Primordial Features in Next-Generation Surveys

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Hypothesis:

Primordial features are (currently)
the best science driver
for a future spectroscopic survey

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- Well motivated theoretically
- Easy to extract from observations
- Leading constraints from large-scale structure
- Huge potential for improvements

cf. Slosar, ..., BW (Astro2020); Snowmass Inflation White Paper (leads: Pimentel, BW & Wu), Snowmass CF5/TF09 Reports (incl. BW), ...

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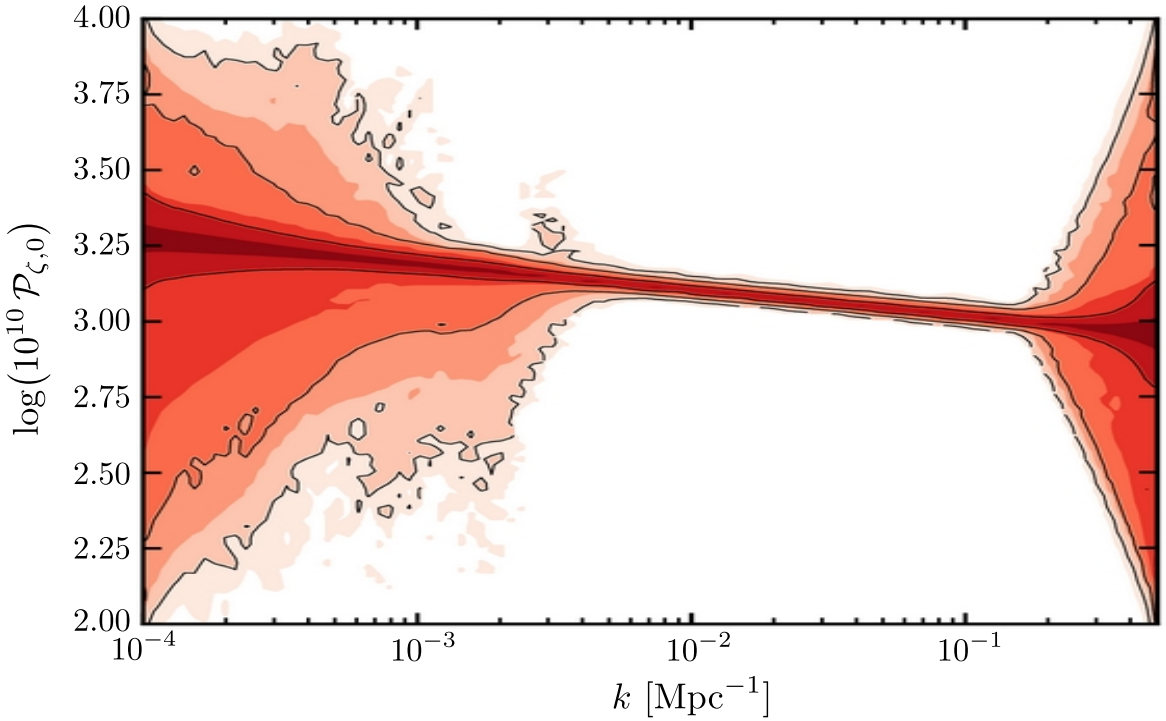
Primordial Power Spectrum

Primordial density fluctuations are inferred from observations as

Gaussian and almost scale invariant.

$\rightarrow$ Power-law power spectrum: $P_{\zeta,0}(k) = \dfrac{2\pi^2}{k^3}\mathcal{P}_{\zeta,0}(k) = \dfrac{2\pi^2 A_\mathrm{s}}{k^3}\left(\dfrac{k}{k_\star}\right)^{n_\mathrm{s}-1}$,



Planck Collaboration

Features in the Primordial Power Spectrum

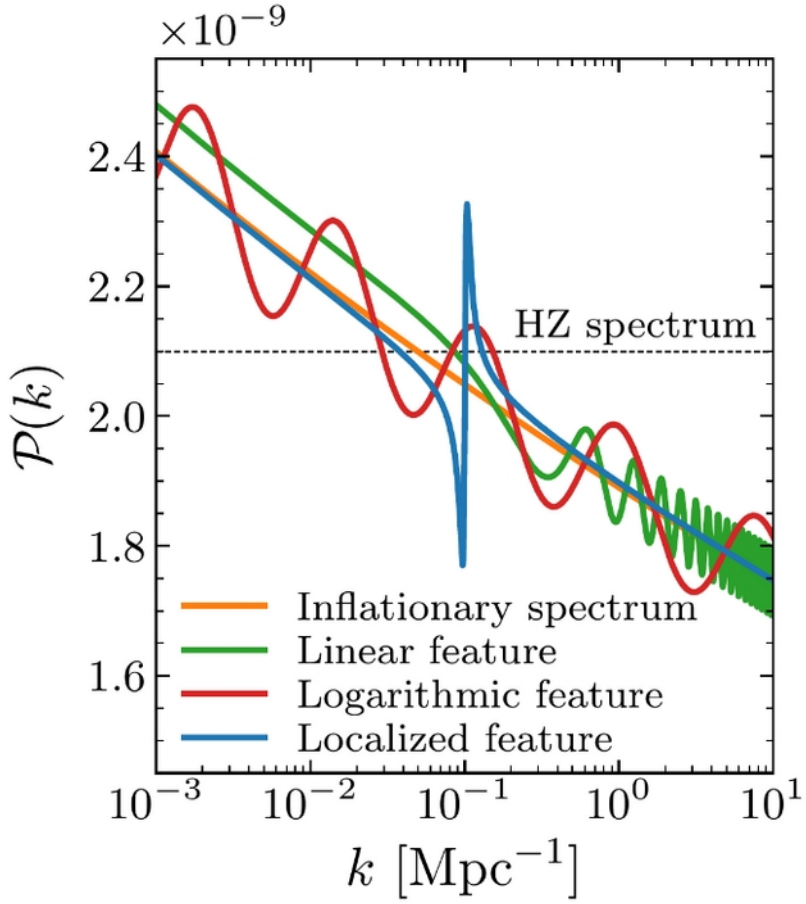
- Primordial dynamics may exhibit a significant departure from scale invariance:
  - → Generic in broad classes of models beyond simplest,
  - → New energy scale(s) during inflation.

- Ubiquitous when connecting inflationary modeling to fundamental physics.

- Strongly scale-dependent deviations from minimal power-law power spectrum:
  - → Oscillatory and/or localized imprints in momentum space:

$$P_\zeta(k) = P_{\zeta,0}(k) + \Delta P_\zeta(k)\,,$$

$$P_{\zeta,0}(k) = \frac{2\pi^2 A_\mathrm{s}}{k^3}\left(\frac{k}{k_\star}\right)^{n_\mathrm{s}-1}$$



cf. Slosar, ..., BW (Astro2020); Snowmass Inflation White Paper (leads: Pimentel, BW & Wu), ...

Theoretical Targets for Primordial Features

- Two main oscillatory classes:
  - Sharp features: momentary departure of evolution from attractor,
  - Resonant features: periodic oscillation around attractor solution.

- Correlated signals in power spectrum and higher-point spectra.

- Oscillatory imprints of higher-point signals in the galaxy power spectrum via scale-dependent bias (e.g. from additional heavy fields and cosmological collider).

- No useful theoretical priors on scale/amplitude of primordial features:
  - $\rightarrow$ Origin: lack of our understanding of fundamental physics,
  - $\rightarrow$ Cover as much of parameter and model space as possible.

cf. Slosar, ..., BW (Astro2020); Snowmass Inflation White Paper (leads: Pimentel, BW & Wu), ...

Focus on Oscillatory Features in the Power Spectrum

Phenomenological parameterization for several inflationary (and other) scenarios:

$$P_\zeta(k) = P_{\zeta,0}(k) + \Delta P_\zeta(k)\,,$$

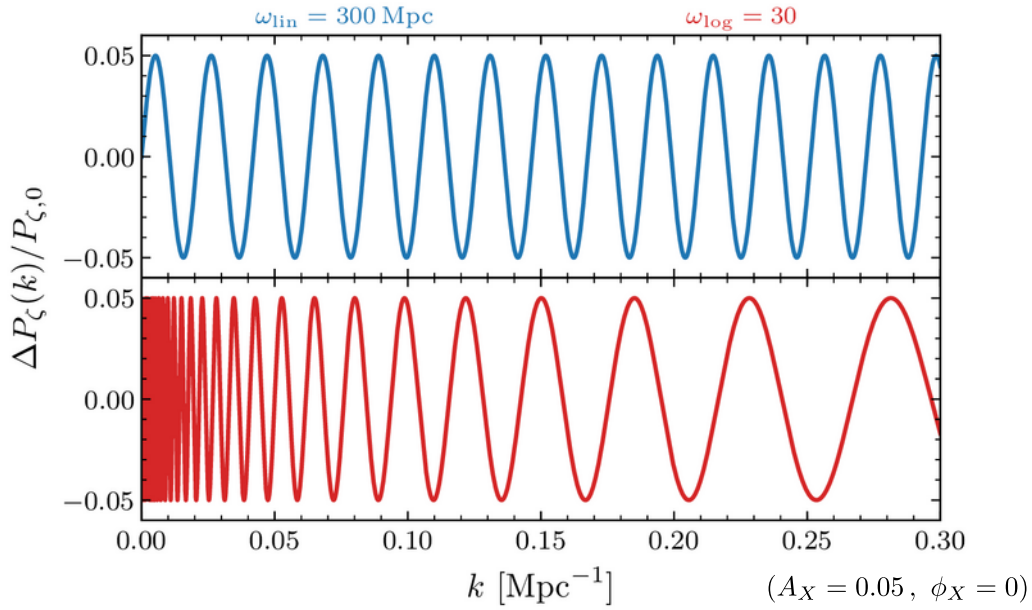
with

– linearly-spaced oscillatory features:

$$\frac{\Delta P_\zeta(k)}{P_{\zeta,0}} = A_{\rm lin}\,\sin(\omega_{\rm lin} k + \phi_{\rm lin})\,,$$

– logarithmically-spaced oscillatory features:

$$\frac{\Delta P_\zeta(k)}{P_{\zeta,0}} = A_{\rm log}\,\sin(\omega_{\rm log}\,\log(k/k_\star) + \phi_{\rm log})\,.$$



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Observing Inflationary Signals

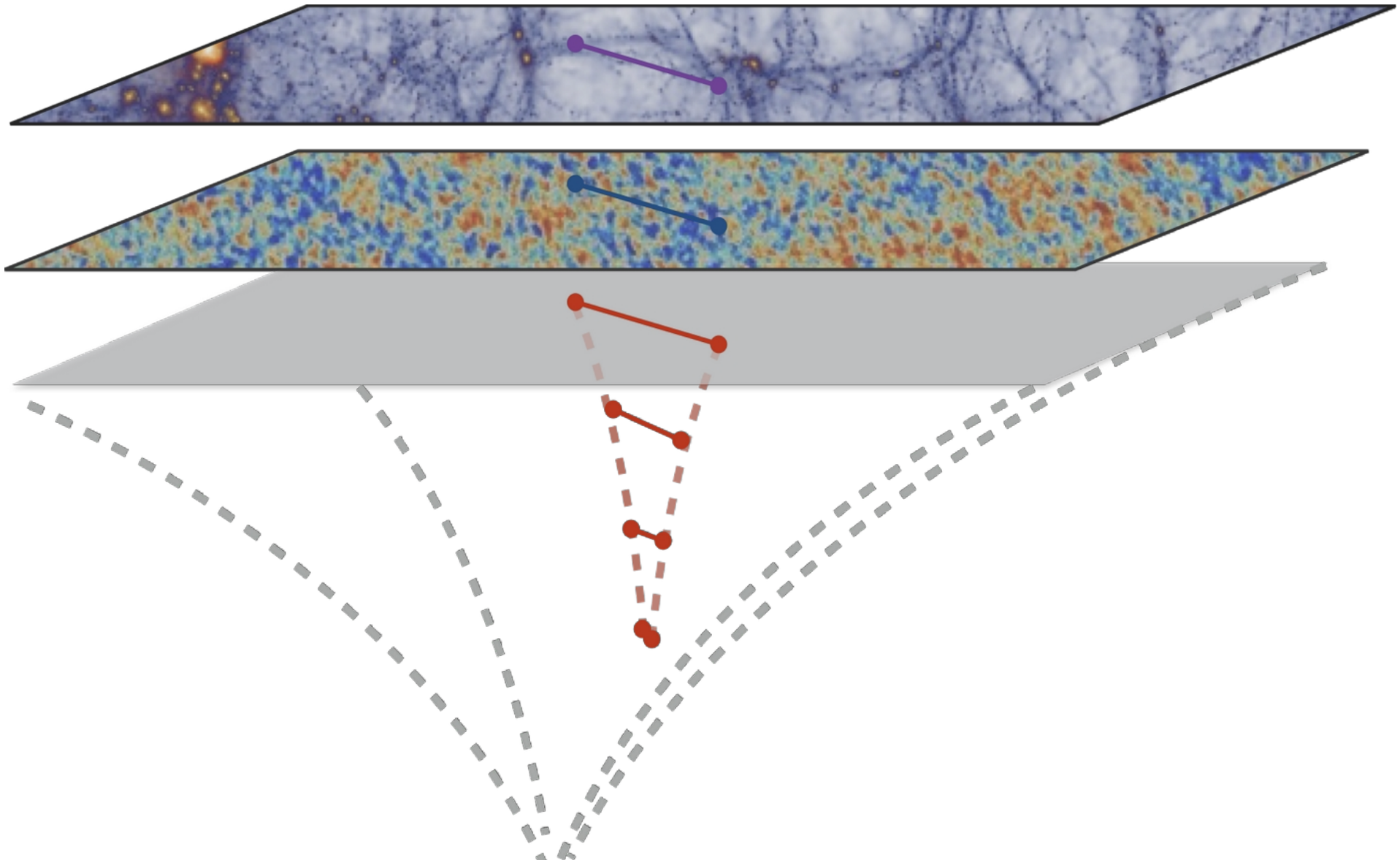
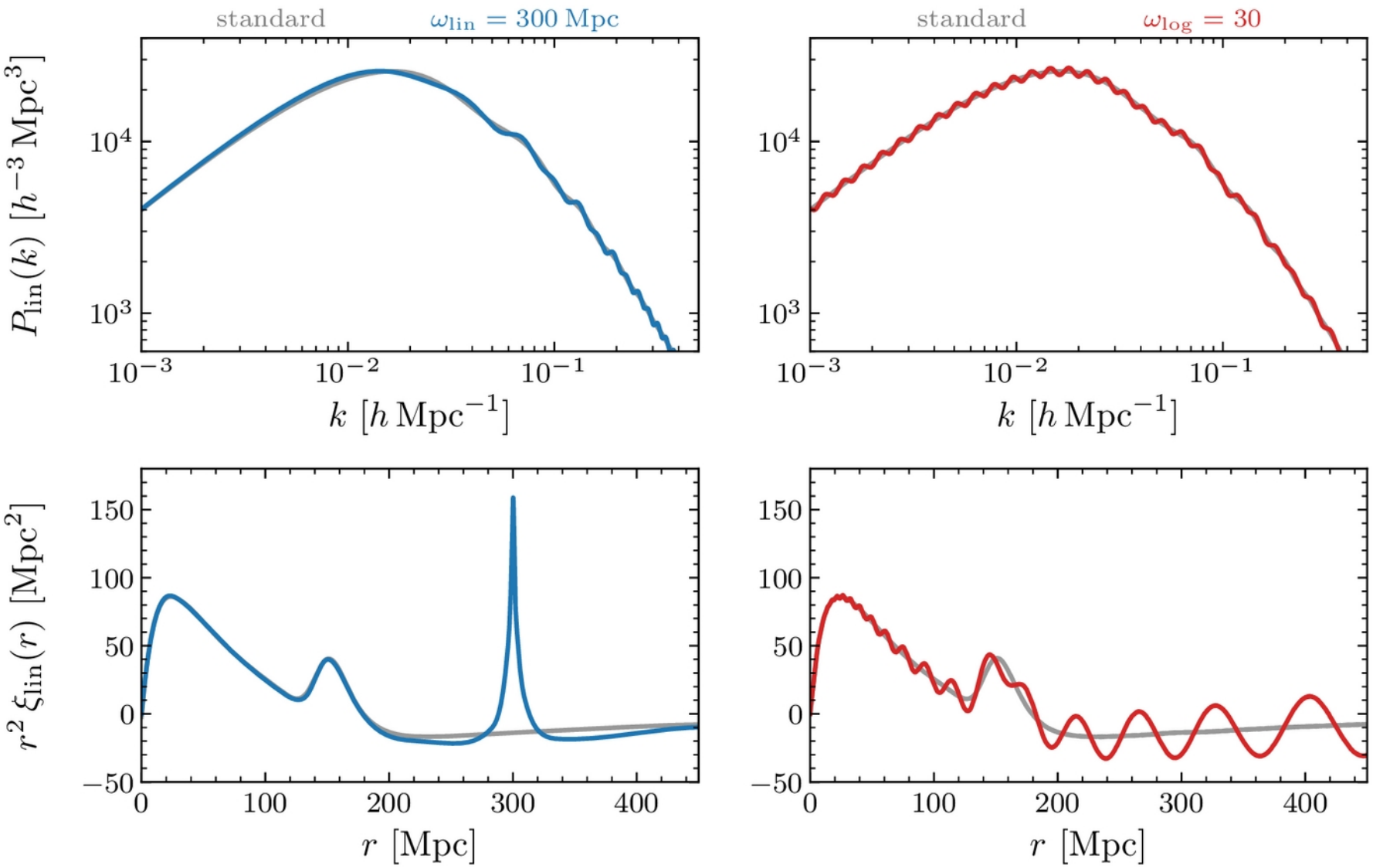


Figure by G. Pimentel

Primordial Features in LSS

Fourier space

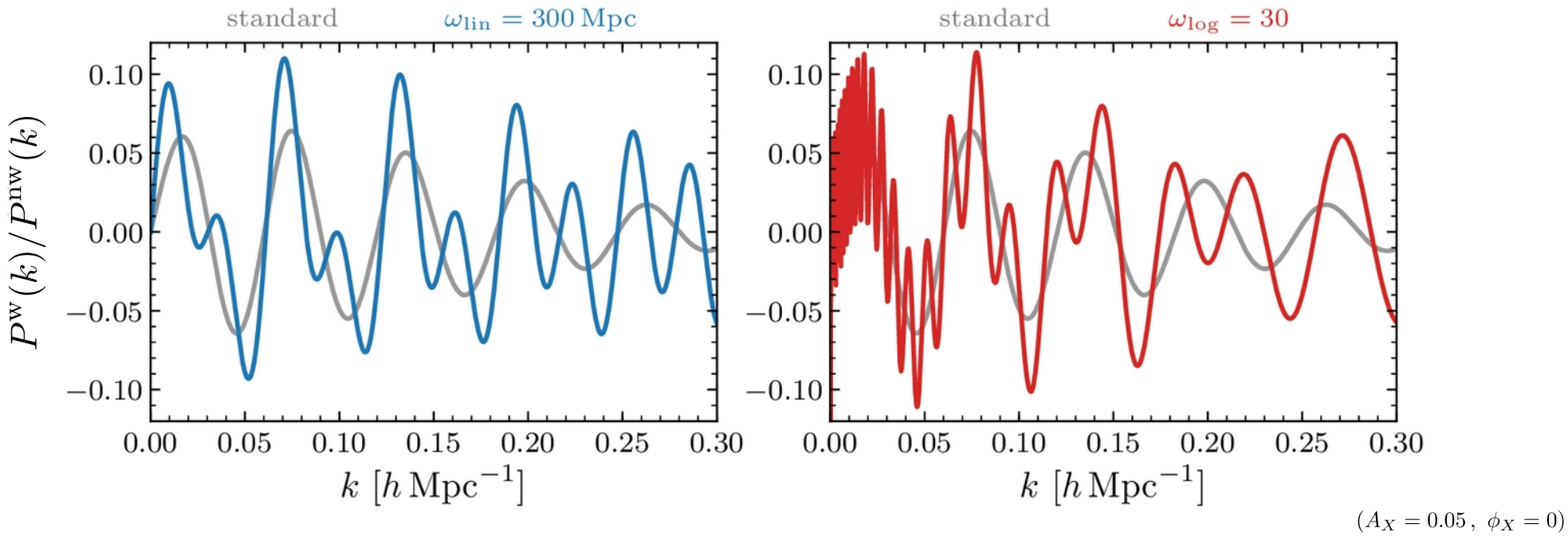
Real space



$(A_X = 0.05\,,\ \phi_X = 0)$

Beutler, Biagetti, Green, Slosar & BW

Primordial Features in the BAO Spectrum



→ Power-law power spectrum $P_{\zeta,0}(k)$ is part of broadband power spectrum.

→ Oscillatory features $\Delta P_\zeta(k)$ imprint oscillations on top of the BAO signal.

Beutler, Biagetti, Green, Slosar & BW

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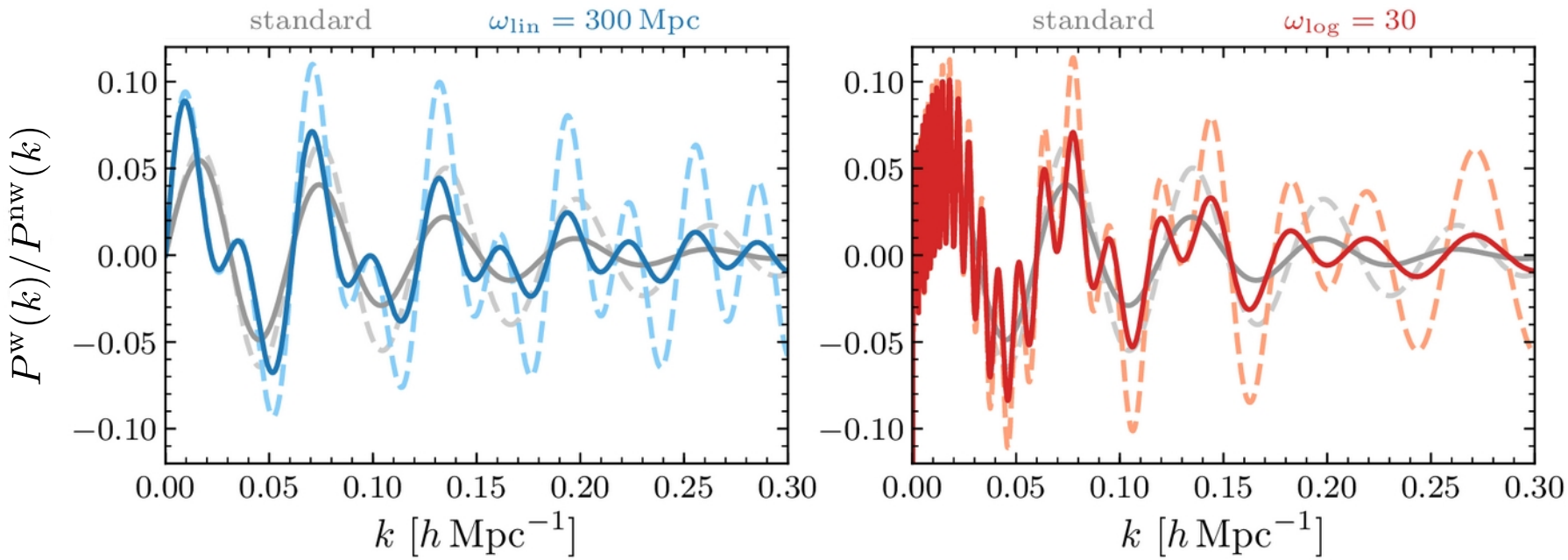

$(A_X = 0.05\,,\ \phi_X = 0,\ \Sigma_{\rm nl} = 3.5\,h^{-1}{\rm Mpc})$

→ Crucial to include nonlinear damping,

→ But known analytically,

→ Use full statistical power of LSS surveys.

Beutler, Biagetti, Green, Slosar & BW; see also Vasudevan, Ivanov, Sibiryakov & Lesgourgues

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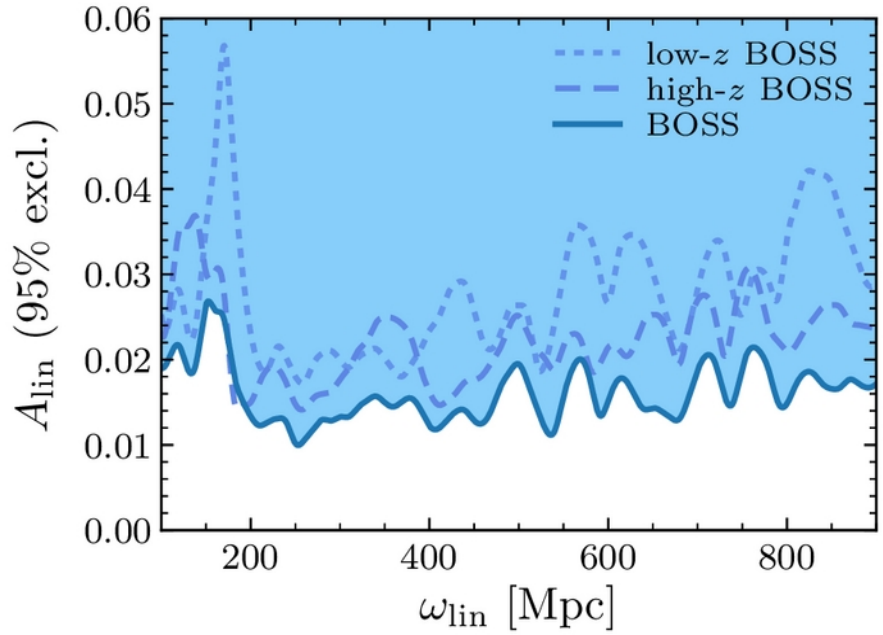
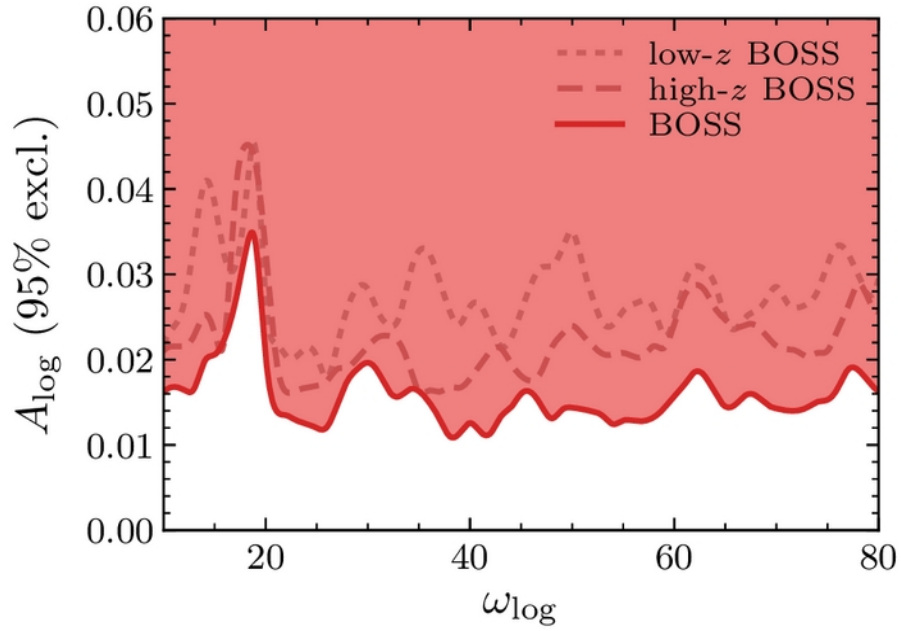
First Upper Limits from LSS in 2018

Upper limits from the BOSS DR12 dataset:





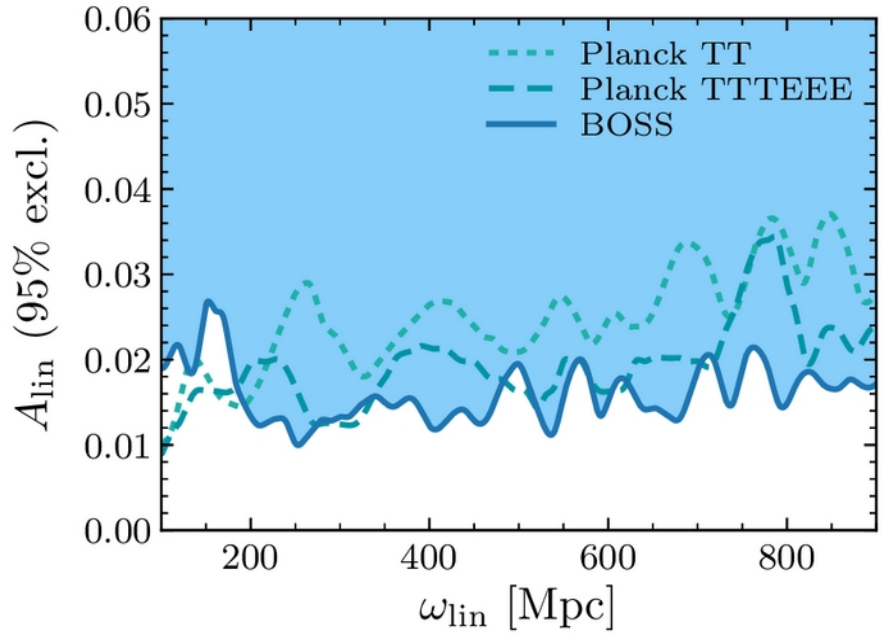
$\rightarrow$ Feature amplitudes are limited to $\mathcal{O}(1\%)$ relative to the primordial amplitude.

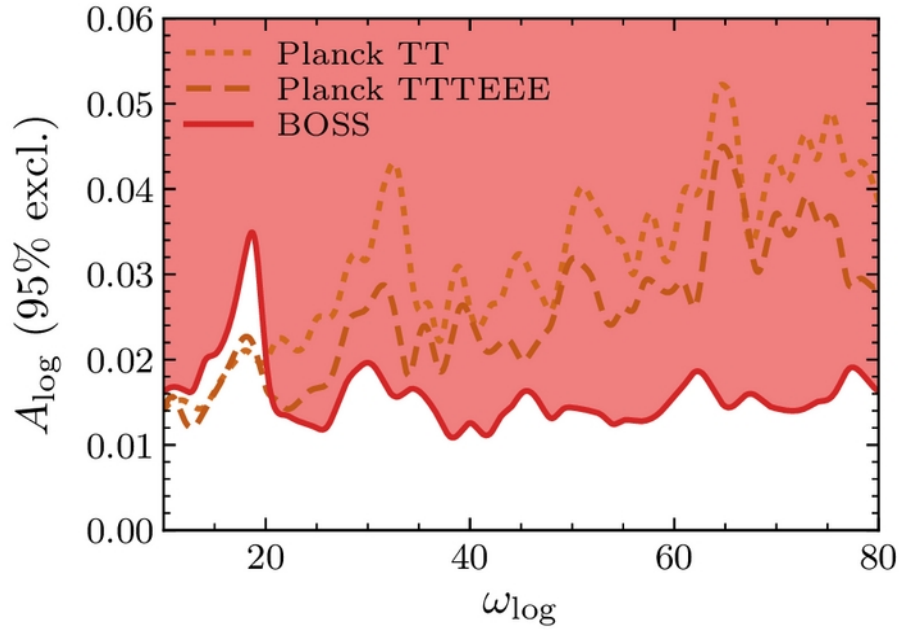
Beutler, Biagetti, Green, Slosar & BW

(see also Ballardini et al. for correlation-function analysis and Mergulhão, Beutler & Peacock for eBOSS)

Upper Limits from LSS and CMB

Upper limits from the BOSS DR12 dataset compared to Planck 2015:





$\rightarrow$ Feature amplitudes are limited to $\mathcal{O}(1\%)$ relative to the primordial amplitude.

$\rightarrow$ Competitive with current CMB constraints in available frequency range.

Beutler, Biagetti, Green, Slosar & BW

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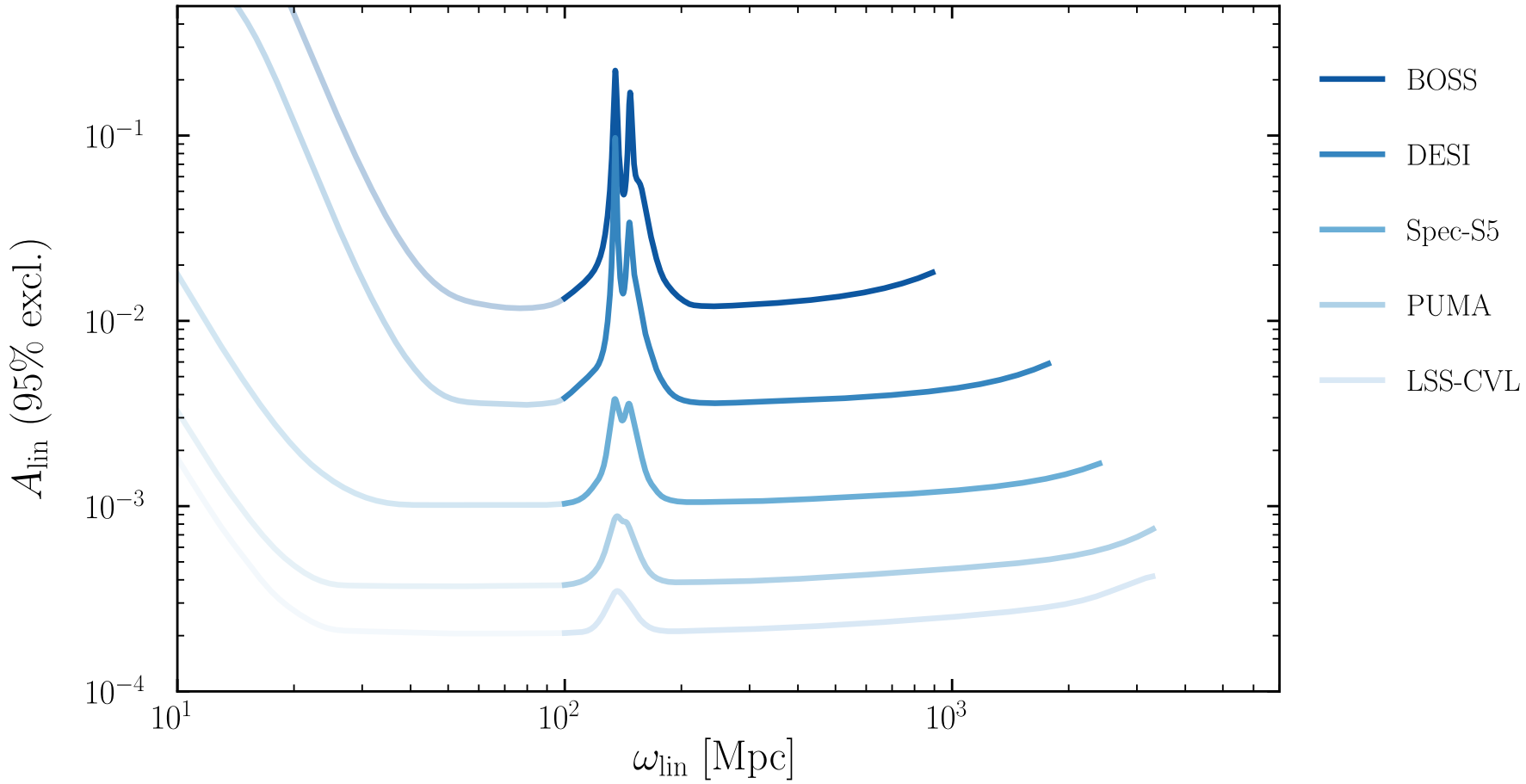
Future Prospects

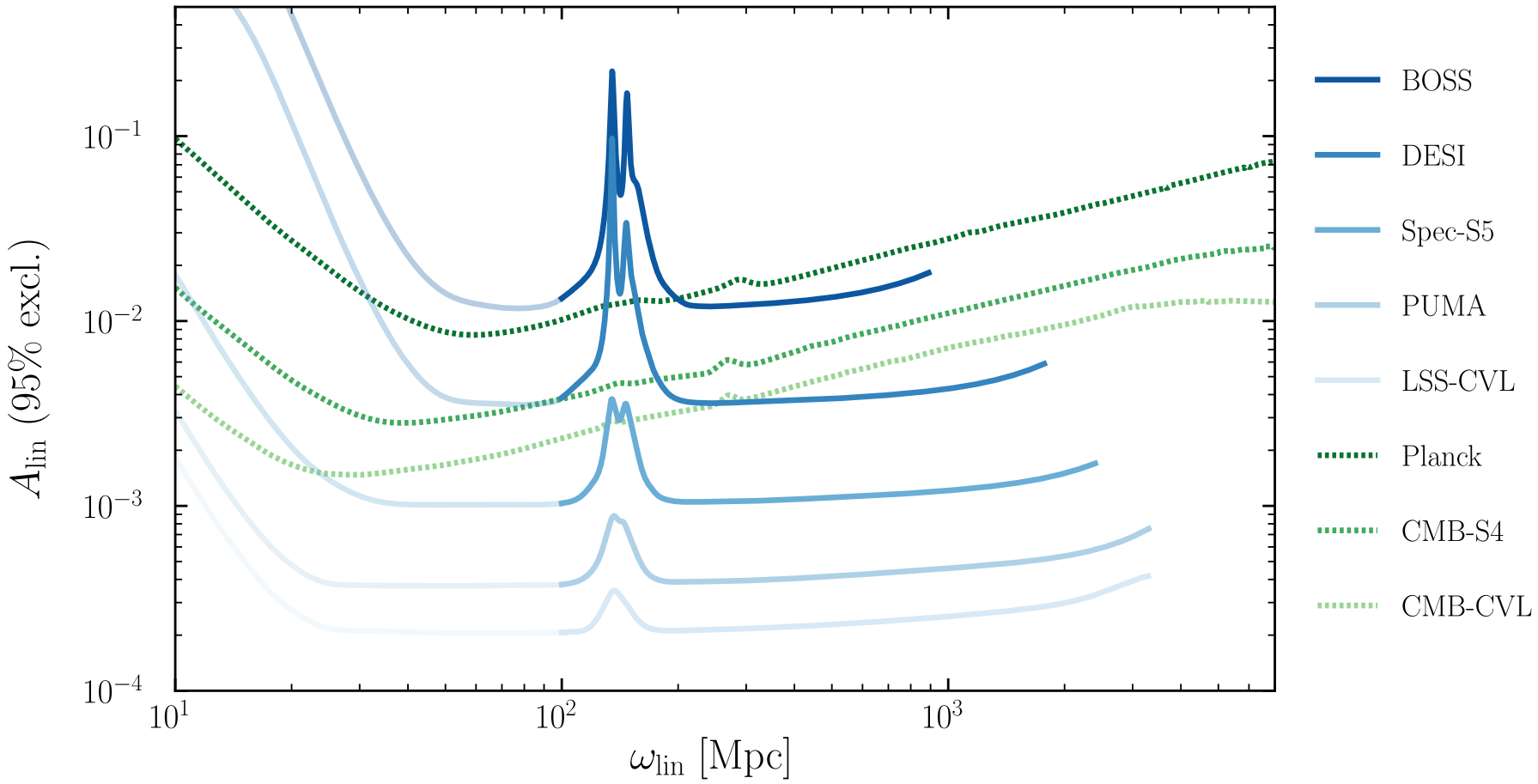
The sensitivity to primordial features will greatly improve with future observations...



following Beutler, Biagetti, Green, Slosar & BW (see also Sailer, Castorina, Ferraro & White and others)

Future Prospects

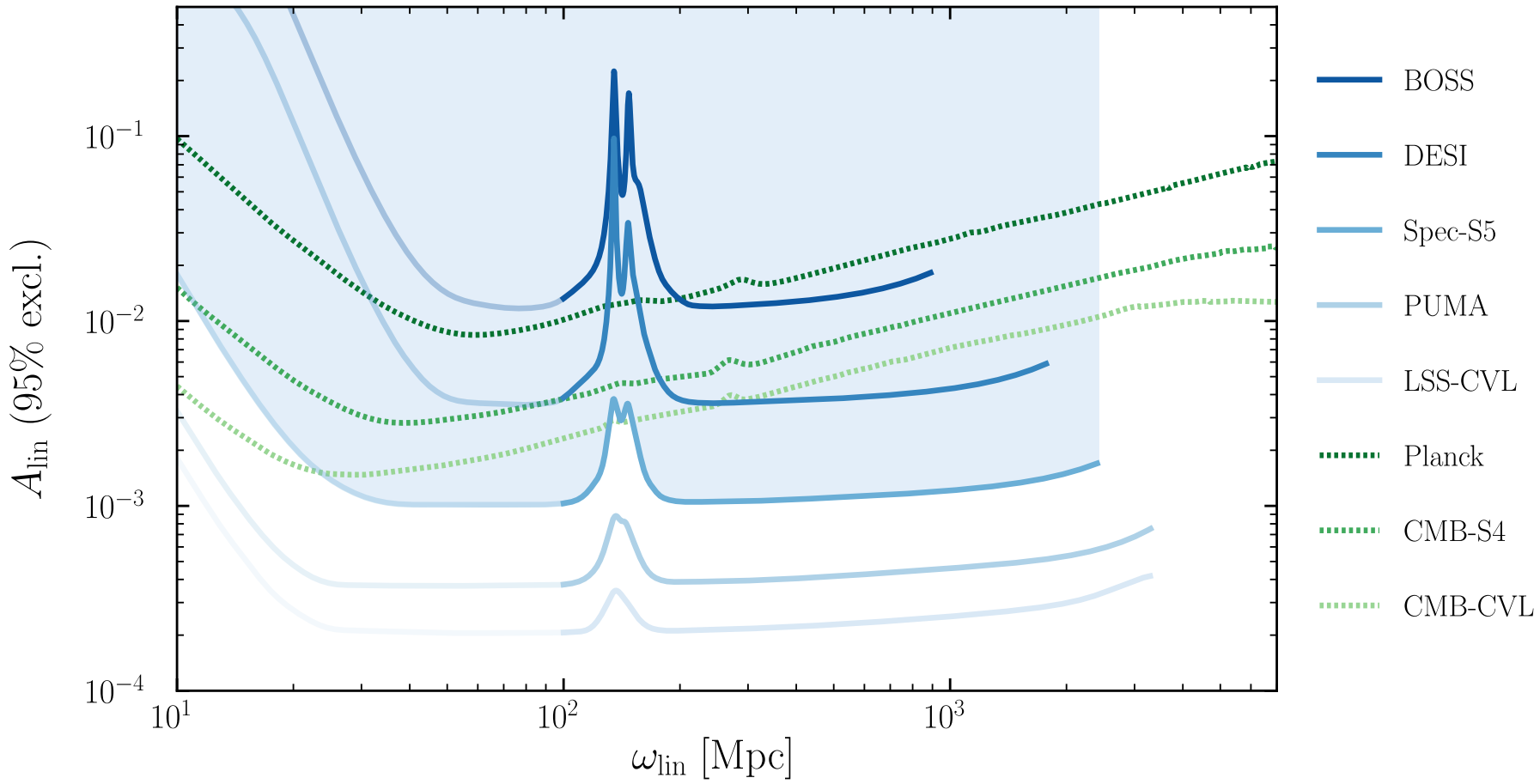
... and LSS surveys will clearly beat CMB observations over large frequency range:



following Beutler, Biagetti, Green, Slosar & BW

Survey Properties Driving the Improvements

Larger number of signal-dominated modes and larger volumes:



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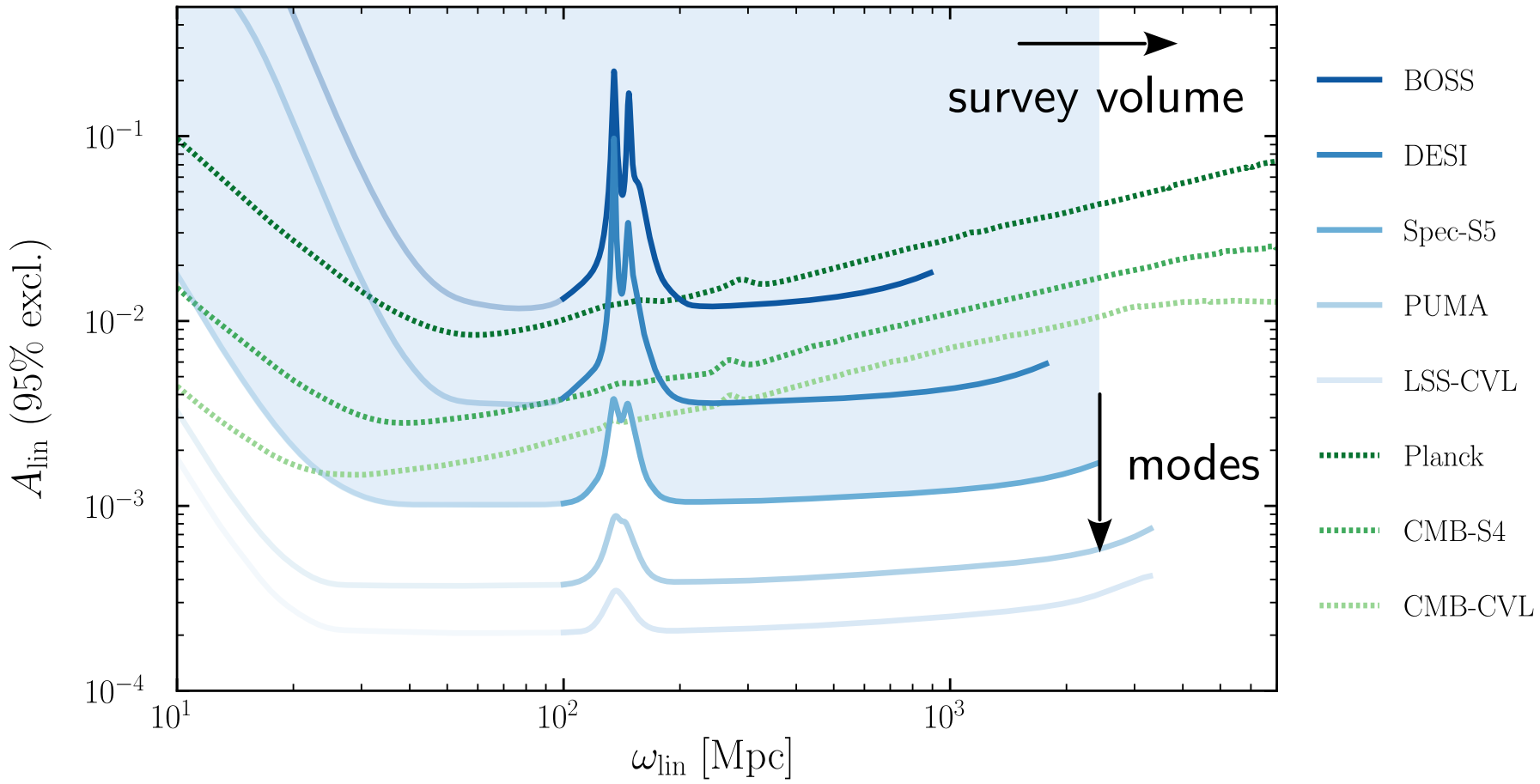

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Summary

- Potential detection of primordial features could have profound implications for our understanding of fundamental physics.
- Upper limits can inform model building efforts and narrow the vast theoretical possibilities.
- Large-scale structure surveys have the best sensitivity and improvement potential.
- We are ready for prime time (after a few additional straightforward checks).

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- Easy to extract from observations!
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- Huge potential for improvements!

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Let us find more!

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