HIR4: Cosmology from the cross-correlation of extragalactic radio and optical surveys with simulated neutral hydrogen full sky using Horizon Run 4

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J. A. et al., 2020, MNRAS 495, 1788 & F. Shi et al., arXiv:2006.01407

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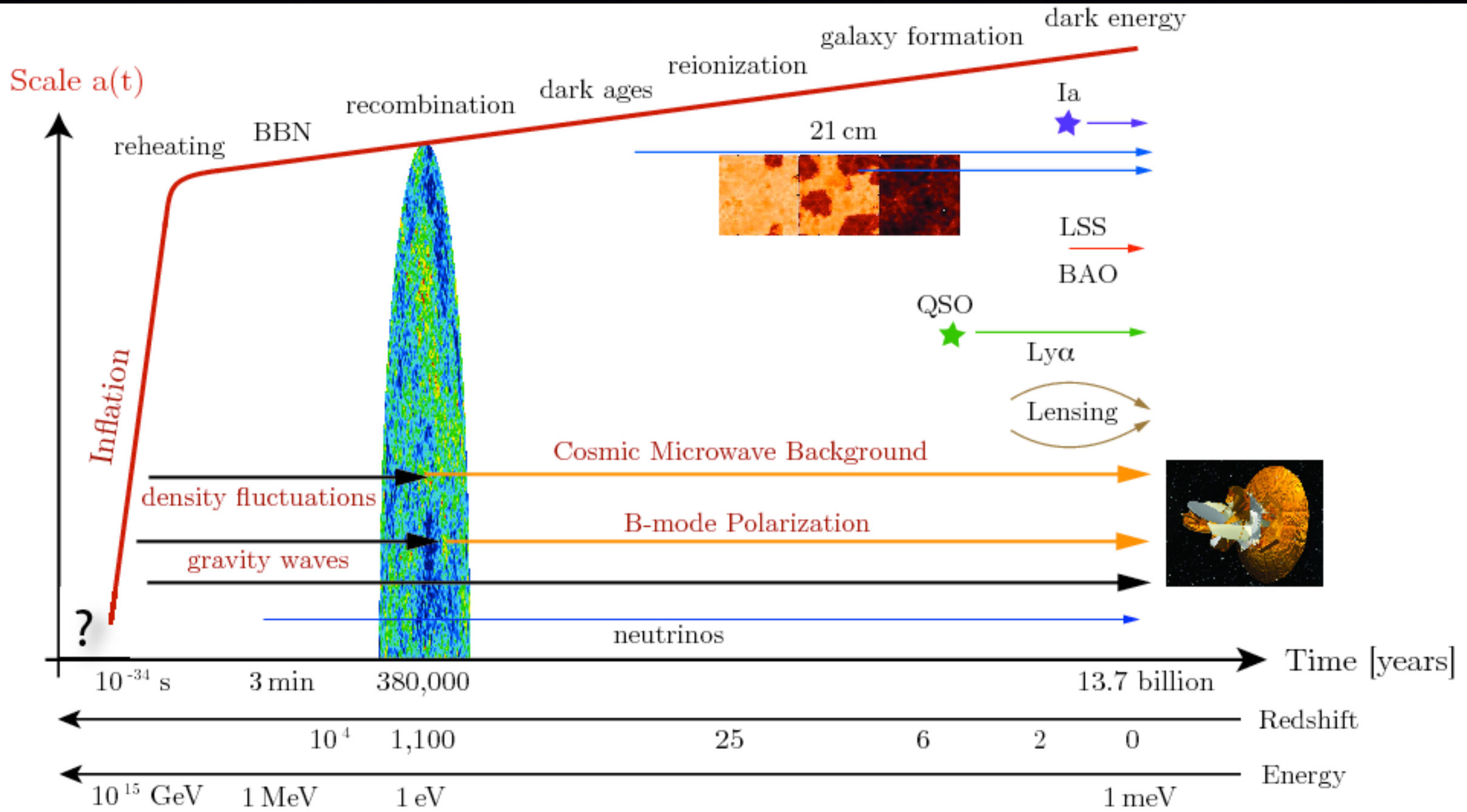
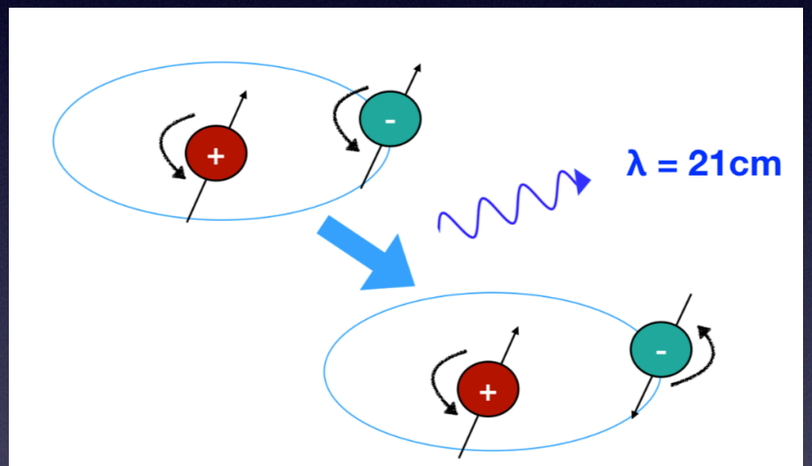
Cosmology from Home, 2020

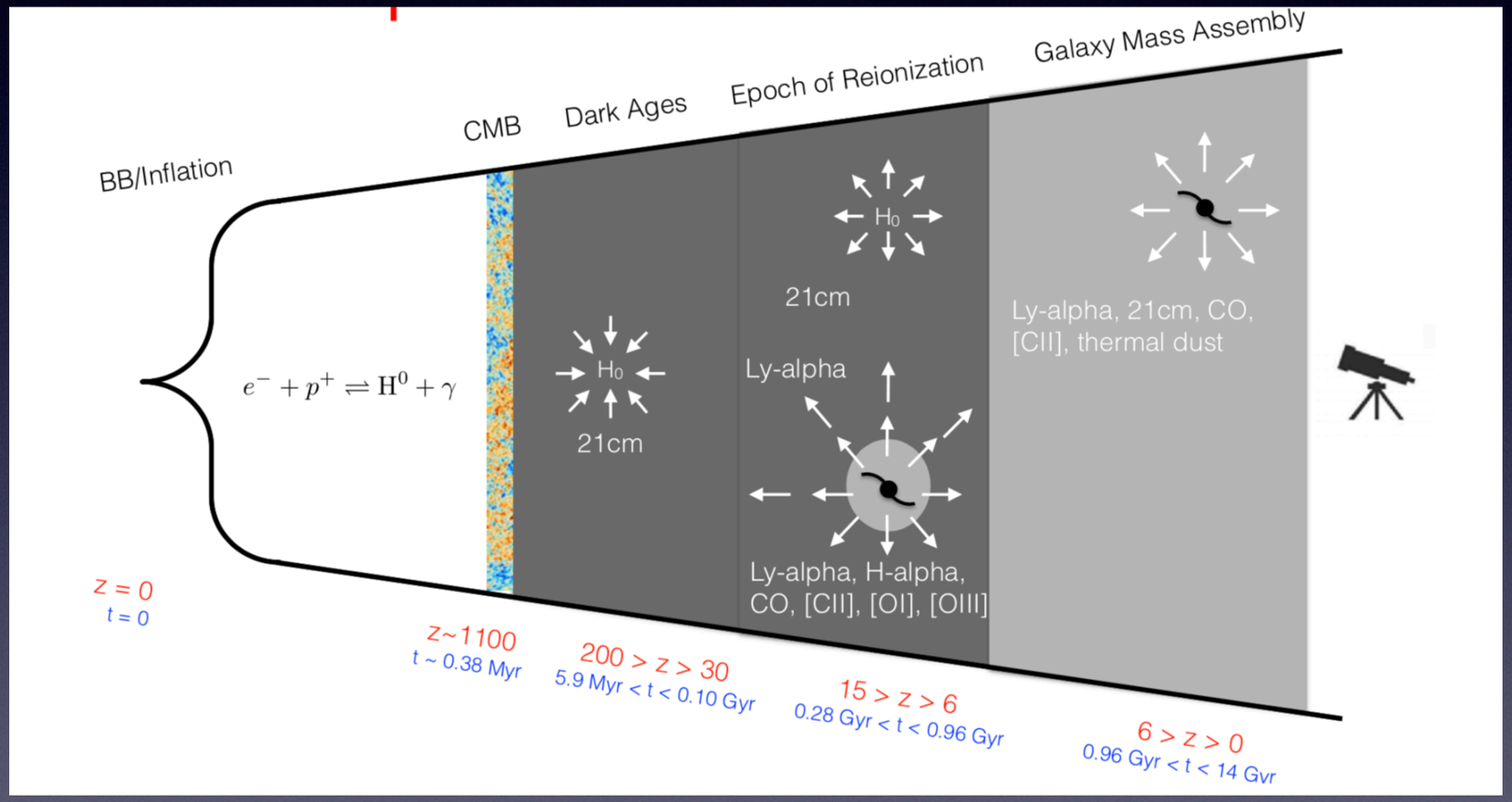
Expansion, Growth and Cross-correlations



D. Baumann, 2009, arXiv:0907.5424

Line intensity mapping





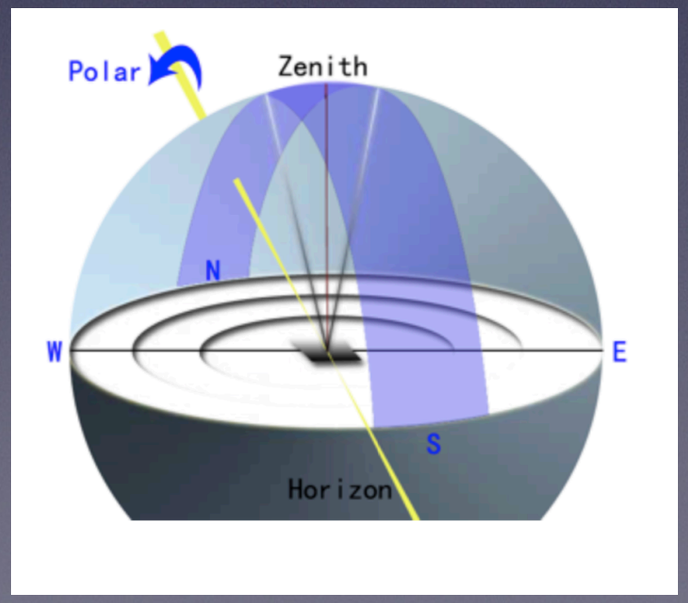
- Line emission allows us to map the Universe from low to high redshift

H1R4: Tianlai x DESI opportunity window

TIANLAI Pathfinder (@Hongliuxia):

- 3 (15x40m) cylinders
- 16 (6m) dishes
- 700-800MHz
- 0.775 < z < 1.03

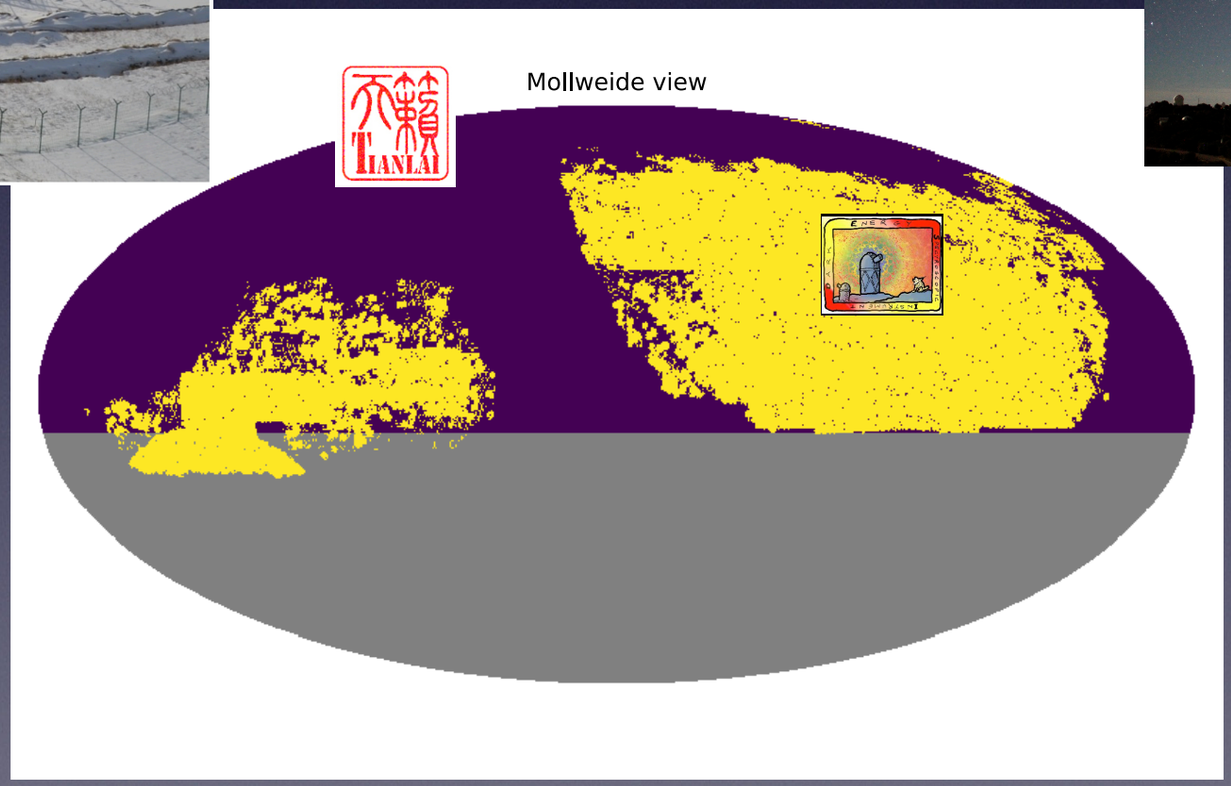
Credit: NAOC



DESI survey (@ 4m Mayall):

- 5000 fibre multi-object
- Footprint of 14000 sq. degs:
  - 35 million ELGs
  - 4 million LRGs
  - 2.4 million QSOs

Credit: R. Lafever

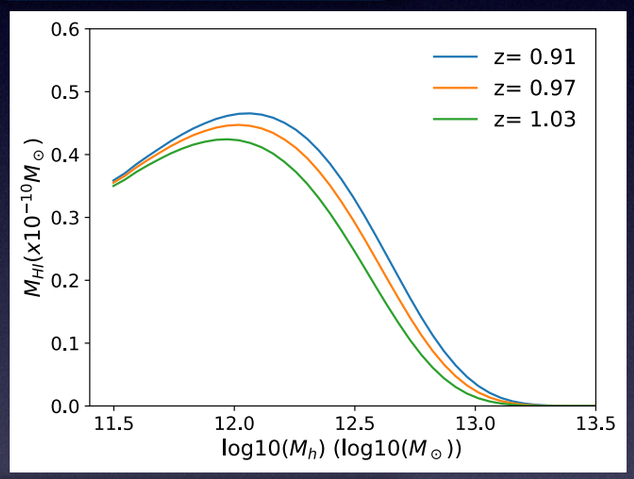


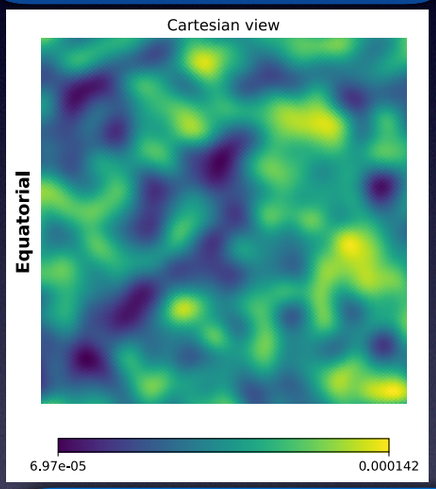
‘Painting’ neutral hydrogen in the Halo canvas

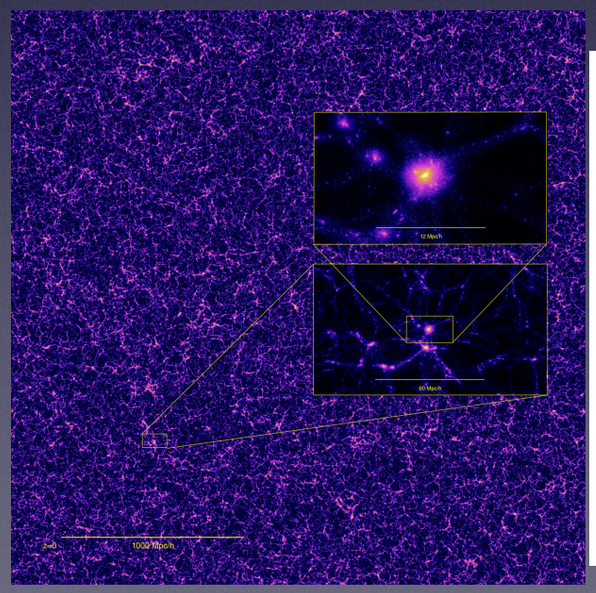
- We start with halo catalogue from **HR4 simulation** (Kim J et al.).

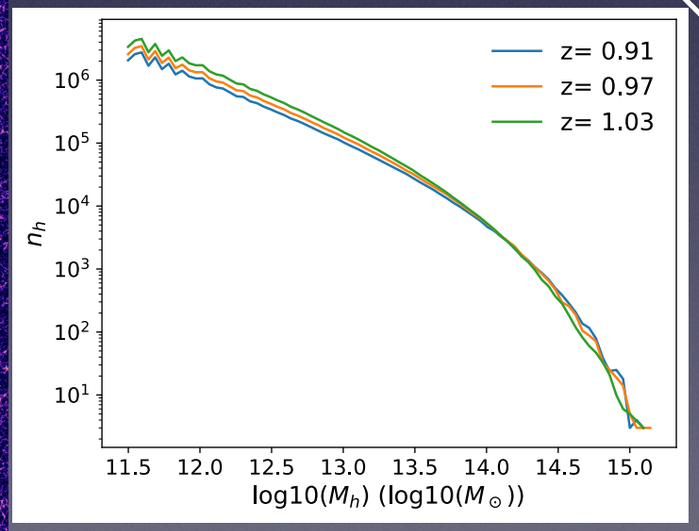
L_{box}=3150 Mpc/h
N_{part} = 6300^3
Light-cone: 0<z<1.5

N-body simulation → Halo catalogue → HI halos → HI brightness T

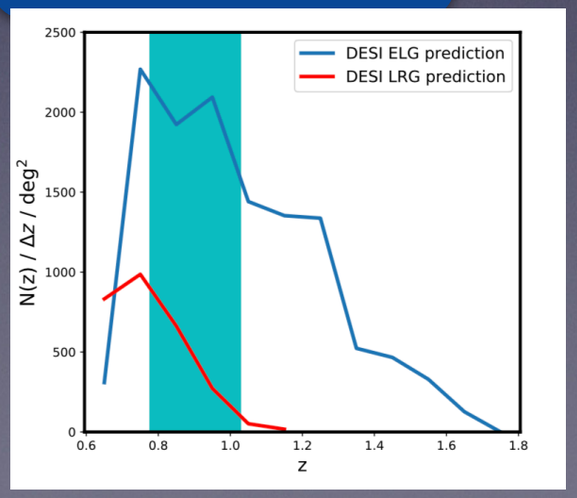


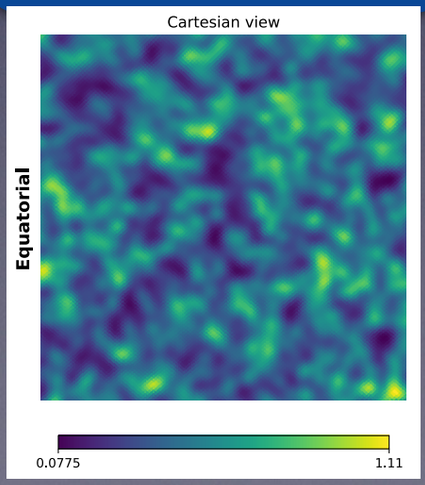






ELG halos → ELG density

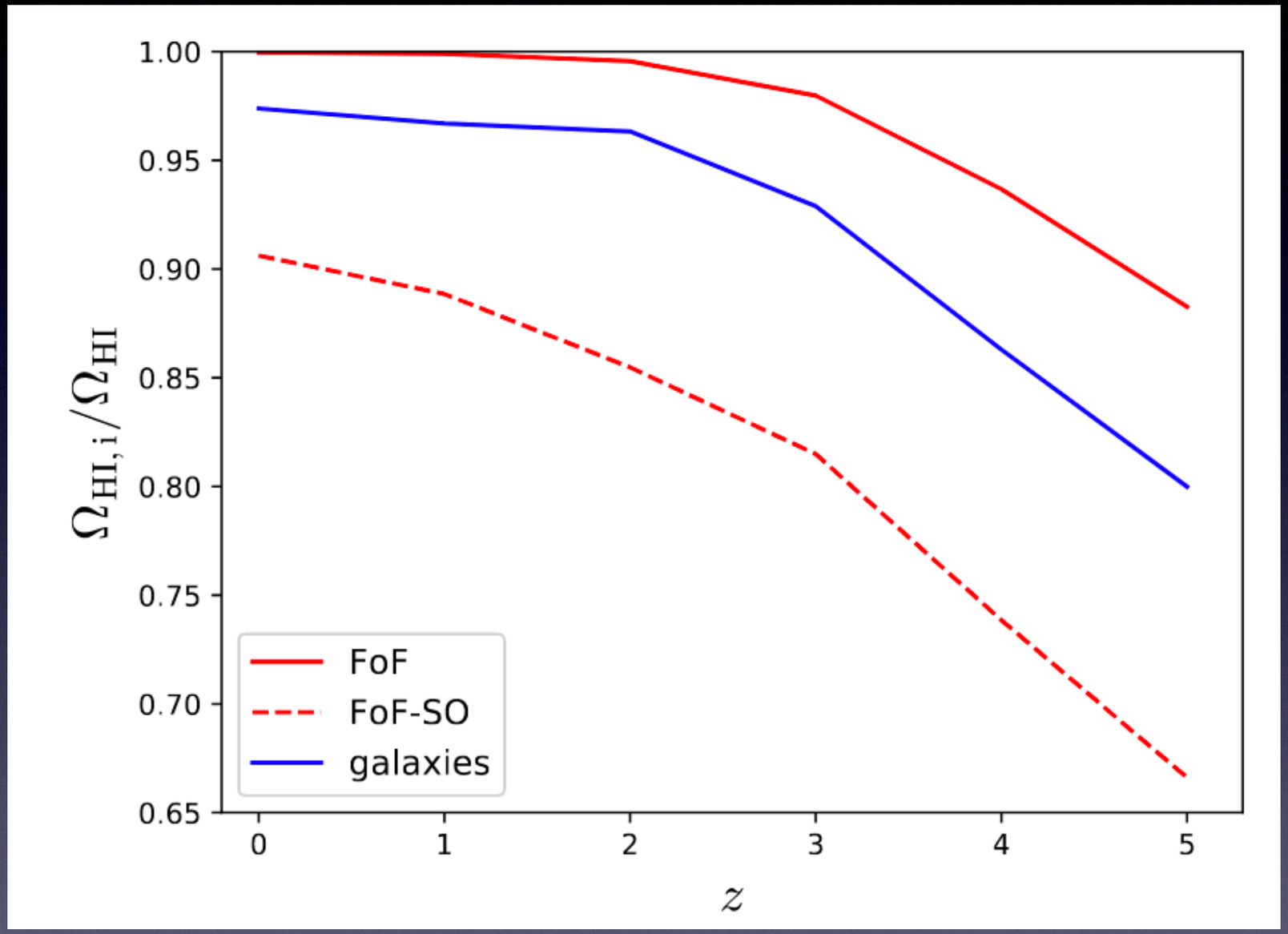




Kim J., Park C., L'Huillier B., Hong S. E. 2015

‘Painting’ neutral hydrogen in the Halo canvas

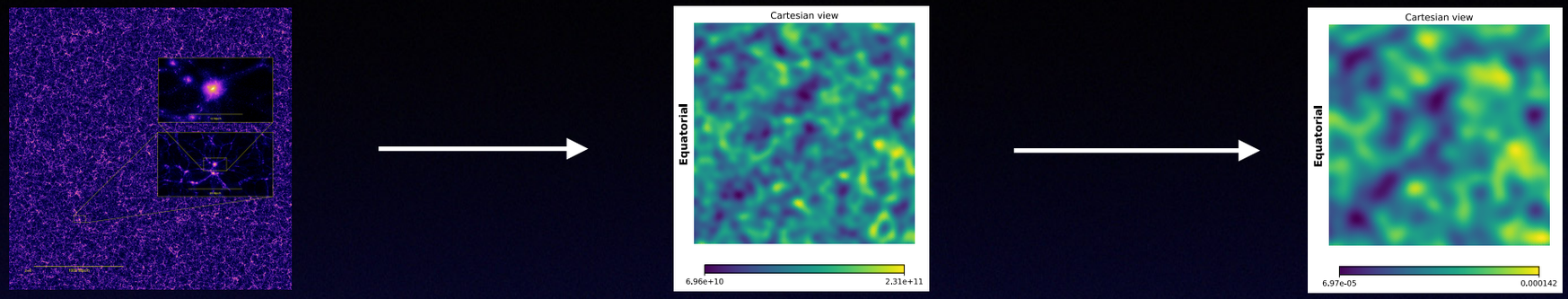
Relative amount of neutral hydrogen in haloes



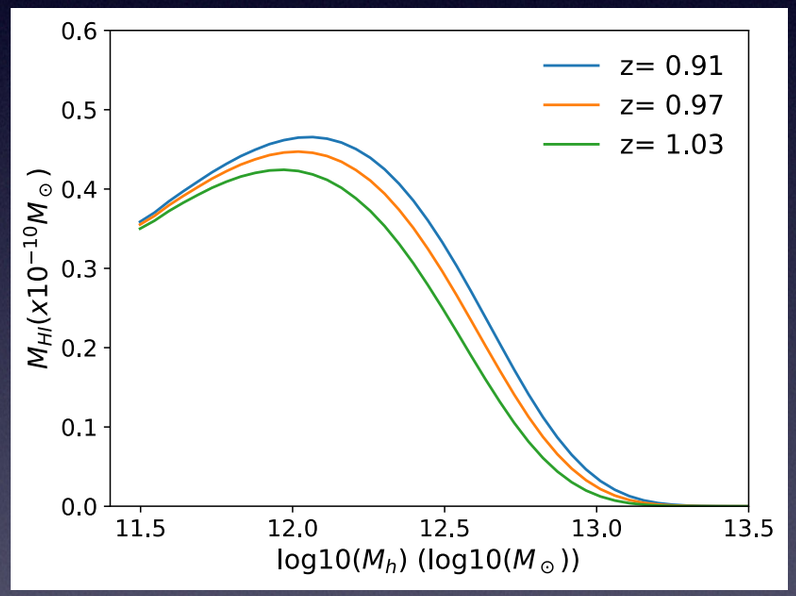
- Most of the neutral Hydrogen at low redshifts is in haloes.

F. Villaescusa-Navarro et al. (2018), ApJ, 886, id135

‘Painting’ neutral hydrogen in the Halo canvas



Hydrogen distribution based purely on halo mass & virial velocity



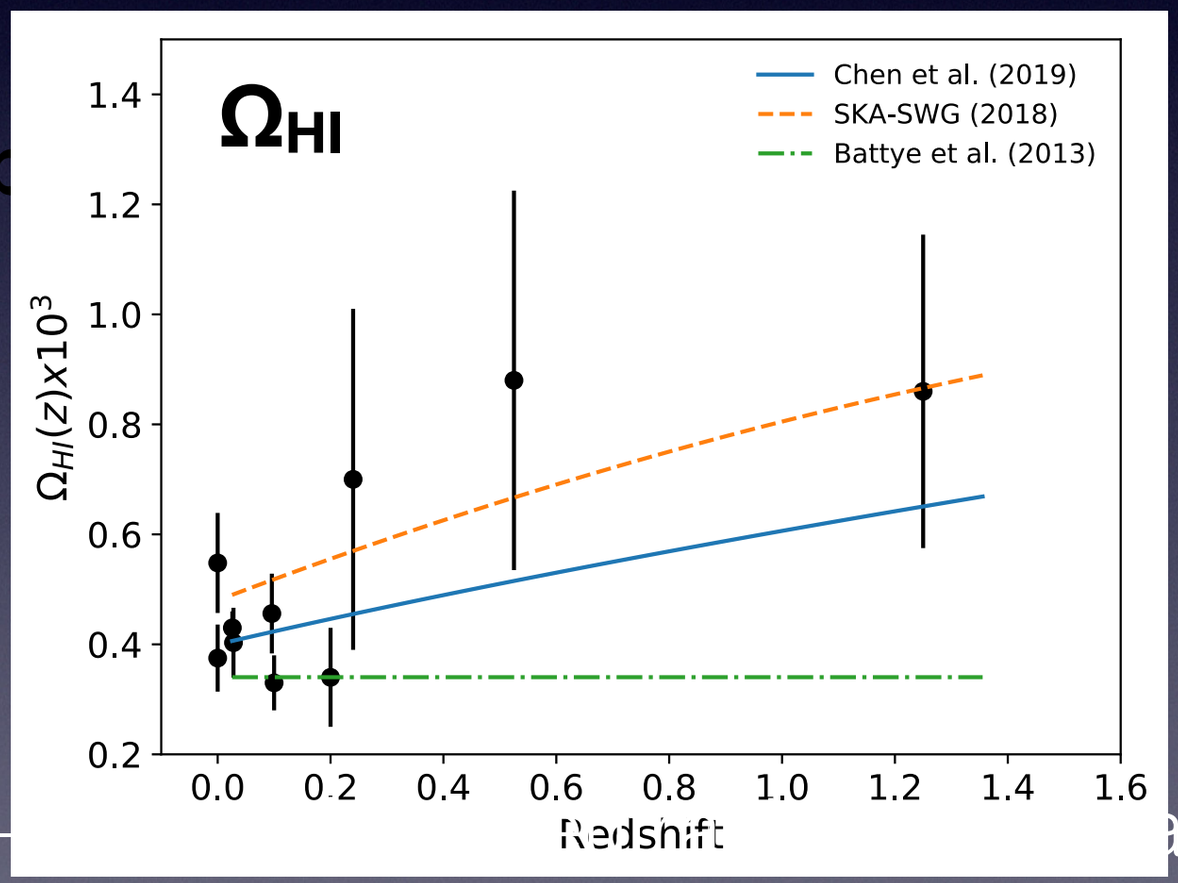
$$M_{HI}(M_h) = f_{HI} f_{H,c} M_h \left(\frac{M_h}{10^{11} h^{-1} M_\odot}\right)^{\beta} \exp\left[-\left(\frac{v_c^{\min}}{v_c(M_h)}\right)^3\right] \exp\left[-\left(\frac{v_c(M_h)}{v_c^{\max}}\right)^3\right]$$

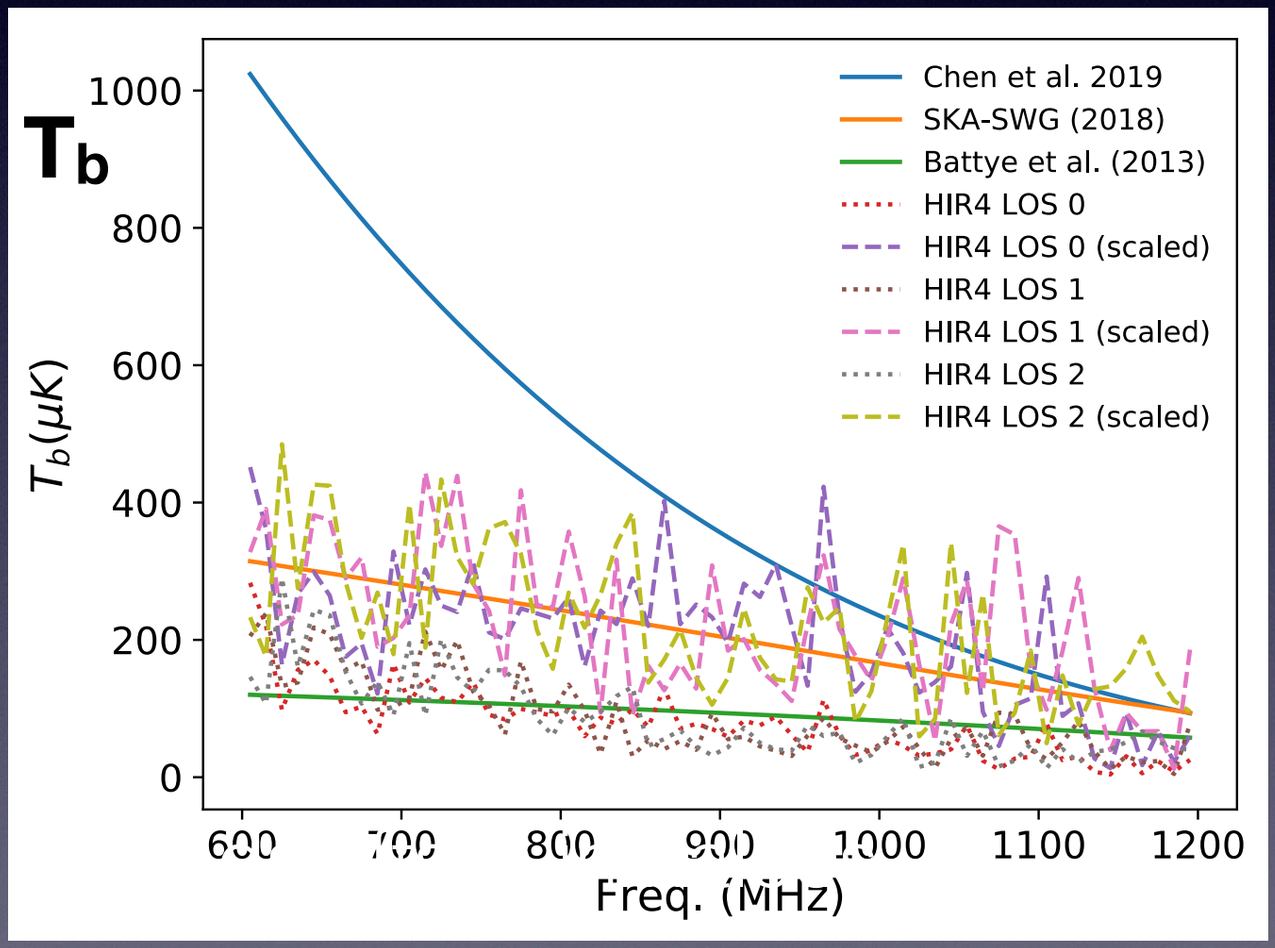
$$T_{21} = \frac{3 h_P c^3 A_{12}}{32 \pi m_h} \frac{(1+z)^2}{H(z)} \rho_{HI}$$

H. Padmanabhan & A. Refregier (2017), MNRAS, 464, 4008
P. Bull & P. G. Ferreira, P. Patel, M. Santos (2015), ApJ, 803, 21

Correcting halo mass limit

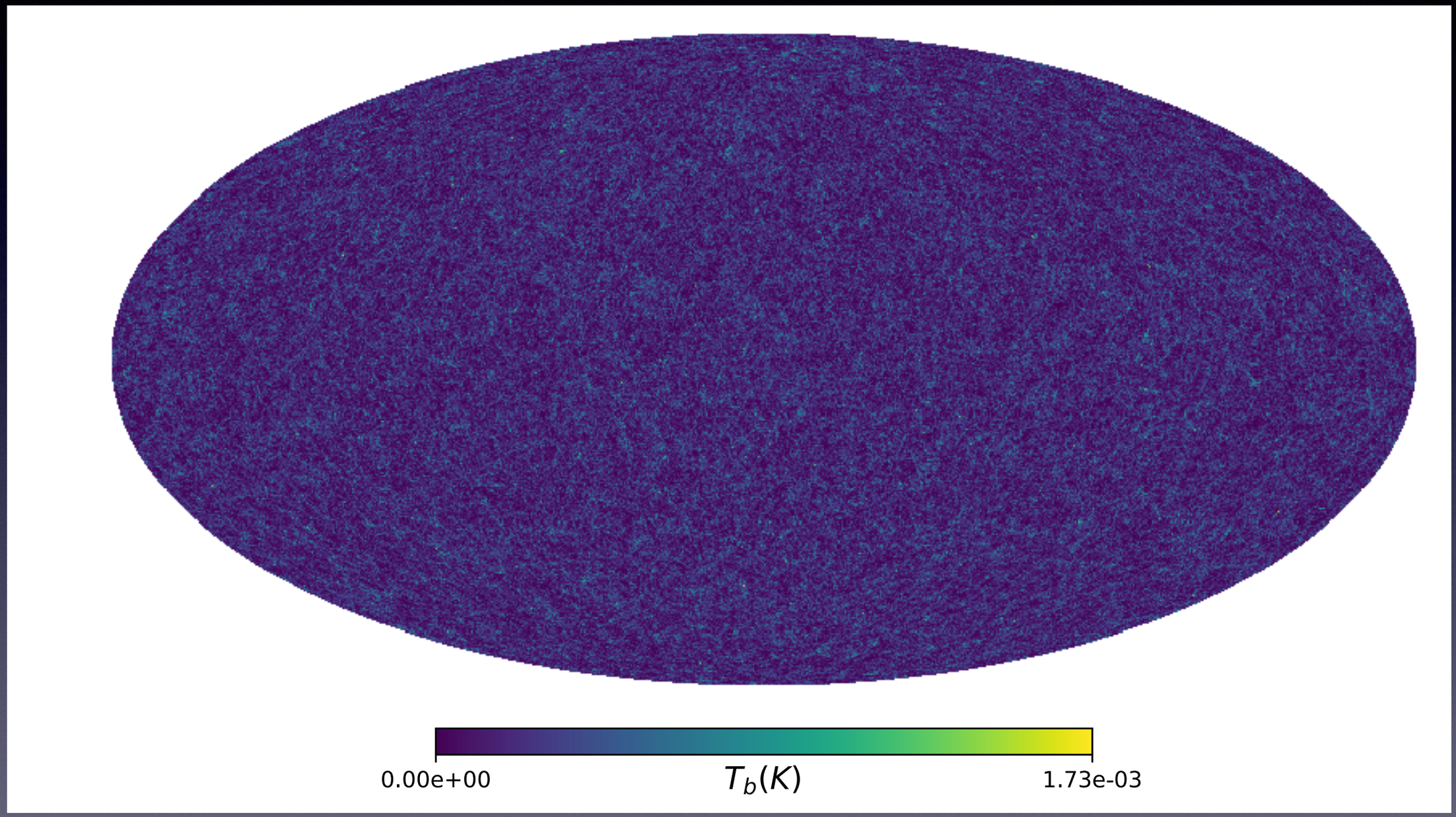
- We re-scale neutral hydrogenTb using fit to hydrogen ratio from data to account for the missed mass in the simulated halo catalogue.





J. A., D. Parkinson, F. Shi, Y-S. Song, K. Ahn, J. Kim, J. Yao, L. Zhang and Sh. Zuo 2020, MNRAS; 495, 1788

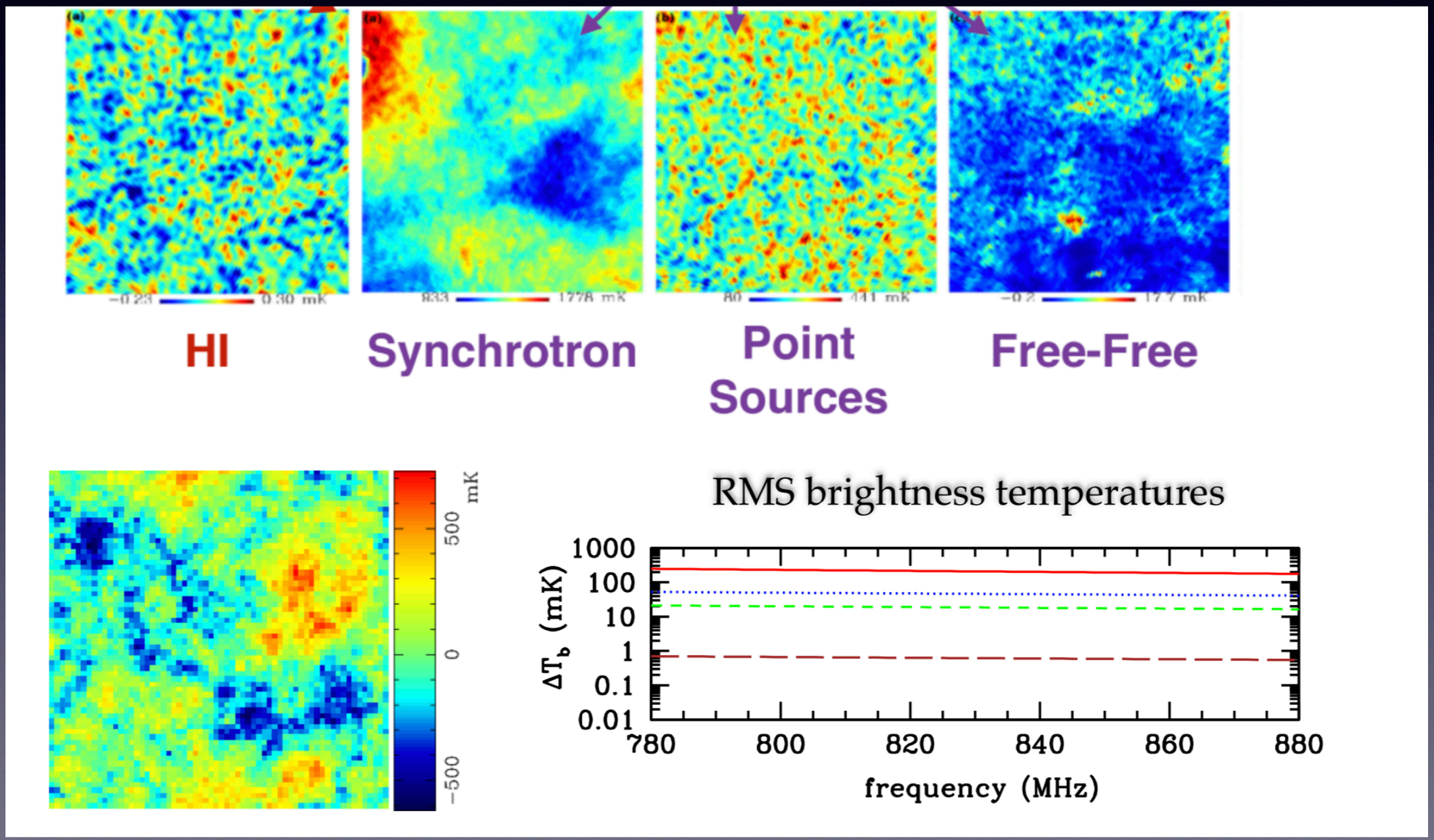
Full-sky 21cm intensity maps



J. A., D. Parkinson, F. Shi, Y-S. Song, K. Ahn, J. Kim, J. Yao, L. Zhang and Sh. Zuo 2020, MNRAS; 495, 1788

Elephant in the room: Foregrounds

- Foreground signal is orders of magnitude stronger than cosmological signal.



Credit: Le Zhang and Tianlai Collaboration

Foreground maps: Global Sky Model

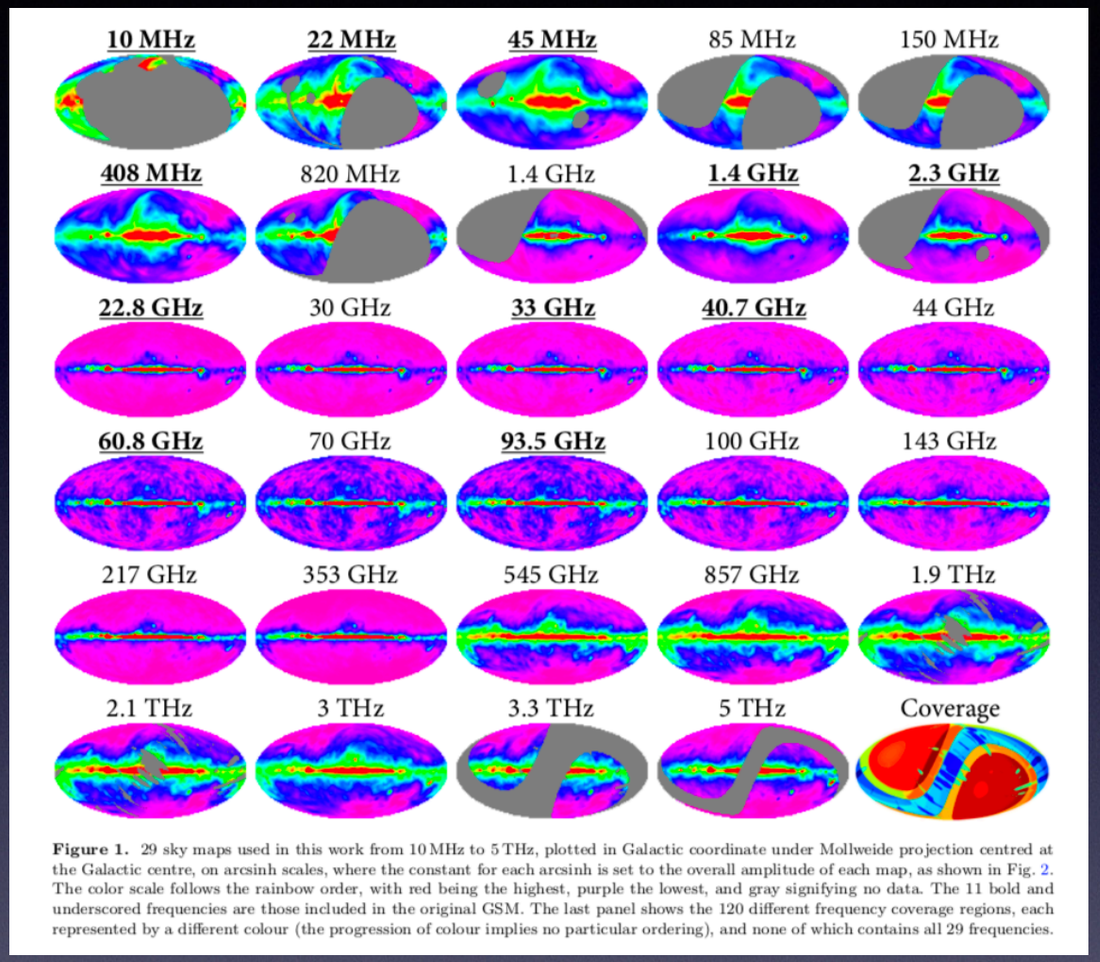
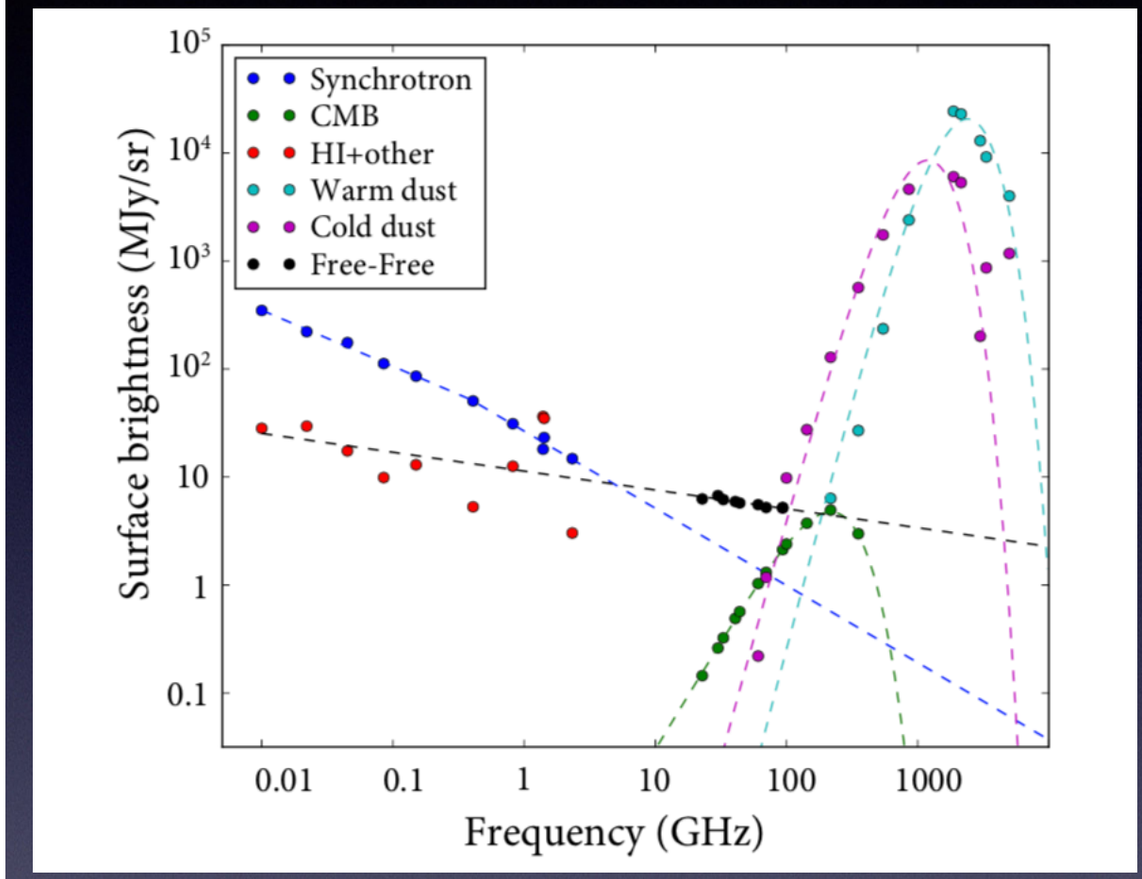


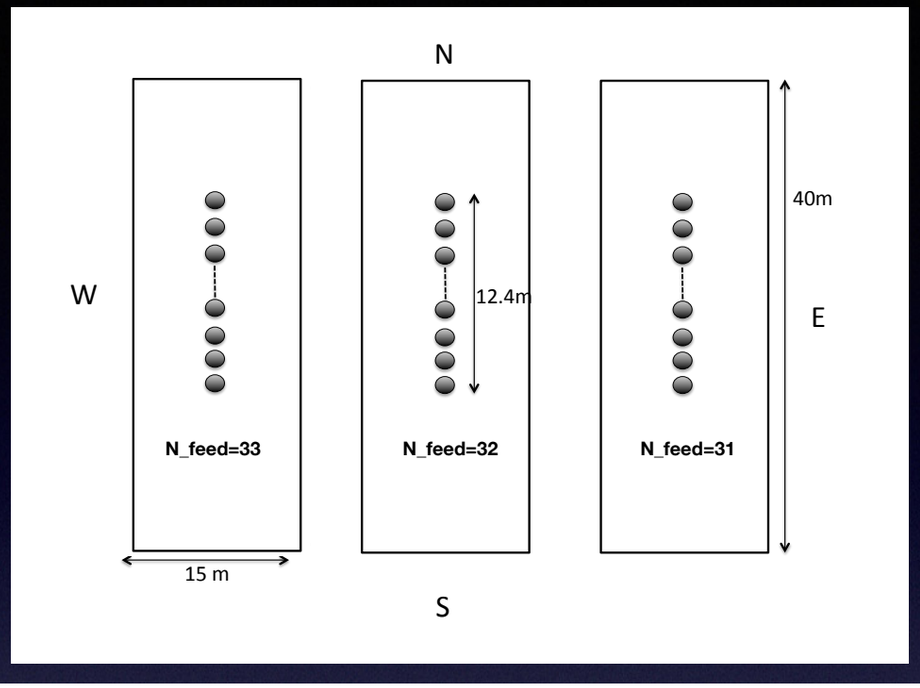
Figure 1. 29 sky maps used in this work from 10 MHz to 5 THz, plotted in Galactic coordinate under Mollweide projection centred at the Galactic centre, on arcsinh scales, where the constant for each arcsinh is set to the overall amplitude of each map, as shown in Fig. 2. The color scale follows the rainbow order, with red being the highest, purple the lowest, and gray signifying no data. The 11 bold and underscored frequencies are those included in the original GSM. The last panel shows the 120 different frequency coverage regions, each represented by a different colour (the progression of colour implies no particular ordering), and none of which contains all 29 frequencies.



- We add the foreground at a given frequency by using a 6 component PCA decomposition that reconstructs smoothed 29 data maps. Can give foregrounds between 10MHz and 5THz

A. de Oliveira-Costa et al. (2008), MNRAS, 388, 247
H. Zheng et al. (2017), MNRAS, 464, 3486

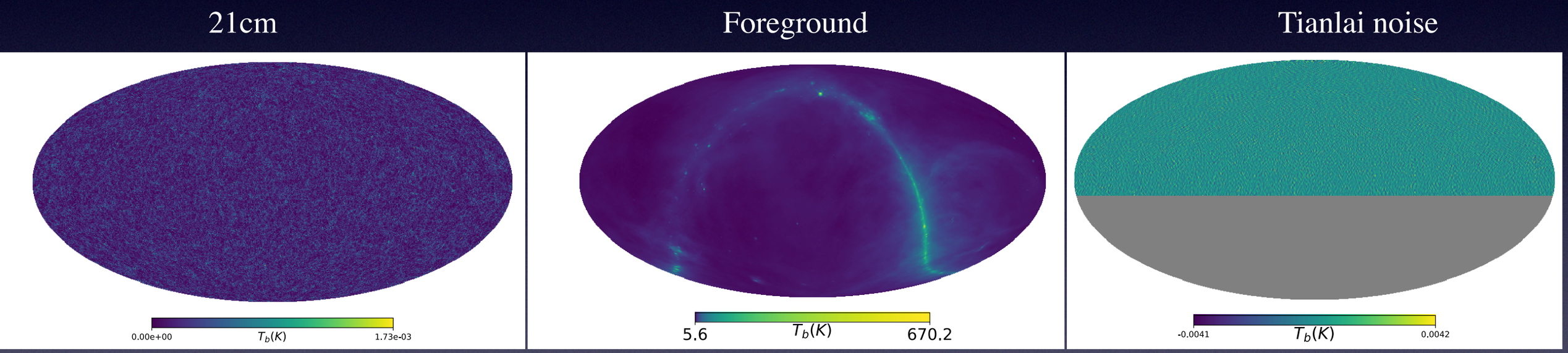
Tianlai noise & beam



Credit: Le Zhang

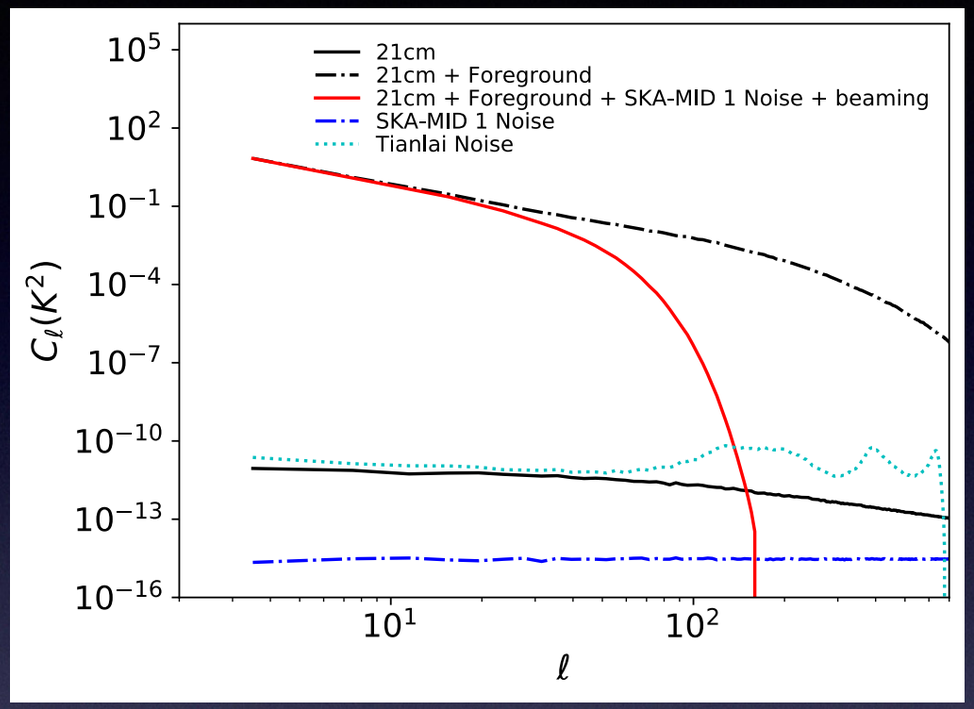
Final Temperature maps

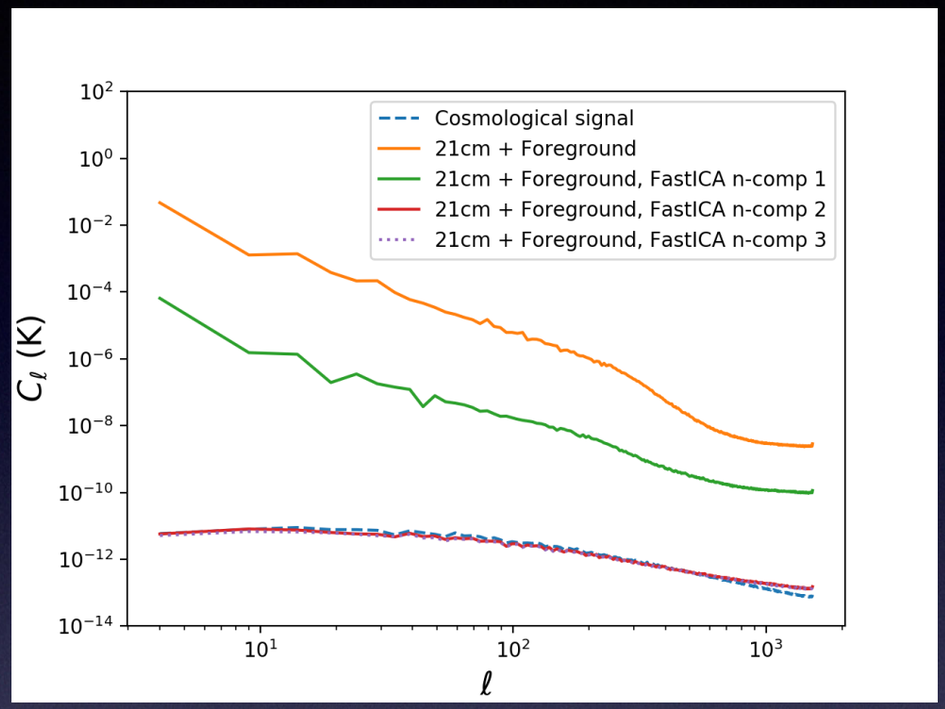
- We finally combine the temperature maps of 21cm extragalactic intensity, foreground signal and Tianlai receiver noise maps to create our set of simulated maps.

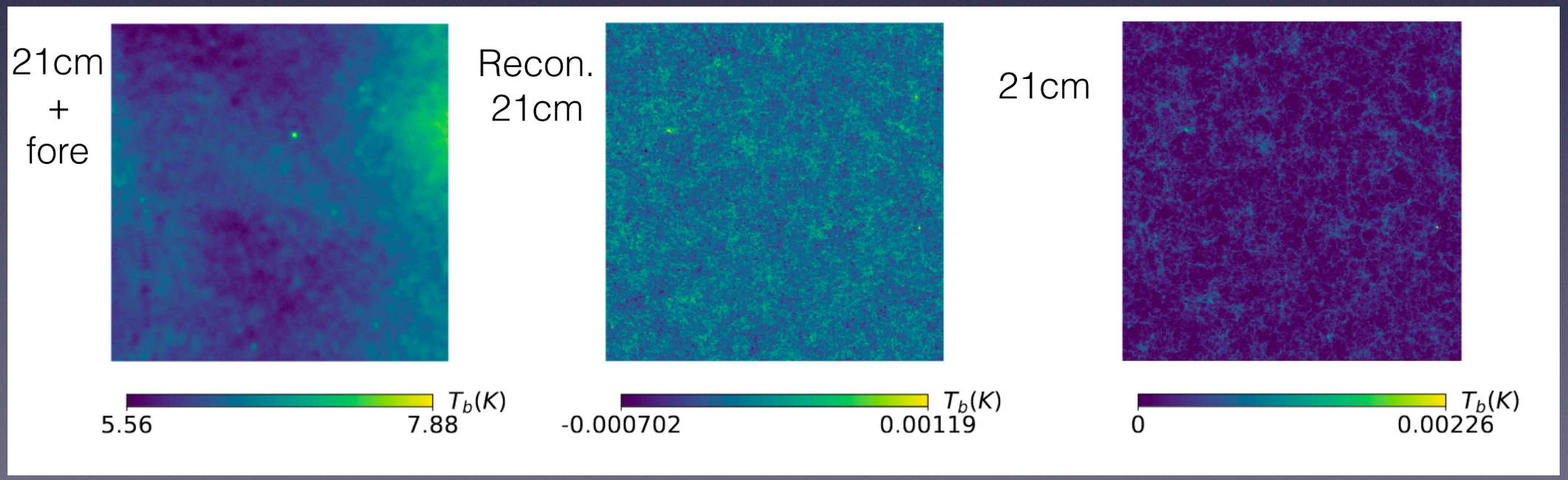


$$T_b^{\rm obs}(\hat{n}) = T_b^{\rm HI}(\hat{n}) + T_b^{\rm foreground}(\hat{n}) + T_b^{\rm noise}(\hat{n}).$$

Systematic errors & foreground removal

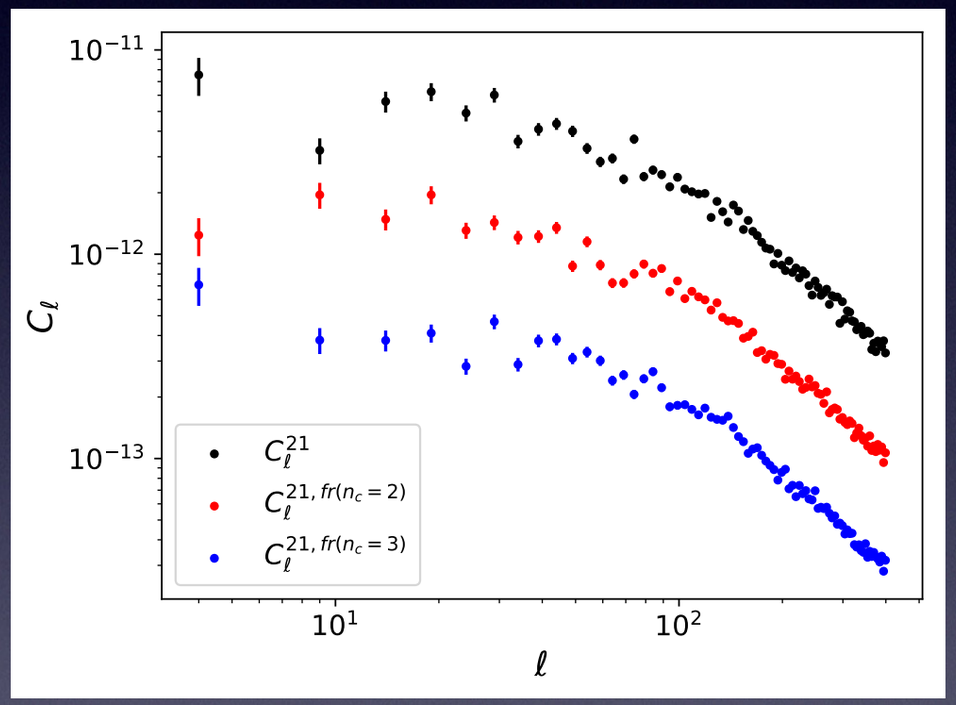


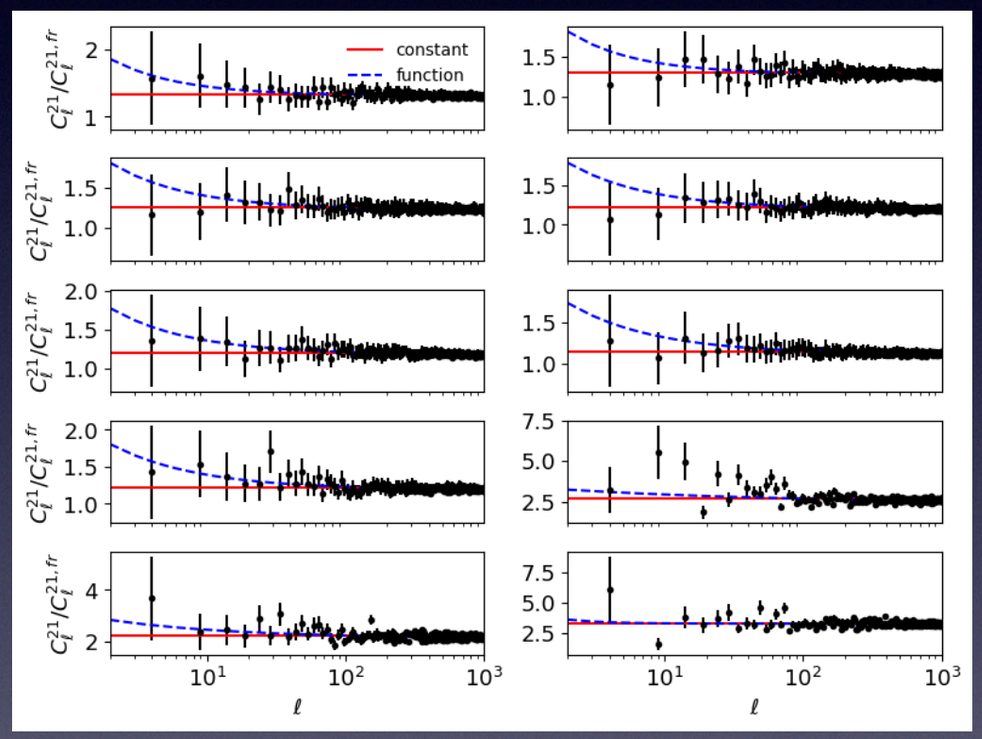




Correction factor on foreground removal

- Transfer function to account for cosmological information removed by foreground removal.

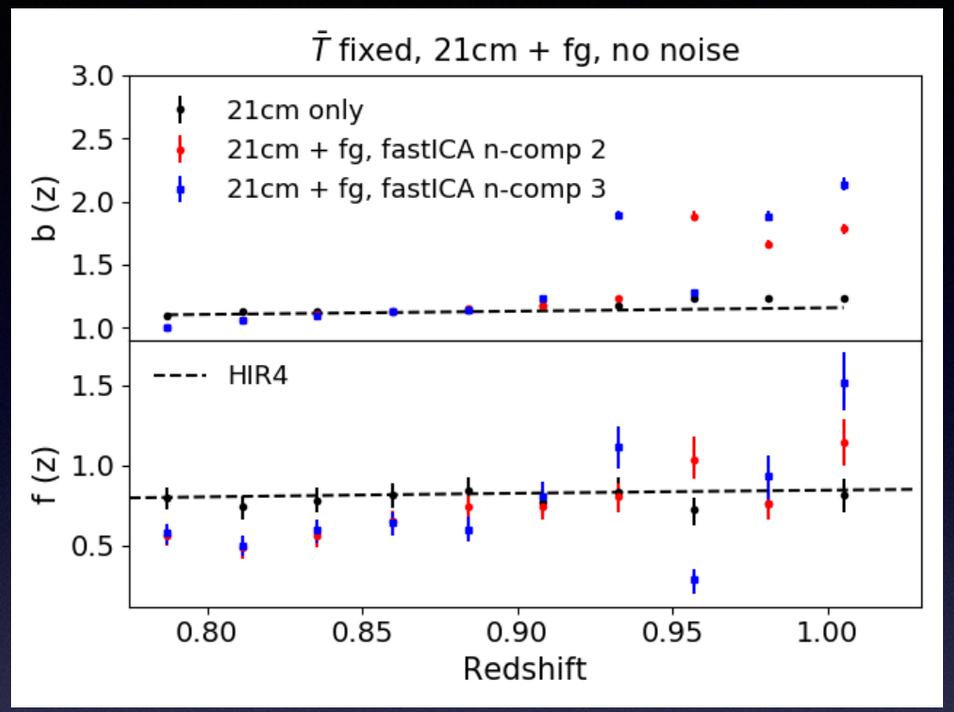




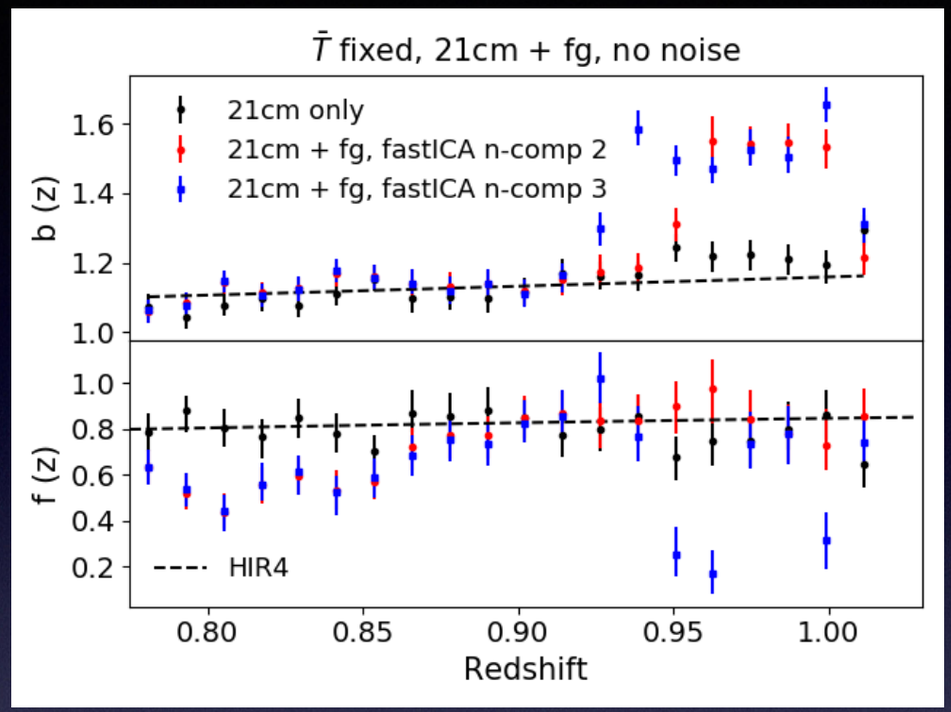
$$C_\ell^{21} = T_\ell C_\ell^{21,fr} \qquad T_\ell = \exp^{-\ell_\star \log \ell} + C$$

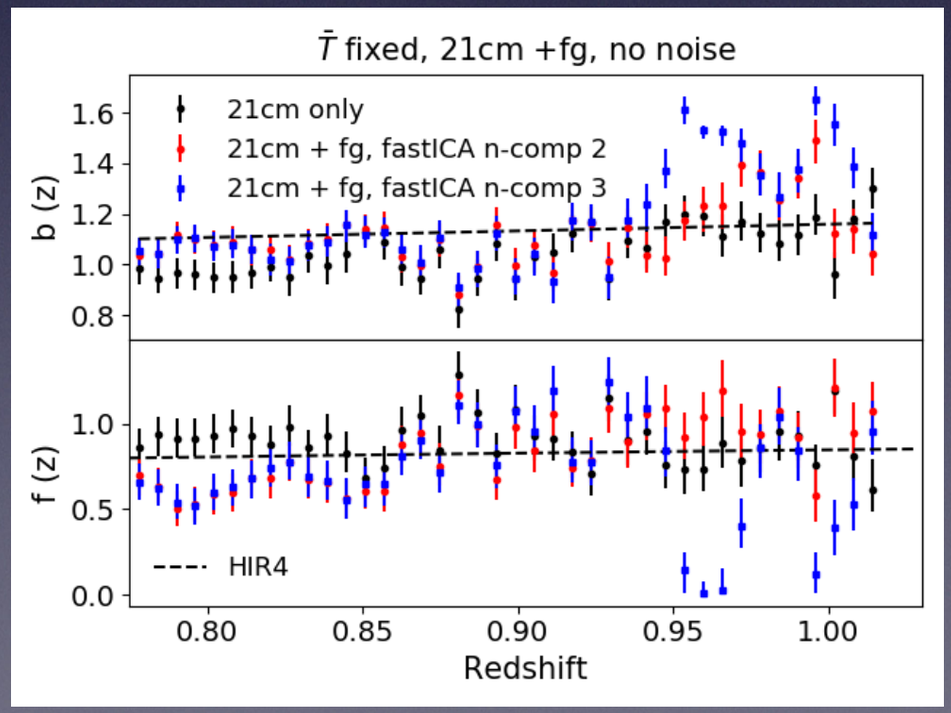
Cosmological parameters: Foregrounds

df=10 MHz



df=5 MHz





df=2.5 MHz

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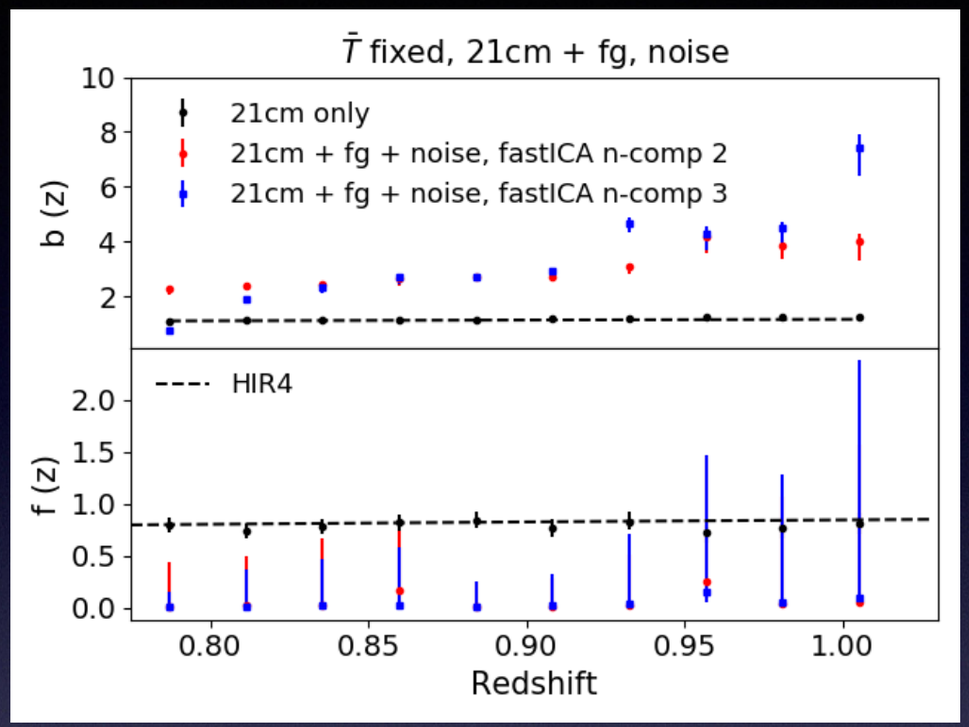
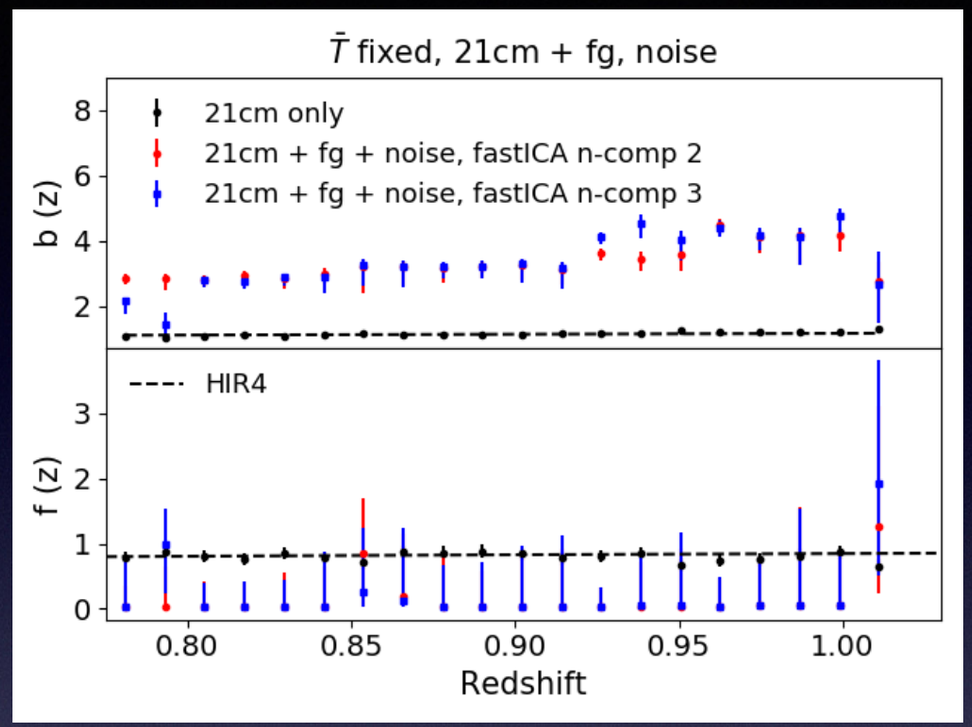
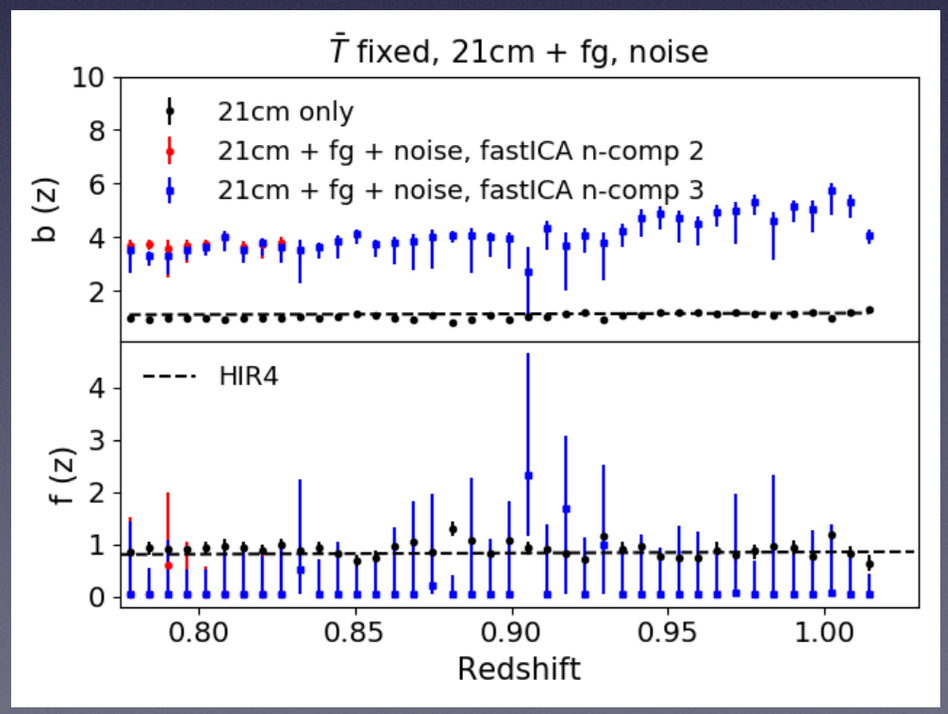
Cosmological parameters: Noise

df=10 MHz



df=5 MHz

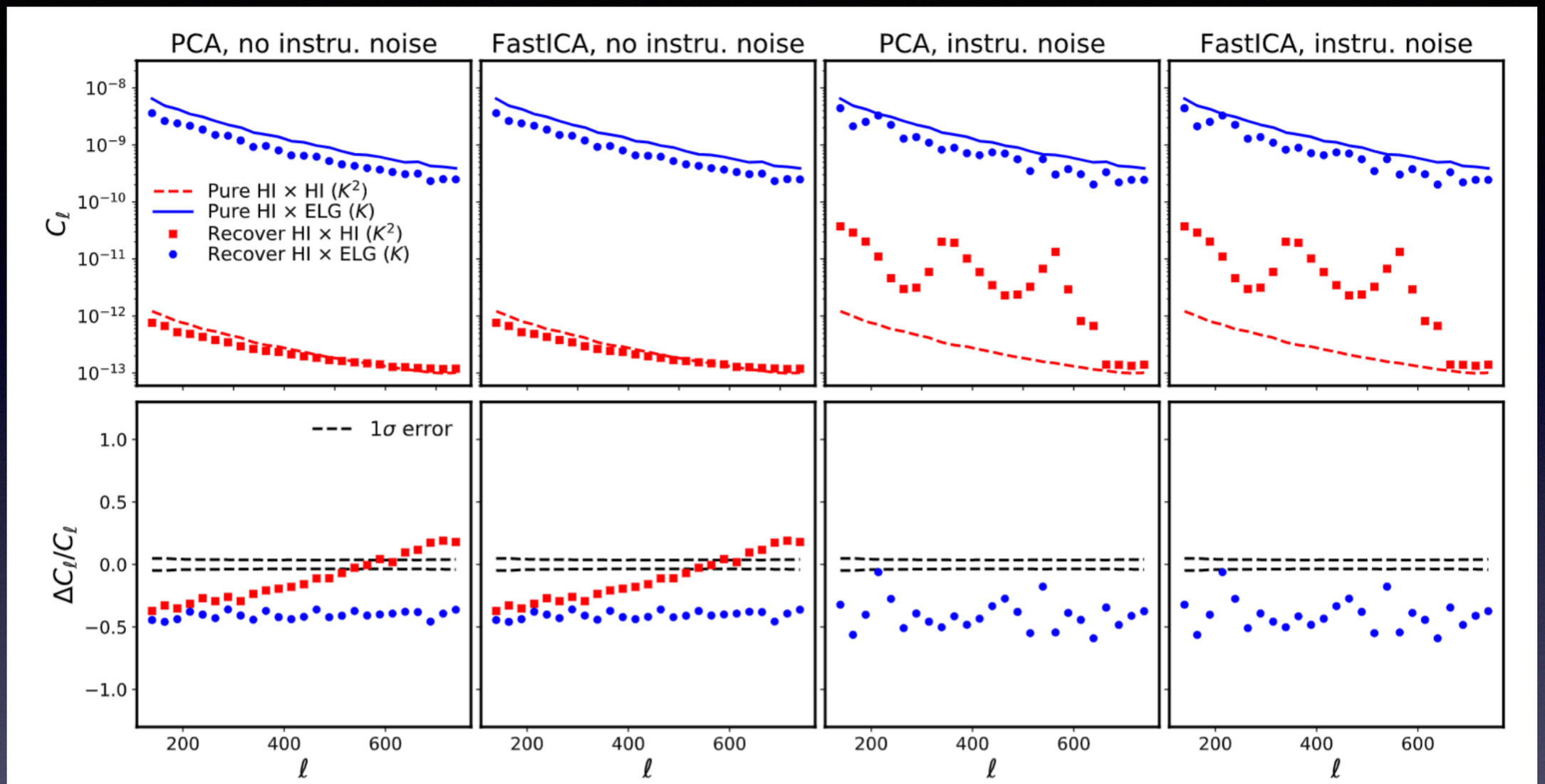




df=2.5 MHz

J. A., D. Parkinson, F. Shi, Y-S. Song, K. Ahn, J. Kim, J. Yao, L. Zhang and Sh. Zuo 2020, MNRAS; 495, 1788

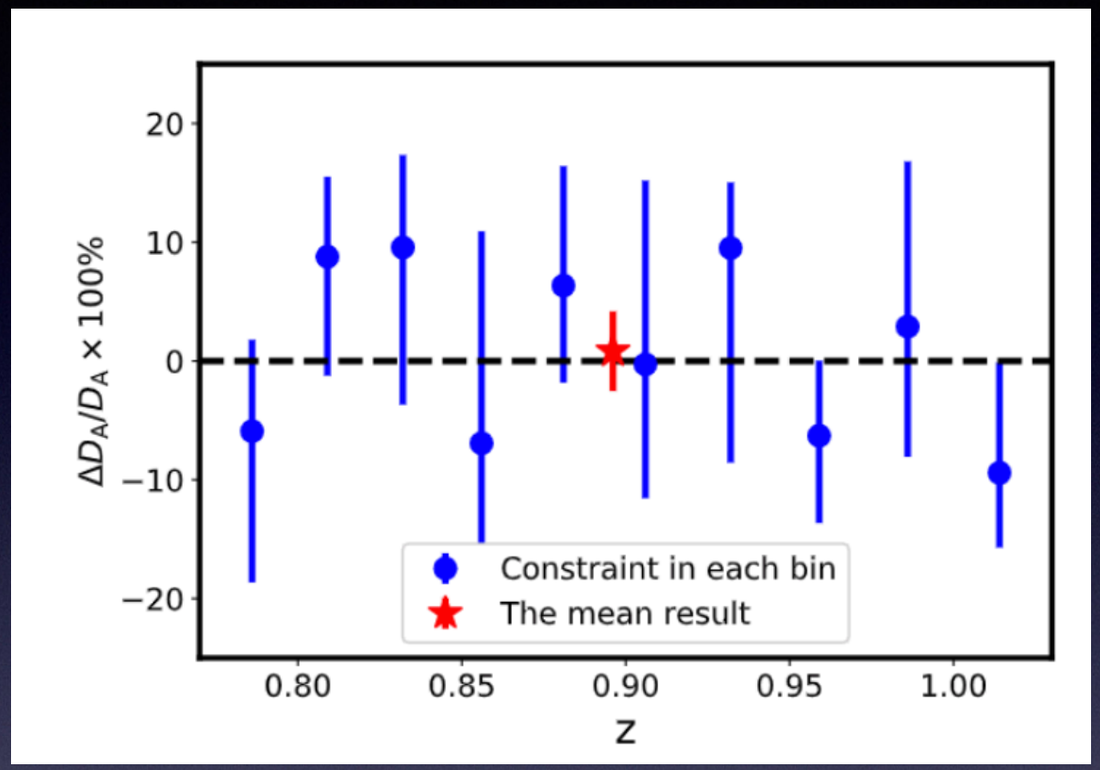
Cross-correlation of ELGs and 21cm maps

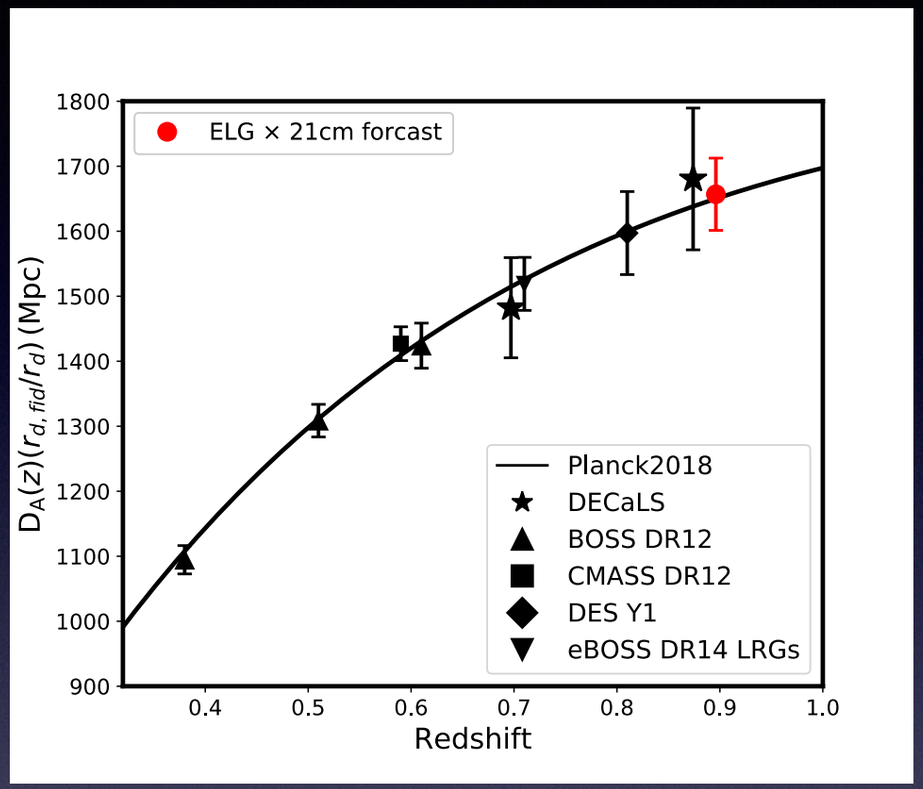


- Cross-correlations between 21cm and optical data -> Different systematics.
- Cross-correlations less influenced by foreground signal and instrument noise.
- Cross-correlation foreground removal bias is scale independent.

F. Shi, Y-S. Song, J. A, D. Parkinson, K. Ahn, J. Kim, J. Yao, L. Zheng. S. Fuo, arXiv: 2006.01407 (2020)

Cross-correlation of ELGs and 21cm maps





- We cross-correlate the HIR4 10 redshift bin configuration with ELG mock catalogue with DESI-like distribution.
- Predicted 3% BAO measurement for Tianlai.

F. Shi, Y-S. Song, J. A, D. Parkinson, K. Ahn, J. Kim, J. Yao, L. Zheng. S. Fuo, arXiv: 2006.01407 (2020)

Summary

- The cross-correlation of information from radio surveys and optical surveys can increase our knowledge about the nature of the Universe.

- We have created a **full-sky mock 21cm intensity mapping** maps using **Horizon Run 4** N-body simulation. Focus on precursors (e. g. Tianlai) but relevant for SKA. Focus on potential cross-correlations with optical surveys.

- Main systematics are **foreground removal**(10^7 factor difference) and **receiver noise** impact on foreground removal. For the auto-HI correlations, receiver noise destroys cosmological information.

- **Cross-correlations** with optical surveys more promising in the presence of noise and foregounds.

- Room for improvement: more foregrounds, account for more systematics, better halo-HI mass relations, …

¡Thank you!