

An aerial photograph of the Five-hundred-meter Aperture Spherical Telescope (FAST) in China. The image shows the massive, white, spherical structure of the telescope, which is composed of many smaller panels. The structure is situated in a valley, surrounded by lush green trees and a winding road. The sky is clear and blue. The text "FAst neuTral HydrOgen intensity Mapping ExpeRiment (FATHOMER)" is overlaid on the image in a bold, black, serif font.

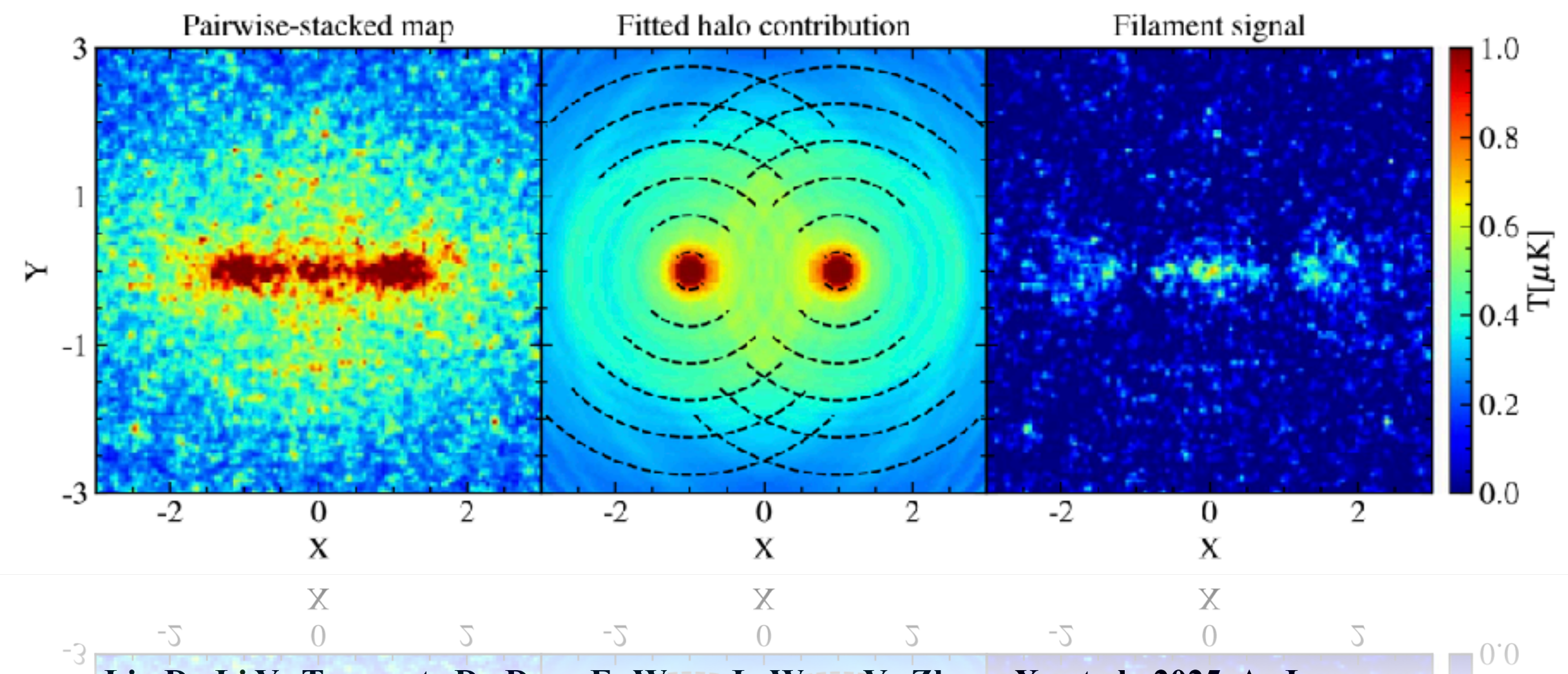
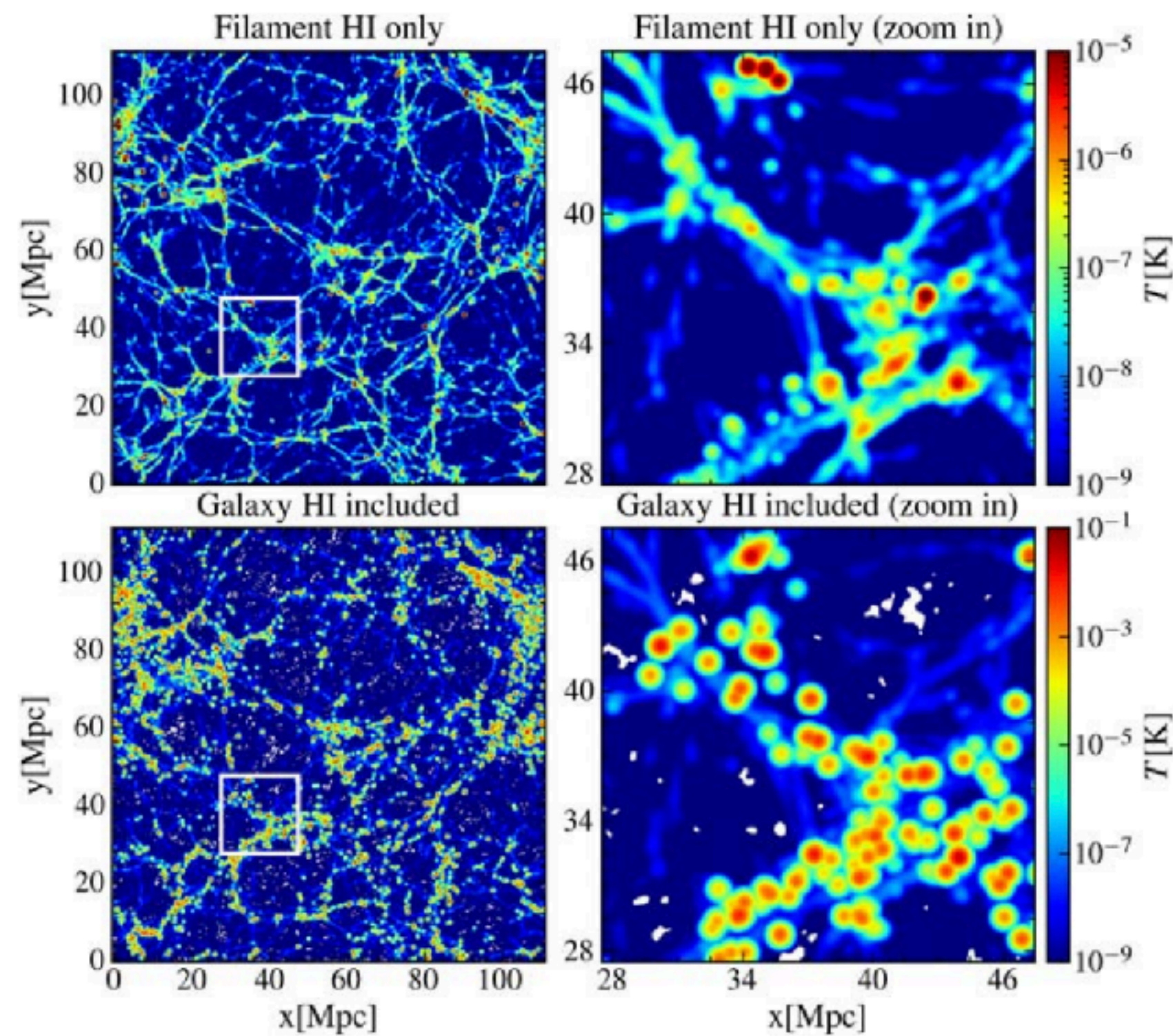
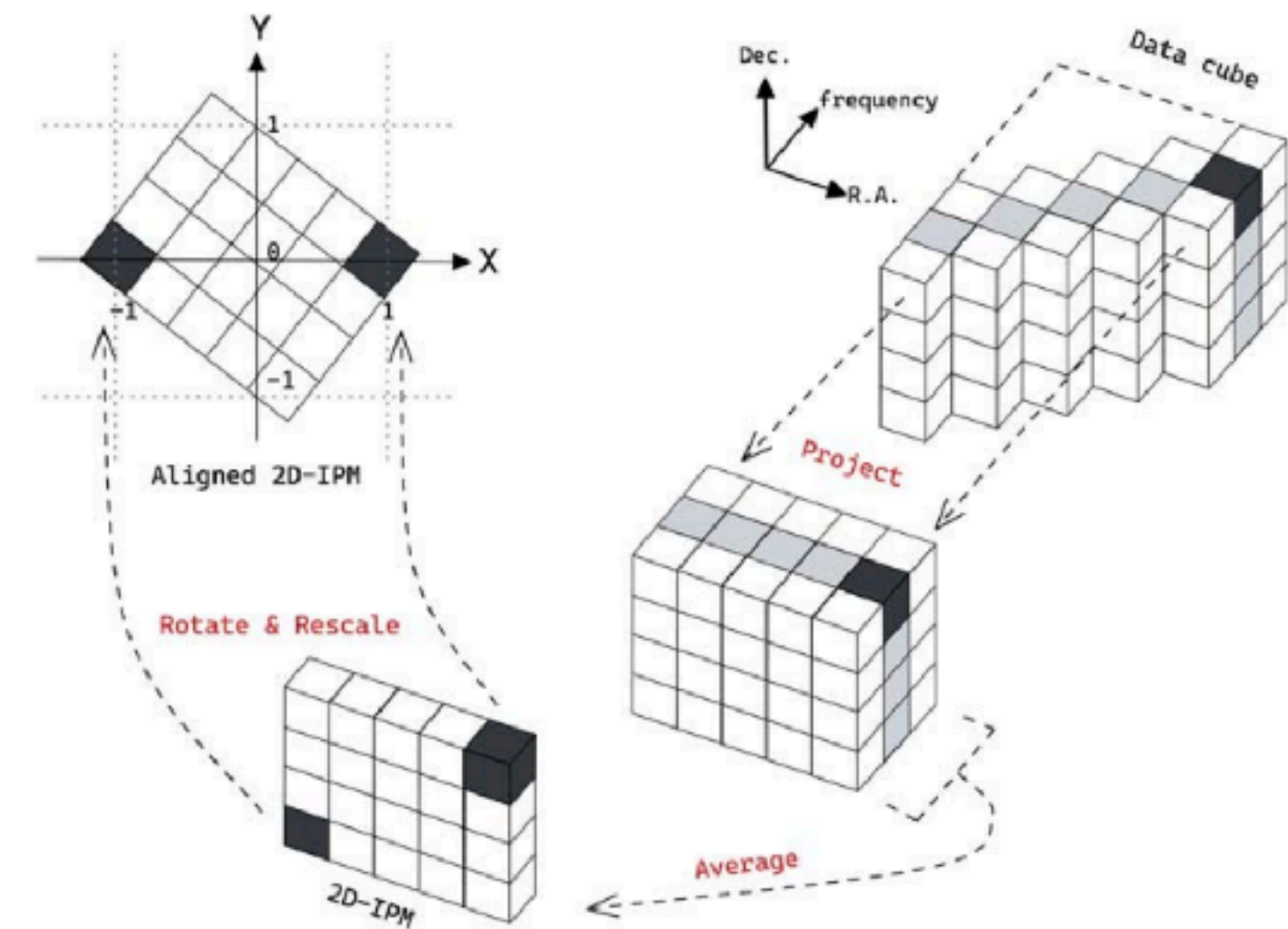
**FAst neuTral HydrOgen intensity Mapping ExpeRiment  
(FATHOMER)**

**Filament stacking with CRAFTS HI map (Diyang Liu)**

**Foreground subtraction with FATHOMER (1050 - 1081 MHz)**

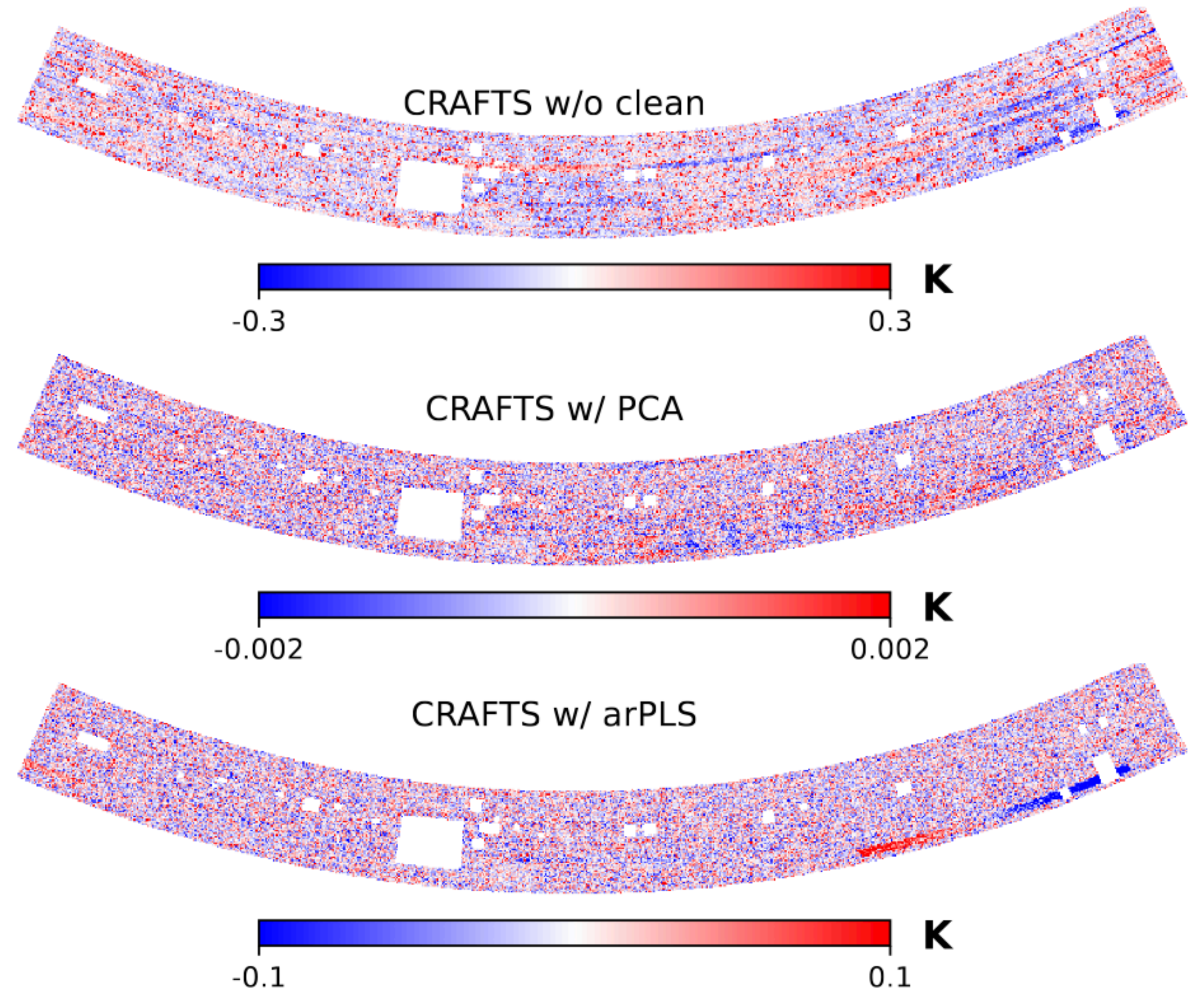
# Filament stacking with CRAFTS HI map

- Simulation of pair-wise stacking



# Filament stacking with CRAFTS HI map

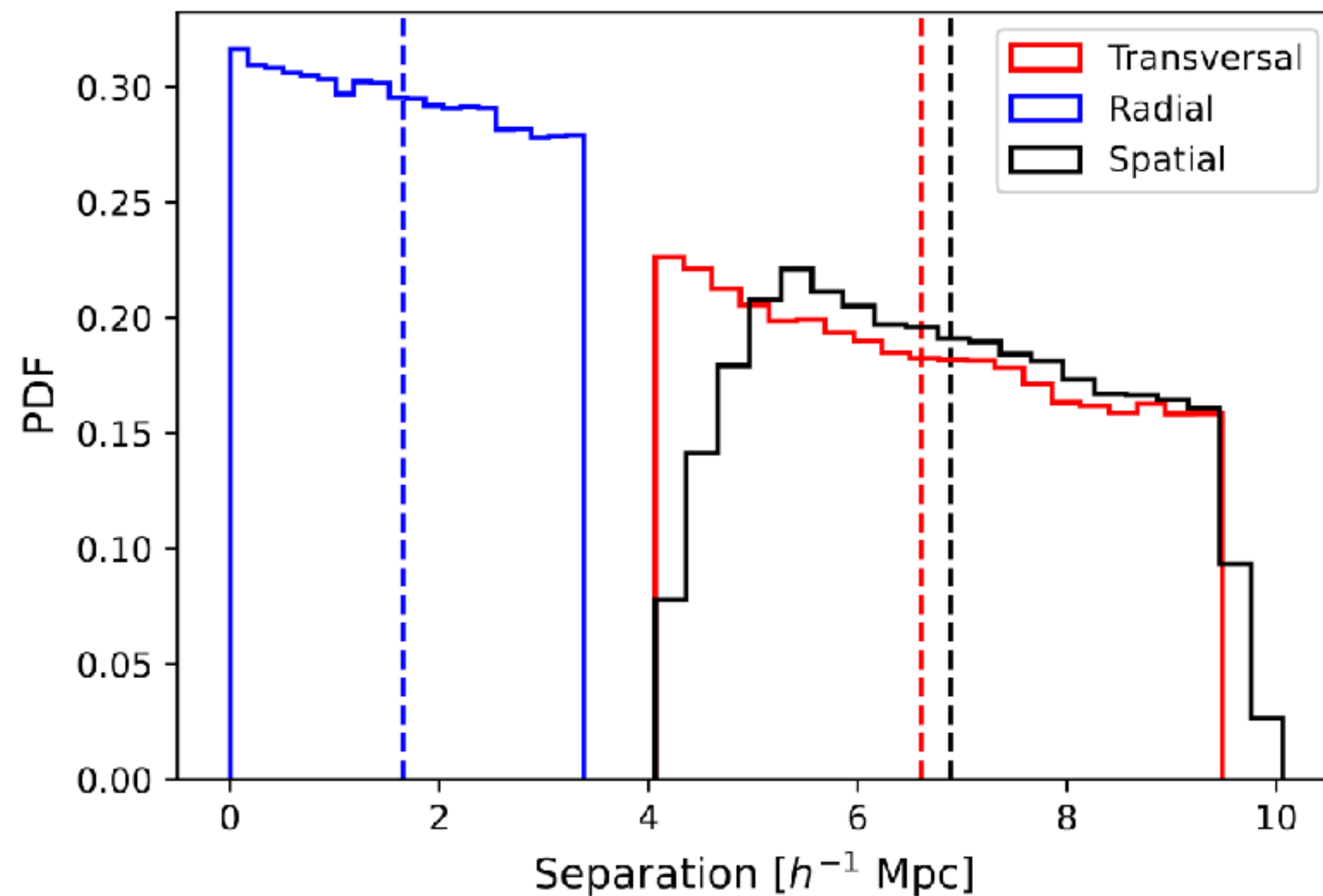
- CRAFTS HI map with different foreground subtraction methods



**Figure 1.** Example CRAFTS maps before and after foreground removal. Plotted maps are extracted slices at 1360MHz, while showing in a Cartesian projection rotated to (218, 42.5) deg. The middle panel showing a slice with 30 PCA modes removal, the arPLS cleaning adopted a smoothness parameter at  $\lambda = 10^5$ .

# Filament stacking with CRAFTS HI map

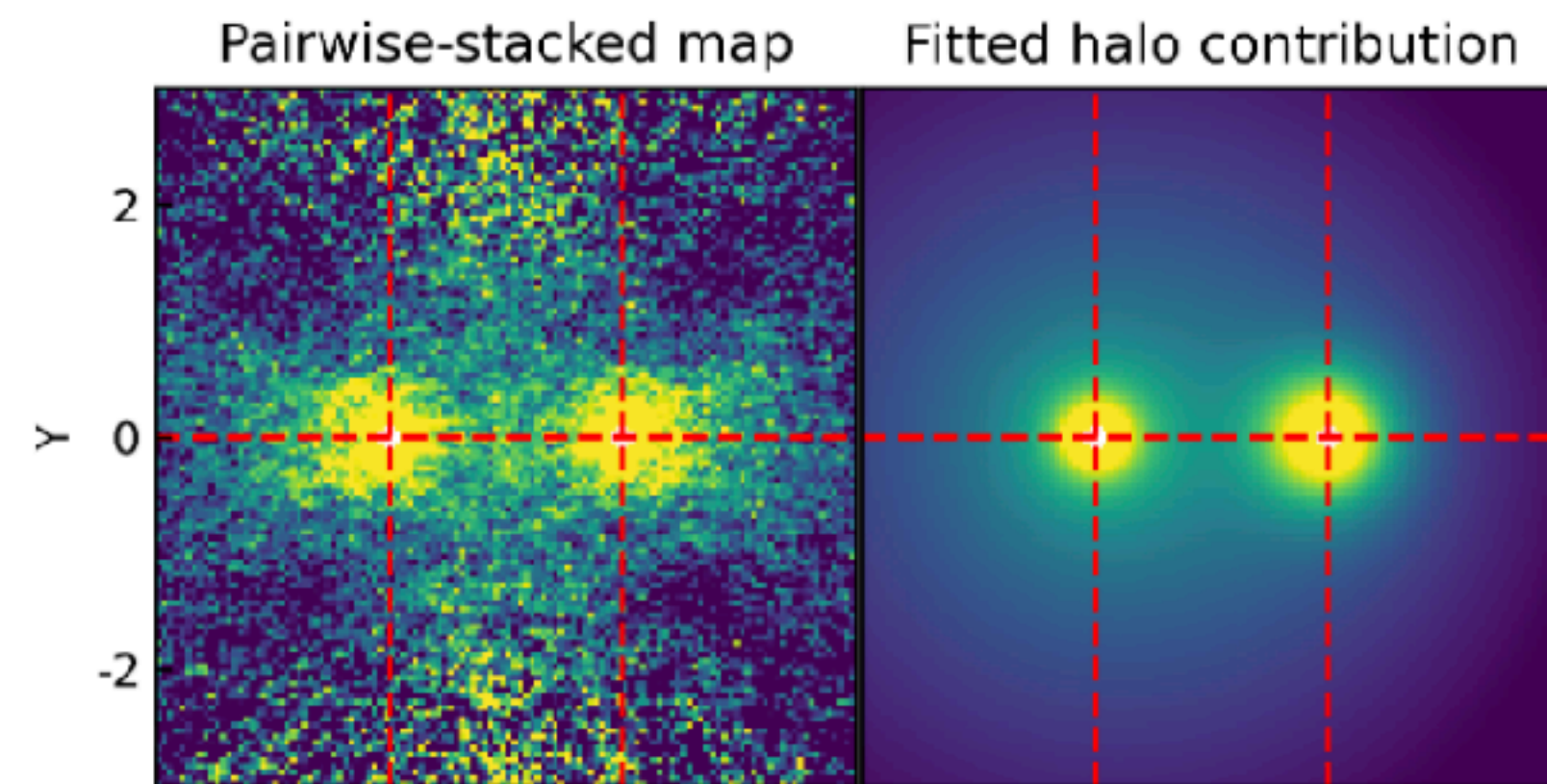
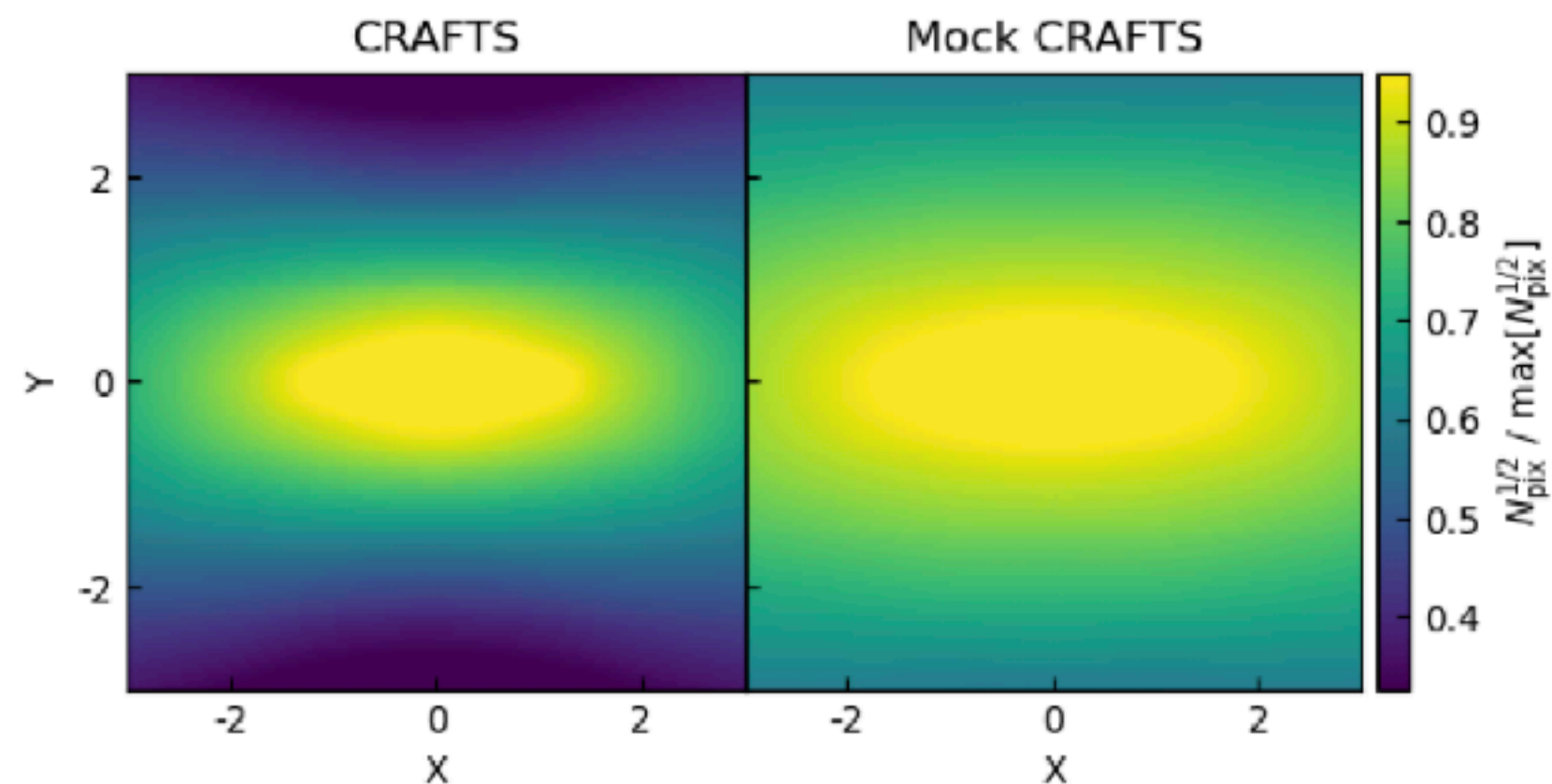
- CRAFTS HI map with different foreground subtraction methods
- Galaxy catalogue ( SDSS Main Sample )



**Figure 3.** The probability density distribution of separation distances of the selected galaxy pairs. The red, blue, and black lines represent the separation distances in the transversal, radial, and spatial directions, respectively. The dashed vertical lines represent their mean separation distances, at about 6.60, 1.68 and 6.88  $h^{-1}$  Mpc respectively.

# Filament stacking with CRAFTS HI map

- CRAFTS HI map with different foreground subtraction methods
- Galaxy catalogue
- Pairwise stacking results
- Halo profile subtraction

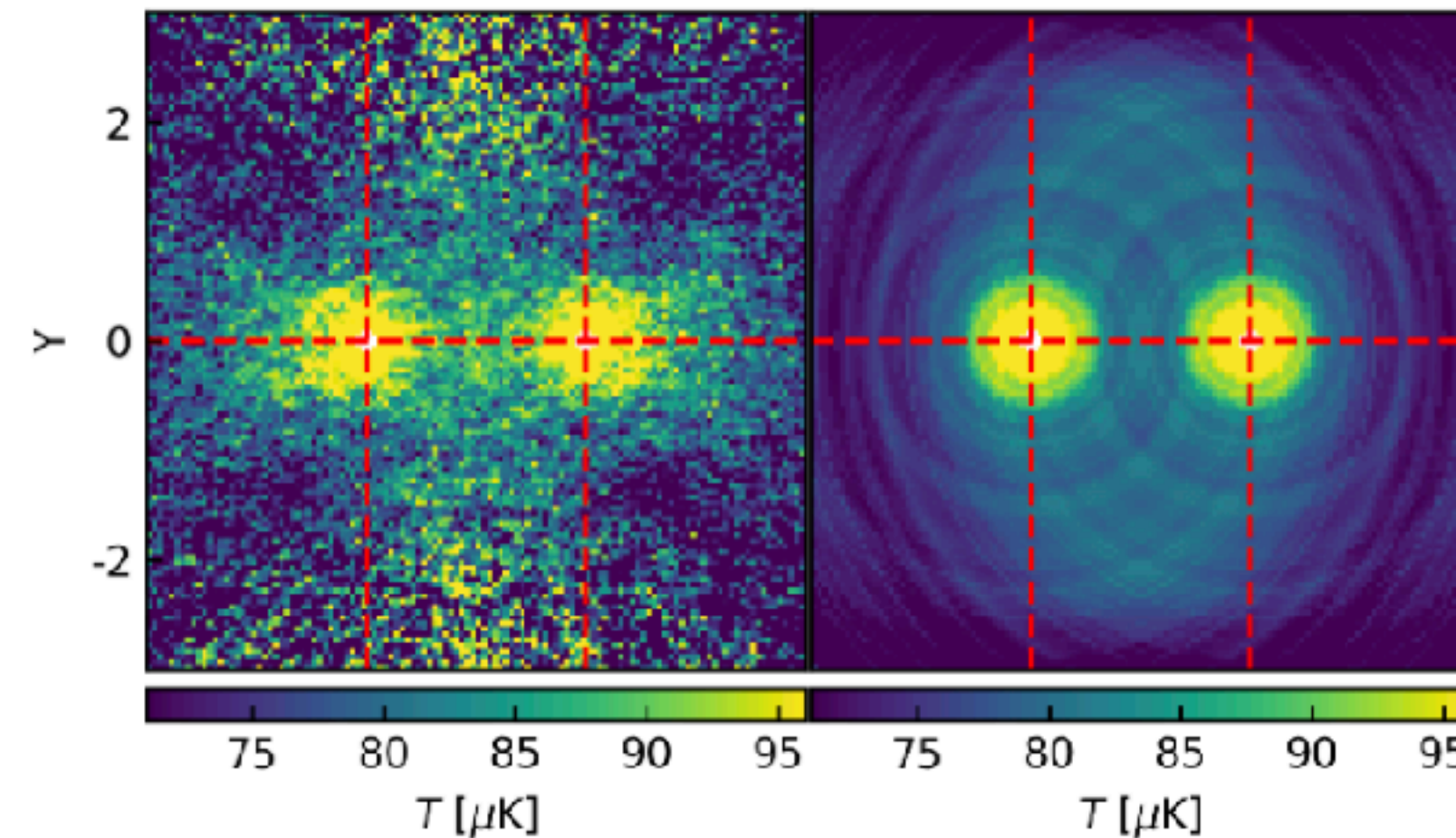


$$h(x, y) = h_{\text{NFW}}(x, y) + h_{\text{G}}(x, y)$$

$$h_{\text{NFW}}(x, y) = \frac{A}{r/r_s(1 + r/r_s)^2}$$

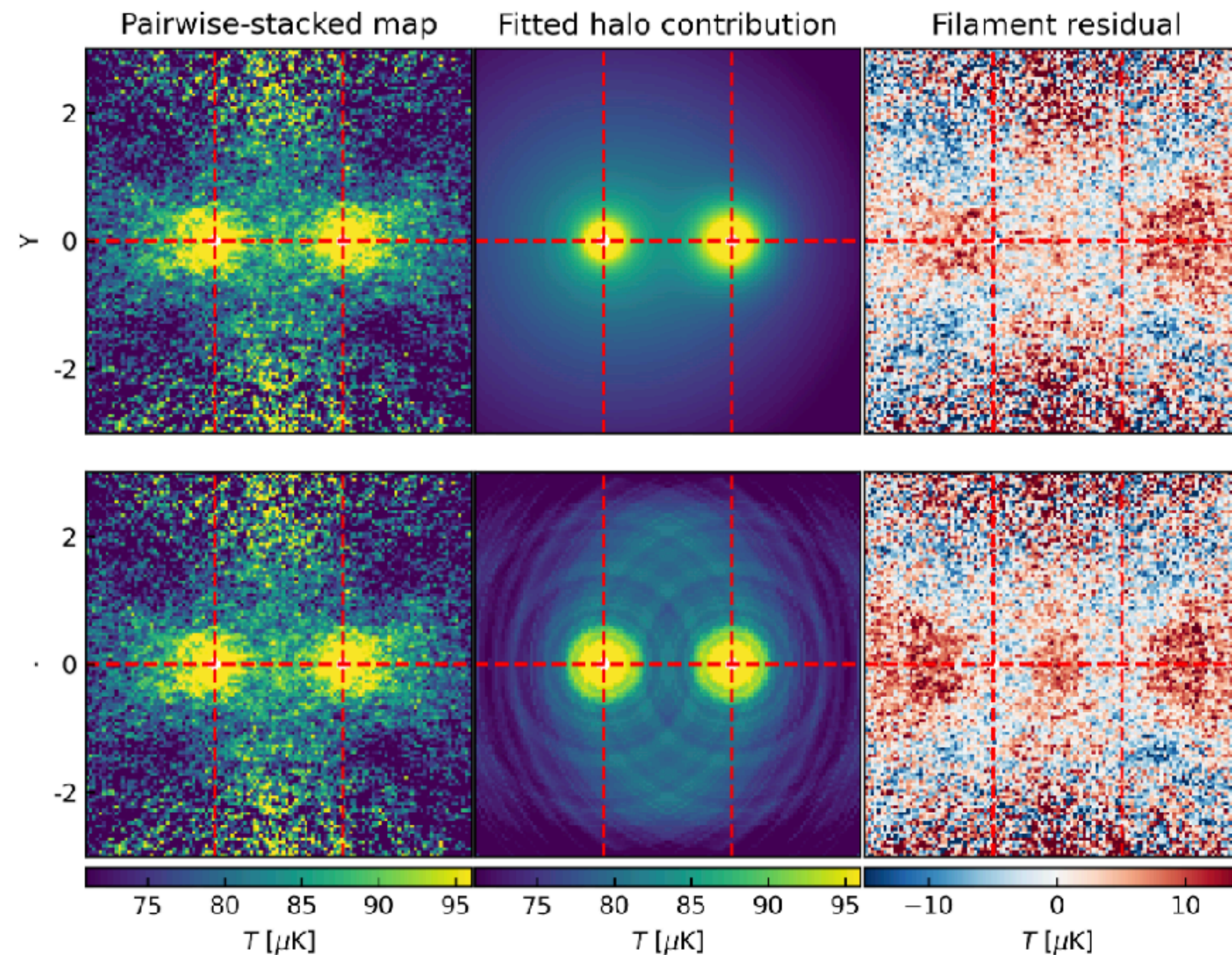
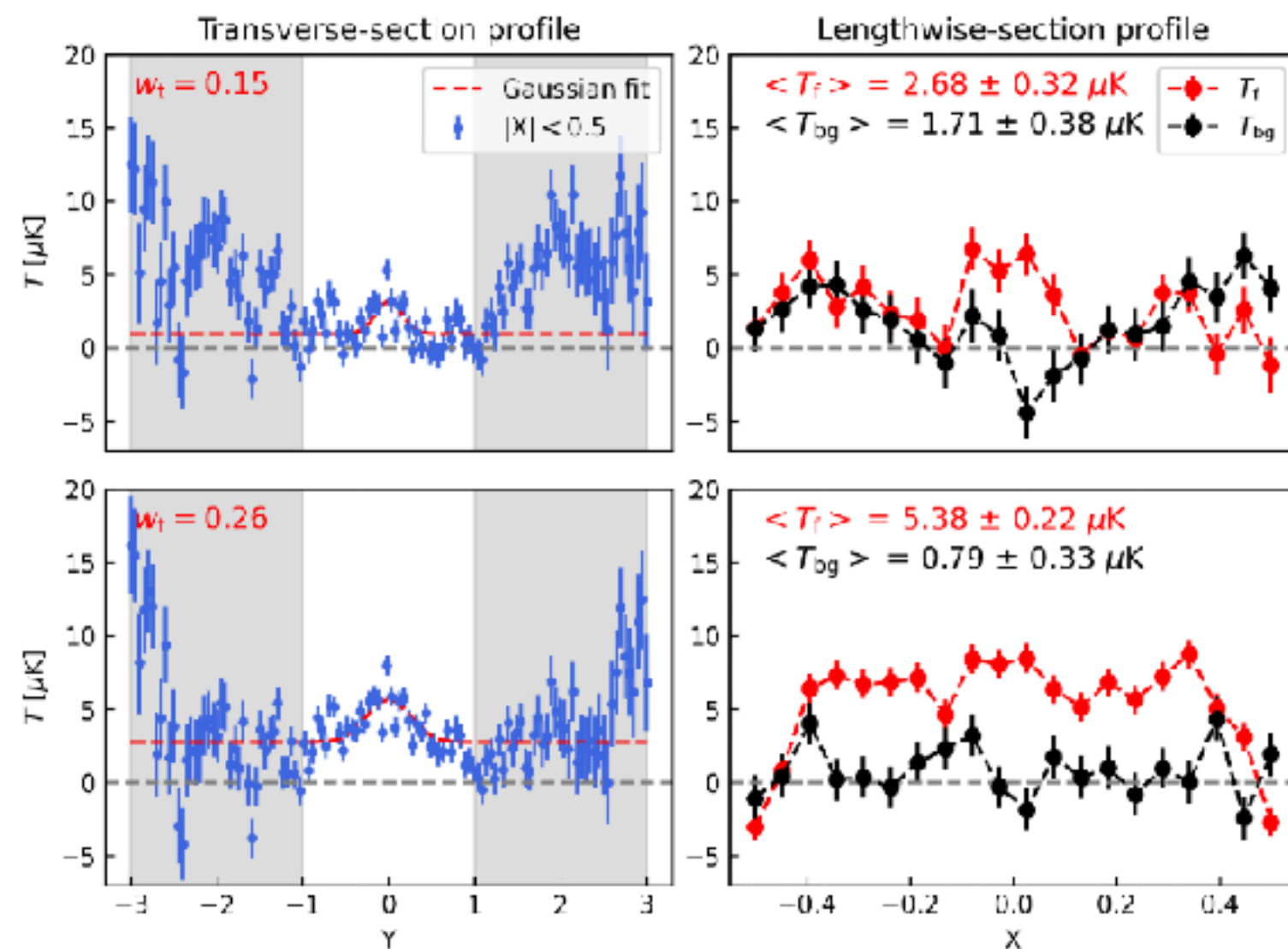
$$h_{\text{G}}(x, y) = B \exp\left(-\frac{x^2 + y^2}{2\sigma^2}\right)$$

$$H(x, y) = h_{-1} + h_{+1} + C$$



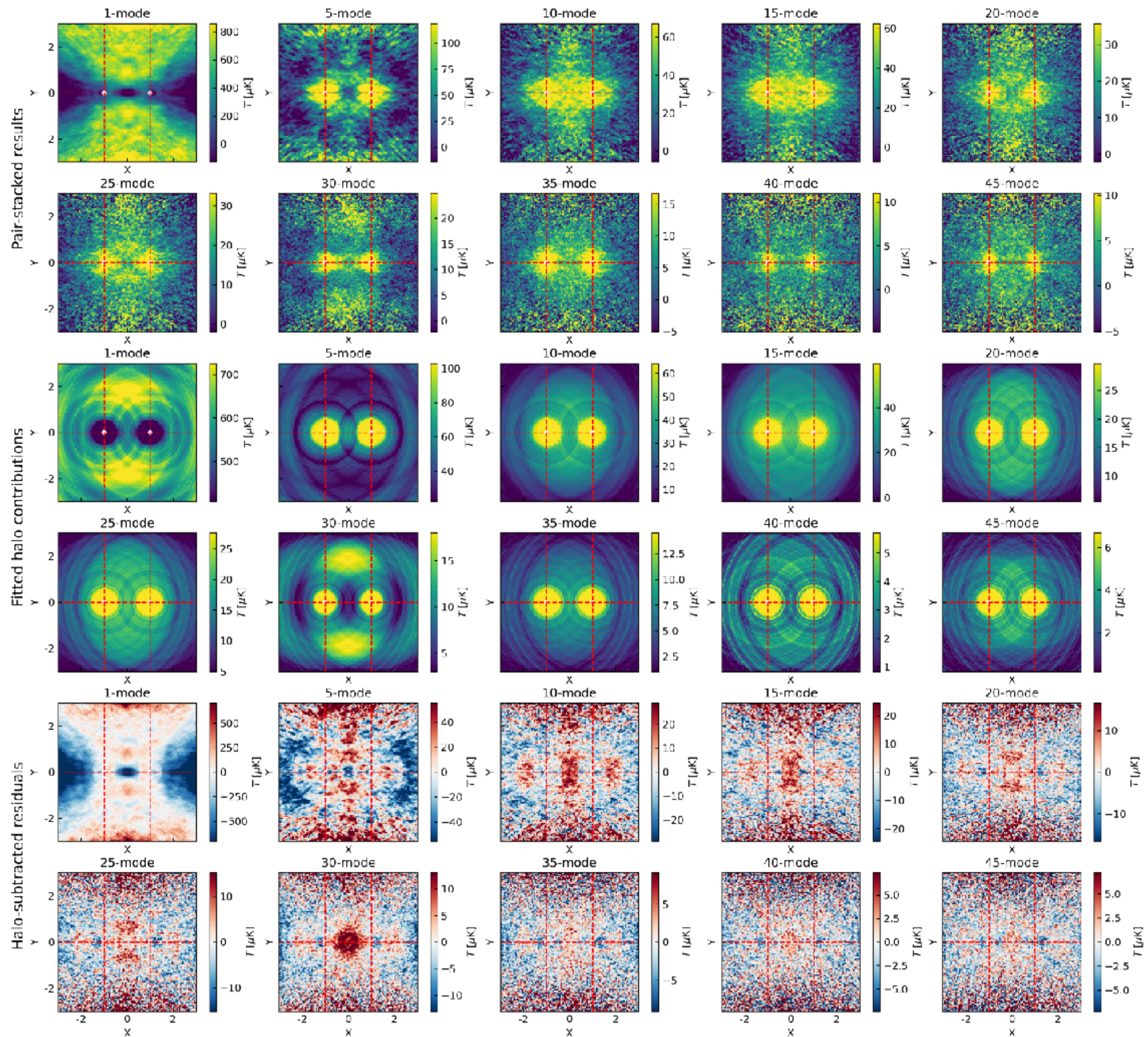
# Filament stacking with CRAFTS HI map

- CRAFTS HI map with different foreground subtraction methods
- Galaxy catalogue
- Pairwise stacking results
- Halo profile subtraction



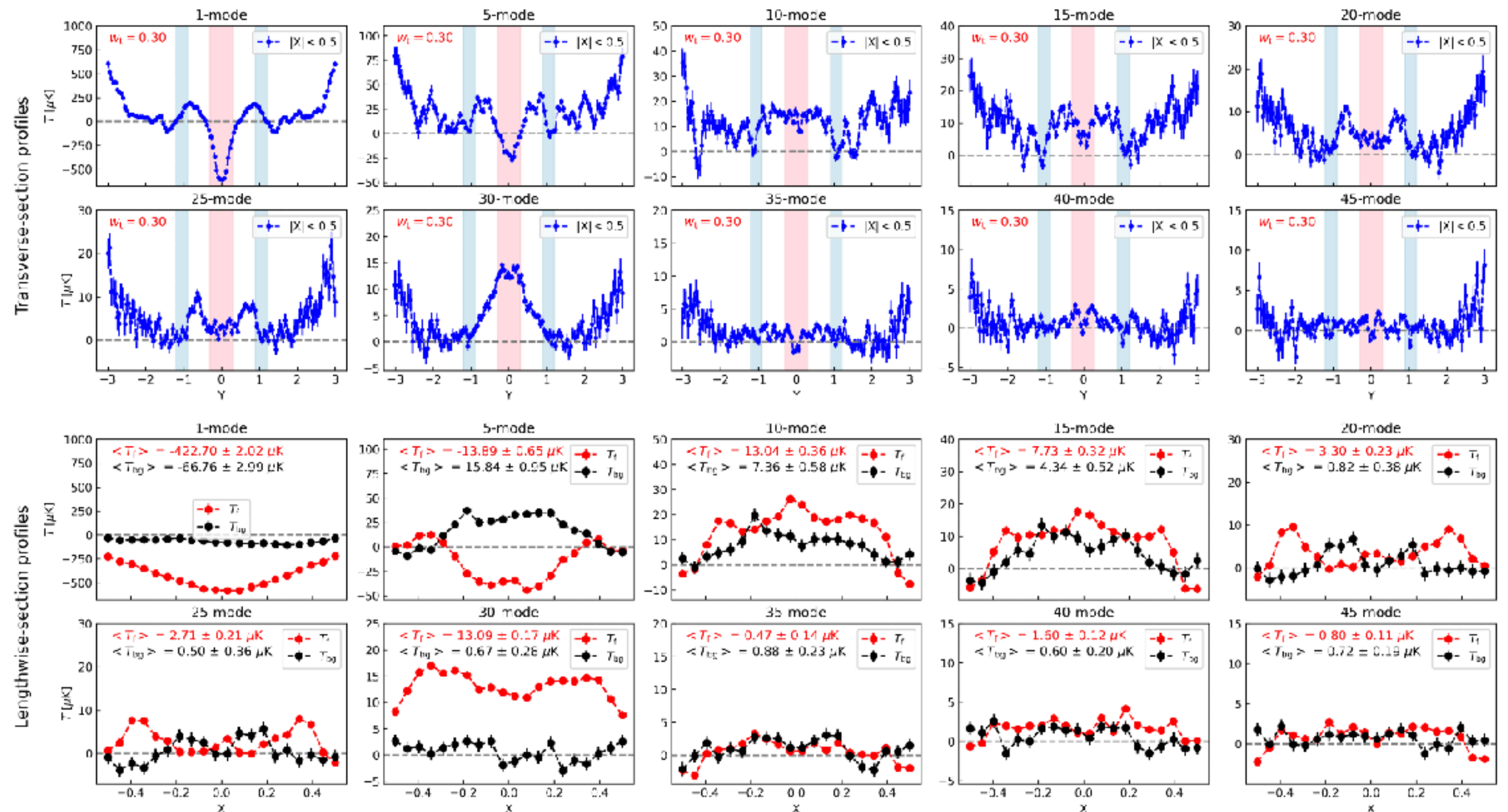
# Filament stack

- CRAFTS HI map with differen
- Galaxy catalogue
- Pairwise stacking results
- Halo profile subtraction
- PCA



# Filament stacking with CRAFTS HI map

- CRAFTS HI map with different foreground subtraction methods
- Galaxy catalogue
- Pairwise stacking results
- Halo profile subtraction
- PCA





# Foreground subtraction with FATHOMER

- 19 nights, 4 hr/night, about 110 square degrees.
- Frequency range 1050 - 1081 MHz
- Frequency resolution 122 kHz
- Redshift range 0.31 - 0.35

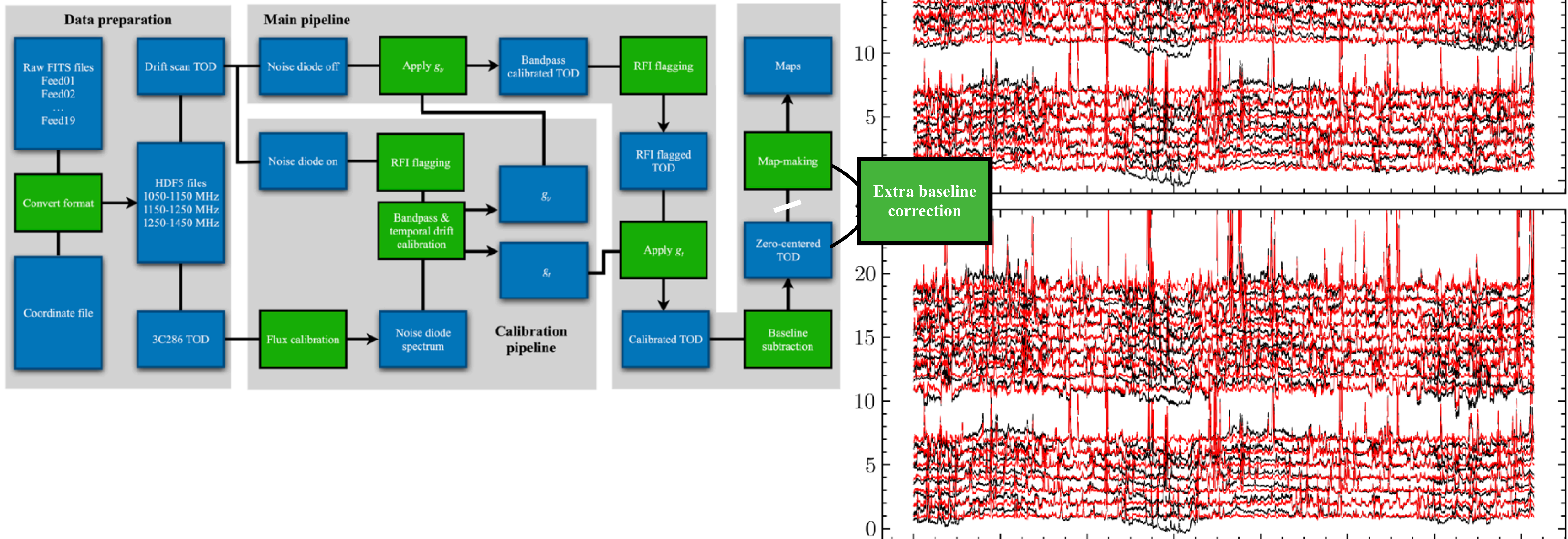
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DATA_Key_list = [  
    '20210314', '20210313', '20210305', '20210302', '20210306', '20210307',  
    '20210309', '20220210', '20220211', '20220212', '20220213', '20220214',  
    '20220215', '20220216', '20220217', '20220218', '20220222', '20220220',  
    '20220219',  
]
```

Data under TOD processing:

20240409, 20240421, 20240402, 20240329,  
20250506, 20250501

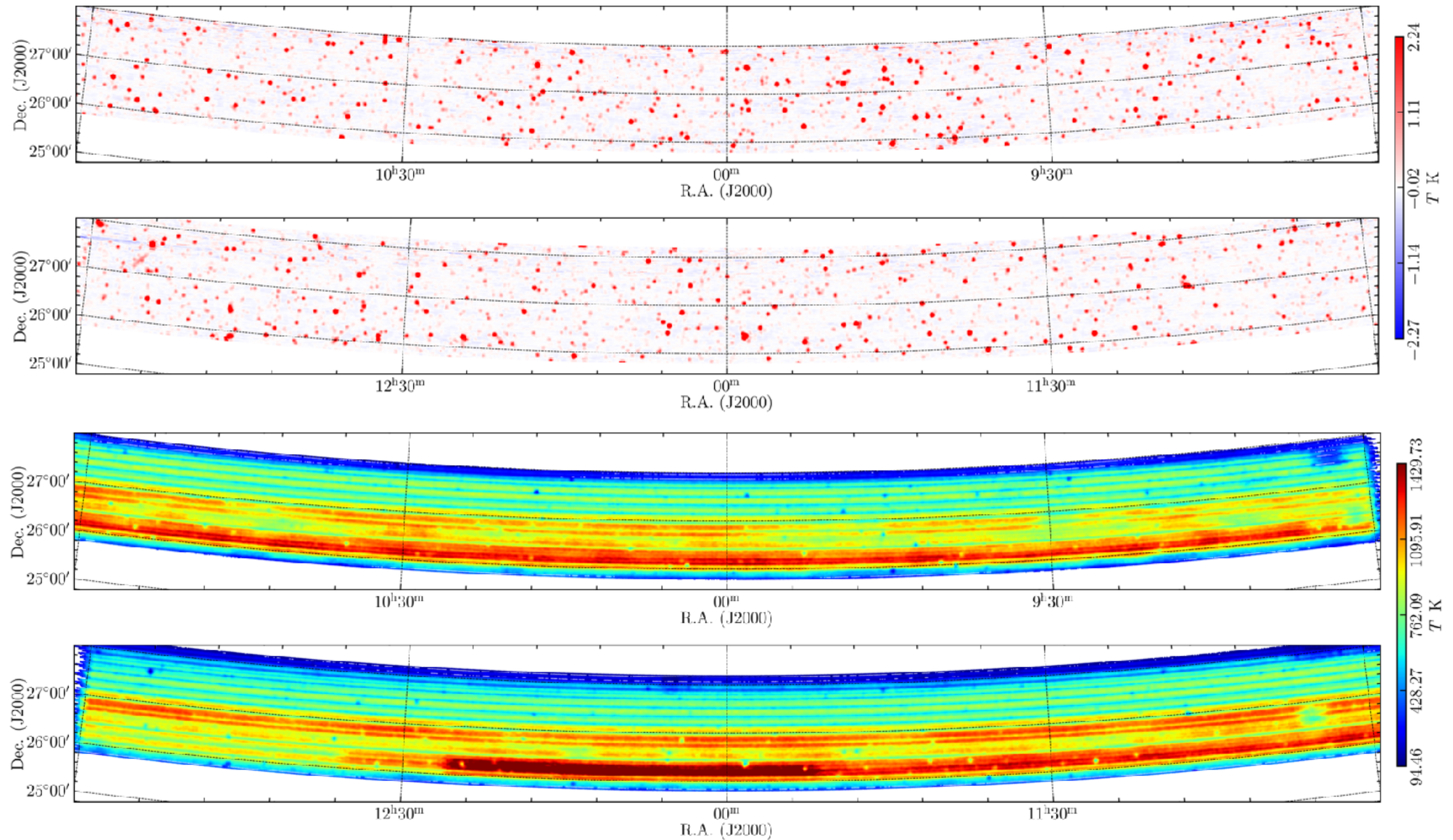
# Foreground subtraction with FATHOMER

- 2nd baseline subtraction



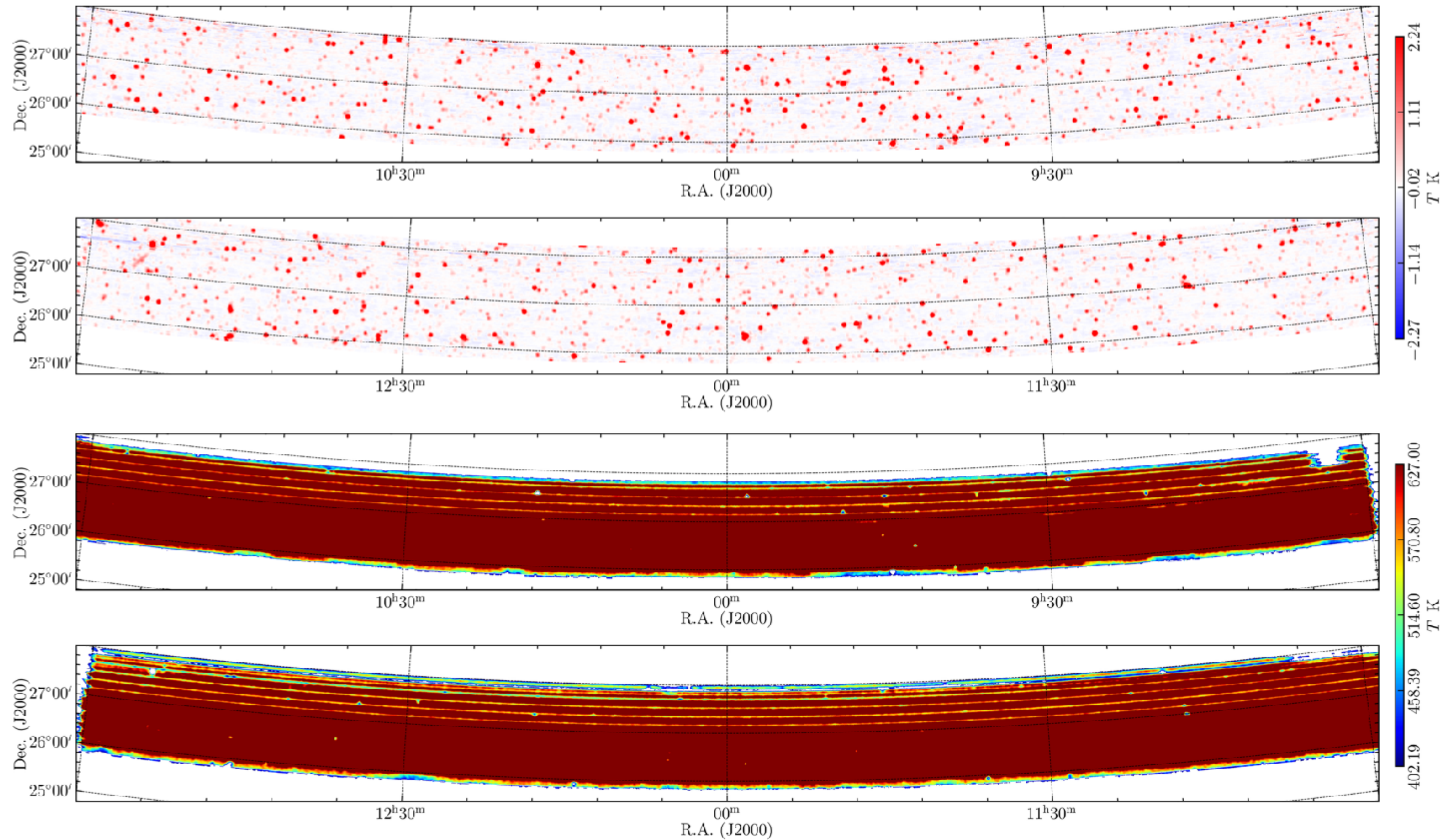
# Foreground subtraction with FATHOMER

- Maps



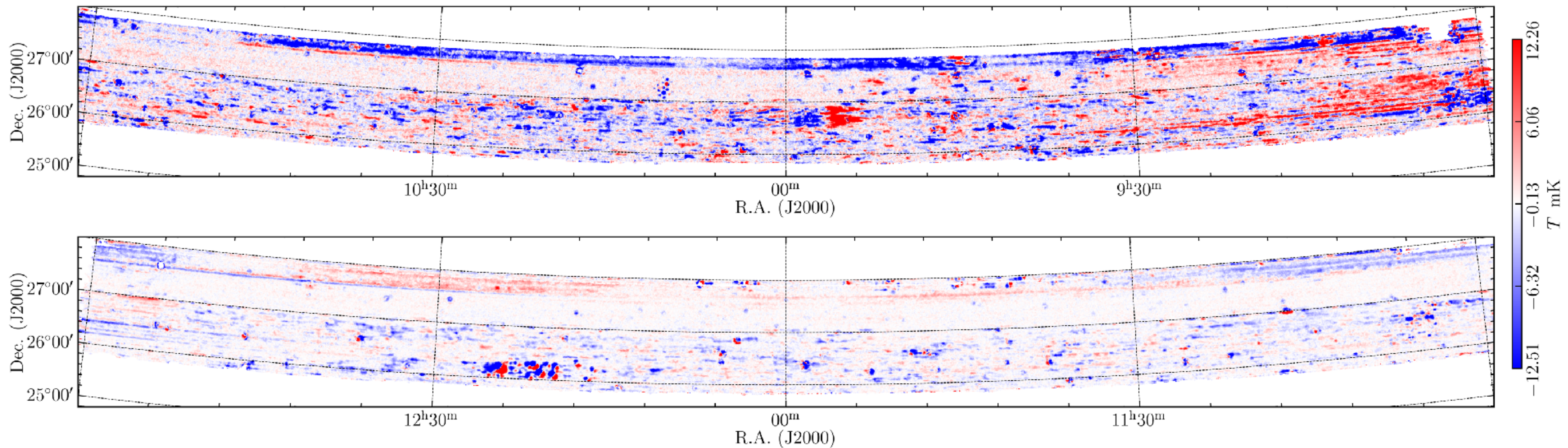
# Foreground subtraction with FATHOMER

- Maps



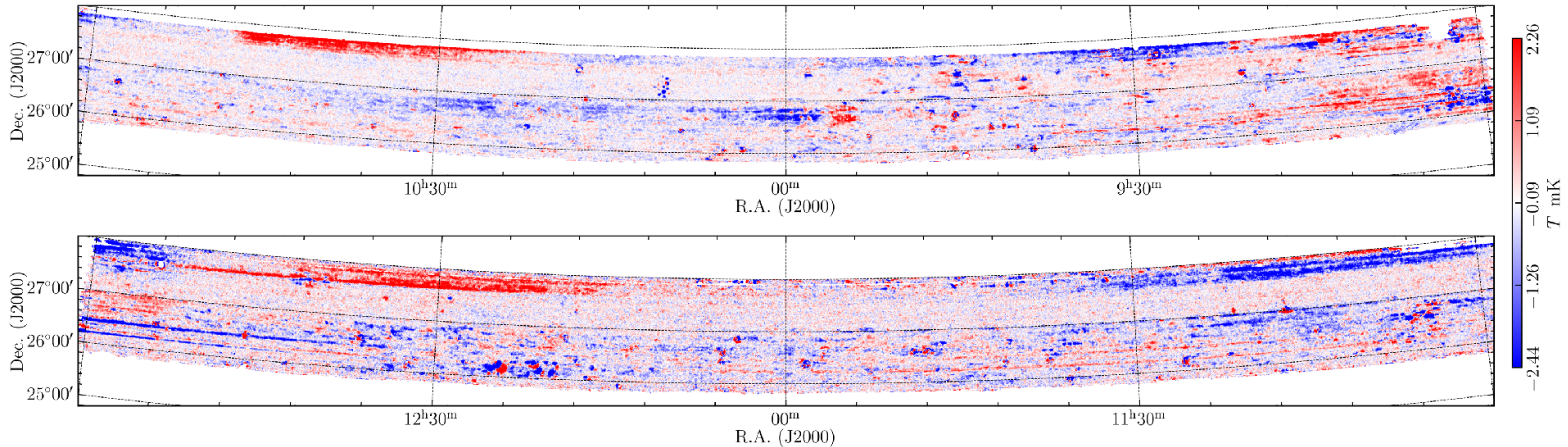
# Foreground subtraction with FATHOMER

- PCA foreground subtraction
- Subtract the first mode



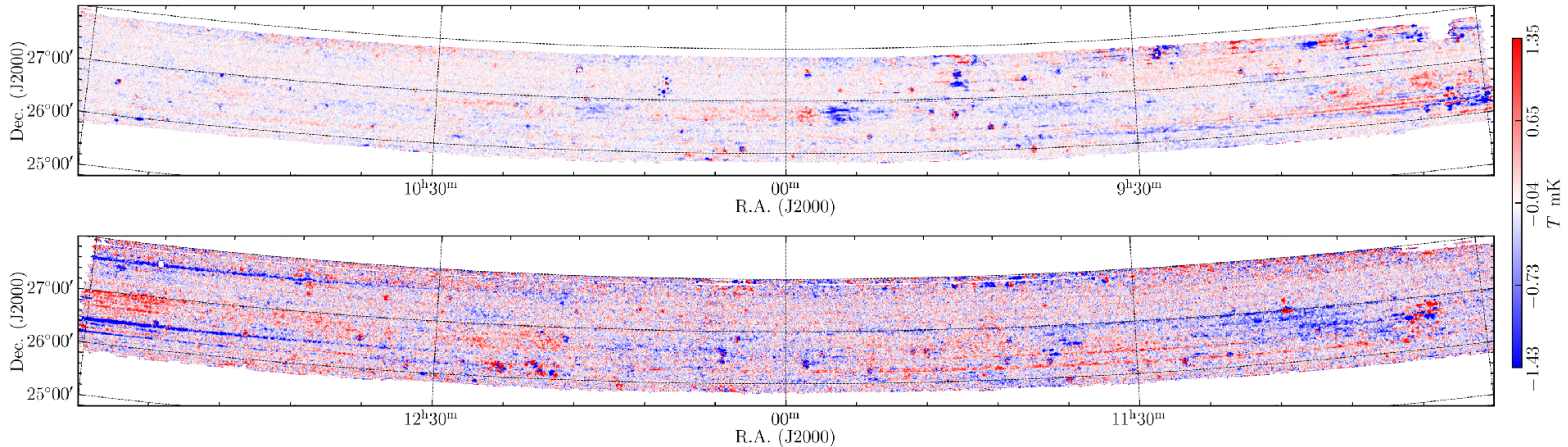
# Foreground subtraction with FATHOMER

- PCA foreground subtraction
- Subtract the first 5 modes



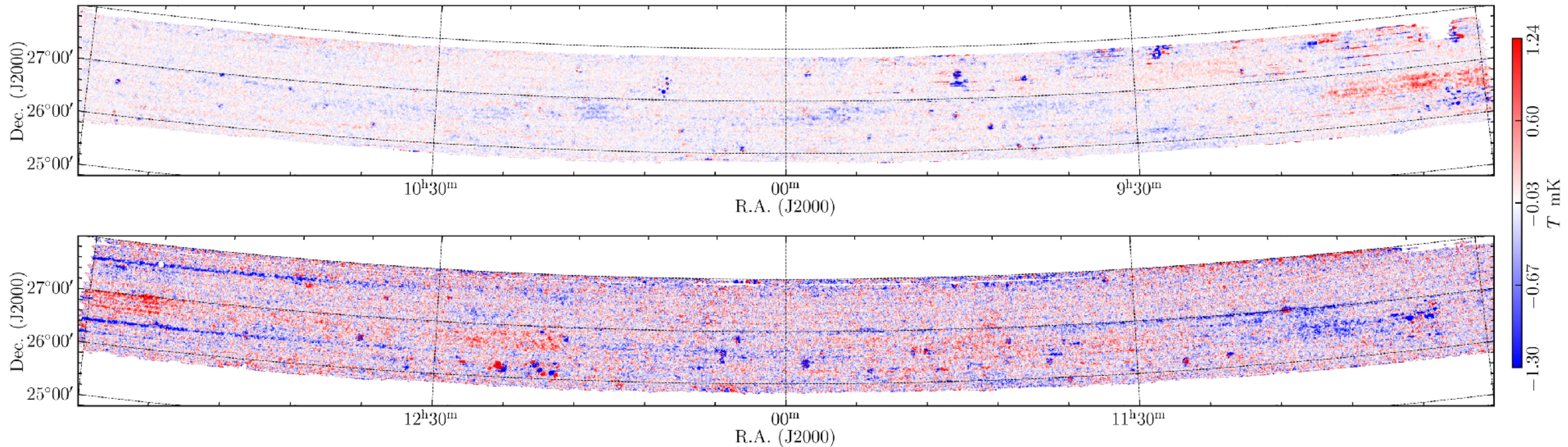
# Foreground subtraction with FATHOMER

- PCA foreground subtraction
- Subtract the first 10 modes



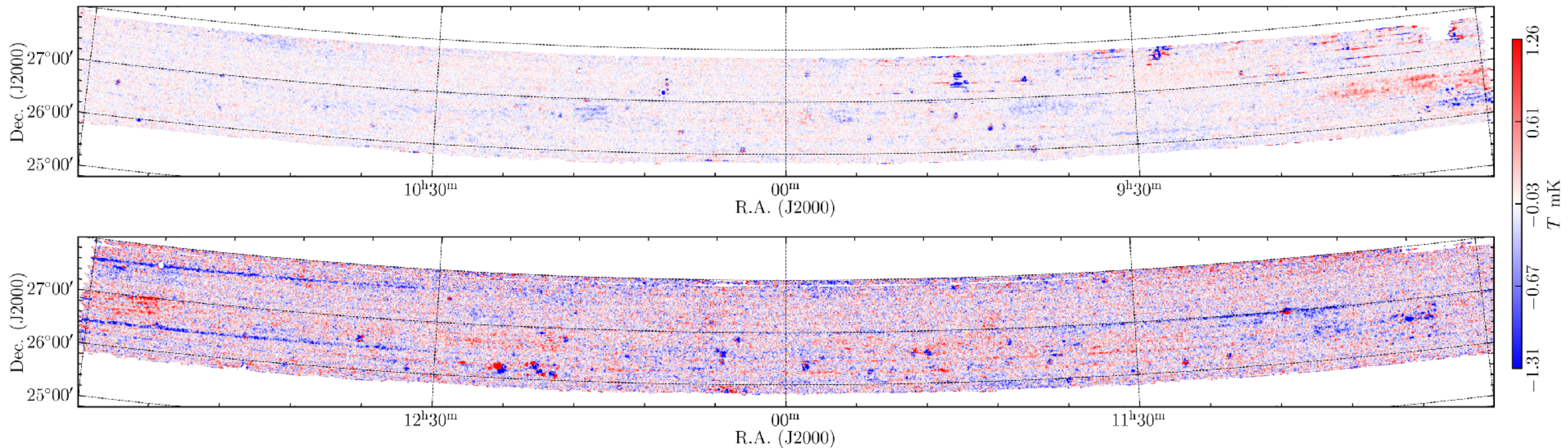
# Foreground subtraction with FATHOMER

- PCA foreground subtraction
- Subtract the first 15 modes



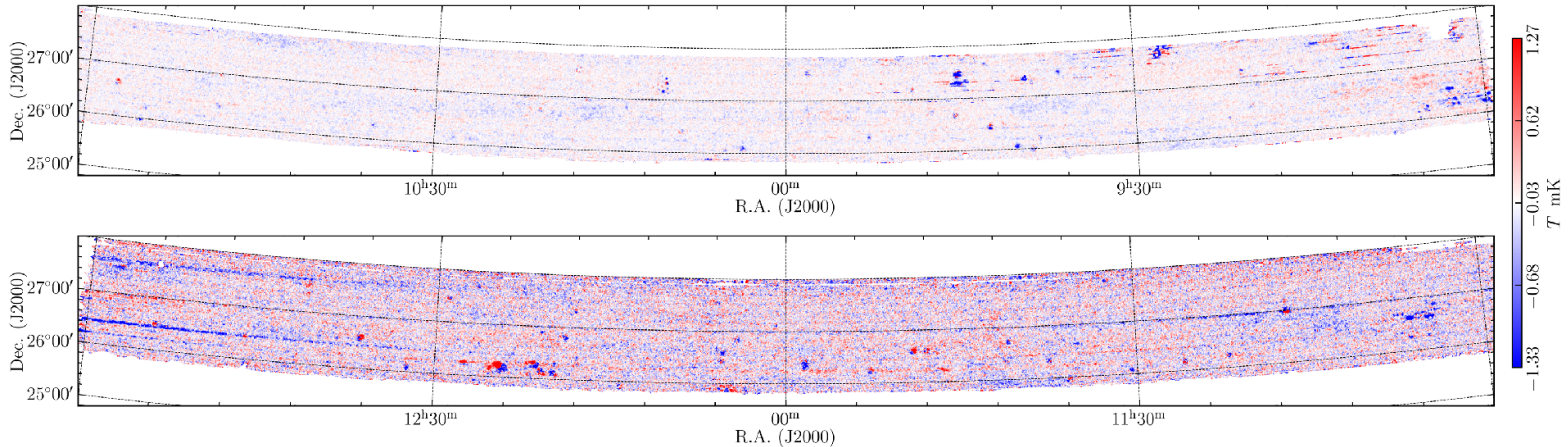
# Foreground subtraction with FATHOMER

- PCA foreground subtraction
- Subtract the first 20 modes



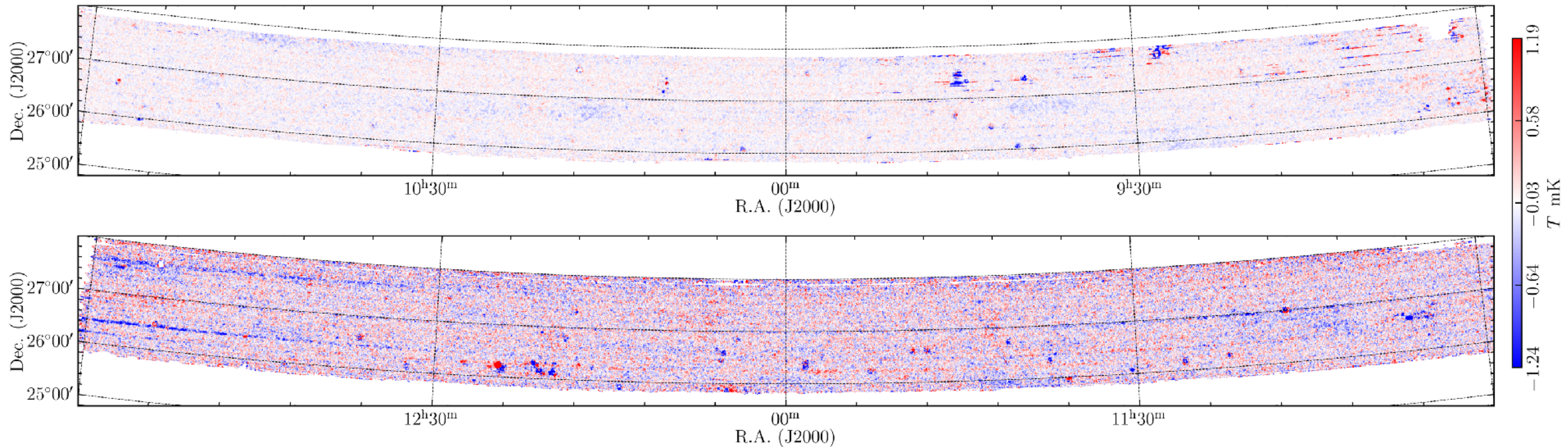
# Foreground subtraction with FATHOMER

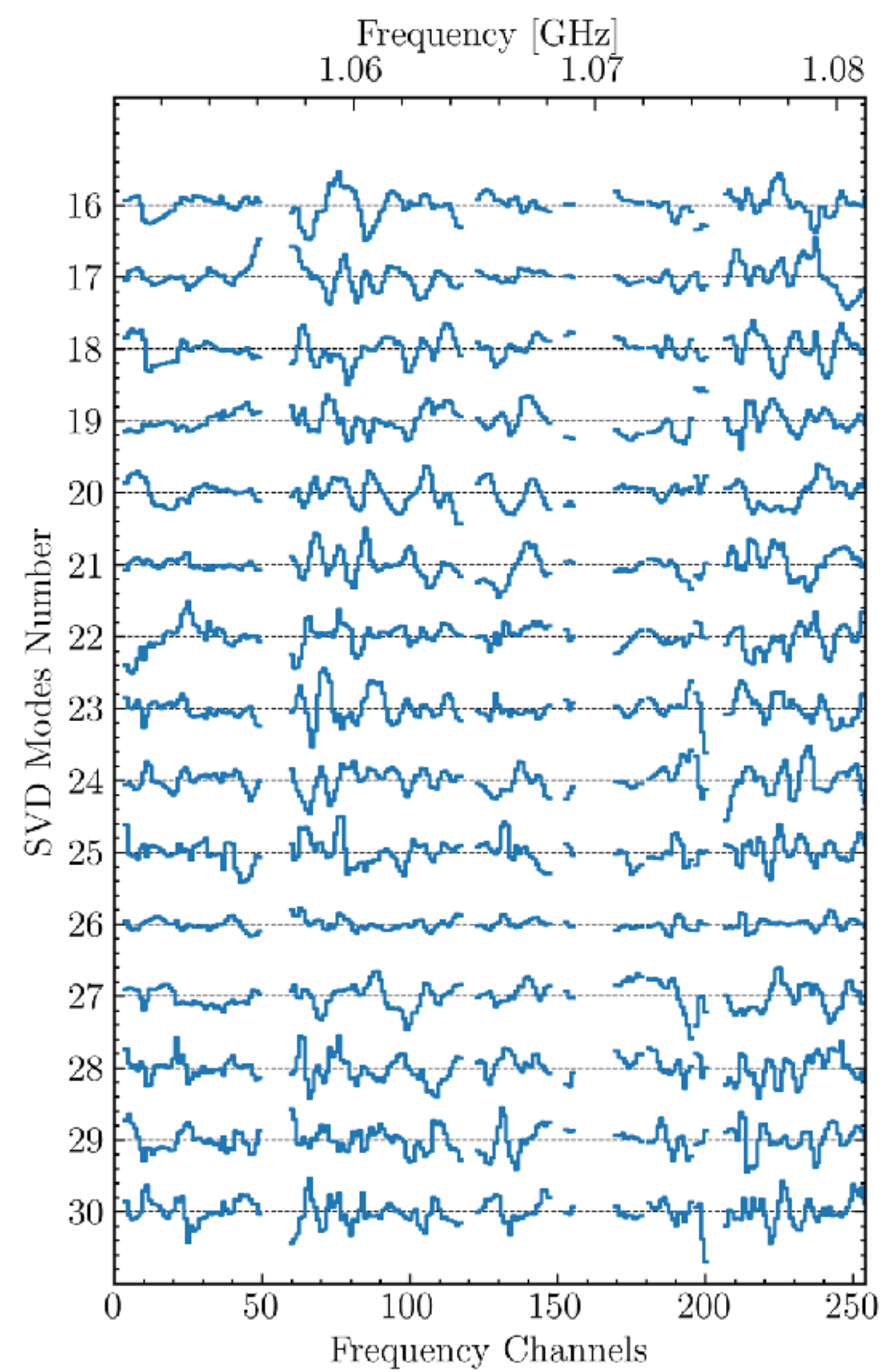
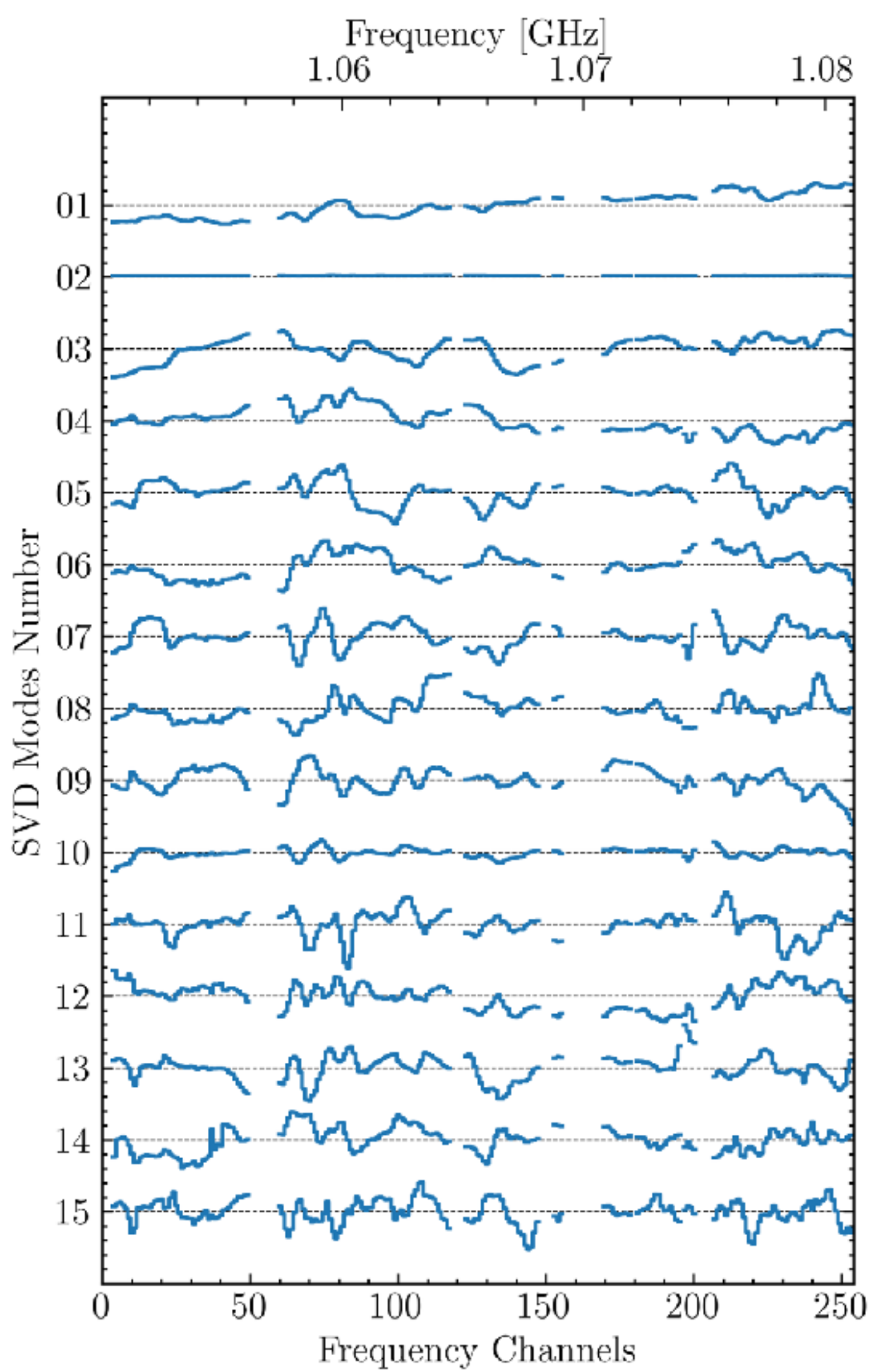
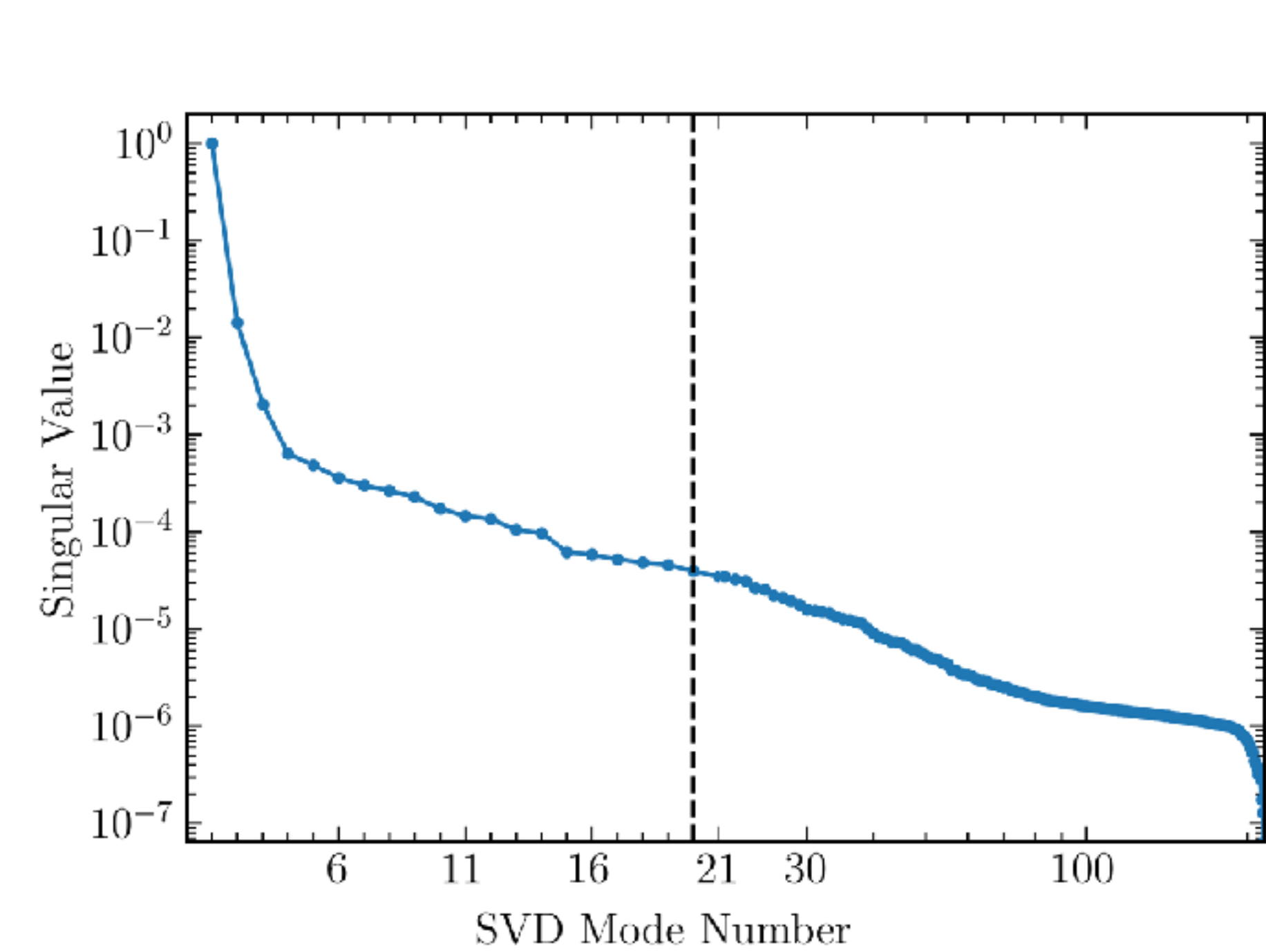
- PCA foreground subtraction
- Subtract the first 25 modes



# Foreground subtraction with FATHOMER

- PCA foreground subtraction
- Subtract the first 30 modes



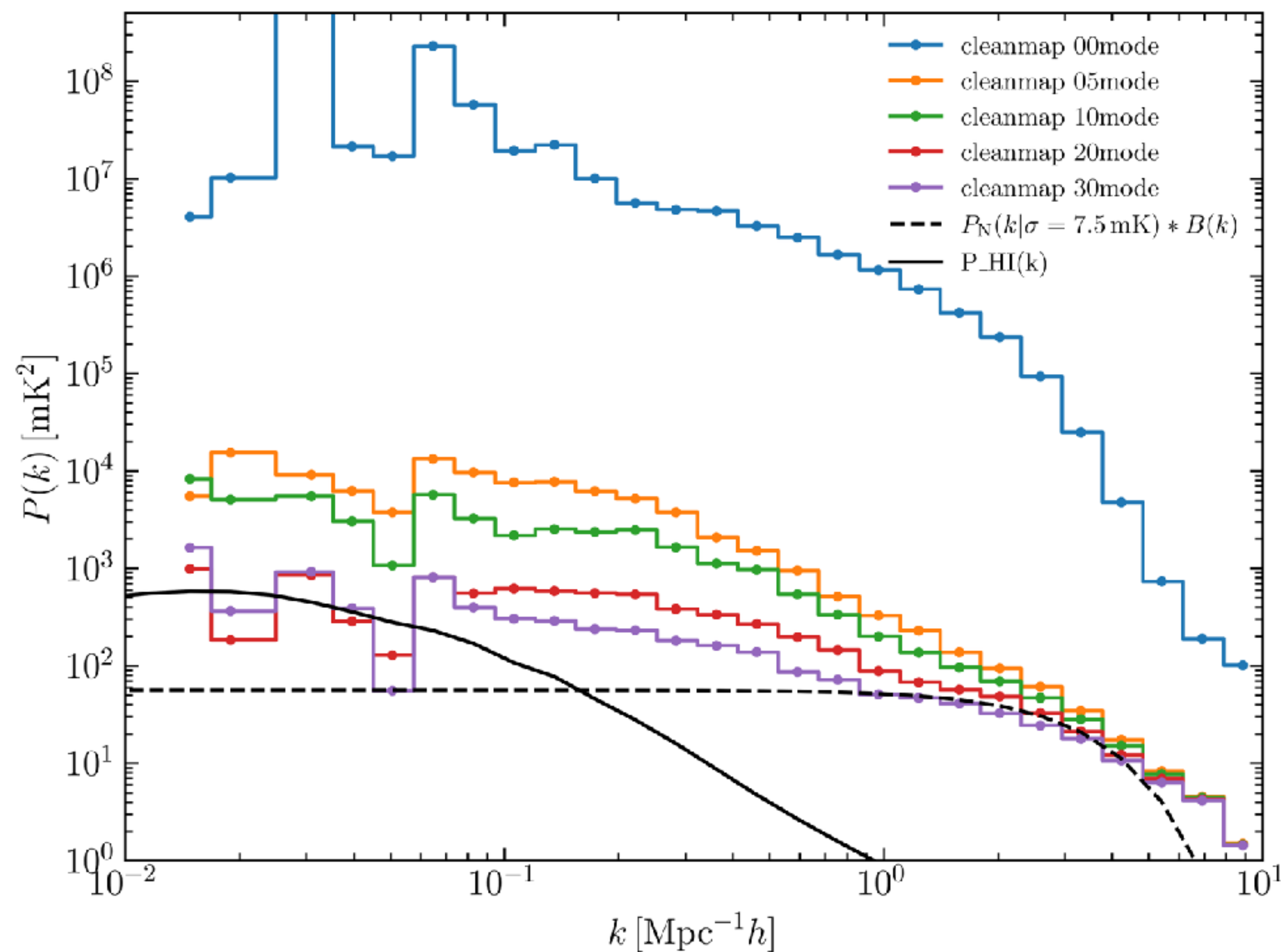
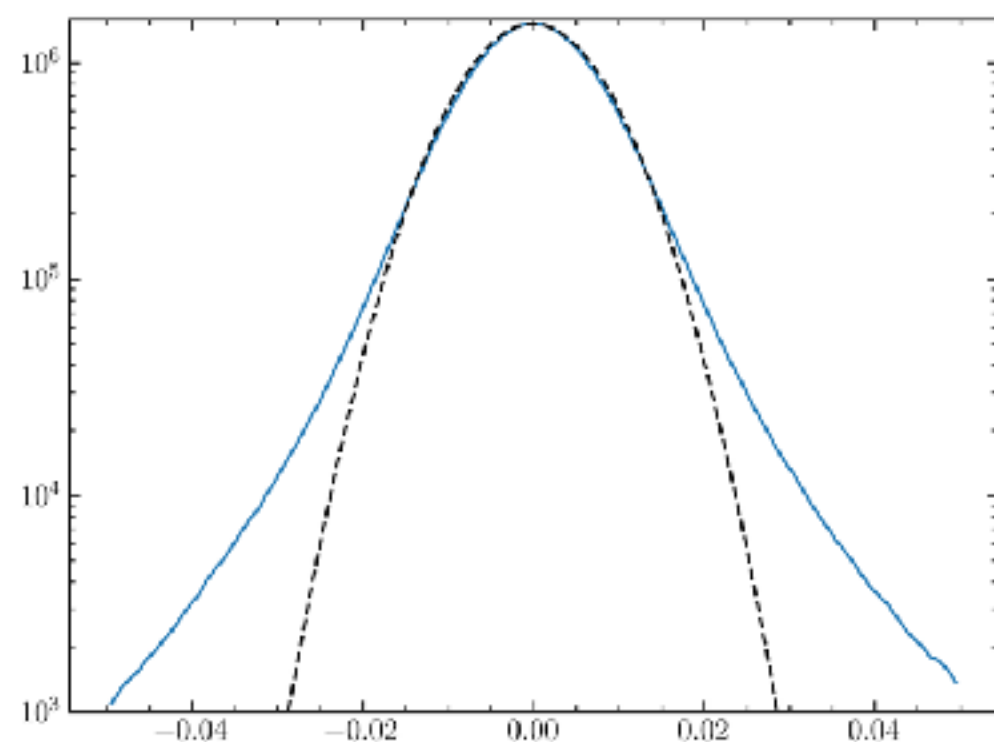


- Auto-power spectrum

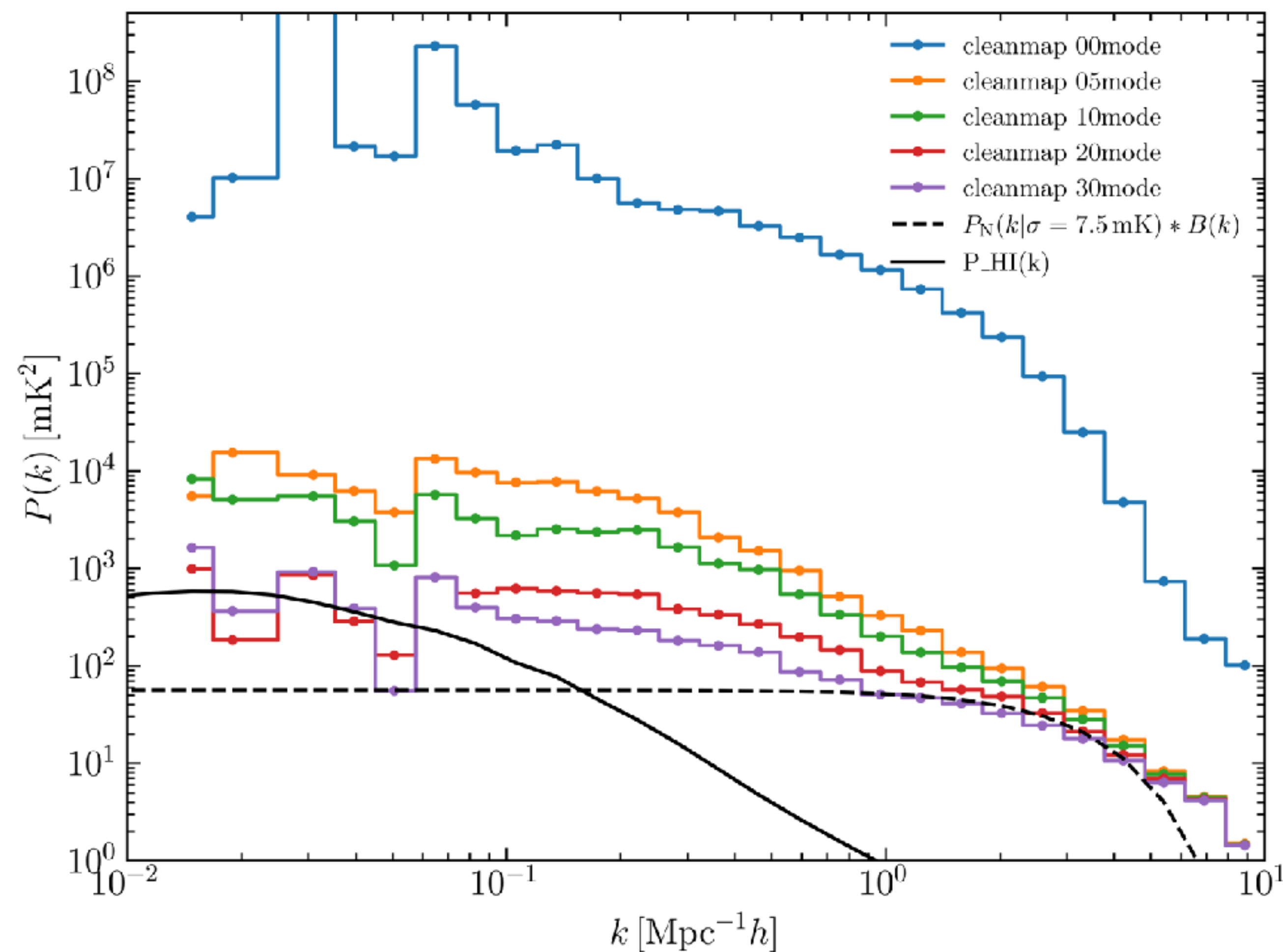
$$\Delta T(\tilde{\nu}) = \frac{1}{2}(T(\nu_1) + T(\nu_3)) - \frac{1}{2}(T(\nu_2) + T(\nu_4)), \quad (38)$$

where  $\nu_1 < \nu_2 < \nu_3 < \nu_4$  are the four adjacent frequency channels and  $\tilde{\nu} = (\nu_1 + \nu_2 + \nu_3 + \nu_4)/4$  is the reduced frequency of the residual data. This can remove most of the continuum emission from the sky that is linear across the frequencies. The rms of the residual data is related to the original data rms via

$$\sigma(\tilde{\nu}) = \sqrt{\frac{1}{4}(\sigma^2(\nu_1) + \sigma^2(\nu_3)) + \frac{1}{4}(\sigma^2(\nu_2) + \sigma^2(\nu_4))}. \quad (39)$$



- Auto-power spectrum
  - More data in a larger field
  - Different time subset map
  - Correct beam differences between feeds.



- Correct beam differences across 19 feeds

$$\hat{m} = (A_{\text{eff}}^T N^{-1} A_{\text{eff}})^{-1} A_{\text{eff}}^T N^{-1} d,$$

Where  $A_{\text{eff}}$  includes both pointing and the feed-dependent beam-matching kernel.

