String Phenomenology – Connecting String Theory to Particle Physics and Cosmology

Susha Parameswaran

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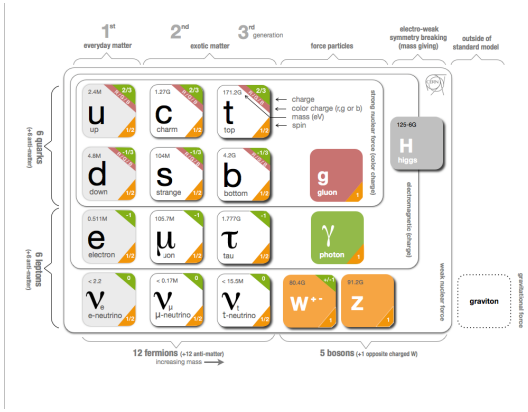

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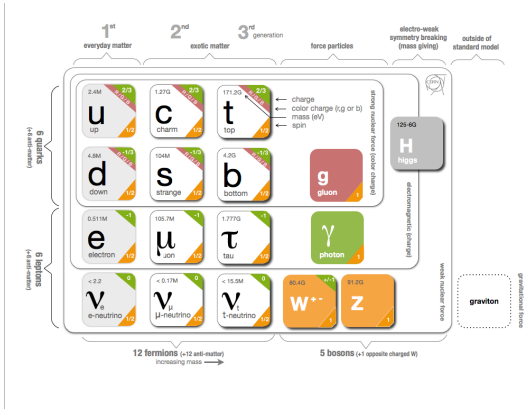

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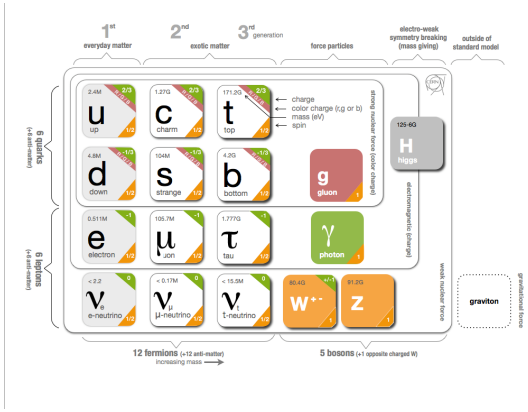

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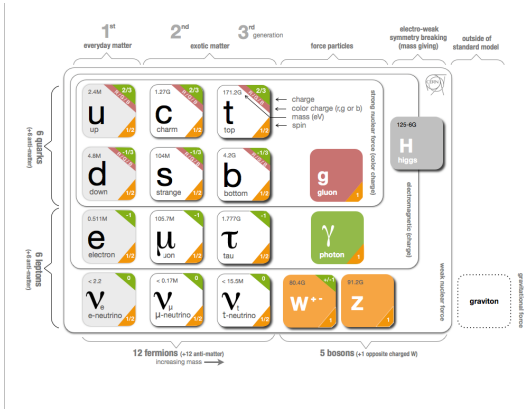

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- We expected new physics at LHC...

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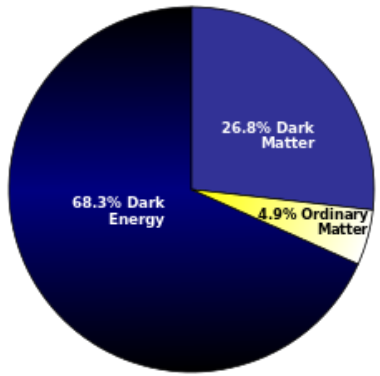

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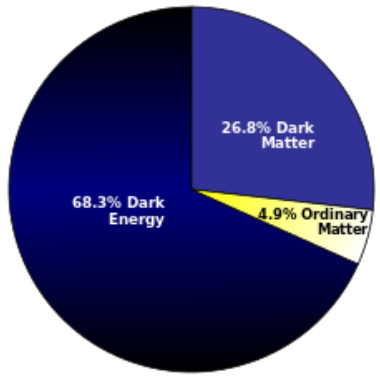

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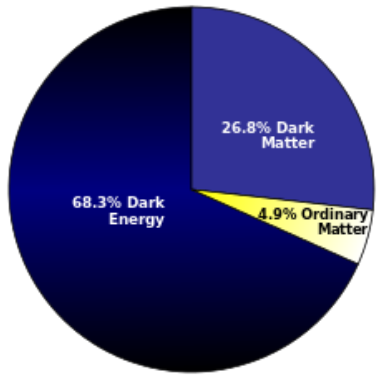

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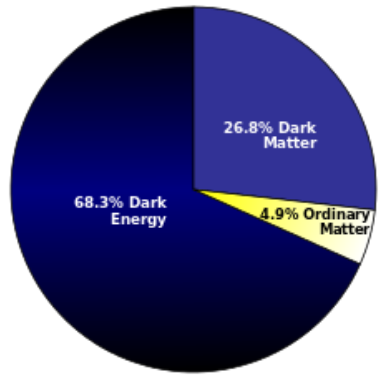

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- Simplest candidate is vacuum energy, but its scale should be $\rho \sim 10^{-120} M_{Pl}^4$. An even harder naturalness problem – even quantum fluctuations of electrons contribute 10^{36} times too much.

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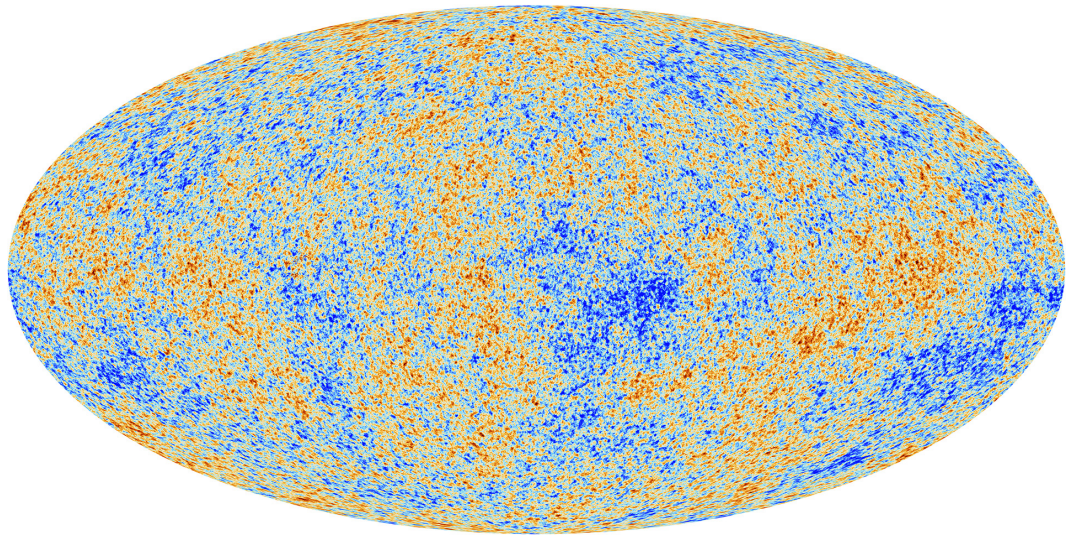
- Consistency of string theory requires ten spacetime dimensions and usually supersymmetry.
- We construct and study models of particle physics and cosmology from string theory, to solve problems and make predictions.
- We are very constrained both from the internal consistency of string theory and from imposing consistency with the standard models and observations.

Cosmic Microwave Background (CMB)

A "baby portrait" of the Universe at $380,000$ years old.



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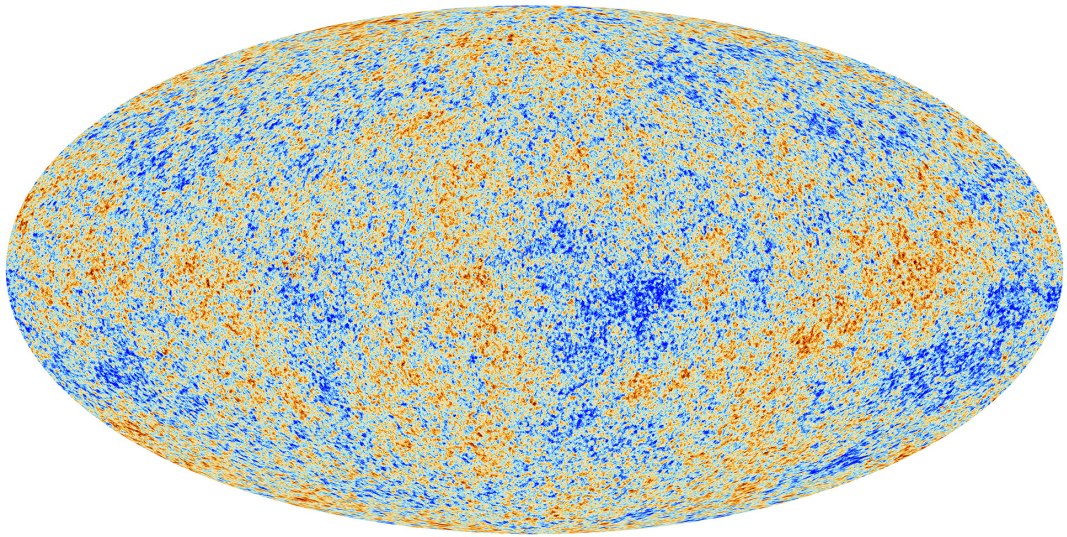

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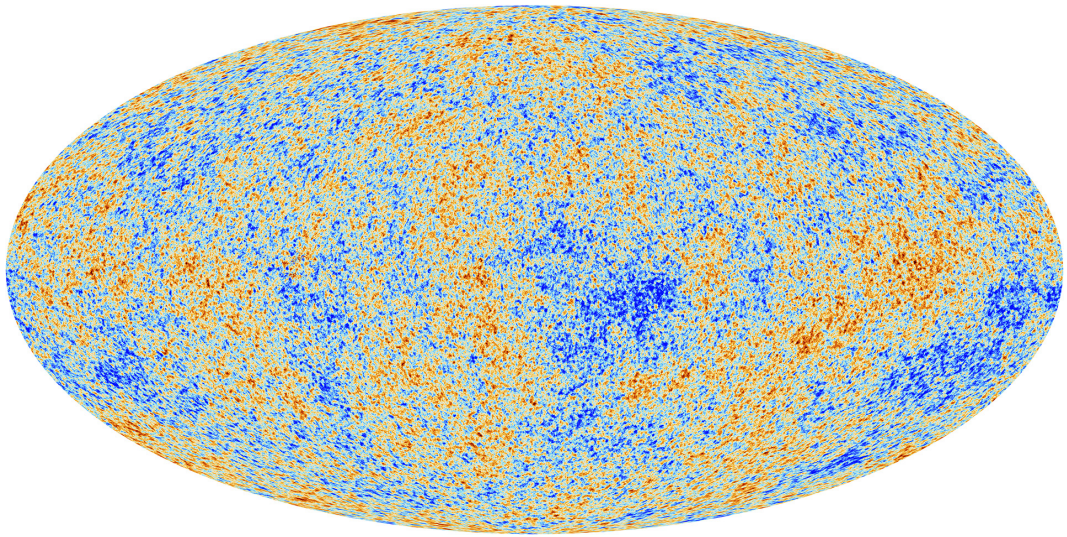

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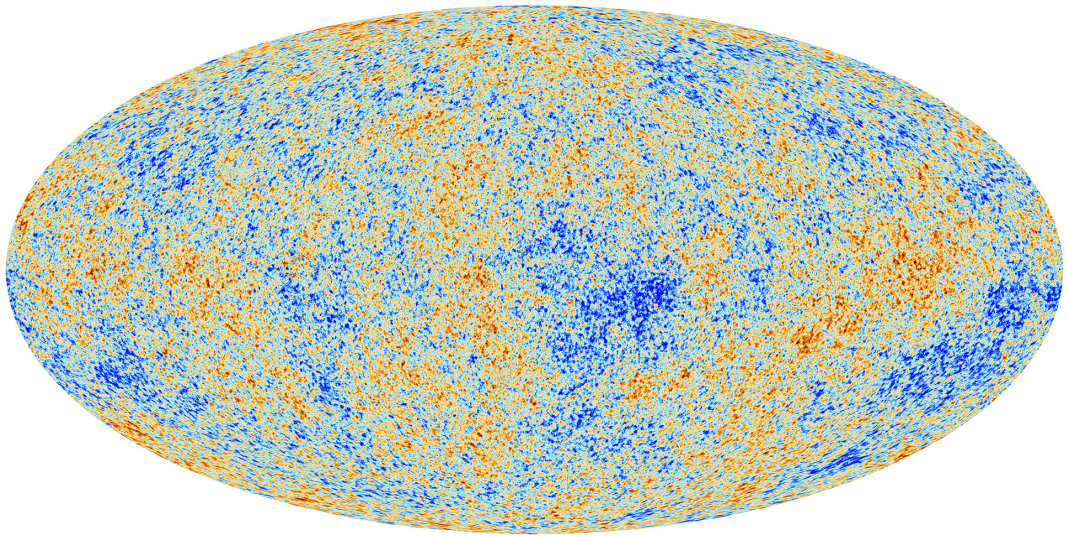

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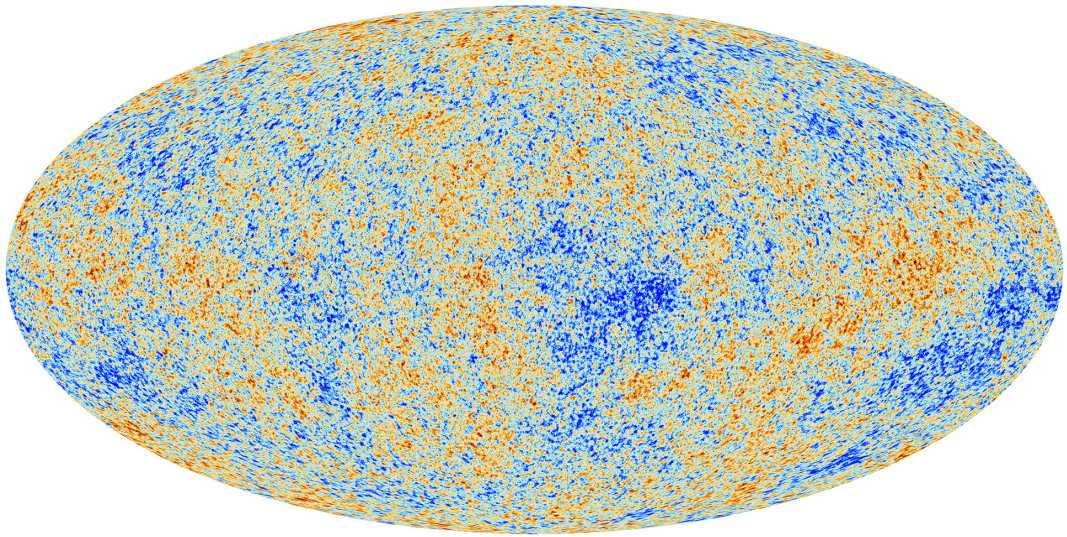

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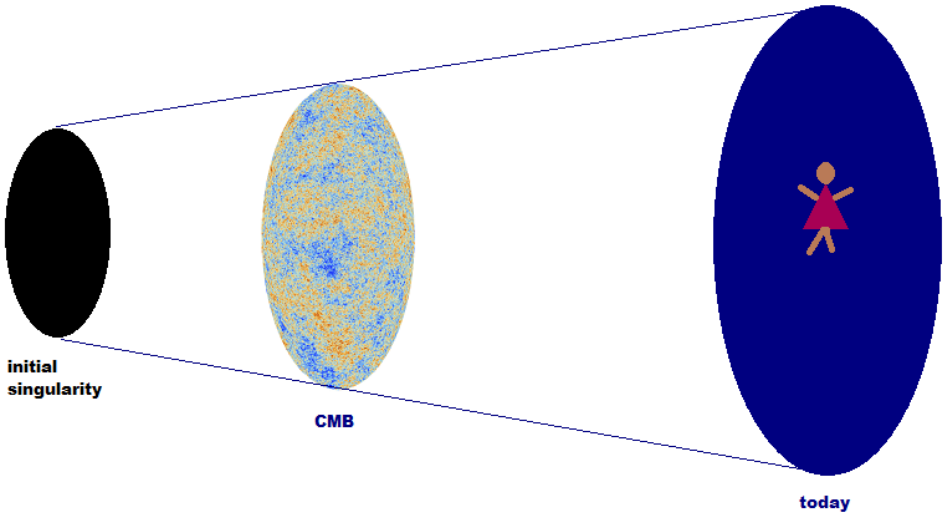
- Temperature of the CMB is almost the same throughout the sky, with tiny anisotropies at less than 1 part in 10,000.

Cosmic Inflation



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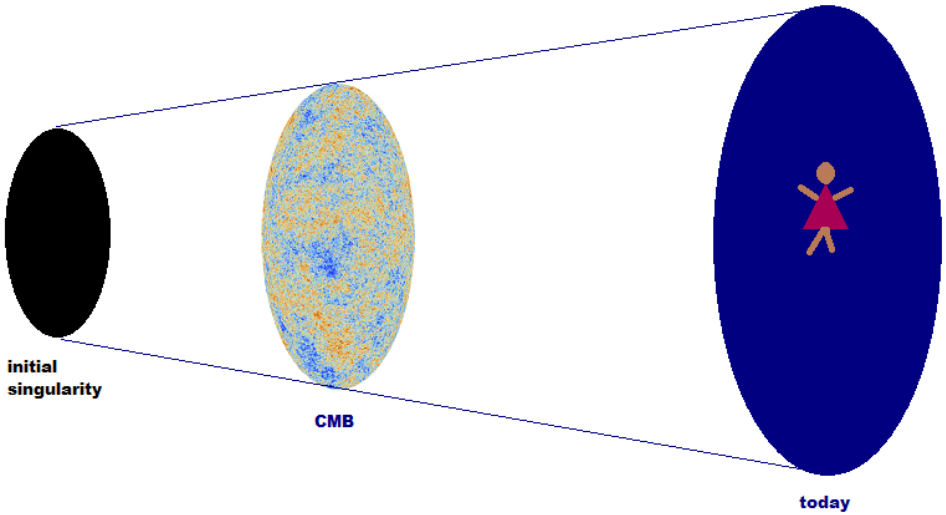

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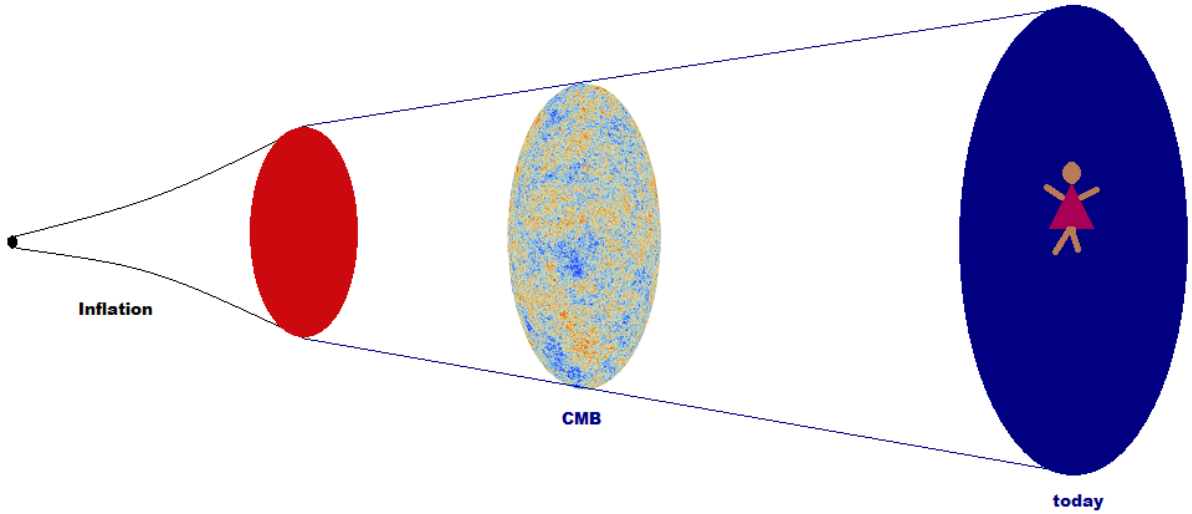

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- Extend the history of Universe with a period of exponential expansion, with space expanding by a factor $\sim 10^{50}$ within the first $\sim 10^{-30}$ sec – inflation!

  Guth '81, Linde '82, Albrecht & Steinhardt '82
- Before inflation, the entire universe was small and causally connected $\Rightarrow$ explains the CMB isotropy... and tiny anisotropies!

Slow Roll Inflation

- Einstein's theory of general relativity:

$$G_{\mu\nu}[g_{\mu\nu}] = T_{\mu\nu}[matter]$$

with inflationary solution $ds^2 = -dt^2 + a(t)\left(dx^2 + dy^2 + dz^2\right)$ and scale factor $a(t) = e^{Ht}$.

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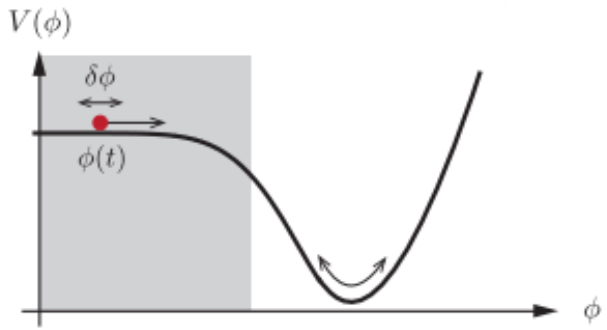

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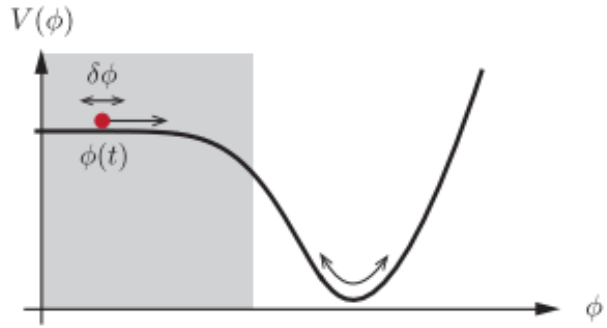

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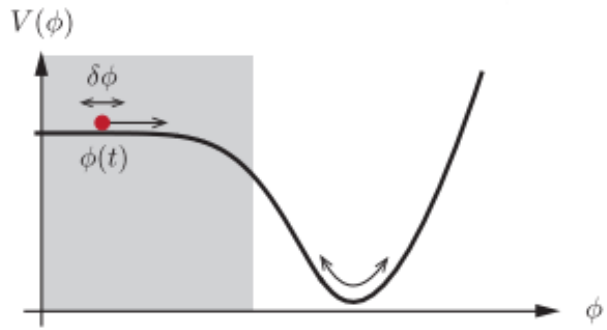

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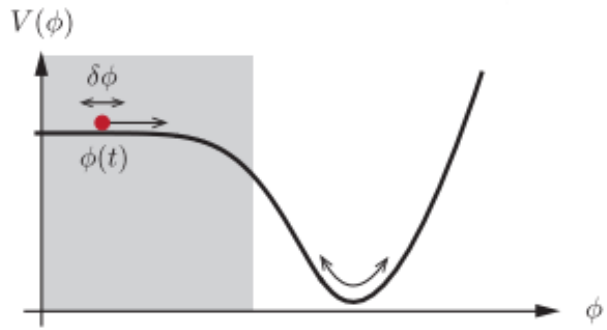

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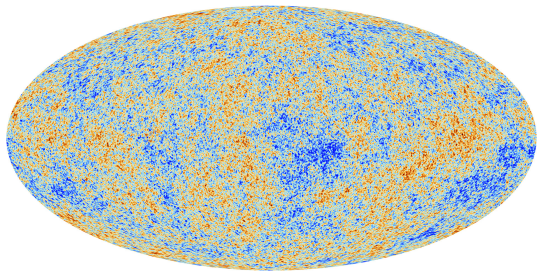
Observational Constraints on Inflation

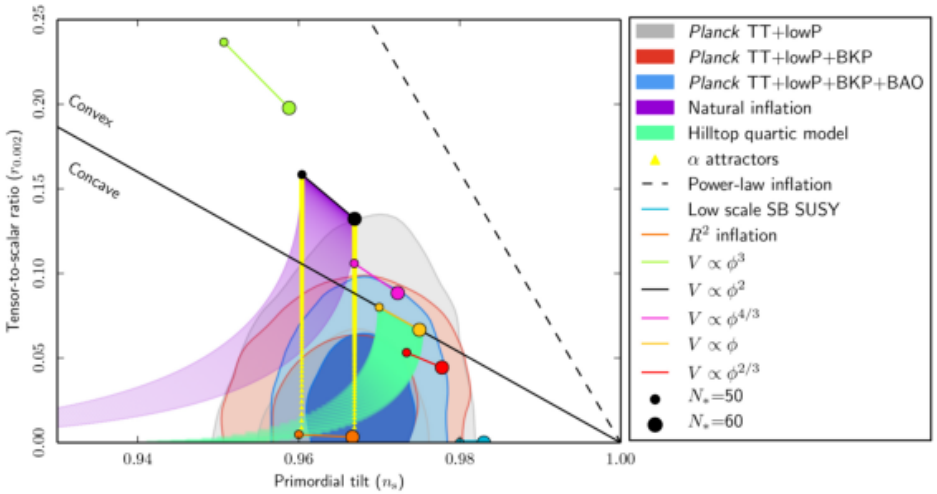
- Inflation was proposed to explain why the CMB is so isotropic, but its big success was to predict the temperature anisotropies subsequently measured in the CMB.

Mukhanov & Chibisov '81



Planck '15

- Precision observations can moreover now be used to test different models of inflation, $V(\phi)$!



Planck '15

Inflation and Quantum Gravity

We can build empirically successful models of inflation using effective field theory GR + $\phi(t, \underline{x})$, but we know this is not a complete theory.

Quantum gravity implies corrections to effective field theory and $V(\phi)$:

$$\Delta V(\phi) = \sum_n c_n V(\phi) \left(\frac{\phi}{M_{pl}}\right)^{\delta_n - 4}$$

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Inflation must be understood within a quantum theory of gravity:

- What is the origin of ϕ and $V(\phi)$?
- Why do quantum gravity corrections not spoil inflation... within slow roll (symmetry) or with new mechanisms?

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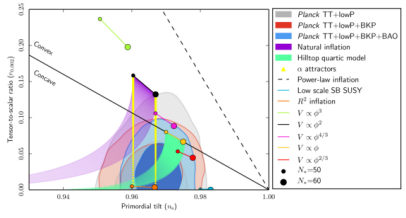
- String theory is unique but has many solutions or vacua... work towards explicit realisations of inflaton and its potential in string theory...
- Do generic properties of string theory prefer or exclude certain regimes of the cosmological parameter space?
- Understanding string inflation connects string theory to observations!

A string model of inflation

One of the simplest field theory candidates for inflation is inflaton with:

$$V(\phi) = \frac{1}{2} m^2 \phi^2$$

Excluded by observations:

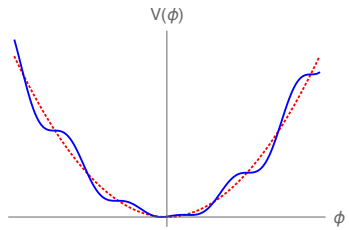


Planck '15

String theory implies corrections to leading potential:

Parameswaran, Tasinato, Zavala '16

$$V(\phi) + \Delta V(\phi) = \frac{1}{2} m^2 \phi^2 + \sum_n \Lambda_n \cos\left(\frac{n\phi}{f}\right)$$



Restores model into favour with Planck - with distinctive predictions for upcoming observations... including primordial black holes as dark matter.

Özsoy, Parameswaran, Tasinato, Zavala '18

Dark Energy in String Theory

- Late-time acceleration of the Universe driven by Dark Energy is similar to early-Universe inflation, involving, however, much lower energy scales

$$\rho_{DE} \sim 10^{-120} M_{pl}^4$$

.

- Because Dark Energy epoch does not have to end, it may simply be vacuum energy – but vacuum energy computed from Standard Model is 55 orders of magnitude too large!
- In string compactifications, many additional contributions to vacuum energy – in some string solutions there may be fine-tuned cancellations to yield the observed vacuum energy – such a solution may be anthropically selected.
- Alternatively, Dark Energy may be a slowly-rolling scalar field, like the inflaton. String theory predicts many light scalar fields, which may interact with each other in interesting ways, to help achieve potential energies that source Dark Energy.

Hardy & Parameswaran '19; Gomes, Hardy & Parameswaran to appear

Summary

- String theory is our leading candidate for a theory of quantum gravity - can it describe our Universe and explain the fundamental problems in particle physics and cosmology? Faraggi, Parameswaran
- String theory is unique but has many distinct solutions - rich in ideas to describe physics Beyond the Standard Model. Hardy
- Building string theory models of the Universe uses modern mathematical tools and has even led to the development of new mathematics. Mohaupt, Tatar
- We are in a Golden Age for Cosmology, with unprecedented precision observations - and a new era of gravitational waves astronomy - perhaps our best hope to connect string theory to experiment.