Component separation for the Simons Observatory Large Aperture Telescope

Benjamin Beringue
- on behalf of the Simons Observatory foreground working group -

Outline

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- Component separation for the Simons Observatory Large Aperture Telescope
- Semi-parametric component separation with `sps4lat`
- First tests on realistic map-based simulations
- Remaining challenges

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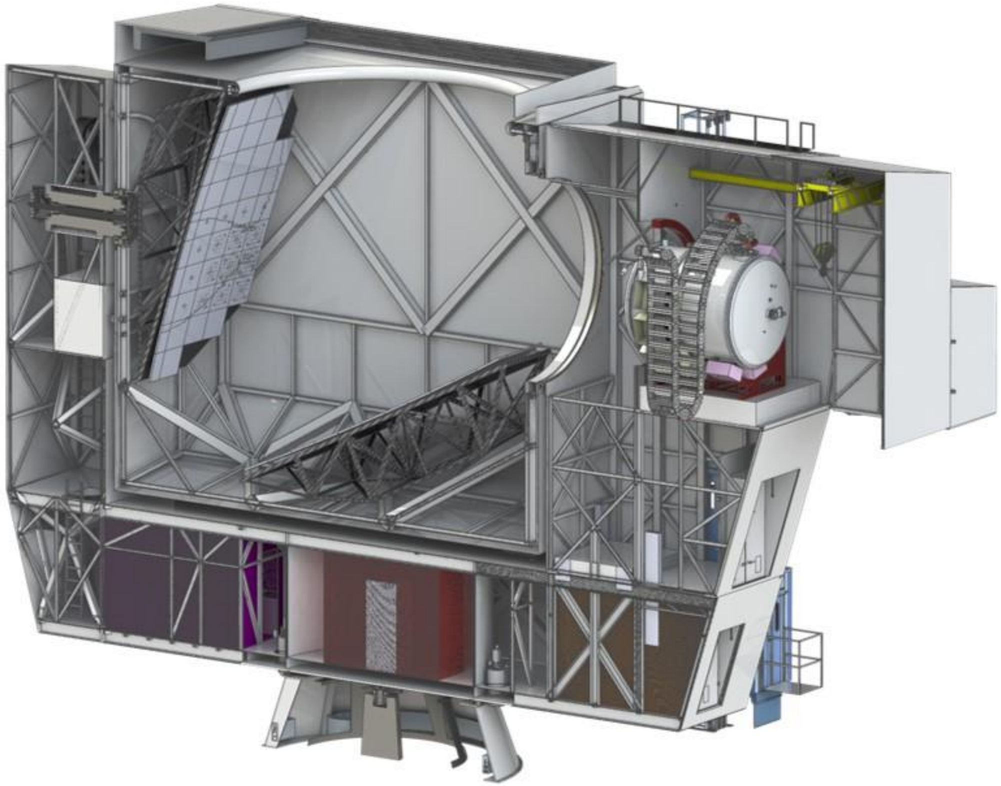
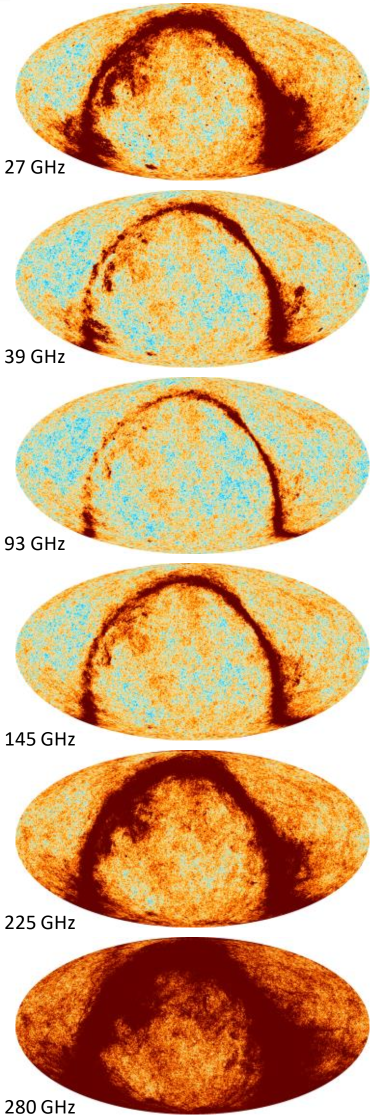
Simons Observatory (SO)



- Currently under construction/deployment
- 40+ institutions, 300+ members
- 3 Small Aperture Telescopes targeting *B-modes*
- 1 Large Aperture Telescope (LAT) :
  - 6m cross-dragone telescope
  - > 30,000 TES detectors
  - 6 frequency channels (27, 39, 93, 145, 225, 280 GHz)
  - Variety of science cases: N_{eff}, $\sum m_\nu$, σ_8, H_0, f_{NL}, …

Component separation

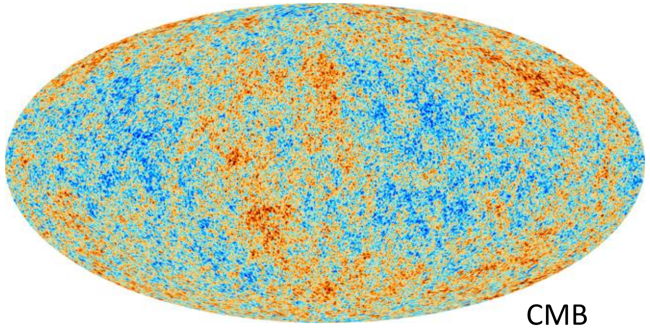


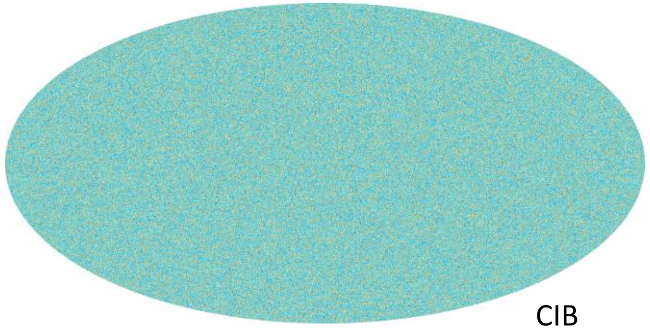
Component separation amounts to isolate the signals with different astrophysical origins.

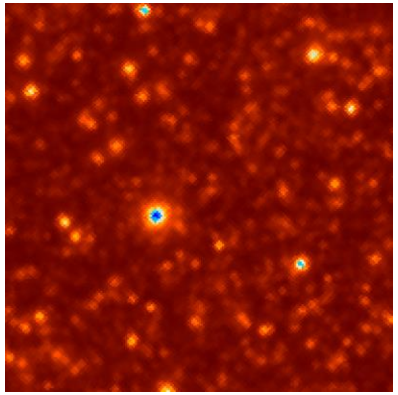
Required step in most science cases:

- ΛCDM and extensions (consistency checks)
- Non-gaussianities
- Compton-y map
- …

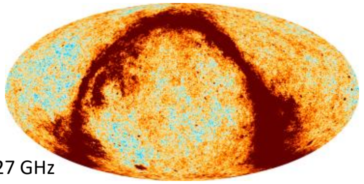
Different methods are implemented with Simons Observatory.

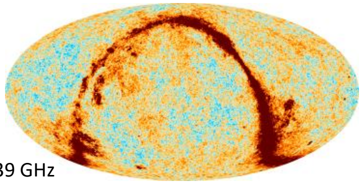

CMB

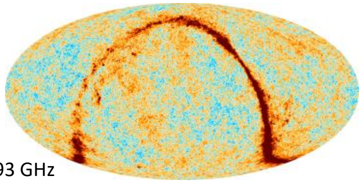

CIB

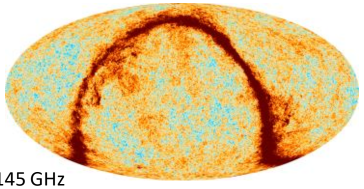

tSZ

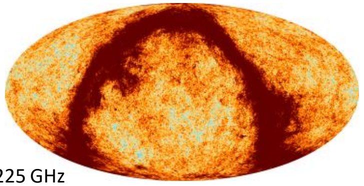
Component separation

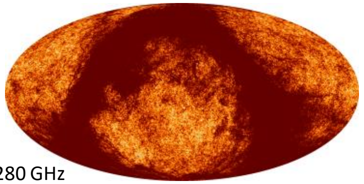

27 GHz


39 GHz

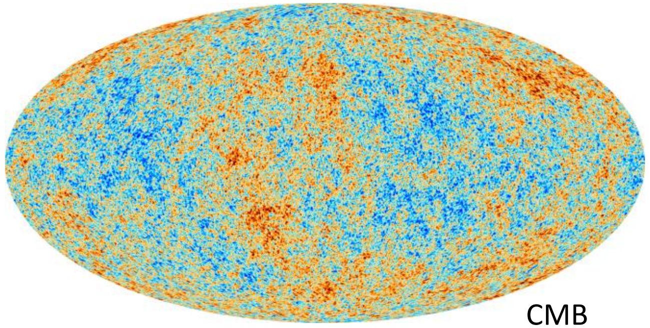

93 GHz

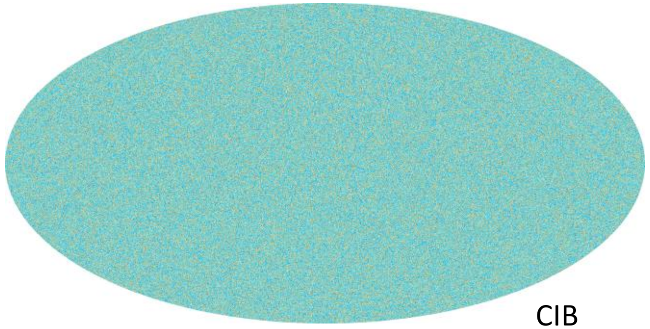

145 GHz

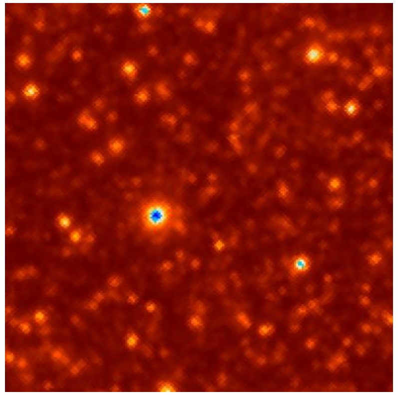

225 GHz


280 GHz

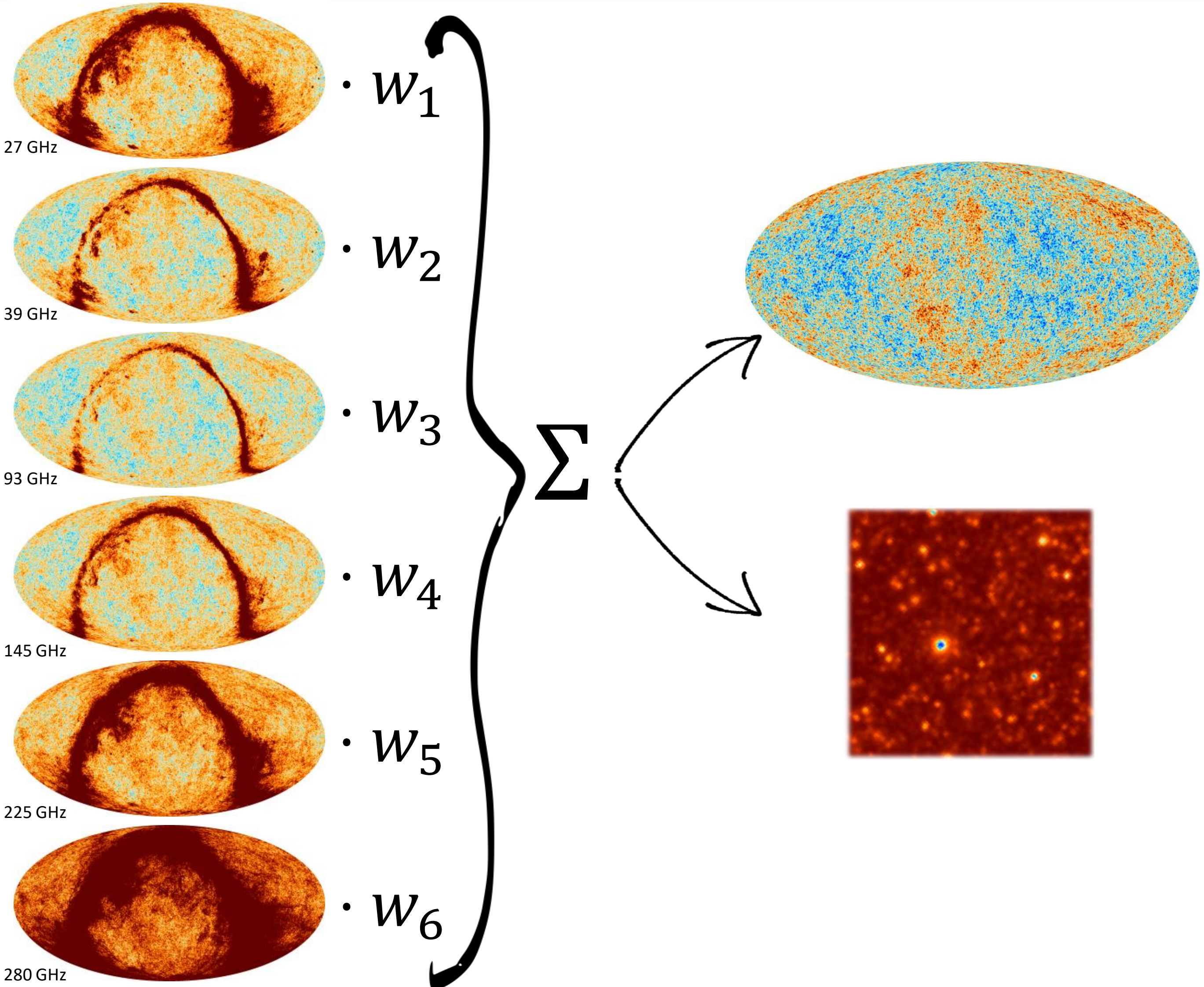
and many others !


CMB


CIB


tSZ

Component separation: ILC



Internal Linear Combination (ILC)

Define a set of weights that

1. Preserves the signal of interest
2. Minimizes the variance of the resulting map
3. Nulls contribution from specific components

Pros:

- Limited assumptions on the signal (blind)
- Easy to implement

Cons:

- Doesn't use any prior knowledge/model on the signal
- Potentially large bias/residual contamination depending on the localization of the statistics

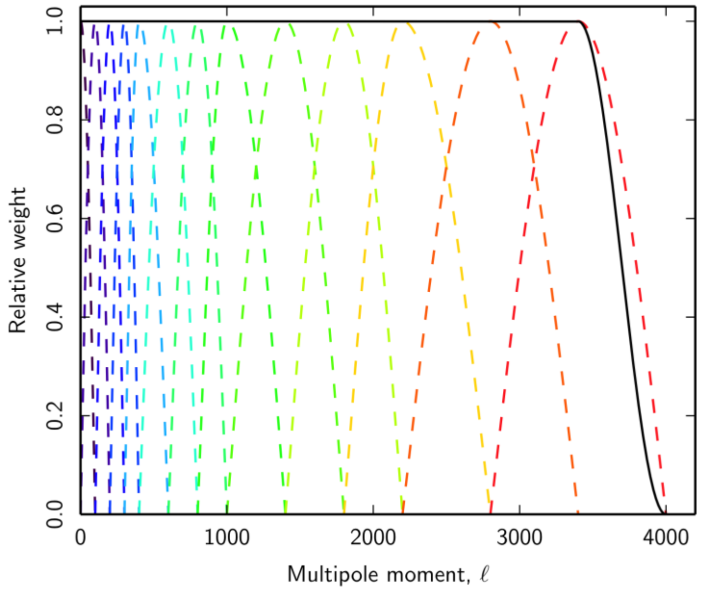
[see eg. Delabrouille et al. 09, Remazeilles et al. 11, 20]

Component separation: Needlet ILC

What are needlets ?

- Alternative basis for projecting signals on the sphere
- Localized in both real and harmonic domain

See Will Coulton's poster for an application on ACT + Planck maps !!



From [Planck iv 2018]

- Use harmonic filter to produce maps at a different needlet scales
- Compute needlet coefficients from these filtered maps
- Determine ILC weights for each of these coefficients

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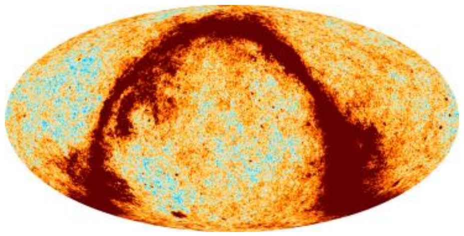
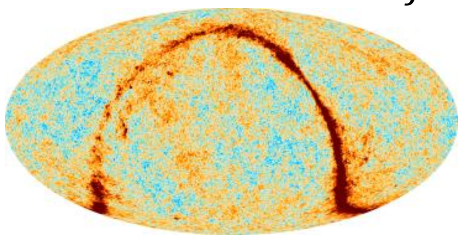
sps4lat

ν_i ν_j

$\langle$  $\times$  $\rangle$

$$\hat{R}_\ell = \begin{pmatrix} \hat{C}_\ell(\nu_1,\nu_1) & \cdots & \hat{C}_\ell(\nu_1,\nu_N) \\ \vdots & \ddots & \vdots \\ \hat{C}_\ell(\nu_N,\nu_1) & \cdots & \hat{C}_\ell(\nu_N,\nu_N) \end{pmatrix}$$

```
Sum:
- FactorizedCrossSpectrum:
  - FreeSED (SED):
      nu: FREQS
      sed: null
  - FreeCls (Cl):
      cls: null
      ell: ELLS
- FactorizedCrossSpectrum:
  - FreeSED (SED):
      nu: FREQS
      sed: null
  - FreeCls (Cl):
      cls: null
      ell: ELLS
- GroundBasedNoise:
    alpha_knee: a_knee
    beam: FWHM
    ell: ELLS
    ell_knee: l_knee
    nred: null
    nu: FREQS
    nwhite: null
```

fgspectra model

$$R(\theta) = A^{CMB} C_\ell^{CMB} A^{CMB,T} + A^{fgs} P_\ell^{fgs} A^{fgs,T} + N_\ell$$

Measure of mismatch:

Computation of **KL divergence** and optimization

$$\mathrm{KL}\left(\hat{R}, R(\theta)\right) = \frac{1}{2}\left(\mathrm{Tr}\left(\hat{R}R(\theta)^{-1}\right) - \log\det\left(\hat{R}R(\theta)^{-1}\right) - n\right)$$

[Planck iv 18, Delabrouille et al. 03, Cardoso et al. 08]

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sps4lat

SIMONS OBSERVATORY

$$R(\theta) = A^{CMB} C_\ell^{CMB} A^{CMB,T} + A^{fgs} P_\ell^{fgs} A^{fgs,T} + N_\ell$$

Allows for a flexible parametrization:

- C_ℓ^{CMB} free bandpowers or pre-computed template with free-amplitude,
- P_ℓ^{fgs} multidimensional space, physically motivated templates or free bandpowers,
- A fixed, free or modelled mixing matrices,
- N_ℓ noise model.

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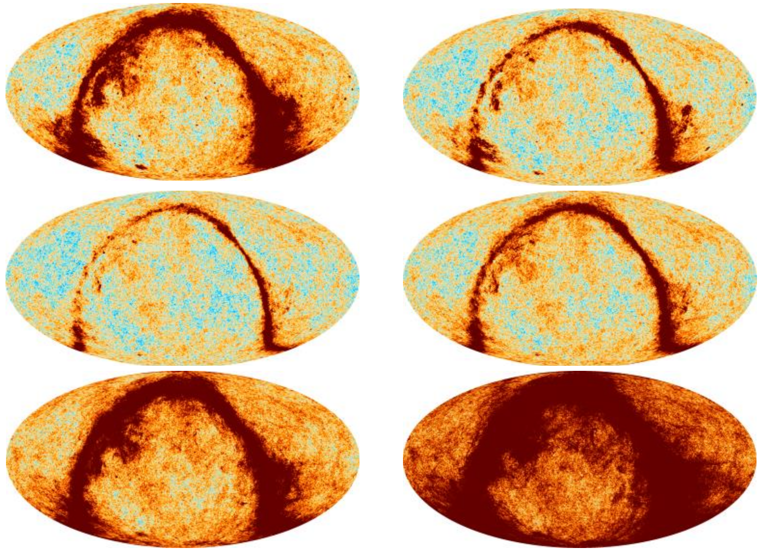
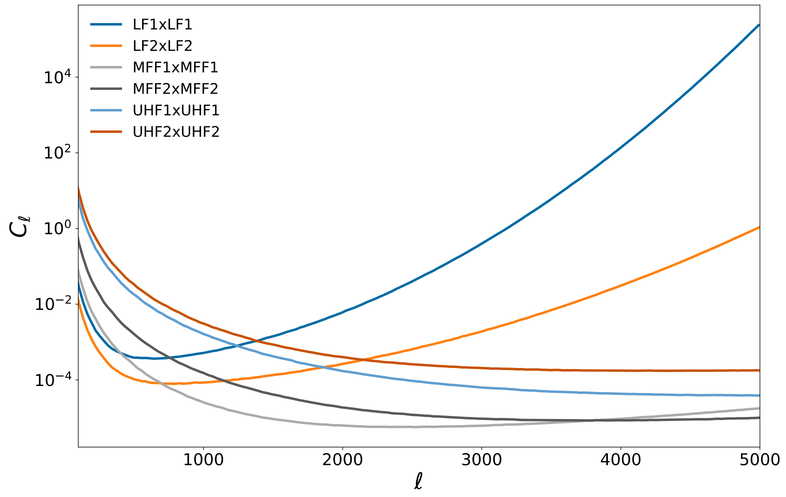
First tests

First tests run on map-based simulations.





- Galactic foregrounds are modelled using **pysm3 [Thorne et al. 17]**
- Extragalactic foregrounds are extrapolated from **Websky [Stein et al. 20]**
- Sensitivities from SO overview paper **[Ade et al. 19]**
- Realistic hitmap and survey strategy
- Top-hat bandpasses

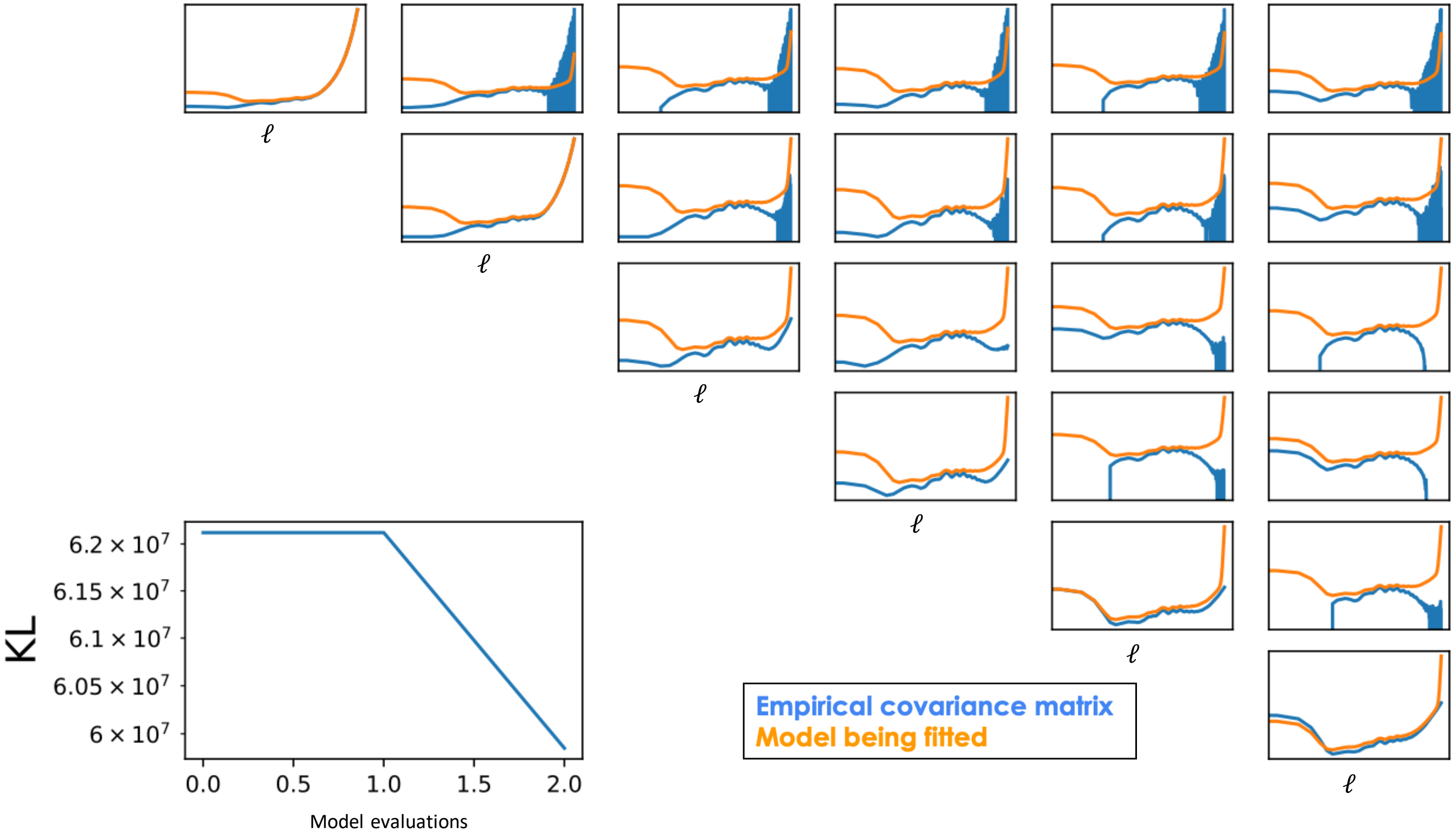
First tests

- Fixing the CMB sed and fitting the bandpowers.
- Varying the dimensionality of “foreground” component
- Noise model includes both atmospheric and instrumental noise:

$$N_\ell = N_{red} * \left(\frac{\ell}{\ell_{knee}}\right)^{\alpha_{knee}} + N_{white}$$

Fixed

Free parameters

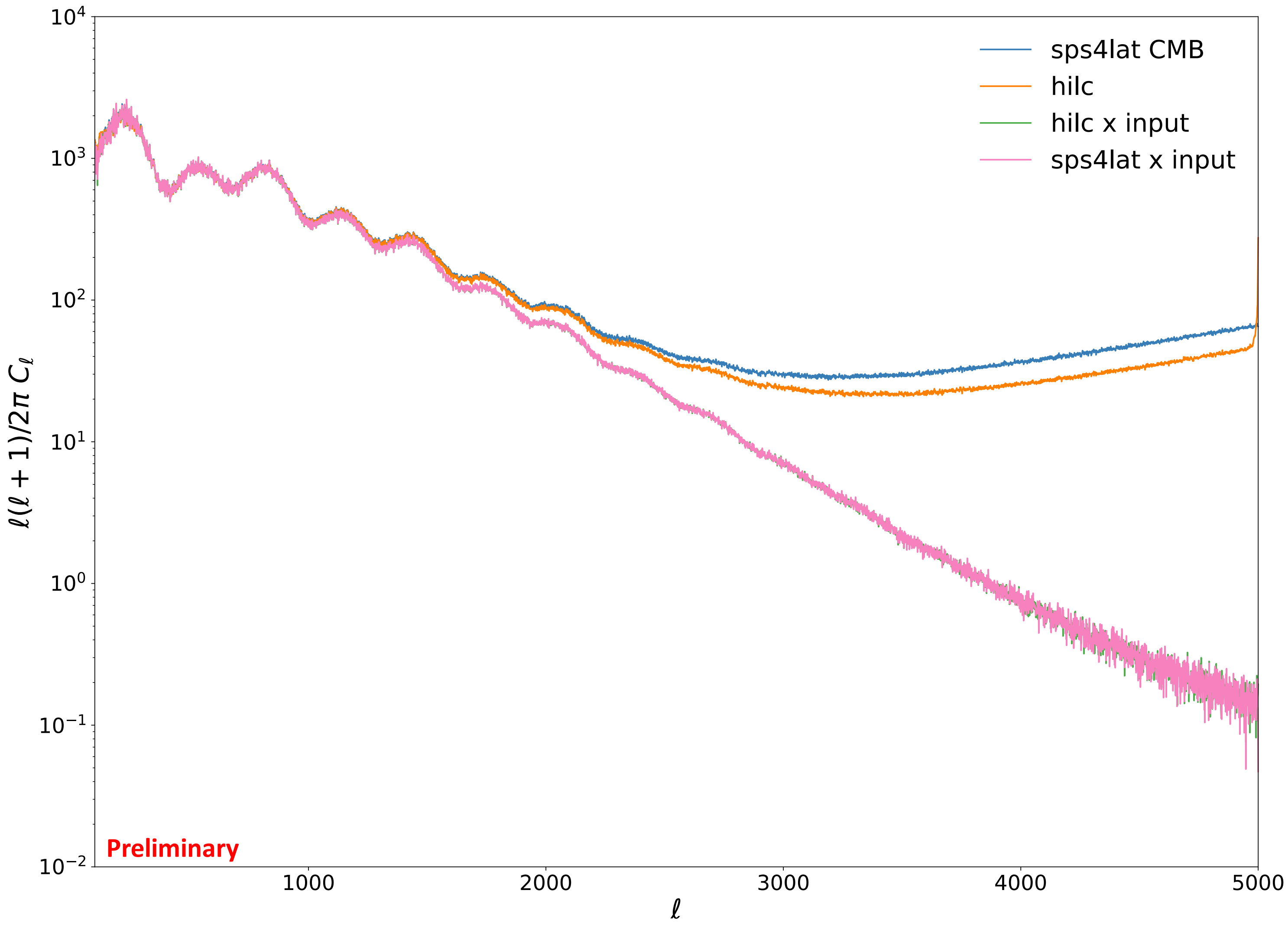


First tests

$$\mathbf{R}(\theta) = \mathbf{a}^{\mathrm{CMB}} \cdot \mathbf{a}^{\mathrm{CMB,T}} C_\ell^{\mathrm{CMB}} + \mathbf{N}_\ell$$

$\mathbf{a} = (1, \ldots, 1)^{\mathrm{T}}$ Fixed

C_ℓ^{CMB} Free bandpowers



First tests

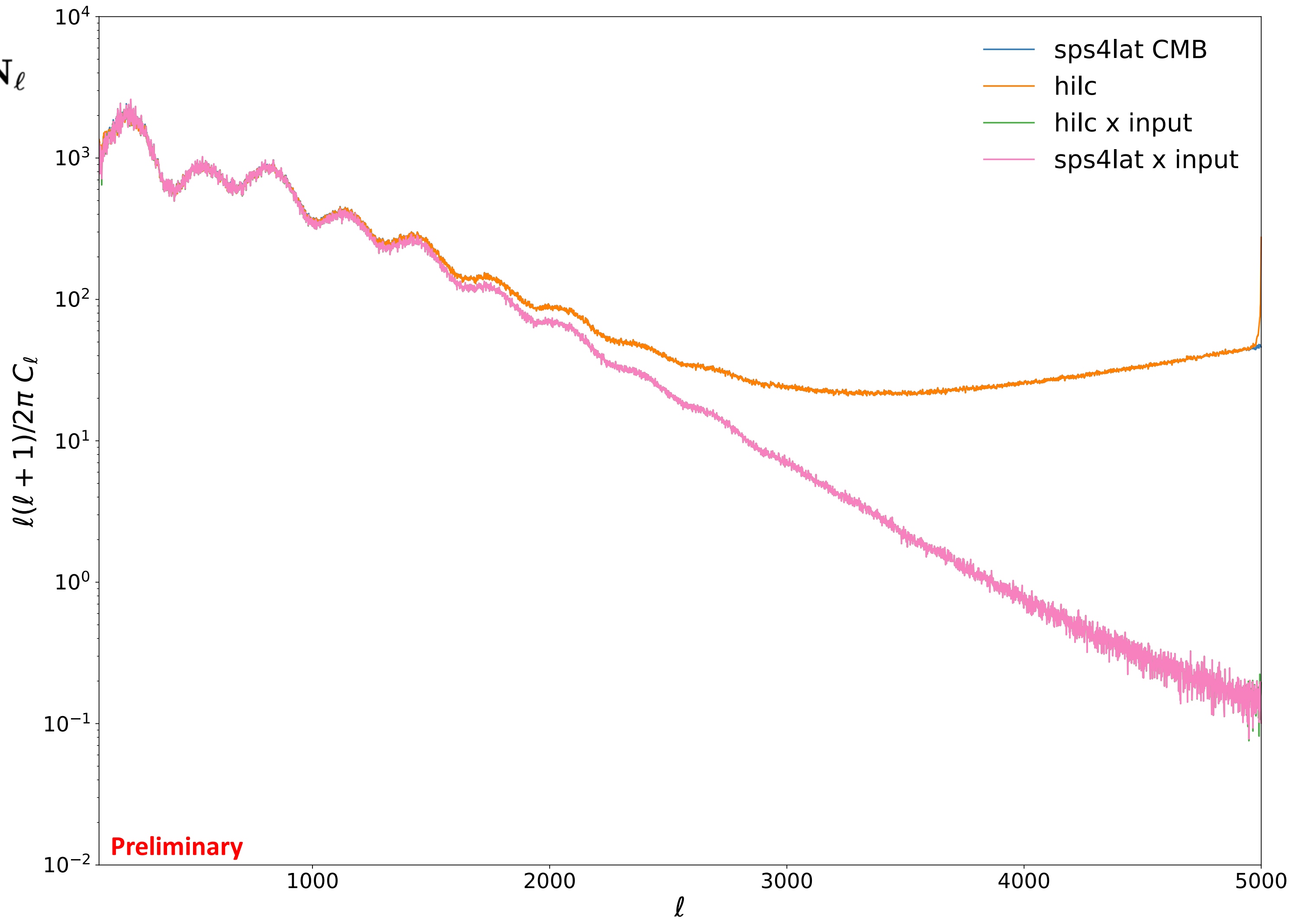
$$\mathbf{R}(\theta) = \mathbf{a}^{\mathrm{CMB}} \cdot \mathbf{a}^{\mathrm{CMB,T}} C_\ell^{\mathrm{CMB}} + \mathbf{b}^{\mathrm{fg}} \cdot \mathbf{b}^{\mathrm{fg,T}} C_\ell^{\mathrm{fg}} + \mathbf{N}_\ell$$

$\mathbf{a} = (1, \ldots, 1)^{\mathrm{T}}$ Fixed

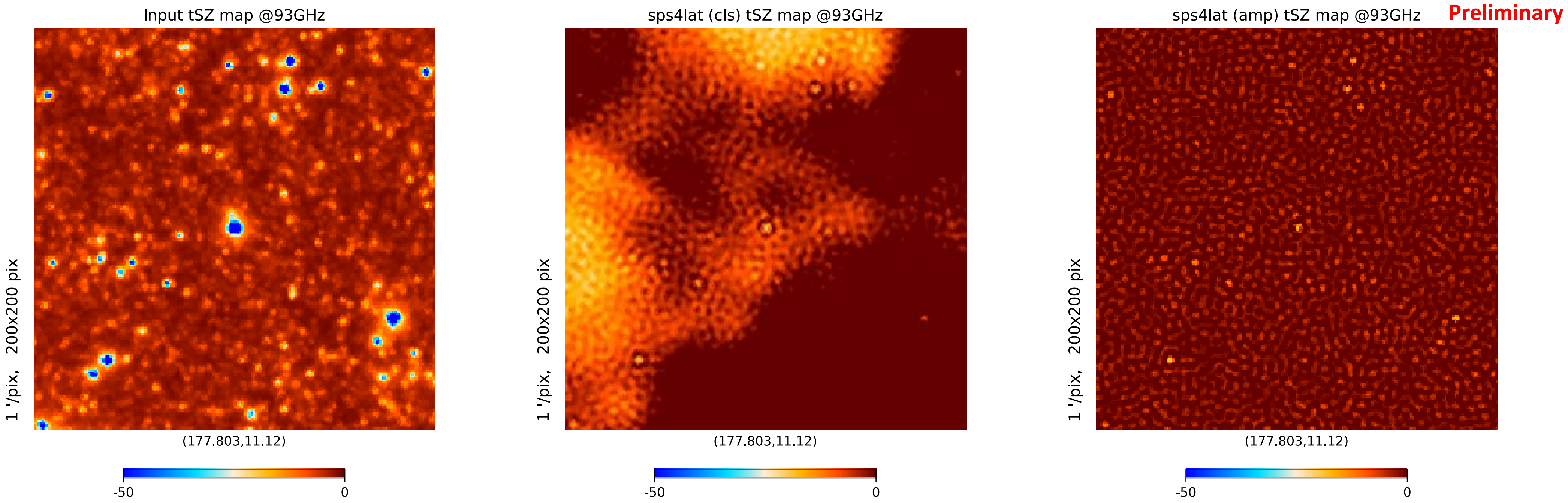
$\mathbf{b} = (b_1, \ldots, b_N)^{\mathrm{T}}$ Free sed

C_ℓ^{CMB} Free bandpowers

C_ℓ^{fg} Free bandpowers



First tests



$$\mathbf{R}(\theta) = \mathbf{a}^{\rm CMB} \cdot \mathbf{a}^{\rm CMB,T} C_\ell^{\rm CMB} + \mathbf{b}^{\rm tSZ} \cdot \mathbf{b}^{\rm tSZ,T} C_\ell^{\rm tSZ} + \mathbf{c}^{\rm fg} \cdot \mathbf{c}^{\rm fg,T} C_\ell^{\rm fg} + \mathbf{N}_\ell$$

Fixed ($\mathbf{a}^{\rm CMB,T}$) — Free ($C_\ell^{\rm CMB}$) — Fixed ($\mathbf{b}^{\rm tSZ,T}$) — Free bandpowers or free amplitude ($C_\ell^{\rm tSZ}$) — Free ($\mathbf{c}^{\rm fg,T}$) — Free ($C_\ell^{\rm fg}$)

Challenges remaining

Next steps:

- Increasing the complexity of the model requires investigating both the starting prescription and the optimization methods,
- Identifying science cases where semi-parametric component separation is beneficial,
- Including polarization,
- Exploring the feasibility of applying sps4lat in the needlet domain.

Thank you !

Thank you for your attention !

-- Feel free to ask any question now, at a coffee break or via email ! --

beringueb@cardiff.ac.uk