Mapping the Hot Gas in the Universe with the LiteBIRD mission

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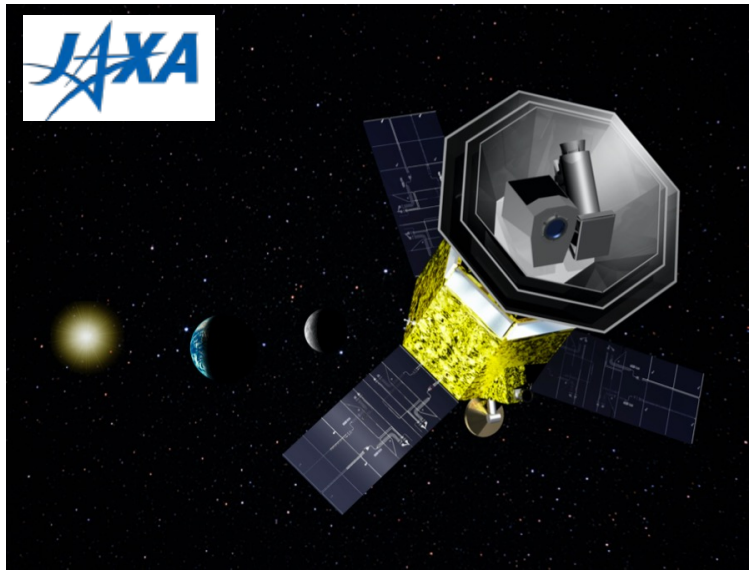
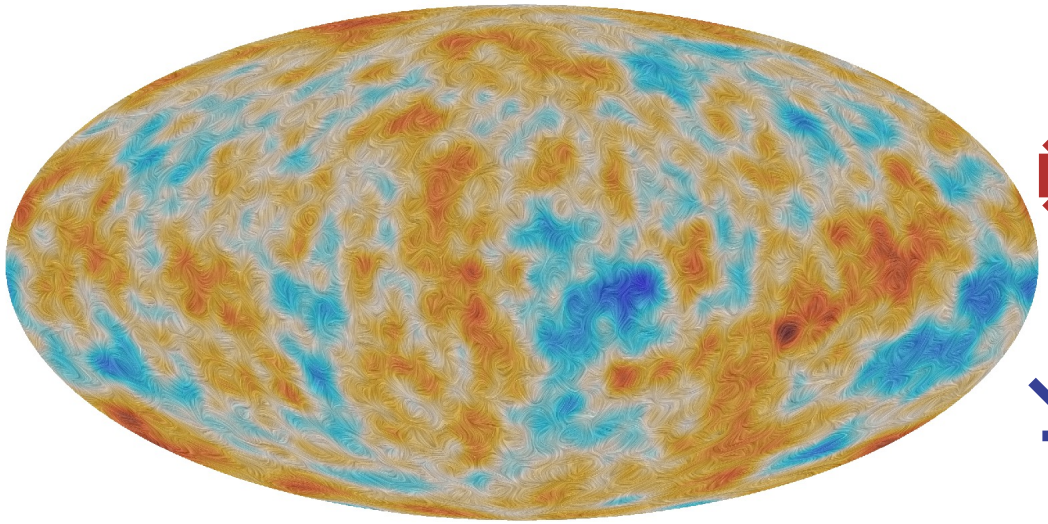
LiteBIRD

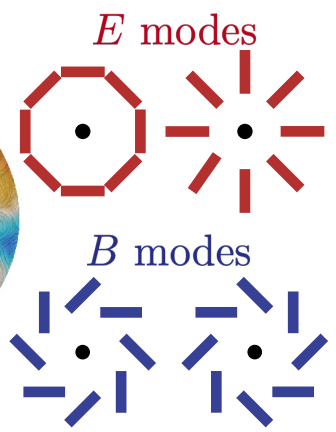
LiteBIRD overview

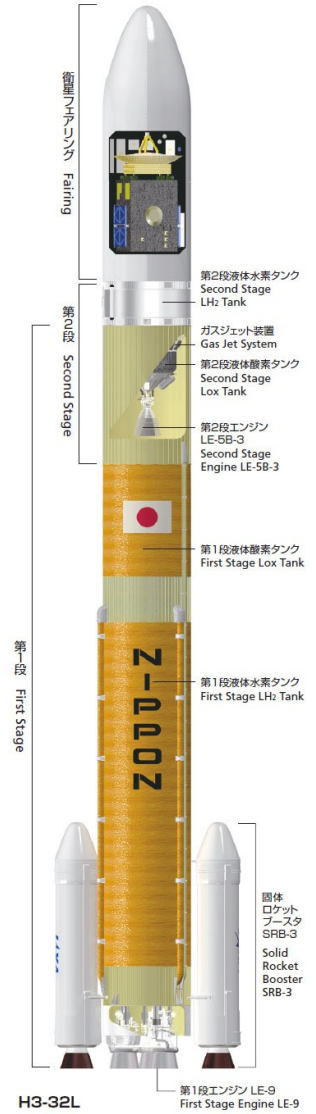
- Lite (Light) satellite for the study of *B*-mode polarization and Inflation from cosmic background Radiation Detection
- JAXA's L-class mission selected in May 2019
- To be launched by JAXA's H3 rocket
- **All-sky 3-year survey**, from Sun-Earth Lagrangian point L2
- Large frequency coverage (**40–402 GHz**, 15 bands) at **70–18 arcmin** angular resolution for precision measurements of the **CMB *B*-modes**
- Final combined sensitivity: **2.2 μK·arcmin**

📖 LiteBIRD collaboration PTEP 2023









Prepared for submission to JCAP

LiteBIRD Science Goals and Forecasts. Mapping the Hot Gas in the Universe

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LiteBIRD Collaboration.

arXiv:2407.17555

- Unlike cluster catalogues, which only capture thermal Sunyaev-Zeldovich (SZ) emission from massive, well-resolved clusters, the Compton y-map probes the entire hot gas distribution over the sky.

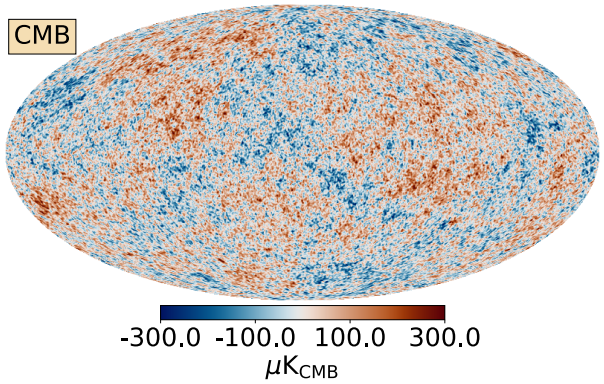
- The Planck Compton y-map is the first and unique all-sky map of the thermal SZ effect to date.

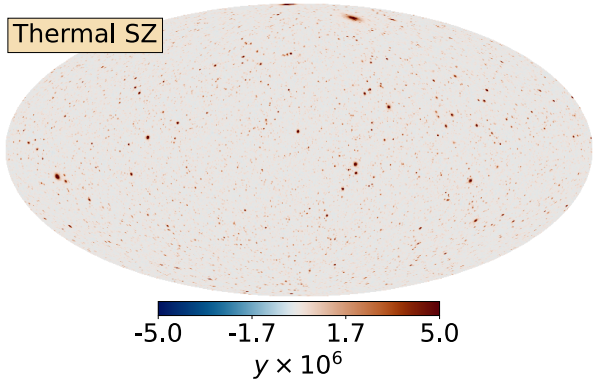
- Despite low angular resolution for galaxy cluster science, LiteBIRD offers **enhanced sensitivity**, **full-sky coverage**, and **multiple frequency bands** compared to Planck.

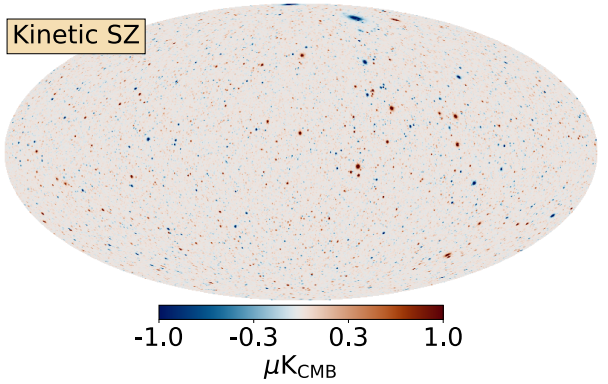
- LiteBIRD is well-positioned to deliver the next all-sky thermal SZ map, with reduced foreground contamination compared to Planck.
  - ➔ *Important legacy data from LiteBIRD*
  - ➔ *Important impact on cosmology and astrophysics*

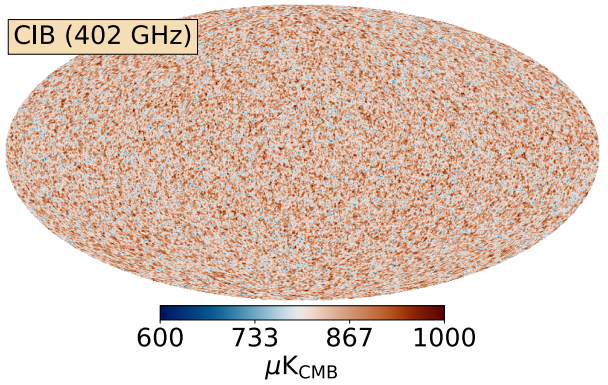
- We propose to combine both LiteBIRD and Planck channels to leverage the advantages of each experiment for optimal y-map reconstruction and improved constraints on σ_8.

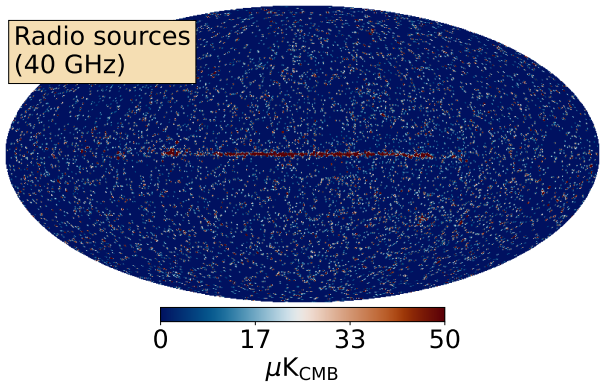
Sky simulations for LiteBIRD and Planck

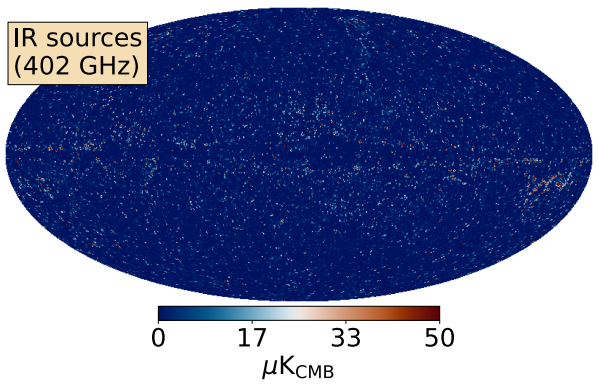


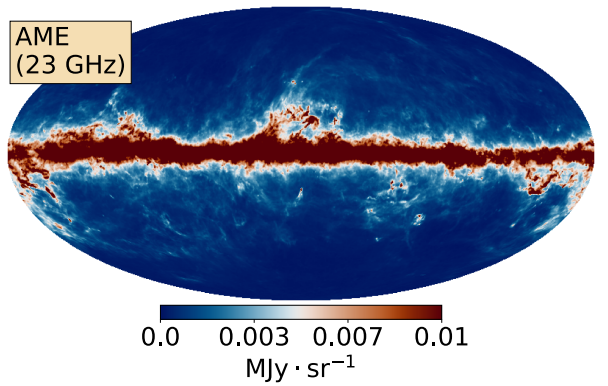


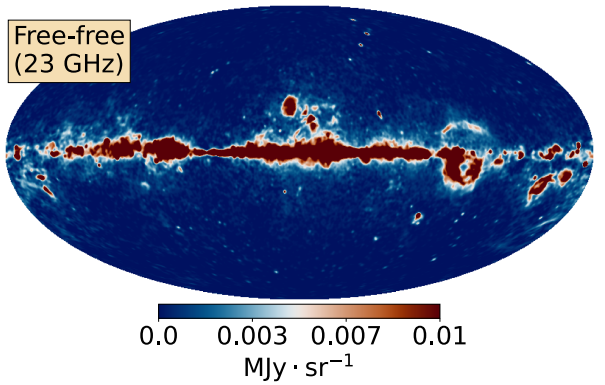


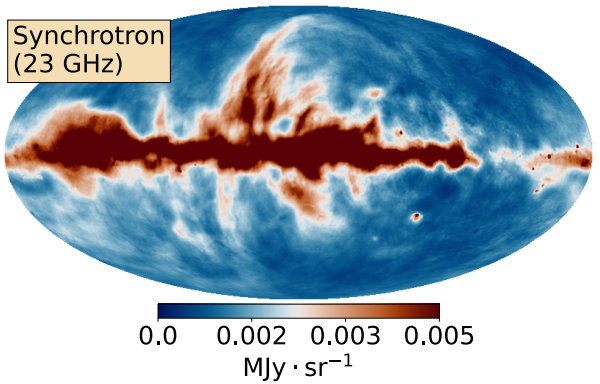


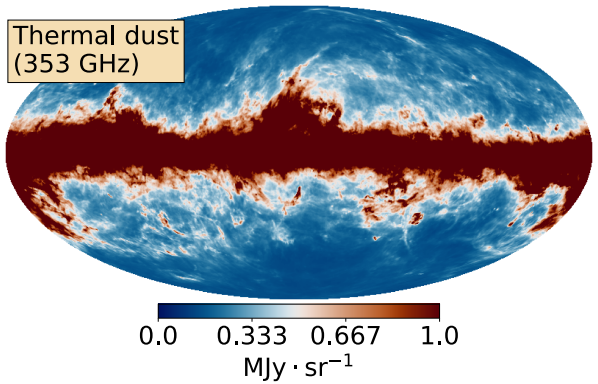












- Comprehensive sky simulations
- Both LiteBIRD and Planck instruments
- Including $1/f$ noise

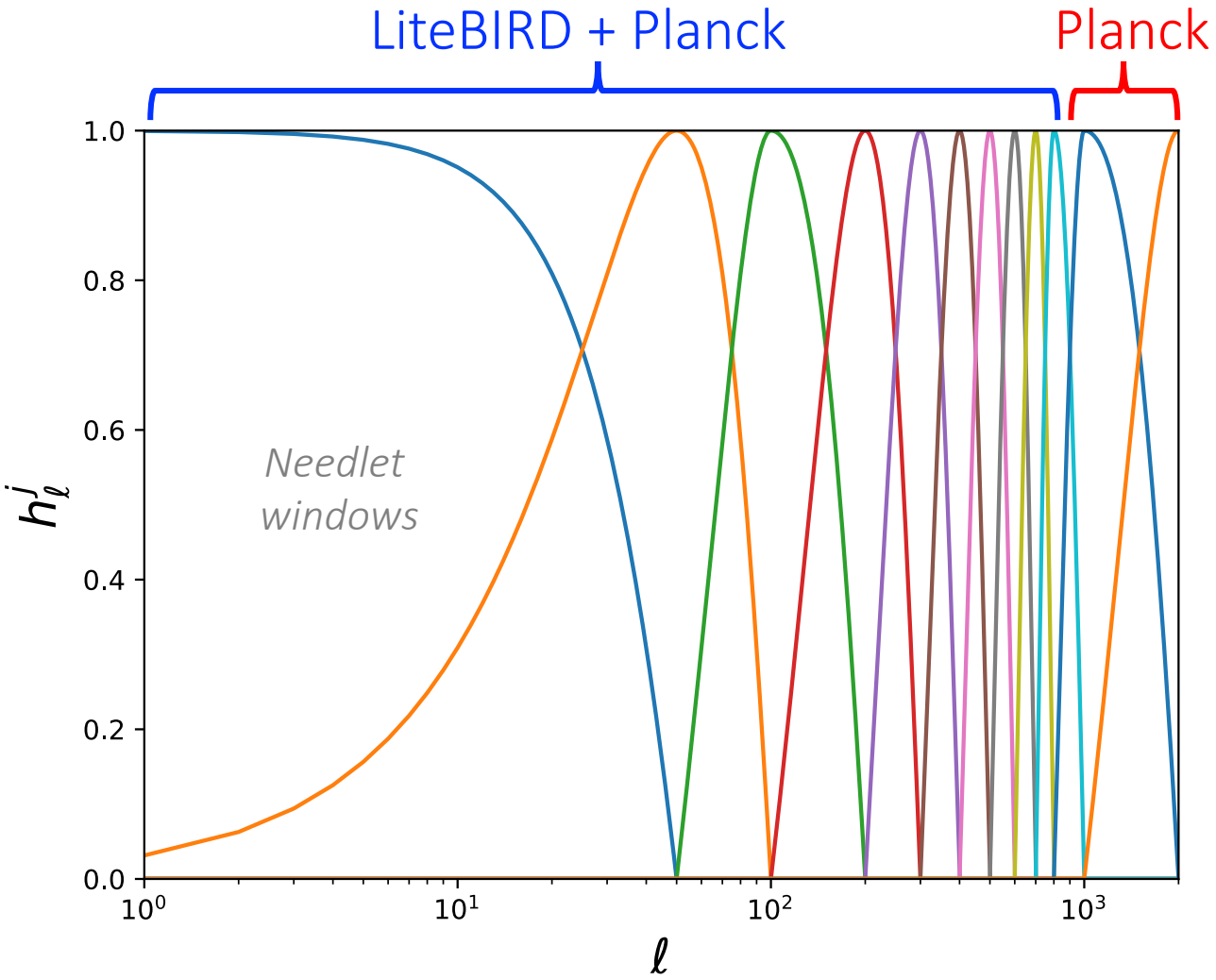
arXiv:2407.17555

Combining LiteBIRD and Planck channels for component separation with NILC

NILC enables the combination of multi-resolution frequency data from different experiments

Remazeilles, Aghanim, Douspis MNRAS (2013)

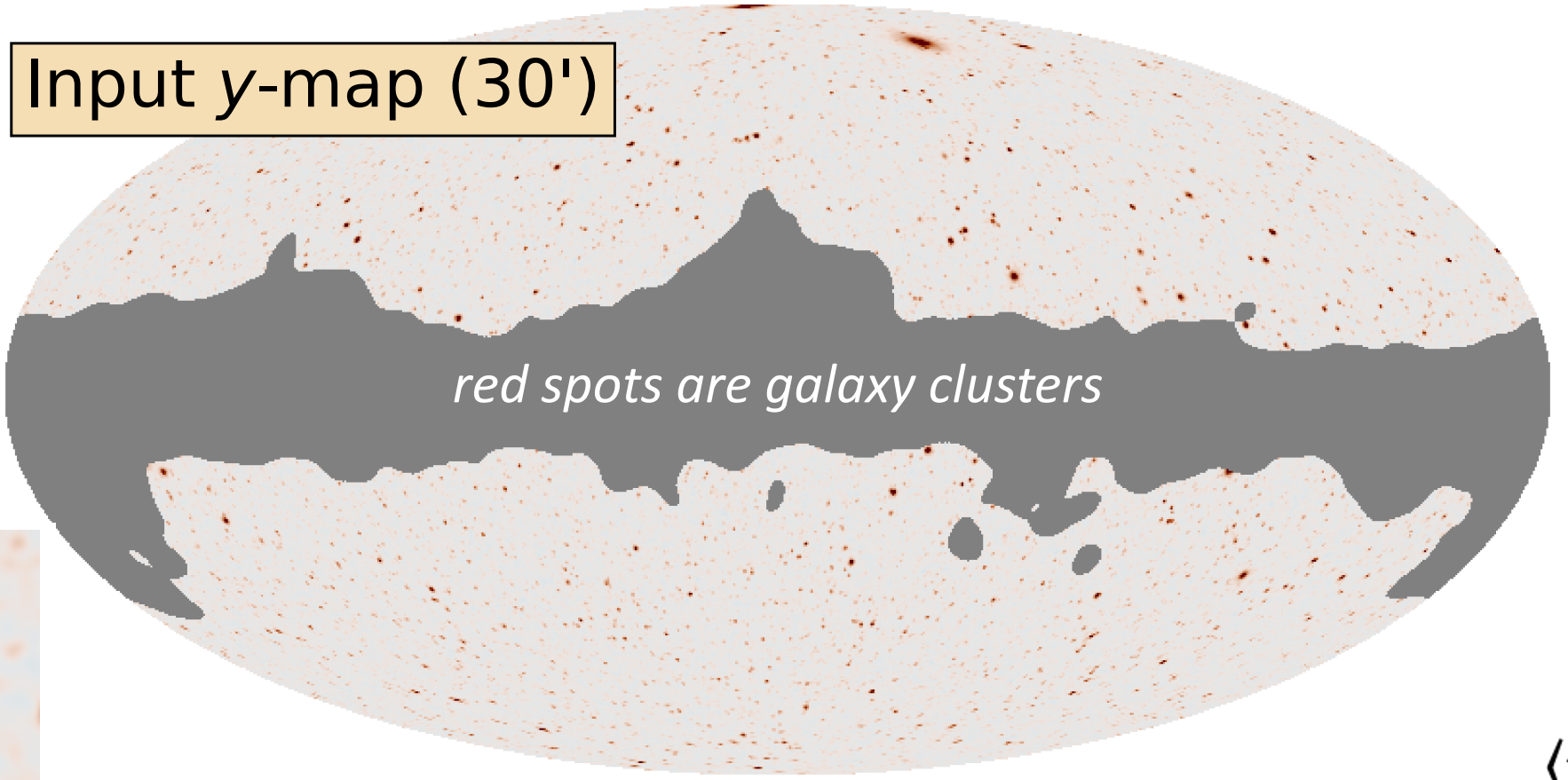
LiteBIRD channels enhance foreground cleaning, while Planck channels provide resolution beyond LiteBIRD beam limits

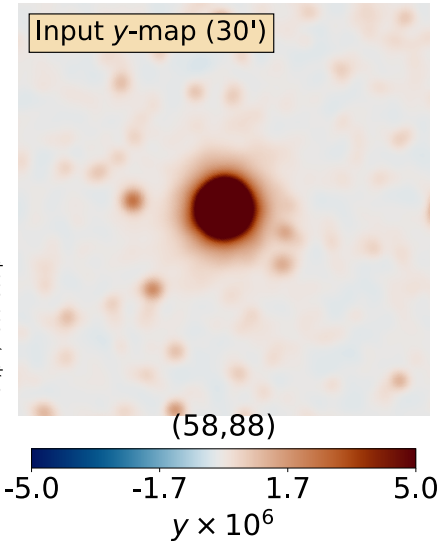


arXiv:2407.17555

Thermal SZ y-map reconstruction

arXiv:2407.17555





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

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

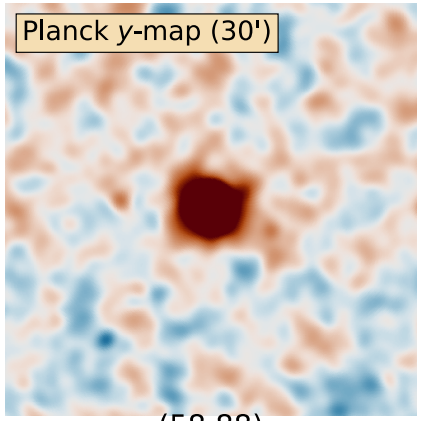
Thermal SZ y-map reconstruction

arXiv:2407.17555

Planck
NILC *y*-map (30')

After component separation

red spots are galaxy clusters



-5.0 -1.7 1.7 5.0

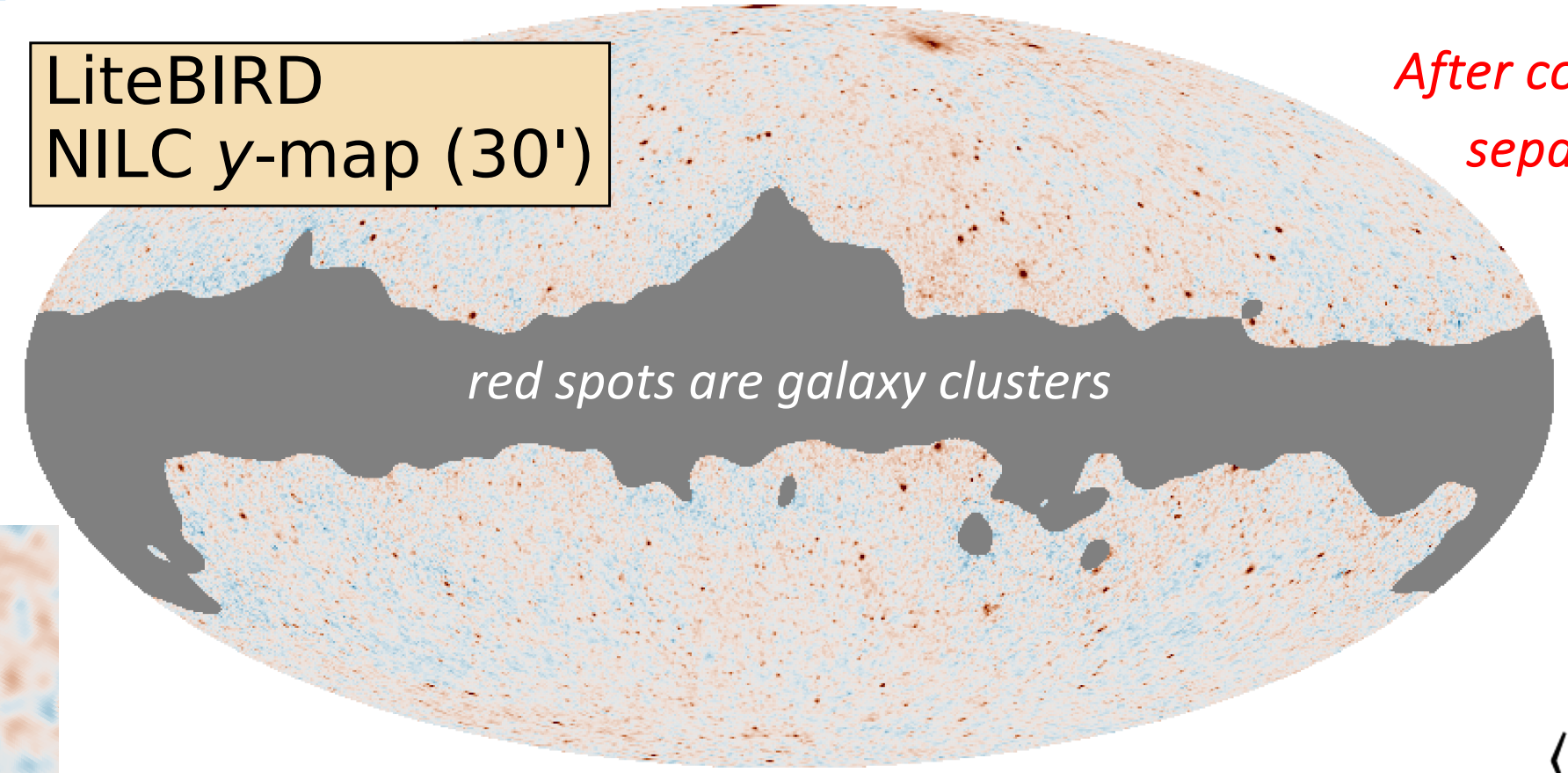
$y \times 10^6$

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

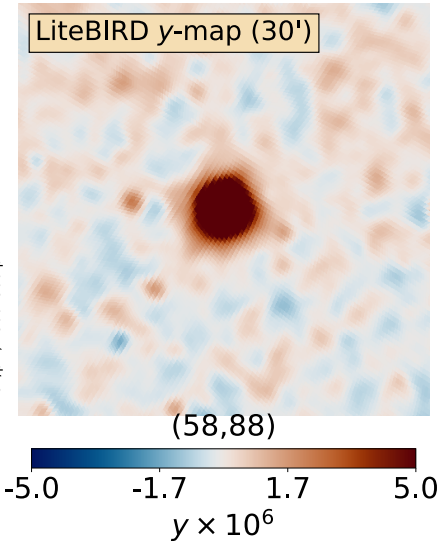
$\langle yyy \rangle \sim \sigma_8^{11}$

Thermal SZ y-map reconstruction

arXiv:2407.17555



After component separation



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Thermal SZ y-map reconstruction

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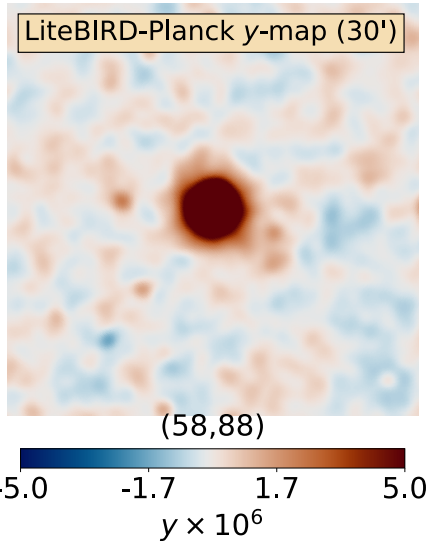
LiteBIRD-Planck
NILC *y*-map (30')

After component separation

red spots are galaxy clusters



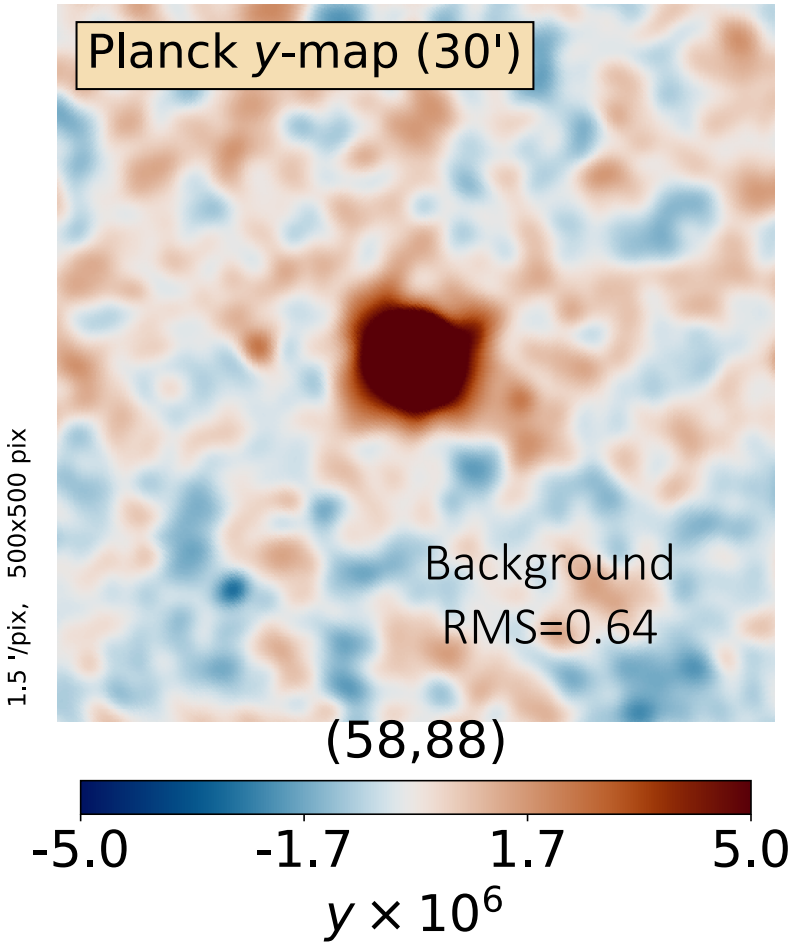
-5.0 -1.7 1.7 5.0

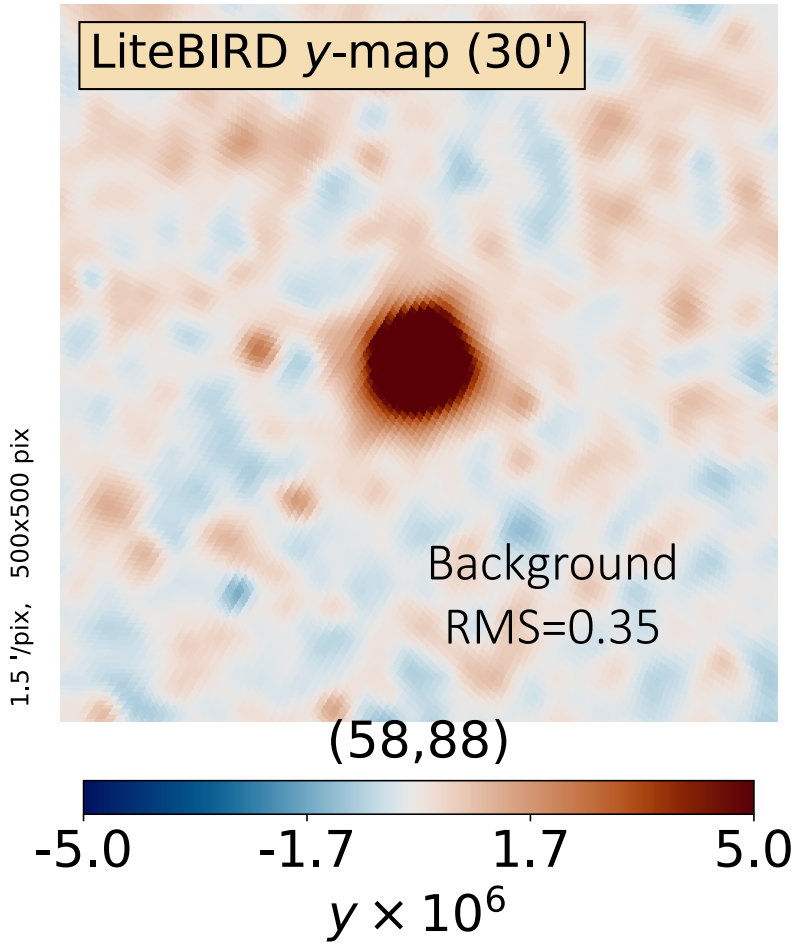
$y \times 10^6$

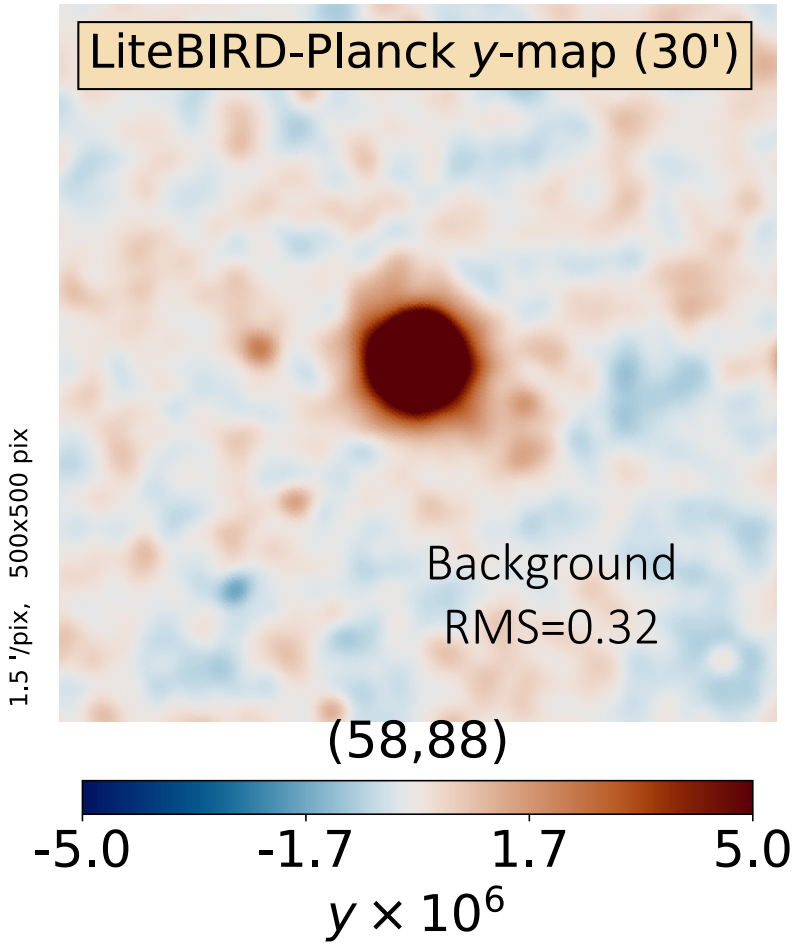
$\langle yy \rangle \sim \sigma_8^8$

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

Comparison of y-maps around Coma



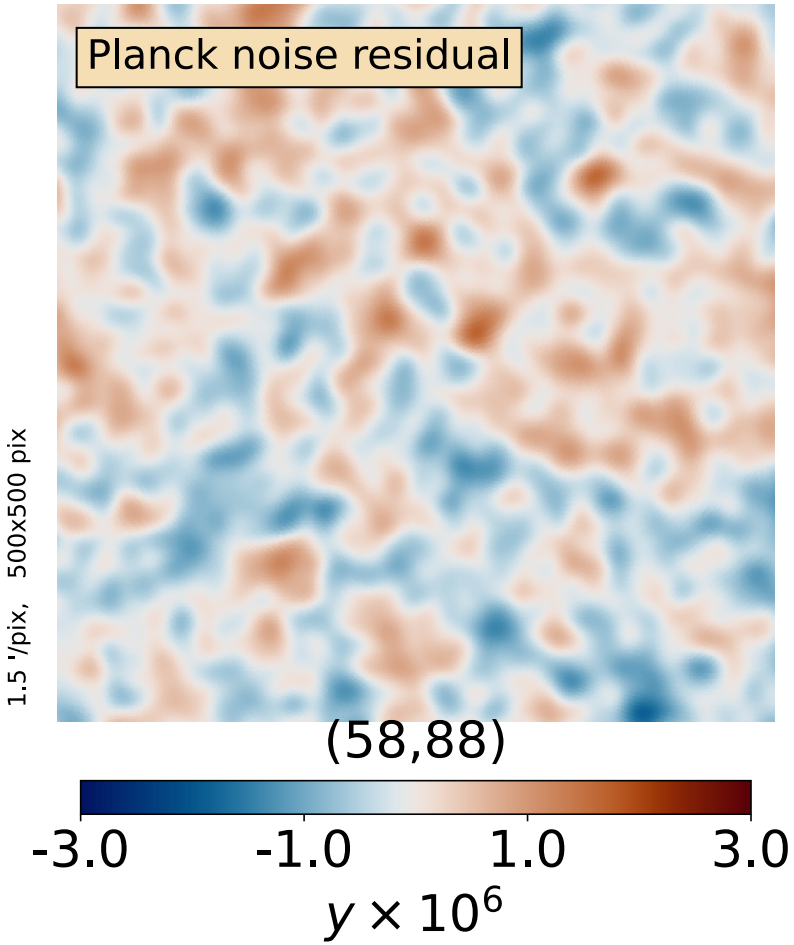


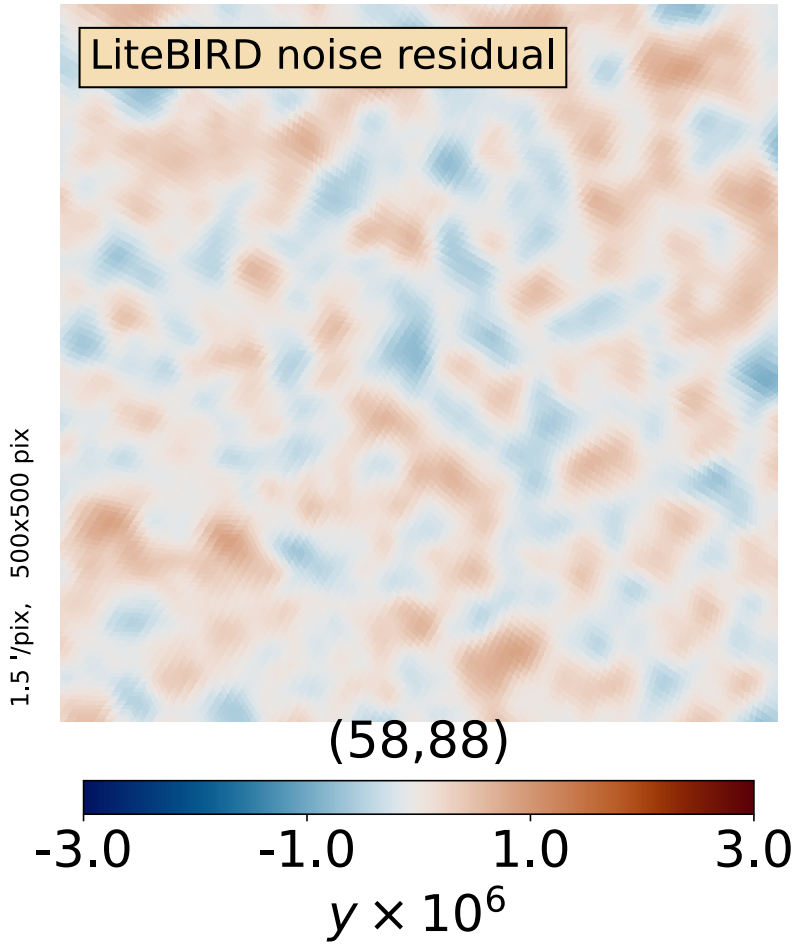


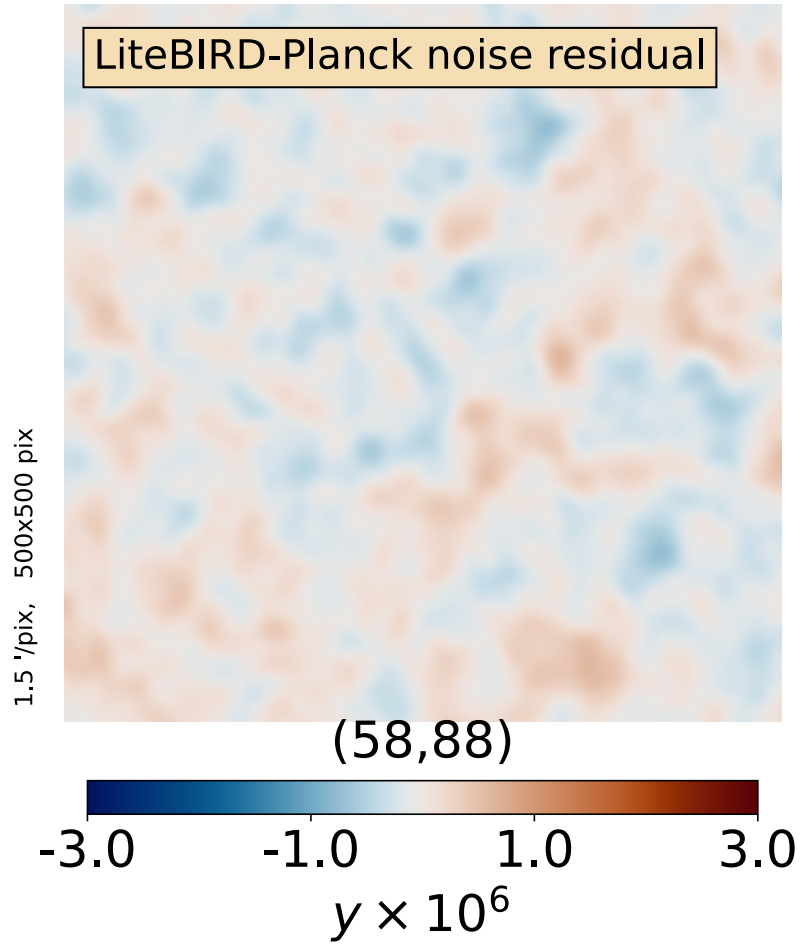
Improvement in SZ map quality from Planck to LiteBIRD, and from LiteBIRD to joint LiteBIRD-Planck

arXiv:2407.17555

Residual noise contamination



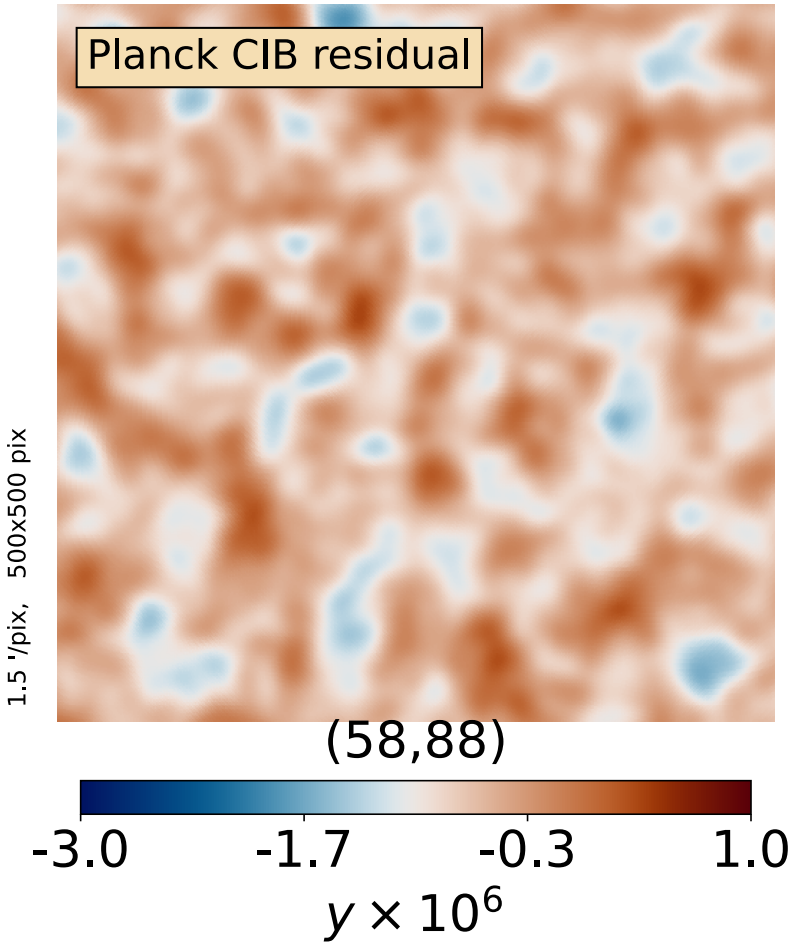


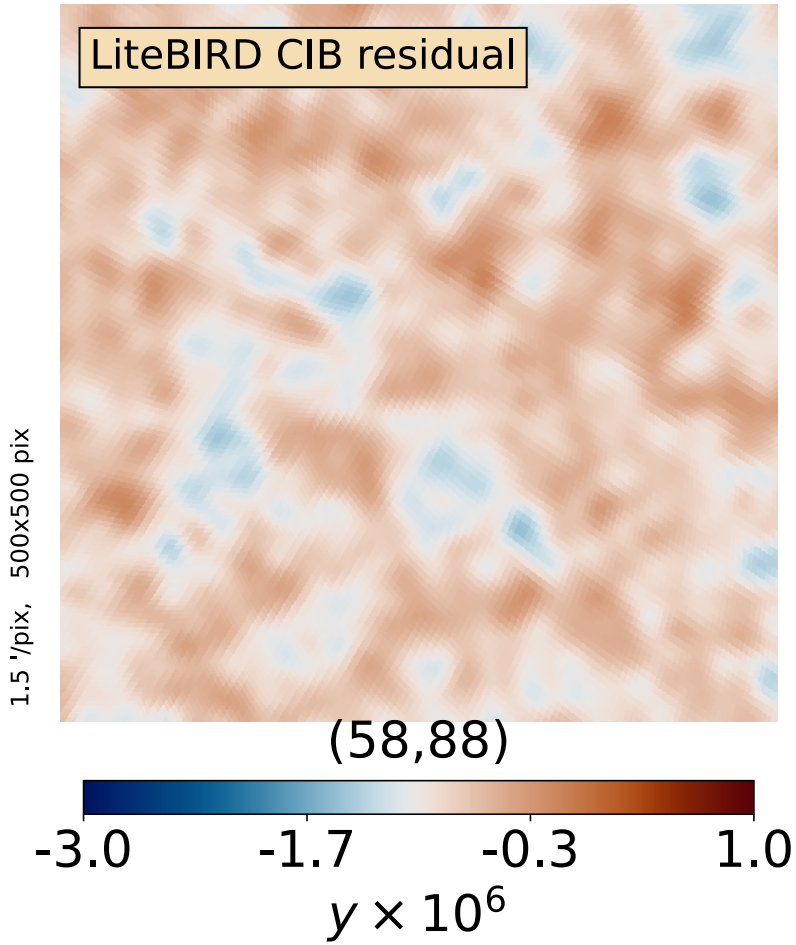


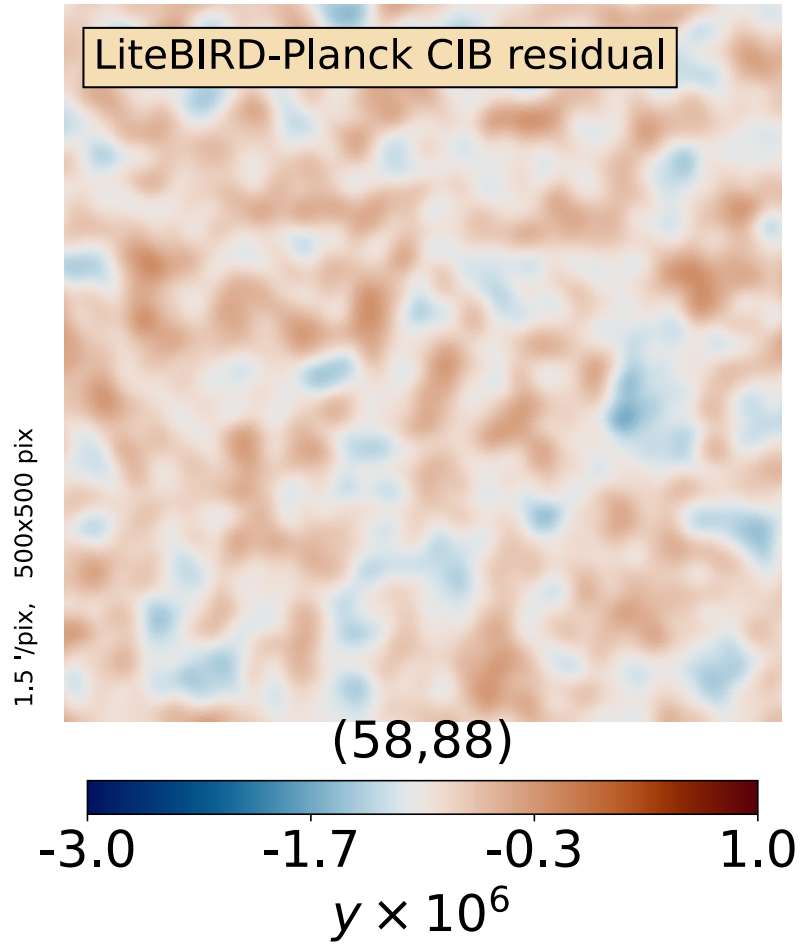
Reduction in noise contamination from Planck to LiteBIRD, with further reduction in the joint LiteBIRD-Planck y-map

arXiv:2407.17555

Residual CIB contamination



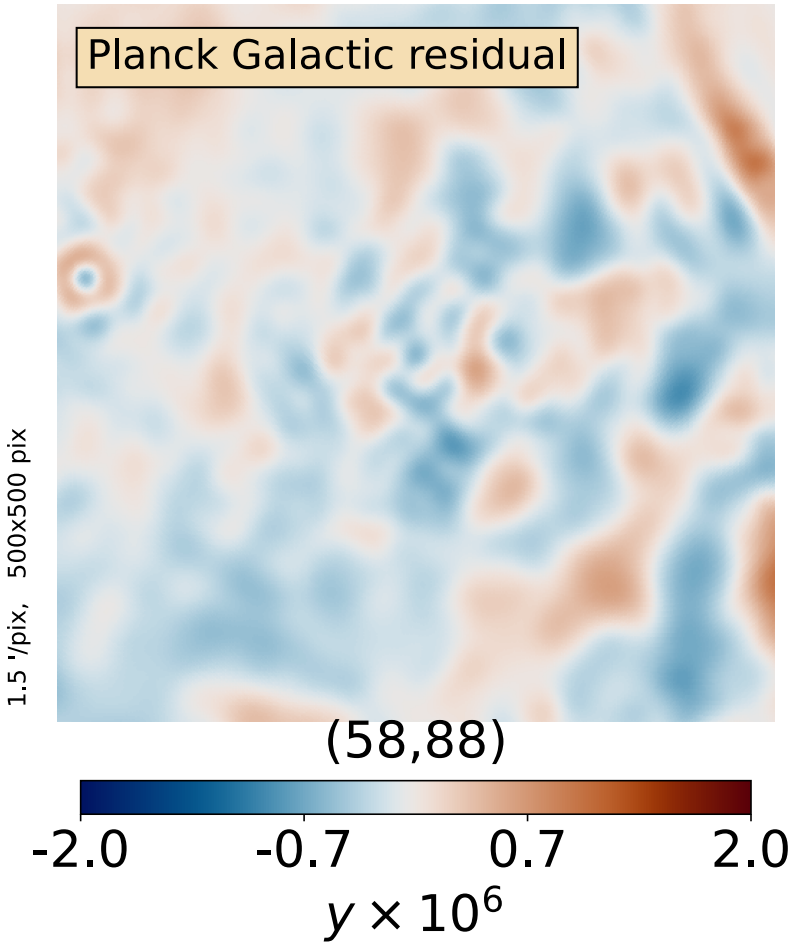


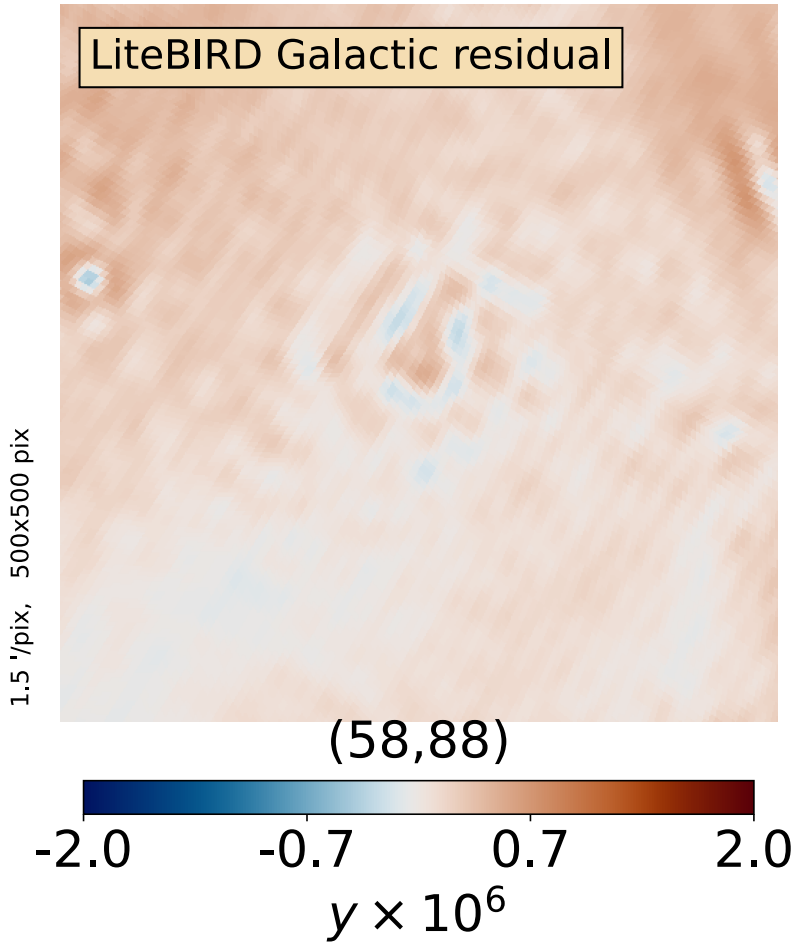


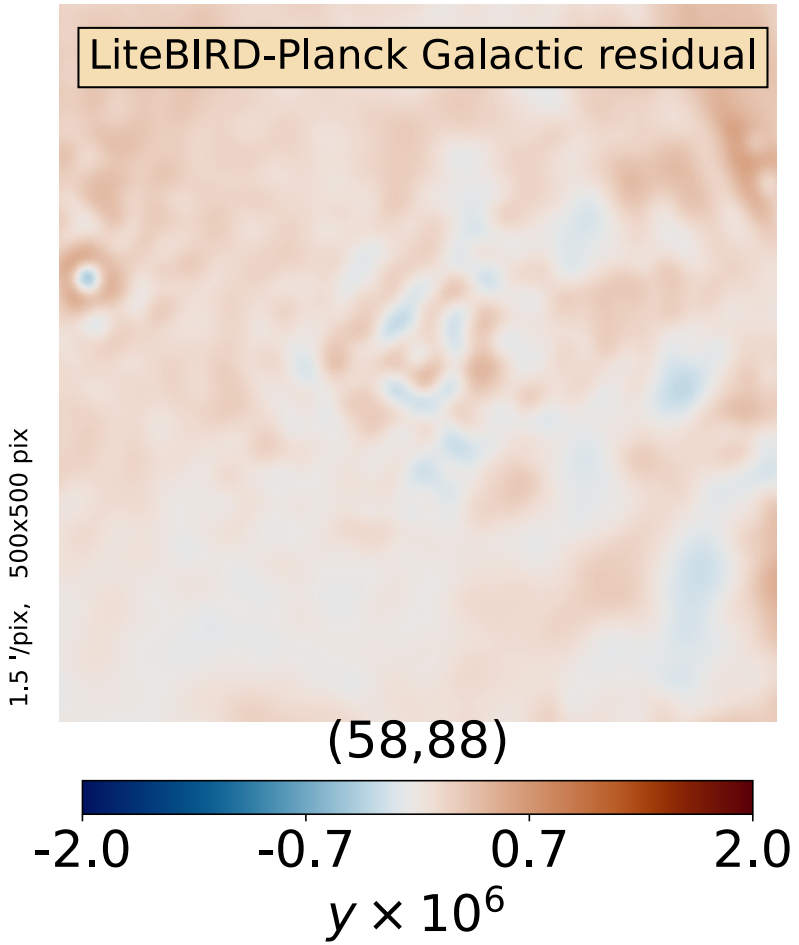
Reduction in CIB contamination from Planck to LiteBIRD, with further reduction in the joint LiteBIRD-Planck y-map

arXiv:2407.17555

Residual Galactic foreground contamination





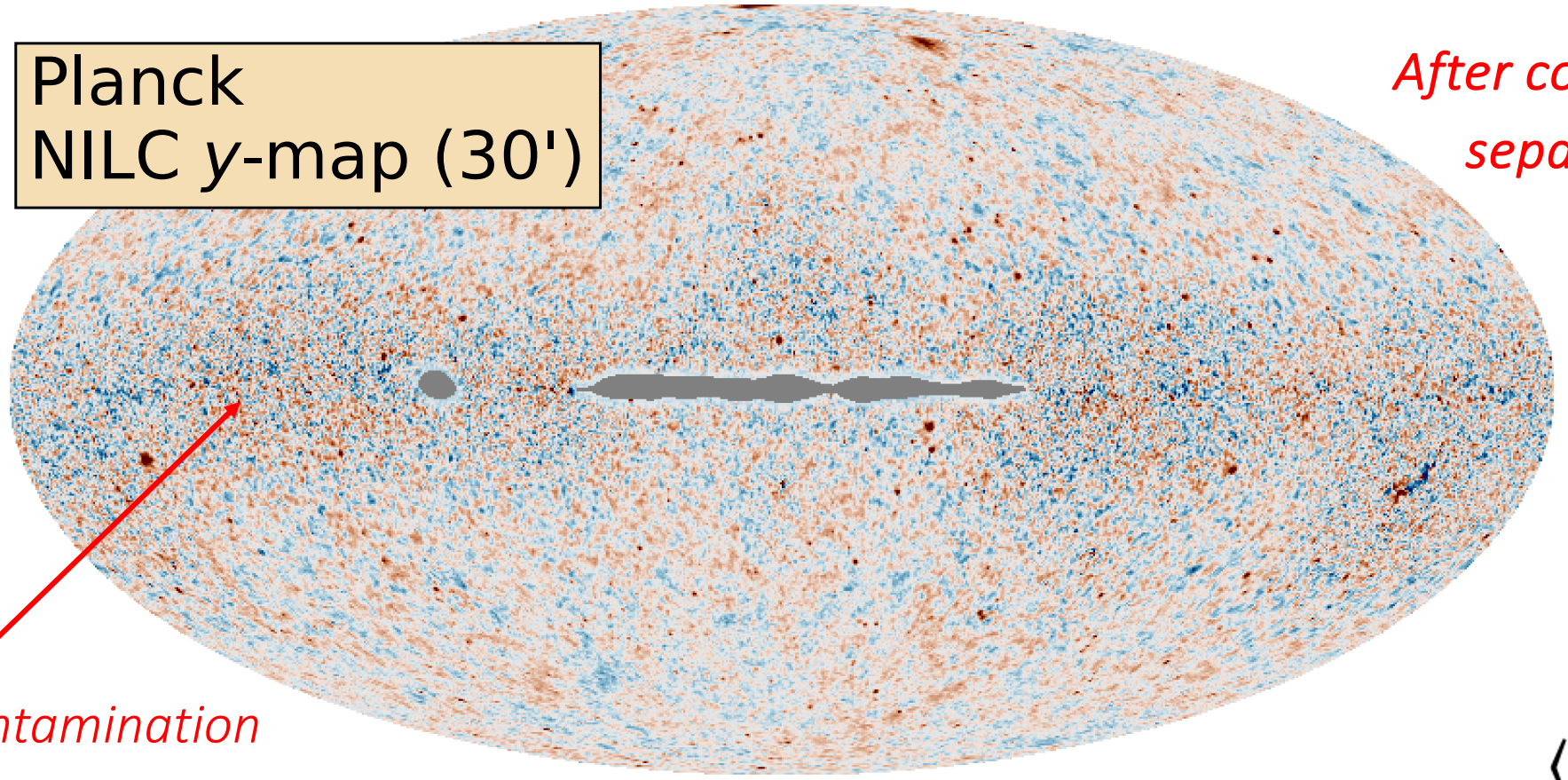


Reduction in Galactic contamination from Planck to LiteBIRD, with further reduction in the joint LiteBIRD-Planck y-map

arXiv:2407.17555

Reconstructed y-map over 98% of the sky

arXiv:2407.17555



After component separation

98% sky

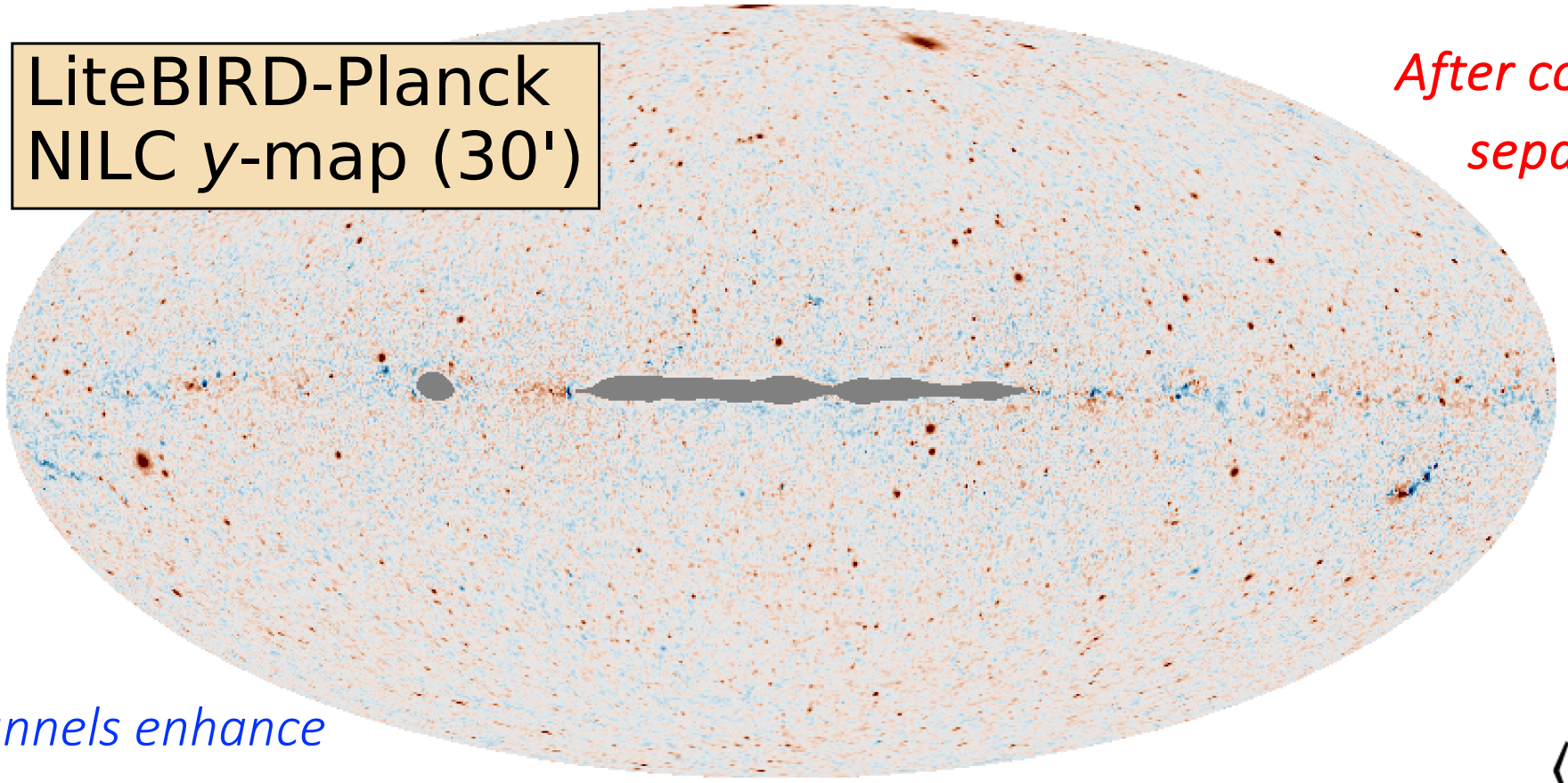
Significant contamination in the Galactic plane

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

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

Reconstructed y-map over 98% of the sky

arXiv:2407.17555



After component separation

98% sky

LiteBIRD channels enhance foreground cleaning, revealing clusters in Galactic plane

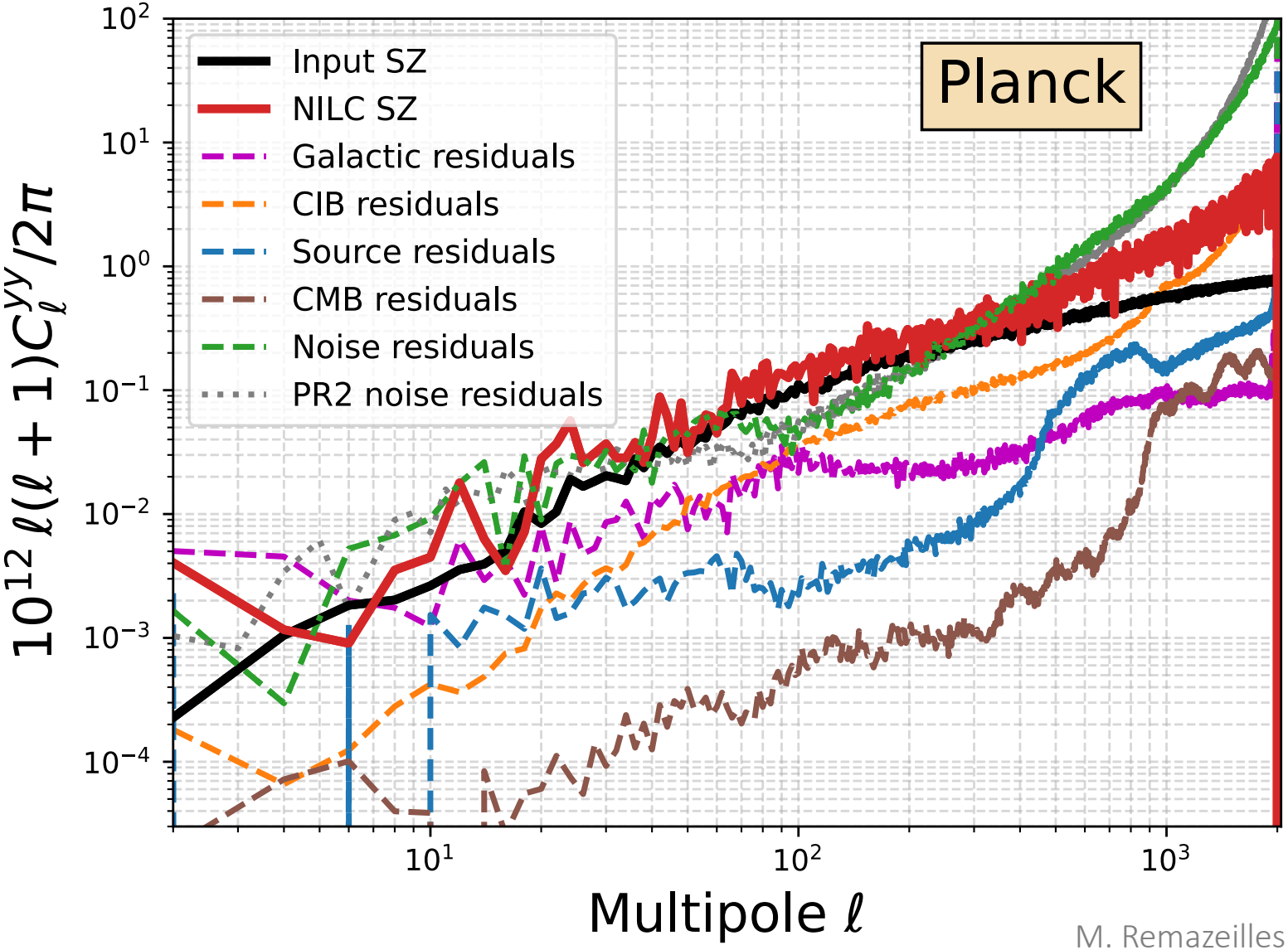
$\langle yy \rangle \sim \sigma_8^8$

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

y-map power spectrum and residuals

SZ power spectrum and residuals

Planck



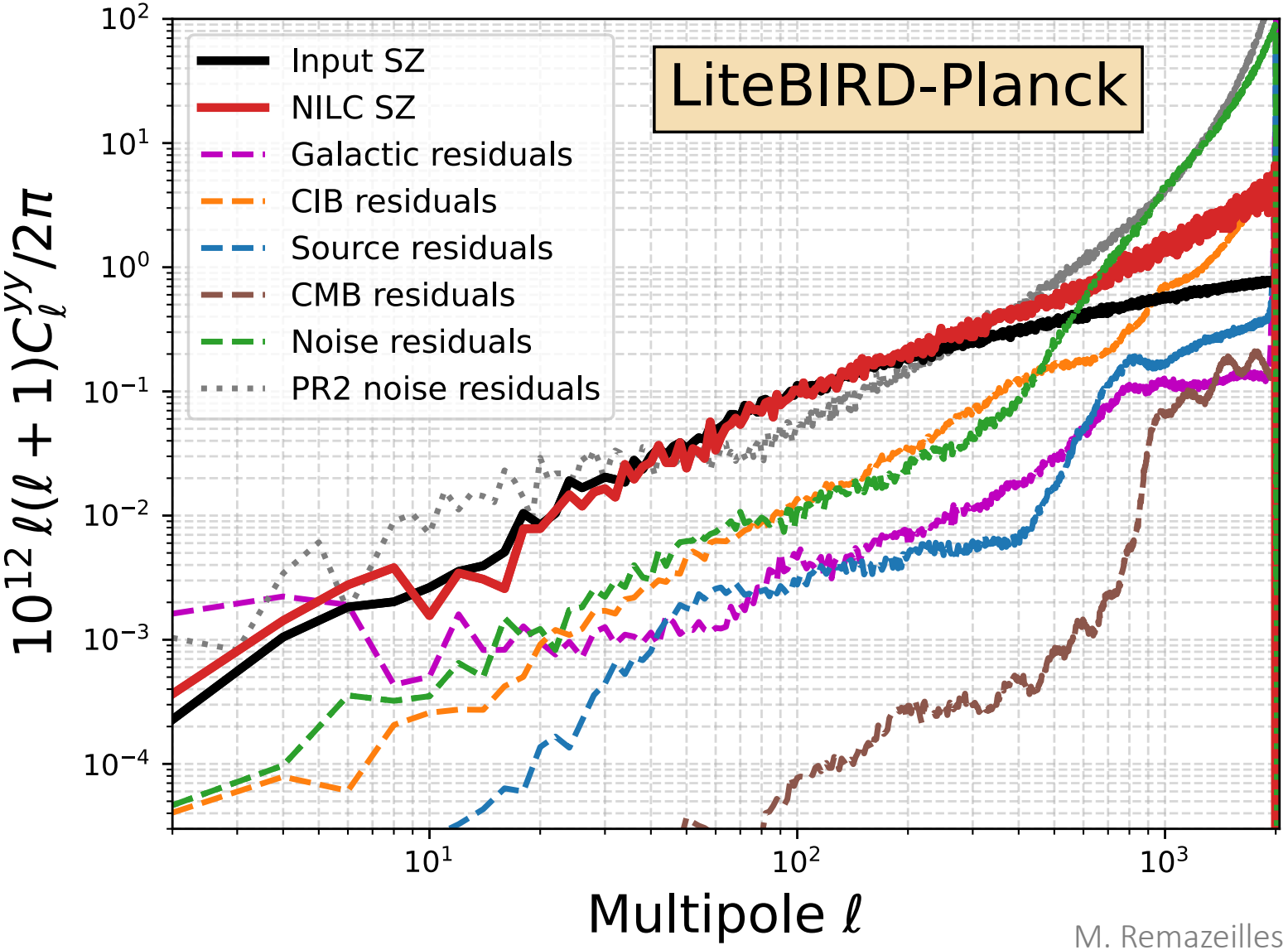
arXiv:2407.17555

y-map power spectrum and residuals

SZ power spectrum
and residuals

LiteBIRD + Planck

Noise and foreground residuals reduced by an order of magnitude at large and intermediate scales



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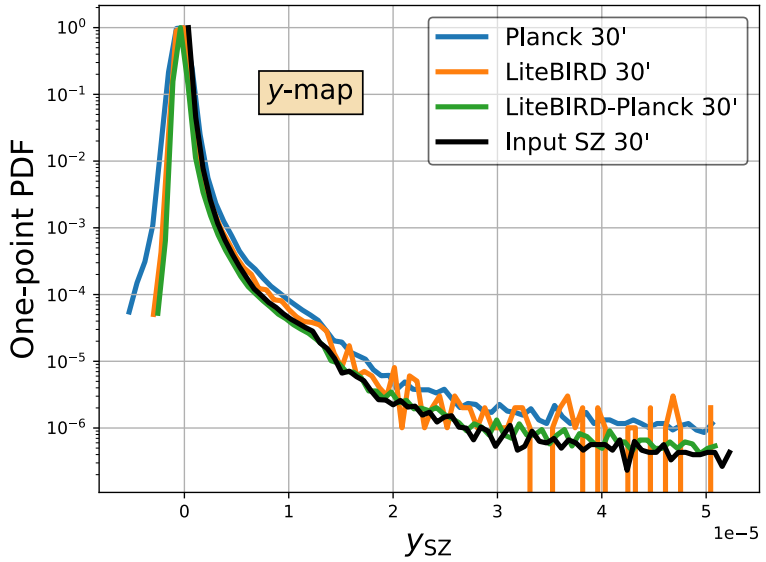
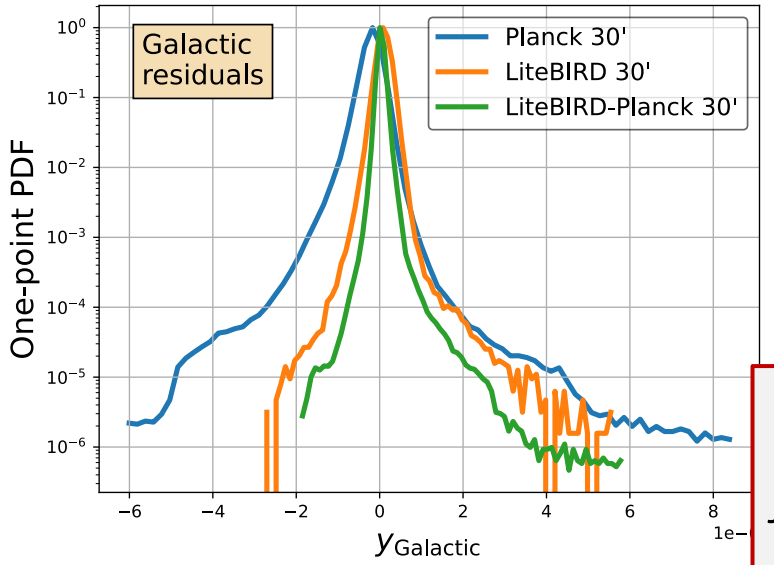
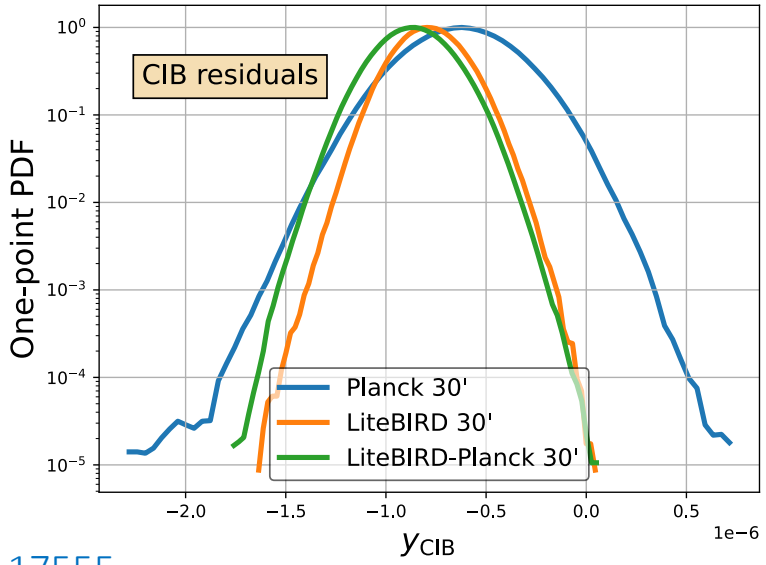
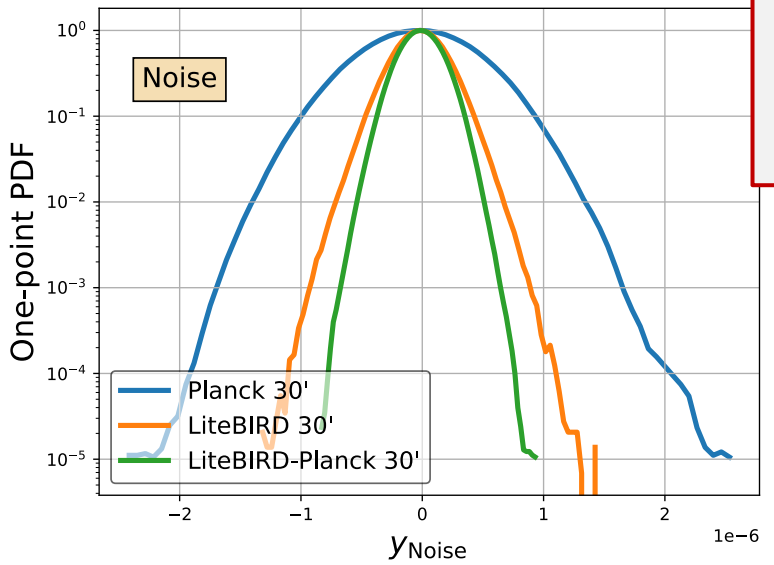
One-point PDF of y-map and residuals







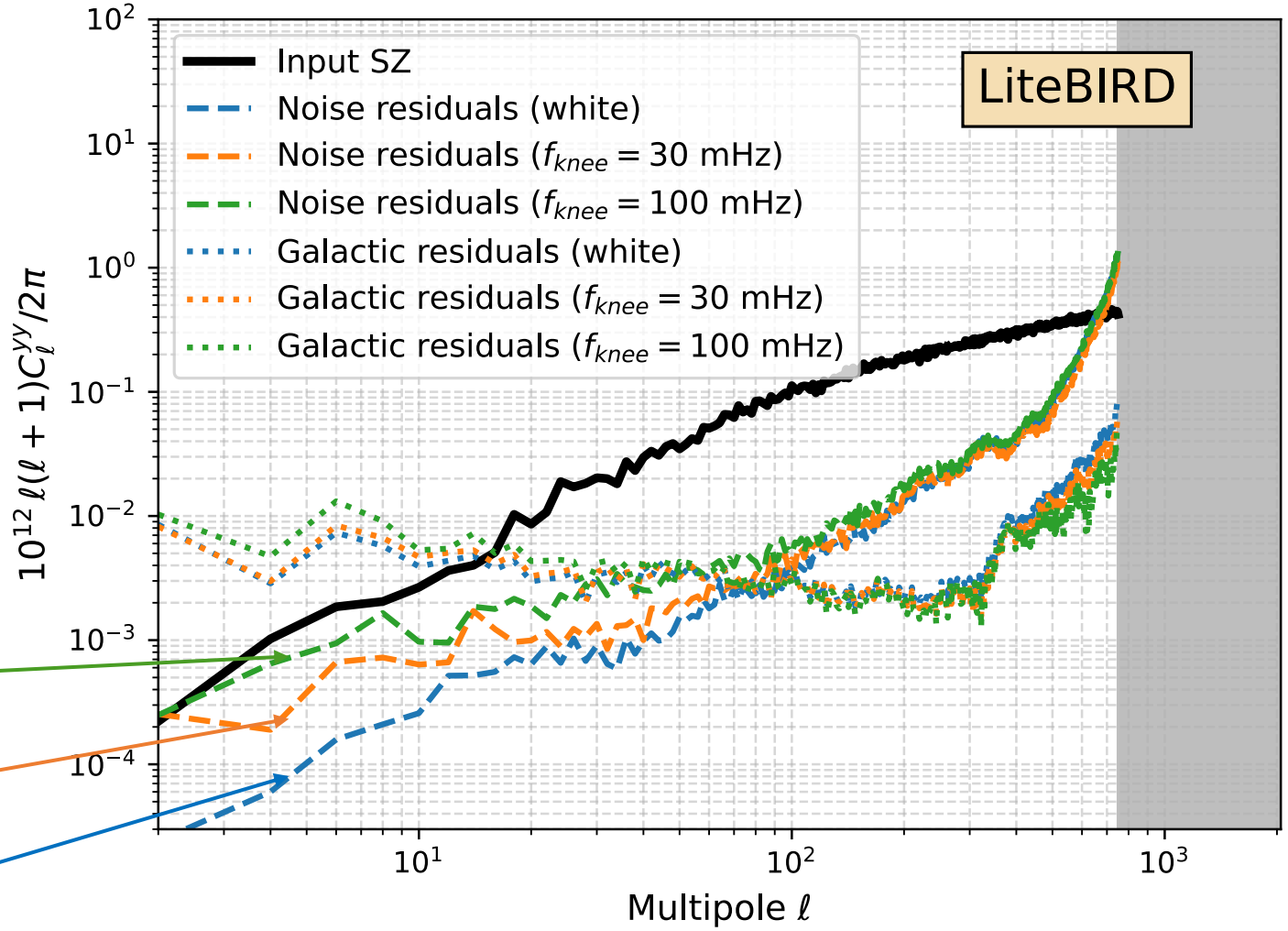


Reduction of noise and foreground residuals from Planck to LiteBIRD, with further reduction in joint LiteBIRD-Planck y-map

arXiv:2407.17555

Impact of LiteBIRD $1/f$ noise

LiteBIRD 1/f noise reduced below the SZ signal at all multipoles after component separation with NILC



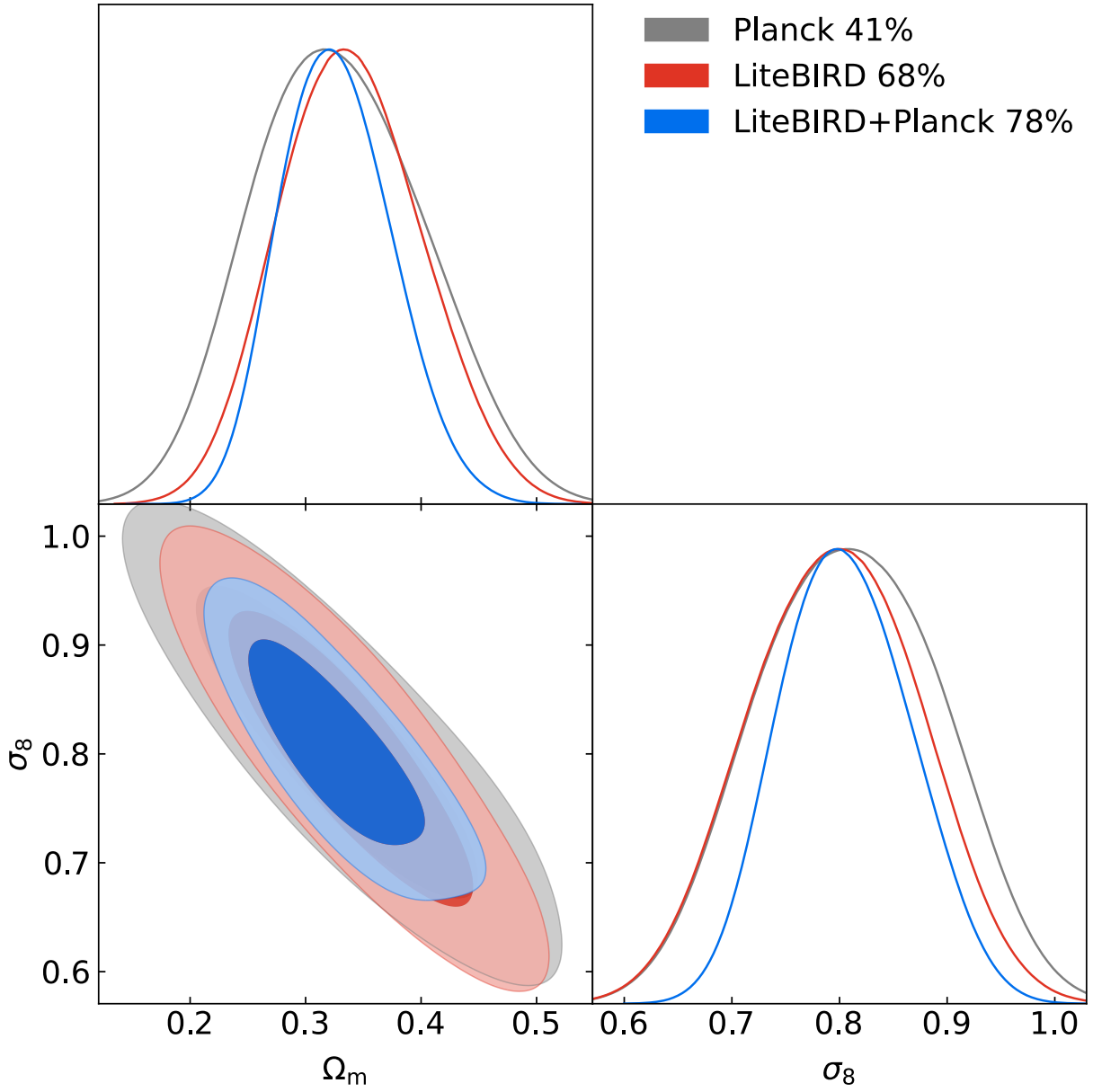
$1/f$ noise ($f_{\mathrm{knee}} = 100$ mHz)

$1/f$ noise ($f_{\mathrm{knee}} = 30$ mHz)

white noise

arXiv:2407.17555

Cosmological parameter constraints



Non-Gaussian contribution to SZ cosmic variance included

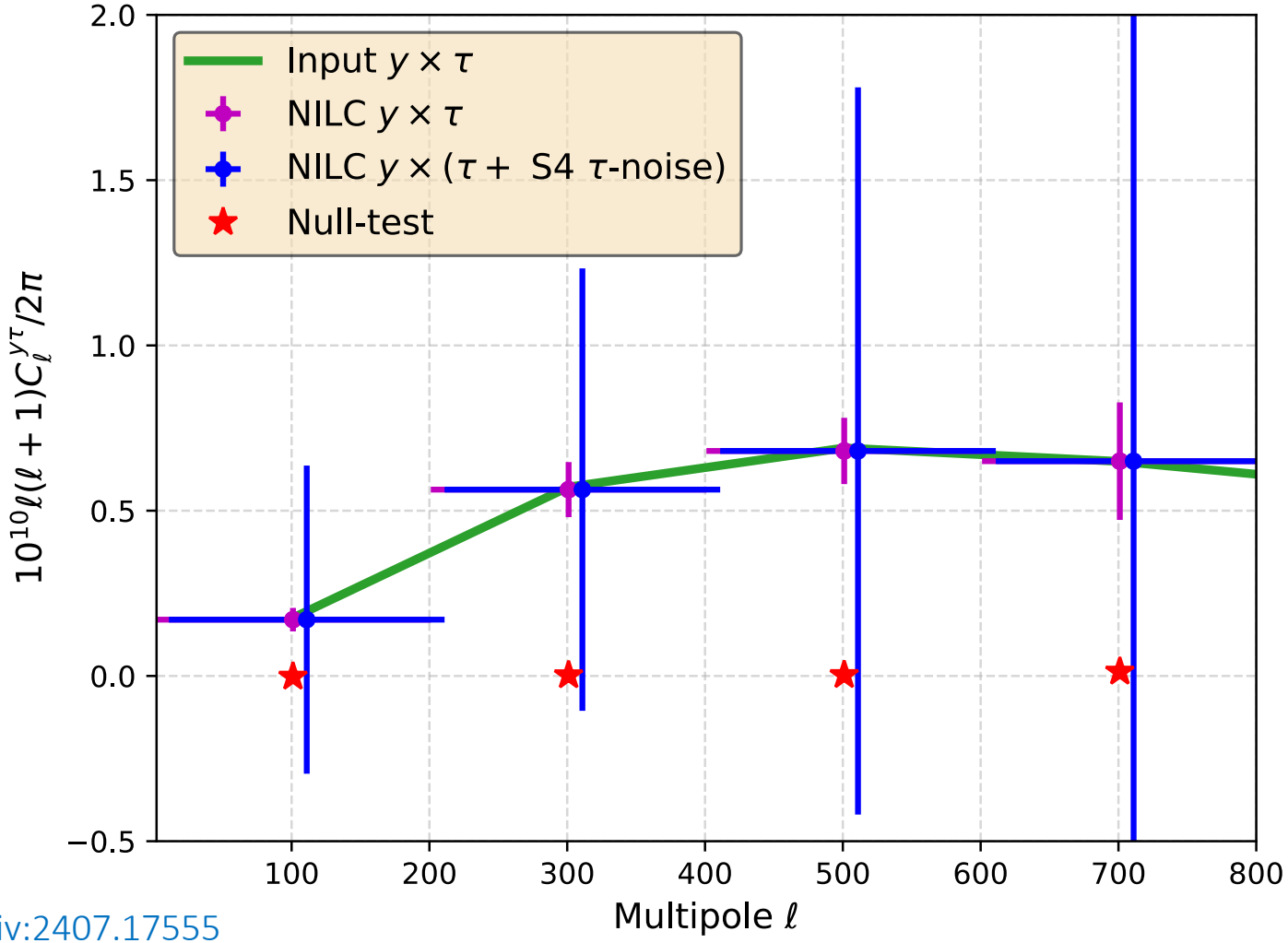
15% reduction in uncertainty on $S_8 = \sigma_8(\Omega_m / 0.3)^{0.5}$ from the combined LiteBIRD-Planck y-map

arXiv:2407.17555

Thermal SZ effect from patchy reionisation

Cross-correlating the LiteBIRD SZ map with the CMB-S4 optical depth map

(following Namikawa, Roy, Sherwin, Battaglia, Spergel, PRD 2021)



LiteBIRD will provide preliminary evidence of the faint thermal SZ signal from pachy reionisation with a modest SNR of 1.6

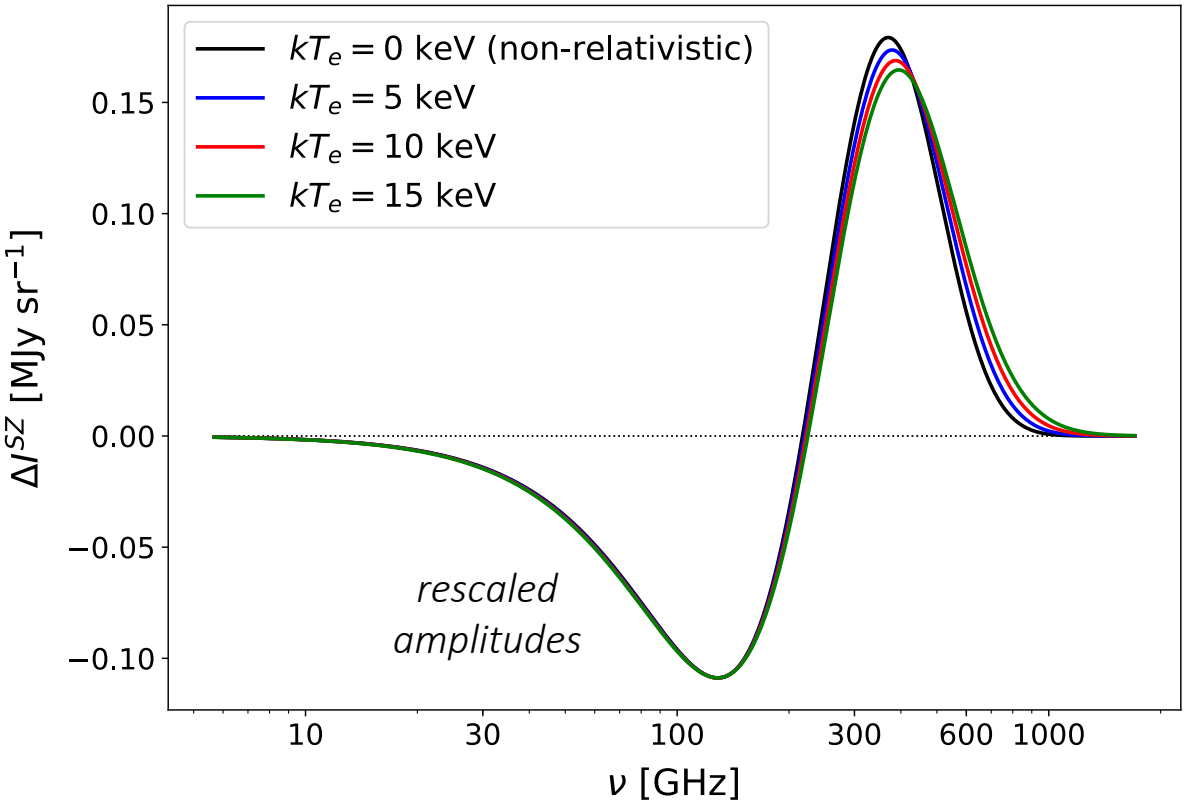
arXiv:2407.17555

Perspectives on diffuse SZ science from a clean all-sky LiteBIRD y-map

- Relativistic SZ effect and gas temperature (capitalizing on LiteBIRD's high frequencies > 300 GHz)
- ISW-SZ cross-correlation at large angular scales
- CMB monopole y-distortion
- Two-halo contribution to SZ power spectrum at low multipoles
- Testing theories of structure formation via hot-gas tomography from SZ-LSS cross-correlations
- Quadrupole-like SZ effect from structures in local Universe such as the Milky Way or local supercluster
- SZ-coloured dipole-modulated CMB anisotropies via SZ-CMB cross-correlation as an alternative measurement of the dipole with higher significance than Planck Collaboration LVI (2020)
- Testing decaying dark matter models with SZ

Relativistic SZ effect

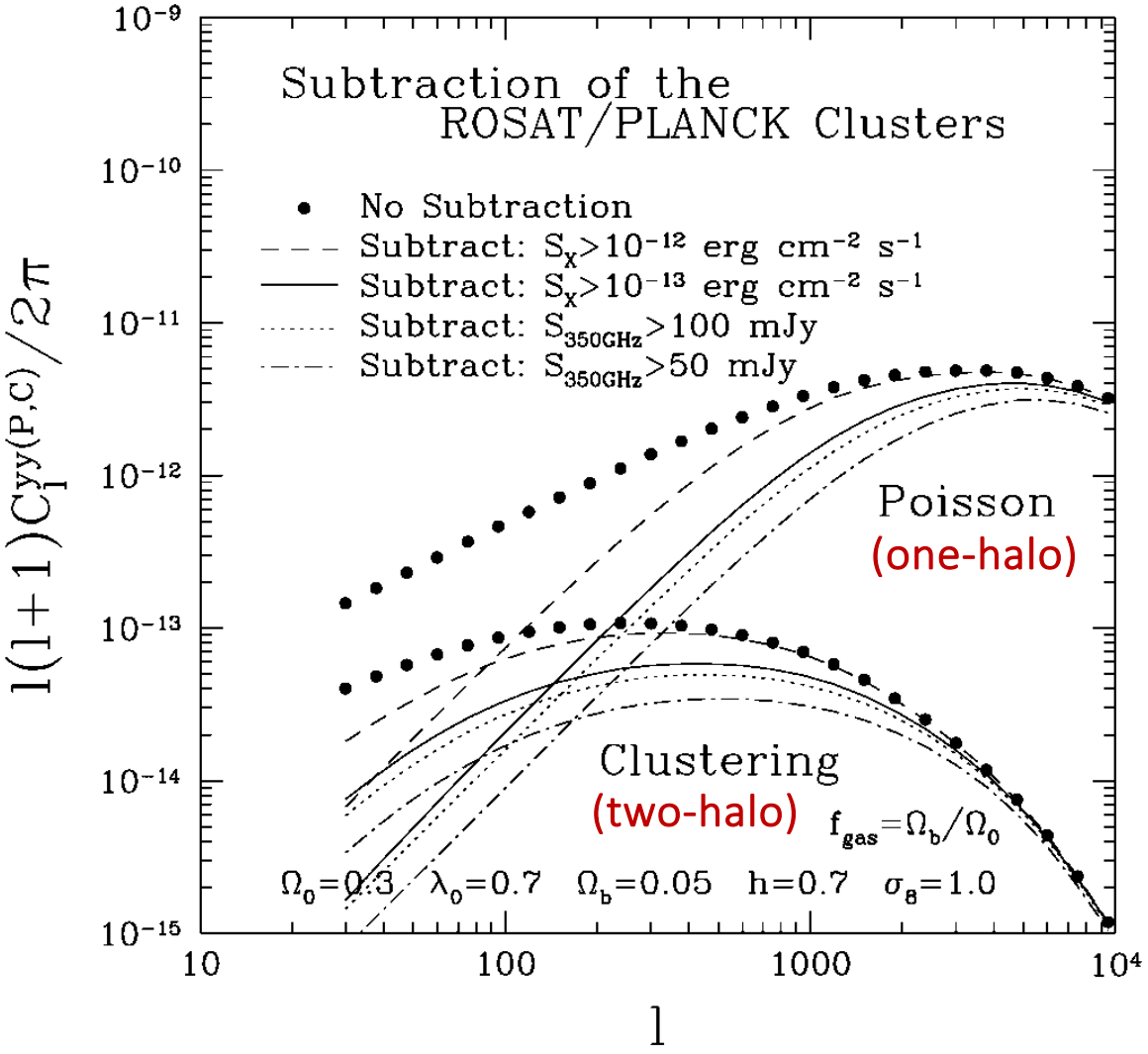
$$I_\nu(\hat{n}) = y(\hat{n}) f(\nu, T_e(\hat{n}))$$



- *Capitalizing on LiteBIRD + Planck high frequencies above 300 GHz to disentangle the relativistic SZ effect*
- *LiteBIRD narrow bandpasses will also help detection*

Two-halo contribution to diffuse SZ effect

Komatsu & Kitayama (1999)

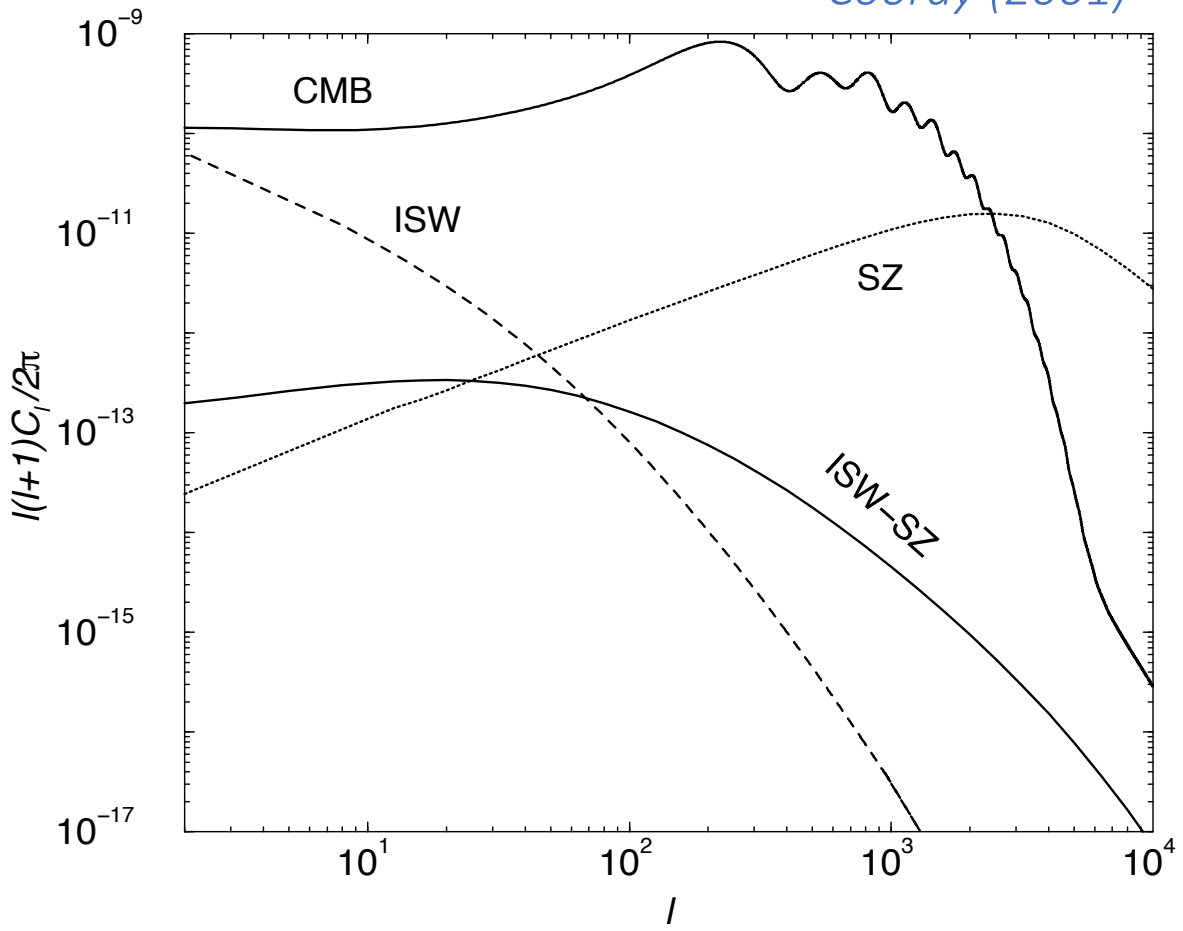


- *Masking massive clusters in the y-map to "gaussianize" it and enhance the two-halo contribution over the one-halo signal in the diffuse SZ power spectrum at low multipoles*

See "Rotti, Bolliet, Chluba, and Remazeilles, MNRAS (2021)"

ISW-SZ cross-correlation at large scales

Cooray (2001)



- *Expected y-T cross-correlation at large angular scales between SZ and CMB temperature anisotropies due to the ISW effect*
- *LiteBIRD all-sky SZ map provides access to largest angular scales*

Conclusions

- An all-sky map of the thermal SZ Compton y-parameter probes the entire hot gas distribution across the Universe
- LiteBIRD's enhanced sensitivity and frequency coverage outperform Planck's SZ mapping results over the entire sky
- The combined LiteBIRD-Planck SZ map leverages both Planck's angular resolution and LiteBIRD's sensitivity
- Noise and foreground contamination reduced by a factor of 10 at large and intermediate scales in the combined LiteBIRD-Planck SZ map compared to the Planck SZ map
- Constraints on $S_8 = \sigma_8(\Omega_m/0.3)^{0.5}$ improved by 15% compared to Planck SZ map
- Many perspectives on diffuse SZ science from the all-sky LiteBIRD y-map