# Constraining primordial tensor features with the CMB

*In collaboration with Jan Hamann [arxiv:2209.00827]*

**DSU Sydney 2022**
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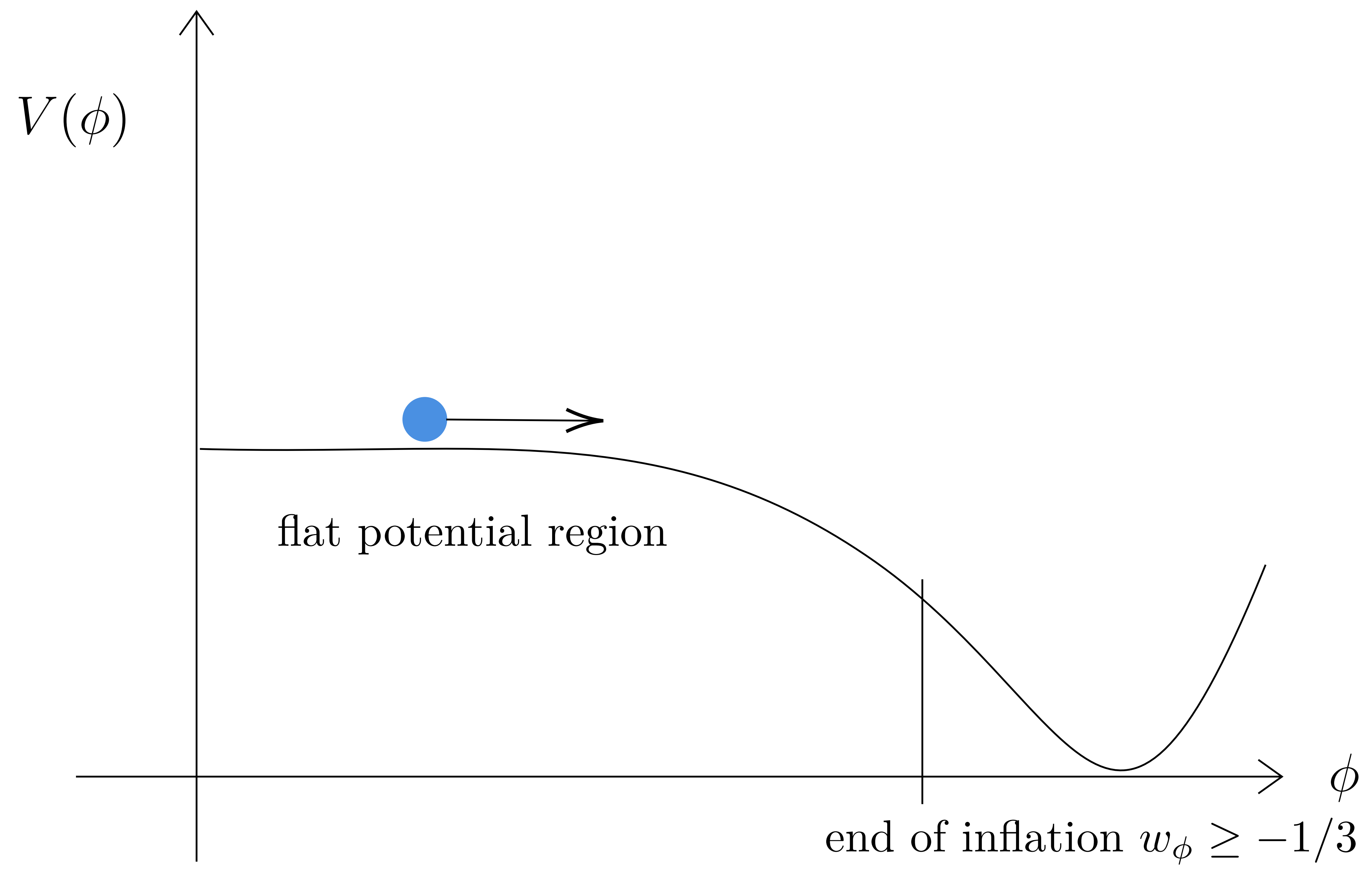
# Outline

- ☑ Tensor Modes from Inflation
- ☑ Primordial tensors in the CMB
- ☑ Constraints and Forecasts

# Inflation

An epoch of near exponential expansion in the early universe, driven by the constant potential energy of some unknown field(s)

$$a \approx e^{Ht}, \quad H^2 \approx \frac{V(\phi)}{3M_{\rm Pl}^2}$$

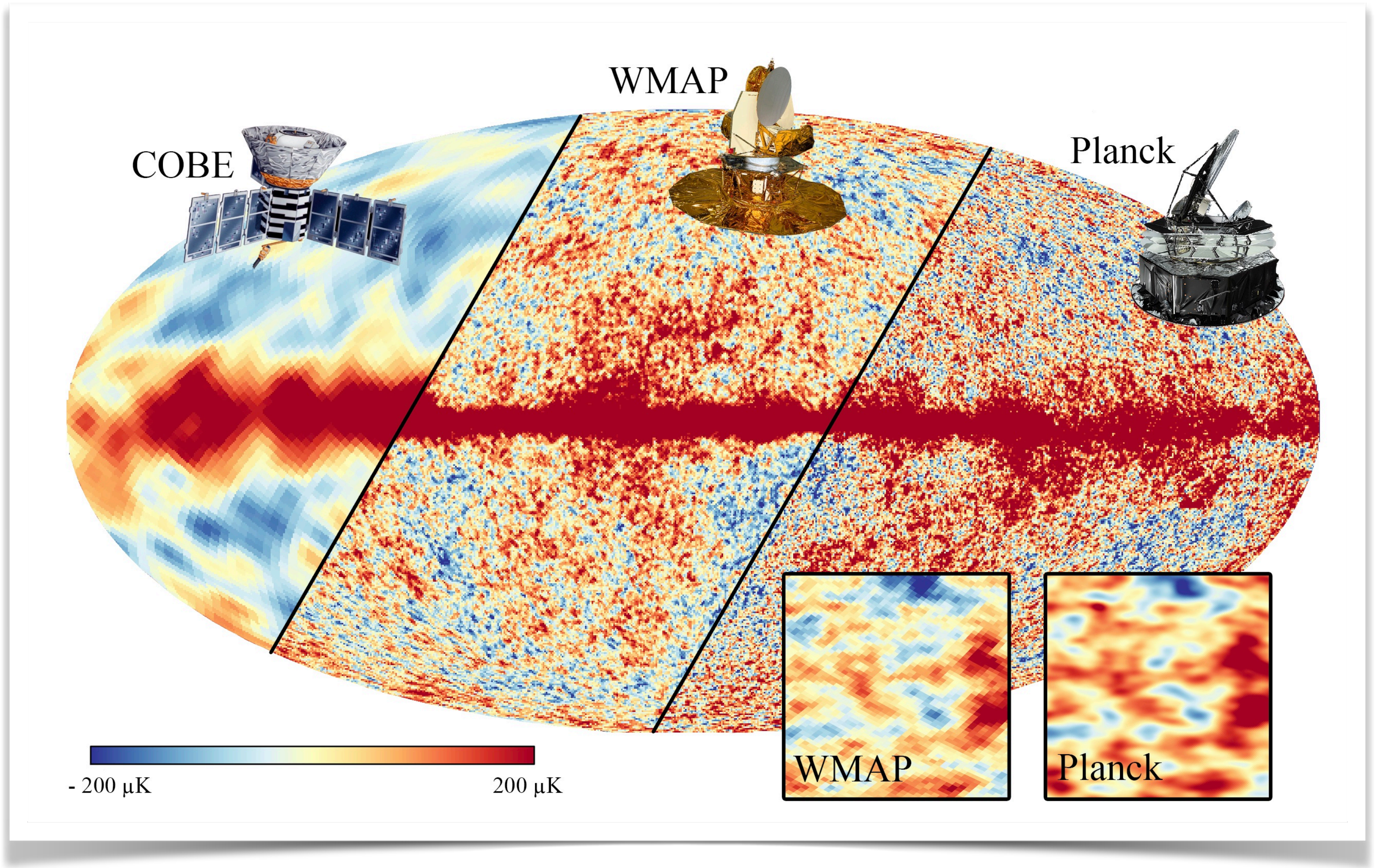


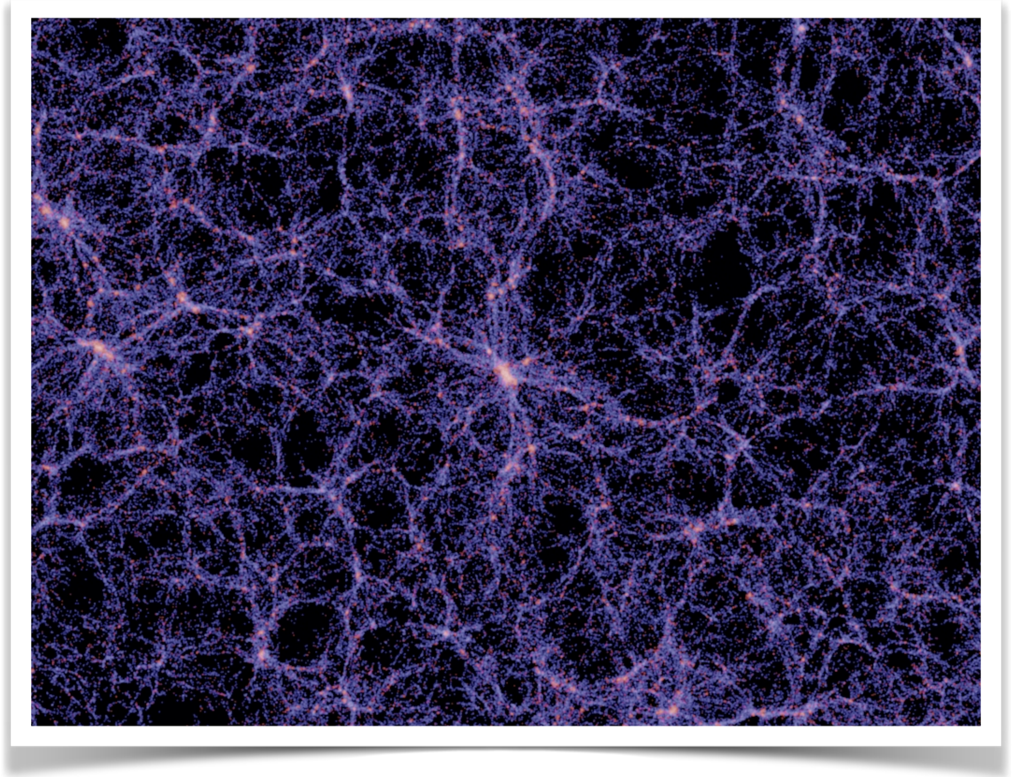

Minimal scenario: single scalar field slowly rolling down the potential

# Inflationary perturbations

$$ds^2 = a^2(\eta)\left[-d\eta^2 + \left(e^{2\zeta}\delta_{ij} + h_{ij}\right)dx^i dx^j\right]$$

$$\mathcal{P}_\zeta(k) = A_s\left(\frac{k}{k_p}\right)^{n_s-1}$$



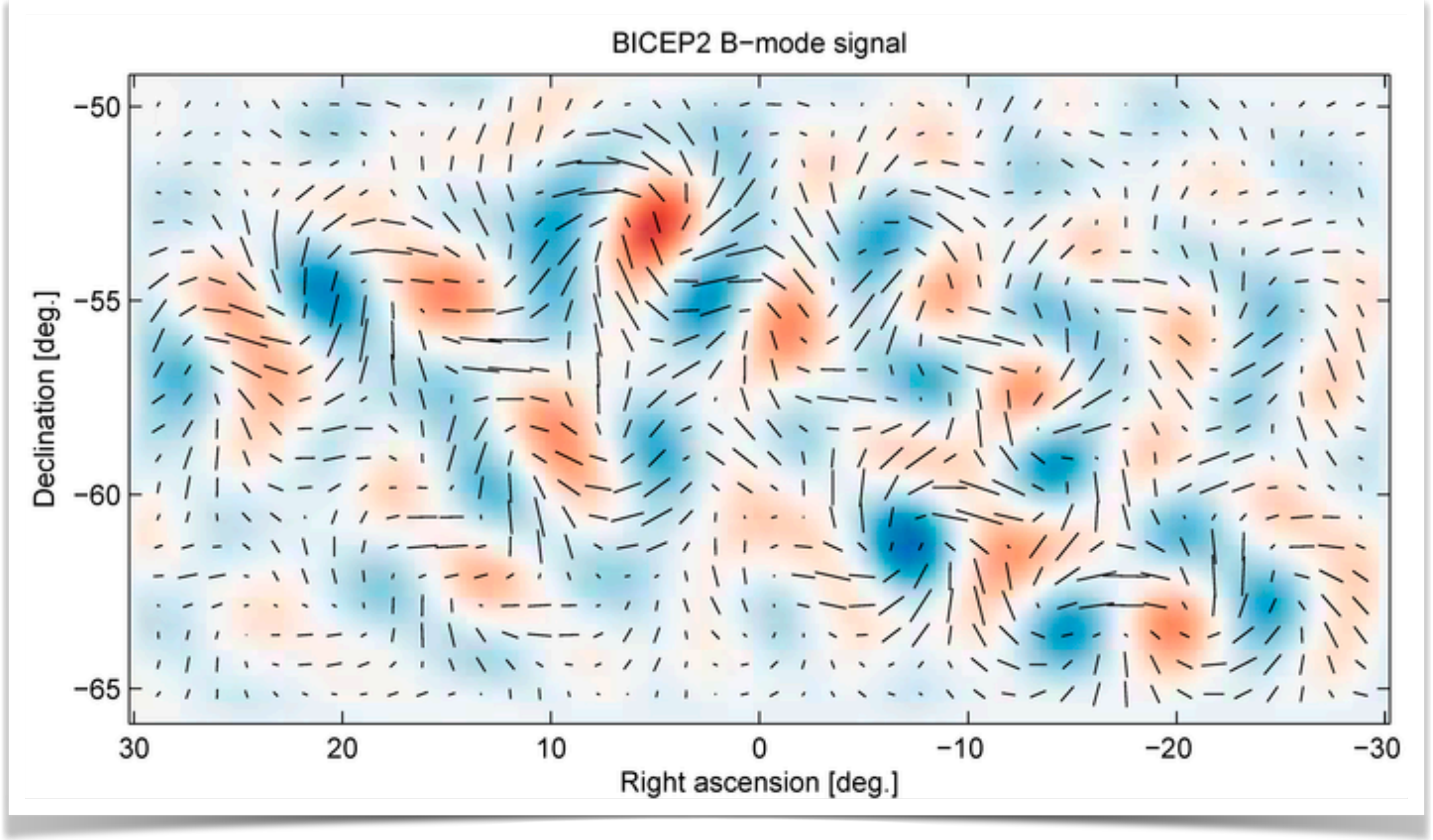



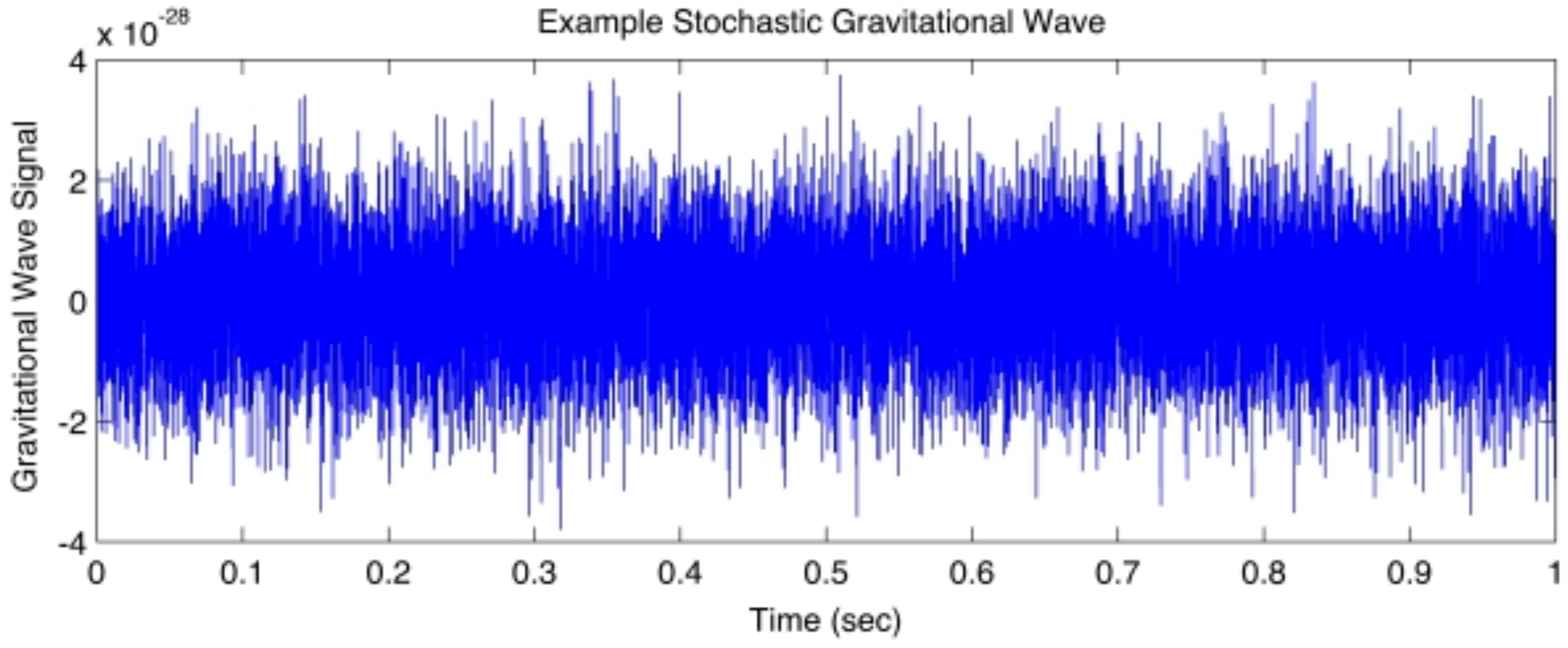
Scalar amplitude and tilt measured precisely on large scales

# Inflationary perturbations

$$ds^2 = a^2(\eta)\left[-d\eta^2 + \left(e^{2\zeta}\delta_{ij} + h_{ij}\right)dx^i dx^j\right]$$

Yet to be observed…




Credit: A. Stuver/LIGO

# Tensor modes in SFSR

$$h''_{ij} + 2\mathcal{H}h'_{ij} + k^2 h_{ij} = 0$$

Free field fluctuations in quasi dS spacetime

$$\mathcal{P}_h(k) \propto \left(\frac{H_{\text{inf}}}{2\pi}\right)^2 \Bigg|_{k=aH}$$

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Free field fluctuations in quasi dS spacetime

$$\mathcal{P}_h(k) \propto \left(\frac{H_{\rm inf}}{2\pi}\right)^2 \Bigg|_{k=aH}$$

Leads to an unpolarised, Gaussian and nearly scale invariant power spectrum

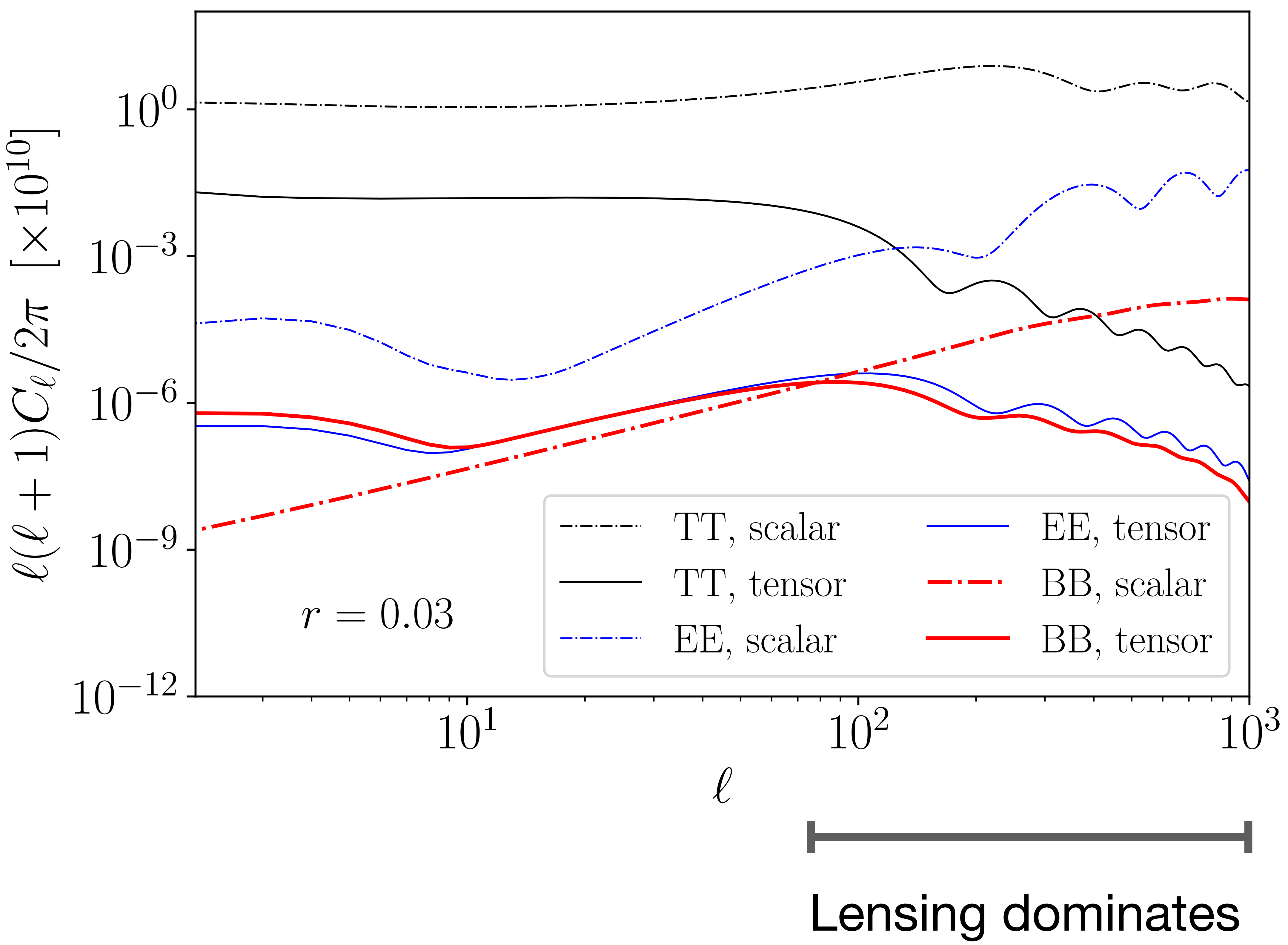
$$\mathcal{P}_h(k) = rA_s \left(\frac{k}{k_p}\right)^{n_T} , \quad \underbrace{n_T = -r/8}_{\text{SFSR consistency}} , \quad r < 0.032 \text{ at } 95\% \text{ C.L.}$$

*Planck*+BK18 [Ade et al. (2021)]

# Tensors in the CMB

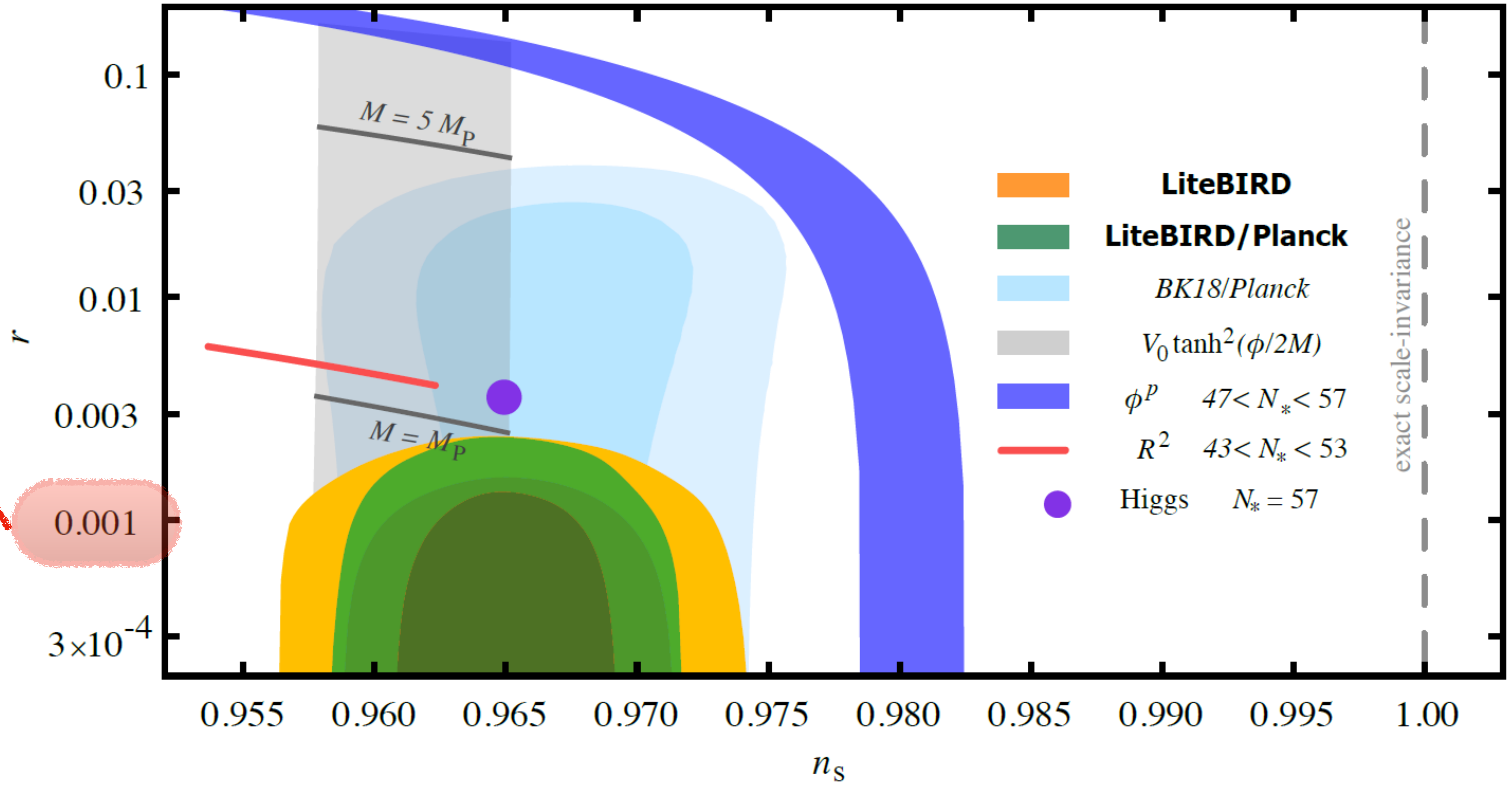
- ☑ Primordial tensor modes affect temperature and polarisation (both E and B mode) anisotropies

- ☑ At linear order, B-modes only sourced by tensors but not scalars



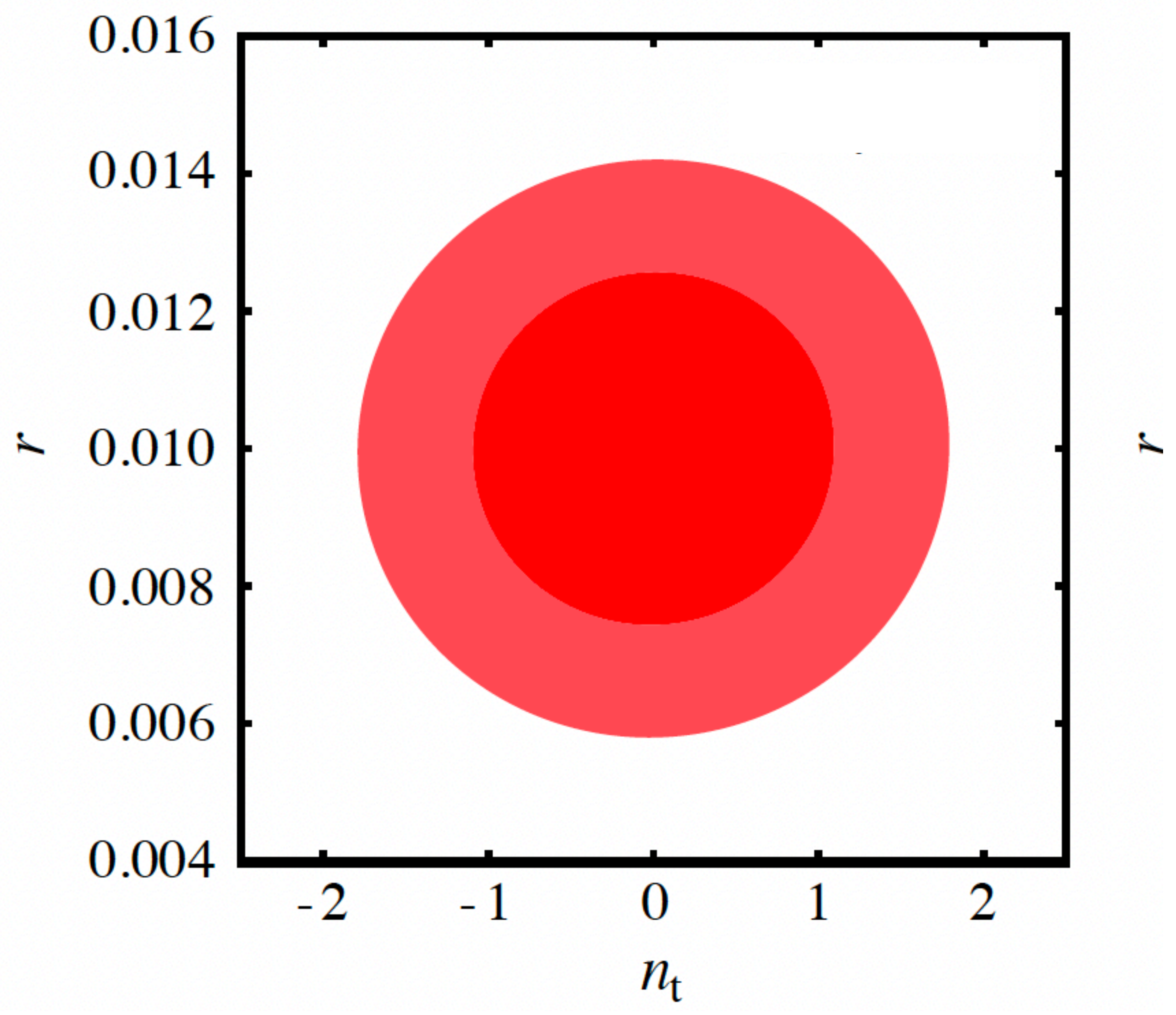
# Sensitivity to SFSR

- ☑ CMB-S4, LiteBIRD sensitivity
- ☑ Some favoured SFSR inflationary models predict $r$ close to above sensitivity, e.g. Starobinsky, Higgs…




Credit: LiteBIRD collaboration [arxiv:2202.02773]

# In the event of a detection can we test $n_T = -r/8$?




CMB-S4 collaboration

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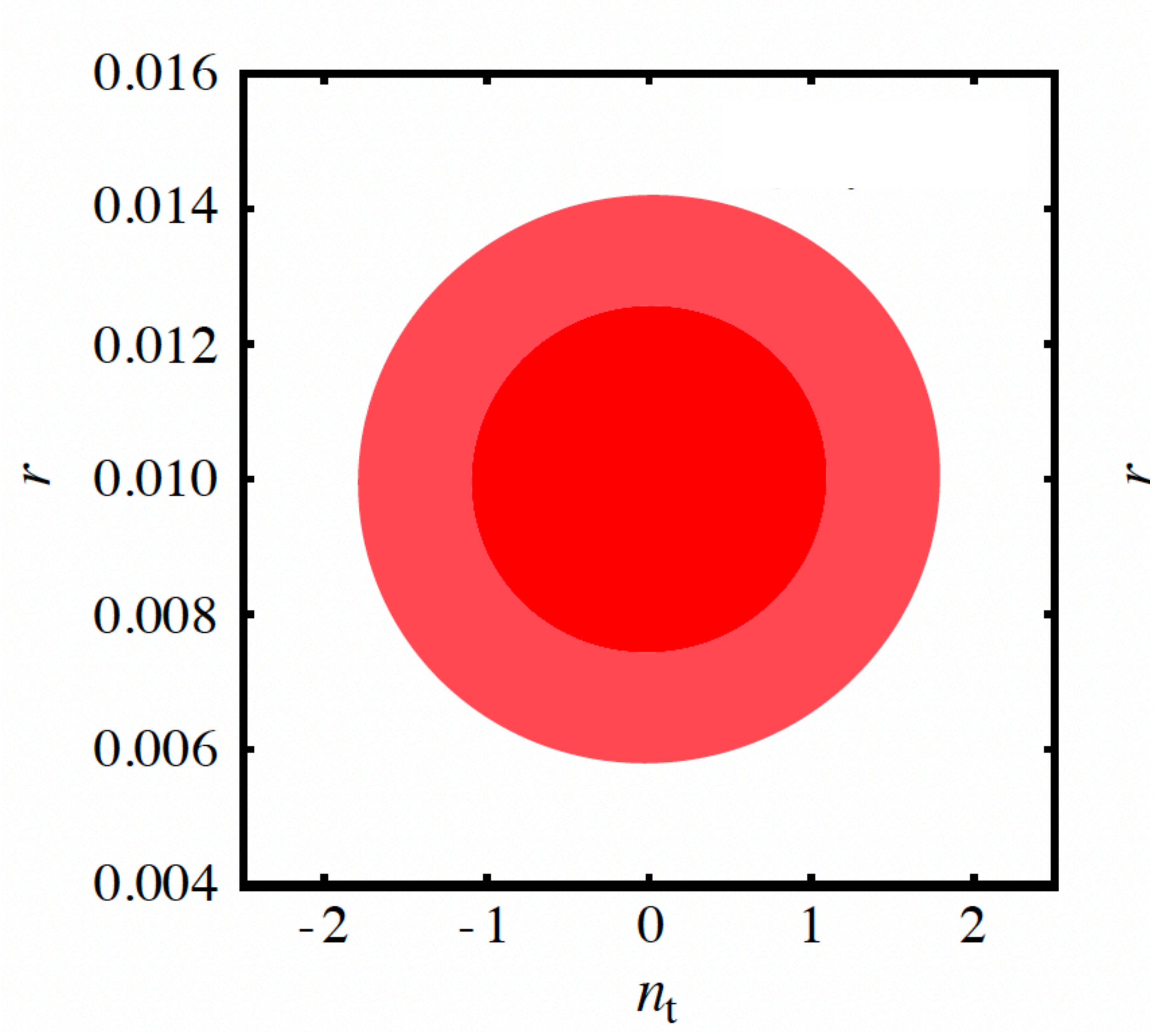



CMB-S4 collaboration

Unlikely that we can confirm SFSR nature from CMB but what about deviations?

# Tensor modes beyond SFSR

e.g Sourced by additional fields

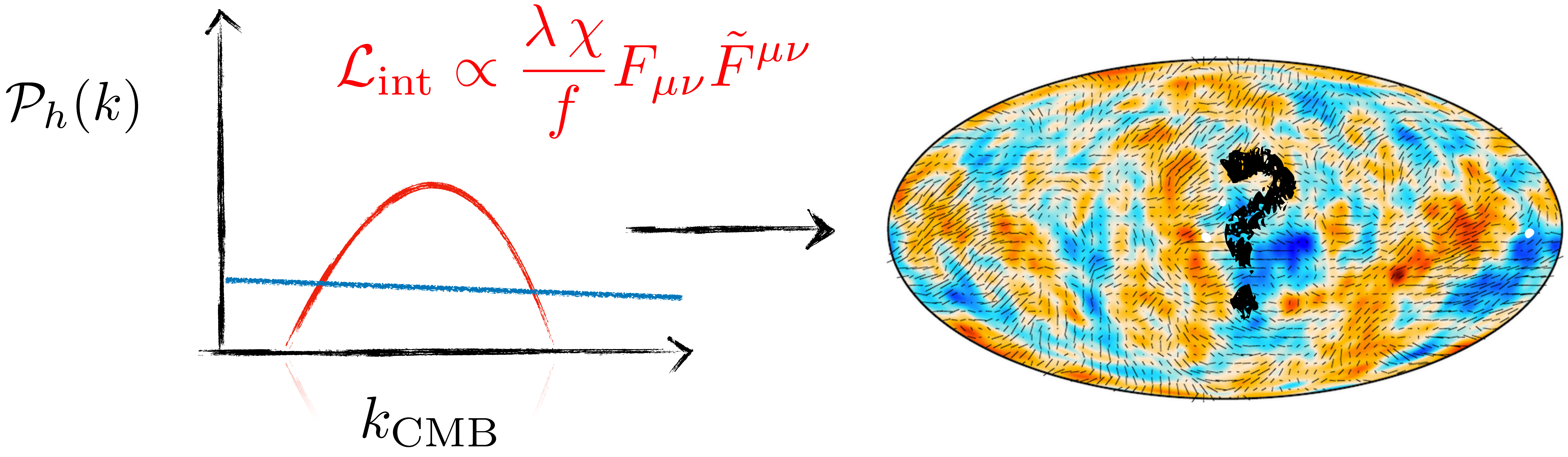
$$h''_{ij} + 2\mathcal{H}h'_{ij} + k^2 h_{ij} = 16\pi a^2 G \Pi^{\mathrm{TT}}_{ij}$$

Can break the consistency relation — different spectral shape at CMB scales

# Deviations from SFSR consistency

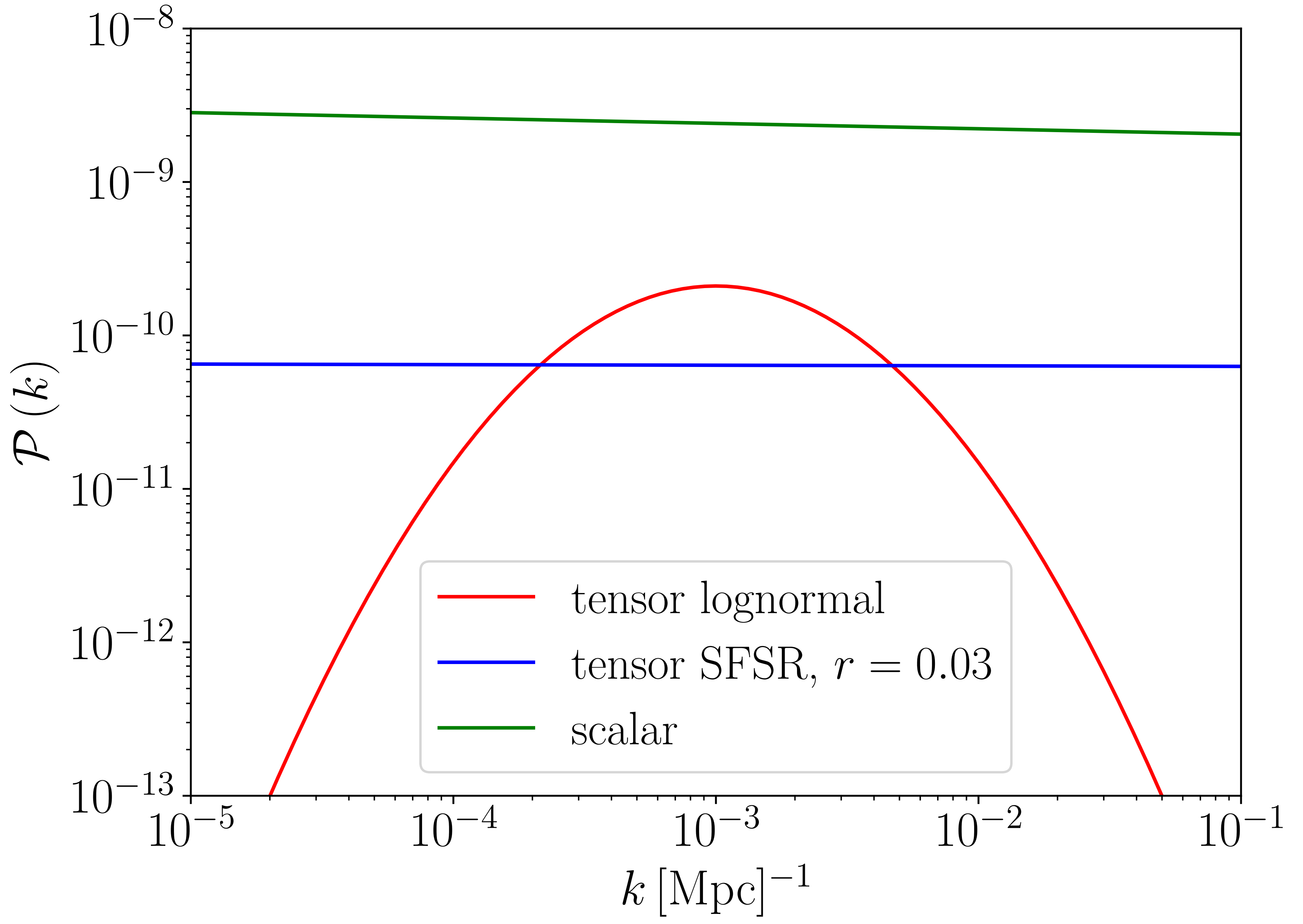
## Example — from axion gauge field models

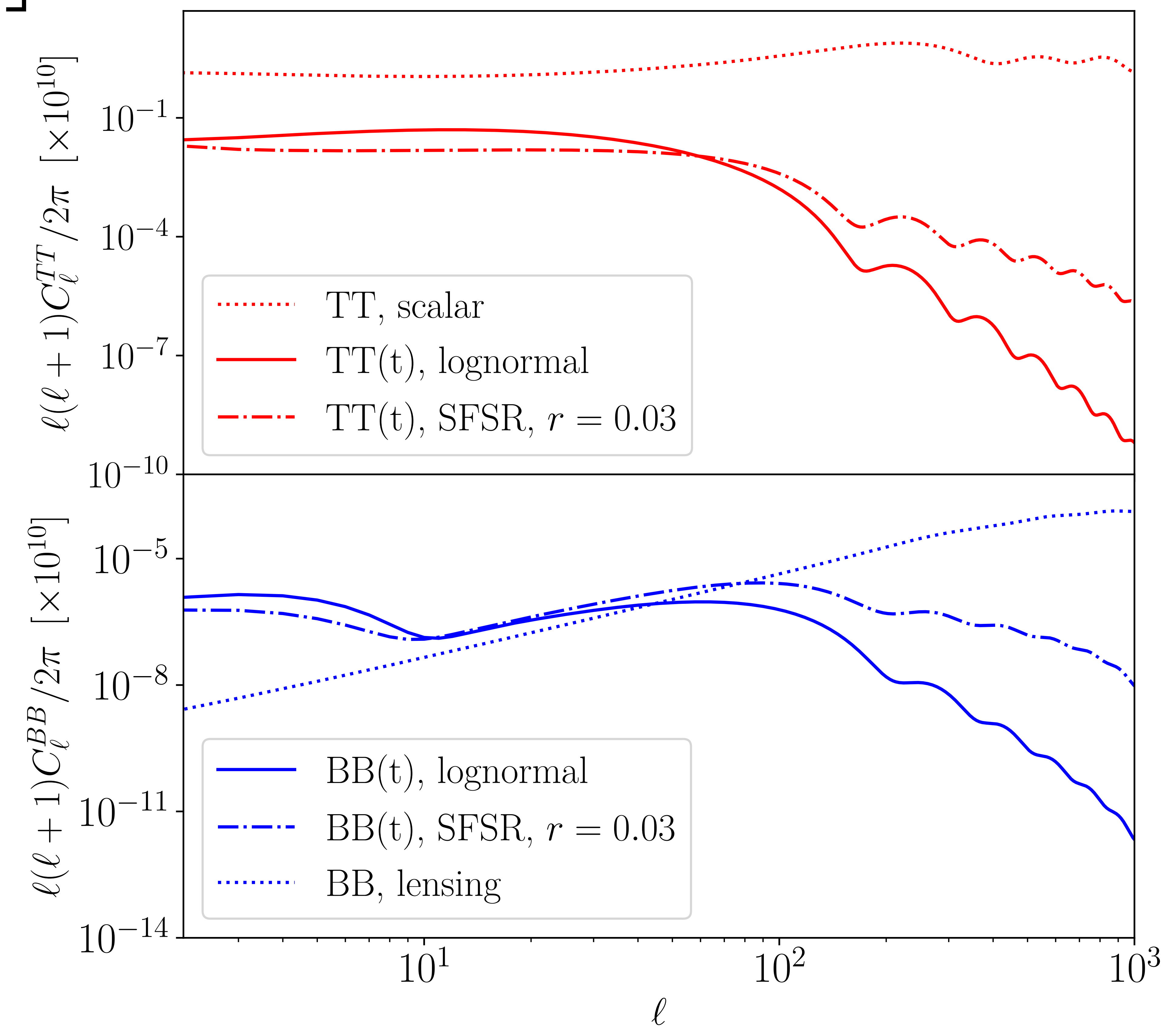
[Dimastrogiovanni et al. 2016, Thorne et al. 2017 + more]



# CMB Anisotropies from bump feature

$$\mathcal{P}_h = r_{\rm pk} A_s \exp\left[-\frac{\ln(k/k_{\rm pk})^2}{2\sigma^2}\right] \longrightarrow C_\ell$$

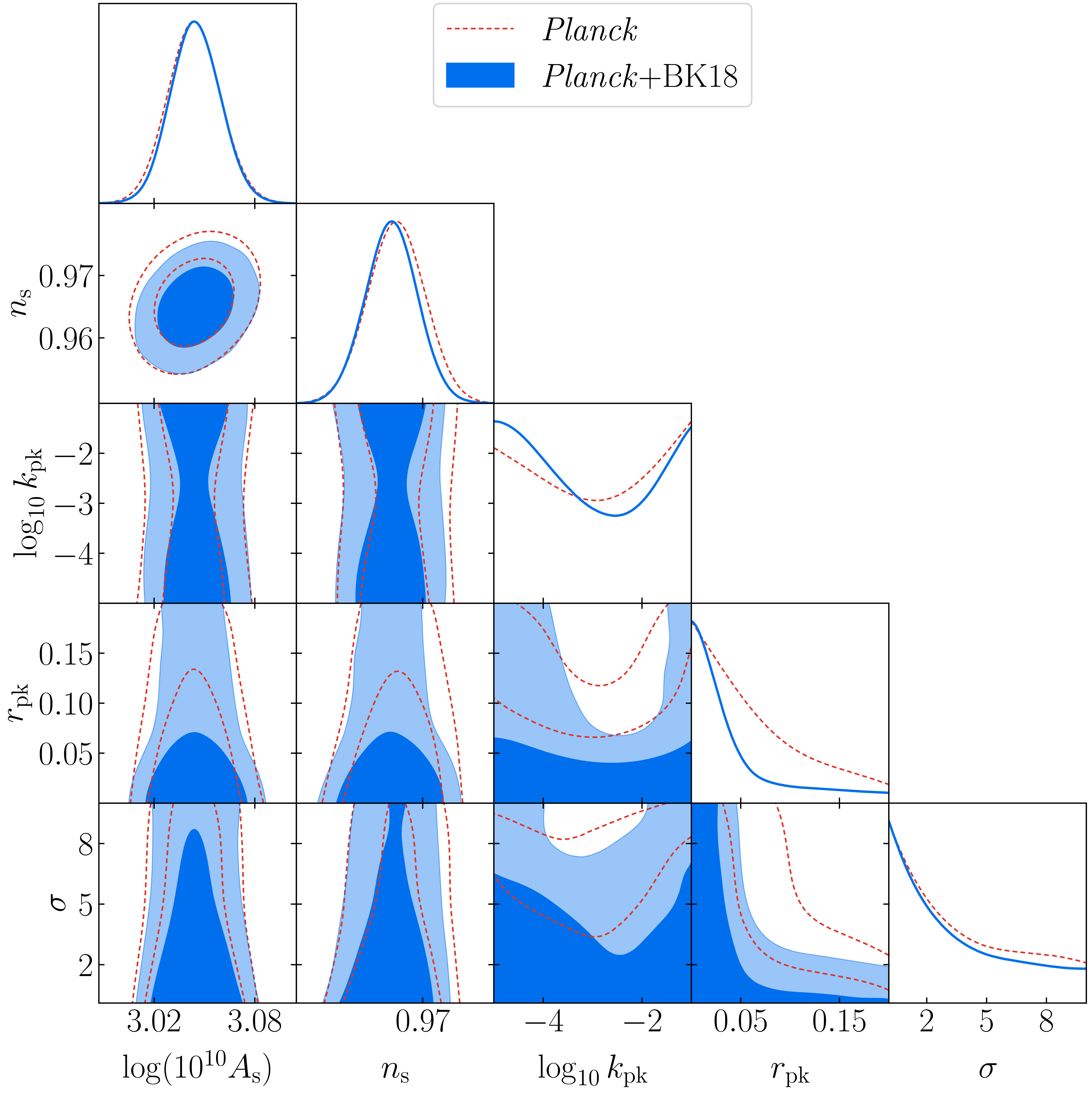


# Current constraints

from Planck temperature + polarisation and BK18 polarisation

| Parameter | 68% limit |
|---|---|
| $\boldsymbol{\sigma}$ | $< 4.83$ |
| $\boldsymbol{r}_{\mathbf{pk}}$ | $< 0.0460$ |



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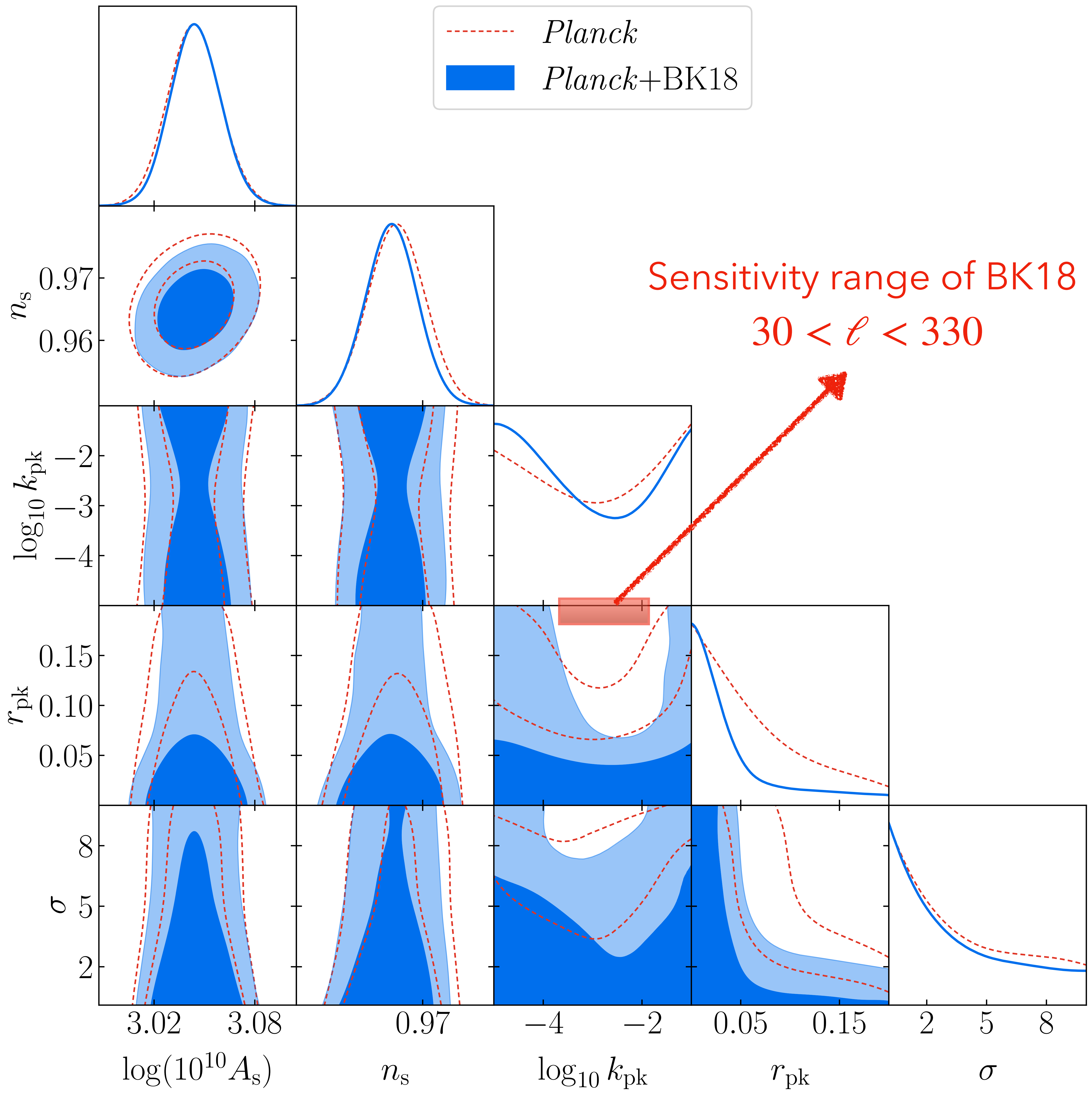
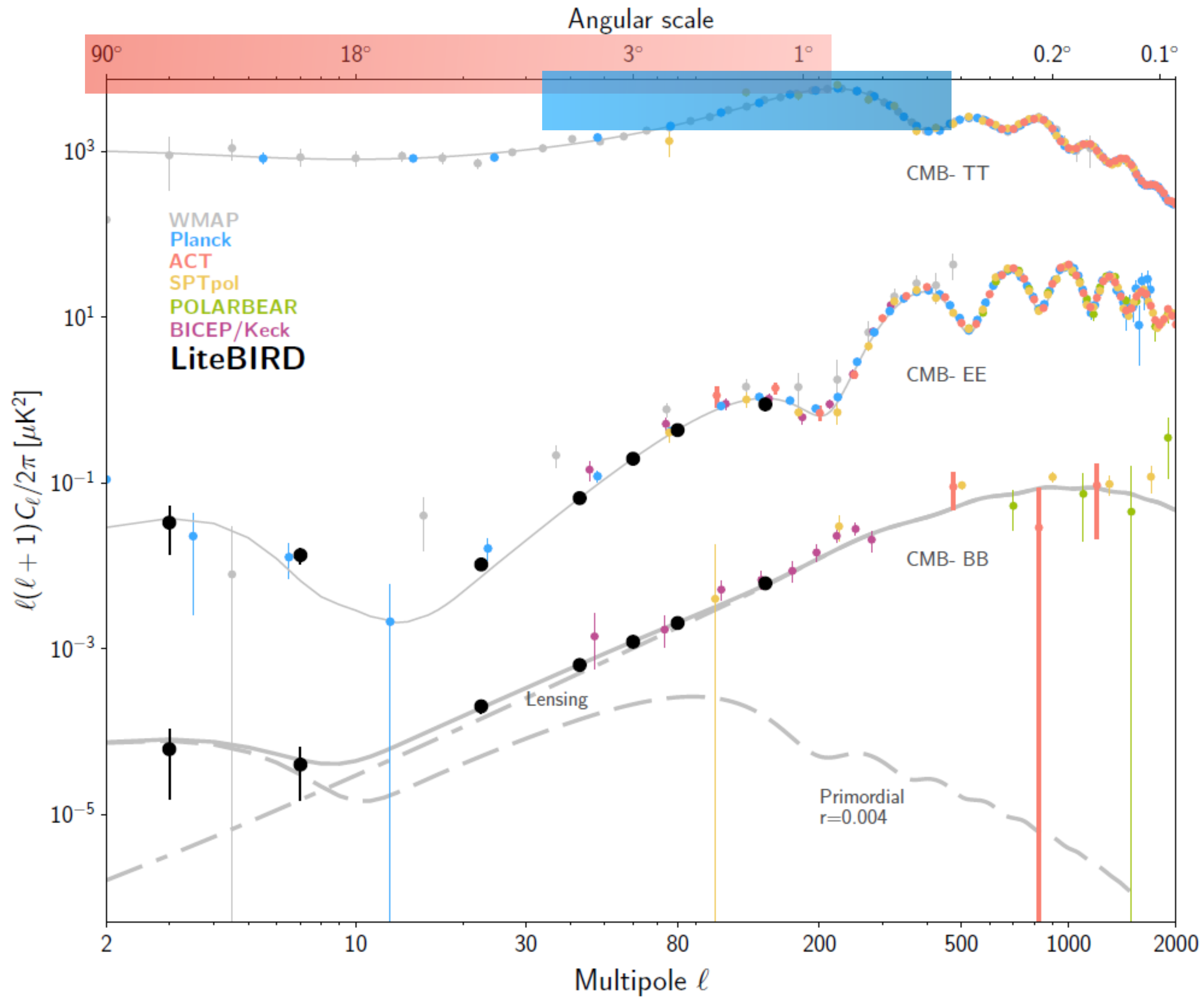


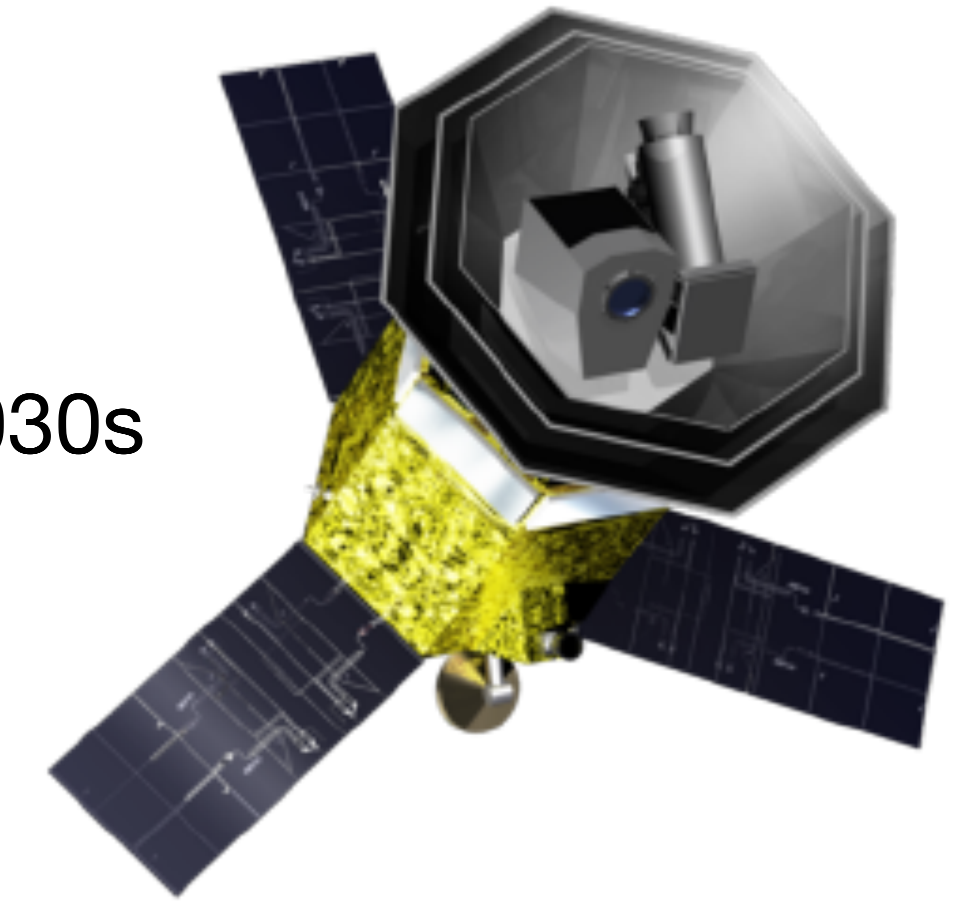
# Forecasts with LiteBIRD + CMB-S4

$2 < \ell < 200$ $30 < \ell < 330$




Credit: LiteBIRD collaboration

2030s

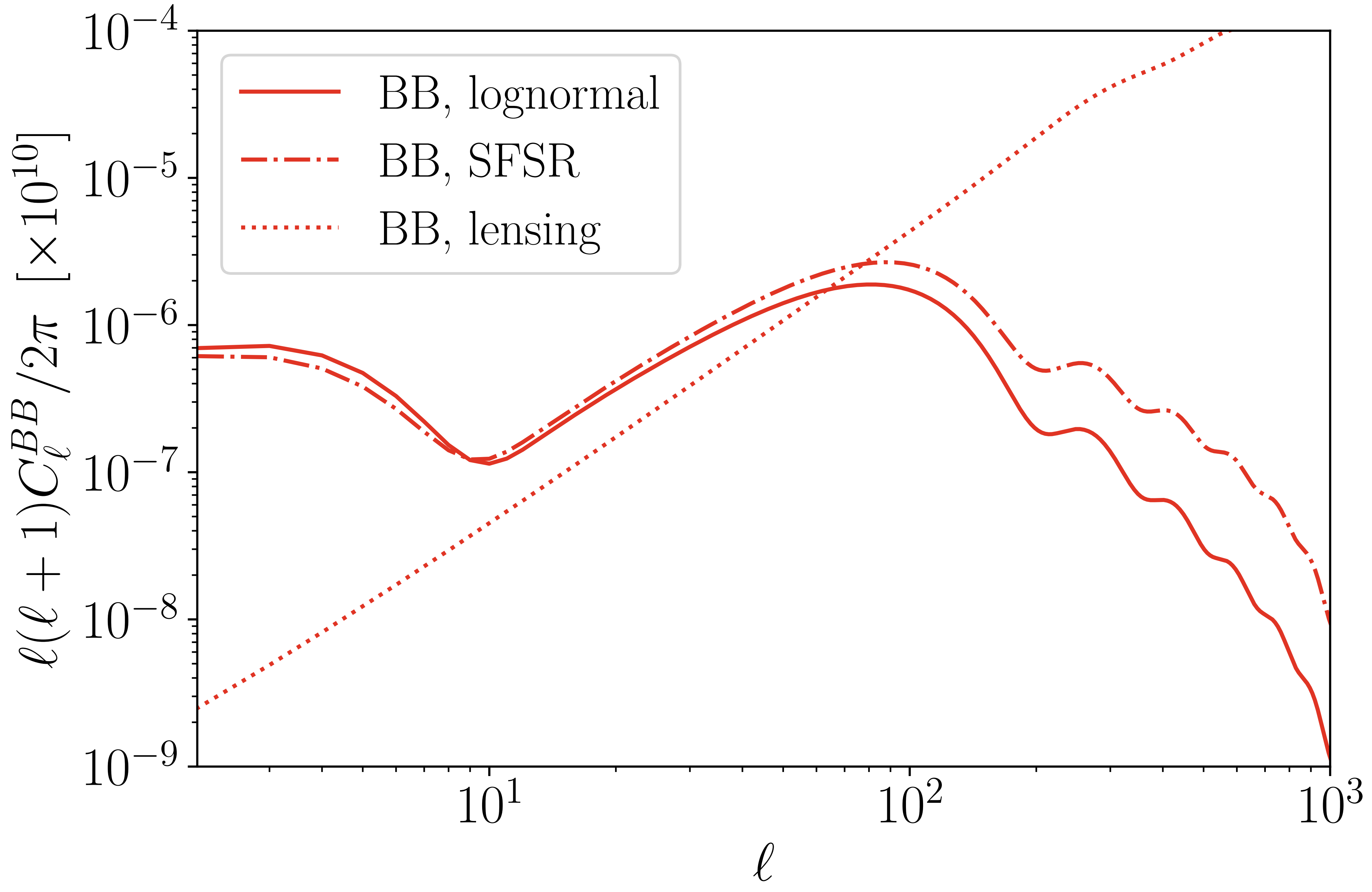


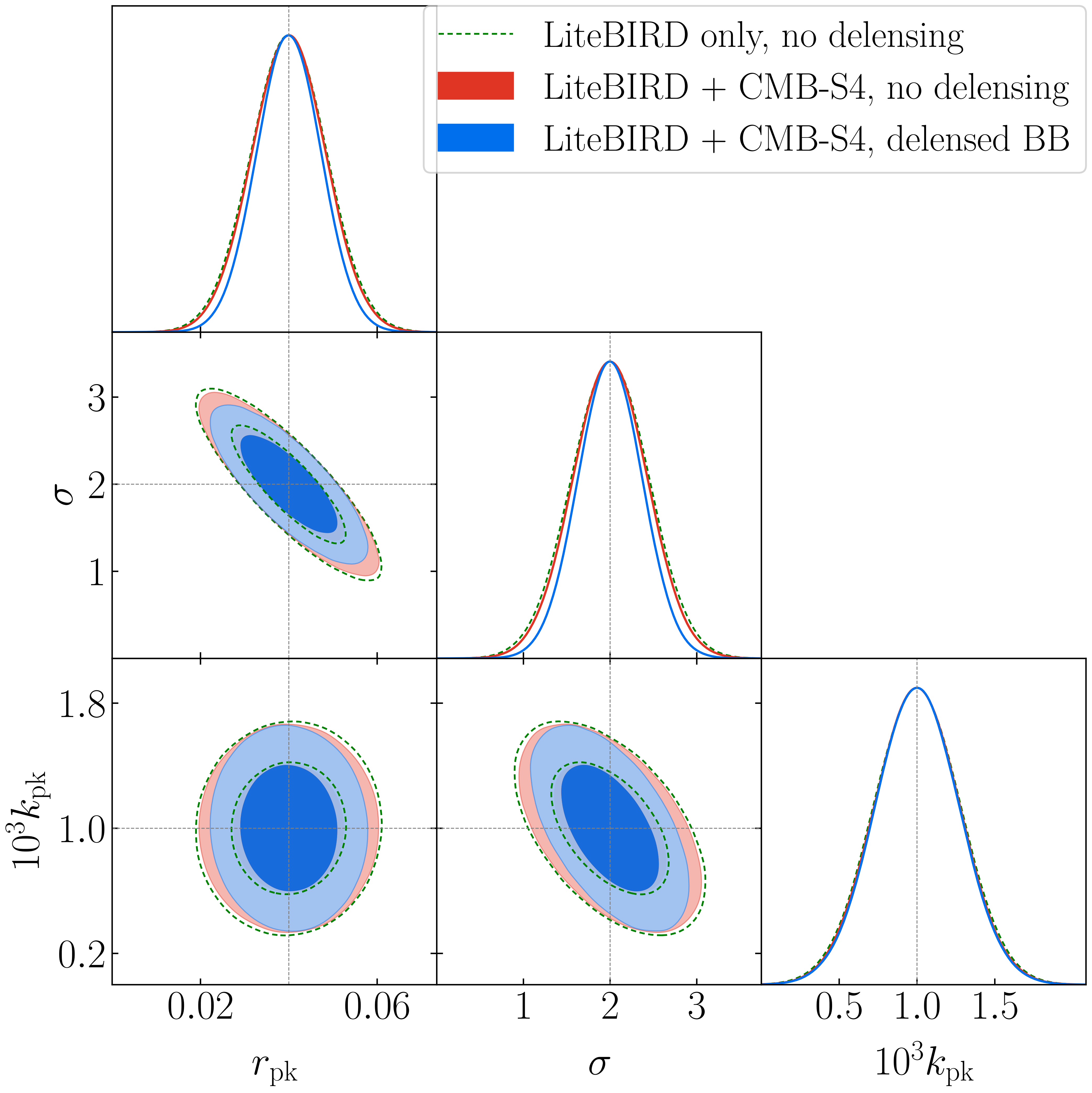
LiteBIRD


CMB-S4 (SPT+)

# Large scale feature

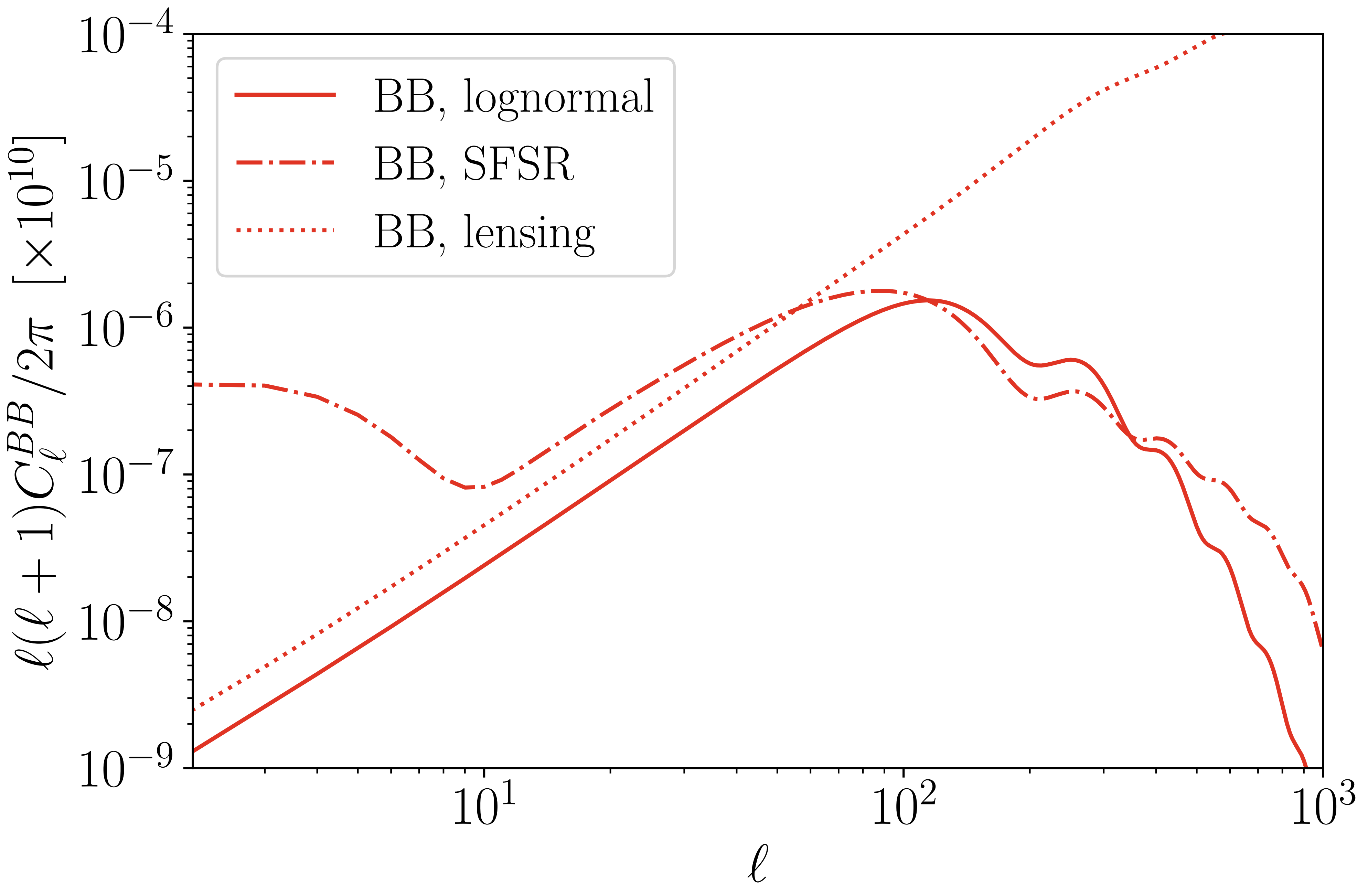
$$r_{\rm pk} = 0.04,\ \sigma = 2,\ k_{\rm pk} = 10^{-3}$$

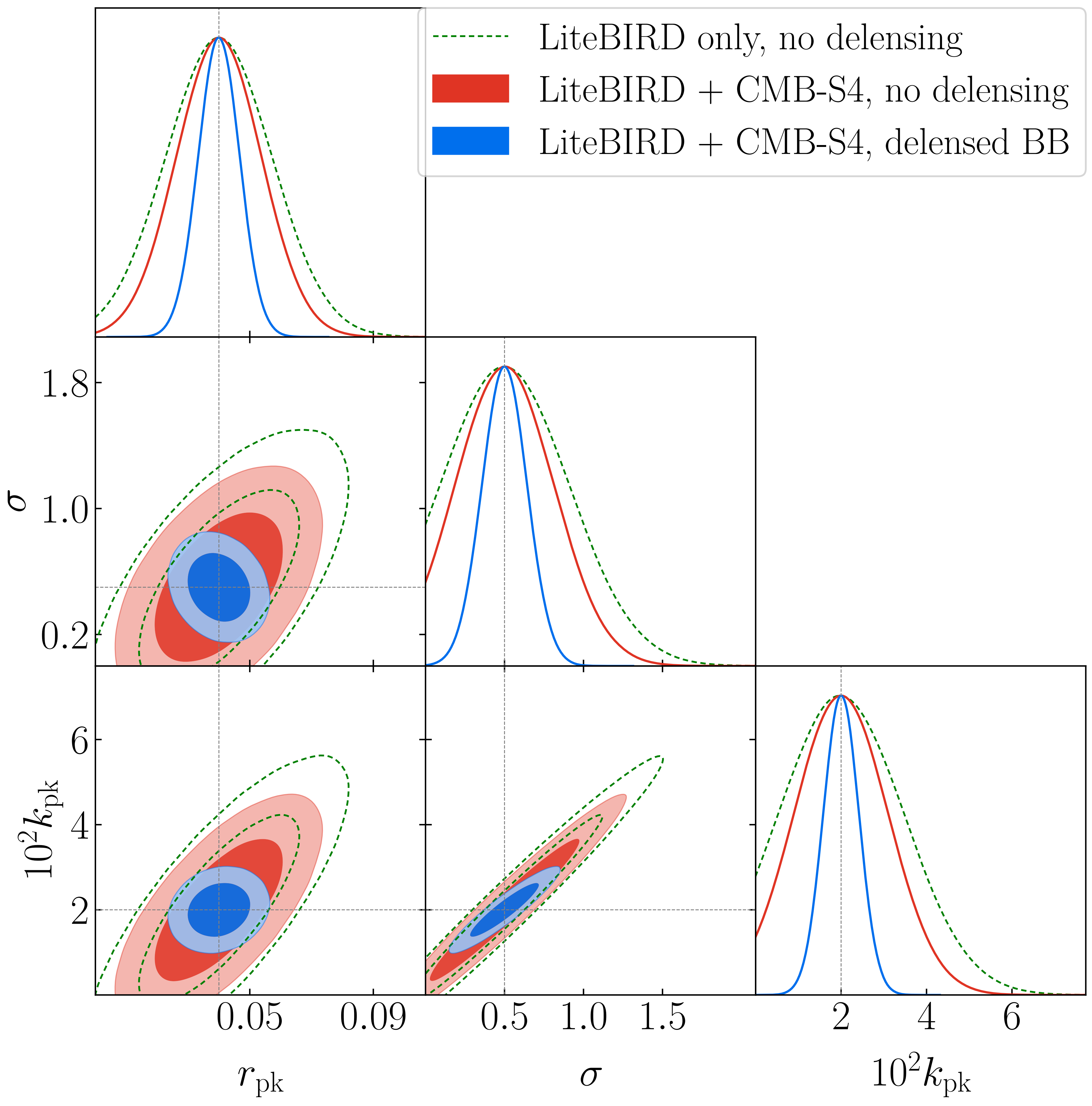


# Small scale feature

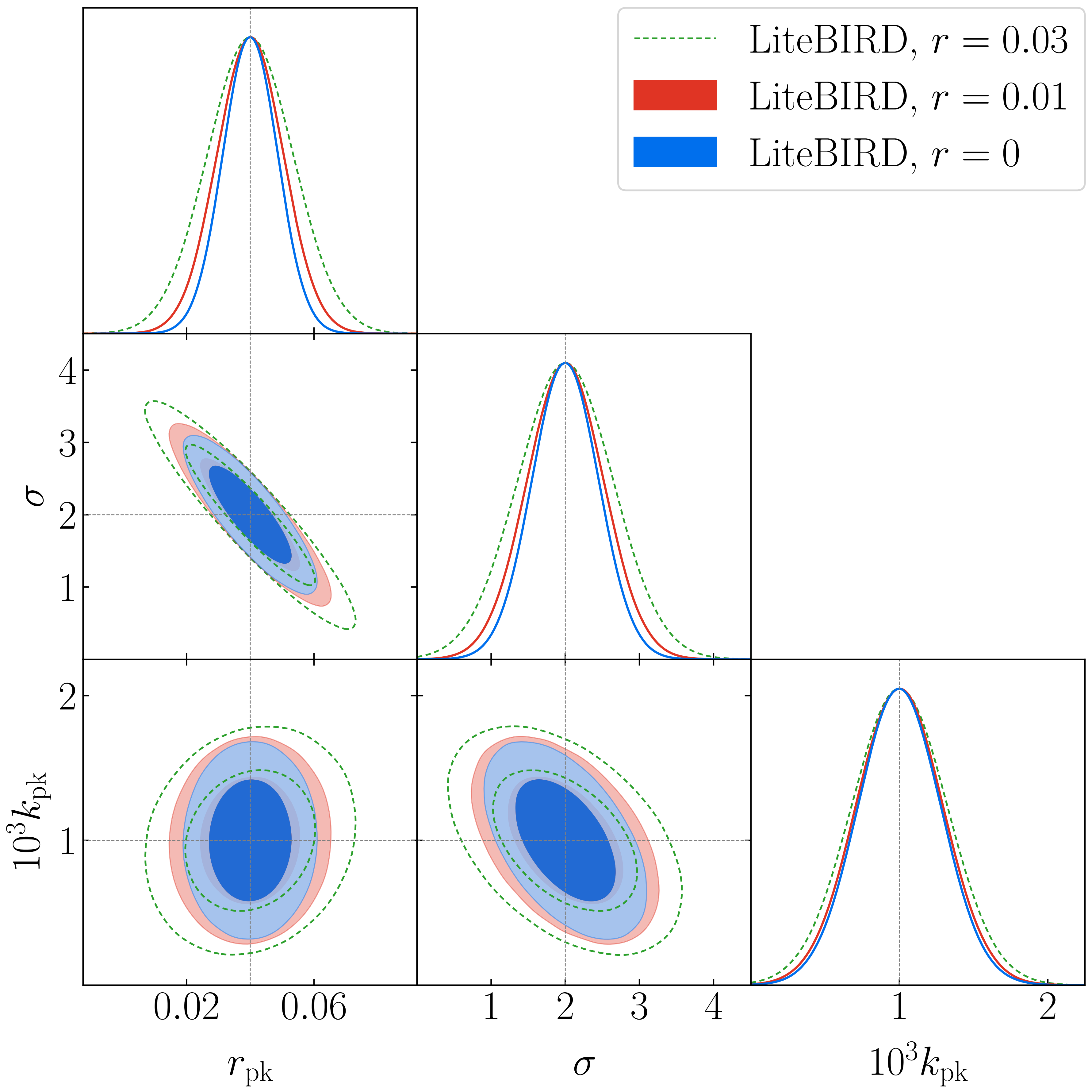
$r_{\rm pk} = 0.04,\ \sigma = 0.5,\ k_{\rm pk} = 2 \times 10^{-2}$



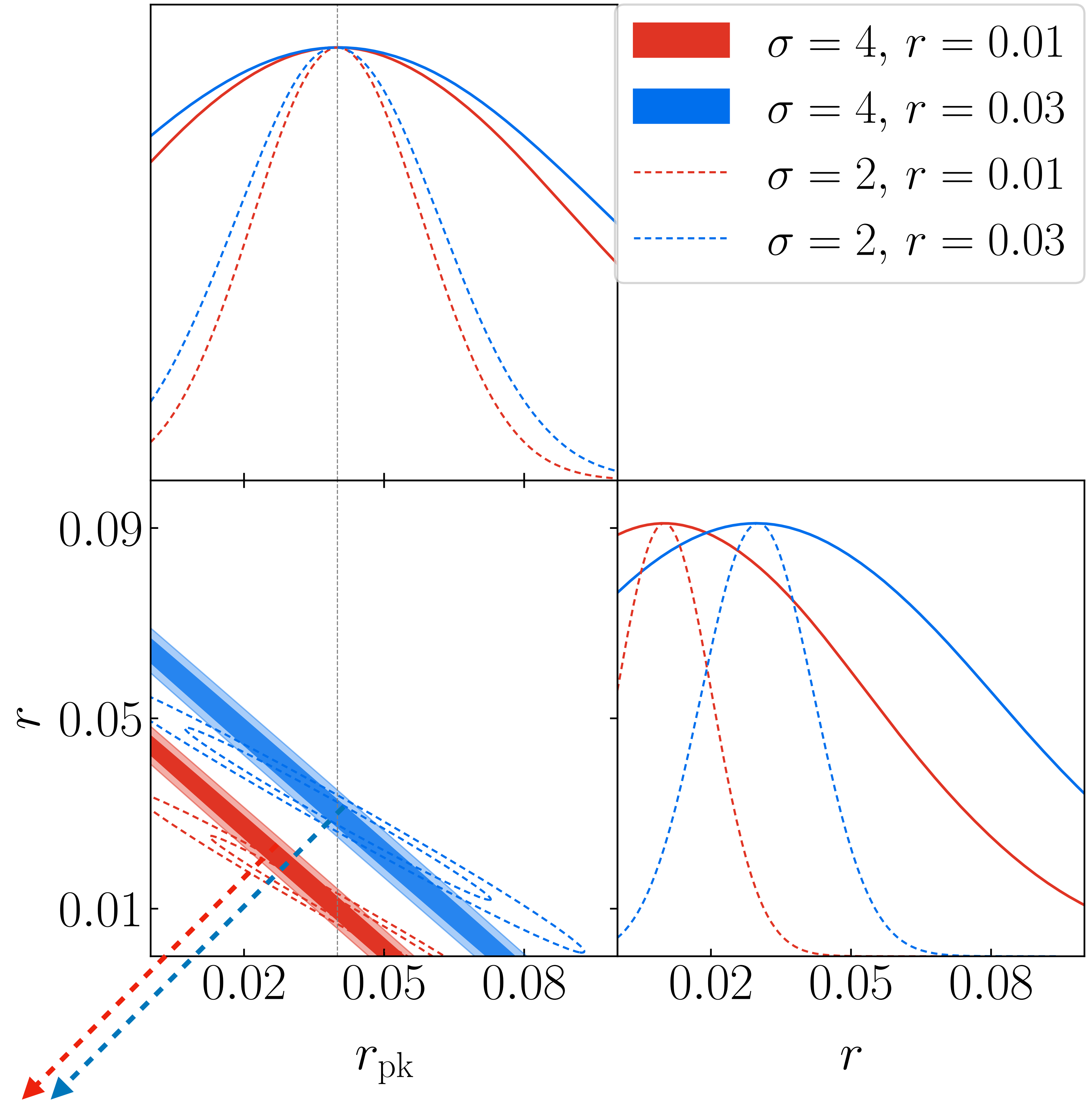




Delensing important for small scale features

# Detecting vacuum + sourced GW




$$r_{\rm pk} = 0.04,\ \sigma = 2,\ k_{\rm pk} = 10^{-3}$$




$$r_{\rm pk} + r \approx \text{constant}$$

## Summary

- ☑ Possibility of features in power spectra — deviations from SFSR dynamics
- ☑ Promising prospects for testing such features with next generation CMB experiments — hints to nature of inflationary interactions

Thank you!