Primordial Features from Linear to Nonlinear Scales

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In collaboration with Matteo Biagetti, Daniel Green, Anze Slosar & Benjamin Wallisch

[arXiv:1906.08758]
Inflation in one plot

Baumann (2009)

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Testing inflation through primordial features

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\[
P\zeta,0(k) = \frac{2\pi^2}{k^3} P\zeta,0(k) = \frac{2\pi^2 A_s}{k^3} \left( \frac{k}{k_*} \right)^{n_s-1}
\]
Testing inflation through primordial features

\[ \Delta P_\zeta(k) = A_{\text{lin}} \sin \left( \omega_{\text{lin}} k + \phi_{\text{lin}} \right) \]

[Sharp Features]
Starobinsky (1992)
Adams, Cresswell & Easther (1997)

\[ P(k) \times 10^{-9} \]

\[ k \text{ [Mpc}^{-1} \text{]} \]

Linear features

\[ \omega_{\text{lin}} = 271.8 \text{ Mpc} \]

\[ k \text{ [Mpc}^{-1} \text{]} \]

HZ spectrum

\[ \Delta P_\zeta(k)/P_{\zeta,0} \]

\[ A_{\text{lin}} \sin \left( \omega_{\text{lin}} k + \phi_{\text{lin}} \right) \]
Testing inflation through primordial features

Logarithmic features

\[ \frac{\Delta P_\zeta(k)}{P_{\zeta,0}(k)} = A_{\log} \sin \left( \omega_{\log} \log \left( \frac{k}{k_*} \right) + \phi_{\log} \right) \]

[Resonant features]
Chen, Easther & Lim (2008)
Silverstein & Westphal (2008)
Flauger, McAllister, Pajer & Westphal (2010)

...
Non-linear gravitational evolution

Crocce & Scoccimarro (2008)

\[ P_g(k) = b_1^2 \left[ e^{-k^2 \Sigma_{nl}^2/2} P_{\text{lin}}(k) + P_{\text{MC}}(k) \right] \]

\[ P_{\text{MC}}(k) \approx 2 \int F_2^2(k - q, q) P_{\text{lin}}(|k - q|) P_{\text{lin}}(q) d^3q \]

Heavens & Matarrese (1998), McDonald (2006),
Smith et al. (2007), Carlson et al. (2009)
Blas et al. (2016)
Density-field reconstruction

\[ \nabla \cdot \Psi + \frac{f}{b} \nabla \cdot (\Psi_s \hat{s}) = -\frac{\delta g}{b} \quad \text{with} \quad f = \frac{d \ln D}{d \ln a} \]

Schmittfull, FB et al. (2016)

\[ \Sigma_{\text{post-recon}}^{\text{nl}} < \Sigma_{\text{pre-recon}}^{\text{nl}} \]

\[ P_{\text{post-recon}}^{\text{MC}} \approx 0 \]

Eisenstein et al. (2007), Padmanabhan et al. (2009)
Padmanabhan et al. (2012) . . .
Fitting the BAO

- Model for the BAO
  \[ P(k) = P^{nw}(k) + e^{-k^2 \Sigma_{nl}^2 / 2} P^w_{BAO}(k / \alpha) \]

- Add broadband nuisance terms
  \[ A(k) = a_1 k + a_2 + \frac{a_3}{k} + \frac{a_4}{k^2} + \frac{a_5}{k^3} \]

\[ P^{fit}(k) = \frac{B^2}{(1 + (k \Sigma_{FOG})^2 / 2)^2} P(k) + A(k) \]

- Marginalize to get \( L(\alpha) \).
→ 2 simulations with the same phase but based on $P_{\text{lin}}$ and $P_{\text{lin}}^{\text{nw}}$
→ Allows to measure the BAO (almost) without sample variance
Modelling the BAO

\[ \alpha = \alpha^{1/3}_{||} \alpha^{2/3}_{\perp} \]
Modelling the BAO

\[ \alpha = \alpha_{\parallel}^{1/3} \alpha_{\perp}^{2/3} \]

Ding, Vlah, FB et al. (2018)

1.5\% in BOSS DR12

2.5\% in BOSS DR12
→ 2 independent $8\sigma$ detections
→ 1% distance constrains (1.5% in $D_A(z)$ and $\sim 2.5\%$ in $H(z)$)
Feature damping

**Linear Feature**
- Damping factor of linear features equal to BAO damping for $\omega_{\text{lin}} \gtrsim 75\,\text{Mpc}$

**Logarithmic Feature**
- Damping factor of log features approx. equal to BAO damping for $\omega_{\text{log}} \gtrsim 10$

$$P(k) = P_{\text{nw}}(k) + e^{-k^2\Sigma^2_{\text{nl}}/2} \left[ P_{\text{BAO}}^w(k/\alpha) \right]$$
Feature damping

### Linear Feature
- Damping factor of linear features equal to BAO damping for $\omega_{\text{lin}} \gtrsim 75$ Mpc

$$P(k) = P_{\text{nw}}(k) + e^{-k^2\Sigma_{\text{nl}}^2/2} \left[ P_{\text{BAO}}^w(k/\alpha) + P_{\text{lin},\log}^w(k) + P_{\text{BAO}}^w(k/\alpha)\delta P_{\text{lin},\log}^\zeta(k) \right]$$

### Logarithmic Feature
- Damping factor of log features approx. equal to BAO damping for $\omega_{\text{log}} \gtrsim 10$

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Feature constraints from BOSS DR12 and Planck

BOSS

BOSS vs. Planck

BOSS + Planck
Feature constraints from BOSS DR12 and Planck

BOSS

BOSS vs. Planck

BOSS + Planck
Feature constraints from BOSS DR12 and Planck

BOSS

BOSS vs. Planck

BOSS + Planck
→ LSS dominates on small frequencies, while the CMB can access higher frequencies
→ DESI/Euclid are going to beat even CVL-CMB experiments
Many well motivated inflationary models introduce features in the primordial power spectrum
And we know how to detect features → BAO

Constraints on primordial features from LSS are already better than Planck for a large frequency range

Future LSS constraints from DESI and Euclid will push into a parameter space, which is even beyond a CVL-CMB experiment
Many well motivated inflationary models introduce features in the primordial power spectrum. And we know how to detect features → BAO.

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Future LSS constraints from DESI and Euclid will push into a parameter space, which is even beyond a CVL-CMB experiment.
1. Many well motivated inflationary models introduce features in the primordial power spectrum. And we know how to detect features → BAO

2. Constraints on primordial features from LSS are already better than Planck for a large frequency range

3. Future LSS constraints from DESI and Euclid will push into a parameter space, which is even beyond a CVL-CMB experiment
\[ \left( \frac{S}{N} \right)^2 = \sum_{k_1, k_2 \leq k_{\text{max}}} C^{-1}(k_1, k_2) P_m(k_1) P_m(k_2) \]
Dependence on fiducial cosmology

\[
\alpha = \alpha_\parallel^{1/3} \alpha_\perp^{2/3}
\]

Carter, FB et al. (2019)

\[\Delta \alpha_\parallel \]

\[\Delta \Omega_M \]

\[\Delta \alpha_\perp \]

\[\Delta A_s 10^{10} \]
Impact of the window function for features search

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