NILC results for PICO

Mathieu Remazeilles

1 July 2021

A variety of realistic foreground skies

NERSC: /project/projectdirs/pico/data_xx.yy/

- **Model 91 (d1s1):** *Planck* dust MBB with β, T variations, synchrotron power-law with β variations
- **Model 92 (d4s3a2):** Two dust MBBs with uniform β_1, β_2 but T_1, T_2 variations, synchrotron curvature, AME 2% polarization
- **Model 93 (d7s3a2):** Physical dust model (not MBB), synchrotron curvature, AME 2% polarization
- **Model 96 (MHD):** dust and synchrotron derived from MHD, multiple MBBs along the line-of-sight
- **Model 98 (Multi-layer):** 3D dust model (decorrelation), MBB layers along the line-of-sight

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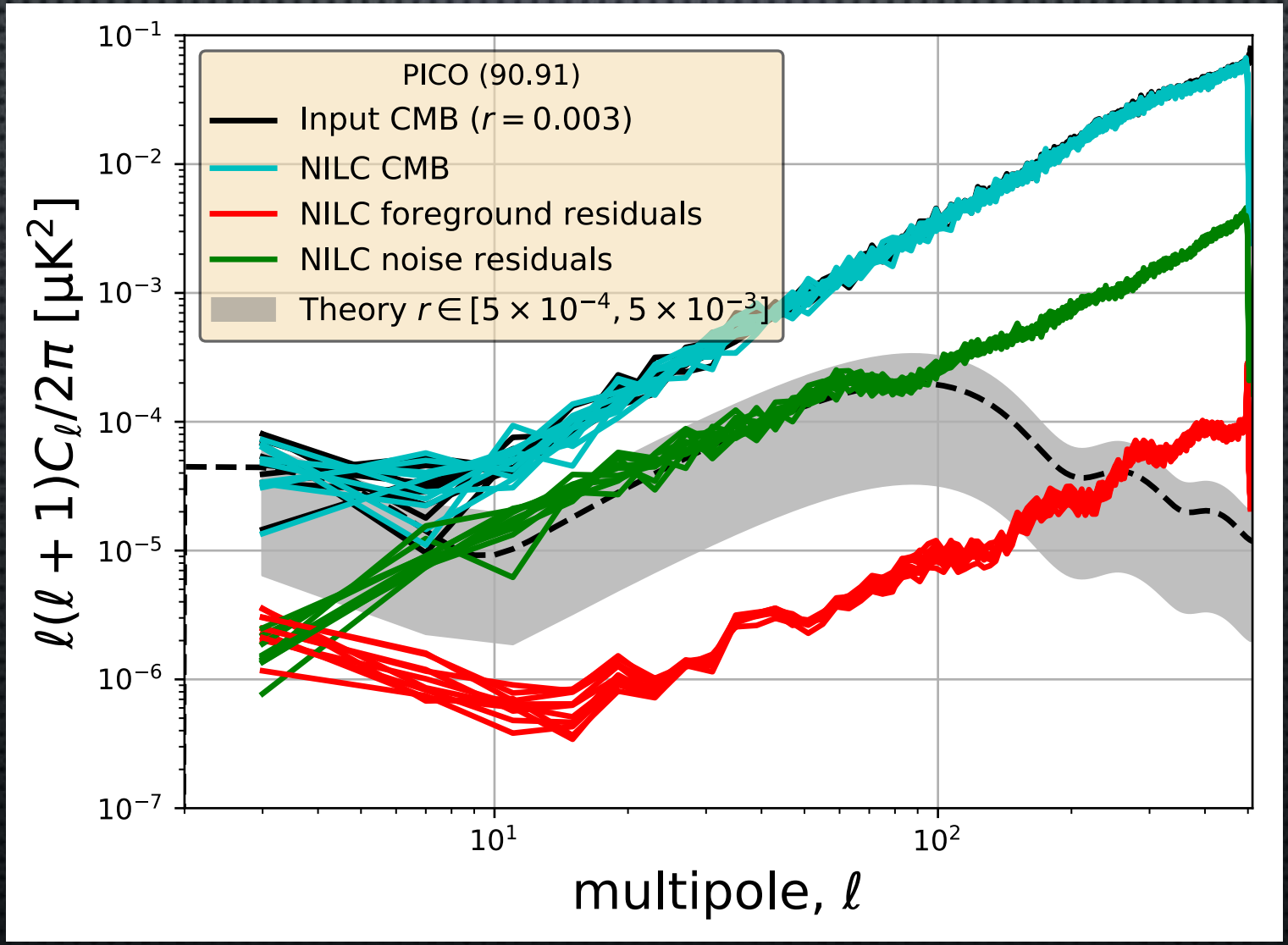
$$r = 0.003$$

Model 91, $r = 0.003$

NILC



10 realizations

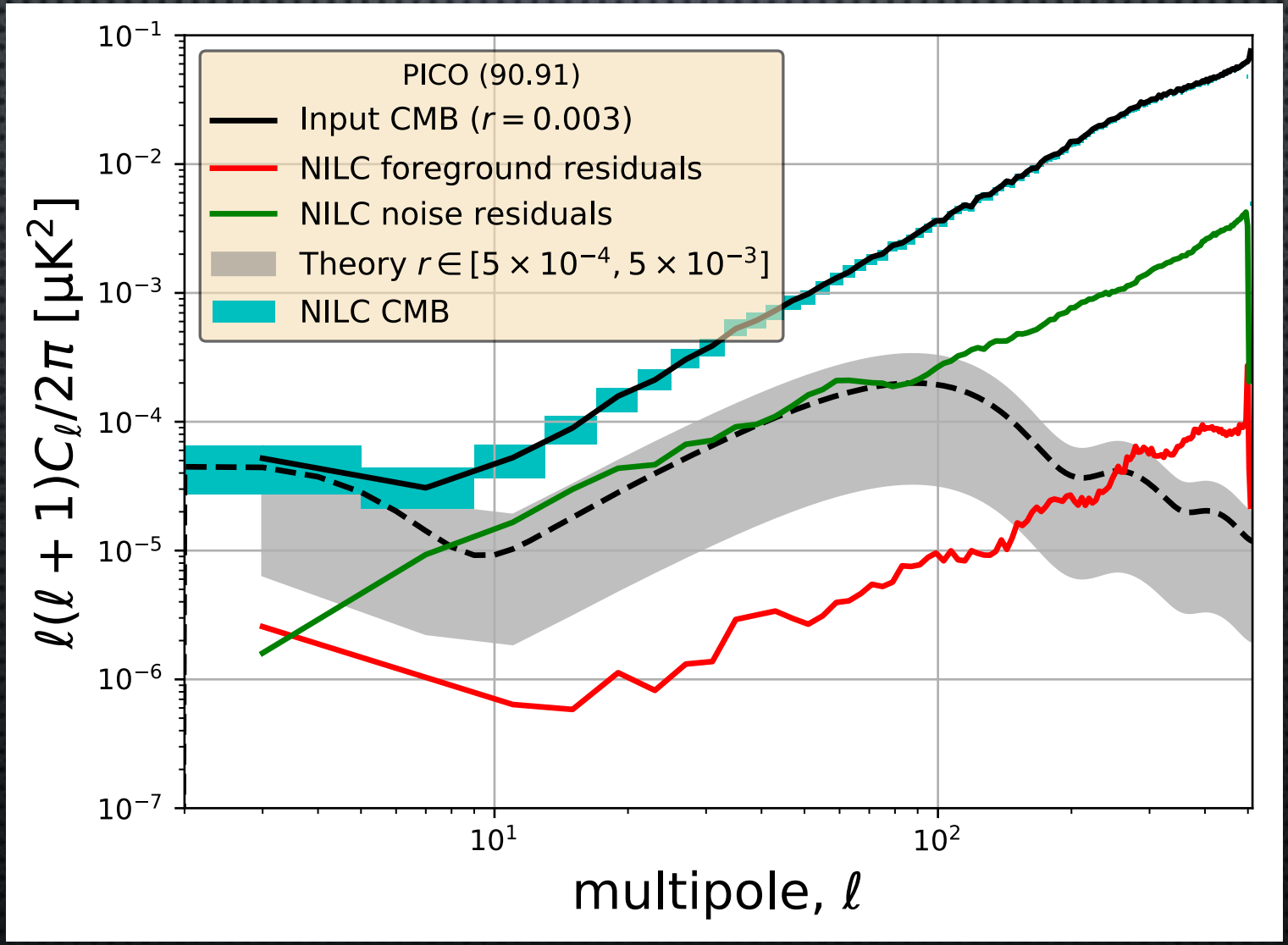
MASTER

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

Binning: $\Delta\ell = 4$

Model 91, $r = 0.003$

NILC



Foreground residuals 10 times lower than $r = 0.003$

10 realizations

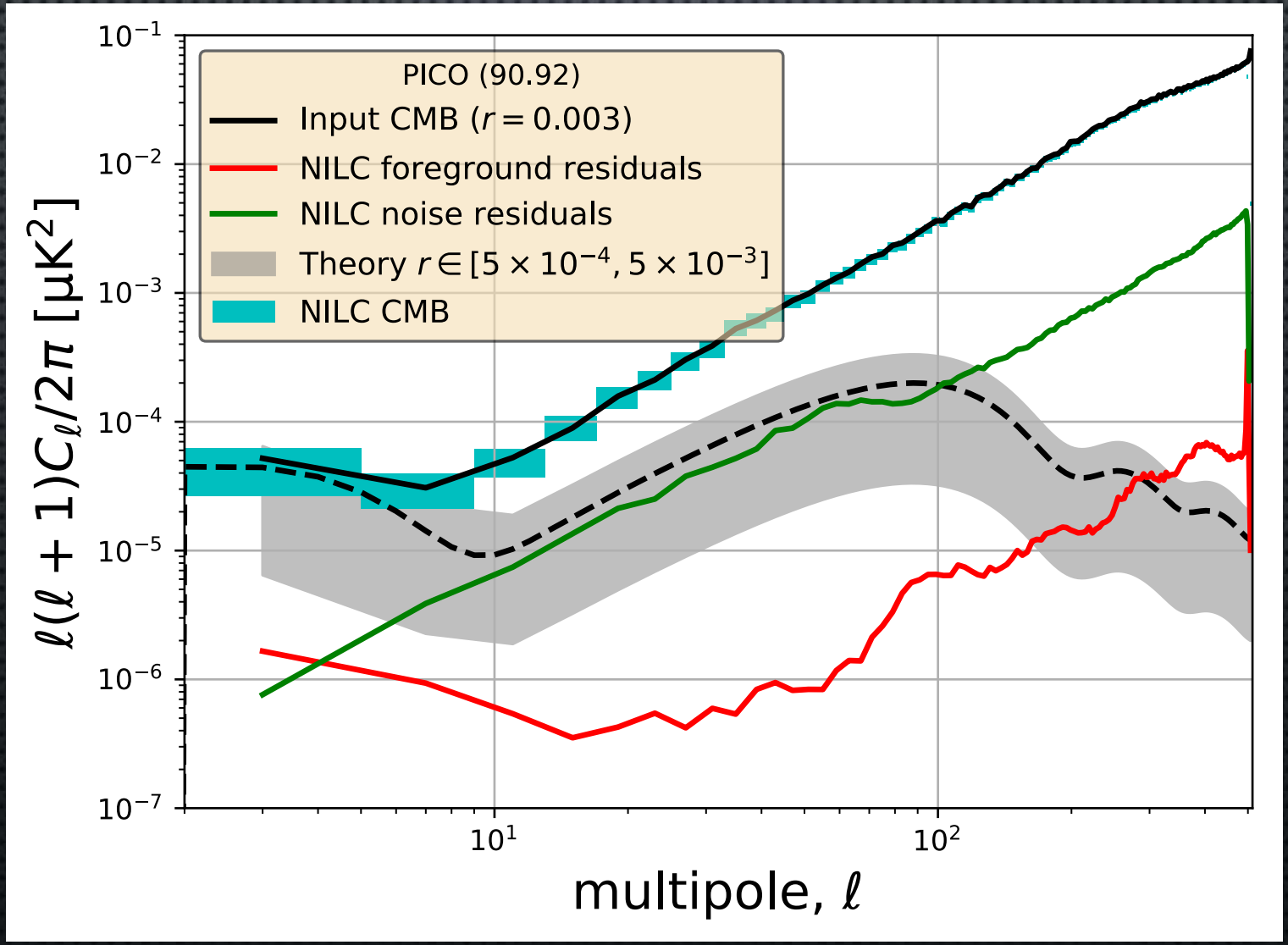
MASTER

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

Binning: $\Delta\ell = 4$

Model 92, $r = 0.003$

NILC



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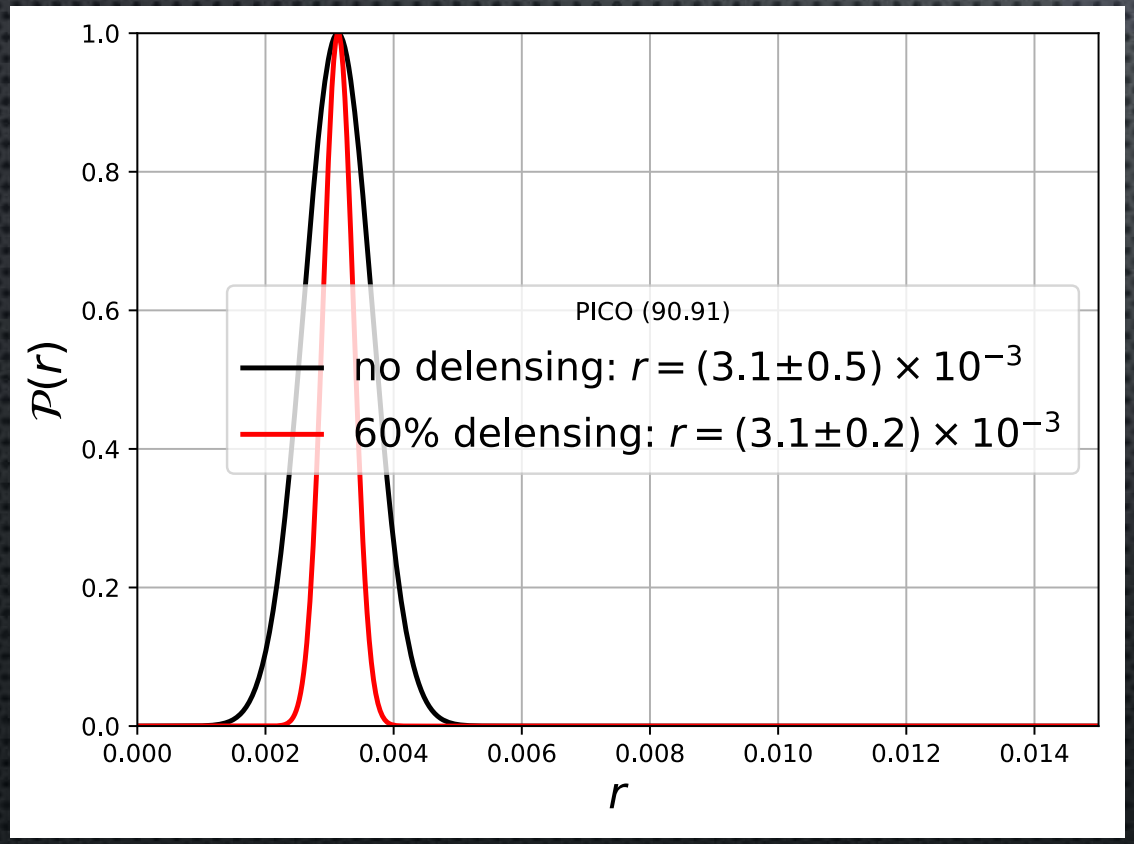

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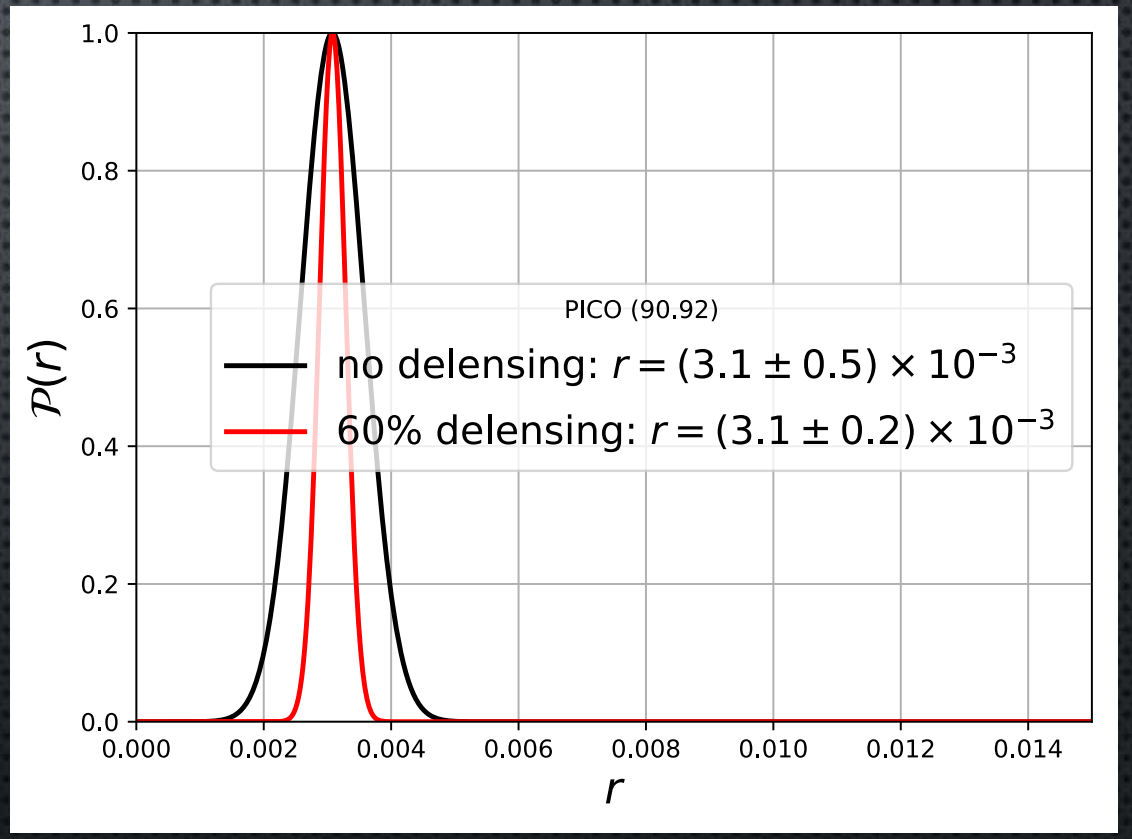
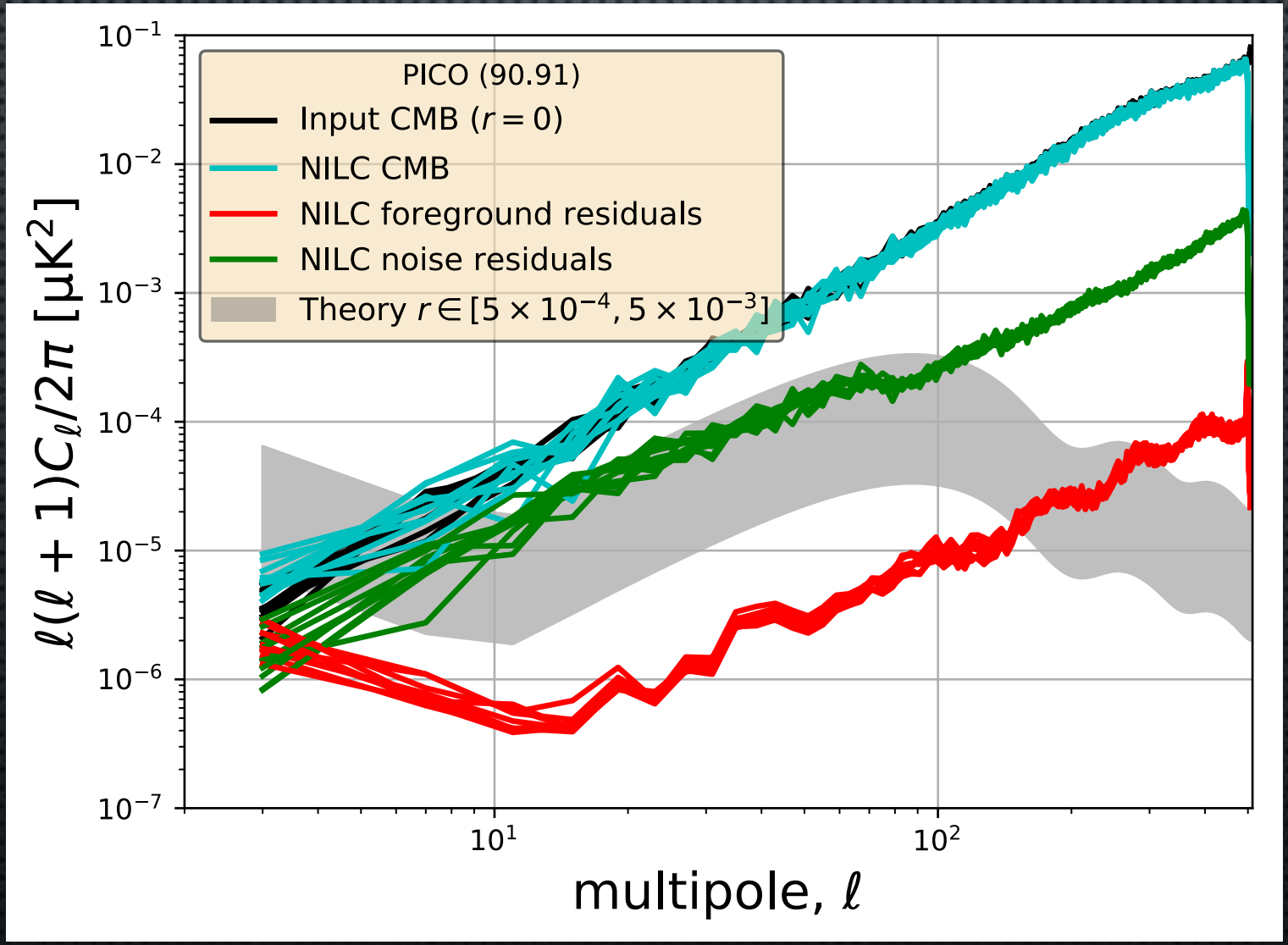


Robust recovery of the tensor-to-scalar ratio:
10 sigma detection for both sky models

$$r = 0$$

Model 91, $r = 0$

NILC



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Binning: $\Delta\ell = 4$

Model 91, $r = 0$

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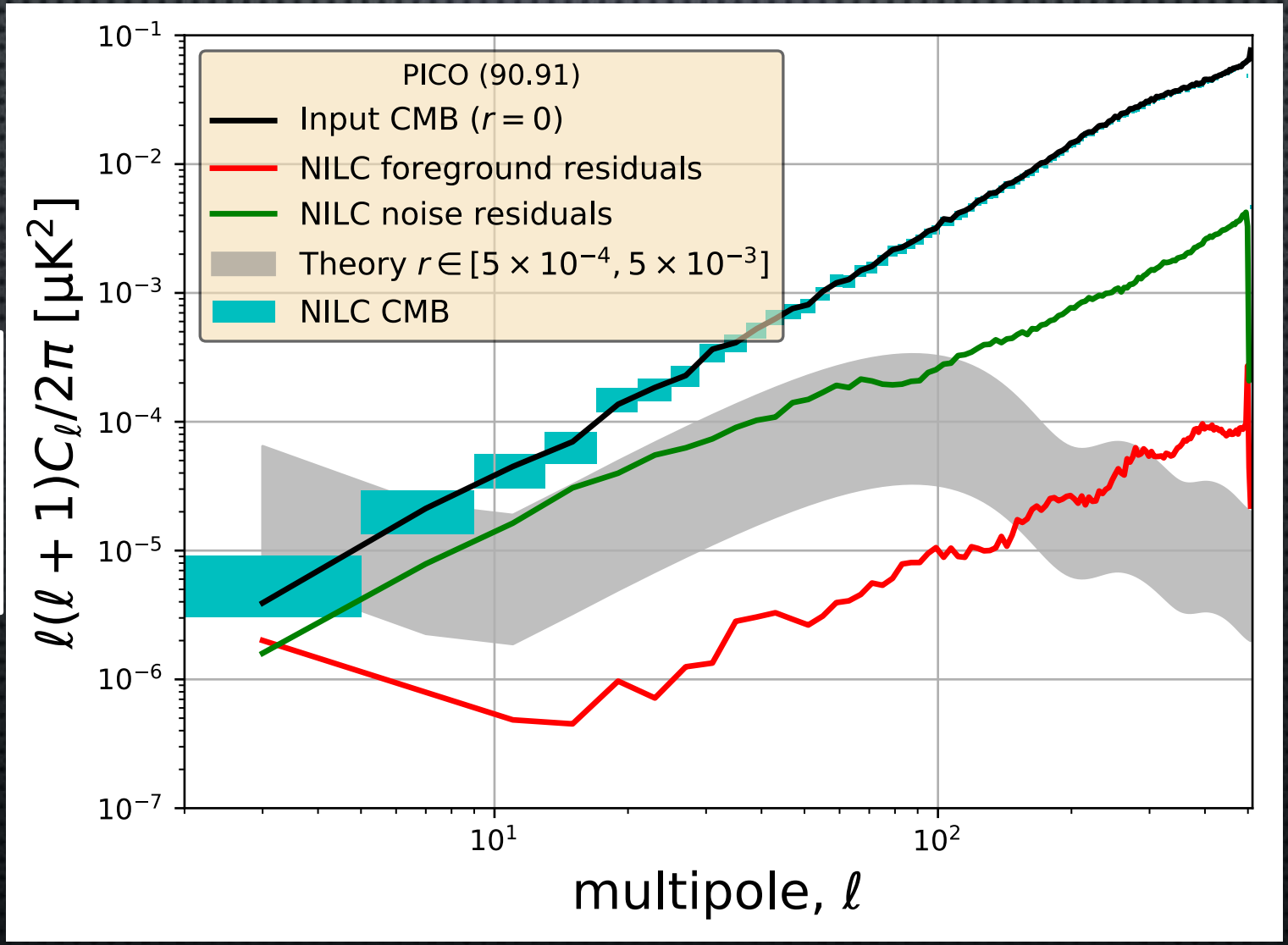


Foreground residuals 3 times lower than $r = 5\times10^{-4}$

10 realizations

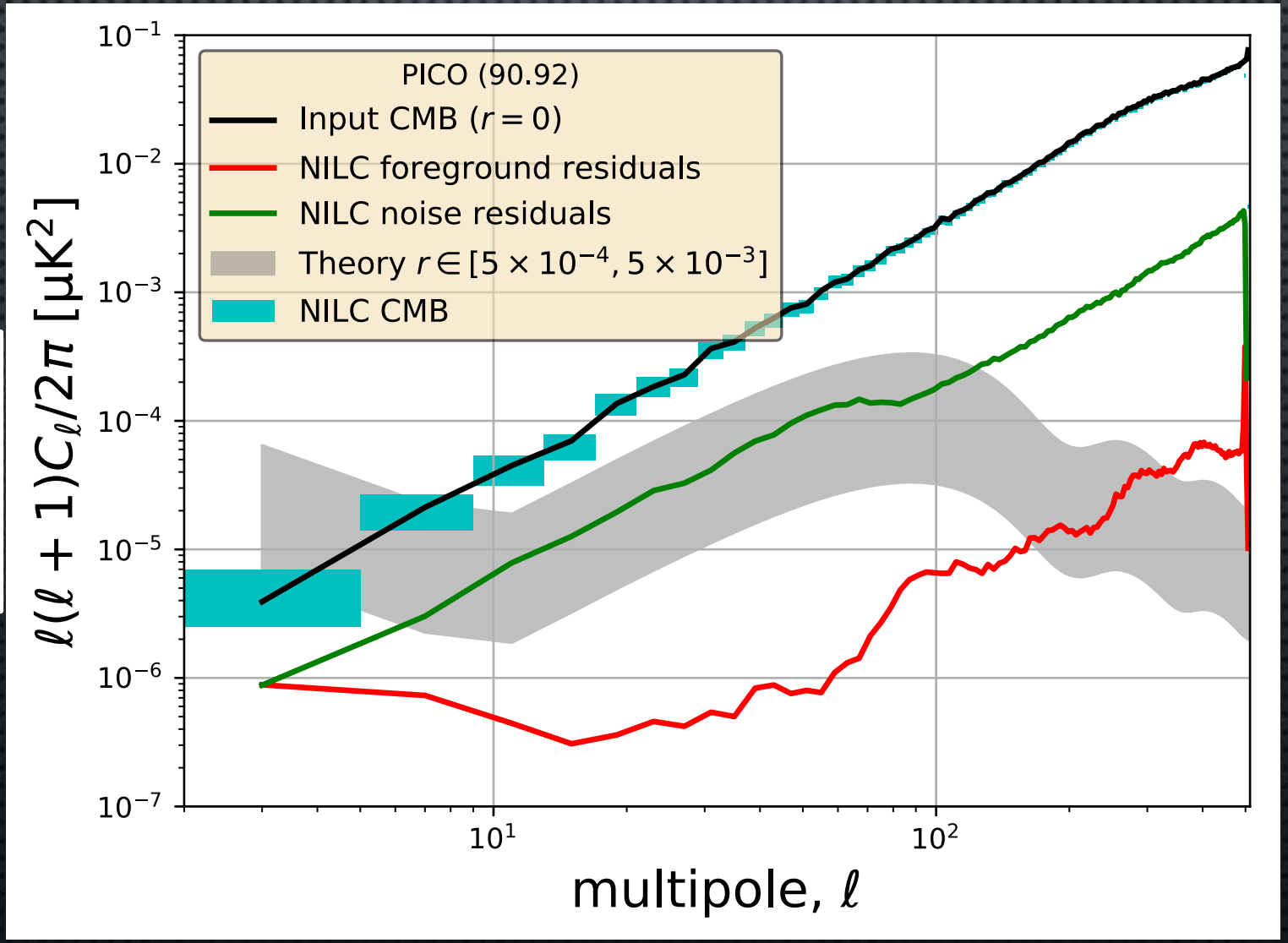
MASTER

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

Binning: $\Delta\ell = 4$

Model 92, $r = 0$

NILC



Foreground residuals 3 times lower than $r = 5\times10^{-4}$

10 realizations

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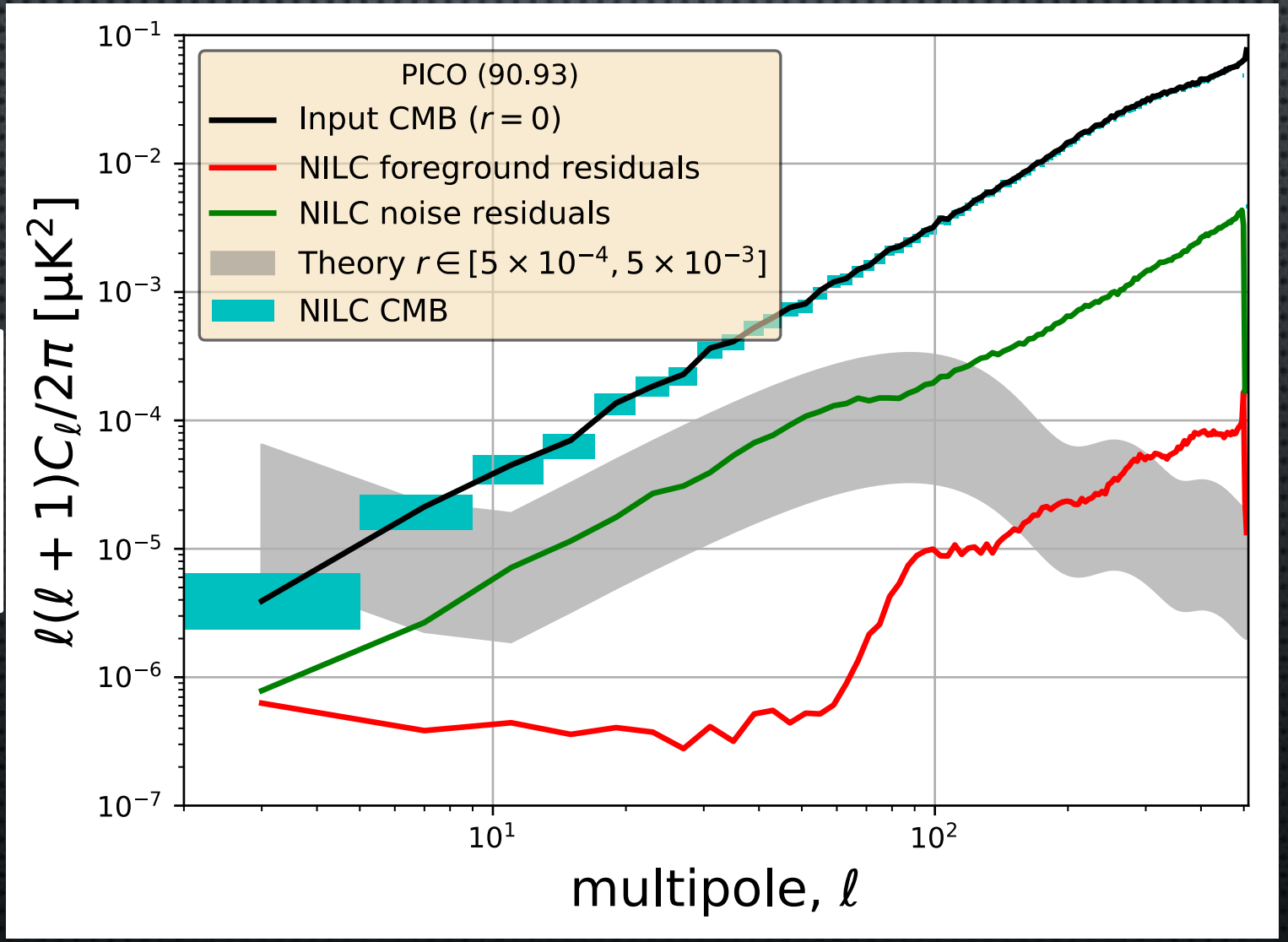
Binning: $\Delta\ell = 4$

Model 93, $r = 0$

NILC



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10 realizations

MASTER

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

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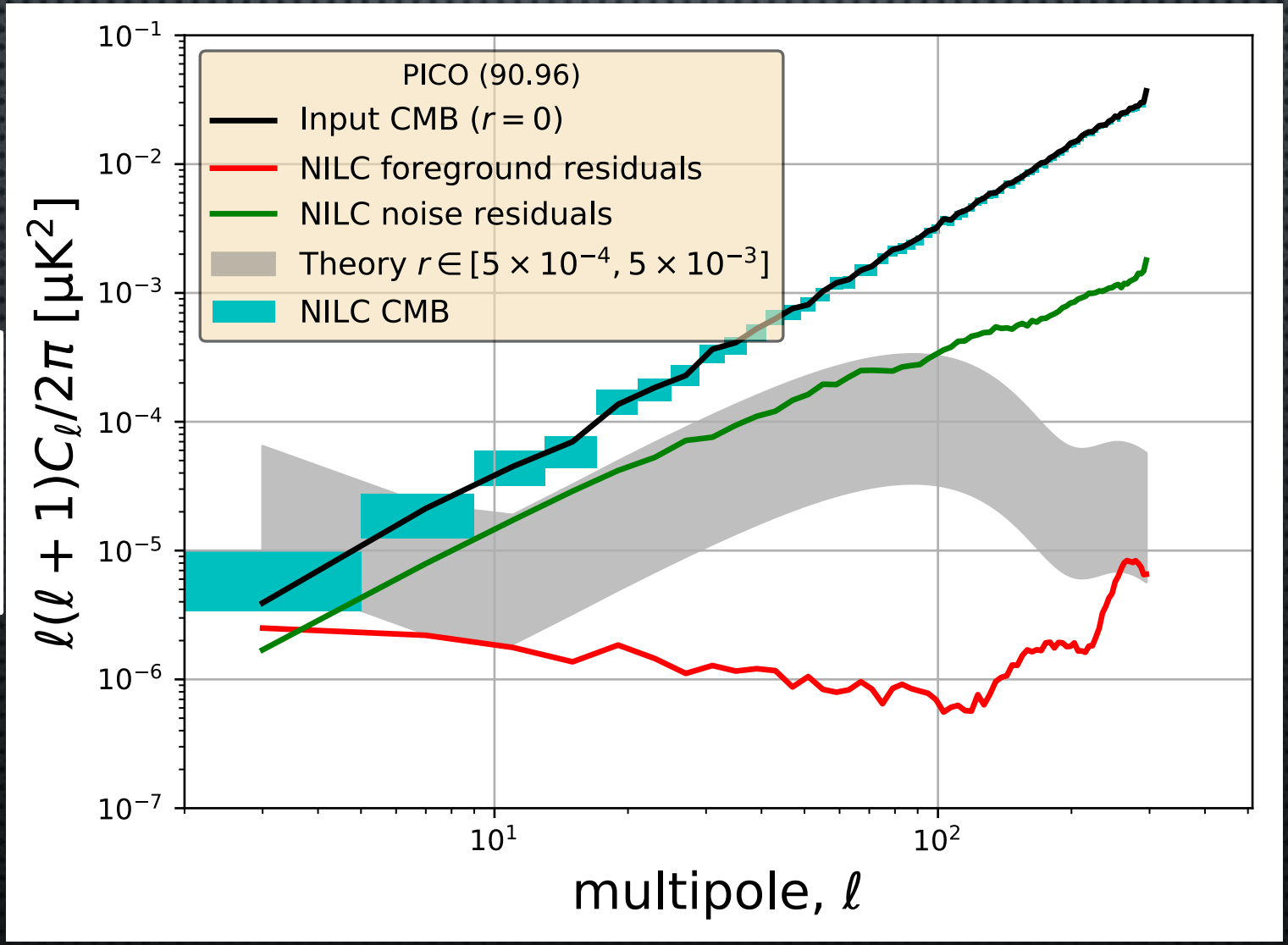
Model 96, $r = 0$

NILC



Foreground residuals just lower than $r = 5{\times}10^{-4}$

10 realizations

MASTER

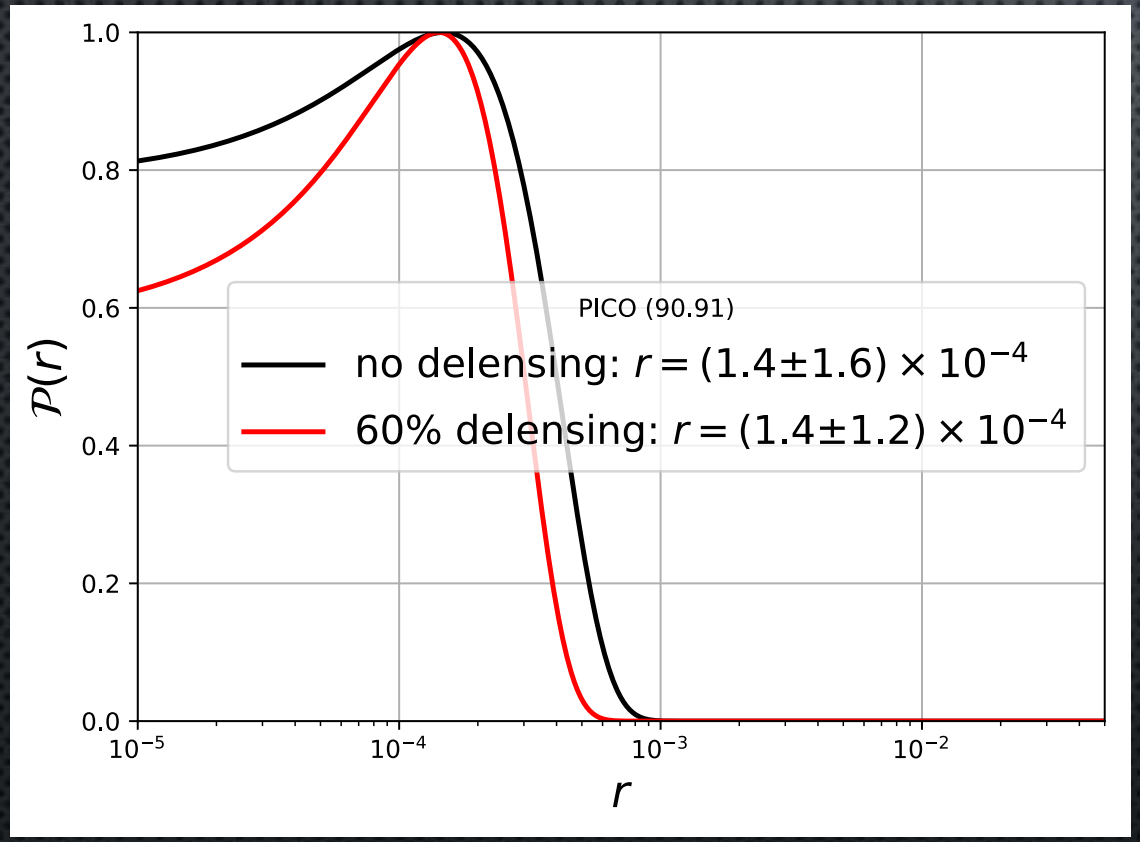
$f_{\rm sky} = 50\%$

Binning: $\Delta\ell = 4$

$r = 0$

NILC

Model 91



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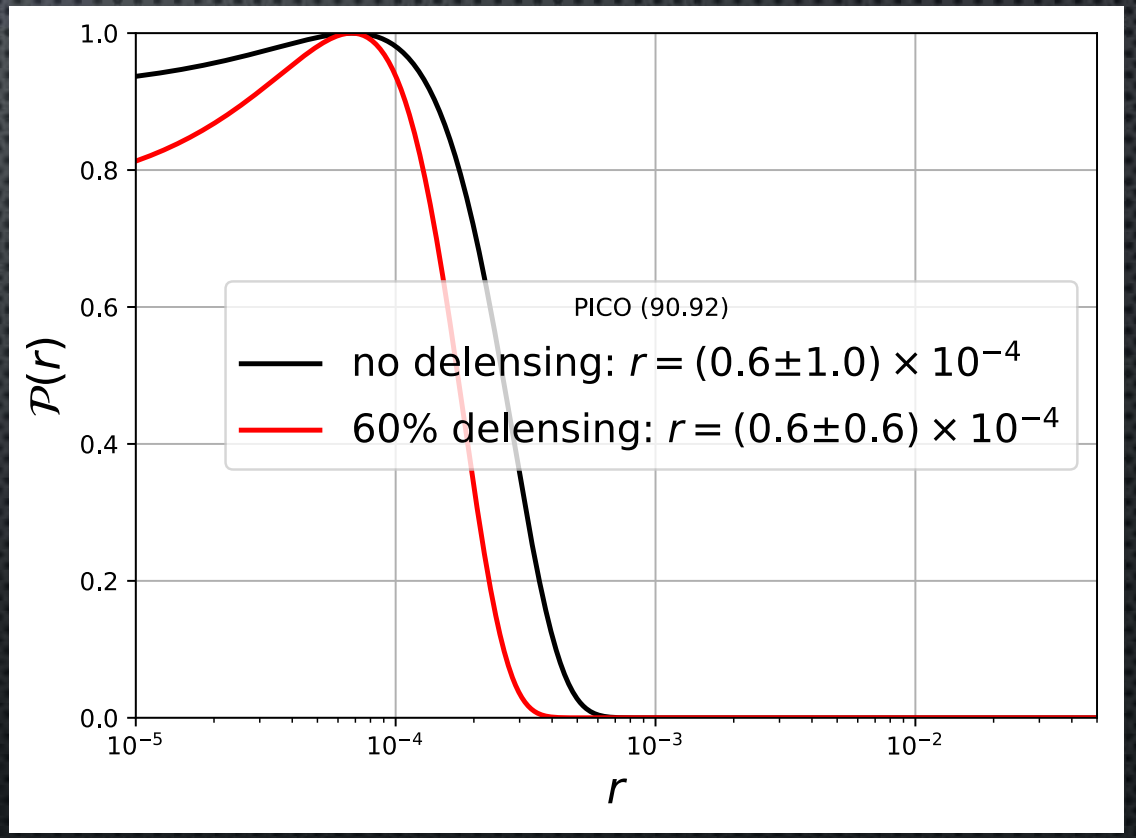
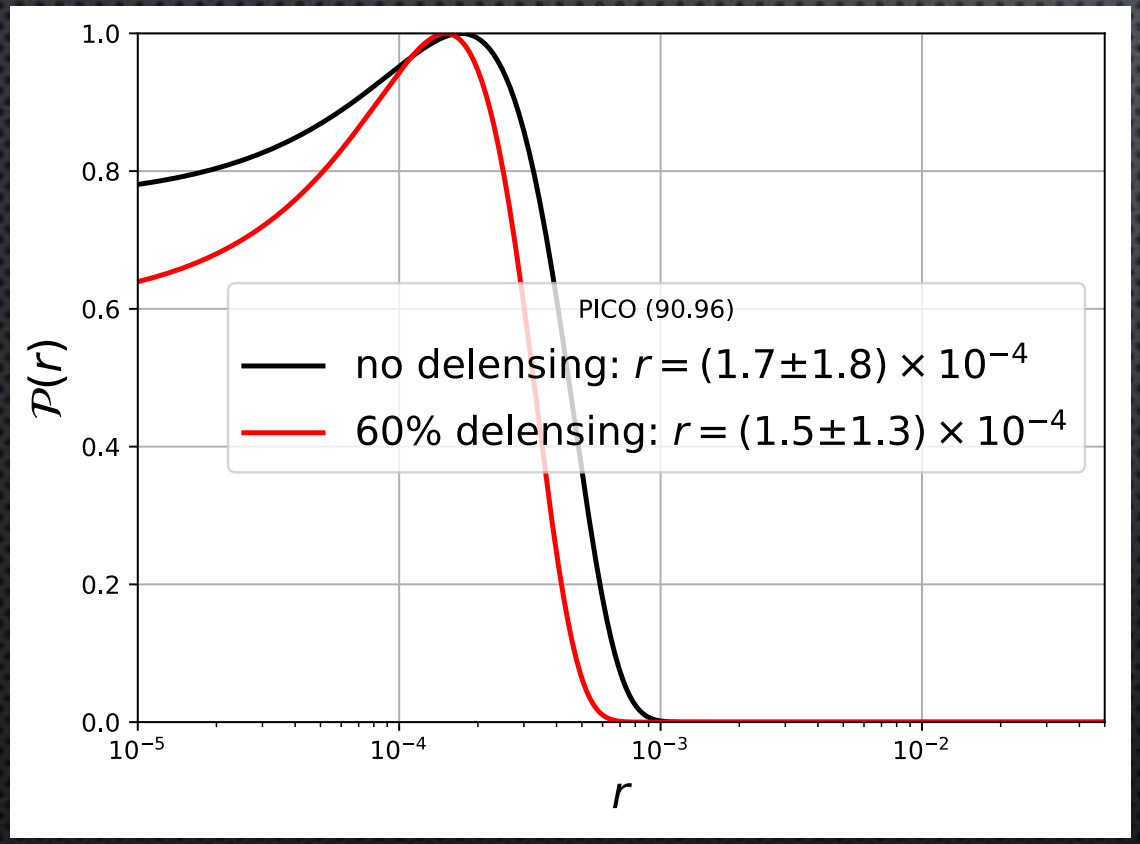


Robust recovery of the tensor-to-scalar ratio:
$\sigma(r) \simeq 10^{-4}$ for both sky models

$r = 0$

NILC

Model 96



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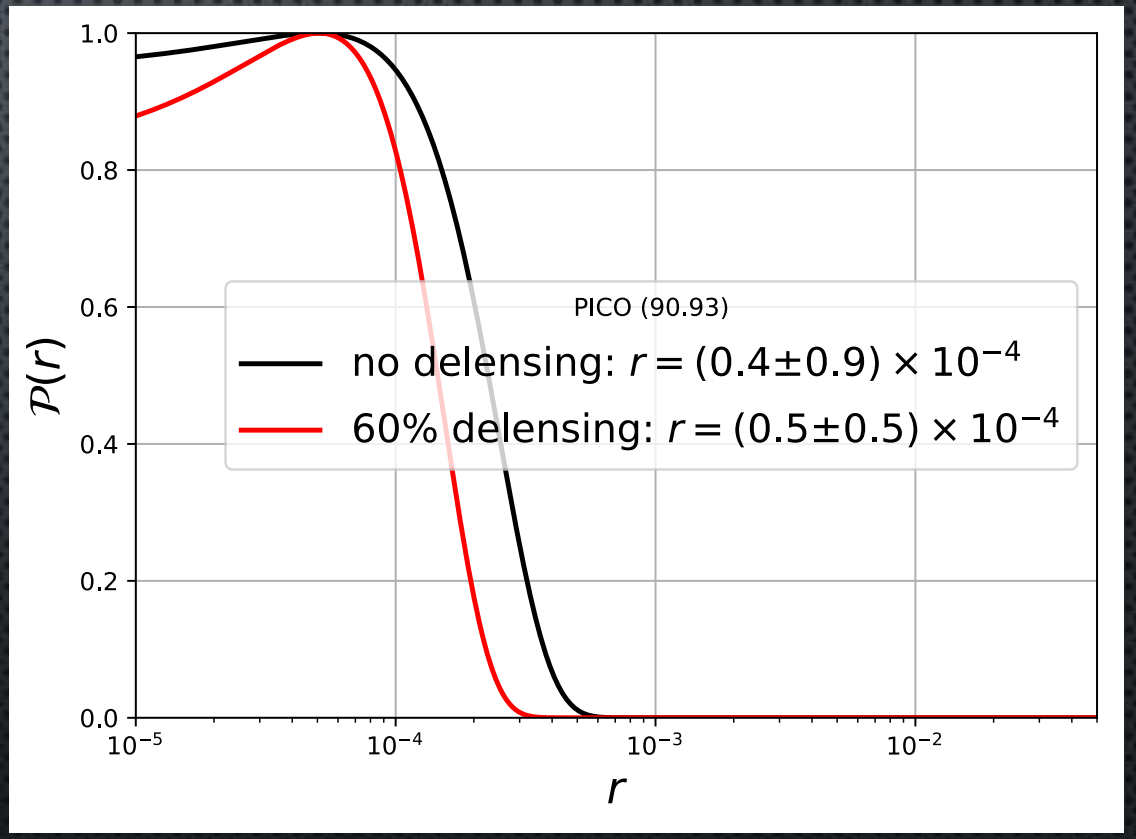

Robust recovery of the tensor-to-scalar ratio:
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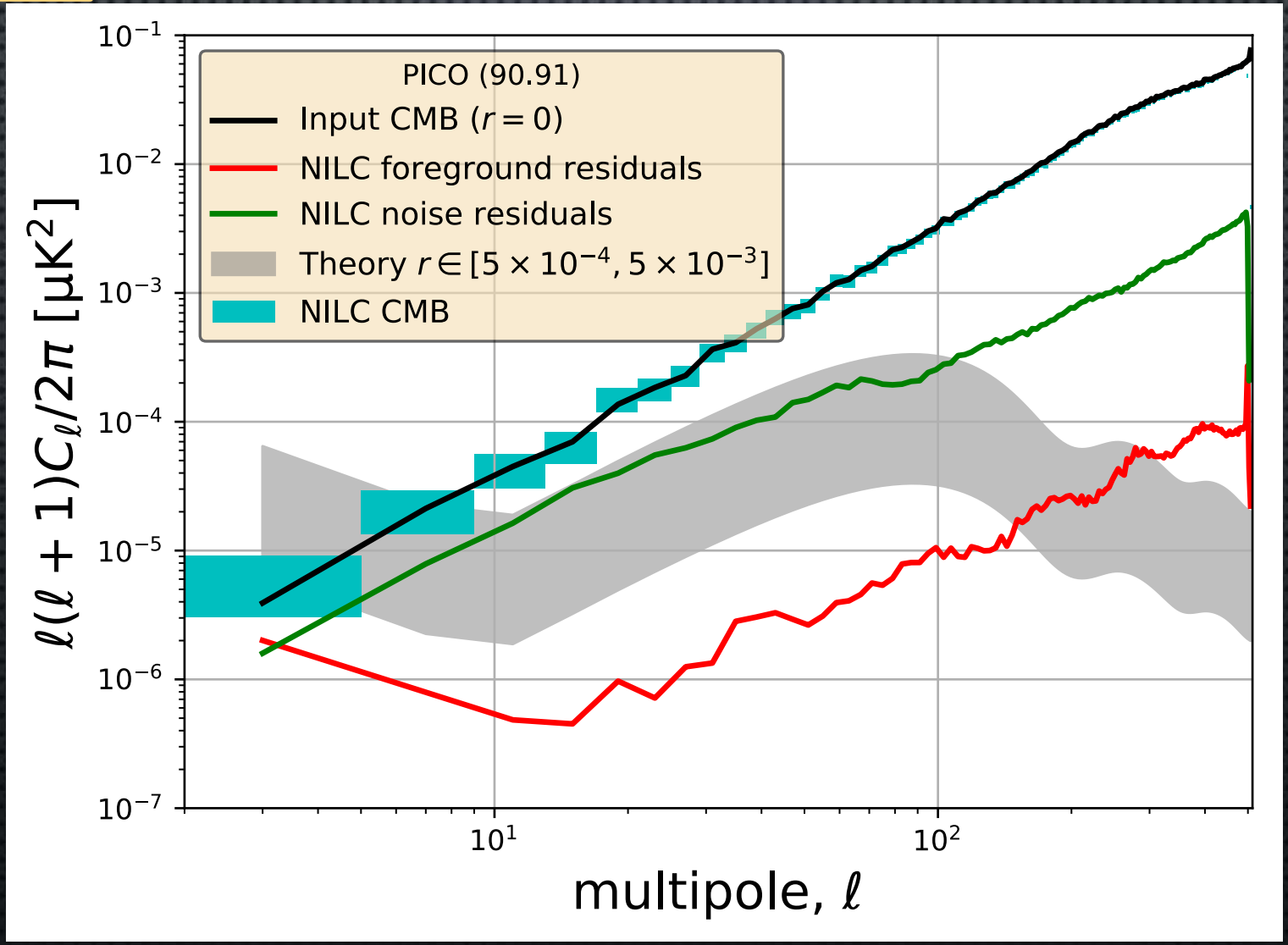
Importance of high/low frequency channels

Baseline
21 - 800 GHz

Model 91, $r = 0$

NILC



10 realizations

MASTER

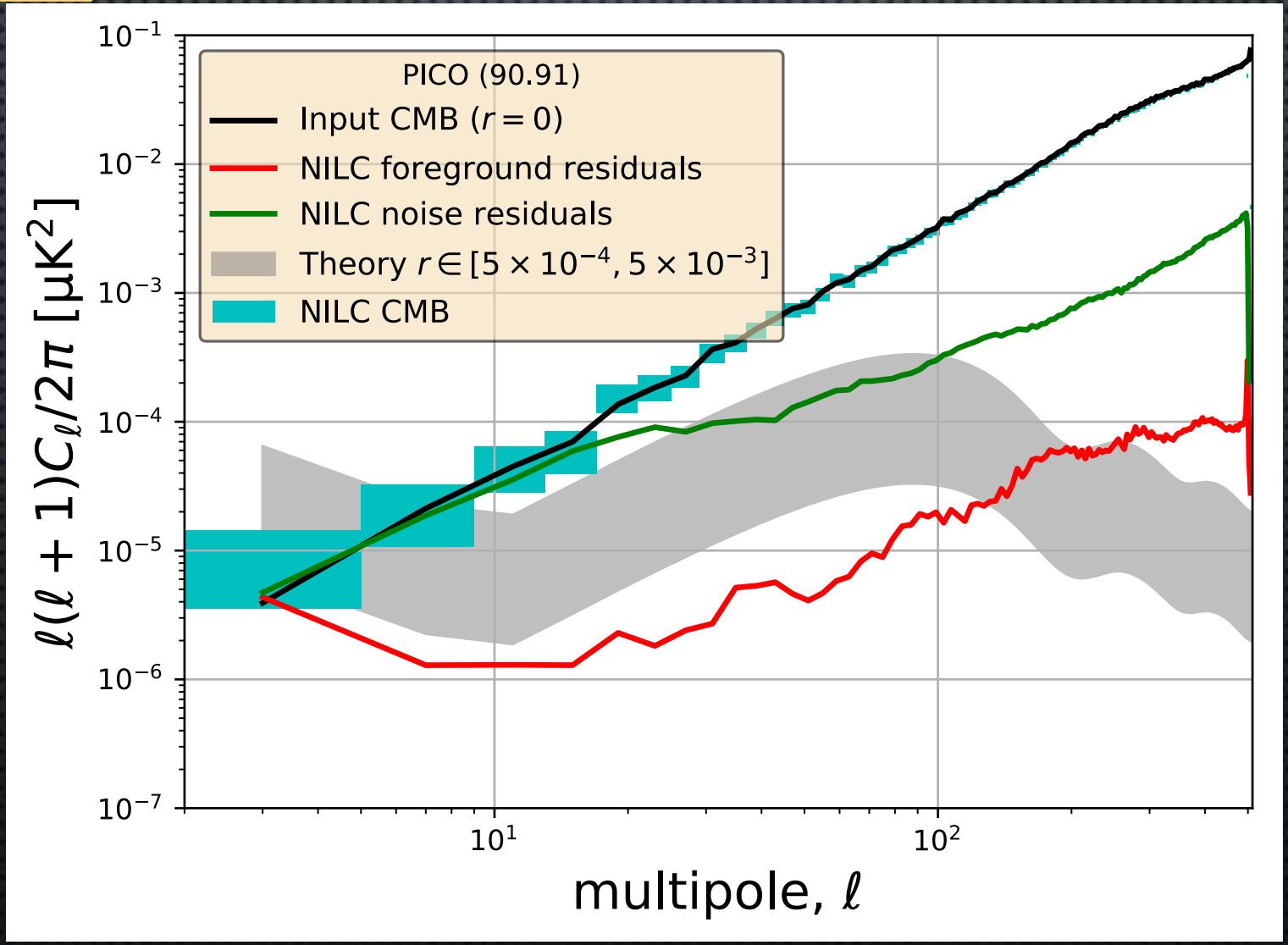
$f_{\rm sky} = 50\%$

Binning: $\Delta\ell = 4$

Without LF
43 - 800 GHz

Model 91, $r = 0$

NILC



10 realizations

MASTER

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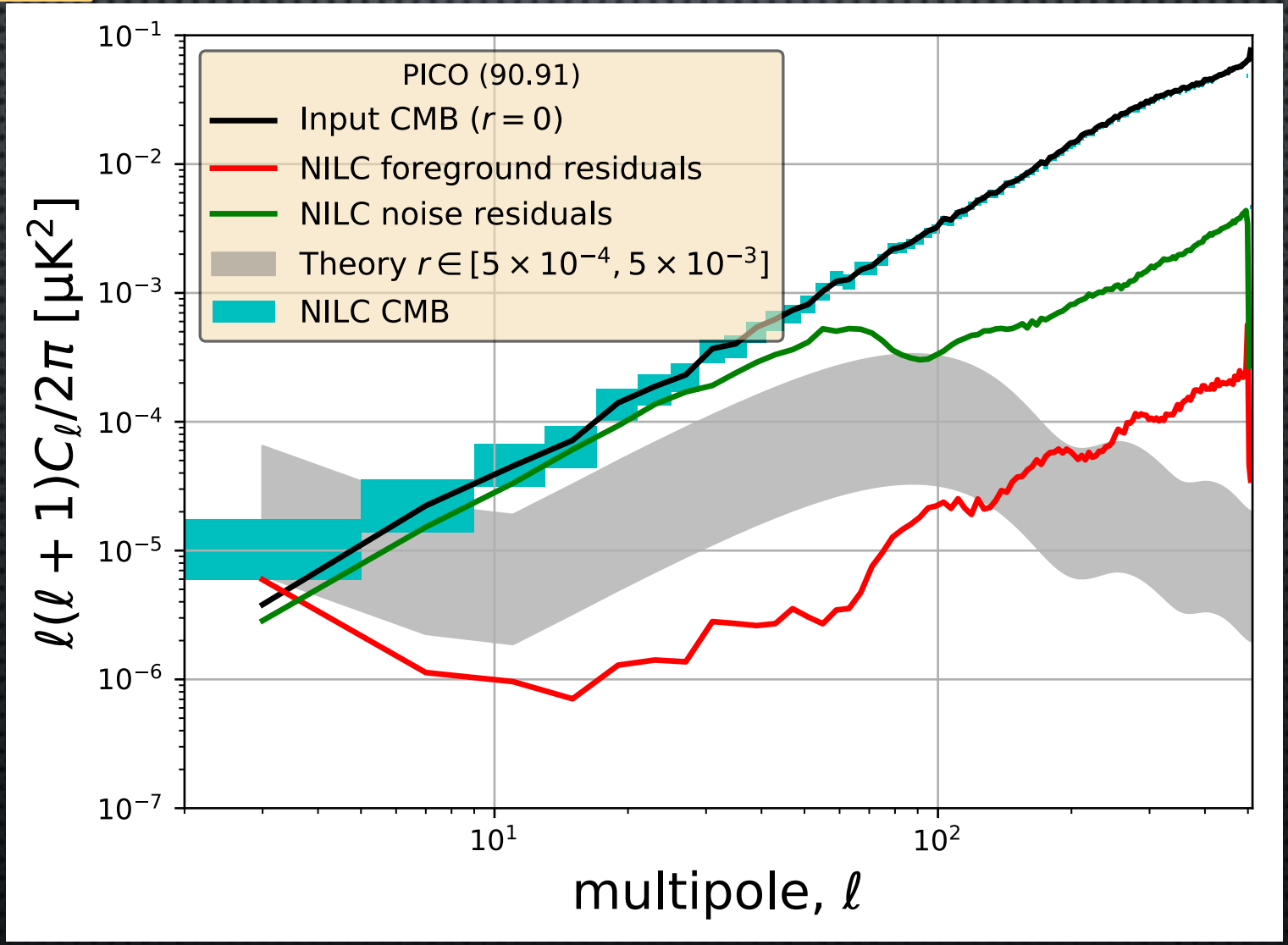
Binning: $\Delta\ell = 4$

Without HF
21 - 462 GHz

Model 91, $r = 0$

NILC



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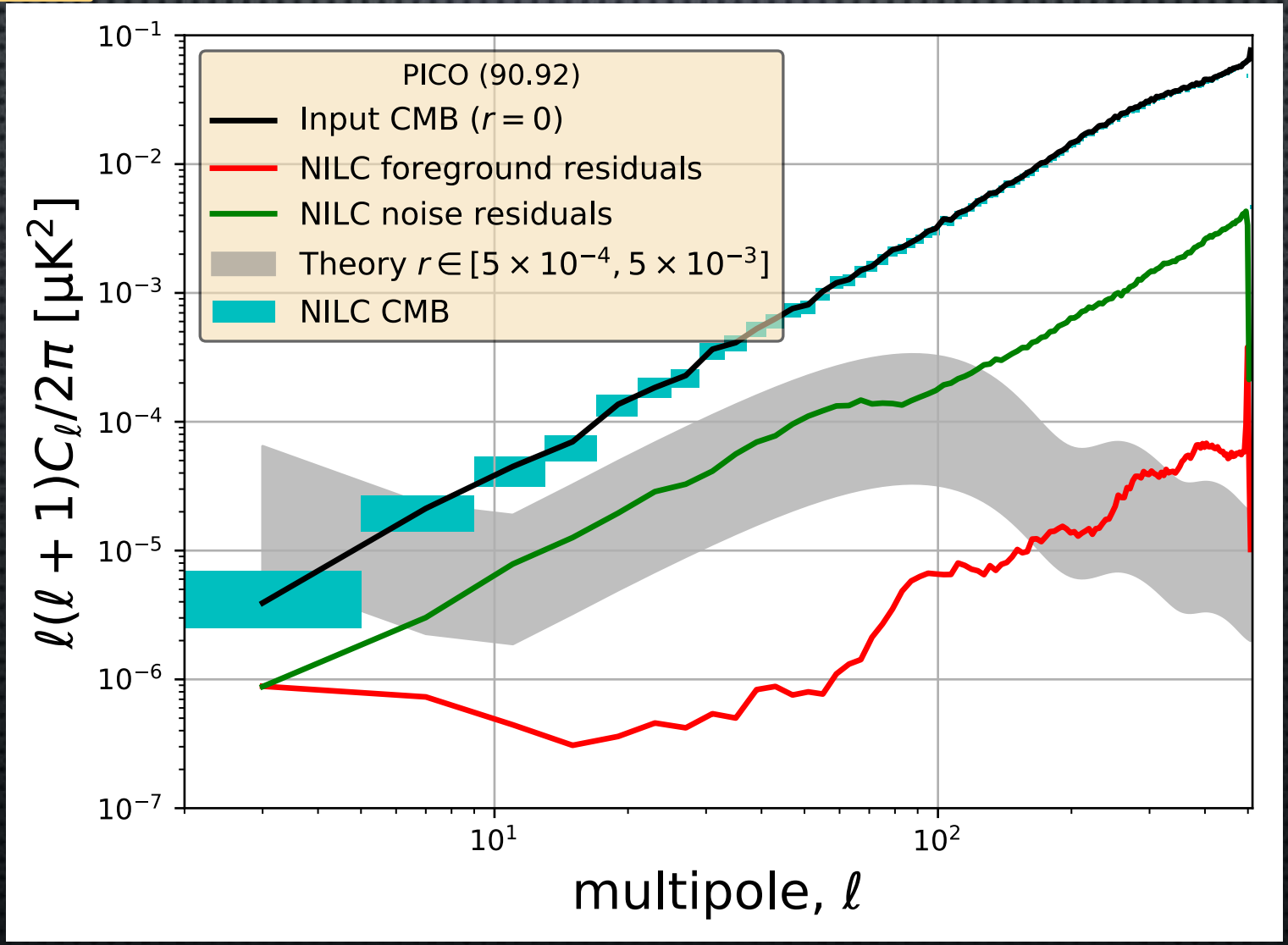

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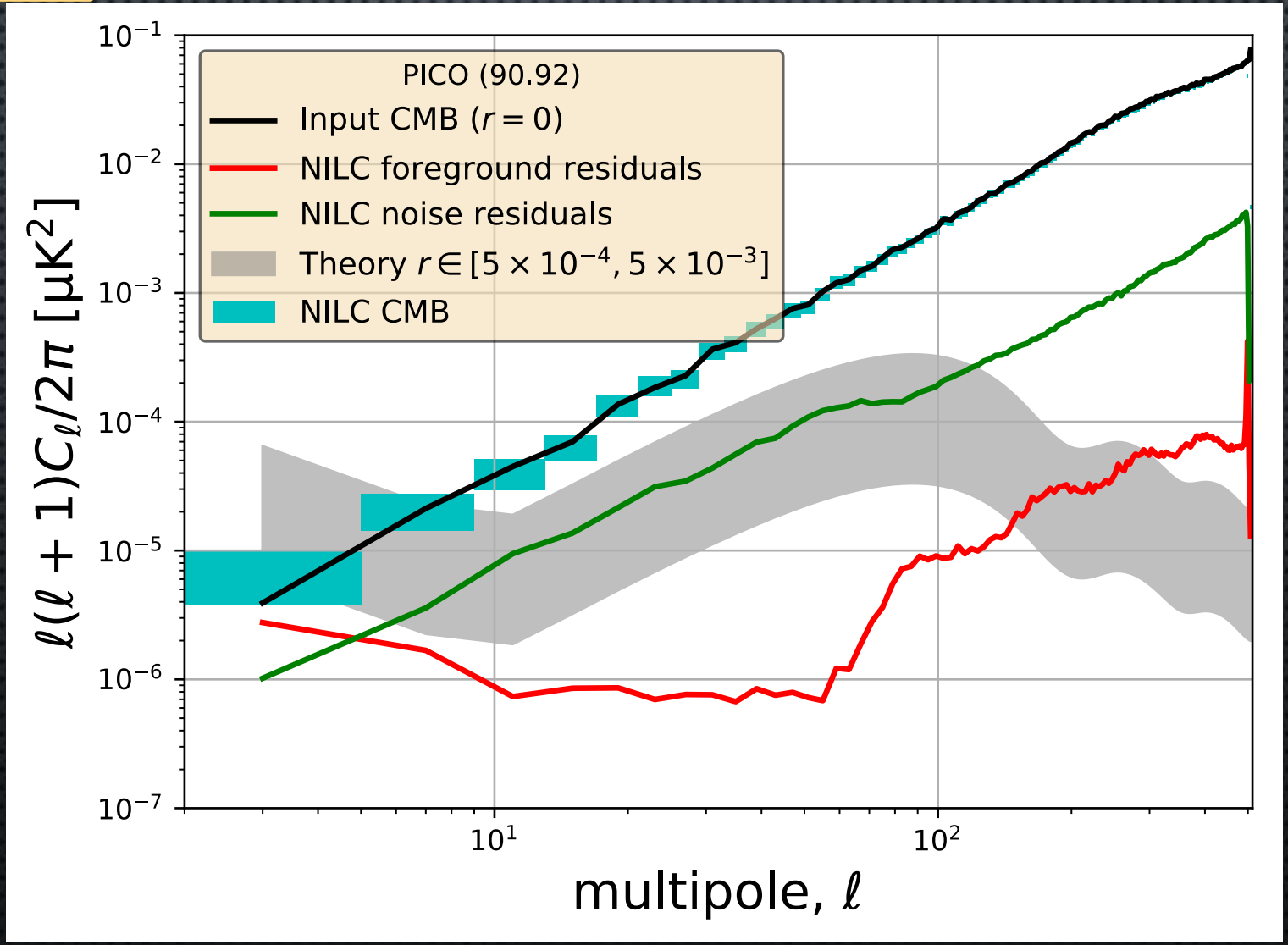

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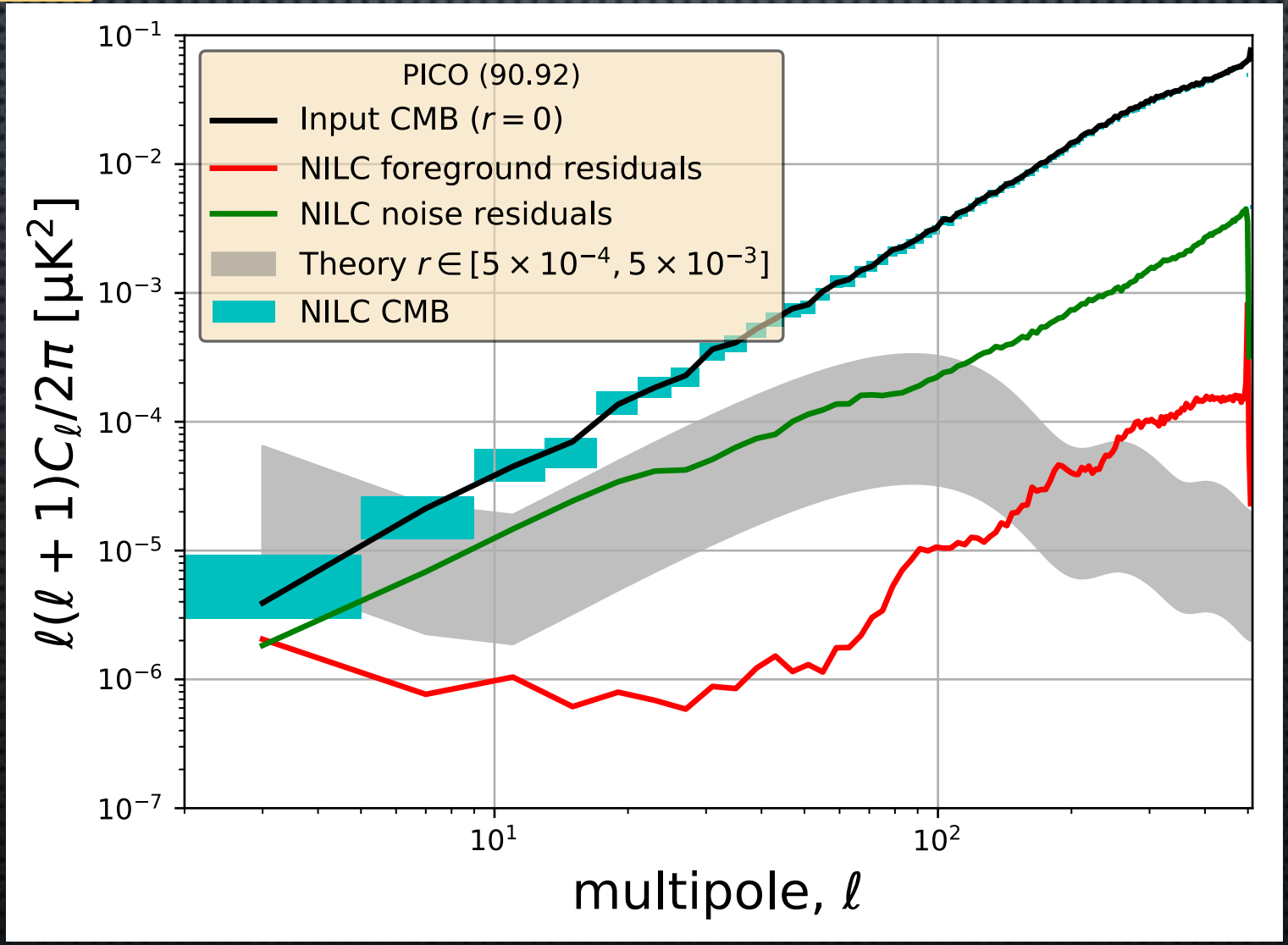

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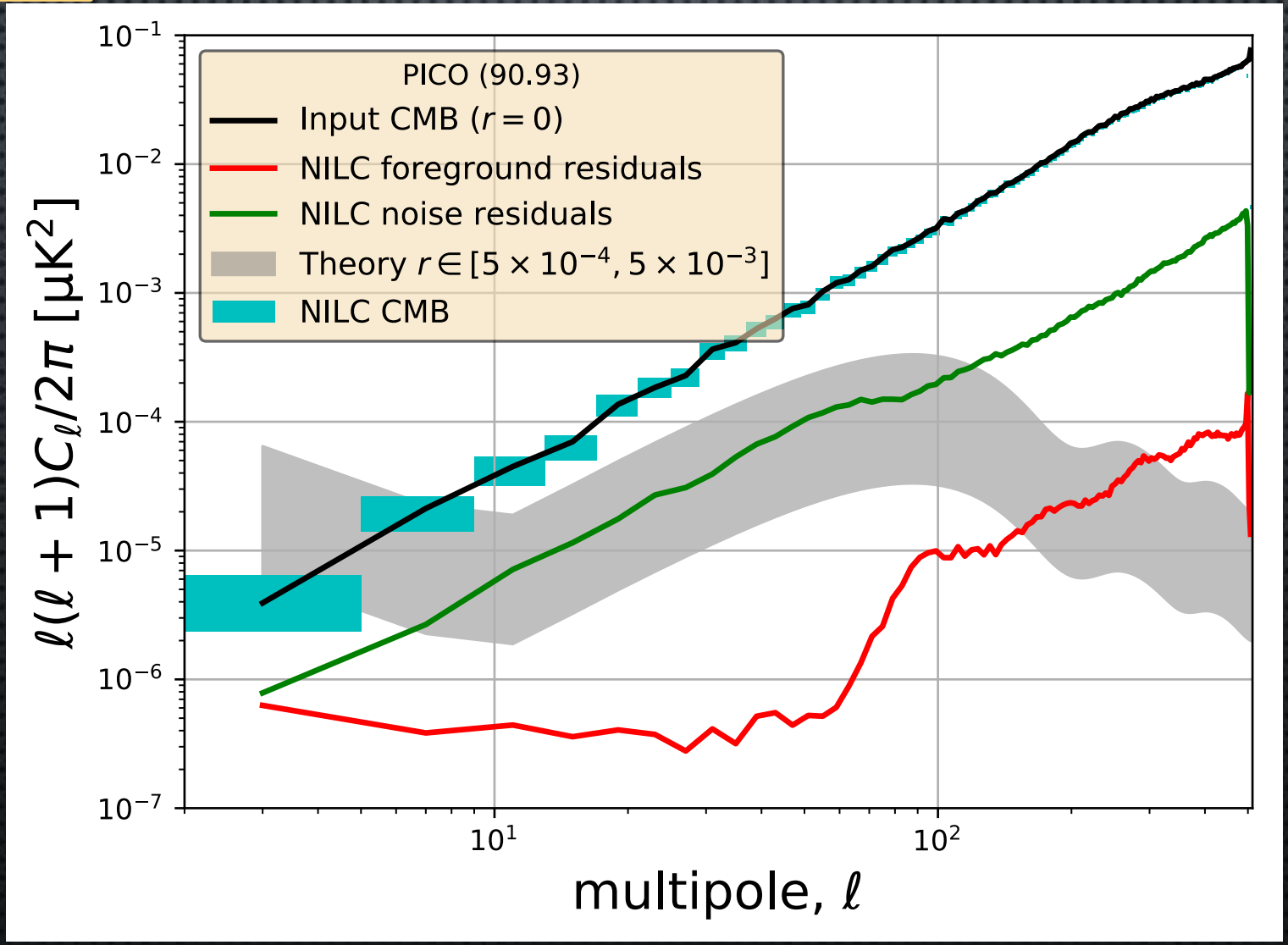

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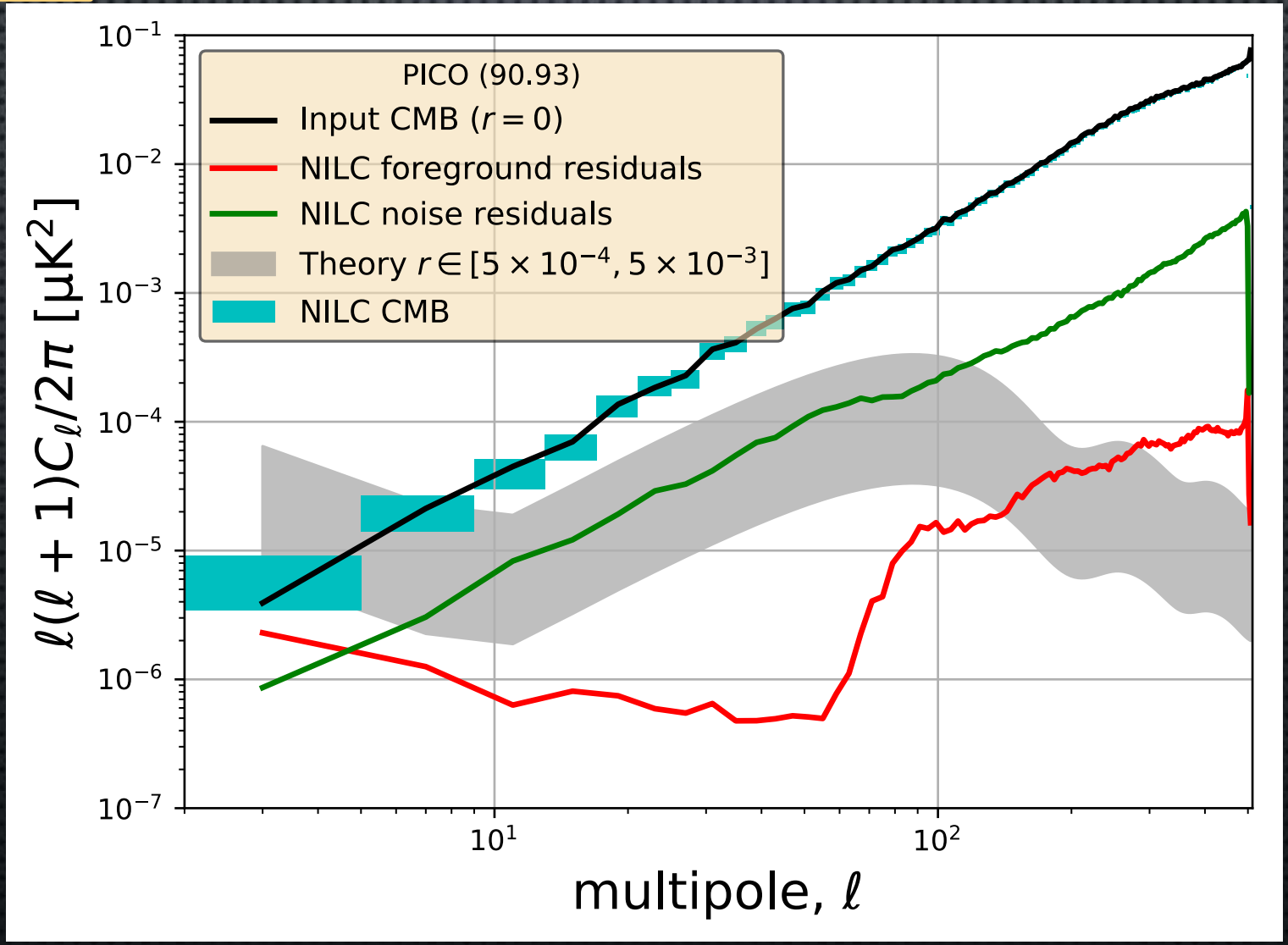

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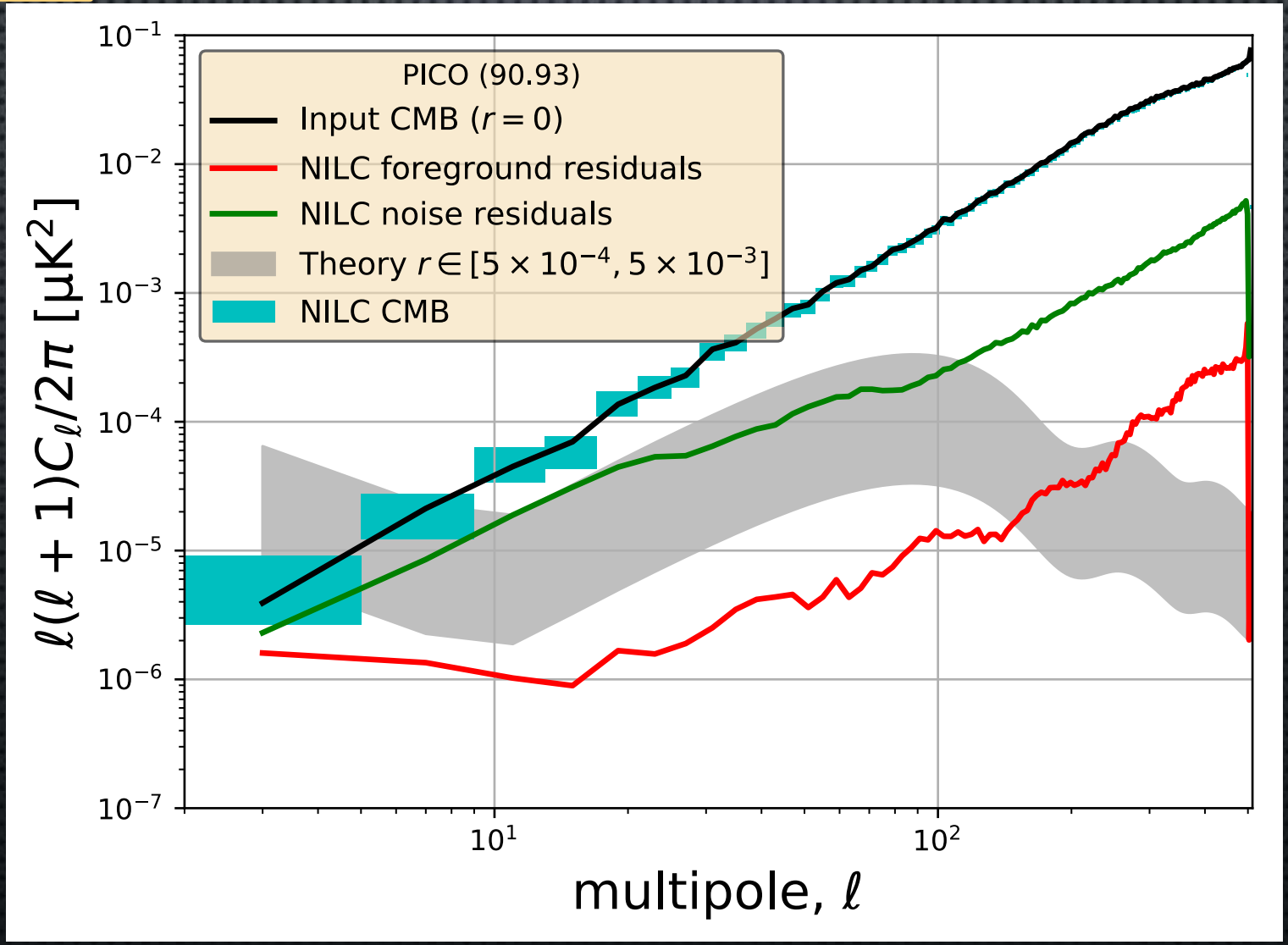

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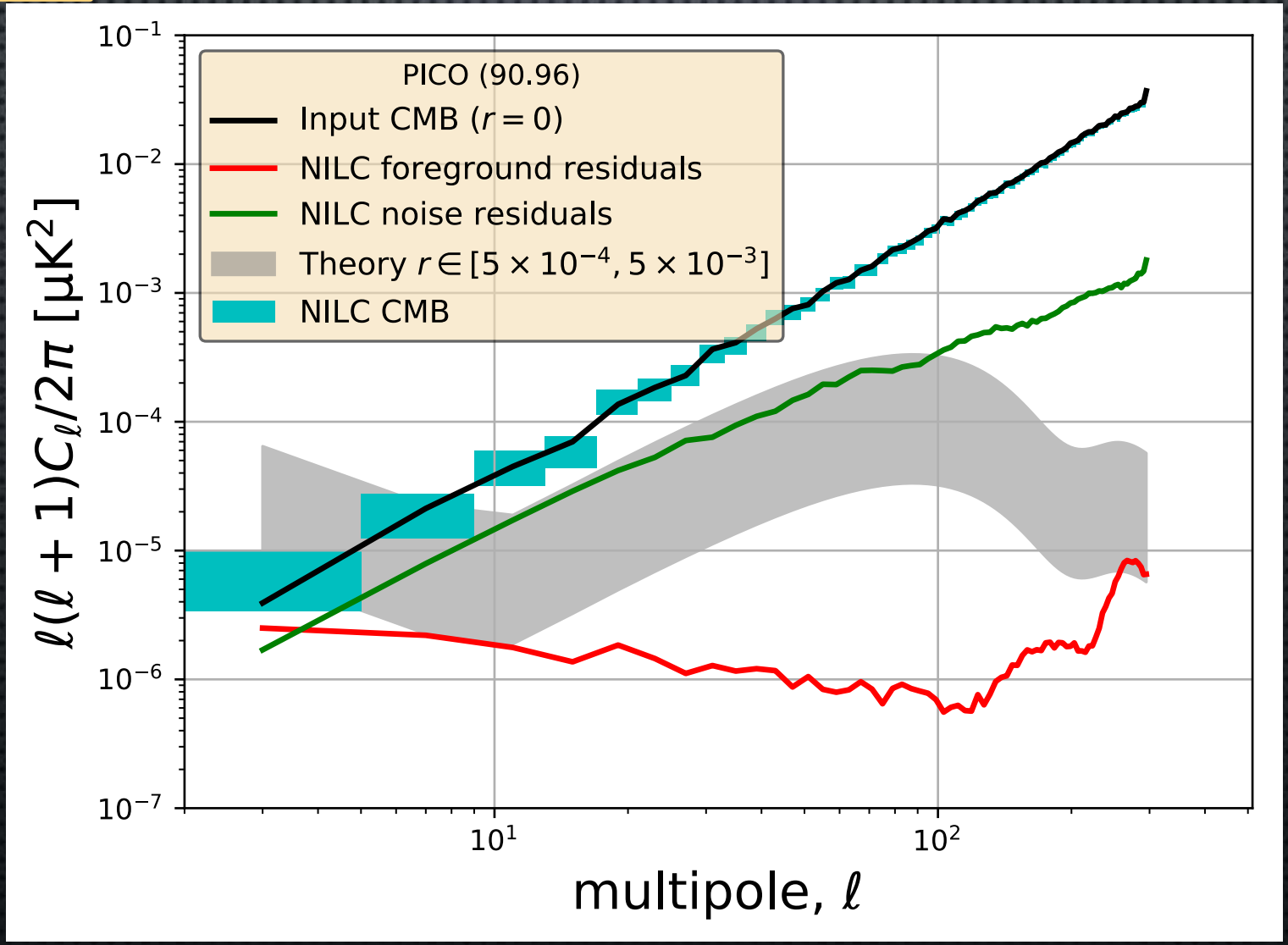

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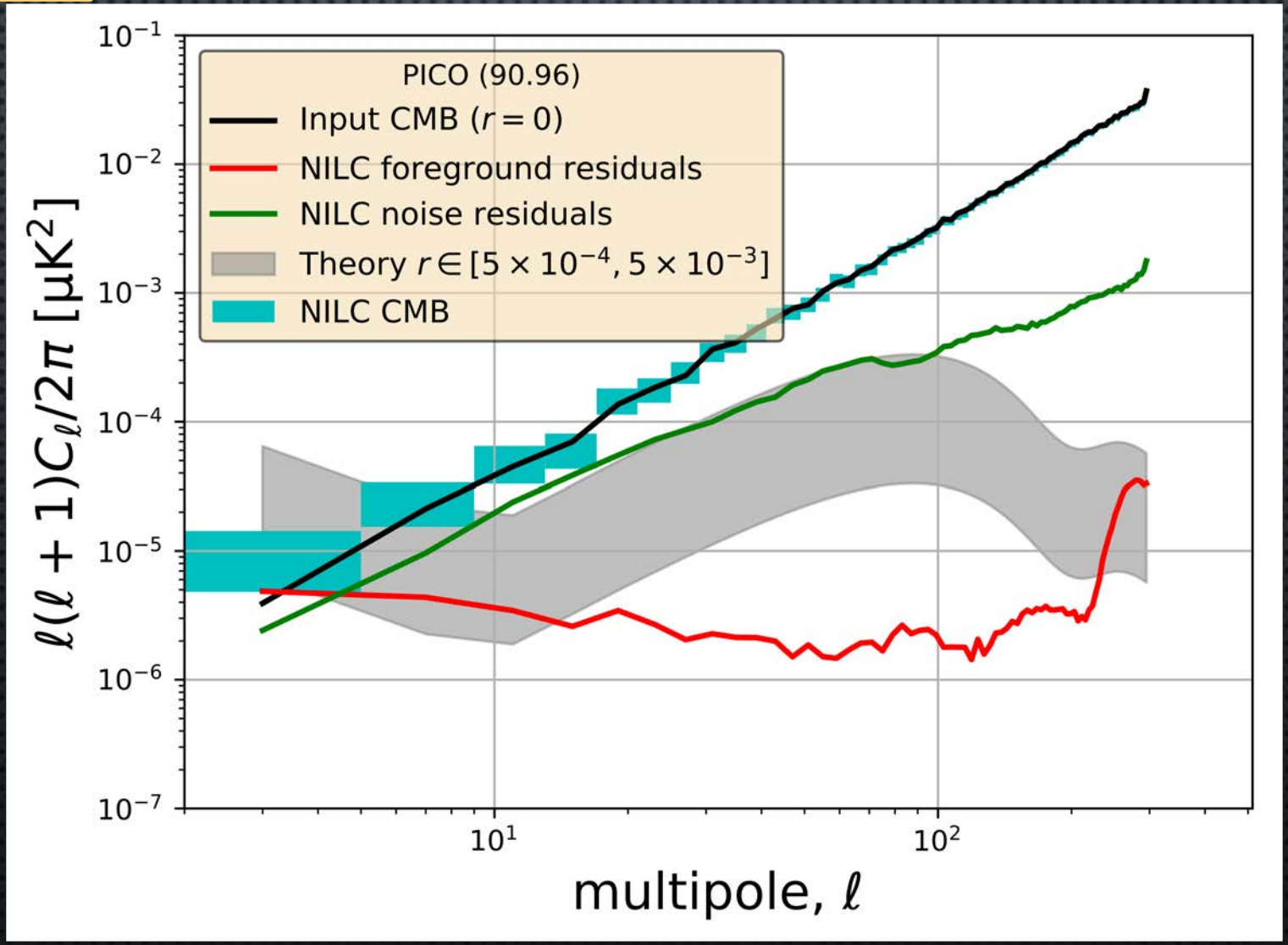

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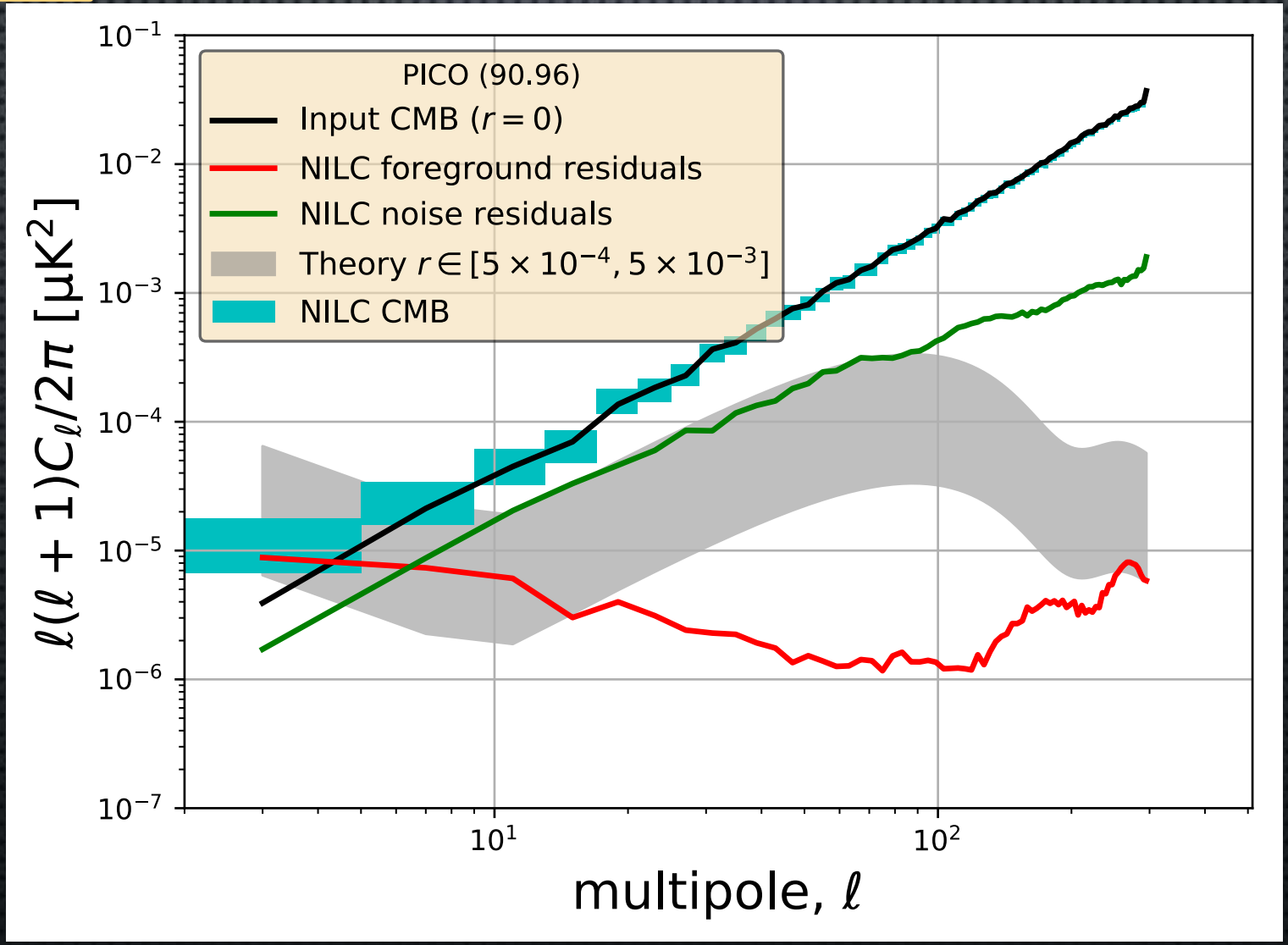

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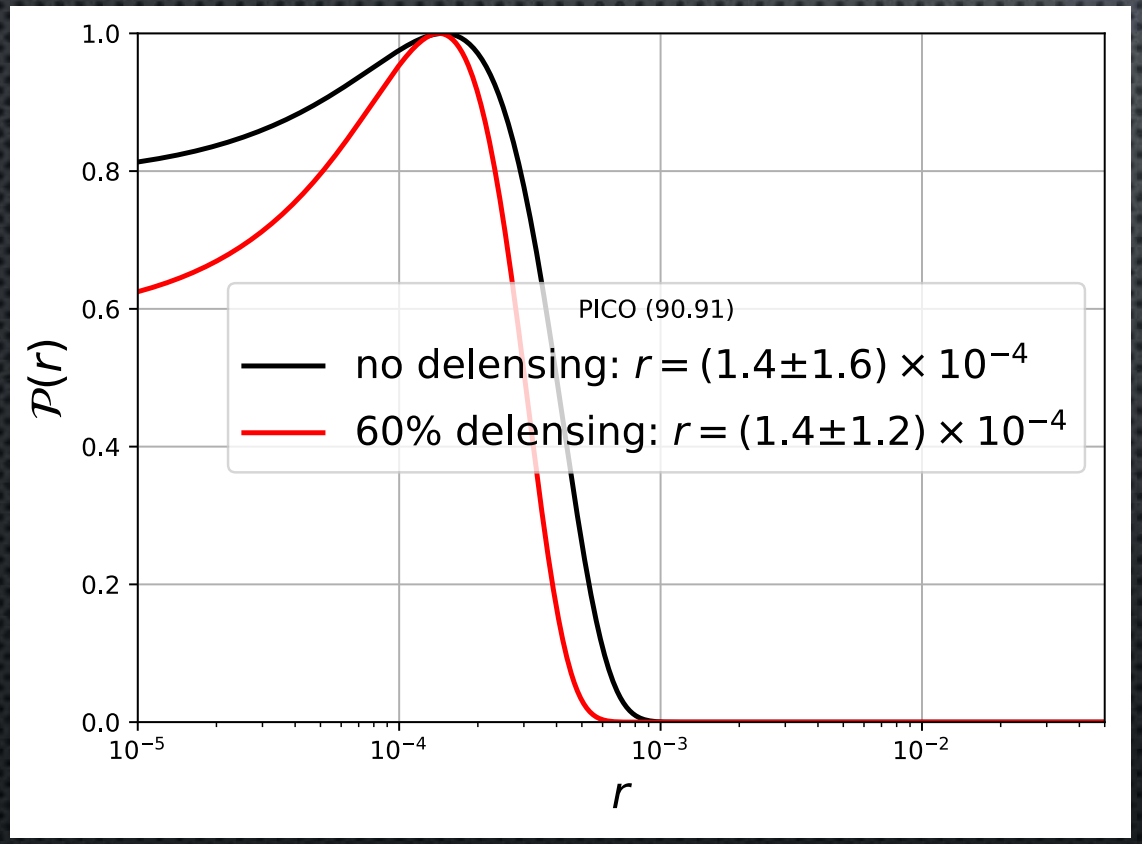

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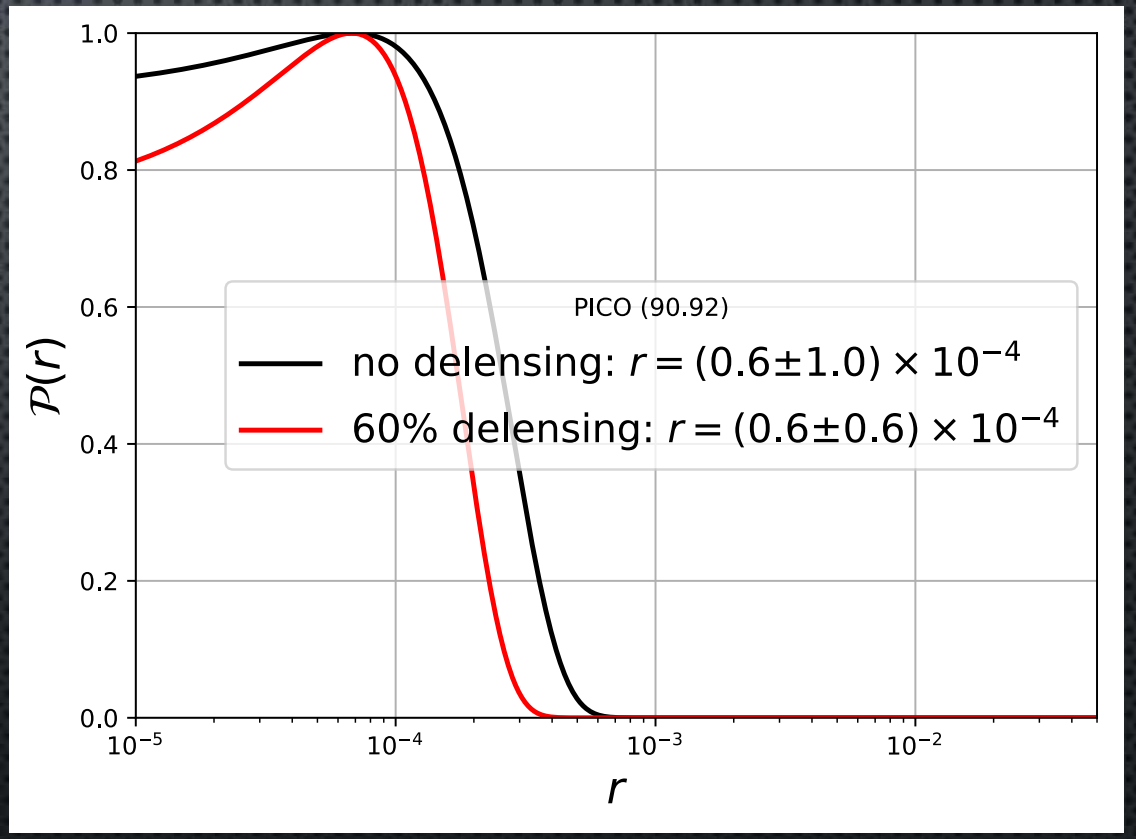


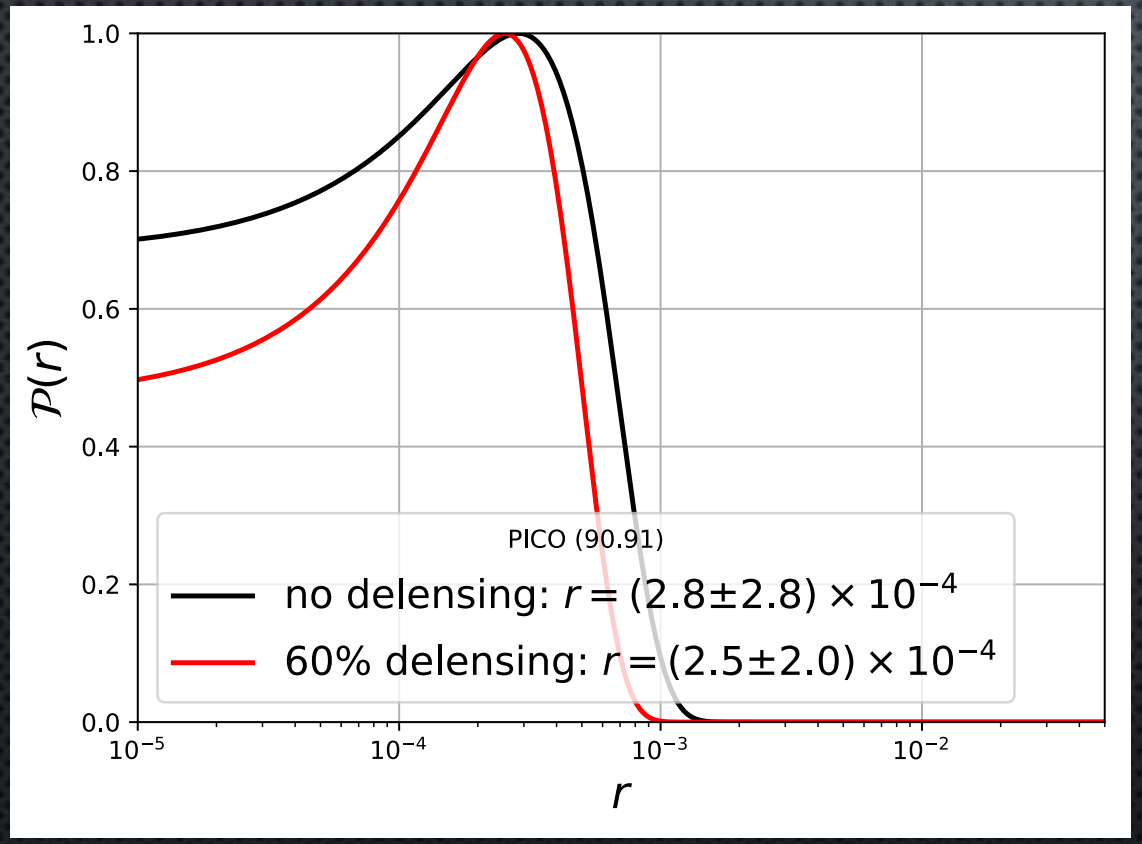
Unbiased recovery of the tensor-to-scalar ratio
Consistent with $r = 0$, $\sigma(r) \simeq 10^{-4}$

Without LF
43 - 800 GHz

$r = 0$

NILC

Model 91



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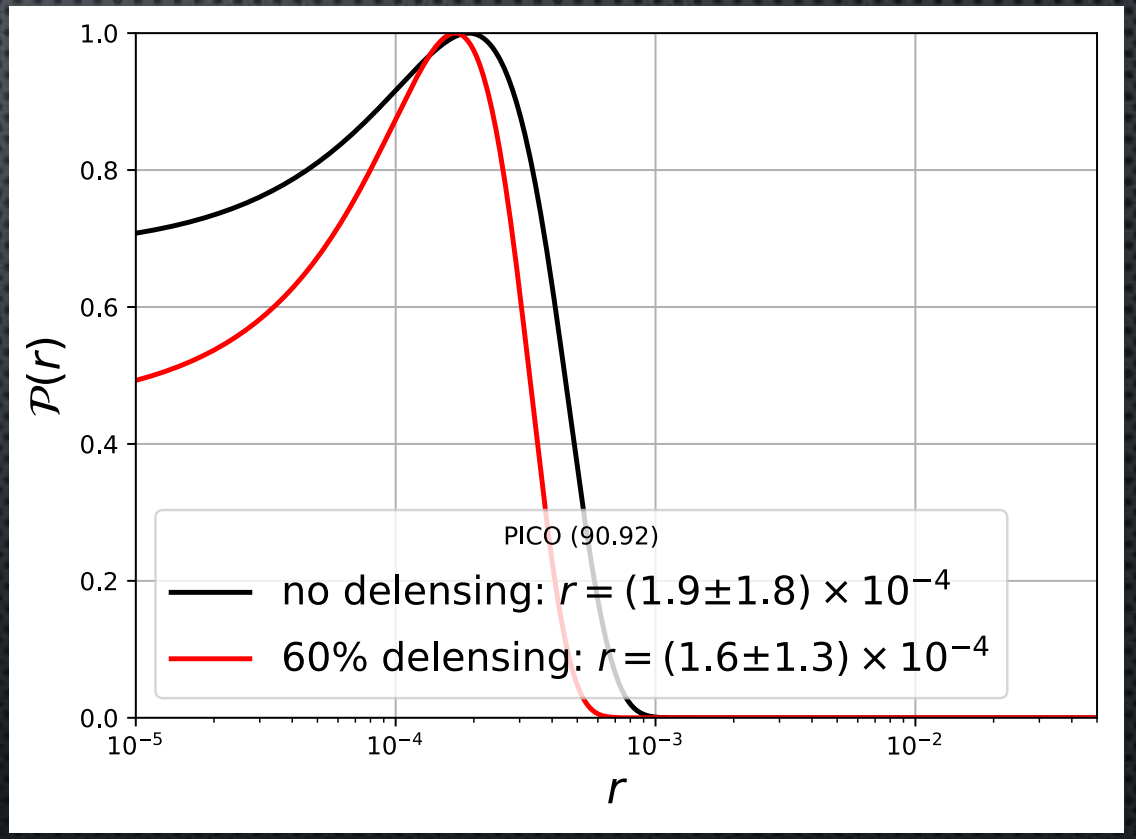


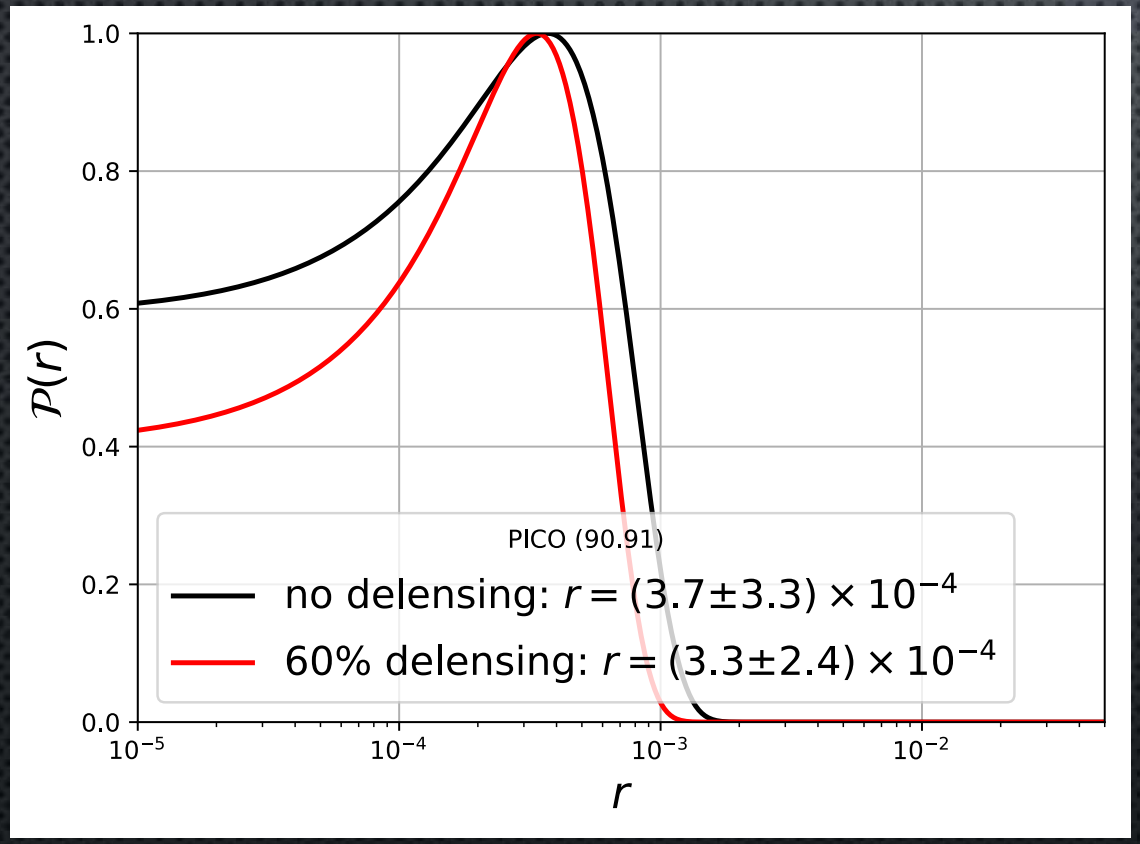
One-sigma bias without low frequencies exceeding the required performance

Without HF
21 - 462 GHz

$r = 0$

NILC

Model 91



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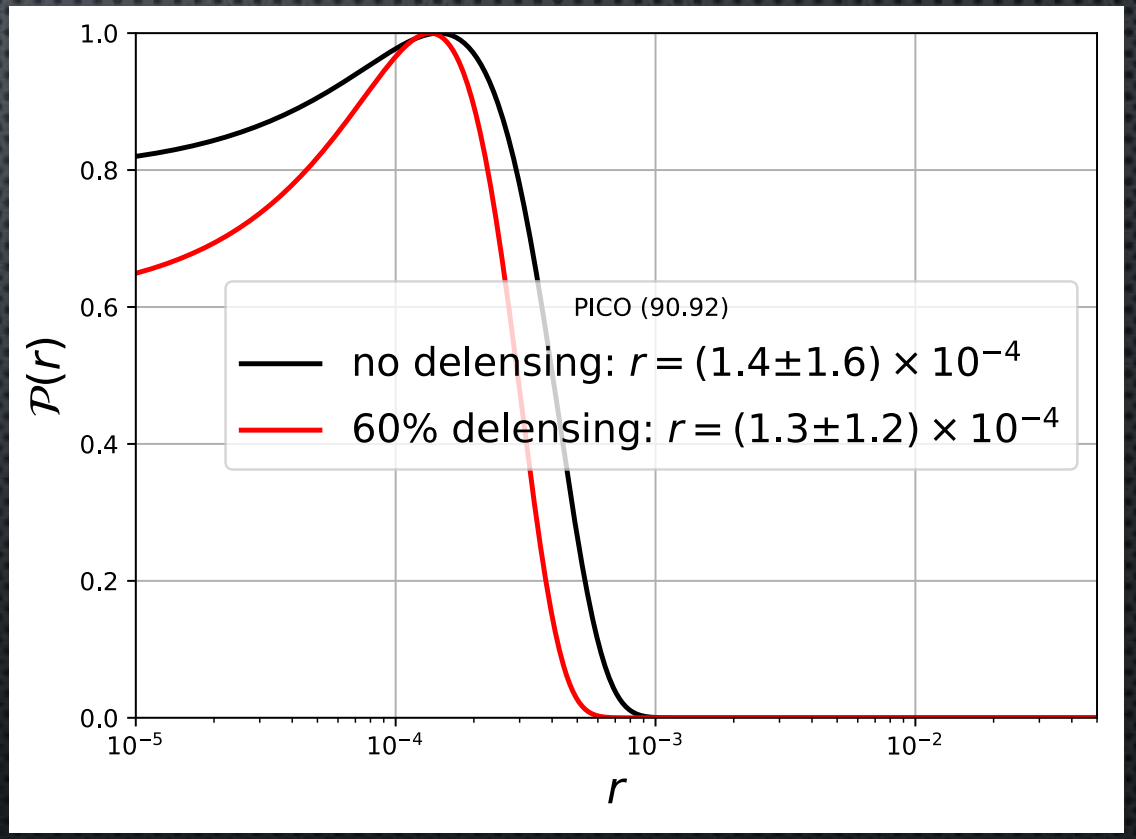


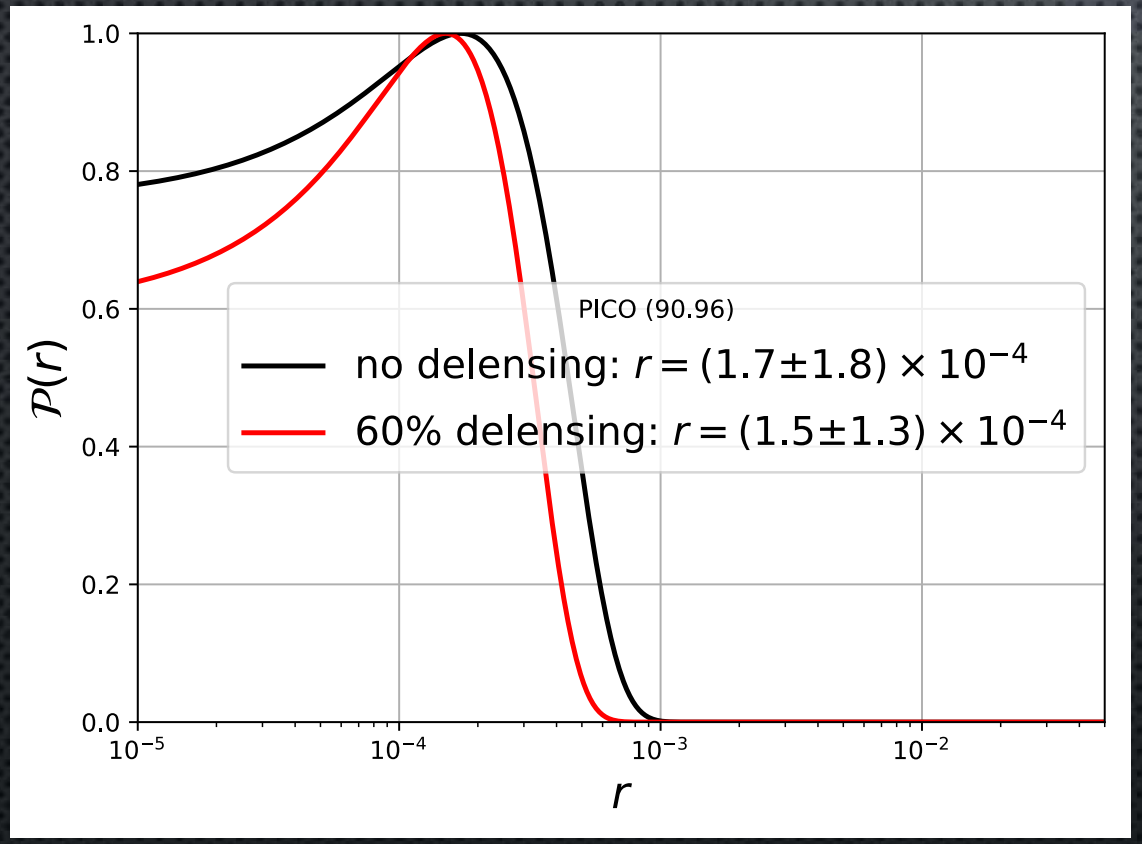
One-sigma bias without high frequencies exceeding the required performance

Baseline
21 - 800 GHz

$r = 0$

NILC

Model 96



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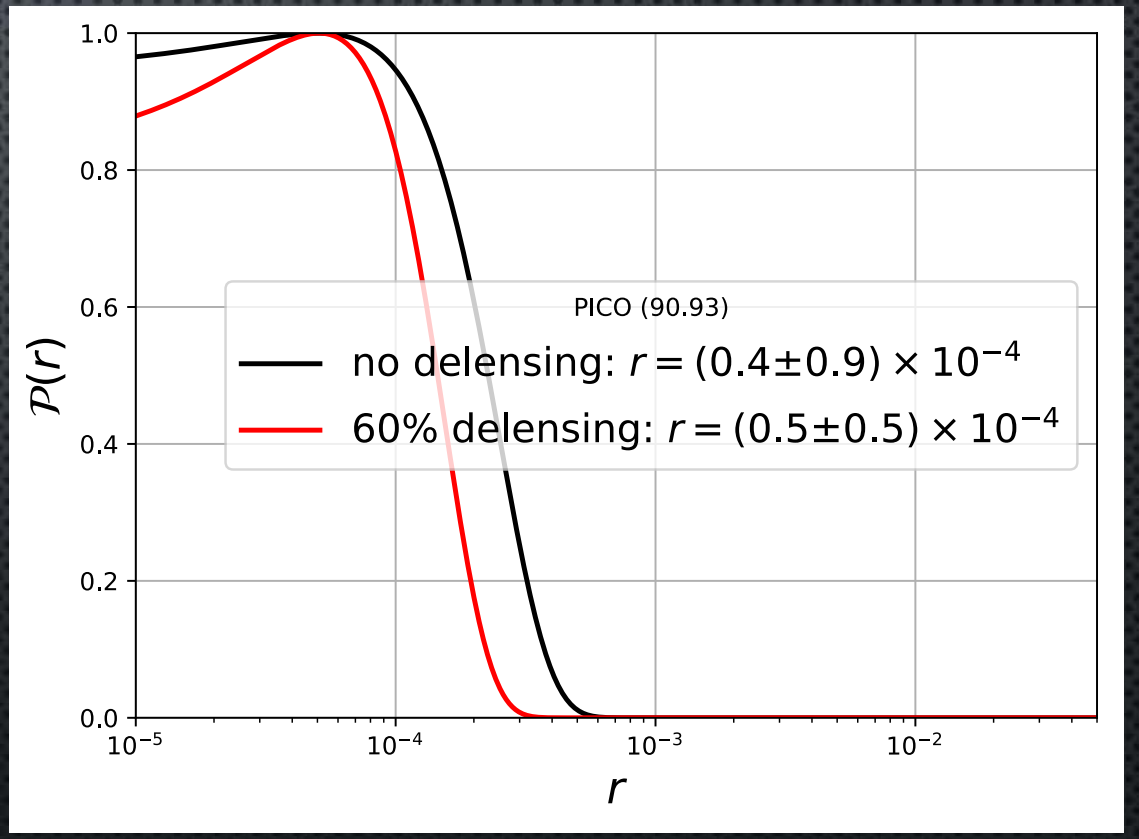

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43 - 800 GHz

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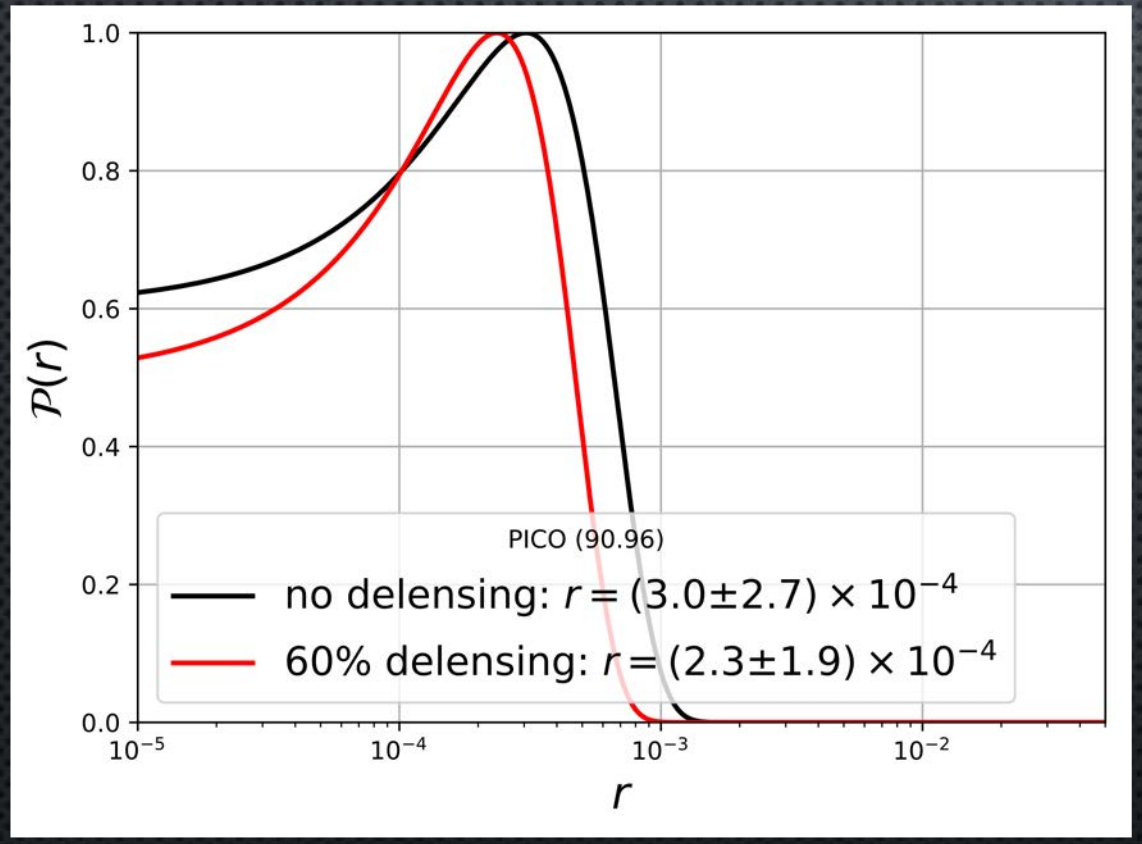

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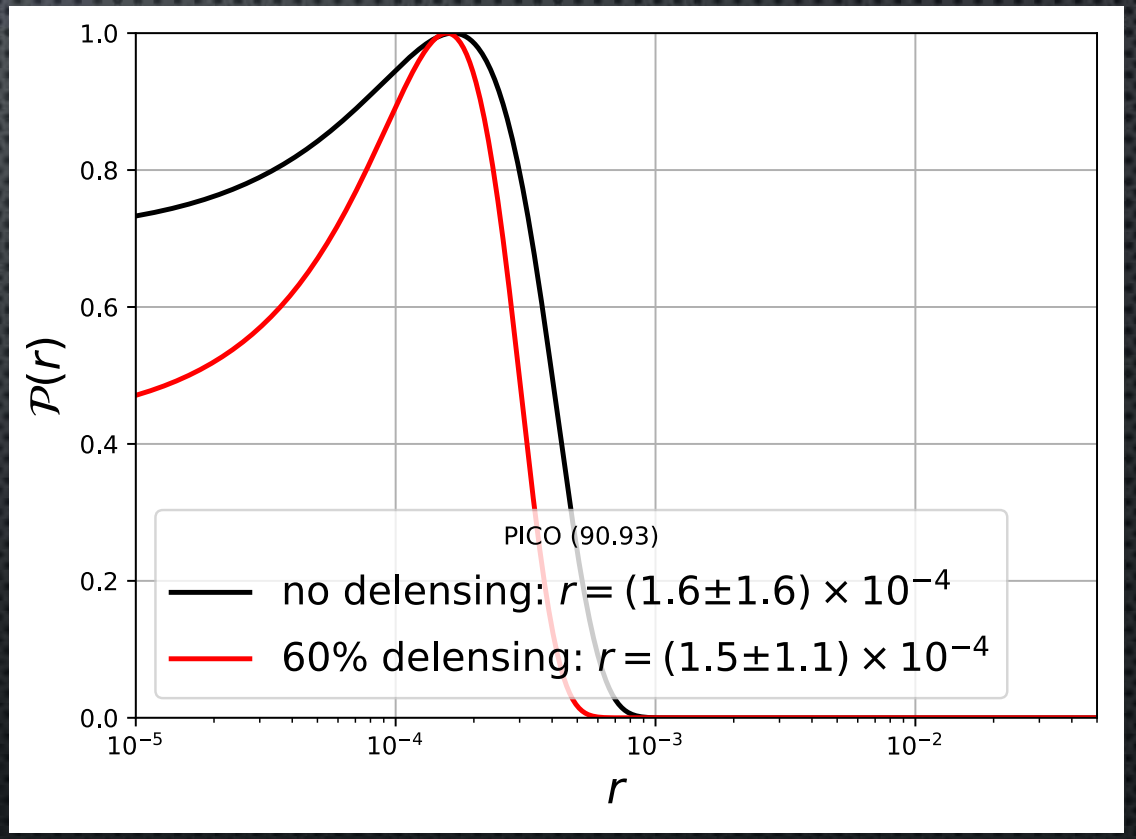


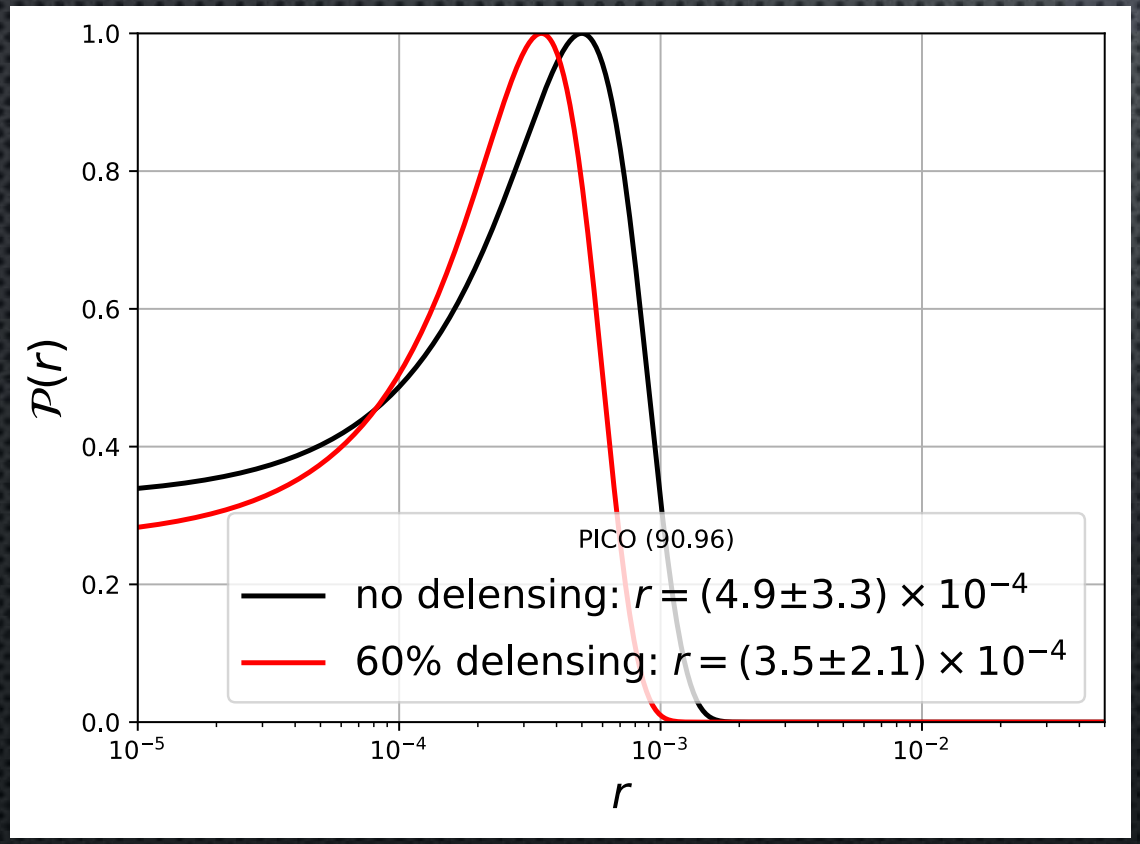
One-sigma bias without high frequencies exceeding the required performance

Without HF
21 - 462 GHz

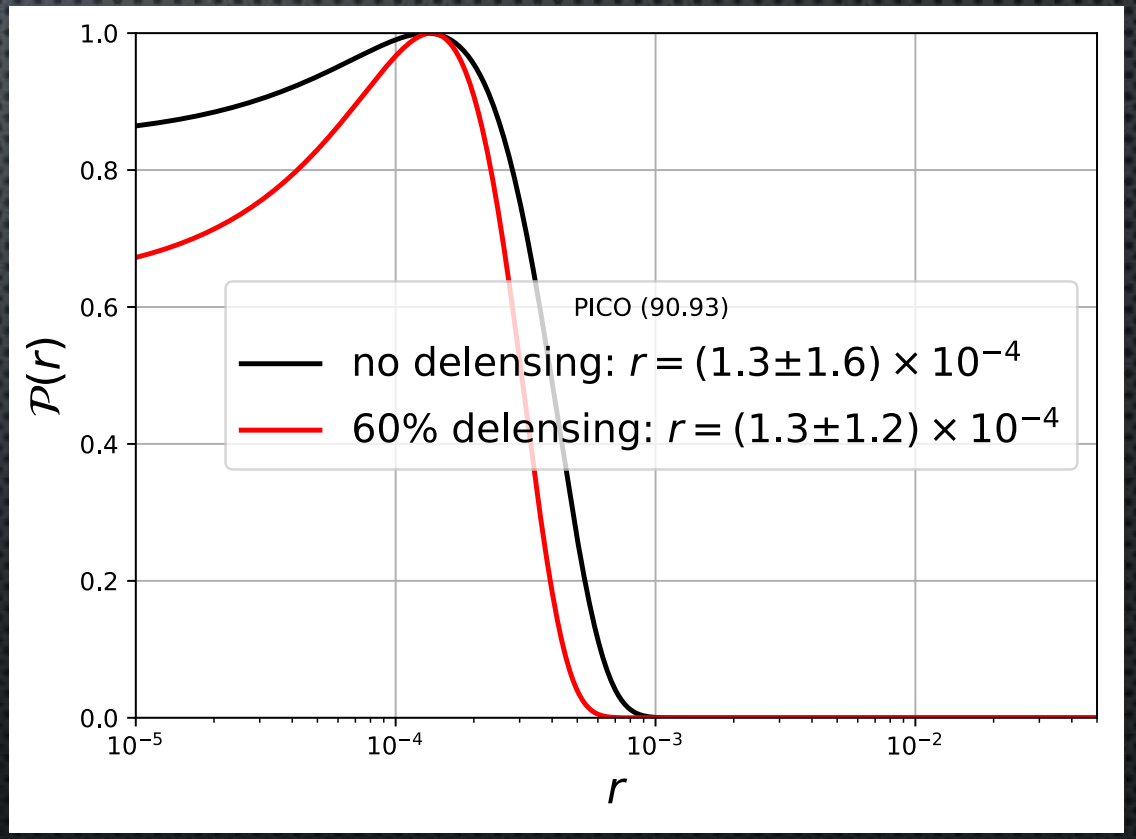
$r = 0$

NILC

Model 96



Model 93



More than one-sigma bias without high frequencies exceeding the required performance

Summary

- PICO allows to control foreground contamination below $r = 5\times10^{-4}$
- Robustness of NILC results irrespective of foreground sky complexity
- Importance of PICO's high/low frequencies to mitigate residual foregrounds

NILC results forthcoming on other foreground skies!

3D multi-layer dust (model 98/MKD)

Next steps (ongoing activities)

- Importance of high frequencies to inform on false detections of r ?
  - → *Break spectral degeneracies over different dust models*
  - → *Provide chi-square evidence for incorrect dust models*
- Importance of low frequencies? Do we need high-resolution at low frequency ?
  - → *Non-gaussian small scales of synchrotron emission may distort baseline SED models at larger angular scale (higher-order moments / effective curvatures)*
- Which of increased number of detectors or extended frequency coverage provides more leverage ?
- Parametric results forthcoming from Commander (Ragnhild Aurlien / Oslo team)

Why PICO, Why Now

- Further progress with CMB requires leaps in sensitivity, foreground characterization, and systematic control.
- PICO is the only instrument with the combination of sky coverage, resolution, frequency bands, and sensitivity to achieve these leaps with one platform.
- Analysis of foreground removal efficacy ongoing.

Figure: R. Flauger

PICO PROBE O AND COS

PICO - community-wide effort + support

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ERSITY OF MINNESOTA

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Diego Herranz [27]
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Johannes Hubmayr [19]
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William Jones [4]
Terry Jones [1]
Lloyd Knox [20]
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Charles Lawrence [6]
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Zack Li [4]
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Jean-Baptiste Melin [12]
Joel Meyers [44]
Calum Murray [5]
Matías Negrello [45]
Giles Novak [46]
Roger O'Brient [6,8]
Christopher Paine [6]
Tim Pearson [8]
Levon Pogosian [47]
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Mathieu Remazeilles [33]
Graca Rocha [6,8]
Marcel Schmittfull [18]
Douglas Scott [50]
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Ian Stephens [51]
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Dark M
Relativistic Species
Cluster Evolution
Interstellar Dust
Cosmic Birefringence
Evo
Quantum Gravity
Dark Energy

https://z.umn.edu/picomission

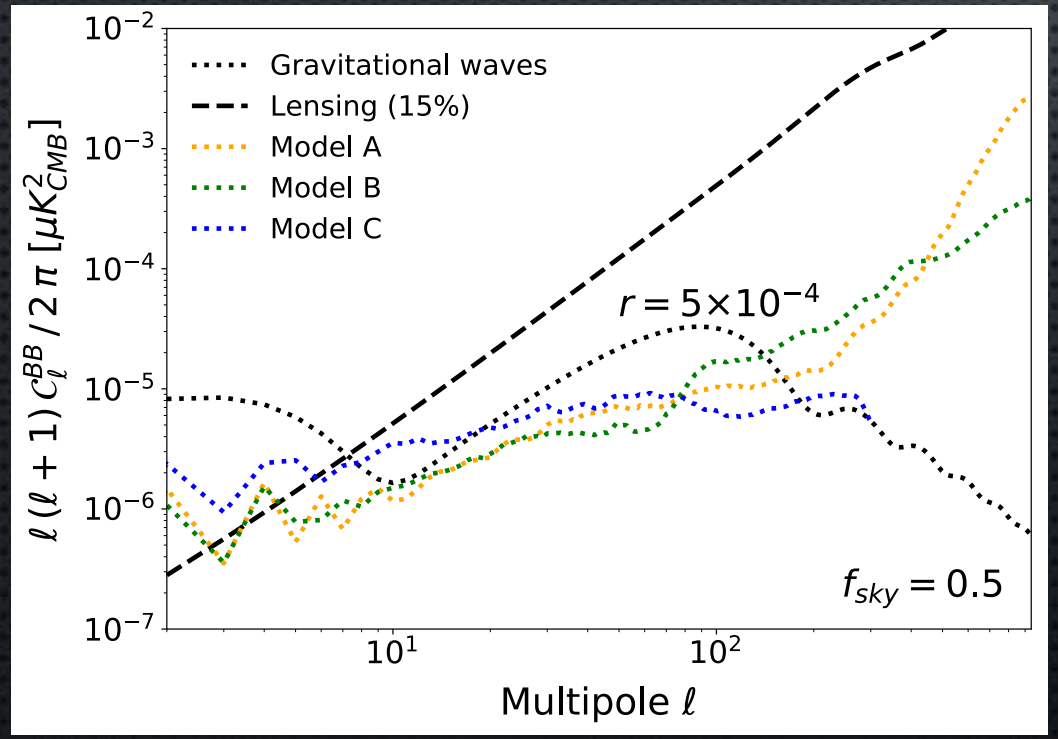
Hanany et al. arXiv 1902.10541; 1908.07495

Backup

Two years ago…

Probe class mission study submitted to NASA and Astro2020 Decadal Panel

arXiv:1902.10541



GNILC

- Foreground residuals controlled below $r = 5\times10^{-4}$ over the whole range of multipoles $2 \leq \ell \leq 200$
- Irrespective of the complexity of the foregrounds:

Two dust MBBs (model A/92) ; Non-MBB physical dust (model B/93) ; MHD with line-of-sight MBBs (model C/96)