Forecasts on foreground removal and CMB B-mode recovery with PICO

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PICO Foregrounds Working Group:

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Inflation Probe Minisymposium
American Physical Society
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Shaul Hanany

PICO in Brief

arXiv:1902.10541

- Millimeter/submillimeter-wave, polarimetric survey of the entire sky
- 21 bands between 20 GHz and 800 GHz
- 1.4 m aperture telescope
- Diffraction limited resolution: 38' to 1'
- 13,000 transition edge sensor bolometers
- 5 year survey from L2
- 0.87 uK*arcmin requirement; 0.61 uK*arcmin goal (=CBE)

https://z.umn.edu/cmbprobe

cmbprobe@lists.physics.umn.edu

PICO in brief

- 3 × more frequency bands than *Planck* for polarization channels
- Extends *Planck* frequency range by more than a factor of 2
- 5 frequency bands above *Planck* 353 GHz channel for dust polarization
- 60 × *Planck* sensitivity: 3300 *Planck* missions

PICO data challenge: public sky map simulations

https://zzz.physics.umn.edu/ipsig/20180424_dc_maps

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

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20180424_dc_maps

Data Challenge Maps I

Apr 24 2018, Clem Pryke

For CMB-S4 project we have made simulations using a number of different foreground models plus lensed-LCDM, noise and tensors. These are described at Data challenge summary page and in a series of logbook postings.

I have exploited this work for PICO to make equivalent sims.

Everything below is available on NERSC under /project/projectdirs/pico/

I first made PySM input maps for the PICO band centers as listed in the v3.2 spreadsheet at imageroptions. I did this for delta function bandwidths to keep things simple. Everything is nside=512.

Under sky_yy we have the sky models where yy designates the sky model number:

- 91=PySM a1d1f1s1
- 92=PySM a2d4f1s3
- 93=PySM a2d7f1s3
- 96=Brandon's MHD model taken from /global/homes/b/bhensley/mhd_maps/maps_v1 on 180424
- cmb = links to the cl's and alm's from which the LCDM component are generated (shared with Plank ffp10 sims)

Under expt_xx we just have single file 90/params.dat which specifies the instrument parameters for this round as taken from the v3.2 spreadsheet.

Under data_xx.yy we have the sets of simulated experimental maps. 90.00 contains the lensed-LCDM (llcdm), noise (noise) and tensor (tenso) components for each band. Noise levels are also as per the v3.2 spreadsheet. The signal components have beam smoothing applied with beam widths as per the v3.2 spreadsheet. There are also combined lLCDM+noise+foreground+tensor maps (comb). These come as four flavors. Straight "comb" has full lensing signal. The "comb_AL" variants have the lensing signal artificially suppressed to the given levels of lensing power. So "comb_AL0p15" is the amount of lensing PICO is supposed to have post de-lensing. "comb_AL0p1" and "comb_AL0p03" are also provided and might be useful.

Band#	nu (GHz)	nu_low (GHz)	nu_high (GHz)	del nu (GHz)	FWHM (arcmin)	PolWeight (uK*arcmin)
1	21	18.2	23.4	5.2	38.4	16.9
2	25	21.9	28.1	6.3	32.0	11.8
3	30	26.3	33.8	7.5	28.3	8.1
4	36.0	31.5	40.5	9.0	23.6	5.7
5	43.2	37.8	48.6	10.8	22.2	5.8
6	51.8	45.4	58.3	13.0	18.4	4.1
7	62.2	54.4	70.0	15.6	12.8	3.8
8	74.6	65.3	84.0	18.7	10.7	2.9
9	89.6	78.4	100.8	22.4	9.5	2.0
10	107.5	94.1	120.9	26.9	7.9	1.6
11	129.0	112.9	145.1	32.3	7.4	1.6
12	154.8	135.4	174.1	38.7	6.2	1.3
13	185.8	162.5	209.0	46.5	4.3	2.6
14	222.9	195.0	250.8	55.7	3.6	3.0
15	267.5	234.0	300.9	66.9	3.2	2.1
16	321.0	280.9	361.1	80.3	2.6	2.9
17	385.2	337.0	433.3	96.3	2.5	3.5
18	462.2	404.4	520.0	115.6	2.1	7.4
19	554.7	485.3	624.0	138.7	1.5	34.6
20	665.6	582.4	748.8	166.4	1.3	143.7
21	798.7	698.9	898.5	199.7	1.1	896.4

PICO data challenge: public sky map simulations

https://zzz.physics.umn.edu/ipsig/20180424_dc_maps

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

Model 91: ***Planck*** **state-of-the-art**

`PySM a1d1s1`

- dust: one modified blackbody with variable β, T
- synchrotron: power-law with variable β

Model 92: **Finkbeiner, Davis, Schlegel, ApJ 1999**

`PySM a2d4s3`

- dust: two modified blackbodies with uniform β_1, β_2 and variable T_1, T_2
- synchrotron: power-law + curvature with variable β
- AME: 2% polarization

Model 93: **Hensley's PhD 2015**

`PySM a2d7s3`

- dust: Hensley & Draine physical model
- synchrotron: power-law + curvature with variable β
- AME: 2% polarization

Model 96: **MHD simulation**

- dust & synchrotron derived from MHD simulation
- multiple modified blackbodies along the line-of-sight (decorrelation)

Two independent component separation methods

- COMMANDER (parametric)

  Joint Bayesian fitting of CMB and foregrounds with Gibbs sampling

$$\begin{cases} s_{\mathrm{CMB}}^{(i+1)} \leftarrow P\left(s_{\mathrm{CMB}} \middle| C_\ell^{(i)}, \beta^{(i)}, d\right) \\ C_\ell^{(i+1)} \leftarrow P\left(C_\ell \middle| s_{\mathrm{CMB}}^{(i)}\right) \\ \beta^{(i+1)} \leftarrow P\left(\beta \middle| s_{\mathrm{CMB}}^{(i+1)}, d\right) \end{cases}$$

- NILC (blind)

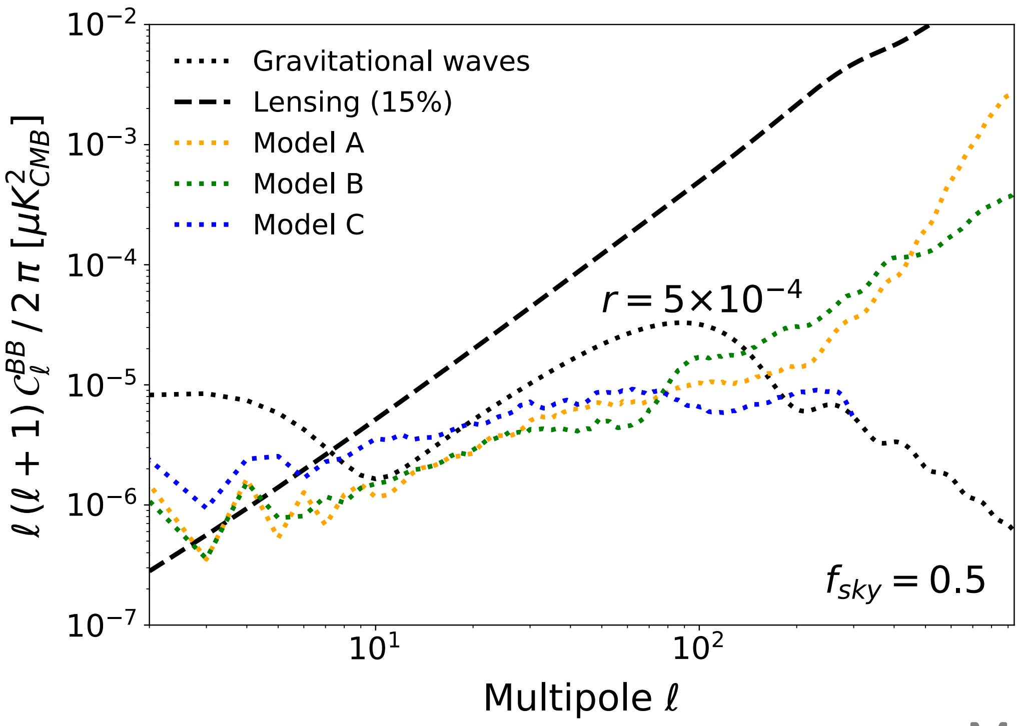
  Blind minimum-variance ILC projection in needlet space

$$s_{\mathrm{CMB}} = \left(a^{\mathrm{t}} \mathrm{C}^{-1} a\right)^{-1} a^{\mathrm{t}} \mathrm{C}^{-1} d$$

Two years ago…

Probe class mission study submitted to NASA and Astro2020 Decadal Panel

arXiv:1902.10541



(G)NILC

- Foreground residuals controlled below $r = 5{\times}10^{-4}$ over the whole range of multipoles $2 \le \ell \le 200$
- Irrespective of the complexity of the foregrounds *Two dust MBBs (model A), non-MBB physical dust (model B), MHD with line-of-sight MBBs (model C)*

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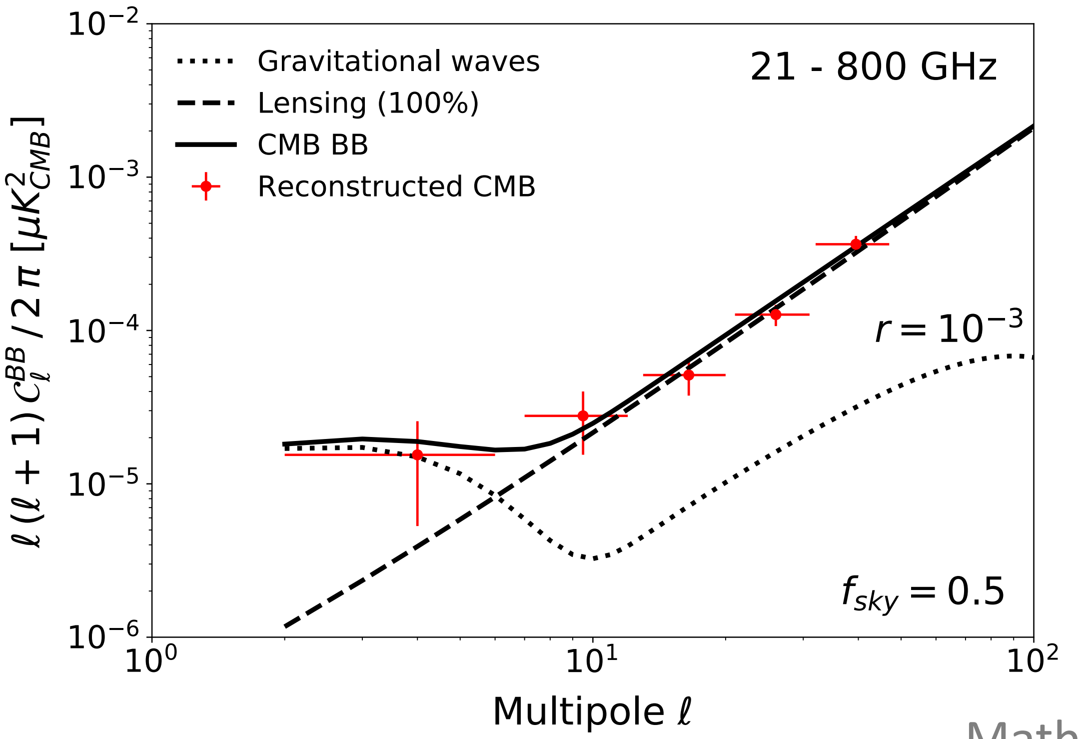
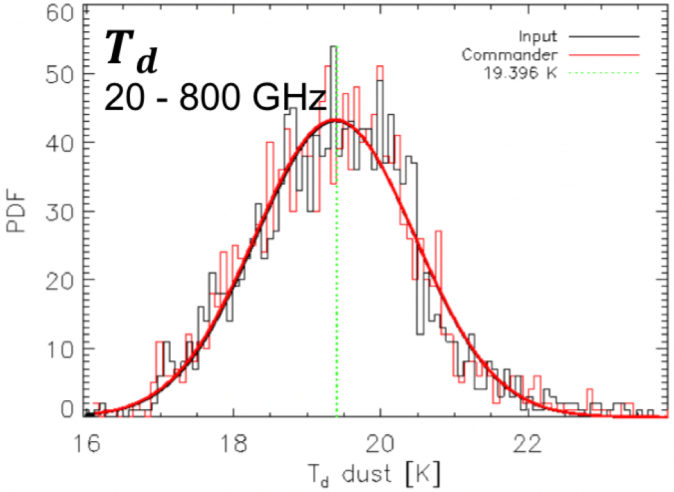


COMMANDER (21 - 800 GHz)



Recovered distribution of dust temperature

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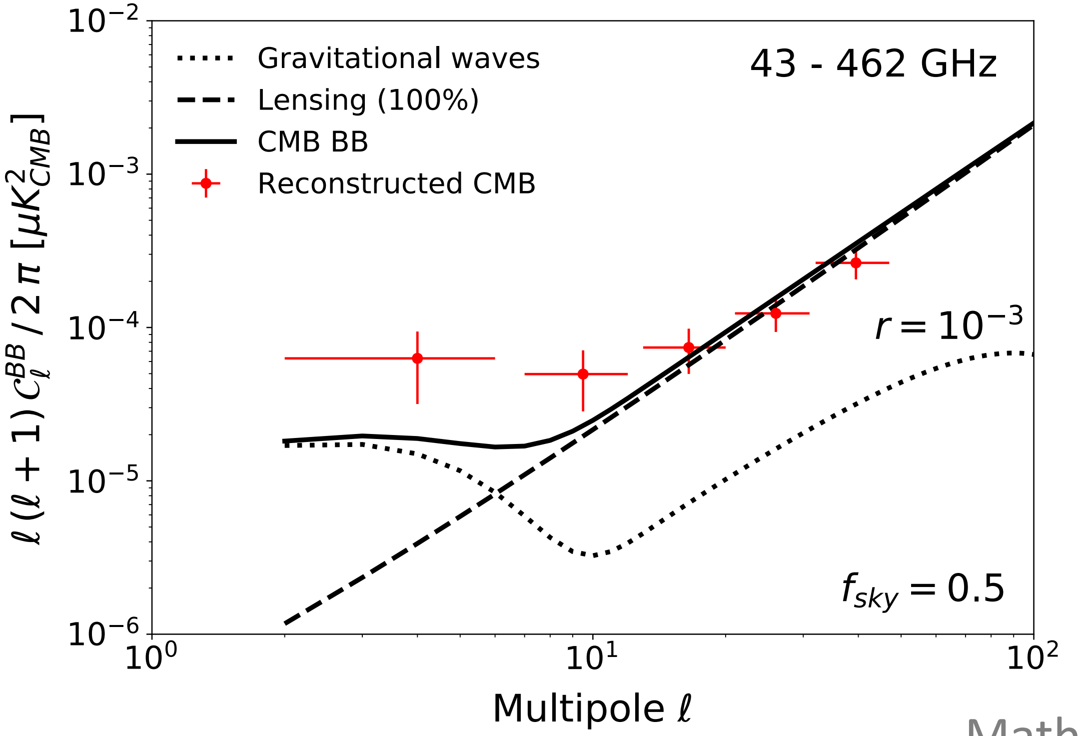
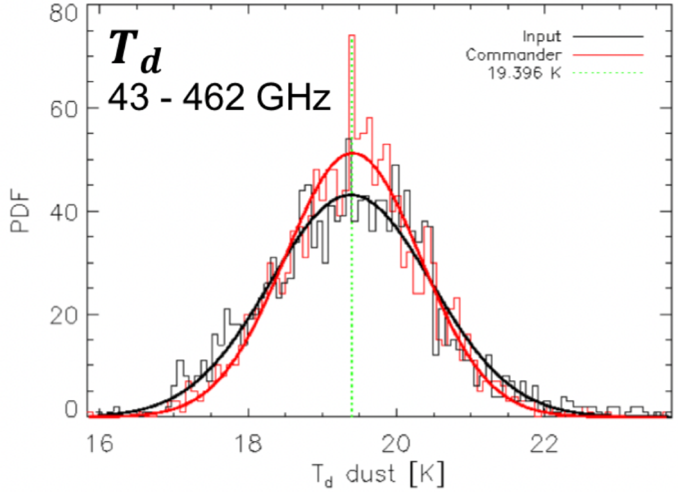


COMMANDER
(43 - 462 GHz)



Recovered distribution of dust temperature

Mathieu Remazeilles

Today

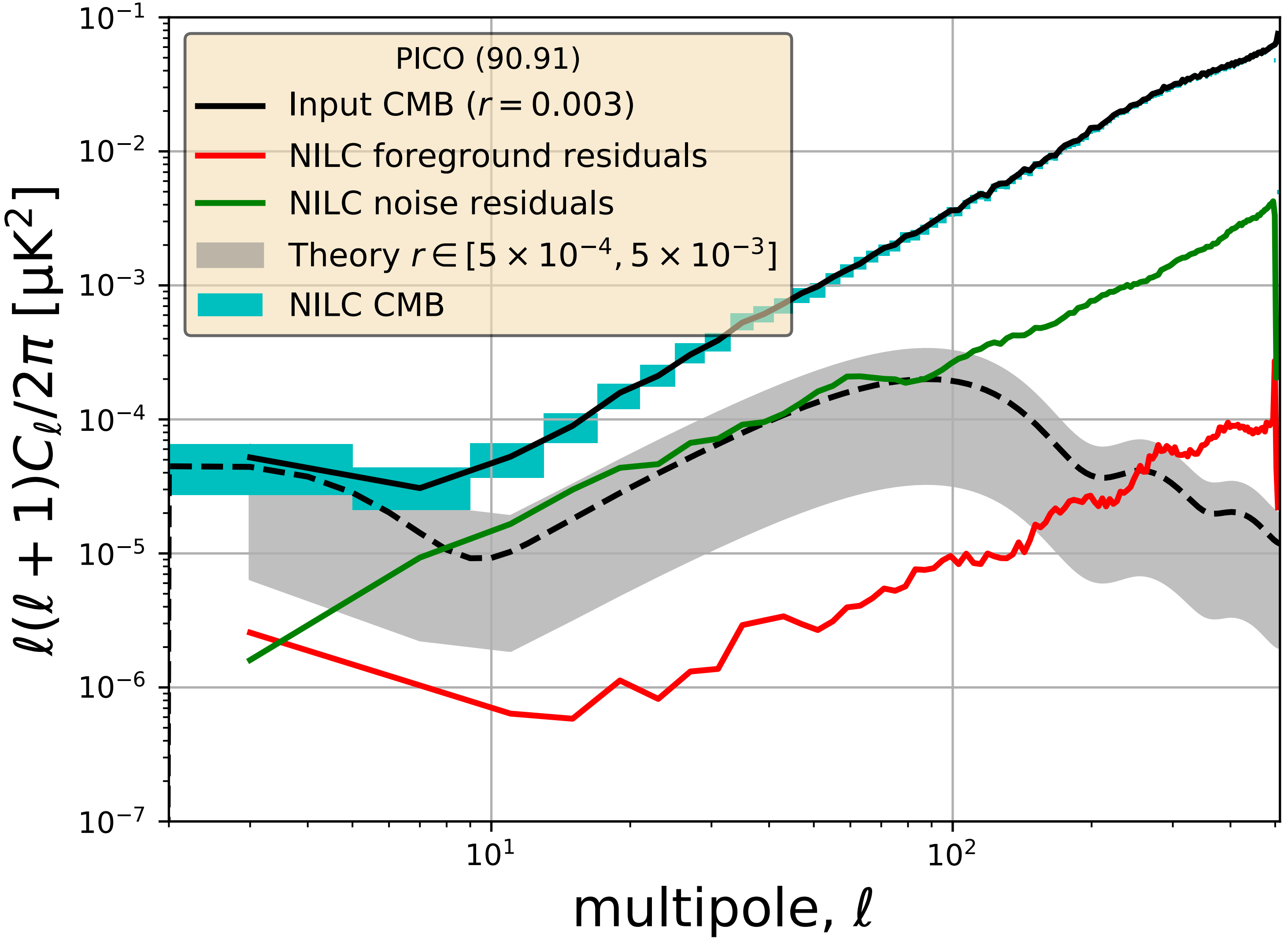
PICO follow-up activities on foregrounds

- Results from NILC by Mathieu Remazeilles: today's focus
- Results from COMMANDER by Ragnhild Aurlien: forthcoming

$$r = 0.003$$

Model 91, $r = 0.003$

NILC



10 realizations

MASTER

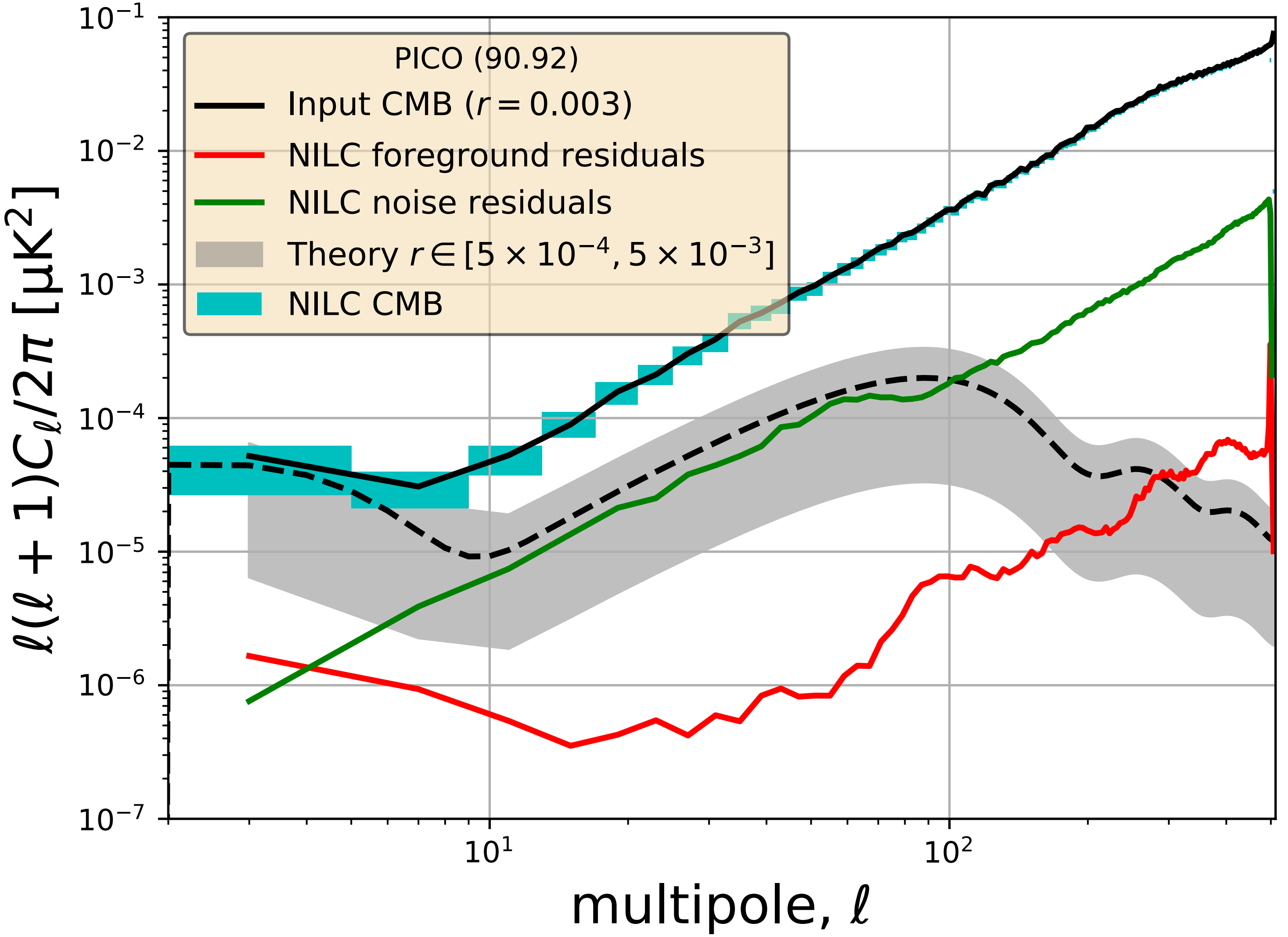
$f_{\text{sky}} = 50\%$

Binning: $\Delta\ell = 4$

Mathieu Remazeilles

Model 92, $r = 0.003$

NILC



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Mathieu Remazeilles

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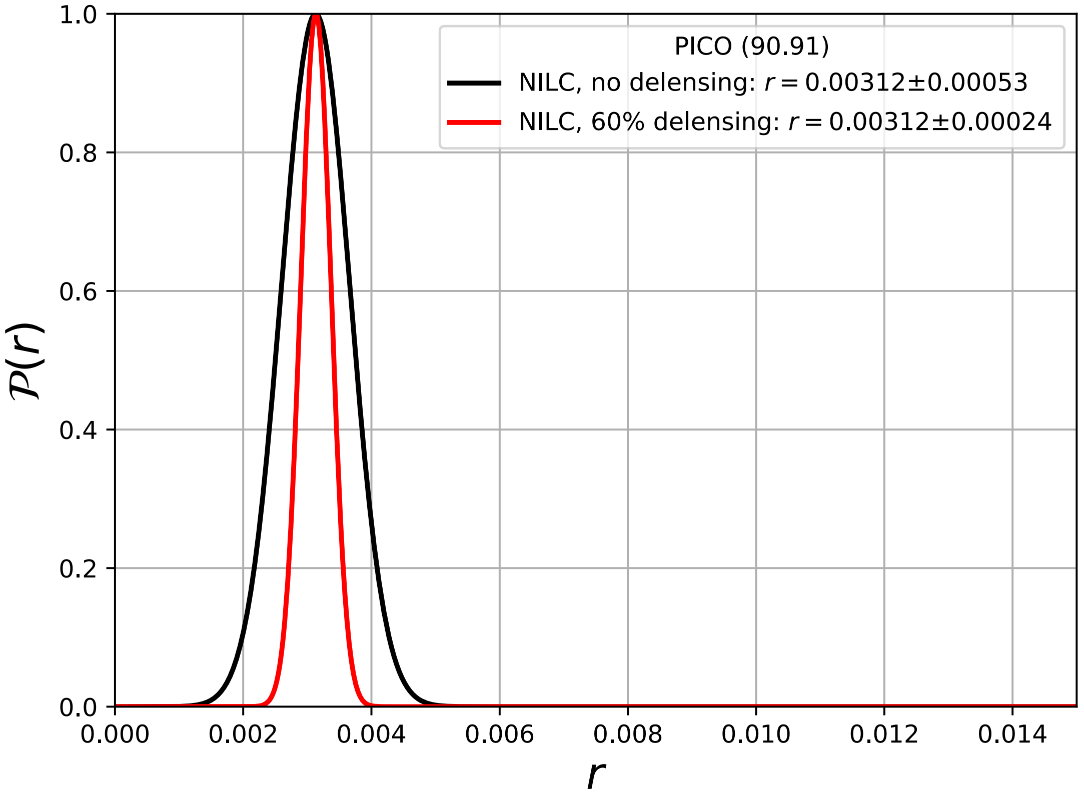
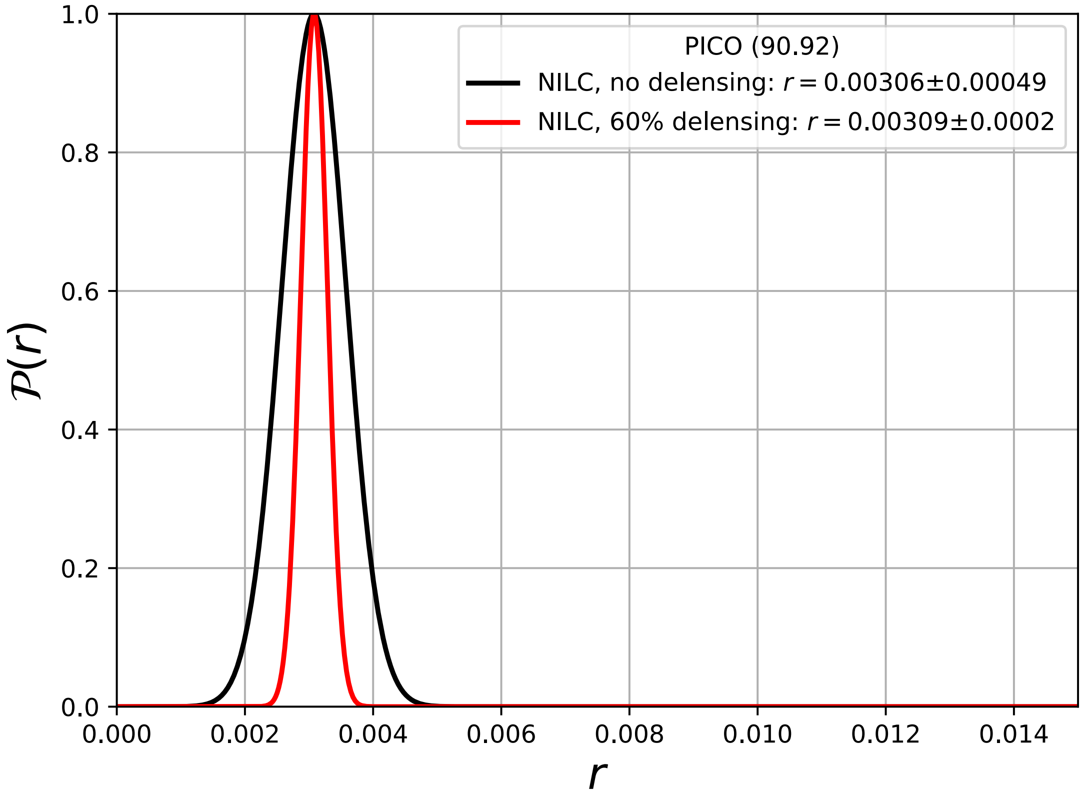
NILC

Model 91



Model 92



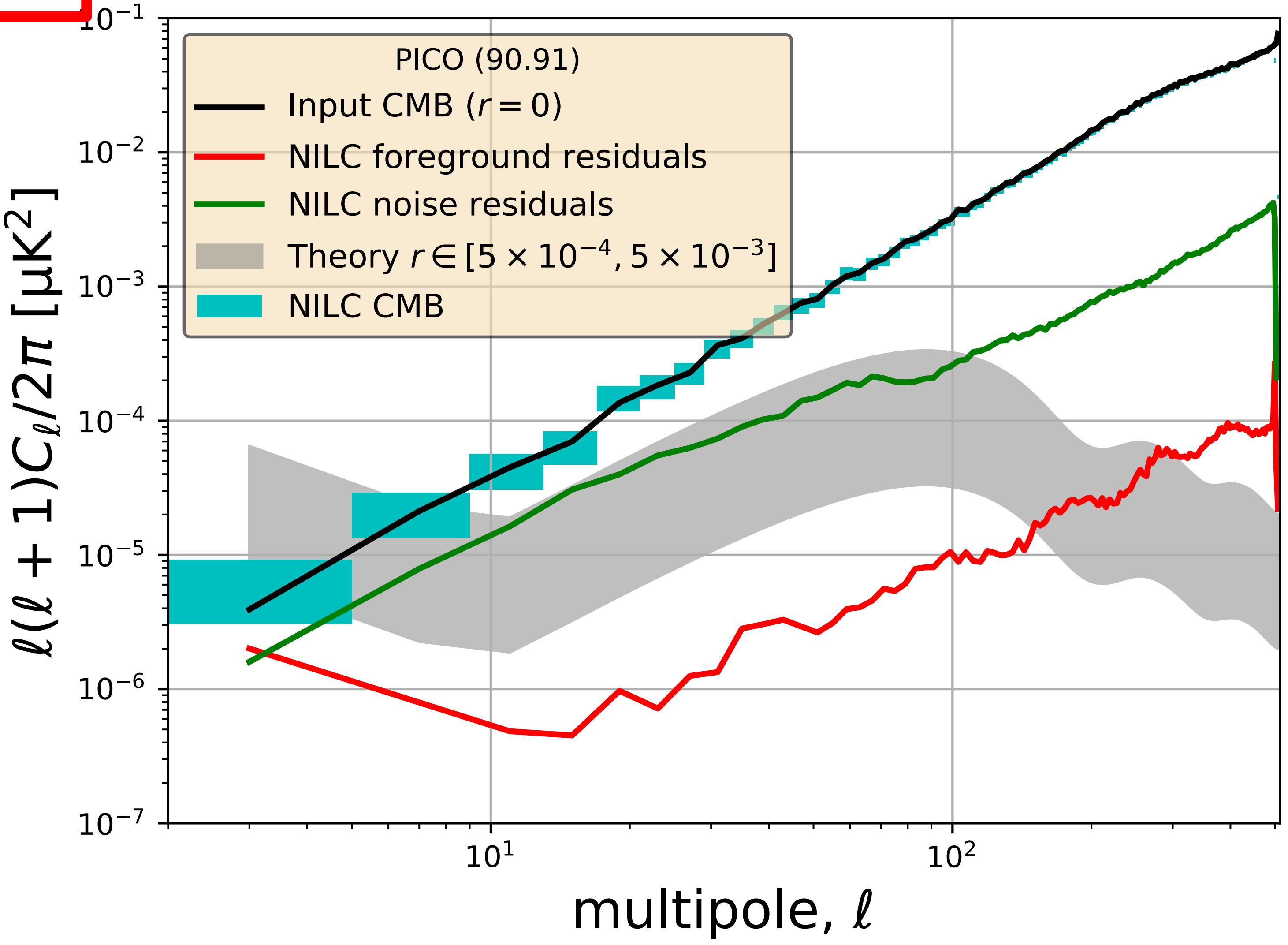
Robust recovery of the tensor-to-scalar ratio irrespective of the foregrounds complexity

$$r = 0$$

Baseline
21-800 GHz

Model 91, $r = 0$

NILC



10 realizations

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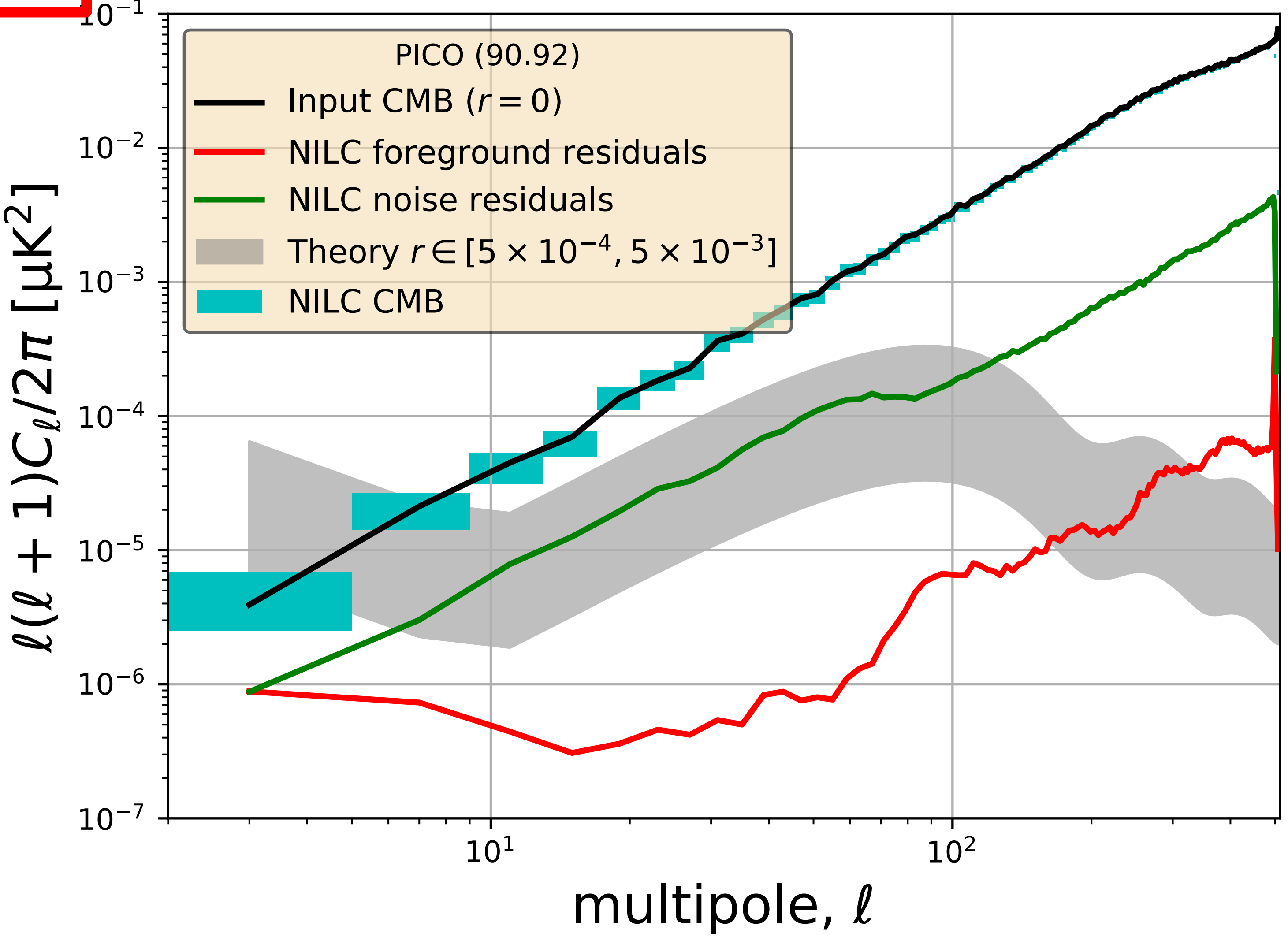
Mathieu Remazeilles

Baseline
21-800 GHz

Model 92, $r = 0$

NILC



10 realizations

MASTER

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

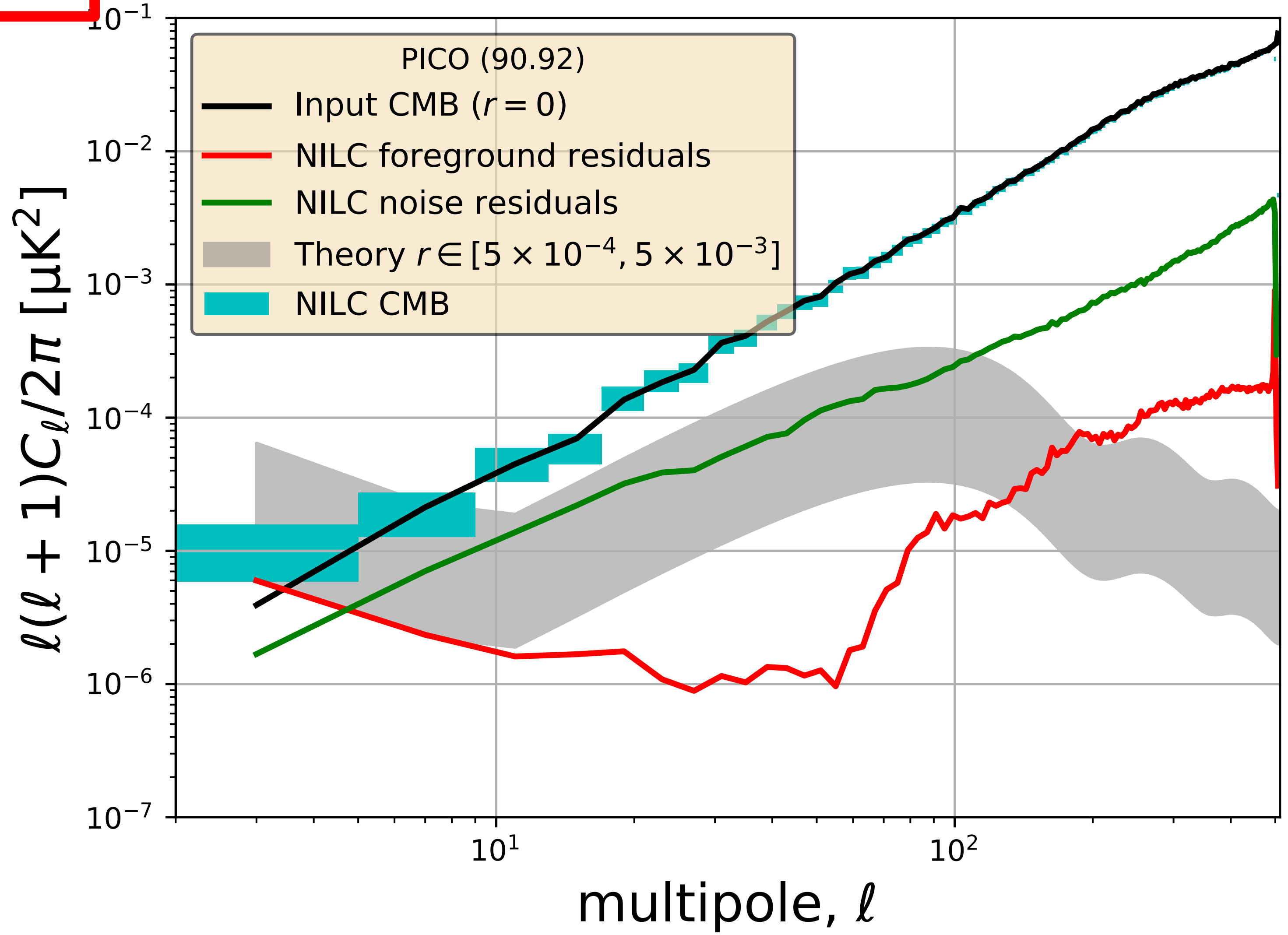
Binning: $\Delta\ell = 4$

Mathieu Remazeilles

Descope
43-462 GHz

Model 92, $r = 0$

NILC



10 realizations

MASTER

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

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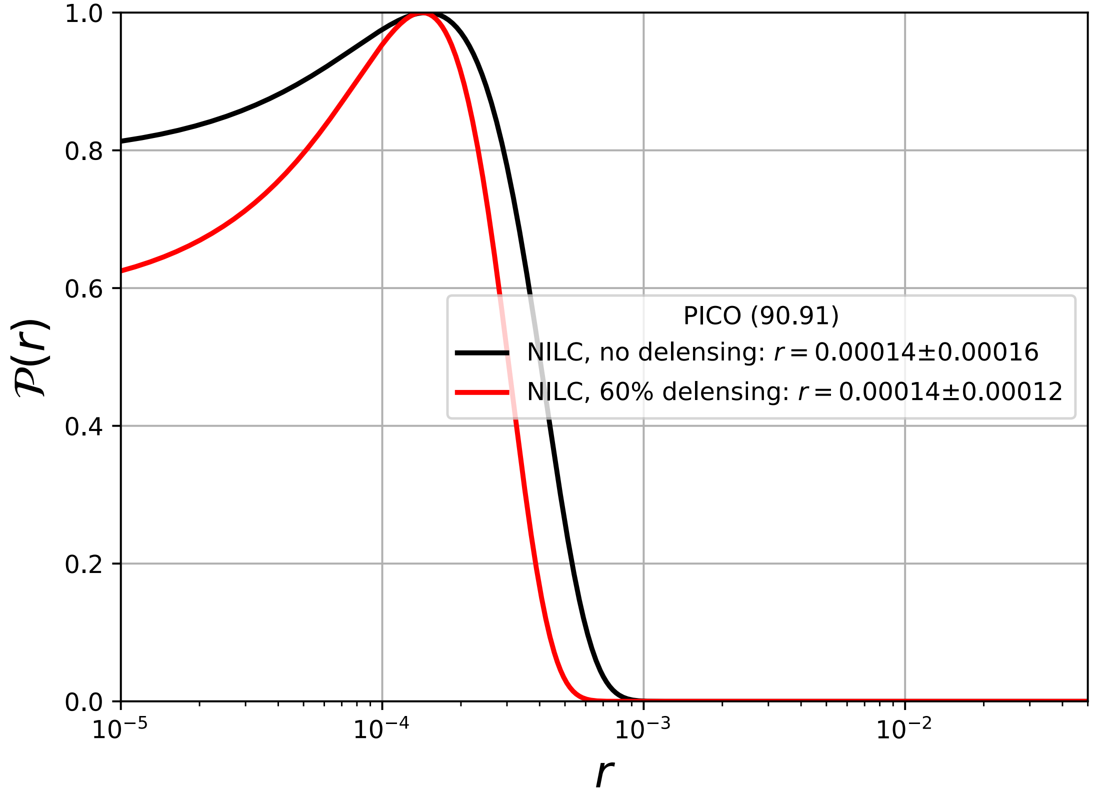
Mathieu Remazeilles

Baseline
21-800 GHz

Model 91, $r = 0$

NILC

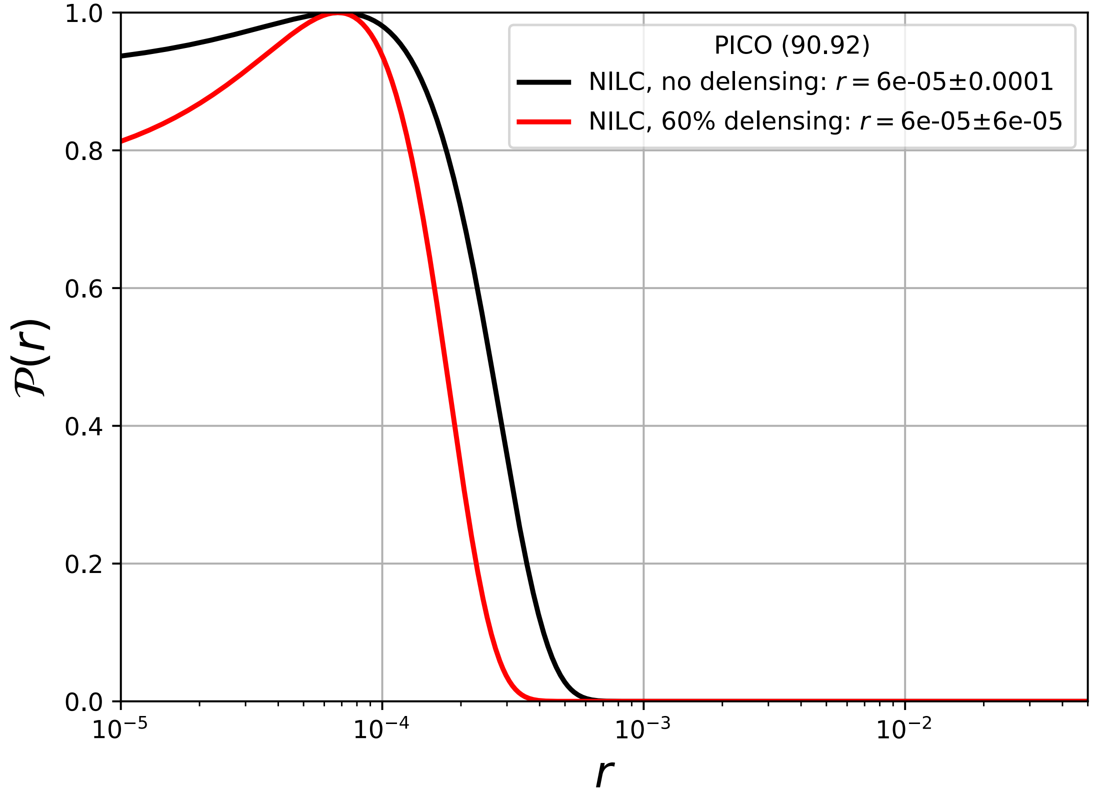


Unbiased estimation of the tensor-to-scalar ratio consistent with $r = 0$

Baseline
21-800 GHz

Model 92, $r = 0$

NILC

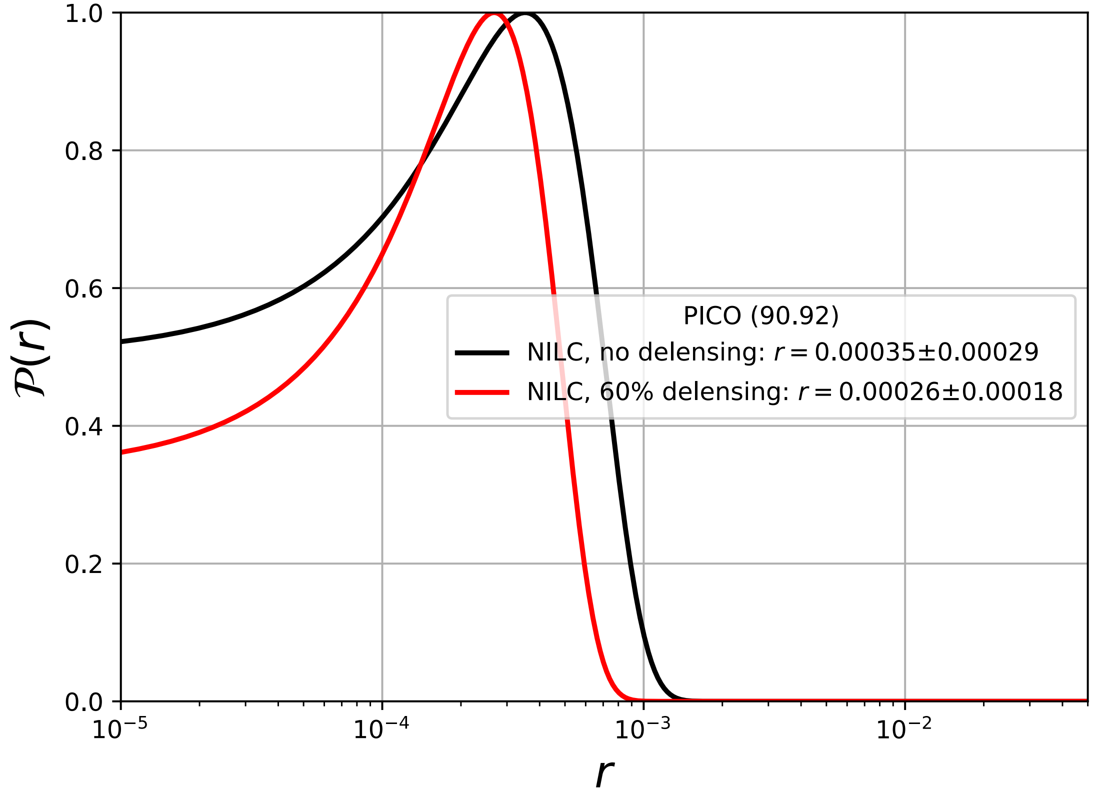


Unbiased estimation of the tensor-to-scalar ratio consistent with $r = 0$

Descope
43-462 GHz

Model 92, $r = 0$

NILC



Discarding low / high frequencies tends to bias the tensor-to-scalar ratio by more than one sigma

Summary

- PICO allows to control foreground contamination below $r = 5{\times}10^{-4}$
- Robustness of PICO results irrespective of different foreground skies
- Importance of PICO high frequencies to help foreground cleaning

Next steps (ongoing activities)

- Importance of PICO high frequencies to inform on dust mismodelling and false detection of r ?

  Breaking foreground model degeneracies
  Chi-square evidence for mismodelling

- Need for high-resolution synchrotron observations at low frequency ?

  Non-gaussian small-scale fluctuations of synchrotron may distort spectral models at large angular scales (higher-order moments / effective curvature)

- Results forthcoming from COMMANDER by Ragnhild Aurlien and the Oslo team!