Probing the signatures of astrophysical scatter in the EoR 21cm signal using auto-bispectrum

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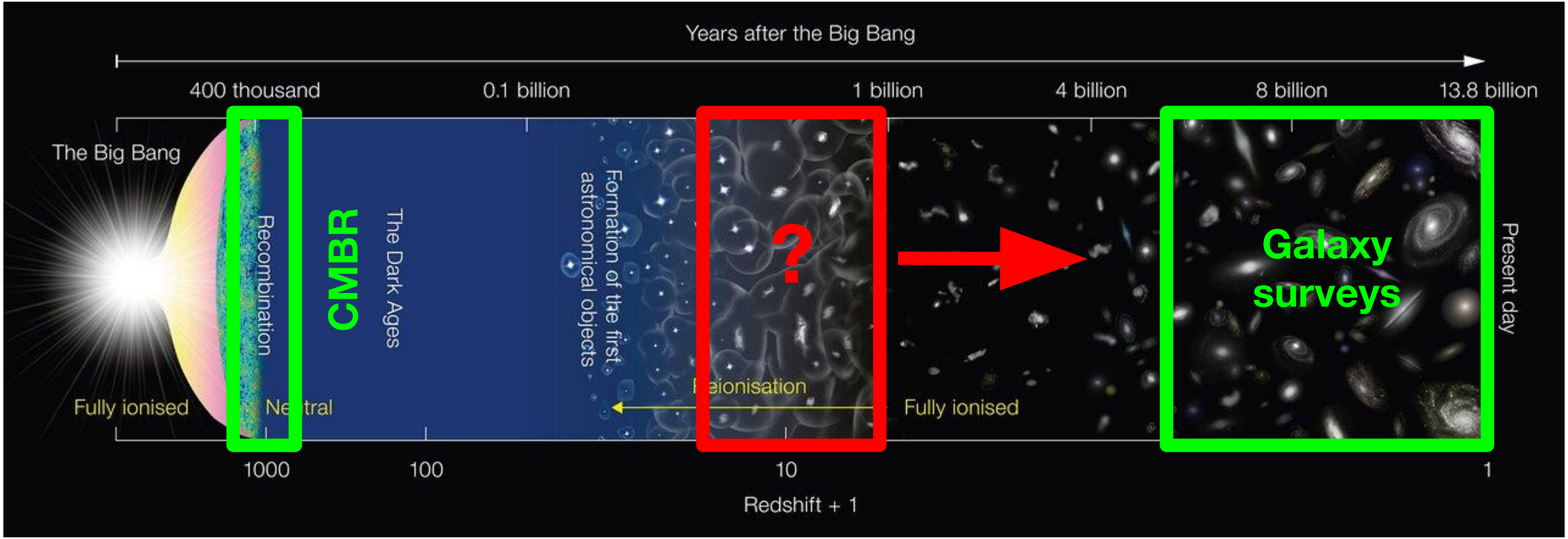
The Epoch of Reionization (EoR)



Credit: NAOJ

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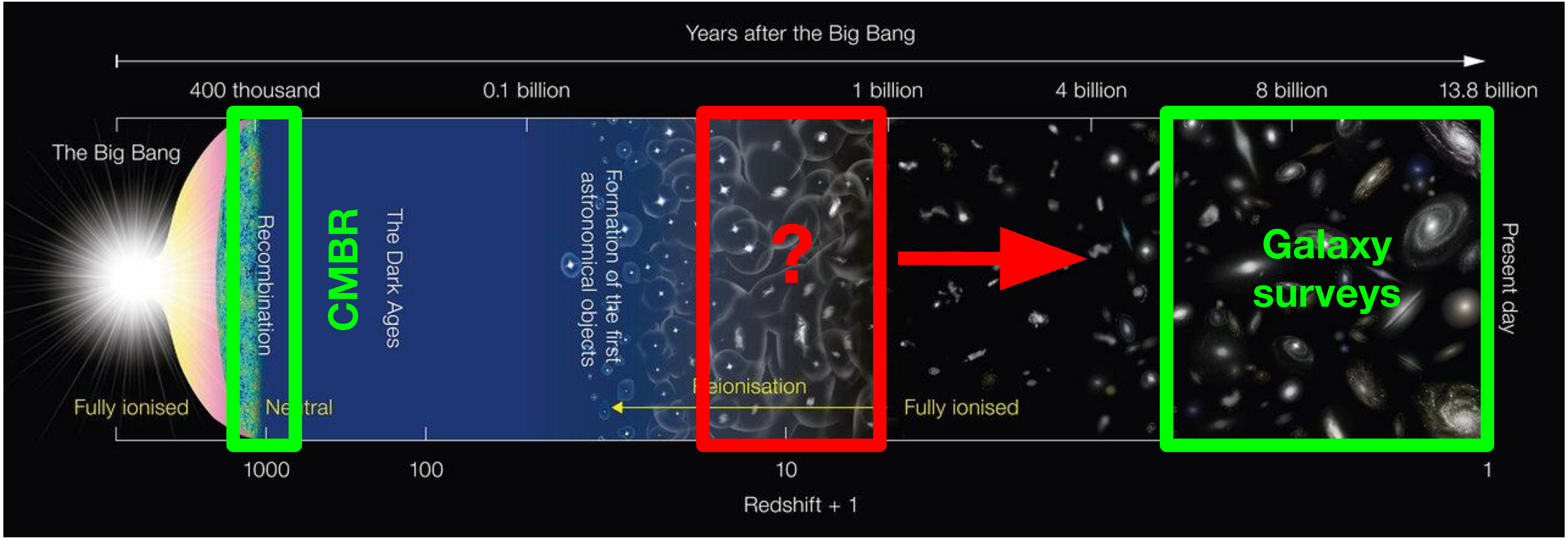

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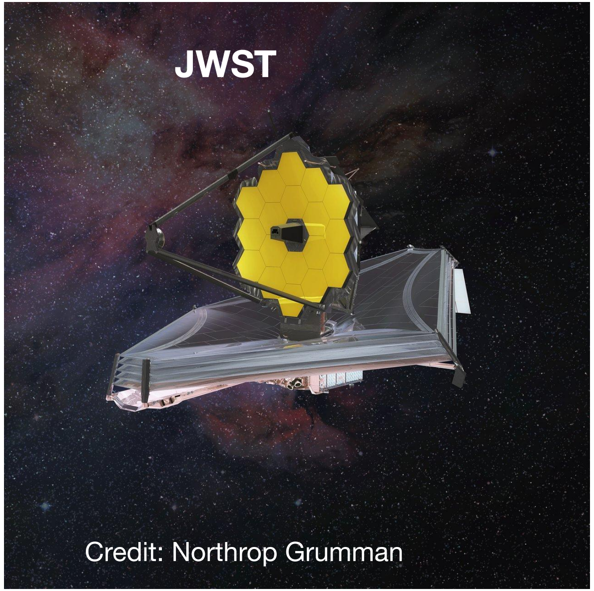
How to probe the EoR universe?

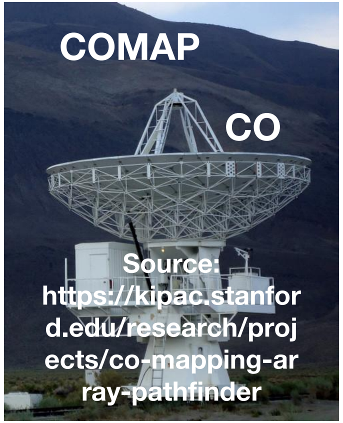
Probing the EoR: galaxies

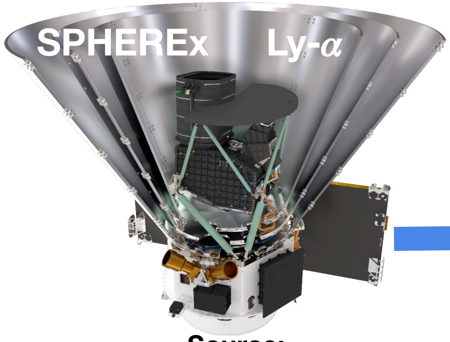


Challenges!

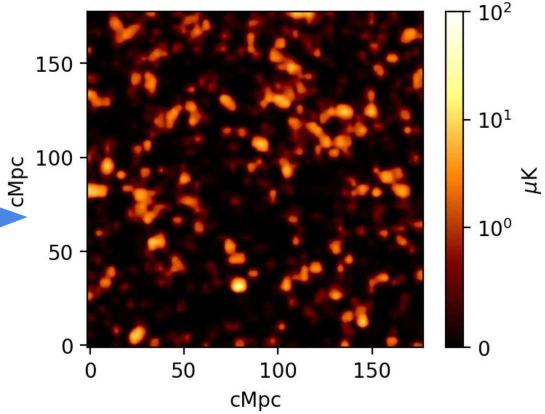
- Demanding sensitivity limits
- Demanding resolutions
- Expensive to operate, therefore it becomes impractical to map large galaxy samples

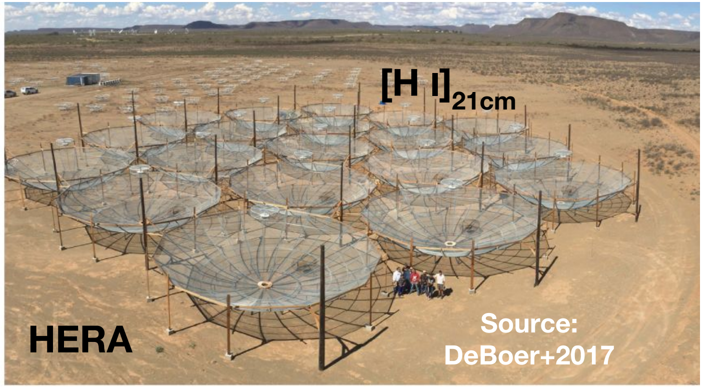
Probing the EoR with Intensity Mapping: galaxies and IGM

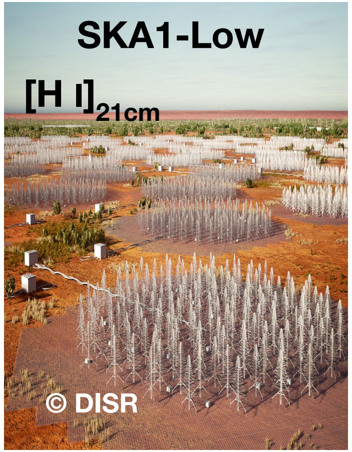


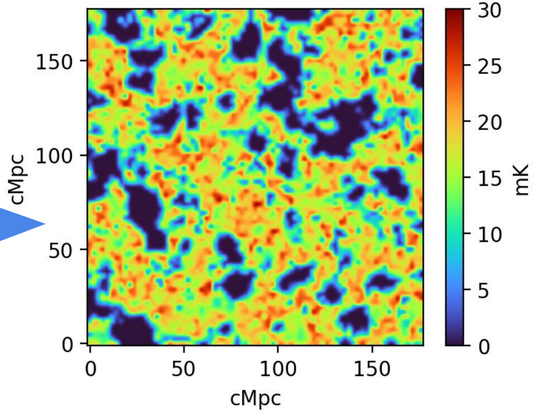


Source: https://spherex.caltech.edu/page/instrument





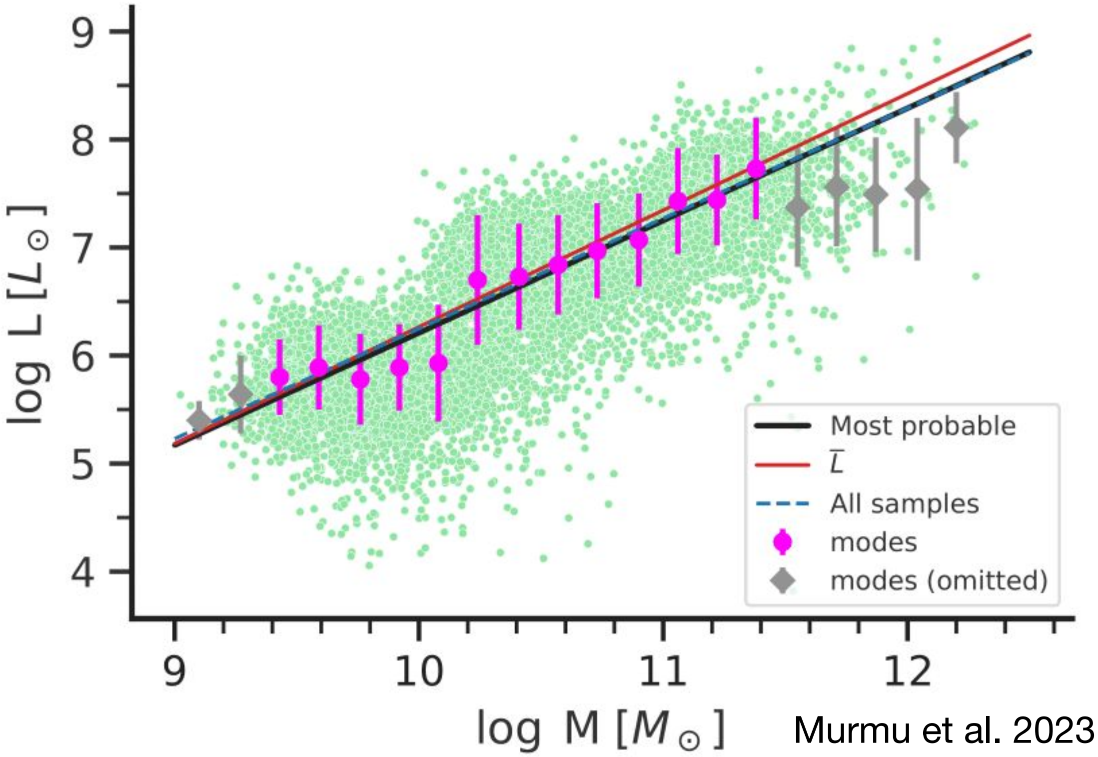




Observable summary statistics

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

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



[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

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

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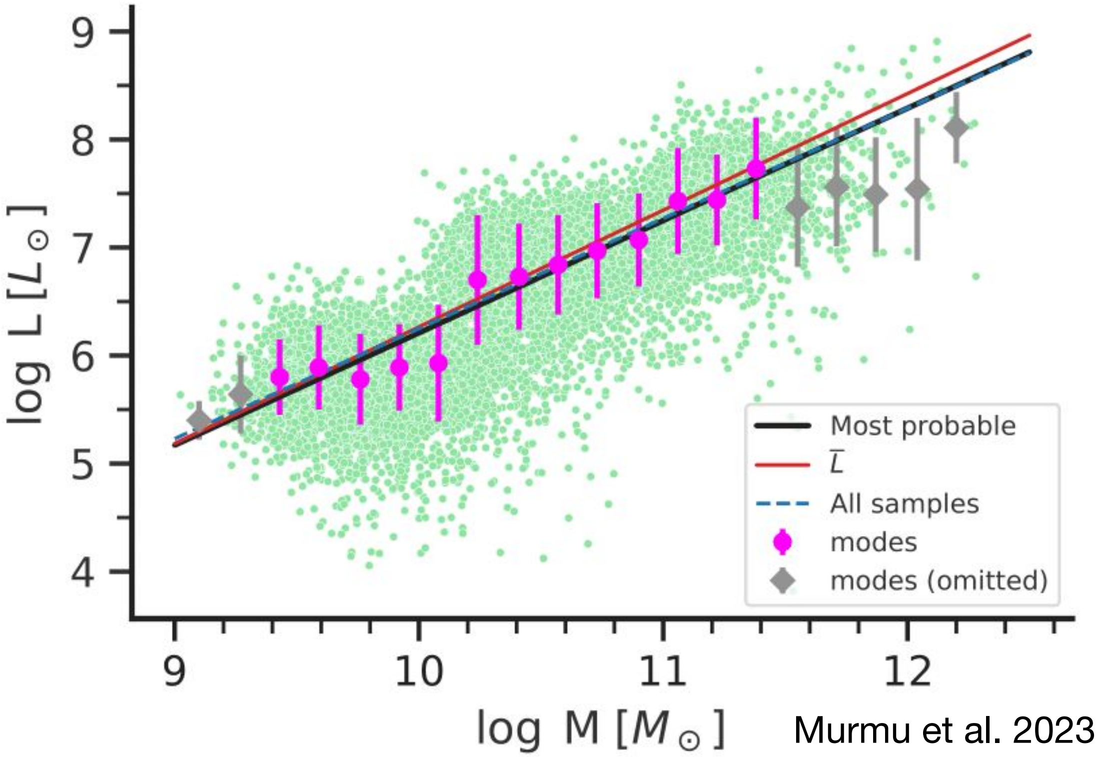

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[C II]$_{158\mu m}$ line-emission exhibits scatter with respect to the host halo mass of the galaxy

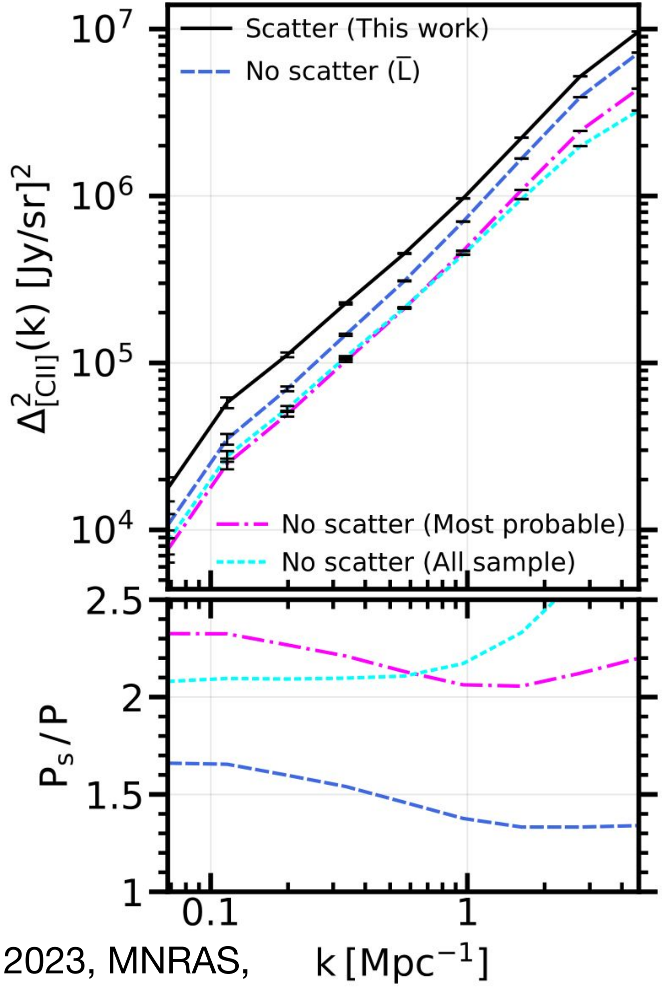
Arises due to the multi-phase state of the ISM

This is expected to impact the observable summary statistic

Impact of line-luminosity scatter on the 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



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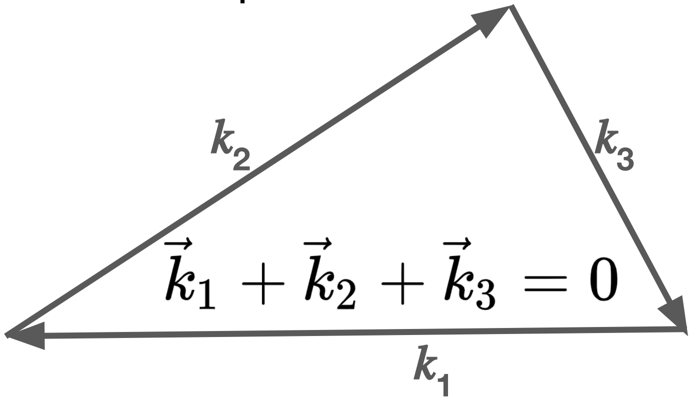
$[\mathrm{H\,I}]_{21\mathrm{cm}}$ bispectrum

Similar astrophysical scatter in the star-formation rates of the galaxies can leave imprints in the IGM (i.e. $[\mathrm{H\,I}]_{21\mathrm{cm}}$ signal)

Hassan et al. 2022 ApJ 931 62 has investigated that the ionization **power spectrum** is not sensitive to these imprints



$$\vec{k}_1 + \vec{k}_2 + \vec{k}_3 = 0$$

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

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

We generate 50 realizations of the [H I]$_{21cm}$ signal introducing log-normal scatter in star-formation rates

The bispectrum is averaged over all the realizations

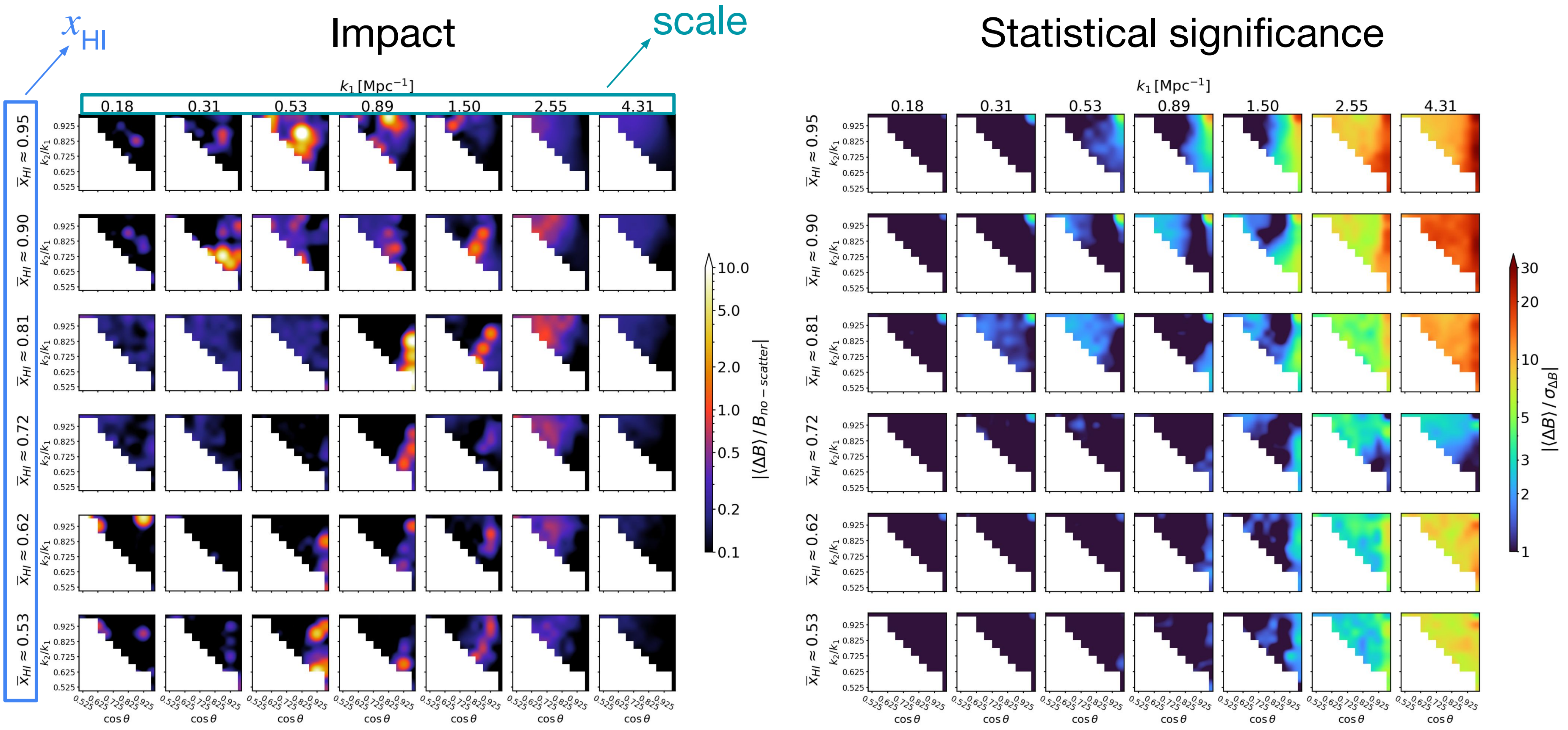
The impact of the scatter is estimated as:

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

The statistical significance is estimated as:

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

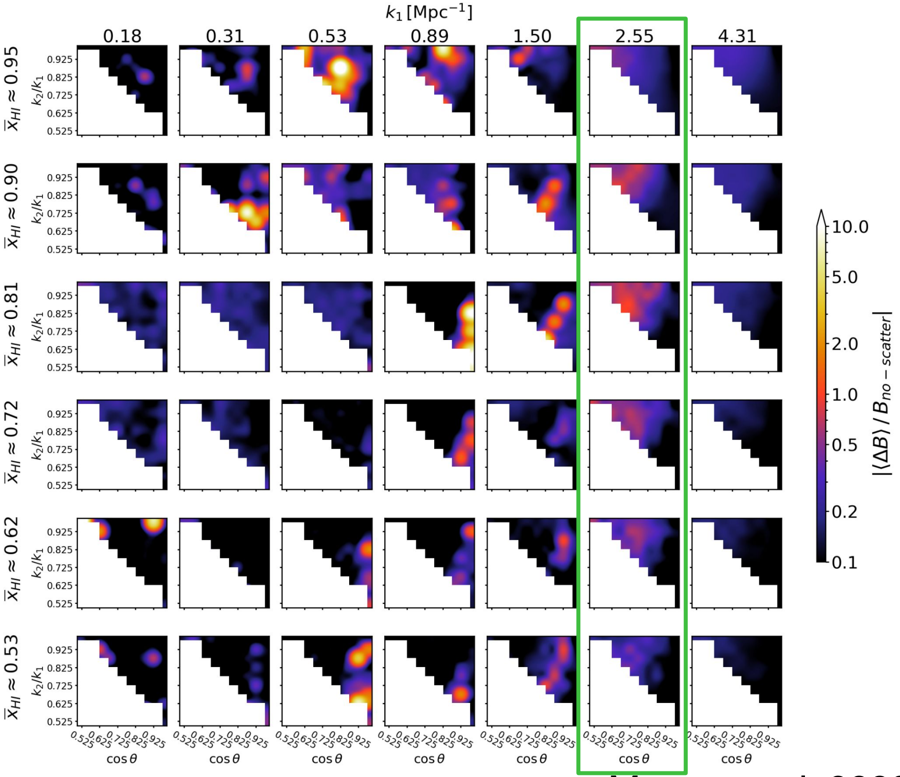
Impact of scatter on the [H I]$_{21cm}$ bispectrum



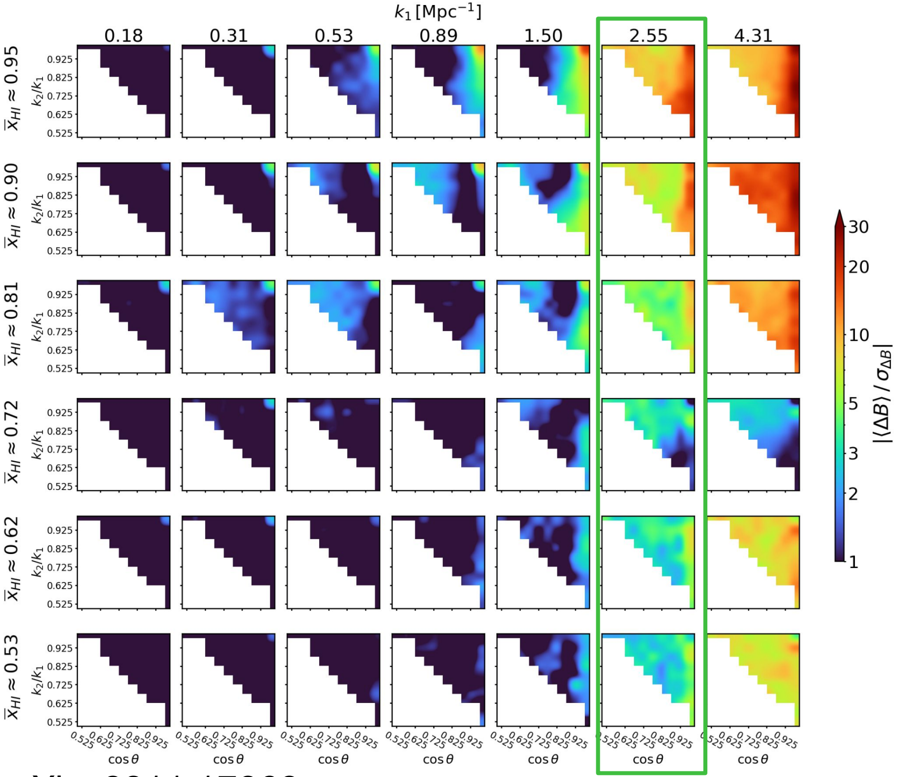
Murmu et al. 2023, arXiv: 2311.17062

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

Impact



Statistical significance



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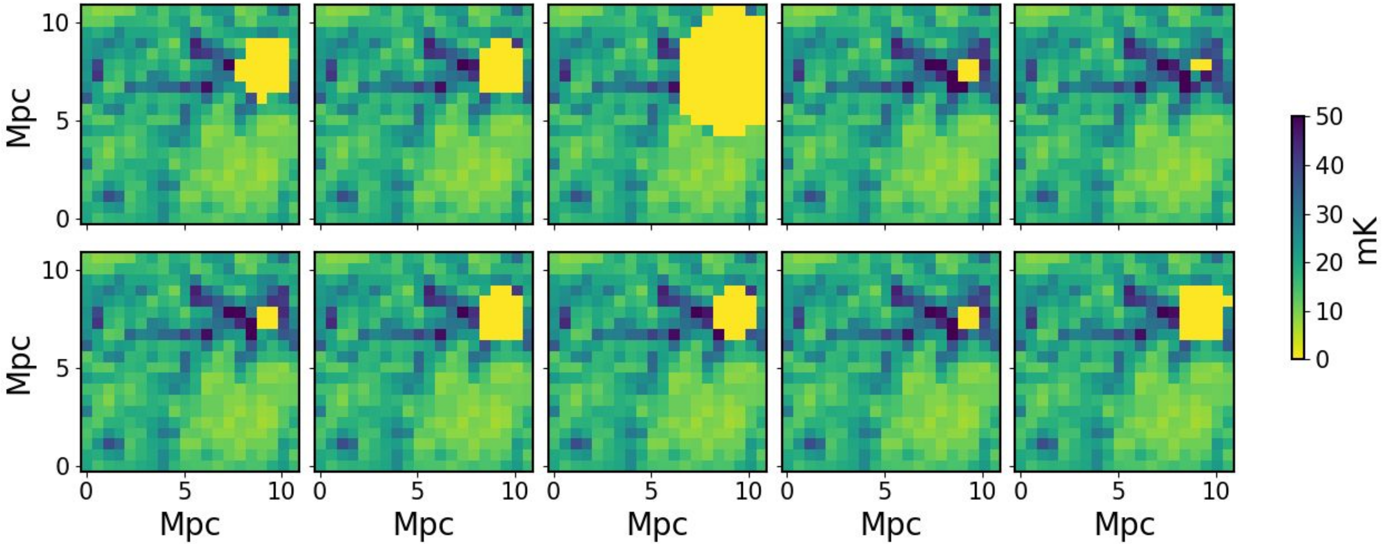
Small-scale ionized bubbles



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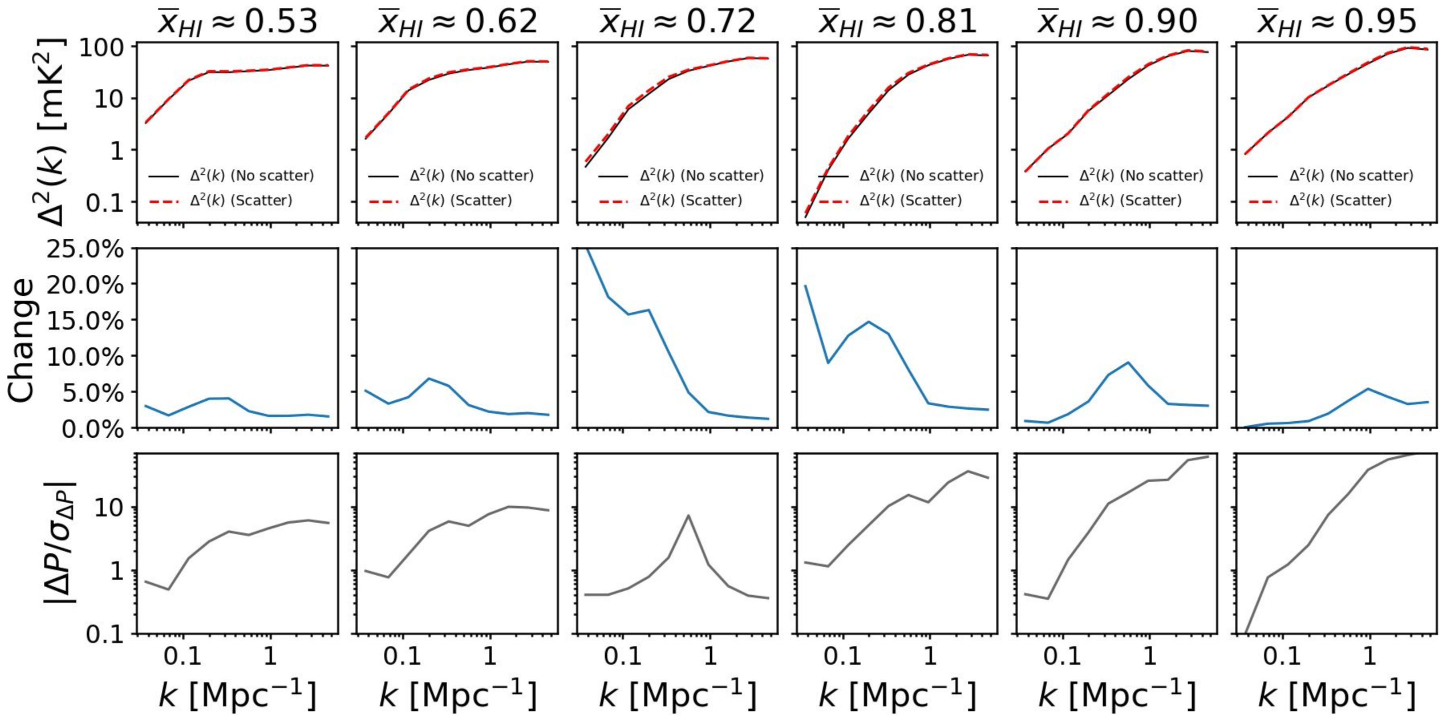
The small-scale ionized bubbles vary across different realizations of the astrophysical scatter

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

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

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



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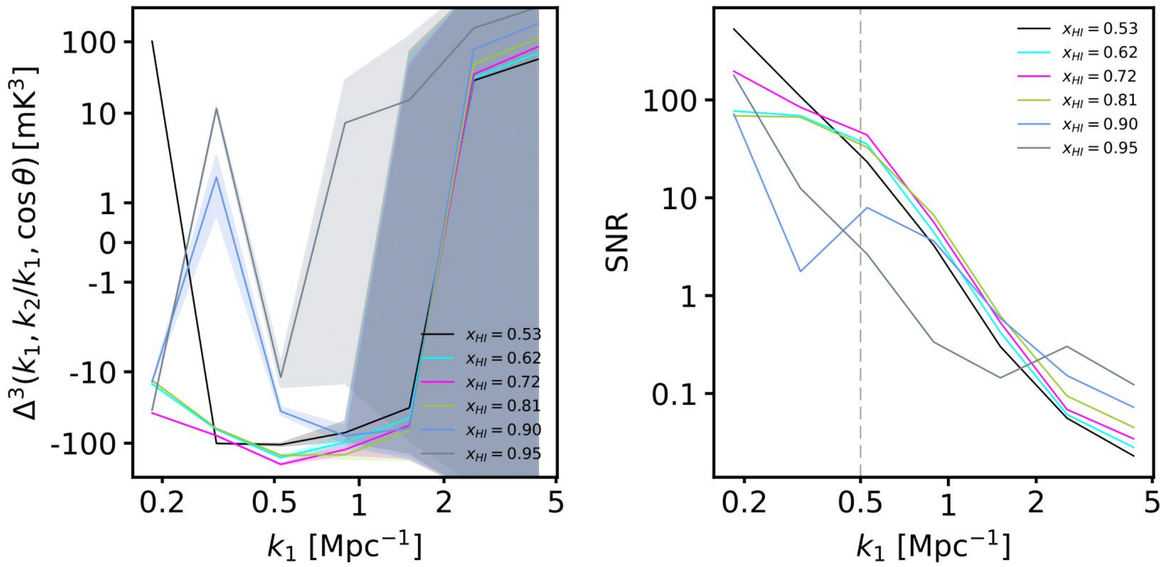
Detectability



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The imprints of astrophysical scatter is **not detectable** in the bispectrum using 1000 hours of SKA1-Low observations

What can be done further?

- Incorporate density dependent recombination
- Other sources of reionization can be included (e.g. Uniform ionizing background)

Thank you