# Tracking Tapered Gridded Estimator: Results from MWA drift scan observations

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# Collaborators

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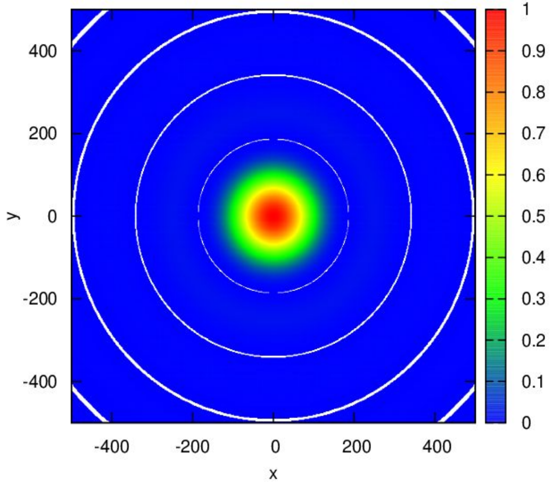
# Aim

Develop an power spectrum estimator for Drift scan radio observation which will increase SNR

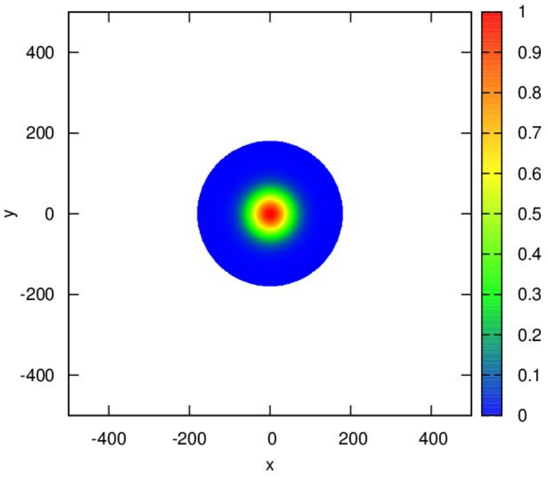
-Tracking Tapered Gridded Estimator (TTGE)

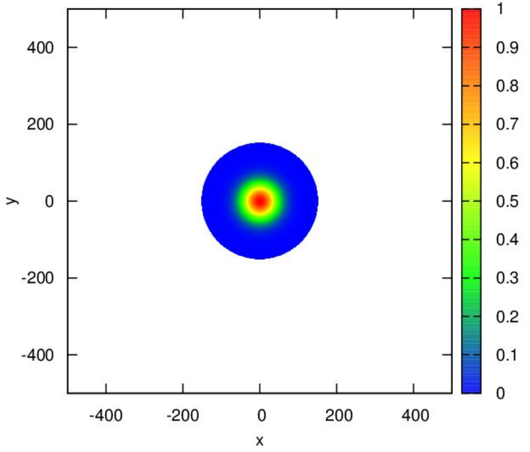
# Tapered Gridded Estimator

# Tapered Gridded Estimator




×



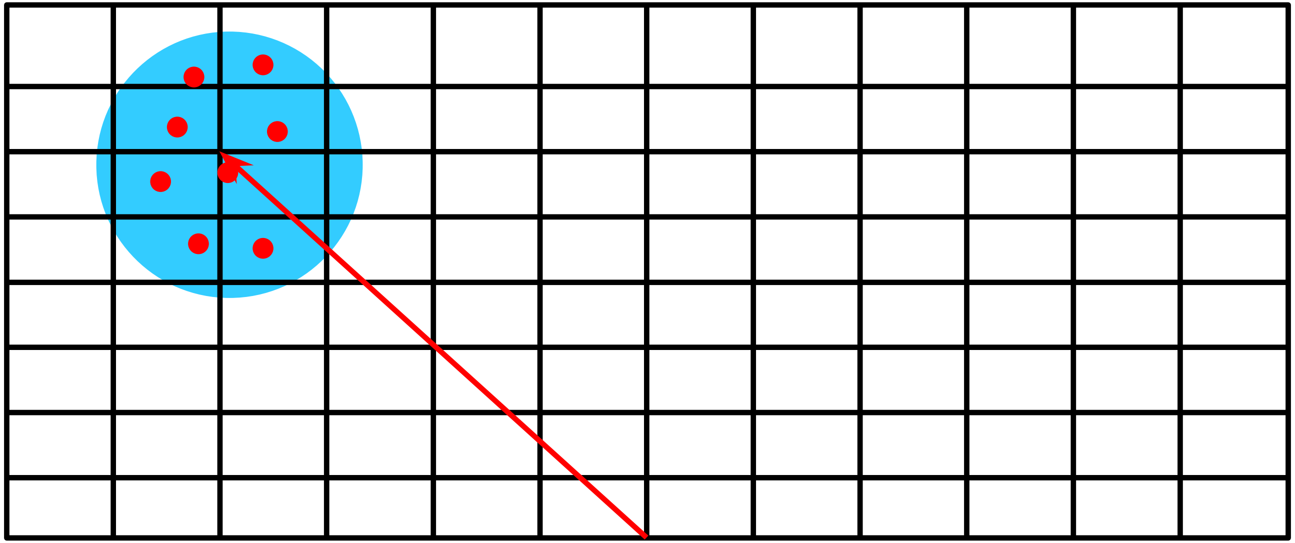




Primary Beam

Taper Window

# Tapering and Gridding

Visibility-based :



$$\mathcal{V}_{cg} = \sum_i \tilde{w}(\mathbf{U}_g - \mathbf{U}_i)\,\mathcal{V}_i$$

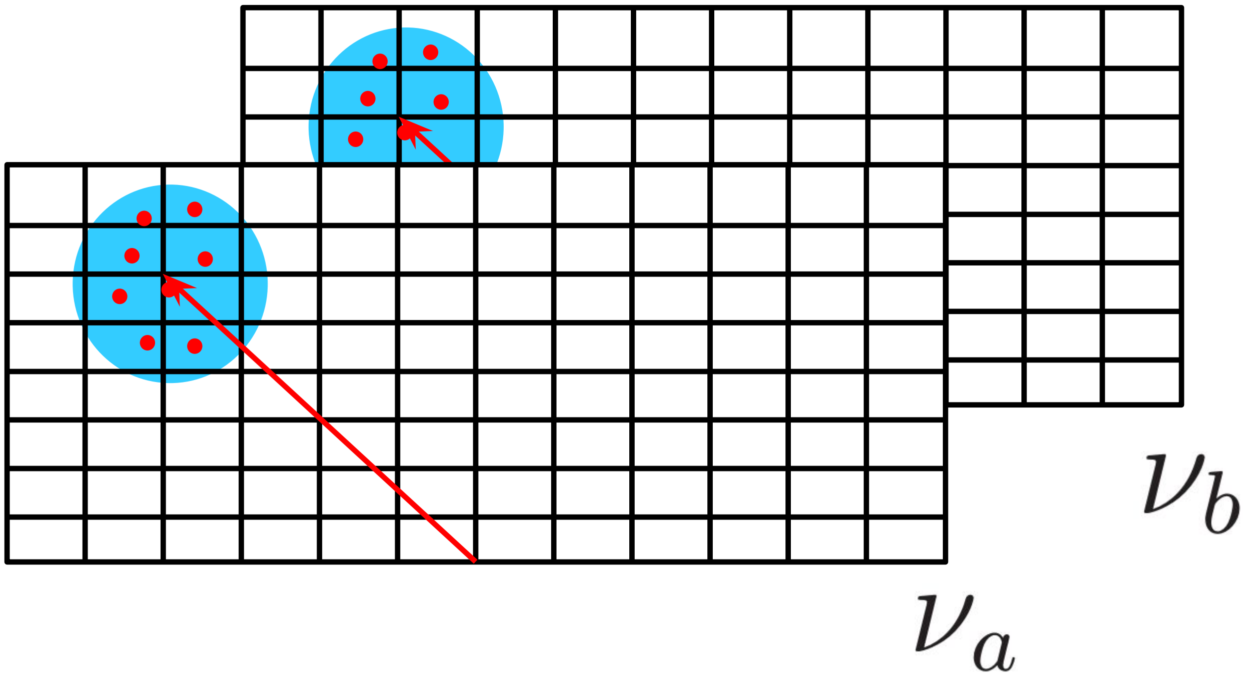
# Tapered Gridded Estimator

1. Gridded Estimator
2. Suppress Side-lobe Response
3. Remove Noise Bias

$$\hat{E}_g = M_g^{-1} \left( \mid \mathcal{V}_{cg} \mid^2 - \sum_i \mid \tilde{w}(\mathbf{U}_g - \mathbf{U}_i) \mid^2 \mid \mathcal{V}_i \mid^2 \right)$$

Choudhuri S et al 2016, MNRAS, 463, 4093

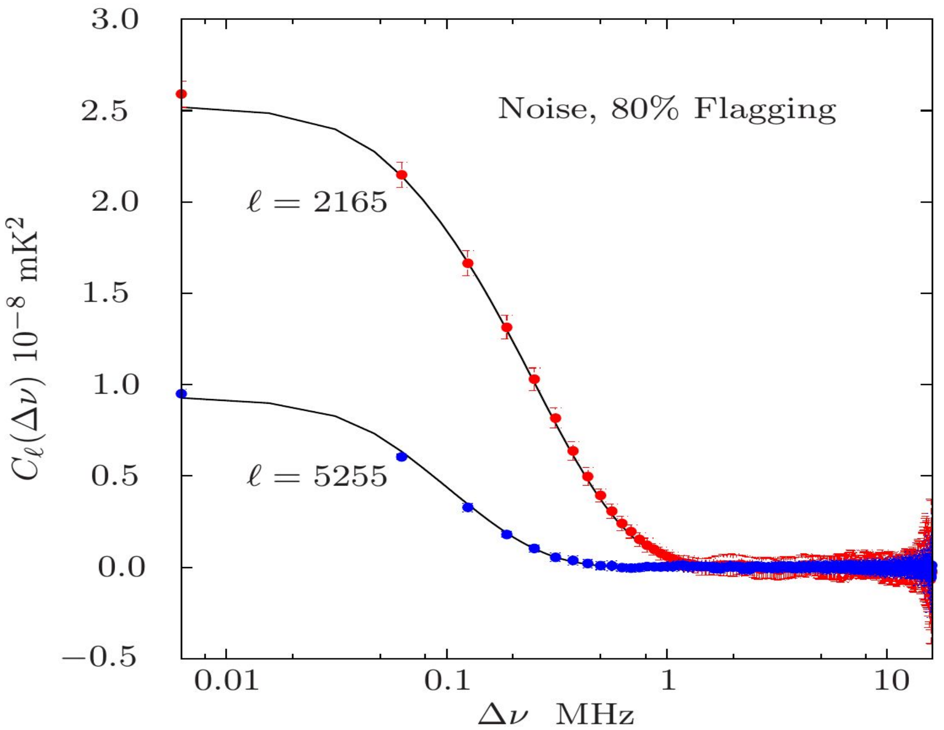
# TGE: the MAPS and the Power-Spectrum

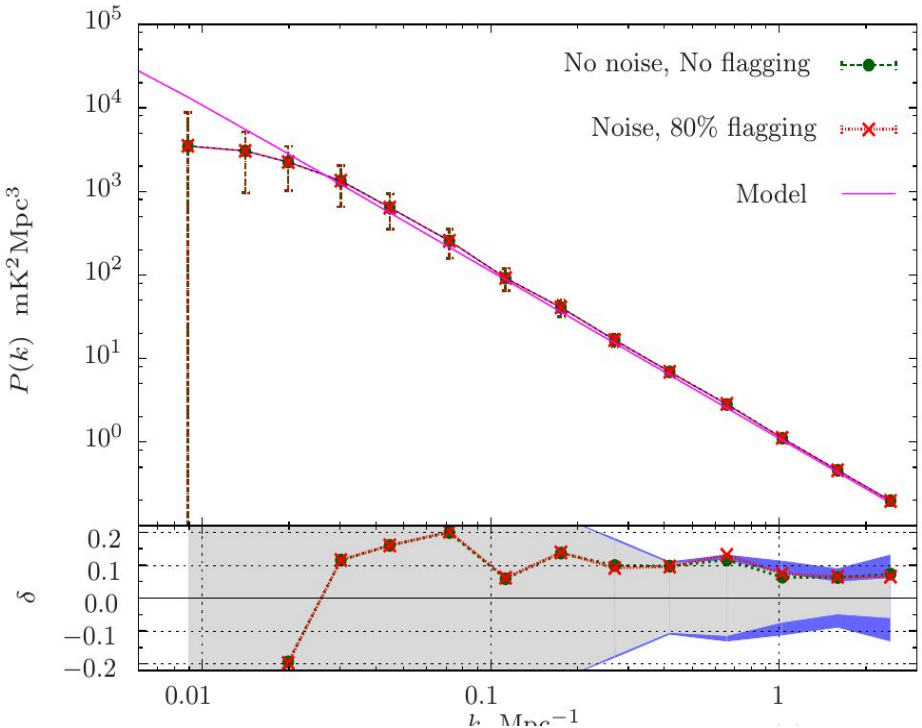



$$P(k_\perp, k_\parallel) = r^2 r' \int_{-\infty}^{\infty} d(\Delta\nu)\, e^{-ik_\parallel r' \Delta\nu}\, C_\ell(\Delta\nu)$$

MAPS

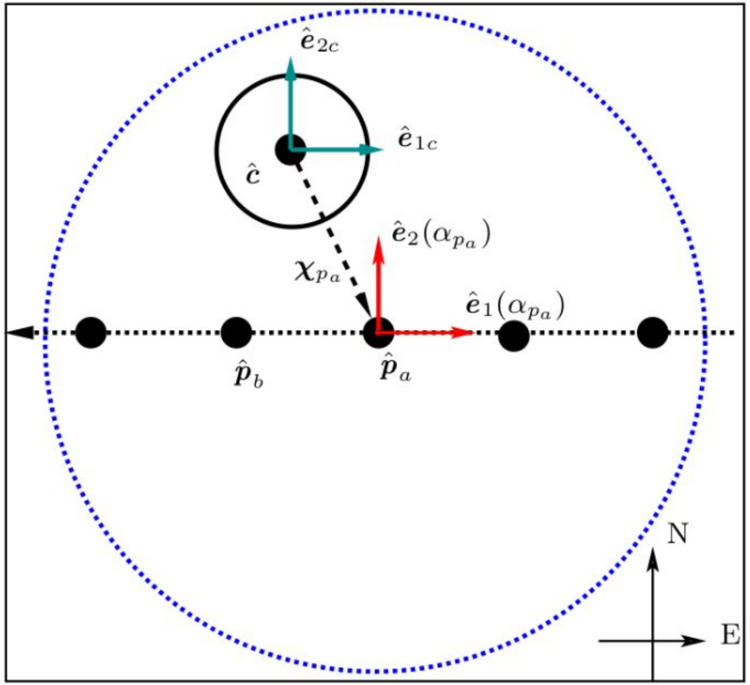
# TGE: the MAPS and the Power-Spectrum



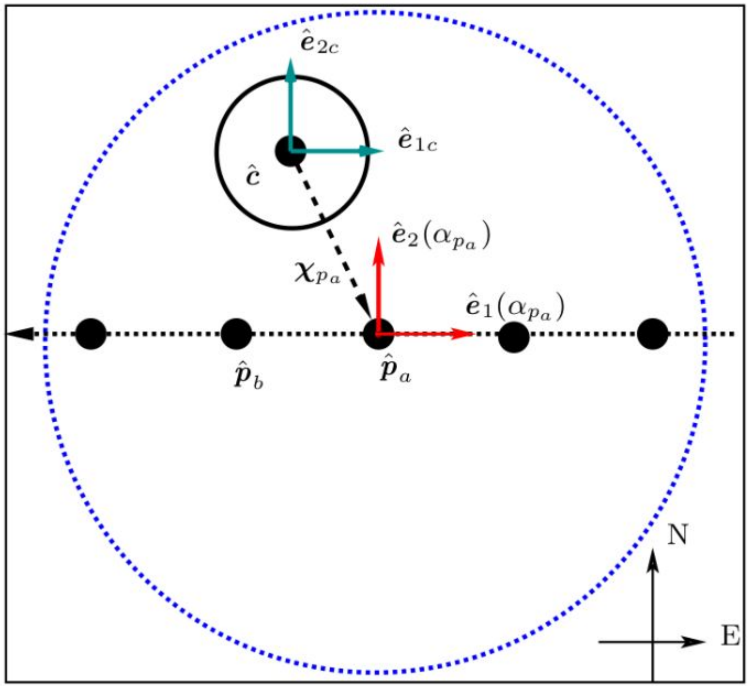




Bharadwaj, Pal, Choudhuri et al 2019, MNRAS

# Tracking TGE

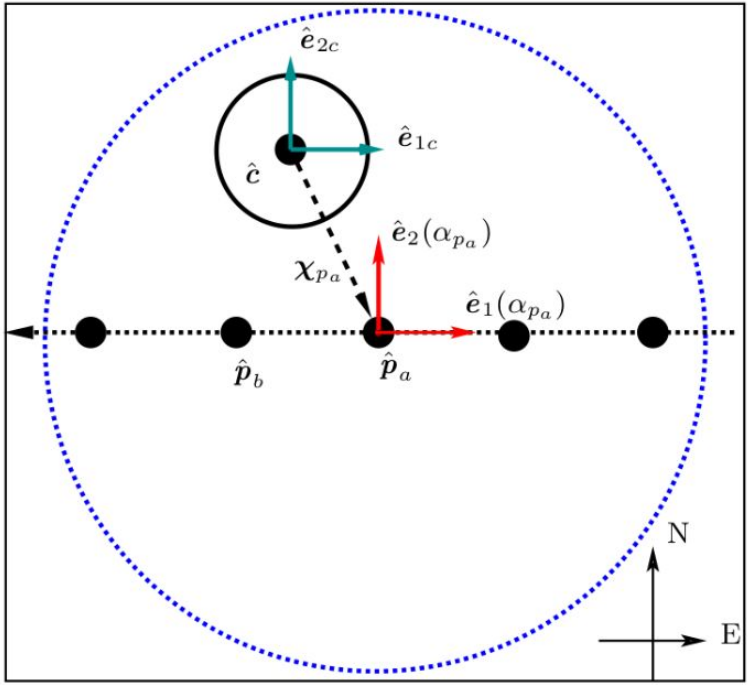


# Tracking TGE



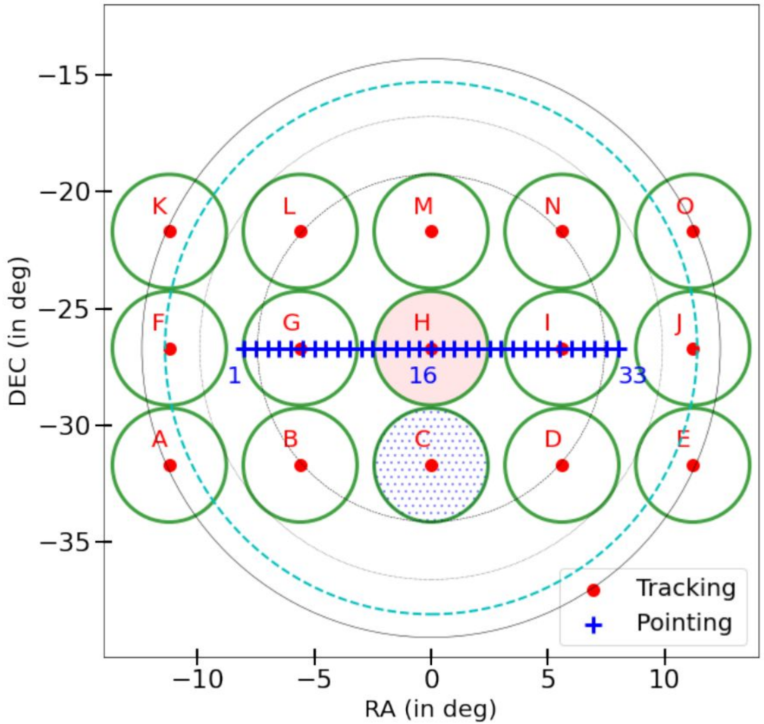

$$\mathcal{V}_{cg}(\nu) = \sum_p s_p \sum_n \tilde{w}(\boldsymbol{U}_g - \boldsymbol{U}_n) e^{2\pi i \boldsymbol{U}_n \cdot \boldsymbol{\chi}_p} \mathcal{V}(\alpha_p, \boldsymbol{U}_n, \nu)$$

# Tracking TGE

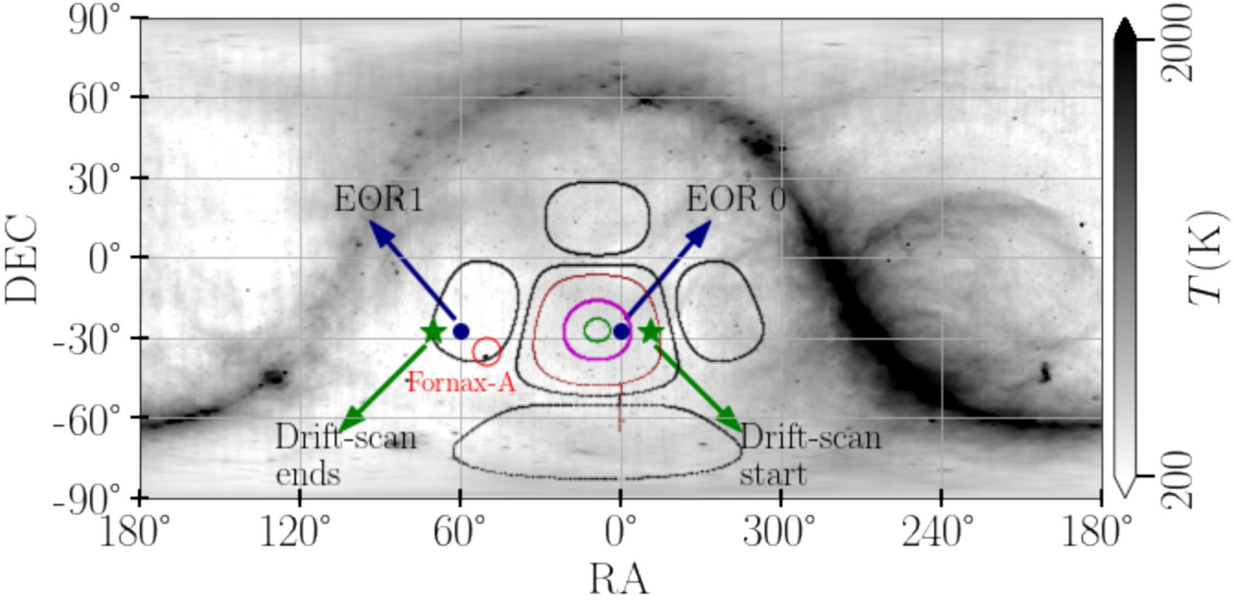



$$\hat{E}_g(\nu_a,\nu_b) = M_g^{-1}(\nu_a,\nu_b)\mathcal{R}e\left[\mathcal{V}_{cg}(\nu_a)\mathcal{V}_{cg}^*(\nu_b) - \delta_{a,b}\sum_{p,n} \mid s_p\tilde{w}(\boldsymbol{U}_g - \boldsymbol{U}_n)\mid^2 \mid \mathcal{V}(\alpha_p, \boldsymbol{U}_n, \nu_a)\mid^2\right].$$

# Tracking TGE



# MWA Observation




Time duration of 5 hr 24 min, 10 nights

RA - 349◦ to 70.3◦, 162 different pointing centers

# MWA Observation

Central frequency = 154.2 MHz ($z = 8.2$)

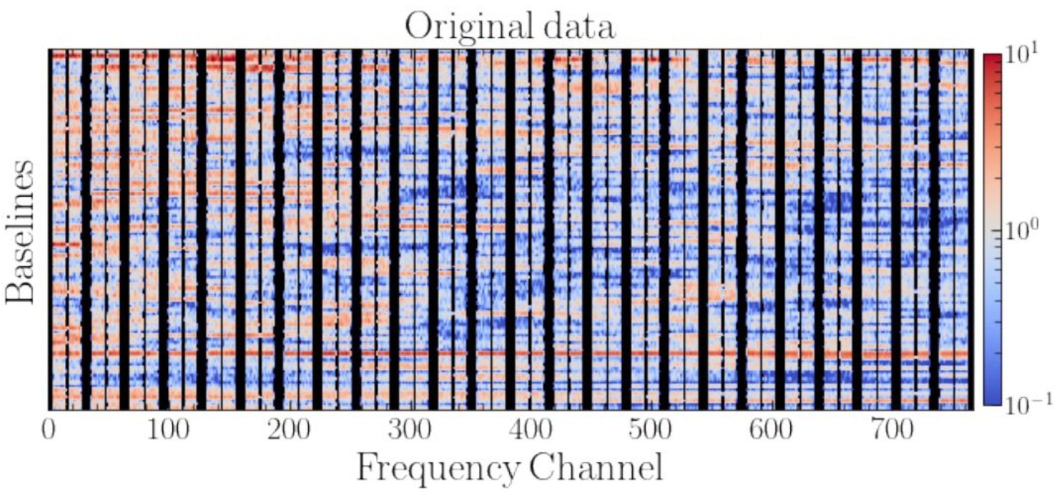
$N_c$ = 768 channels

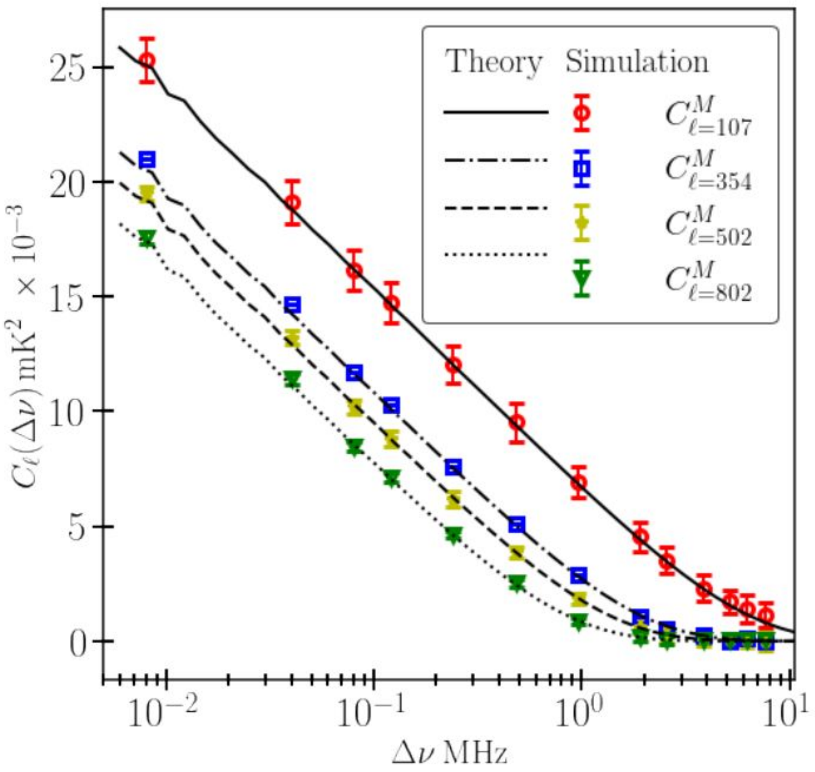
resolution of $\Delta\nu_c$ = 40 kHz (BW = 30.72 MHz)

This is further divided into 24 coarse bands each containing 32 channels or 1.28 MHz

Patwa, Sethi, Dwarkanath 2021, MNRAS

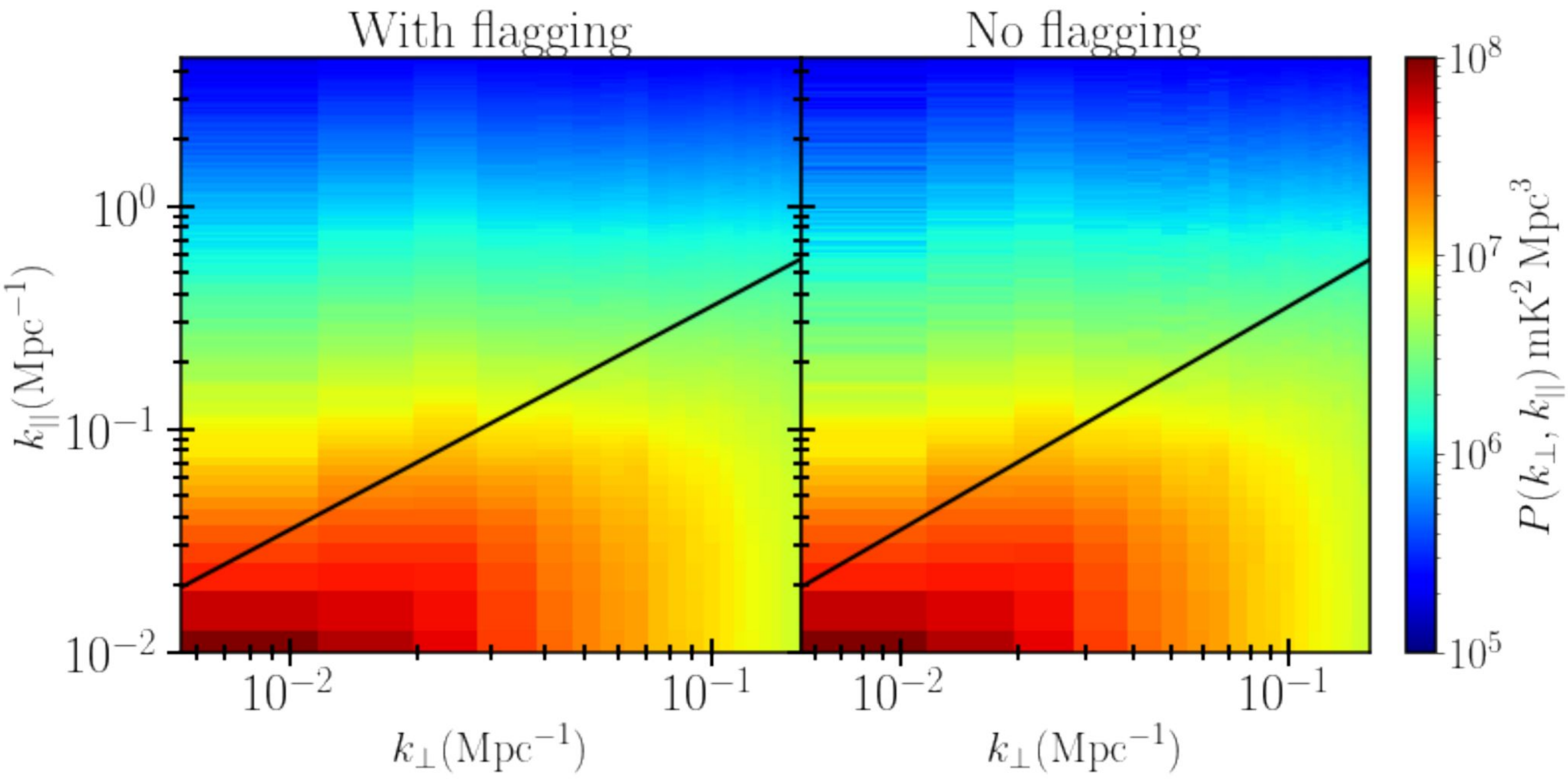
# Results: Validation



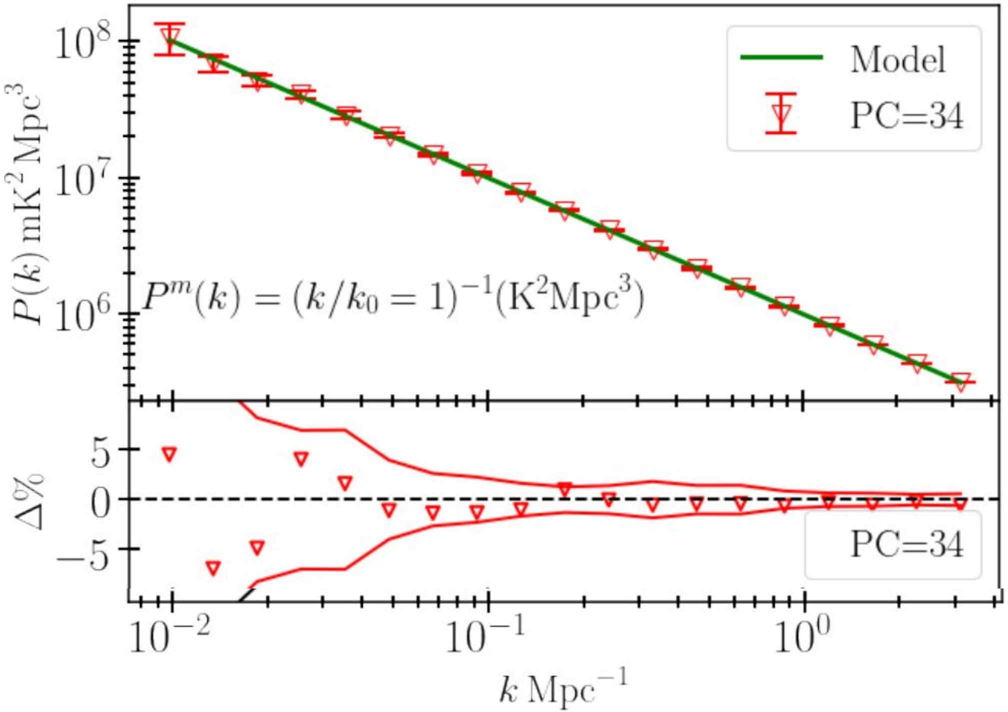

Chatterjee et al 2024, PASA

# Results: Validation



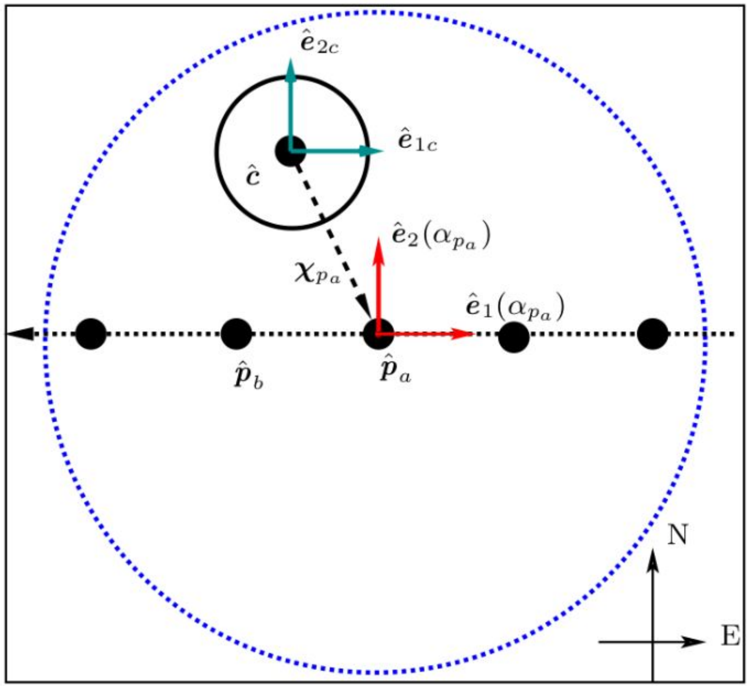

Chatterjee, Elahi, .., **SC** et al 2024, PASA

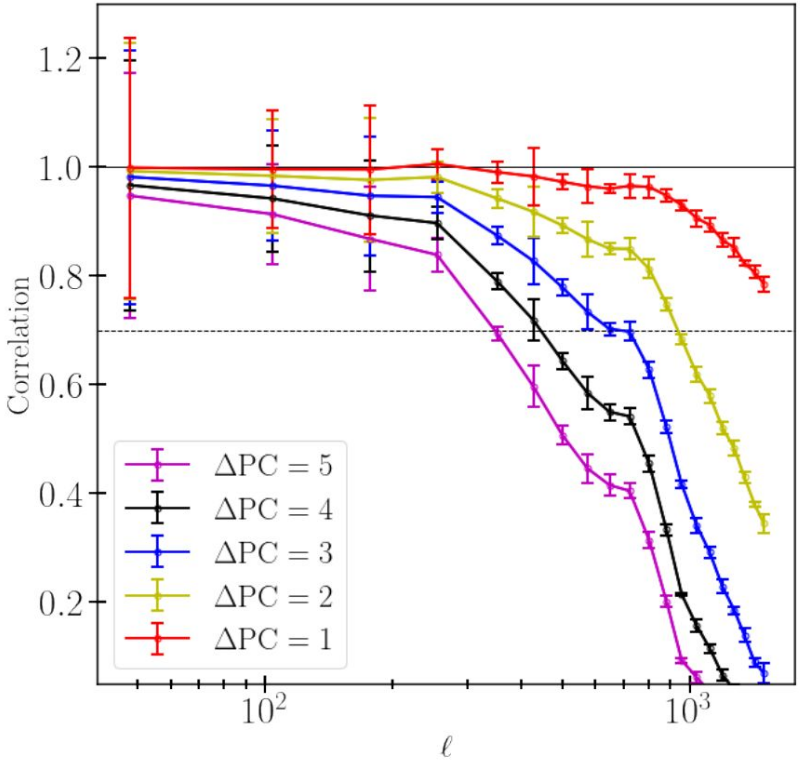
# Results: Validation



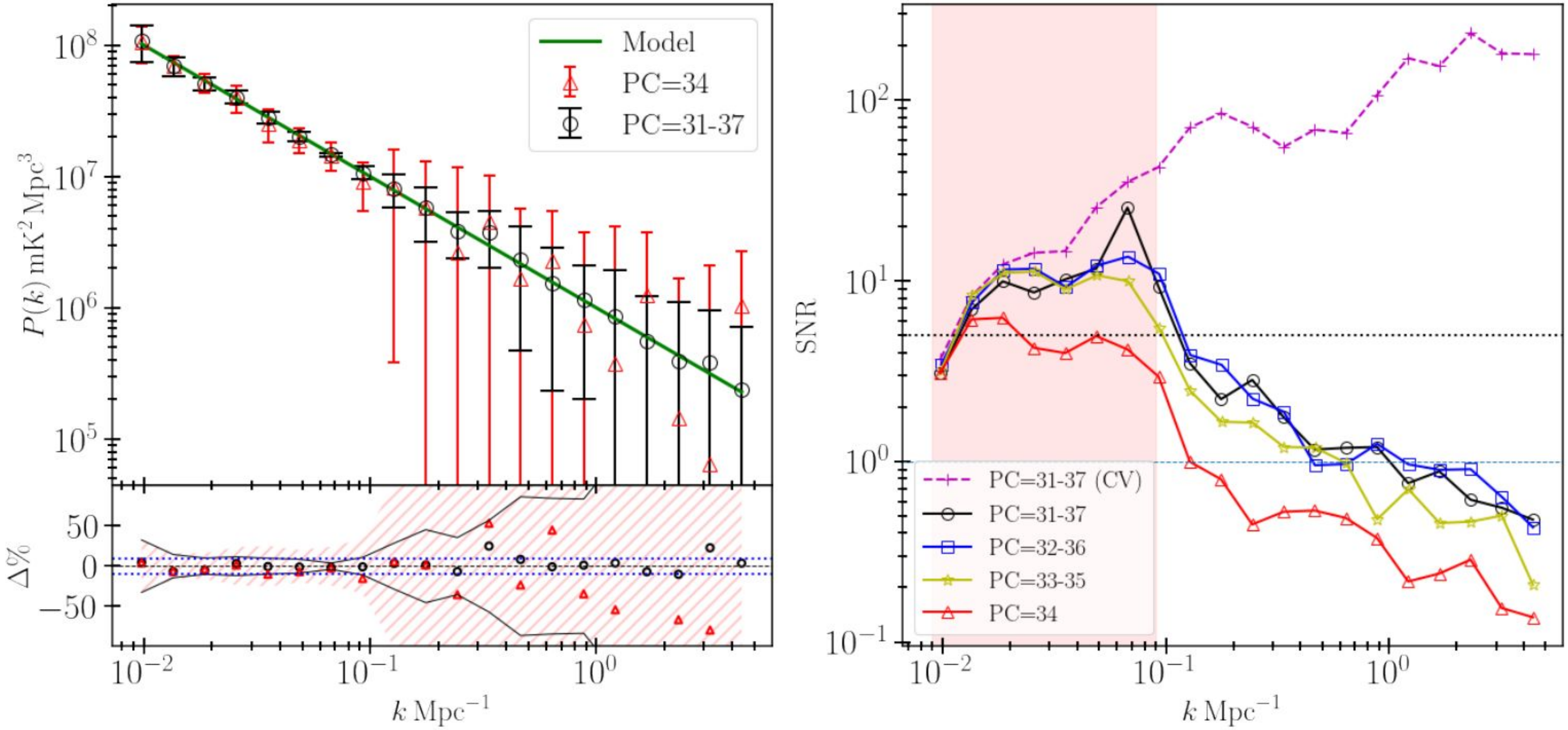

Chatterjee et al 2024, PASA

# Results: Simulation

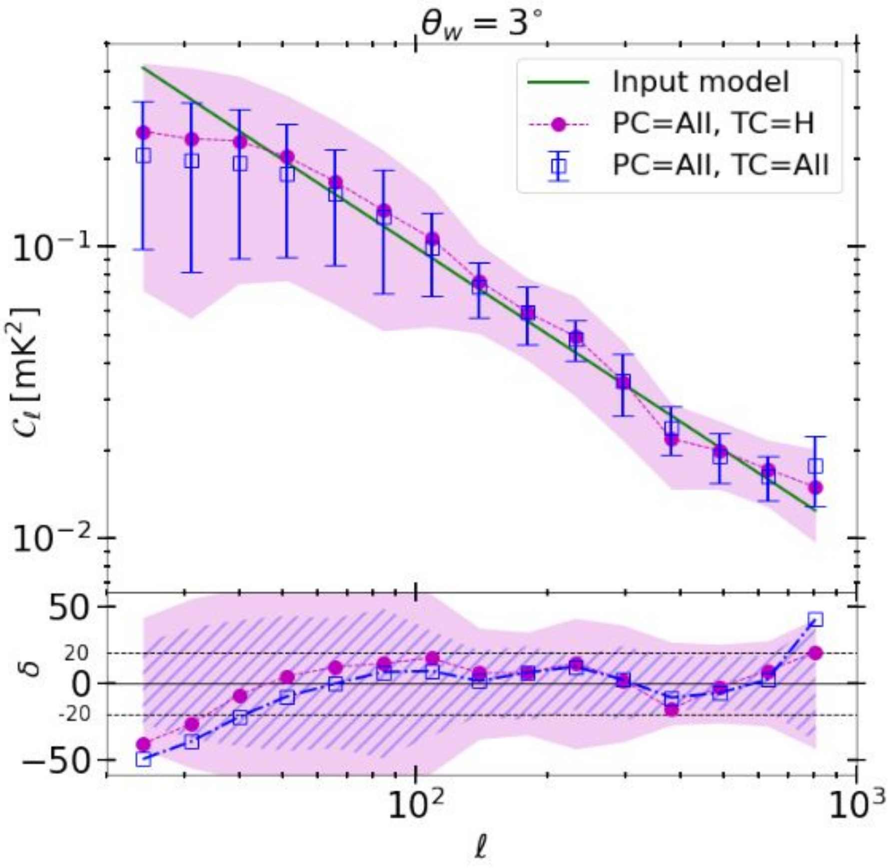


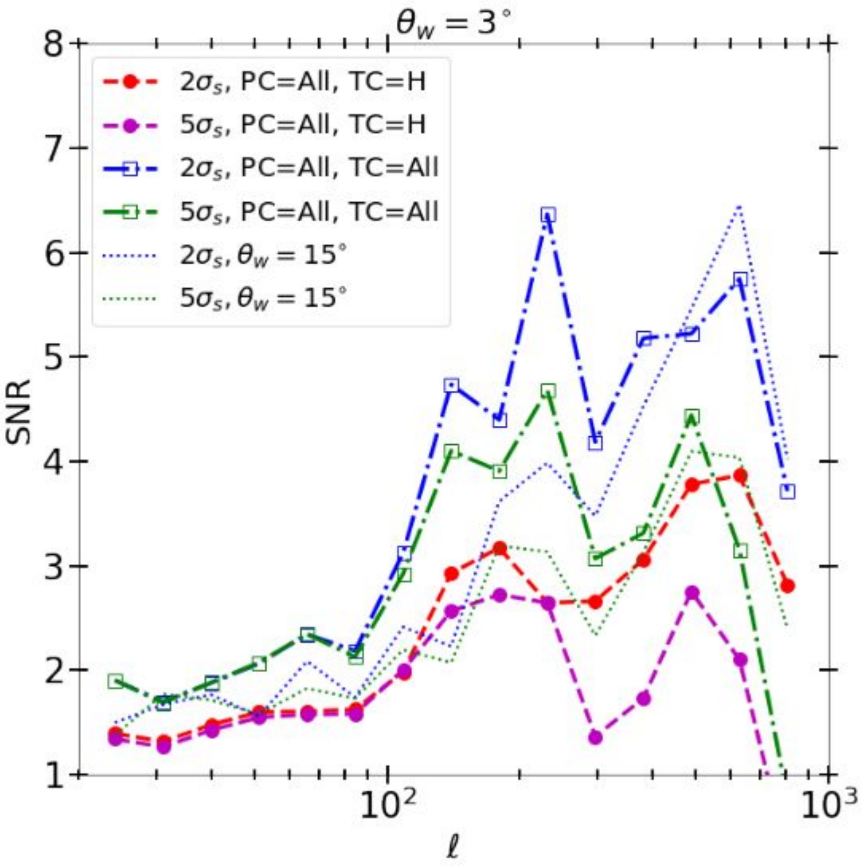



# Results: Simulation

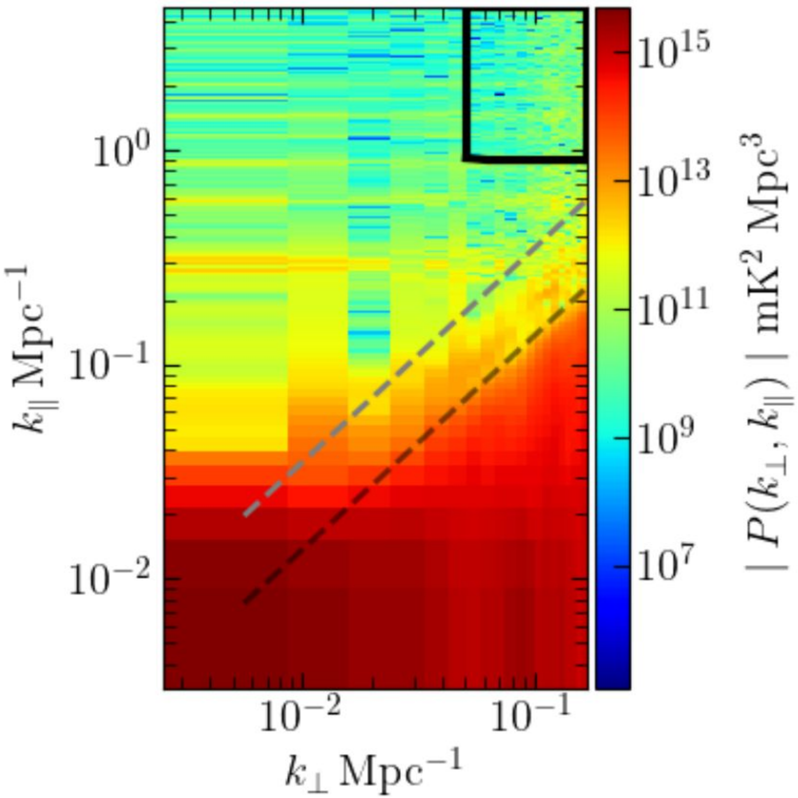


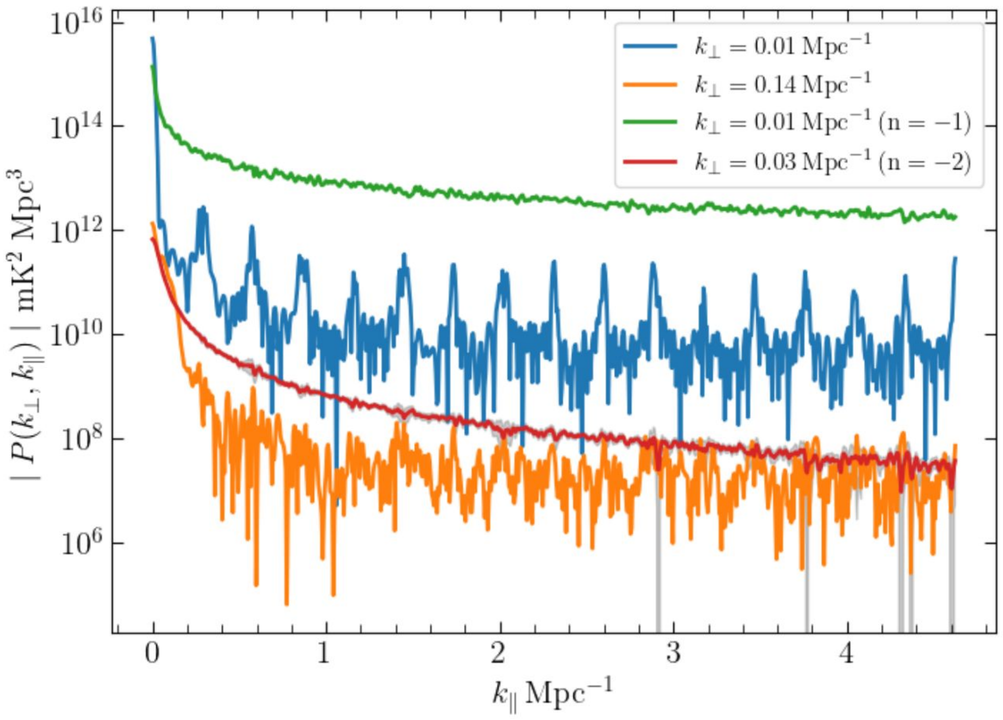
# Results: Simulation



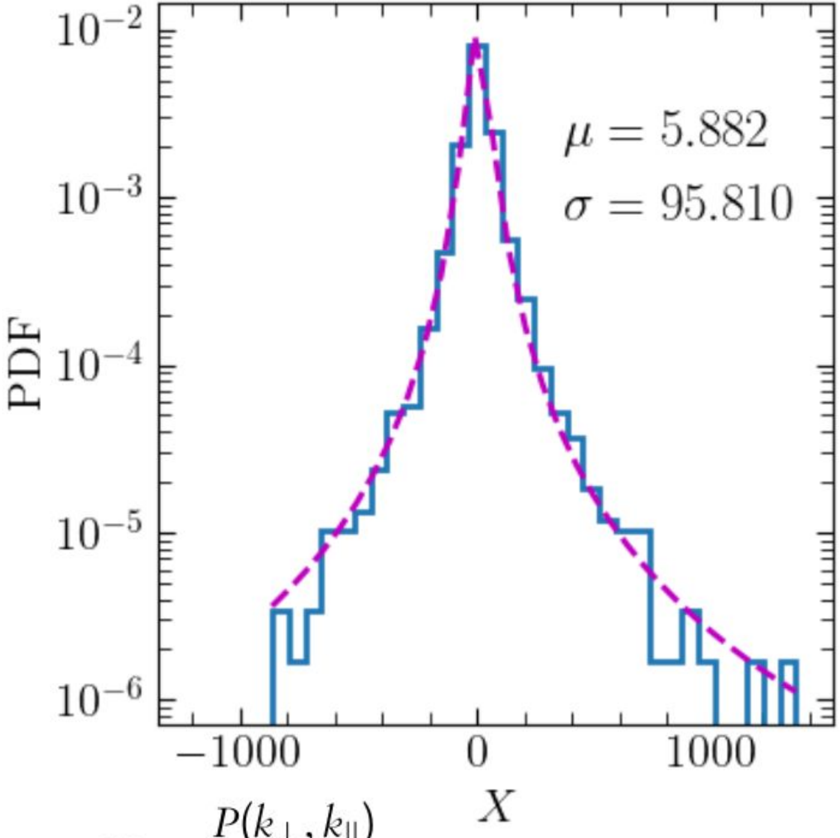



# Results: Data

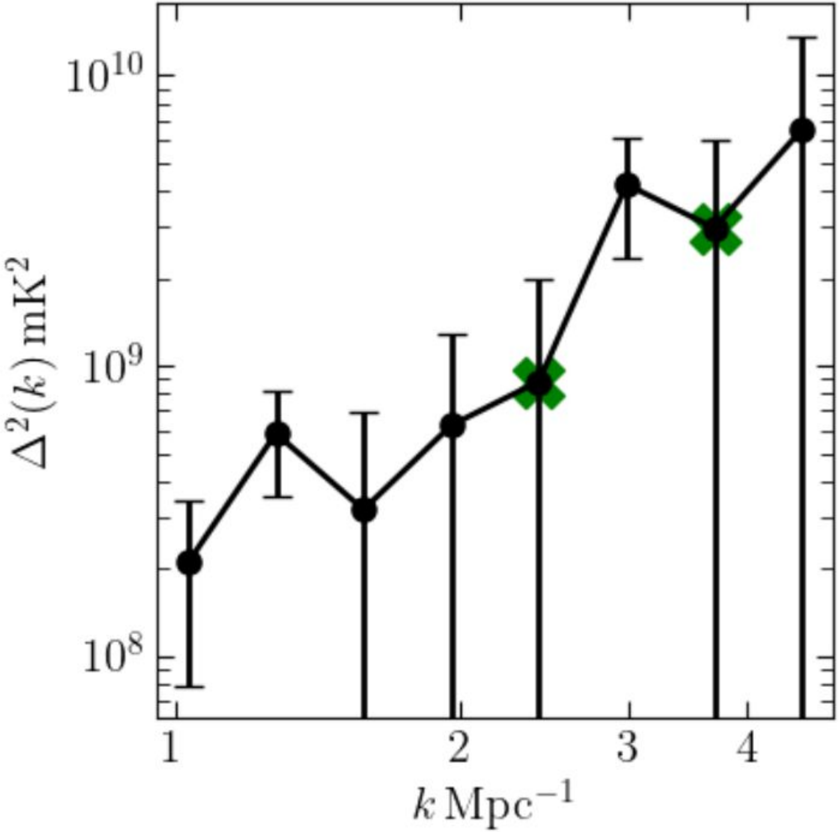


# Results

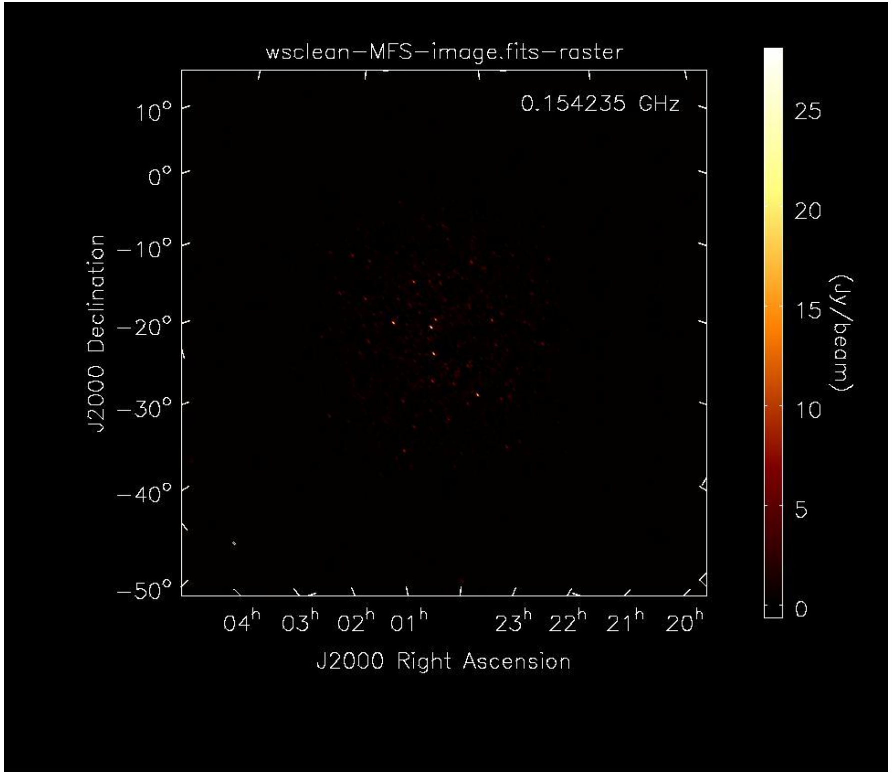


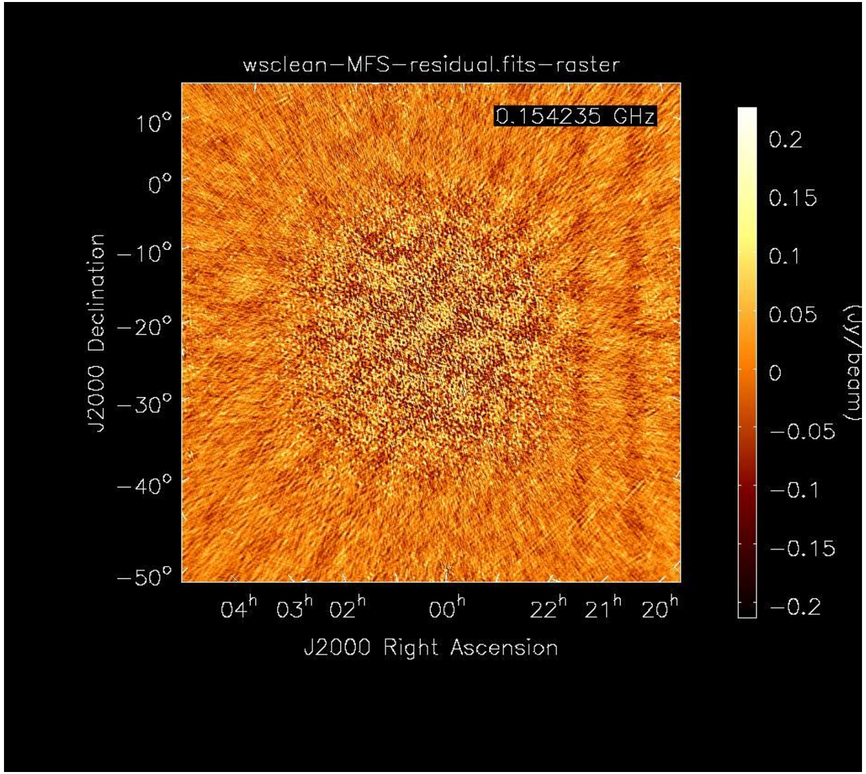

$$X = \frac{P(k_\perp, k_\parallel)}{\delta P_N(k_\perp, k_\parallel)}$$



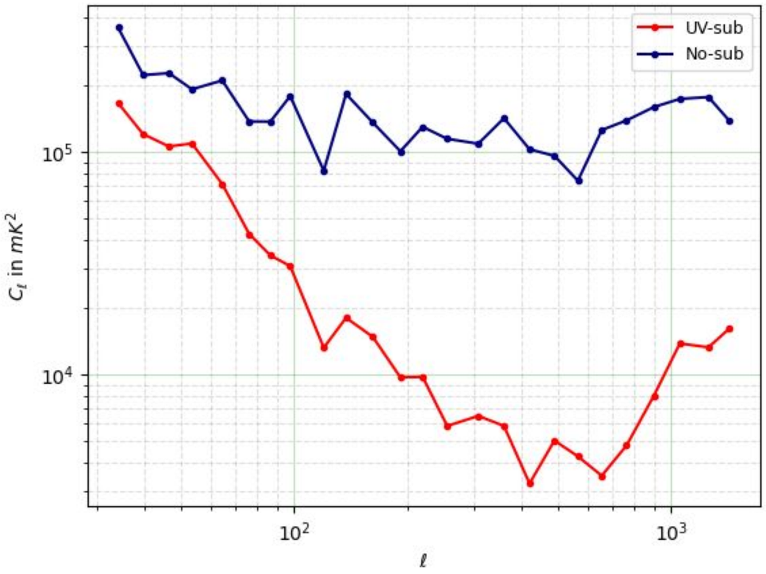

$\Delta^2(\hat{k}) < (1.85 \times 10^4)^2\,\mathrm{mK}^2$ $\quad k = 1\,\mathrm{Mpc}^{-1}$

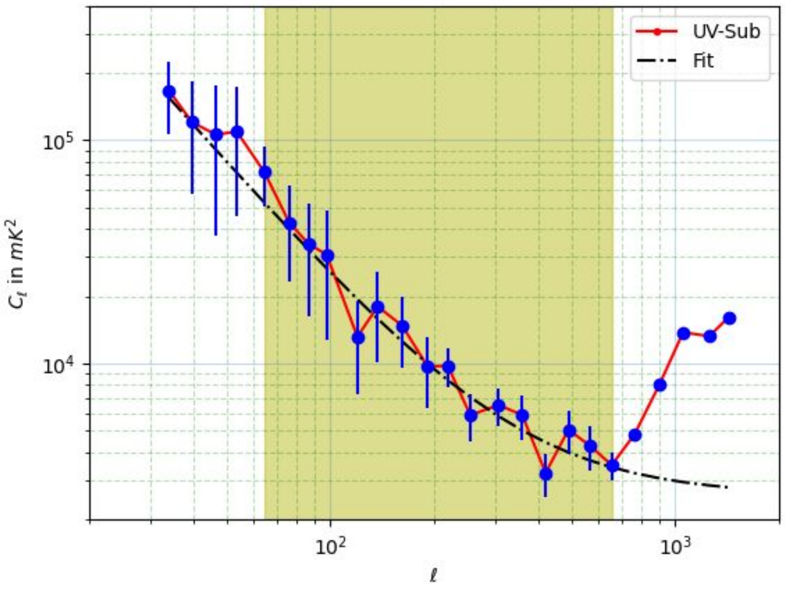
# Results


wsclean−MFS−image.fits−raster
0.154235 GHz
J2000 Declination
10°
0°
−10°
−20°
−30°
−40°
−50°
04h 03h 02h 01h 23h 22h 21h 20h
J2000 Right Ascension
25
20
15
10
5
0
(Jy/beam)


wsclean−MFS−residual.fits−raster
0.154235 GHz
J2000 Declination
10°
0°
−10°
−20°
−30°
−40°
−50°
04h 03h 02h 00h 22h 21h 20h
J2000 Right Ascension
0.2
0.15
0.1
0.05
0
−0.05
−0.1
−0.15
−0.2
(Jy/beam)

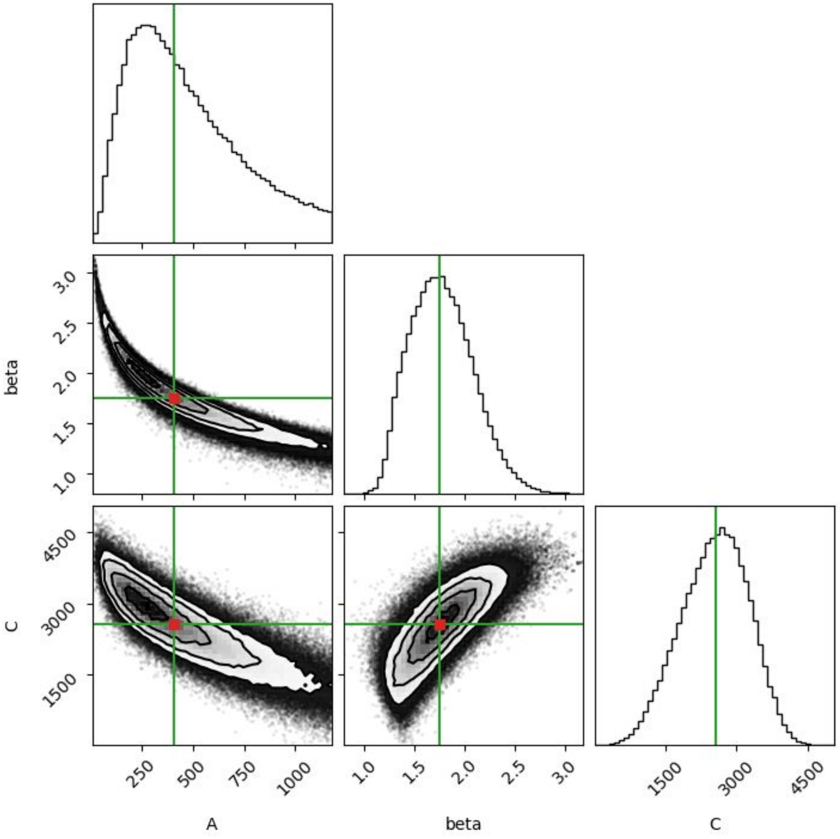
# Results




$$\mathcal{C}_\ell^M = A \times \left(\frac{1000}{\ell}\right)^\beta + C$$

# Results



beta
C
3.0
2.5
2.0
1.5
1.0
4500
3000
1500
250
500
750
1000
A
1.0
1.5
2.0
2.5
3.0
beta
1500
3000
4500
C

# Summary

- We have developed a novel estimator tracking TGE for the drift scan radio observation.
- We combined different pointing and tracking centres to increase the SNR.
- We validated using MWA simulation with real flagging pattern.
- We applied in a small MWA drift scan data set to get an upper limit.

***Thank You***

# MWA Observation

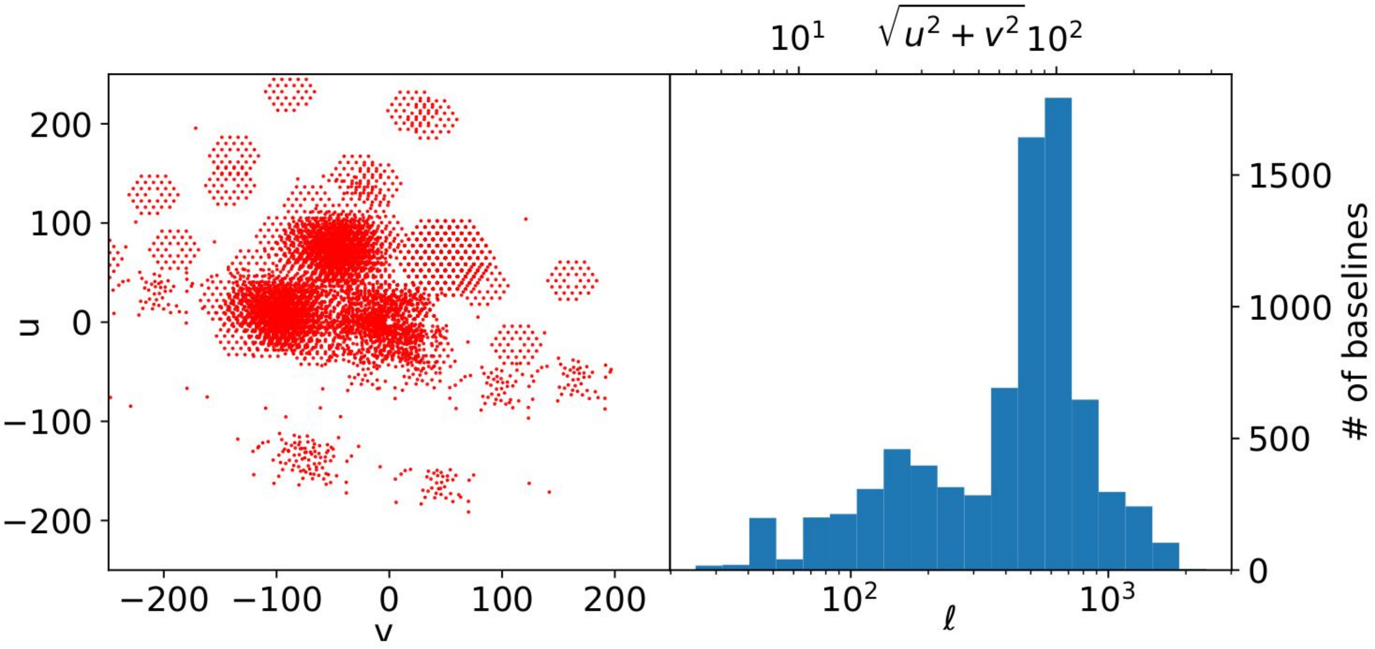
frequency bands ranging from 80 MHz to 300 MHz.

time resolution 0.5 s

right ascension (RA) 349$^{\circ}$ to 70.3$^{\circ}$

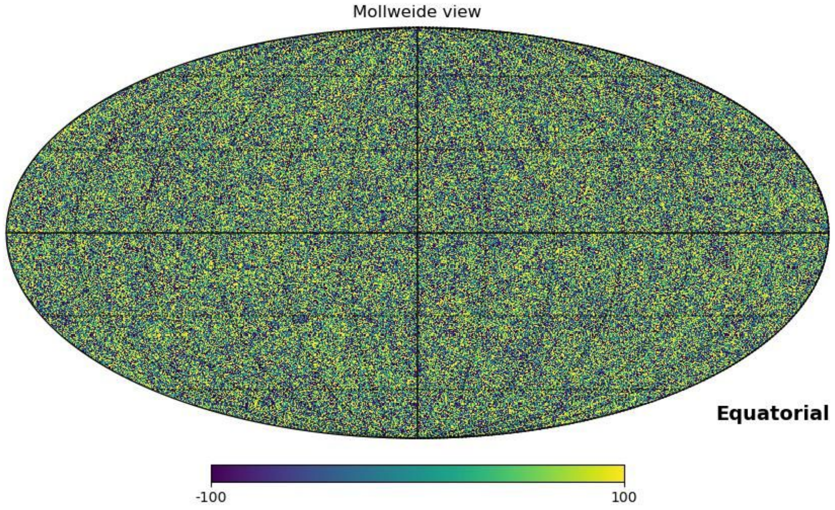
time duration of 5 hr 24 min.

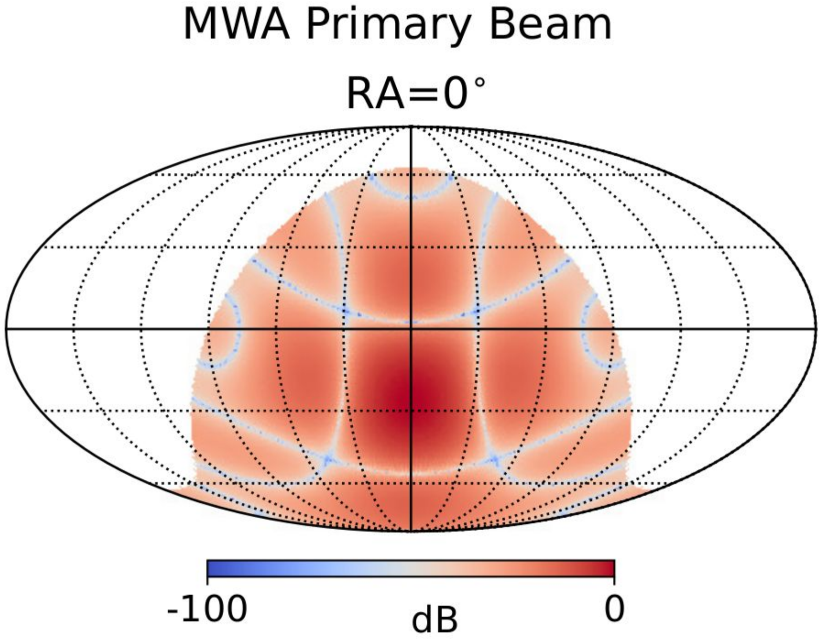
# Validation



200
100
0
−100
−200
u
−200
−100
0
100
200
v
$10^1$
$\sqrt{u^2+v^2}$
$10^2$
1500
1000
500
0
# of baselines
$10^2$
$10^3$
$\ell$

# Validation



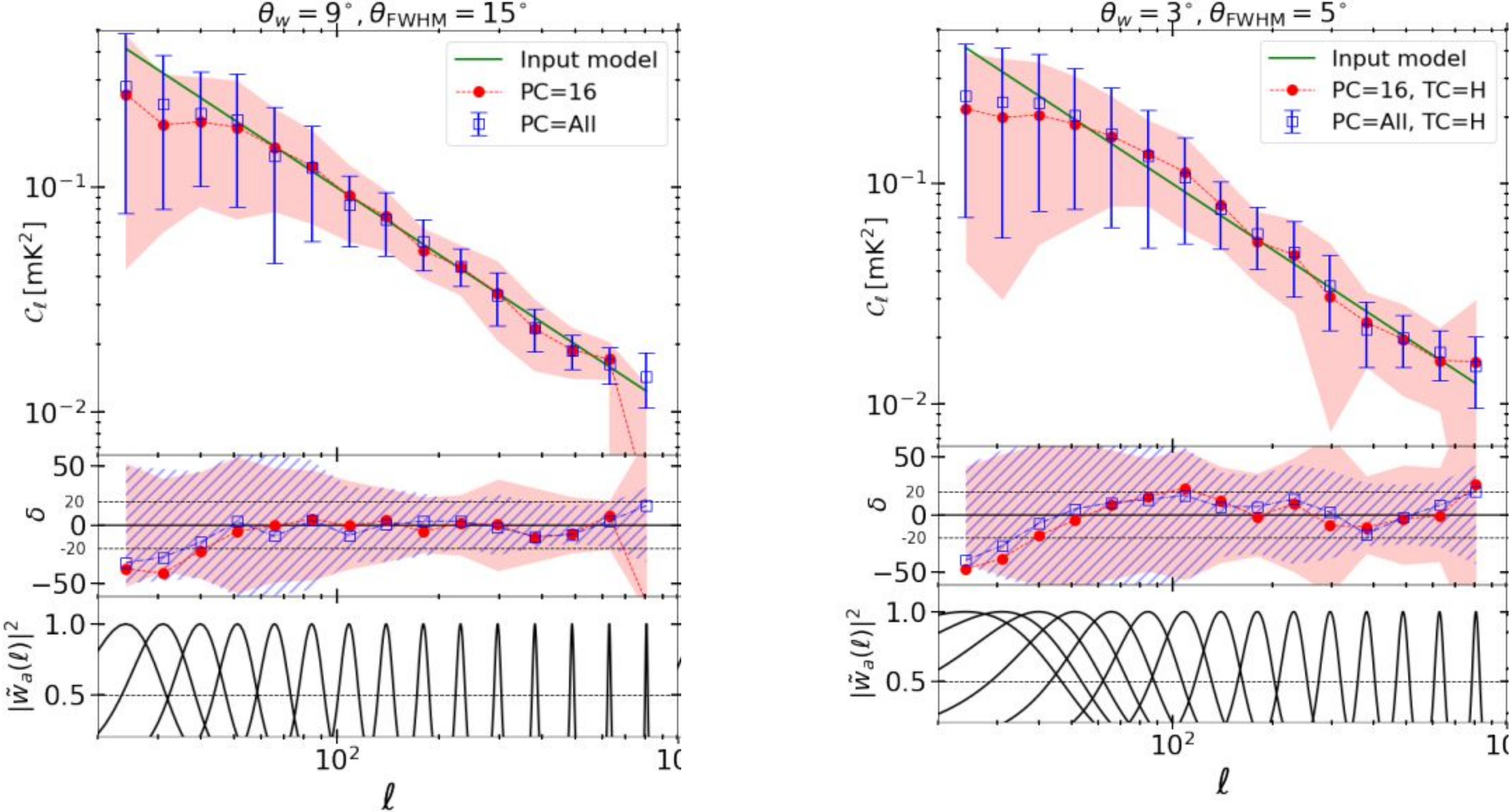

$$C_\ell^M = A\left(\frac{\ell}{\ell_0}\right)^n$$

$$A(\Delta \boldsymbol{n}, \nu) = \mathrm{sinc}^2\left(\frac{\pi b \nu\, \Delta \boldsymbol{n} \cdot \hat{\boldsymbol{e}}_1(\alpha_p)}{c}\right) \mathrm{sinc}^2\left(\frac{\pi b \nu\, \Delta \boldsymbol{n} \cdot \hat{\boldsymbol{e}}_2(\alpha_p)}{c}\right)$$

$$A = 10\,\mathrm{mK}^2 \text{ at } \ell = \ell_0 = 1$$

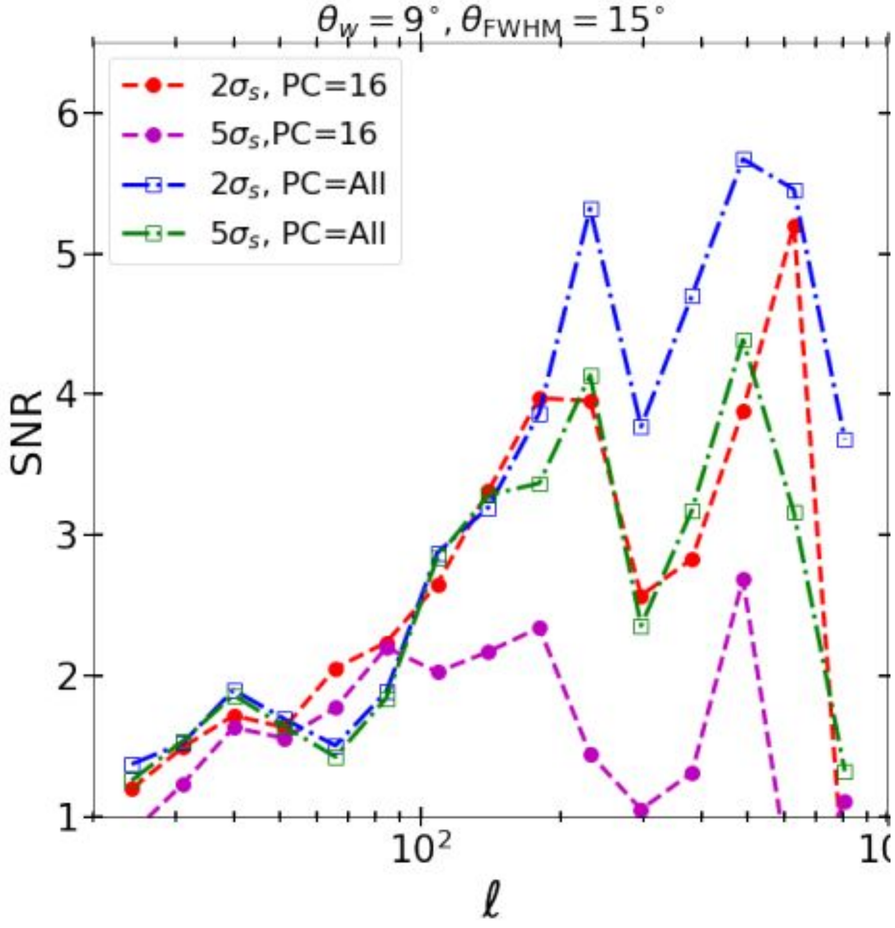
$$n = -1$$

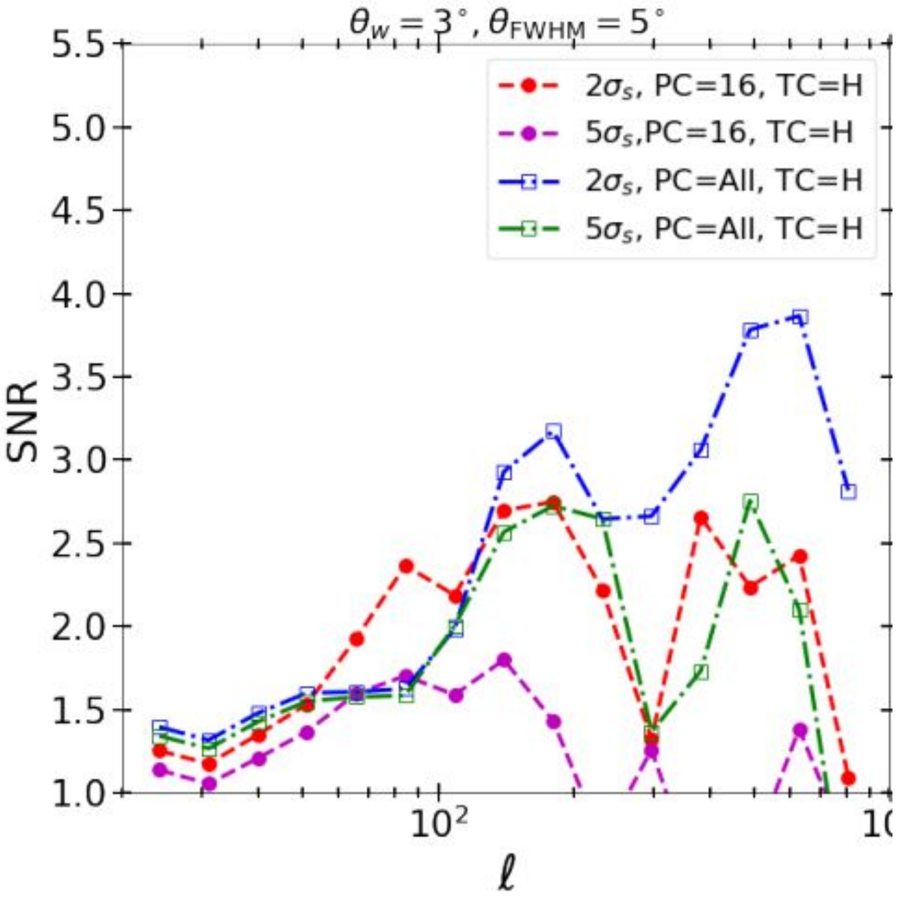
# Results



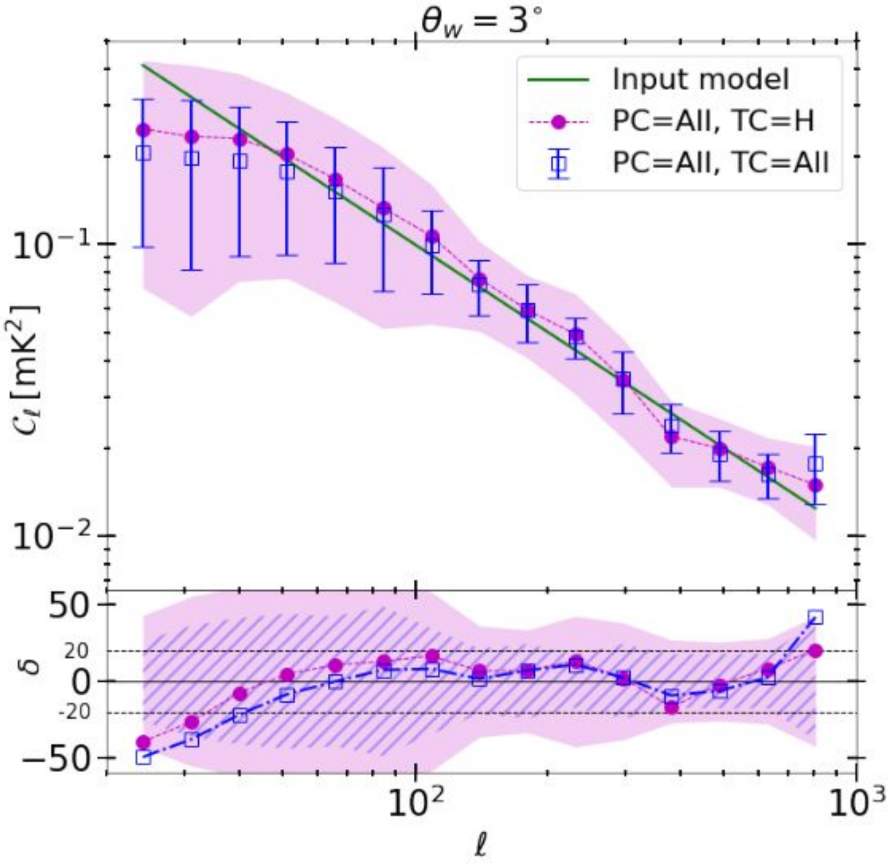
$\theta_w = 9^\circ, \theta_{\rm FWHM} = 15^\circ$
Input model
PC=16
PC=All
$\mathcal{C}_\ell\,[{\rm mK}^2]$
$10^{-1}$
$10^{-2}$
$\delta$
50
20
0
-20
−50
$|\tilde{W}_a(\ell)|^2$
1.0
0.5
$10^2$
$\ell$
$\theta_w = 3^\circ, \theta_{\rm FWHM} = 5^\circ$
Input model
PC=16, TC=H
PC=All, TC=H
$\mathcal{C}_\ell\,[{\rm mK}^2]$
$10^{-1}$
$10^{-2}$
$\delta$
50
20
0
-20
−50
$|\tilde{W}_a(\ell)|^2$
1.0
0.5
$10^2$
$\ell$

# Results

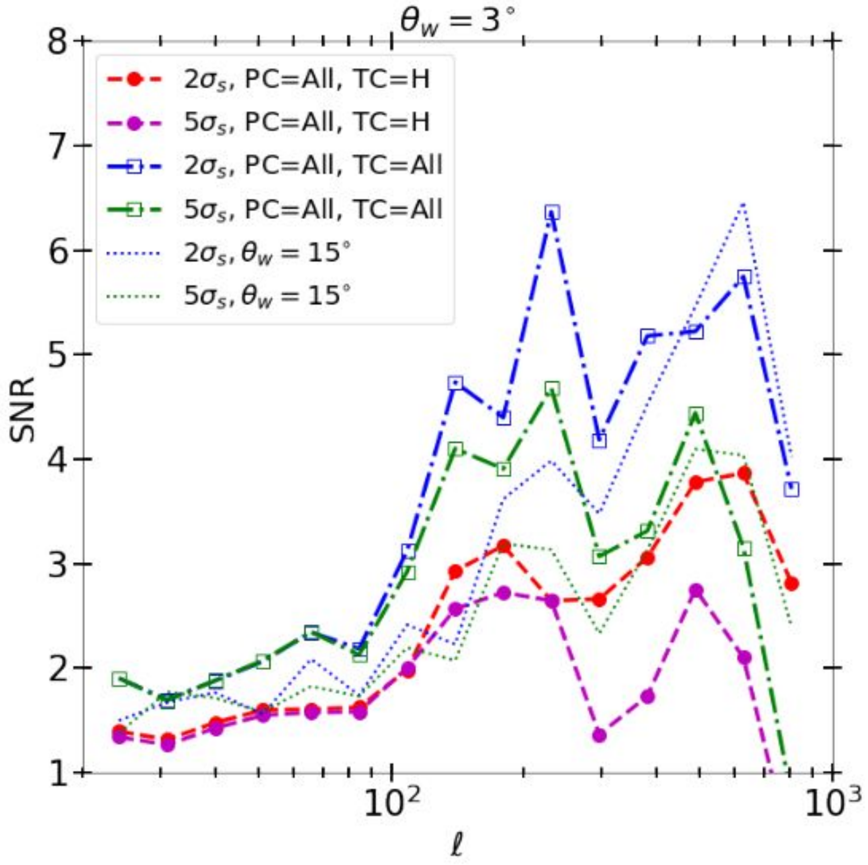

$\theta_w = 9^\circ, \theta_{FWHM} = 15^\circ$
$2\sigma_s$, PC=16
$5\sigma_s$,PC=16
$2\sigma_s$, PC=All
$5\sigma_s$, PC=All
SNR
1
2
3
4
5
6
$10^2$
$\ell$


$\theta_w = 3^\circ, \theta_{FWHM} = 5^\circ$
$2\sigma_s$, PC=16, TC=H
$5\sigma_s$,PC=16, TC=H
$2\sigma_s$, PC=All, TC=H
$5\sigma_s$, PC=All, TC=H
SNR
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
5.5
$10^2$
$\ell$

# Results



$\theta_w = 3^\circ$
Input model
PC=All, TC=H
PC=All, TC=All
$10^{-1}$
$10^{-2}$
$C_\ell\,[\mathrm{mK}^2]$
50
20
0
-20
−50
$\delta$
$10^2$
$10^3$
$\ell$

$\theta_w = 3^\circ$
$2\sigma_s$, PC=All, TC=H
$5\sigma_s$, PC=All, TC=H
$2\sigma_s$, PC=All, TC=All
$5\sigma_s$, PC=All, TC=All
$2\sigma_s, \theta_w = 15^\circ$
$5\sigma_s, \theta_w = 15^\circ$
SNR
8
7
6
5
4
3
2
1
$10^2$
$10^3$
$\ell$