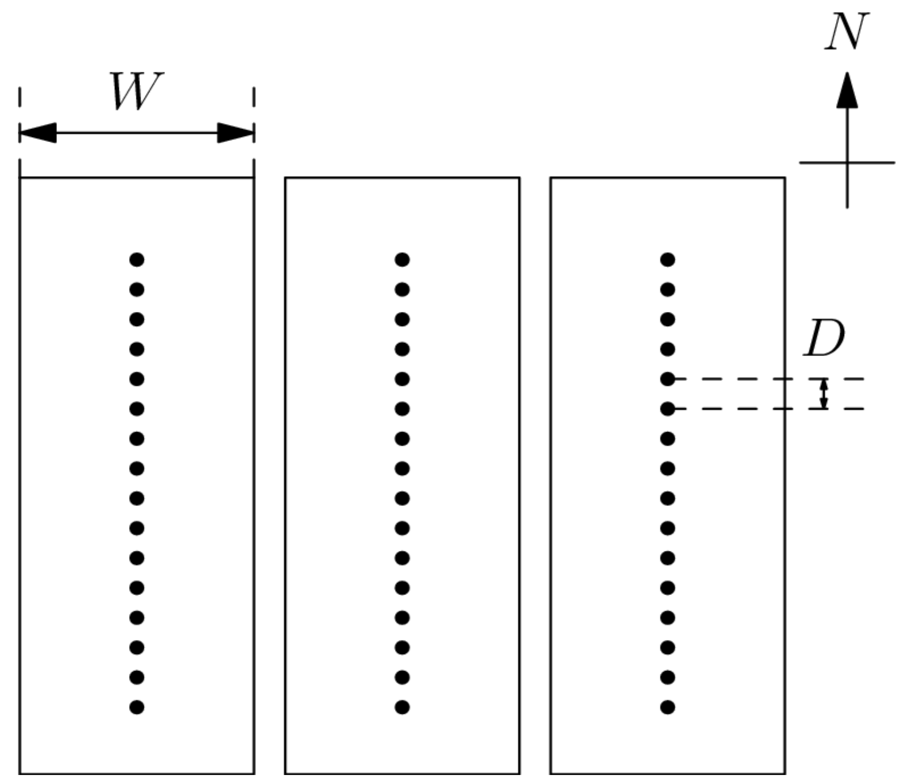
# Simulations of Tianlai project's observation and data reduction process

Shifan Zuo

# Simulation Parameters

Table: Parameters of simulated cylinder telescope

| Paramters | Value |
|---|---|
| Number of cylinders | 3 |
| Cylinder width [m] | 15 |
| Feeds per cylinder | 32 (dual-pol) |
| Feed spacing [m] | 0.5 |
| Tsys [K] | 50 |
| Bandwidth [MHz] | 700 - 800 |
| Channel width [MHz] | 6.25 |
| Number of Channels | 16 |
| Telescope latitude | 45 degree |

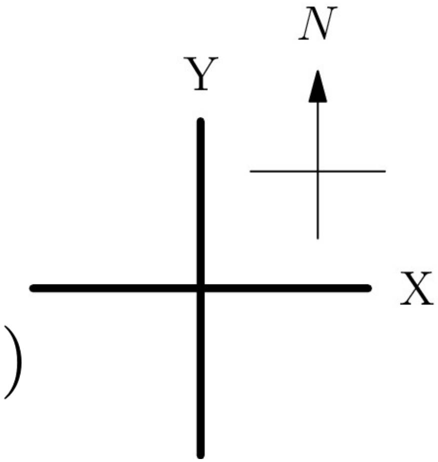



A schematic of a 3 cylinder telescope

# Flow of the Simulation

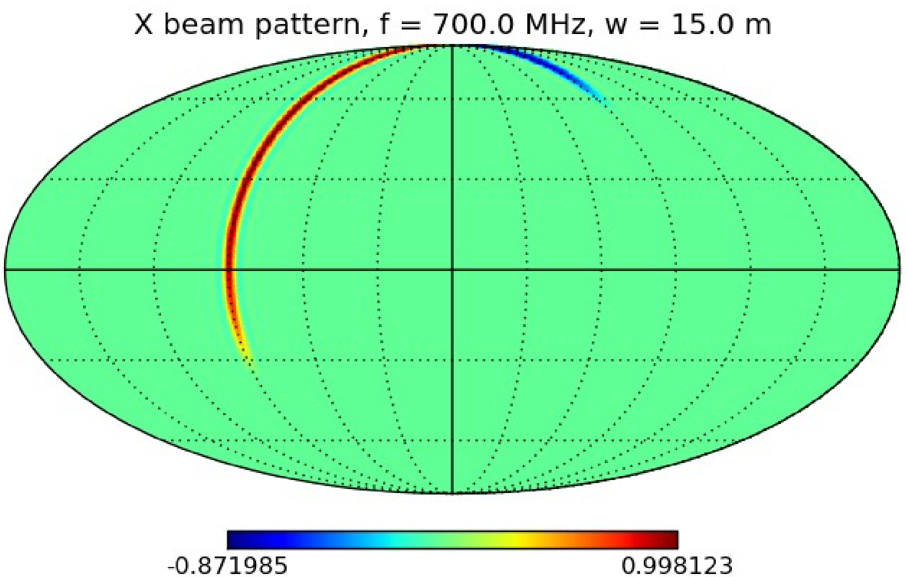
- Beam model
- Input sky maps
- Map-making
- SVD projection for data compression
- Foreground removal
- Power spectrum estimation

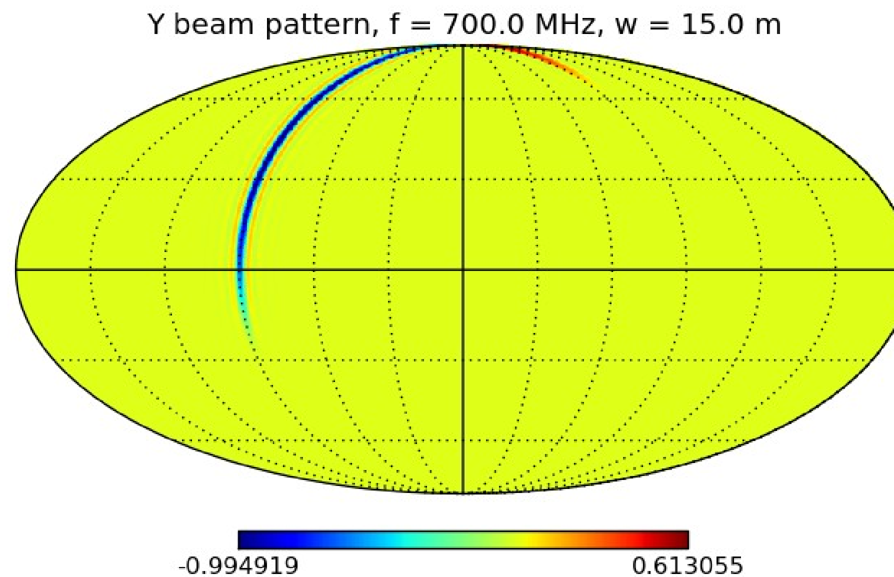
# Beam Model




X feed $A_a^X(\hat{\boldsymbol{n}})$

Y feed $A_a^Y(\hat{\boldsymbol{n}})$

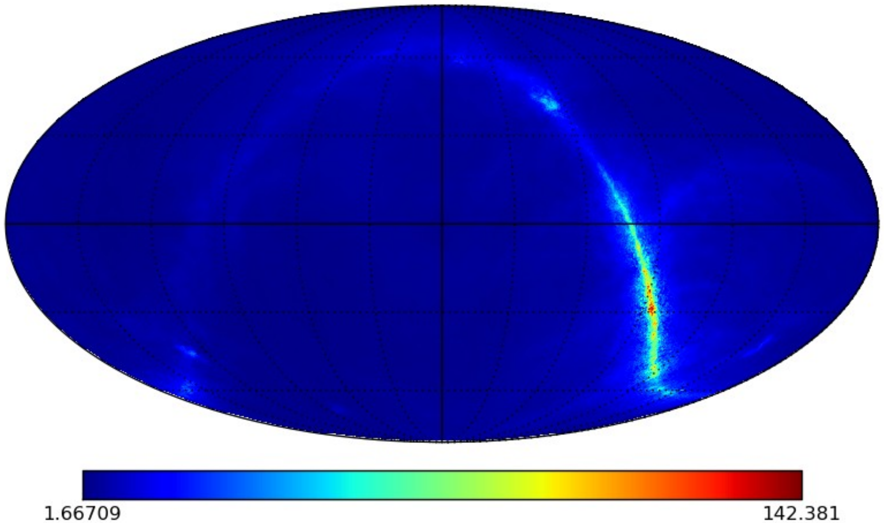


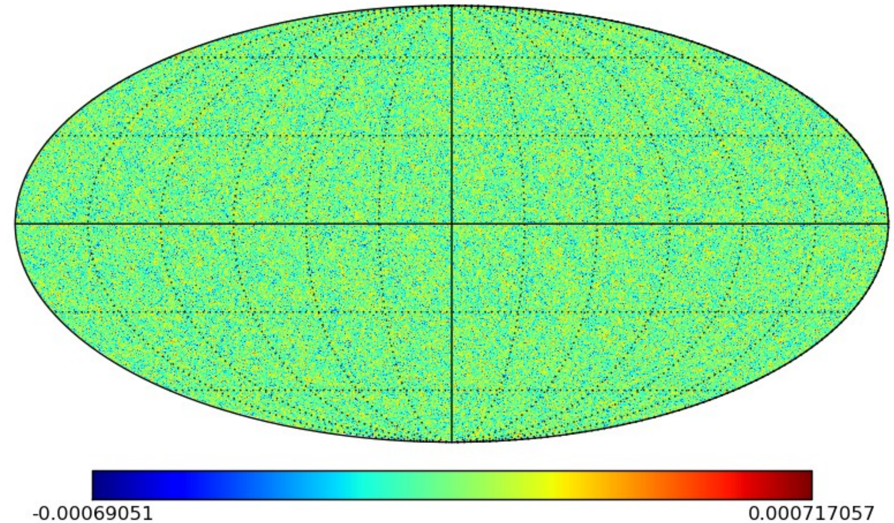

Response to Stokes I:

$$R_{I\to I} = \left(A_X^a A_X^b + A_Y^a A_Y^b\right)\mathcal{P}_{ab}^I \qquad \mathcal{P}_{ab}^I = \frac{1}{2}\begin{pmatrix}1 & 0\\ 0 & 1\end{pmatrix}$$

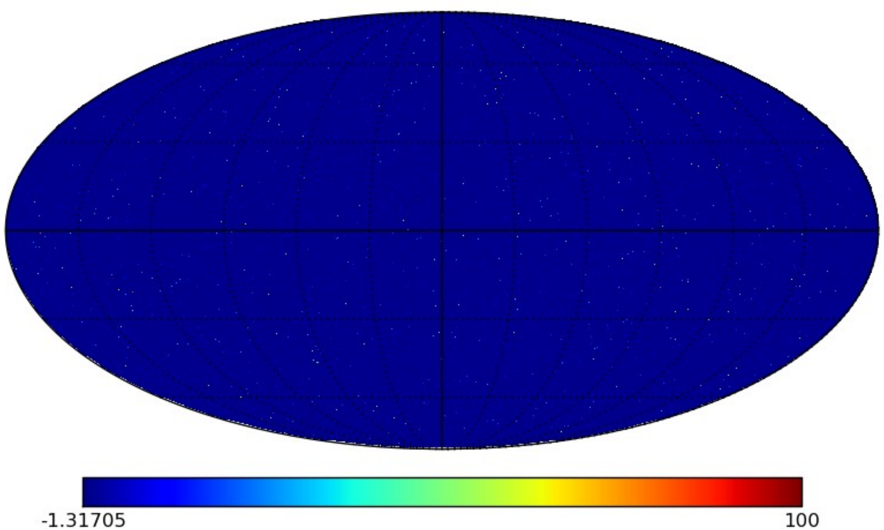
# Simulated sky maps



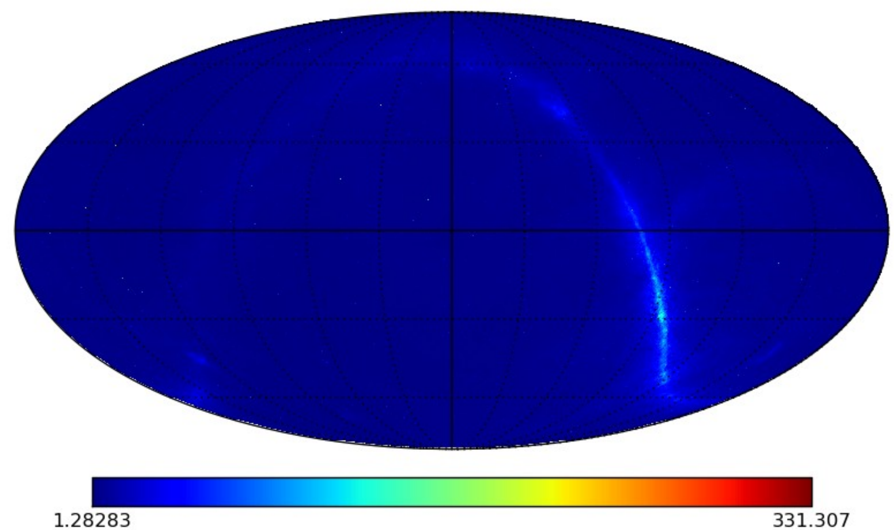

(a) Simulated synchrotron emission.




(b) Simulated 21 cm temperature perturbations.

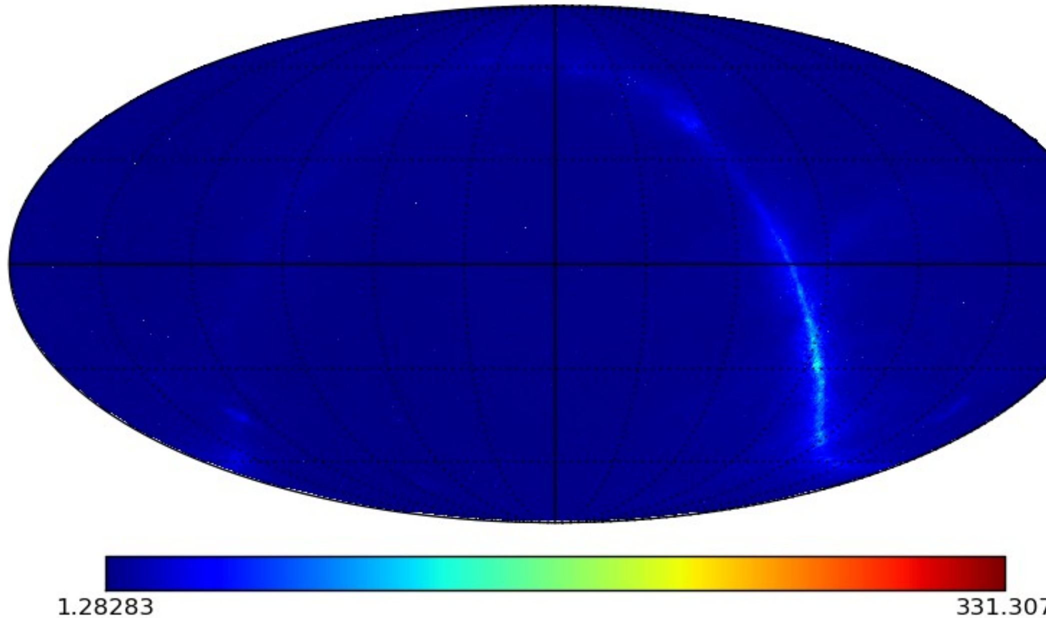


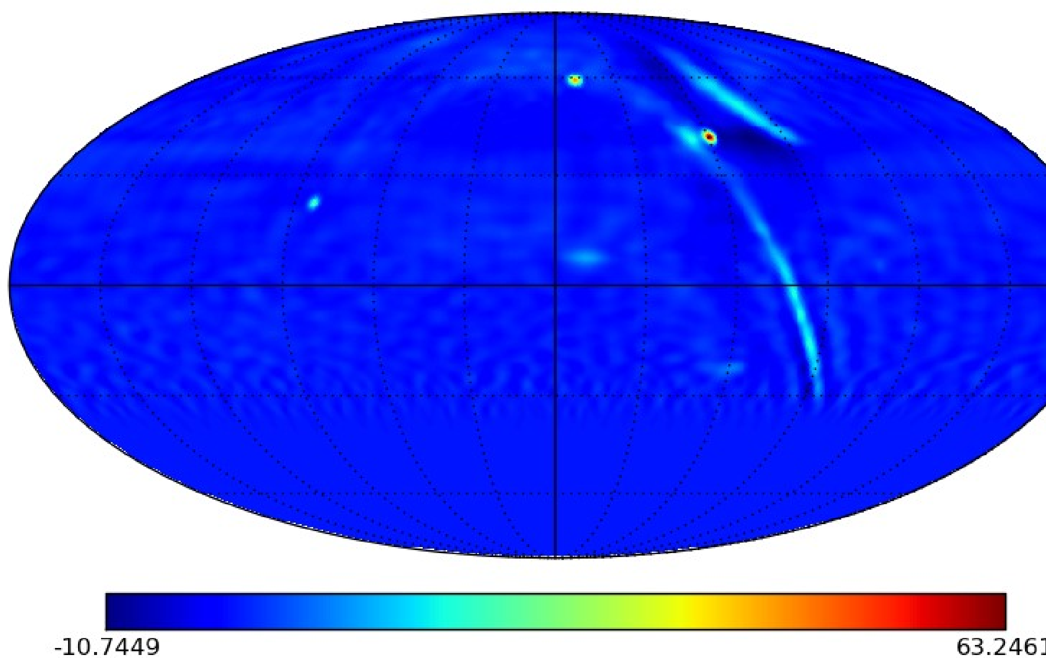

(c) Simulated point source.




(d) Simulated full sky brightness temperature.

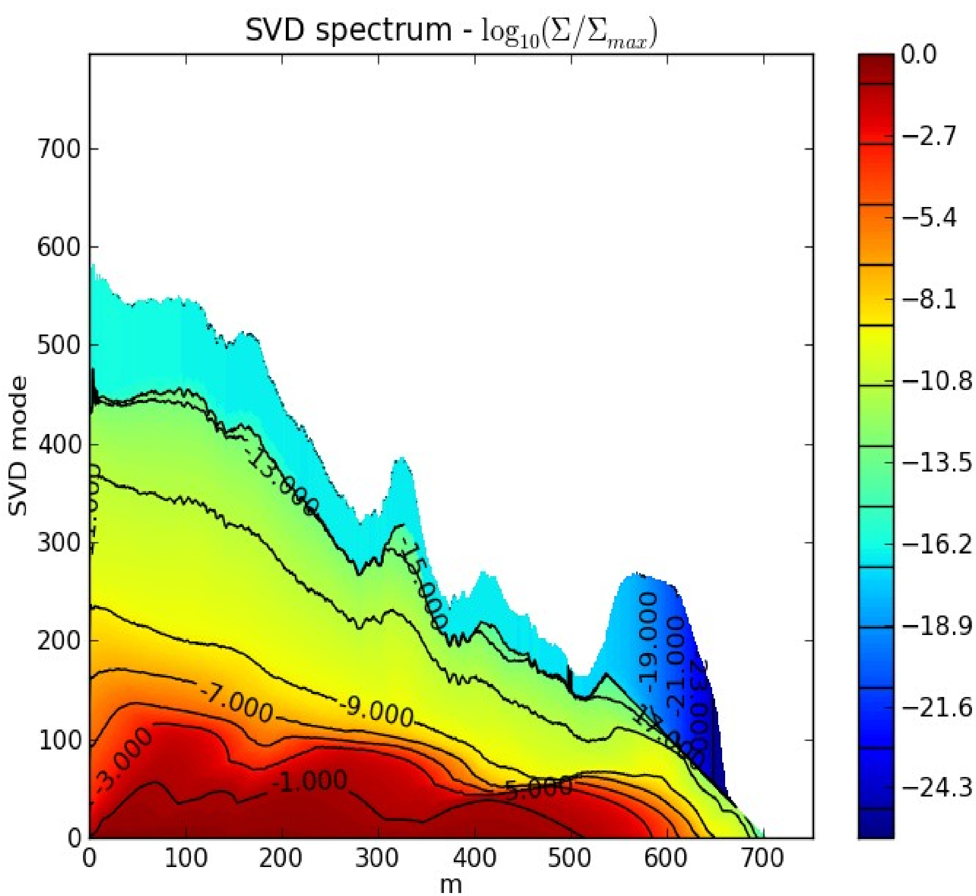
# Map-Making

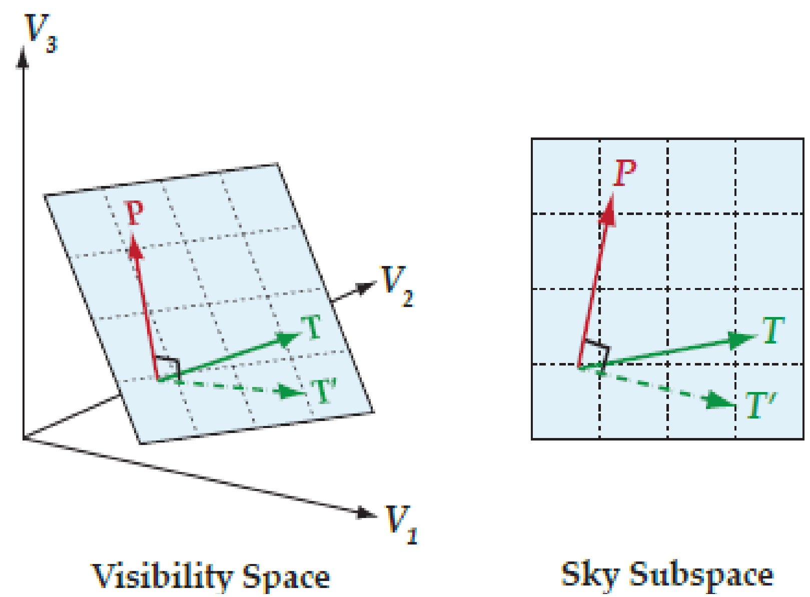


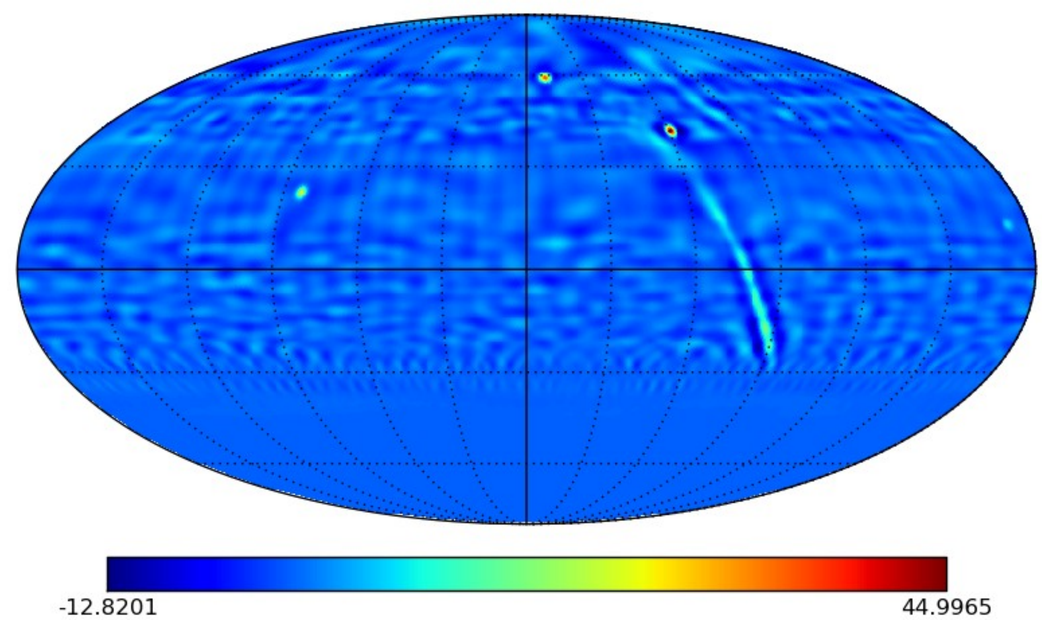



# SVD Data Compression

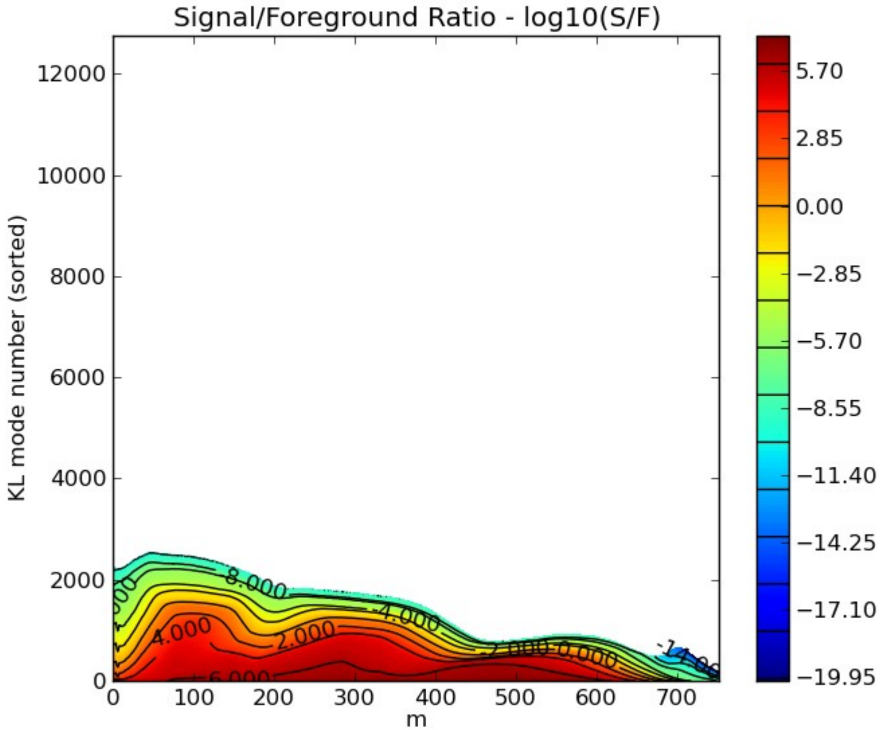
SVD: Singular Value Decomposition

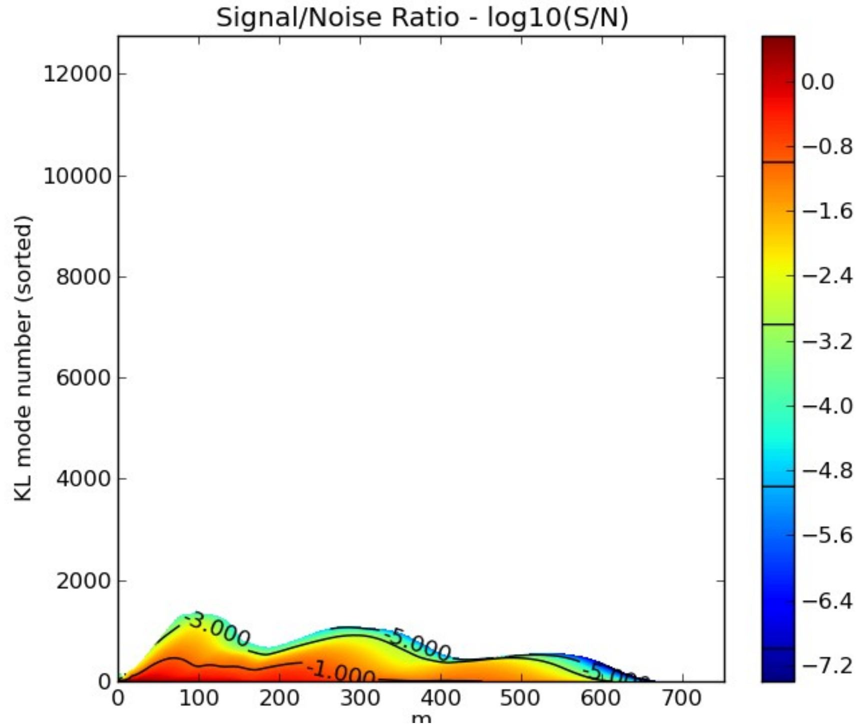


# Foreground Removal

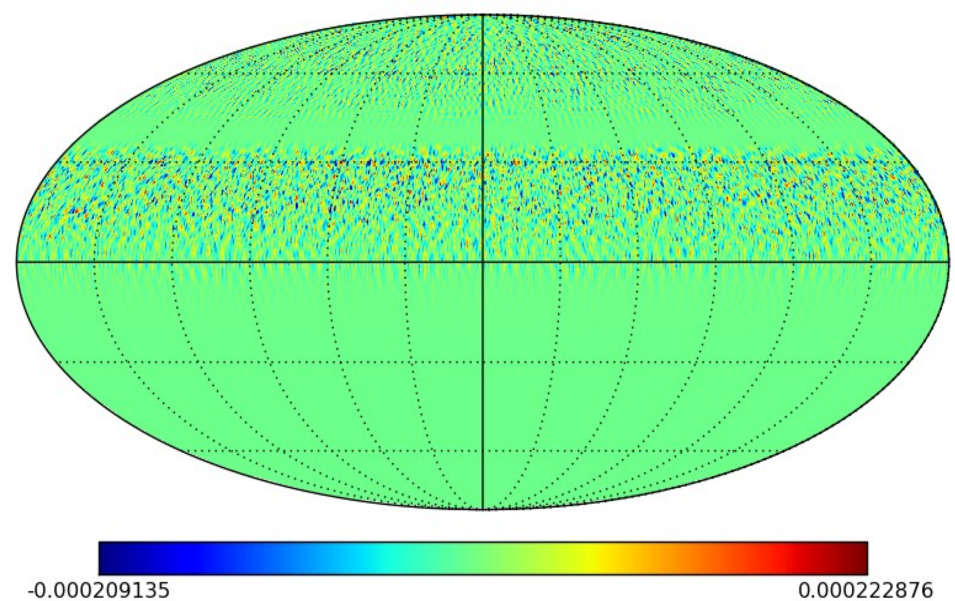



Karhunen-Loeève (K-L) transform

Signal covariance $S \rightarrow \mathbf{\Lambda}$

Noise covariance $N \rightarrow \mathbf{I}$



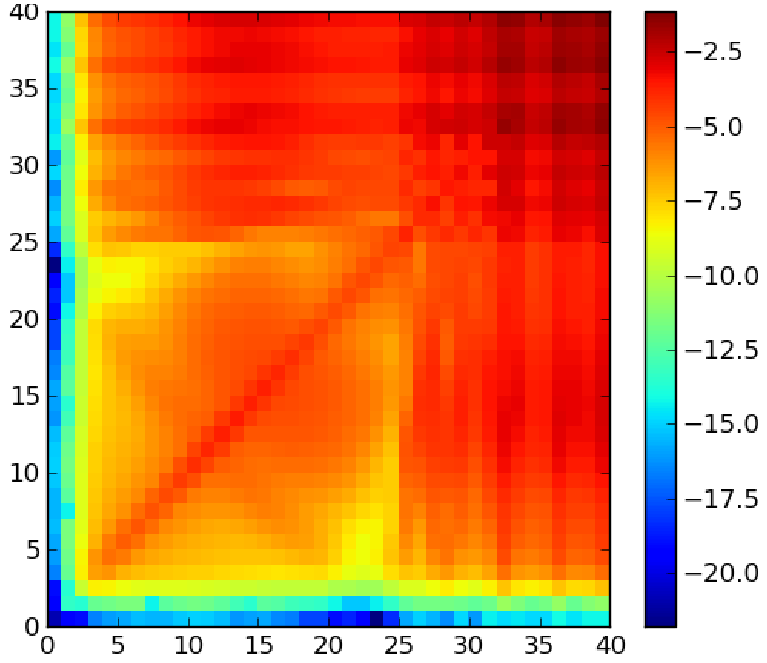
# Power Spectrum Estimation

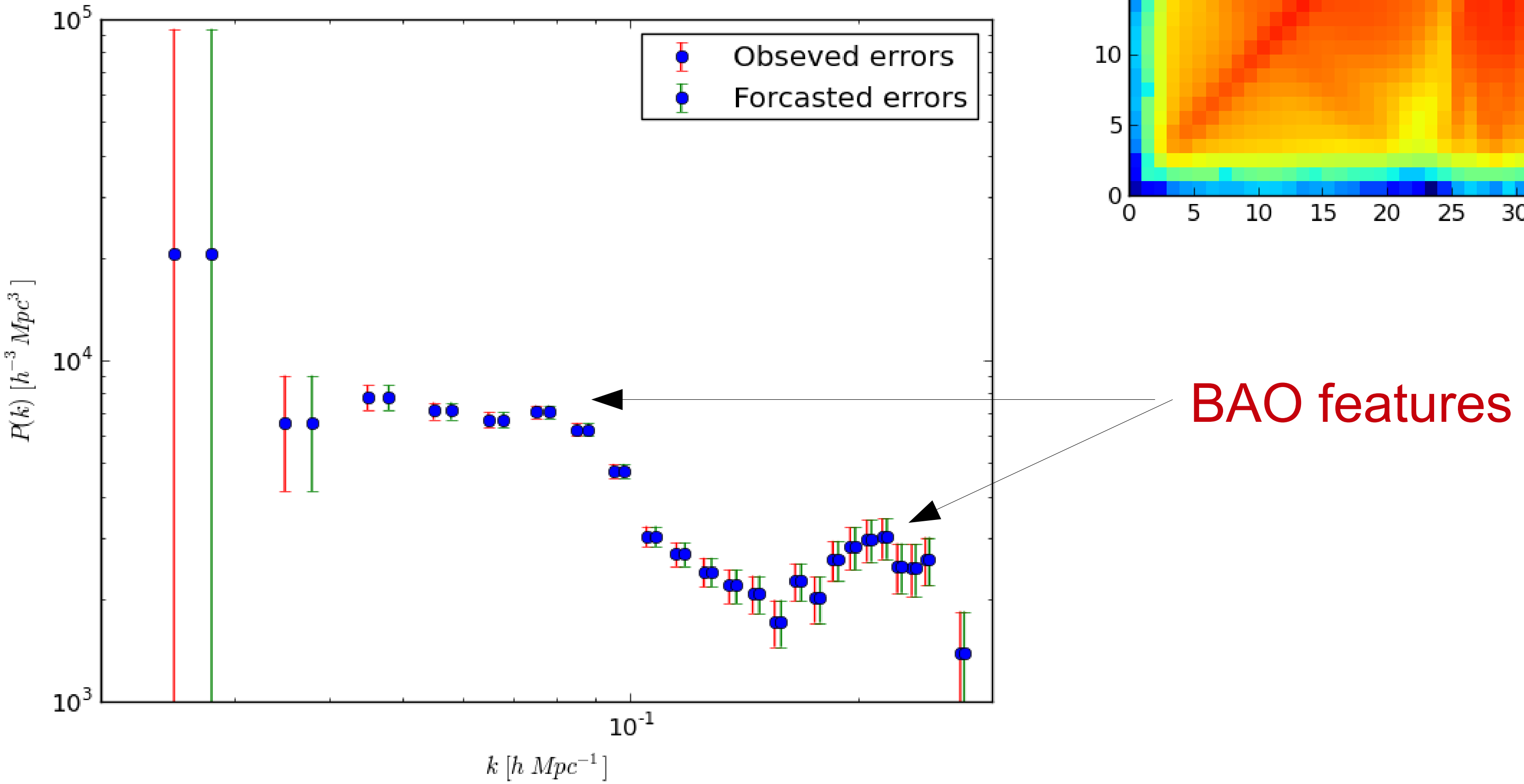
$$P(\boldsymbol{k}) = \sum_a p_a P_a(\boldsymbol{k})$$

$$\hat{p}_a = \sum_b F_{ab}^{-1} (\hat{q}_b - b_b)$$

Where the quadratic estimator $\hat{q}_a = \tilde{\boldsymbol{v}}^\dagger \mathbf{E}_a \tilde{\boldsymbol{v}}$

The Fisher matrix $F_{ab}$



# Thank you !

# The m-mode formalism

Measurement equation: Shaw et al. 2014, ApJ

$$V_{ij}(\phi) = \int d^2\hat{\boldsymbol{n}}\, B_{ij}(\hat{\boldsymbol{n}};\phi) T(\hat{\boldsymbol{n}}) + n_{ij}(\phi)$$

where the beam transfer function is

$$B_{ij}(\hat{\boldsymbol{n}};\phi) = \frac{1}{\Omega_{ij}} A_i(\hat{\boldsymbol{n}};\phi) A_j^*(\hat{\boldsymbol{n}};\phi) e^{2\pi i \hat{\boldsymbol{n}}\cdot\boldsymbol{u}_{ij}(\phi)} \ .$$

Fourier transform the system

$$V_m^{ij} = \int \frac{d\phi}{2\pi} V_{ij}(\phi) e^{-im\phi} = \sum_{lm'} \int \frac{d\phi}{2\pi} B_{lm'}^{ij}(\phi) a_{lm'} e^{-im\phi} + n_m^{ij}$$

Spherical harmonic expand the sky temperature and the beam transfer function

$$T(\hat{\boldsymbol{n}}) = \sum_{lm} a_{lm} Y_{lm}(\hat{\boldsymbol{n}}) \ , B_{ij}(\hat{\boldsymbol{n}};\phi) = \sum_{lm} B_{lm}^{ij}(\phi) Y_{lm}^*(\hat{\boldsymbol{n}})$$

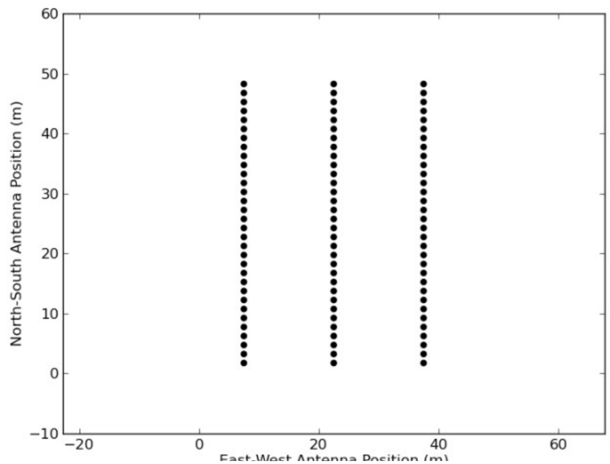
We get

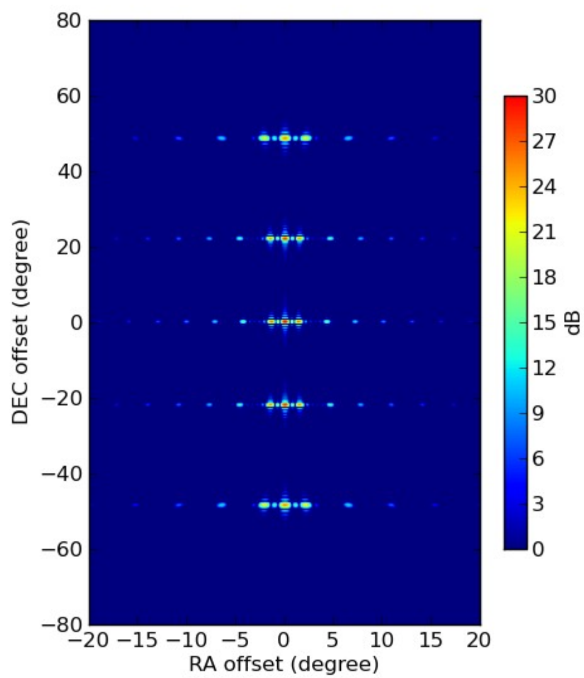
$$V_m^{ij} = \sum_l B_{lm}^{ij} a_{lm} + n_m^{ij}$$

$$\boxed{\boldsymbol{v} = \mathbf{B}\,\boldsymbol{a} + \boldsymbol{n}}$$

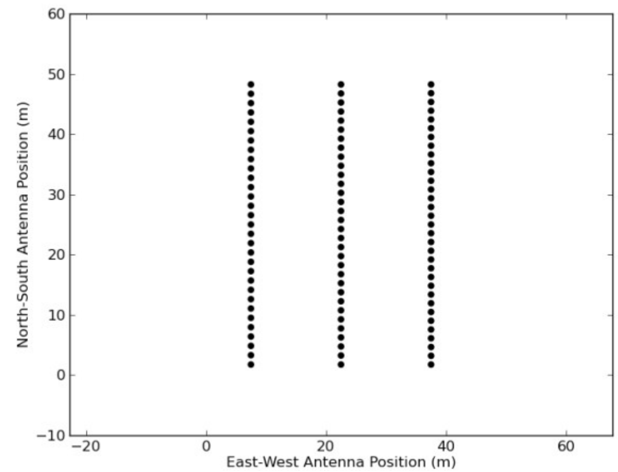
# Array Configuration and Synthesized Beam

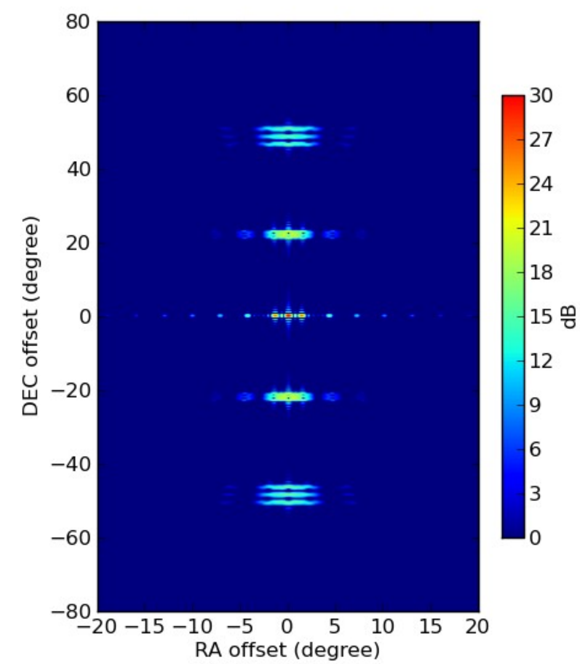
## 32 + 32 + 32 feeds



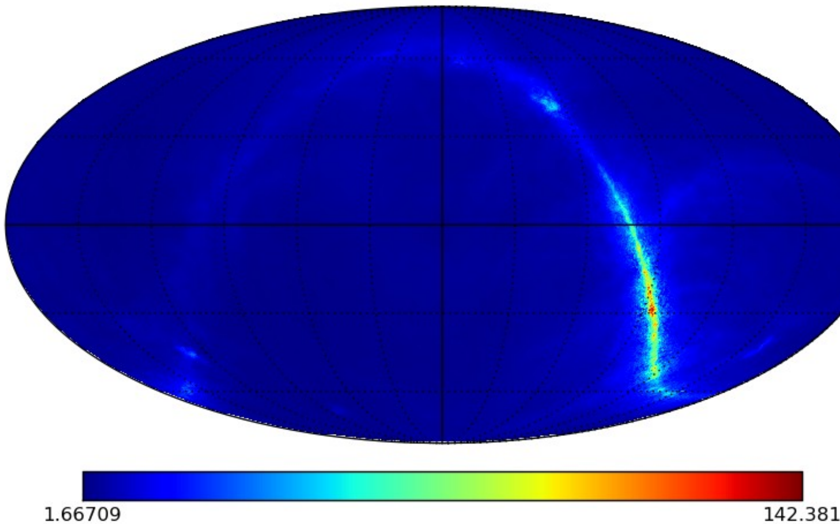



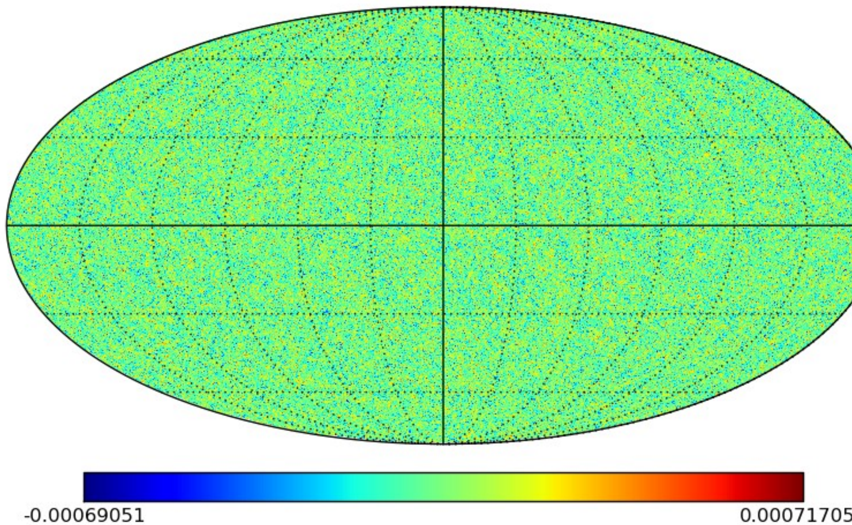

## 31 + 32 + 33 feeds



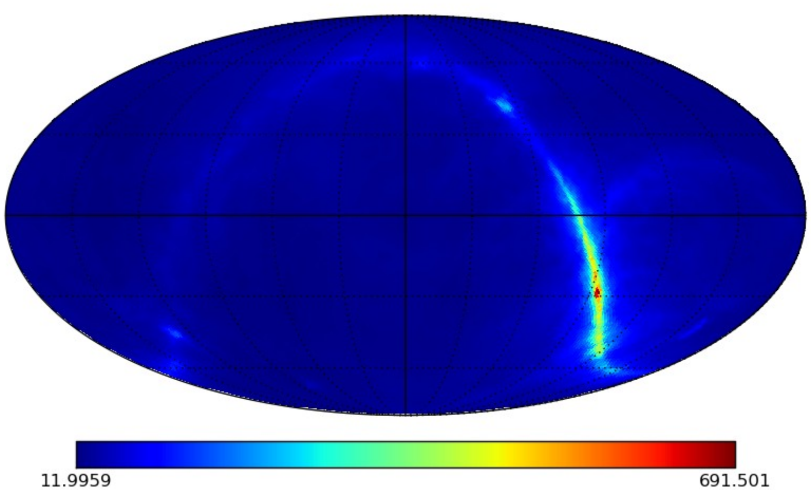



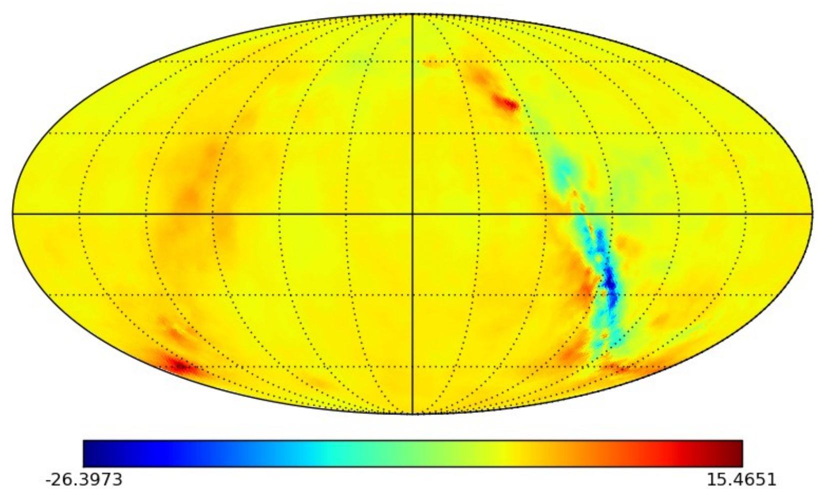
# Foreground Removal
# ---- Method 2: SVD



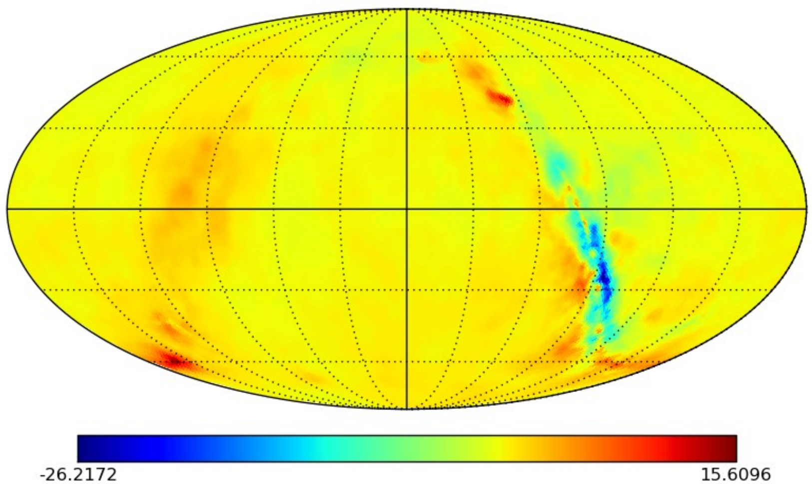

- mode 1

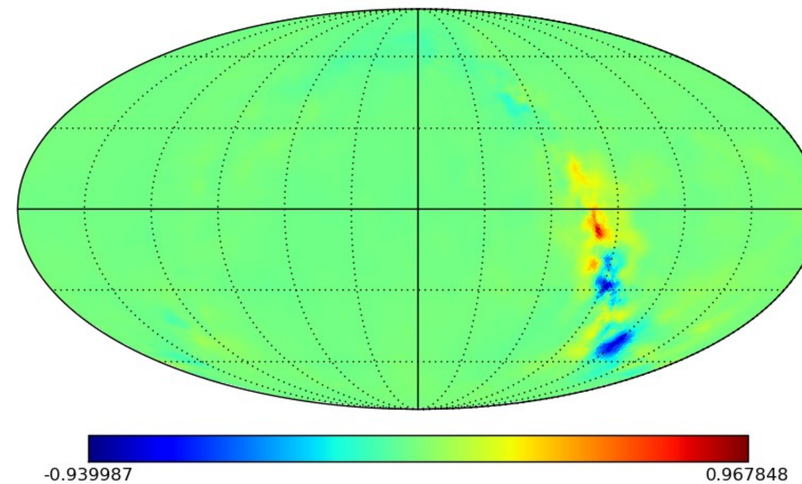


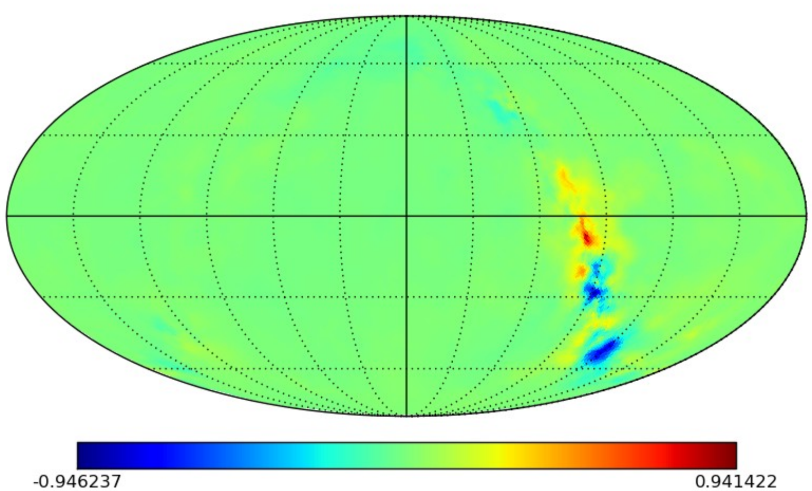
# SVD Foreground Removal Process

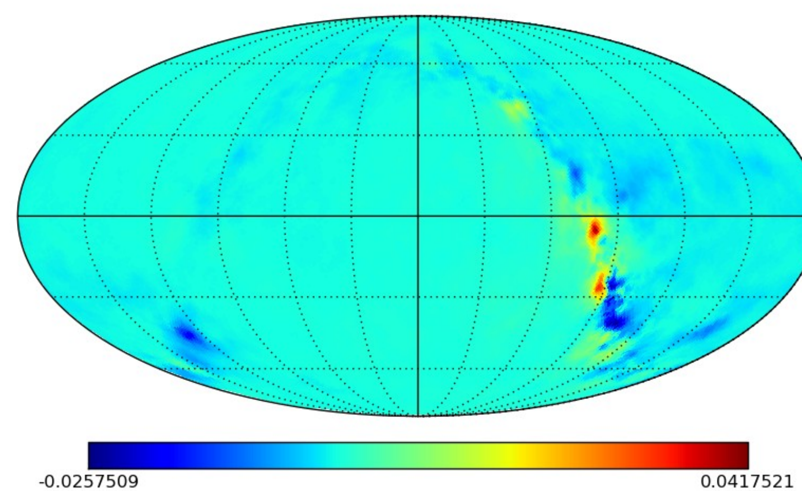
- mode 2



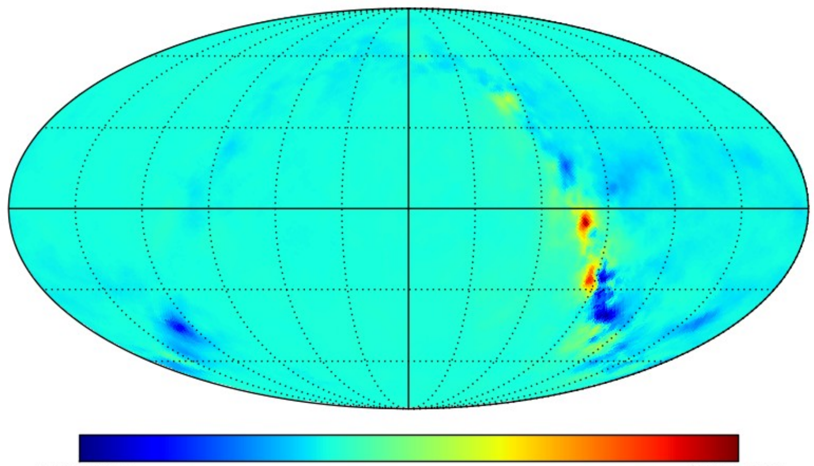

- mode 3

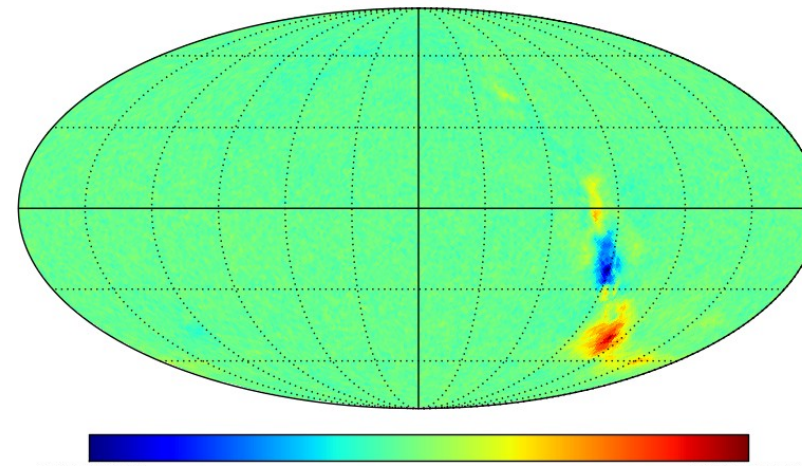


# SVD Foreground Removal Process

- mode 4




- mode 5