Dissecting the Primordial Signal in Large-Scale Structure Power Spectra

Benjamin Wallisch

Stockholm University & UT Austin

Based on work with Daniel Green, Yi Guo & Jiashu Han (on arXiv soon!),
and published work with Florian Beutler, Matteo Biagetti, Daniel Green & Anže Slosar

New Physics from Galaxy Clustering II, Trieste, November 2023

Observing Inflationary Signals

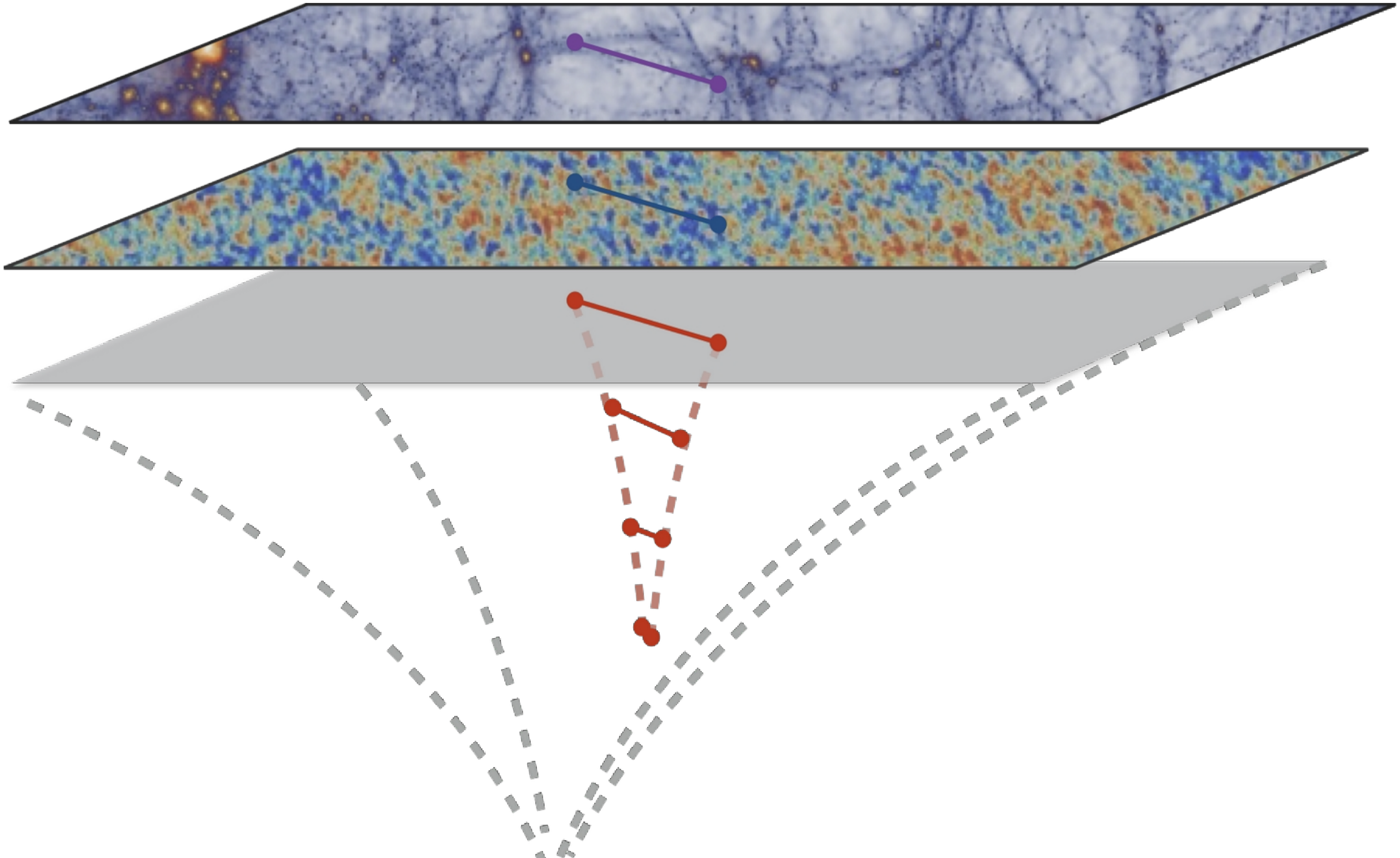
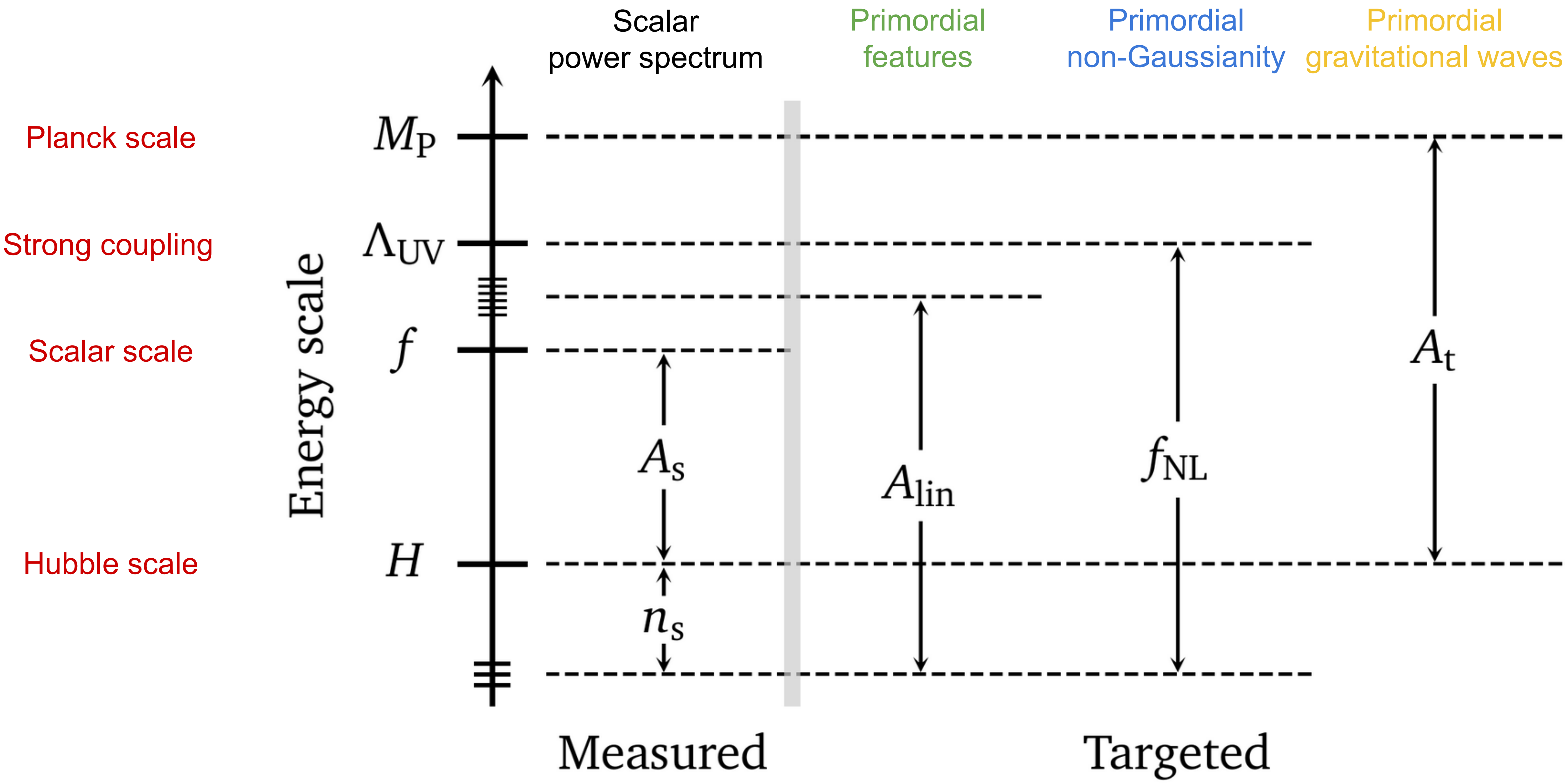


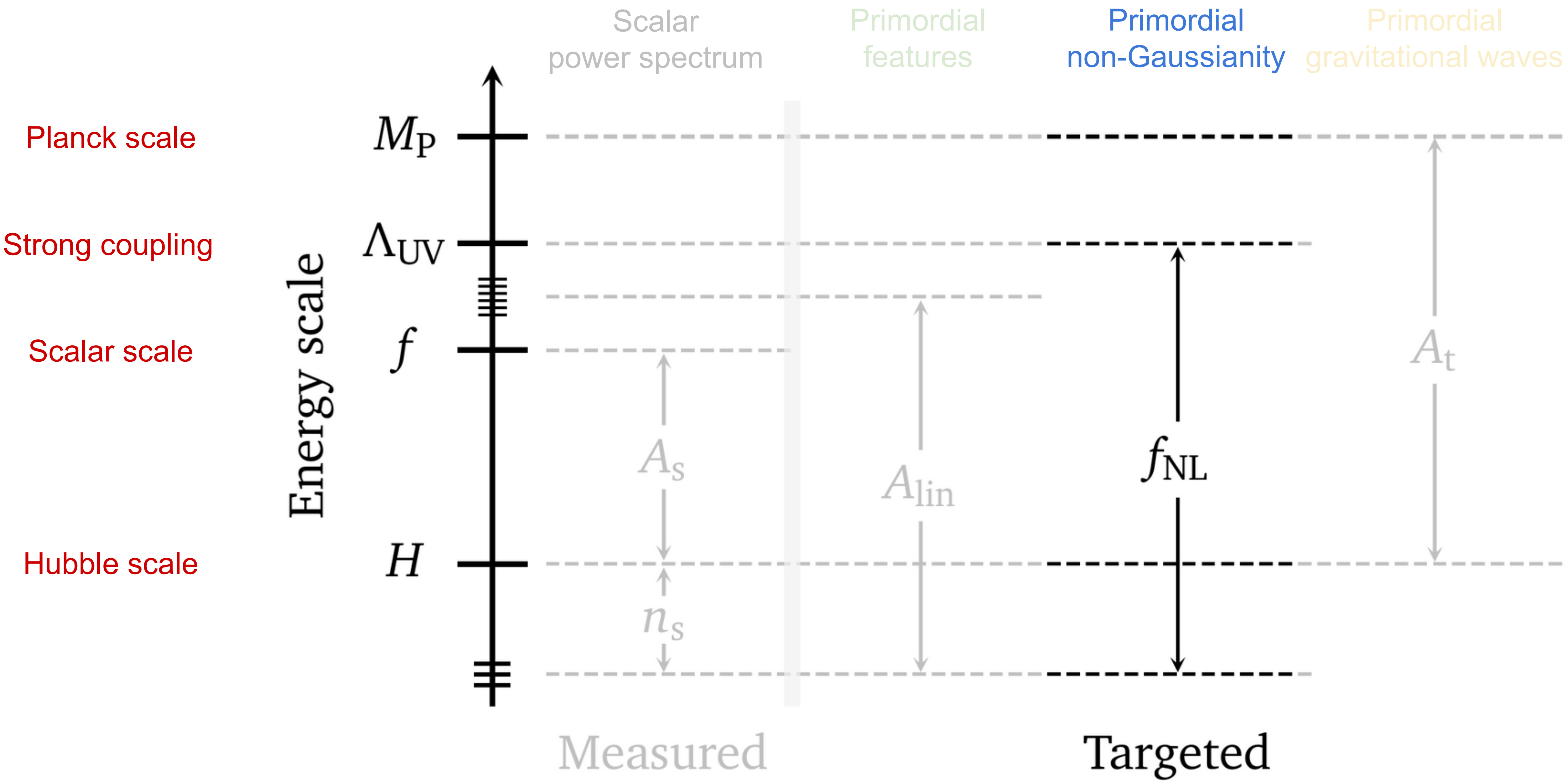
Figure by G. Pimentel

Inflationary Scales and Observational Imprints



Snowmass Inflation White Paper (leads: Pimentel, BW & Wu)

Inflationary Scales and Observational Imprints



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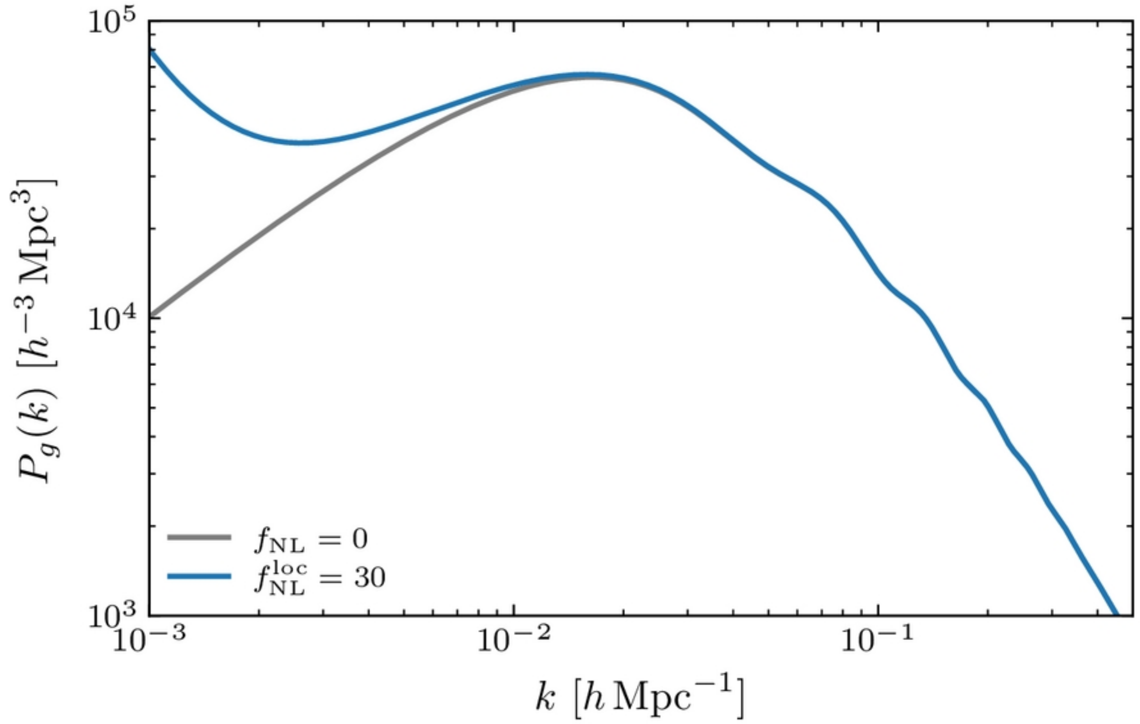
Scale-Dependent Bias as PNG Signal in LSS

Well known: Enhancement of the galaxy power spectrum on the largest scales from local primordial non-Gaussianity

$$b_{\rm NG}^{\rm loc}(k,z) \quad = \quad f_{\rm NL}^{\rm loc}\frac{b_\phi(z)}{k^2\mathcal{T}(k,z)} \qquad b_\phi(z) = 2\delta_c(b_1(z)-p)$$

transfer function



Dalal, Dore, Huterer & Shirokov; Slosar et al.; see Snowmass Inflation White Paper (leads: Pimentel, BW & Wu) and many other reviews for details

Scale-Dependent Bias Beyond the Standard Shapes

Less known: Other shapes can also induce a scale-dependent bias!

Additional (massive) fields induce a nonlocal long-distance correlation between galaxy and matter density

$\rightarrow$ Scale-dependent bias:

$$b(k,z) = b_1(z) + A f_{\rm NL} \frac{b_\phi(z)}{k^2 \mathcal{T}(k,z)} (kR_*)^\Delta$$

$$\Delta = 3/2 - \sqrt{9/4 - m^2/H^2}$$

Baumann, Green, Ferraro & Smith

Scale-Dependent Bias Beyond the Standard Shapes

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→ Scale-dependent bias:

$$b_{\rm NG}^{\rm loc}(k,z) = f_{\rm NL}^{\rm loc}\frac{b_\phi(z)}{k^2\mathcal{T}(k,z)} \quad \text{(local)}, \qquad \overset{k\to 0}{\sim} k^{-2}$$

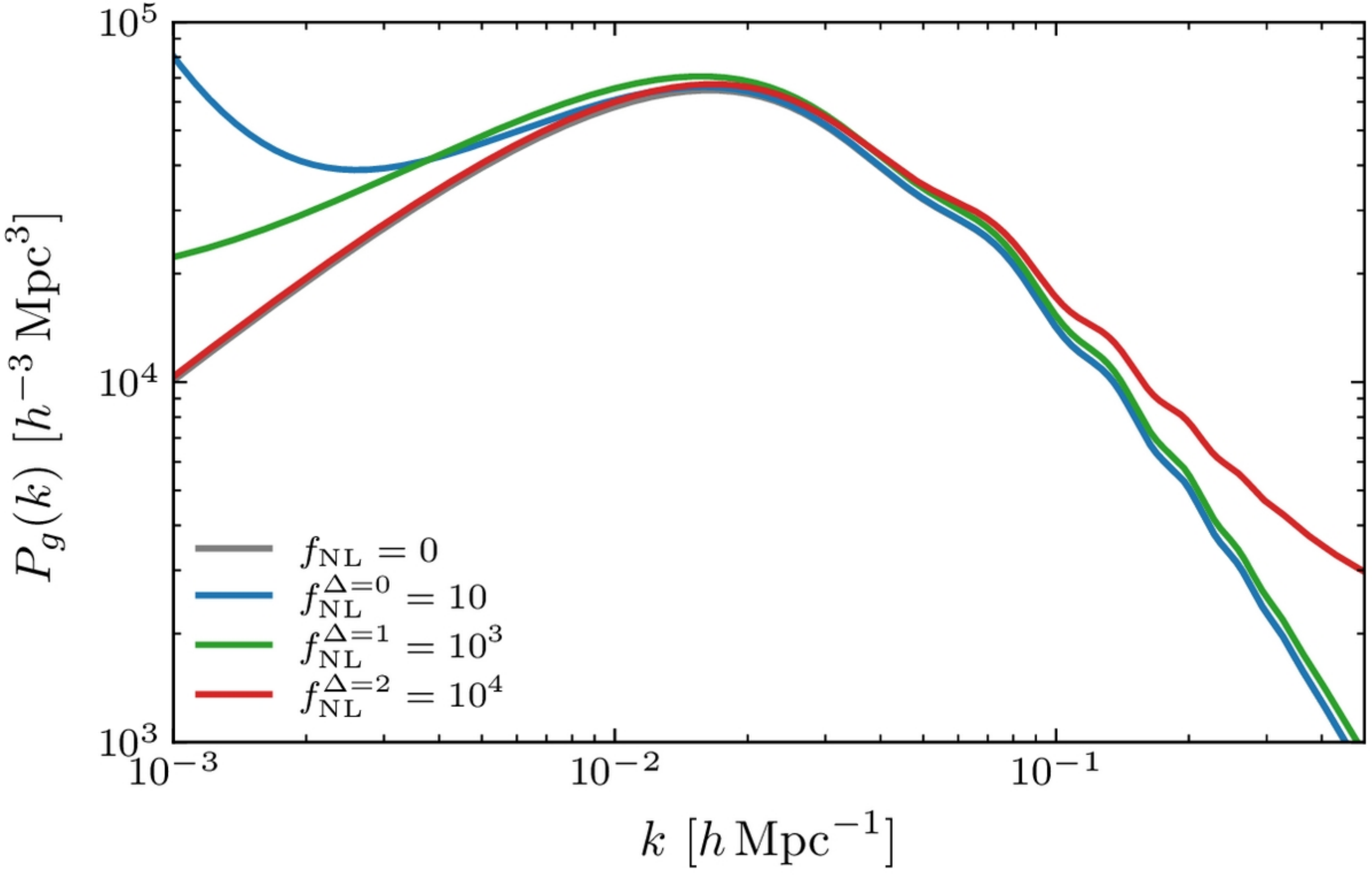
$$b_{\rm NG}^{\rm eq}(k,z) = 3f_{\rm NL}^{\rm eq}\frac{b_\phi(z)}{k^2\mathcal{T}(k,z)}(kR_*)^2 \quad \text{(equilateral)}, \qquad \overset{k\to 0}{\sim} k^{0}$$

$$b_{\rm NG}^{\Delta}(k,z) = 3f_{\rm NL}^{\Delta}\frac{b_\phi(z)}{k^2\mathcal{T}(k,z)}(kR_*)^\Delta \quad \text{(general exponent } \Delta\in[0,2])$$

Matarrese & Verde, Schmidt & Kamionkowski, Desjacques et al., Giannantonio et al, ...

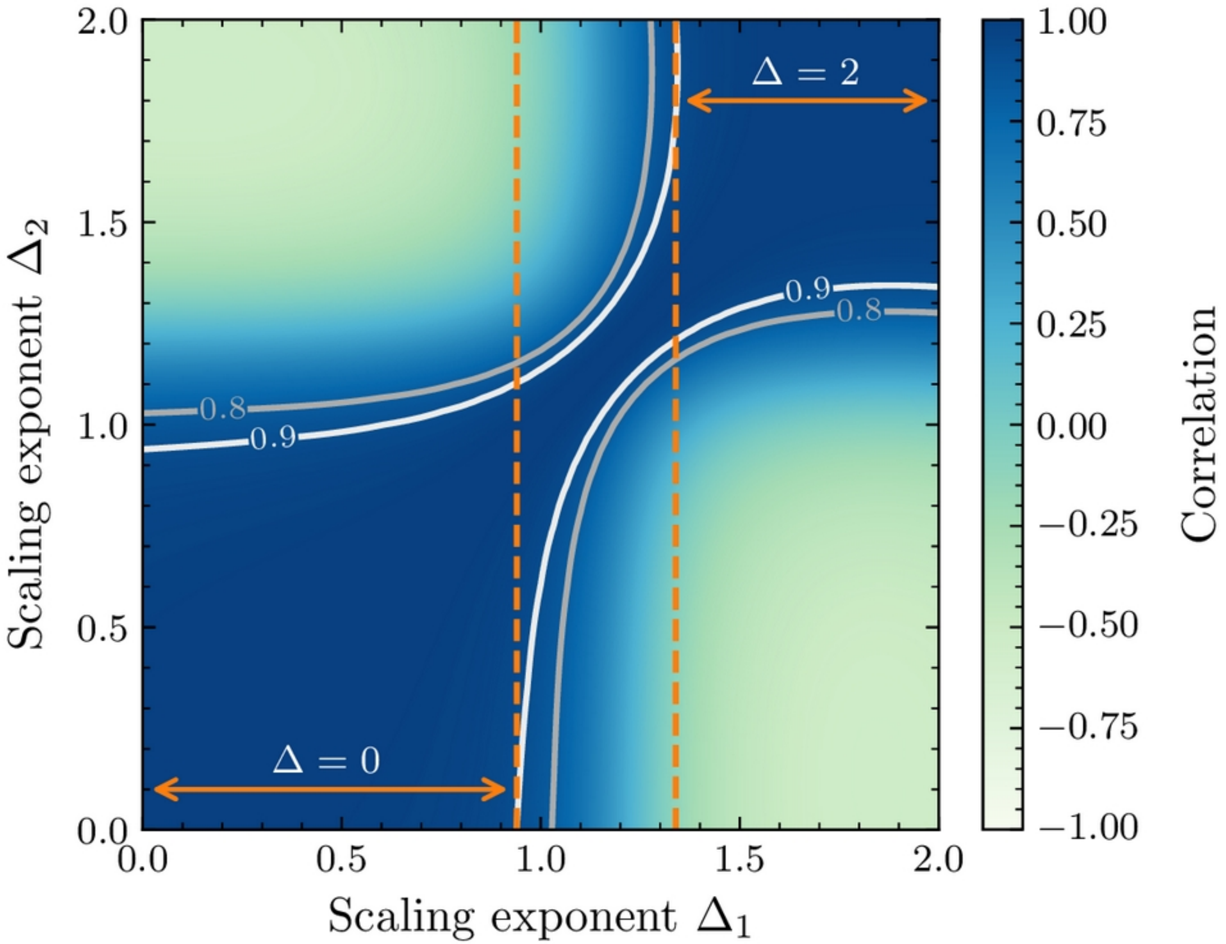
Scale-Dependent Bias Beyond the Standard Shapes

Less known: Other shapes can also induce a scale-dependent bias!



Constraints from BOSS DR12: Option 1

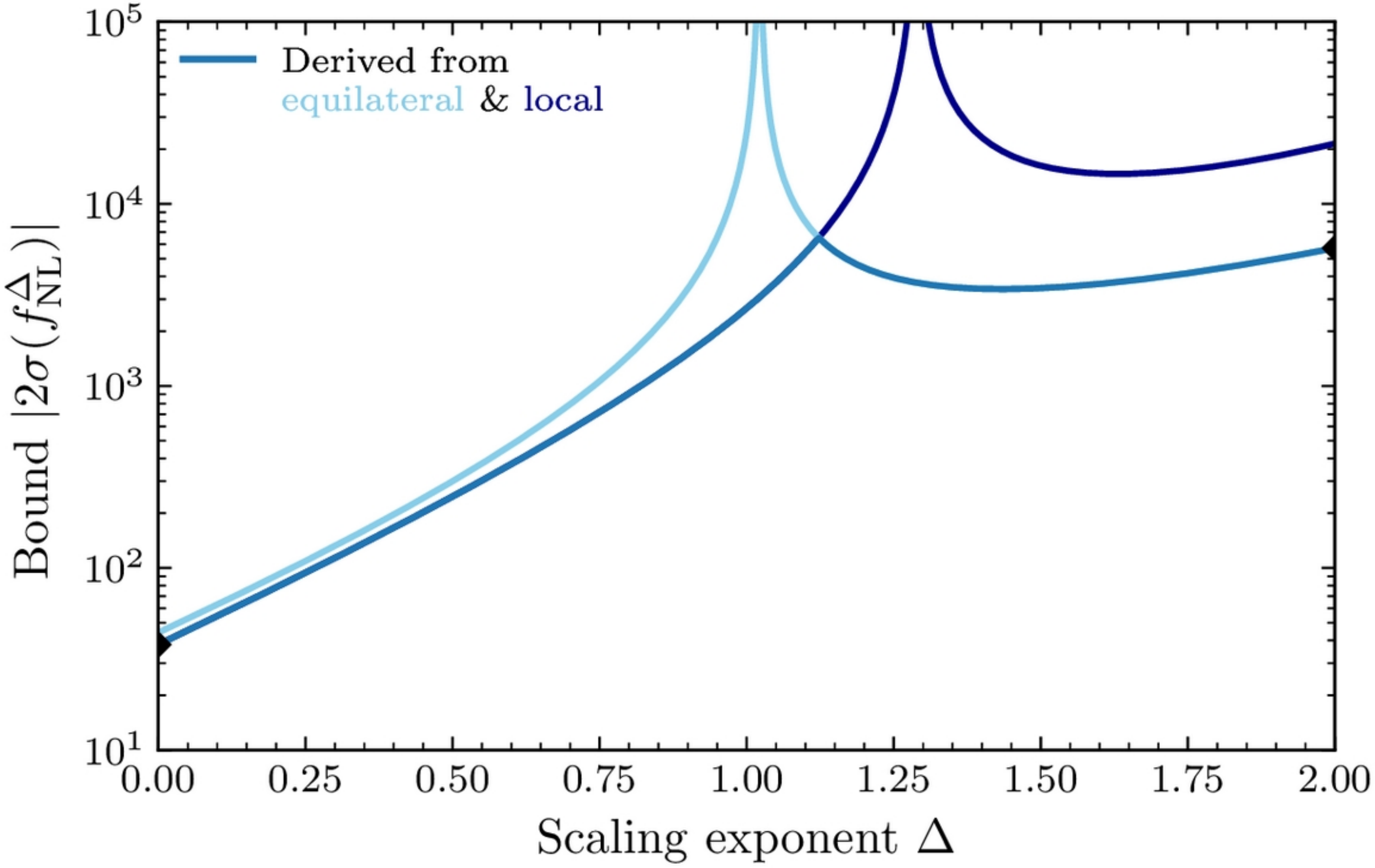
From the galaxy power spectrum alone and marginalizing over the galaxy bias expansion, we find large correlations:



Green, Guo, Han & BW (in prep.)

Constraints from BOSS DR12: Option 1

From the galaxy power spectrum alone and marginalizing over the galaxy bias expansion, we find large correlations and can derive from local and equilateral:

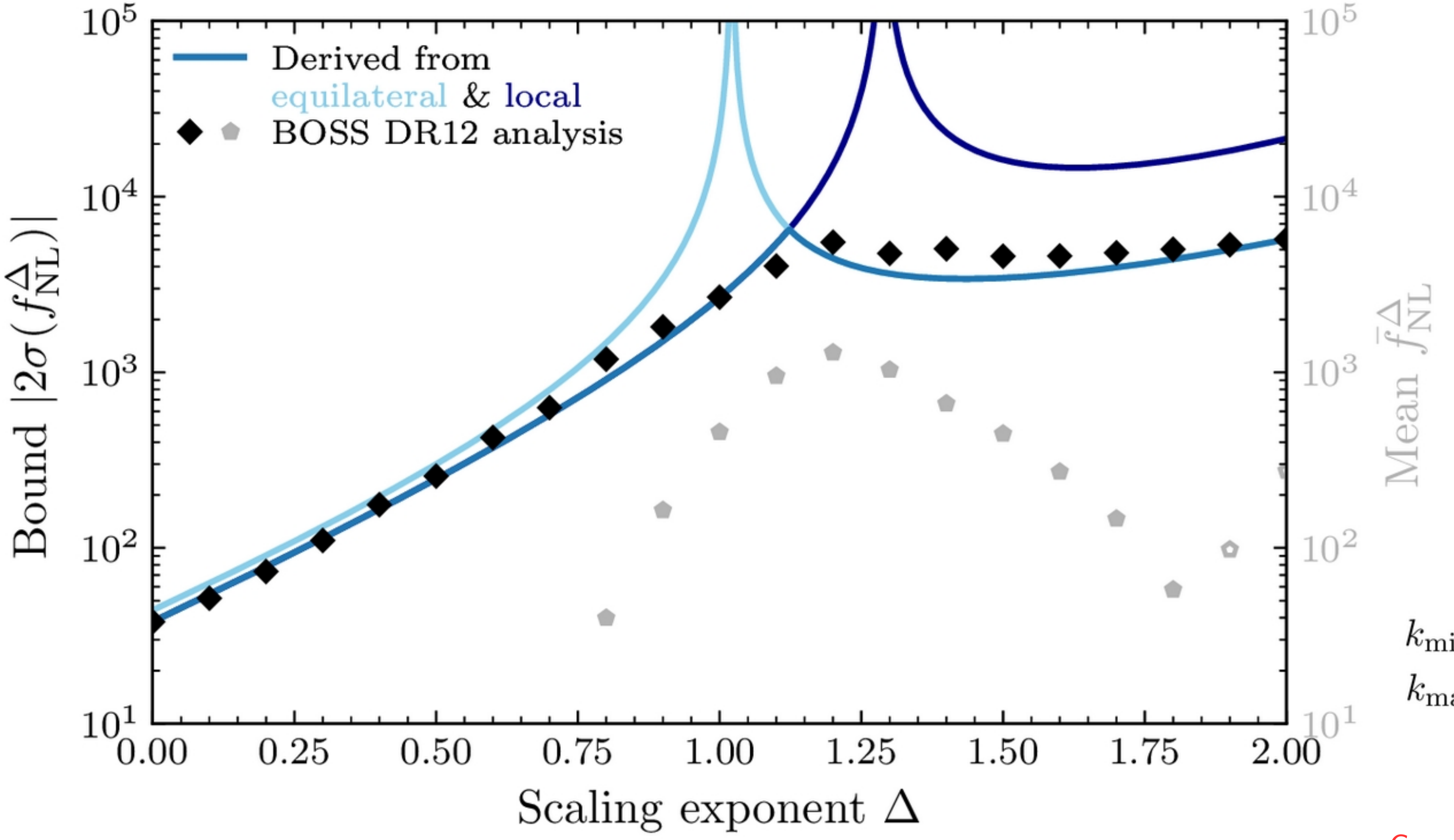


$k_{\rm min} = 0.01\,h\,{\rm Mpc}^{-1}$,
$k_{\rm max} = k_{\rm nl} \sim 0.15\,h\,{\rm Mpc}^{-1}$

Green, Guo, Han & BW (in prep.)

Constraints from BOSS DR12: Option 2

From the galaxy power spectrum alone and marginalizing over the galaxy bias expansion, we can directly constrain from BOSS DR12 data:

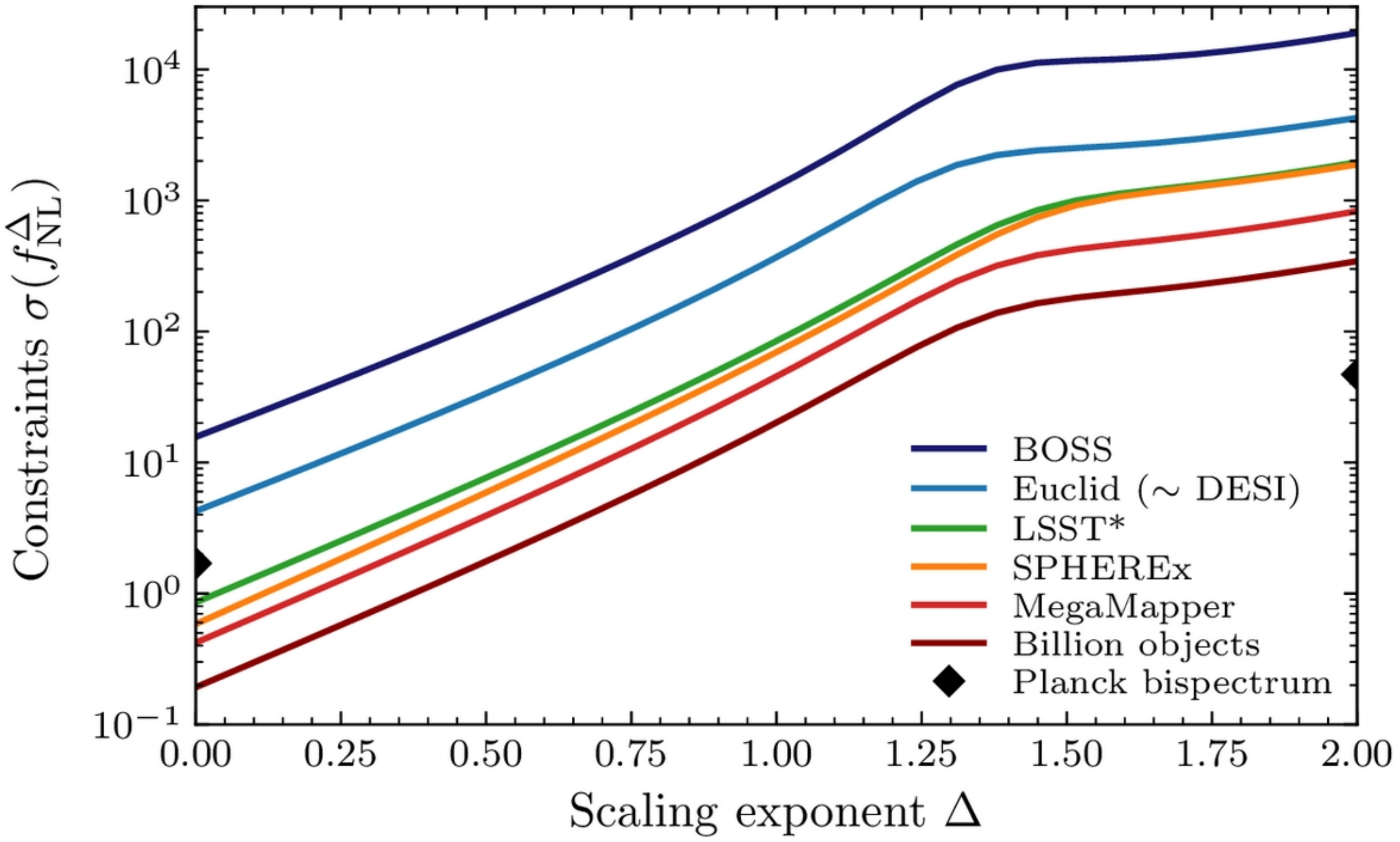


$k_{\rm min} = 0.01\, h\, {\rm Mpc}^{-1}\,,$
$k_{\rm max} = k_{\rm nl} \sim 0.15\, h\, {\rm Mpc}^{-1}$

Green, Guo, Han & BW (in prep.)

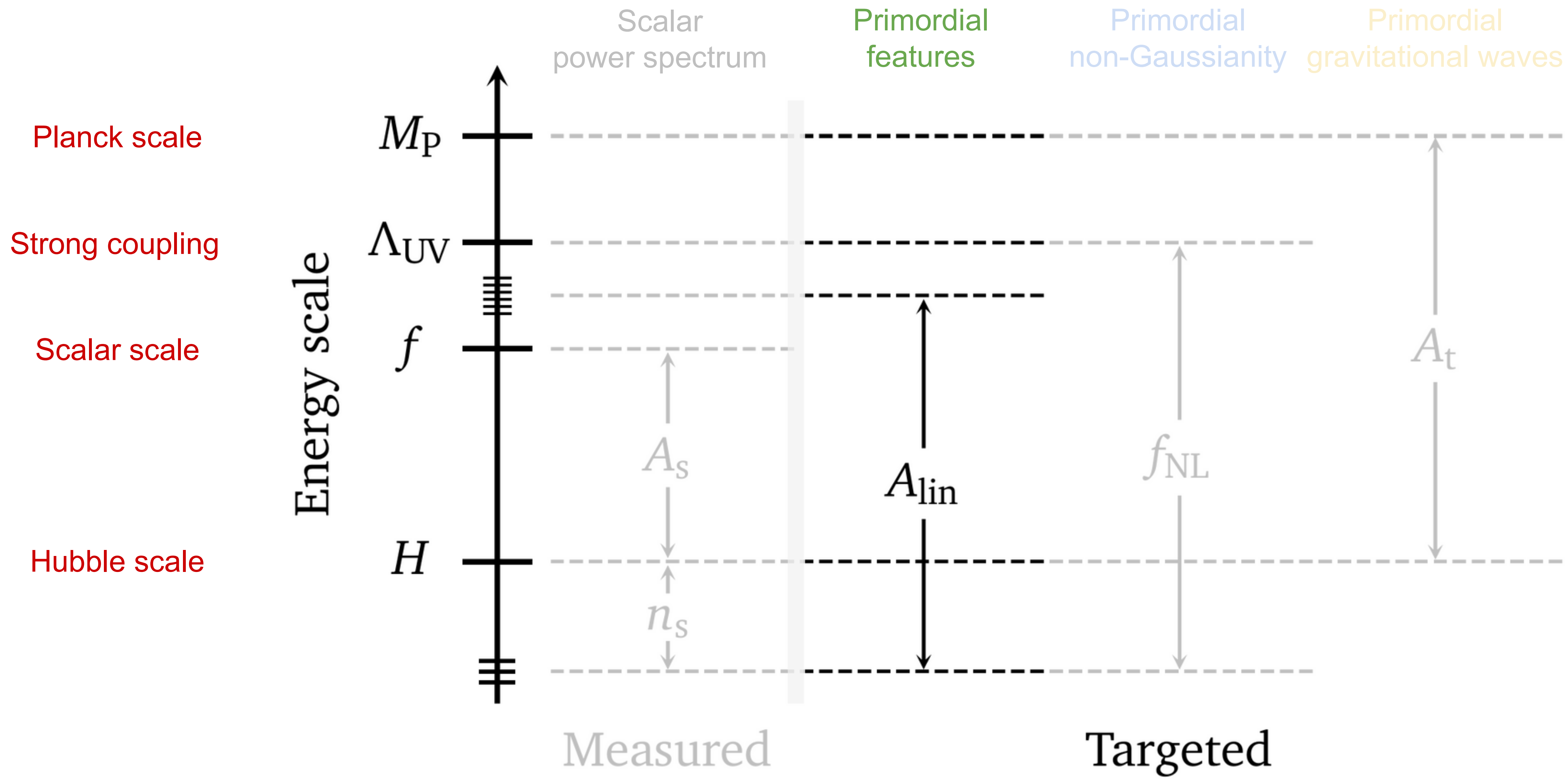
Constraining Power of Future Surveys

From the galaxy power spectrum *alone*, and marginalizing over the galaxy bias expansion and cosmology (with CMB priors), we conservatively forecast:



(See the upcoming paper for more detailed forecasts, including survey specifications, multi-tracer comparisons, multi-tracer LSST, ...) Green, Guo, Han & BW (in prep.)

Inflationary Scales and Observational Imprints



Snowmass Inflation White Paper (leads: Pimentel, BW & Wu)

Features in the Primordial Power Spectrum

Several inflationary (and other primordial) scenarios predict additional features:

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

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

such as

– sharp features: new physics at a certain time for all scales,

Starobinsky; Adams, Cresswell & Easther; Bean, Chen, Hailu, Tye & Xu; ...

– resonant features: background oscillates around attractor (e.g. axion monodromy),

Chen, Easter & Lim; Silverstein & Westphal; Flauger, McAllister, Pajer, Westphal & Xu; ...

– primordial standard clocks: excitation of massive fields.

Chen; Chen & Ringeval; Chen & Namjoo; Chen, Namjoo & Wang; ...

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

Features in the Primordial Power Spectrum

Several inflationary (and other primordial) scenarios predict additional features:

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

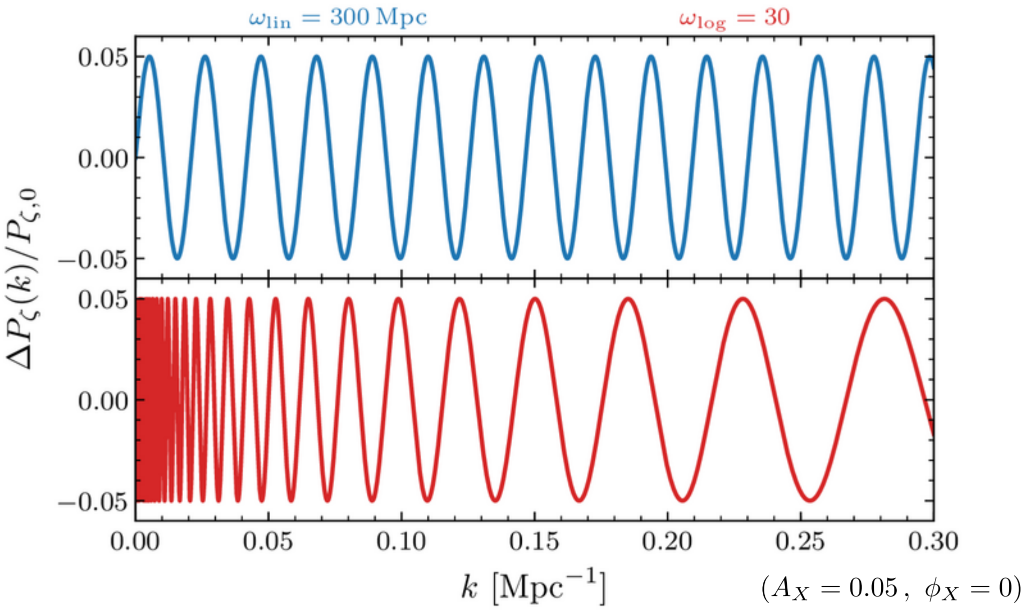
such as

- linearly-spaced oscillatory features:

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

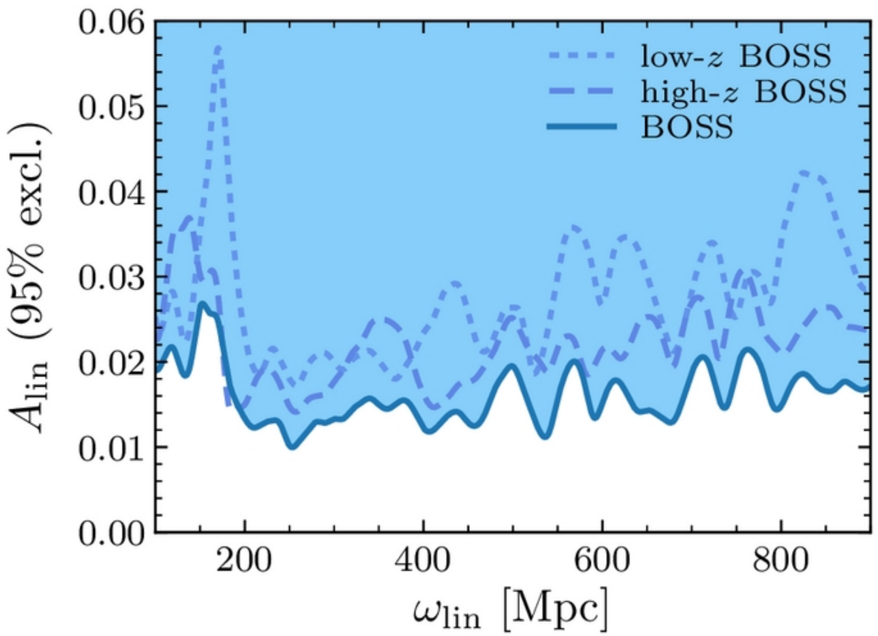
- logarithmically-spaced oscillatory features:

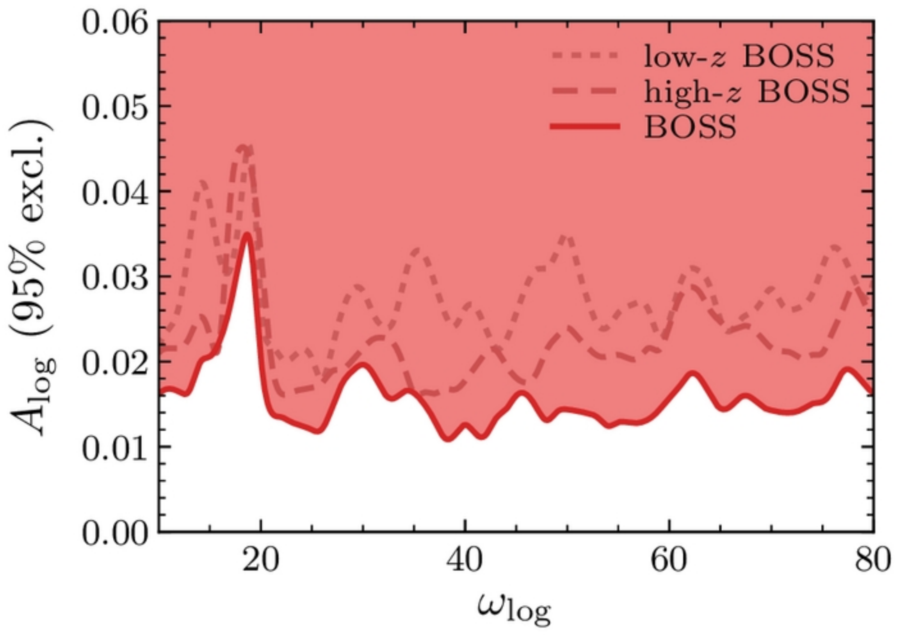
$$\frac{\Delta P_\zeta(k)}{P_{\zeta,0}} = A_{\rm log}\,\sin(\omega_{\rm log} \log(k/k_\star) + \phi_{\rm log})\,.$$



First Upper Limits from LSS

Upper limits from the BOSS DR12 dataset:



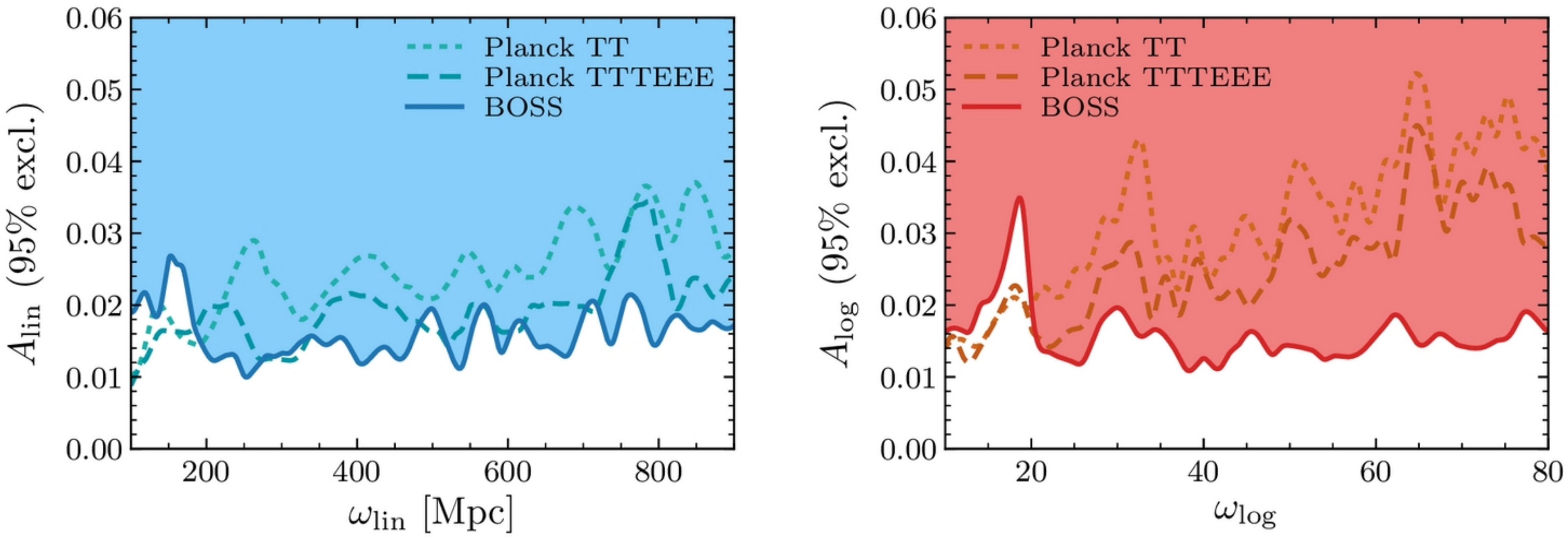


$\rightarrow$ Feature amplitudes are limited to $\mathcal{O}(1\%)$ relative to the primordial amplitude.

Beutler, Biagetti, Green, Slosar & BW (see also Mergulhão, Beutler & Peacock for eBOSS)

Upper Limits from LSS and CMB

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



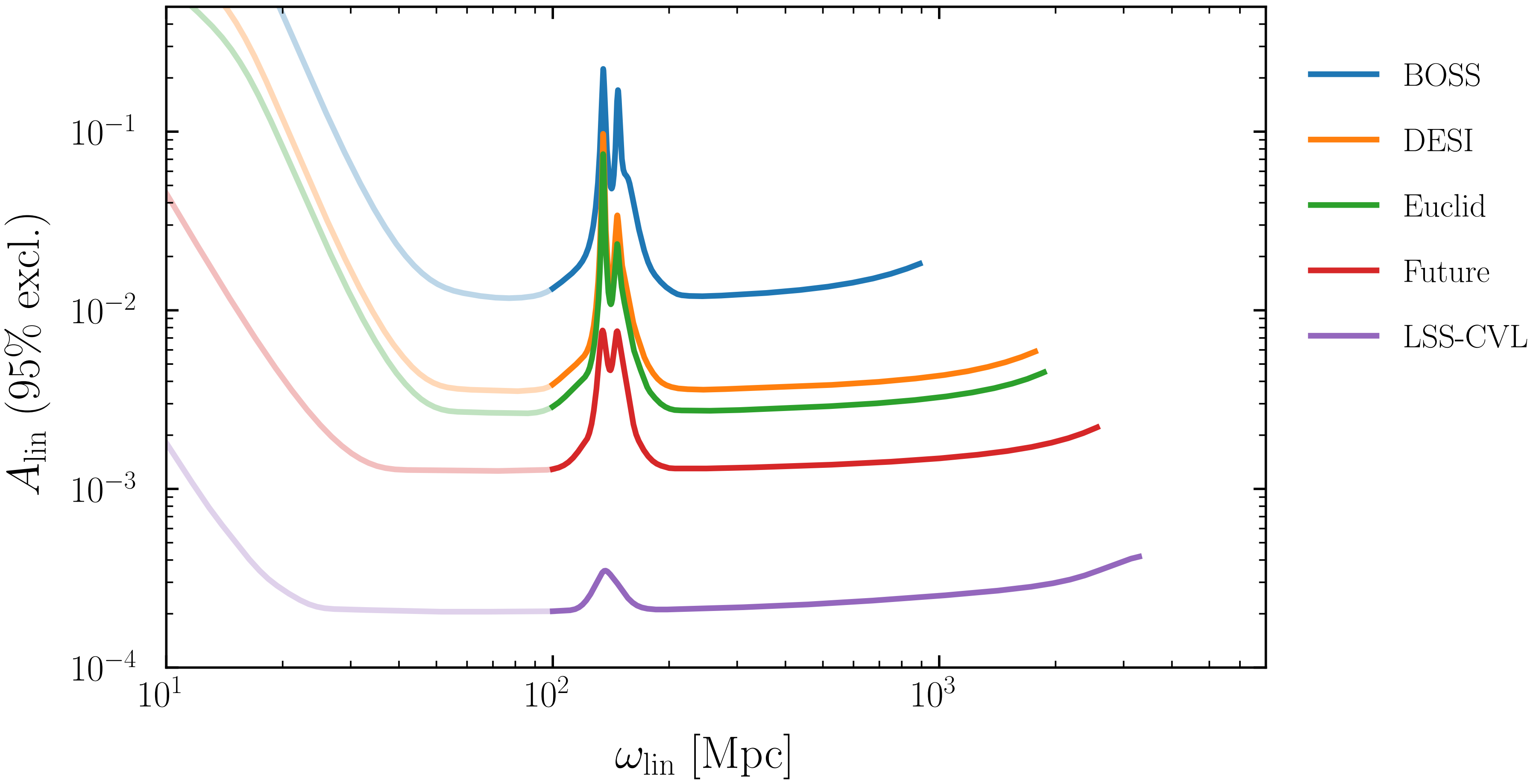
→ Feature amplitudes are limited to $\mathcal{O}(1\%)$ relative to the primordial amplitude.

→ Competitive with current CMB constraints in available frequency range.

Beutler, Biagetti, Green, Slosar & BW

Future Prospects

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



Beutler, Biagetti, Green, Slosar & BW

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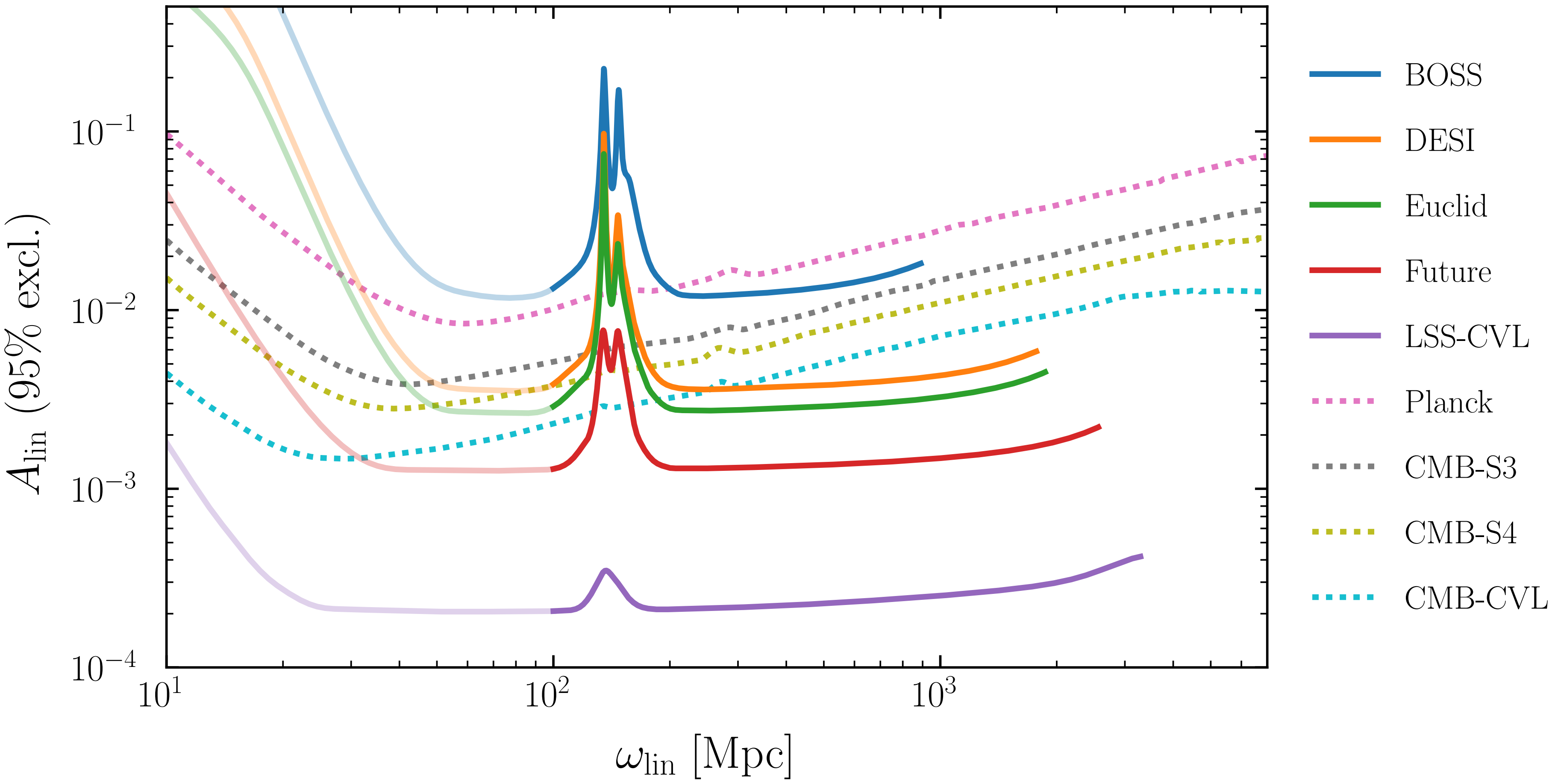


Beutler, Biagetti, Green, Slosar & BW

Summary

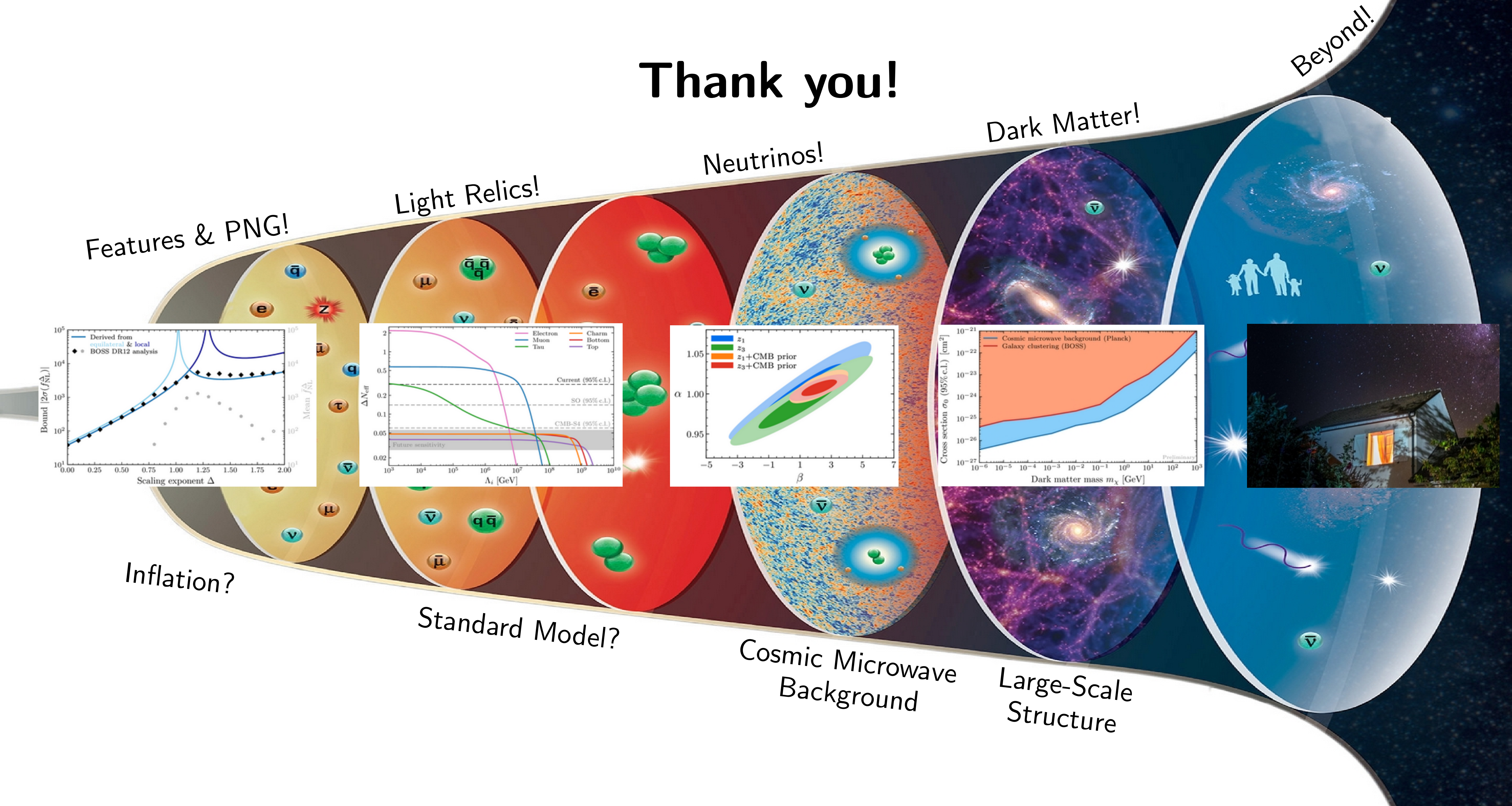
Theoretical insights into and observational control of LSS power spectrum analyses allow for extraction of inflationary information, in particular

$\rightarrow$ Primordial non-Gaussianity, also beyond the standard shapes,

$\rightarrow$ Primordial feature models.

Future work on higher-order spectra, cross-correlations and further non-Gaussian shapes.

Thank you!



benjamin.wallisch@fysik.su.se