Impact of astrophysical scatter on the $[\mathrm{H\,I}]_{21\mathrm{cm}}$ bispectrum

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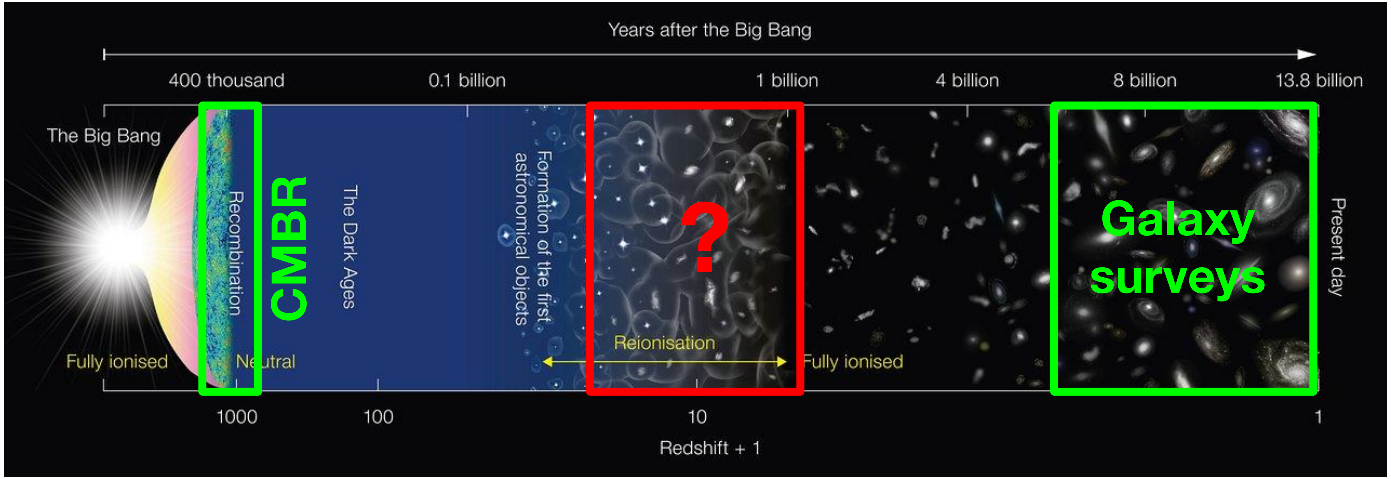
Background

- I work on simulations of cosmic reionization and line-intensity mapping (LIM)
- I investigate models of reionization and work on forecasting and interpretation of observable LIM summary statistics
- Soon to submit my PhD thesis

Outline of the Talk

- Epoch of Reionization and line-intensity mapping
- Impact of line-luminosity scatter on $[\mathrm{C\,II}]_{158\mu\mathrm{m}}$ LIM signal
- Astrophysical scatter in star-formation rate
- Simulating $[\mathrm{H\,I}]_{21\mathrm{cm}}$ signal with scatter
- Impact of scatter on the $[\mathrm{H\,I}]_{21\mathrm{cm}}$ bispectrum
- Detectability
- Future scope

The Epoch of Reionization (EoR)

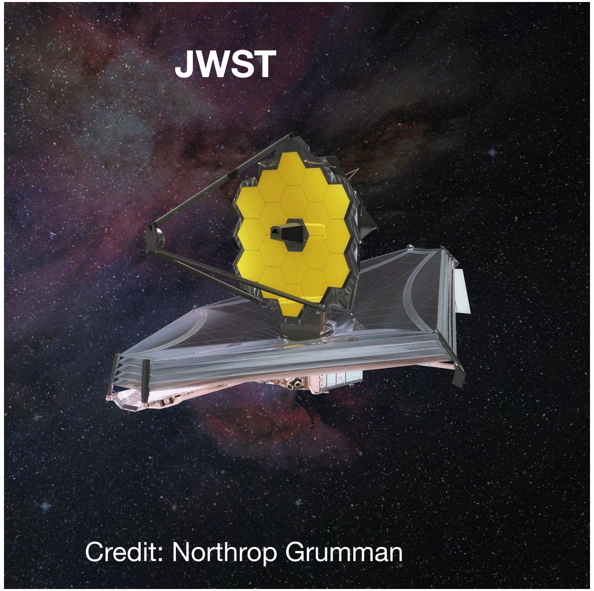


Credit: NAOJ

- First luminous sources (galaxies) were formed
- Ionizing radiation from the luminous sources reionized the neutral IGM

How to probe the EoR universe?

Probing the EoR: galaxies

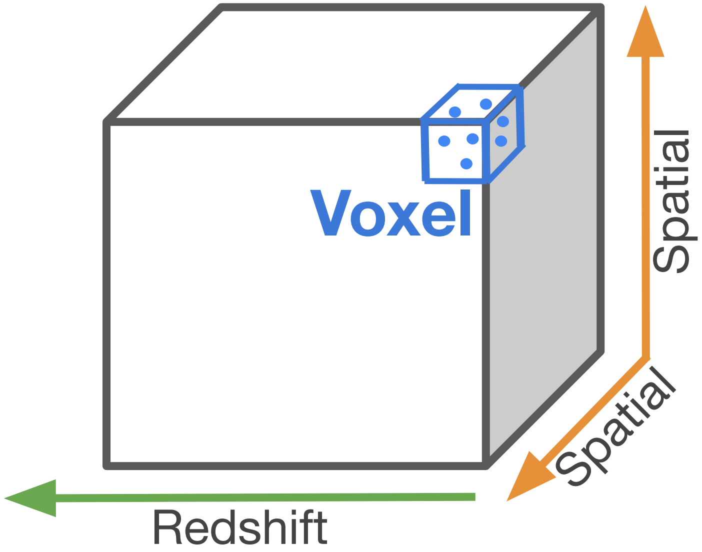


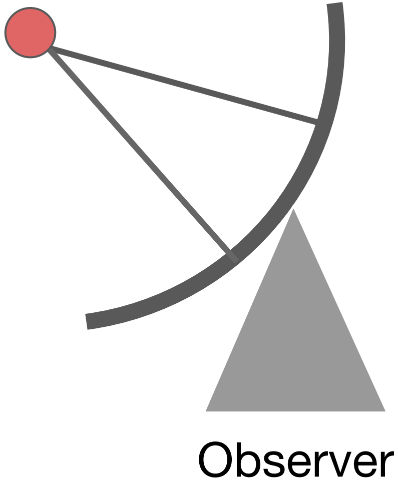
Challenges!

- Demanding sensitivity limits
- Demanding resolutions
- Expensive to operate, therefore it becomes impractical to map large galaxy samples

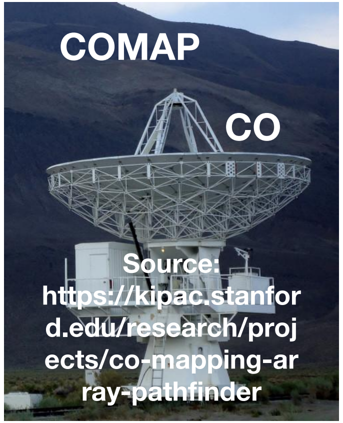
Line-intensity mapping

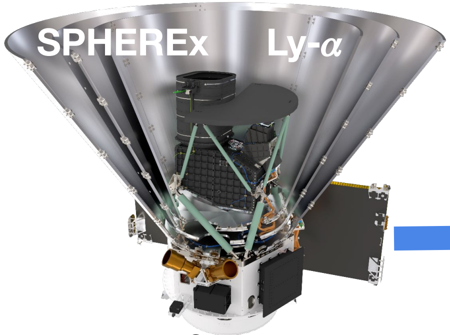
Accumulate the cumulative flux of numerous sources from a comparatively small region (Voxel)



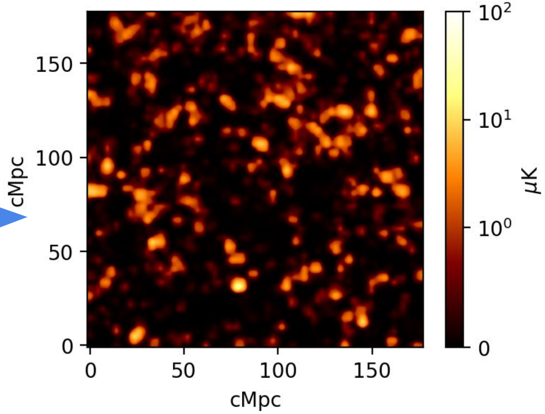


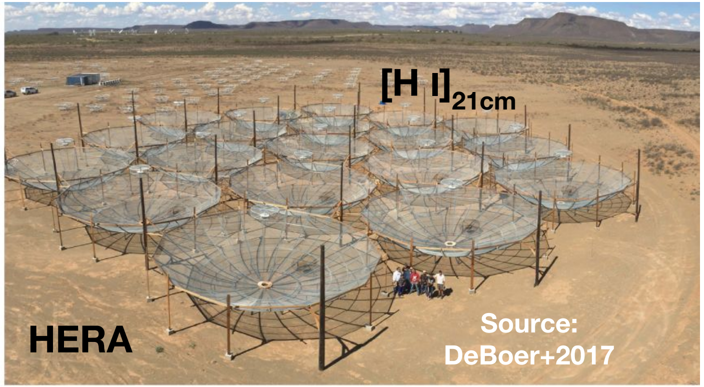
Probing the EoR with Intensity Mapping: galaxies and IGM

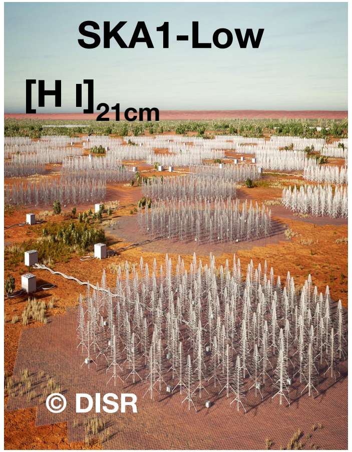


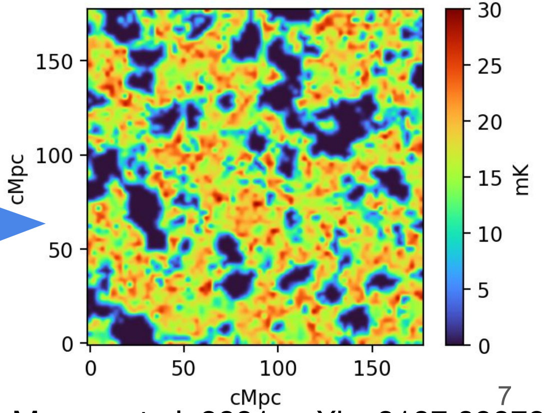


Source: https://spherex.caltech.edu/page/instrument







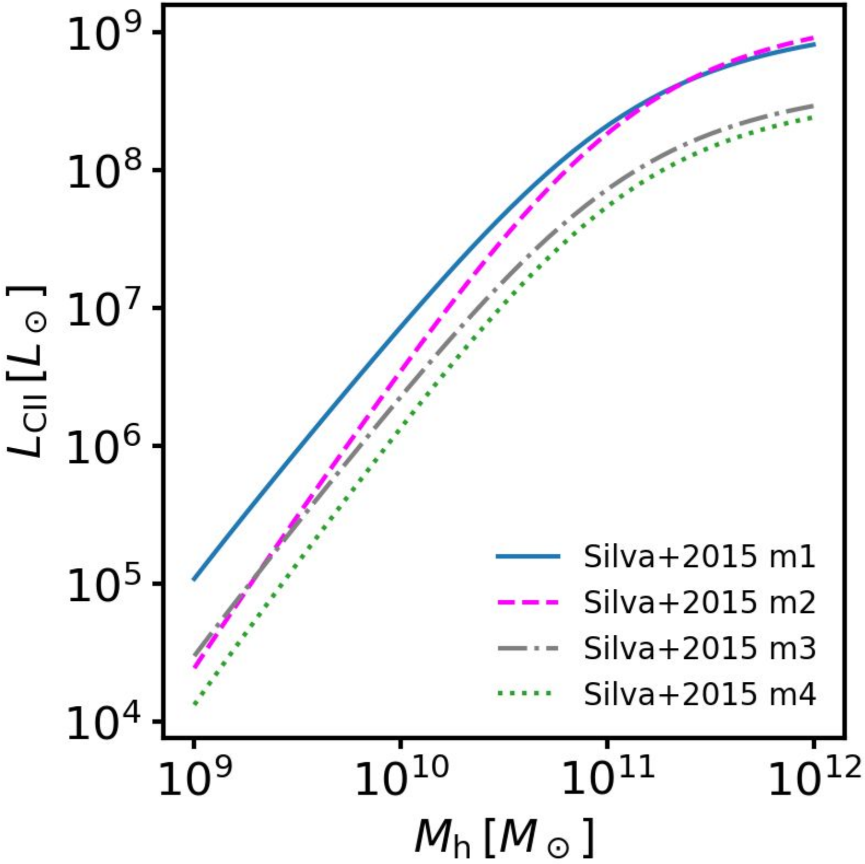


Murmu et al. 2021, arXiv: 2107.09072

Observable summary statistics

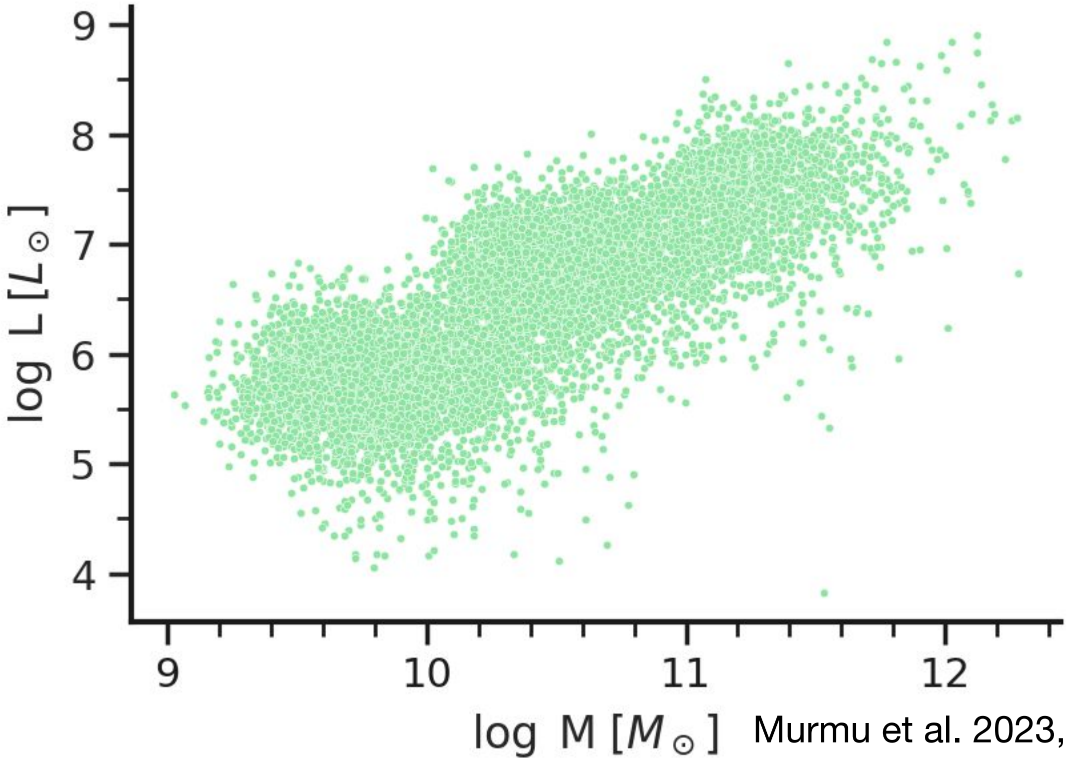
Modelling (analytical/numerical) of observable summary statistics (e.g. power spectrum) is essential to interpret LIM observations

[C II]$_{158\mu m}$ vs $M_{\rm halo}$ relation



Halo mass → SFR → $L_{\rm CII}$

[C II]$_{158\mu m}$ line-luminosity scatter: SIMBA + SIGAME

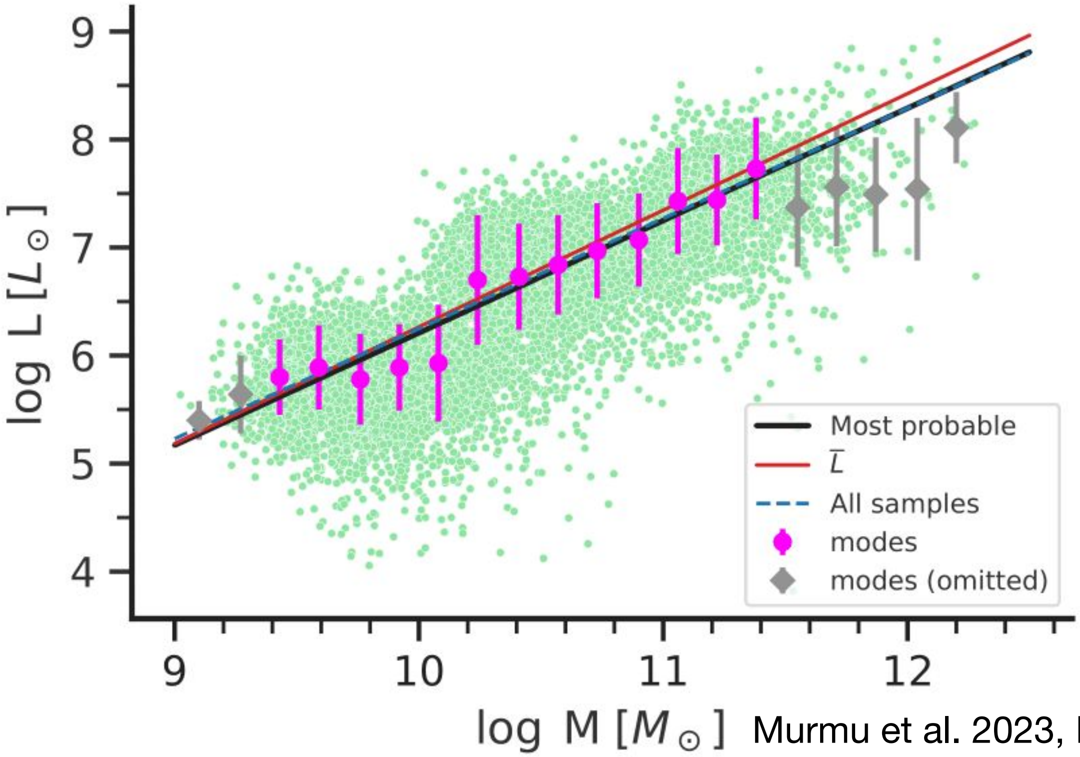


Murmu et al. 2023, MNRAS, 518(2), 3074

[C II]$_{158\mu m}$ line-emission exhibits scatter with respect to the host halo mass of the galaxy

Arises due to the multi-phase state of the ISM

[C II]$_{158\mu m}$ line-luminosity scatter: SIMBA + SIGAME



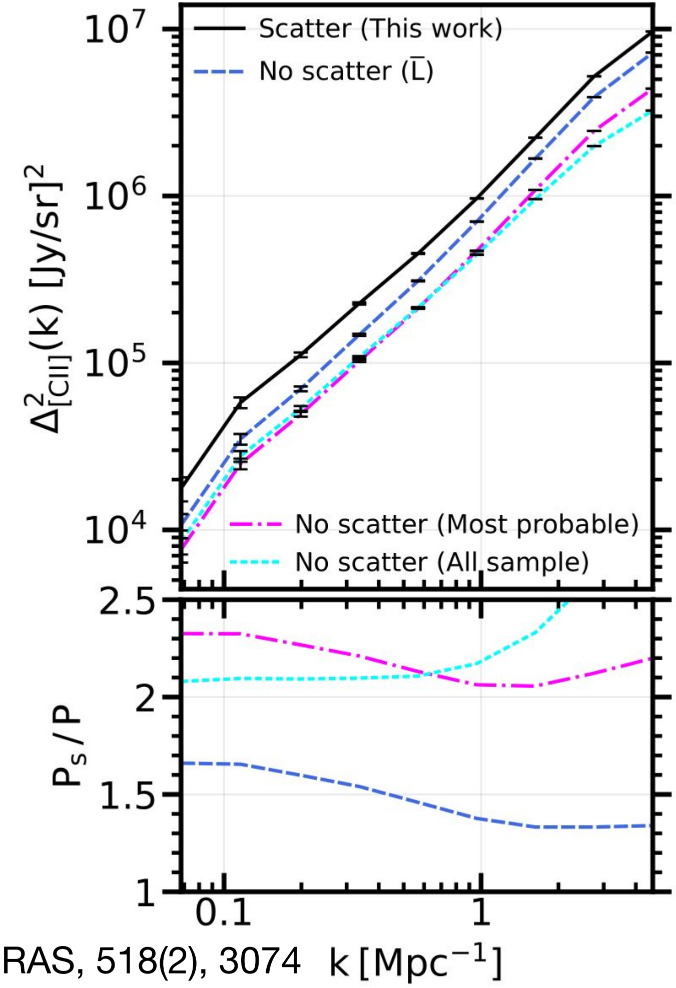
Murmu et al. 2023, MNRAS, 518(2), 3074

This is expected to impact the observable summary statistics (e.g. power spectrum)

Impact of line-luminosity scatter on the [C II] power spectrum

The non-uniform scatter impacts the power spectrum regardless of the fit used for comparison

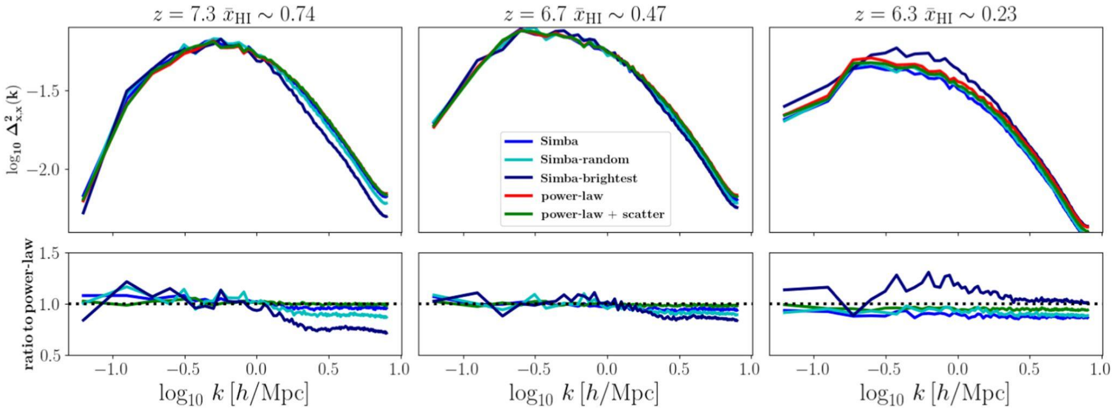
When compared against the most-probable fit, this impact can be modelled robustly, unlike the mean fit



Murmu et al. 2023, MNRAS, 518(2), 3074

How variability in the star-formation rate (astrophysical scatter) affects reionization of the IGM?

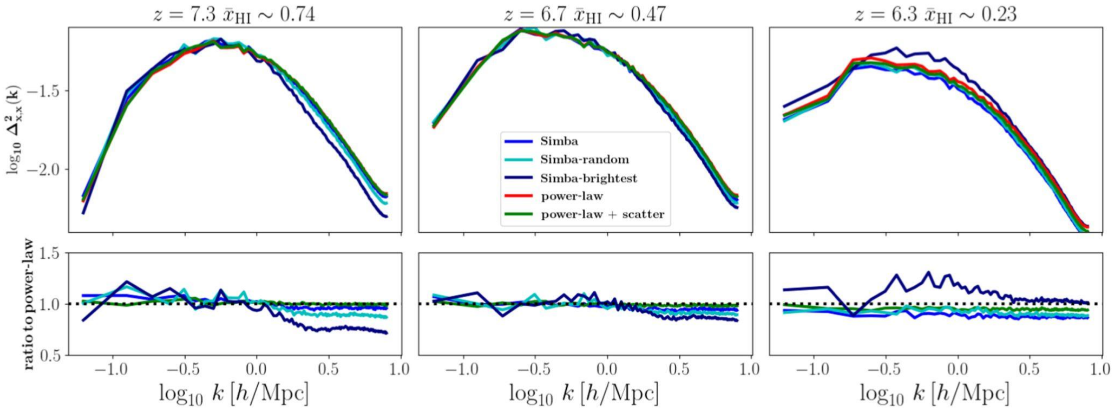
Impact on power spectrum



Hassan et al. 2022, *ApJ*, 931, 62

The ionization power spectrum is mostly unaffected, when astrophysical scatter is included in modelling reionization

Impact on power spectrum



Hassan et al. 2022, *ApJ*, 931, 62

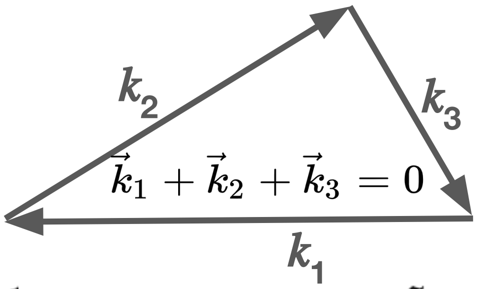
The ionization power spectrum is mostly unaffected, when astrophysical scatter is included in modelling reionization

- Ionization field is not directly observable, unlike the brightness temperature fluctuations of the $[H\ I]_{21cm}$ signal
- $[H\ I]_{21cm}$ signal is known to be highly non-Gaussian and astrophysical scatter might introduce additional non-Gaussianities

[H I]$_{21cm}$ bispectrum

[H I]$_{21cm}$ signal is known to be highly non-Gaussian and astrophysical scatter might introduce additional non-Gaussianities

Higher order statistics such as bispectrum can capture non-Gaussianities in the [H I]$_{21cm}$ signal



$$B_m(\vec{k}_1, \vec{k}_2, \vec{k}_3) = \frac{1}{N_{\rm tri} V} \sum_{[\vec{k}_1+\vec{k}_2+\vec{k}_3=0]\in m} \tilde{\Delta} T_b(\vec{k}_1) \tilde{\Delta} T_b(\vec{k}_2) \tilde{\Delta} T_b(\vec{k}_3)$$

Simulations of the [H I]$_{21cm}$ signal

Usual reionization source model:

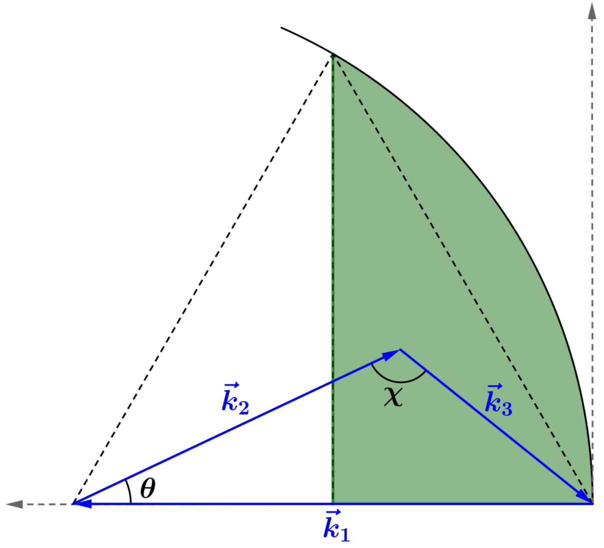
$$N_\gamma \propto \overline{\mathrm{SFR}}(M_h, z)$$

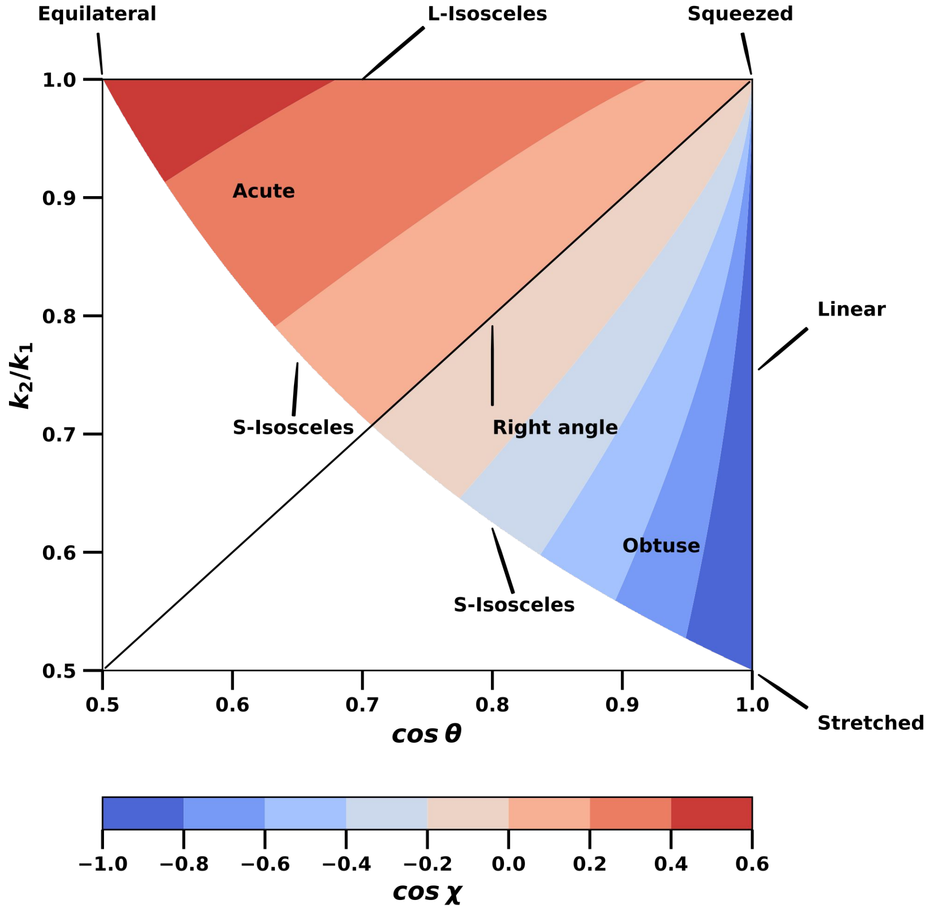
Simplistic model for astrophysical scatter:

$$N_\gamma \propto \overline{\mathrm{SFR}}(M_h, z) + \text{Log-normal scatter}$$

We generate 50 realizations of the [H I]$_{21cm}$ signal for each of six neutral fractions that we considered (a total of 300 simulations were done)

Bispectrum triangle configurations





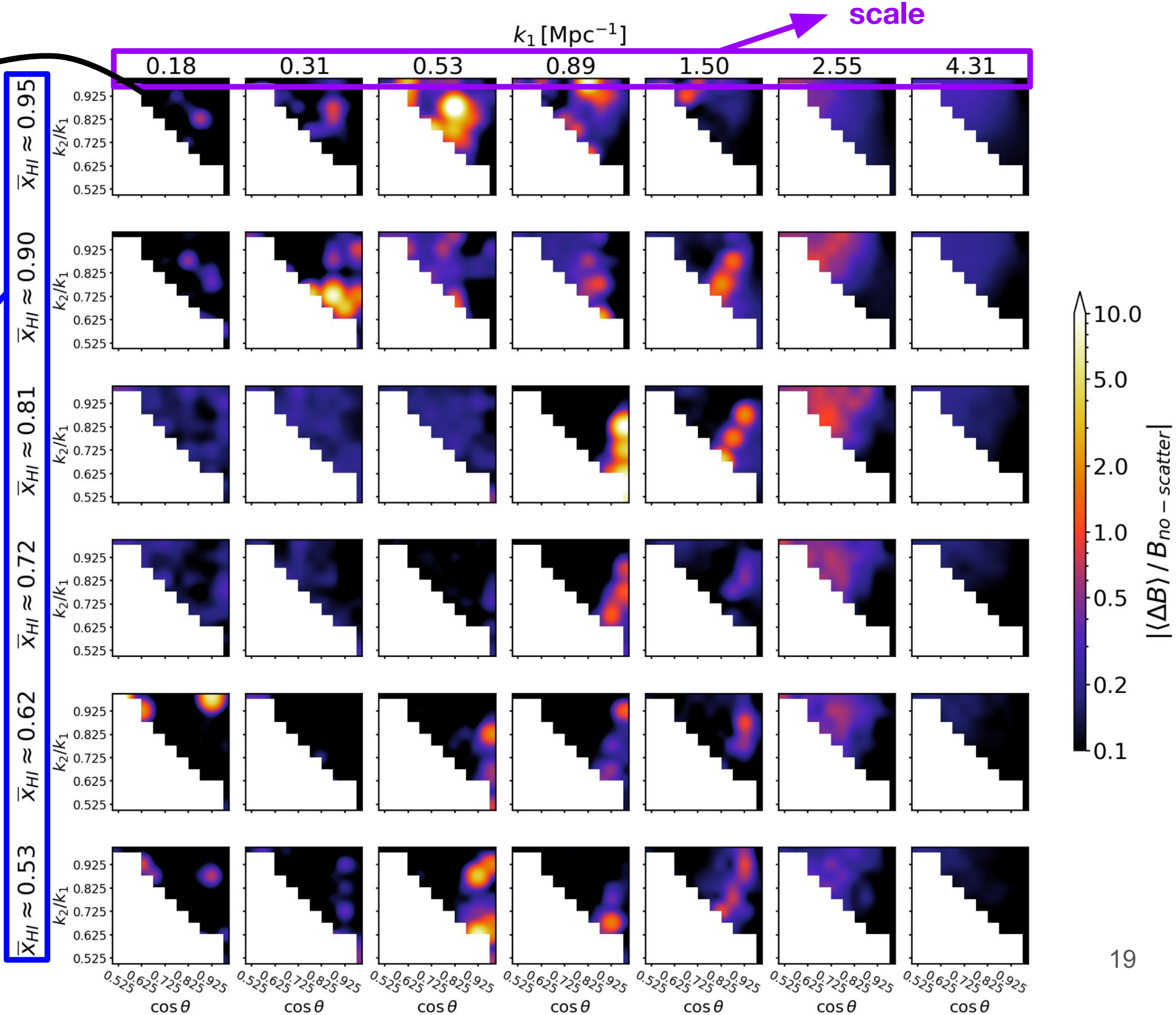
Majumdar et al. 2020, MNRAS, 499(4), 5090

Impact of scatter

$$\langle \Delta B \rangle / B_{\text{no scatter}}$$

x_{HI}

A total of 300 realizations were simulated

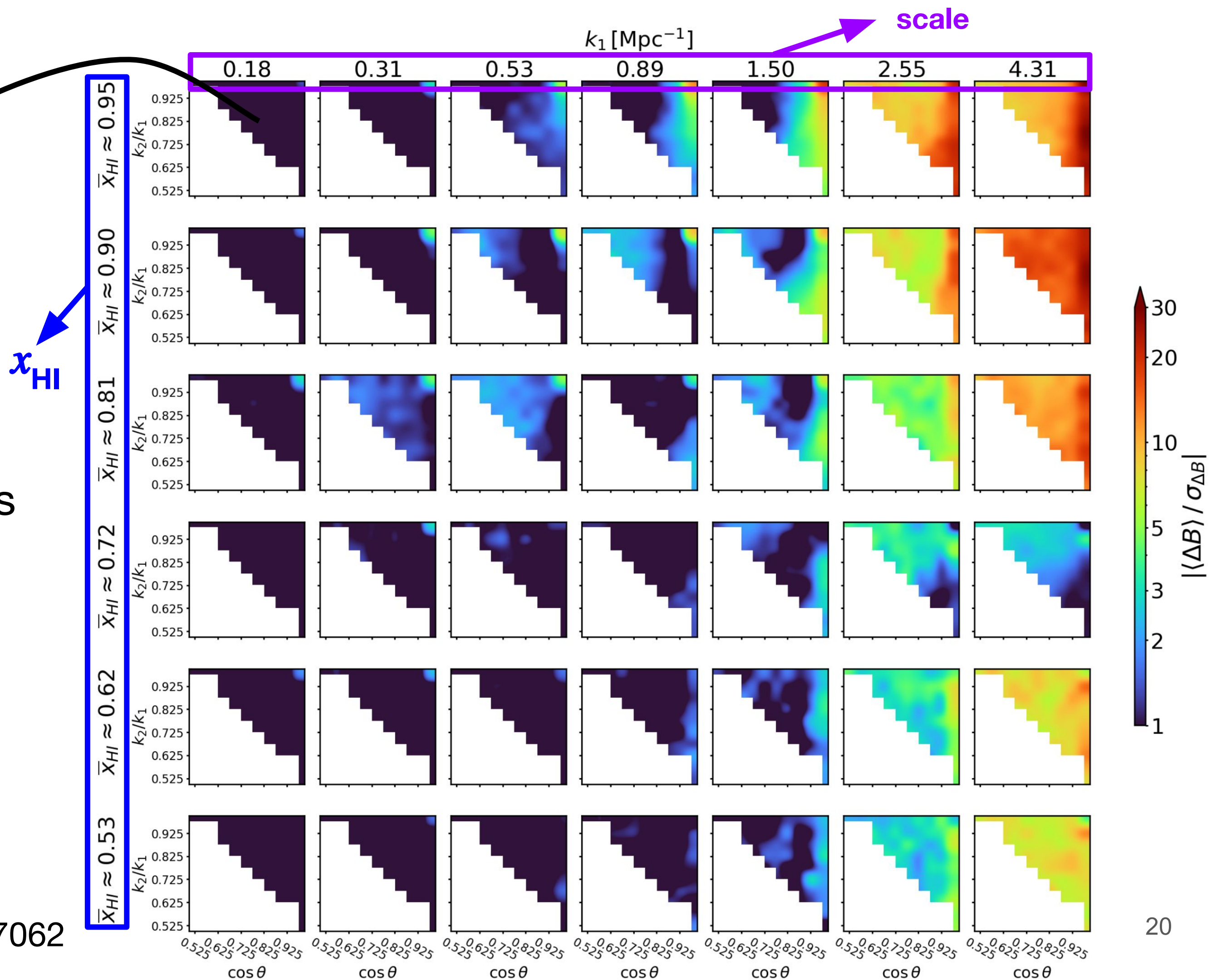


Murmu et al. 2023, arXiv: 2311.17062

Statistical significance

$$\langle \Delta B \rangle / \sigma_{\Delta B}$$

A total of 300 realizations were simulated



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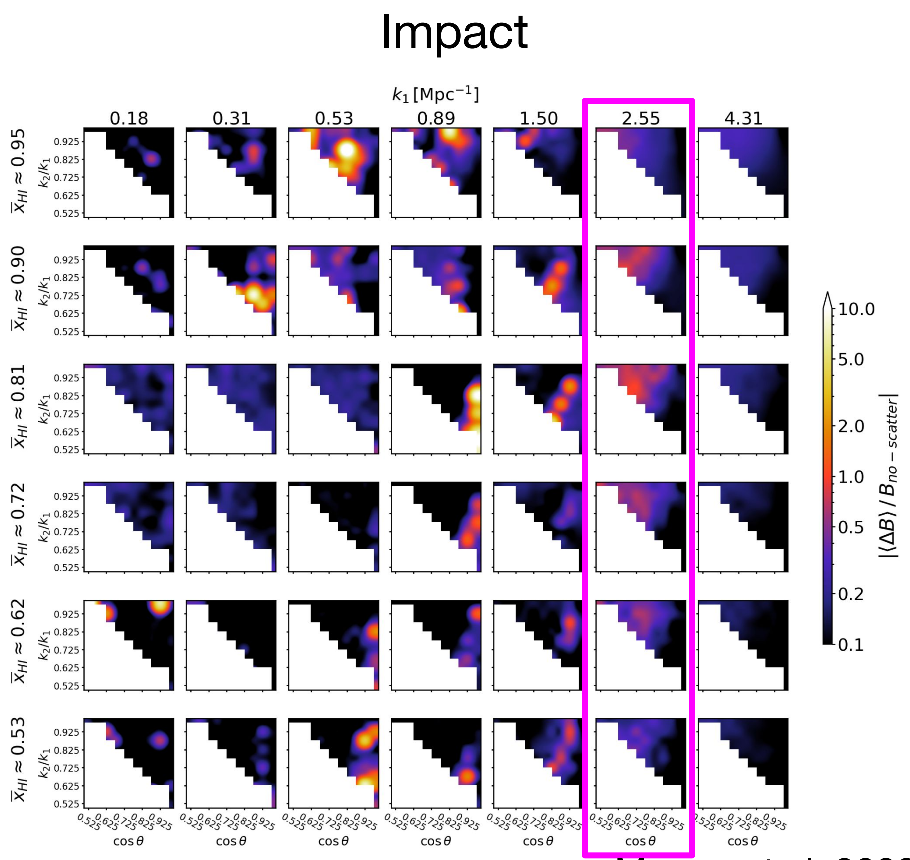
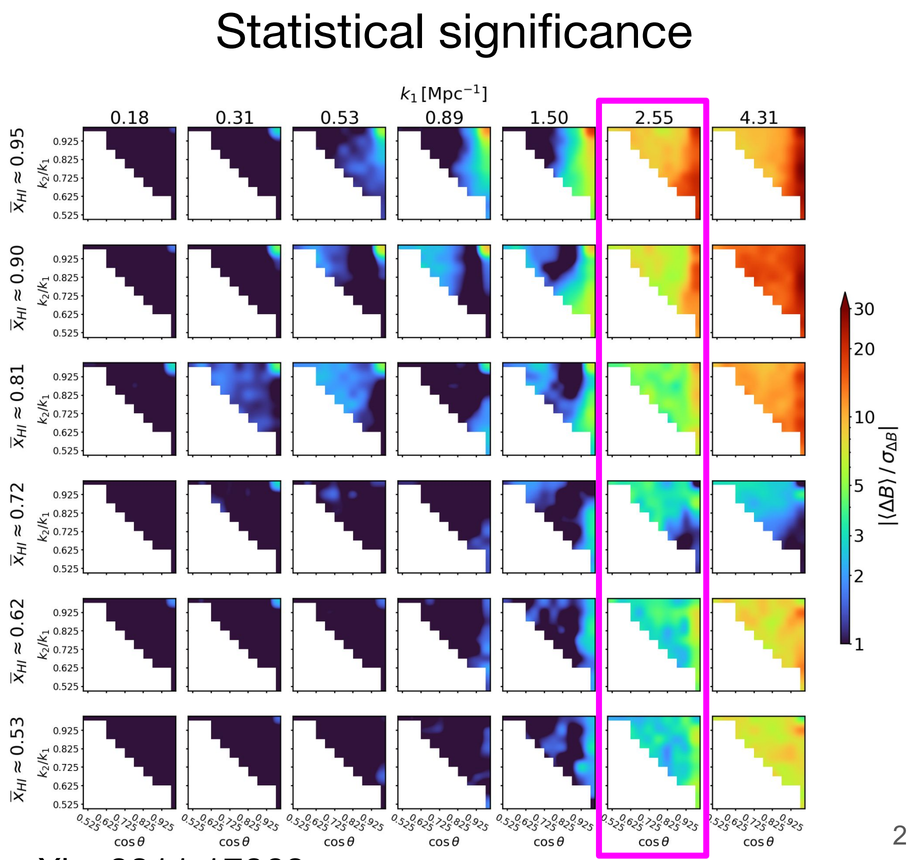
Impact of scatter on the $[\mathrm{H\,I}]_{21cm}$ bispectrum



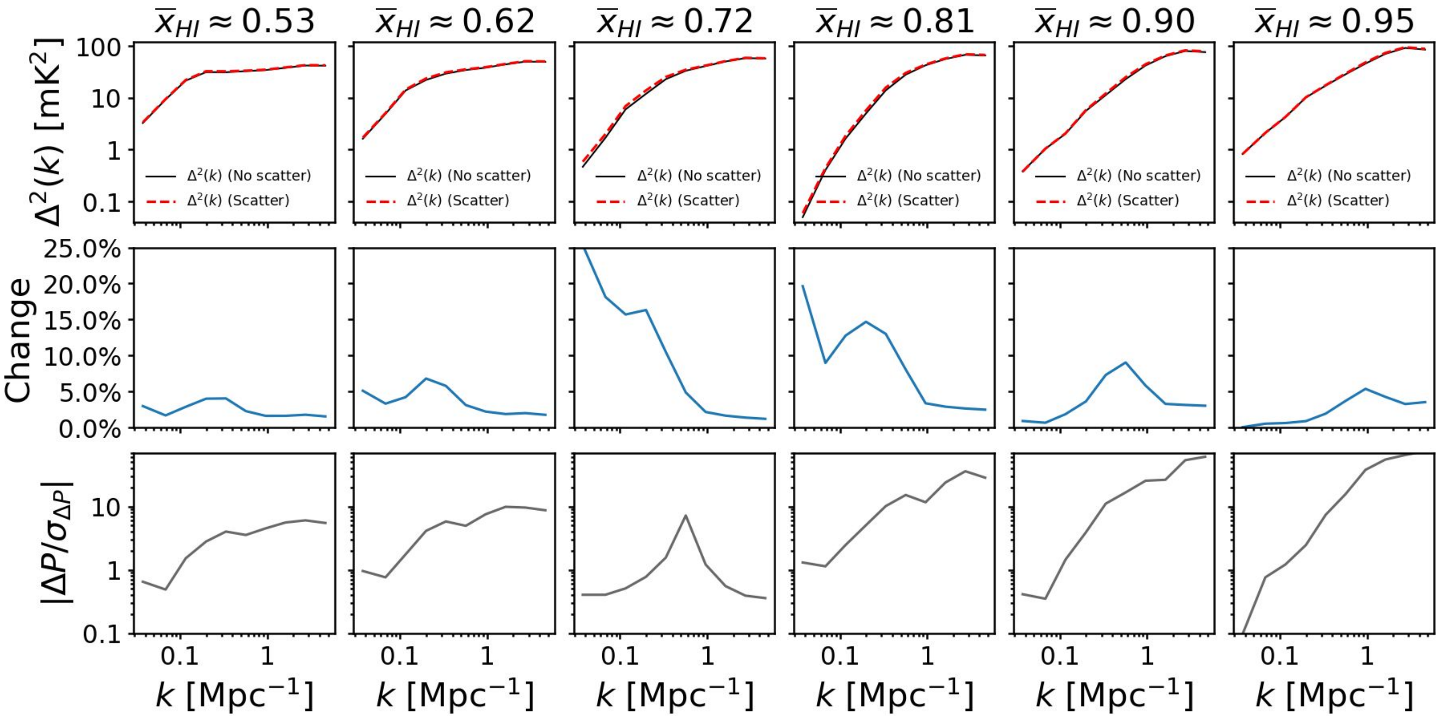


Murmu et al. 2023, arXiv: 2311.17062

Impact of scatter on the [H I]$_{21cm}$ power spectrum

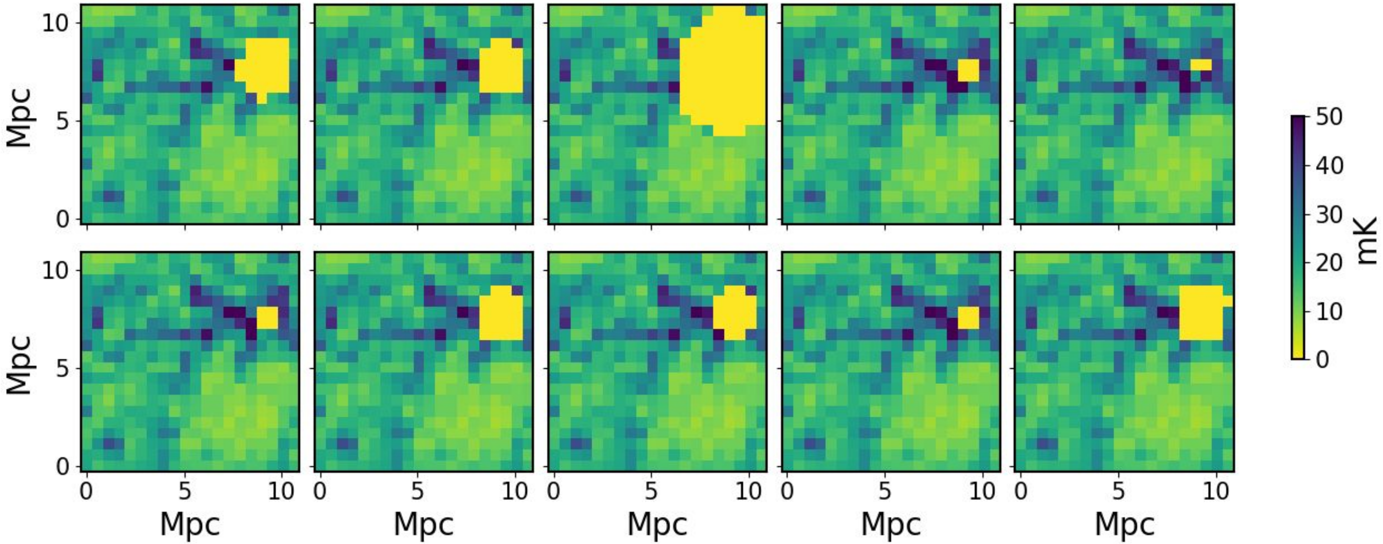
$$\langle \tilde{\delta}(\mathbf{k})\tilde{\delta}^*(\mathbf{k'})\rangle = V\delta_{k,k'}P(k)$$

$$\Delta^2(k) = \frac{k^3 P(k)}{2\pi^2}$$



Murmu et al. 2023, arXiv: 2311.17062

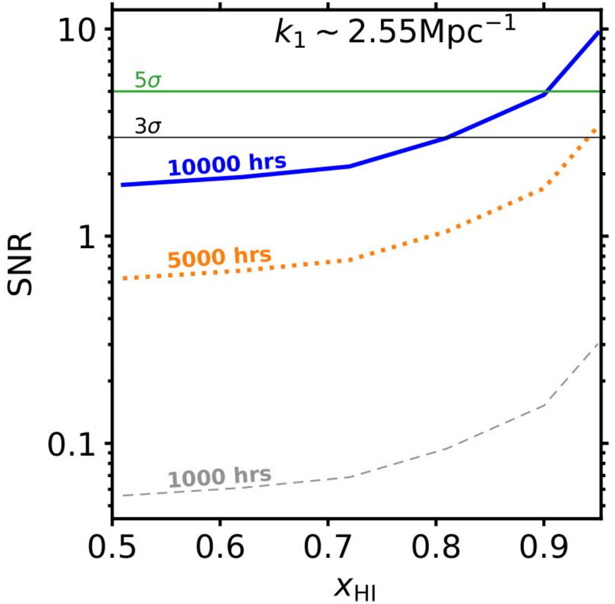
Small-scale ionized bubbles



Murmu et al. 2023, arXiv: 2311.17062

The small-scale ionized bubbles vary across different realizations of the astrophysical scatter

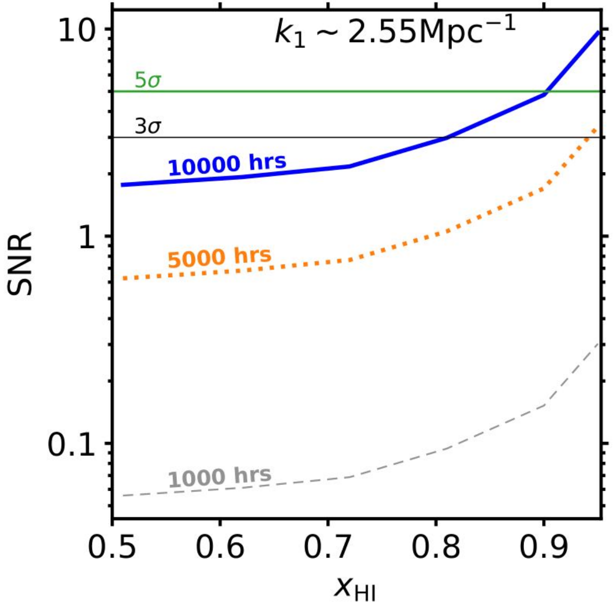
Detectability



Murmu et al. 2023, arXiv: 2311.17062

The signal-to-noise ratio is not sufficient when observed with 1000 hrs of SKA1-Low

Detectability



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However, more optimistic scenarios can be adopted which observes for a fixed duration per year (e.g. 1000 hrs/year)

This can be extended for a couple of years after SKA1-Low is operational

Future scope

- **Impact of astrophysical scatter on the cross-correlation of [H I]$_{21cm}$ and [C II]$_{158\mu m}$, CO LIM signals**

- Incorporate density dependent recombination

- Other sources of reionization can be included

- Line-of-sight (anisotropies), such as redshift space distortion and light-cone effect might affect the impact of scatter

Once again…

- I am interested to explore further avenues in LIM

- Soon to submit my PhD thesis (currently looking for Postdoctoral positions)

Thank you