An updated and improved thermal SZ *y*-map from *Planck* PR4 data

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mmUniverse 2023, Grenoble

Chandran, Remazeilles and Barreiro (arXiv:2305.10193)

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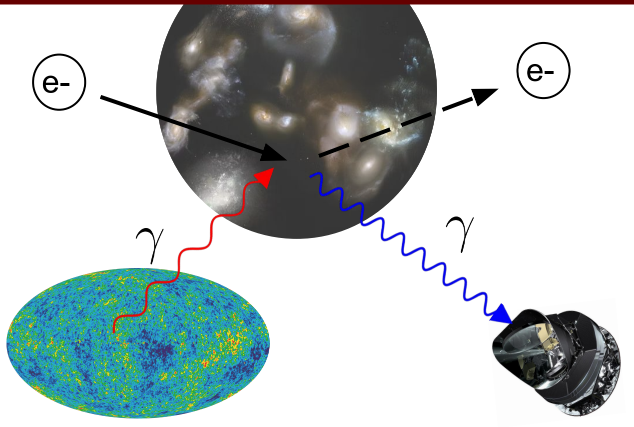
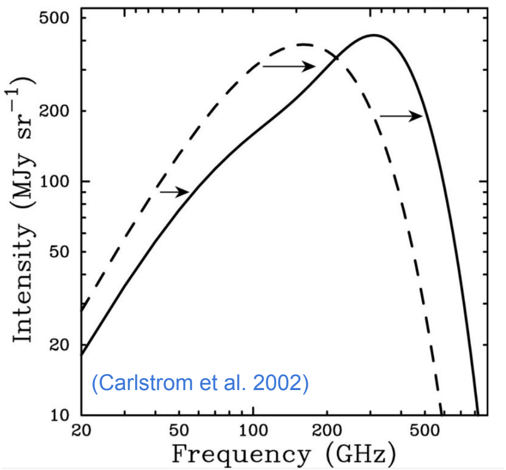
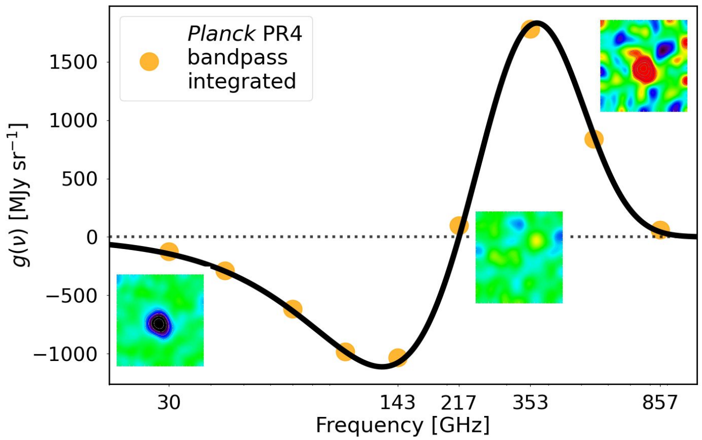
Consejo Superior de Investigaciones Científicas
Universidad de Cantabria

Thermal Sunyaev-Zeldovich (tSZ) Effect



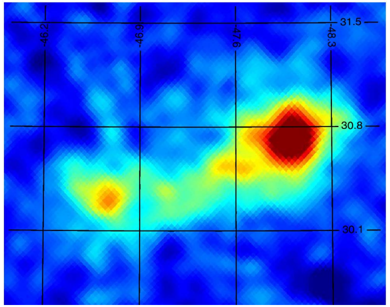




Compton scattering of CMB photons by hot e$^-$ gas in galaxy clusters and IGM (traced by **Compton *y*-parameter**)

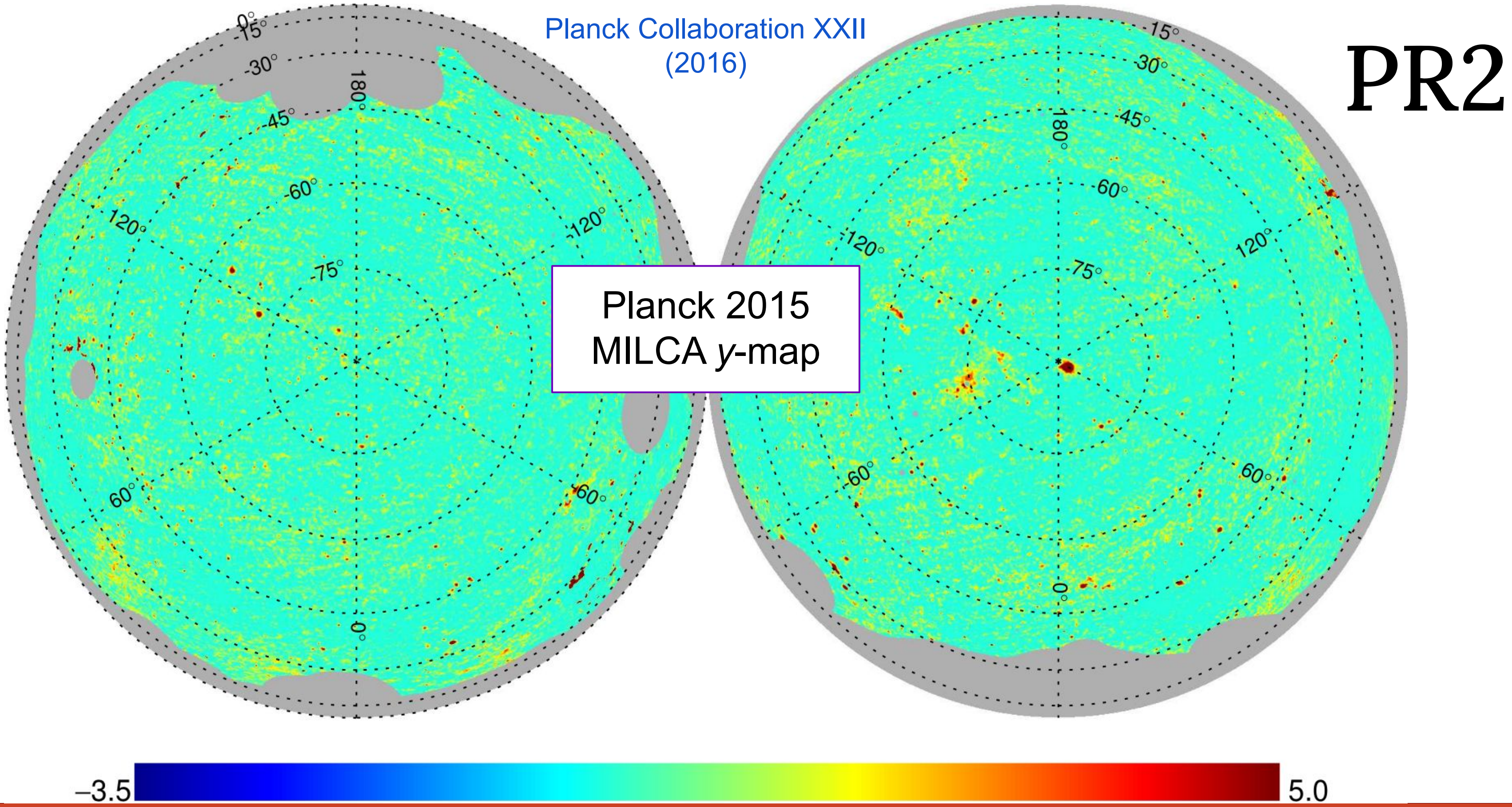
Average shift to higher frequencies causes a **spectral distortion of CMB blackbody spectrum**

Planck frequencies have been designed to trace **frequency dependence** of tSZ

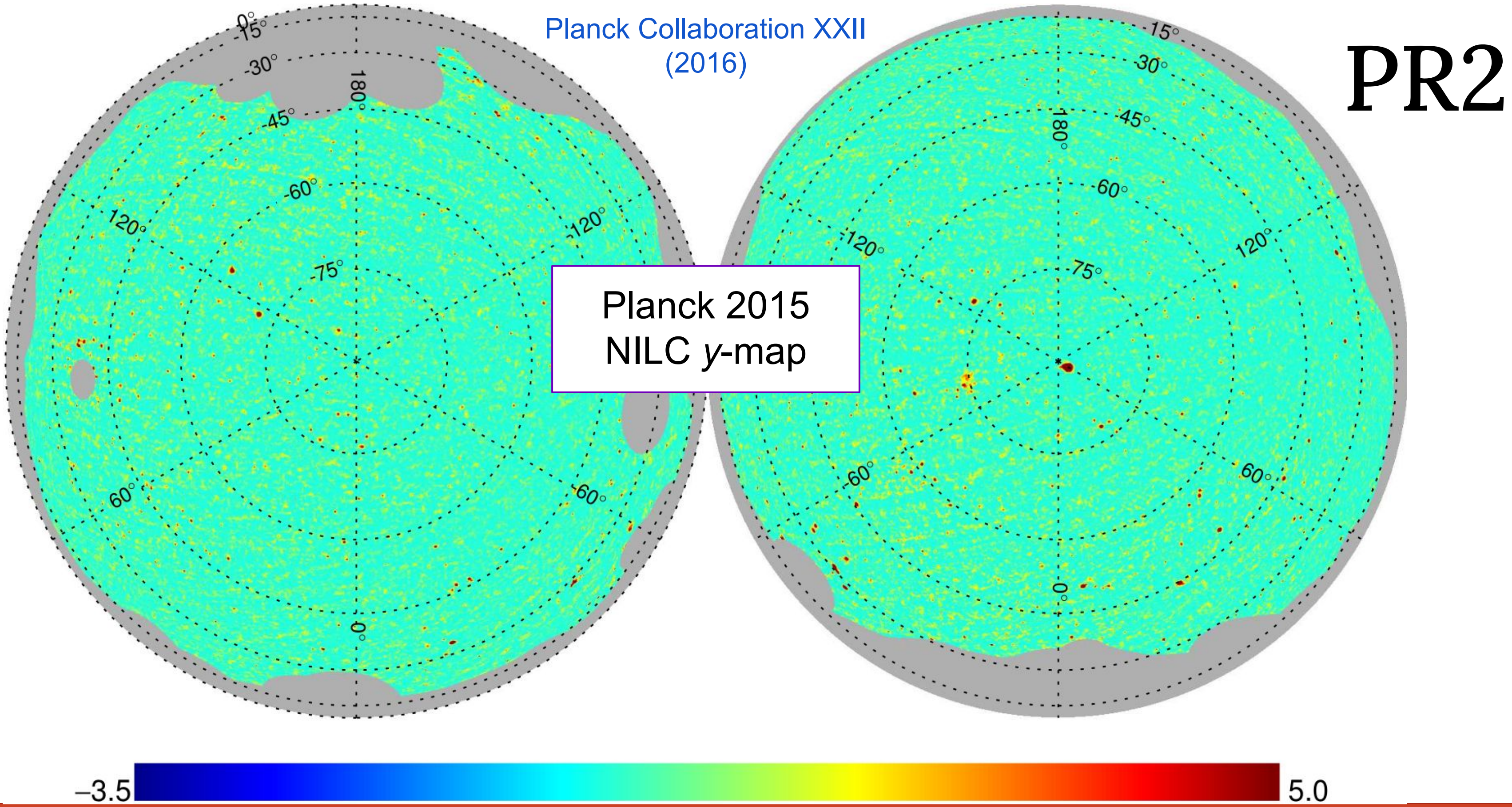


$$\frac{\Delta T_{tSZ}}{T_{CMB}} = g(\nu)y(\hat{\mathbf{n}}) = \left[x(\nu)\coth\frac{x(\nu)}{2} - 4\right] \cdot \frac{\sigma_T}{m_e c^2}\int_{los} n_e k T_e(\hat{\mathbf{n}})dl$$

Planck 2015 tSZ *y*-map



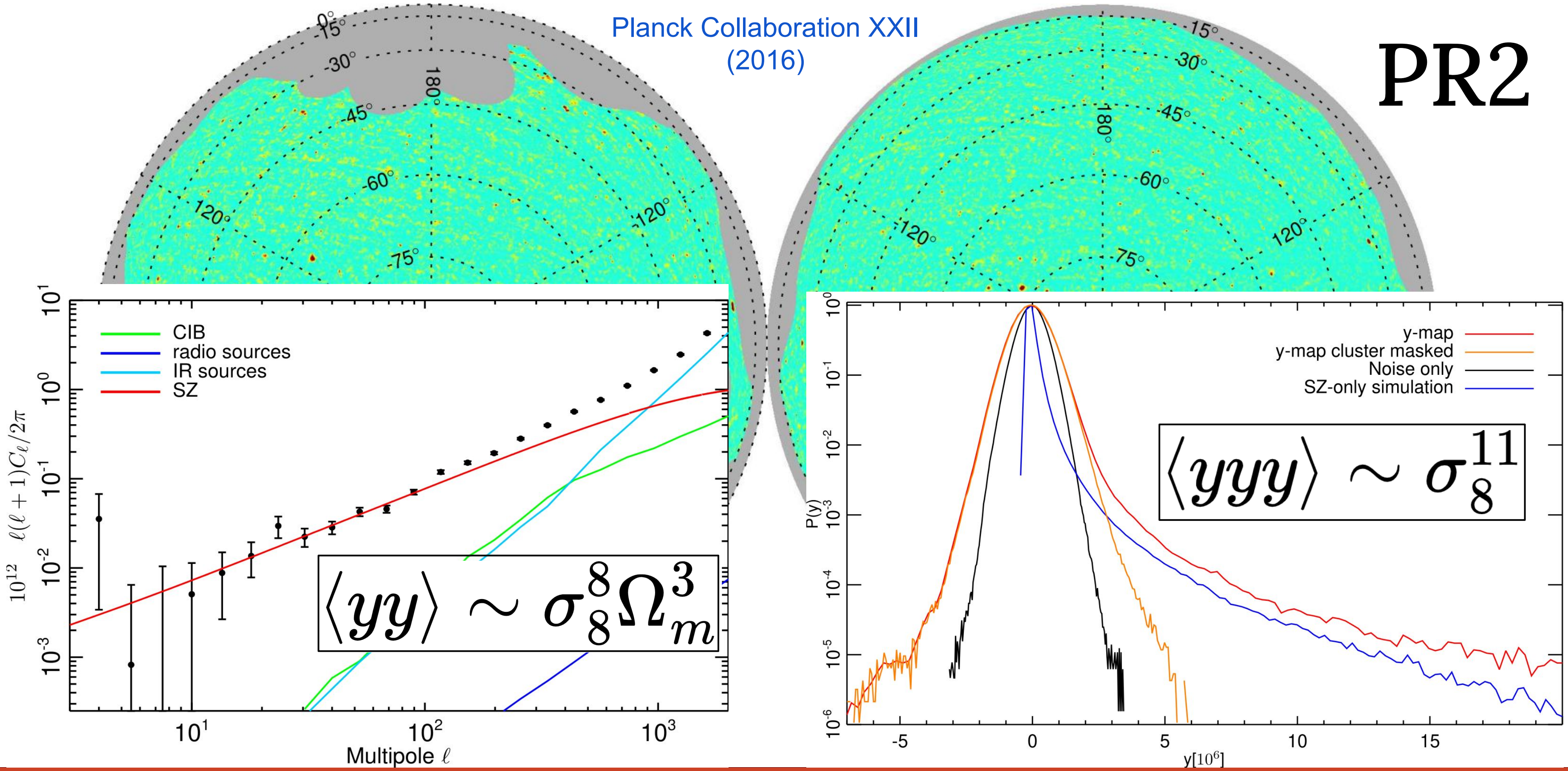
Planck 2015 tSZ *y*-map



Planck 2015 tSZ *y*-map

Planck Collaboration XXII (2016)

PR2



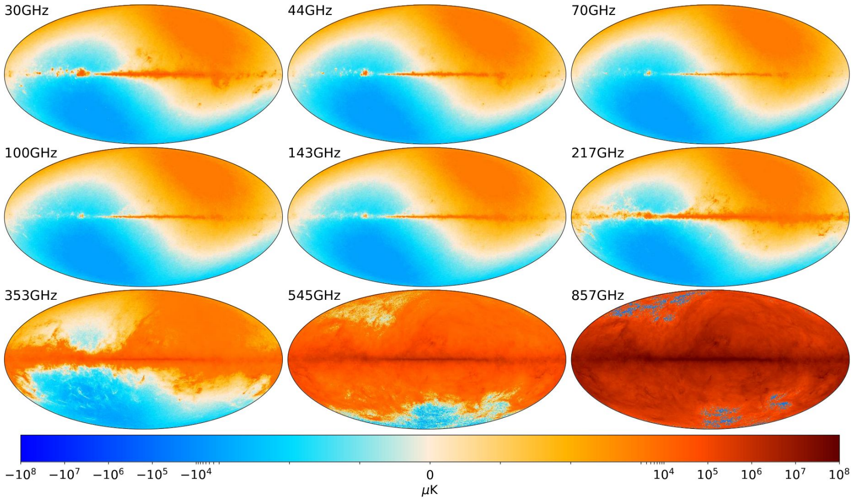
$$\langle yy \rangle \sim \sigma_8^8 \Omega_m^3$$

$$\langle yyy \rangle \sim \sigma_8^{11}$$

Planck PR4 (NPIPE) Data

Planck NPIPE: [Planck Collaboration LVII (2020)]

- **Lower noise**: Additional data, better destriping
- Coherent processing of LFI and HFI data
- Different calibration and HFI frequency bandpass



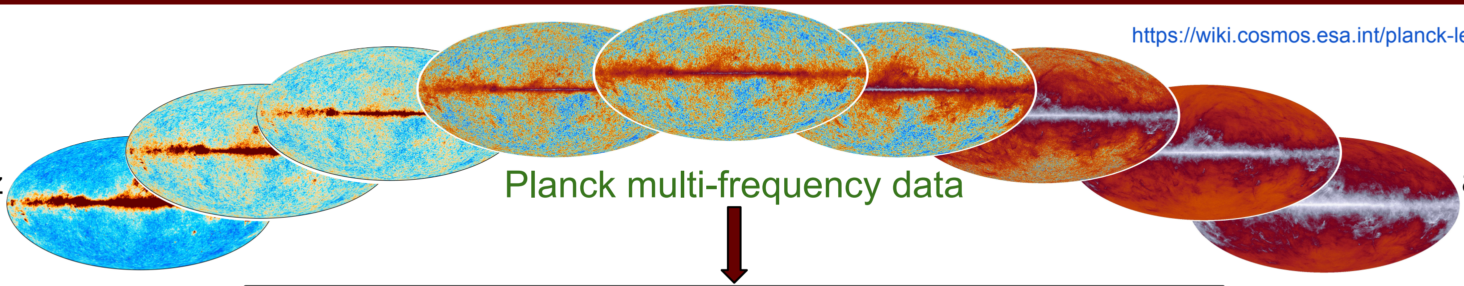
Public Planck y-maps (NILC and MILCA) still rely on Planck 2015 PR2 data.

Update with improved PR4 (NPIPE) data is required:

- NILC: Chandran, Remazeilles and Barreiro (arXiv:2305.10193)
- MILCA: Tanimura et al. 2022

Reconstruction of Compton y-map

https://wiki.cosmos.esa.int/planck-legacy-archive



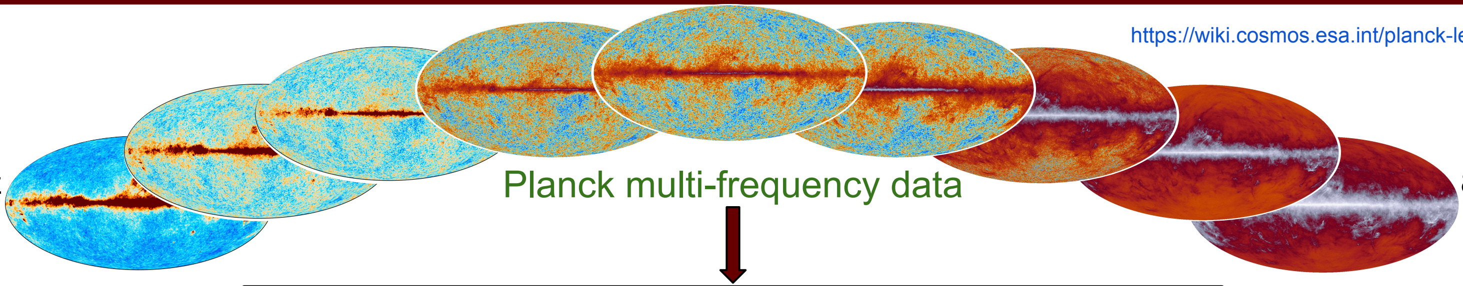
$$\boxed{x(\nu, \hat{\mathbf{n}}) = g(\nu)\, y(\hat{\mathbf{n}}) + n(\nu, \hat{\mathbf{n}})}$$

Unparameterized contaminants

Reconstruction of Compton *y*-map with Needlet ILC

https://wiki.cosmos.esa.int/planck-legacy-archive

30 GHz



857 GHz

Planck multi-frequency data

$$\boxed{x(\nu, \hat{\mathbf{n}}) = g(\nu) y(\hat{\mathbf{n}}) + n(\nu, \hat{\mathbf{n}})}$$

Unparameterized contaminants

$$w_j^{\nu} = \frac{\sum_{\nu'} g_{\nu'} [C_j^{-1}(p)]^{\nu\nu'}}{\sum_{\nu,\nu'} g_{\nu'} [C_j^{-1}(p)]^{\nu\nu'} g_{\nu}}$$

$$\boxed{\hat{y}(p) \longleftarrow \hat{y}_j(p) = \sum_{\nu} w_j^{\nu} \gamma_j^{\nu}(p)}$$

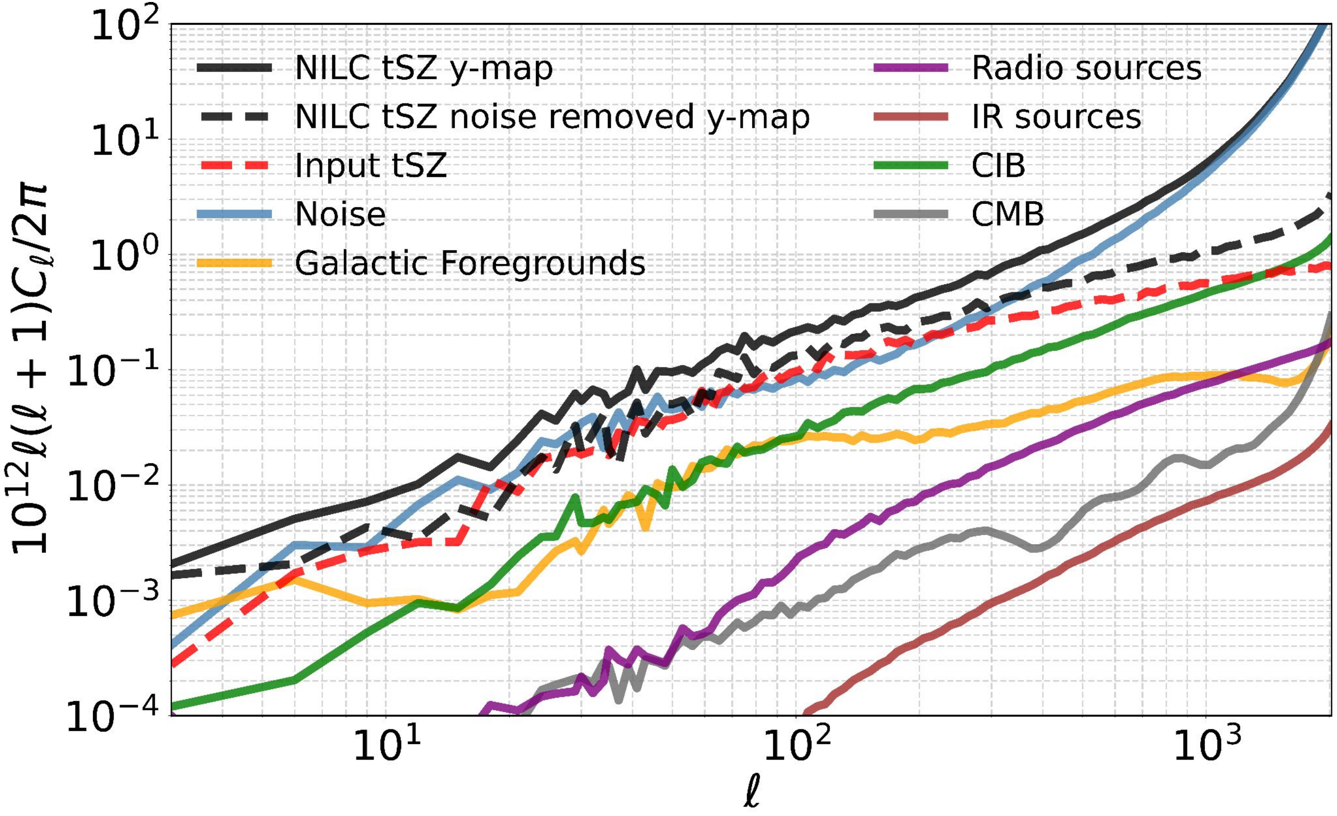
Inversion

Needlet ILC (NILC) [Delabrouille et al. 2009, Remazeilles et al. 2011, 2013]

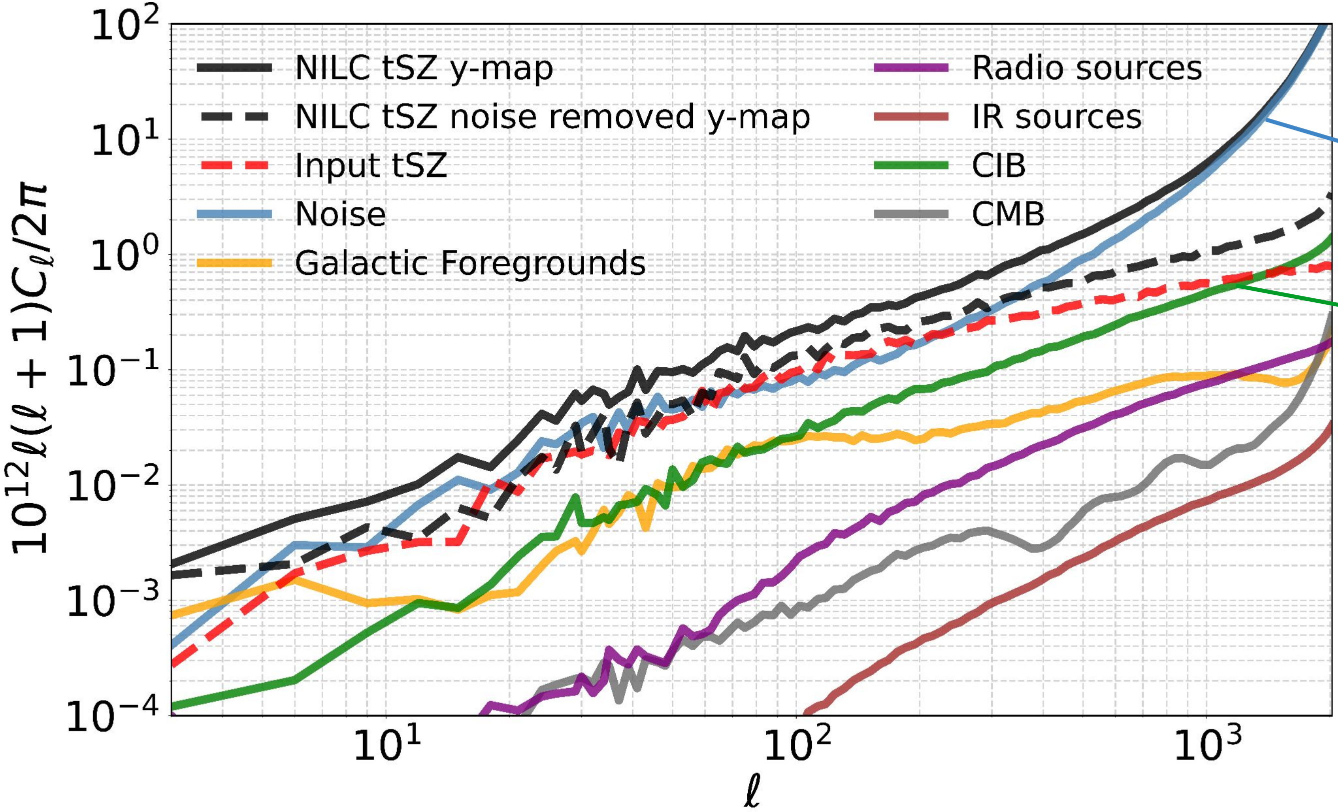
- Simultaneous localization in spatial (pixel) and spectral (harmonic) domains
- Not dependent on knowledge of contaminants (blind)

Planck thermal SZ NILC y-map

NILC *y*-map and contaminants from *Planck* simulations



NILC *y*-map and contaminants from *Planck* simulations

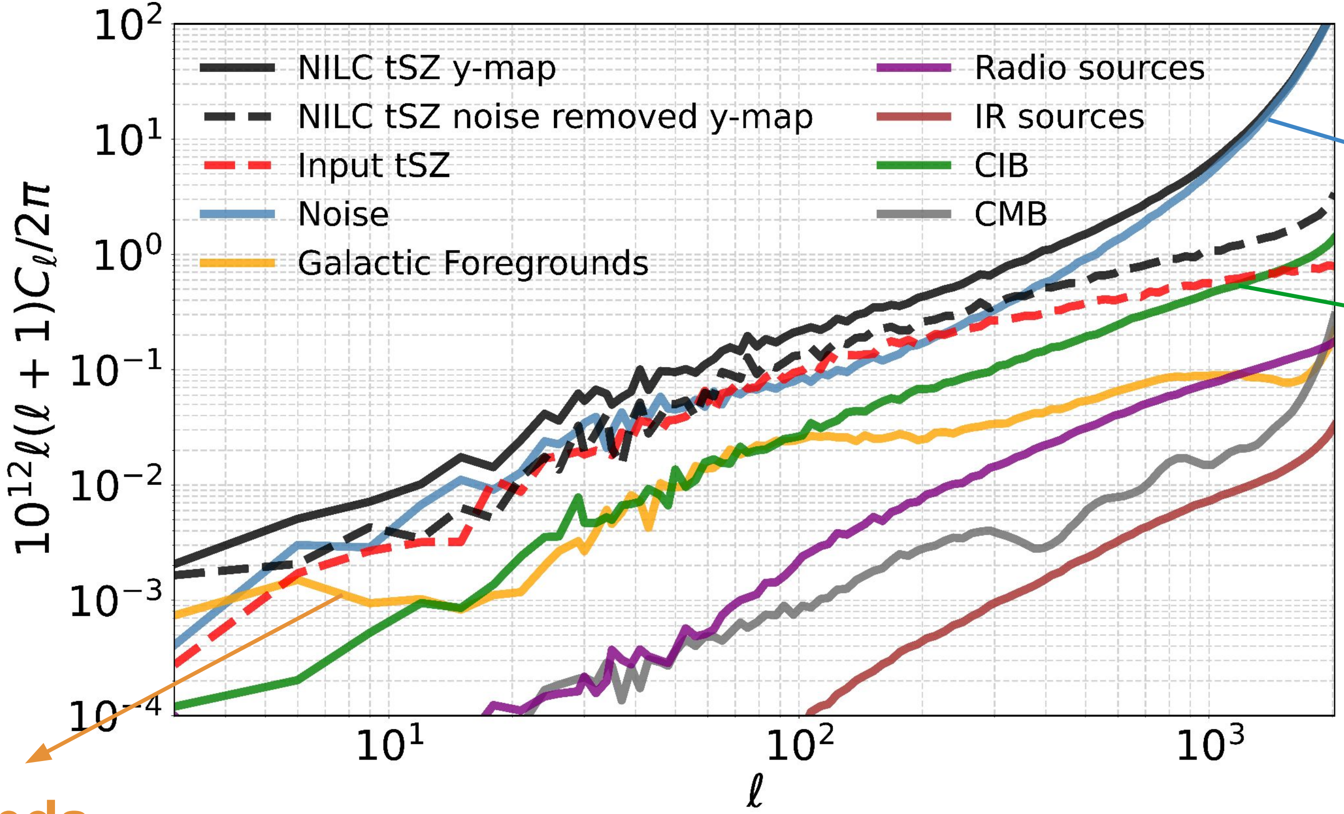


Small scales:

Noise

CIB

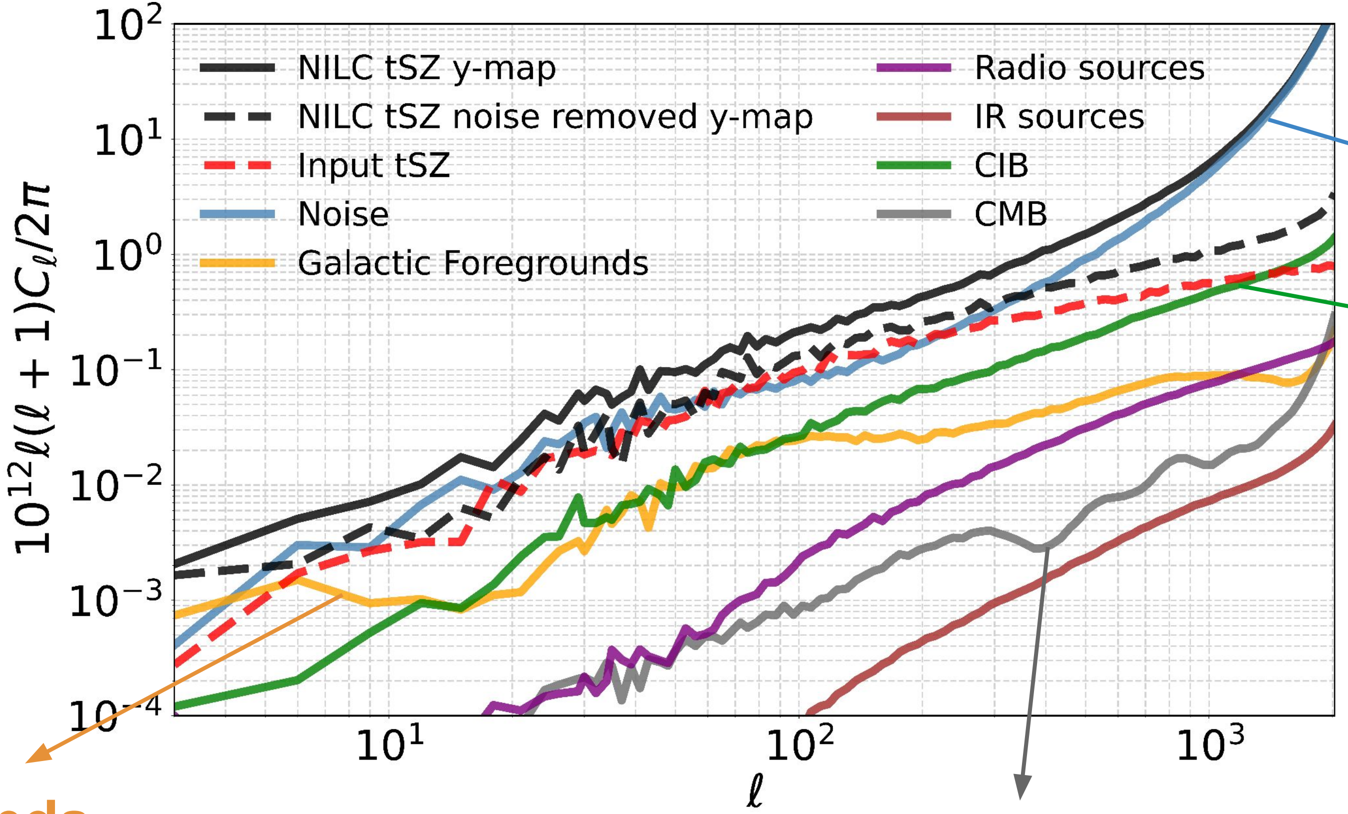
NILC *y*-map and contaminants from *Planck* simulations



Small scales:
Noise
CIB

Large scales:
Galactic foregrounds

NILC *y*-map and contaminants from *Planck* simulations



Small scales:

Noise

CIB

Large scales:

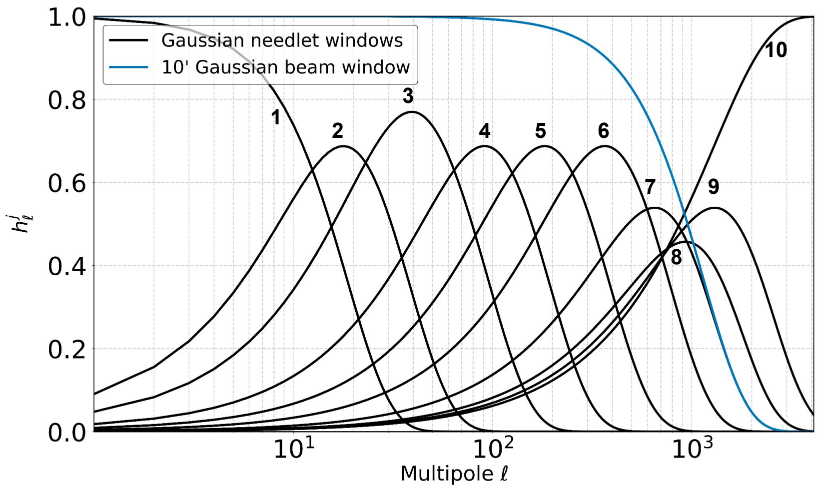
Galactic foregrounds

CMB subdominant

NILC with *Planck* PR4 (NPIPE) data

NILC Processing:

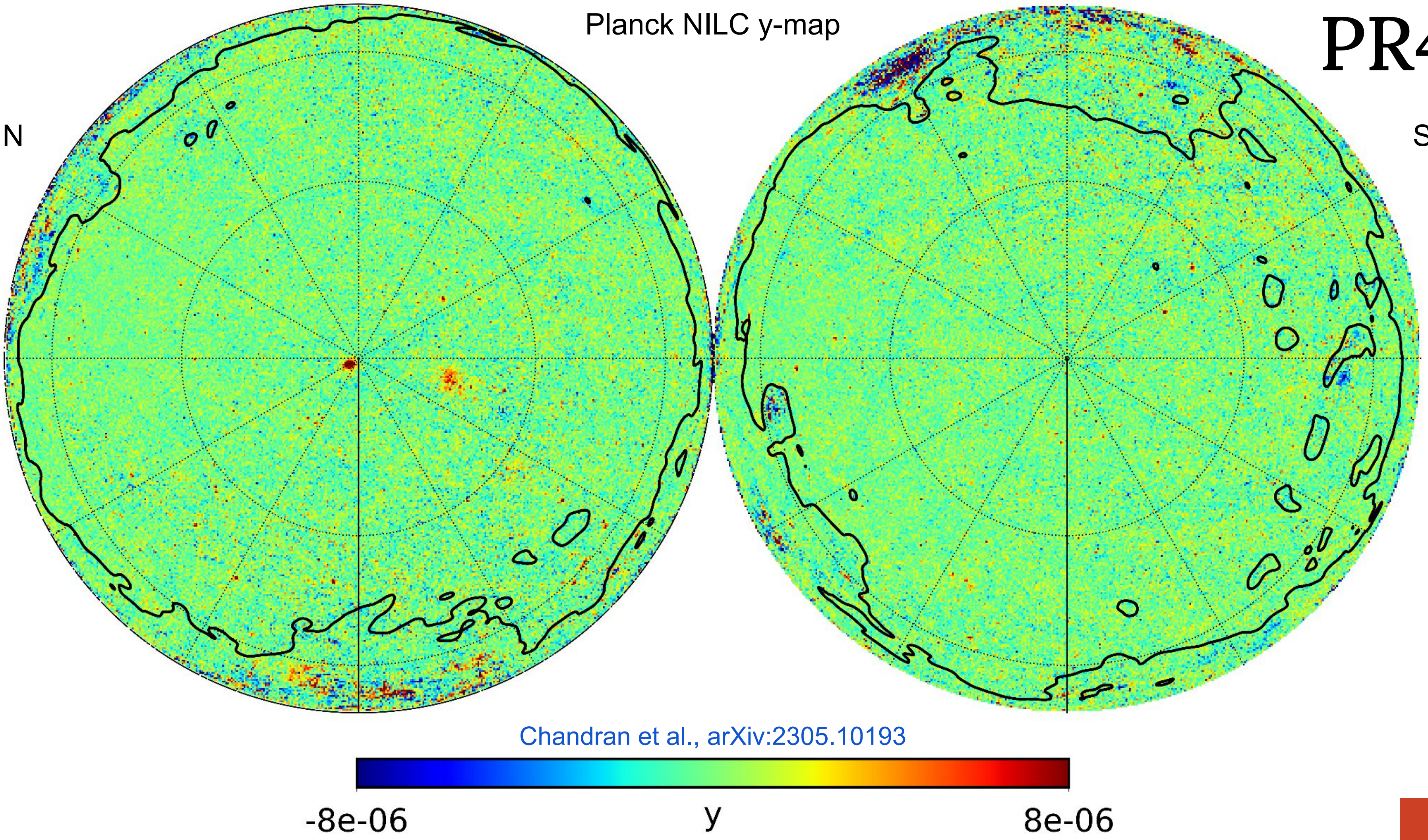
- **NILC performed in 10 ranges of multipoles**
- **Selective use of frequencies in different scales**
- Isotropic **non-gaussian beams** used.
- 2% of sky masked
- Resolution of 10 arcmin
- Half-ring data split maps for noise characterization



	Needlet band									
Frequency	1	2	3	4	5	6	7	8	9	10
30 GHz	✓	✓	✓	X	X	X	X	X	X	X
44 GHz	✓	✓	✓	X	X	X	X	X	X	X
70 GHz	✓	✓	✓	X	X	X	X	X	X	X
100 GHz	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
143 GHz	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
217 GHz	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
353 GHz	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
545 GHz	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
857 GHz	✓	✓	✓	✓	✓	✓	X	X	X	X

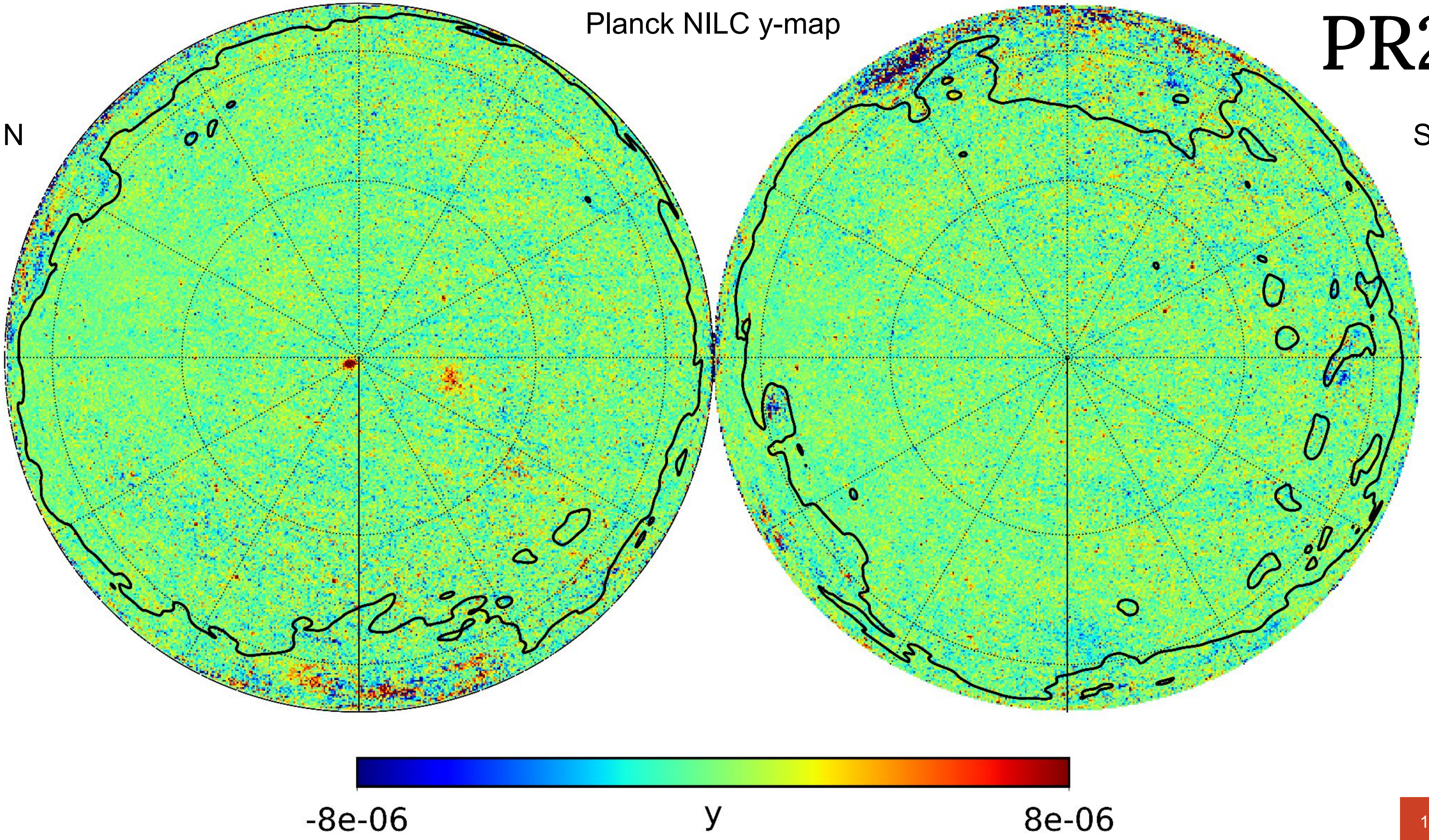
Planck NILC y-map

PR4

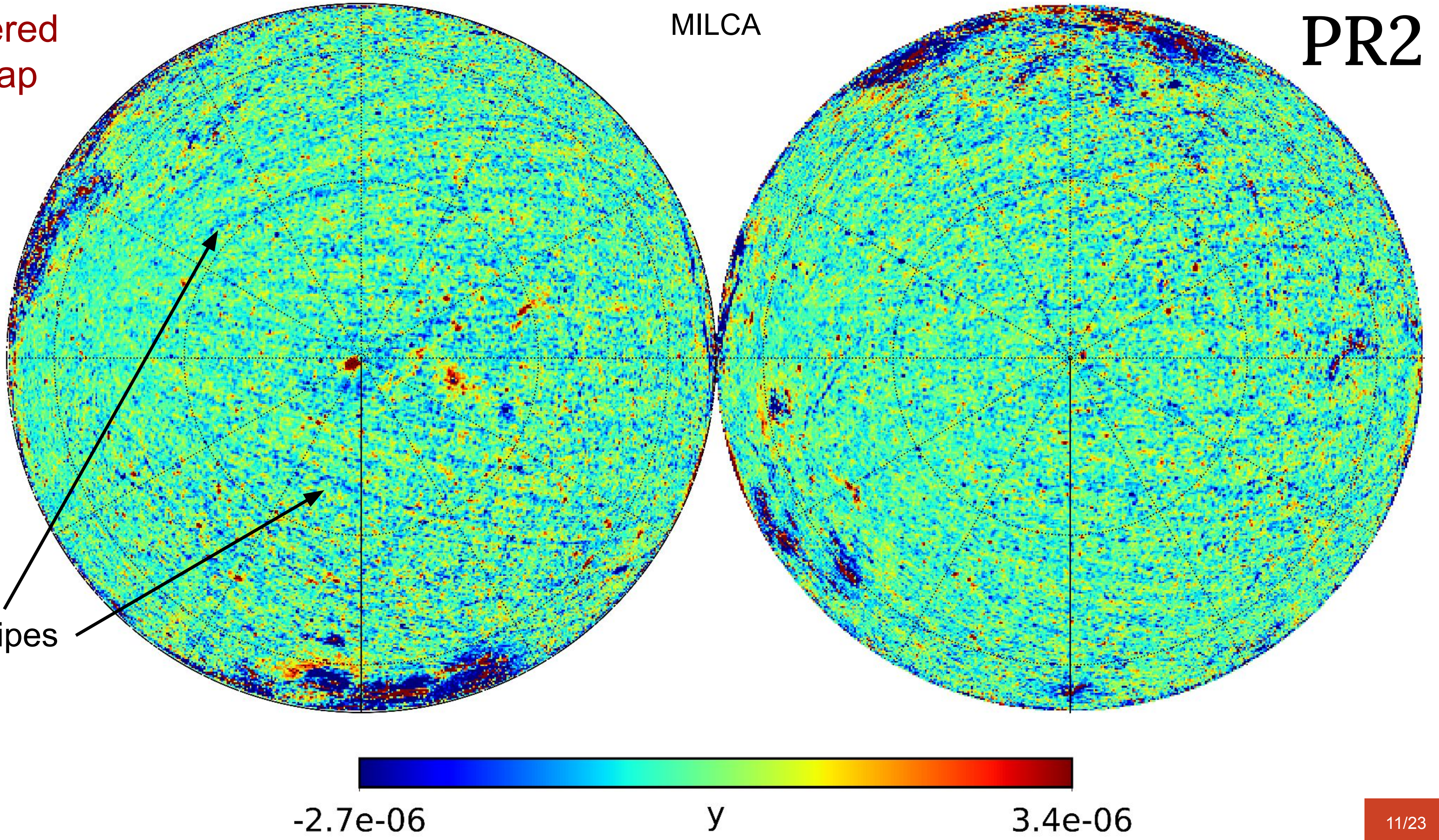


Chandran et al., arXiv:2305.10193

PR2

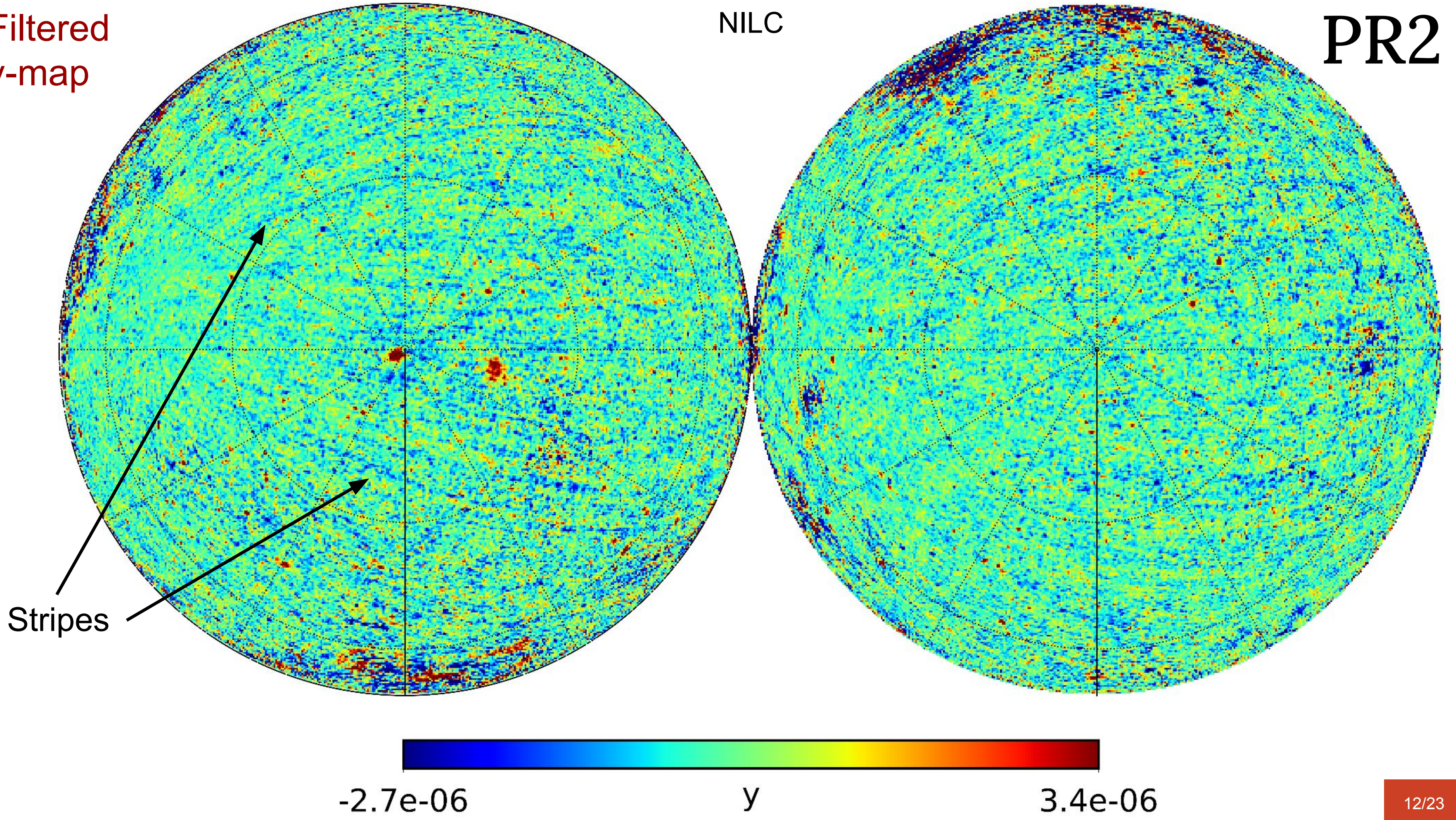


Filtered y-map



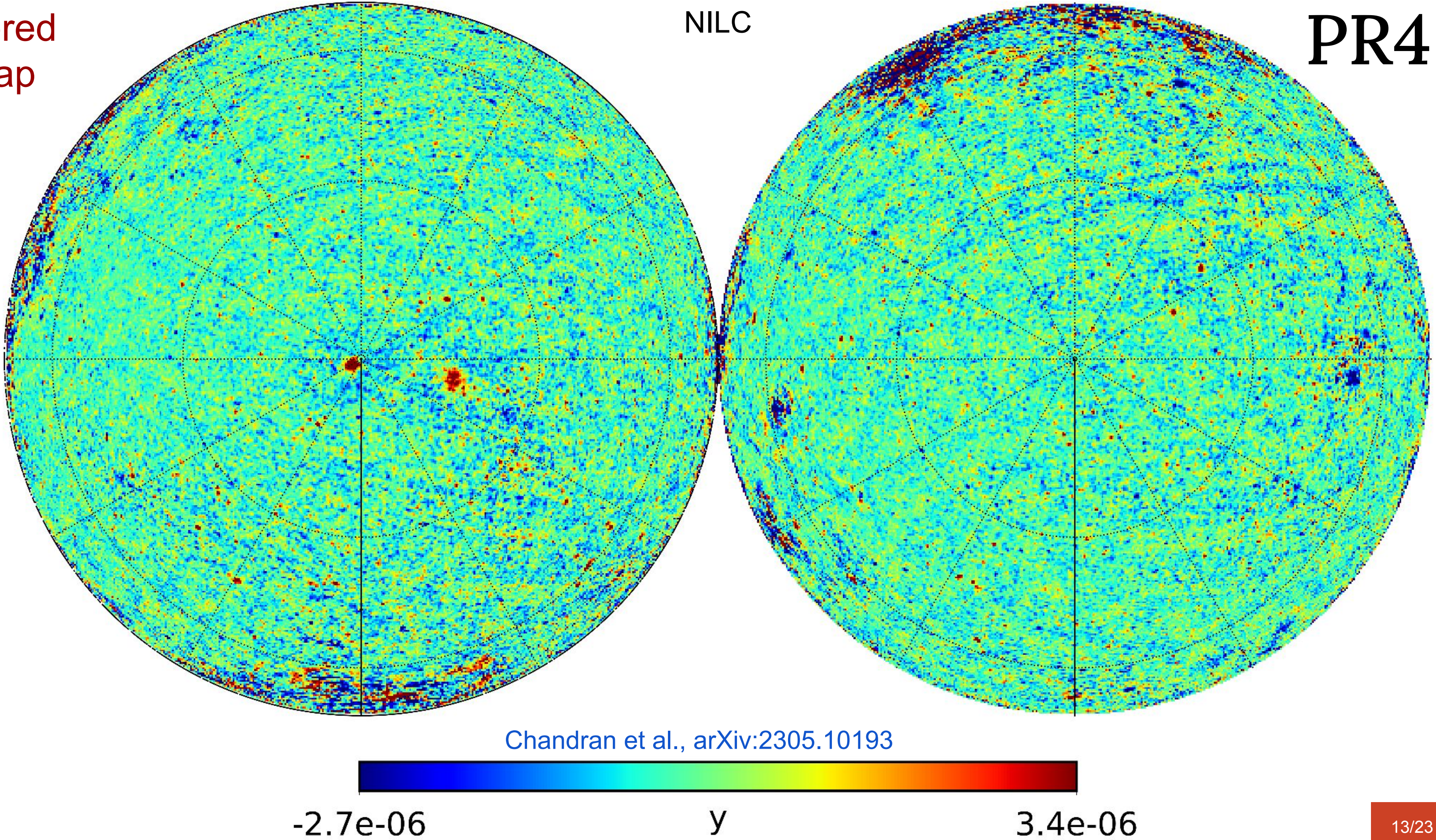
Filtered y-map

PR2



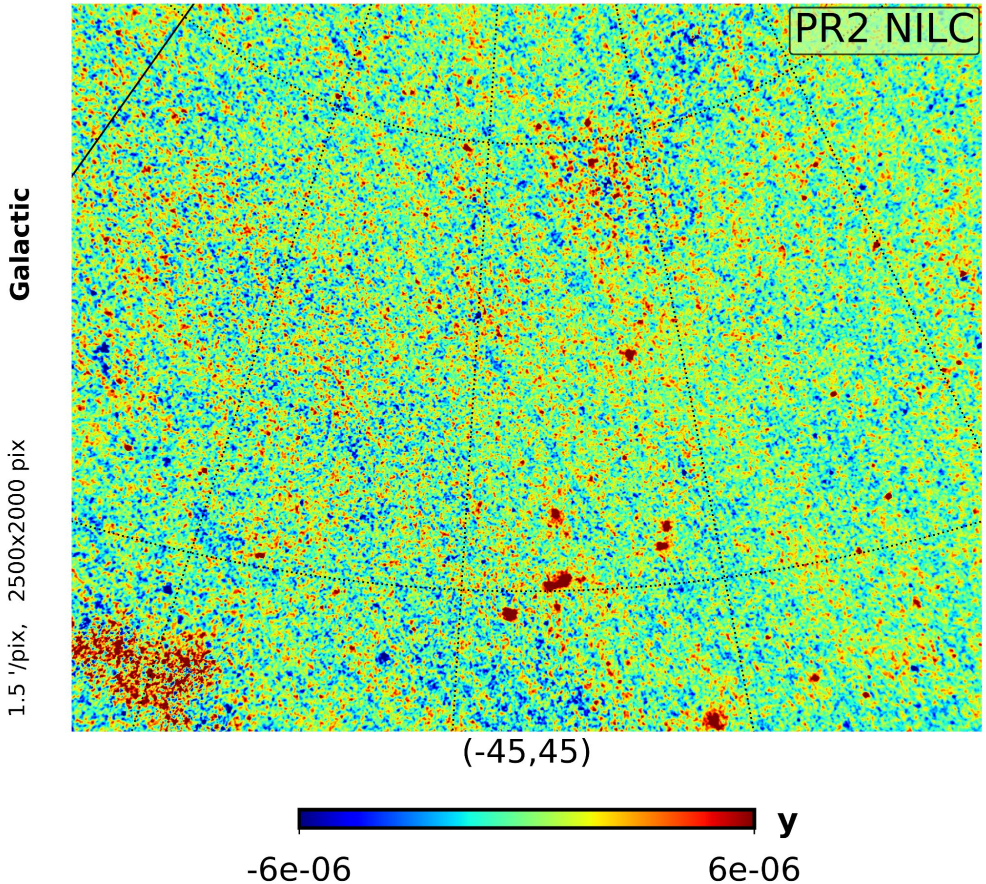
Filtered y-map

PR4

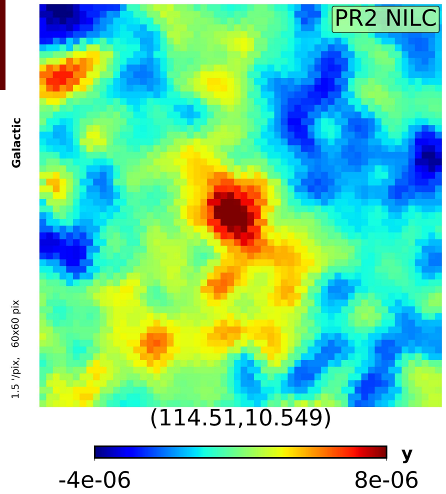


Chandran et al., arXiv:2305.10193

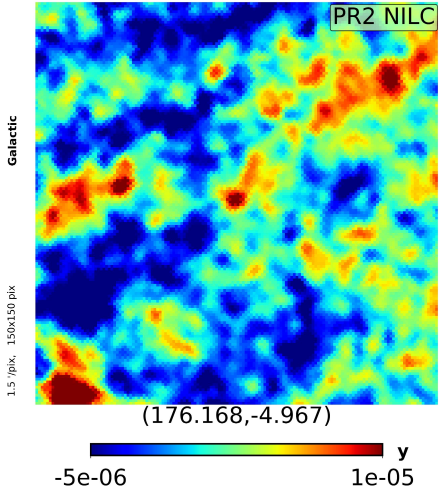
Map Characterization: Stripes, noise and dust



CIZA J0516.9+2925

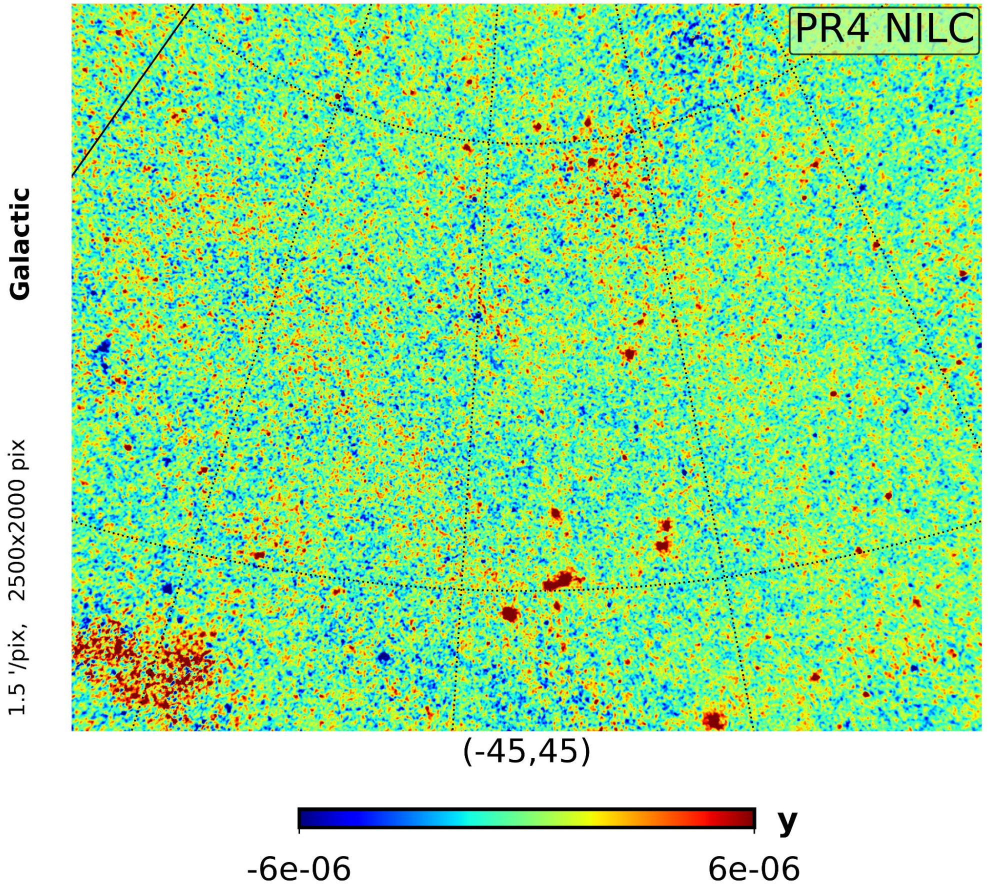


Old NILC
y-map



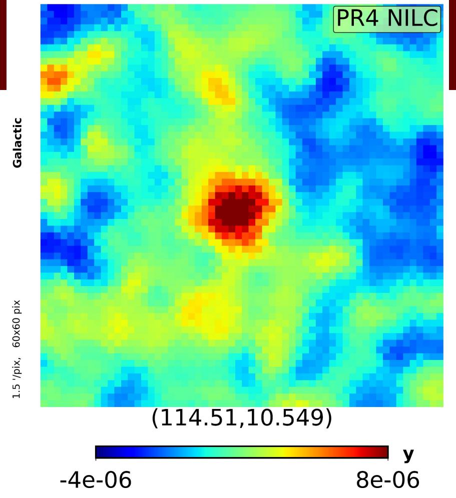
CIZA J2302.7+7137

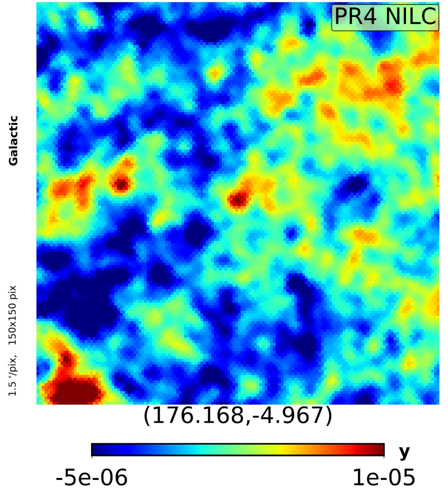
Map Characterization: Stripes, noise and dust



New NILC
y-map

CIZA J0516.9+2925





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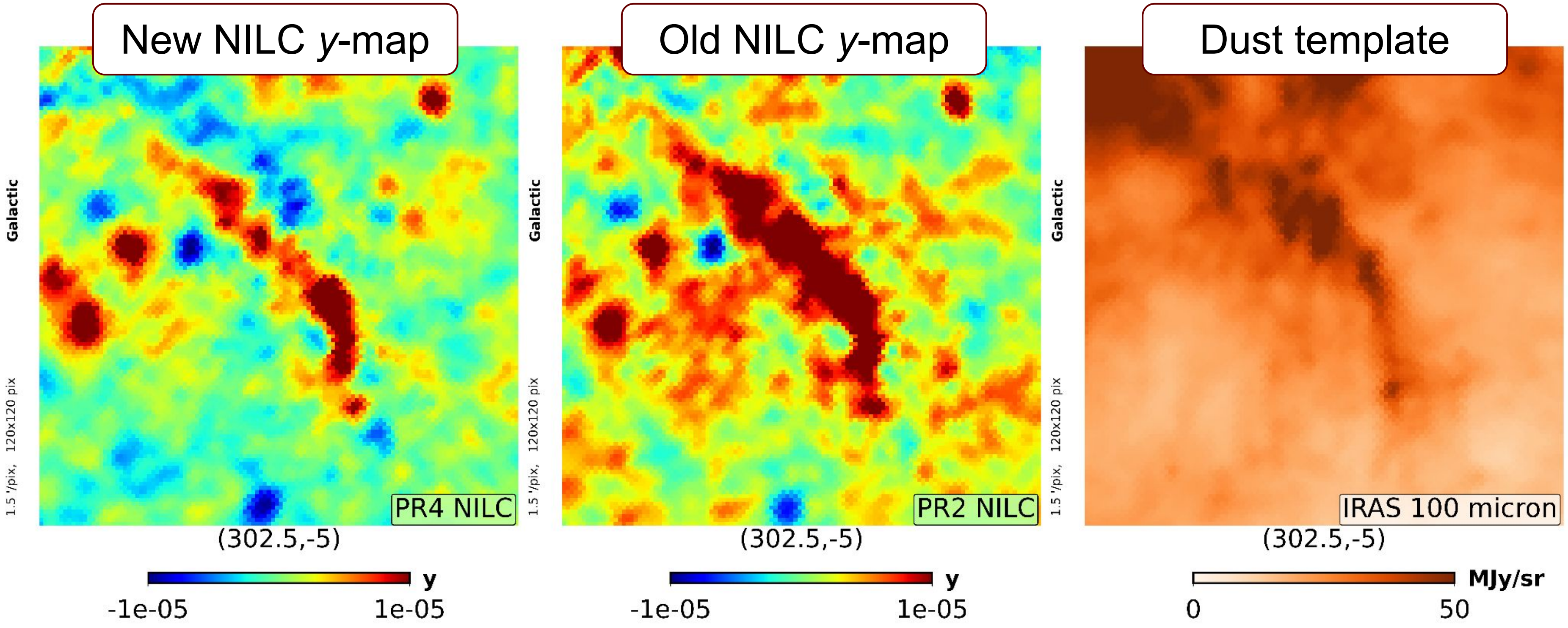
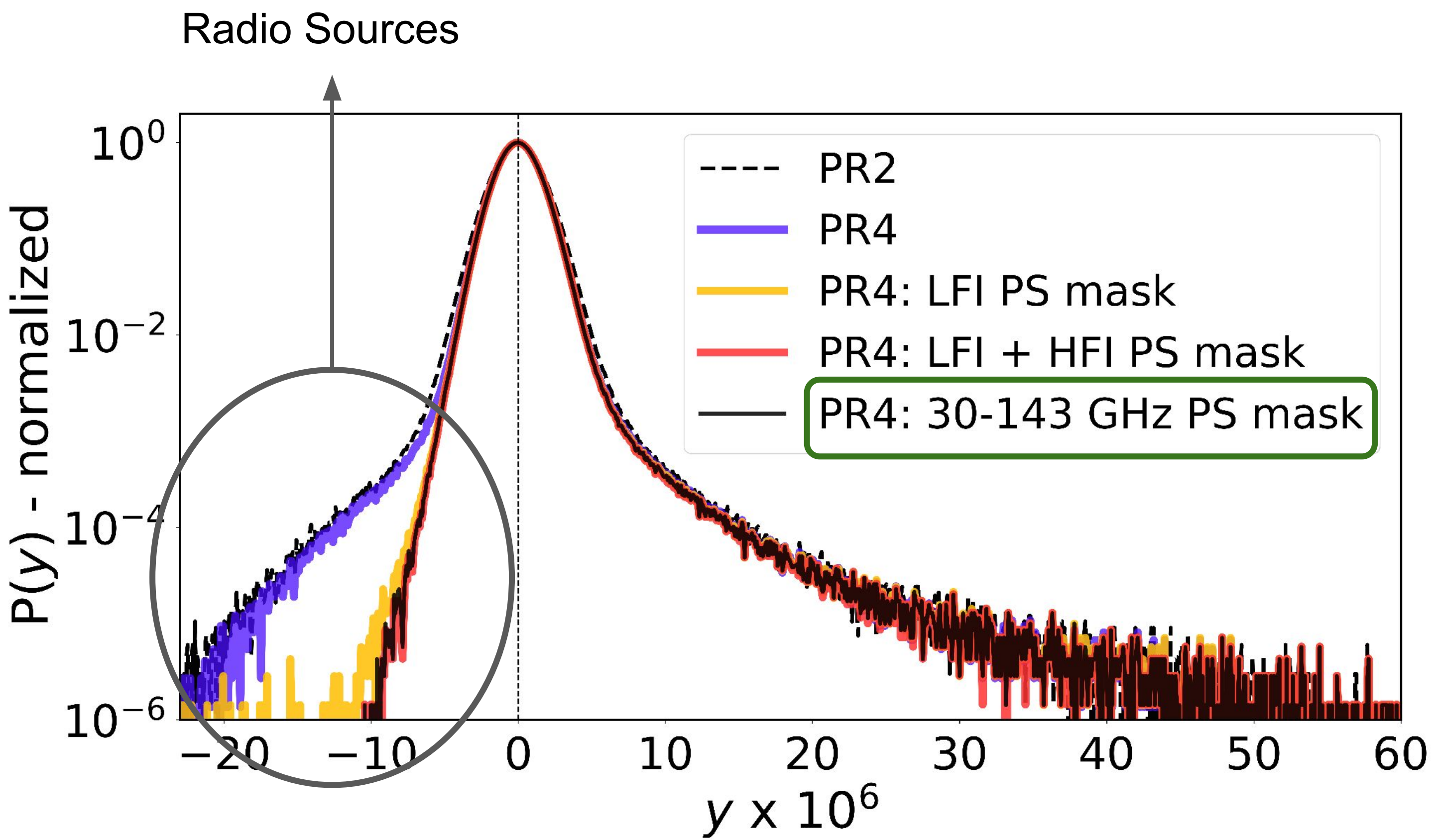


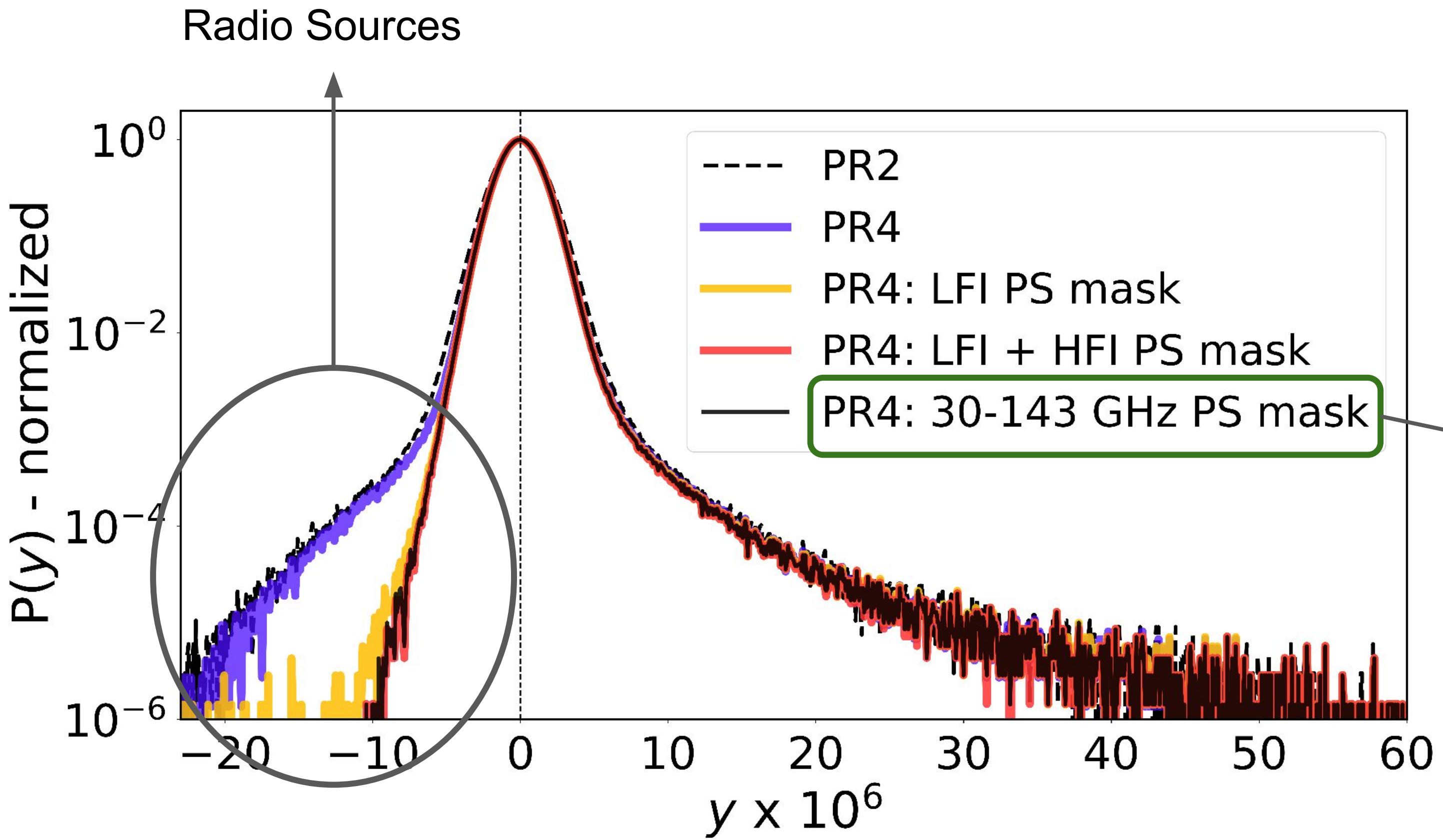
Lower level of contamination by diffused galactic dust emission

Point Sources



Chandran et al., arXiv:2305.10193; López-Caniego et al. 2006

Point Sources



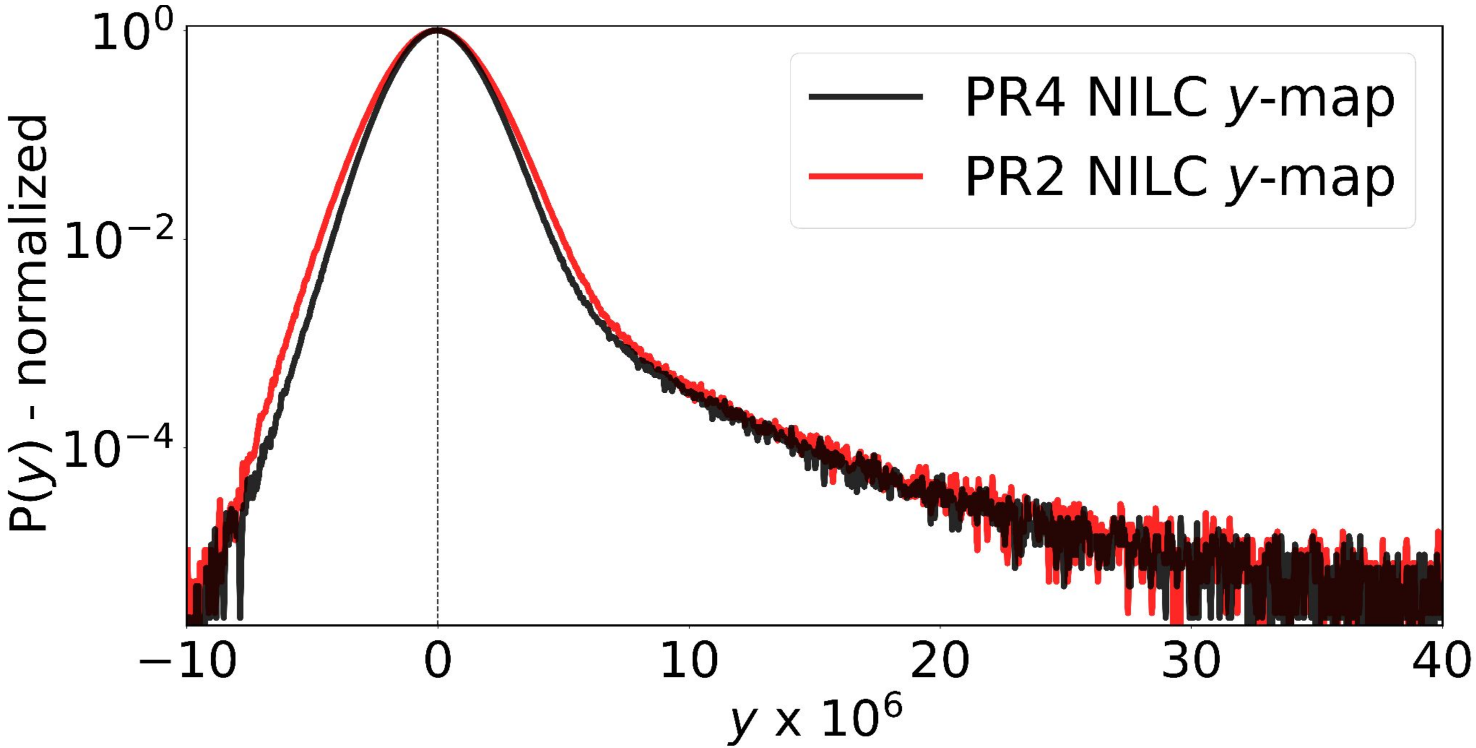
60% Galactic mask

+

Optimal PS mask

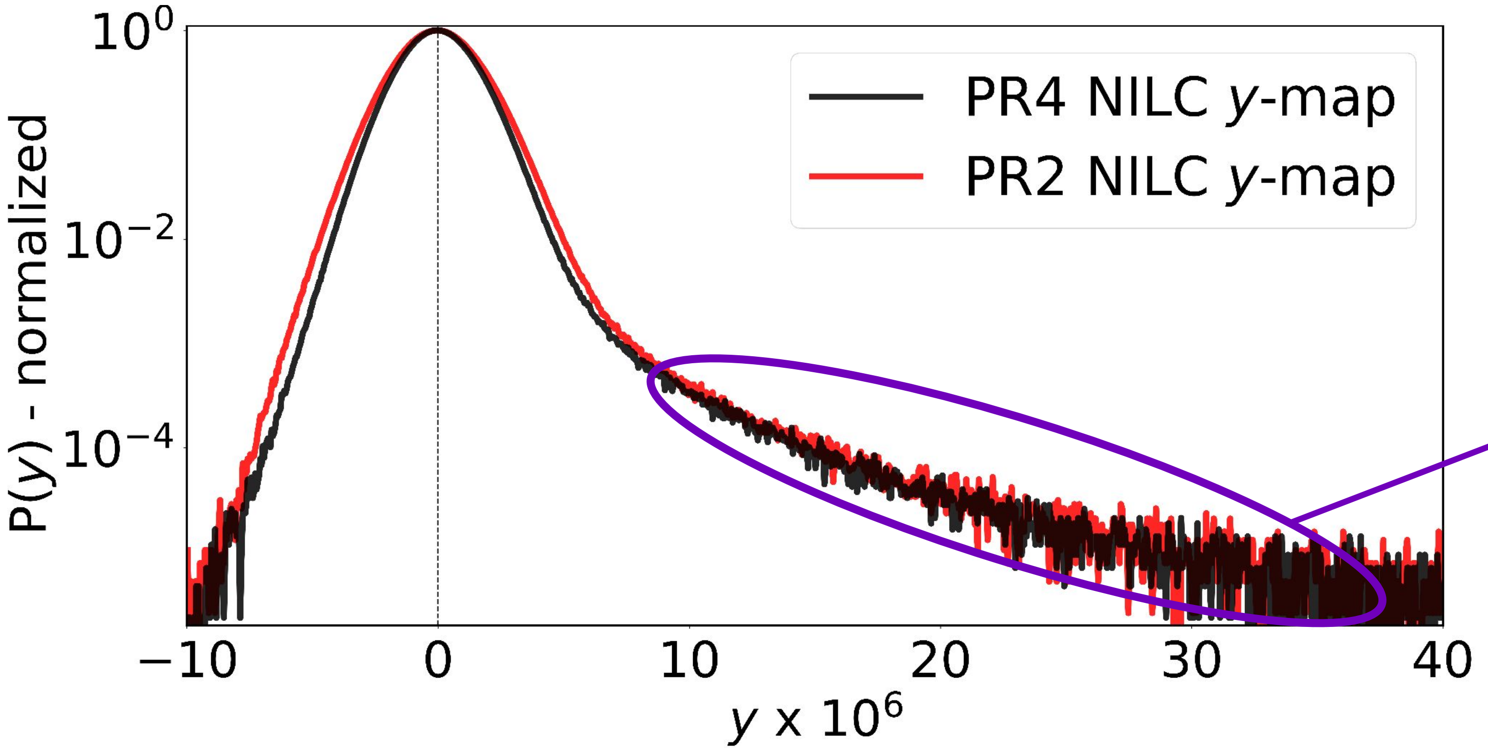
Chandran et al., arXiv:2305.10193; López-Caniego et al. 2006

1-PDF: NILC y-map



Chandran et al., arXiv:2305.10193

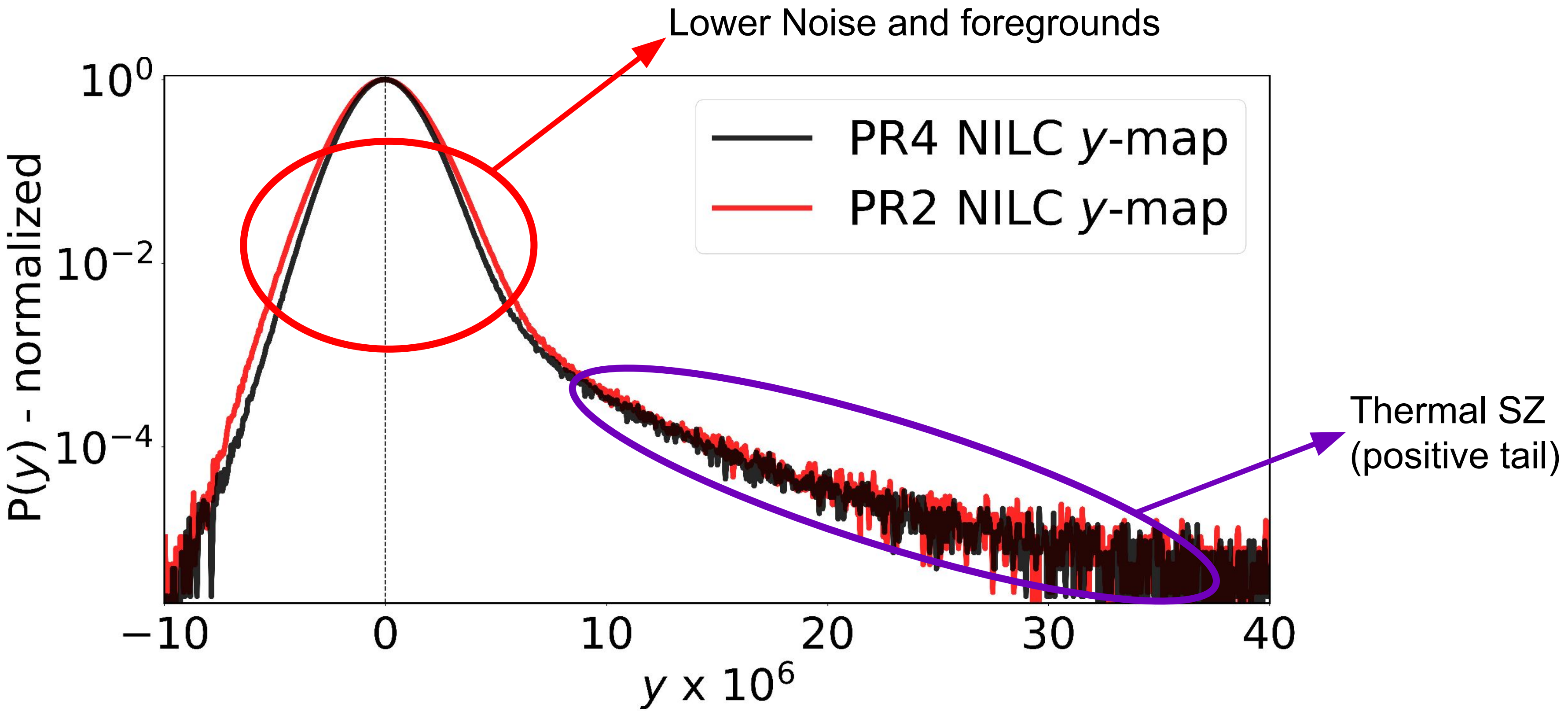
1-PDF: NILC y-map



Thermal SZ (positive tail)

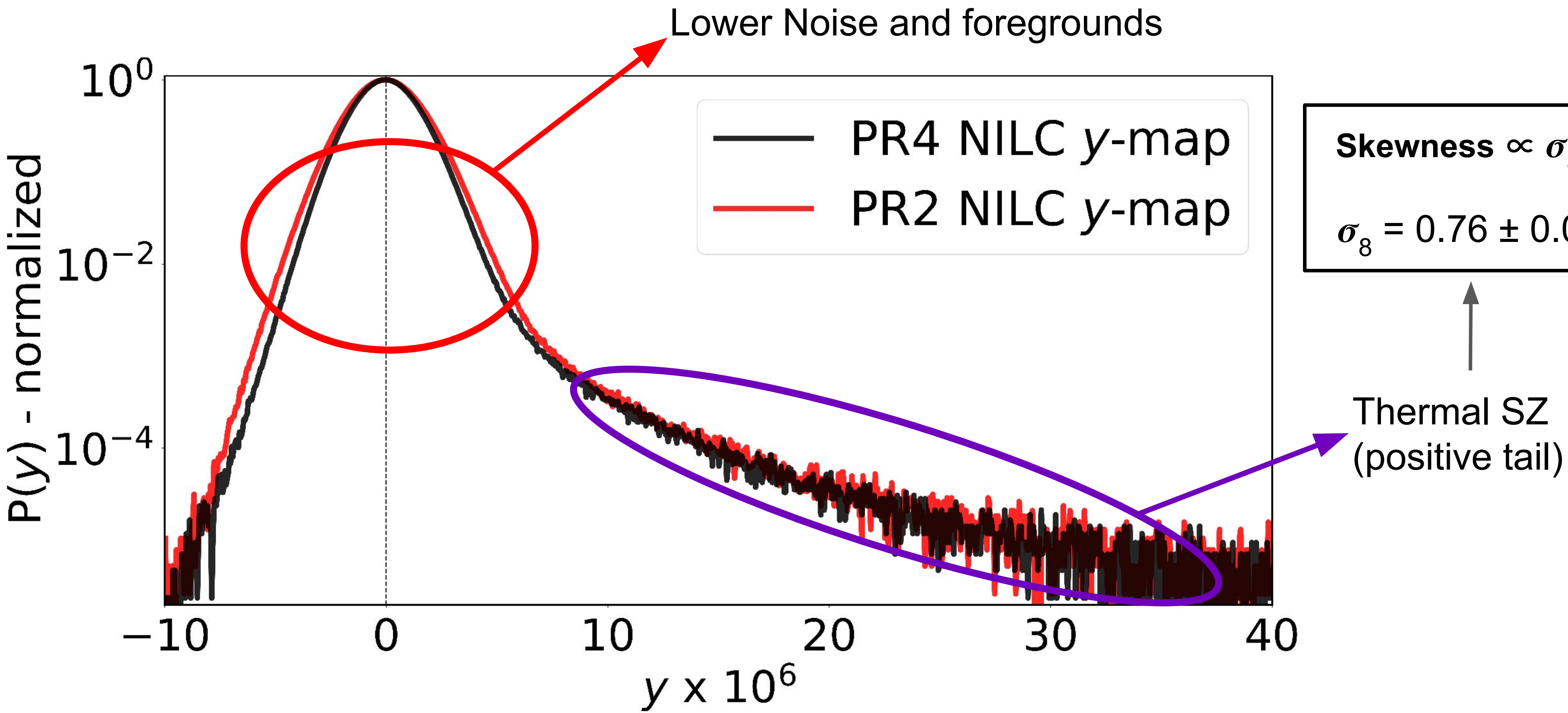
Chandran et al., arXiv:2305.10193

1-PDF: NILC y-map



Chandran et al., arXiv:2305.10193

1-PDF: NILC y-map



Skewness $\propto \sigma_8^{11}$

$\sigma_8 = 0.76 \pm 0.02$

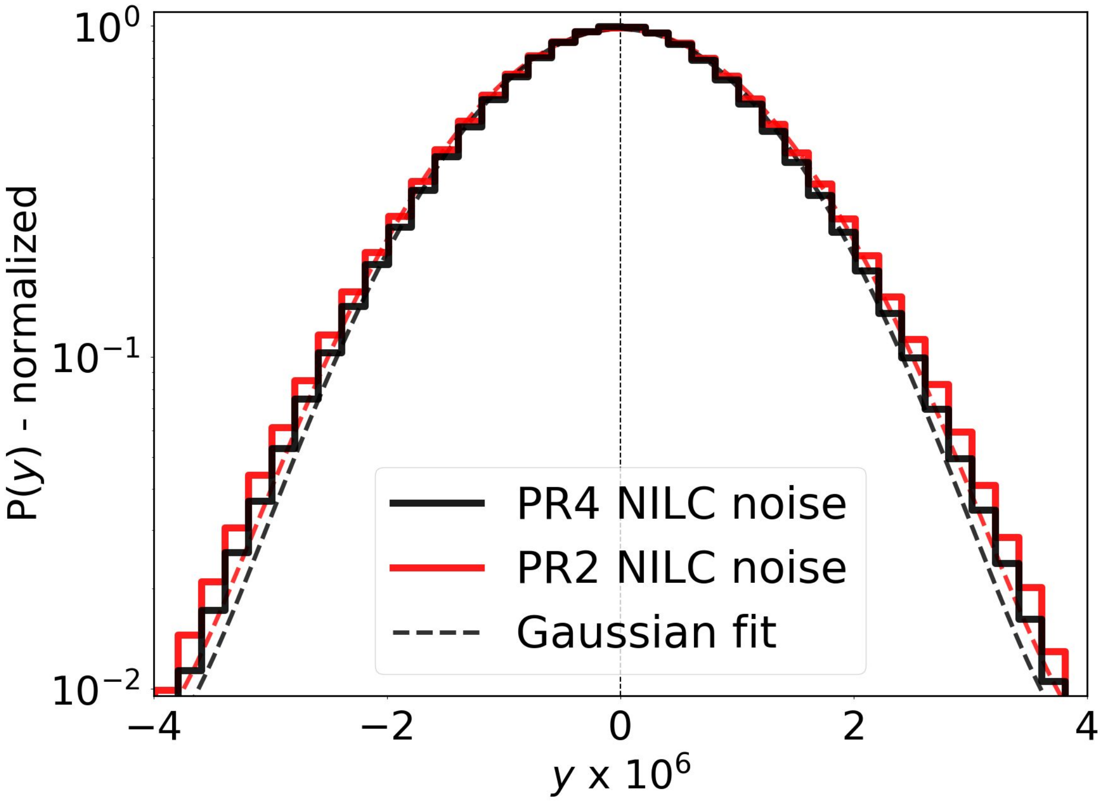
Chandran et al., arXiv:2305.10193

1-PDF: Noise

Noise estimate: Half difference of half ring (HR) y-maps.

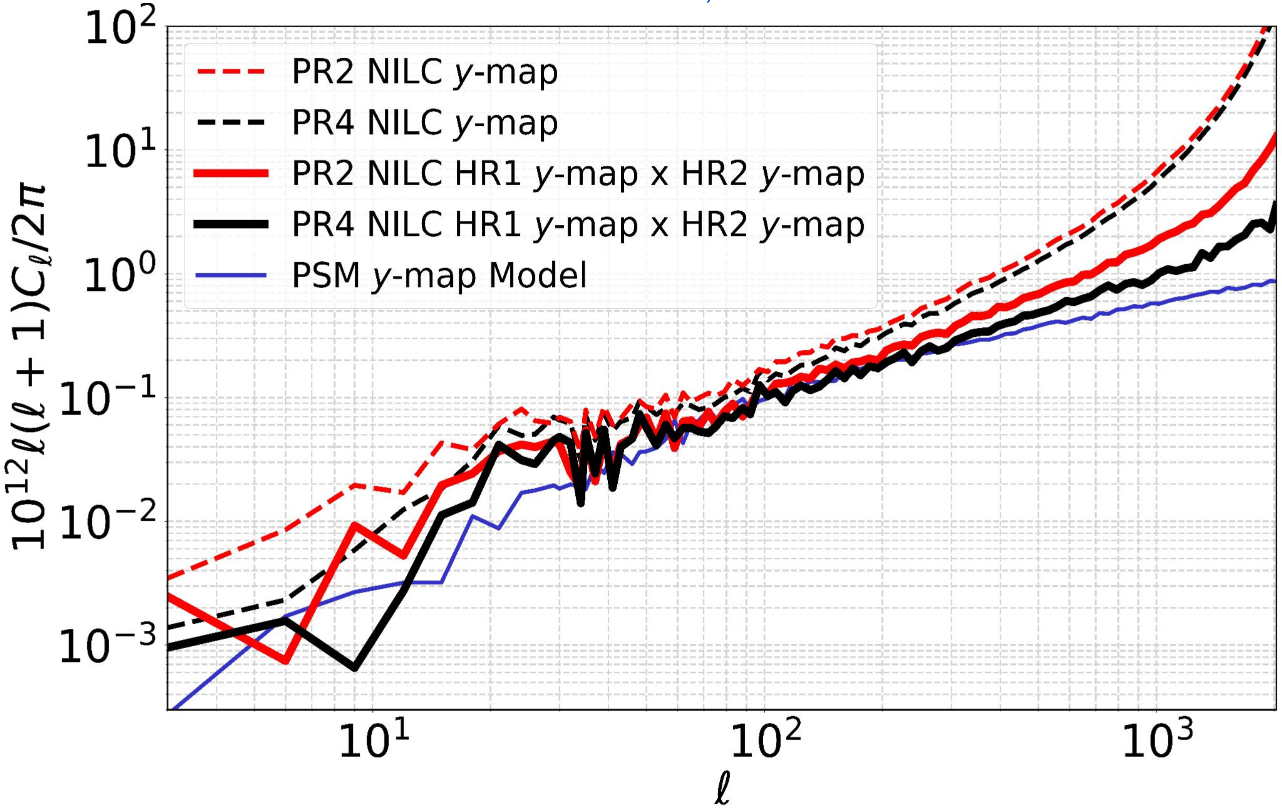
~ **7%** reduction in noise contamination

Chandran et al., arXiv:2305.10193



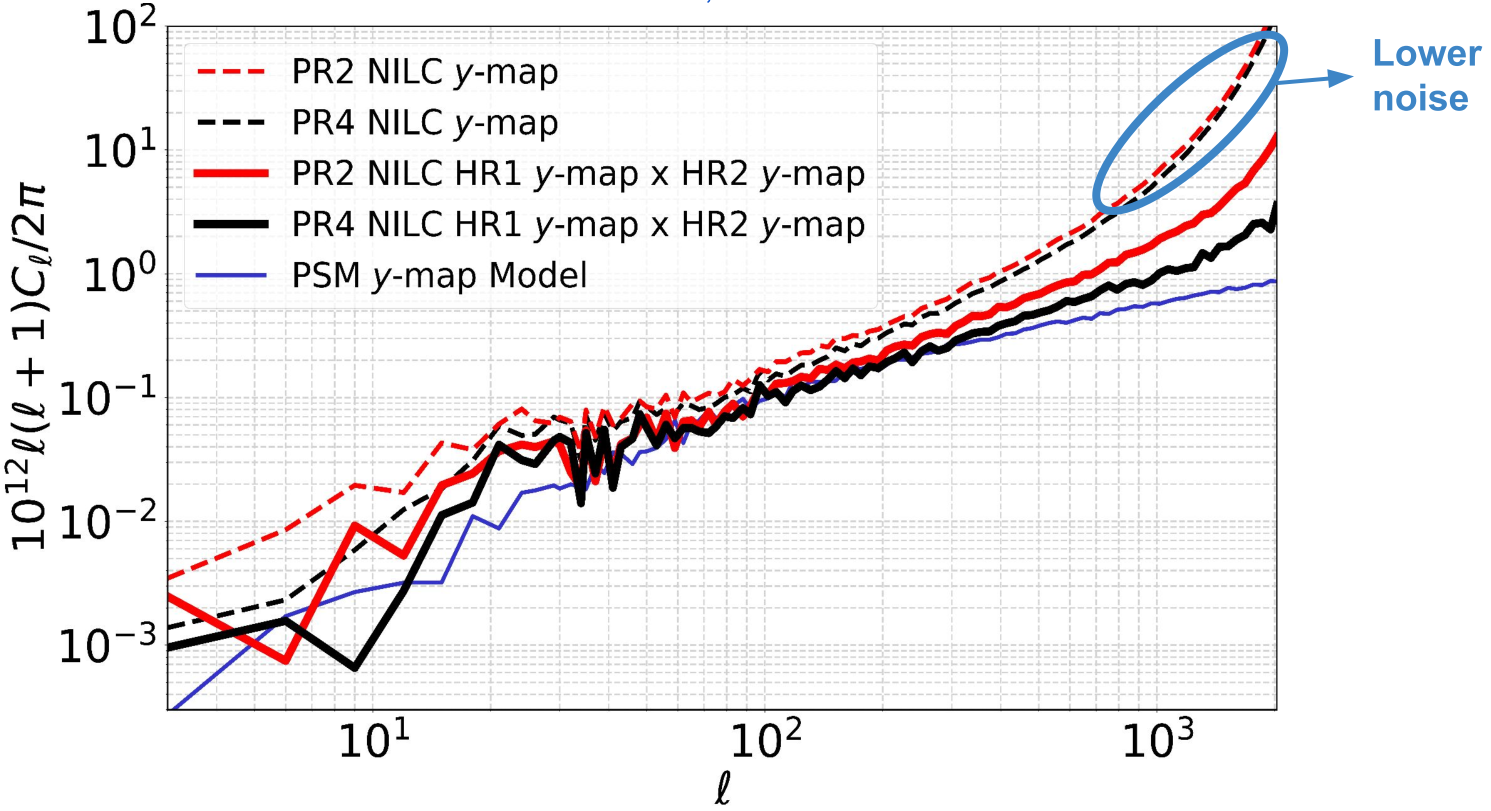
Power spectra

Chandran et al., arXiv:2305.10193



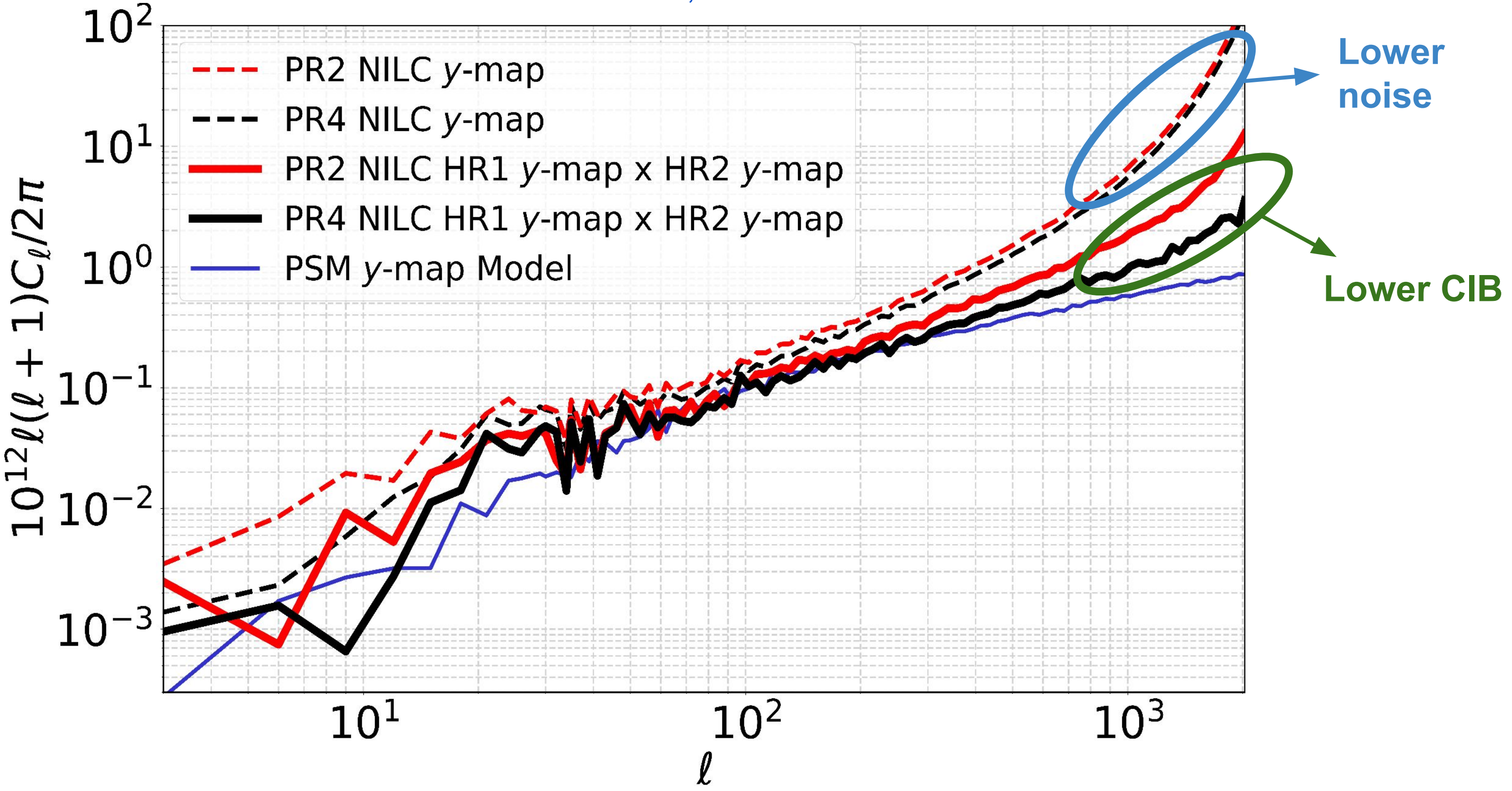
Power spectra

Chandran et al., arXiv:2305.10193



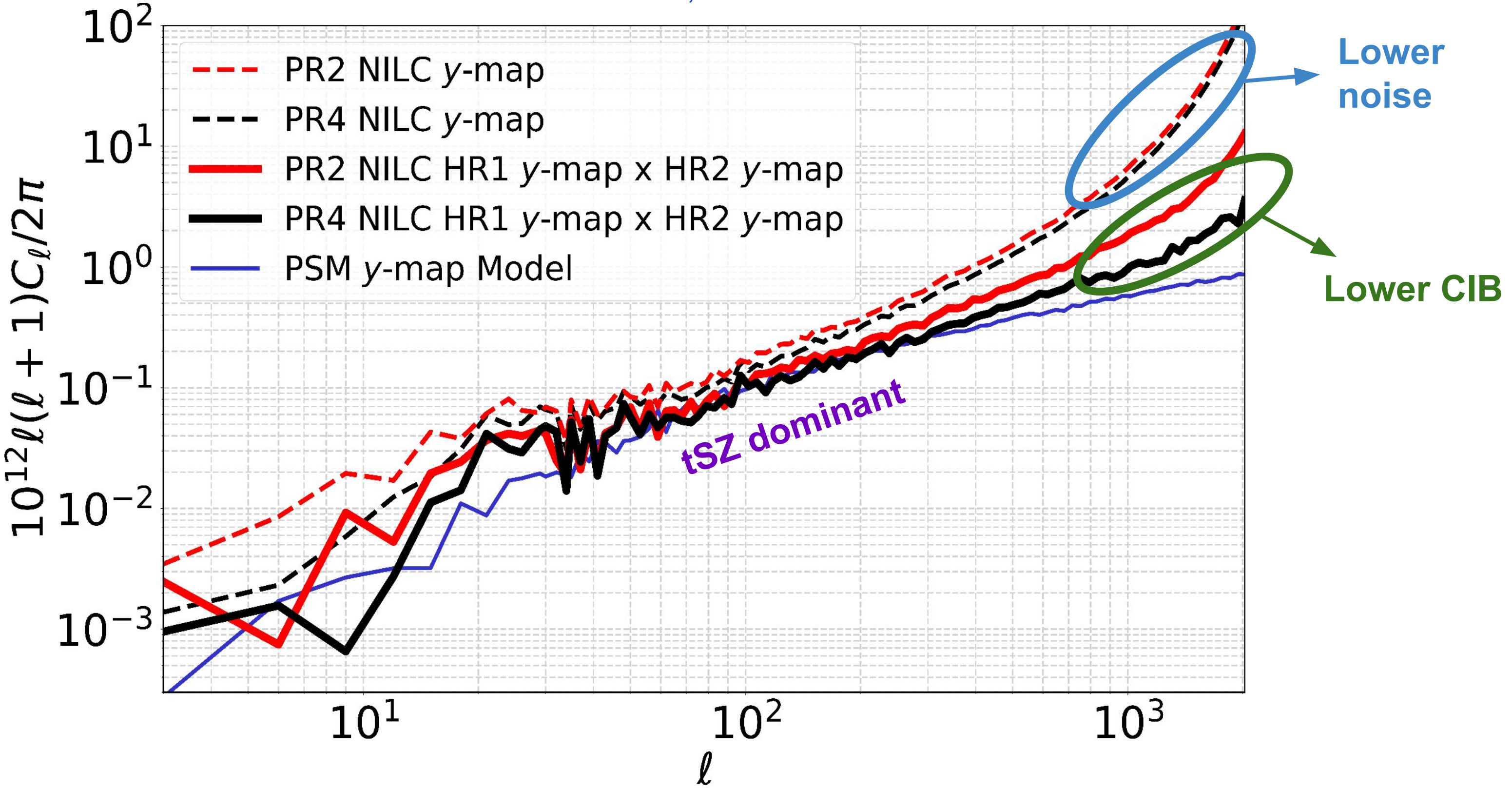
Power spectra

Chandran et al., arXiv:2305.10193



Power spectra

Chandran et al., arXiv:2305.10193



Contaminants in y-map: Cosmic Infrared Background (CIB)

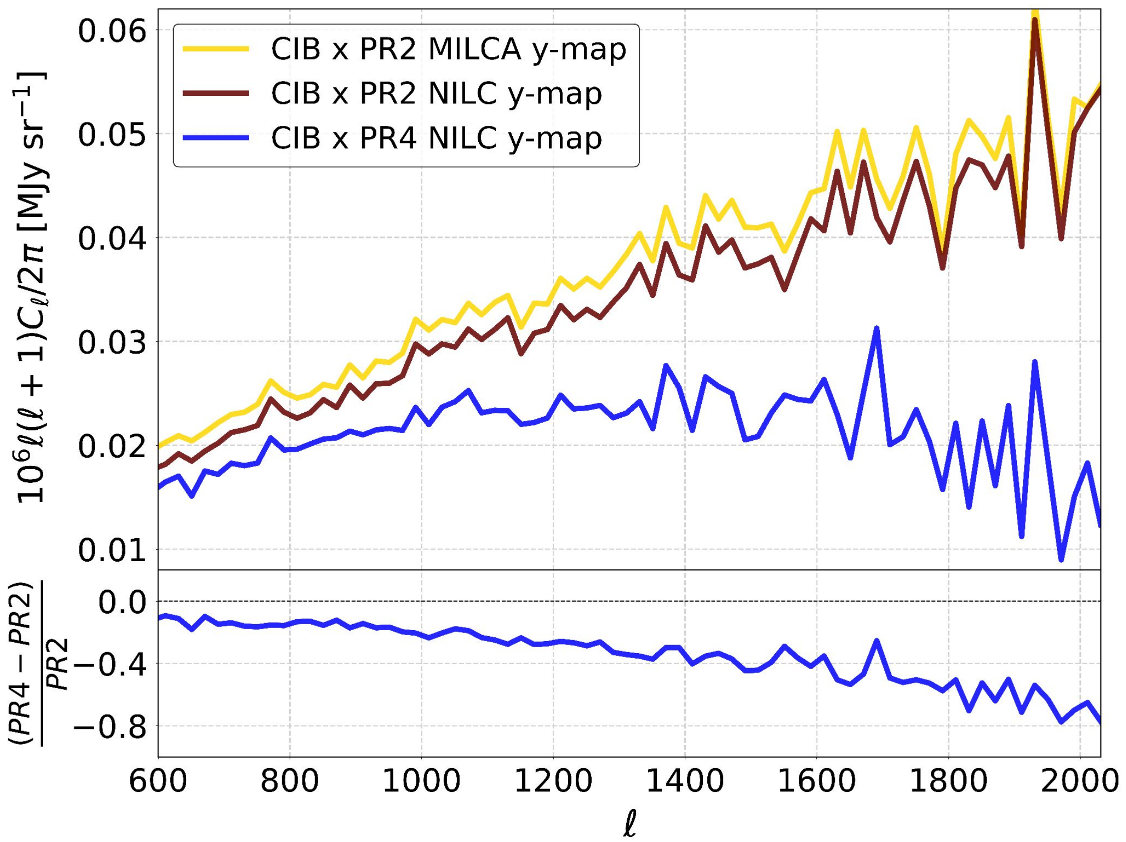
y-map X CIB template

CIB template: GNILC 857 GHz CIB map

(Planck Collaboration Int. XLVIII 2016)

Sky fraction: 50%

34% improvement



Chandran et al., arXiv:2305.10193

Contaminants in y-map: Cosmic Infrared Background (CIB)

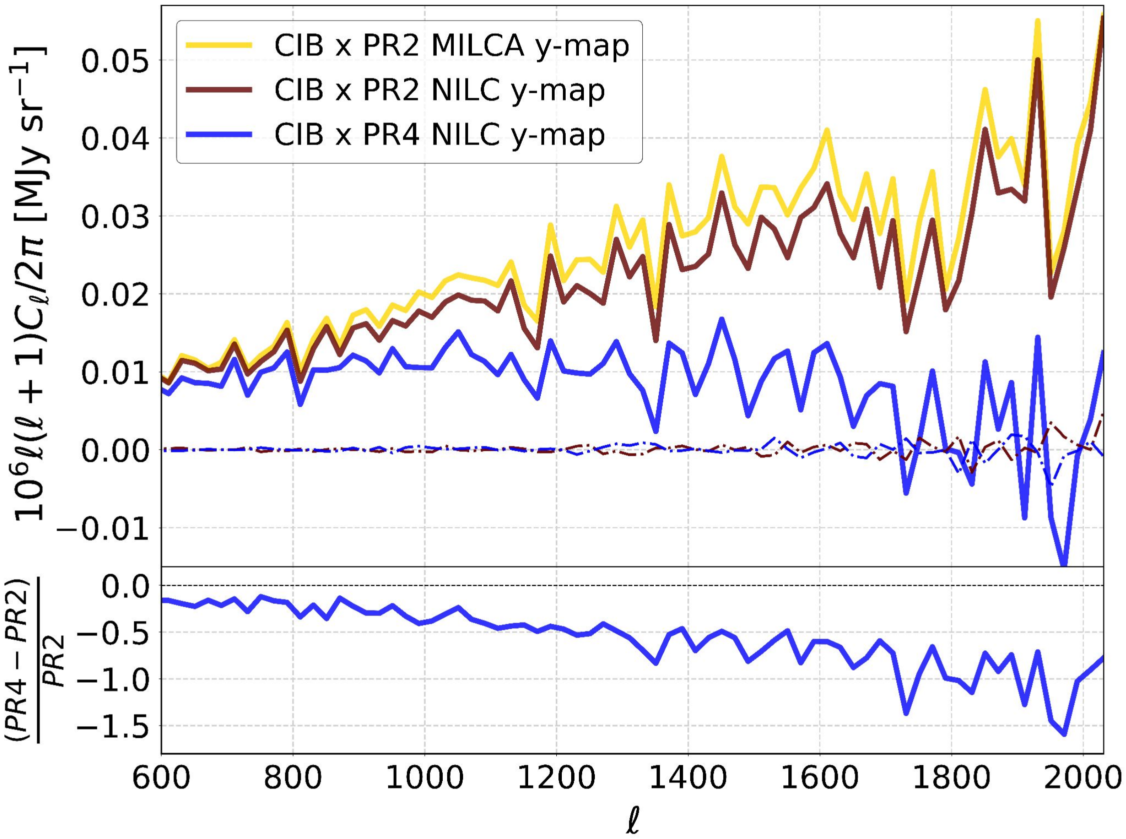
y-map X CIB template

CIB template: Lenz’19 857 GHz CIB map

(Lenz et al. (2019))

Sky fraction: 15%

57% improvement



Chandran et al., arXiv:2305.10193

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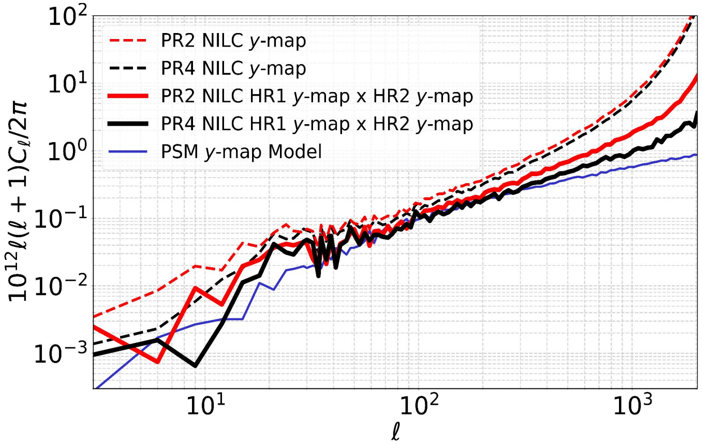
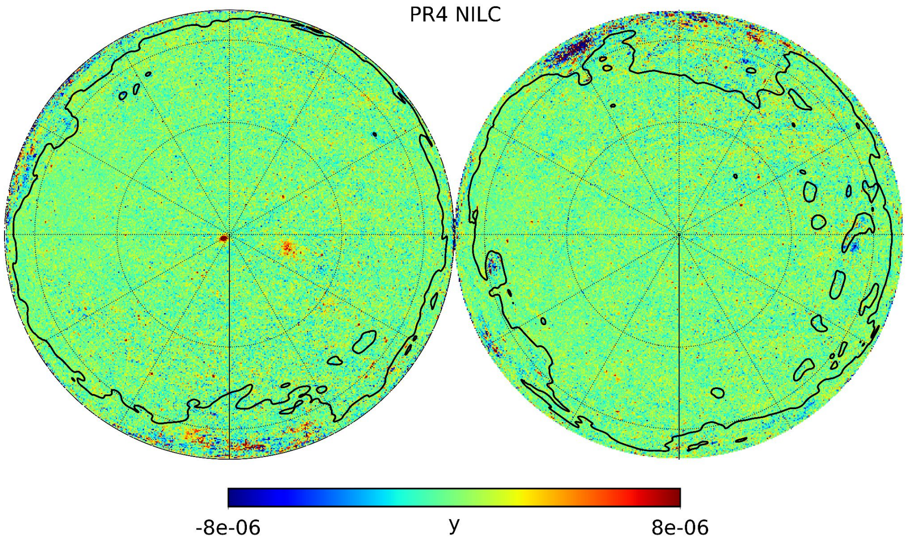
- New all-sky improved thermal SZ Compton y-parameter map
- Publicly available at https://doi.org/10.5281/zenodo.7940376
- Lower noise, CIB and thermal dust contamination
- Lower level of stripes
- Validated on detailed simulations

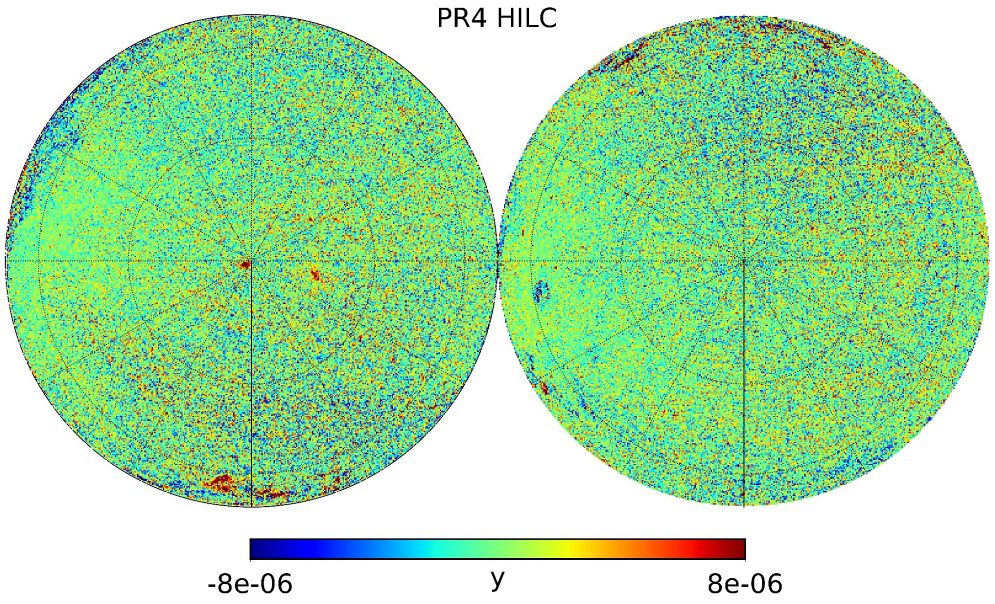
Chandran, Remazeilles and Barreiro (arXiv:2305.10193)

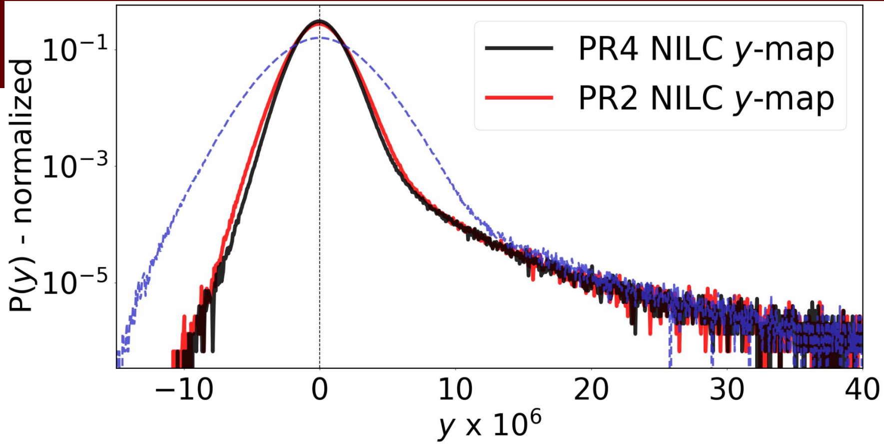


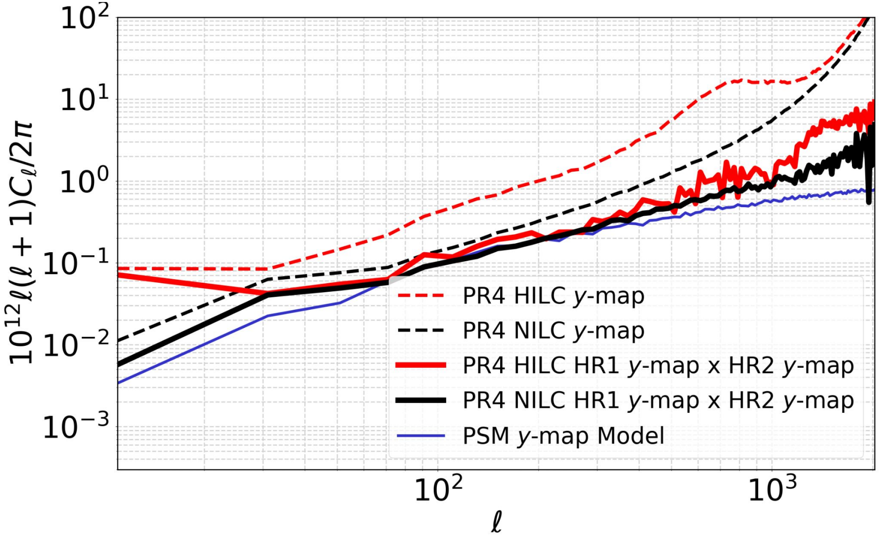


Backup Material

HILC: Don't do it for tSZ!

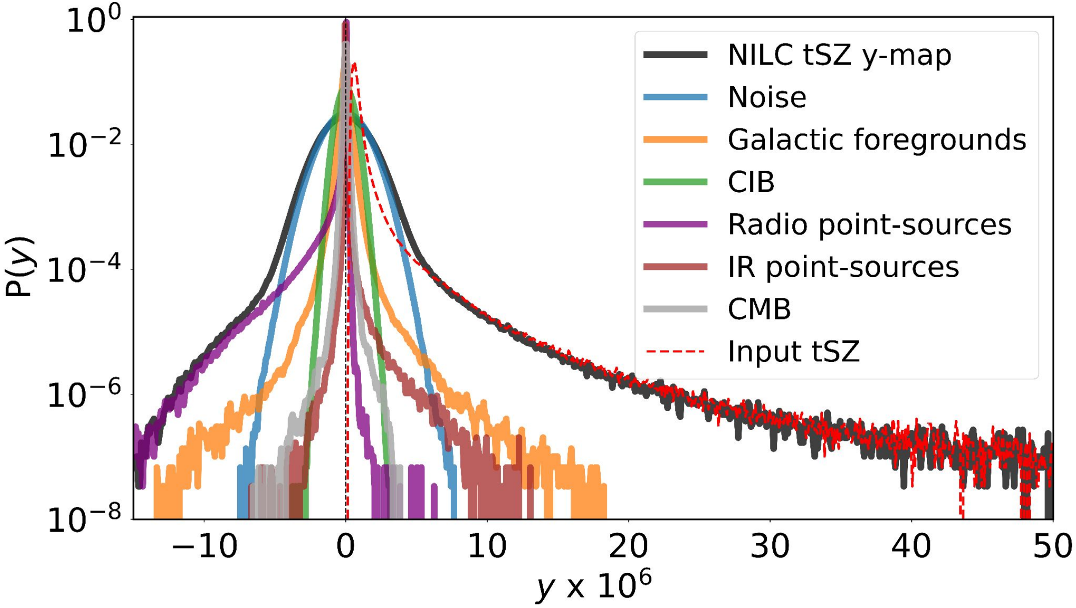


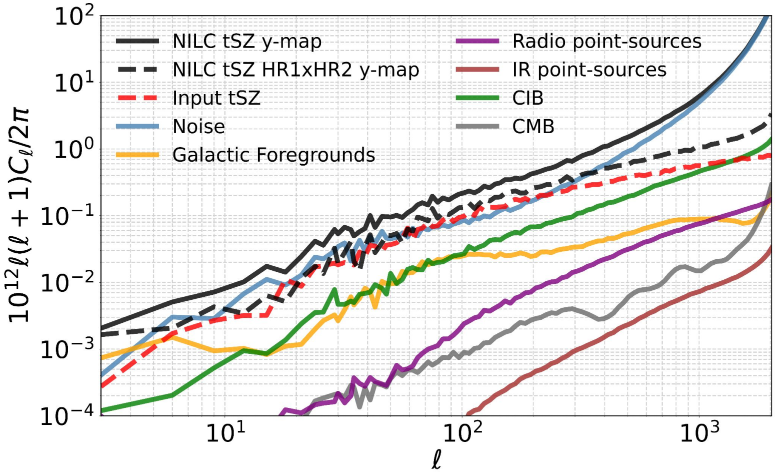




SNR^{HILC} ~ 178; SNR^{NILC} ~ 61 for $\ell \in [30, 1000]$

NILC tSZ y-map from Simulations: 1-PDF

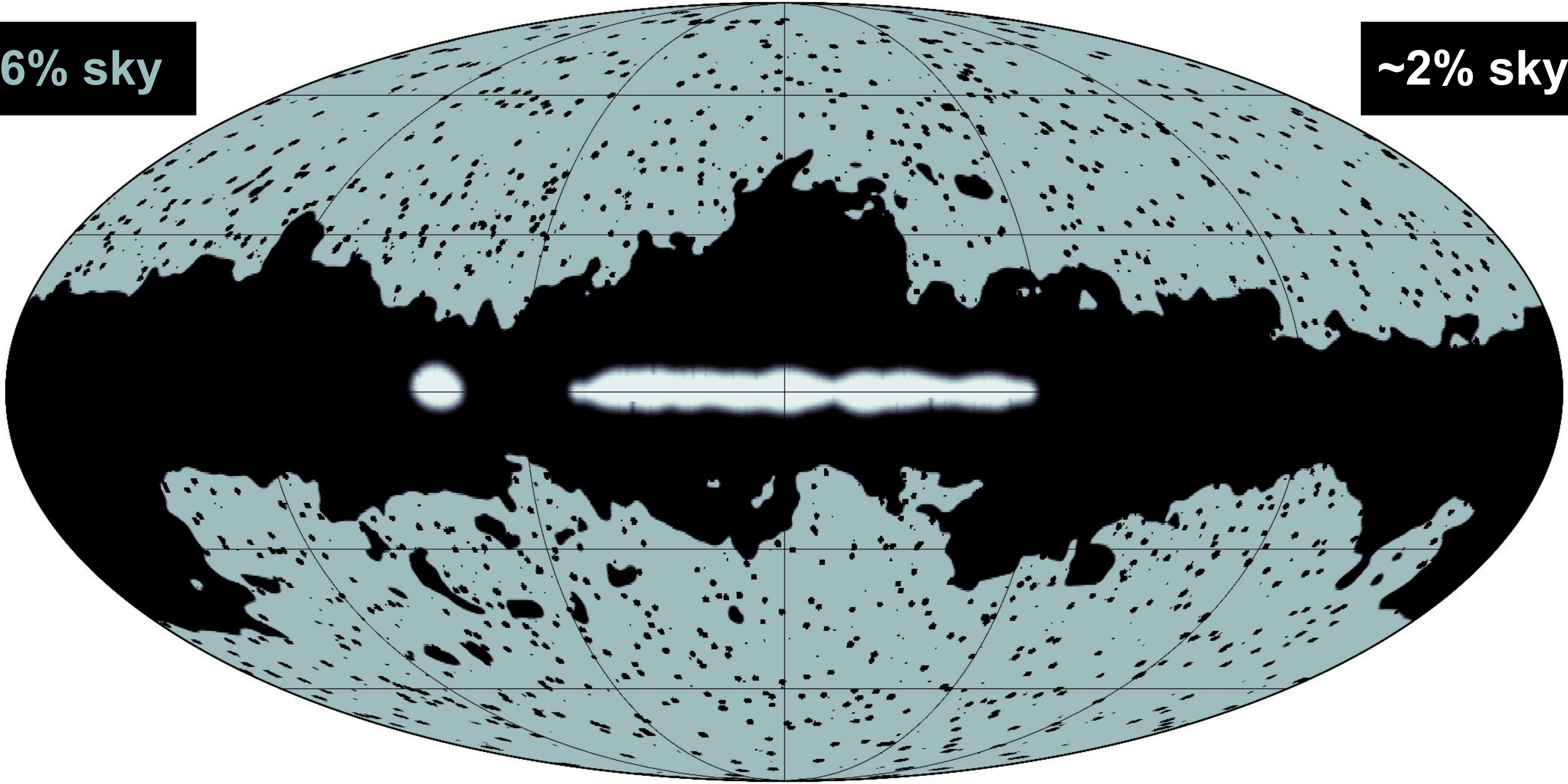




- Negative tail: Radio sources
- Gaussian: Noise + CIB
- Positive tail: thermal SZ
- IR sources: very low

- Large scale: Noise and galactic foregrounds
- Small scale: Noise, CIB and point sources
- CMB is not dominant

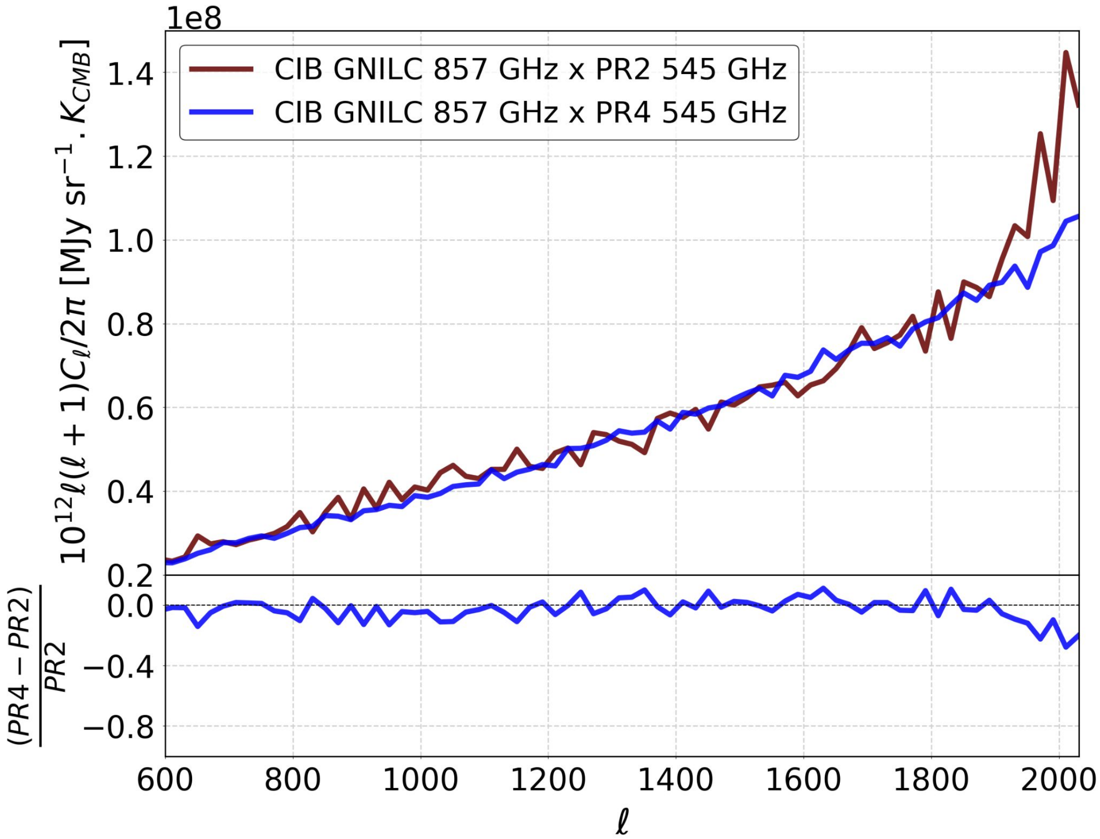
Masks



~56% sky

~2% sky

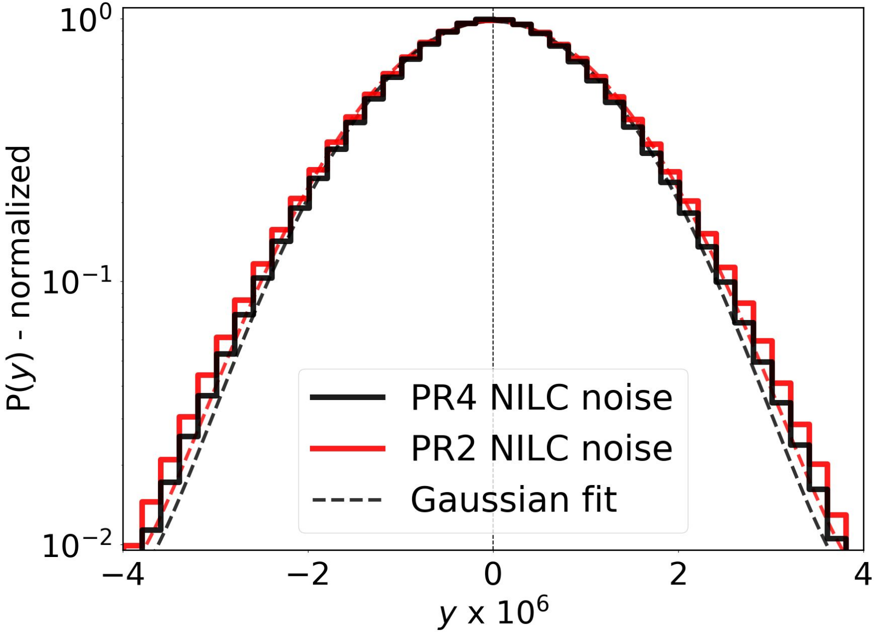
PR2/PR4 545 GHz X CIB GNILC 857



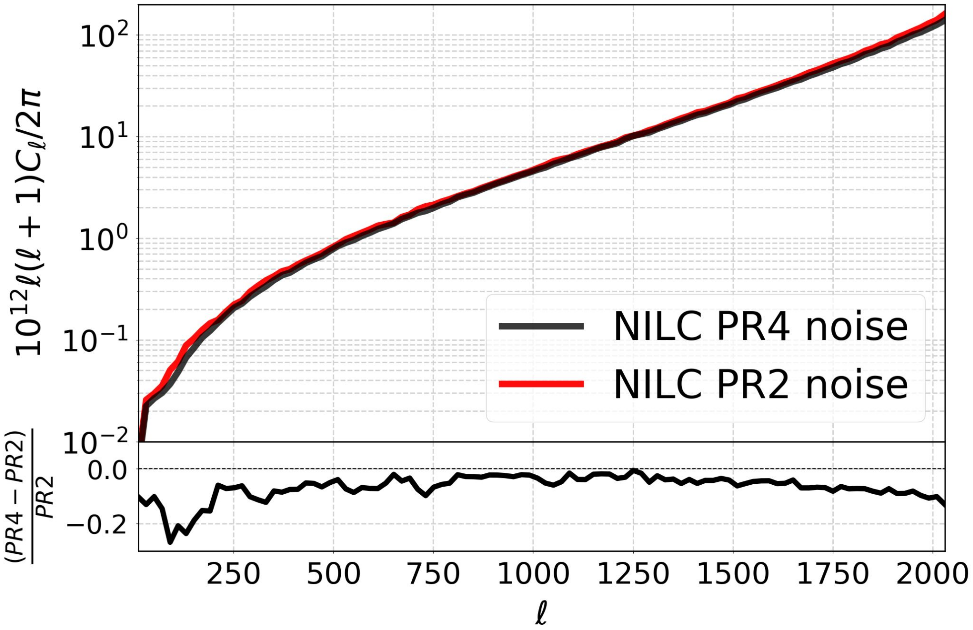
- *Planck* 545 does not contribute significantly to GNILC 857.
- So, different contribution from *Planck* 545 GHz to y-map cannot account for the difference in CIB levels in PR4 and PR2 *y*-maps.

Contaminants in y-map: Noise

- **Noise**: Estimated from half-ring data splits
- Improvement in variance: ~7%

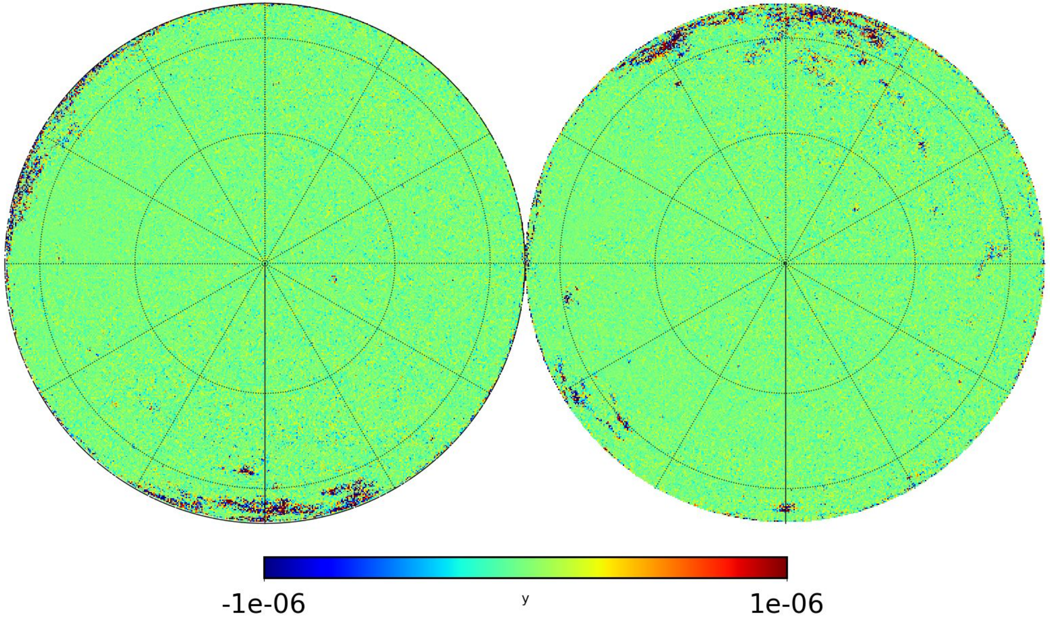


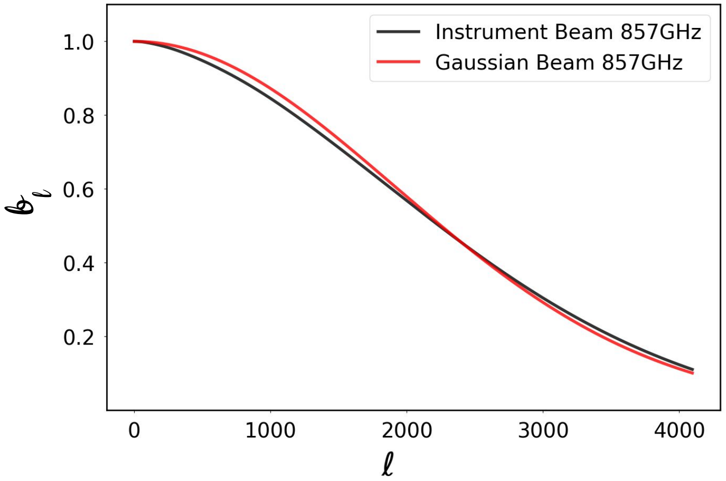
- Improves at all angular scales
- Average improvement for l∈[30,2048] : ~7%

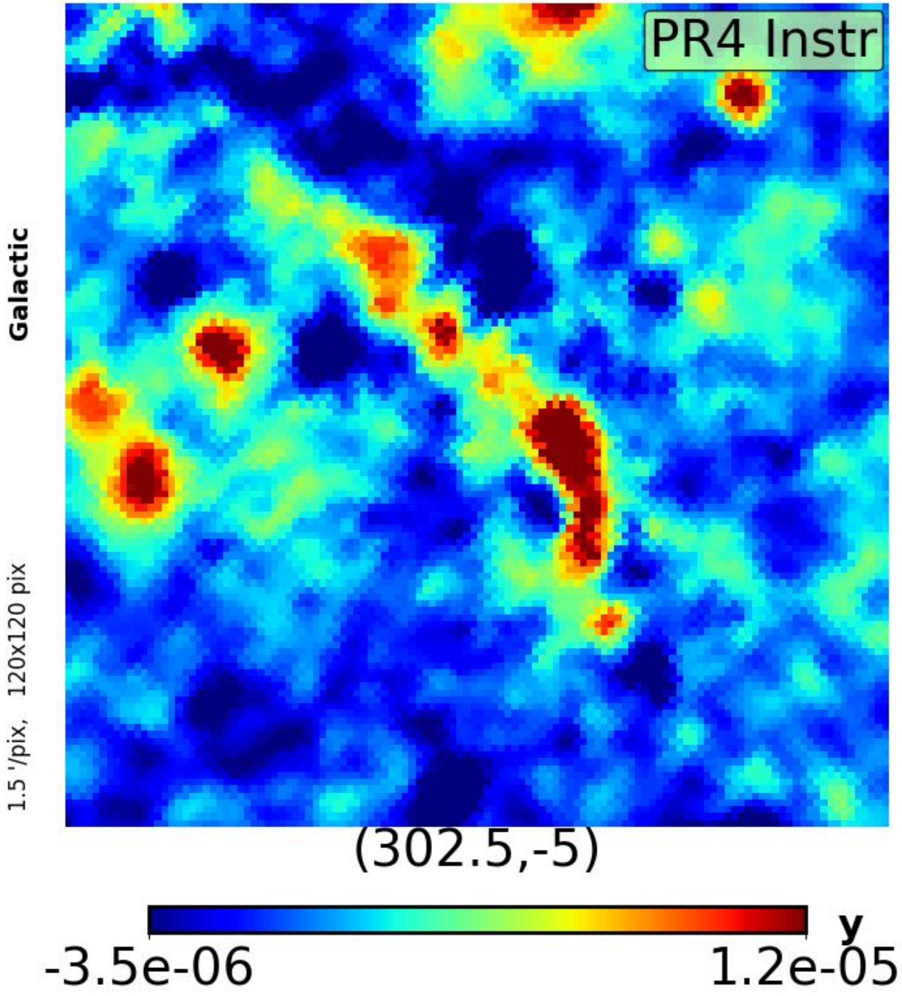


Beams deconvolved: Gaussian approximate vs non-gaussian beams

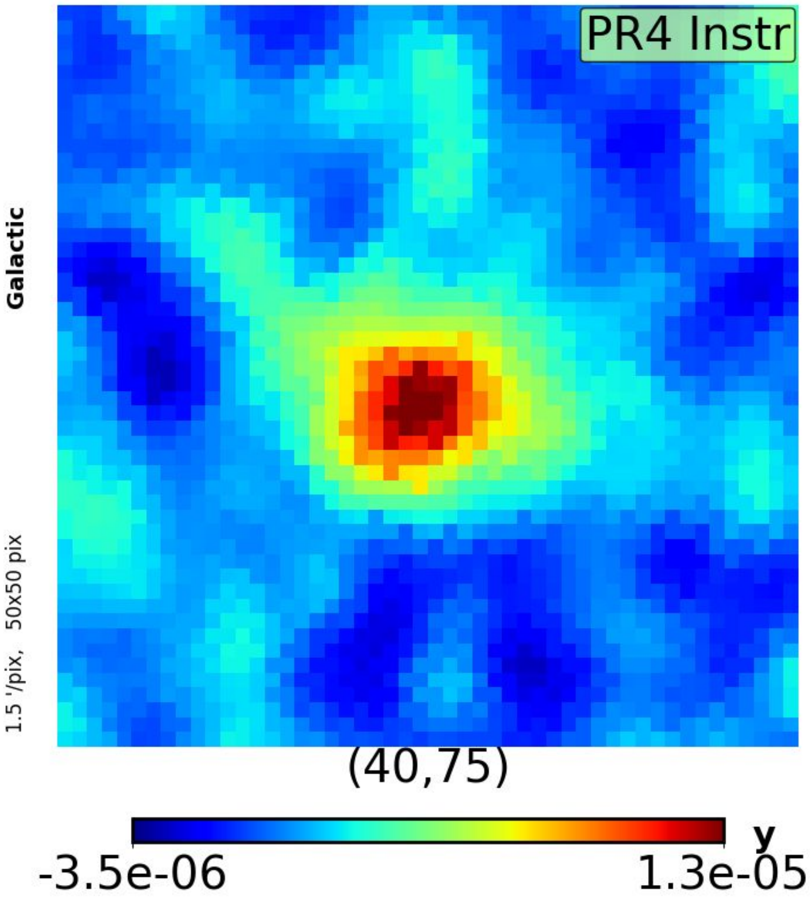
PR4 tSZ (Gaussian beam) - PR4 tSZ (Instrument beam)



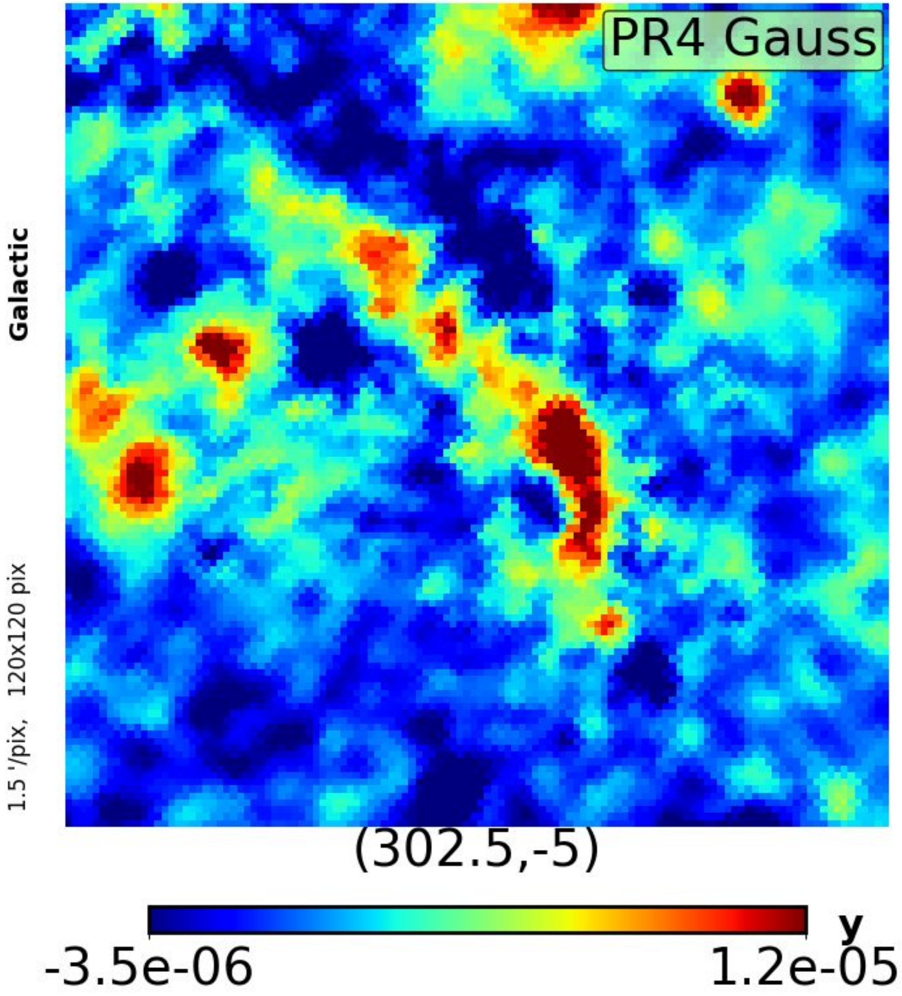


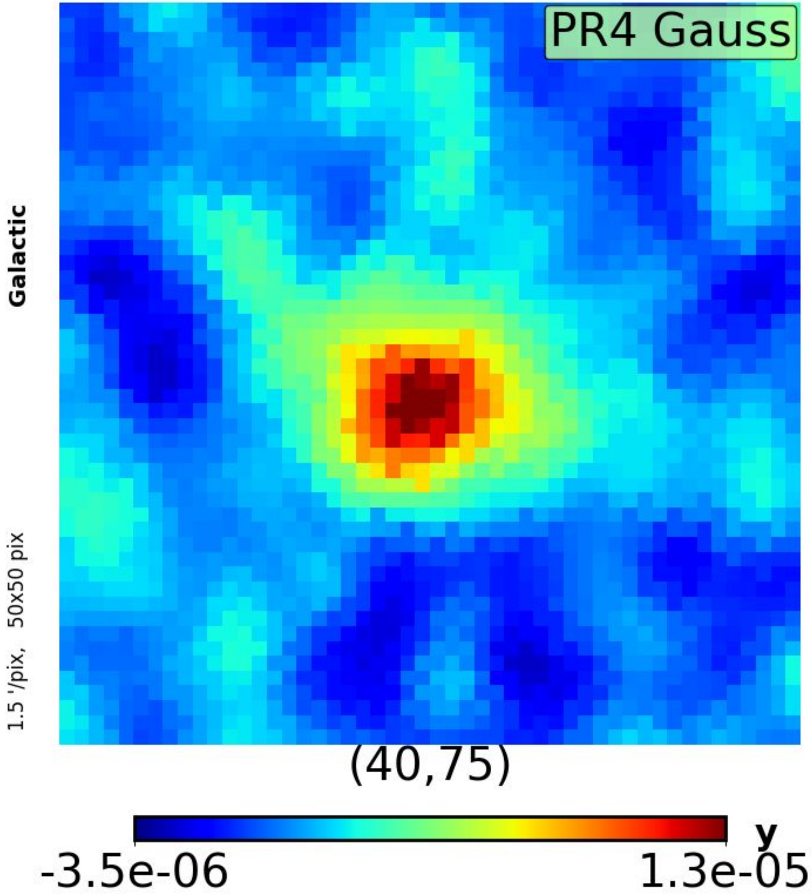


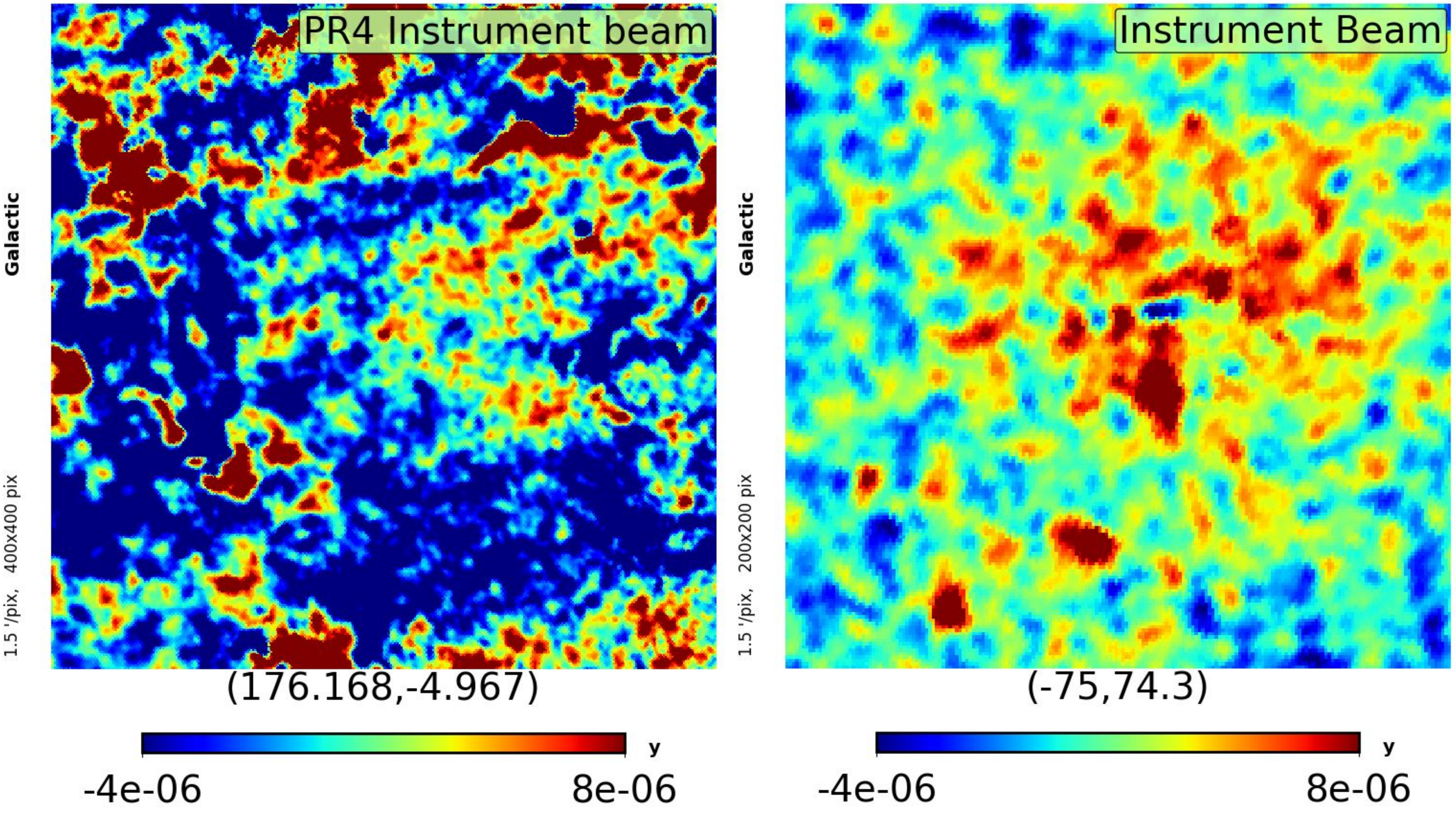
PR4 Instr
Galactic
1.5 '/pix, 120x120 pix
(302.5,-5)
y
-3.5e-06
1.2e-05



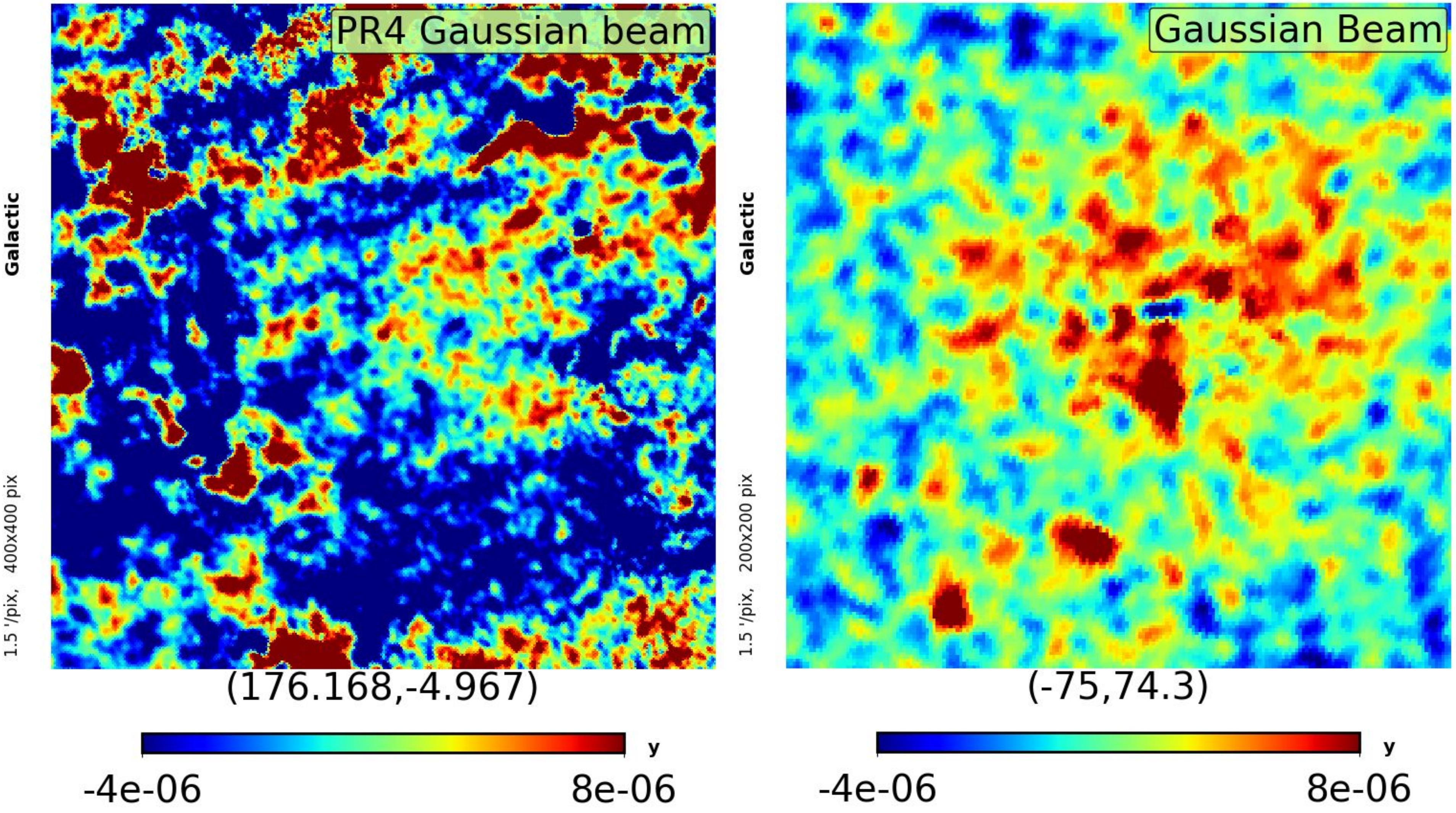
PR4 Instr
Galactic
1.5 '/pix, 50x50 pix
(40,75)
y
-3.5e-06
1.3e-05


PR4 Gauss
Galactic
1.5 '/pix, 120x120 pix
(302.5,-5)
-3.5e-06
1.2e-05
y


PR4 Gauss
Galactic
1.5 '/pix, 50x50 pix
(40,75)
-3.5e-06
1.3e-05
y

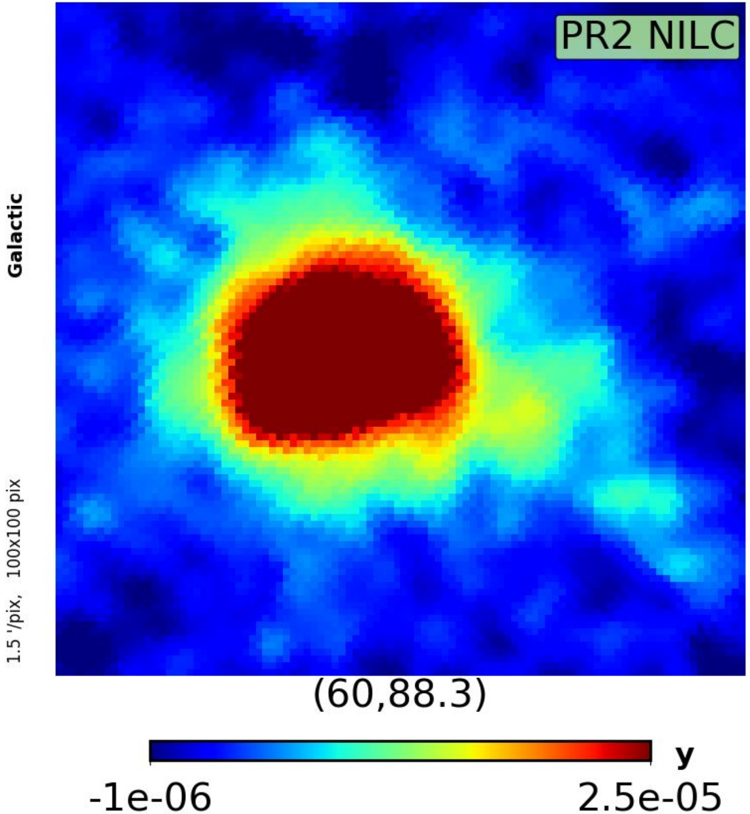


PR4 Instrument beam
Galactic
1.5 '/pix, 400x400 pix
(176.168,-4.967)
y
-4e-06
8e-06
Instrument Beam
Galactic
1.5 '/pix, 200x200 pix
(-75,74.3)
y
-4e-06
8e-06

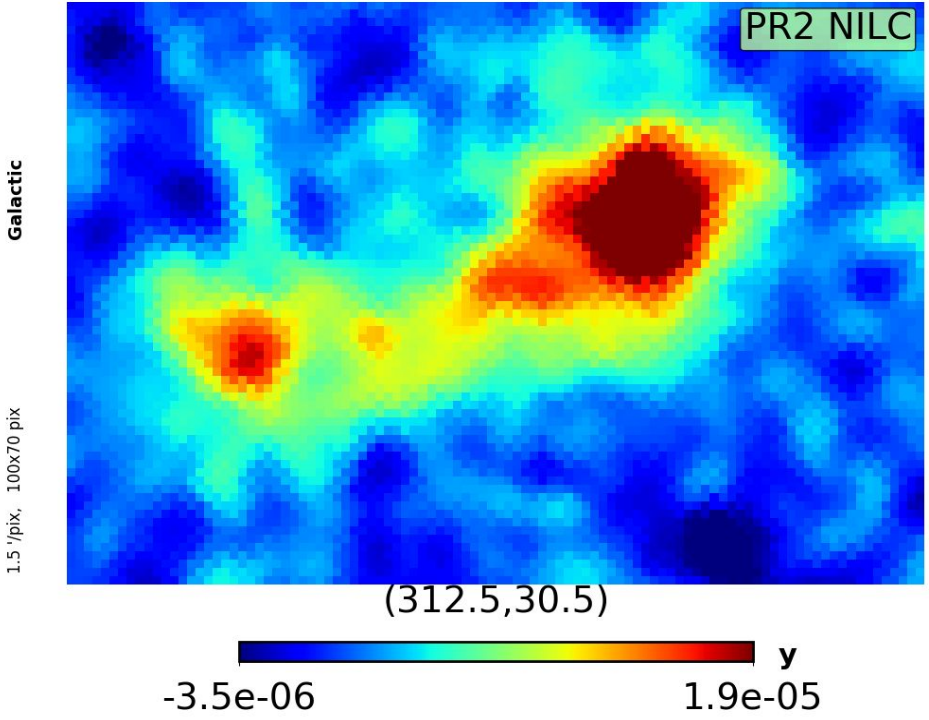

PR4 Gaussian beam
Galactic
1.5 '/pix, 400x400 pix
(176.168,-4.967)
y
-4e-06
8e-06
Gaussian Beam
Galactic
1.5 '/pix, 200x200 pix
(-75,74.3)
y
-4e-06
8e-06

Massive clusters: PR2 NILC *y*-map vs PR4 NILC *y*-map

Coma Cluster

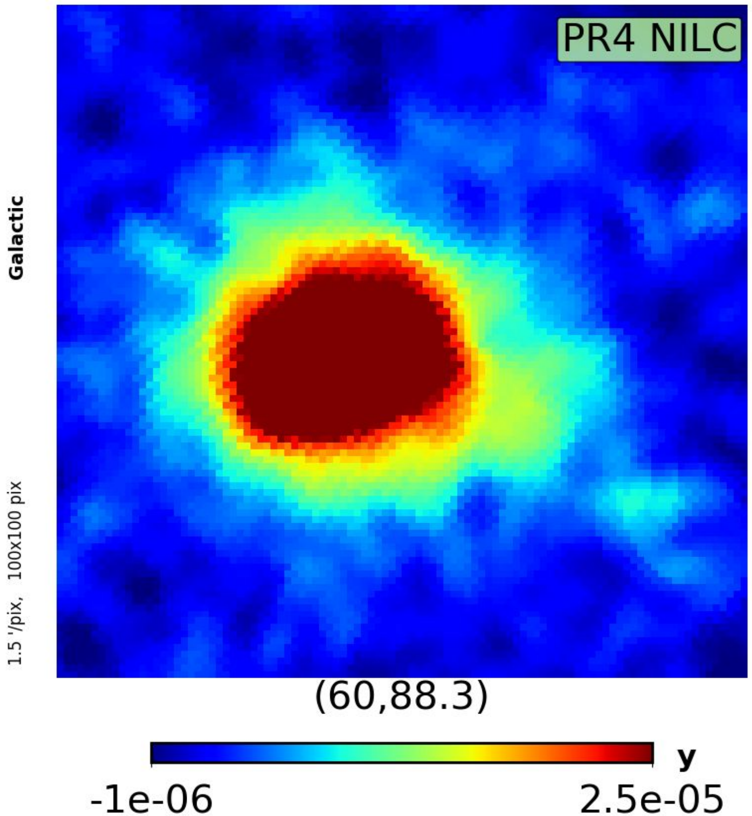


Merging system: Shapley supercluster

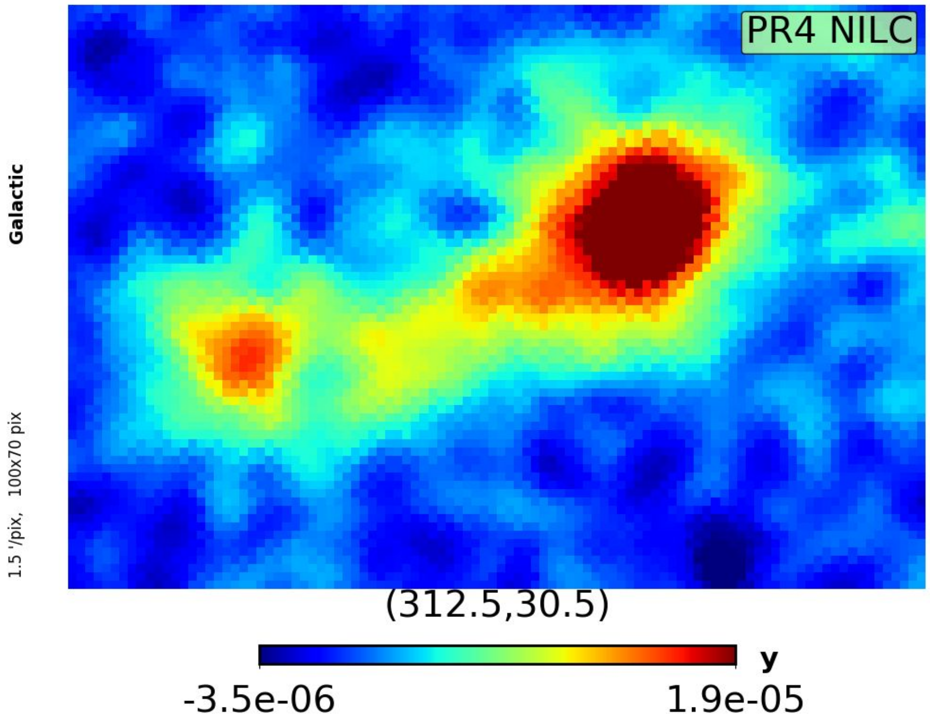


Massive clusters: PR2 NILC *y*-map vs PR4 NILC *y*-map

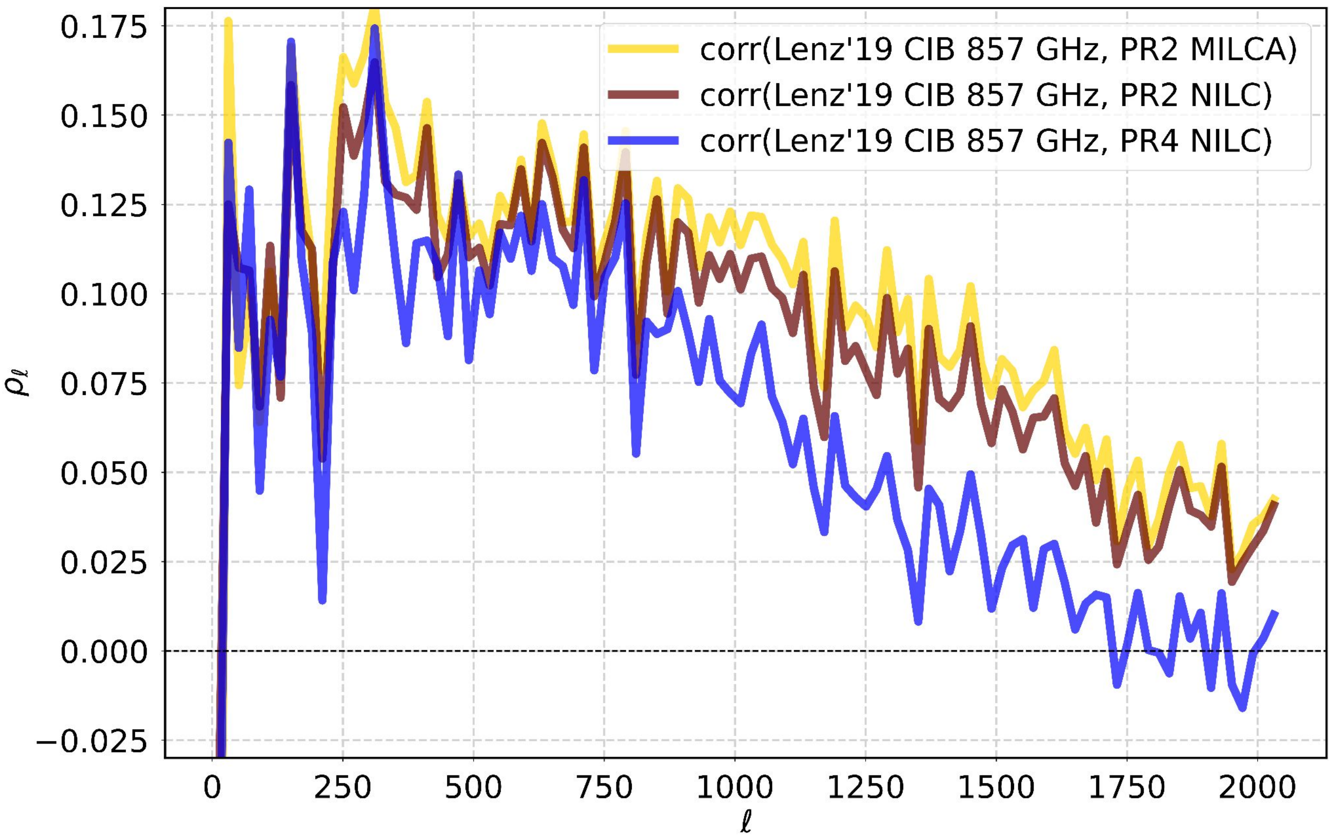
Coma Cluster



Merging system: Shapley supercluster



y-maps cross-correlation with CIB templates



PR4 NILC *y*-map has lower level of contamination of CIB as well as lower correlation with CIB.