Available component separation tools

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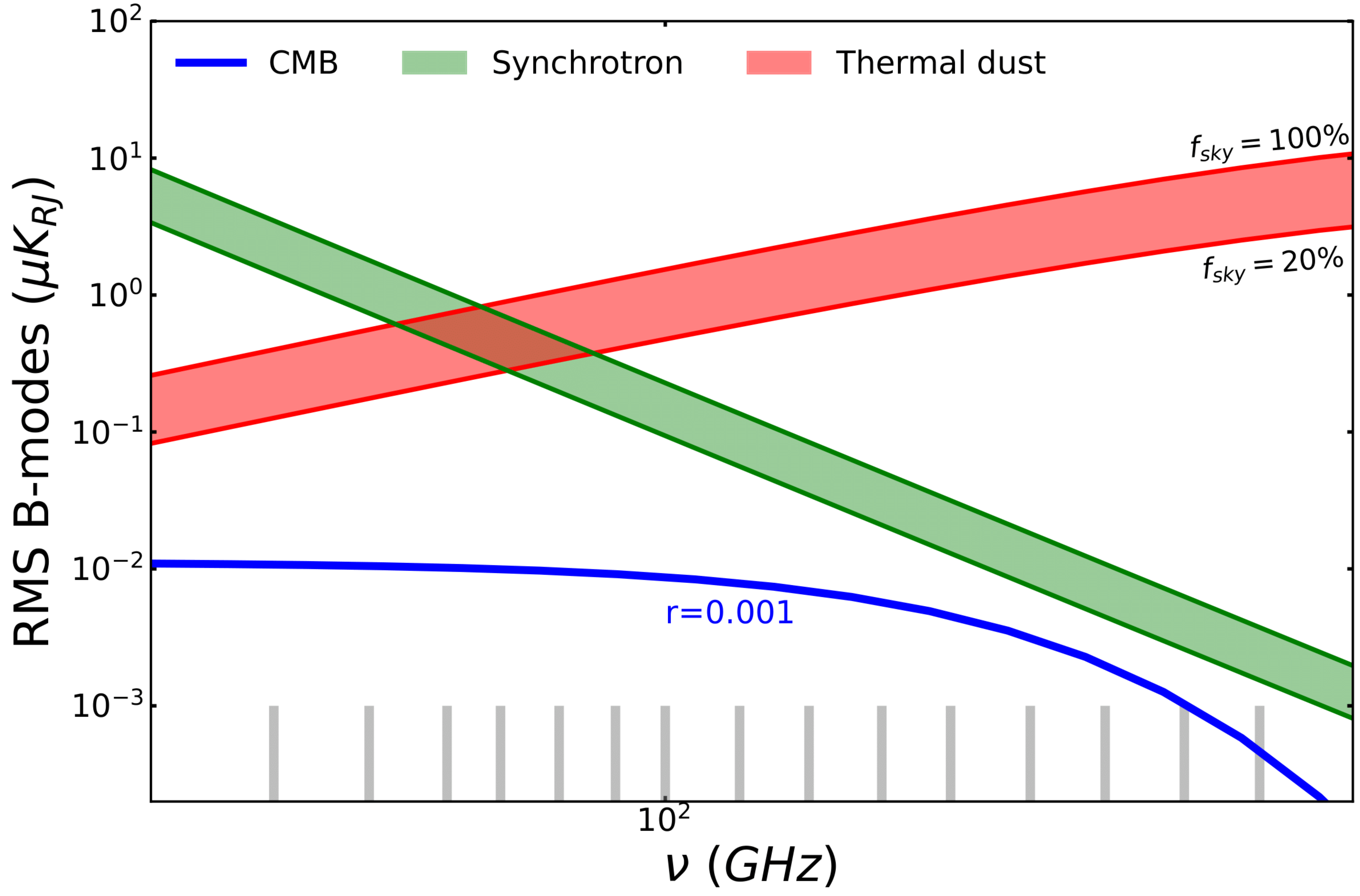
Workshop LiteBIRD-Italia

B-modes Foregrounds

ID	Title	Requirement description
Lv1.01	Tensor-to-scalar ratio r measurement sensitivity	The mission shall measure r with a total uncertainty of $\delta r < 1 \times 10^{-3}$. This value shall include contributions from instrumental statistical noise fluctuations, instrumental systematics, residual foregrounds, lensing B modes, and observer bias, and shall not rely on future external data sets.



Component separation

$$d = A\,s + n$$

frequencies
pixels
pixels
frequencies
components
components
pixels
frequencies
pixels

Data

Mixing Matrix (SED)

Sky signals (CMB, dust,…)

Noise

Component separation approaches

Parametric

Global chi-square minimization

$$\chi^2(p) = \sum_i \left(\frac{d_i(p) - m_i(p)}{\sigma_i(p)} \right)^2$$

Commander (Fuskeland et al., 2023)

FGBuster (LiteBIRD Collaboration, 2022)

B-SeCRET (Krachmalnicoff et al., 2022)

Moment fitting (Vacher et al., 2022)

Blind

Global variance minimization

$$\mathbb{E}\left[\left(\sum_i w_i d_i \right)^2 \right]$$

NILC (Remazeilles et al., 2021; Carones et al., 2022)

cMILC (Remazeilles et al., 2021)

MCNILC (Carones et al., 2022)

Foreground cleaning in PTEP paper

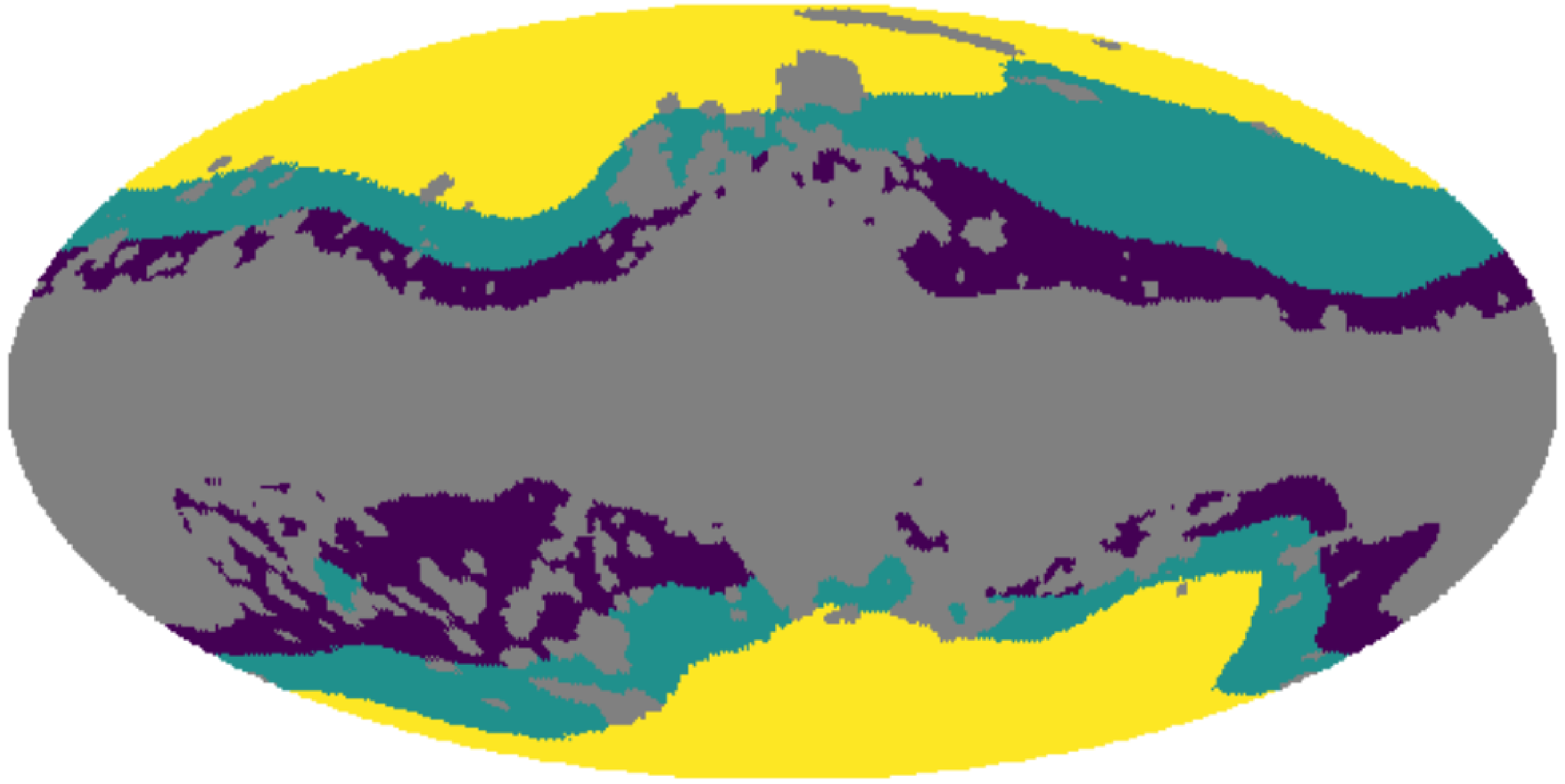
Foreground modeling and fitting

- **Synchrotron**: power law (PySM 's1')

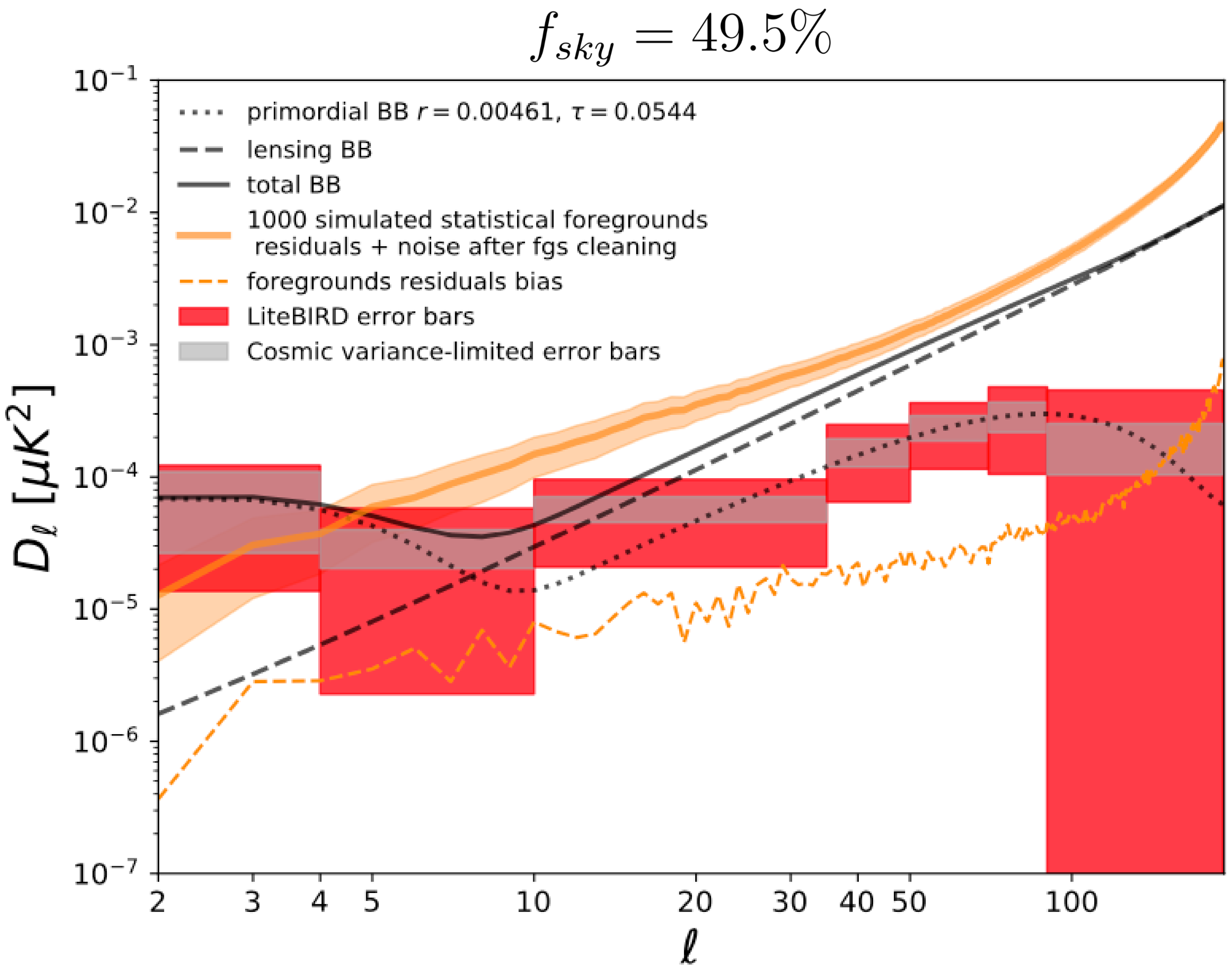
$$[Q_s, U_s](\nu, p) = [Q_s, U_s](\nu_s, p) \cdot \left(\frac{\nu}{\nu_s}\right)^{\beta_s(p)}$$

- **Dust**: modified blackbody (PySM 'd1')

$$[Q_d, U_d](\nu, p) = [Q_d, U_d](\nu_d, p) \cdot \left(\frac{\nu}{\nu_d}\right)^{\beta_d(p)-2} \frac{B(\nu, T_d(p))}{B(\nu_d, T_d(p))}$$



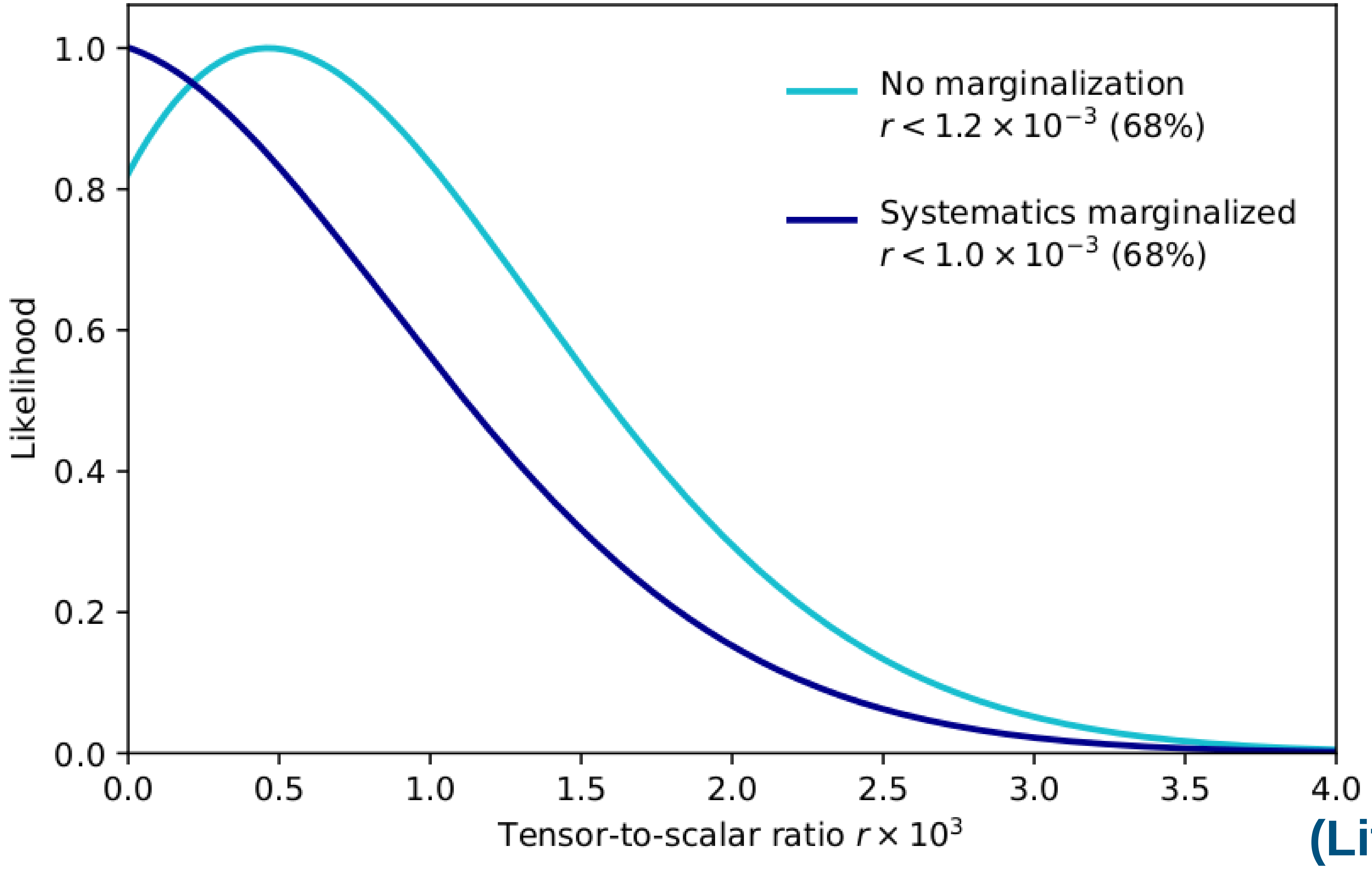
Impact of residuals



(LiteBIRD Collaboration, 2022)

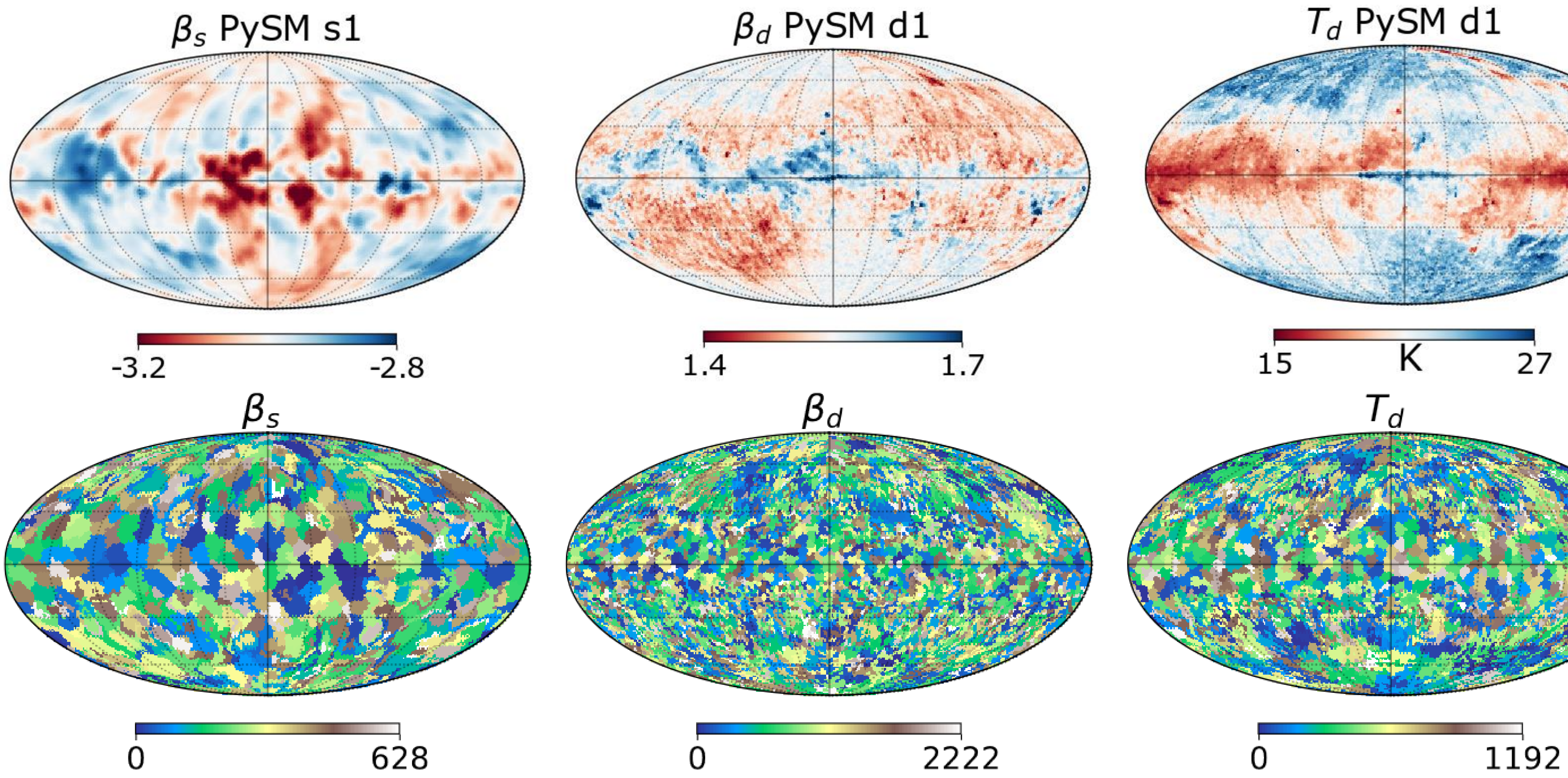
Constraints on the tensor-to-scalar ratio

$$\log L(r) = \sum_{\ell=\ell_{\rm min}}^{\ell_{\rm max}} \log P_\ell(r), \qquad \log P_\ell(r) = -f_{\rm sky}\frac{2\ell+1}{2}\left[\frac{\hat{C}_\ell}{C_\ell} + \log C_\ell - \frac{2\ell-1}{2\ell+1}\log \hat{C}_\ell\right]$$



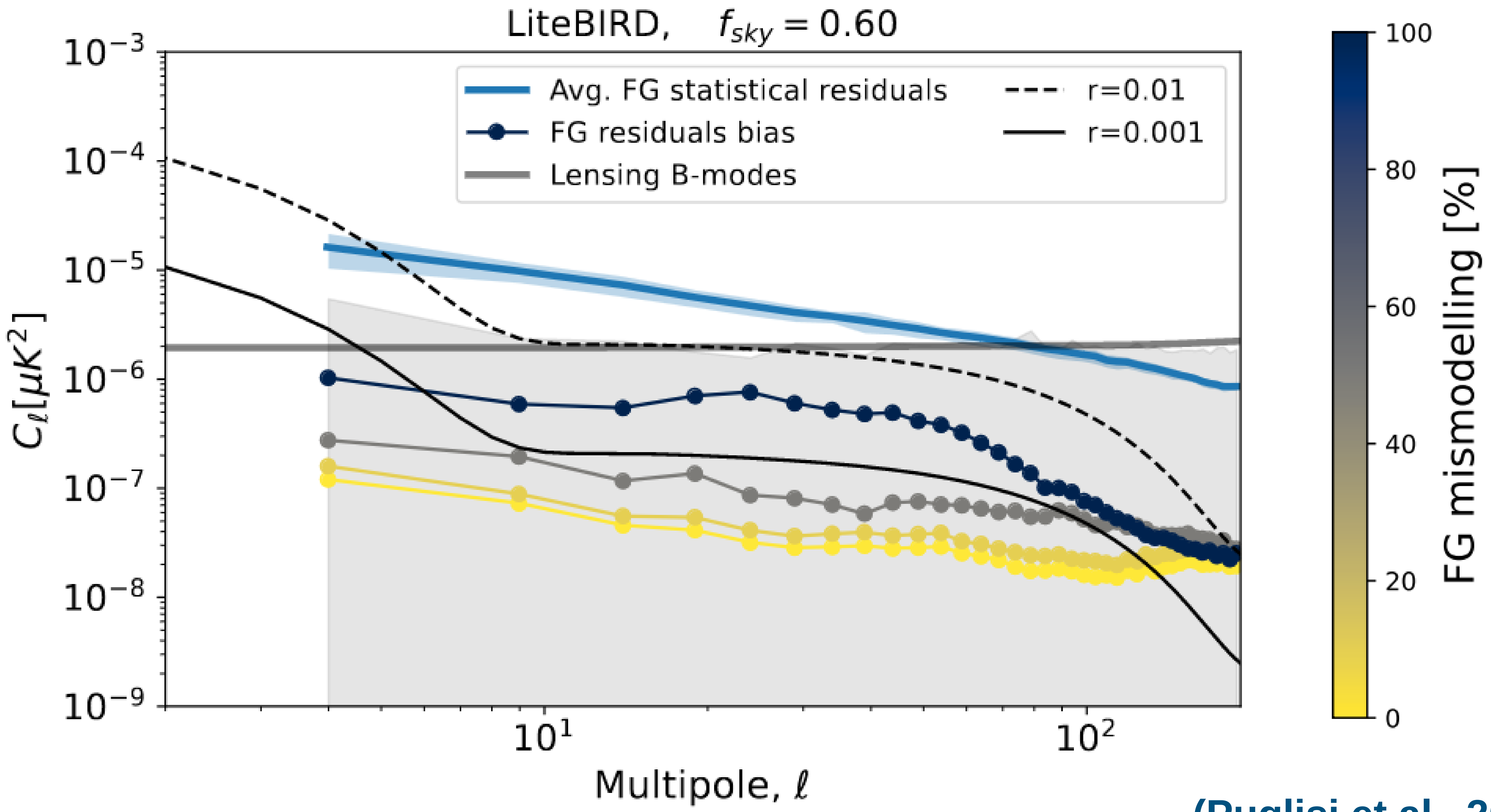
(LiteBIRD Collaboration, 2022)

Domains optimisation



(Puglisi et al., 2022)

Constraints on the tensor-to-scalar ratio



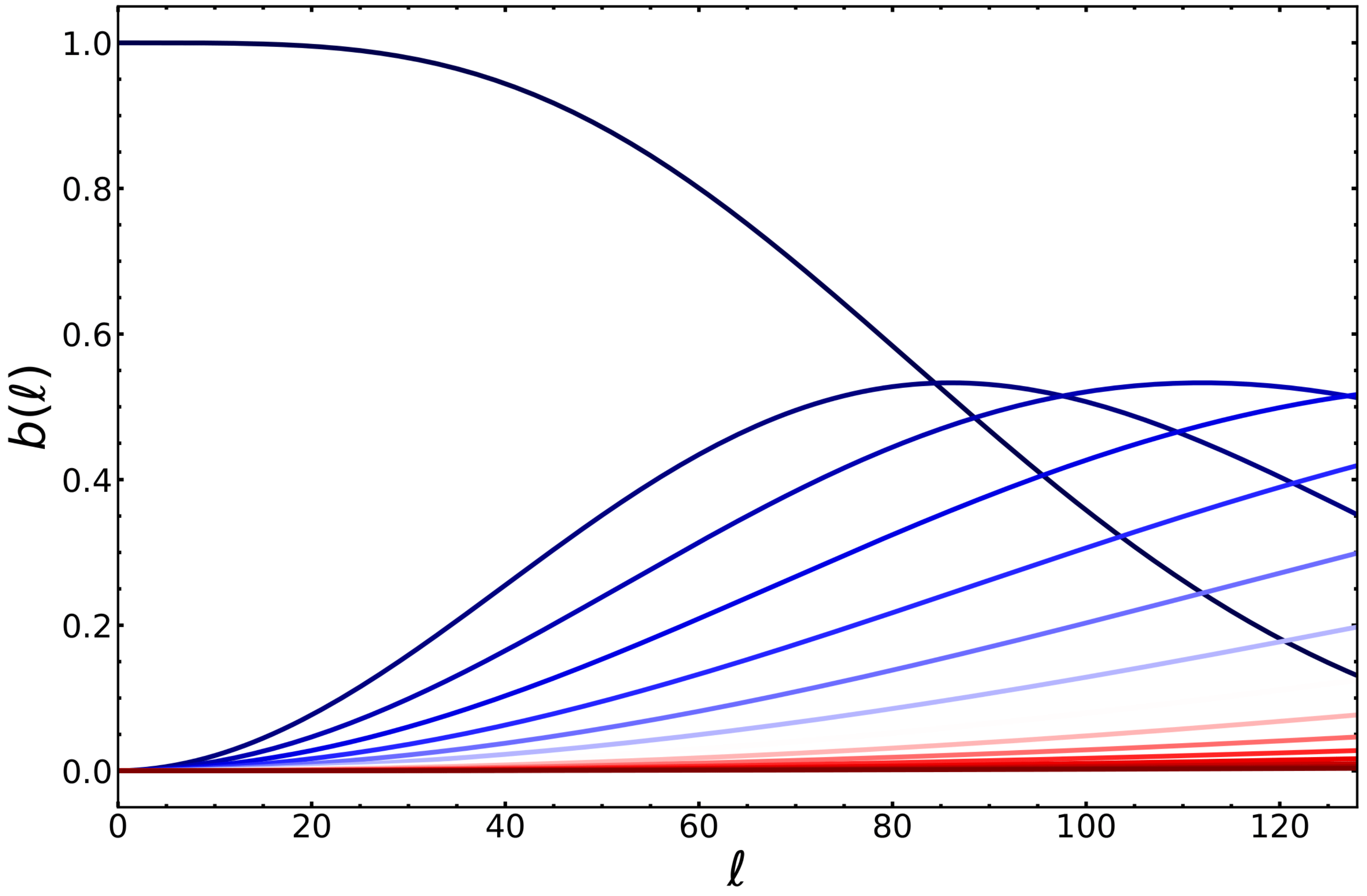
(Puglisi et al., 2022)

Needlet ILC (NILC)

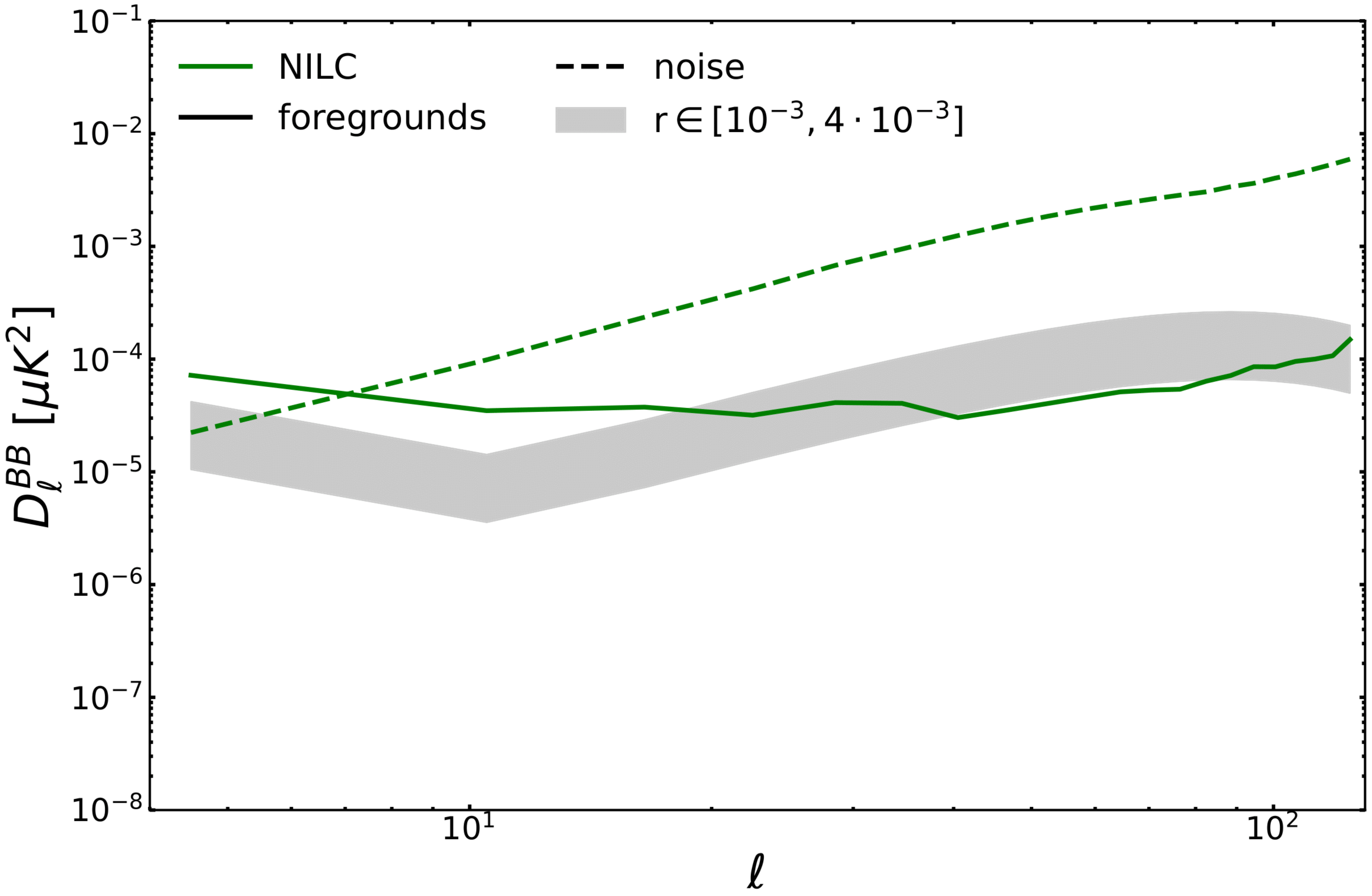
$$\beta_j^i(\hat{n}) = \sum_{\ell m} (a_{\ell m}^{B,i} \cdot b_j(\ell)) \cdot Y_{\ell m}(\hat{n}),$$

$$\beta_j^{NILC}(\hat{n}) = \sum_i w_j^i(\hat{n}) \cdot \beta_j^i(\hat{n}),$$

$$w_j^i(\hat{n}) = \frac{\sum_{ik} {C_{ik}^{(j)}}^{-1}(\hat{n})}{\sum_{zk} {C_{zk}^{(j)}}^{-1}(\hat{n})},$$



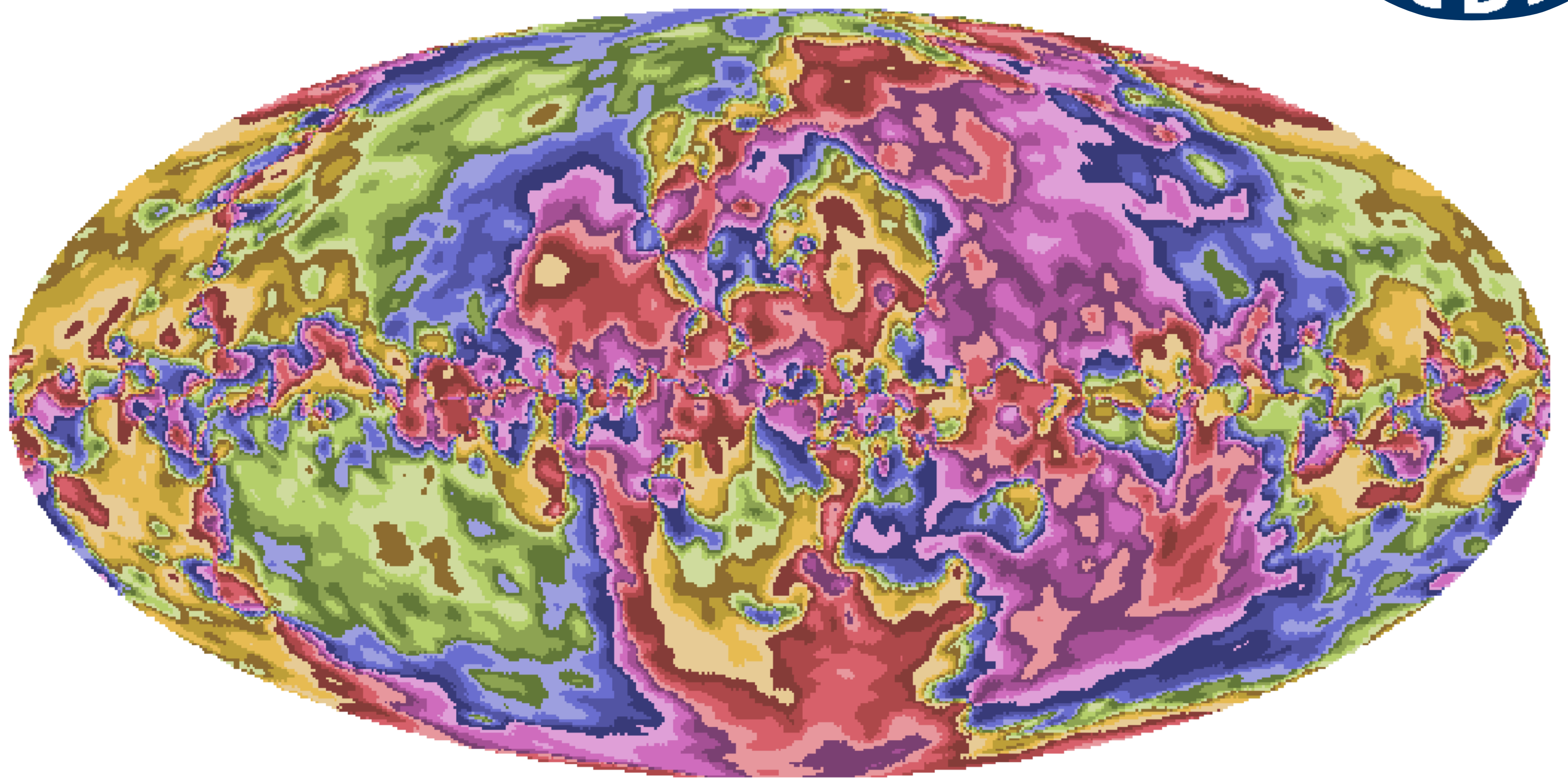
$f_{\mathbf{sky}} = \mathbf{50\%}$



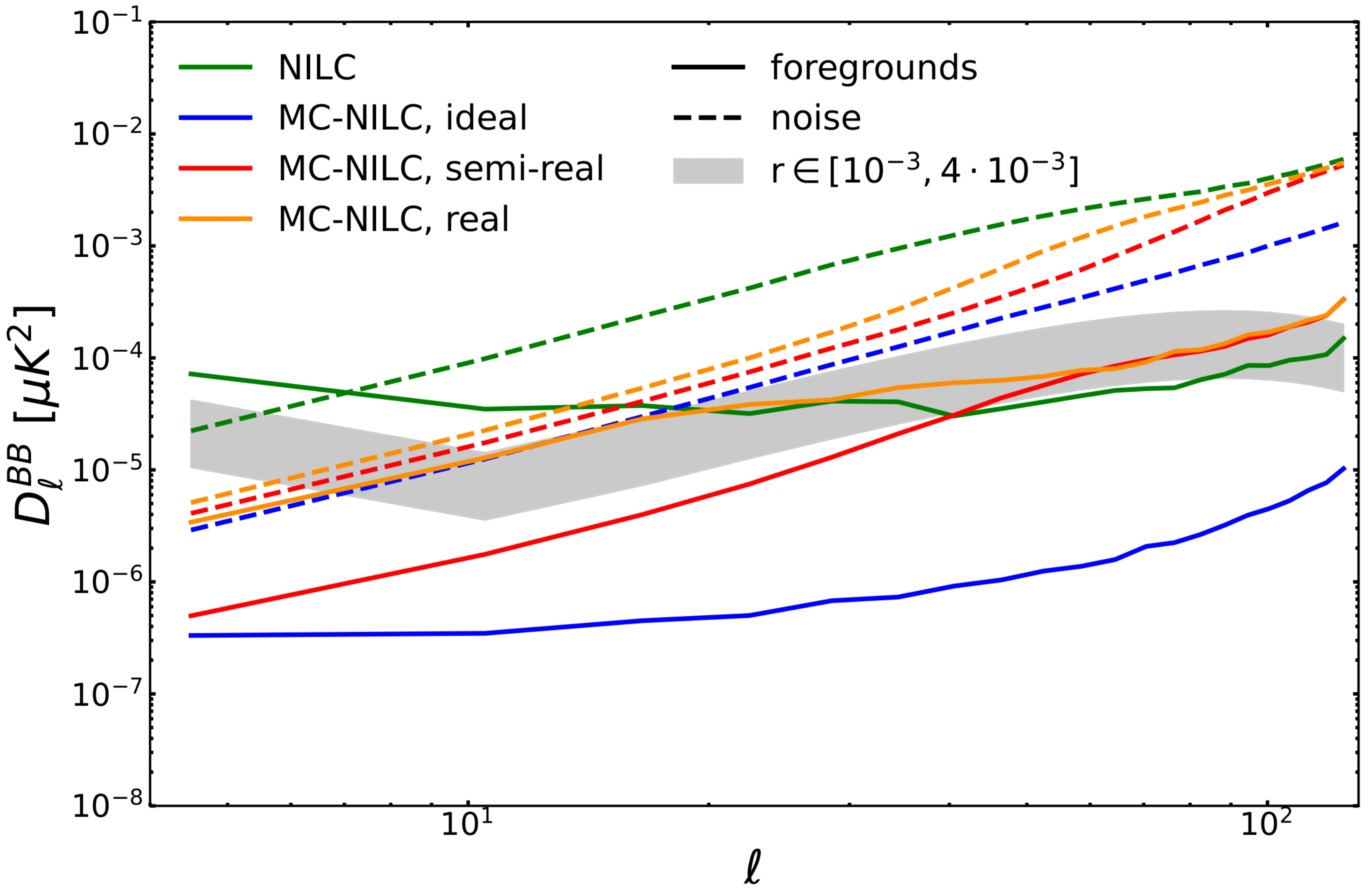
Multi-Clustering NILC (MC-NILC)

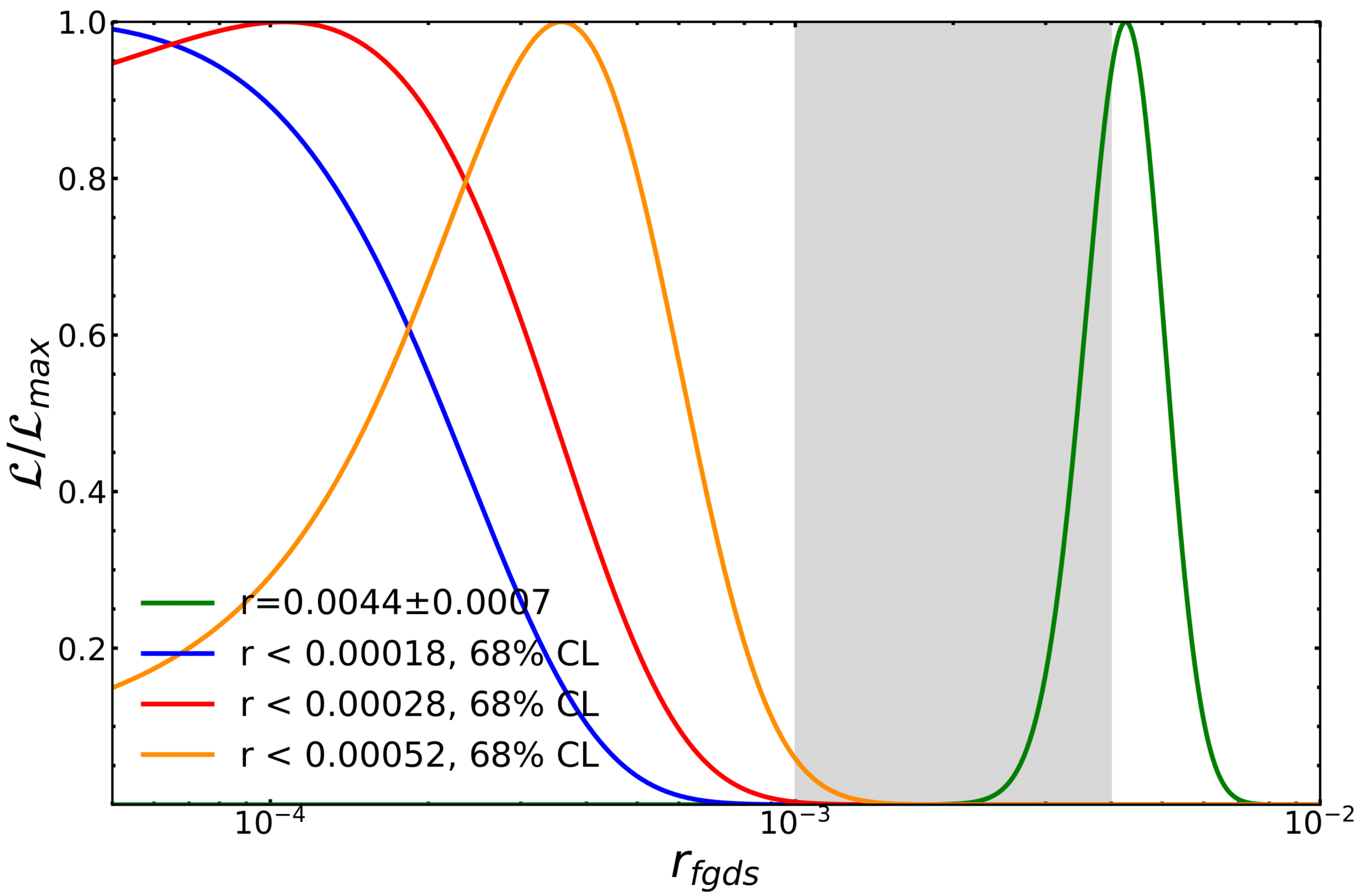
(Carones et al., 2022)

$$\frac{B^{337}_{fgds}}{B^{119}_{fgds}} = \frac{B^{337}_{dust} + B^{337}_{sync}}{B^{119}_{dust} + B^{119}_{sync}} = \frac{B^{337}_{dust}}{B^{119}_{dust}} \cdot \frac{1 + B^{337}_{sync} / B^{337}_{dust}}{1 + B^{119}_{sync} / B^{119}_{dust}}$$



$$f_{\text{sky}} = 50\%$$





Not only B-modes

LiteBIRD will provide measurements of large-scale E-modes at unprecedented sensitivity:

- **Constraints on τ**
- **Reionization history**
- **Sum of neutrino masses**
- **Cosmic inflation**
- **Primordial magnetic fields**
- **…**

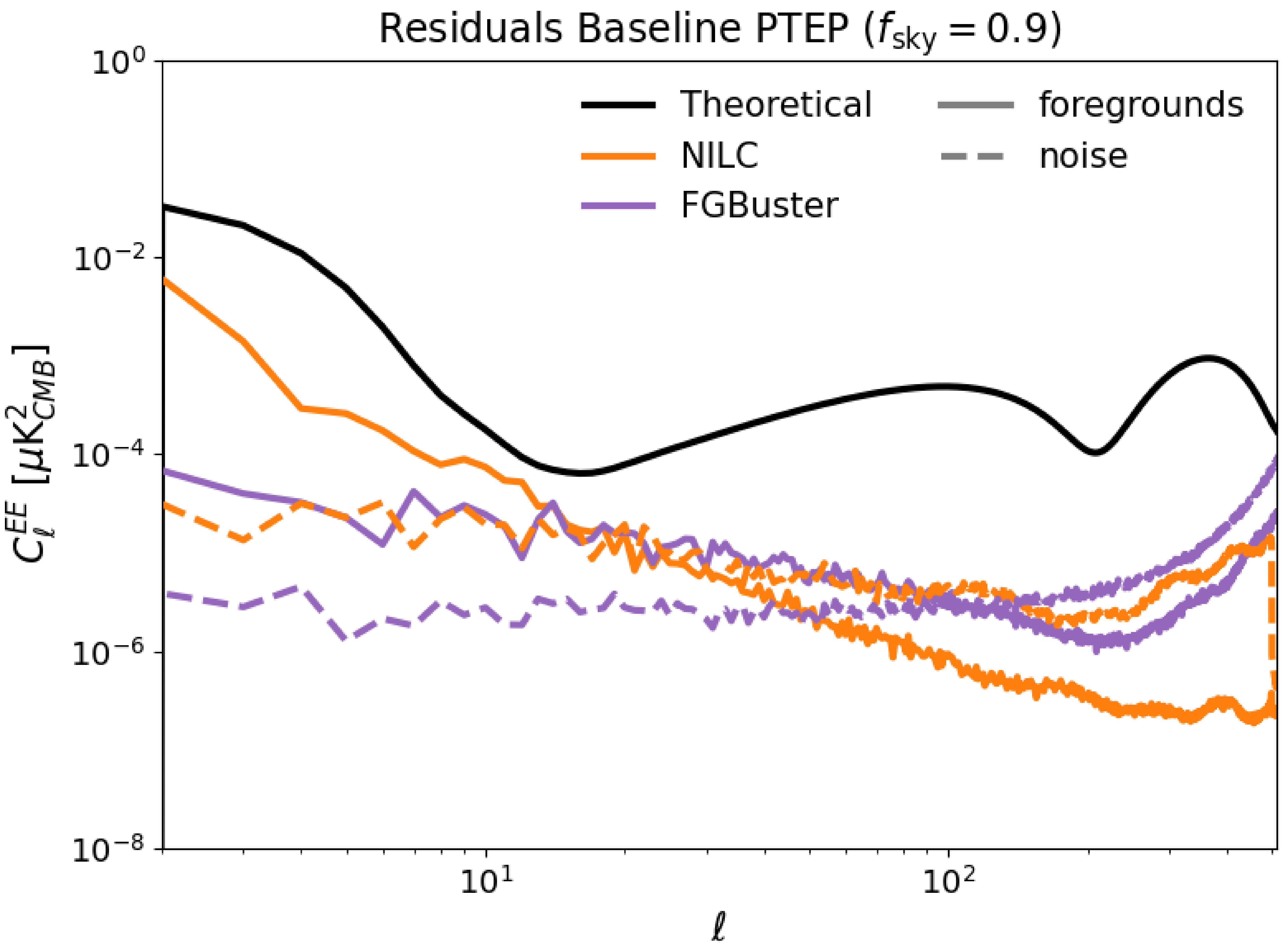
E-modes from LiteBIRD Project Paper (coordinators: E. de la Hoz, A. Carones)

wiki : https://wiki.kek.jp/display/cmb/E+Modes+from+LiteBIRD

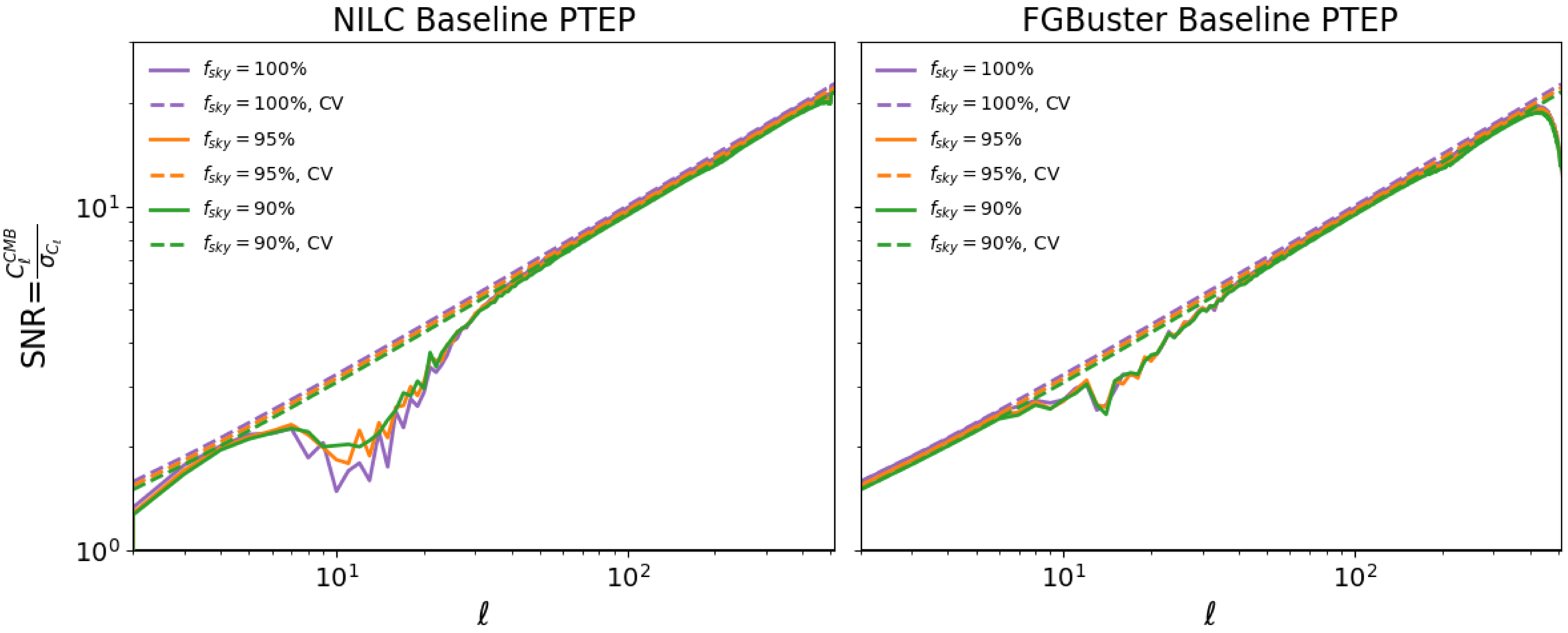
- **Assess the reconstruction of CMB E-modes from realistic LiteBIRD simulated data**
- **Deliver new products to be exploited by other PSGs**
- **Test the impact of the scanning strategy and more complex foregrounds emission on the performance of component separation pipelines in E-modes**

E-modes from LiteBIRD

Baseline PTEP : (d1s1) + isotropic white noise



E-modes from LiteBIRD



Conclusions

- Subtracting B-modes foregrounds at the required sensitivity will be one of the major challenges of LiteBIRD data-analysis

Within the LiteBIRD Italian community:

- We have a set of consolidated pipelines to be applied:
  - Parametric
  - Blind

- These methods have been optimised with a specific selection of the domains where component separation is separately performed

- Further work needed to deal with all possible uncertainties in foregrounds emission

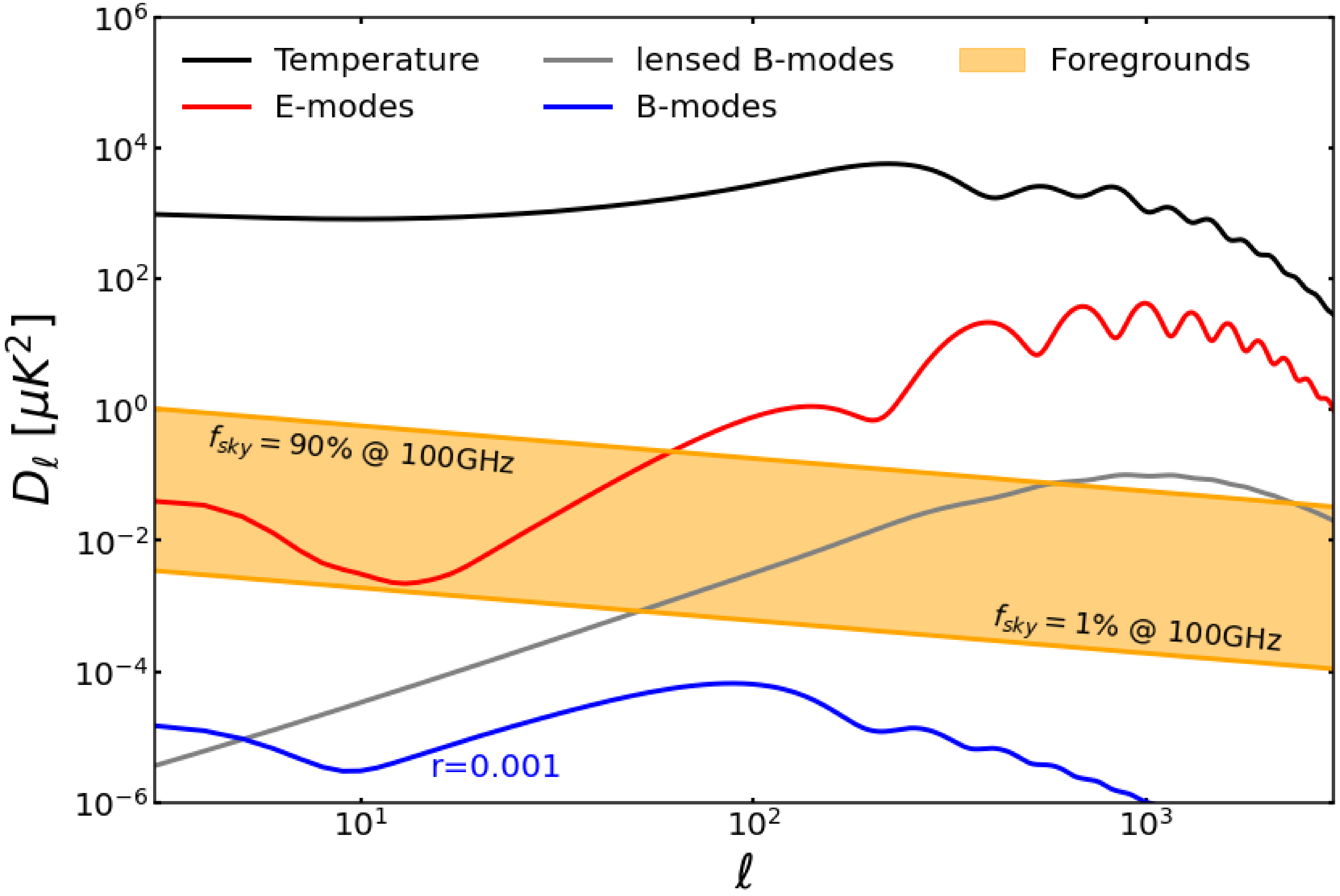
- We are targeting a cosmic-variance limited measurement of large-scale E-modes: optimisation of the methods and masking strategies

THANK YOU FOR THE ATTENTION

BACK-UP

SLIDES

CMB B-modes



Temperature
lensed B-modes
Foregrounds
E-modes
B-modes
$f_{sky} = 90\%$ @ 100GHz
$f_{sky} = 1\%$ @ 100GHz
r=0.001
$D_\ell\ [\mu K^2]$
ℓ
10^6
10^4
10^2
10^0
10^{-2}
10^{-4}
10^{-6}
10^1
10^2
10^3

FGBuster

$$-2\log \mathcal{L}_{\rm data}(s,\theta) \propto (d - As)^T N^{-1}(d - As)$$

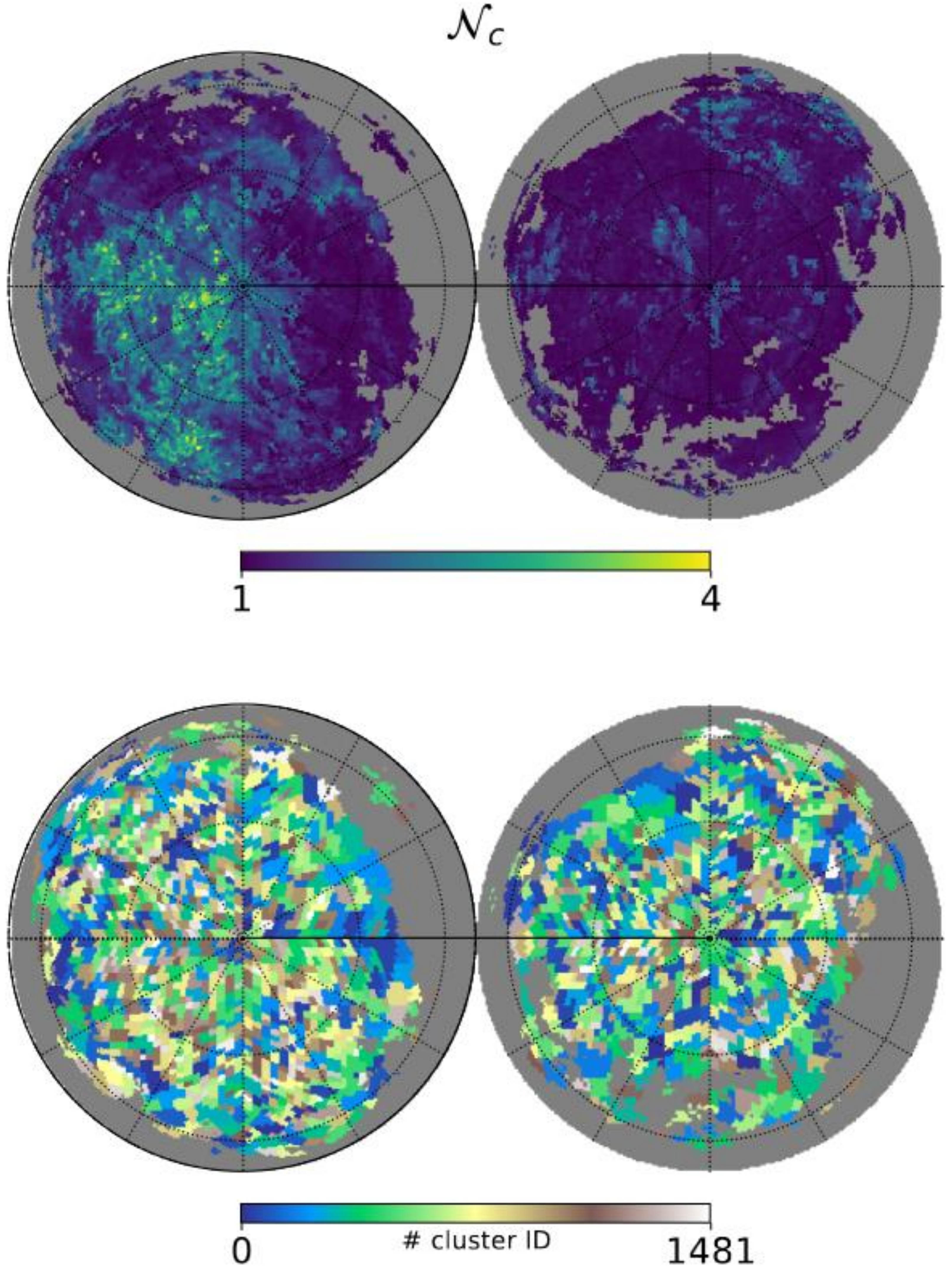
Maximum if:

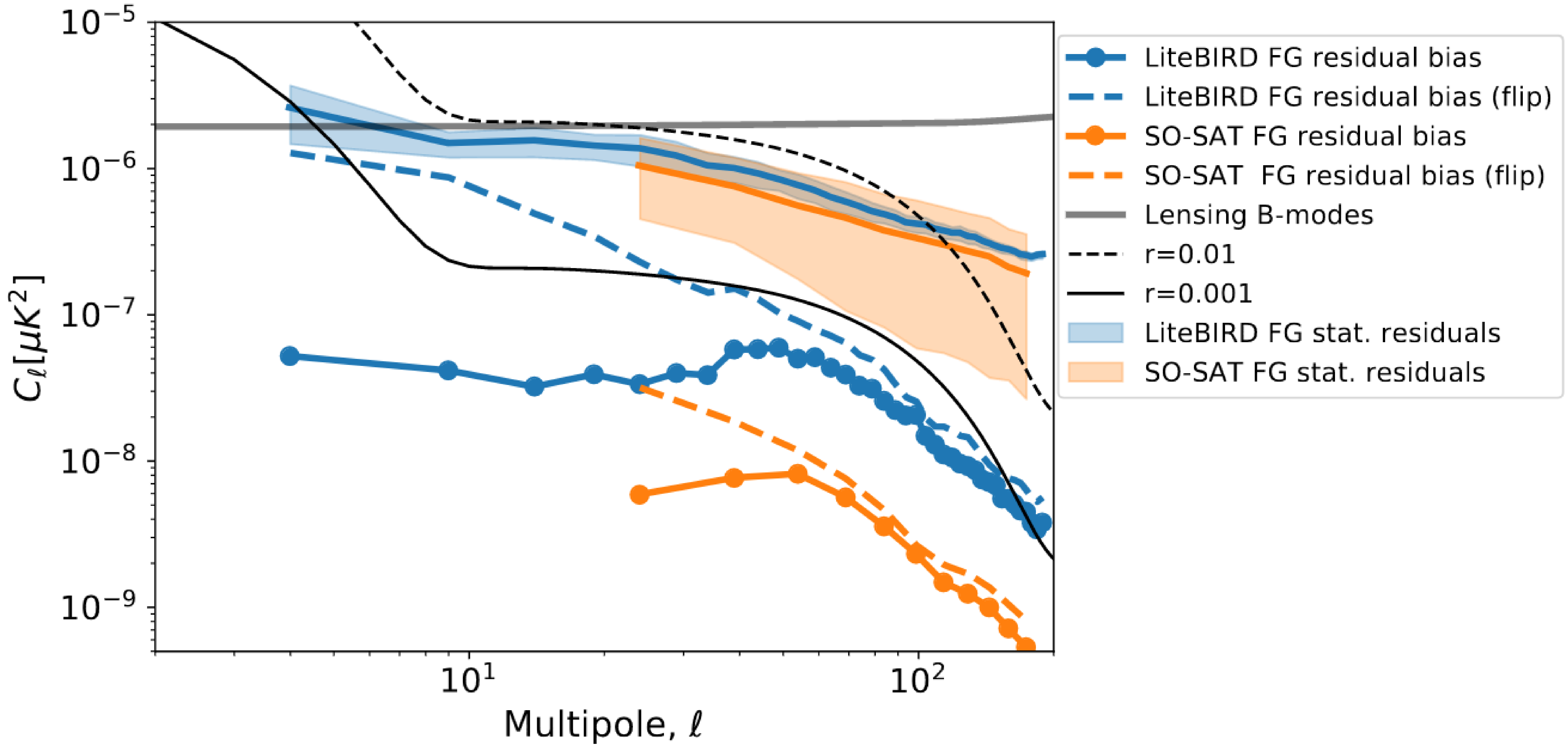
$$-(A_{,\theta}(\theta_{\rm m})s_{\rm m})^T N^{-1}(d - A(\theta_{\rm m})s_{\rm m}) = 0$$

$$s_{\rm m} = (A^T(\theta_{\rm m})N^{-1}A(\theta_{\rm m}))^{-1}A^T(\theta_{\rm m})N^{-1}d$$

$$-2\log \mathcal{L}_{\rm spec}(\theta) \propto -(A^T N^{-1}d)^T(A^T N^{-1}A)^{-1}(A^T N^{-1}d)$$

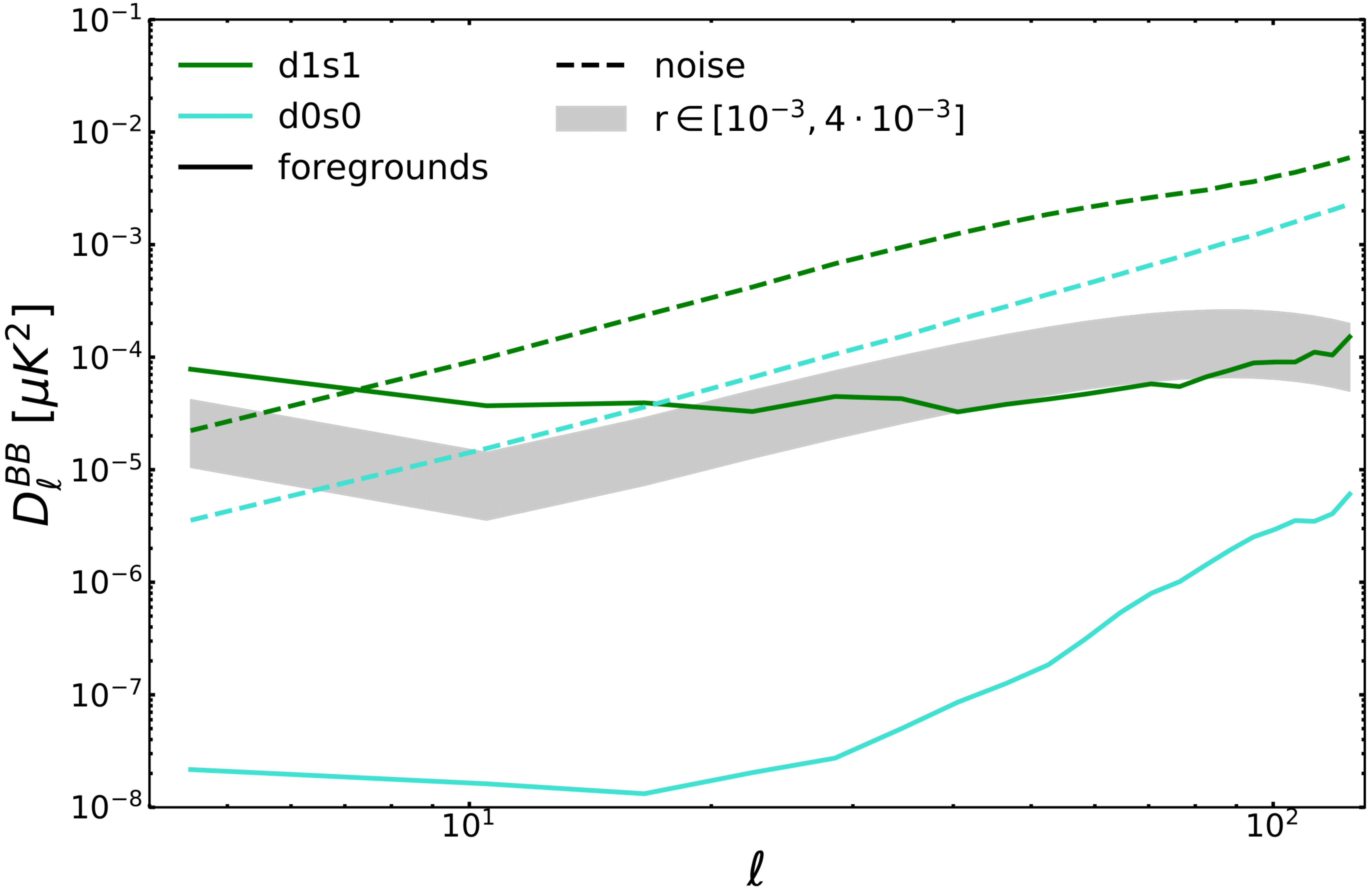
Test with HI clouds





(Puglisi et al., 2022)

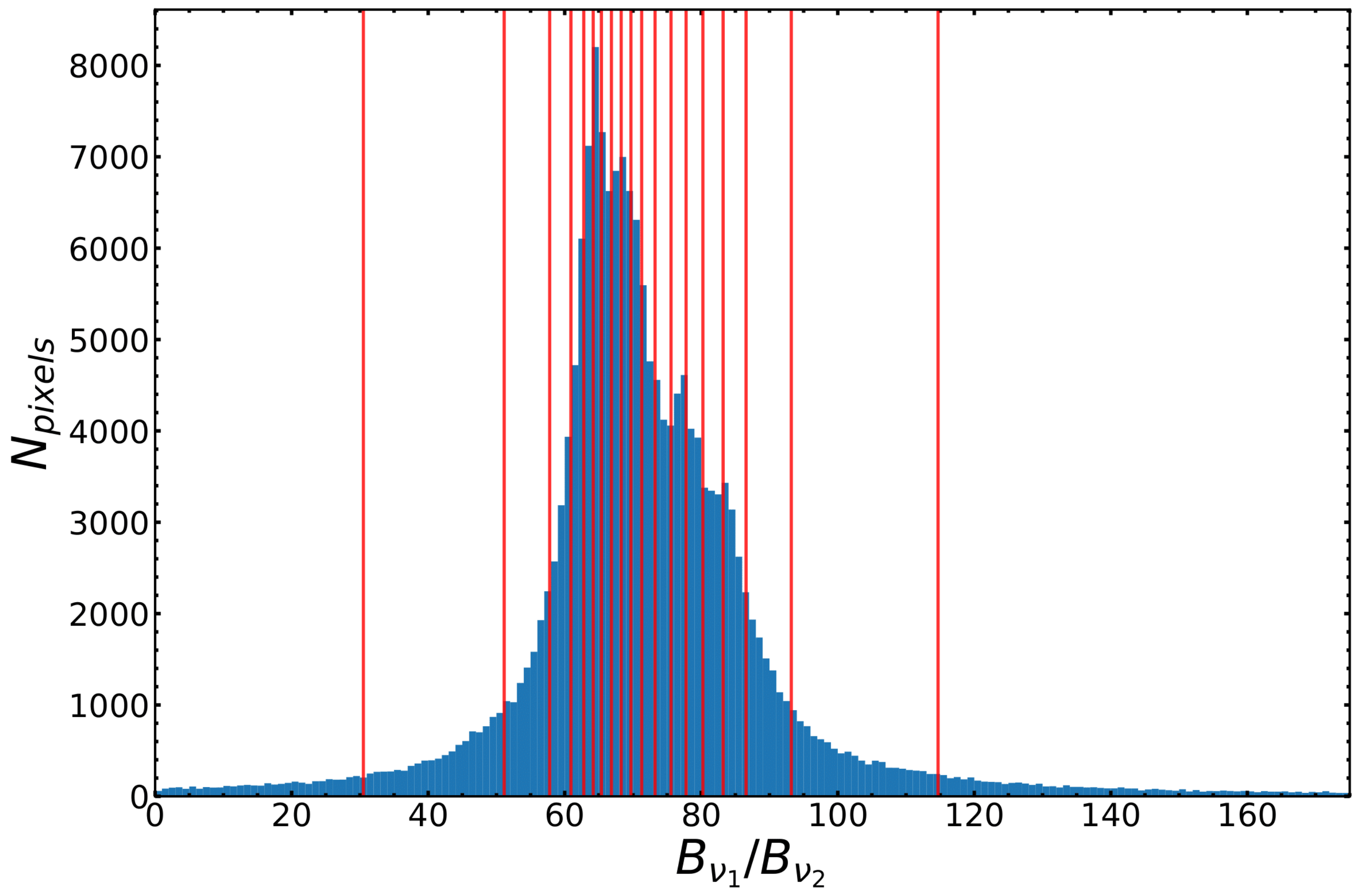
Effect of spectral variations

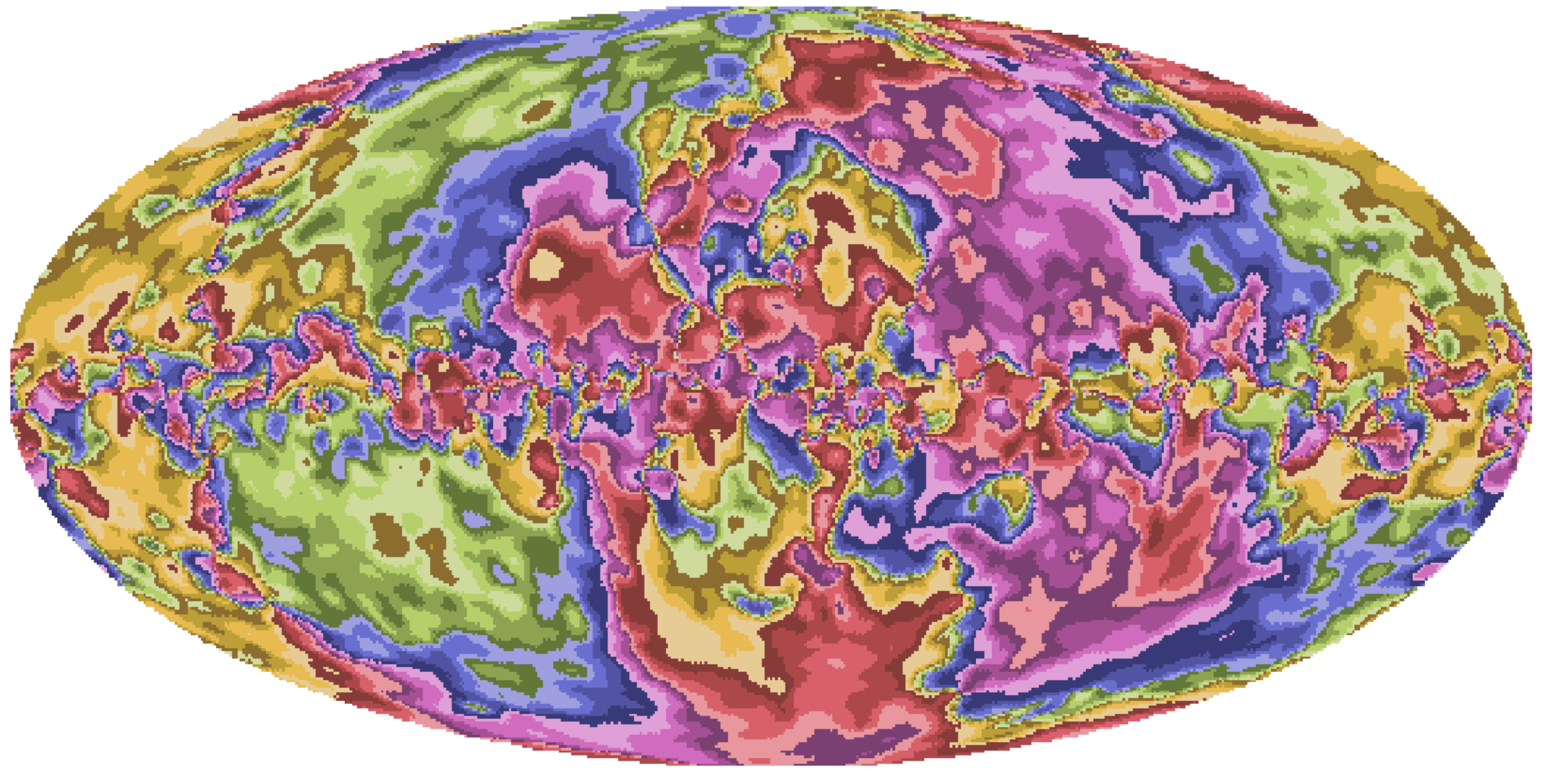


Multi-Clustering NILC (MC-NILC)

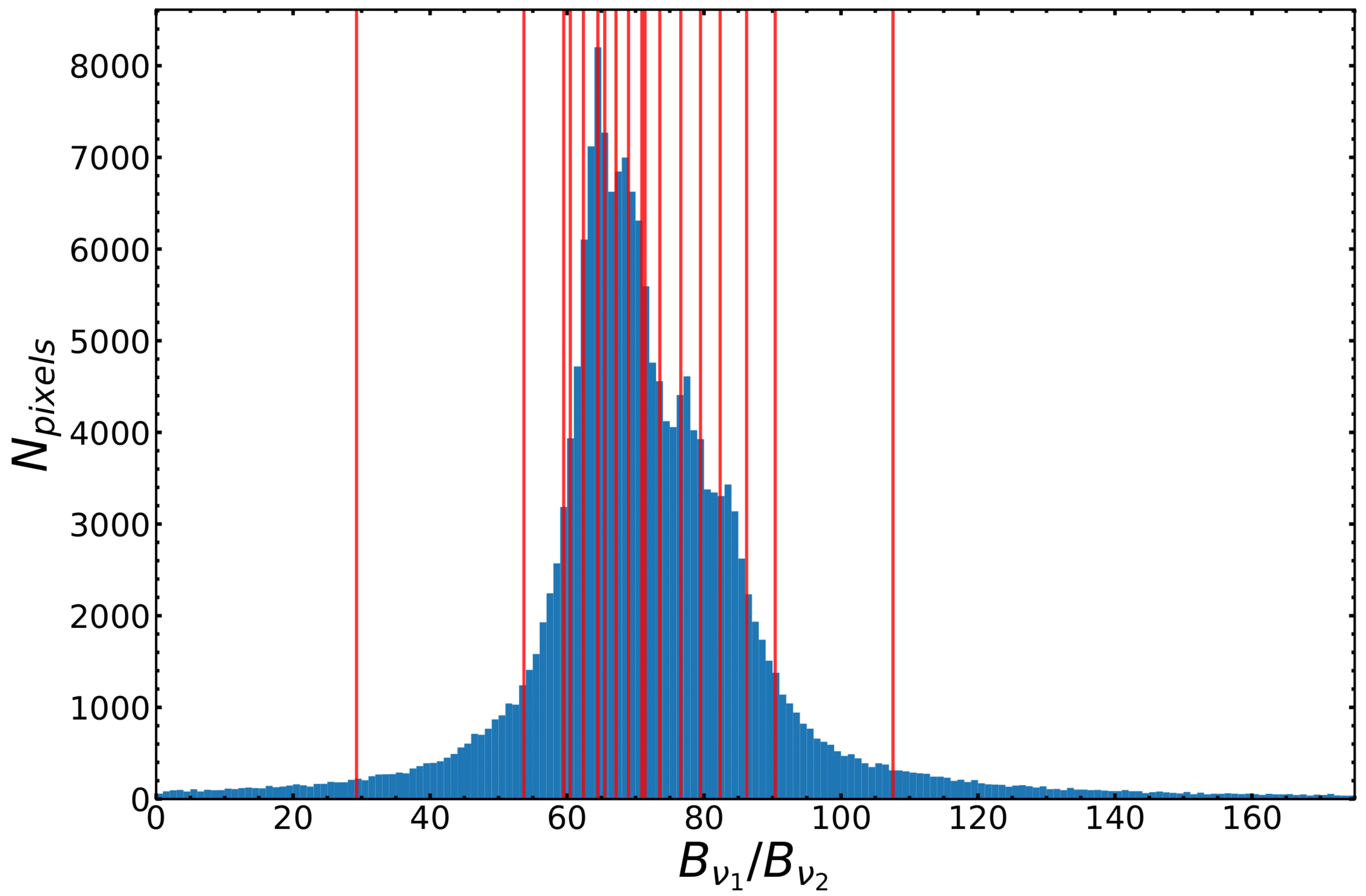
2. CLUSTERING TECHNIQUES

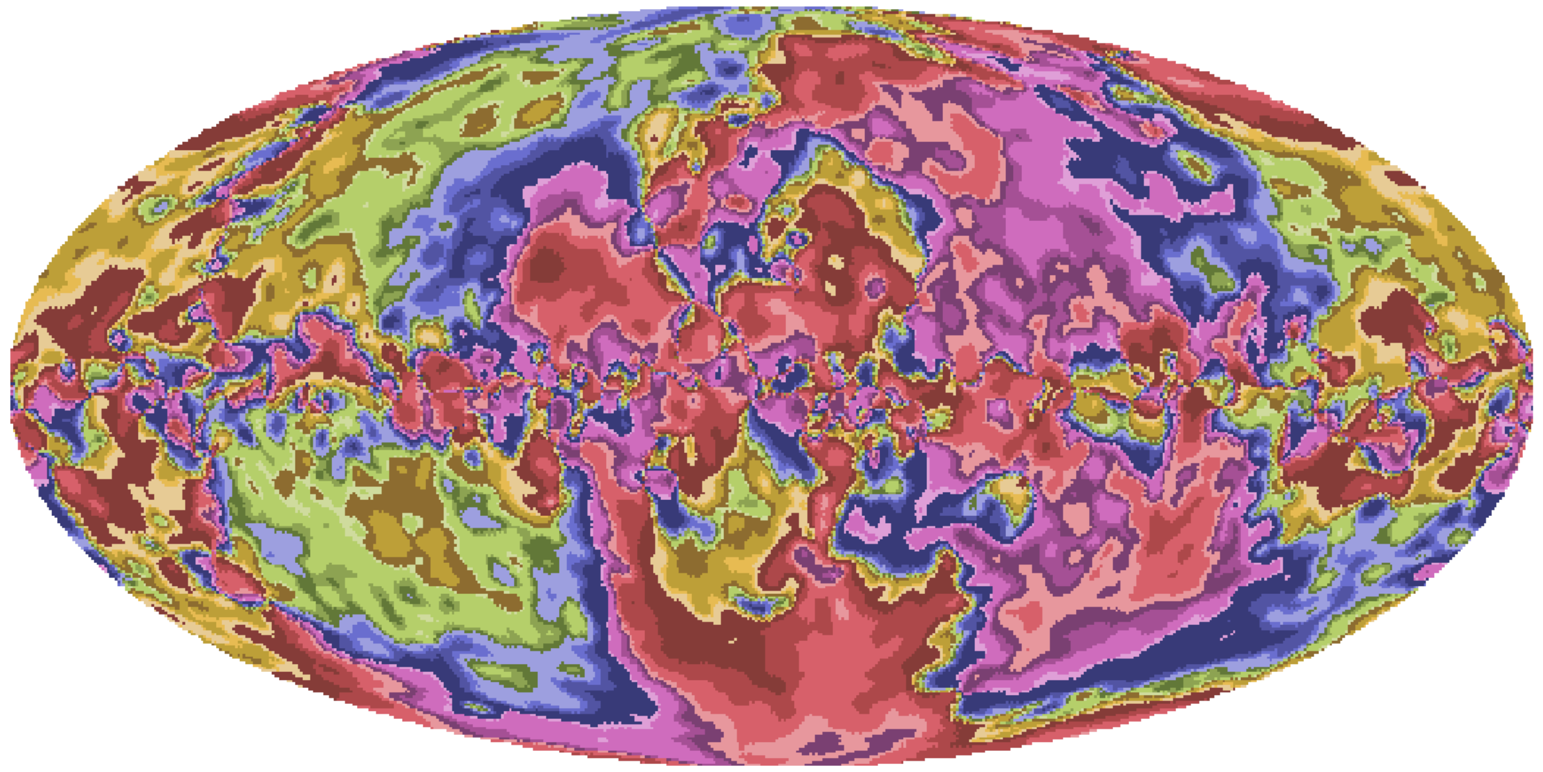
Clusters of Equal Area (CEA)





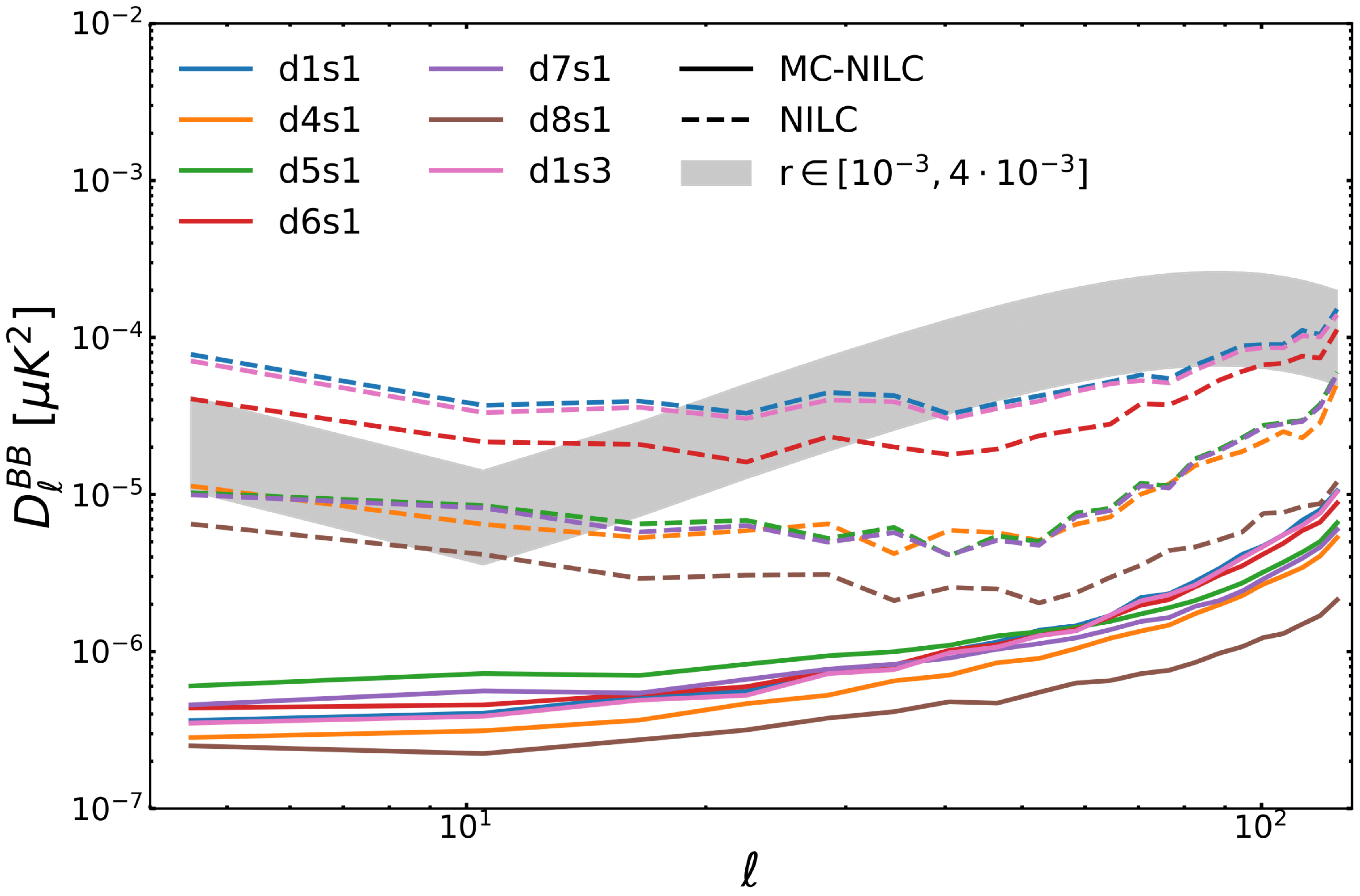
Random Partitions (RP)



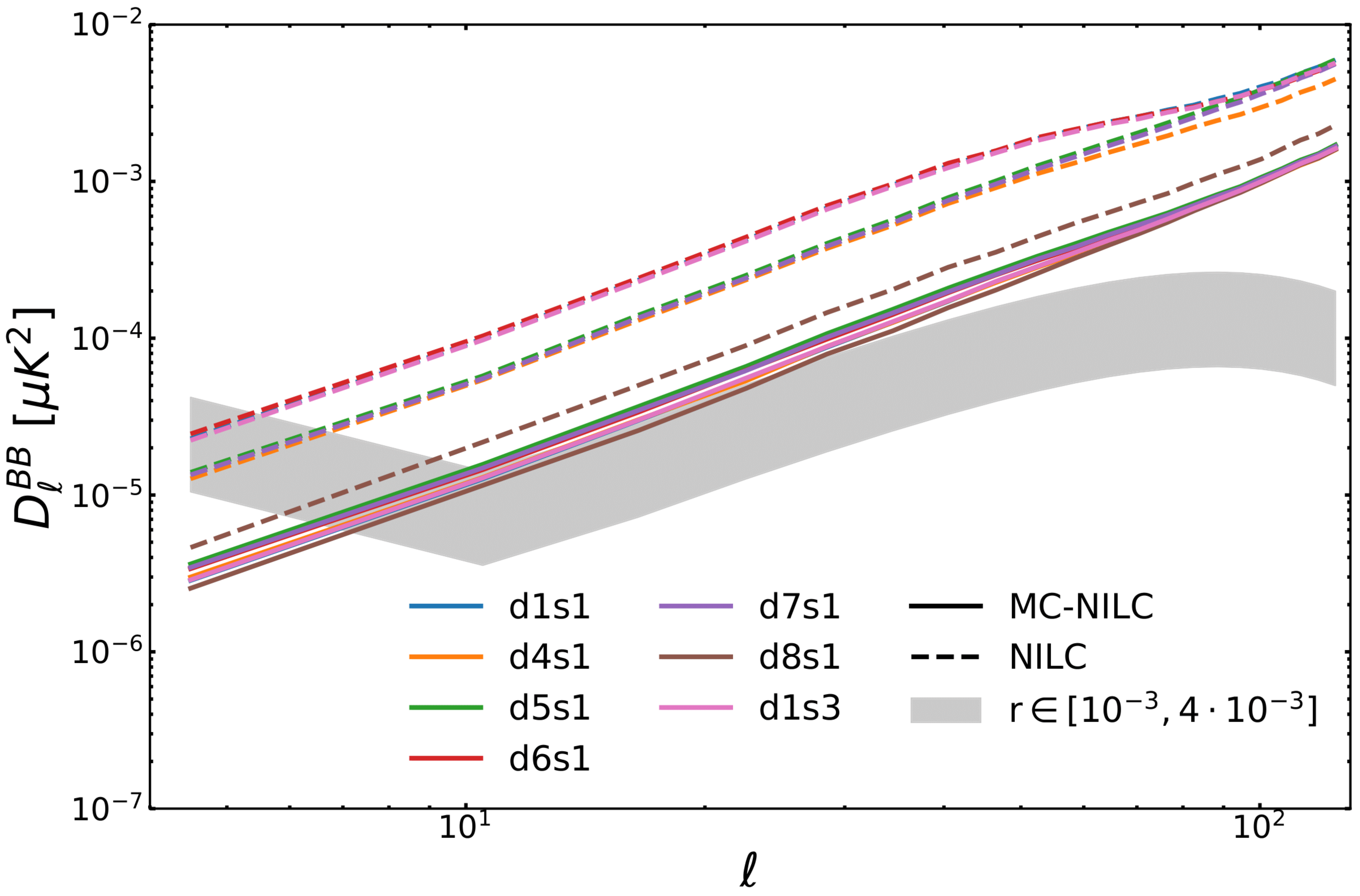


Robustness test for MCNILC

Foregrounds residuals



Noise residuals



E-modes from LiteBIRD

Approach:

going from less to more complex simulations:

Baseline PTEP : (d1s1) + isotropic white noise

Baseline + (anisotropic+1/f) noise - Post-PTEP simulations

Realistic: d10s5f1a1co3 + (anisotropic+1/f) noise

Pessimistic: d12s7f1a2co3 + (anisotropic+1/f) noise

E-modes from LiteBIRD