

# Detecting the Universe's structure with the SKAO precursor MeerKAT in cross-correlation with galaxy surveys

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MeerKLASS

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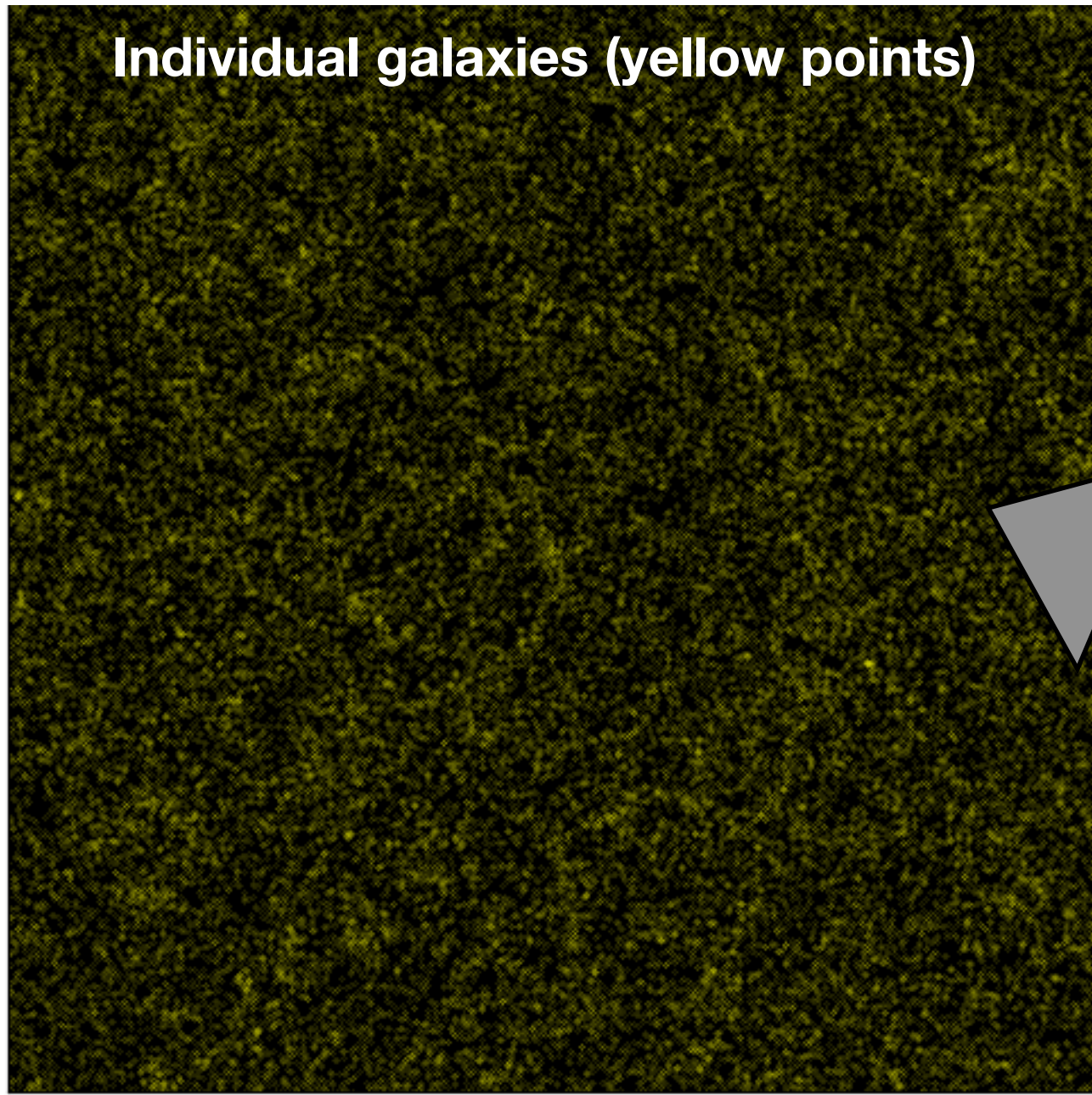
# Large-scale cosmic structure

## Conventional approach

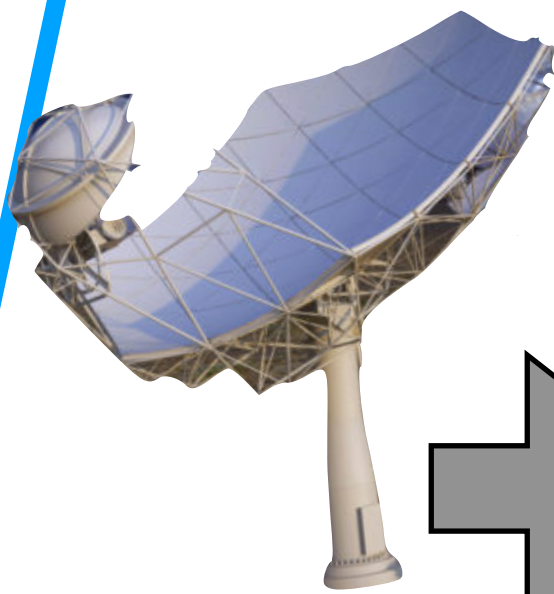
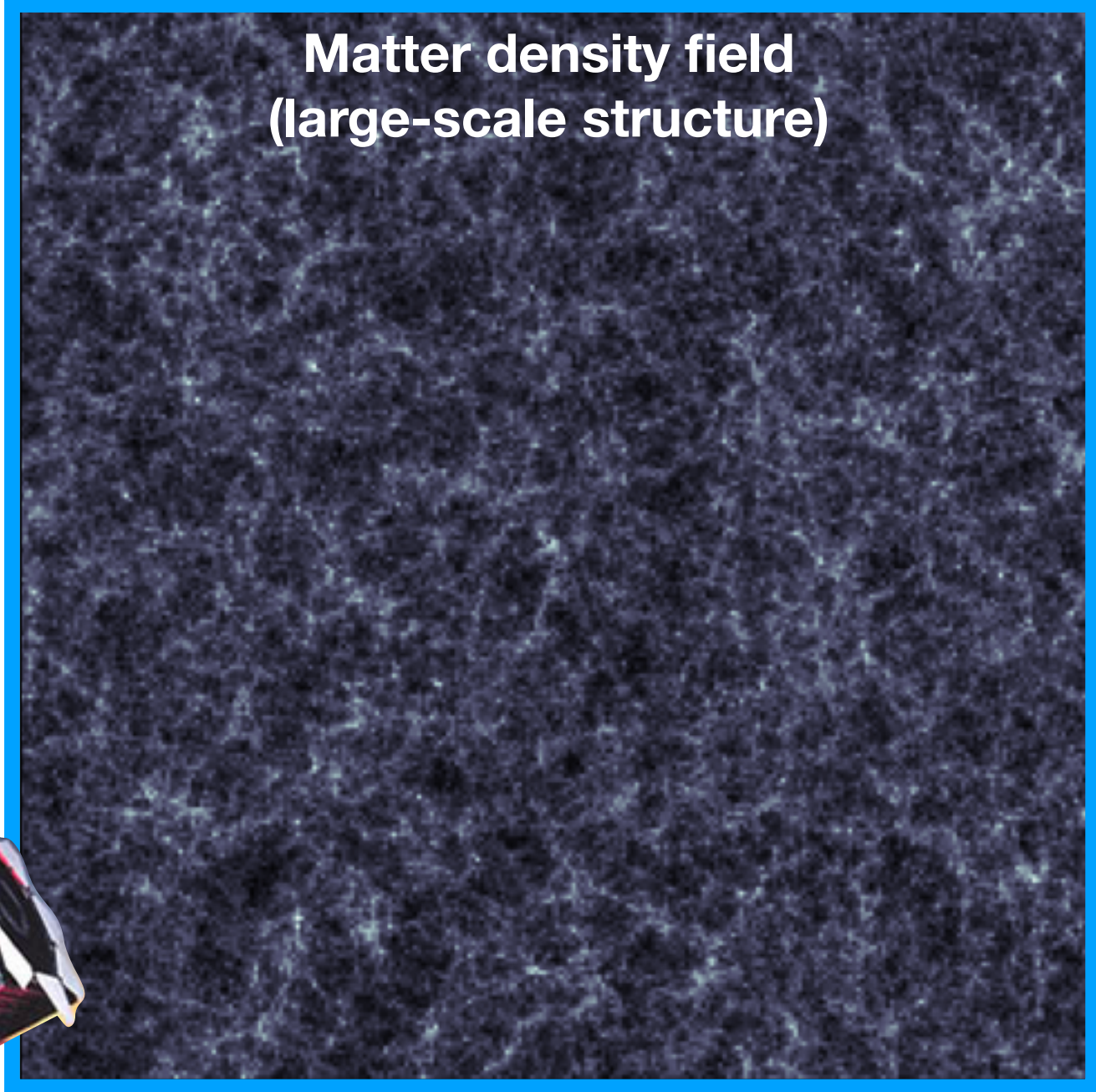
Individual galaxies (yellow points)



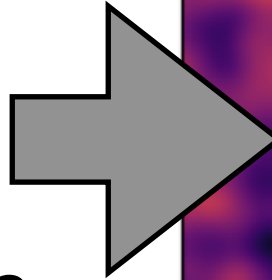
*optical*



Matter density field  
(large-scale structure)

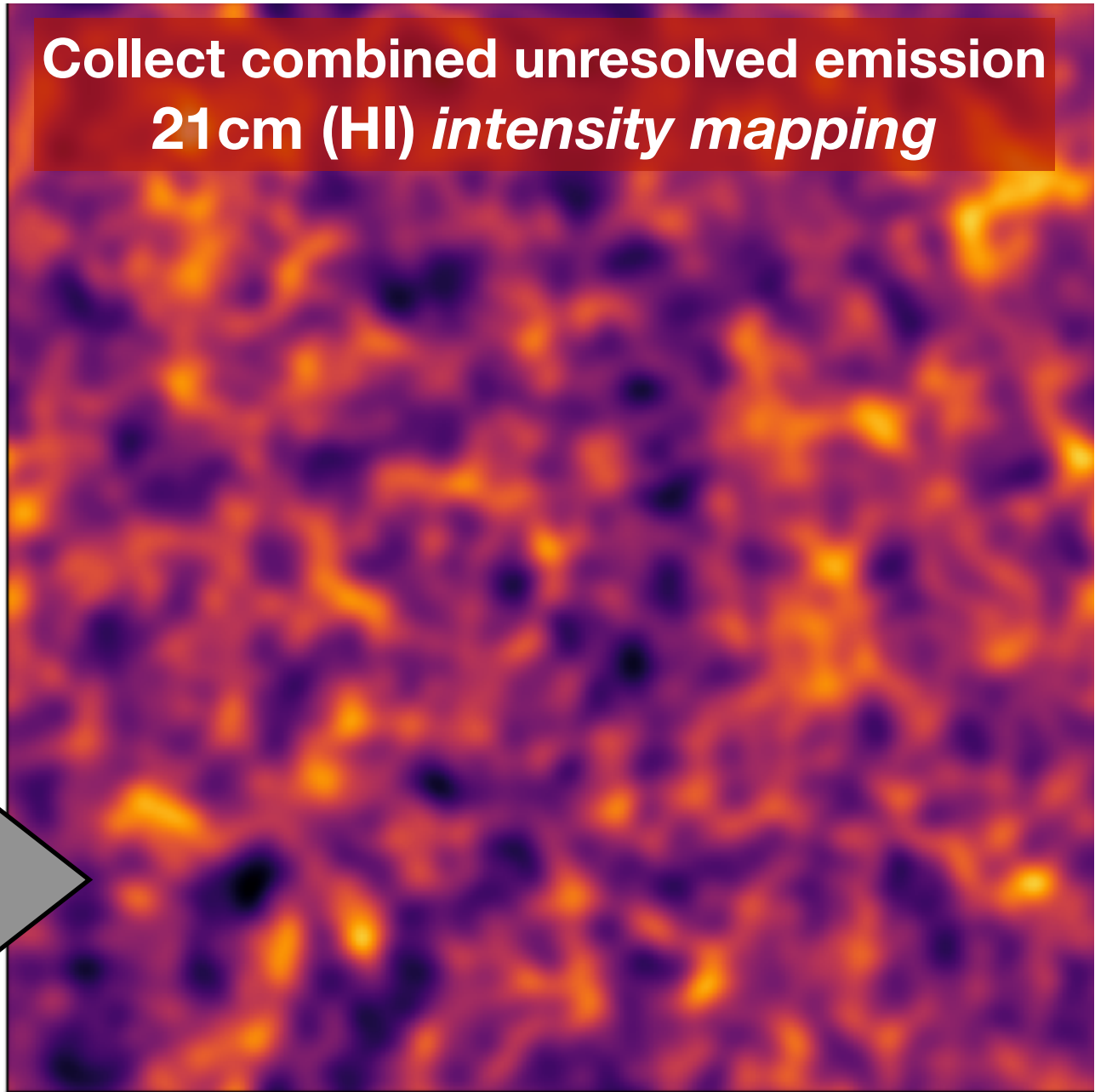


*radio*

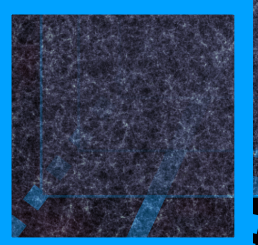
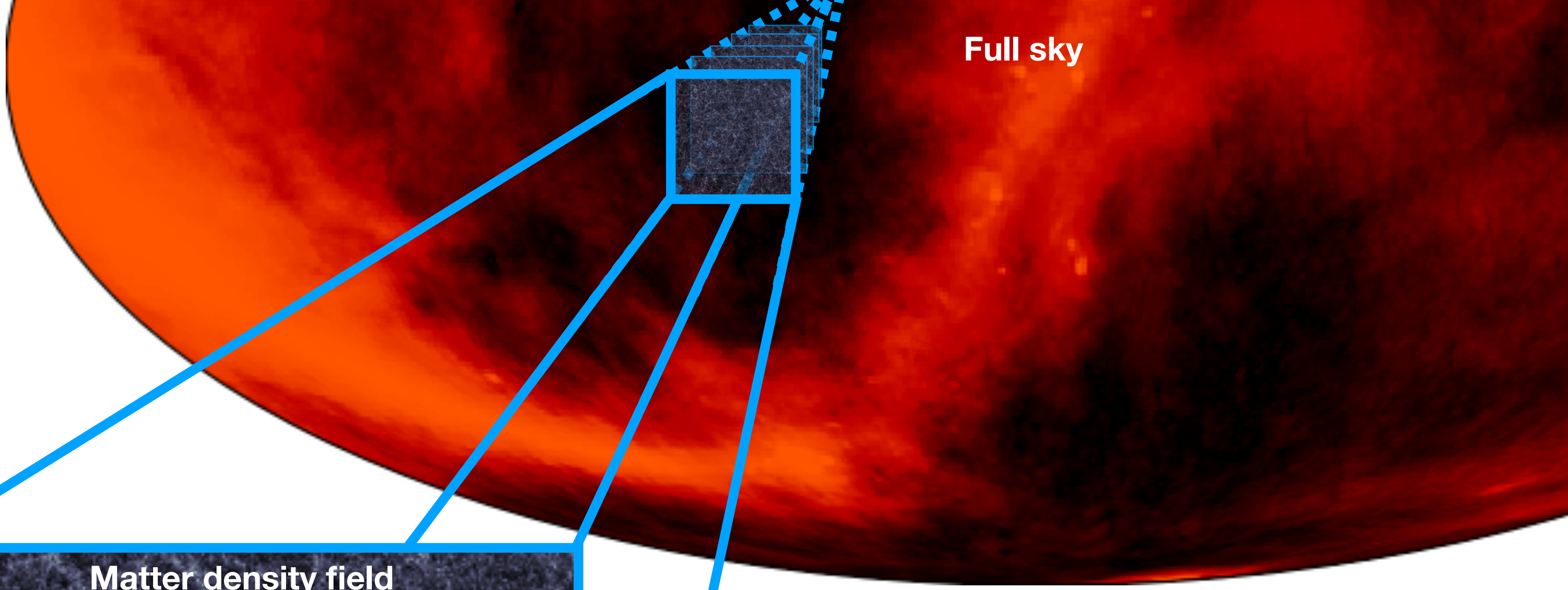


## alternative to galaxy cataloguing...

Collect combined unresolved emission  
21cm (HI) *intensity mapping*



Full sky





# SKAO precursor: MeerKAT

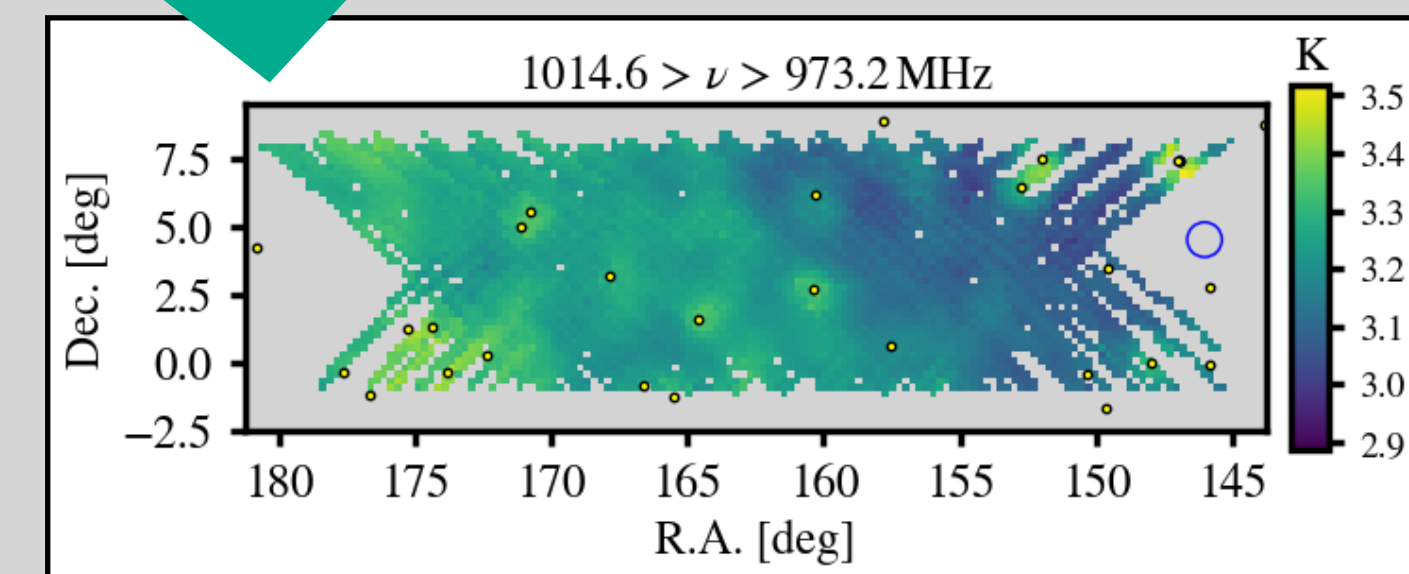
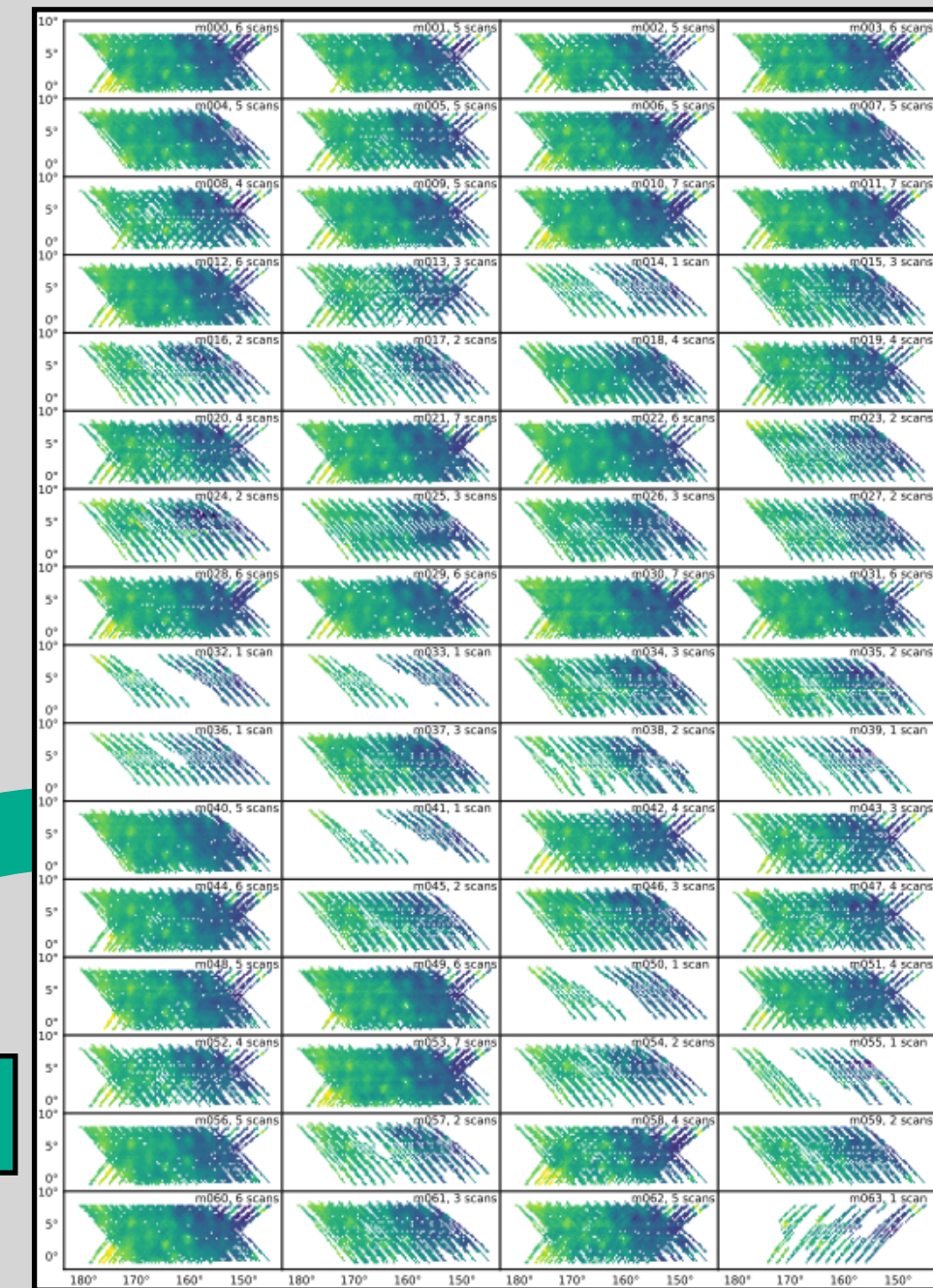
- ▶ 64 dishes to merge with SKA-MID
- ▶  $0.2 < z < 0.58$  (L-band)
- ▶  $0.4 < z < 1.45$  (UHF-band)



Karoo Desert, South Africa

Map  
obtained  
for every  
dish

averaged



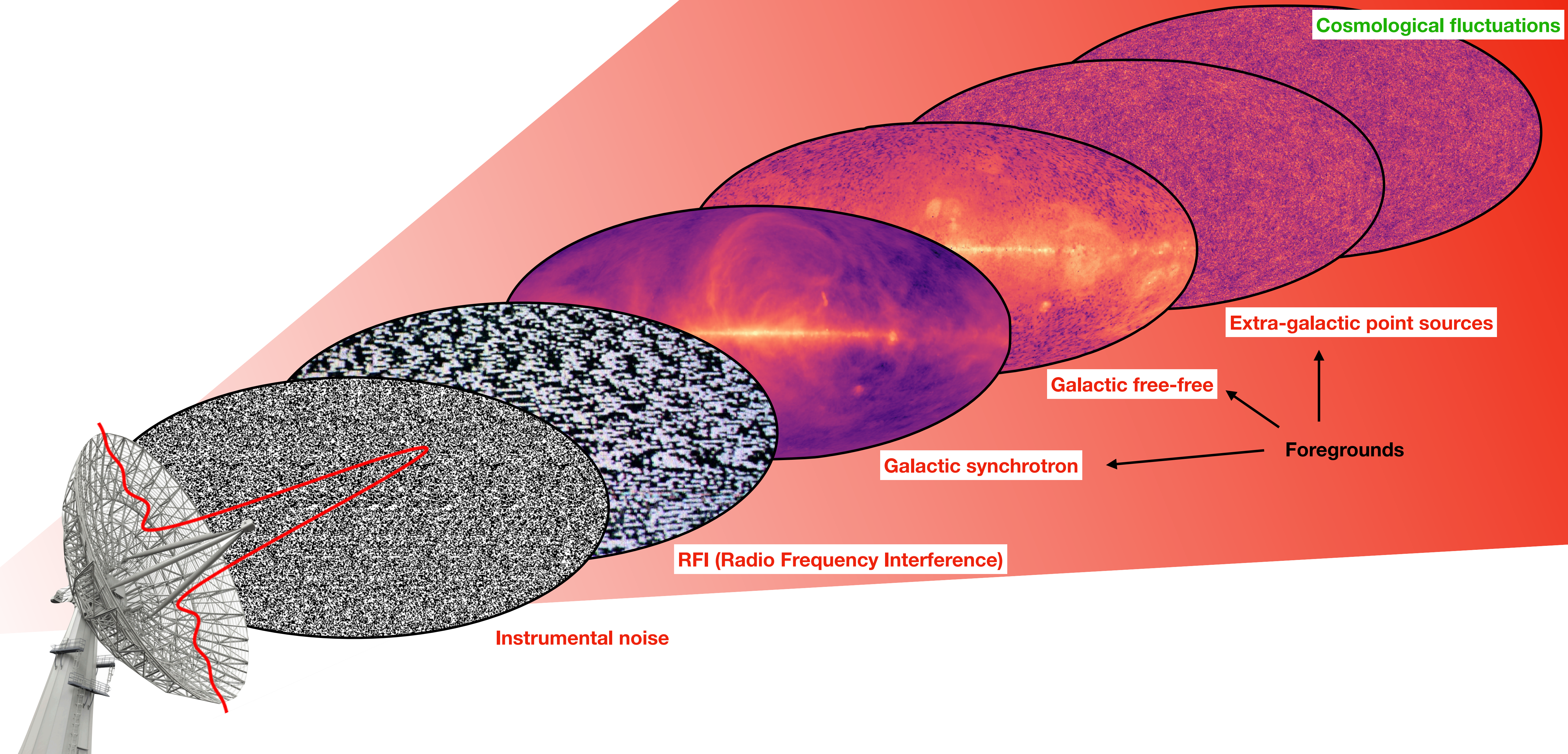
## MeerKLASS

(MeerKAT's Large Area Synoptic Survey)  
- rely on single-dish mode observations (not interferometer)

- ▶ Several pilot surveys already complete
- ▶  $\sim 10,000 \text{ deg}^2$  UHF-band survey **underway**  
(100's of observation hours already obtained)

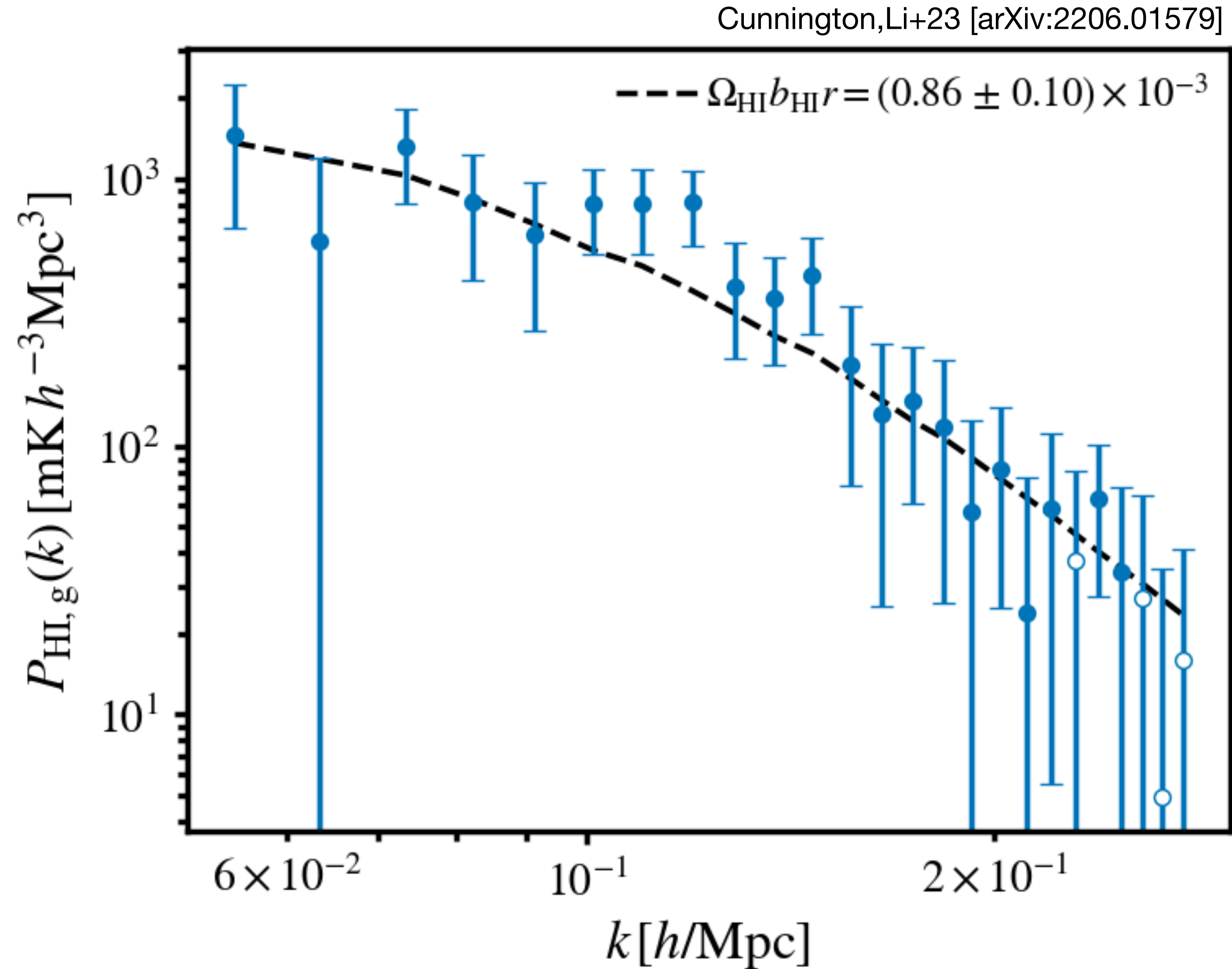
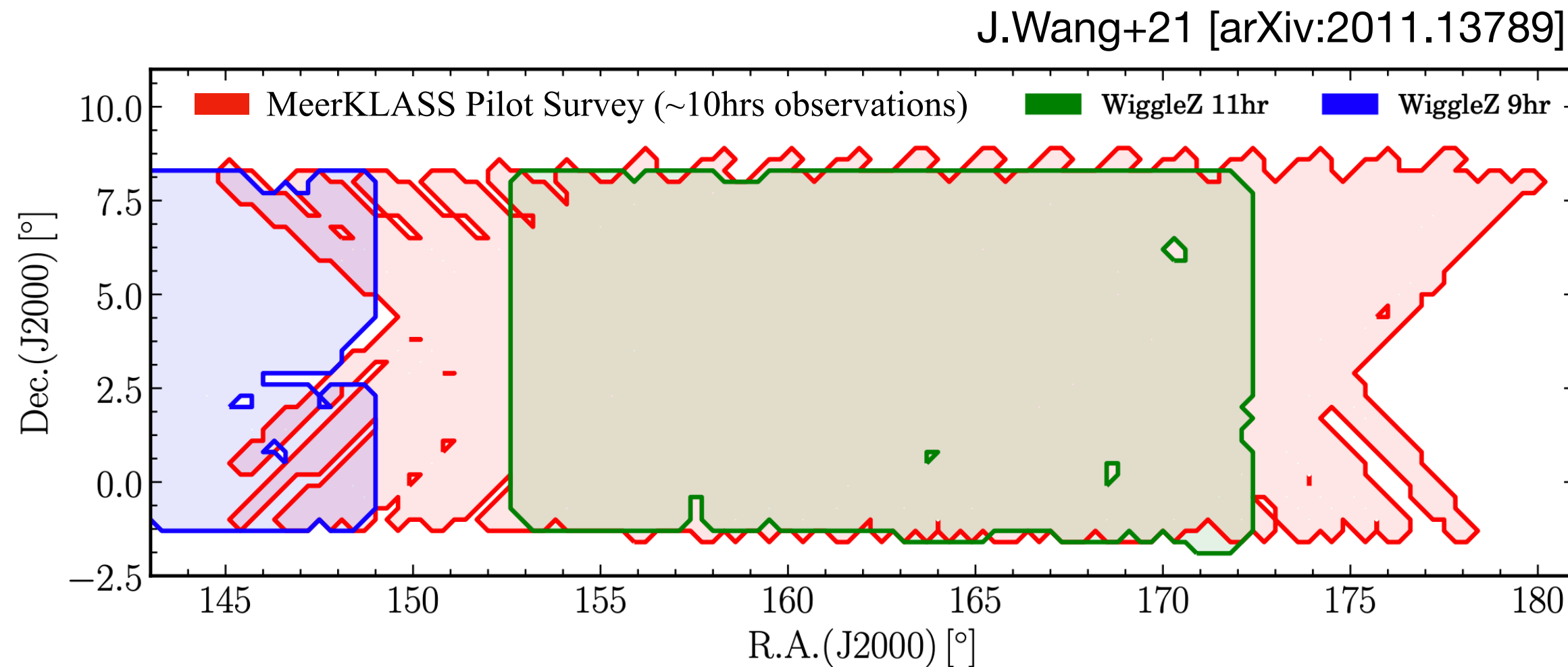


# Challenges for 21cm intensity mapping





# Detecting cosmological clustering with MeerKLASS pilot intensity mapping survey



- Positive correlation ( $7.7\sigma$ ) between galaxy survey and array of dishes in single-dish mode
- The first detection of its kind
- Important milestone for doing LSS cosmology with SKA intensity mapping

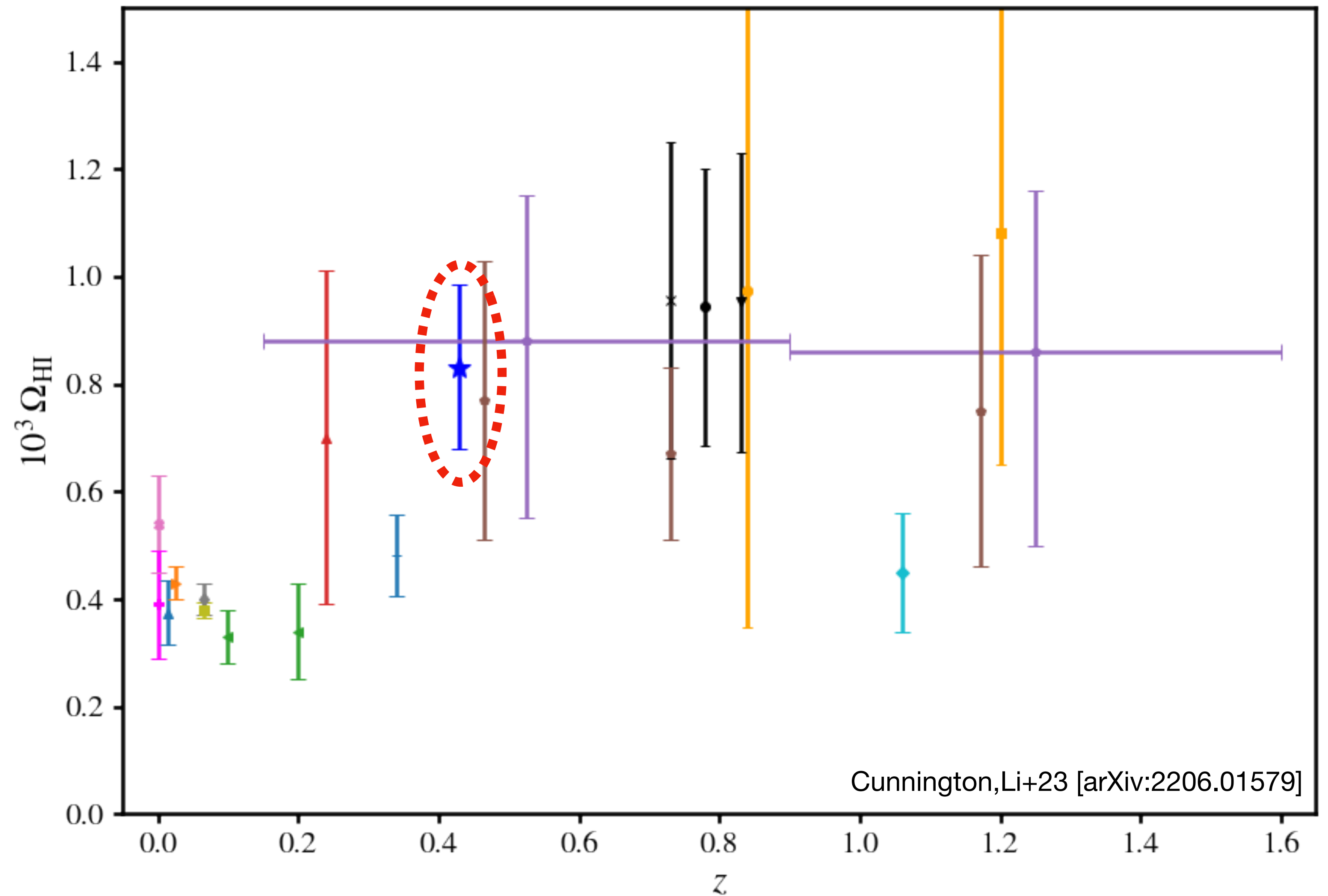
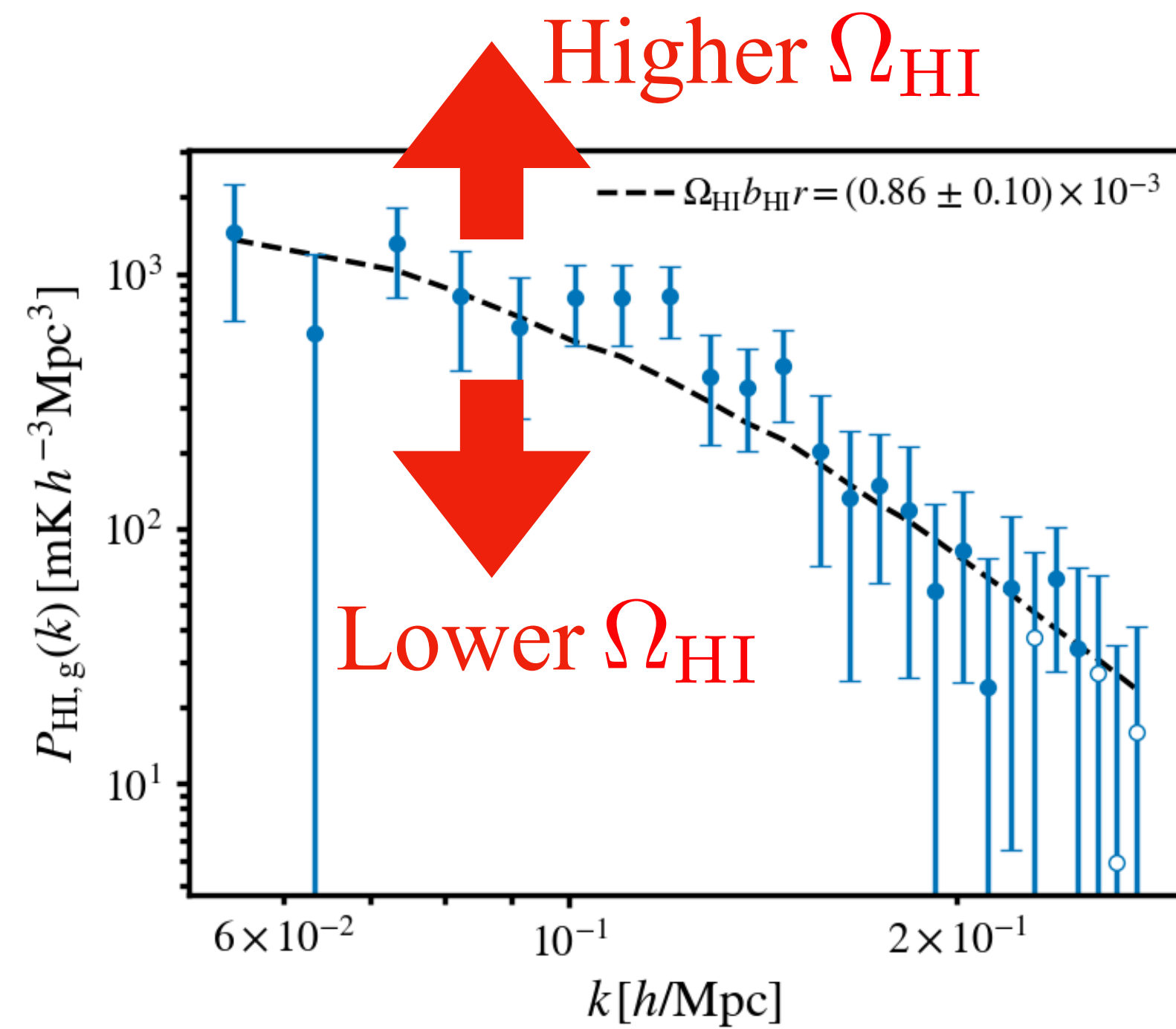
MeerKLASS

Public data releases here: [meerklass.org/data](https://meerklass.org/data)



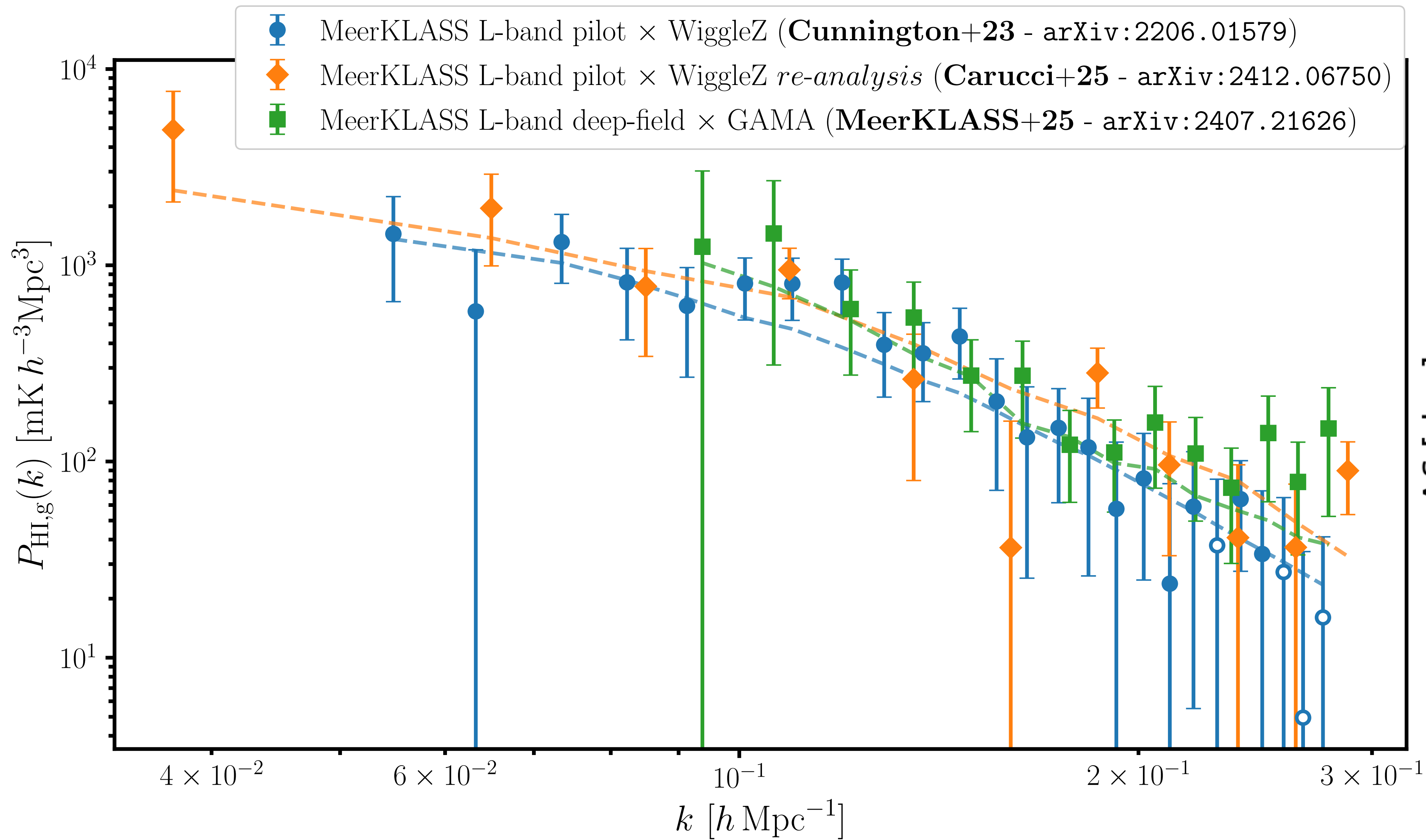
# Parameter constraints (HI *abundance*)

|                                                                                                |                                                                                                 |                                                                                            |                                                                                           |                                                                                              |                                                                                               |
|------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------|
|  MKxWiggleZ |  GBTxWiggleZ |  Zwaan  |  Lah   |  Braun    |  Chowdhury |
|  CHIMExLRG  |  GBTxLRGs    |  Martin |  Rao06 |  Hu       |  Bera      |
|  CHIMExQSO  |  GBTxELGs    |  Rhee   |  Rao17 |  Hoppmann |  Jones     |

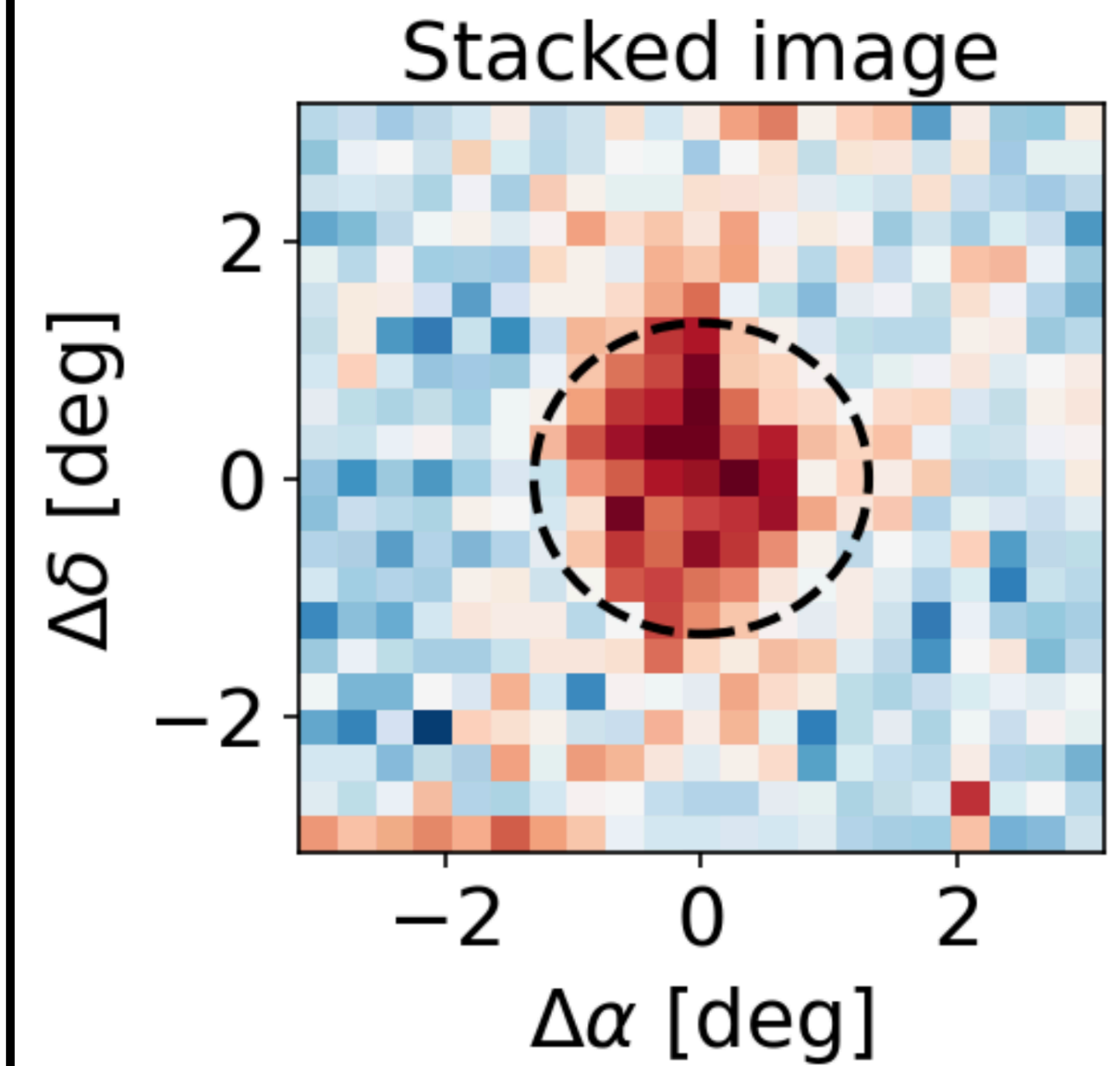




# Multiple cross-correlation detections now obtained



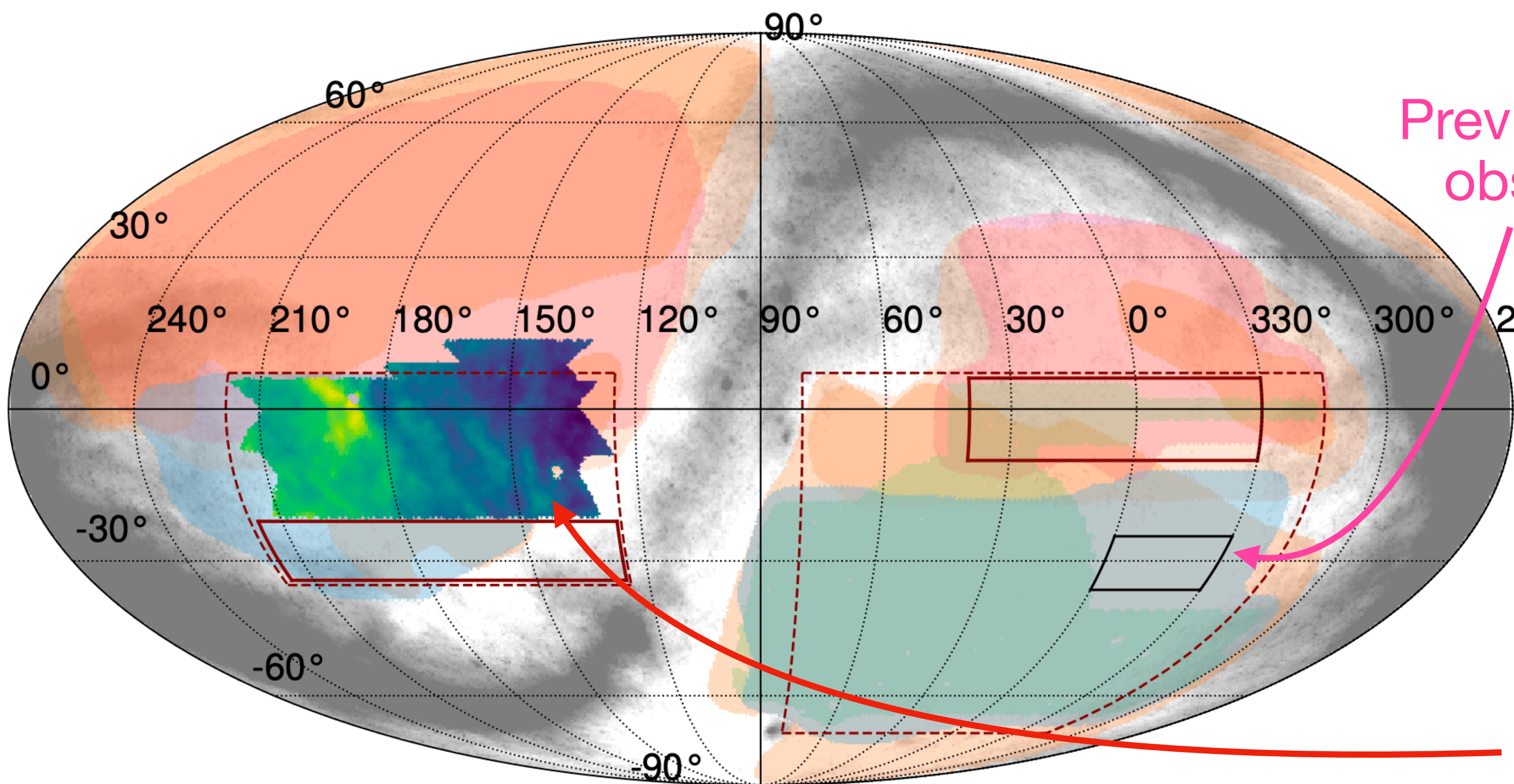
**Chen+25 (arXiv:2504.03908)**  
*stacking detection*





# Exciting times ahead...

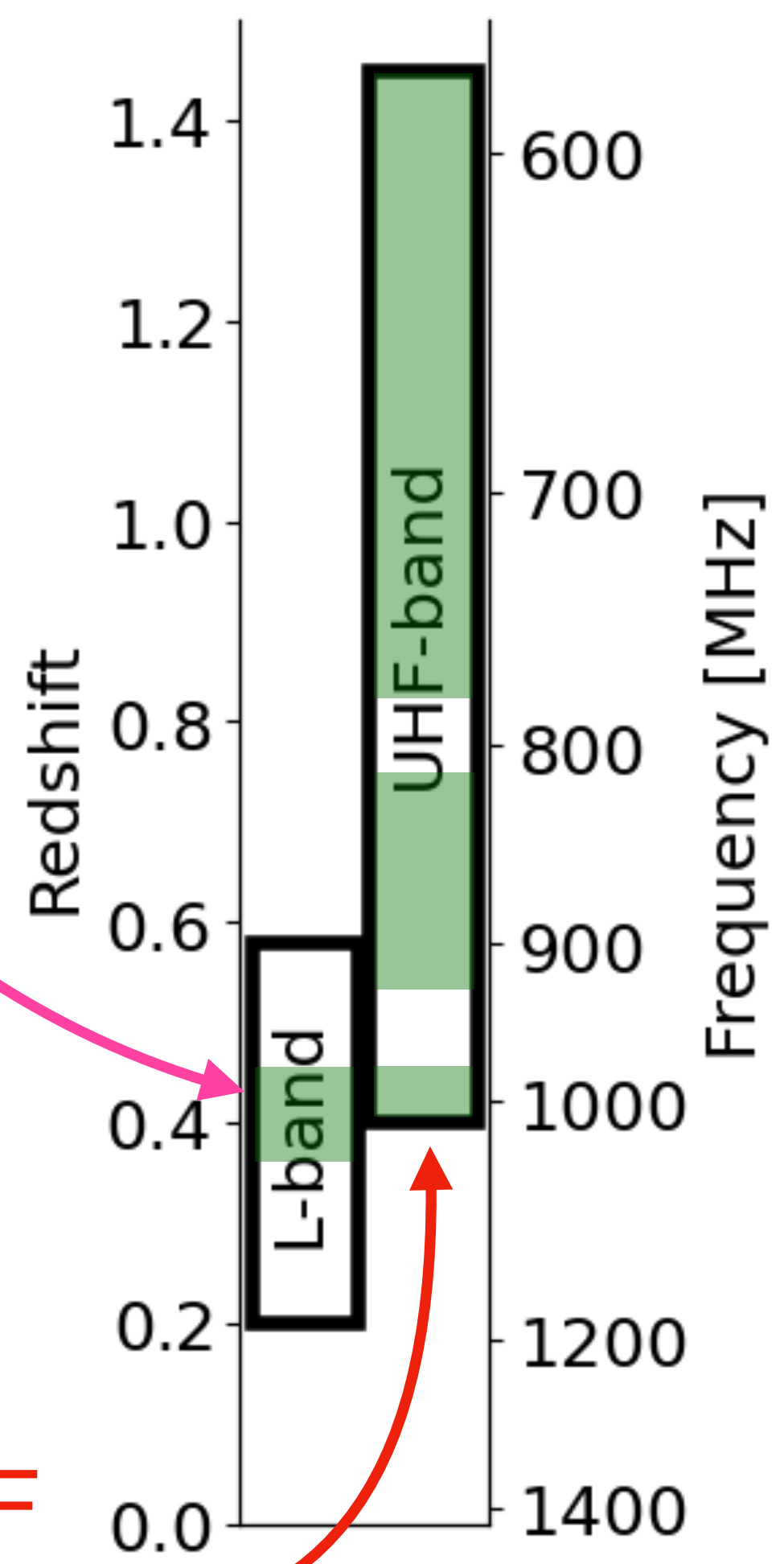
## MeerKLASS



- SDSS
- Euclid
- 4MOST
- MeerKLASS 2024-2025
- DES
- DESI
- L-band 2021
- MeerKLASS 2023-2028

Previous L-band observations

270hrs UHF observations (in 2024)



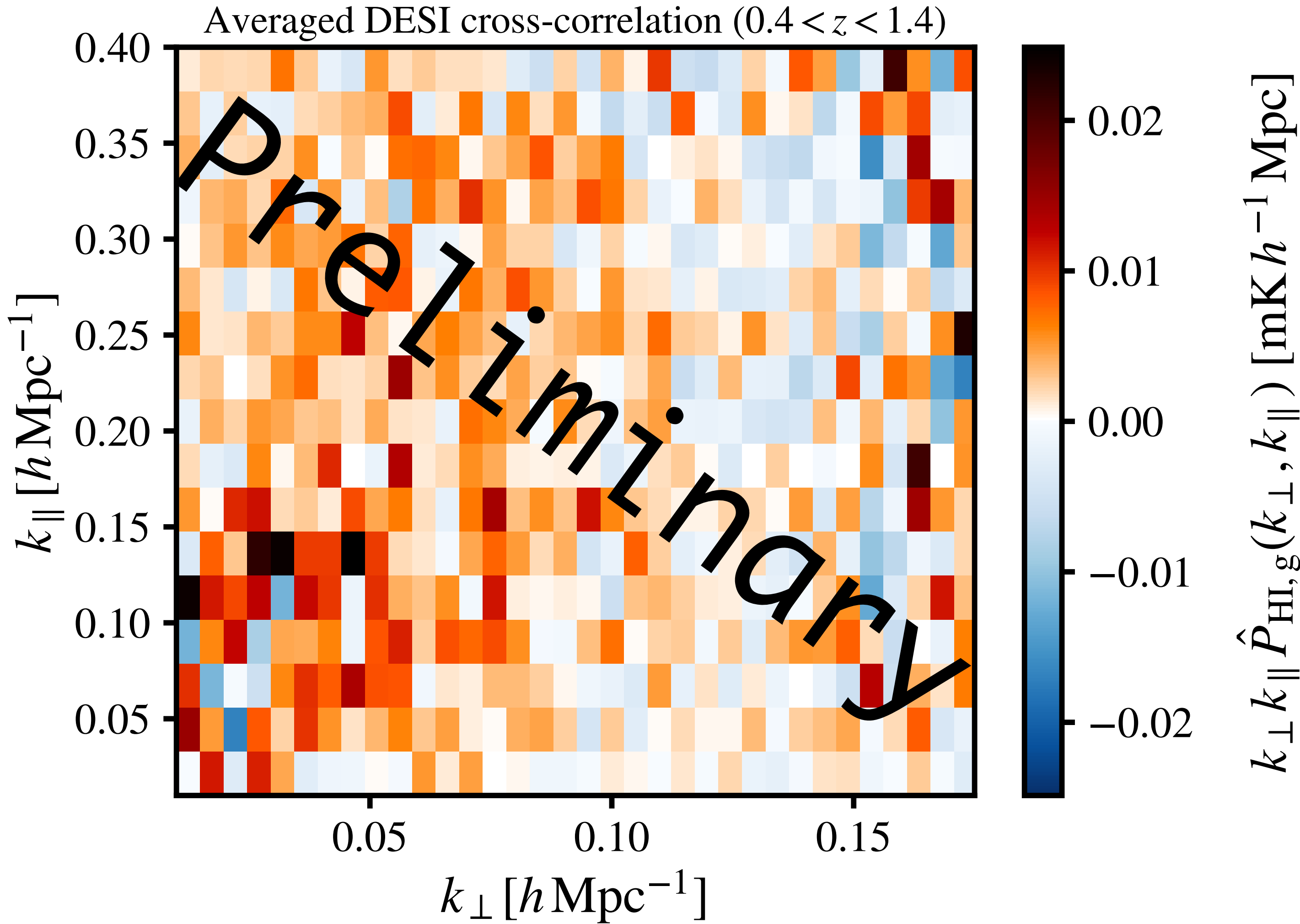
500hrs in 2025  
500hrs in 2026



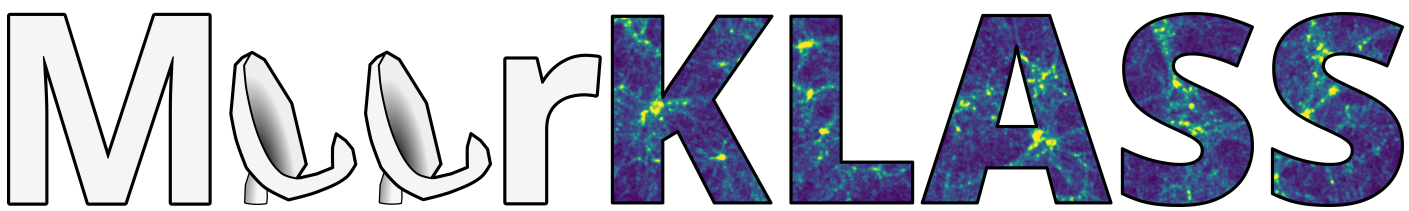
# Higher-redshift signal with MeerKLASS UHF-band

subset of UHF  
observations  
**(52.8 hours)**

cross-correlation  
with overlapping  
**DESI** galaxies



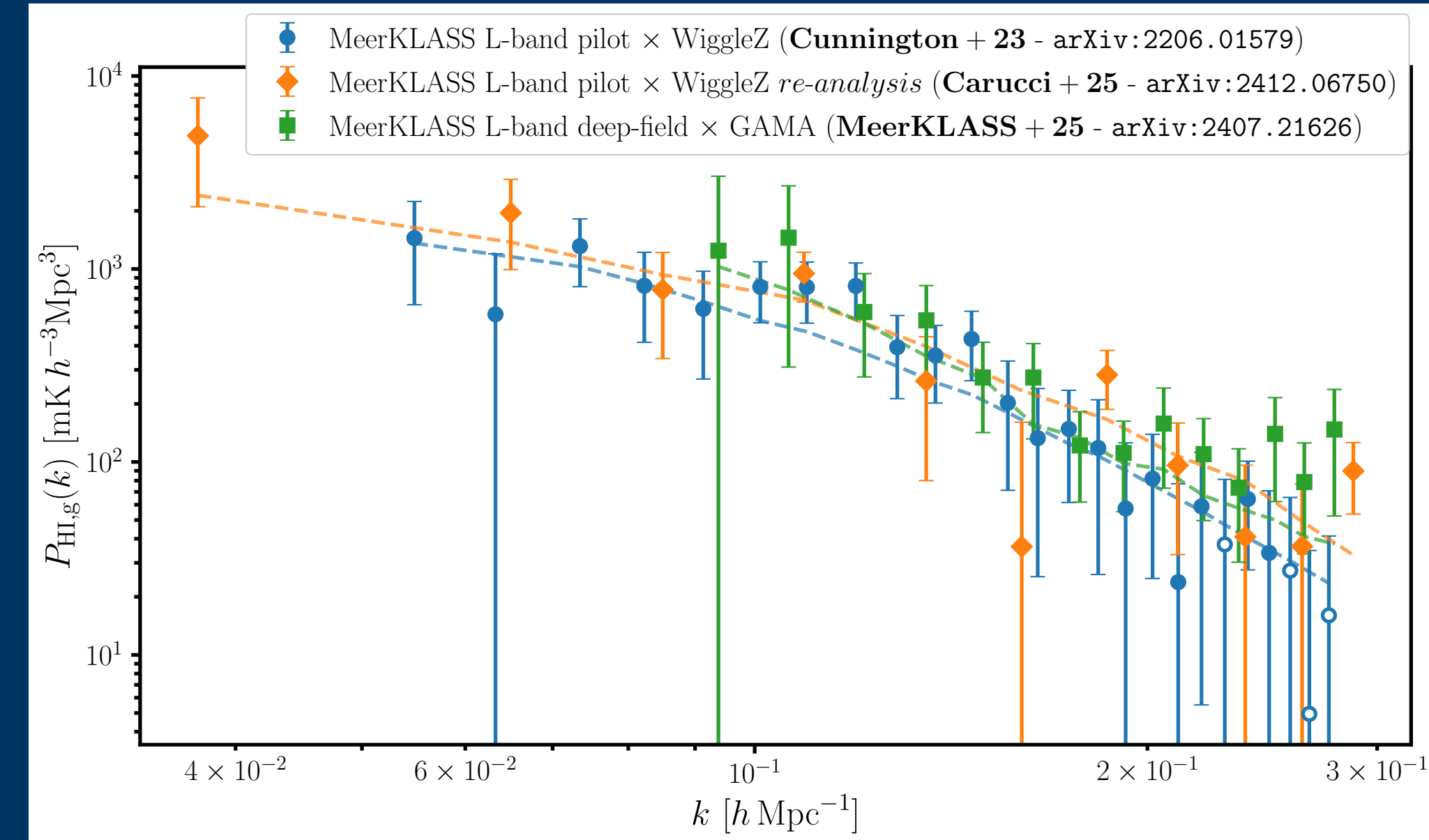
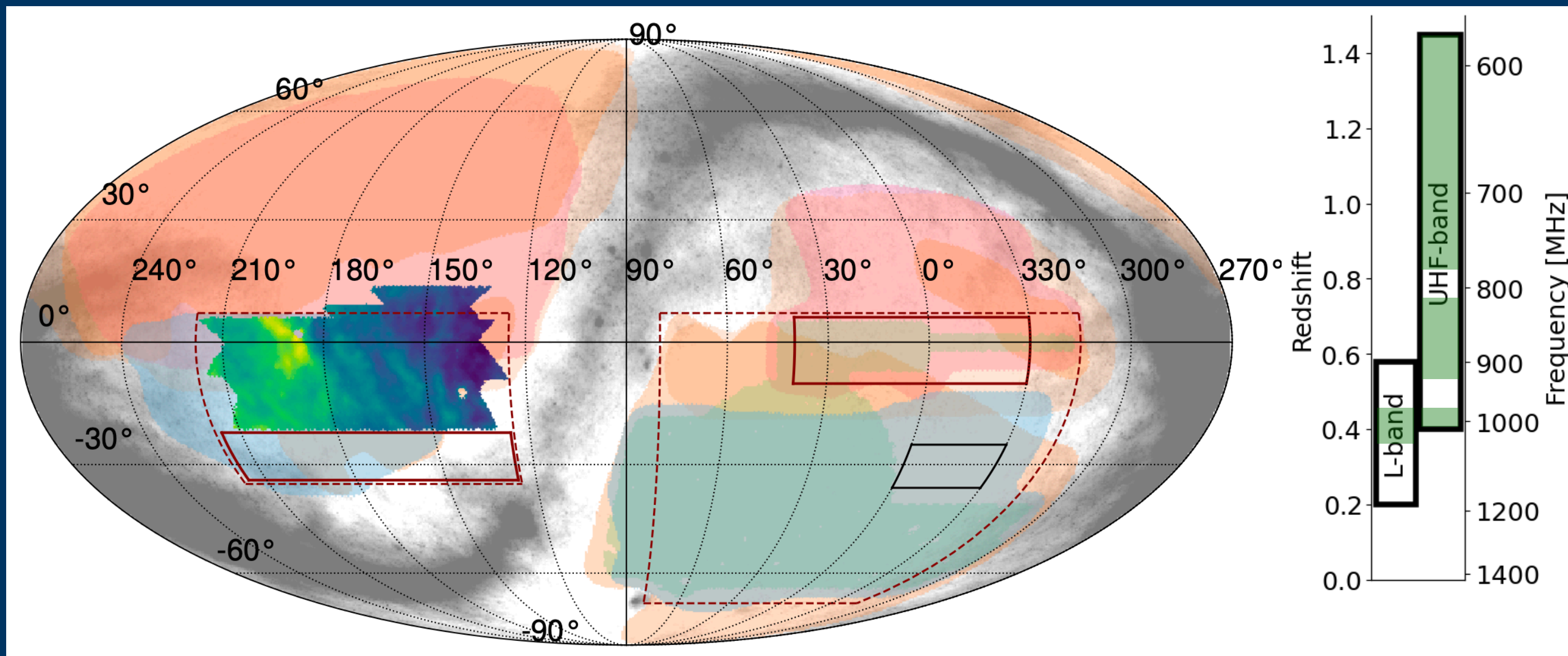
- Future Aims**
- HI constraints
  - detect BAO
  - cosmological parameter inference





# In Summary...

- Probing **ultra-large scales** can be efficiently achieved with 21cm intensity mapping
- L-band surveys with **MeerKLASS** are now consistently demonstrating this →
- UHF-band observations aiming for a **~10,000 deg<sup>2</sup>** survey are underway...



- First higher redshift ( $z < 1.4$ ) detections already made - next steps: **probe cosmology**

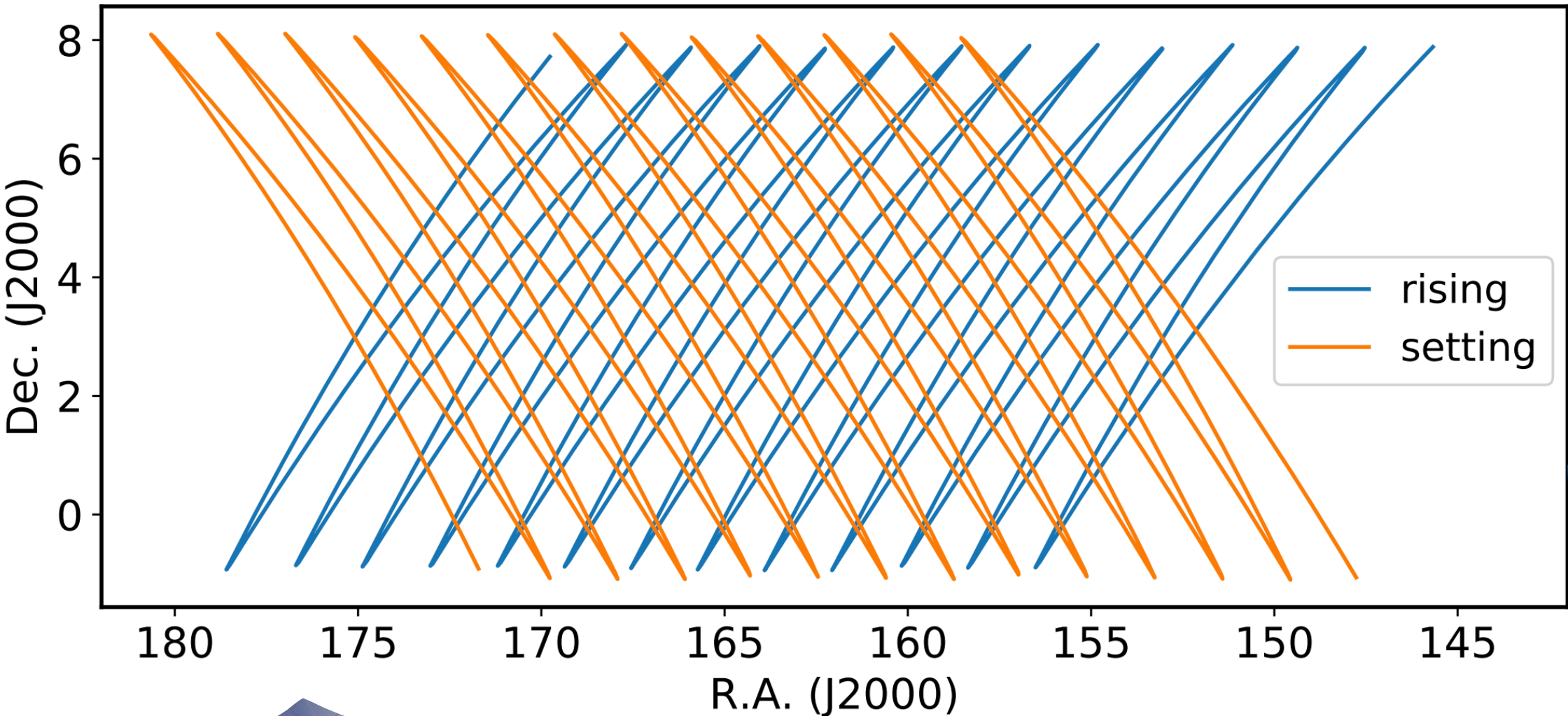
**Thank you!**



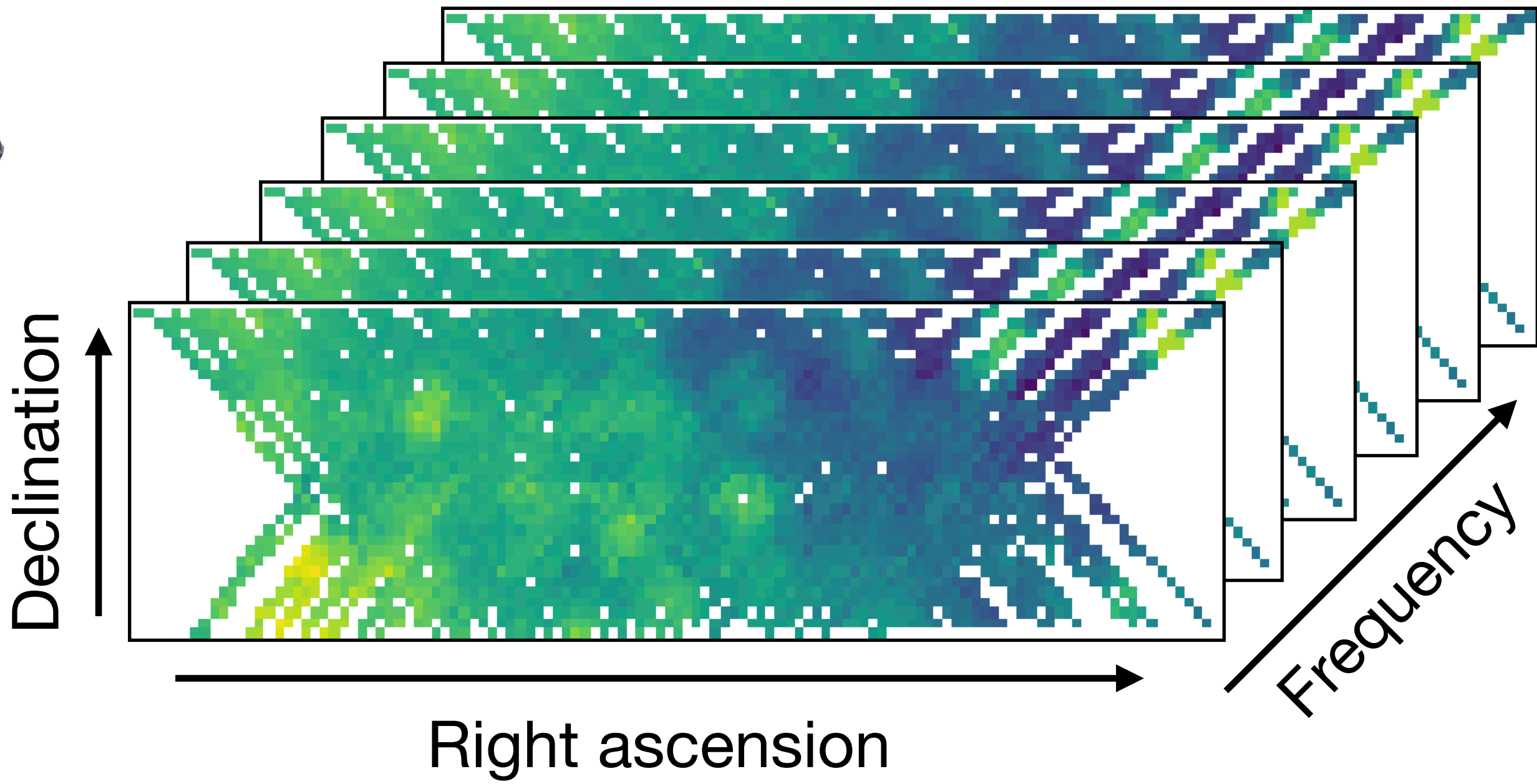
# Backup Slides



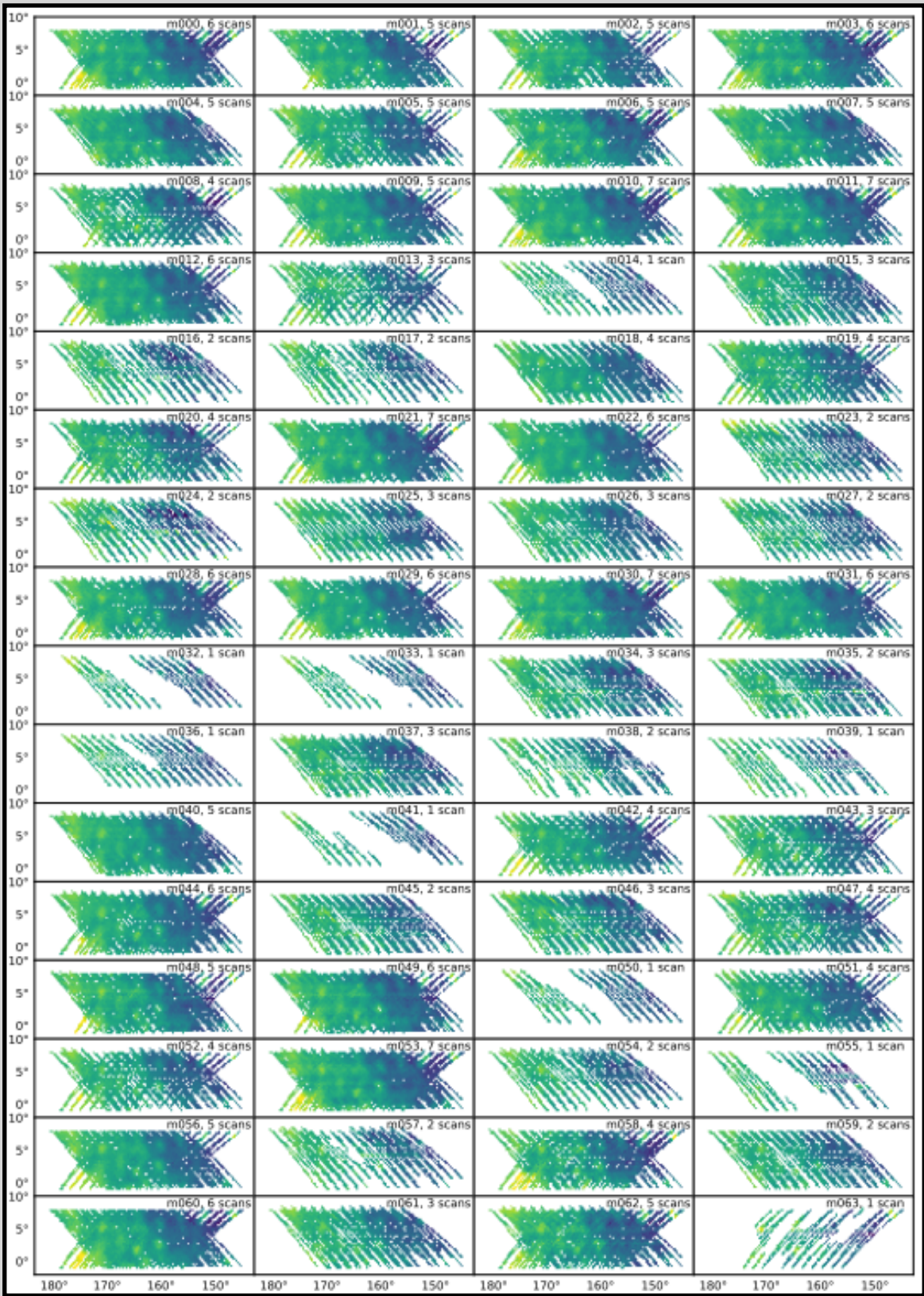
# Single-dish mode observations



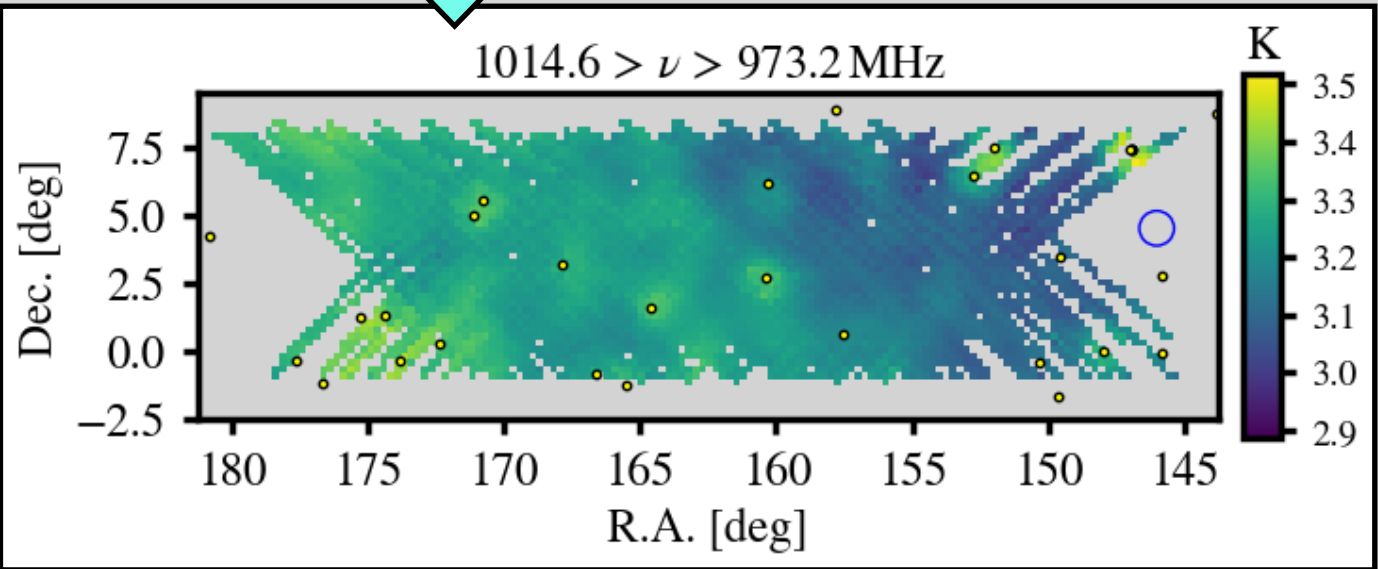
MeerKLASS pilot survey  
scanning strategy  
Wang+21  
[arXiv:2011.13789]



Map obtained  
for every dish

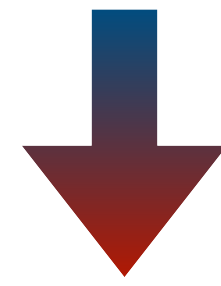


averaged





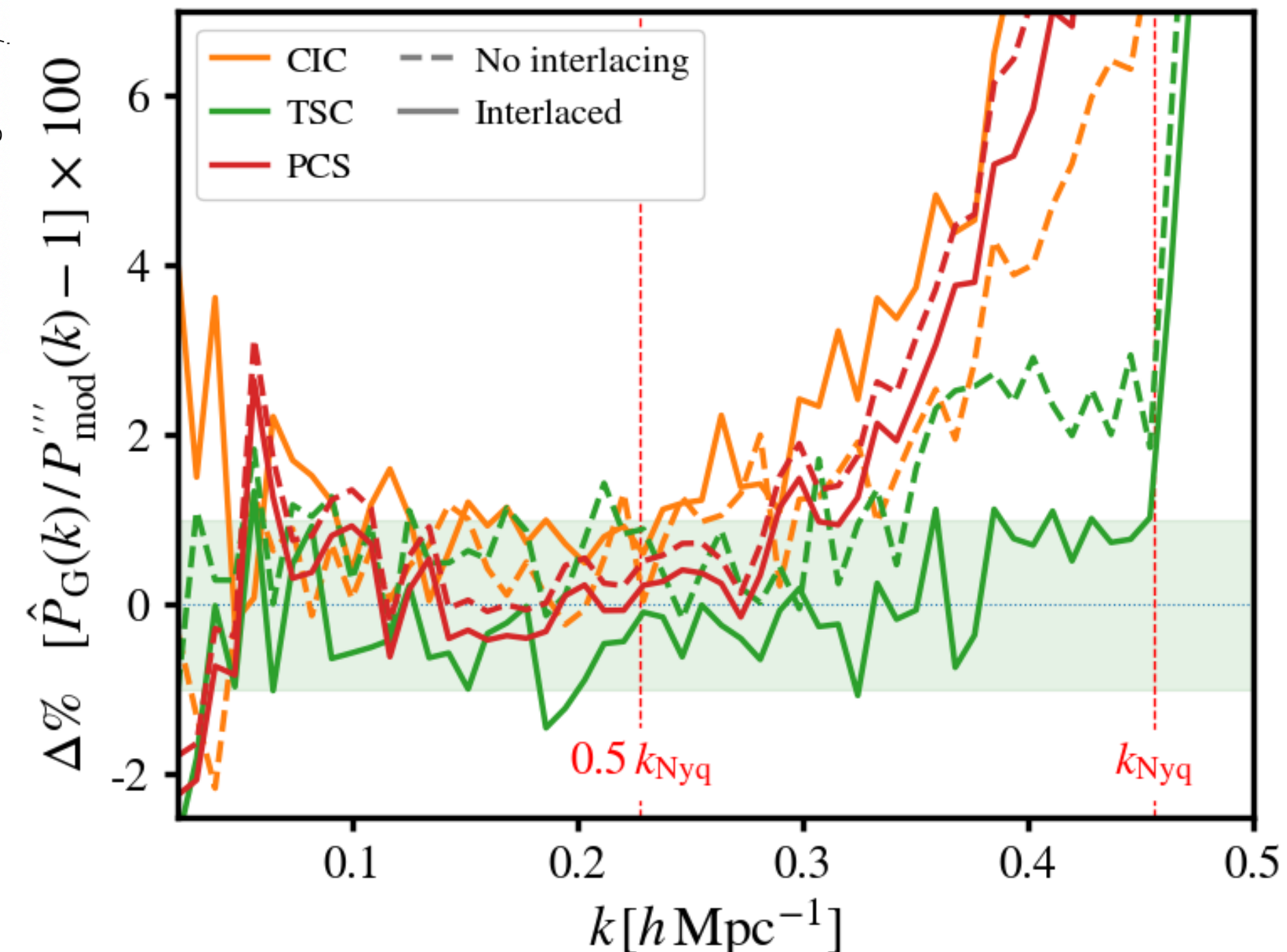
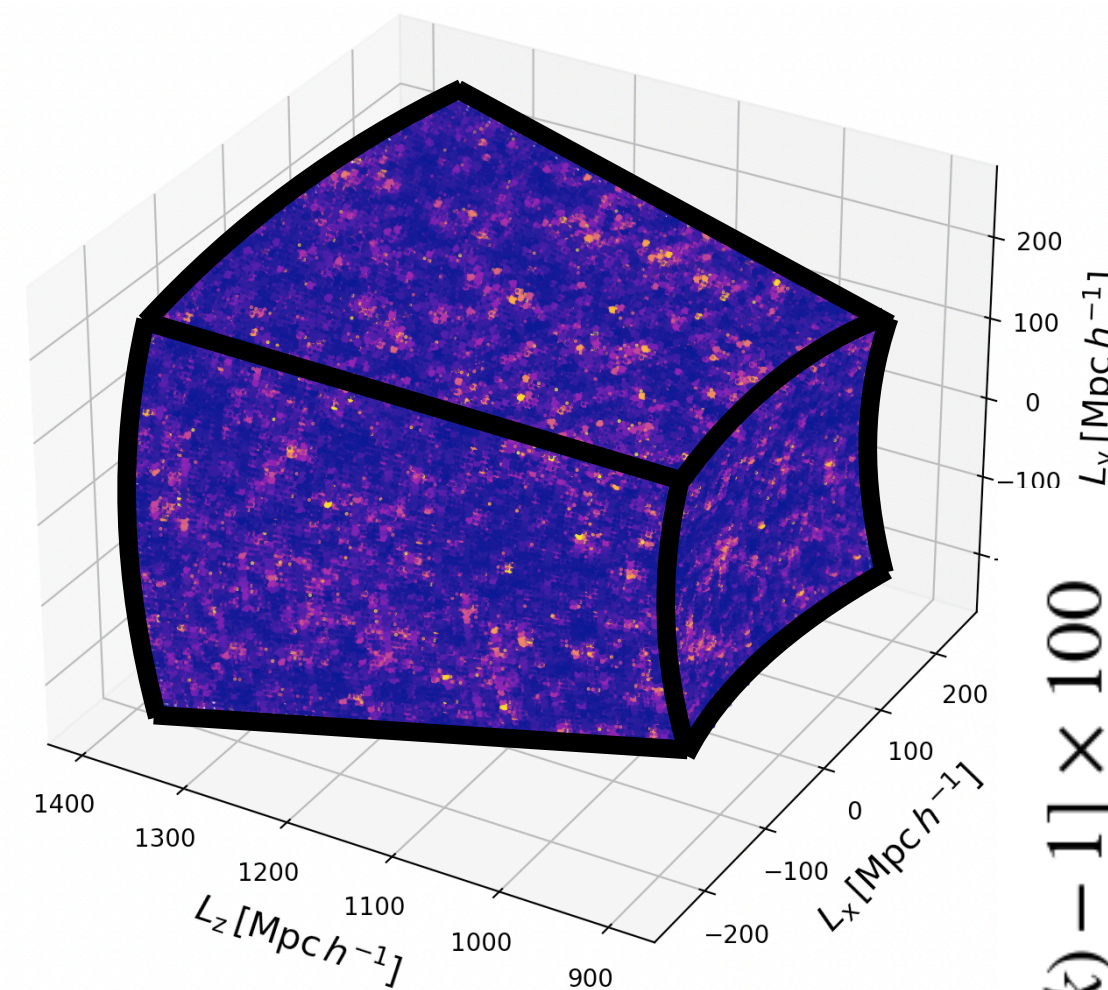
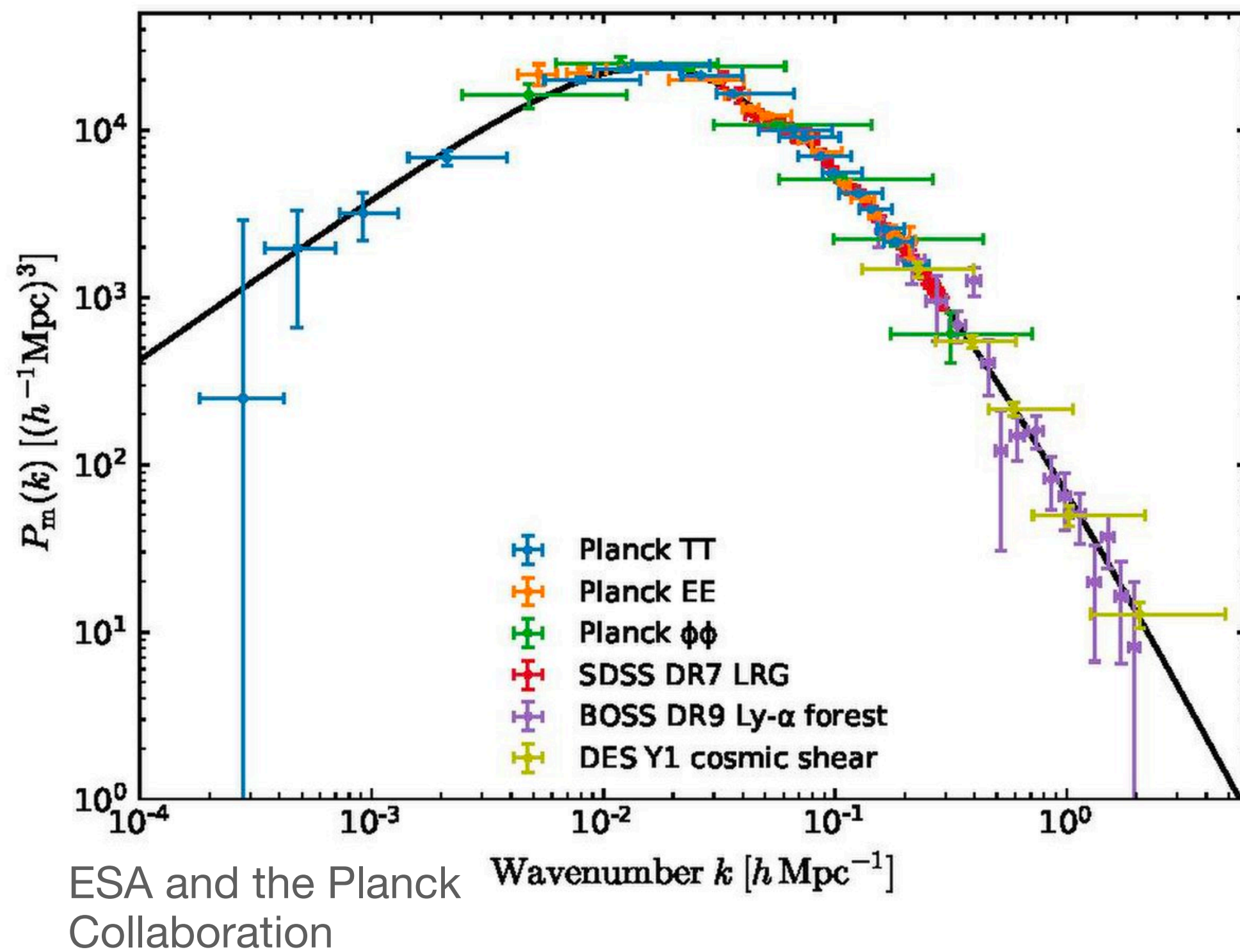
# Observations on the sky



3D **Fourier-space** clustering analysis  
require observations in **Cartesian**  
*comoving* (Mpc/h) space

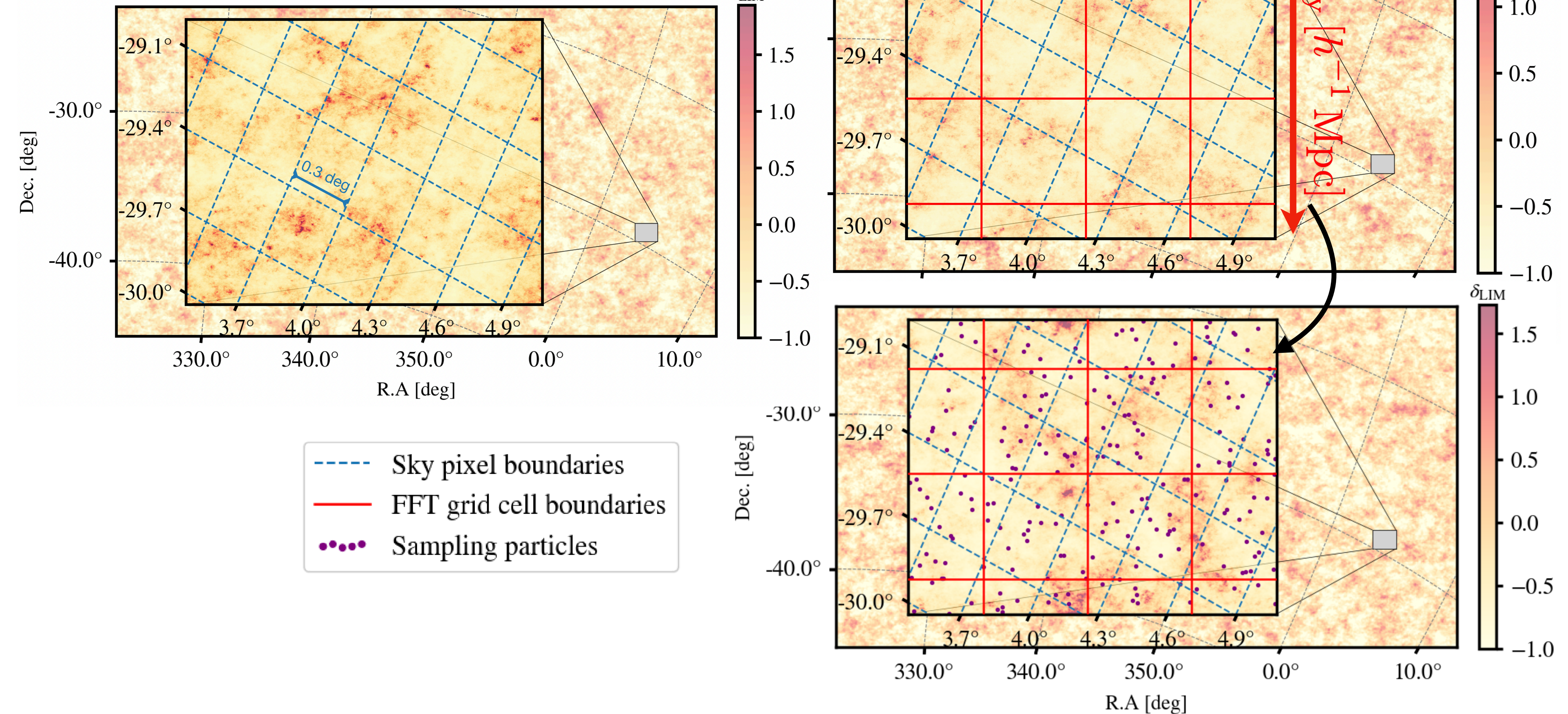
➔ Require transformation  
of voxel intensities

## Analysis in Cartesian space



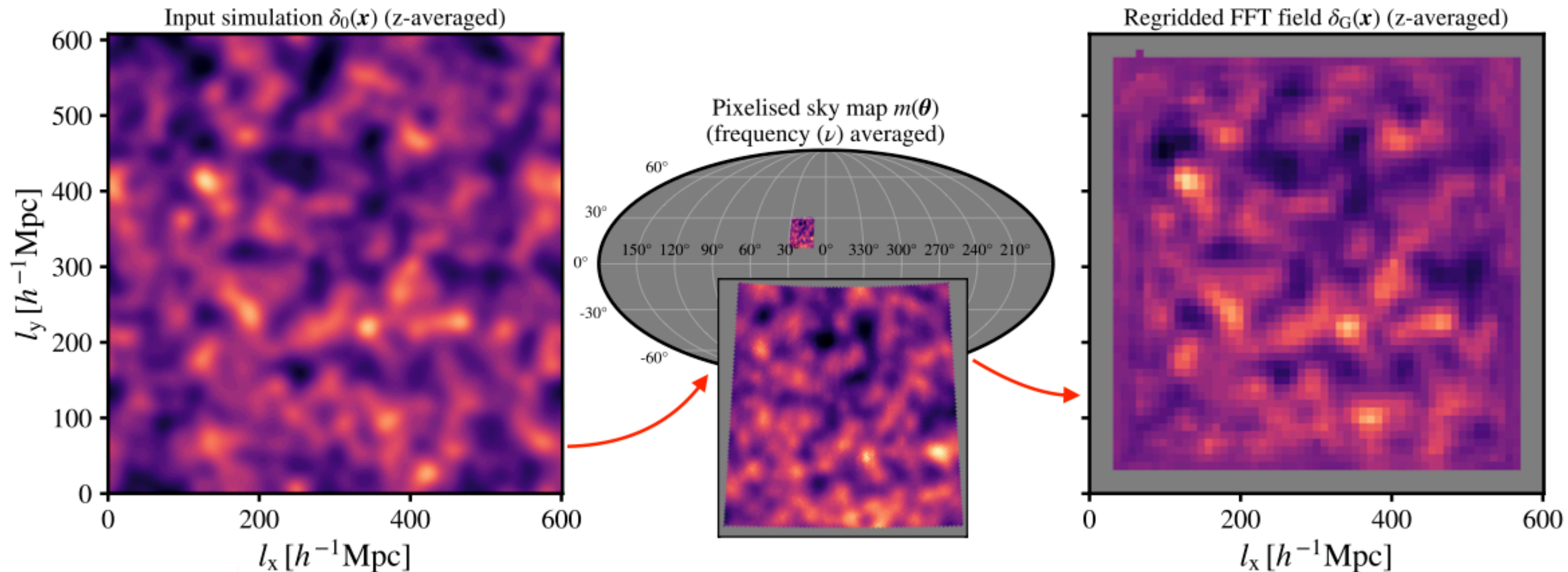


# Monte Carlo sampling to a Cartesian grid





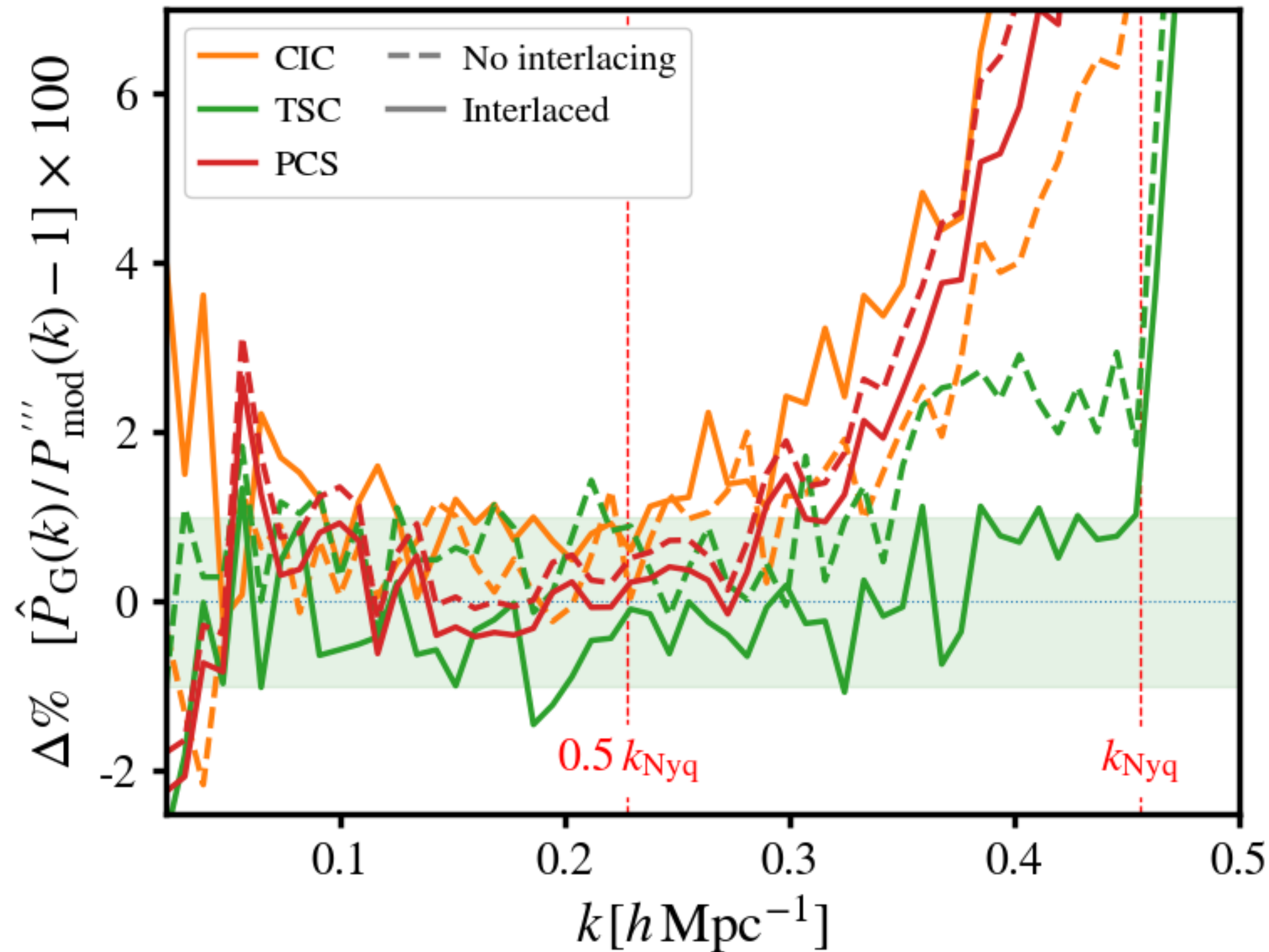
# Testing regridding pipeline with simulations



→ <https://github.com/stevecunnington/gridimp>



# Mitigating regridding effects with modelling and higher-order *mass* assignment



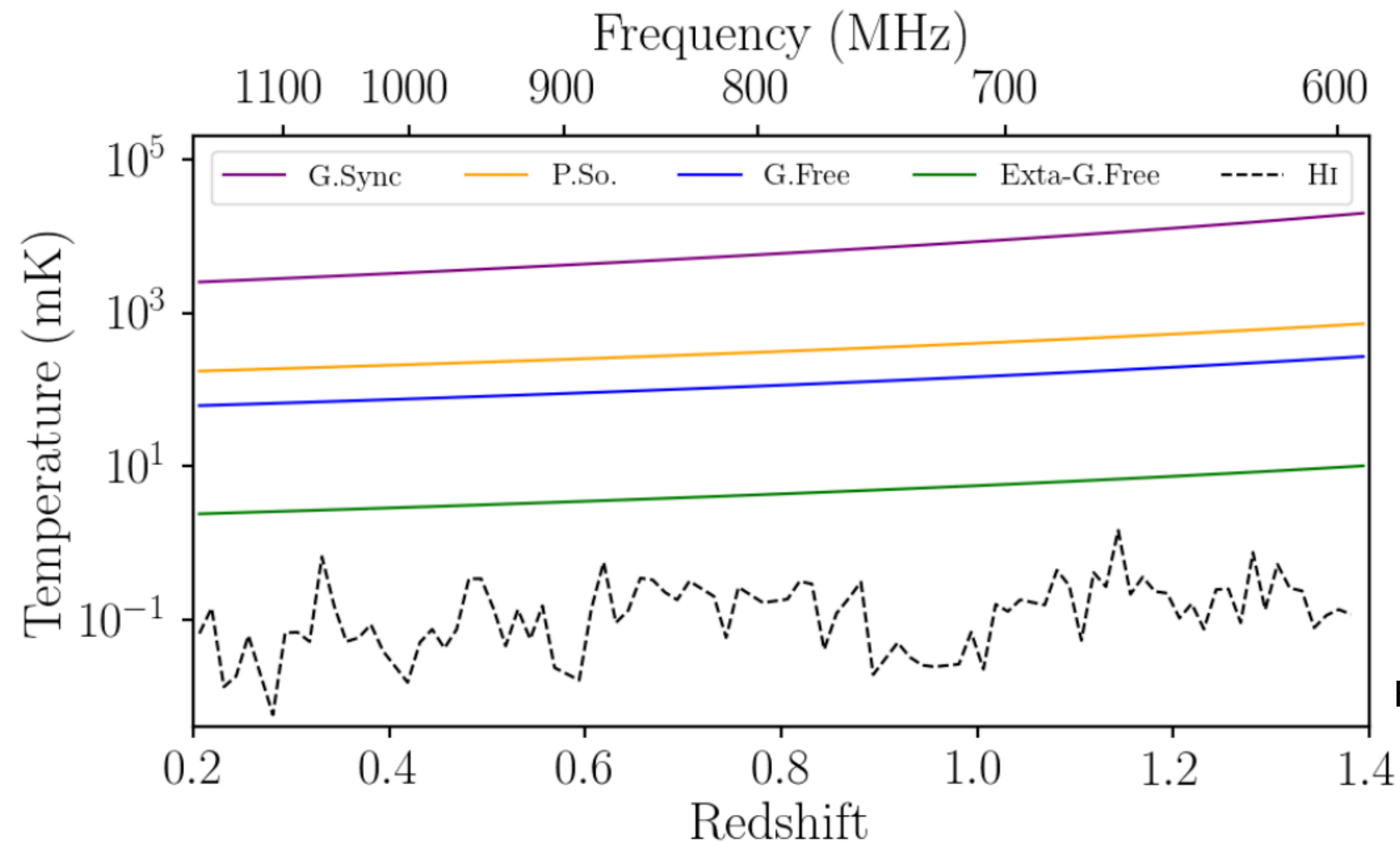
## Results include:

- modelling power damping from HEALPix pixelisation
- modelling power damping from frequency channels
- higher-order mass-assignment to test suppression of **aliasing**

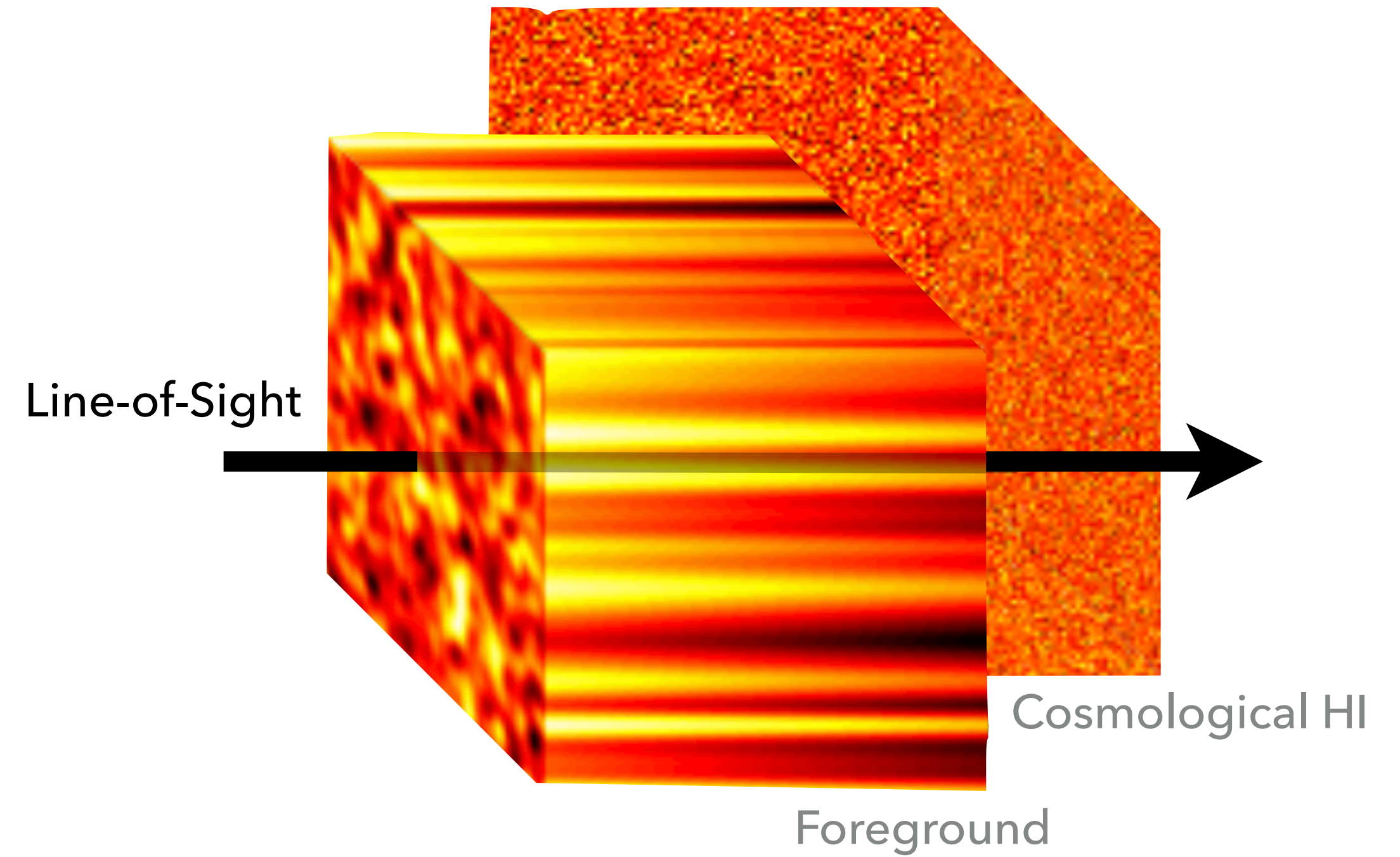


# Foreground cleaning MeerKAT HI intensity maps

## Idealised simulation demo:



From S.Cunnington+19 [arXiv:1904.01479]

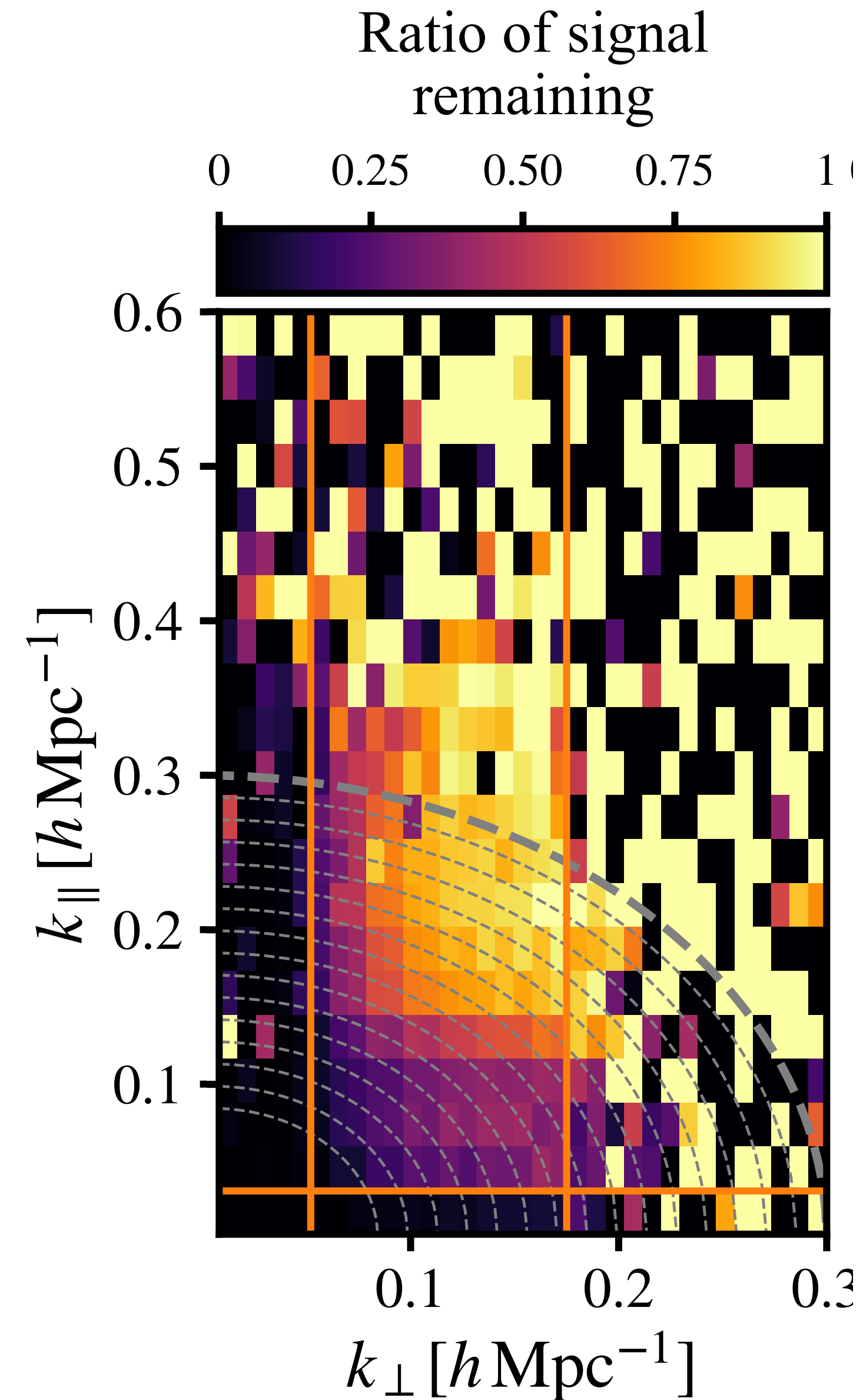
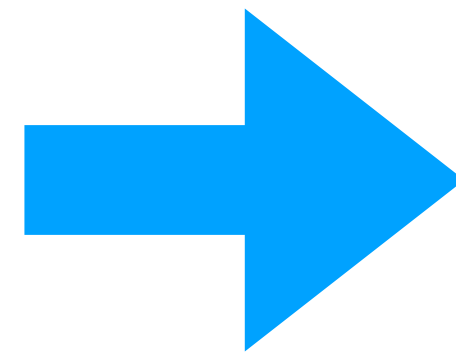


- We utilise smooth foreground spectra to distinguish them from cosmological signal



# How much (HI) signal is lost in foreground cleaning?

Inject mocks into  
real observational  
data and clean to  
**estimate signal loss**





# Testing signal loss reconstruction with simulations

Constructing a foreground cleaning transfer function for signal reconstruction:

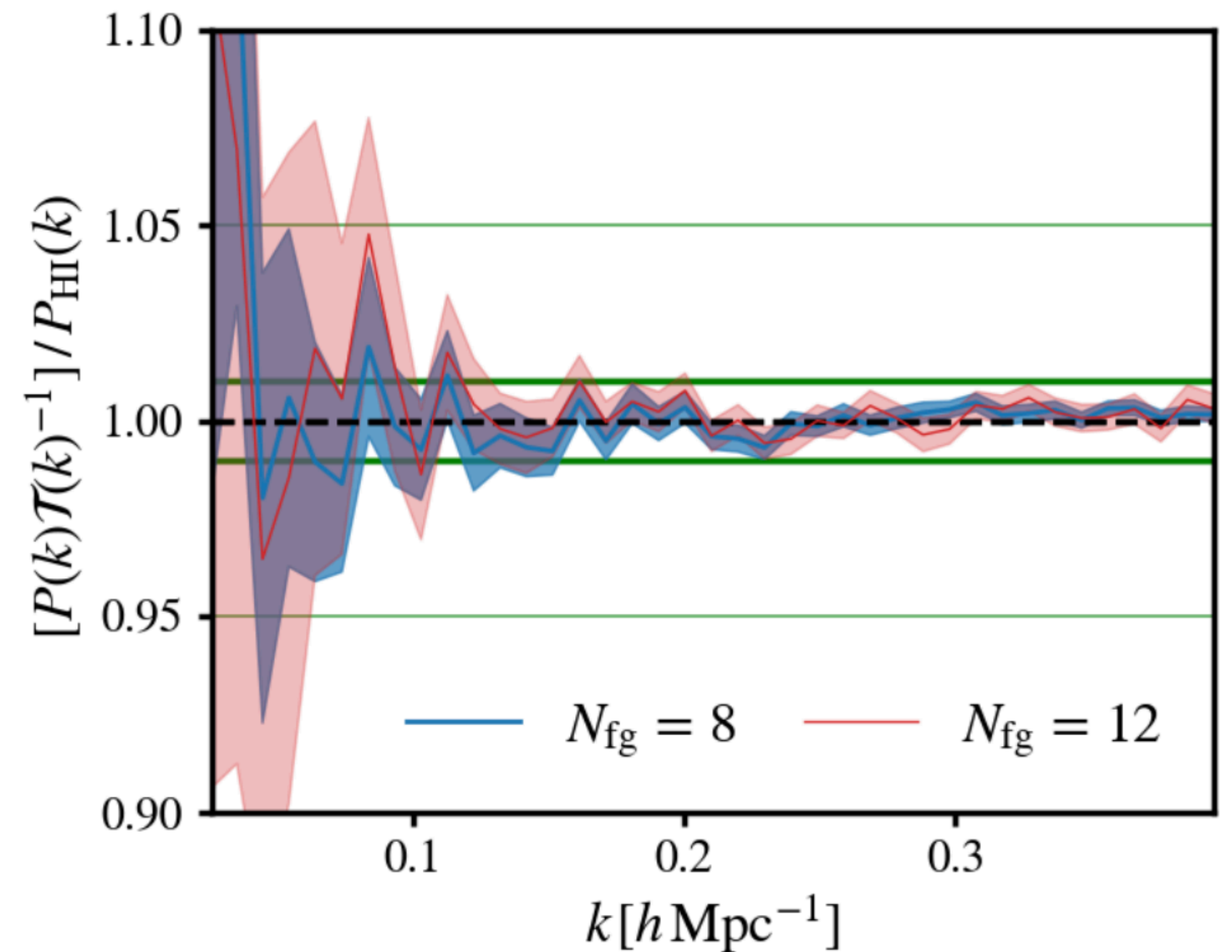
Inject mocks into real  
observational data and clean:

$$\mathbf{X}_{\text{clean}}^{\text{m}} = \mathbf{X}_{\text{f+s+m}} - \mathbf{U}_{\text{f+s+m}} \mathbf{S} \mathbf{U}_{\text{f+s+m}}^{\text{T}} \mathbf{X}_{\text{f+s+m}}$$

“Cleaned” mock      Uncleaned (original) mock

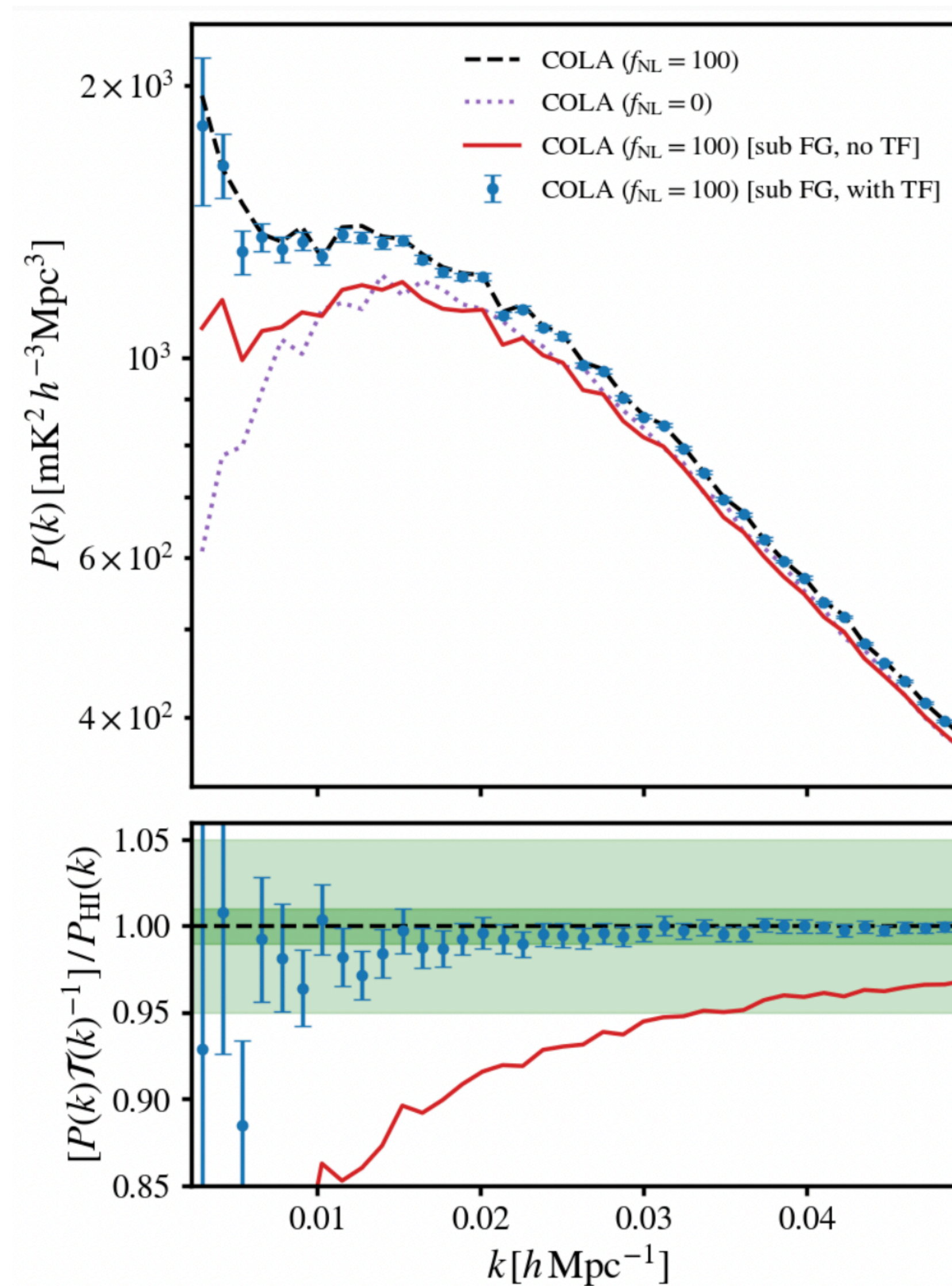
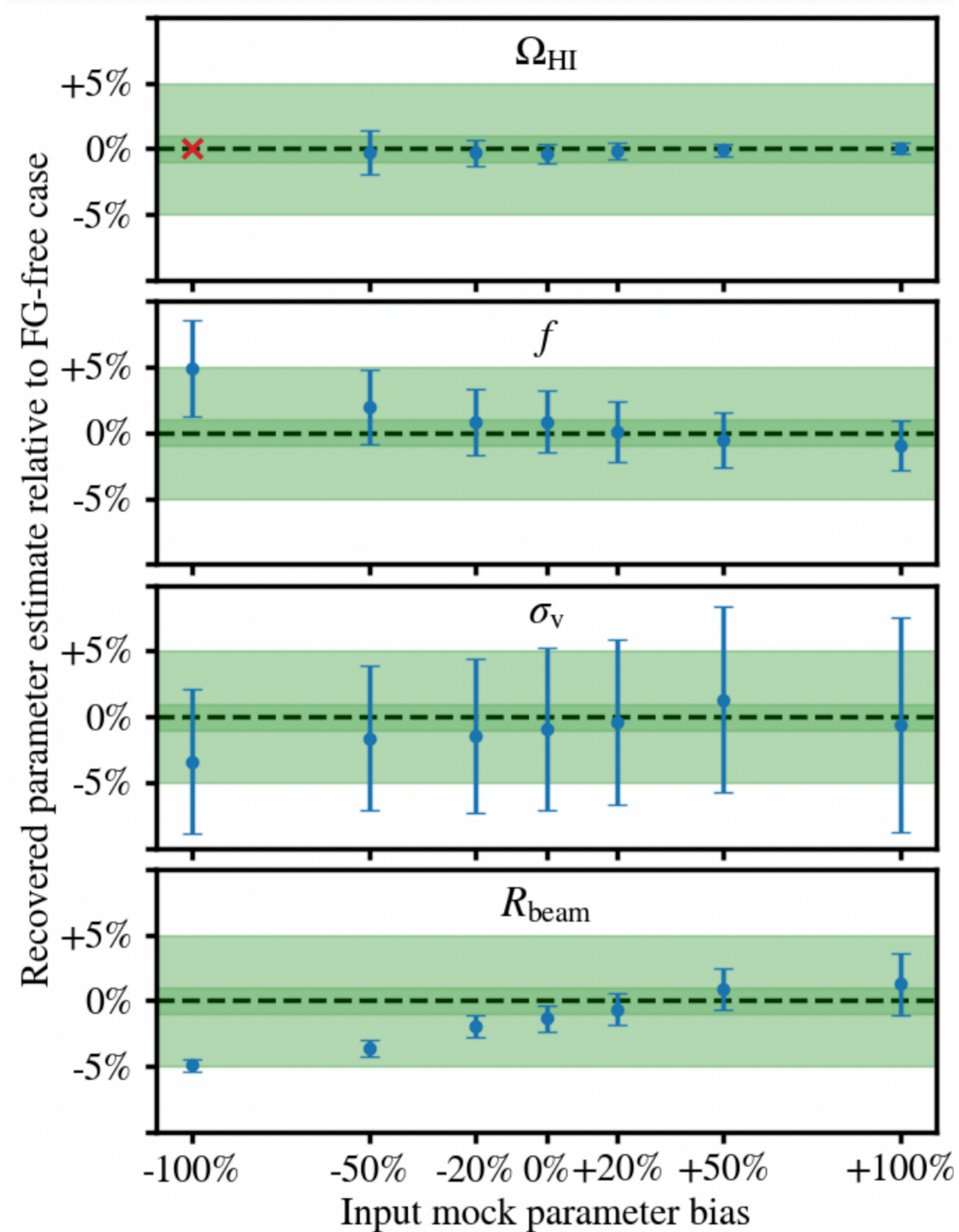
$$\mathcal{T}(k) = \left\langle \frac{\mathcal{P}(\mathbf{X}_{\text{clean}}^{\text{m}}, \mathbf{X}_{\text{m}})}{\mathcal{P}(\mathbf{X}_{\text{m}}, \mathbf{X}_{\text{m}})} \right\rangle$$

$$P_{\text{corrected}}(k) = P_{\text{cleaned}}(k) / \mathcal{T}(k)$$





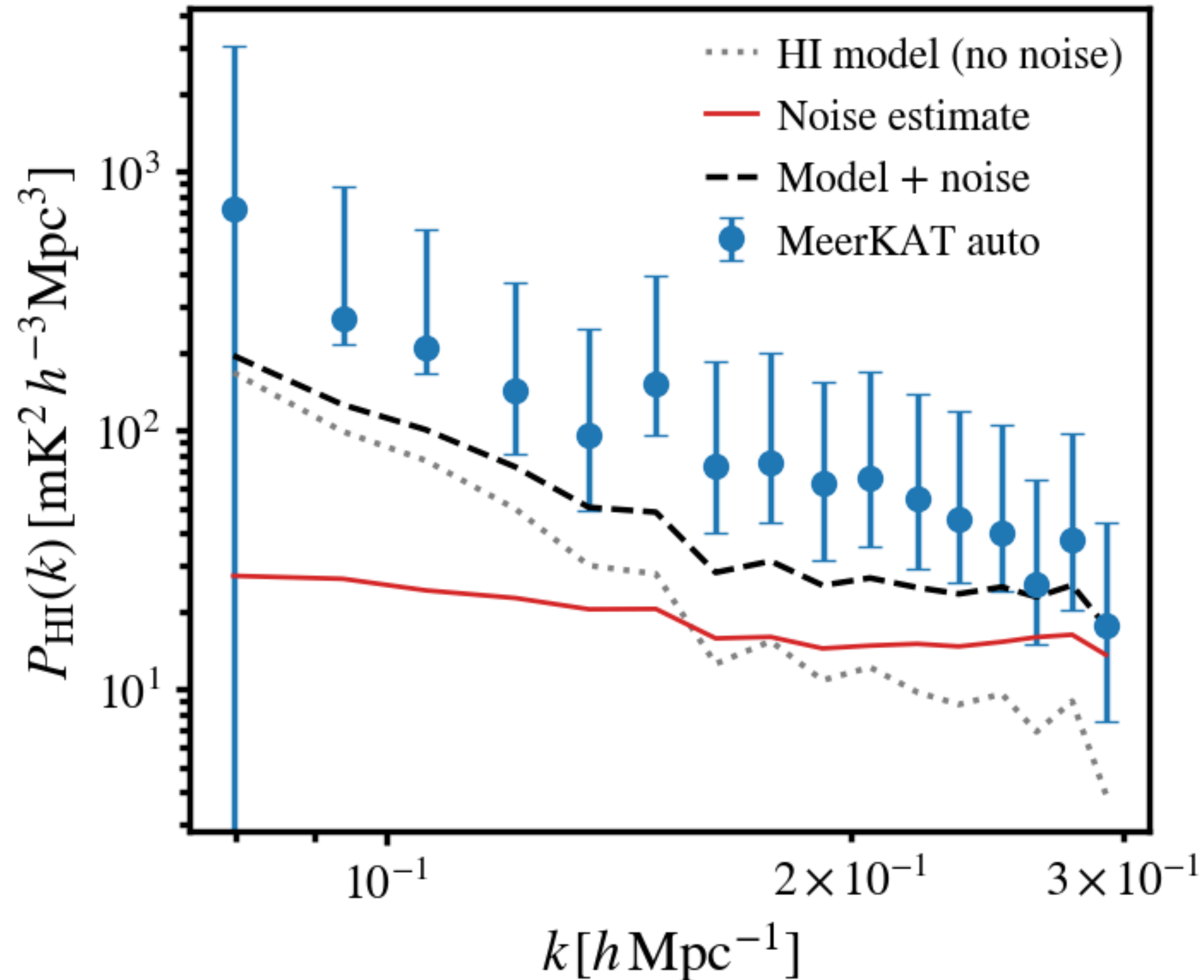
# Foreground cleaning signal loss reconstruction for precision cosmology





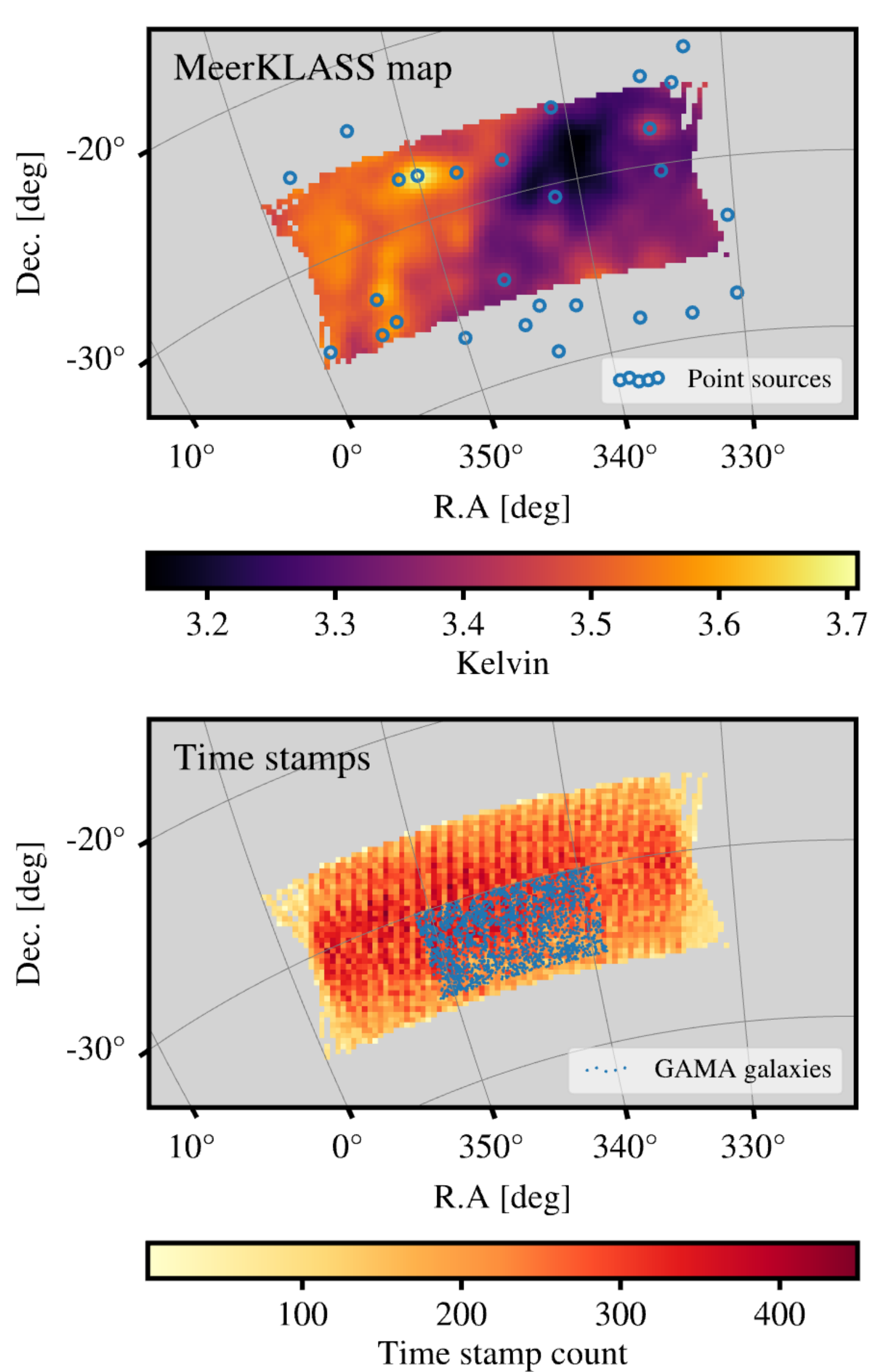
# HI auto power spectrum MeerKLASS L-band *deep-field*

“lowest upper-limit”...





# Results from MeerKLASS deep-field



Cross-correlation with small field of GAMA galaxies

