Testing Inflation with High Precision Measurements of the Primordial Power Spectrum

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Precision cosmology

We are the first generation of human beings to have accurately measured the global properties of our universe...
...and build an understanding of its global history
Dark Ages → CMB → Inflation → Nucleosynthesis

Story of the primordial universe | WMAP/NASA
Two Questions
One: Why is the universe so smooth?
Two: Why isn’t it completely smooth?
Universe evolves; current form is a set by its earlier state...
So what did the universe look like, right after the Big Bang?
A baby, with a high level of fine-tuning…
Problems solved by inflation

• Period of *accelerated* expansion, just after the big bang
  • In fact, the universe could be “born” inflating
  • Universe grows (at least) $10^{30}$ times larger during inflation

• Smooths out any initial bumps and lumps
  • Generates ripples via quantum fluctuations...

• No-one knows why inflation happens

• “Flatness”
But why?

- Why does inflation happen?
  - Needs matter with negative pressure…
  - Relies on high energy physics
  - But not *known* high energy physics
- Problem is not finding mechanisms that could drive inflation
  - Problem is also that we have found tooooo many
All happy families are alike; each unhappy family is unhappy in its own way.
All smooth universes are alike; each lumpy universe is lumpy in its own way.
Measure the power spectrum...

- Look at perturbations
  - Via microwave background, galaxy clustering, Lyman-
    Baryon acoustic oscillations
  - High redshift 21cm
- Must also pin down other key variables (dark matter, dark energy, Hubble constant, reionization history)
- And back out evolution to get primordial spectrum
Take A Fourier Transform…

- Regular spatial transform for 3D structures
- Spherical harmonics for the CMB
- Three variables
  - Amplitude (almost always a free parameter)
  - Spectral index — how does the amplitude change with wavelength
  - Running — how does spectral index change with wavelength
- Plus gravitational waves (may be effectively zero)
Inflationary Model Space

Planck, 2015
Generic Inflationary Model

- 4th order polynomial potential
  - Bird, Peiris & RE arXiv:0807.3745
  - [And that’s just me]

- But (so far as I know) no-one has catalogued all possible inflationary behaviours
The Potential

- Original form
  \[ V(\phi) = \frac{m^2}{2} \phi^2 - \frac{g}{3} \phi^3 + \frac{\lambda}{4} \phi^4 \]

- Complex degeneracies between \( m, g \) and \( \lambda \)

- However, choose \( m^2 = \lambda M^2, \ g=2\lambda M \Delta \)

\[ V(\phi) = \lambda \left( \frac{M^2}{2} \phi^2 - \frac{2}{3} \Delta M \phi^3 + \frac{1}{4} \phi^4 \right) \]
Specify “Physical” Priors

- Details in paper (and largely a matter of taste)
  - But this formulation gives “orthogonal” parameters
  - Location of plateau; minimal $V’$, overall scale...
- Compare to uniform distributions for $n_s$, $r$ and $\alpha_s$
  - Bayesian network; view $M$ and $\Delta$ as hyperparameters
- cf Price, Peiris, Frazer & RE arXiv:1511.00029
- Inflationary model selection problem (to do)
Spectral index, derived prior
Tensor: scalar ratio derived prior
Spectral running derived prior
Joint Distributions…

- Strong covariance between $n_s$, $r$ and $\alpha_s$
  - But: not all combinations are possible
- Rule of thumb: given measured $n_s$, one of $r$ and $\alpha_s$ above "observable" threshold
  - $\sim 0.001$ for either parameter (??)
- Possible to rule out all these models…
  - Needs high redshift 21cm? Maaaaaybe CMB
Possible future bounds ($r < 0.001$, $n_s = 0.96 \pm 0.006$, $\alpha_s = 0.0 \pm 0.001$)

Allowed regions
$n_s$: red, $r$: blue, $\alpha_s$: green
Conclusions…

- Can describe a huge catalog of inflationary models via a single potential

- Possible (but futuristic) observations could rule out the full parameter volume for this scenario

- Traction from very high z / very low frequency 21cm

- Need a long “lever arm” in frequency to resolve the running

- Wait and see…