Inflation after Planck

and Two Conceptual Questions about Inflation

Eugene A. Lim
LCDM Sept 19 2013

Why Inflation?

PHYSICAL REVIEW D VOLUME 23, NUMBER 2 15 JANUARY 1981

Inflationary universe: A possible solution to the horizon and flatness problems

Alan H. Guth*
Stanford Linear Accelerator Center, Stanford University, Stanford, California 94305

(Received 11 August 1980)

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Horizon, Flatness, No Monopoles

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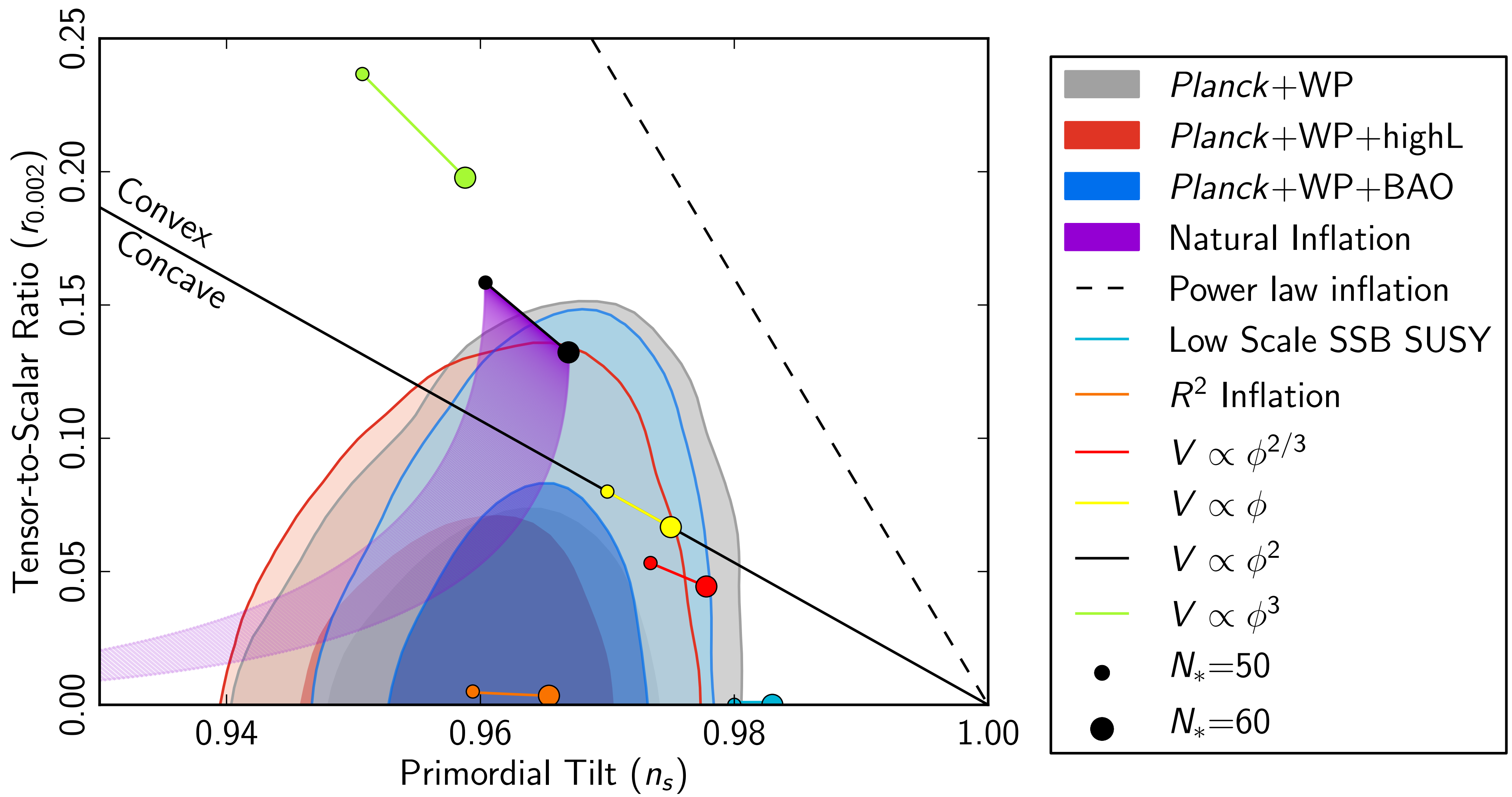
Horizon, Flatness, No Monopoles

Many essentially equivalent approaches to quantizing the linearized cosmological fluctuations can be found in the original literature (see, e.g., Mukhanov & Chibisov, 1981; Hawking, 1982; Guth & Pi, 1982; Starobinsky, 1982; Bardeen et al., 1983).

excerpt from PLANCK XXII

Provides mechanism to source primordial fluctuations.

What Planck tells us



PLANCK XXII

The simplest inflationary models have passed an exacting test with the *Planck* data. The full mission data including *Planck*'s polarization measurements will help answer further fundamental questions, including the possibilities for non-smooth power spectra, the energy scale of inflation, and extensions to more complex models.

What Planck *really* tells us

- Primordial spectrum scale invariant Gaussian and adiabatic primordial power spectrum.
- Spatially flat.

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- Spatially flat.

Vanilla Inflation Predicts exactly these

Give the Nobel to Alan already!

Why the Long Face?

The blogosphere weighs in...

Saturday, 20 April 2013

Planck about inflation

The CMB spectrum measured by the Planck satellite points to a perfectly boring universe: the vanilla ΛCDM cosmological model, no hint of new light degrees of freedom beyond the standard model, no hint of larger-than-expected neutrino masses, etc. However at the quantitative level things are a bit more interesting, as Planck has considerably narrowed down the parameter space of inflation. We may not be far from selecting a small class out the huge zoo of inflationary models.

Why the Long Face?

The blogosphere weighs in...

IN THE DARK

A blog about the Universe, and all that surrounds it

Has Planck closed the window on the Early Universe?

... so the upper limit on the level of non-Gaussianity allowed by Planck really is minuscule. This is one of the reasons why some people have described the best-fitting model emerging from Planck as the *Maximally Boring Universe*...

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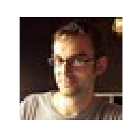
Twitter!



Andrew Pontzen
@apontzen

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Hearing that some people are calling the new model universe the Maximally Boring Universe (MBU) #planck

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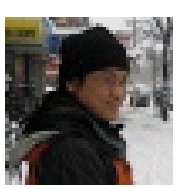
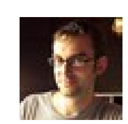
It's my (and Takemi Okamoto's) fault



Eugene Lim
December 13, 2011 at 9:39pm ·

is one step closer to the Maximally Boring Universe.

Twitter!



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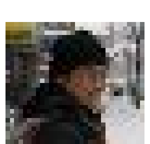


Eugene Lim Maximally Boring Universe also applies to cosmology : we find that w =−1, no non−G, r −> 0, dark sector totally dark, Omega_k=0, statistically isotropic, on top of SM Higgs, no SUSY.
December 13, 2011 at 10:10pm · Like · 1

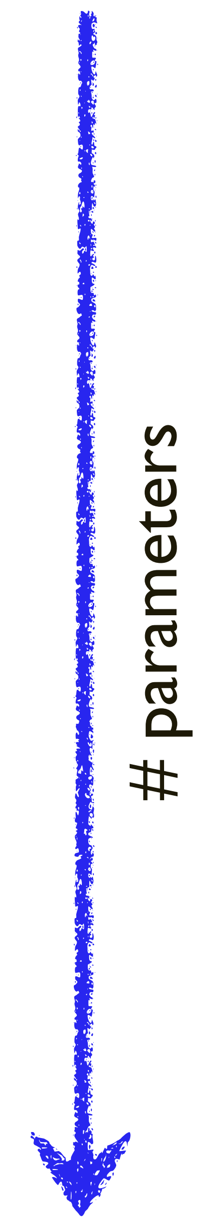
Conceptual Question 1

Can we ever construct a Unique model of Inflation?

Occam's view : Less parameters = simple model of inflation.

V.S.

Wilsonian view : Fundamental theory like string theory predicts lots of light degrees of freedom (e.g. scalars) = complicated model of inflation



Conceptual Question I

Can we ever construct a Unique model of Inflation?

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Our Hope :
More data
+ Bayes

v.s.

Wilsonian view : Fundamental theory like string theory predicts lots of light degrees of freedom (e.g. scalars) = complicated model of inflation

parameters

Conceptual Question 1

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Reality :(

Our Hope : More data + Bayes

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\# parameters

Wilsonian view : Fundamental theory like string theory predicts lots of light degrees of freedom (e.g. scalars) = complicated model of inflation

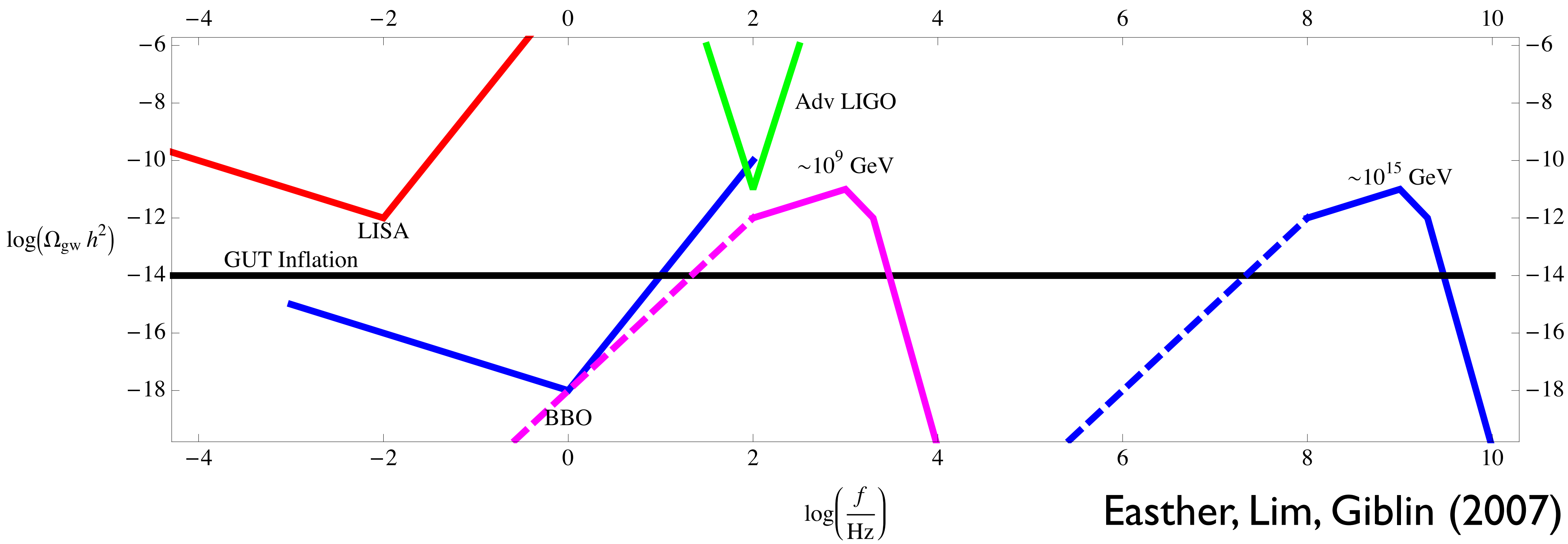
We want to embed Inflation in a UV theory, so this makes things harder.

What Next?

- Data Mining : Lots of data to be analyze still. Hidden features in the data? Non scale-invariant type non-Gaussianities? Cross-correlations with other data sets?
- Planck compatible model building : See John's Talk!
- Start looking for other probes : Gravitational Waves, 21 cm lines, B modes.
- Figure out Reheating

Directly detected SGW : the next CMB?

Stochastic Gravitational Waves from preheating



Easther, Lim, Giblin (2007)

$$\text{peak freq } f_{peak} \propto \sqrt{H}$$

Easther, Lim (2006)

Low scale inflation is good for observability

$$\text{peak amplitude } \Omega_{gw} h^2 < 10^{-6}$$

(Amin and Lim, in prep)

Bound does *not* depend on scale of inflation (i.e. universal)

Bound on preheating SGW

(Amin and Lim, in prep)

$$h''_{ij} + k^2 h_{ij} = \frac{T_{ij}^{TT}}{M_p^2} = \frac{1}{M_p^2} \times \text{Spatial Gradients}^{TT}$$

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$$T_{ij} = \text{Kinetic} + \text{Gradient} + \text{Potential}$$

Turbulence leads to rough **equipartition**

$$T^{TT}_{ij} \sim V \approx H^2 M_p^2 \implies kh \sim \frac{H^2}{k}$$

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But modes excited must be shorter than Hubble so $k > H$

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But modes excited must be shorter than Hubble so

$$k > H$$

e.g. For $V = m^2\phi^2$

$$\frac{k_{peak}}{H} \sim 100 \implies \Omega_{gw} h^2 \approx 10^{-10}$$

$$\text{peak amplitude } \Omega_{gw} h^2 < 10^{-6}$$

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Conceptual Question 2

Does Inflation solve the Cosmological Problems?

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The standard model of hot big-bang cosmology requires initial conditions which are problematic in two ways: (1) The early universe is assumed to be highly homogeneous, in spite of the fact that separated regions were causally disconnected (horizon problem); and (2) the initial value of the Hubble constant must be fine tuned to extraordinary accuracy to produce a universe as flat (i.e., near critical mass density) as the one we see today (flatness problem). These problems would disappear if, in its early history, the universe supercooled to temperatures 28 or more orders of magnitude below the critical temperature for some phase transition. A huge expansion factor would then result from a period of exponential growth, and the entropy of the universe would be multiplied by a huge factor when the latent heat is released. Such a scenario is completely natural in the context of grand unified models of elementary-particle interactions. In such models, the supercooling is also relevant to the problem of monopole suppression. Unfortunately, the scenario seems to lead to some unacceptable consequences, so modifications must be sought.

I. INTRODUCTION: THE HORIZON AND FLATNESS PROBLEMS

The standard model of hot big-bang cosmology relies on the assumption of initial conditions which are very puzzling in two ways which I will explain below. The purpose of this paper is to suggest a modified scenario which avoids both of these puzzles.

completely described.

Now I can explain the puzzles. The first is the well-known horizon problem.[2-4] The initial universe is assumed to be homogeneous, yet it consists of at least $\sim 10^{83}$ separate regions which are causally disconnected (i.e., these regions have not yet had time to communicate with each other via light signals).[5] (The precise assumptions

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*Why **Initial Conditions** are set up such that we are spatially flat, homogenous and isotropic? Seems "fine tuned" and implausible.*

*Inflation "solves" this by a **dynamical** mechanism*

The Blind Dart-thrower

R. Wald (2005), R. Penrose (1979)

"Inflation requires an even more highly implausible initial conditions than without inflation"

High/Low Entropy = Messy/Special State

Today, roughly isotropic/homogenous/flat =
"*we are in a low entropy state*"

By 2nd law of Thermodynamics (assuming ergodicity etc), we must be in *an even lower entropy state at the beginning.*

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Inflation : universe starts in some completely random state, but some dynamical mechanism drives some *portion* of it to some special state (ours)

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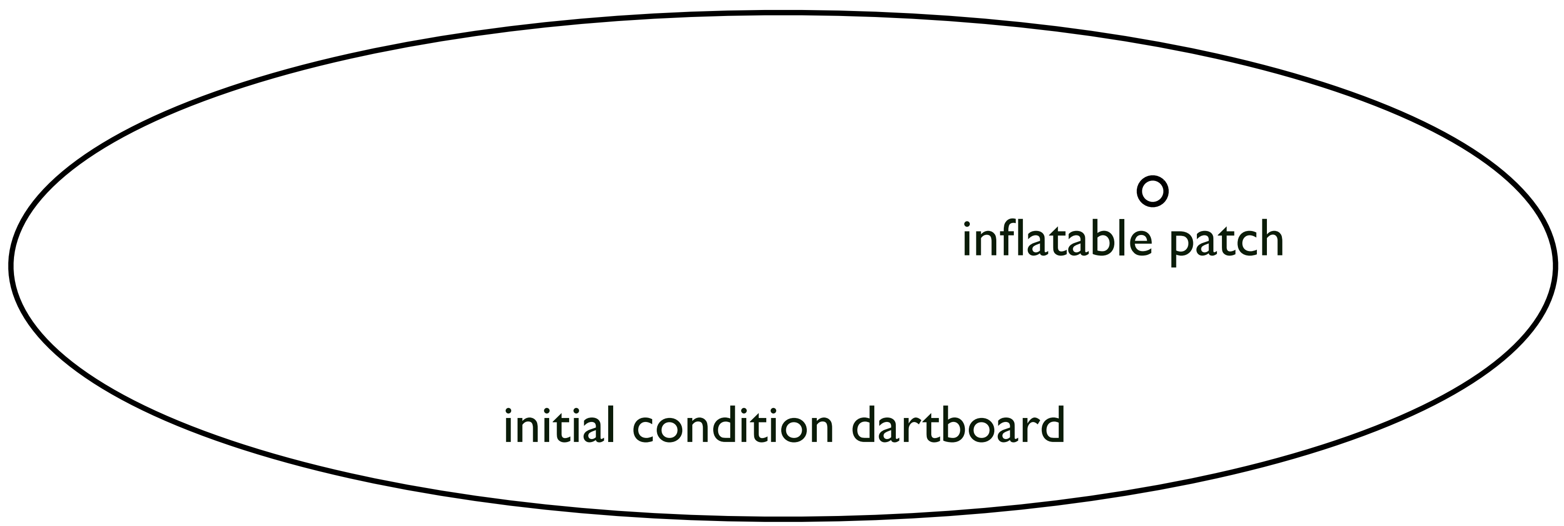
To inflate, *some* portion of the initial surface must be sufficiently "tuned" (e.g. the scalar field lying ontop of the potential hill)

Highly unlikely, but initial surface is *infinite*, so Probability = 1 !



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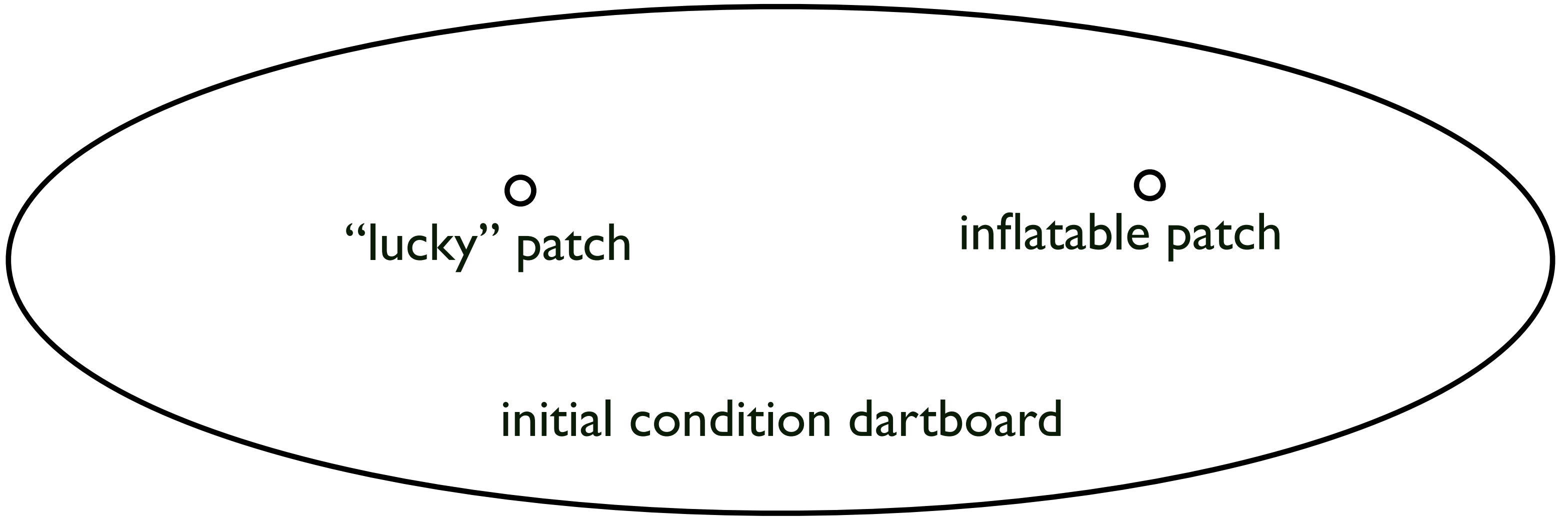

But Probability of us "by chance" living in a patch which leads to our observable universe without inflation is also 1 !!

The problem is *not* whether we can inflate, the question is *how more likely* do we live in such a patch compared to just one that has the right initial conditions *by chance* (without inflation).

The Blind Dart-thrower

R. Wald (2005), R. Penrose (1979)

How do we compare probabilities??

Need to understand (1) Role of the quantum mechanical observers (2) quantum gravity notion of entropy

Some Dirty Words :

"Anthropic" Principle, Measure problem, Arrow of time problem etc. (they are really the same "problem")

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Is this Science? If you invoke Inflation, you've already used the "Probability" argument.

Summary

- Vanilla Inflation is a great fit to Planck (hard to make progress without additional info)
- Need more probes to guide our understanding of the inflationary mechanism from string theory
- Inflation still faces challenging conceptual issues. (Don't be turned off by dirty words.)