FAST HI Intensity Mapping Survey

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21 cm Cosmology Workshop 2024 & Tianlai Collaboration Meeting

July 21st, 2024, Hangzhou, P. R. China

HI Intensity mapping

Cross-correlation function with GBT HIIM x DEEP2
T.-C. Chang et al. 2010 Nature Vol 466

GBT Auto PS
Switzer E. R., et al., 2013, MNRAS, 434, L46.

Cross PS GBT HIIM x WiggleZ
K. Masui et al 2013 ApJ 763L 20M

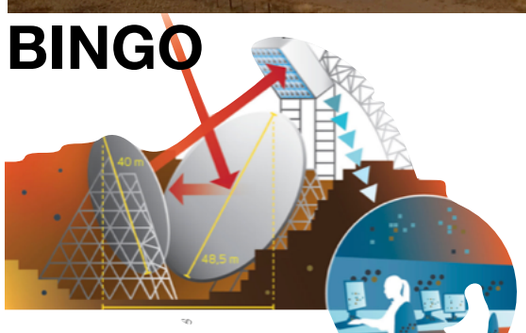
MIGHTEE Auto PS
Paul S., et al., 2023, arXiv:2301.11943

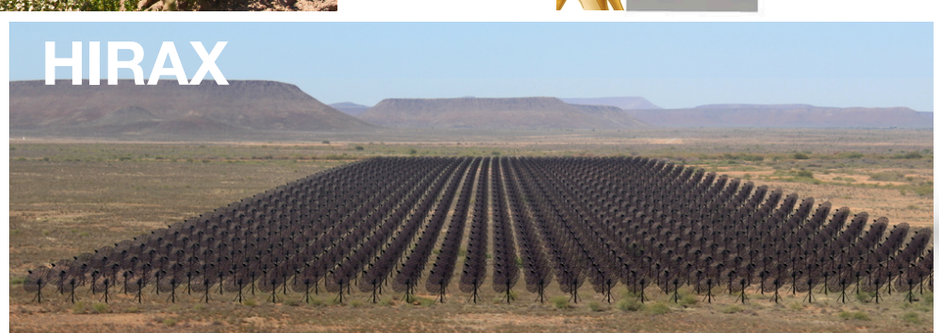
Cross PS PKS x 2dF
C. Anderson, N. J. Luciw, Y. Li et, al 2018, MNRAS, 476, 3382.

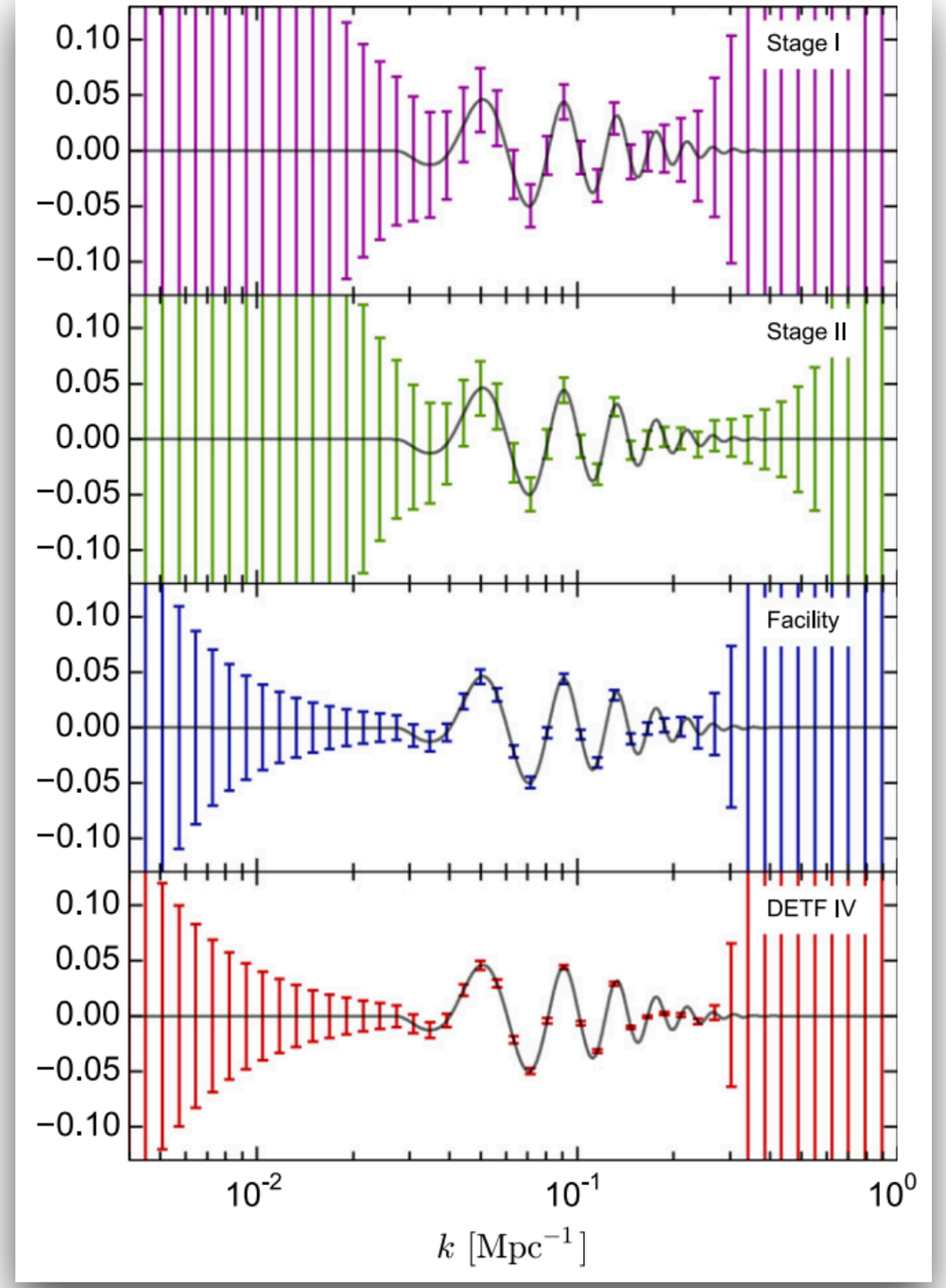
Cross PS GBT x BOSS
L. Wolz et. al. 2022, MNRAS, 510, 3495.

Bayes stacking
the CHIME Collaboration arXiv:2202.01242.

Cross PS MeerKAT x WiggleZ
Cunnington S., Li Y., Santos M. G., MNRAS, 518, 6262.







GBT
Parkes

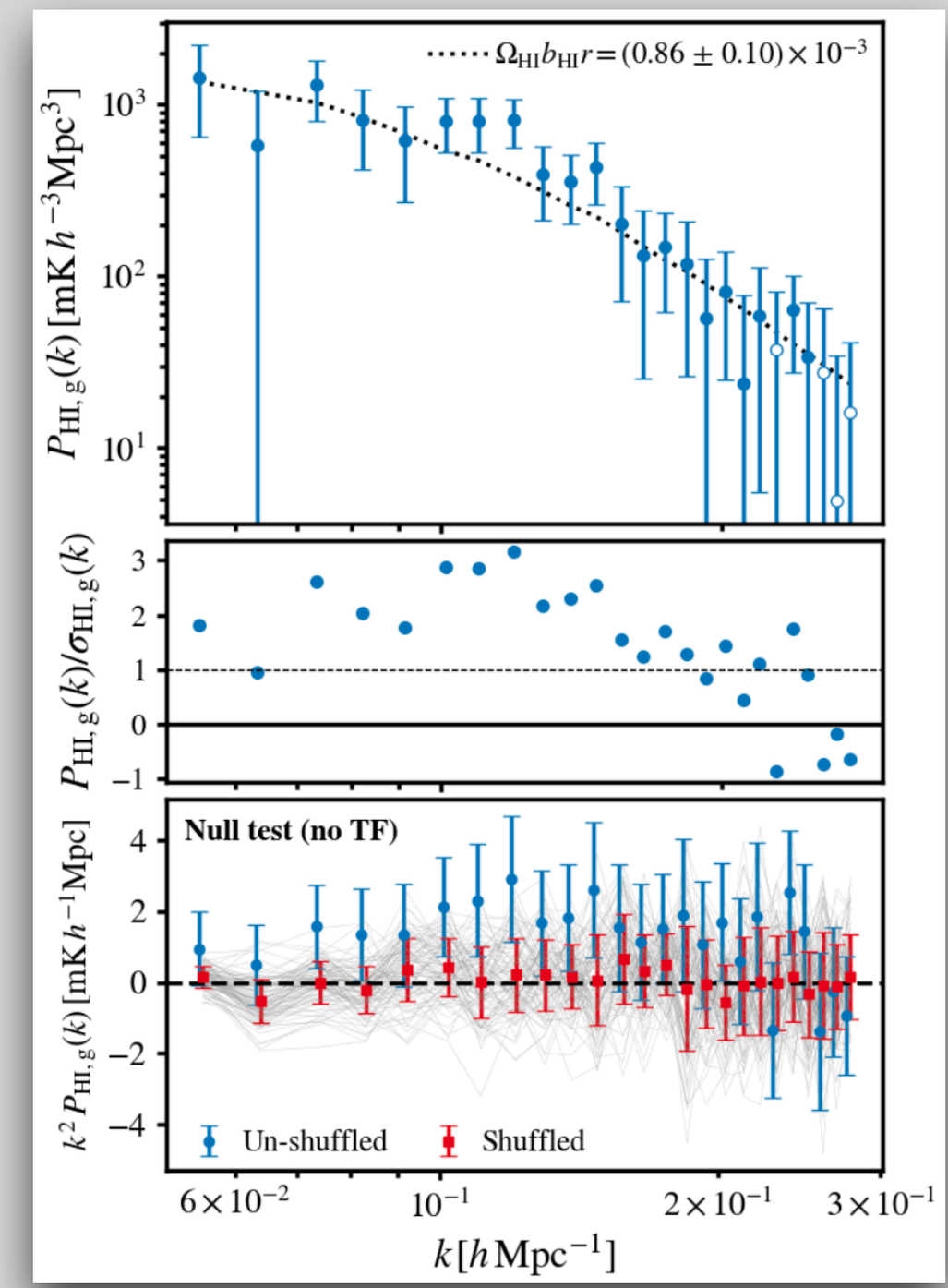
MeerKAT
ASKAP

Tianlai
CHIME
BINGO

SKA
Full Tianlai
Full CHIME

- Late-time cosmology with 21 cm intensity mapping experiments

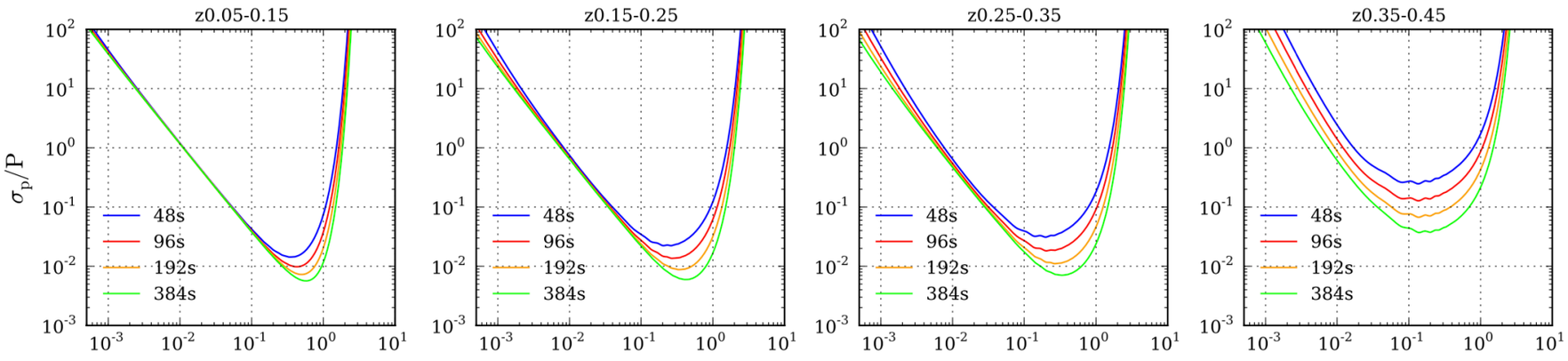
Bull P. et al 2015, ApJ, 803, 21.
arXiv: 1405.1452



- 10.5 hour HI IM observation using MeerKAT 64 dishes, we achieve 7.7σ detection of the cross-correlation power spectrum;

Cunnington S., Li Y., Santos M.~G., et al.
arXiv: 2206.01579

FAST HI IM Survey

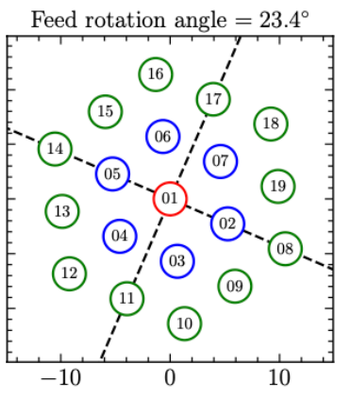


The project error on HI power spectrum with FAST L-band 20000 deg2 HI IM survey.
Hu. WK et al. 2020 MNRAS 493, 5854.

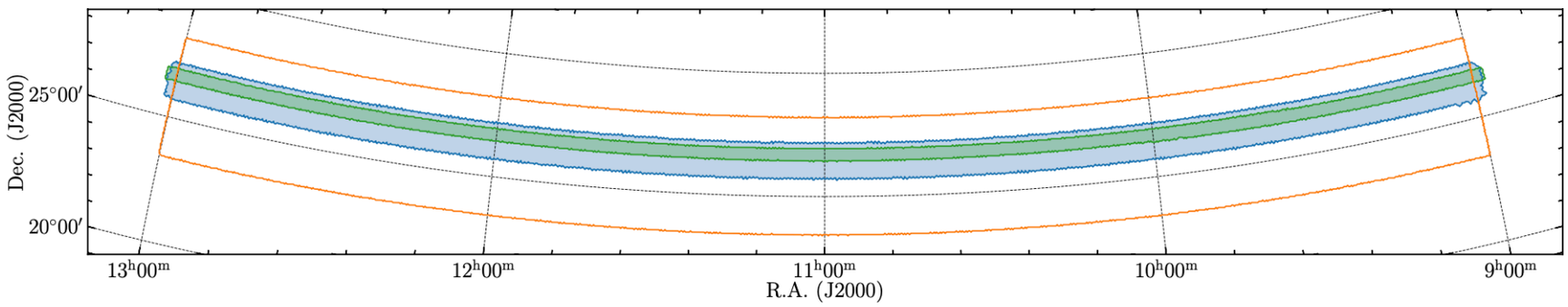
FAST HI pilot survey:

- **Investigate the systematic effect;**
- **Build data analysis pipeline;**
- **Science output:**
  - Cross correlation power spectrum
  - HI galaxy

Field center	Date	Frequency resolution [kHz]	Integration time [s]	Noise diode level	Rotation angle [°]
HIMGS 1100+2539	2019-05-27	0.5	1	high	0
HIMGS 1100+2554	2019-05-28	0.5	0.1	high	0
HIMGS 1100+2609	2019-05-29	7.6	0.1	low	0
HIMGS 1100+2554	2019-05-30	7.6	1	low	0
HIMGS 1100+2639	2019-05-31	7.6	1	low	23.4
HIMGS 1100+2639	2020-05-08	7.6	1	low	23.4
HIMGS 1100+2600	2021-03-02	7.6	1	low	23.4
HIMGS 1100+2632	2021-03-05	7.6	1	low	23.4
HIMGS 1100+2643	2021-03-06	7.6	1	low	23.4
HIMGS 1100+2654	2021-03-07	7.6	1	low	23.4
HIMGS 1100+2610	2021-03-09	7.6	1	low	23.4
HIMGS 1100+2621	2021-03-13	7.6	1	low	23.4
HIMGS 1100+2610	2021-03-14	7.6	1	low	23.4

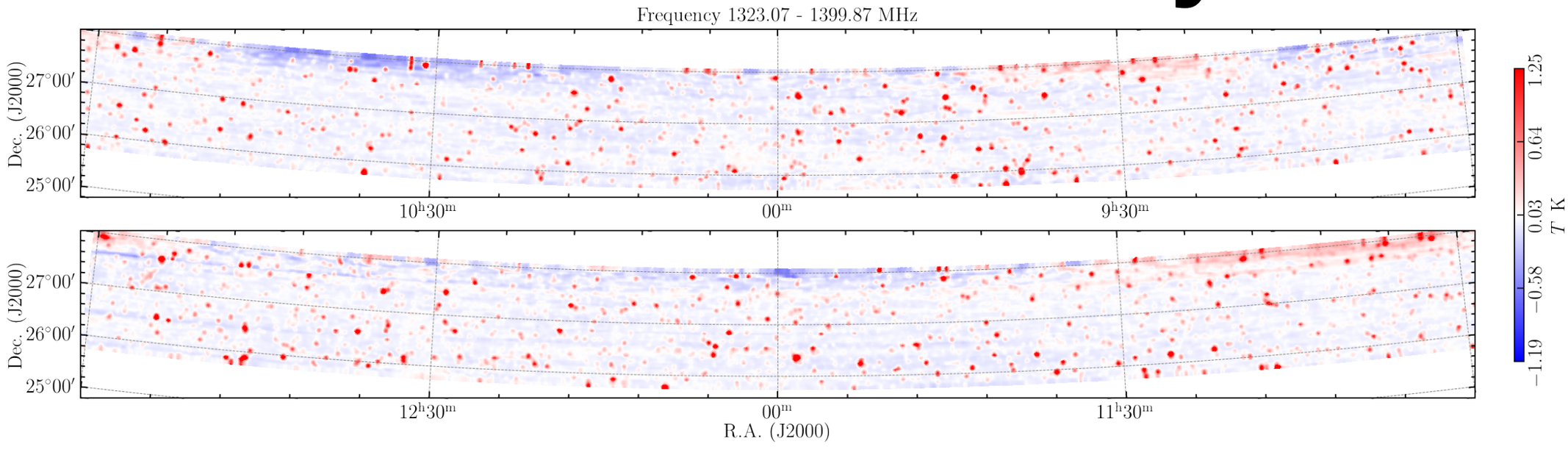


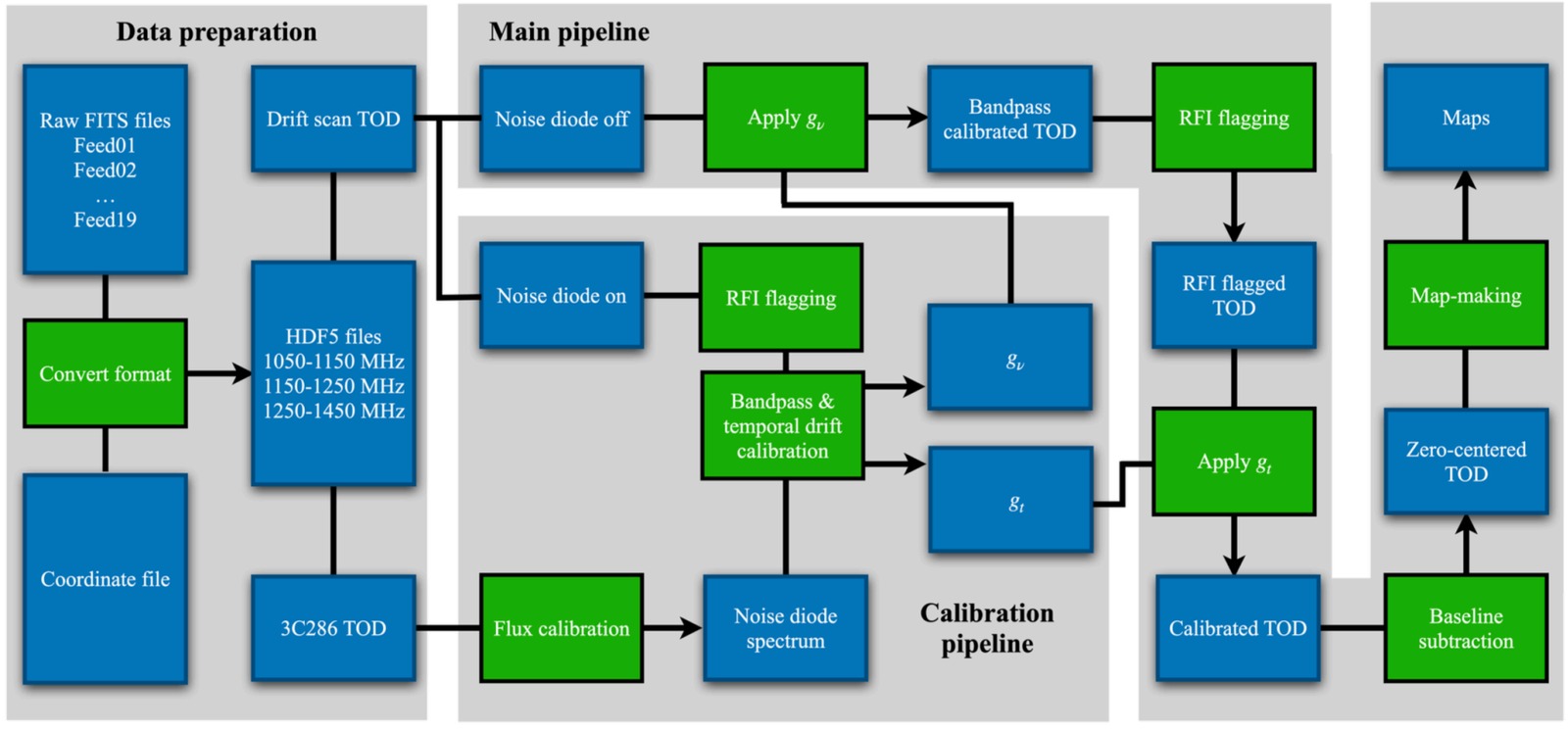
The survey area of FAST HI IM pilot survey.



Li Y.C., Wang Y.G. et al. 2023, ApJ, 954, 139.

FAST HI IM Survey





FAST HI drift scan data analysis pipeline.

Li Y.C., Wang Y.G. et al.
2023, ApJ, 954, 139.
liyichao@mail.neu.edu.cn

fpipe

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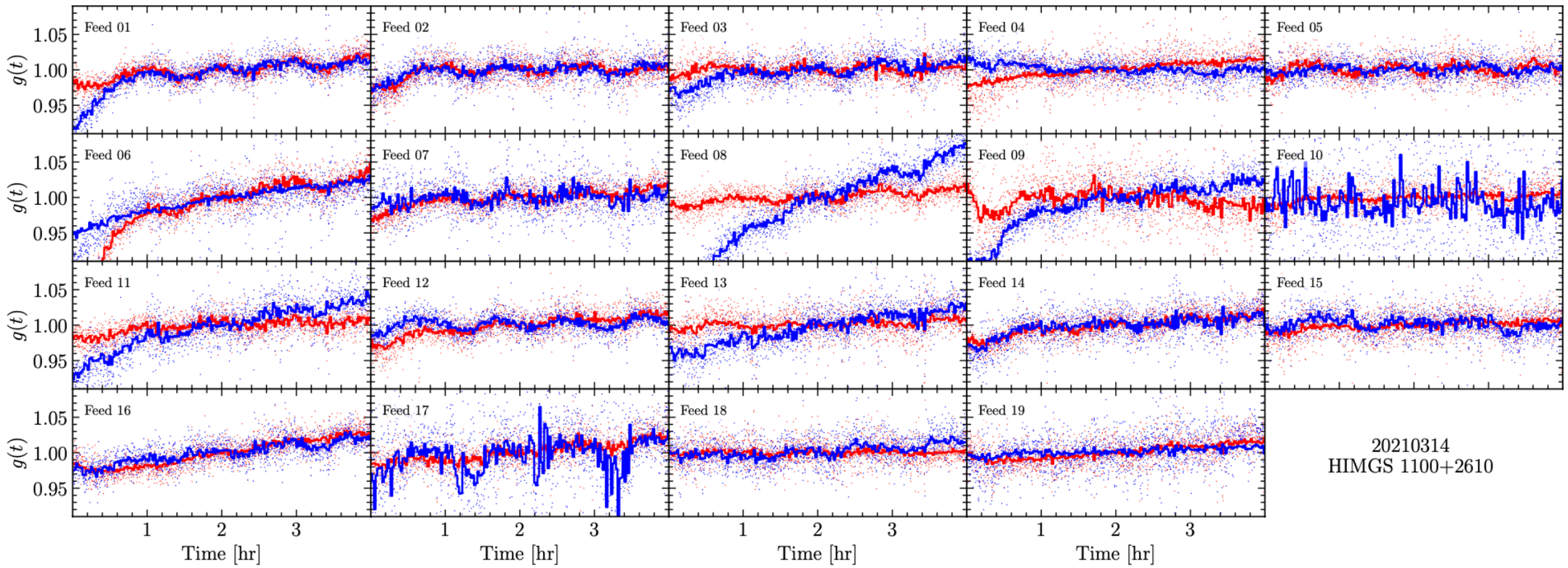
Temporal gain drift

Temporal gain drift (1/f noise):

- **Noise diode real-time calibrator**
- **Wiener filter smoothing**



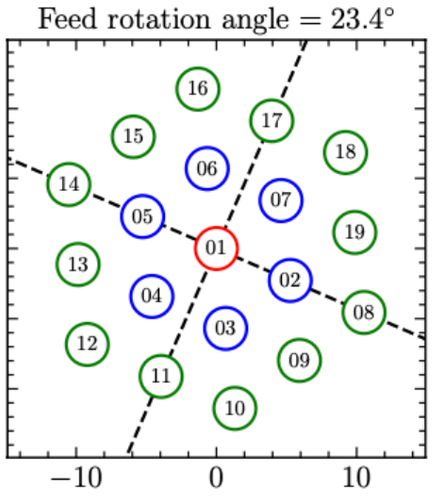
$$\mathbf{g}_{\mathrm{m}} = \mathbf{g}_t + \mathbf{n} \quad \rightarrow \quad \hat{\mathbf{g}} = \left(\mathbf{F}^{\mathrm{T}}\mathbf{N}^{-1}\mathbf{F} + \mathbf{C}_g^{-1}\right)^{-1} \mathbf{F}^{\mathrm{T}}\mathbf{N}^{-1}\mathbf{g}_m$$

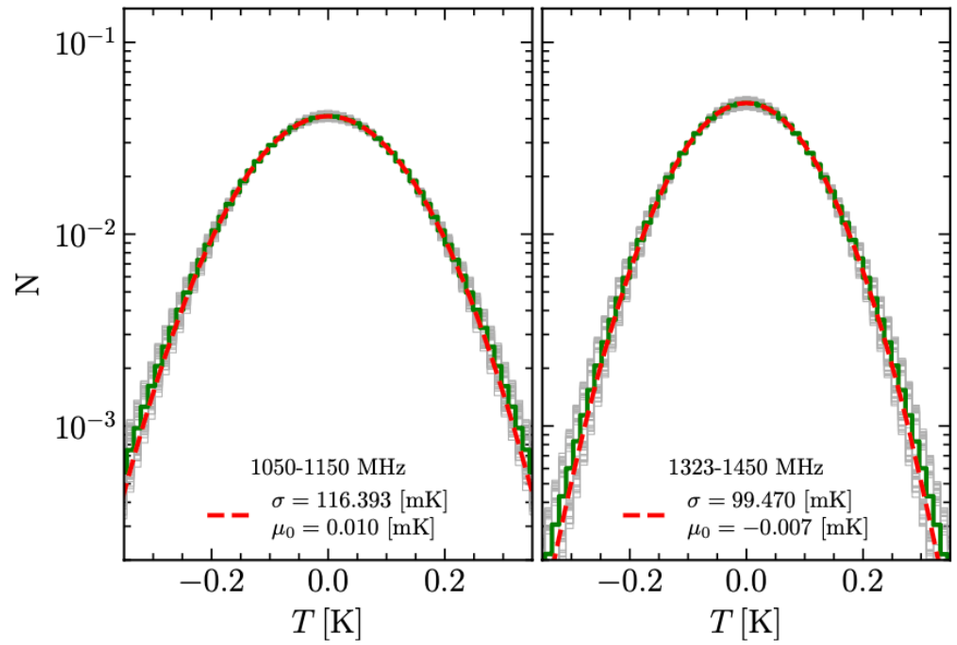
$$\mathbf{C}_g = \left(\mathbf{F}^{\mathrm{T}}\mathbf{F}\right)^{-1} \mathbf{F}^{\mathrm{T}}\mathbf{C}_N\mathbf{F} \left(\mathbf{F}^{\mathrm{T}}\mathbf{F}\right)^{-1}, C_N(\delta t) = \int P(f)e^{2\pi i f \delta t}\mathrm{d}f$$

Li. YC, Wang, YG et al. 2023 arXiv 2305.06405.

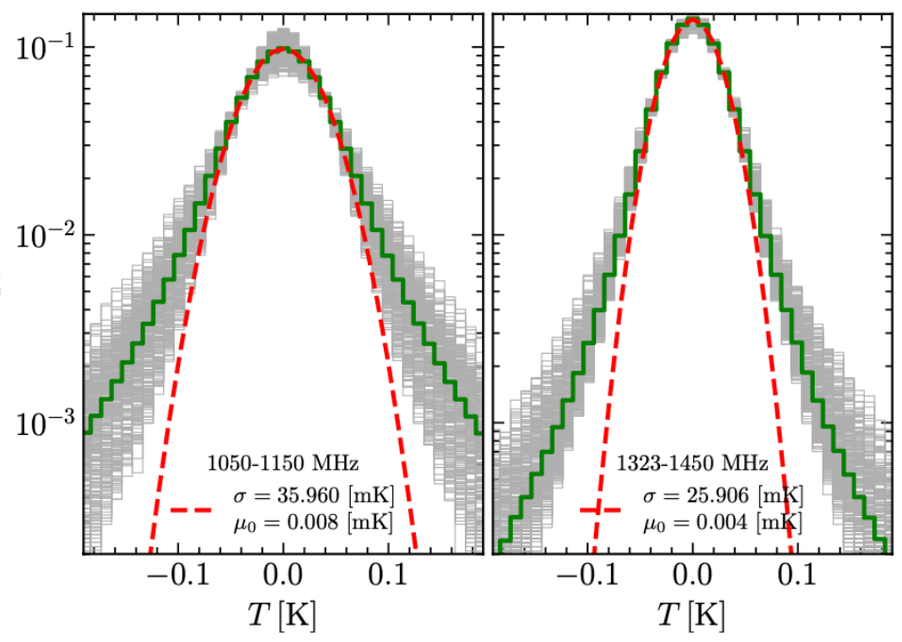
The system noise level

$$\Delta T(\hat{\nu}) = \frac{1}{2}\left(T(\nu_1) + T(\nu_3)\right) - \frac{1}{2}\left(T(\nu_2) + T(\nu_4)\right)$$

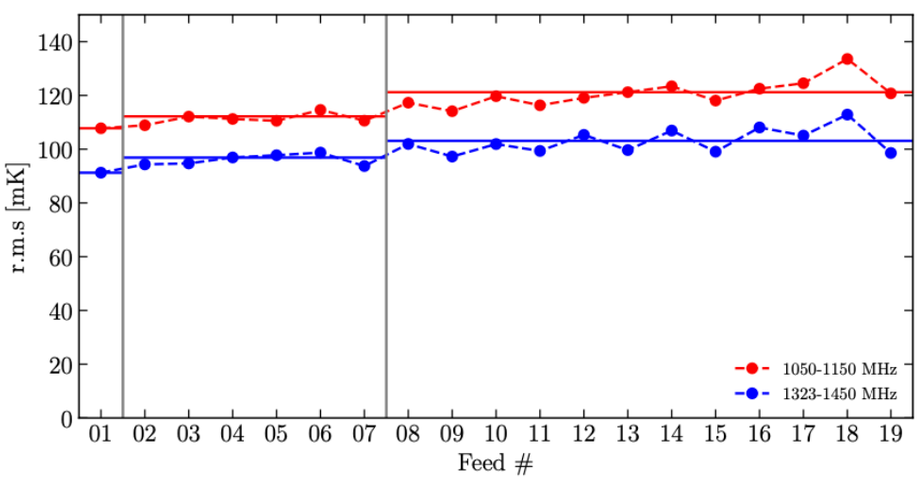




Noise level of time-ordered data



Noise level of the map



Noise level of different feeds

	TOD	Map
Freq. resol. = 28 kHz	Int. time = 1 s	Int. time ~10s Pixel size ~1.7’
Low-band	116.4 mK	36.0 mK
High-band	99.5 mK	25.9 mK

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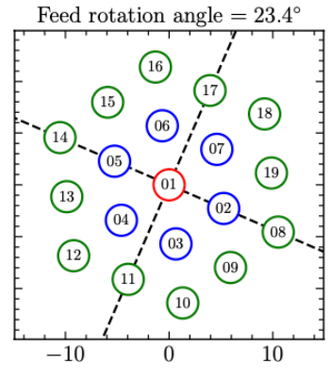
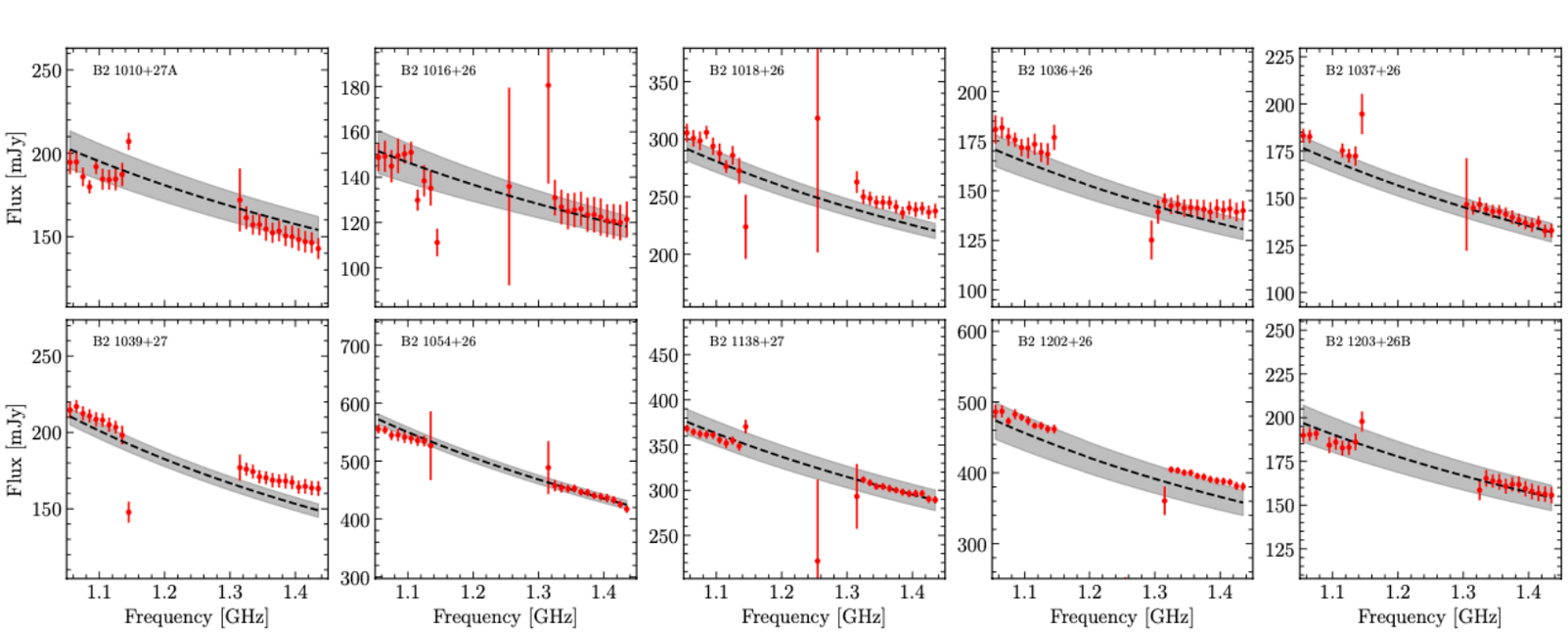
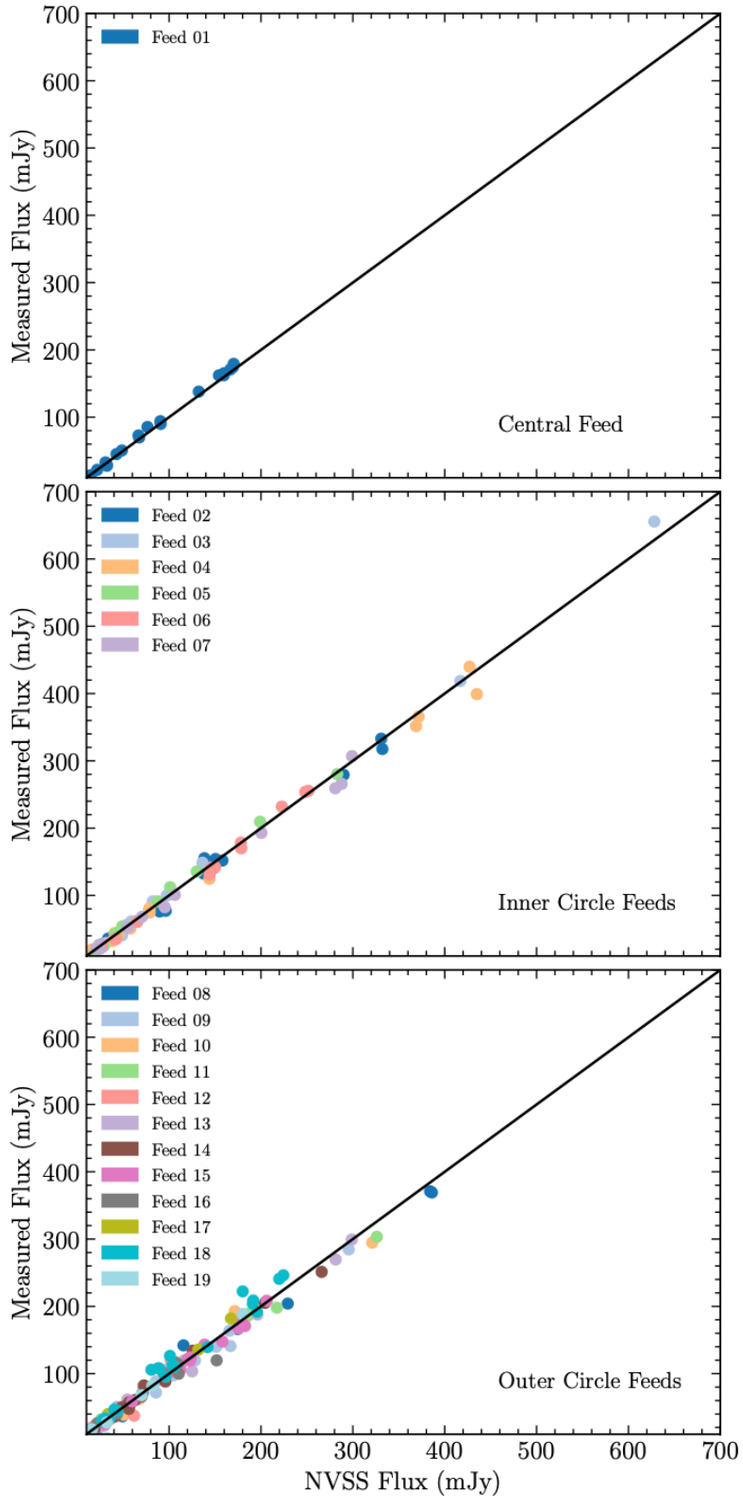
Flux measurements



- **Source-by-source spectra comparison**
- **Source-by-source comparison using 88 NVSS sources in the FAST drift scan survey field.**

- **6% calibration accuracy on average during 4 hr drift scan.**





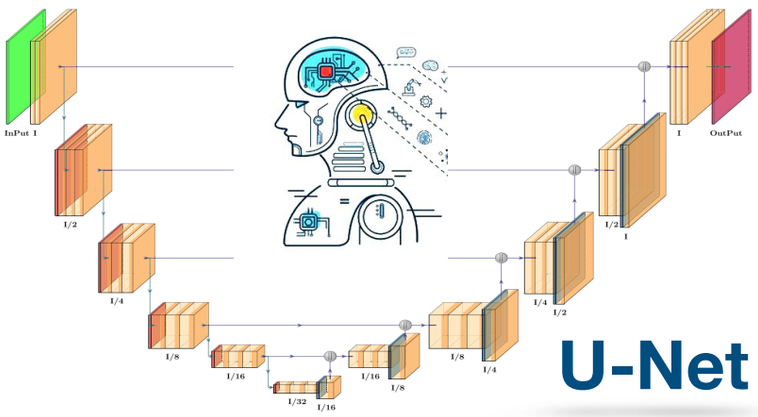
Foreground subtraction

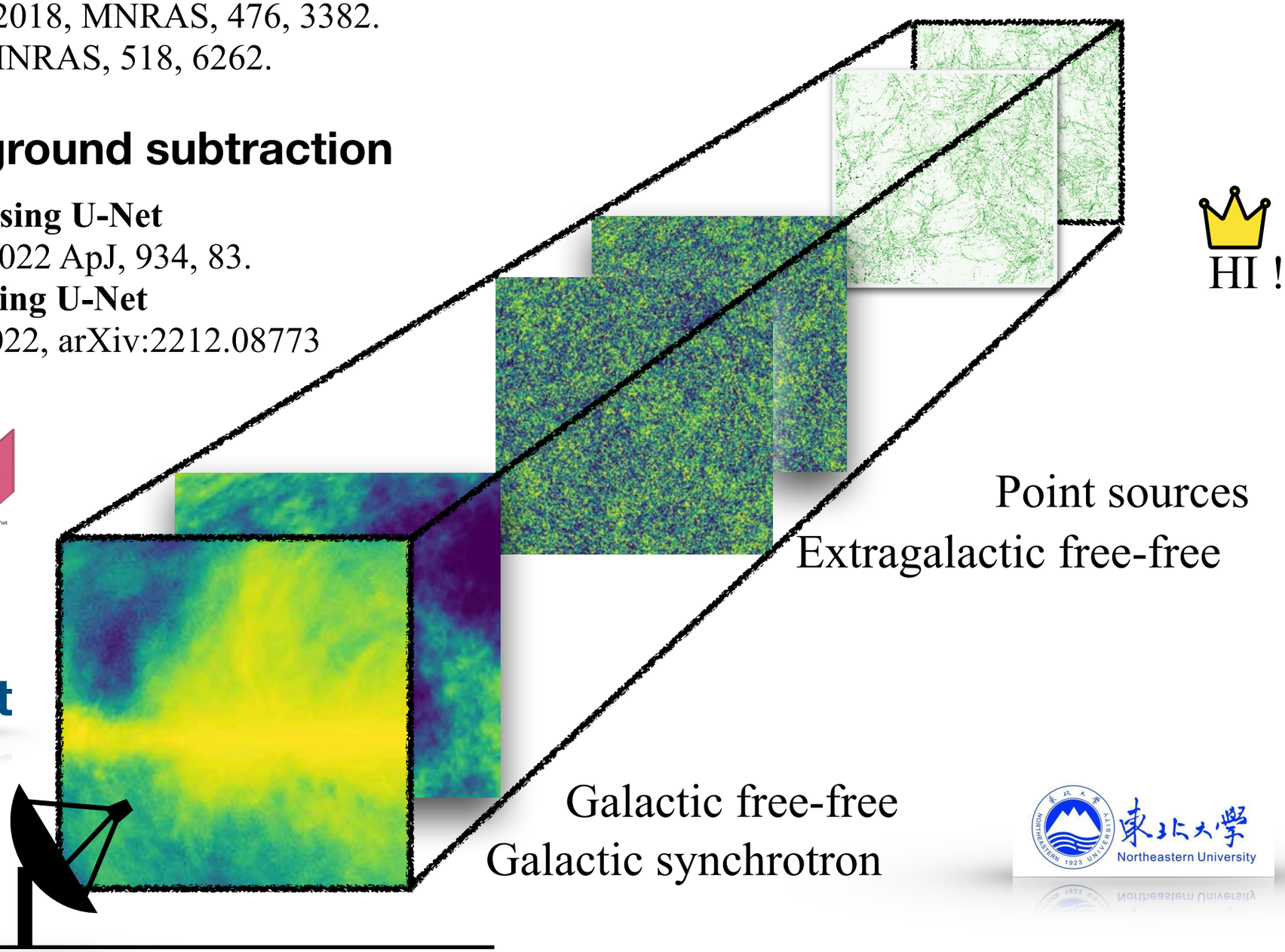
Model independent foreground subtraction

K. Masui et al 2013 ApJ 763L 20M
Switzer E. R., et al., 2013, MNRAS, 434, L46.
C. Anderson, N. J. Luciw, Y. Li et, al 2018, MNRAS, 476, 3382.
Cunnington S., Li Y., Santos M. G., MNRAS, 518, 6262.

Deep leaning based foreground subtraction

Eliminating Primary Beam Effect using U-Net
Ni S., Li Y., Gao L.-Y., Zhang X., 2022 ApJ, 934, 83.
Eliminating Polarization leakage using U-Net
Gao L.Y., Li Y., Ni, S. Zhang X., 2022, arXiv:2212.08773





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Eliminating Systematic

Model independent foreground subtraction

K. Masui et al 2013 ApJ 763L 20M
Switzer E. R., et al., 2013, MNRAS, 434, L46.
C. Anderson, N. J. Luciw, Y. Li et, al 2018, MNRAS, 476, 3382.
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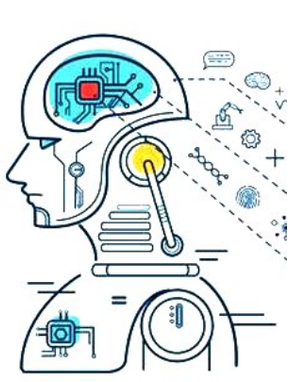
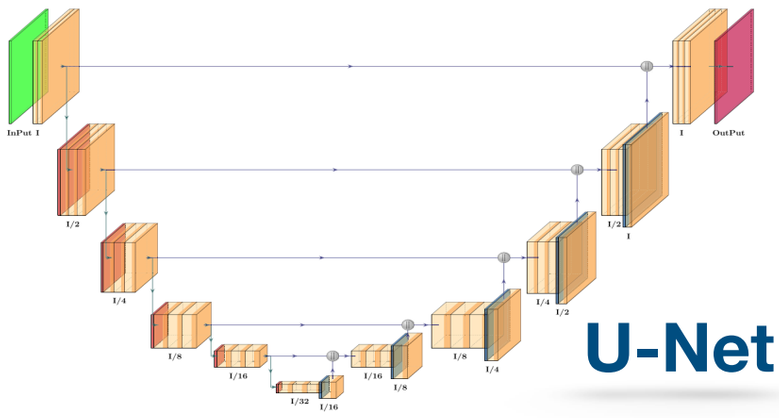
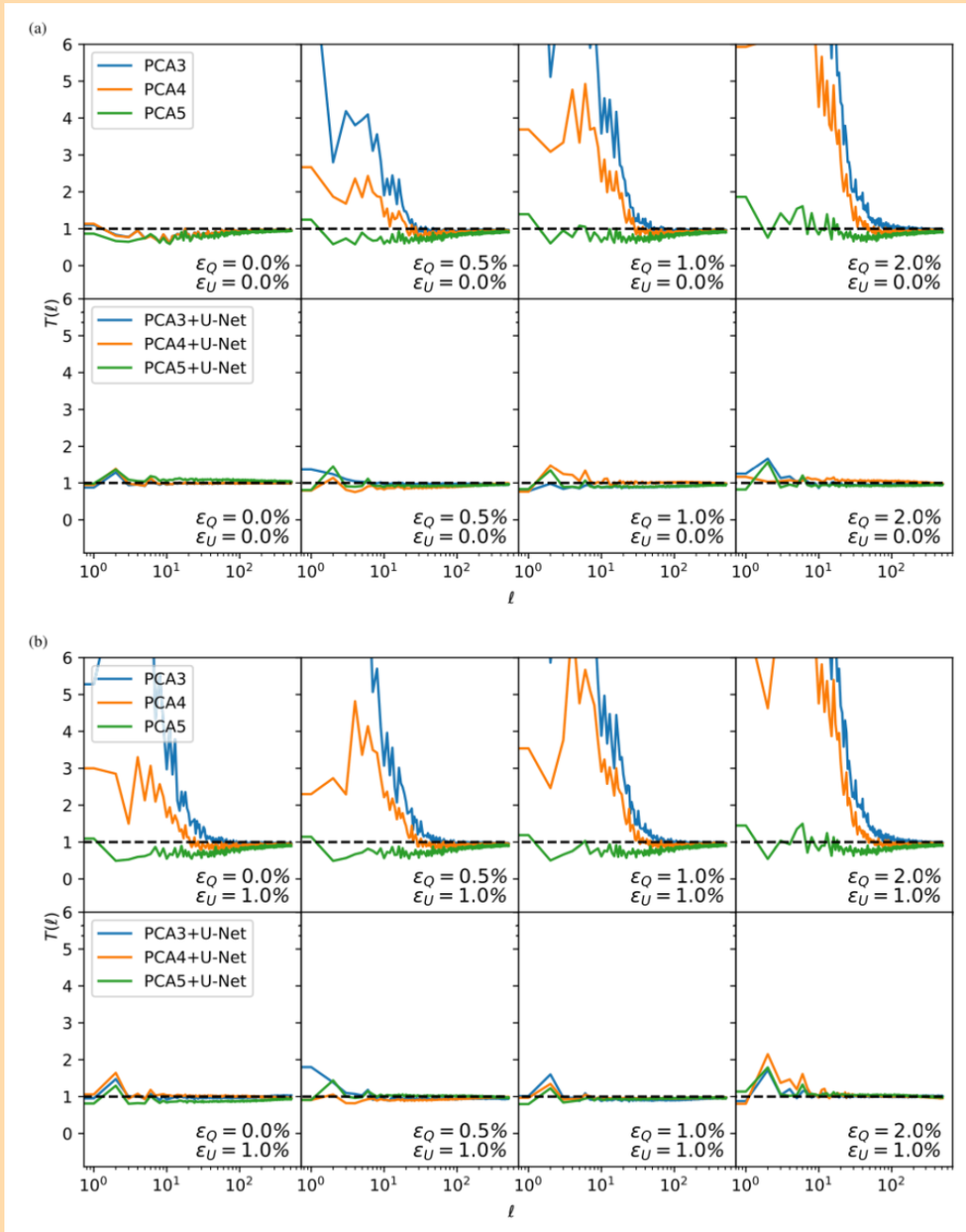
Gao L.Y., Li Y., Ni, S. Zhang X.,
2023, MNRAS, 525, 5278.







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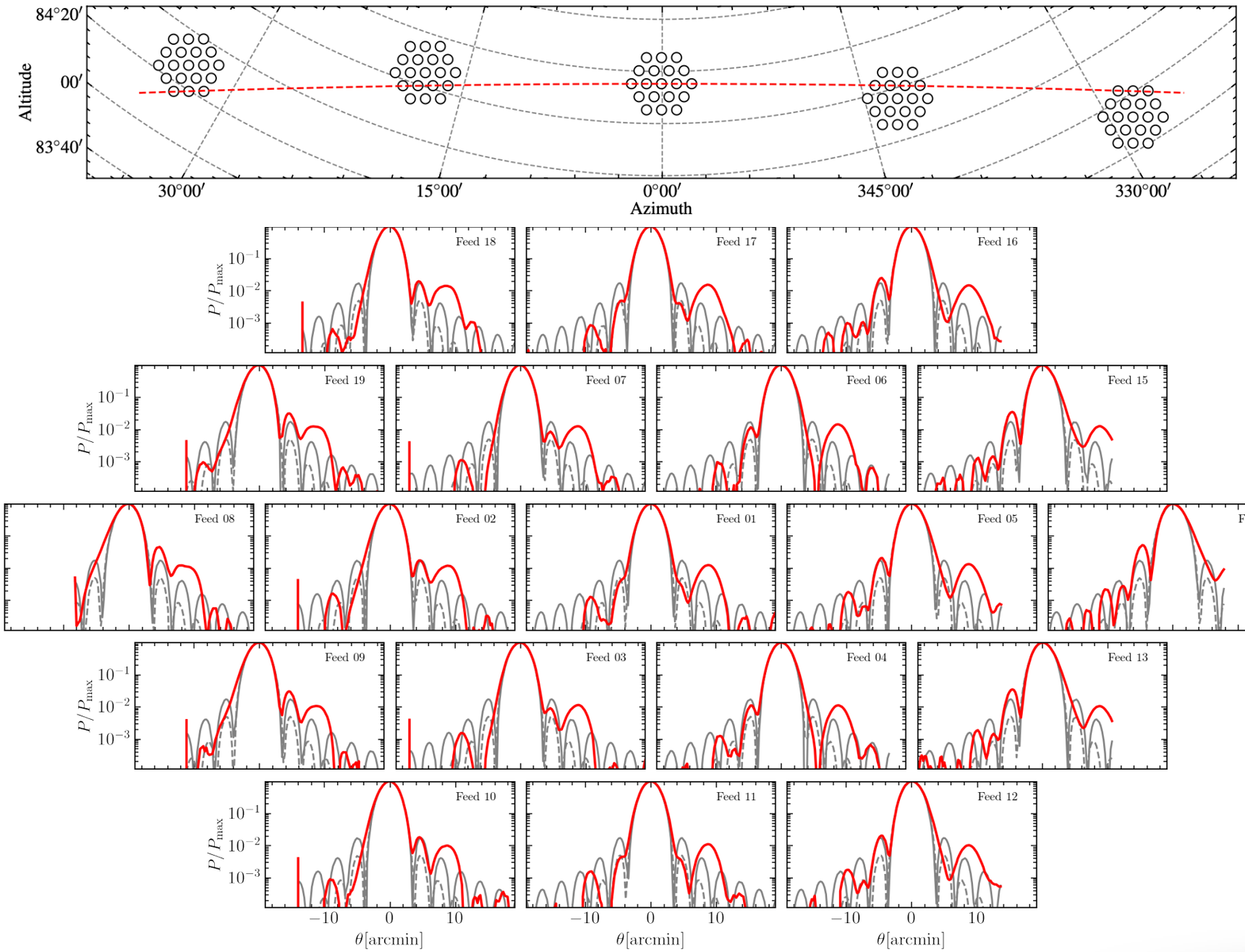
Beam measurements



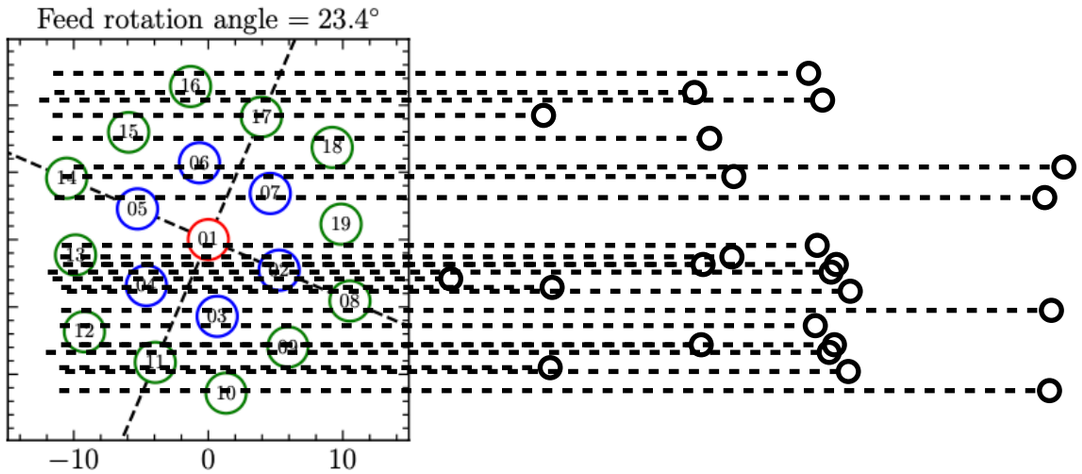
Beam measurements

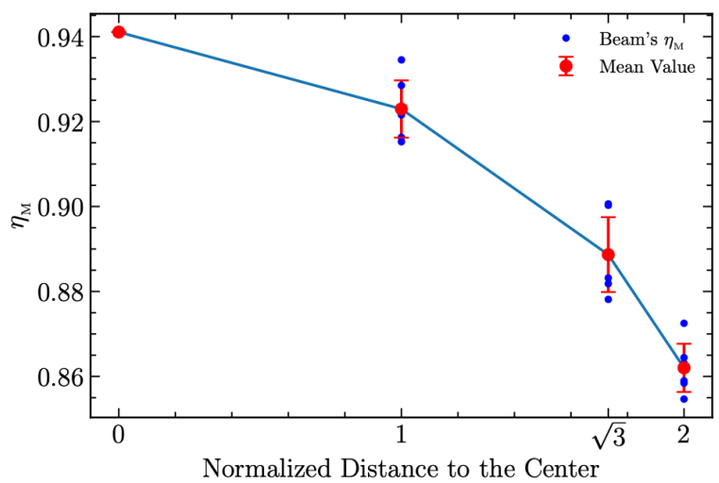
- Beam measurements by stacking NVSS sources

$$\boldsymbol{d} = \boldsymbol{PMb} + \boldsymbol{n}$$

$$\chi^2 = \left(\boldsymbol{d} - \boldsymbol{PMb}\right)^{\mathrm{T}} C_{\mathrm{N}}^{-1} \left(\boldsymbol{d} - \boldsymbol{PMb}\right)$$

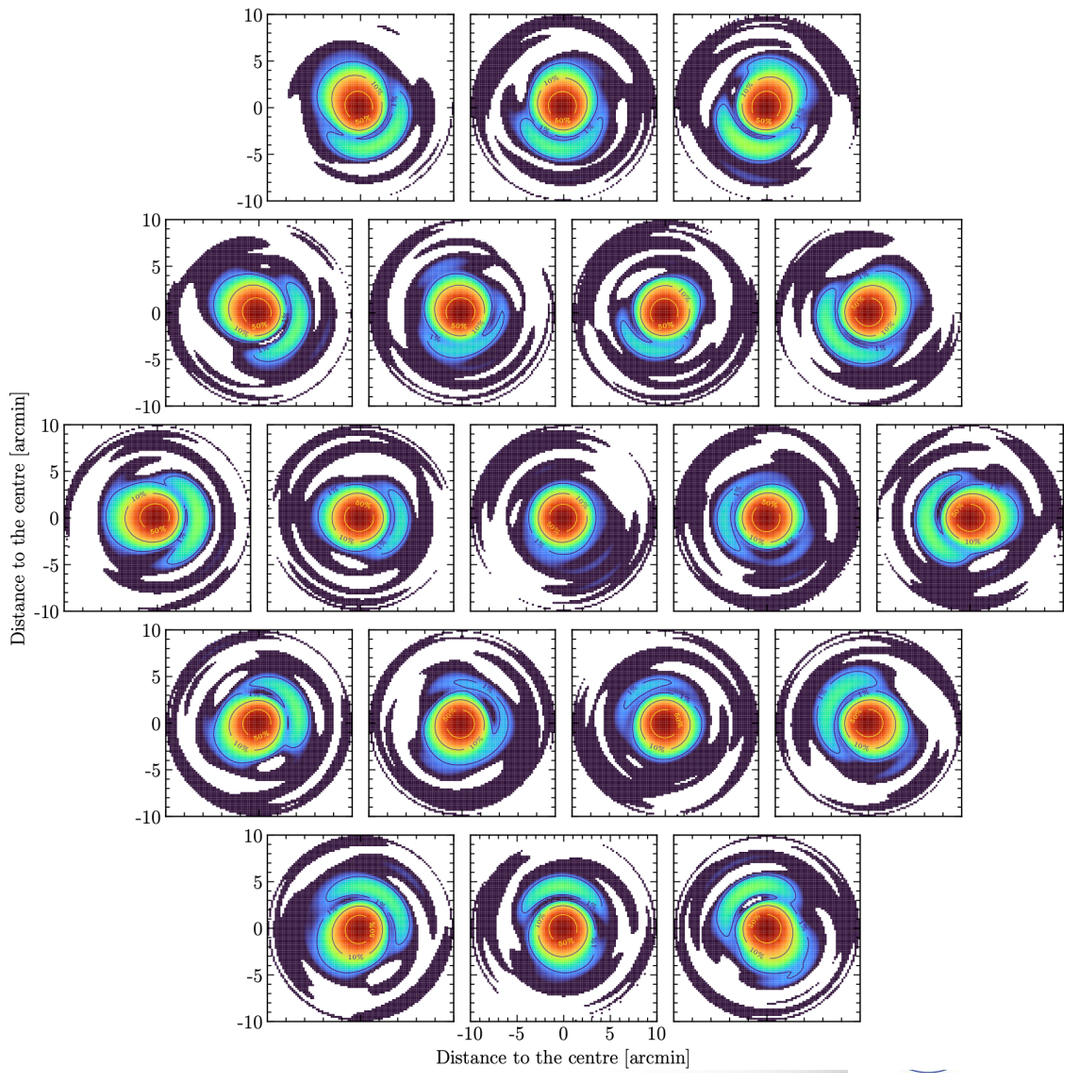
$$\hat{\boldsymbol{b}} = \left((\boldsymbol{PM})^{\mathrm{T}} C_{\mathrm{N}}^{-1} (\boldsymbol{PM}) \right)^{-1} (\boldsymbol{PM})^{\mathrm{T}} C_{\mathrm{N}}^{-1} \boldsymbol{d} \,.$$





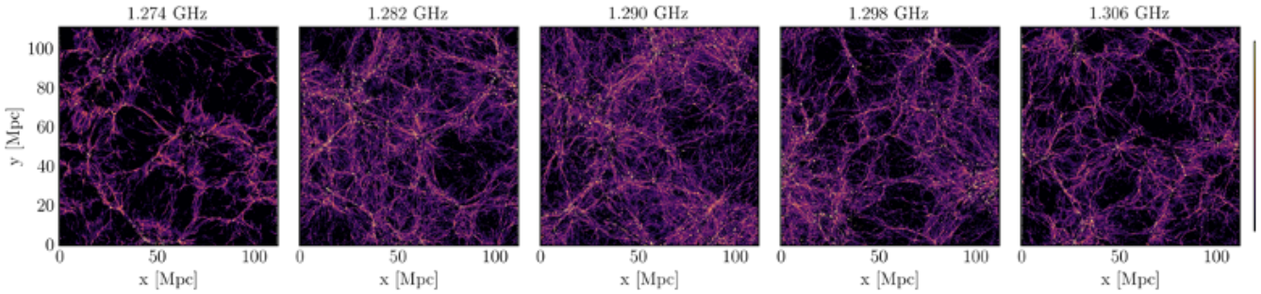
Observation mode between FATHOMS and CRAFTS. Column (1): The observation date. Column (2): The observation time. Column (3-4): The sample rate for recording the data. Column (5): The level of noise diode. Column (6): The rotated angle of the feed array.

Field center	Date	Observation time [hr]	Frequency resolution [kHz]	Integration time [s]	Noise diode level	Rotation angle [°]
FATHOMS 1100+2600	20210302	4	7.6	1	low	23.4
FATHOMS 1100+2654	20210307	4	7.6	1	low	23.4
FATHOMS 1100+2705	20220216	4	7.6	1	low	23.4
FATHOMS 1100+2748	20220219	4	7.6	1	low	23.4
CRAFTS 0330+2715	20220418	5	7.6	0.2	low	23.4
CRAFTS 0330+2904	20200805	5	7.6	0.2	low	23.4
CRAFTS 0330+3030	20200810	5	7.6	0.2	low	23.4
CRAFTS 0330+3135	20220330	5	7.6	0.2	low	23.4



Zhao, X.Y.; et al. in prep.

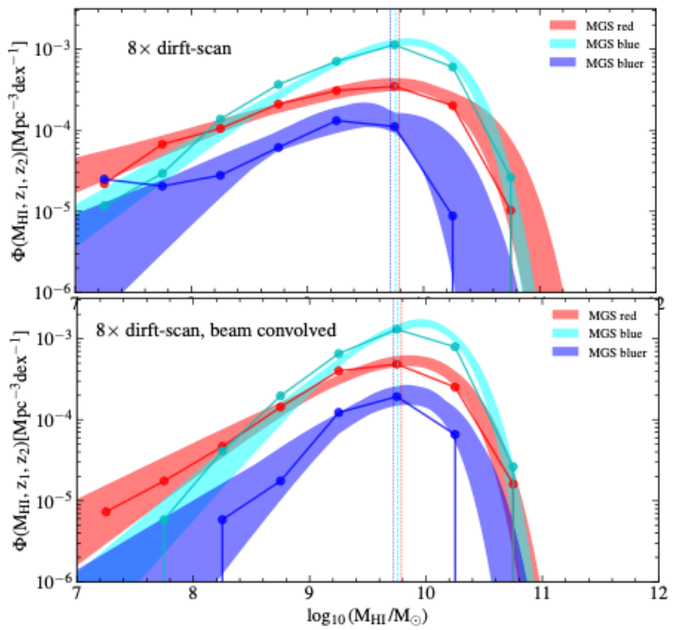
Sciences with FAST HI IM

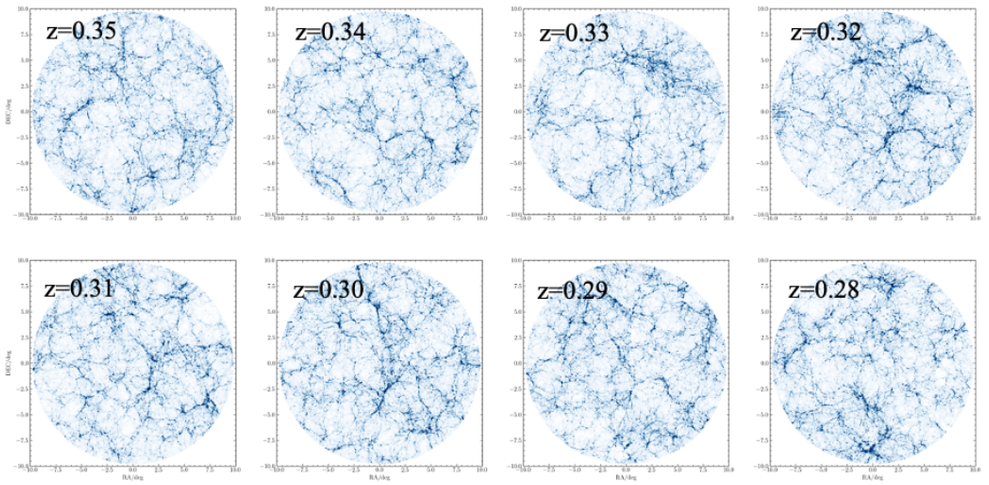


TNG-100 simulation 200 deg2
Simulation on FAST x SDSS Main Galaxy Sample

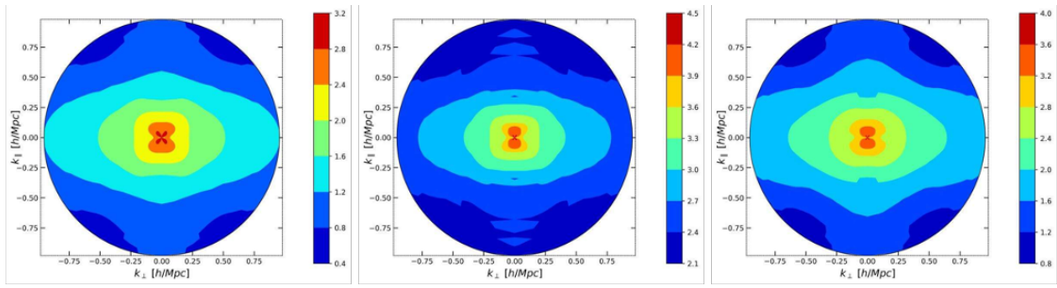
Bayesian Stacking Analysis
For HI mass function

- MGS vs LowZ LRG
- Beam confusion effect
- Catalog completeness issue

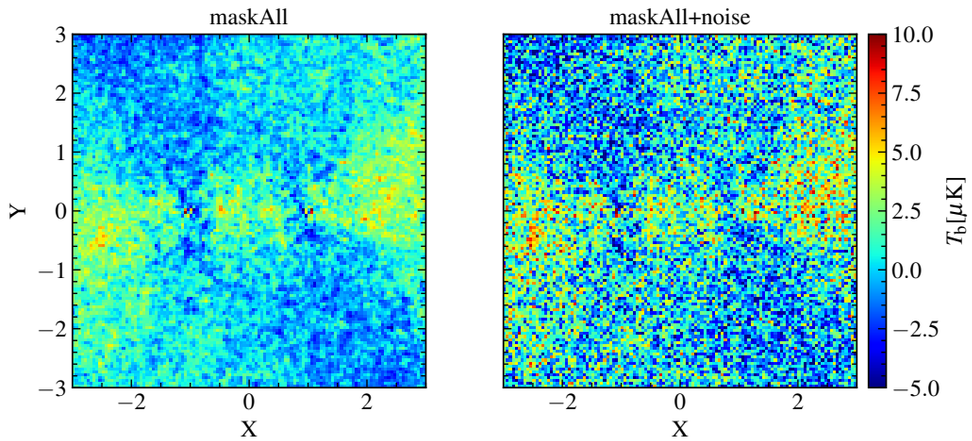




Simi-analytical simulation 400 deg2
Simulation on FAST x SDSS Main Galaxy Sample
Direction-dependent 2D PS estimator



Shang, Z-H et al in prep.



Liu, D-Y et al in prep.
Referring to Diyang's talk for tomorrow

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Summary

- **Next generation HI intensity mapping survey has great potential for cosmology studies.**
- **FAST HI pilot survey (~240 deg2 survey).**
- **Investigate the systematic 1/f noise for FAST L-band receiver.**
- **Developed the temporal and bandpass gain calibration strategy.**
- **Build the data analysis pipeline for FAST HI intensity mapping drift-scan survey.**
- **Systematic investigation for next stage FAST HI intensity mapping observation.**

- **Apply the pipeline to the 120 deg^2 data**
- **Perform the PCA foreground subtraction**
- **Perform the cross PS estimation**
- **Stacking analysis (HIMF, filaments)**

Summary

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Thanks for your attention !

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