Inflationary Observables beyond r

Raphael Flauger

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Question

We would like to do well on r,
neutrino masses, and $N_{\rm eff}$, dark energy.

Are there other inflationary observables that should be kept in mind for the design of the CMB S4 experiment?

Aiming for Thresholds

Can we identify values of cosmological parameters for which we learn something *qualitatively* new?

Can we reach these values in an ideal experiment?

Can we realistically reach them with CMB S4 without sacrificing r, neutrino mass, $N_{\rm eff}$?

r

There are two thresholds for r that are interesting for various reasons

- $r \sim 0.01$
- $r \sim 0.003$

r

- $r \sim 0.01$

(Motivated by Lyth bound,
stringy constructions, $n_s - 1 \propto 1/N, ...$)

This would likely be "seen" by other experiments before CMB S4 takes data

r

- $r \sim 0.003$

(Starobinsky model, non-minimally coupled inflaton with large ξ ,$n_s - 1 \propto 1/N$, ...)

Values (significantly) below this are possible and inflation is not ruled out altogether, but

$$\sigma_{\mathrm{realistic}}(r) \sim 0.001$$

would disfavor two large classes of inflationary models at $> 3\,\sigma$ (or to detect a signal.)

Consistency Condition

Single field slow-roll with canonical kinetic term predicts

$$n_t = -\frac{r}{8}$$

Given current constraints on r, the consistency condition cannot be tested with the CMB alone.

Scalar Spectral Index

If r is detected, a precise measurement of n_s becomes very interesting to distinguish between models

Are there interesting thresholds?

Running

Slow-roll inflation makes a prediction for the running of the scalar spectral index.

$$\alpha_s = \frac{(n_s - 1)r}{2} + \frac{3r^2}{32} - 2\xi$$

with $$\xi = \frac{V'V'''}{V^2}$$

Running

For the two classes of models interesting for the B-mode search

Monomial: $$\alpha_s = -\frac{1+p/2}{N^2} = -\frac{(n_s-1)^2}{1+p/2}$$

Starobinsky: $$\alpha_s = -\frac{2}{N^2} = -\frac{(n_s-1)^2}{2}$$

The simplest models are certainly out of the reach of a CMB S4 experiment ($\sigma(\alpha) \approx 0.002$)

Running

The same is true in “most” other models

For the monomial models, oscillatory contributions to the potential are natural

$$V(\phi) = V_0(\phi) + \Lambda^4 \cos\left(\frac{\phi}{f}\right)$$

For large axion decay constants ($f \gtrsim 0.01\ \mathrm{M}_p$) these can lead to large running

Running

The amplitude can be arbitrarily small so that there are no natural thresholds.

Are there thresholds in other models with potentially observable running?

Features, Wiggles, etc.

While well motivated, the amplitude can again be arbitrarily small.

Any thresholds?

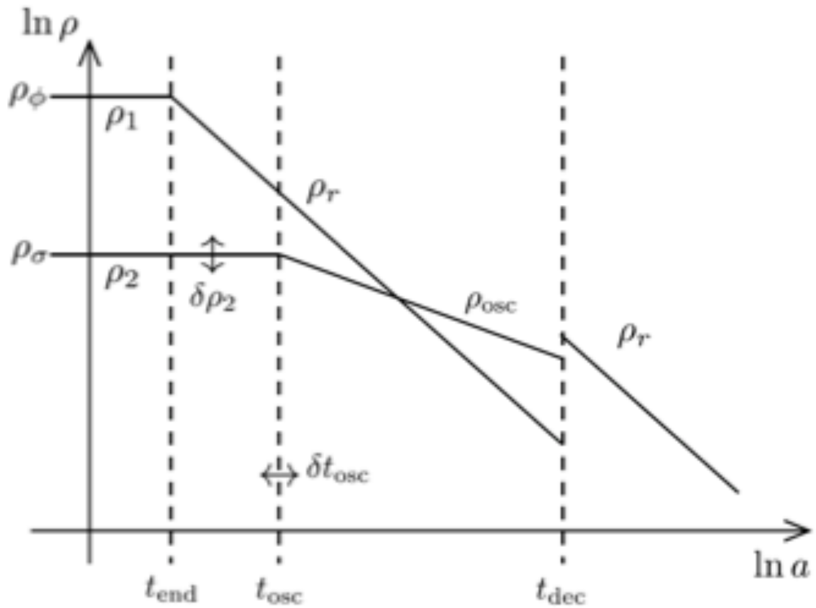
Non-Gaussianity

There are several interesting thresholds for the three-point function

- $f_{\rm NL}^{\rm loc} \sim 1$ (expected in multi-field models)
- $f_{\rm NL}^{\rm eq} \sim 1$ (expected in single-field models with non-trivial dynamics)
- non-Gaussianity from slow-roll inflation

Unfortunately all out of reach of primary CMB

Non-Gaussianity



Curvaton Scenario:

$$f_{\rm NL}^{\rm loc} = \left(\frac{\mathcal{P}_\zeta^\sigma}{\mathcal{P}_\zeta^\sigma + \mathcal{P}_\zeta^\phi}\right)^2 \left[\frac{5}{4r_{\rm dec}}\left(1 - \frac{gg''}{g'^2}\right) - \frac{5}{3} - \frac{5r_{\rm dec}}{6}\right]$$

Modulated Reheating:

$$f_{\rm NL}^{\rm loc} = \left(\frac{\mathcal{P}_\zeta^\sigma}{\mathcal{P}_\zeta^\sigma + \mathcal{P}_\zeta^\phi}\right)^2 \left[5\left(1 - \frac{\Gamma\Gamma''}{\Gamma'^2}\right)\right]$$

- Simple ‘spectator field’ models of multiple field inflation predict f_{NL}~O(1) making that level of sensitivity a natural theory target
- Are there other theoretically interesting thresholds for local non-Gaussianity?
- Are there other observables which inform our view of single versus multiple field inflation (e.g. r is predicted to be small in spectator field models)?

slide by Joel Meyers

See discussion in Alvarez, et al. (2014), 1412.4671

Non-Gaussianity

For the four-point function a natural target is

$$\tau_{NL} \sim f_{NL}^2$$

Unfortunately also out of reach.

Constraints on other shapes are interesting but no thresholds?

Will making progress require, LSS, SPHEREx?

Spatial Curvature

Tunneling events "generically" lead to negative spatial curvature ($\Omega_K > 0$).

If the number of e-folds is close to the lower limit (within ~6), this leads to $\Omega_K > 10^{-5}$.

Given current bounds, this seems unlikely (about 3 e-folds left), but the low multipole data might be reason for hope and the payoff would be huge.

Together with BAO data, CMB S4 will set interesting limits.

Isocurvature modes

Any thresholds?

Are we missing anything?

- Primordial magnetic fields?

Tentative conclusions

- There are no obvious thresholds that should be taken into account in the design beyond those for r, neutrino mass, $N_{\rm eff}$, dark energy

- Spectral index, running, non-Gaussianity, etc. benefit from large sky fraction and multipole range, similar to neutrino mass, $N_{\rm eff}$.

- We should try to reliably achieve

$$\sigma_{\rm realistic}(r) \sim 0.001$$

  beyond that maximize sky coverage and multipole range.

Expected Signals