Galactic Foregrounds
&
Lensing

Workshop LiteBIRD-Italy @ INFN-LNF

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+
Giuseppe Puglisi, Jian Yao, Anto Lonappan et al.

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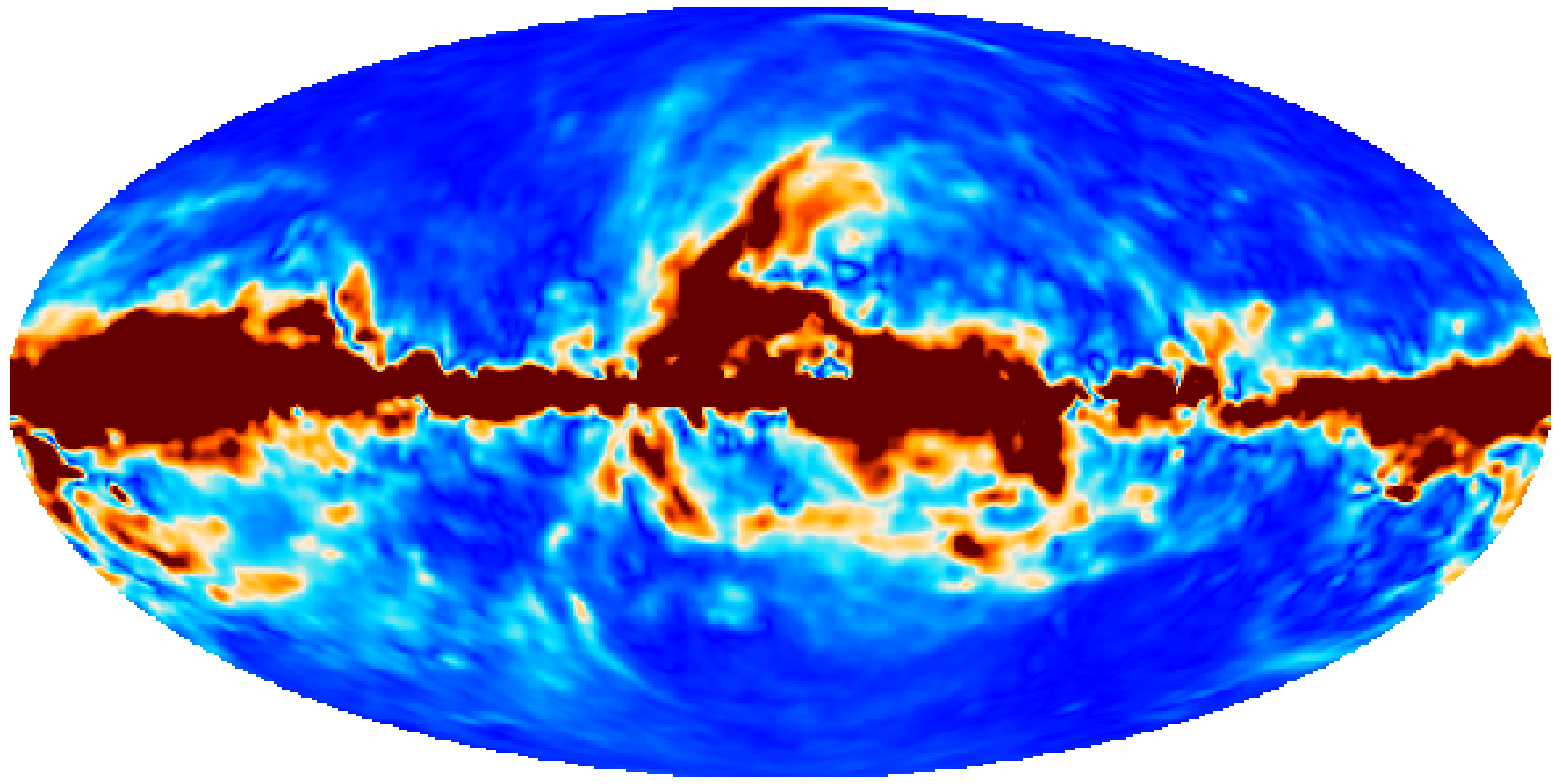
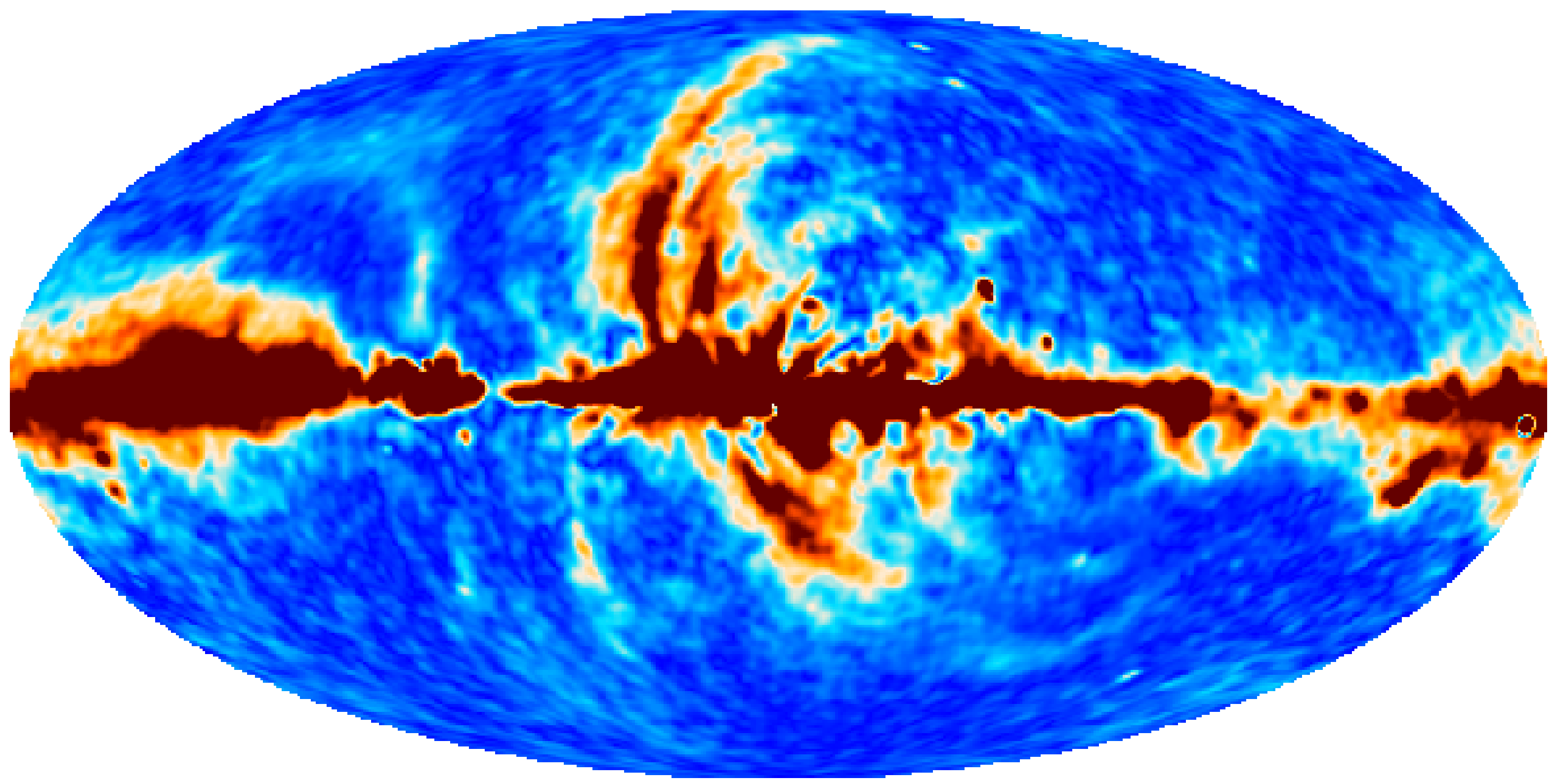
Foregrounds modeling

Available data

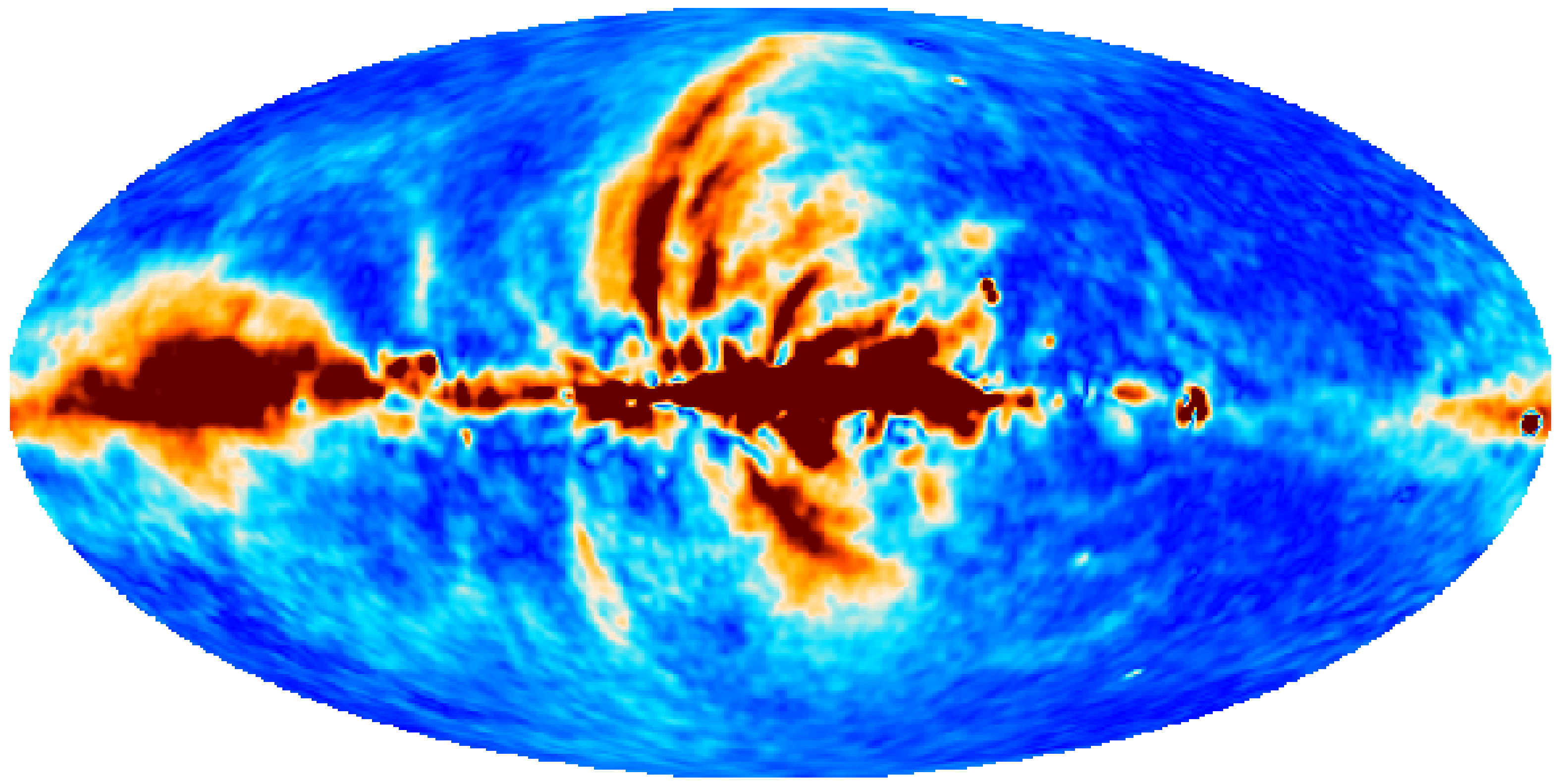
HFI 353 GHz
2deg



LFI 30 GHz
2deg



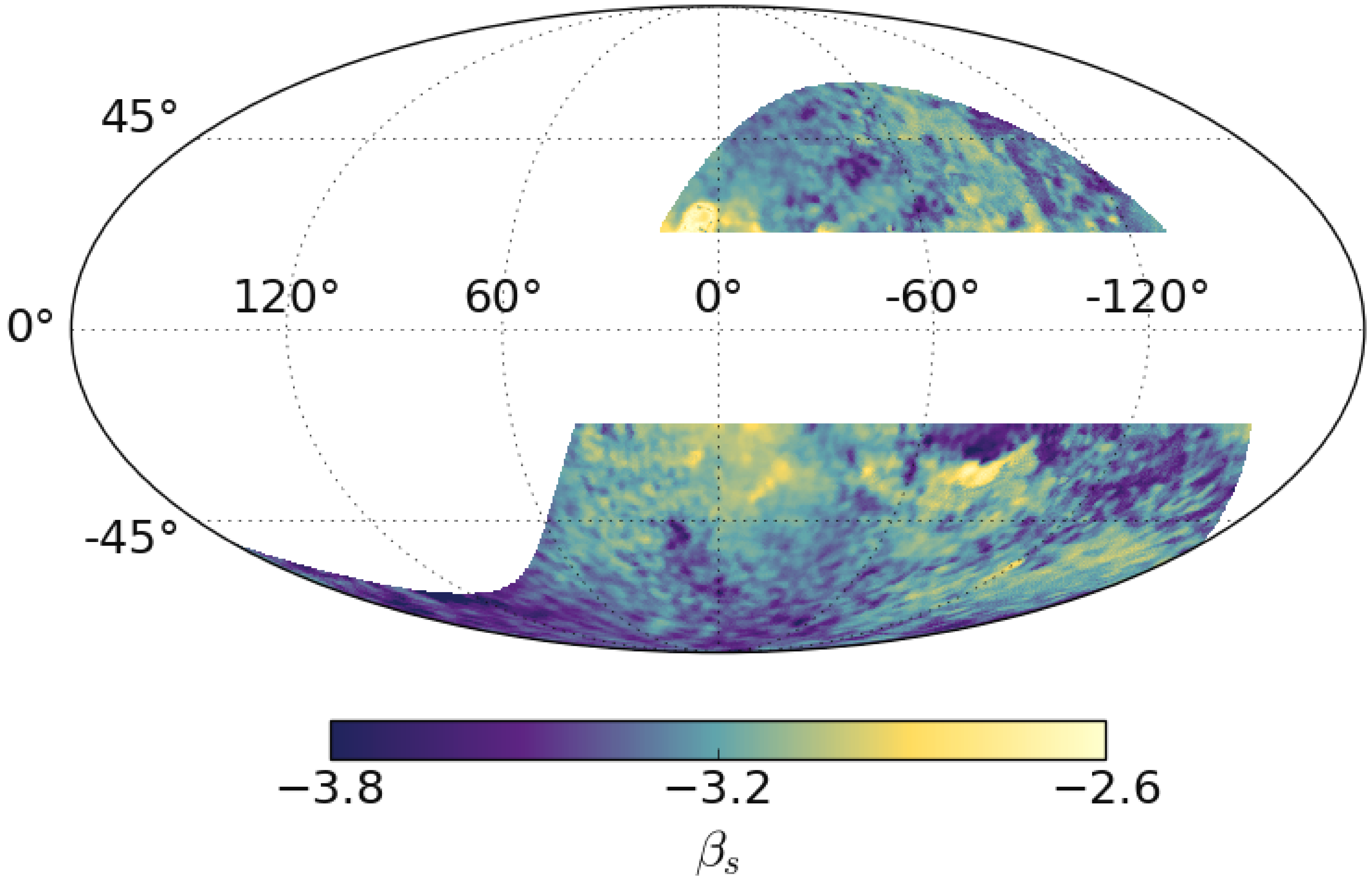
WMAP-K
2deg

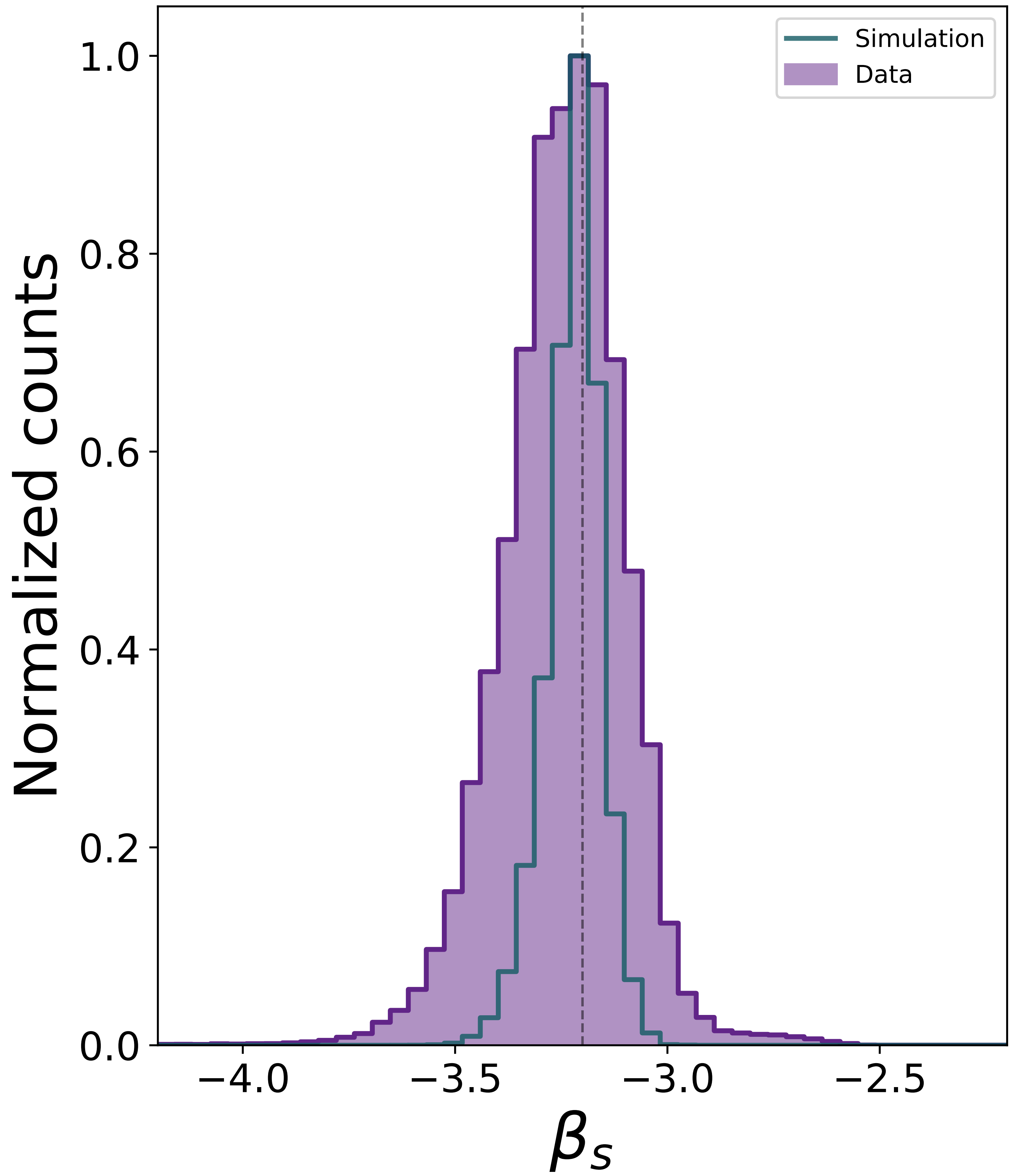


- Characterization and modeling of foreground emission for CMB experiments relies mostly on **Planck and WMAP full sky maps** + **ancillary data** (HI, low frequency observations, stellar polarimetry…)

- Great datasets, but not enough to characterize FG polarization at the level needed to avoid surprises in the analysis of the next generation of CMB experiments

Synchrotron with low frequency data



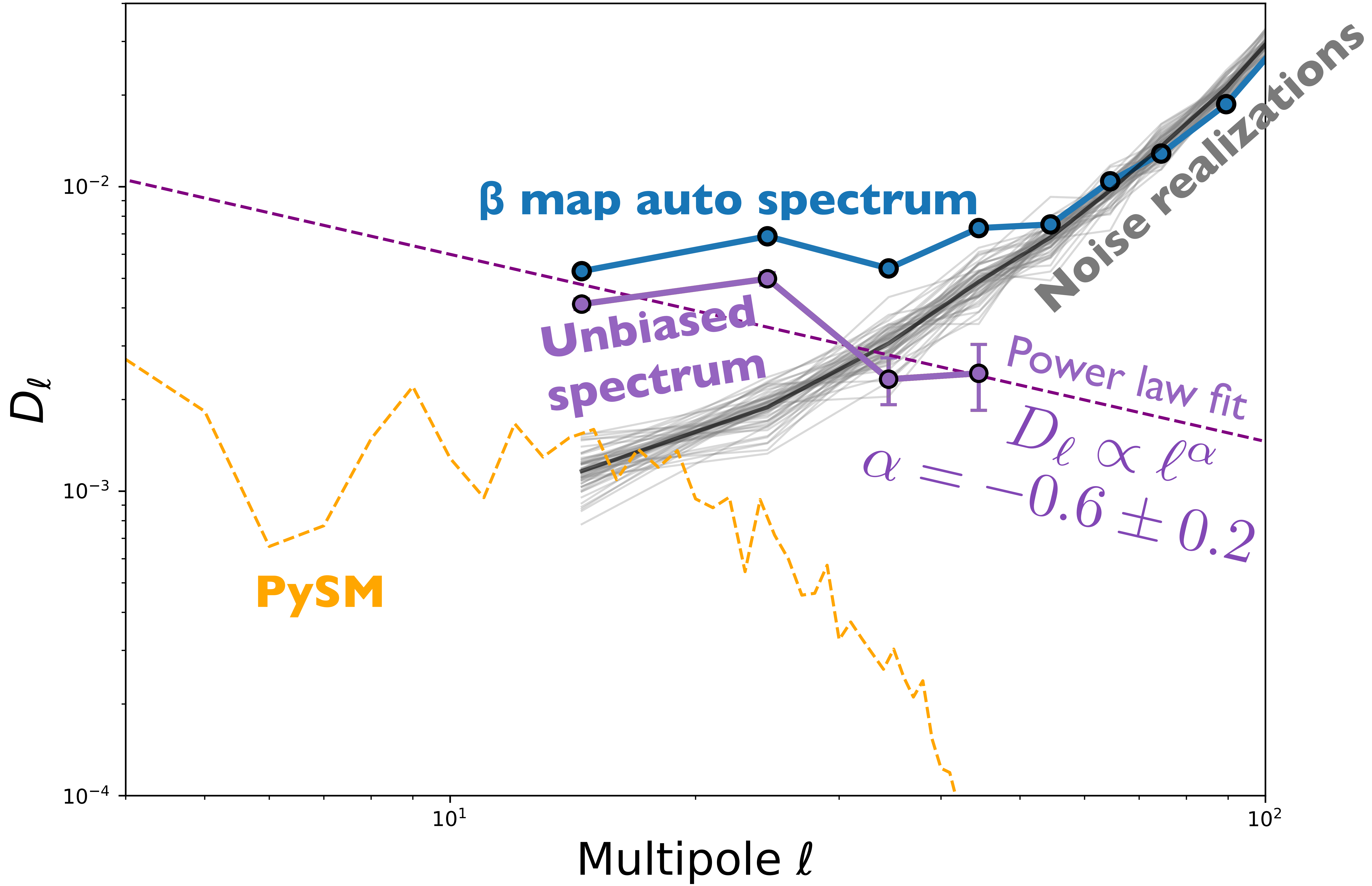


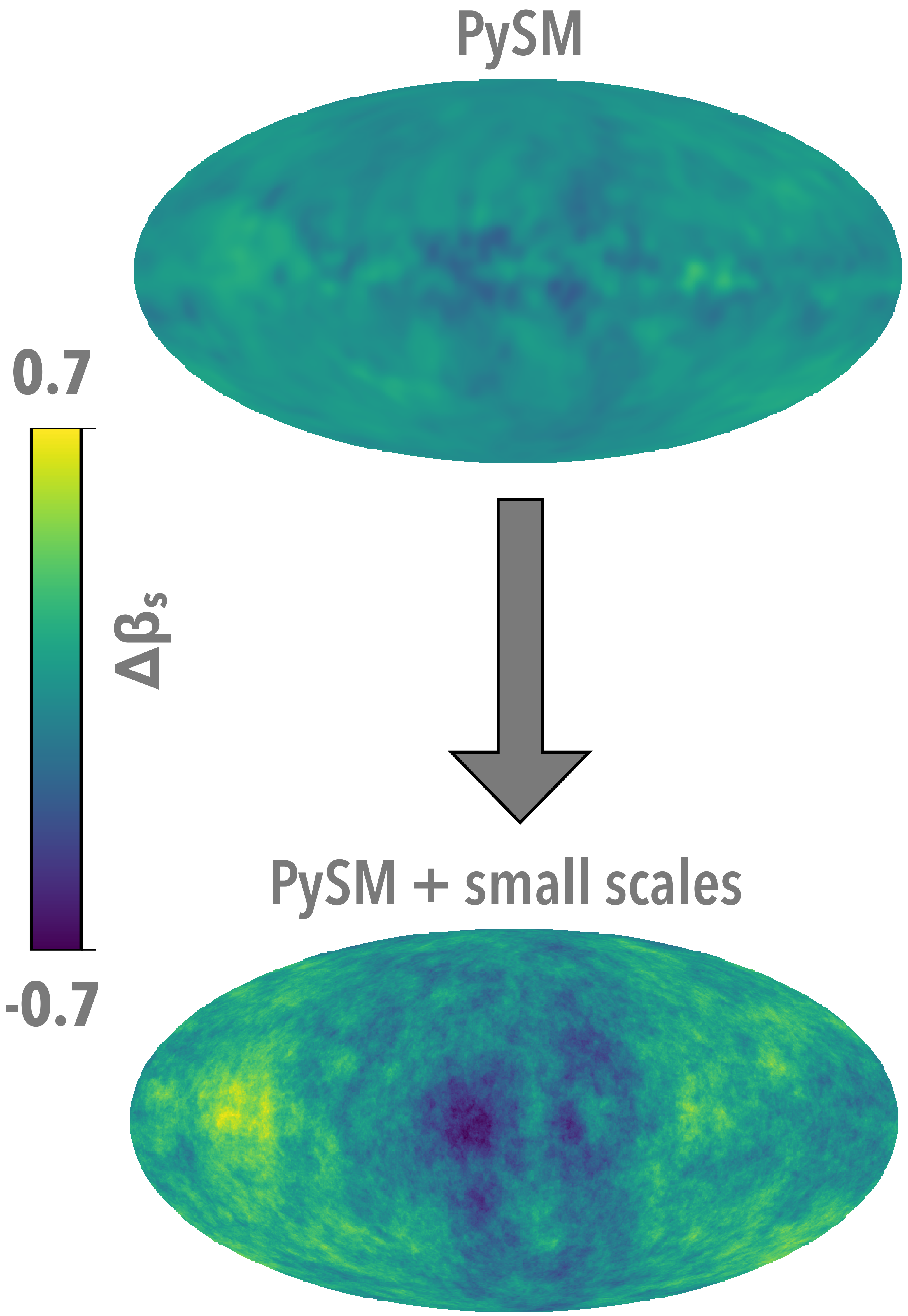
- Power law fit in range **2.3 - 33 GHz**
- Fit in each pixel in **total polarized intensity** taking into account the noise bias
- **Angular resolution of 2°**
- Sky coverage ~ 30%
- Flat prior

Krachmalnicoff et al. 2018

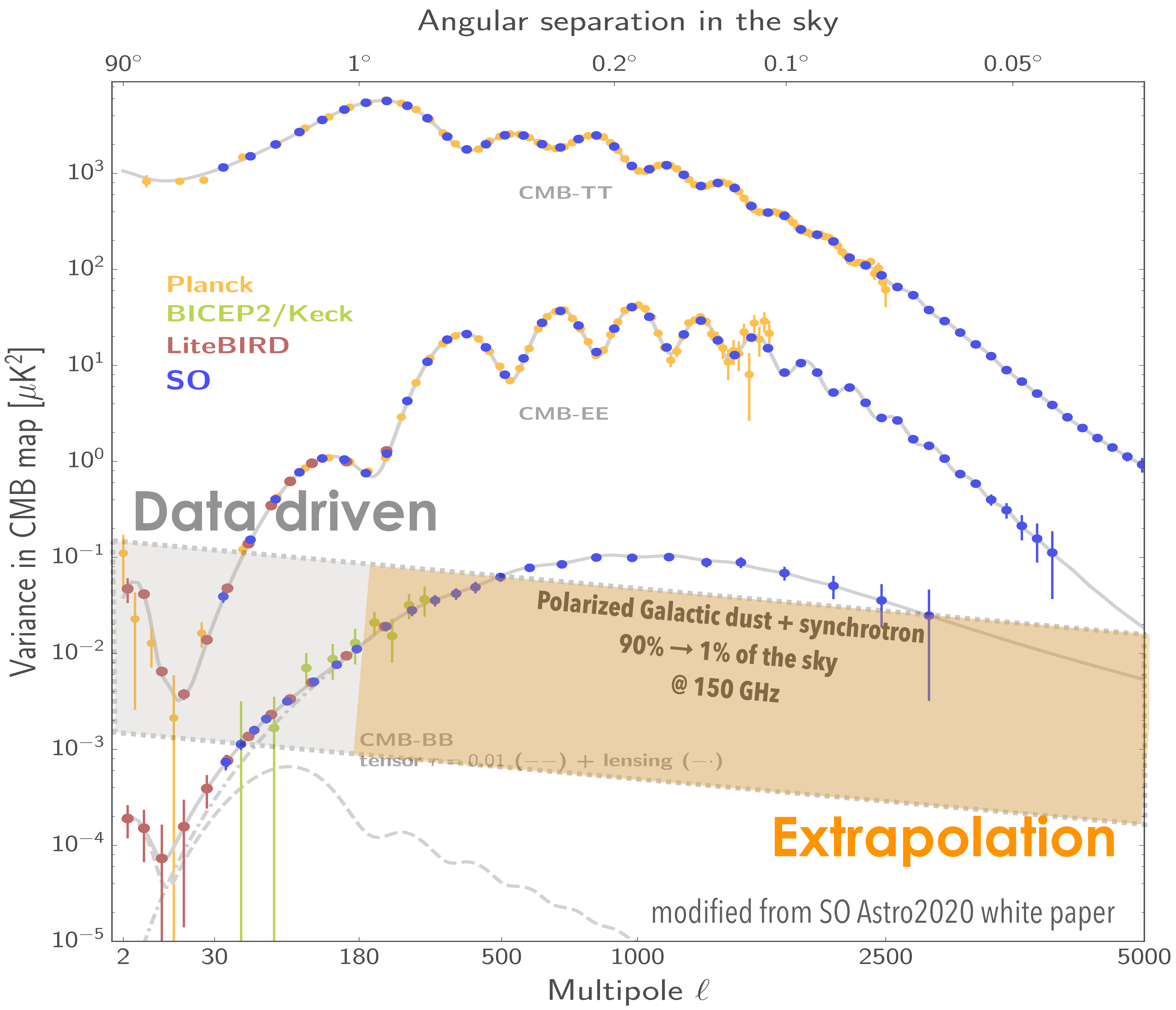
β_s PySM3 model

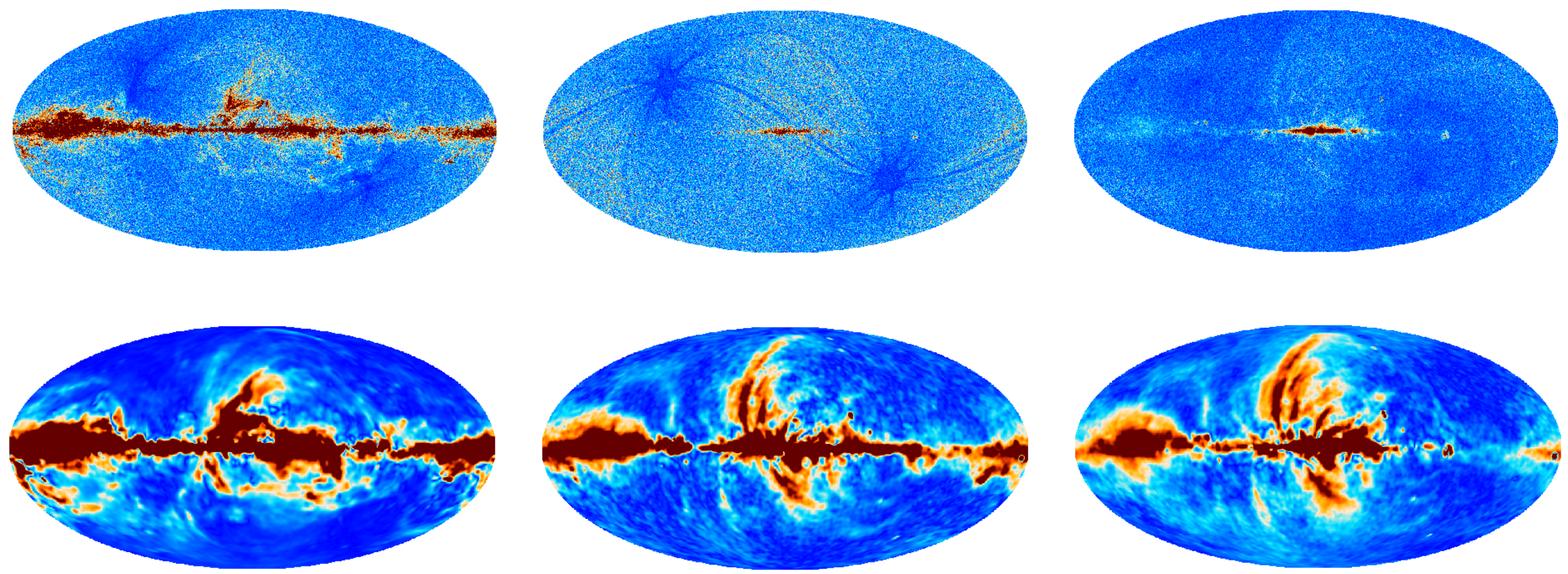
- The new synchrotron PySM model for β_s takes into account S-PASS evidence for larger spatial variation





Foregrounds at small scales

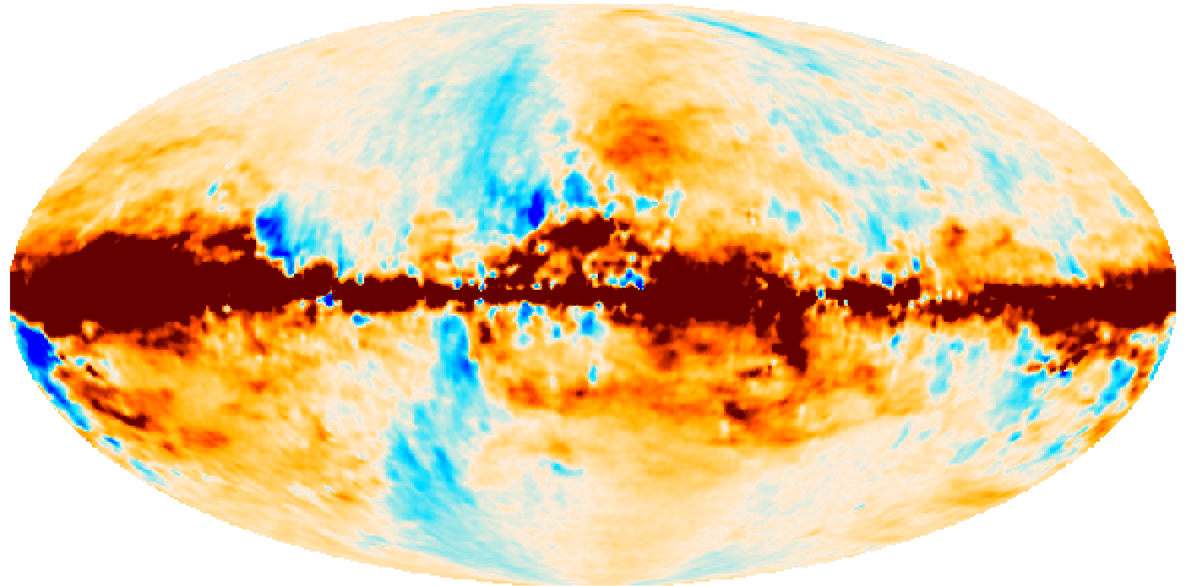


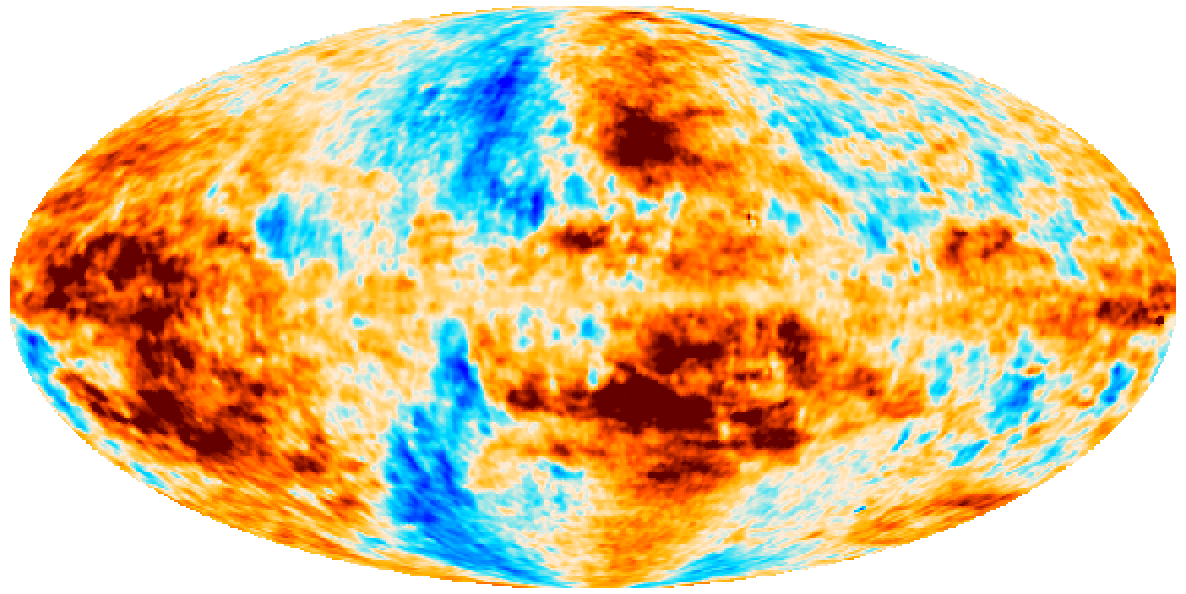


- From available data we only have information of large scale polarized foregrounds (> 1deg)
- What's the amplitude of small scales?
- Statistical properties?
- Impact on lensing, de-lensing, component separation?

New PySM3 models

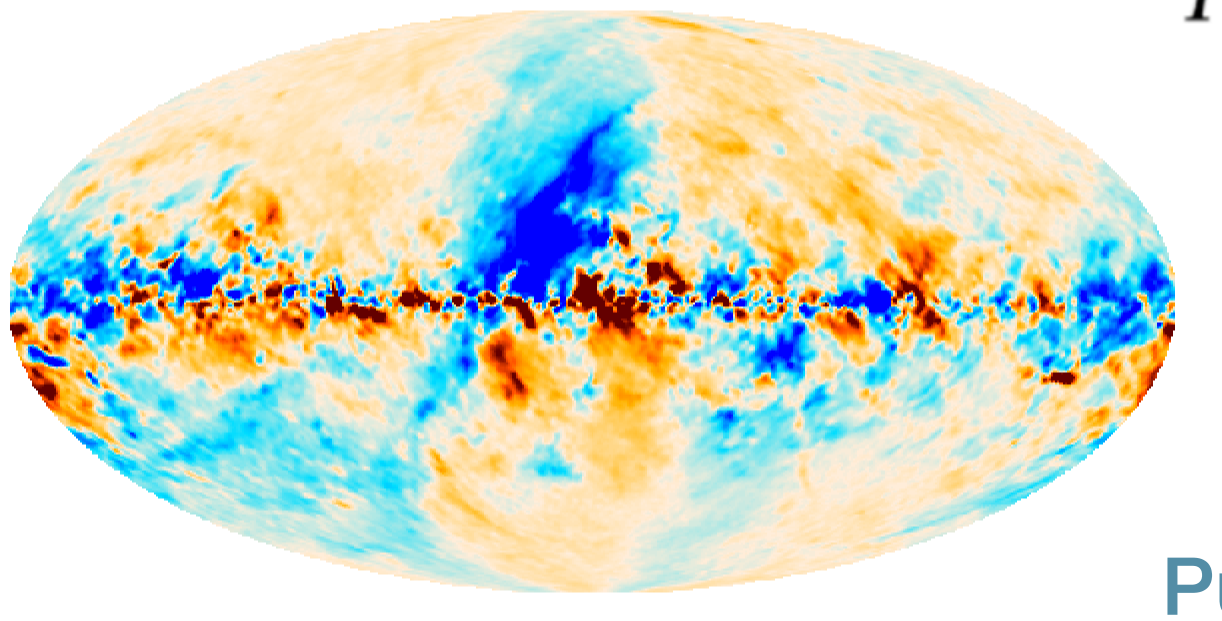
- New foreground models have been implemented and are now available in PySM
- Main difference wrt old models:
  i. Templates for thermal dust emission are based on GNILC products (less contaminated by CIB)
  ii. Small scales are added as Gaussian realization in polarization tensor quantities

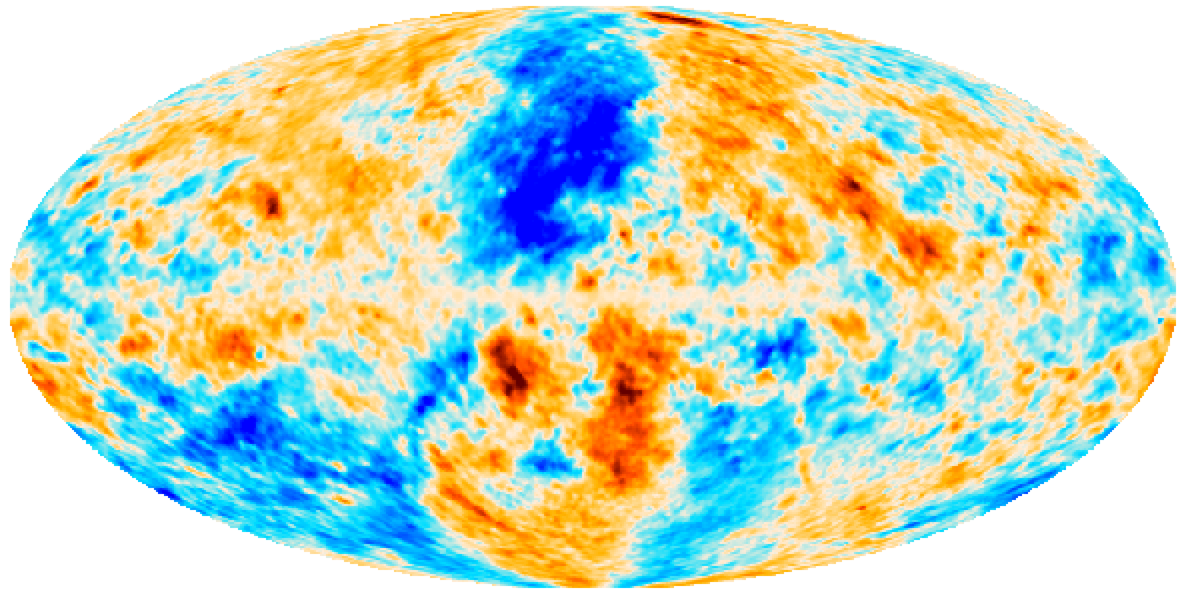




$$i = \frac{1}{2}\ln\left(I^2 - P^2\right), \quad q = \frac{1}{2}\frac{Q}{P}\ln\frac{I+P}{I-P}, \quad u = \frac{1}{2}\frac{U}{P}\ln\frac{I+P}{I-P}$$

$$I = e^i \cosh p, \quad Q = \frac{q}{p} e^i \sinh p, \quad U = \frac{u}{p} e^i \sinh p$$

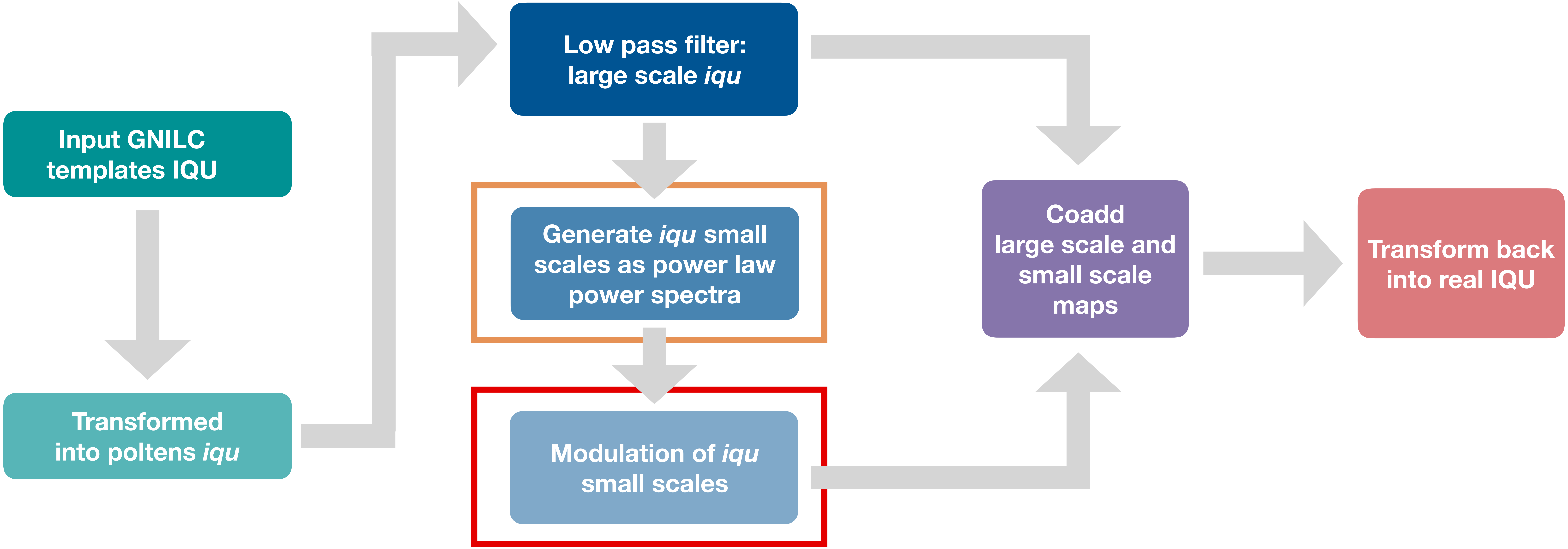




Puglisi, Krachmalnicoff, Jian + Pan-Ex working group

PySM3 models

Puglisi, Krachmalnicoff, Jian + Pan-Ex working group



- Break in polarization power law was introduced to avoid polarization fraction > 1 since from data: $C_\ell^{\mathrm{dust,TT}} \propto \ell^{-3}$ vs $C_\ell^{\mathrm{dust,EE/BB}} \propto \ell^{-2.4}$
- Modulation is critical, being the link between global and local properties

Non-Gaussian small scales

ForSE(e):

ForSE extended

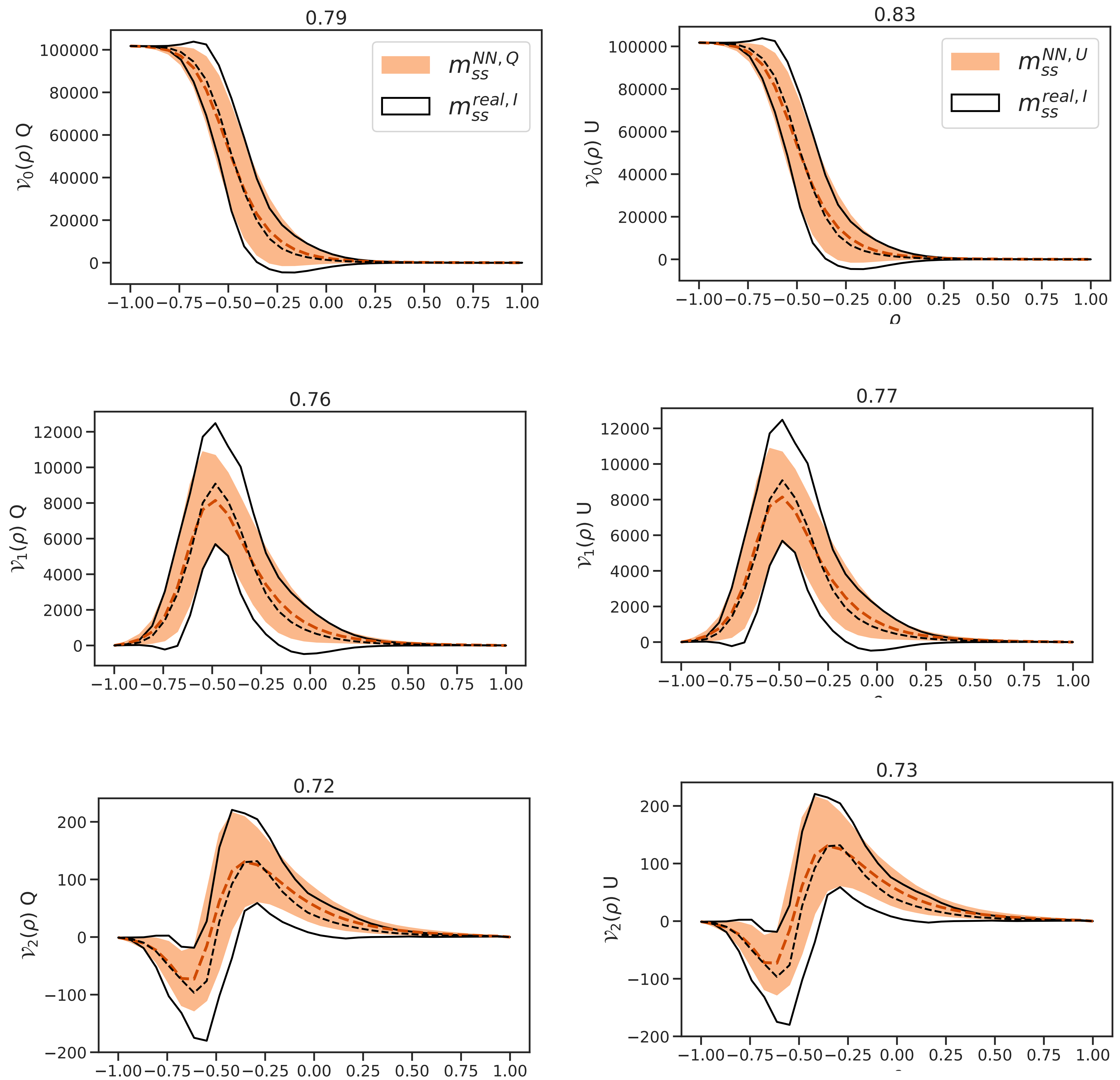
- Neural Networks to learn the statistical properties of small scales FG where observed
- Iterative approach to go from 80 arcmin to 3 arcmin
- Stochasticity: multiple high resolution maps can be generated

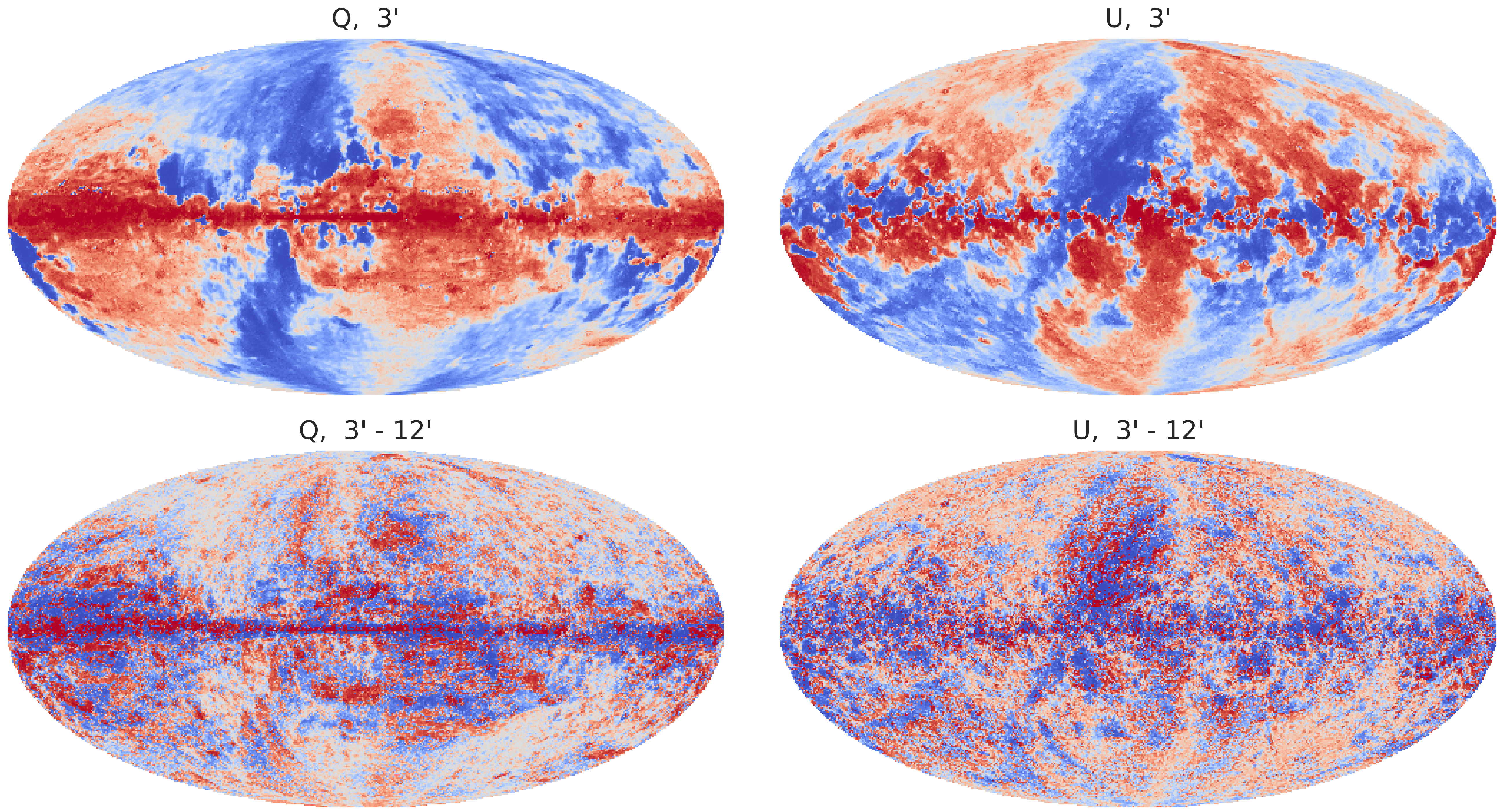
First NN iteration

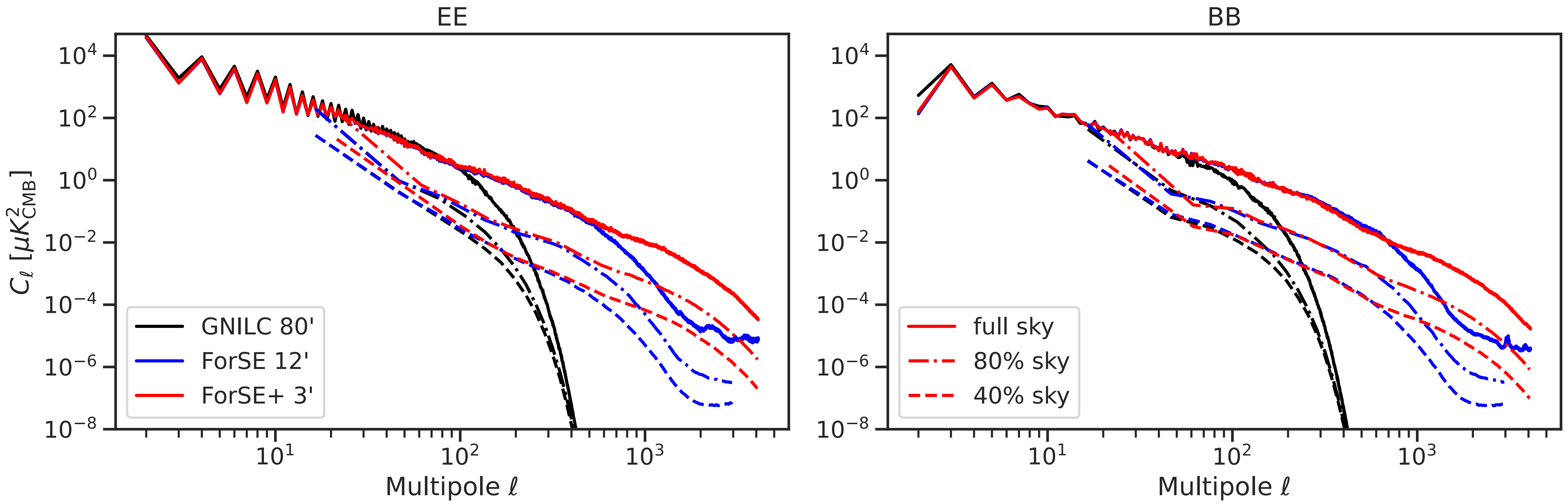
Second NN iteration

Jian, Krachmalnicoff, Puglisi

Non-Gaussian small scales





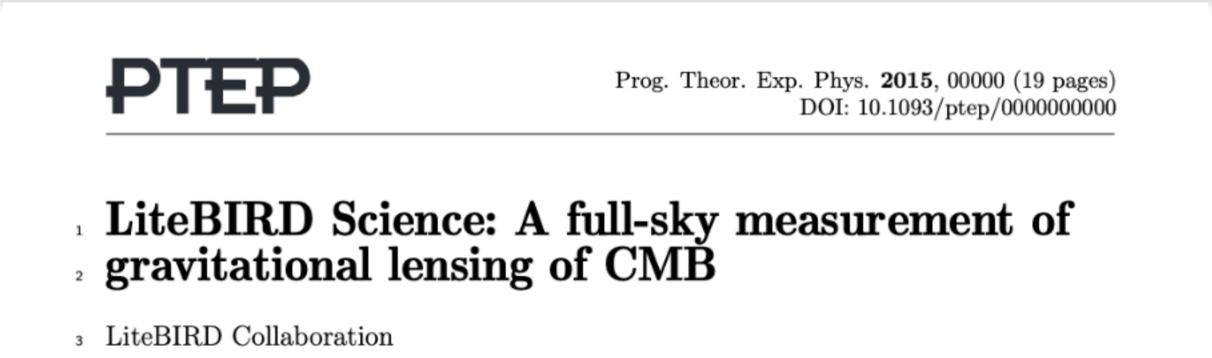


Jian, Krachmalnicoff, Puglisi

Lensing reconstruction

Credits: A. Lonappan

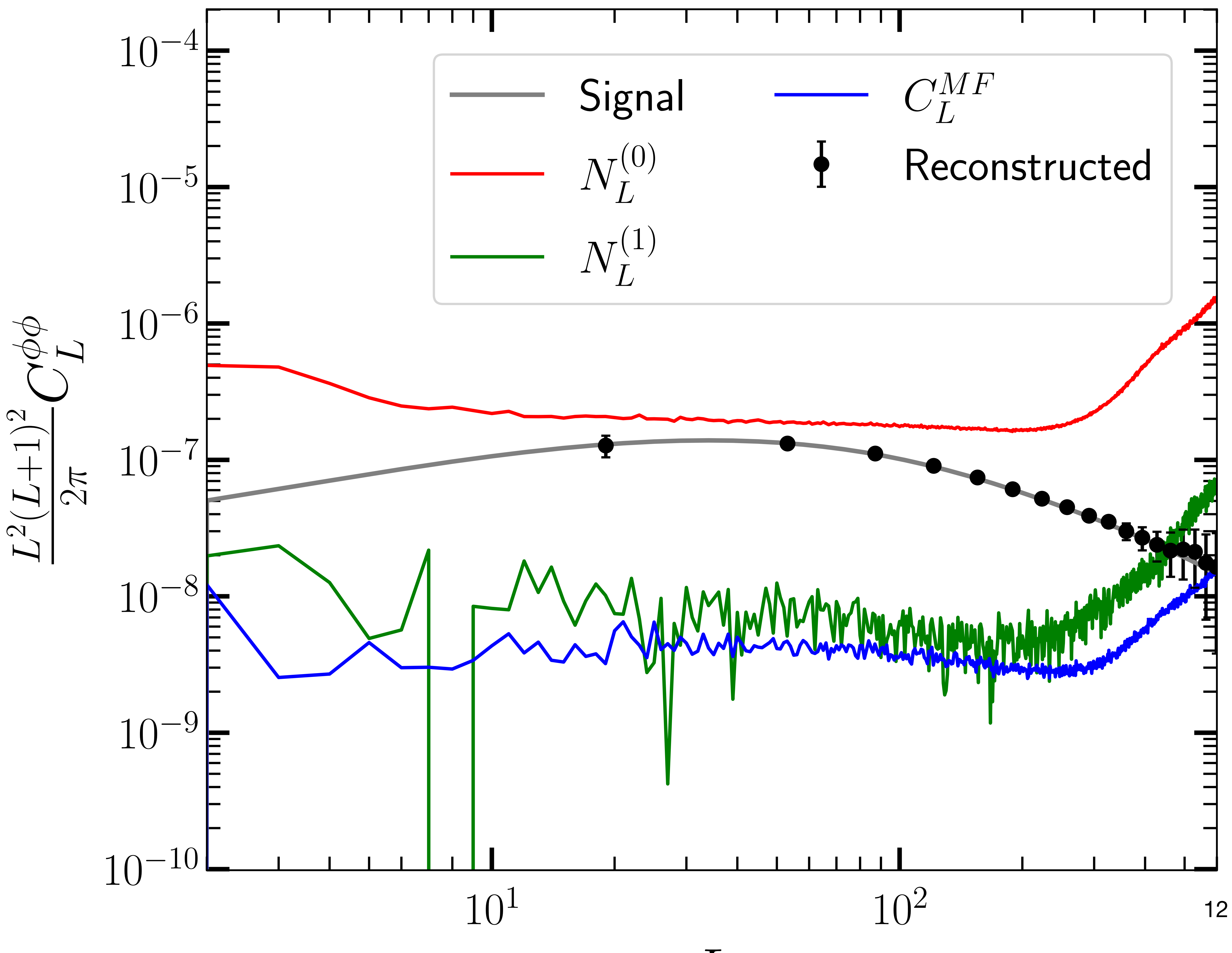
Lensing Reconstruction: LiteBIRD


PTEP
Prog. Theor. Exp. Phys. **2015**, 00000 (19 pages)
DOI: 10.1093/ptep/0000000000

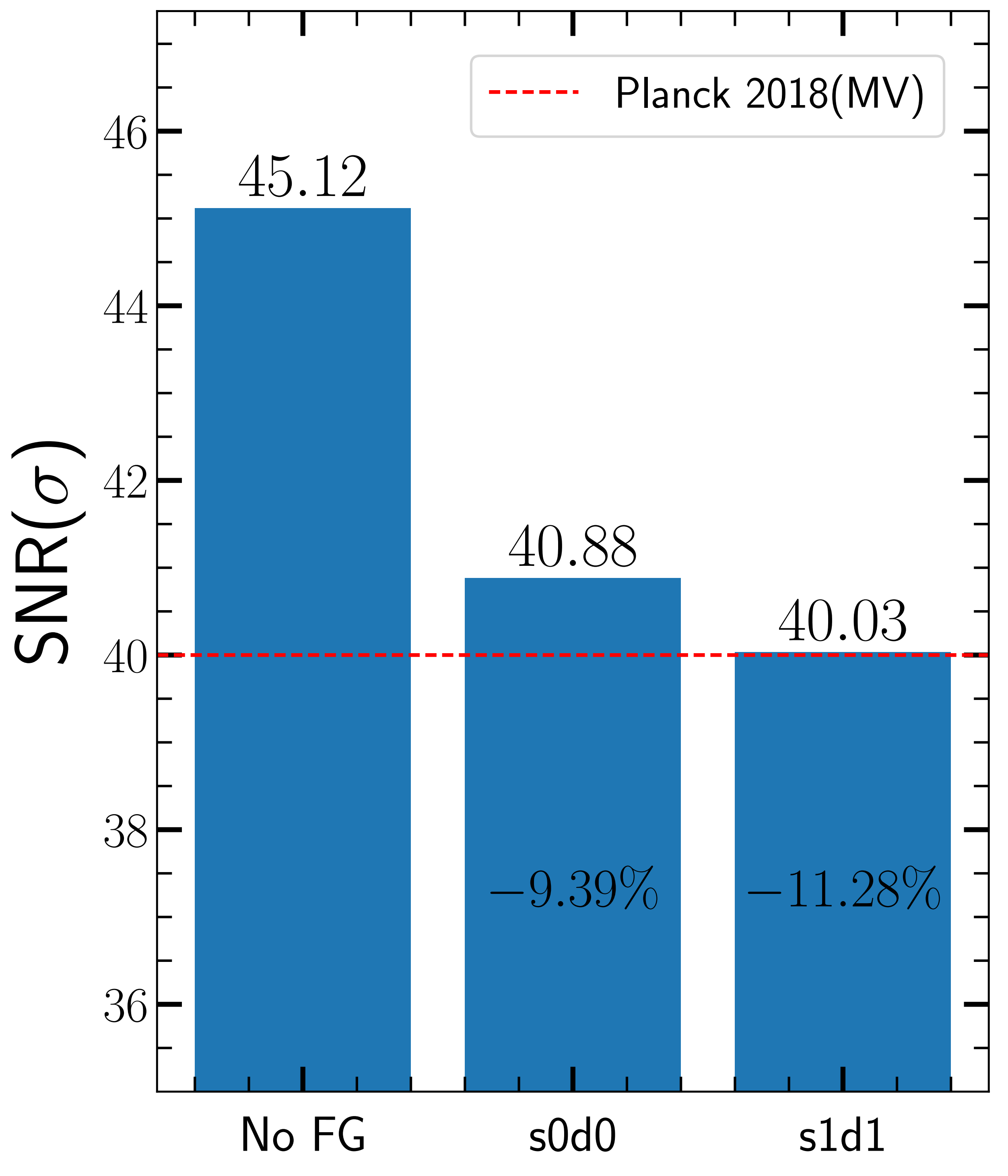
LiteBIRD Science: A full-sky measurement of gravitational lensing of CMB

LiteBIRD Collaboration

EB Quadratic Estimator



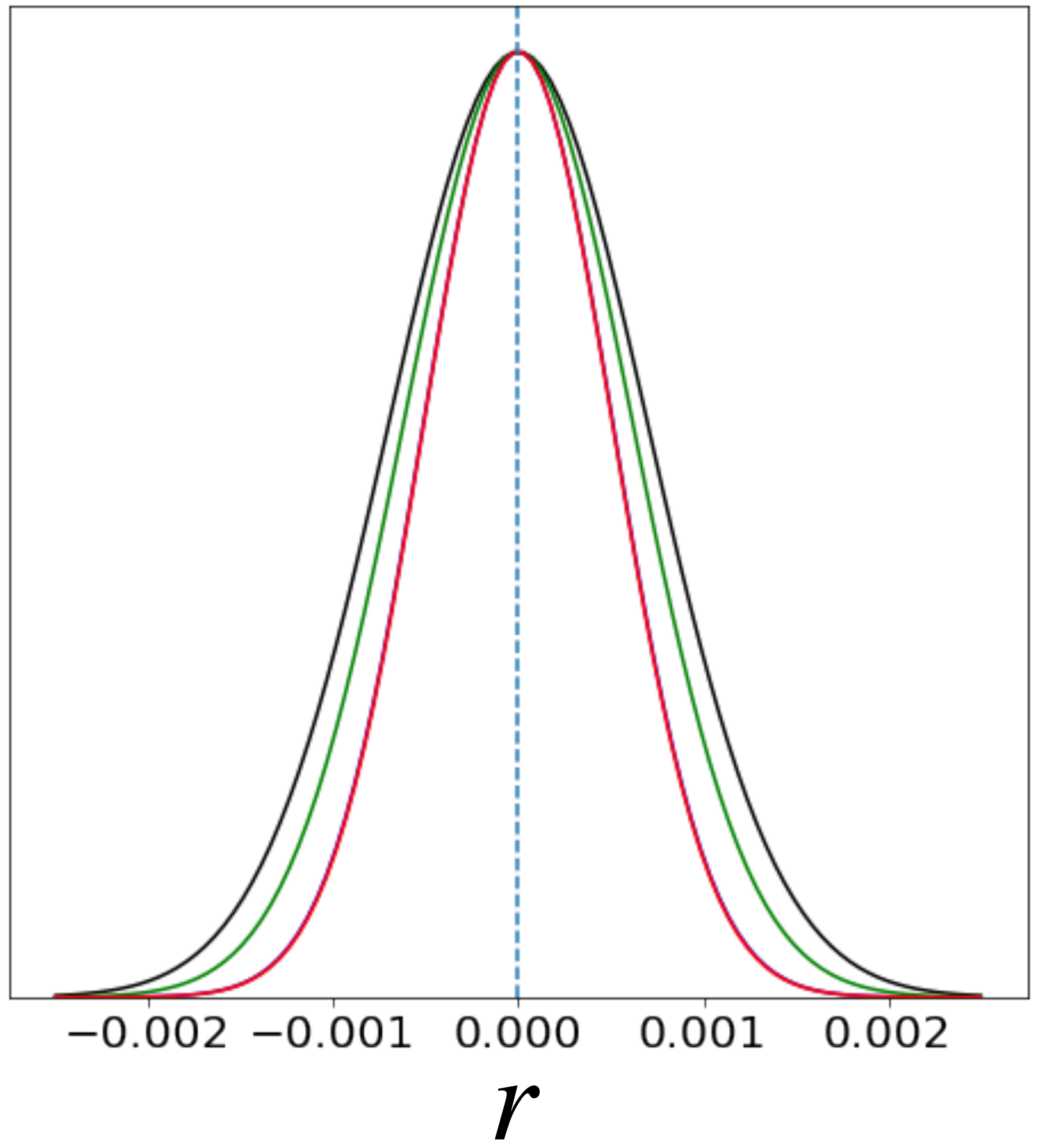
- **CMB:** $2 < \ell < 600$
- f_{sky} **= 0.80**
- **Harmonic ILC**



Credits: A. Lonappan

Probe Combination: LiteBIRD X CMB-S4

Template by LiteBIRD E Modes



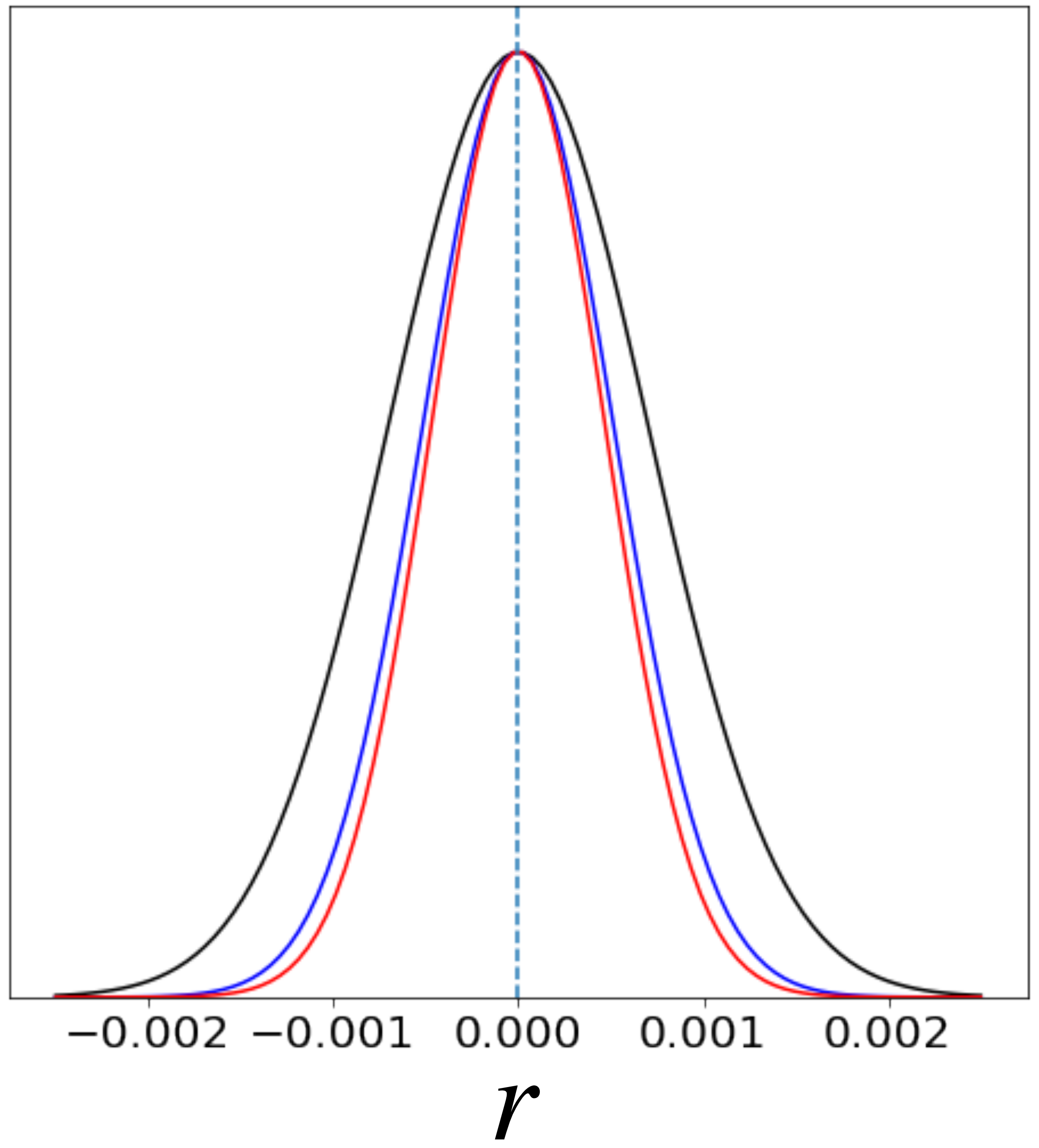
Black Line
Lensed
$\sigma(r) = 7.00\,e-4$

Green Line
Internal Delensing of LiteBIRD

Blue Line
Delensed LiteBIRD using CMB-S4

Red Line
Delensed LiteBIRD using Combination

Template by S4 or combined E Modes



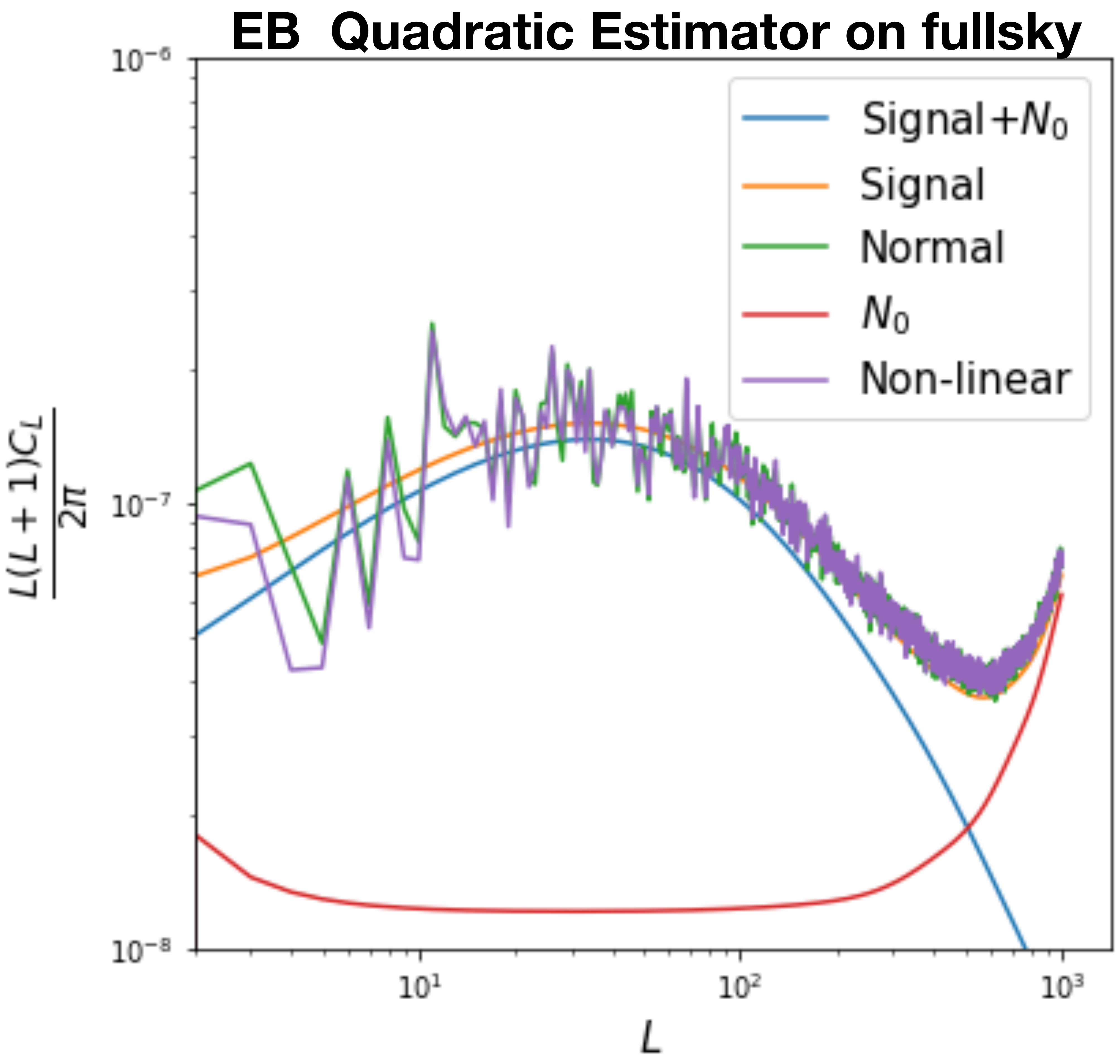
E-Mode	Kappa	$\sigma(r) \times 1e-4$	Efficiency(%)	f_{sky}
LiteBIRD	LiteBIRD	6,20	11.4	0.80
LiteBIRD	CMB-S4	5,12	26.8	0.40
LiteBIRD	Combined	5,10	27.1	0.40

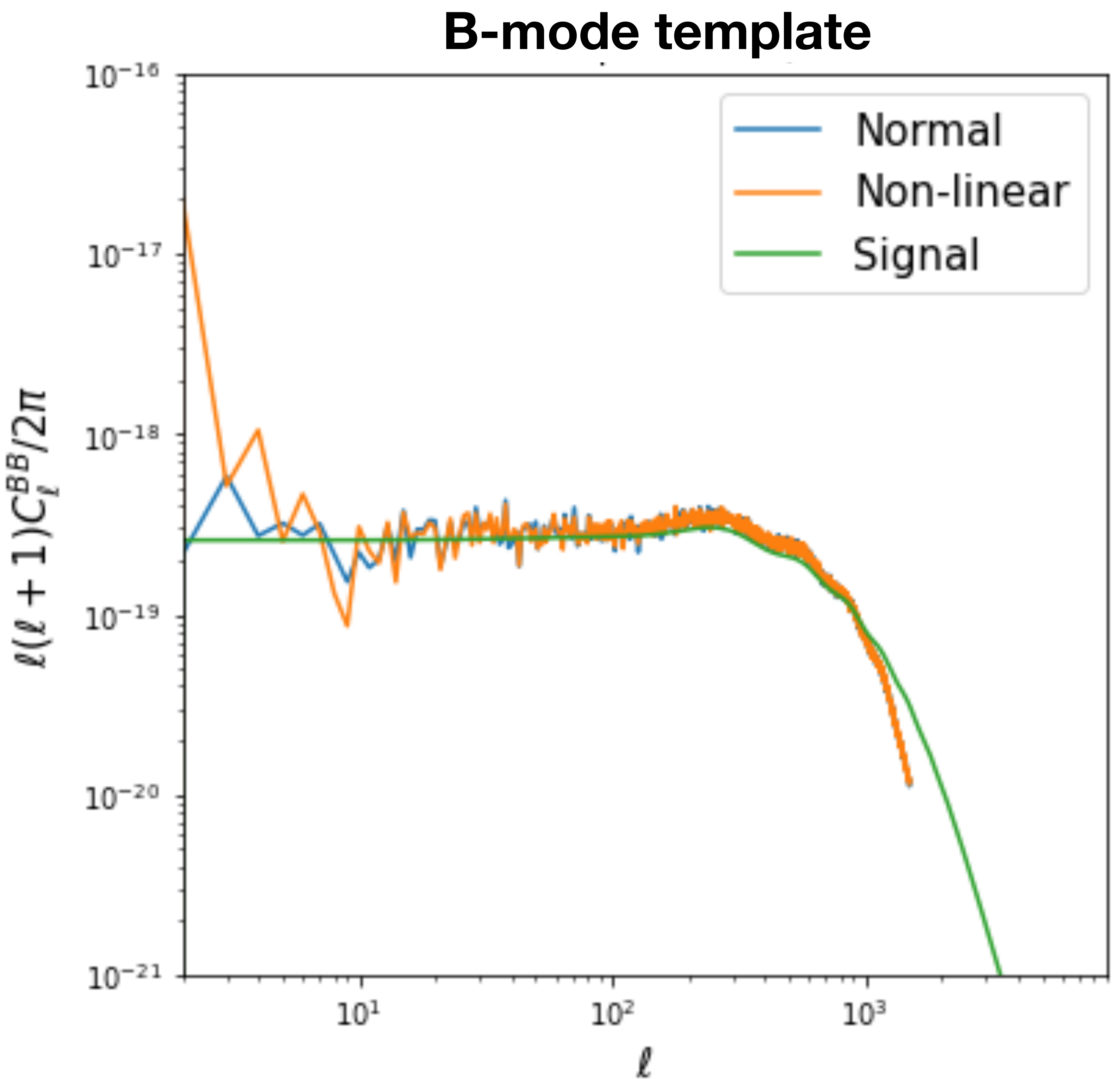
E-Mode	Kappa	$\sigma(r) \times 1e-4$	Efficiency(%)	f_{sky}
LiteBIRD	LiteBIRD	6.20	11.4	0.80
CMB-S4	CMB-S4	5.02	28.2	0.40
Combined	Combined	4.68	33.1	0.40

Credits: A. Lonappan

Impact of Non-linearity in Detectors

- **Non-linear model =** $M(1+\alpha M)$, $\alpha = 0.001$
- $N_p = 2\mu k - arcmin$, **fwhm =** $4\ arcmin$





Prospectives

- New PySM3 models for synchrotron and thermal dust emission are now available (paper in preparation) and ready to be used for component separation testing (both E- and B-modes)

- Neural Networks non-Gaussian dust maps are being fully validated, will be integrated in PySM in the next months (paper in preparation Jian, Y. et al.)

- Next step is to test impact of non-Gaussianity on lensing reconstruction of LiteBIRD (and combination with CMB-S4)

- Impact of systematic effects on LiteBIRD lensing reconstruction is on-going (non-linearity and beam)