Credits: Aman Chokshi

Building the SPT-3G19/20 likelihood

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on behalf of SPT-3G collaboration

Paris-Saclay Astroparticle Symposium 2022 - Early and Late Universe Cosmology session

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Content

1. SPT-3G 2019-2020 winter field
2. Forecasts
3. Robust likelihood pipeline: focus on covariance matrix
   A. Analytical covariance matrices for 19/20 likelihood [https://arxiv.org/abs/2204.13721]
   B. High-precision inpainting [Benabed, Camphuis, in prep]
   C. Adapting framework to filtering [Hivon, Doussot, in prep]

1. South Pole Telescope

Current survey: SPT-3G

- 10-meter diameter telescope located at the South Pole in optimal conditions for microwave observations, observing CMB anisotropies
- SPT-3G: state-of-the art instrument with 3 frequencies 90, 150, 220 GHz
- Beam: 1.6'/1.2'/1.0' (*Planck*: 5')
- See Sobrin et al. 2022 for more details

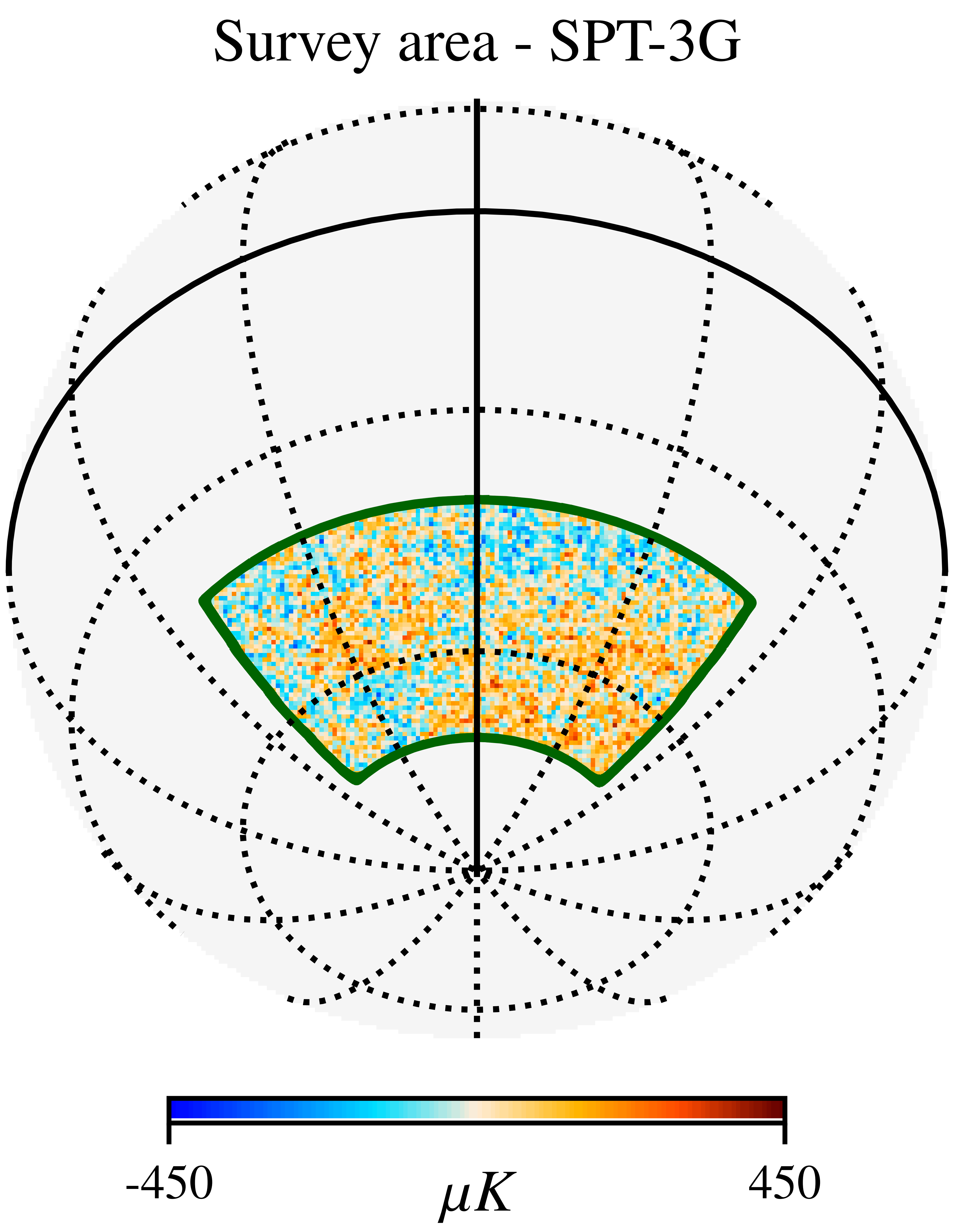
Kavli Institute
for Cosmological Physics
at The University of Chicago

1. SPT-3G Winter Field

2019-2023

- Winter field covers 4.1% of the sky = 1700 deg²
- Aimed final map-depth after 5 years: 2.3 μKarcmin in T @ 150GHz (*Planck*: ~40 μKarcmin)

- Additional summer fields: see F. Guidi's presentation

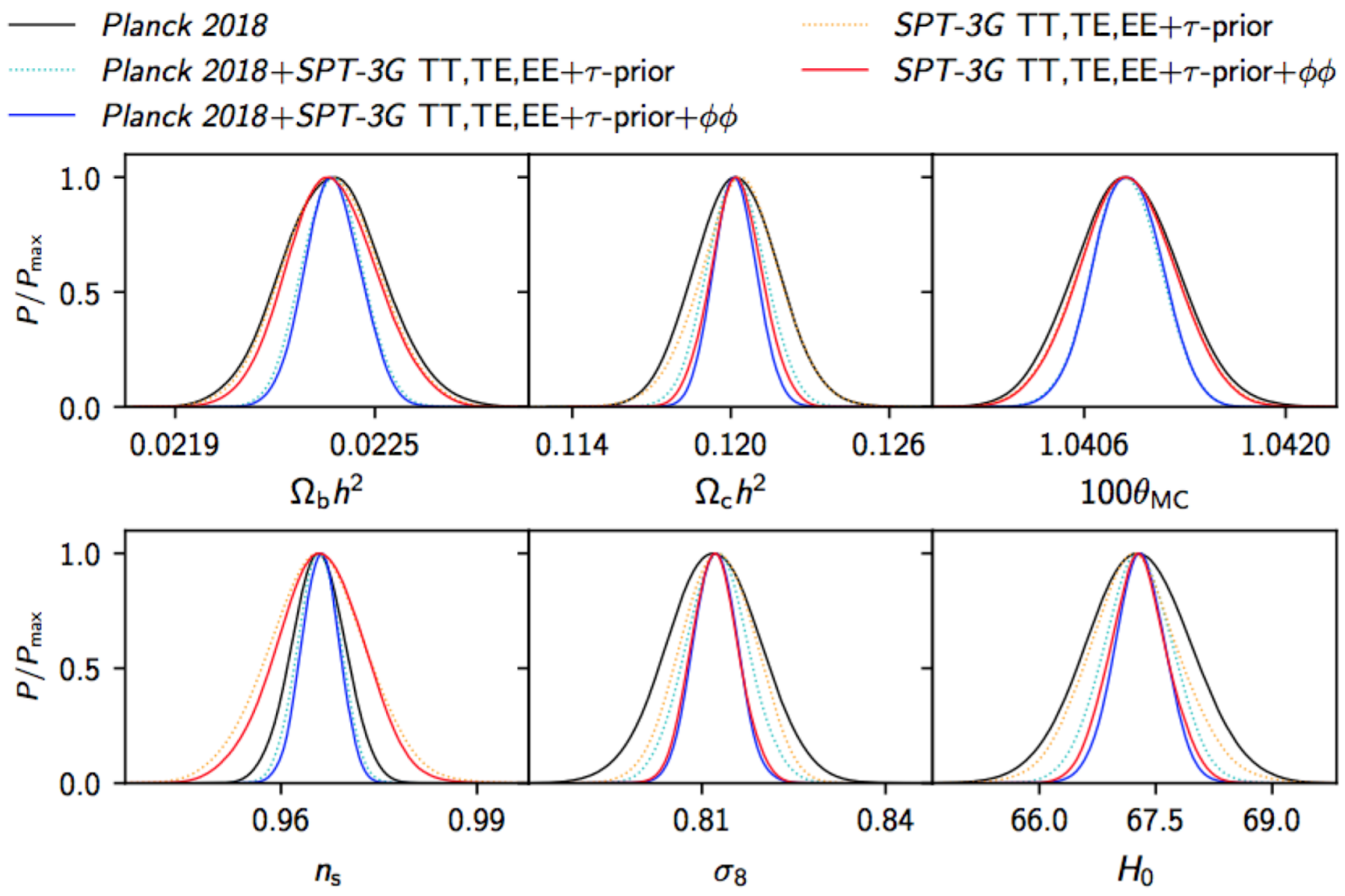


2. Forecasts

From full 2019-2023 survey (winter field only)

- All (but n_s) parameters constrained as well or better than Planck
- Combined constraints: twice as good !
- We will test consistency and extensions
- More improvements including summer fields

Forecasts on ΛCDM parameters



Credits: Silvia Galli

Planck 2018 + lensing:

- $\sigma(H_0) = 0.54$ km.s^{-1}Mpc^{-1}, $\sigma(\sigma_8) = 0.0060$

SPT-3G TTTEEE+tau-prior+lensing (but ignoring correlations with lensing):

- $\sigma(H_0) = 0.34$ km.s^{-1}Mpc^{-1}, $\sigma(\sigma_8) = 0.0040$

3. Analytical covariance

- **Robust pipeline** = **light pipeline**
- Accurate covariance matrices are required for a unbiased estimation of the cosmological parameters and their error bars. [Sellentin&Starck 2019]
- Mock-observations are used to build the covariance matrix of the data vector of primary anisotropies (TTTEEE) => **we replace it by a precise and fast analytical computation of the covariance**

Power spectrum gaussian likelihood :

$$-\ln \mathscr{L}(\hat{C} \,|\, \Lambda\mathrm{CDM}) \propto \frac{1}{2}(\hat{C} - C^{\mathrm{th}})^T \boxed{\Sigma^{-1}} (\hat{C} - C^{\mathrm{th}}))$$

This work can be applied to any power spectrum based gaussian likelihood!

3. A. Accurate covariance matrices on small survey area

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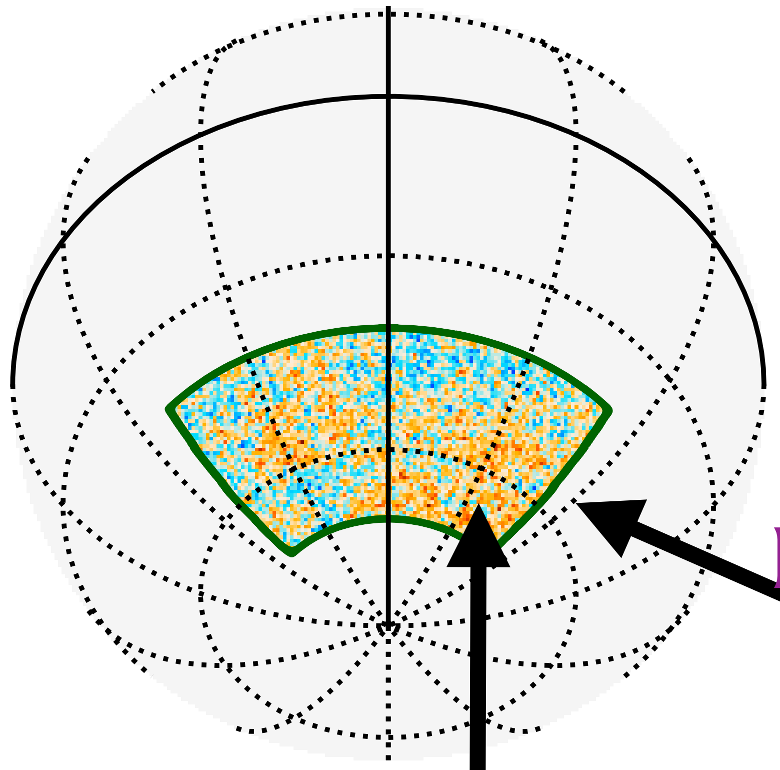


$$\mathrm{Cov}(\hat{C}_\ell, \hat{C}_{\ell'}) = 2\boxed{\Xi_{\ell\ell'}[W^2]} \sum_{\ell_1 \ell_2} \boxed{C^{\mathrm{th}}_{\ell_1}} \boxed{\bar{\Theta}^{\ell_1 \ell_2}_{\ell\ell'}[W]} \boxed{C^{\mathrm{th}}_{\ell_2}}$$

Fiducial power spectrum

Pure geometric coupling

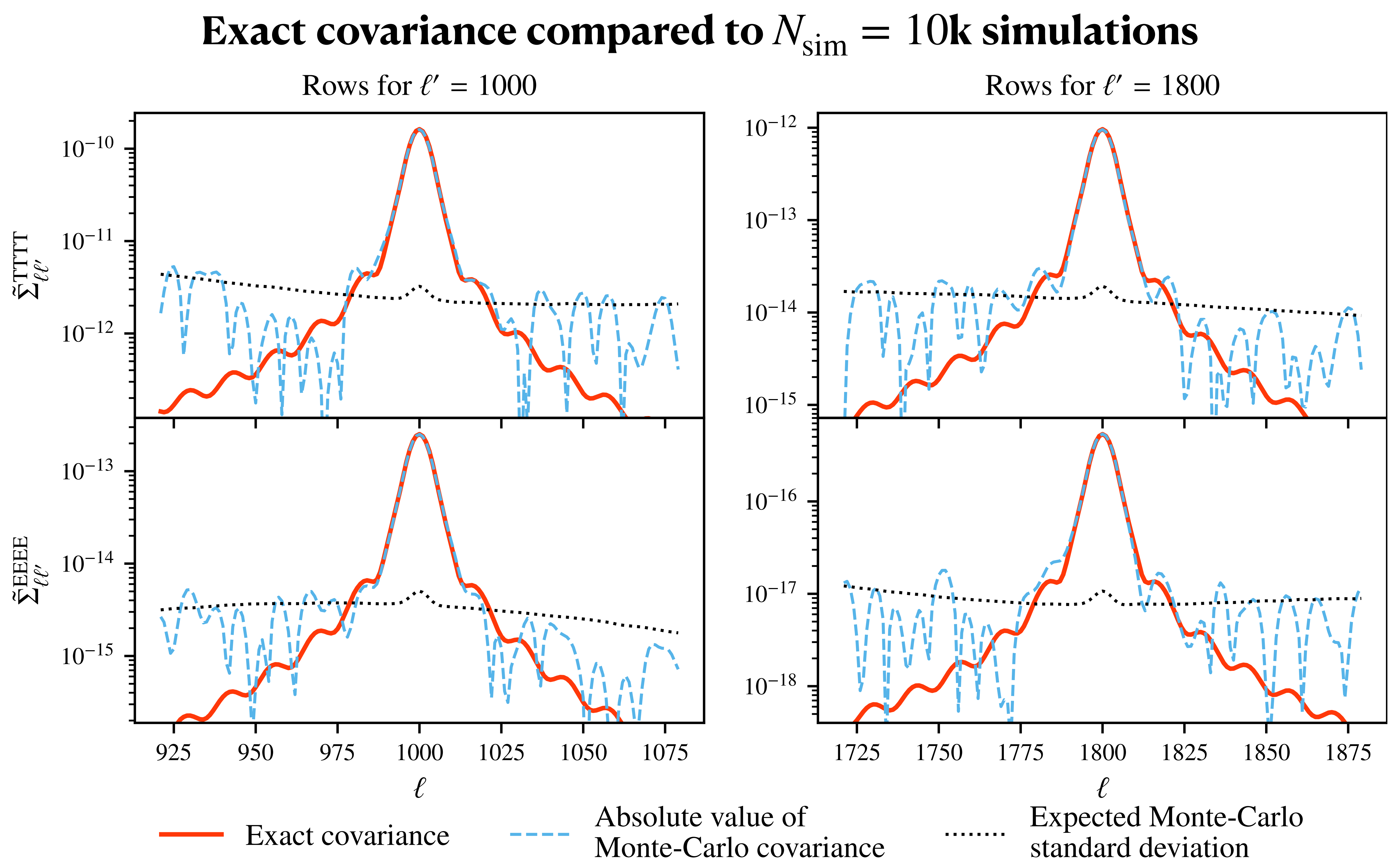
- MASTER matrix

Covariance coupling kernel

Computationally expensive

3. A. Accurate covariance matrices on small survey area

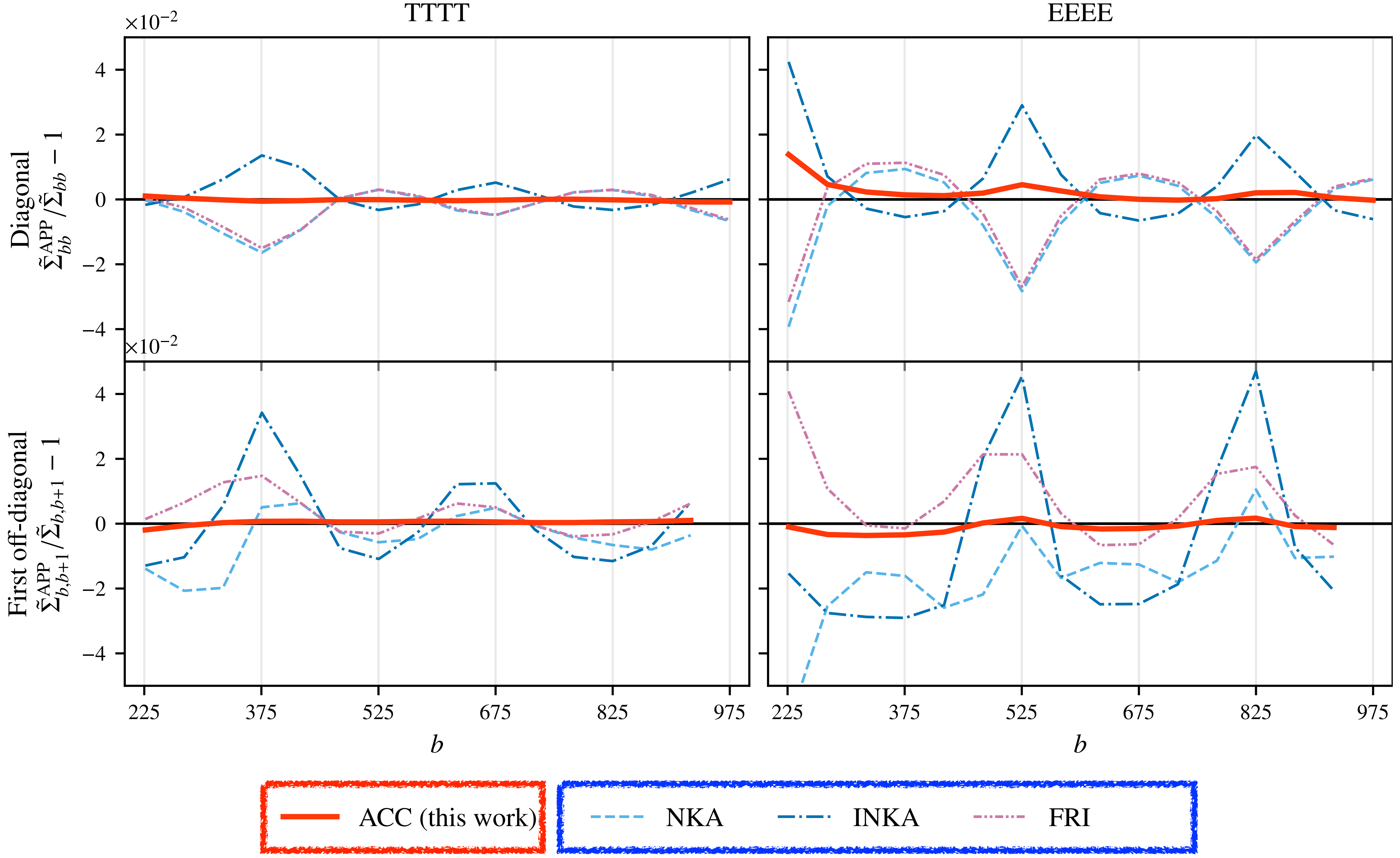
1. For the first time, we implemented a speed-up allowing to compute **exactly** the covariance



3. A. Accurate covariance matrices

1. For the first time, we implemented a speed-up allowing to compute **exactly** the covariance matrix
2. Then, we used that exact covariance to **assess the accuracy** of existing (NKA, INKA, FRI) and a **new** (ACC) **fast approximations** of the covariance
3. See [Camphuis et al. 2022] in A&A

Relative difference of binned approximations vs exact computation

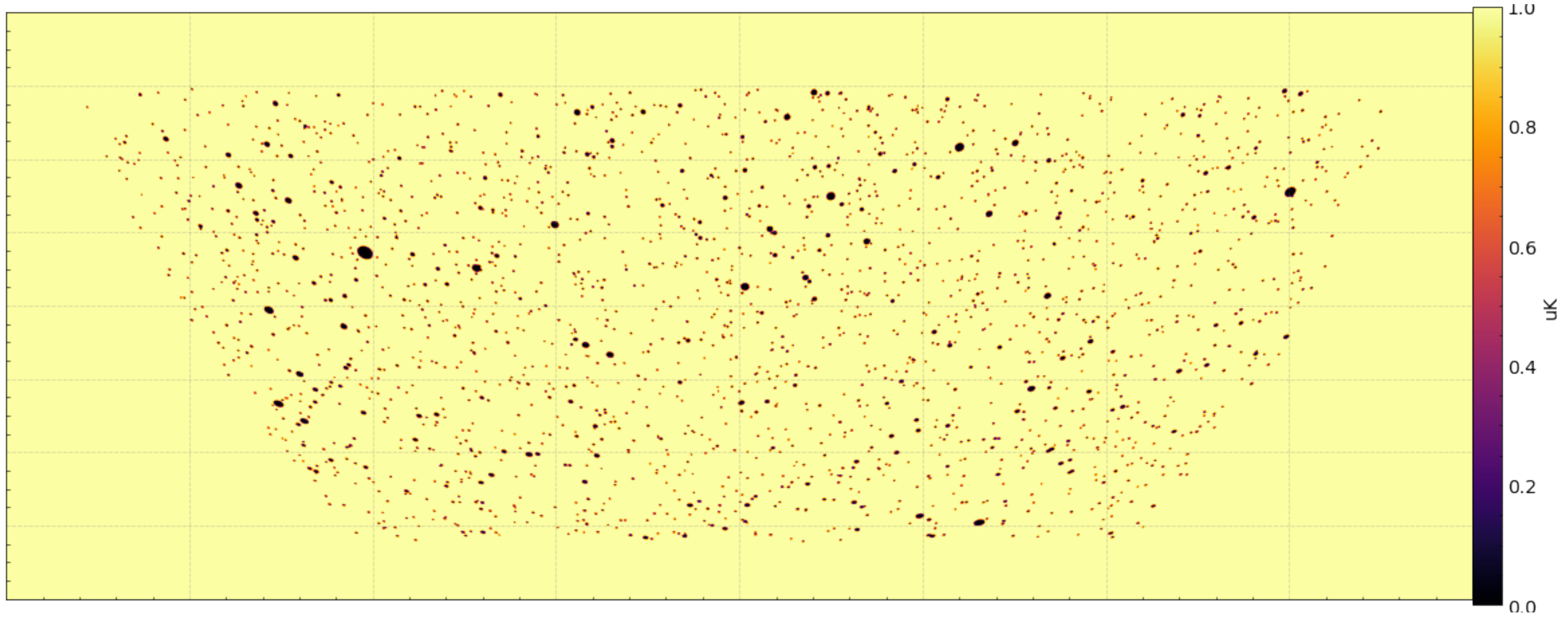


[Camphuis et al., 2022]

Previous works:
[Efstathiou 2004]+[Challinor&Chon 2004],
[Friedrich et al. 2021], [Nicola et al. 2021]

3. B. High-precision inpainting

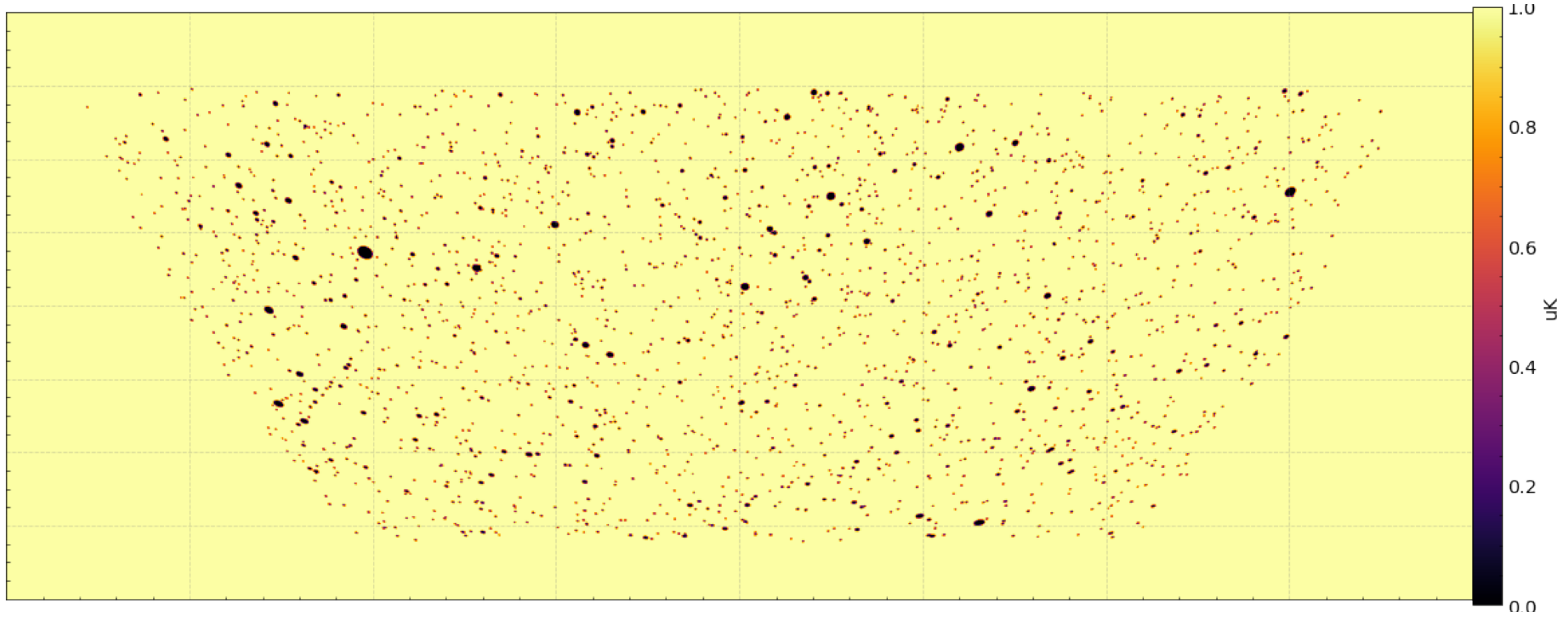
1. Small scale features in the mask (source-masking) makes analytical framework fail



Holes in the map to mask emitting sources

3. B. High-precision inpainting

1. Small scale features in the mask makes analytical framework fail
2. We use high-precision inpainting to fill the holes in the data, thus simplifying the mask geometry: **Gaussian constrained realization**



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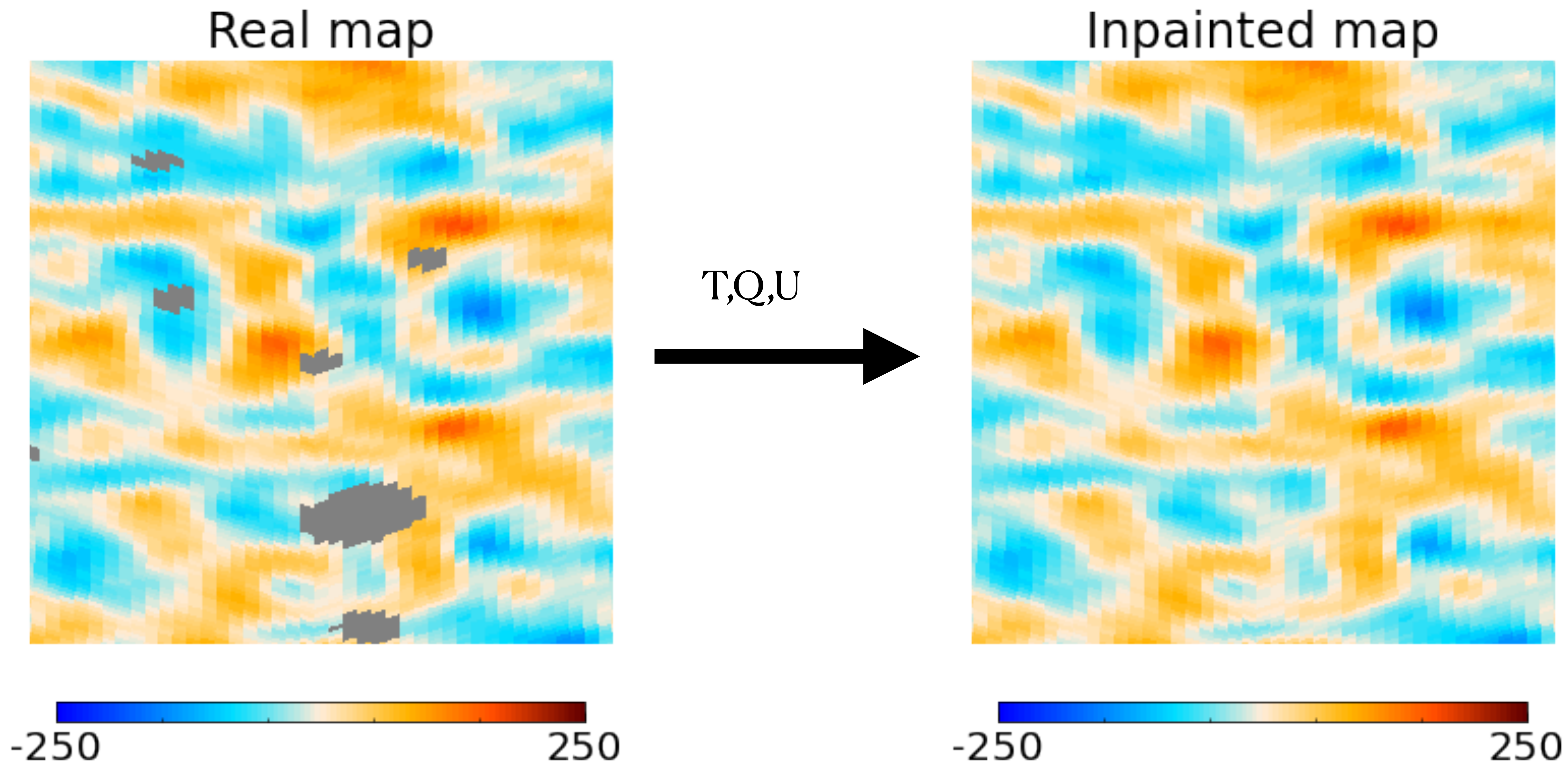

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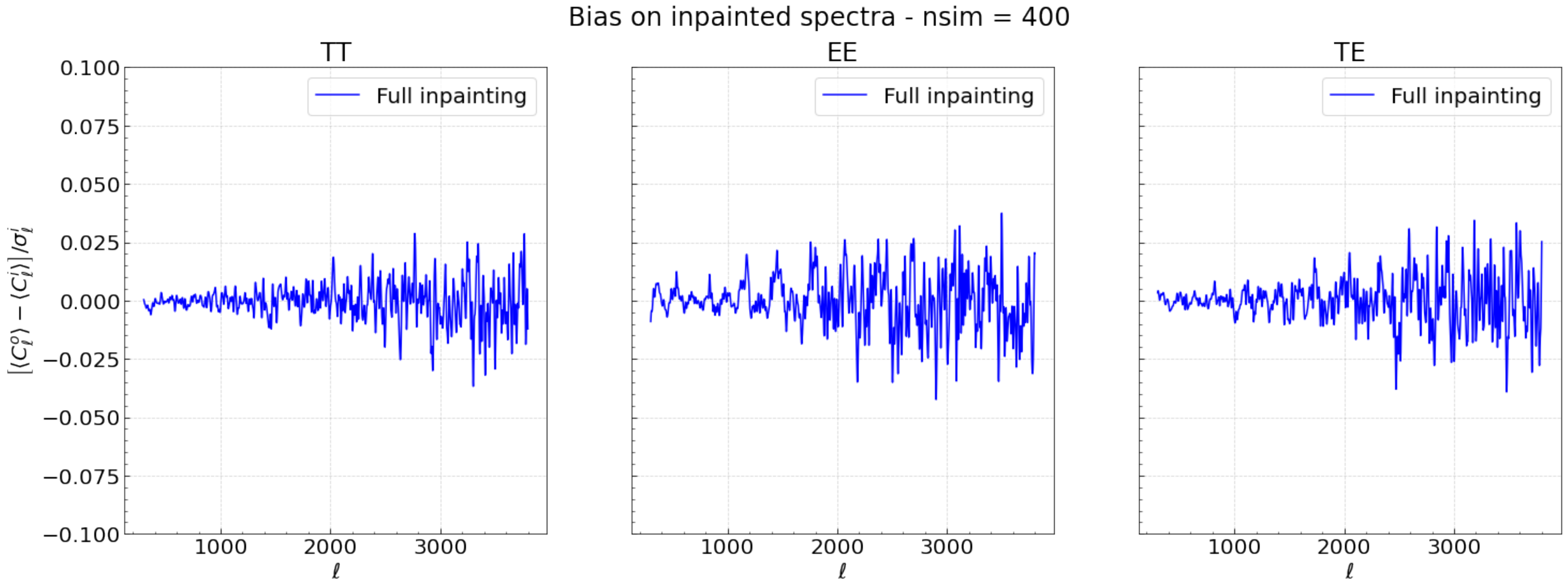
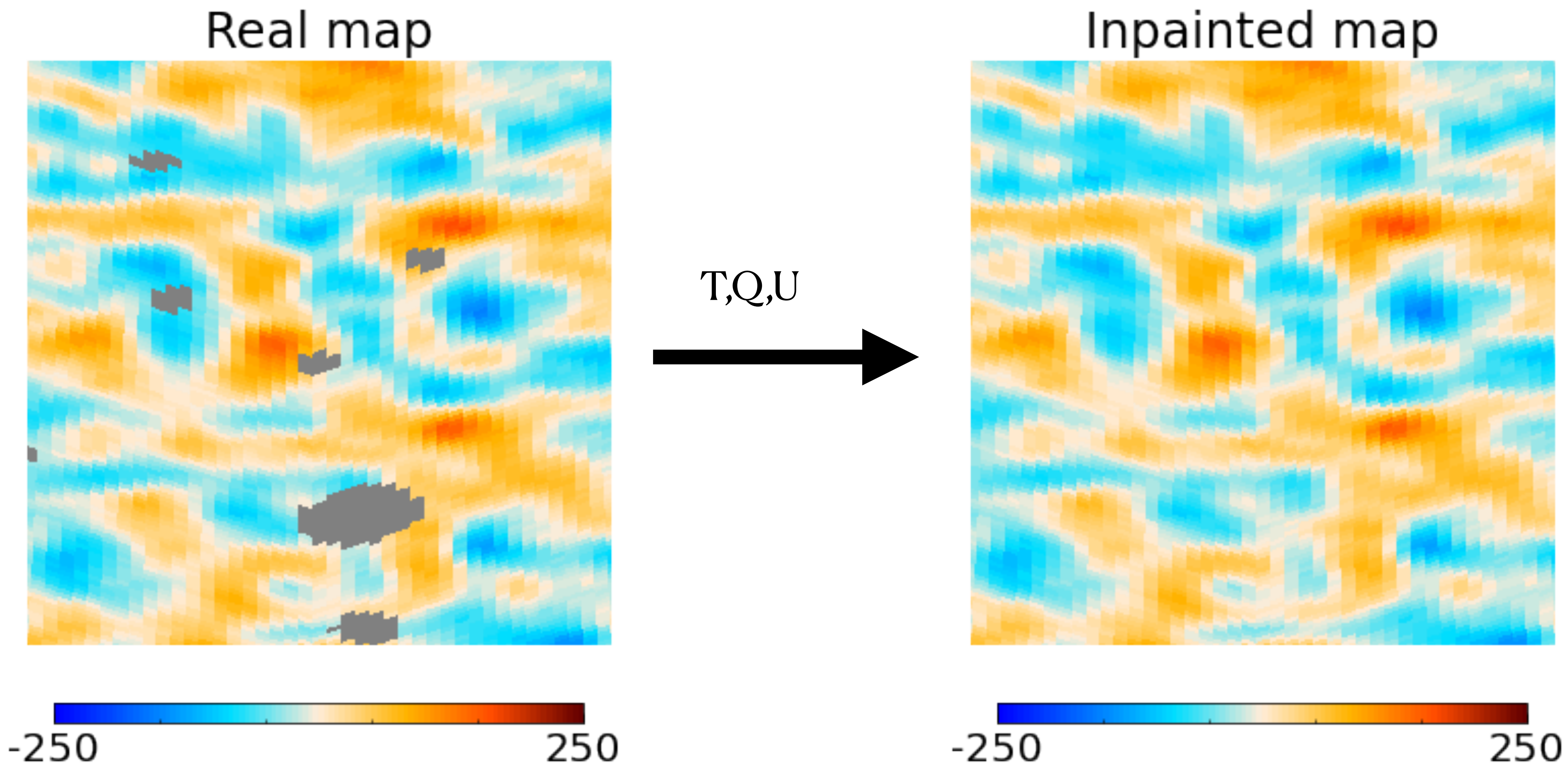
3. We show that we have very small bias on the spectra of inpainted maps



Bias on spectra of unpainted maps in units of standard deviation



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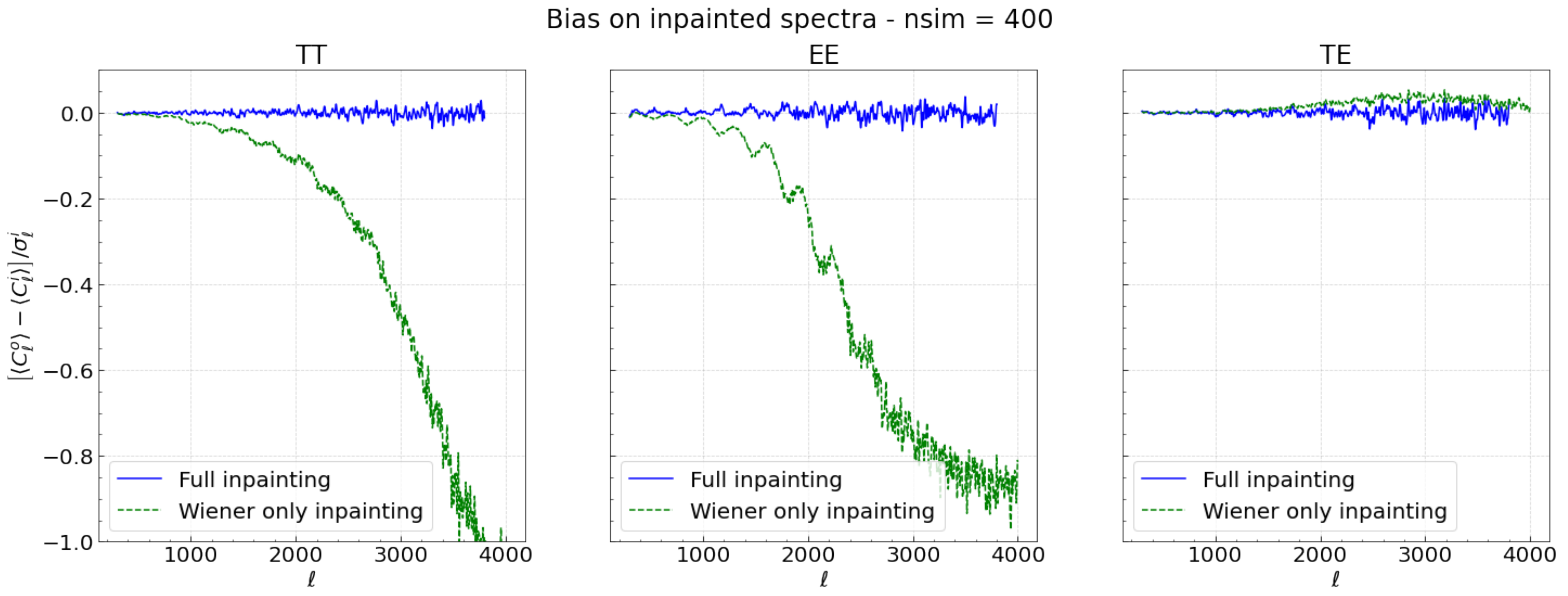
3. We show that we have very small bias on the spectra of inpainted maps
4. We correct the covariance to down-weight the fake information in the map



Bias on spectra of unpainted maps in units of standard deviation

Corrects for the bias

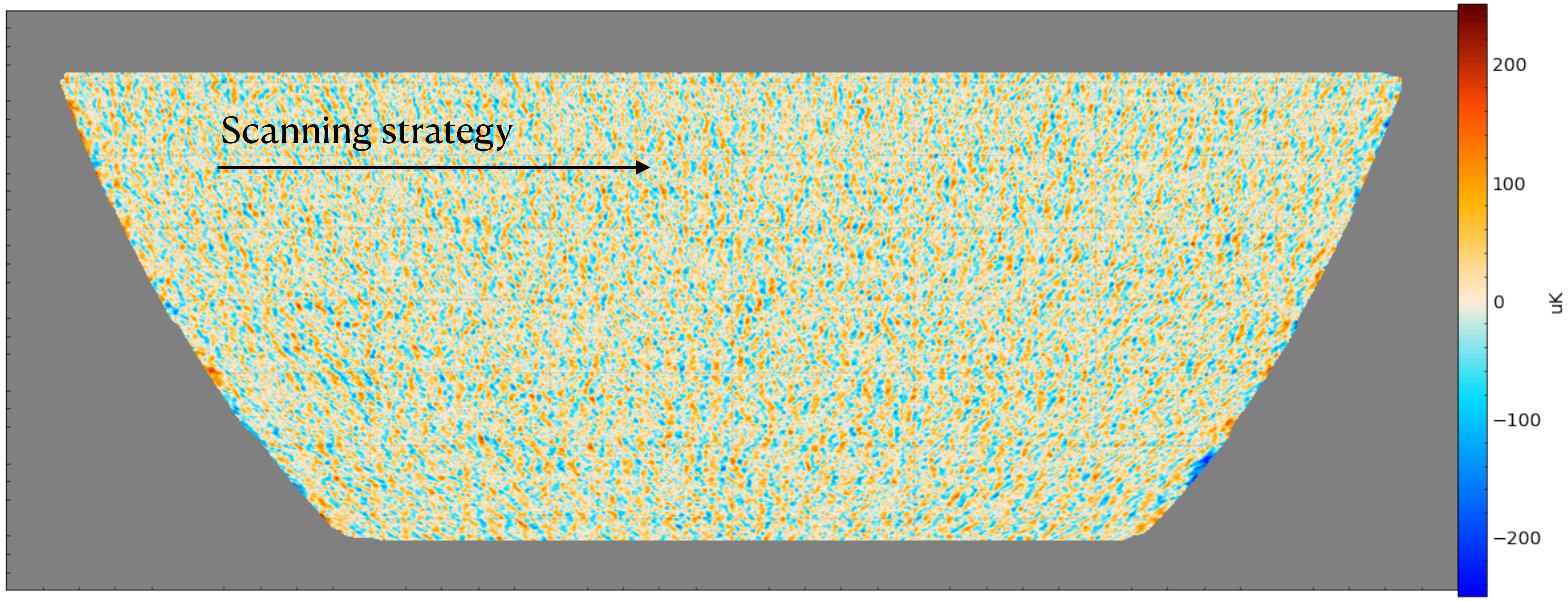
$$T^{\mathrm{I}} = WT^{\mathrm{D}} + (1-W)T^{\mathrm{R}} \implies \langle C_\ell^{\mathrm{I}} \rangle = C_\ell^{\mathrm{th}}$$

Fake data, so you boost your covariance

We define $\rho = \dfrac{C_\ell^{\mathrm{th}}}{\langle C_\ell^{WT^{\mathrm{D}}} \rangle}$ then $\Sigma^{\mathrm{inpainted}} = \rho \otimes \rho \Sigma^{\mathrm{bare}}$

3. C. Covariance with anisotropies

1. For SPT-3G, the maps are treated with an **anisotropic filtering**. The analytical framework should fail

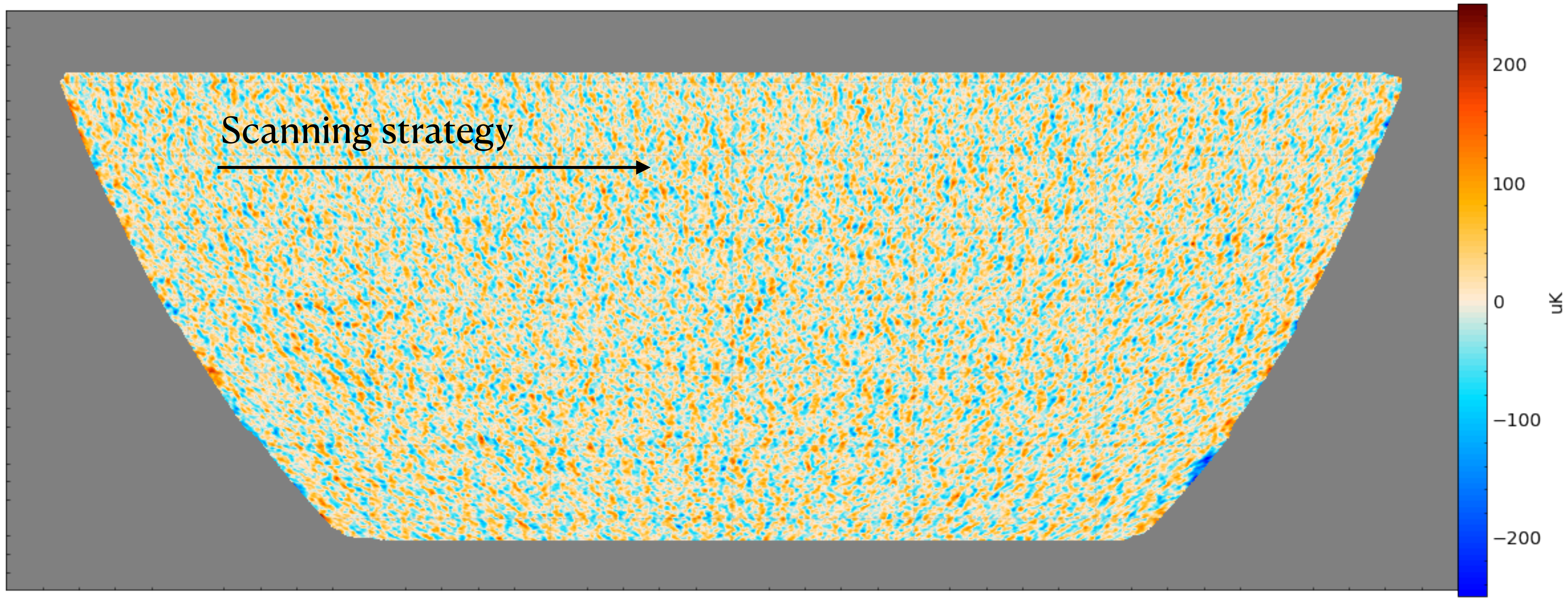


CMB temperature map with anisotropic filter

3. C. Covariance with anisotropies

1. For SPT-3G, the maps are treated with an **anisotropic filtering**. ~~The analytical framework should fail~~

2. We **adapted the analytical covariance framework** to take into account those anisotropies, using a 1D correction [Hivon, Doussot et al. in prep]
Plot: ratio of diagonals analytical framework over simulations, we always overestimate the variance by less than 5%.



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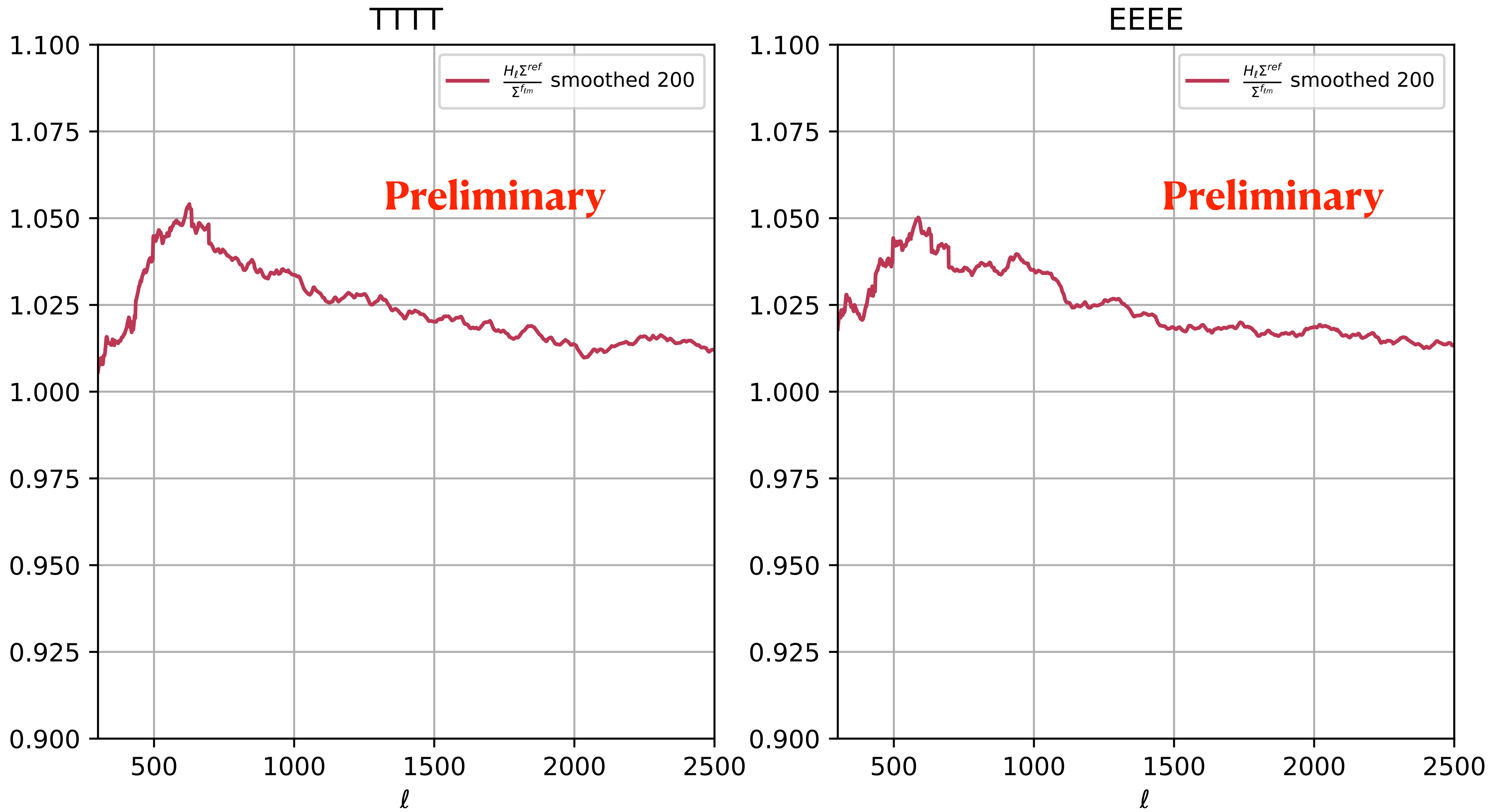

Ratio of diagonals : (Analytical covariance)/(Simulations with 2D filtering)

Conclusions

- The SPT-3G 2019-2020 data set will allow us to put tight constraints on cosmological parameters. Such constraints require a robust likelihood
- In [https://arxiv.org/abs/2204.13721], we show that we are able (1) to compute exactly covariance matrices, (2) to evaluate precision of approximations on small footprints and (3) to build a high-accuracy new approximation ACC.
- We are inpainting with high-precision the maps to allow for the analytical computation, taking into account every instrumental effect and correcting accordingly the covariance [Camphuis, Benabed, in prep]
- We have adapted this analytical framework to anisotropies [Hivon, Doussot, in prep]

3. Final covariance

Preliminary multi-frequency covariance matrix for the likelihood pipeline obtained with our analytical framework !

Future work: extensively test the likelihood