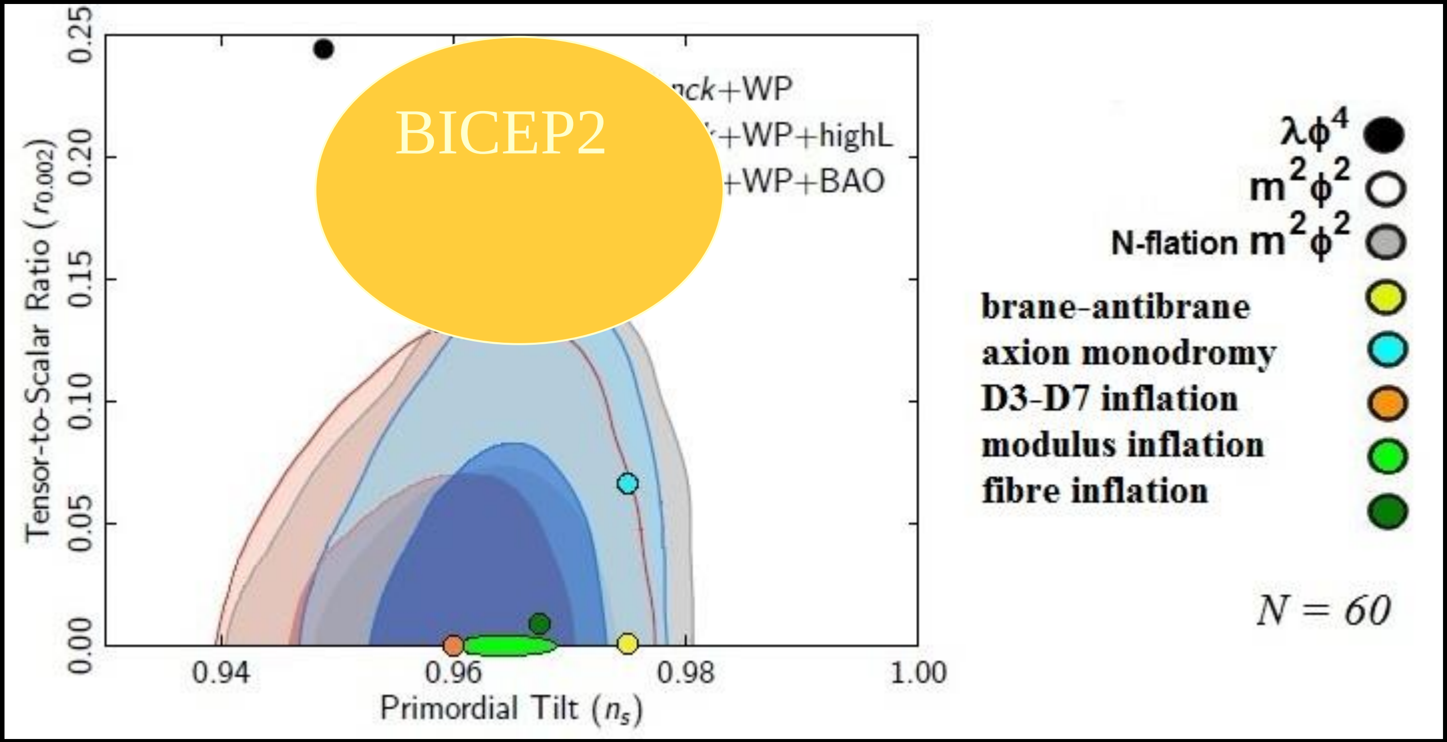

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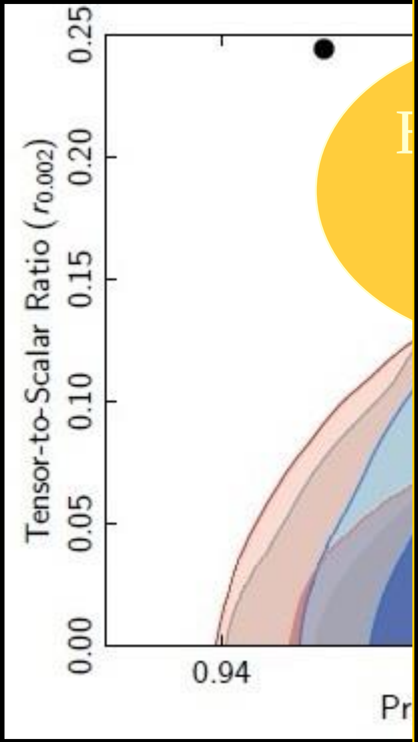
UV Issues: large fields and tensors

Lyth

Early models tend



Usually large r corresponds to large excursions in field space

$$\Delta\phi > M_p \ (r/4\pi)^{1/2}$$

In examples these turn out to require things like branes rolling further than extra dimensions are large.

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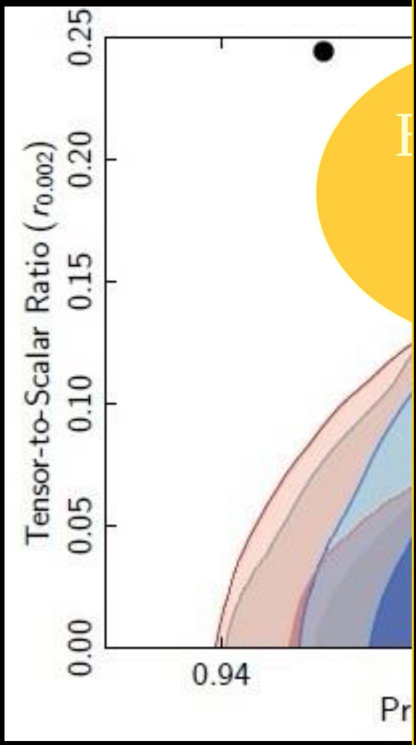
UV Issues: large fields and tensors

Early models ten



Clearly large fields are not in themselves impossible to get, as the exponential potentials show:

$$r = \ell \, e^{\varphi/f}$$

These start life as flat directions so large fields cost little energy (and so make sense in an EFT).

But how to inflate? $V = V_0 + \cdots$

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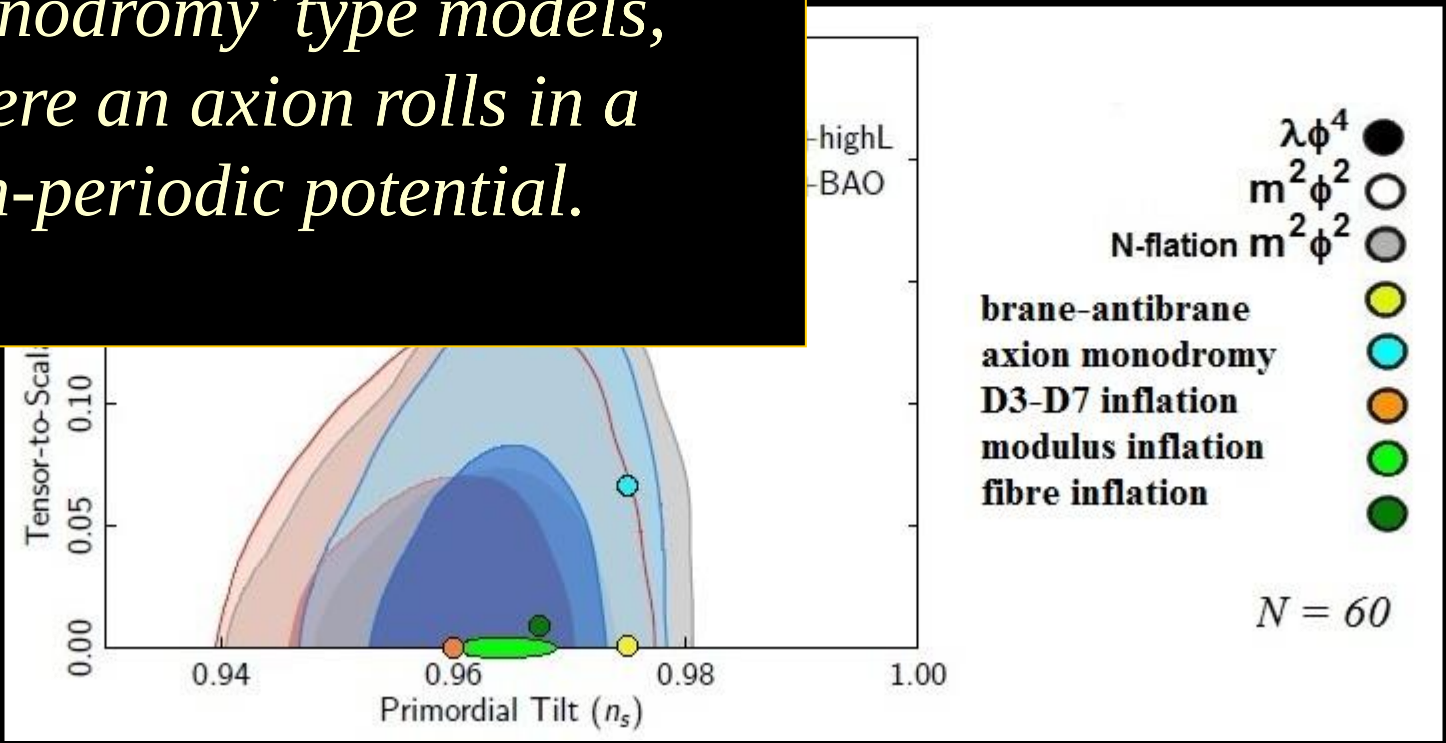
UV Issues: large fields and tensors

Silverstein & Westphal
McAllister, Silverstein & Westphal
Conlon

First counter-examples were 'monodromy' type models, where an axion rolls in a non-periodic potential.

ference for small *r*



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UV Issues: large fields and tensors

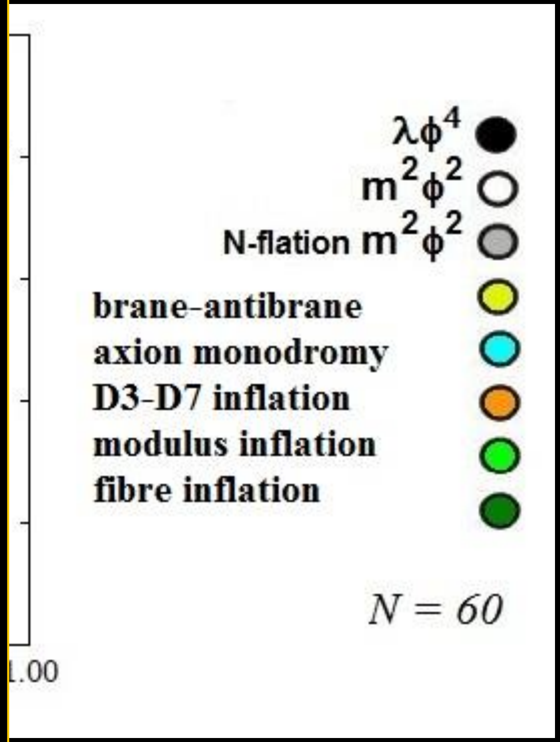
Kim, Niilles & Peloso
Kappl, Krippendorf & Nilles

Field-theoretic mechanisms exist for getting larger f (and so also larger tensors), such as 'alignment' mechanisms.

$$V(\varphi_1, \varphi_2) = U_1(a\varphi_1 + b\varphi_2) + U_1(c\varphi_1 + d\varphi_2)$$

By ensuring $f > M_p$ *these can reproduce predictions of simple* $m^2\varphi^2$ *models because* $\varphi/f \ll 1$

nce for small *r*



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UV Issues

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- Mind broadening

UV Issues: robustness

Brandenberger & Martin

Do observers need to worry about any of this?

- *If inflation stretches scales, why doesn't it also stretch unknown trans-Planckian physics to observable scales?*

UV Issues: robustness

Do observers need to worry about any of this?

- *If inflation stretches scales, why doesn't it also stretch unknown trans-Planckian physics to observable scales?*

String physics in string theory seems to decouple…

UV Issues: robustness

McAllister et al

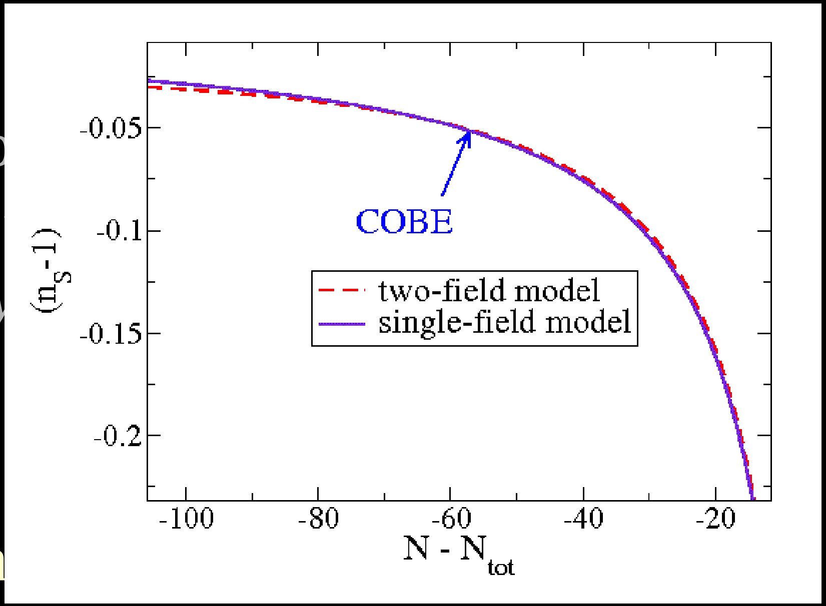
Do observers need to worry about any of this?

- *If inflation stretches scales, why doesn't it also stretch unknown trans-Planckian physics to observable scales?*

String models often have many light scalars if they have one: should we generically expect nongaussianity and isocurvature perturbations?

UV Issues: robustness

'Racetrack 8'



Do observers need to worry abo

- *If inflation stretches scales, unknown trans-Planckian phy scales?*

String models often have man have one: should we generically expect nongaussianity and isocurvature perturbations?

Multi-field models usually are moving along target-space geodesics near horizon exit so are usually effectively single field models…

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UV Issues: reheating

Does string theory have anything useful to say about reheating?

in principle it should eventually, once we have a single model that both inflates and contains the Standard Model….

UV Issues: reheating

Sarangi & Tye
Copeland, Myers & Polchinski

Does string theory have anything useful to say about reheating?

In principle it should eventually, once we have a single model that both inflates and contains the Standard Model….

Can bring surprises like post-inflationary cosmic string production, …

UV Issues: reheating

Barnaby, CB & Cline,

Does string theory have anythi
reheating?

strings already show why studies of a single inflaton oscillating while coupled to SM fields may be inadequate: *a good furnace is not adequate to reheat if you do not also have good insulation. Must know ALL the degrees of freedom at the relevant energies*

UV Issues

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UV Issues: mind-broadening

Some novel features to string-motivated models:

CB, Majumdar, Nolte, Rajesh, Quevedo & Zhang

Inflaton field might not even exist in our present-day world (such as if it describes the distance between a brane-antibrane pair that annihilate at the end of inflation)

Silverstein & Tong,

Slow roll need not be inconsistent with relativistic kinematics (such as in DBI inflation)

$$\mathcal{L}_{\rm DBI} = -f(\phi)^{-1}\sqrt{1 - 2f(\phi)g^{\mu\nu}\partial_\mu\phi\partial_\nu\phi} + f(\phi)^{-1} - V(\phi)$$

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Scorecard

- Mechanisms
- Robustness
- Initial Conditions
- Naturalness
- Reheating & scales
- Signatures
- Mind broadening

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The Cosmological Constant?

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