Expression of Interests

Preparing for Science with the SKAO

Dr. LI, Yichao

On behalf of joint research in NEU and NAOC

SKA Cosmology SWG Meeting
4-6 Nov. Nice, France (Remote)

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- **The 1/f noise feature analysis for the SKA HI intensity mapping survey**
  - Yichao Li; Wenkai Hu; et. al.

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1/f Noise

- **1/f in the literature**
  - Maino, D.,et al., 2002. Removing 1/f noise stripes in cosmic microwave background anisotropy observations. Astronomy & Astrophysics 387, 356–365.
  - Maino, D.,et al, 1999. The Planck-LFI instrument: analysis of the 1/f noise and implications for the scanning strategy.
  - Seiffert, M.,et al. A&A 1197, 14.
  - …

Harper S. E., et al., 2018, MNRAS, 478, 2416

Temporal PS model

$$S^t(f,\nu) = \frac{A}{\delta\nu}\left(1+\left(\frac{f_k}{f}\right)^{\alpha}\right)$$

2D PS model

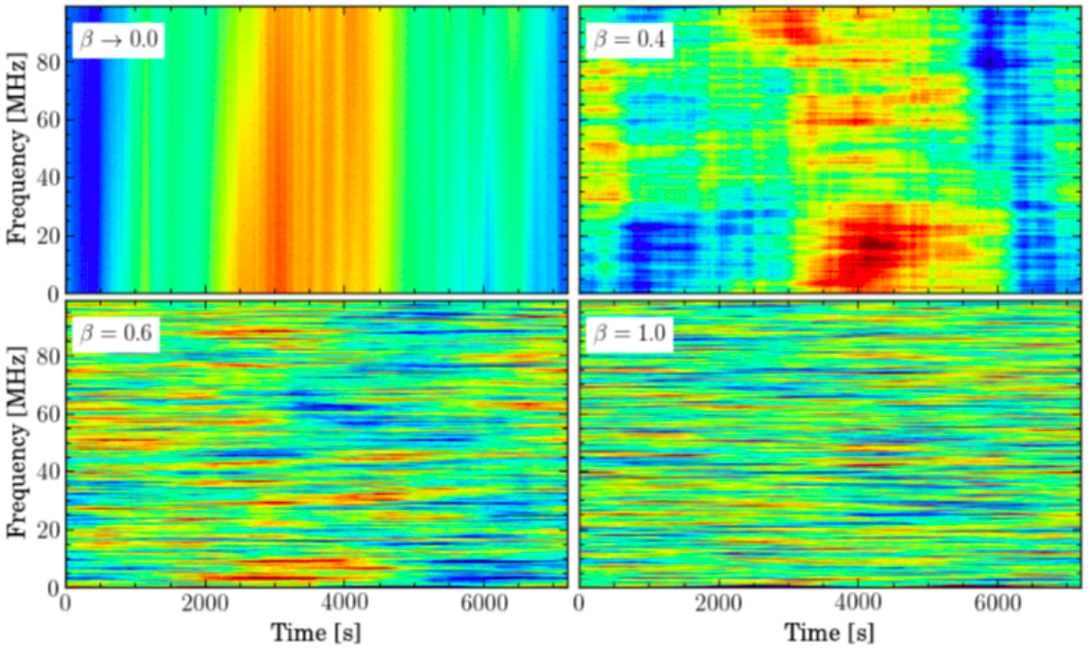
$$S(f,\tau) = A\left(1+\frac{1}{K\delta\nu}\left(\frac{f_k}{f}\right)^{\alpha}\left(\frac{\tau_0}{\tau}\right)^{\frac{1-\beta}{\beta}}\right),$$

White Noise

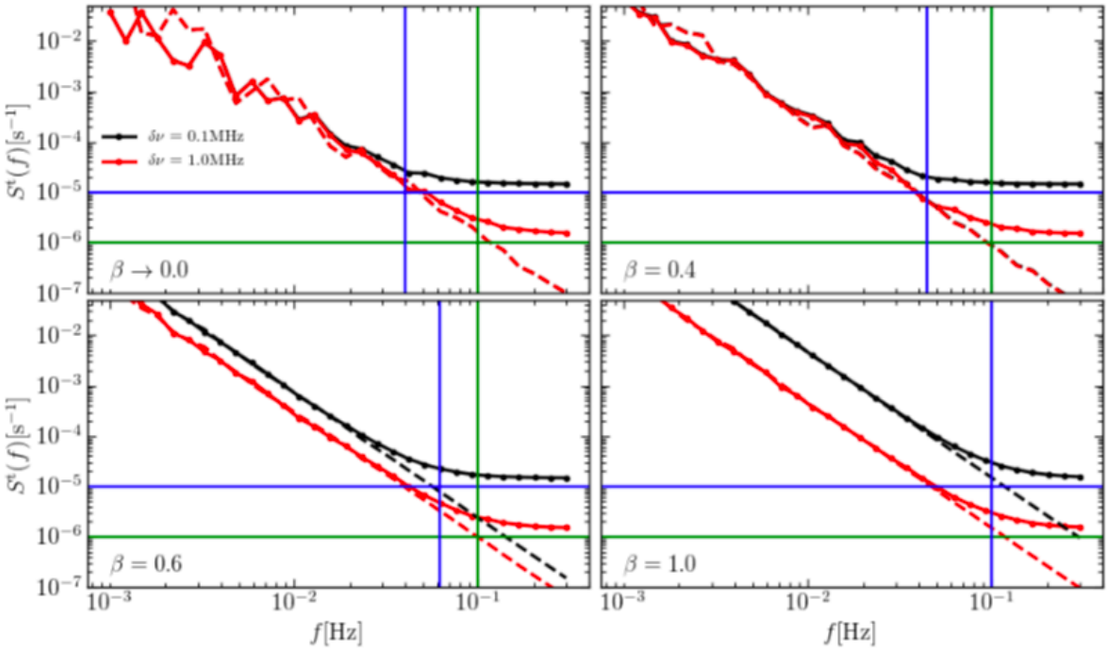
Temporal Correlation

Frequency Correlation

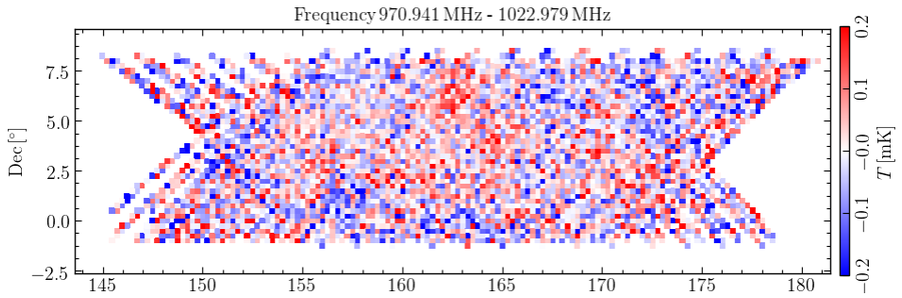
Simulated TOD with different frequency correlation

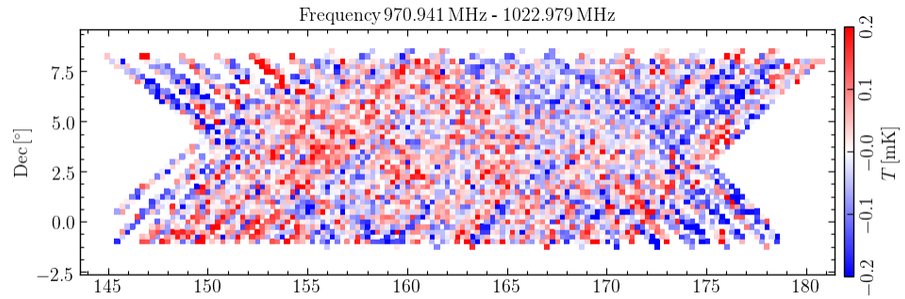


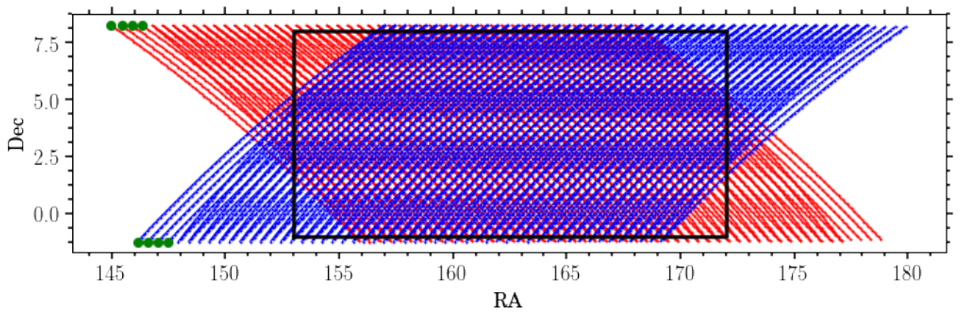
Temporal PS with different frequency resolution

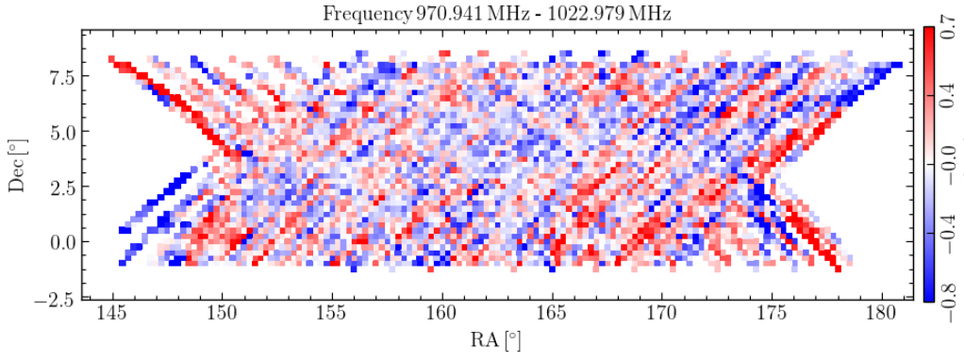


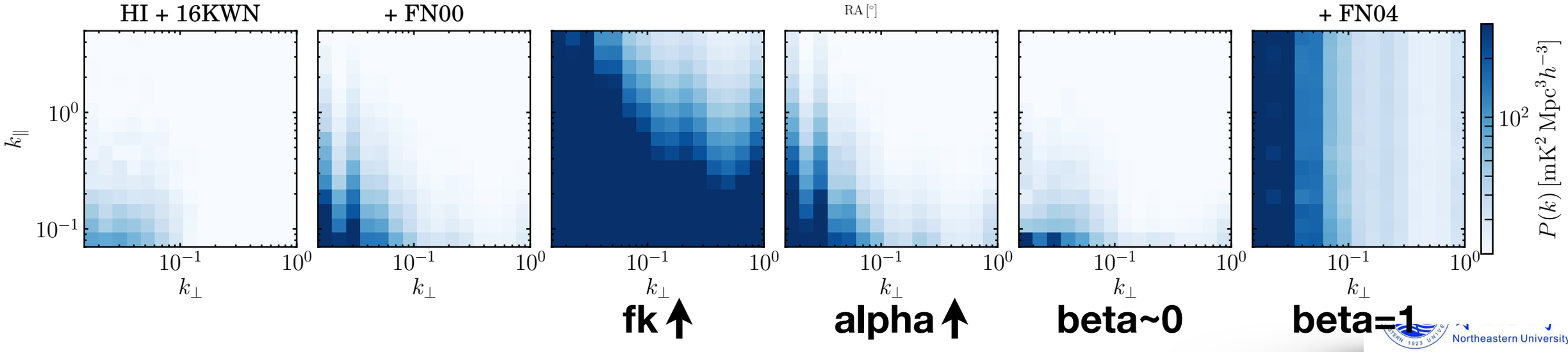
1/f Noise





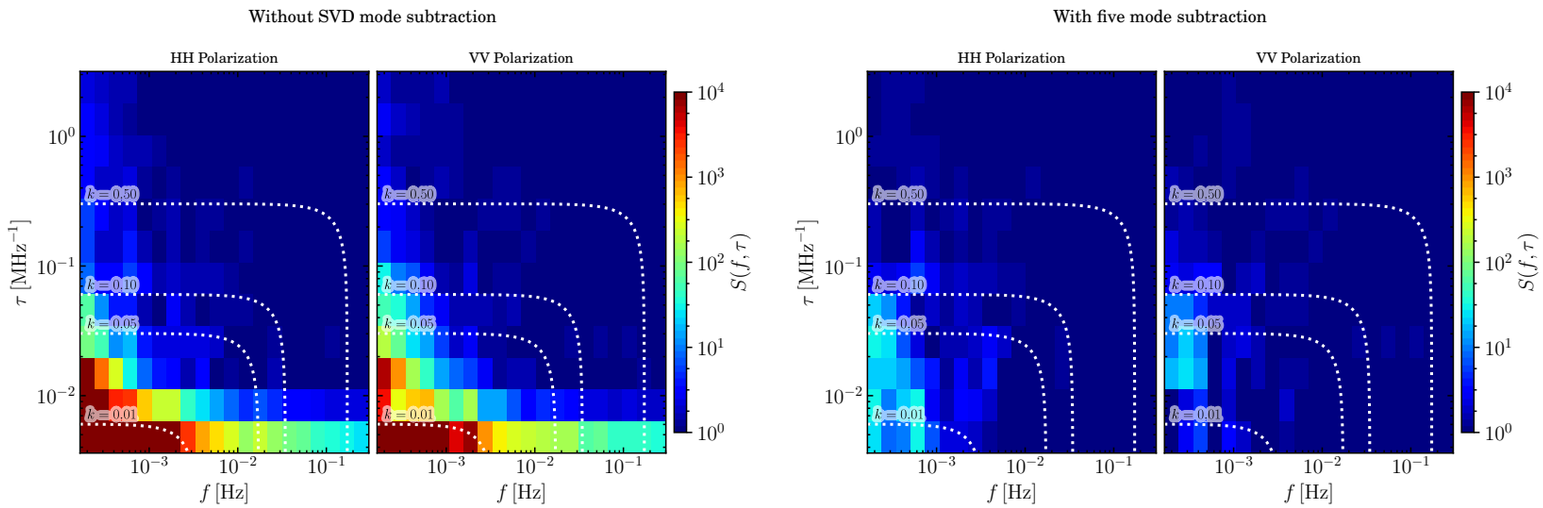


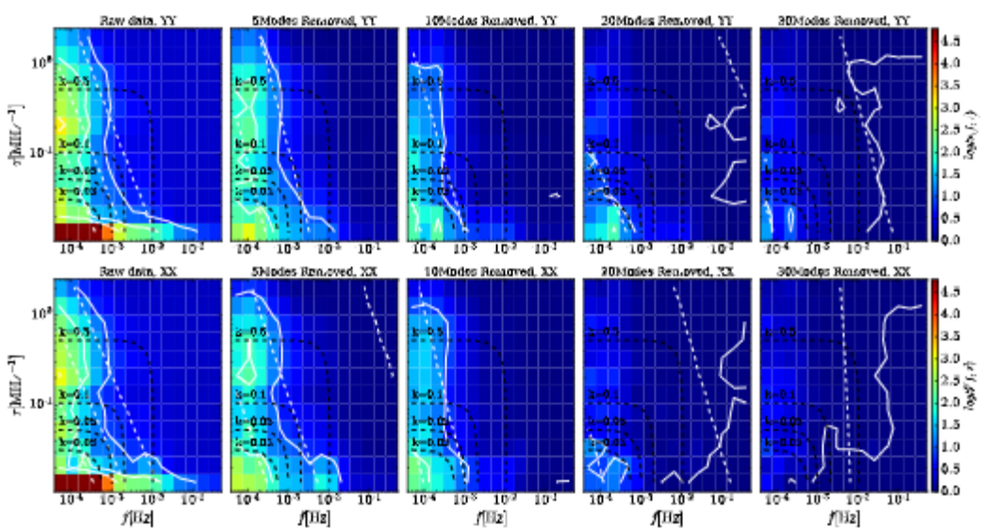


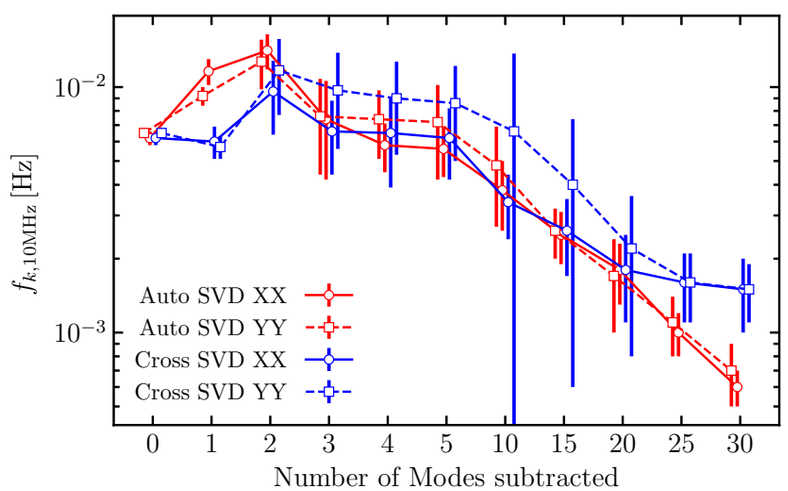


1/f Noise

- **Investigations on 1/f Noise for HI intensity mapping:**
  - Harper S. E., et al., 2018, MNRAS, 478, 2416.
  - Li Y., Santos M.G., et al, 2021, MNRAS, 501, 4344.
  - Hu W., Li Y., et al., 2021, MNRAS, 508, 2897.
  - Irfan M.O., Li Y., Santos M.G., 2024, MNRAS, 527, 4717.





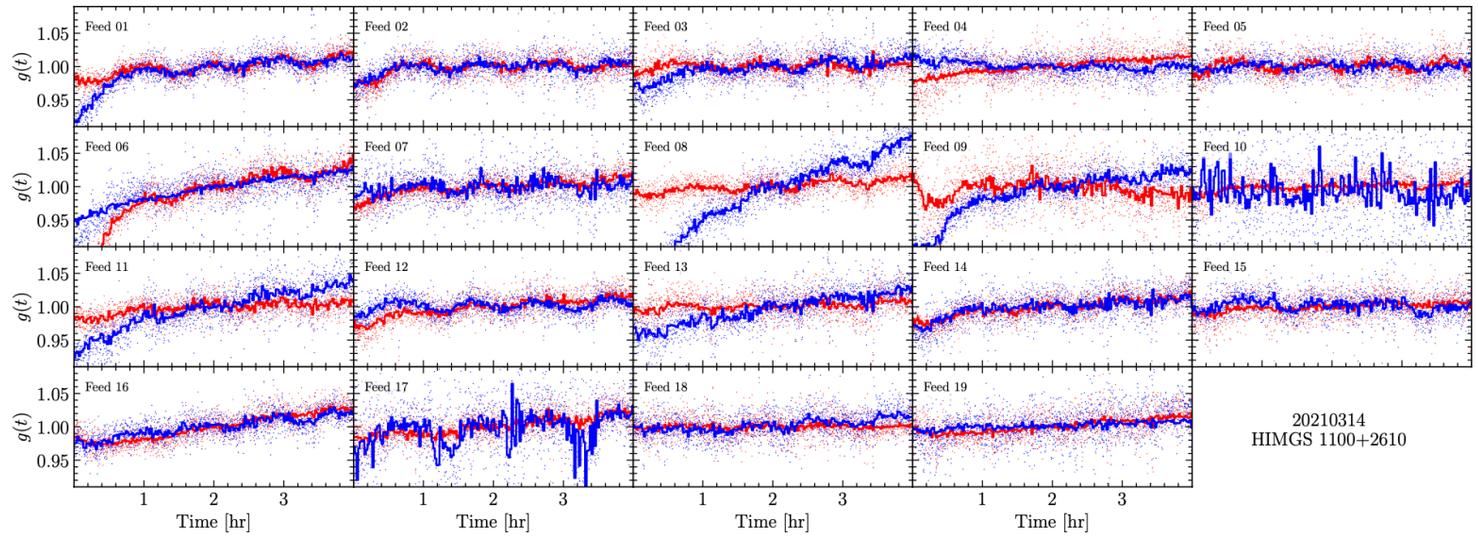


1/f Noise

- **Elimation of 1/f noise**
  - Map-making processing.
  - De-striping
- **For future SKA sciences**
  - 1/f noise feature
  - Elimination method
  - Effects on cosmological parameter

No.	Method	Specification
1	Generalized COBE	$\mathbf{W} = [\mathbf{A}^t\mathbf{M}\mathbf{A}]^{-1}\mathbf{A}^t\mathbf{M}$
2	Bin averaging	$\mathbf{W} = [\mathbf{A}^t\mathbf{A}]^{-1}\mathbf{A}^t$
3	COBE	$\mathbf{W} = [\mathbf{A}^t\mathbf{N}^{-1}\mathbf{A}]^{-1}\mathbf{A}^t\mathbf{N}^{-1}$
4	Wiener 1	$\mathbf{W} = \mathbf{S}\mathbf{A}^t[\mathbf{A}\mathbf{S}\mathbf{A}^t + \mathbf{N}]^{-1}$
5	Wiener 2	$\mathbf{W} = [\mathbf{S}^{-1} + \mathbf{A}^t\mathbf{N}^{-1}\mathbf{A}]^{-1}\mathbf{A}^t\mathbf{N}^{-1}$
6	Saskatoon	$\mathbf{W} = [\eta\mathbf{S}^{-1} + \mathbf{A}^t\mathbf{N}^{-1}\mathbf{A}]^{-1}\mathbf{A}^t\mathbf{N}^{-1}$
7	TE96	$\mathbf{W} = \mathbf{\Lambda}\mathbf{S}\mathbf{A}^t[\mathbf{A}\mathbf{S}\mathbf{A}^t + \mathbf{N}]^{-1},\ (\mathbf{W}\mathbf{A})_{ii} = 1$
8	TE97	$\mathbf{W} = \mathbf{\Lambda}[\eta\mathbf{S}^{-1} + \mathbf{A}^t\mathbf{N}^{-1}\mathbf{A}]^{-1}\mathbf{A}^t\mathbf{N}^{-1},\ (\mathbf{W}\mathbf{A})_{ii} = 1$
9	Maximum probability	Nonlinear method if non-Gaussian
10	Maximum entropy	Nonlinear method

MAX TEGMARK THE ASTROPHYSICAL JOURNAL, 480:L87–L90, 1997 May 10



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

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

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

- **The 1/f noise feature analysis for the SKA HI intensity mapping survey**
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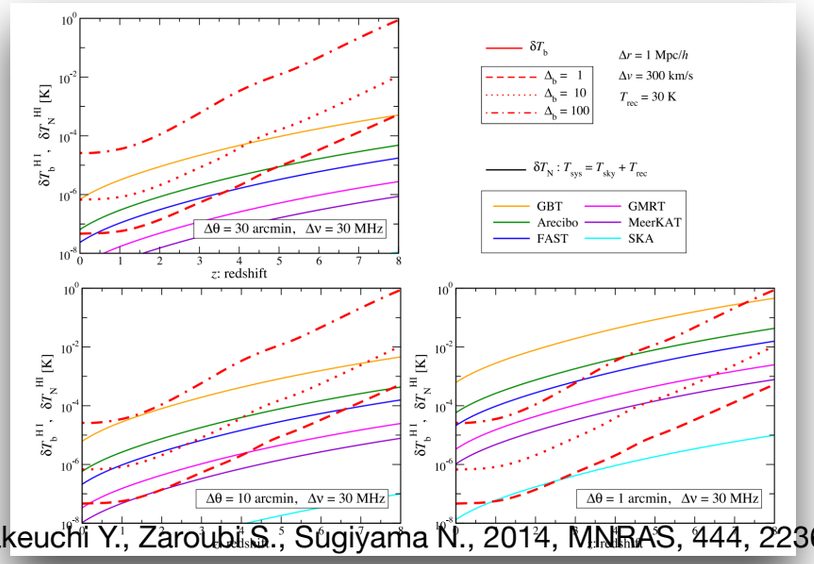
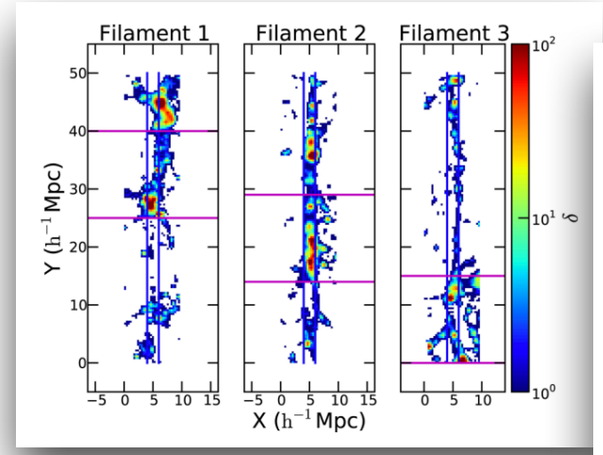
HI in the filament

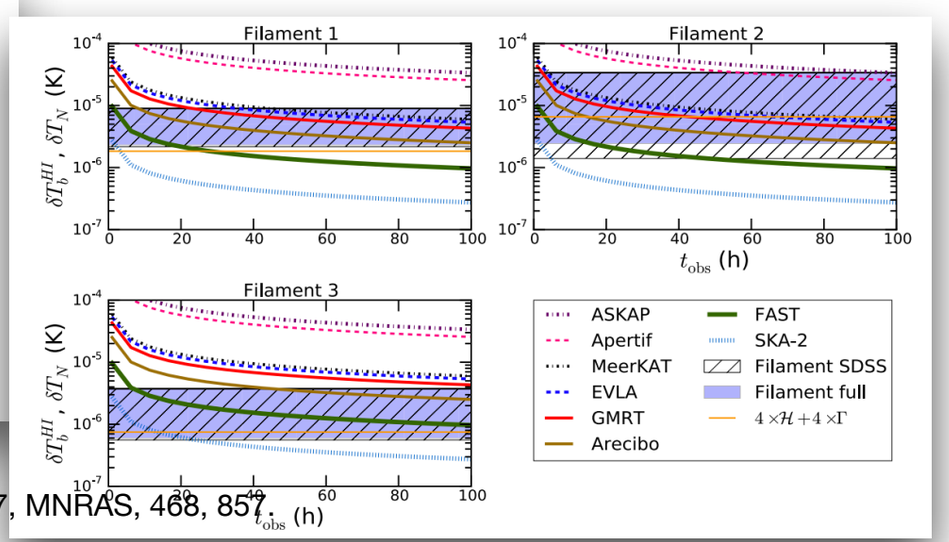
- **HI in the IGM are highly ionized after EoR**
- **Simulation shows that it is still detectable with ~100 hr integration time**



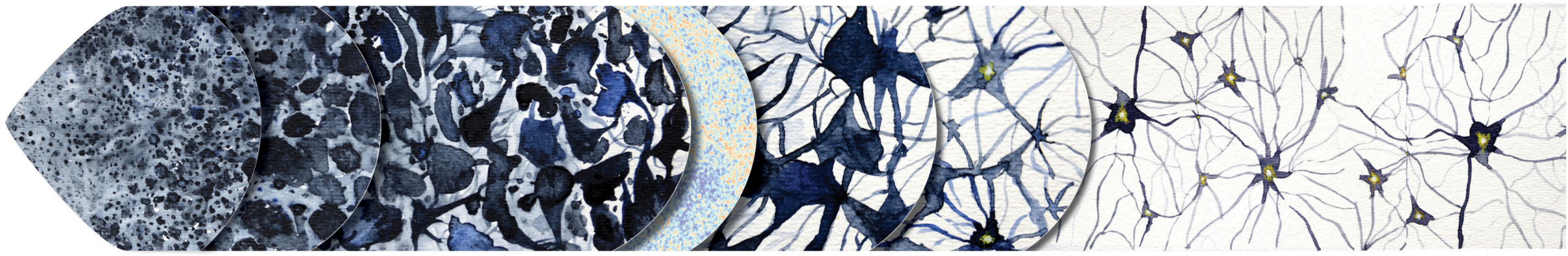
Takeuchi Y., Zaroubi S., Sugiyama N., 2014, MNRAS, 444, 2236.



Kooistra R., Silva M.~B., Zaroubi S., 2017, MNRAS, 468, 857.



10^{-32} seconds | **1 second** | **100 seconds** | **380 000 years** | **300–500 million years** | **Billions of years** | **13.8 billion years**



Beginning of the Universe

Inflation
Accelerated expansion of the Universe

Formation of light and matter

Light and matter are coupled
Dark matter evolves independently: it starts clumping and forming a web of structures

Light and matter separate
- Protons and electrons form atoms
- Light starts travelling freely: it will become the Cosmic Microwave Background (CMB)

Dark ages
Atoms start feeling the gravity of the cosmic web of dark matter

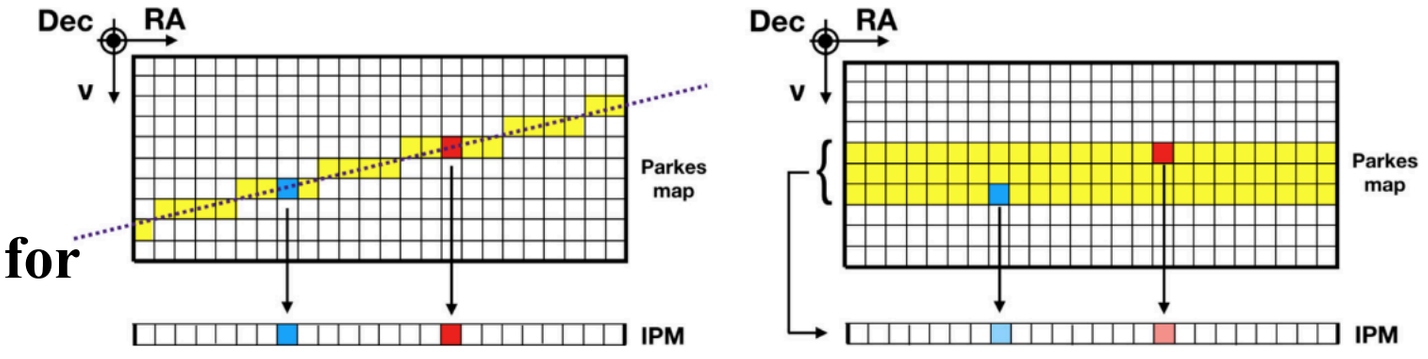
First stars
The first stars and galaxies form in the densest knots of the cosmic web

Galaxy evolution

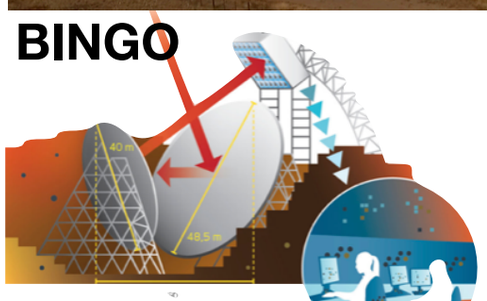
The present Universe

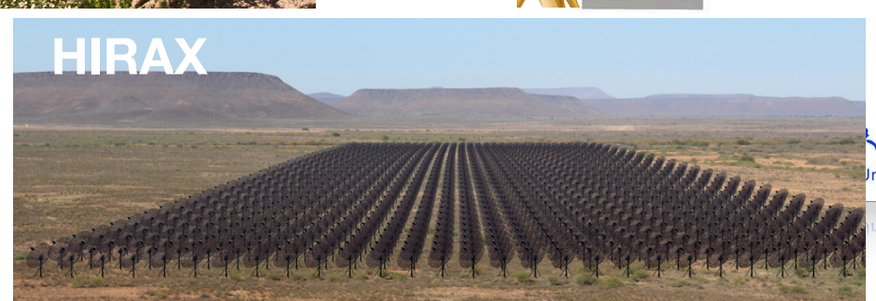
HI Intensity Mapping (IM) Survey with Galaxy Pairwise-Stacking (GPS)

- **HI IM can be quickly carried out and maps LSS within a large cosmic volume.**
- **Assume filaments connect clusters.**
- **We use the galaxies as proxies for the cluster positions.**



Tramonte D., Ma Y.-Z., Li Y.-C., Staveley-Smith L., 2019, MNRAS, 489, 385.



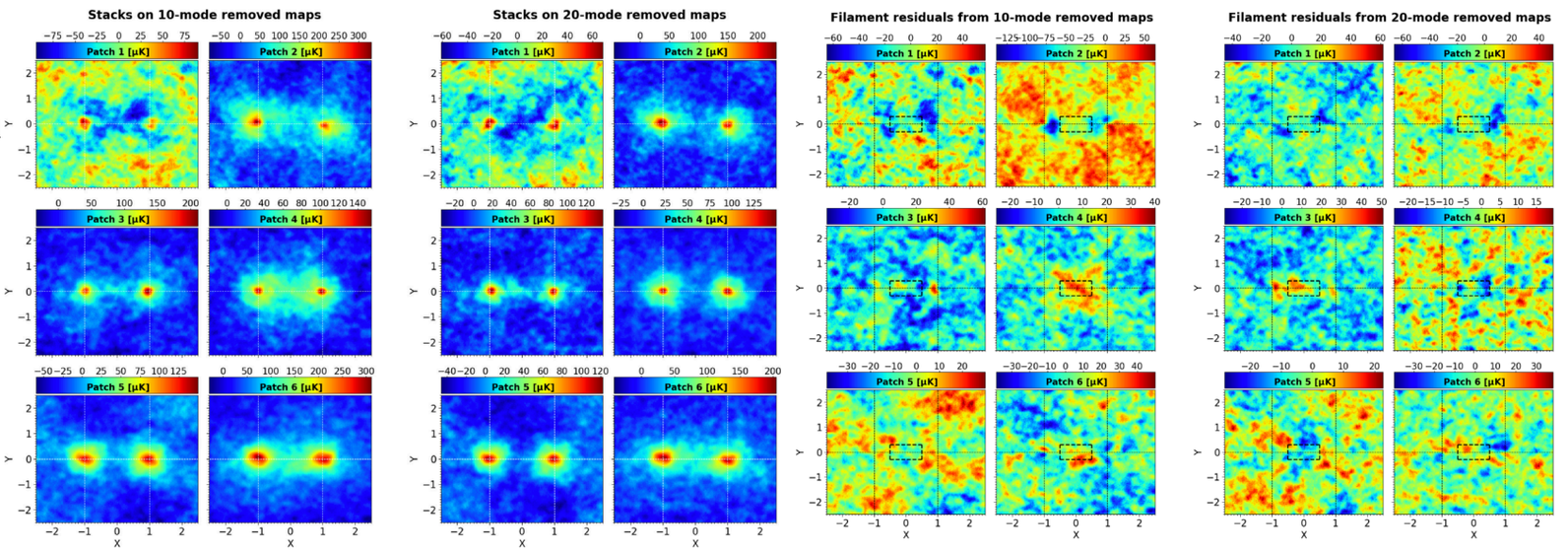


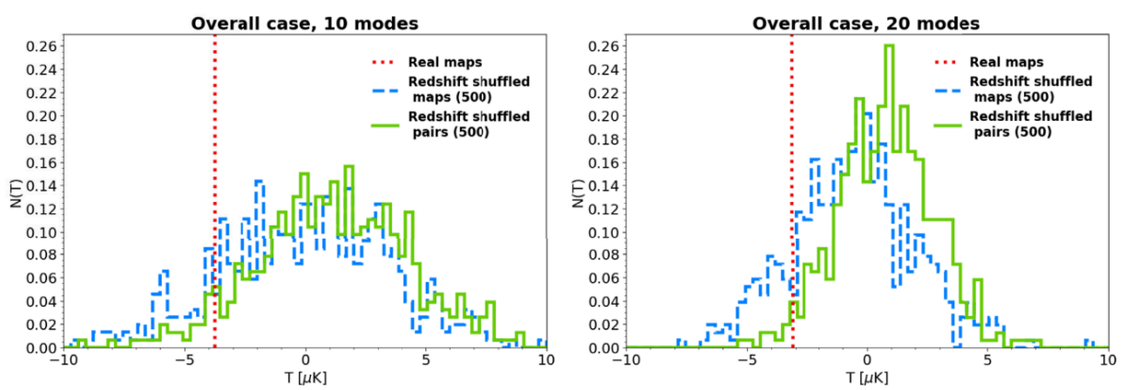
GPS with Parkes

- **GPS of HI maps**

Time-ordered data	HI maps	Foreground-cleaned HI maps	Filaments

- **Achieve an upper limit for filament HI**
- **Limited by the lower angular resolution**
- **Limited by the lower sensitivity**
- **Limited by foreground residule**





Tramonte D., Ma Y.-Z., Li Y.-C., Staveley-Smith L., 2019, MNRAS, 489, 385.

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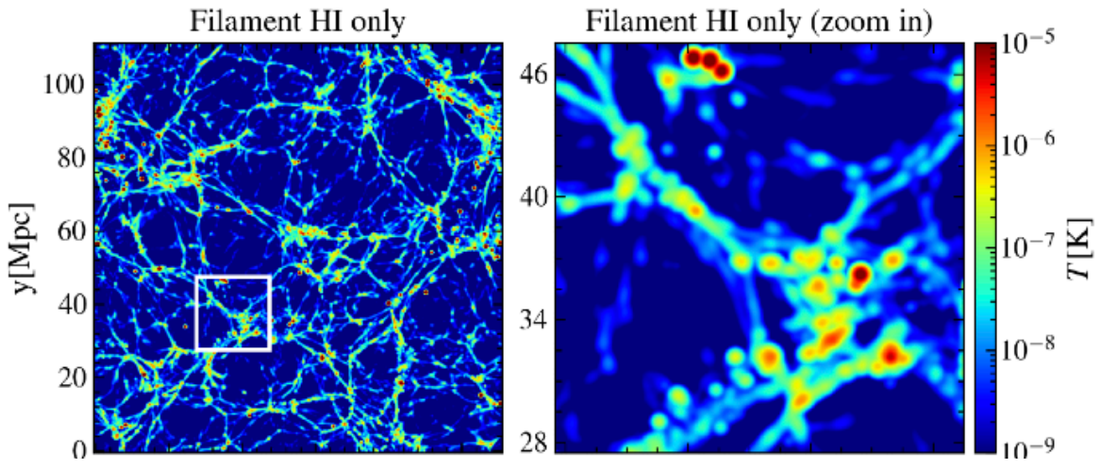
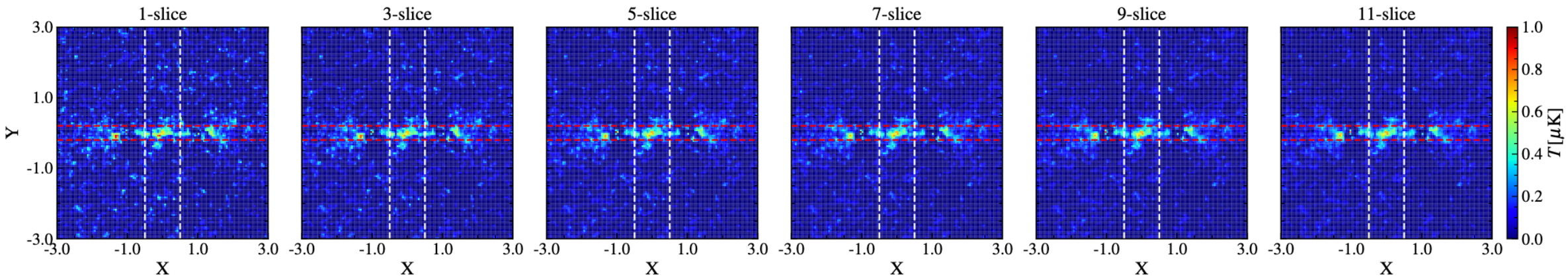
Simulations Test

based on FAST HI Pilot survey





- **Using TNG simulation snapshot at z~0.1**
- **Remove particles belonging to galaxies**
- **Make the HI cube with filament HI only**
- **Simulate the SDSS Main Galaxy Sample**
- **Apply the galaxy pairwise-stacking**

Liu, Diyang and Li, Yichao et. Al. under review.

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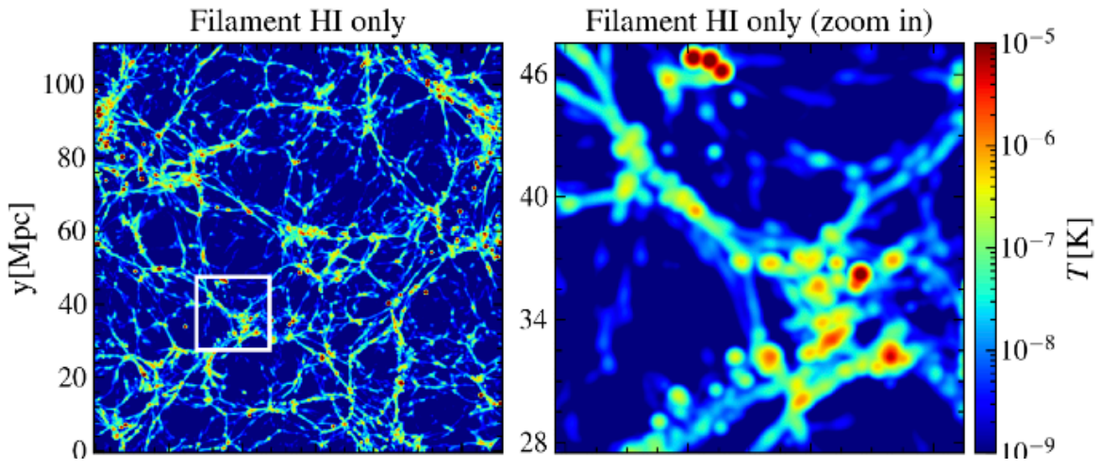
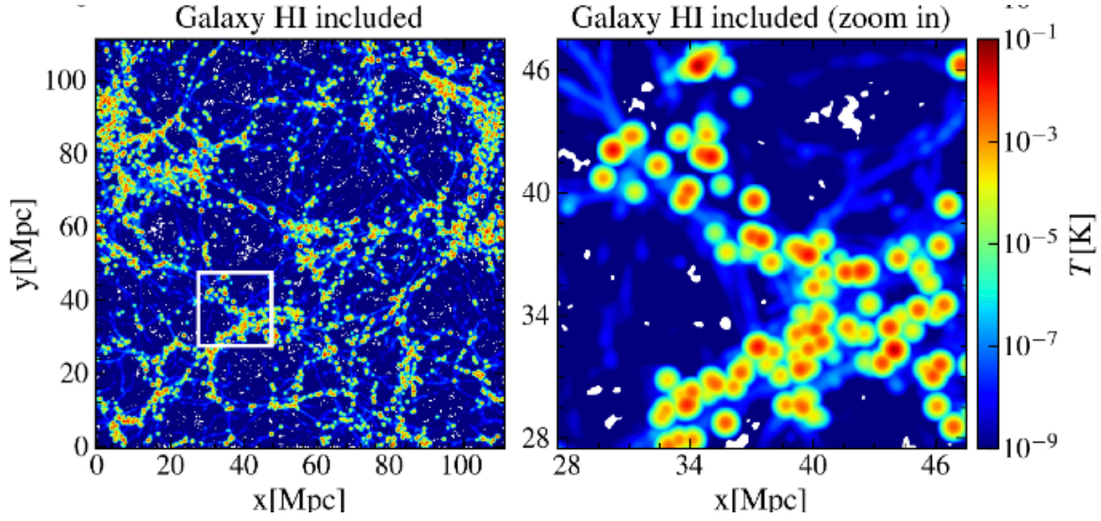
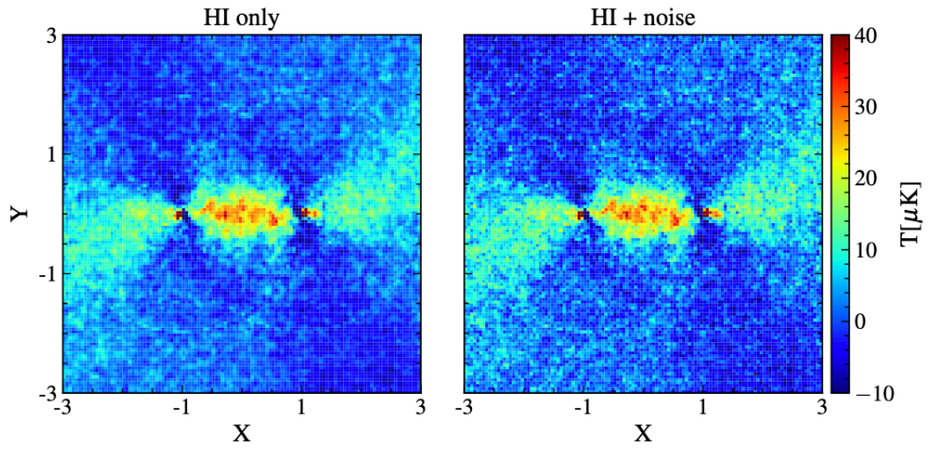
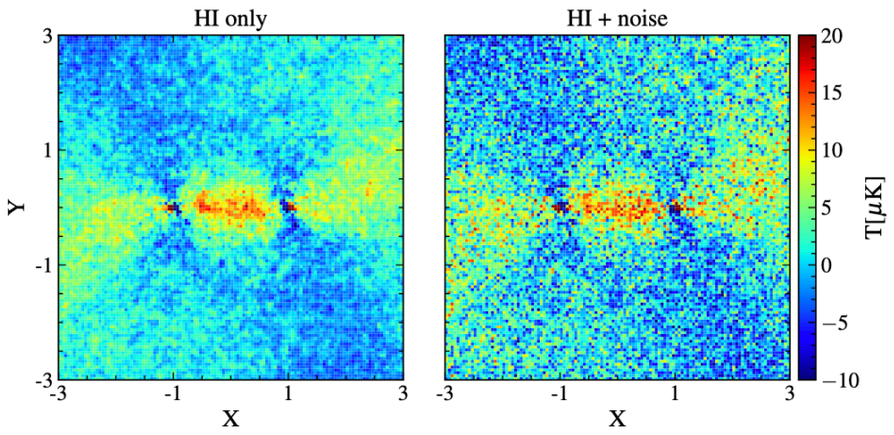
based on FAST HI Pilot survey









Liu, Diyang and Li, Yichao et. al. under review.

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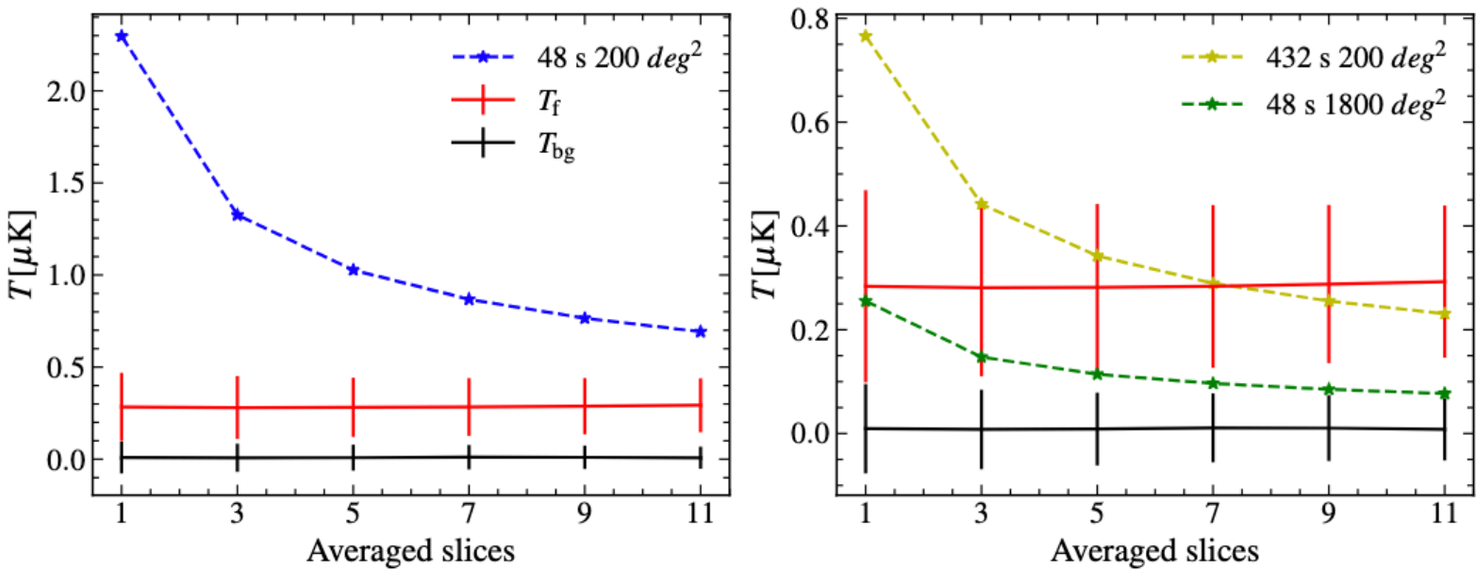
- ~~**Remove particles belonging to galaxies**~~
- **Make the HI cube with filament HI only**
- **Simulate the SDSS Main Galaxy Sample**
- **Apply the galaxy pairwise-stacking**

Simulation Forecast

- **Combining multiple frequency slices**
- **Cosmic variance dominating**
- **Large-area survey has better performance than small-area deep survey**
- **The next-generation HI intensity mapping survey has great potential for filament studies.**



Liu, Diyang and Li, Yichao et. al. under review

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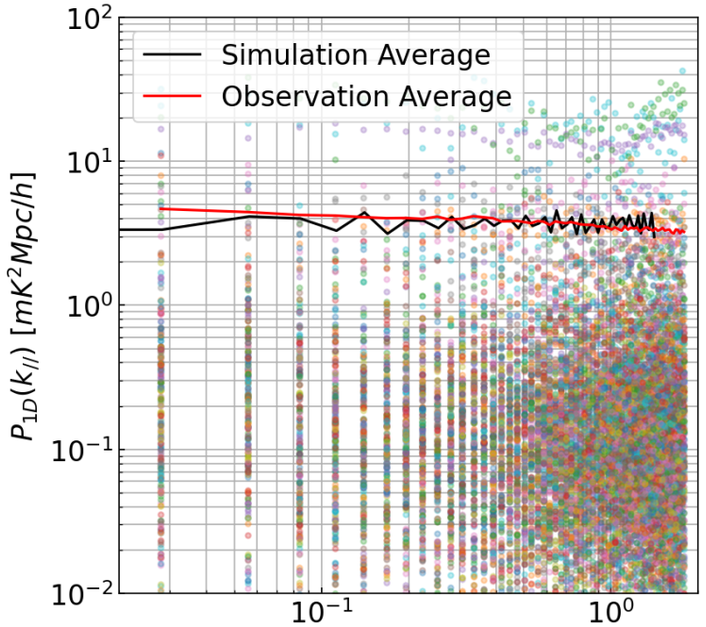
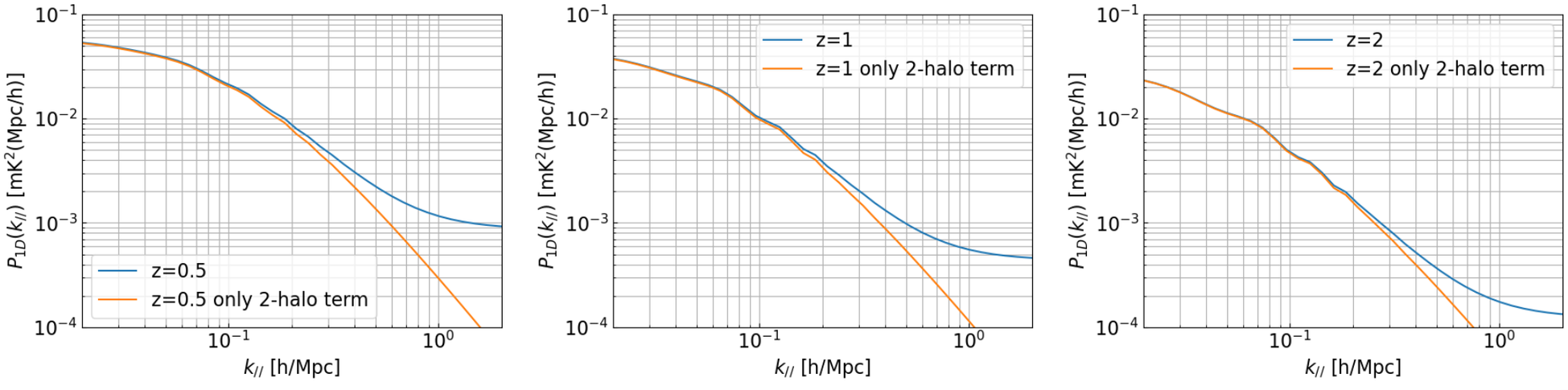
One-Dimensional PS

- **FAST 1D power spectrum**
  - $P_{1\mathrm{D}}\left(k_{\parallel}, z\right)=\int \frac{\mathrm{d}\boldsymbol{k}_{\perp}}{(2\pi)^2} P_{3\mathrm{D}}\left(k_{\parallel}, \boldsymbol{k}_{\perp}, z\right)$
  - Single pointing observation for FRB
    - 250 pointings, with each 20-30 min integration time
    - Redshift 0.007 - 0.084
  - Shot noise dominated
- **SKA 1D power spectrum**
  - Larger beam size
  - Lower shot noise
  - A crucial method for future HI cosmology.



1D PS estimation using FAST single pointing observations
Zhao, Boyan; Liu, Yingfeng; Wang, Yougang et. al. In prep.



1D PS simulation for SKA
Zhao, Boyan; Wang, Yougang et. al. In prep.

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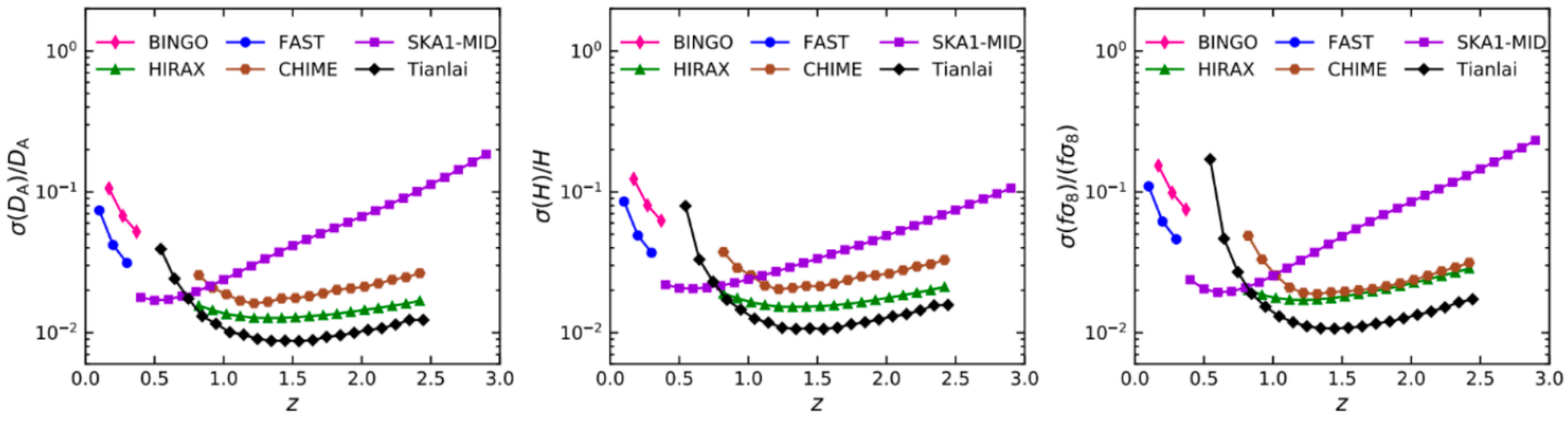
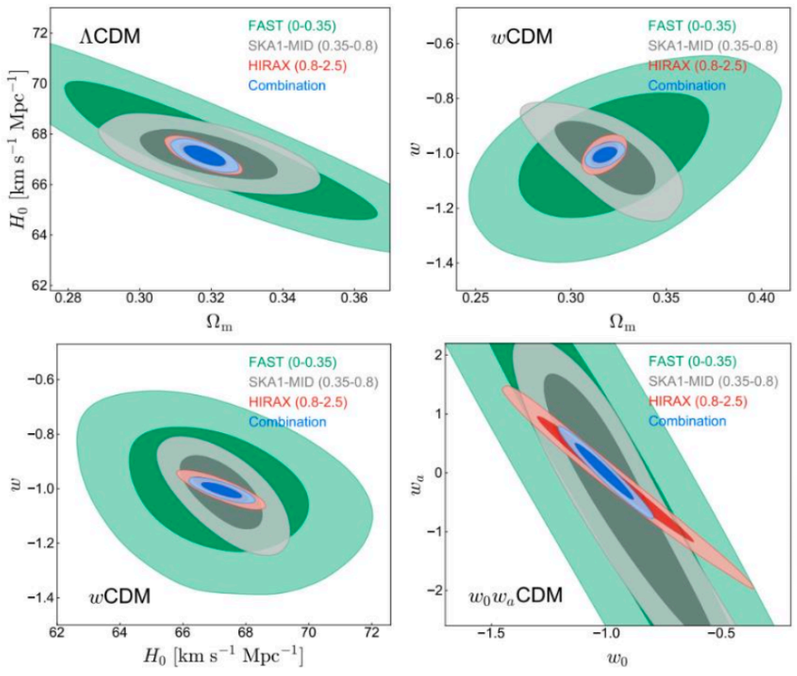
Precise Probe for Late Universe

- **The synergy between current HI experiments**



P.-J. Wu, X. Zhang, 2022 JCAP 01 060

P.-J. Wu, Y. Li, J.-F. Zhang, X. Zhang, 2023, Sci. China Phys. Mech. Astron. 66 7, 270413



HIRAX
(z = 0.8 ~ 2.5)

SKA
(z = 0.35 ~ 0.8)

FAST
(z = 0 ~ 0.35)

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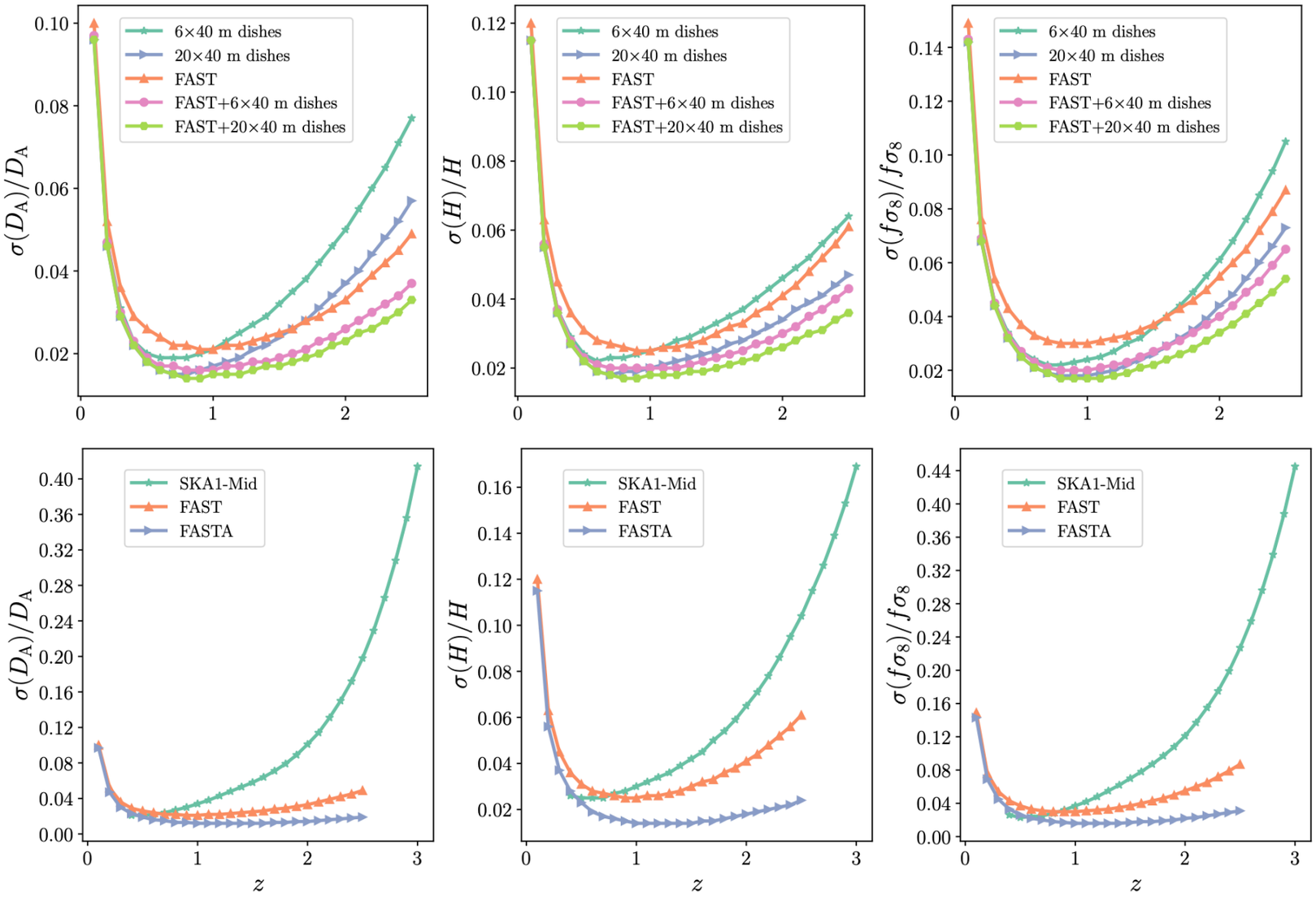
Precise Probe for Late Universe

- **The synergy between current HI experiments**
- **The synergy between future HI experiments**



Pan J.-D., Wu P.-J., Du G.-H., Li Y., Zhang X., 2024, arXiv, arXiv:2408.00268.

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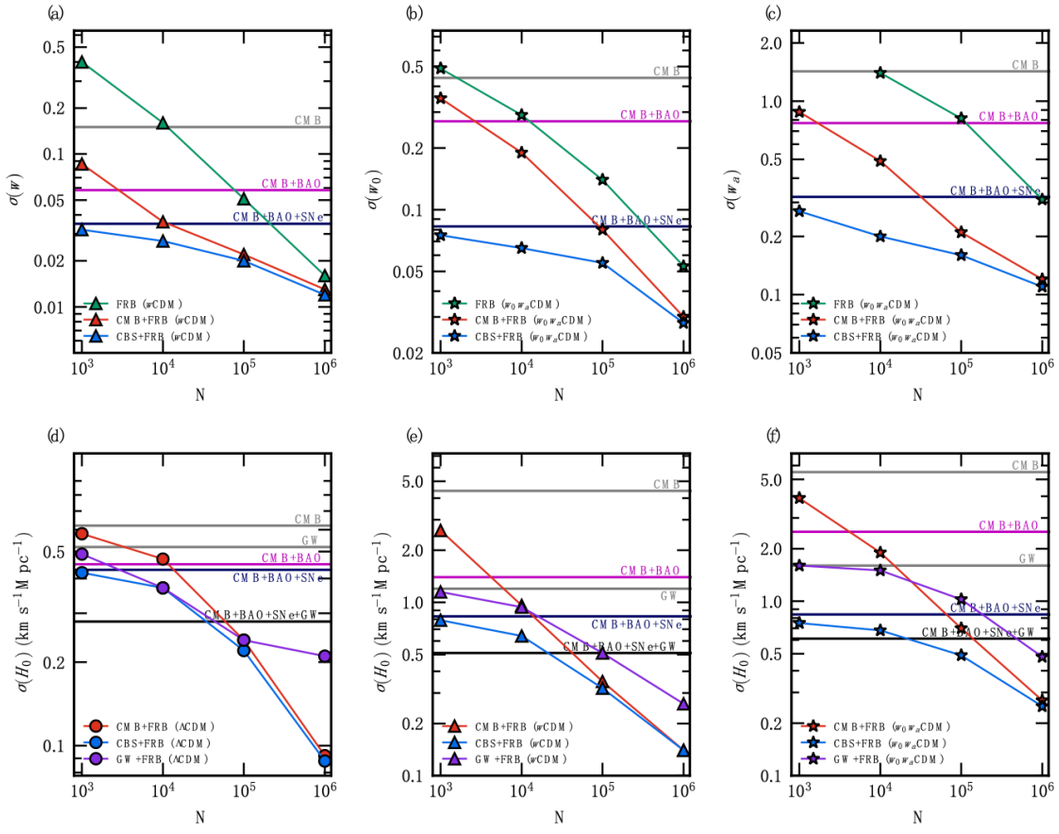
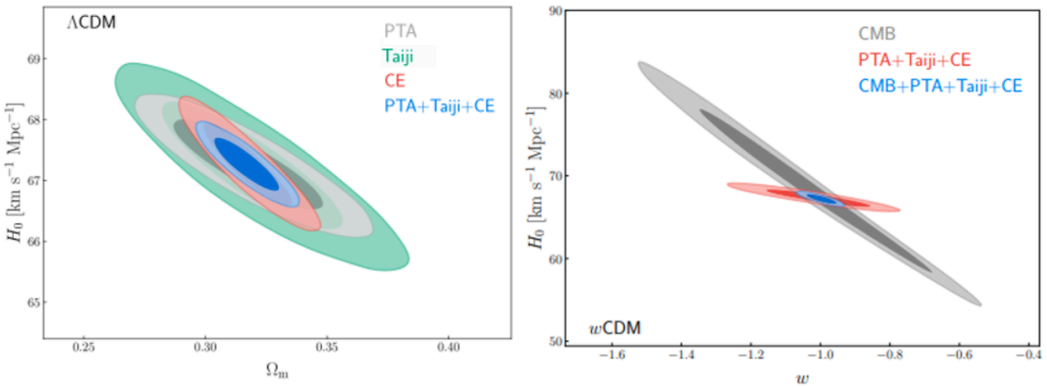
Precise Probe for Late Universe

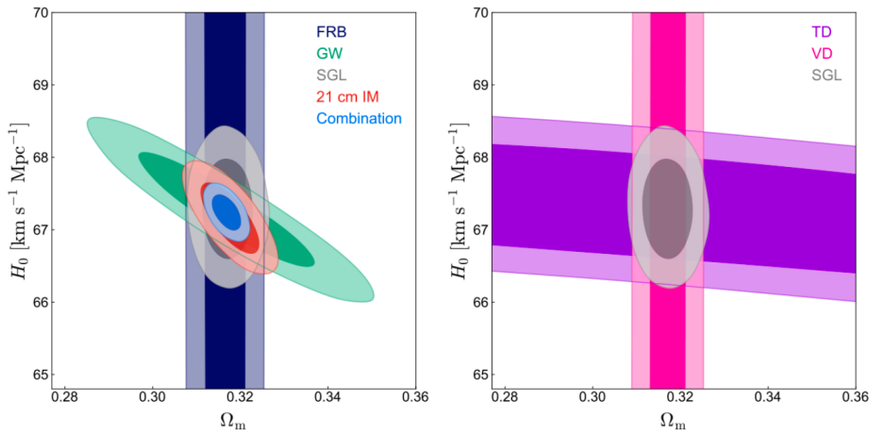
- **The synergy between current HI experiments**
- **The synergy between future HI experiments**
- **The synergy between different cosmic probes**
  - FRB, GW, SGL



J.-G. Zhang, Z.-W. Zhao, Y. Li, J.-F. Zhang, D. Li, X. Zhang, 2023 SCPMA 66, 120412



S.-J. Jin, S.-S. Xing, Y. Shao, J.-F. Zhang, X. Zhang, 2023 CPC 6, 065104



Wu, Peng-Ju; Shao, Yue; Jin, Shang-Jie; Zhang, Xin; 2023,JCAP, Volume 2023, id. 052.

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Summary

- **The 1/f noise feature analysis for the SKA HI intensity mapping survey**
  - Yichao Li; Wenkai Hu; et. al.
    - **One of the key systematic issues for HI intensity mapping**
- **Hunting HI filament via galaxy pairwise stacking analysis with future HI intensity mapping survey**
  - Yichao Li; Diyang Liu; et. al.
    - **The next-generation HI intensity mapping survey has great potential for filament studies.**
- **One-dimensional power spectrum with the SKA**
  - Yougang Wang; Yichao Li; et. Al.
    - **1D power spectrum is a crucial method for future HI cosmology.**
- **Forging a precise probe for the late universe based on 21-cm cosmology**
  - Xin Zhang; Yichao Li; et. al.
    - **The synergies between HI experiments, as well as different cosmic probes, are crucial for future precise cosmology.**

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Summary

- **The 1/f noise feature analysis for the SKA HI intensity mapping survey**
  - Yichao Li; Wenkai Hu; et. al.
    - **One of the key systematic issues for HI intensity mapping**
- **Hunting HI filament via galaxy pairwise stacking analysis with future HI intensity mapping survey**
  - Yichao Li; Diyang Liu; et. al.
    - **The next-generation HI intensity mapping survey has great potential for filament studies.**
- **One-dimensional power spectrum with the SKA**
  - Yougang Wang; Yichao Li; et. Al.
    - **1D power spectrum is a crucial method for future HI cosmology.**
- **Forging a precise probe for the late universe based on 21-cm cosmology**
  - Xin Zhang; Yichao Li; et. al.
    - **The synergies between HI experiments, as well as different cosmic probes, are crucial for future precise cosmology.**

Many thanks for your attention!

Dr. Yichao Li on behalf of joint research in NEU and NAOC

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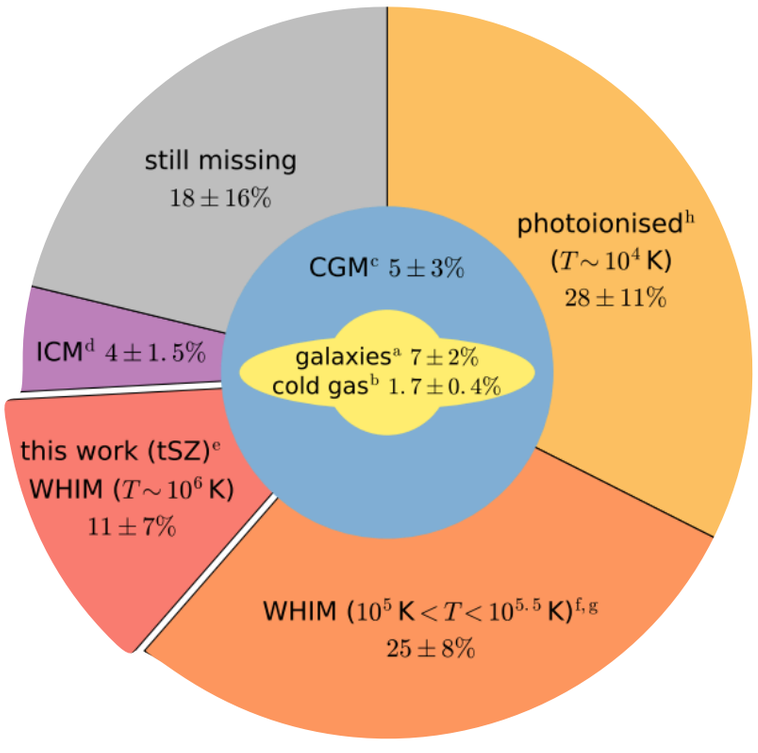
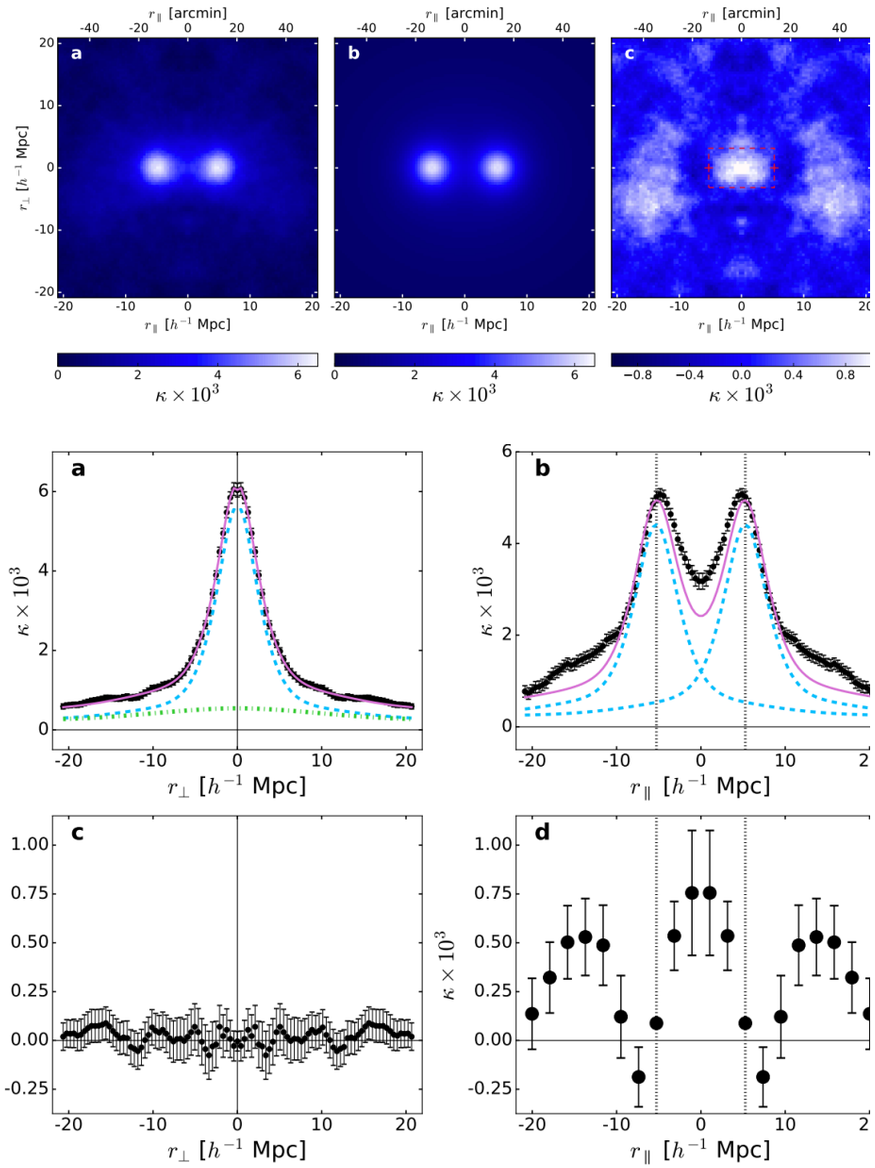
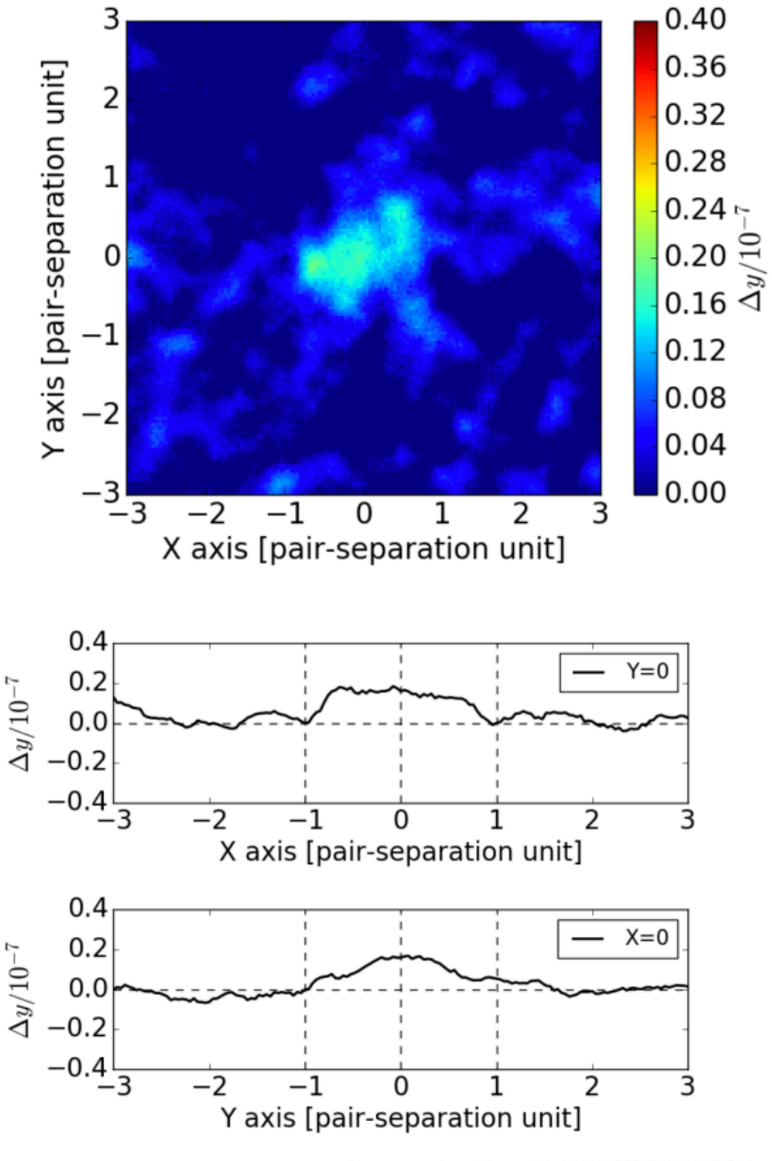
GPS on tSZ effect

- **GPS of tSZ effect with Planck data**
  - LOOKING FOR THE MISSING BARYONS LOCATED IN THE FILAMENTS.





de Graaff A., Cai Y.-C., Heymans C., Peacock J. A., 2019, A&A, 624, A48.



Tanimura H., Hinshaw G., McCarthy I. G., Van Waerbeke L., Aghanim N., Ma Y.-Z., Mead A., et al., 2019, MNRAS, 483, 223.