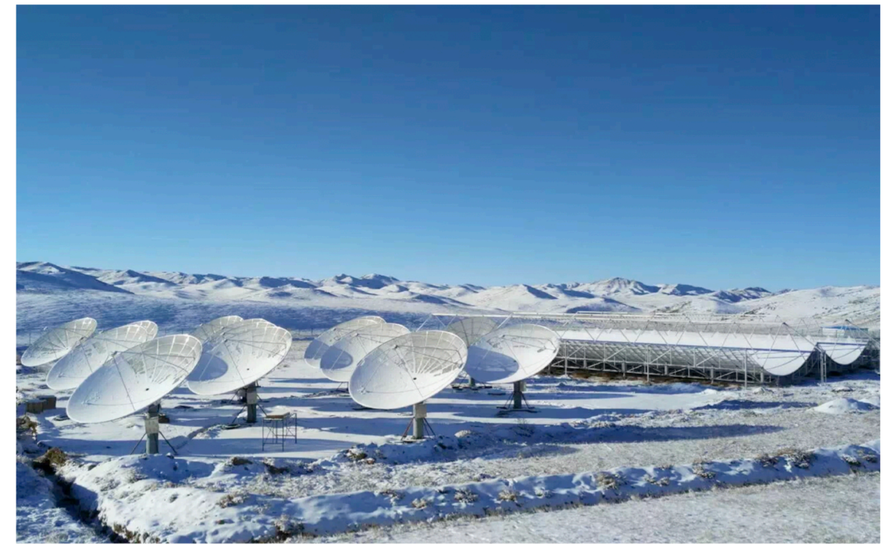
Cross-correlation between DESI galaxies and TIANLAI 21cm



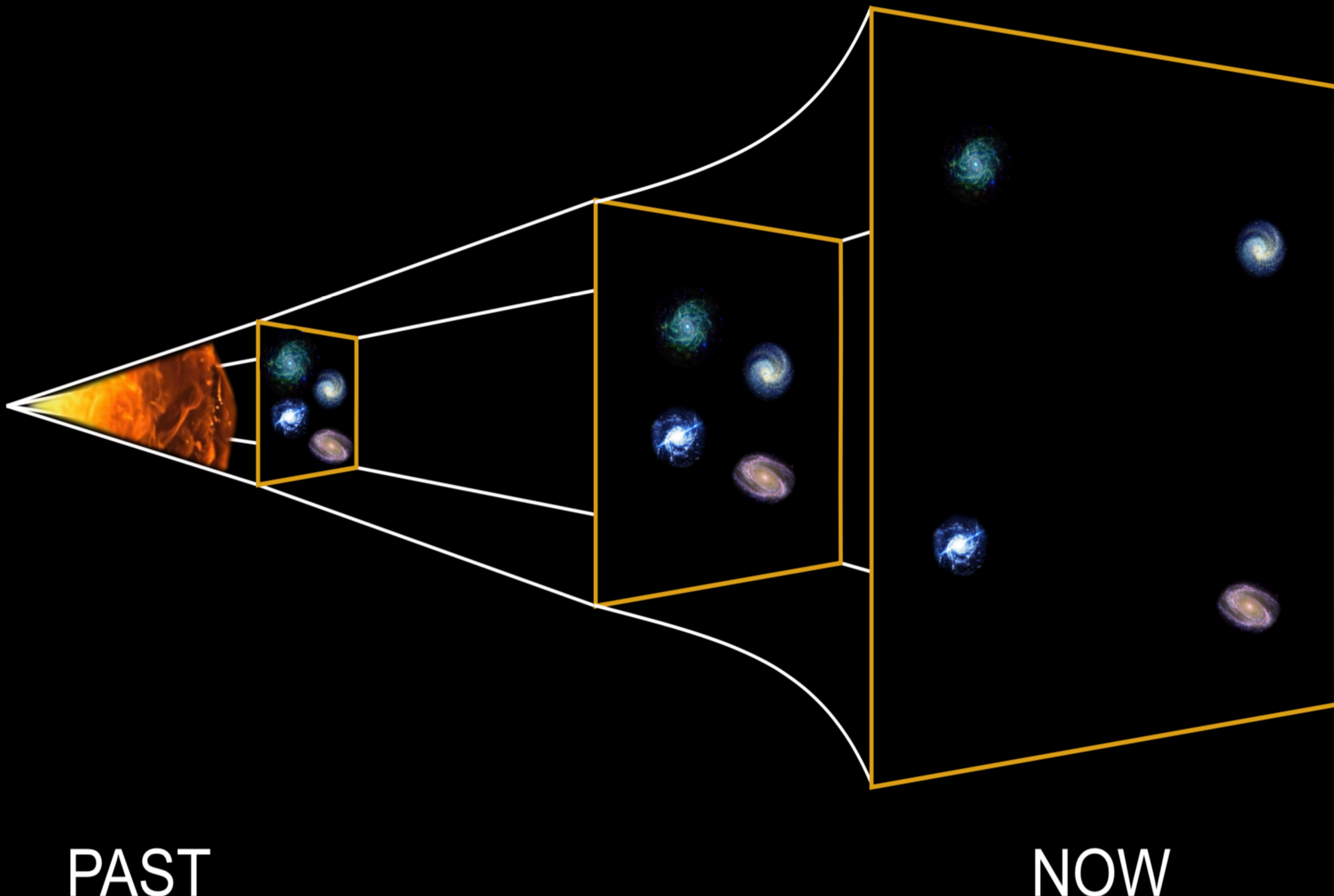
Feng Shi

with Yong-Seon Song, Jacobo Asorey, David Parkinson, Le Zhang, Kyungjin Ahn

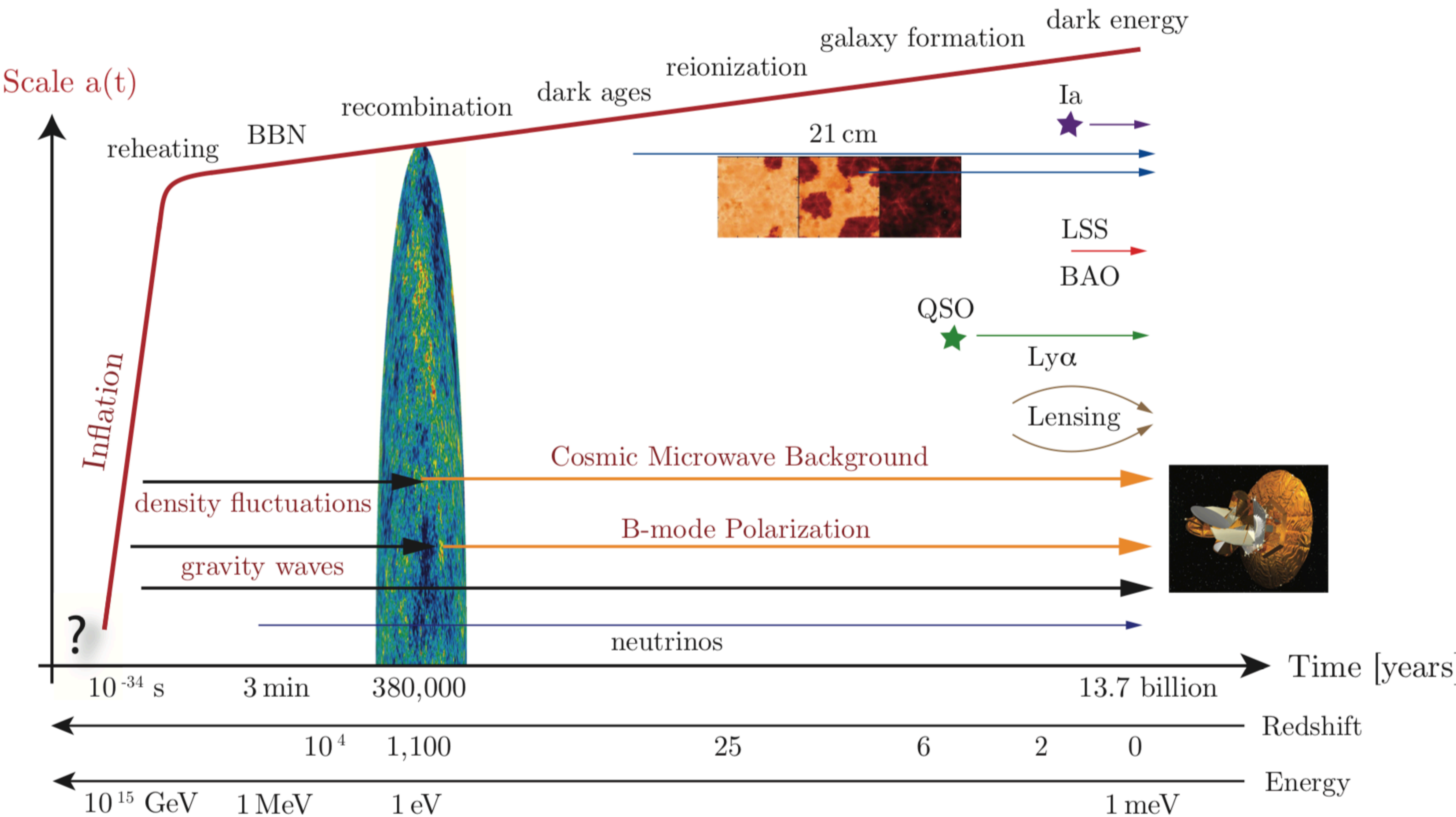
CosKASI

Cosmology Group at
Korea Astronomy and Space Science Institute

Biggest Question: Cosmic Acceleration



New challenge to detect BAO using 21cm signal



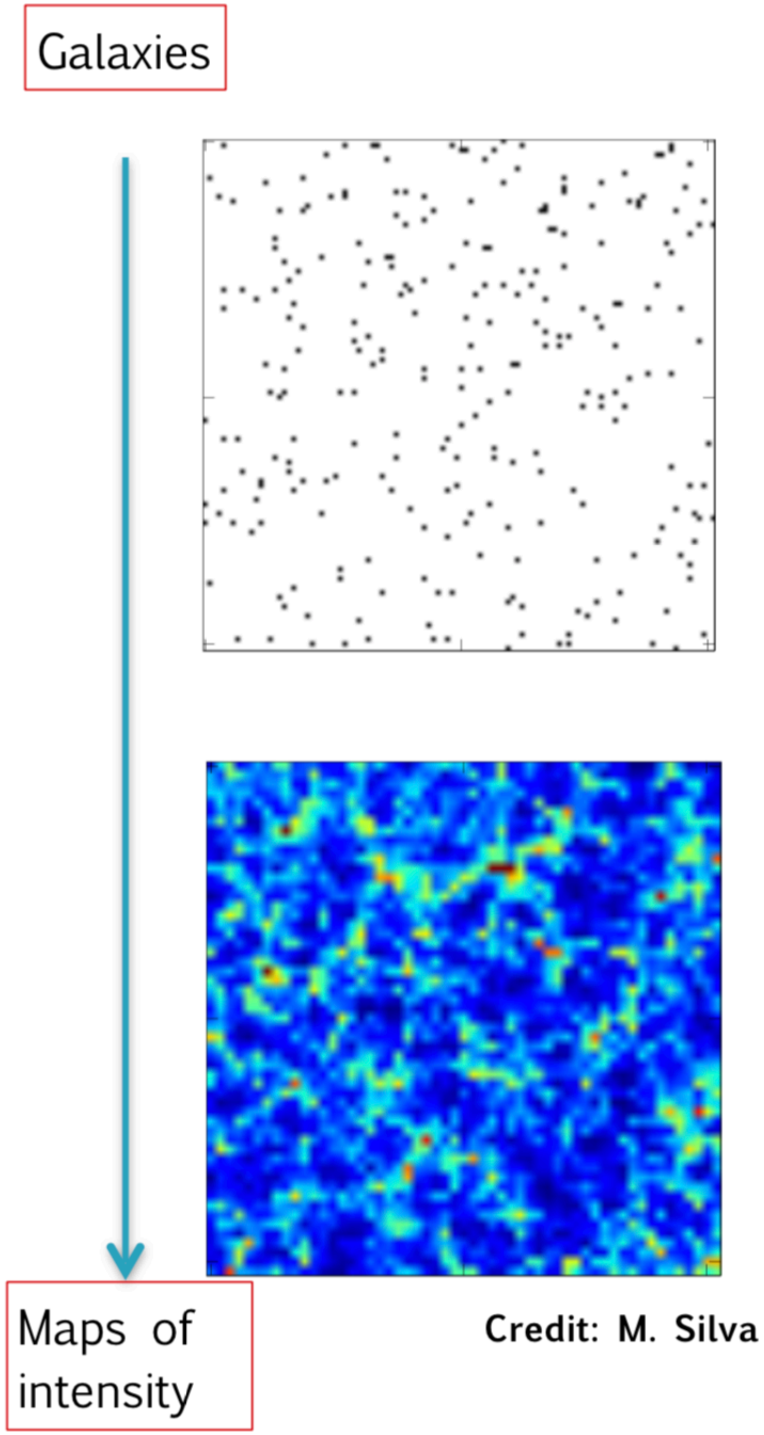
D. Baumann, 2009, arXiv:0907.5424

HI intensity mapping

- Tracer: follows fluctuation in the underlying cosmic density field
- 3D map: redshifted by the expansion of the Universe
- Low resolution but higher precision redshift
- Expected to provide a sensitive probe of cosmic dark energy at 0.5 <z< 2.5.(Chang et al 2008, Loeb & Wyithe 2009)

  Galaxies: affected by the infrared opacity of the atmosphere at z~1, where the Universe begin to be accelerated.

- No shot noise
- Main challenge: Foreground!



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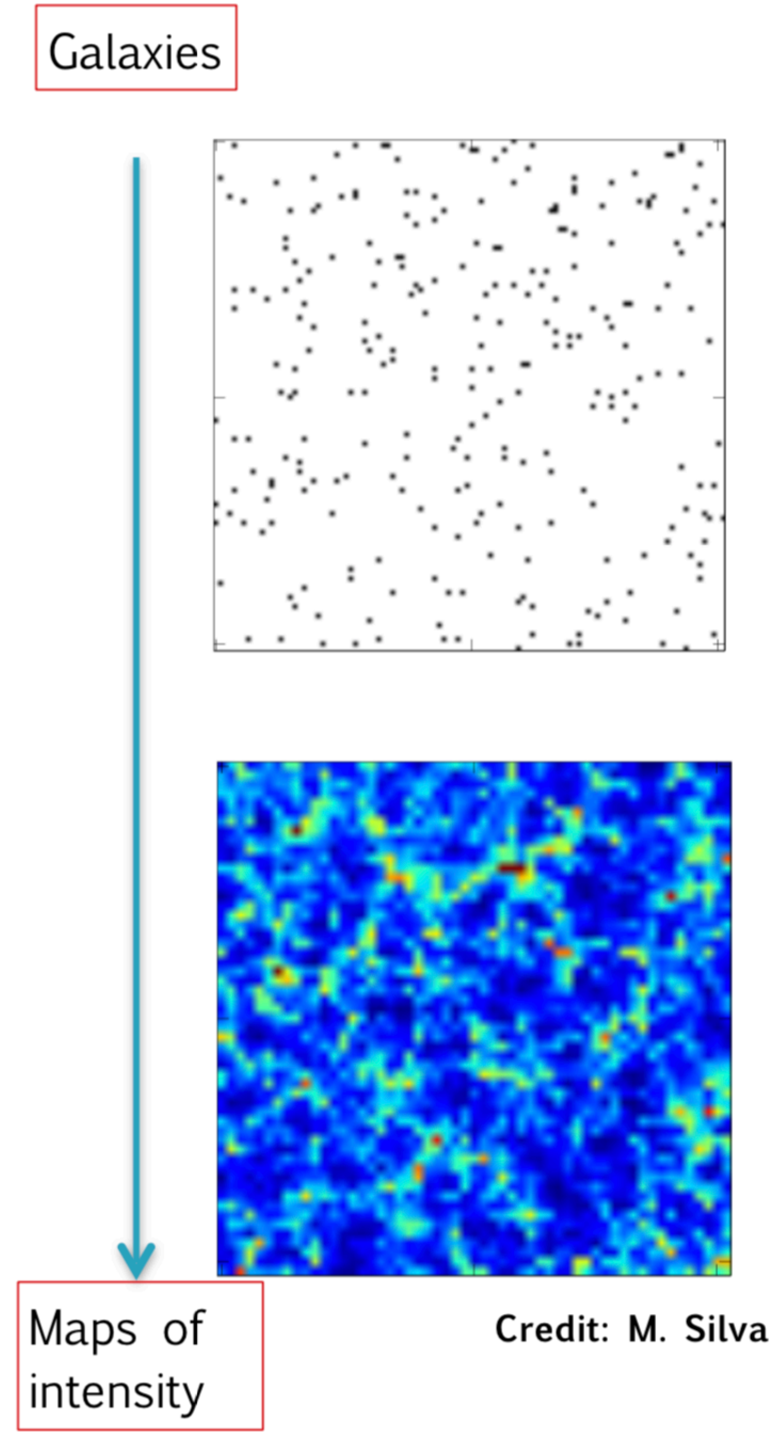
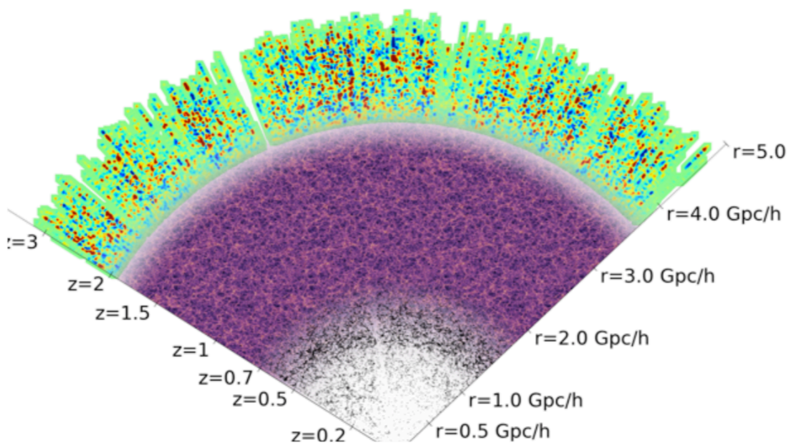


In our case, we will do the cross-correlation with optical galaxies

Why?

DESI galaxy survey

DESI aims to study a very large volume of the Universe by targeting specific classes of objects out to redshift 3.5 over 14,000 deg of sky.

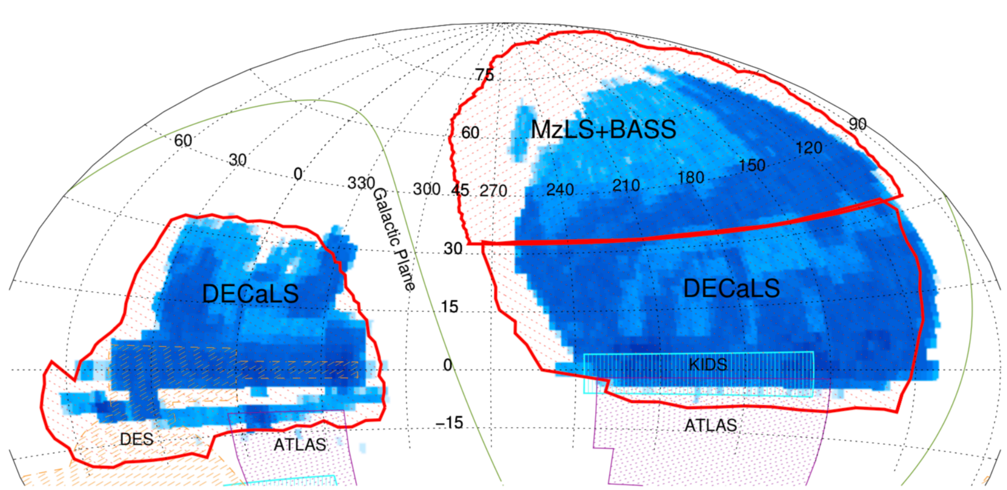


Object Class	Number of Spectra	Redshift Range
bright galaxies, r < 19.5	10 million	0 < z < 0.4
luminous red galaxies (LRGs)	4.2 million	0.4 < z < 1.0
emission line galaxies (ELGs)	18 million	0.6 < z < 1.6
quasars (QSOs)	2.4 million	0.5 < z < 3.5
Milky Way stars	10 million	---

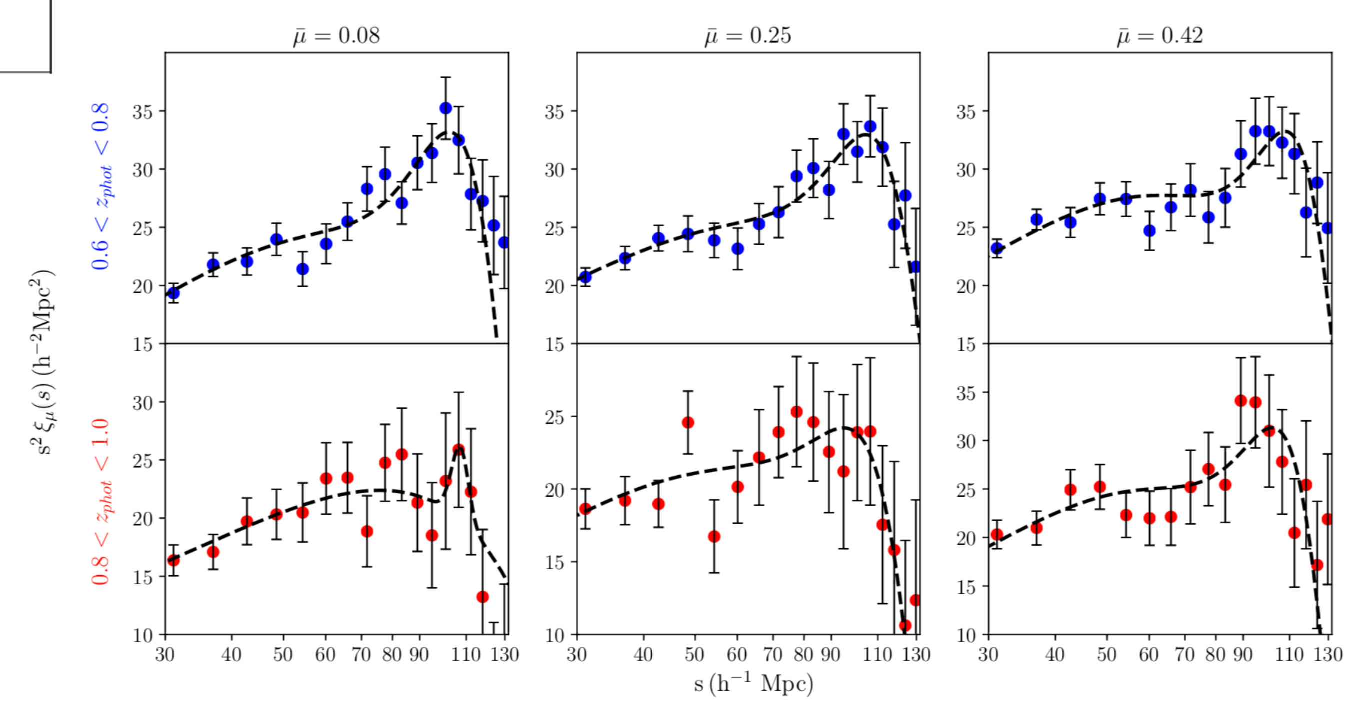
$SDSS\ 2h^{-3}Gpc^{-3}$ → $BOSS\ 6h^{-3}Gpc^{-3}$ → $DESI\ 50h^{-3}Gpc^{-3}$

The DESI image survey has already completed

The Beijing-Arizona Sky Survey (BASS)	*The DECam Legacy Survey* (DECaLS)	*The Mayall z-band Legacy Survey* (MzLS)



Sridhar et al (2019):
Succeed in measuring BAO using DESI photo-z data!



Tianlai x DESI opportunity window

H1R4:Verification based on simulation data

TIANLAI Pathfinder (@Hongliuxia):

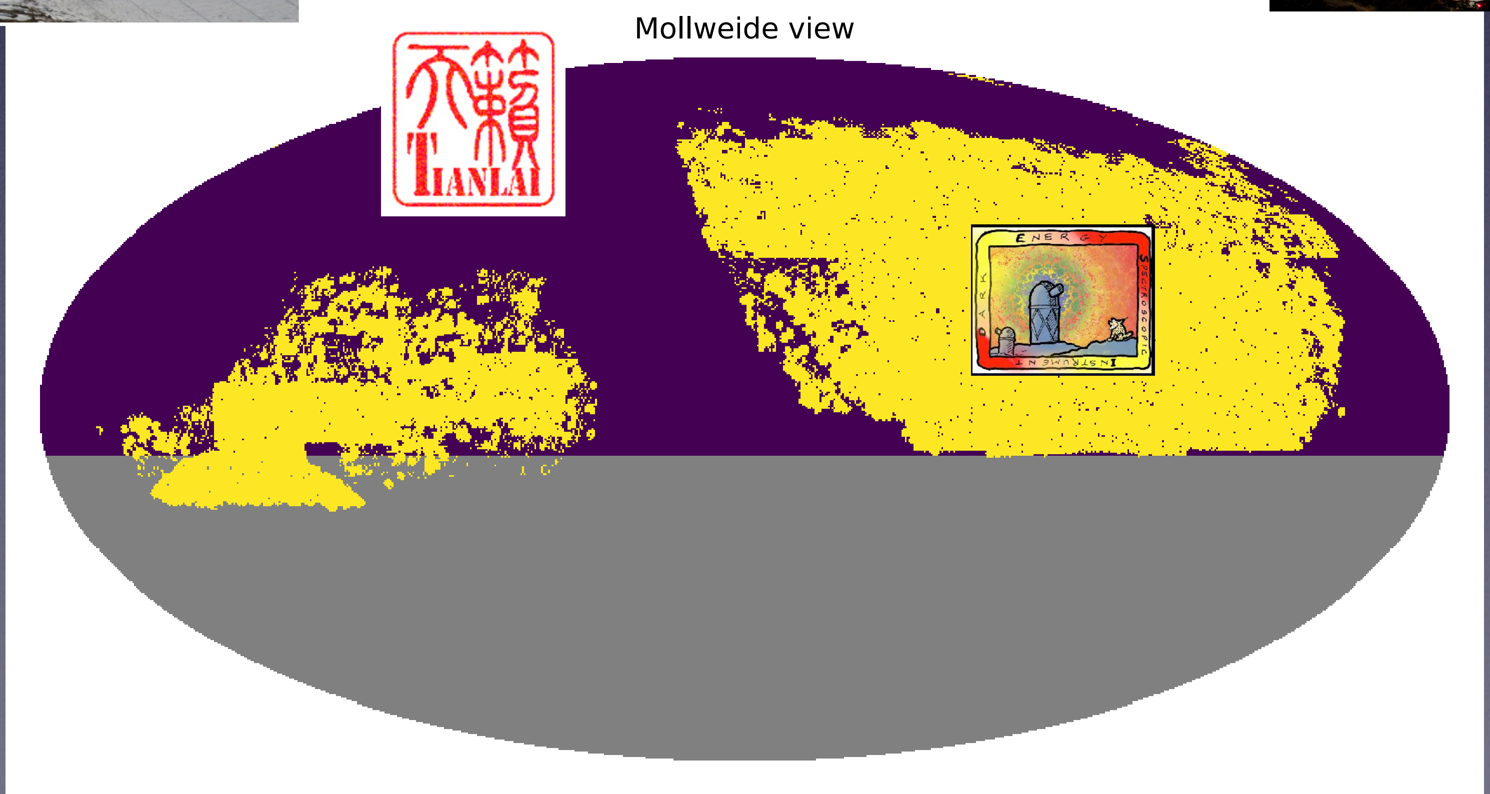
- 3 (15x40m) cylinders
- 16 (6m) dishes
- 700-800MHz
- 0.775 < z < 1.03

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

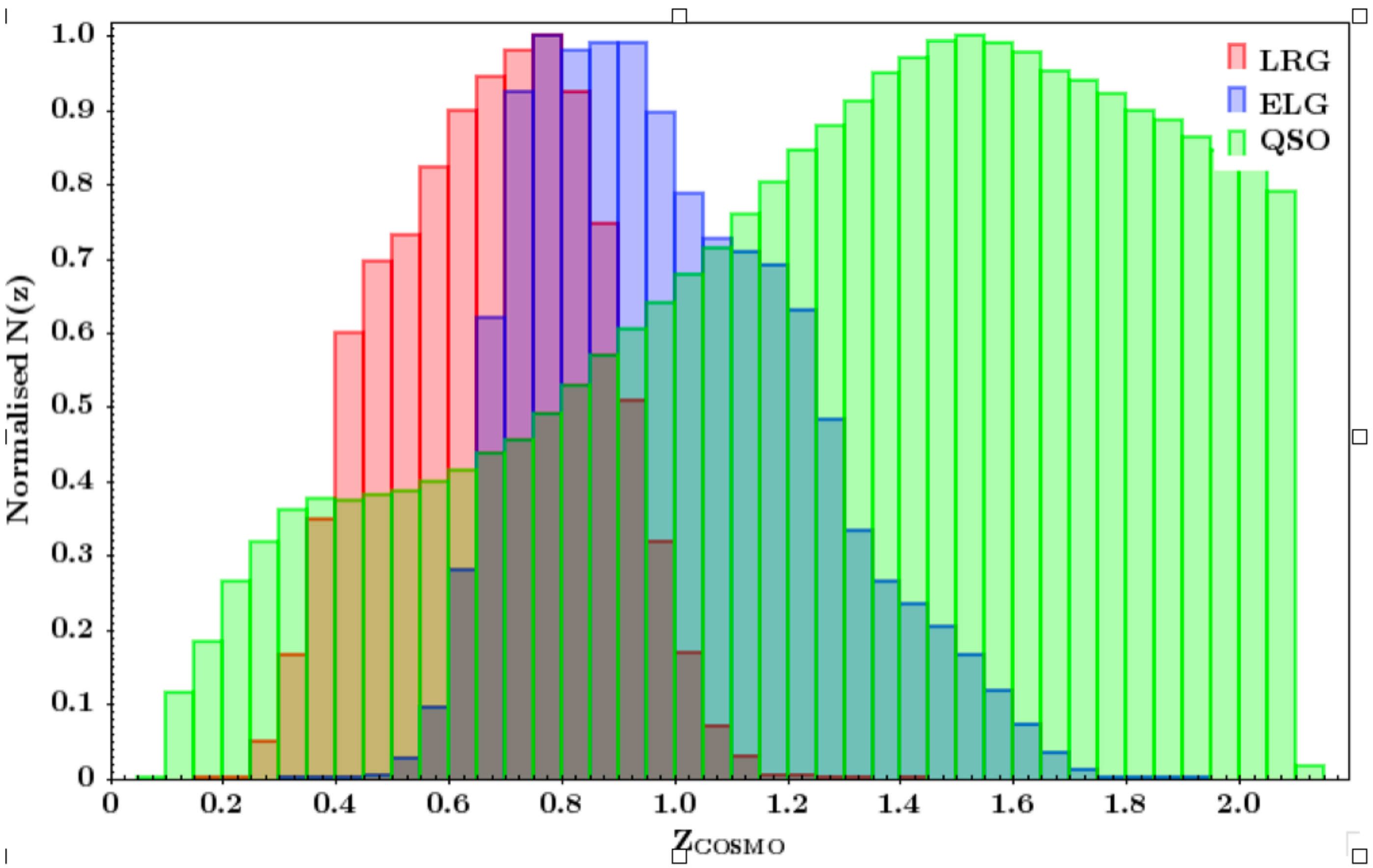


Cross-correlated with LRG or ELG?

Table 1
The Experiment Parameters for Tianlai

	Cylinders	Width	Length	Dual Pol. Units/Cylinder	Frequency
Pathfinder	3	15 m	40 m	32	700–800 MHz
Pathfinder+	3	15 m	40 m	72	700–800 MHz
Full scale	8	15 m	120 m	256	400–1420 MHz

$0.775 < z < 1.03$



Redshift distribution from DarkSky

LRG is not complete in this redshift range
We prefer using ELG

‘Painting’ neutral hydrogen in the Halo canvas

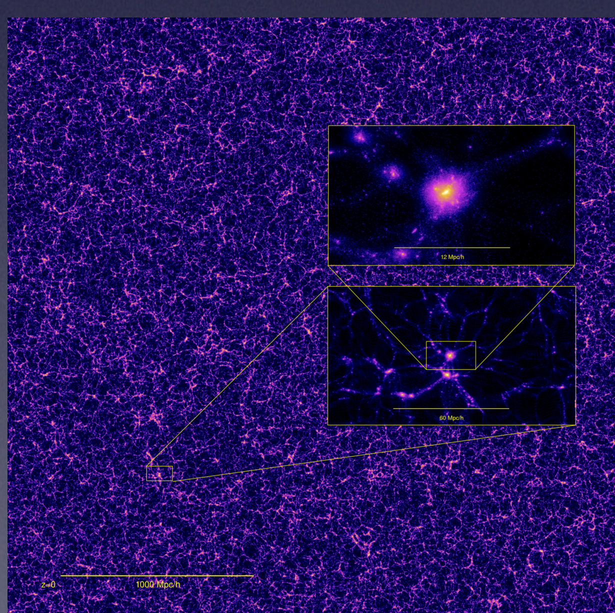
HR4 simulation:
L=3150 Mpc/h
6300^3 particles
Lightcone: 0<z<1.4

0.775<z<1.03

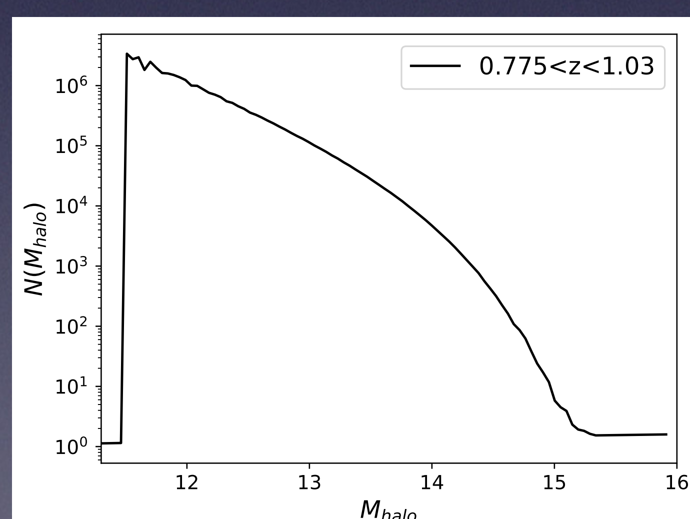
N-body simulation → Halo catalogue

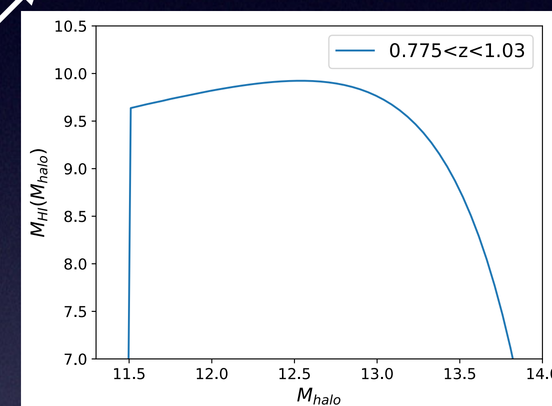
Halo catalogue → HI halos → HI brightness T

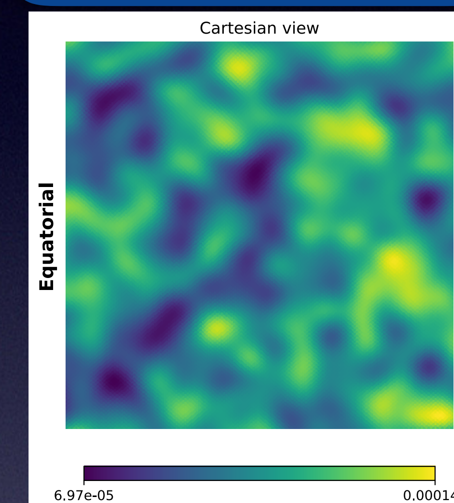
Halo catalogue → ELG halos → ELG density

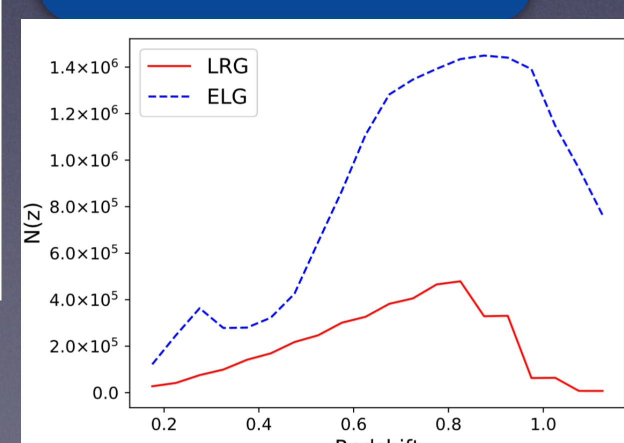


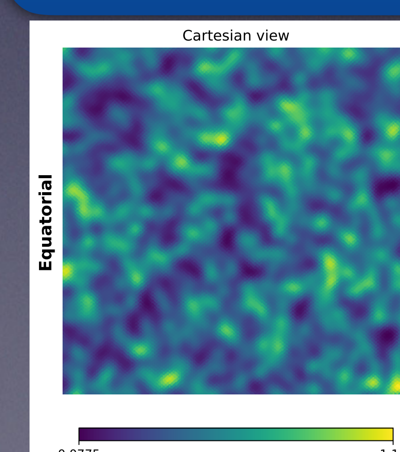
Kim J., Park C., L'Huillier B., Hong S. E. 2015





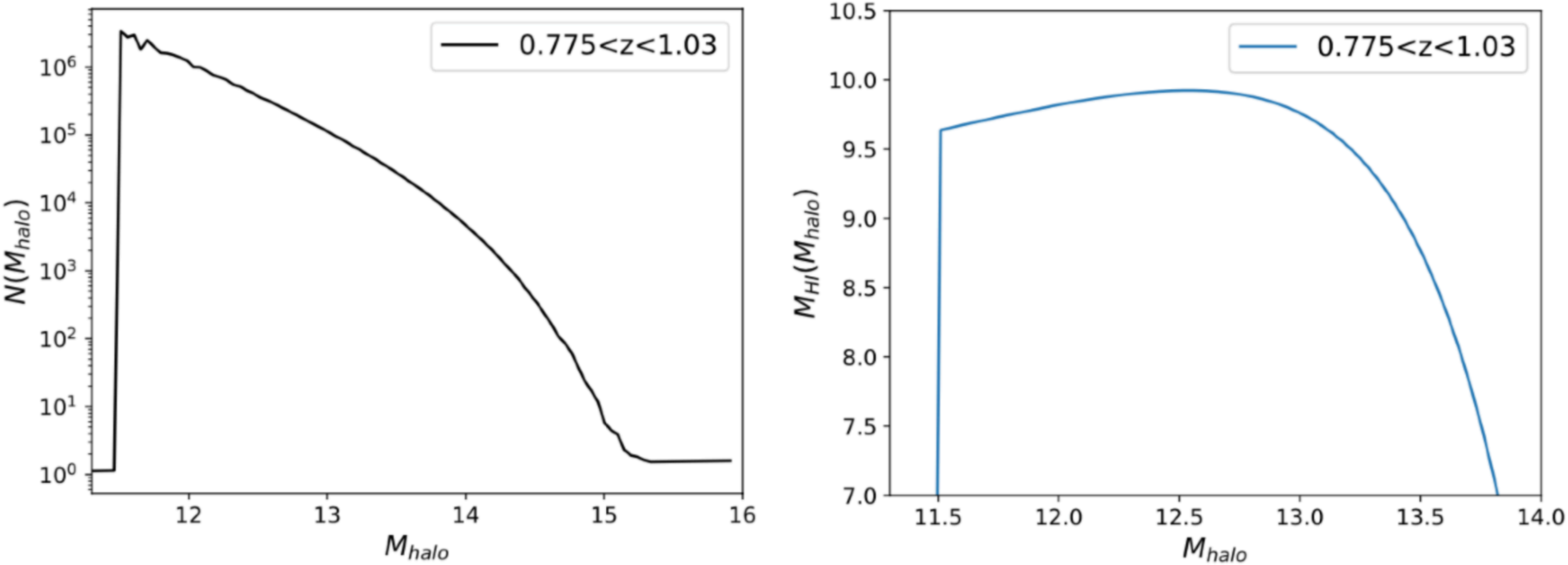






Jacobo Asorey et al in preparation

‘Painting’ neutral hydrogen in the Halo canvas



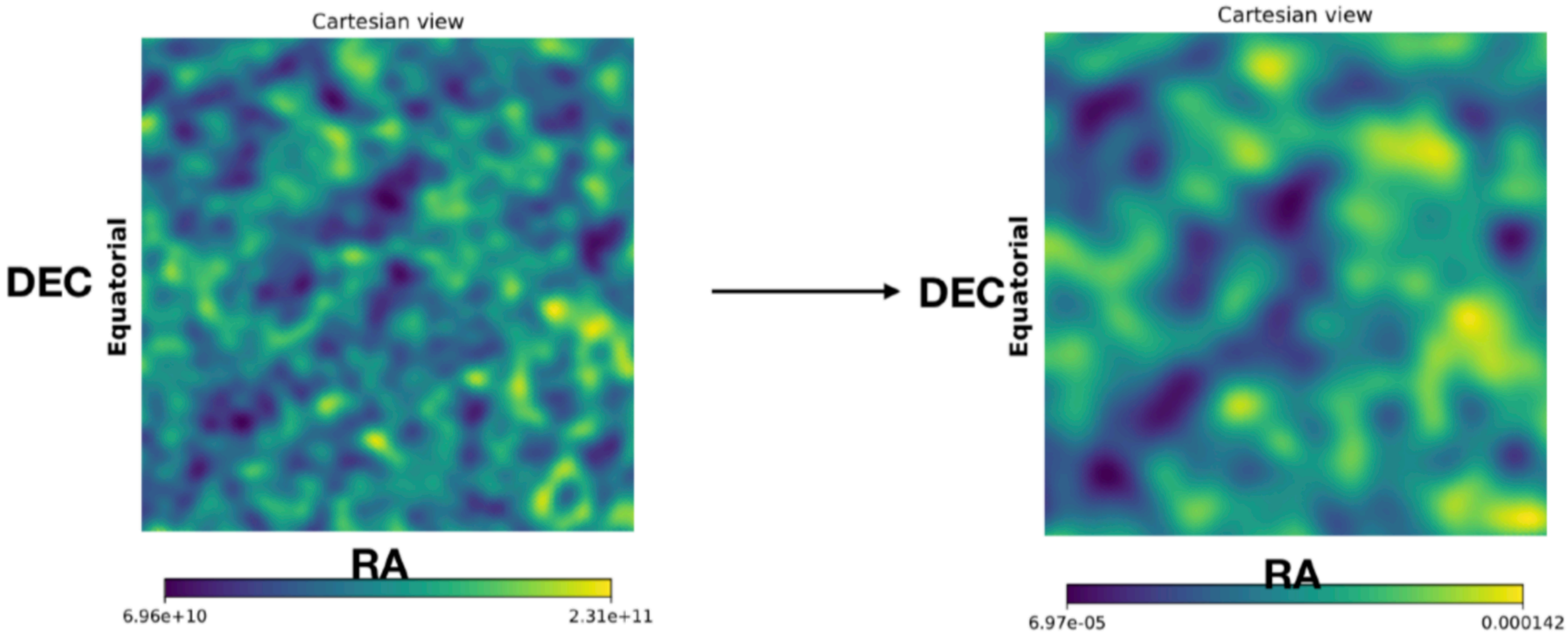
- velocity dispersion
- halo mass

$$M_{HI}(M_h) = f_{HI} f_c M_h \left(\frac{M_h}{10^{1}1M_\odot}\right)^{\beta} \exp\left[-\left(\frac{v_{vc0}}{\sigma_v(M_h)}\right)^3\right] \exp\left[-\left(\frac{\sigma_v(M_h)}{v_{c1}}\right)^3\right]$$

H. Padmanabhan & A. Refregier (2017), MNRAS, 464, 4008

'Painting' neutral hydrogen in the Halo canvas

- Given a neutral hydrogen density in a frequency bin, we assign a brightness temperature to a given pixel in the sky



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

P. Bull & P. G. Ferreira, P. Patel, M. Santos (2015), ApJ, 803, 21

Adding the foregrounds: Global Sky Model

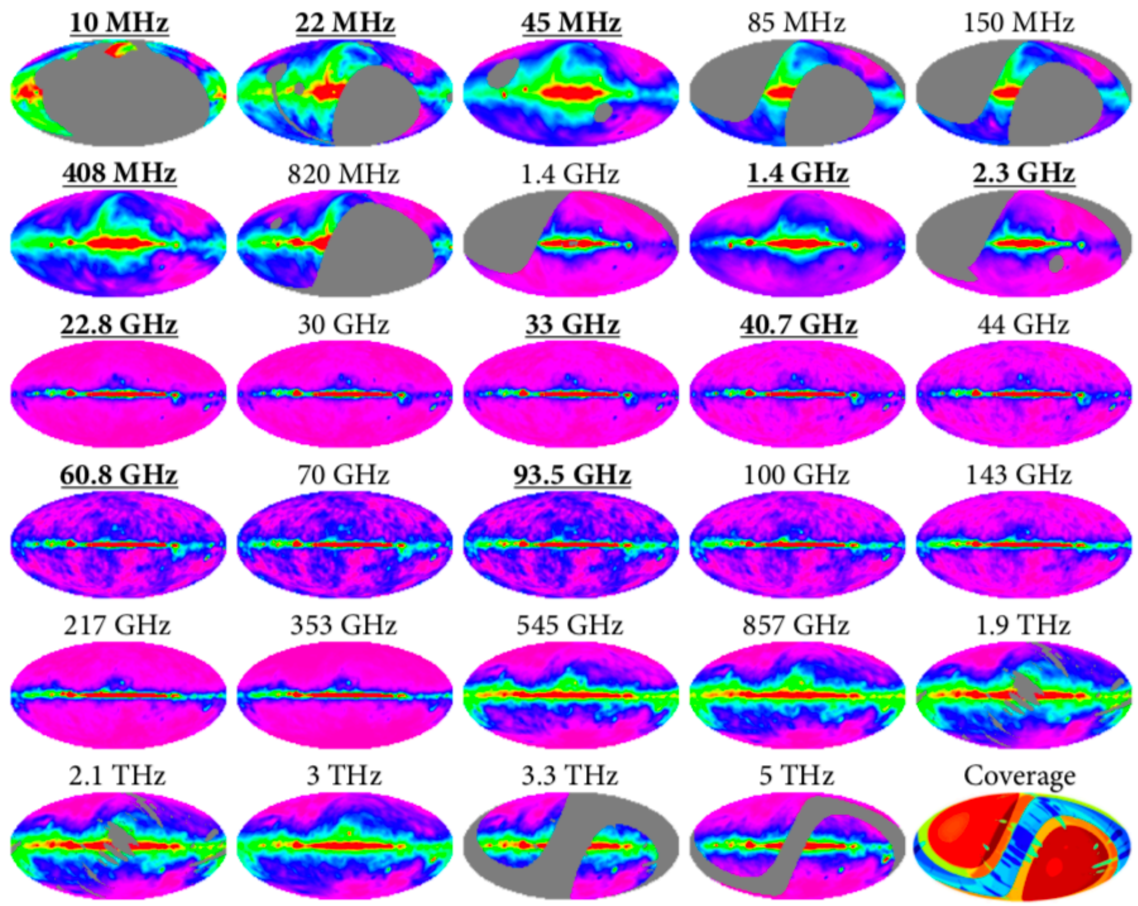
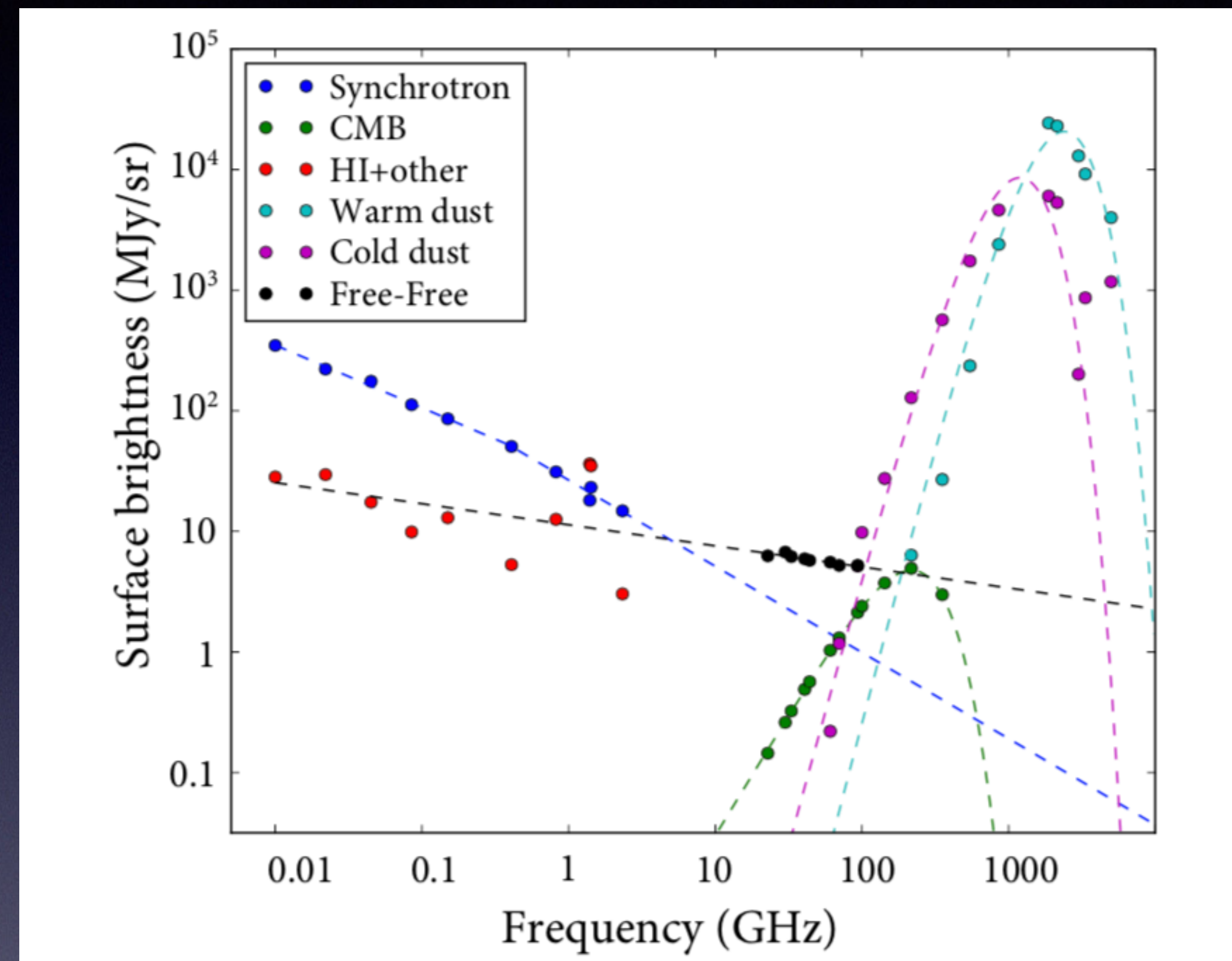


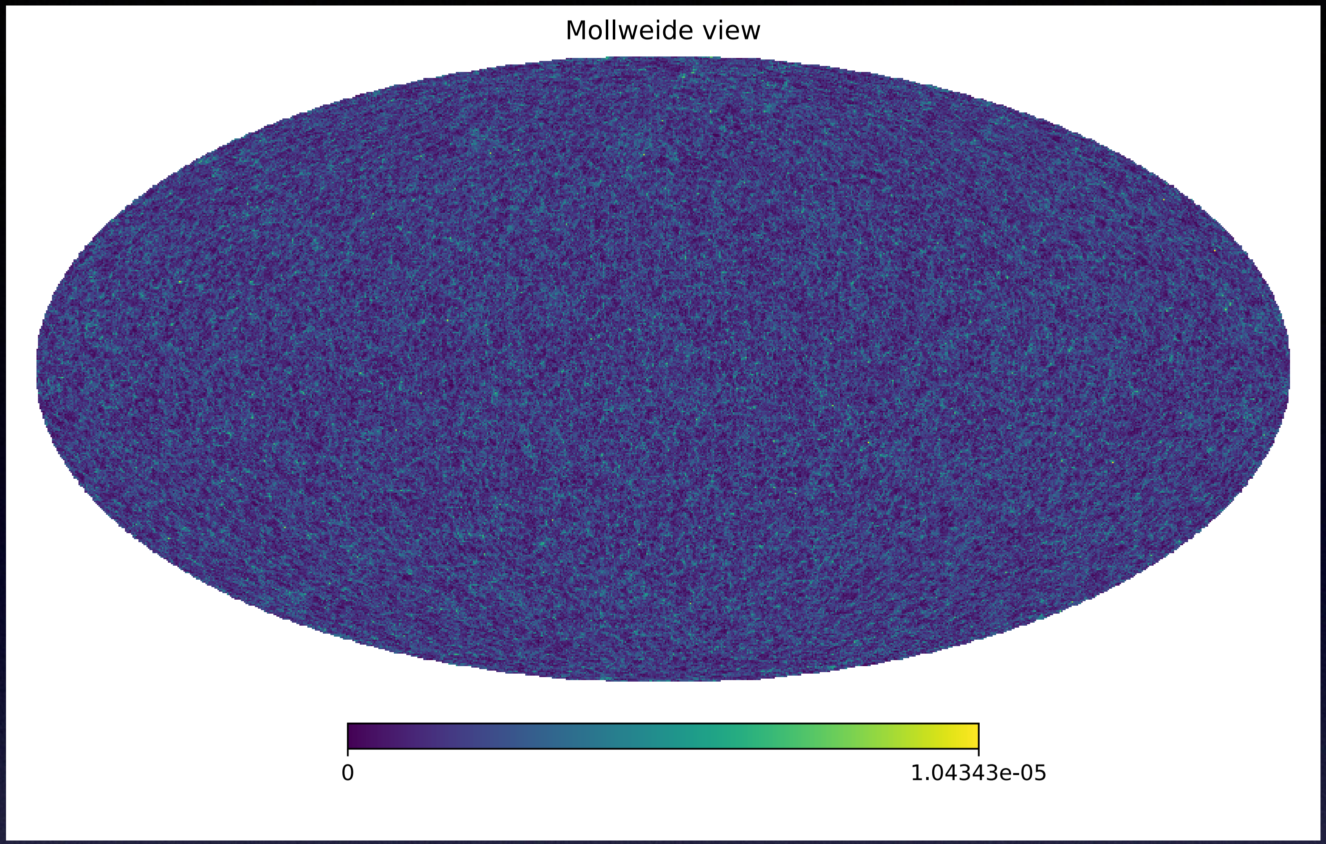
Figure 1. 29 sky maps used in this work from 10 MHz to 5 THz, plotted in Galactic coordinate under Mollweide projection centred at the Galactic centre, on arcsinh scales, where the constant for each arcsinh is set to the overall amplitude of each map, as shown in Fig. 2. The color scale follows the rainbow 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.



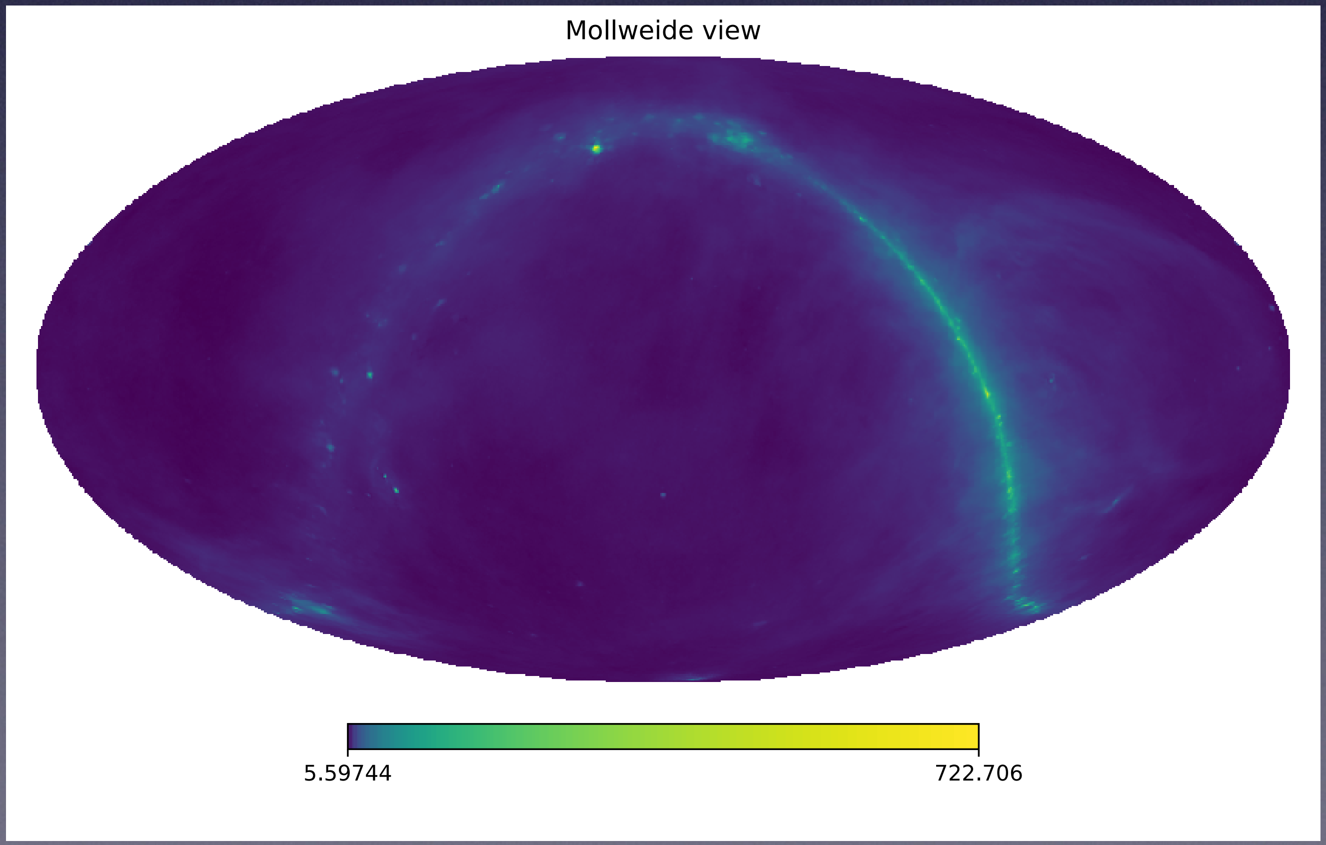
- We add the foreground at a given frequency by using the PCA solution from GSM.

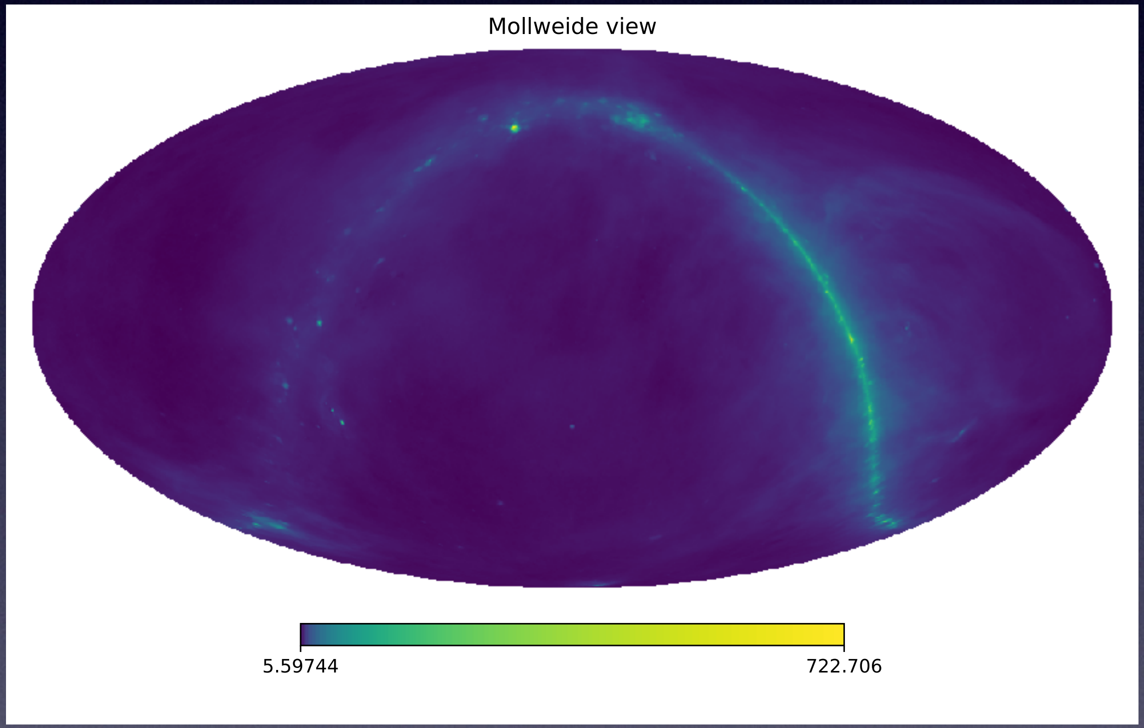
A. de Oliveira-Costa et al. (2008), MNRAS, 388, 247
H. Zheng et al. (2017), MNRAS, 464, 3486

Hydrogen maps

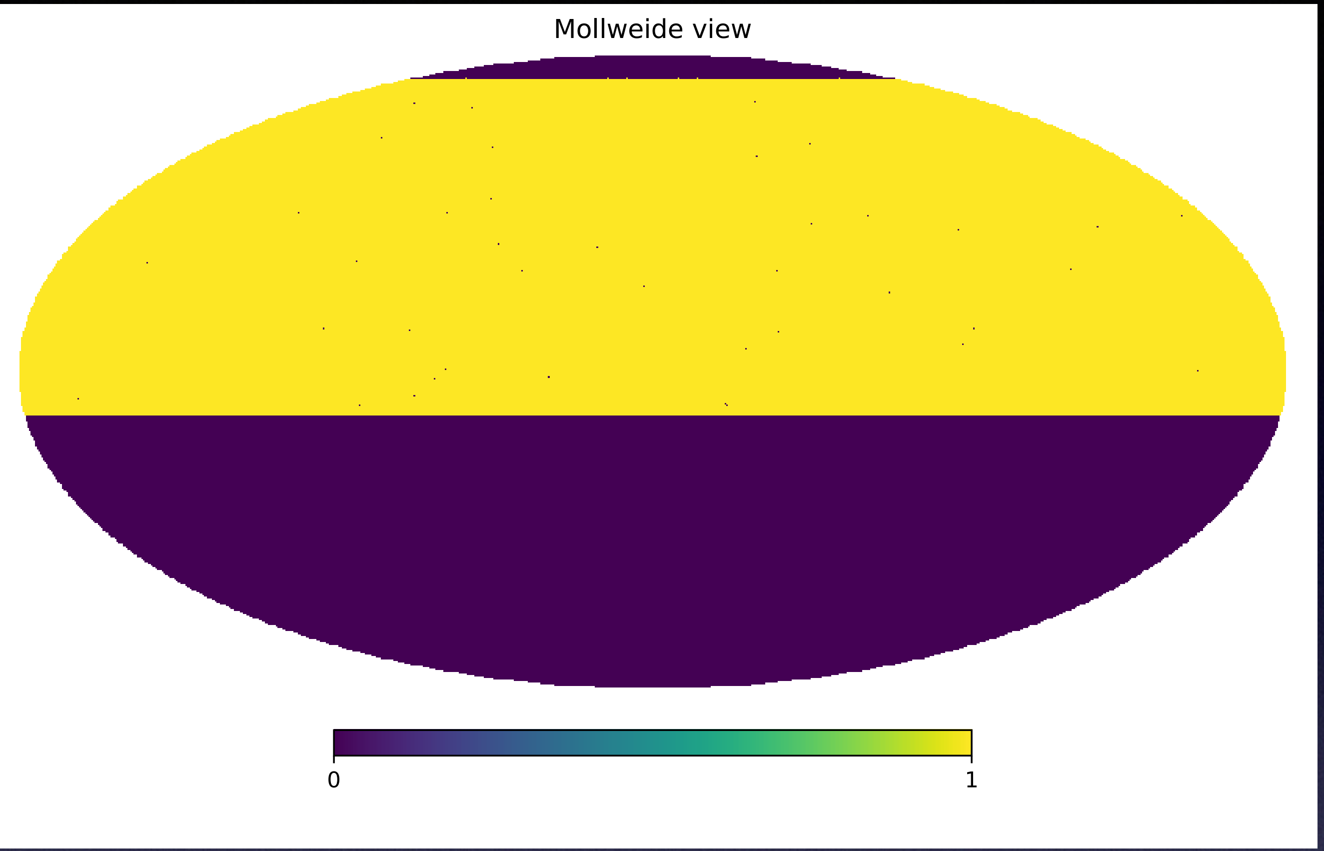


+

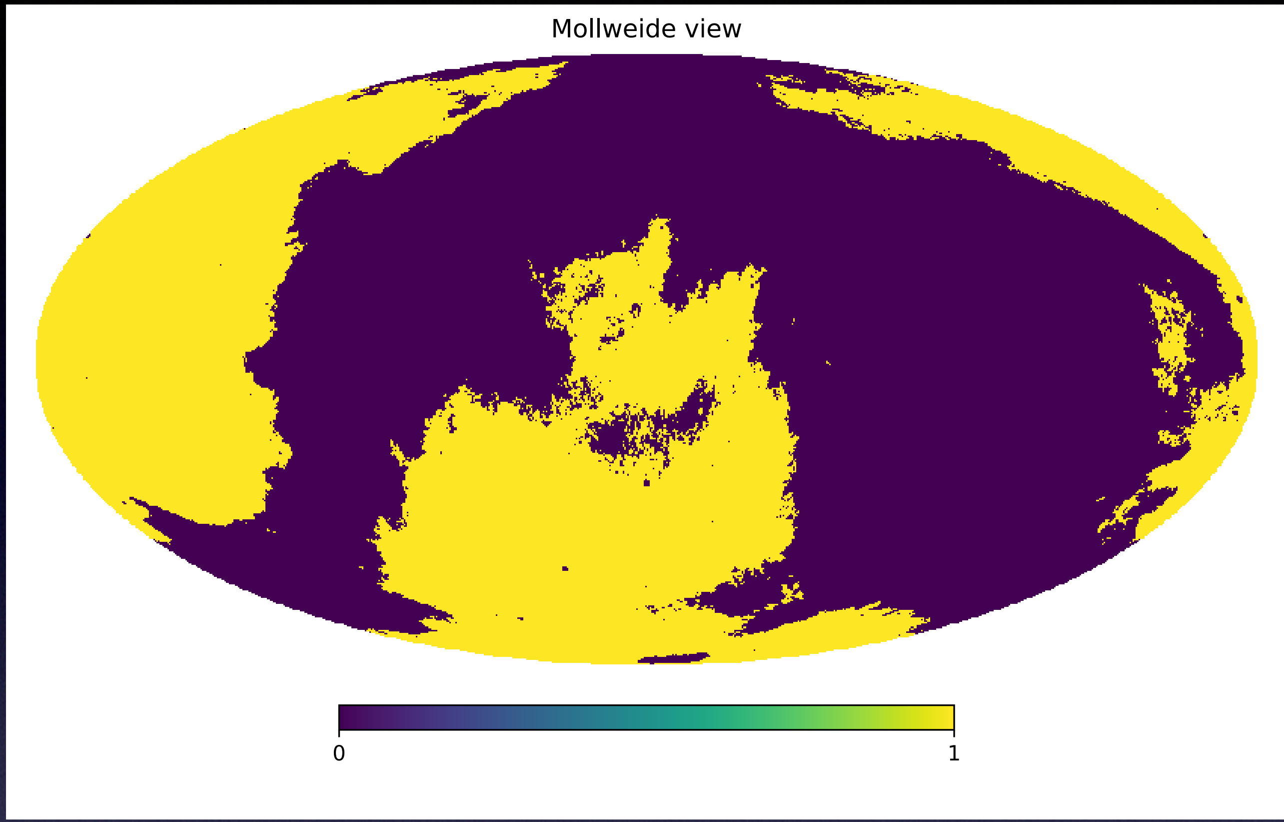




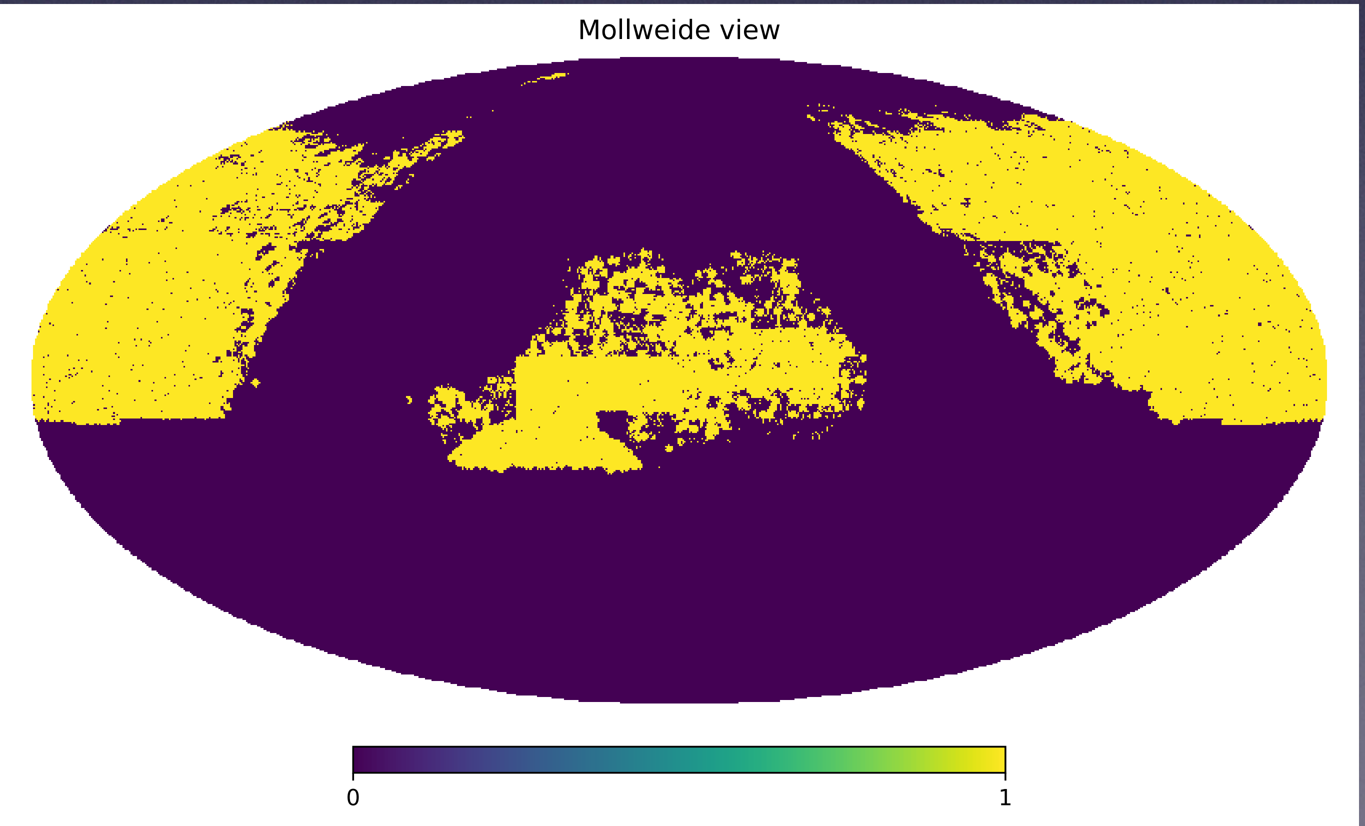
Masking the Milky Way and DESI



Mock 'Tianlai' mask

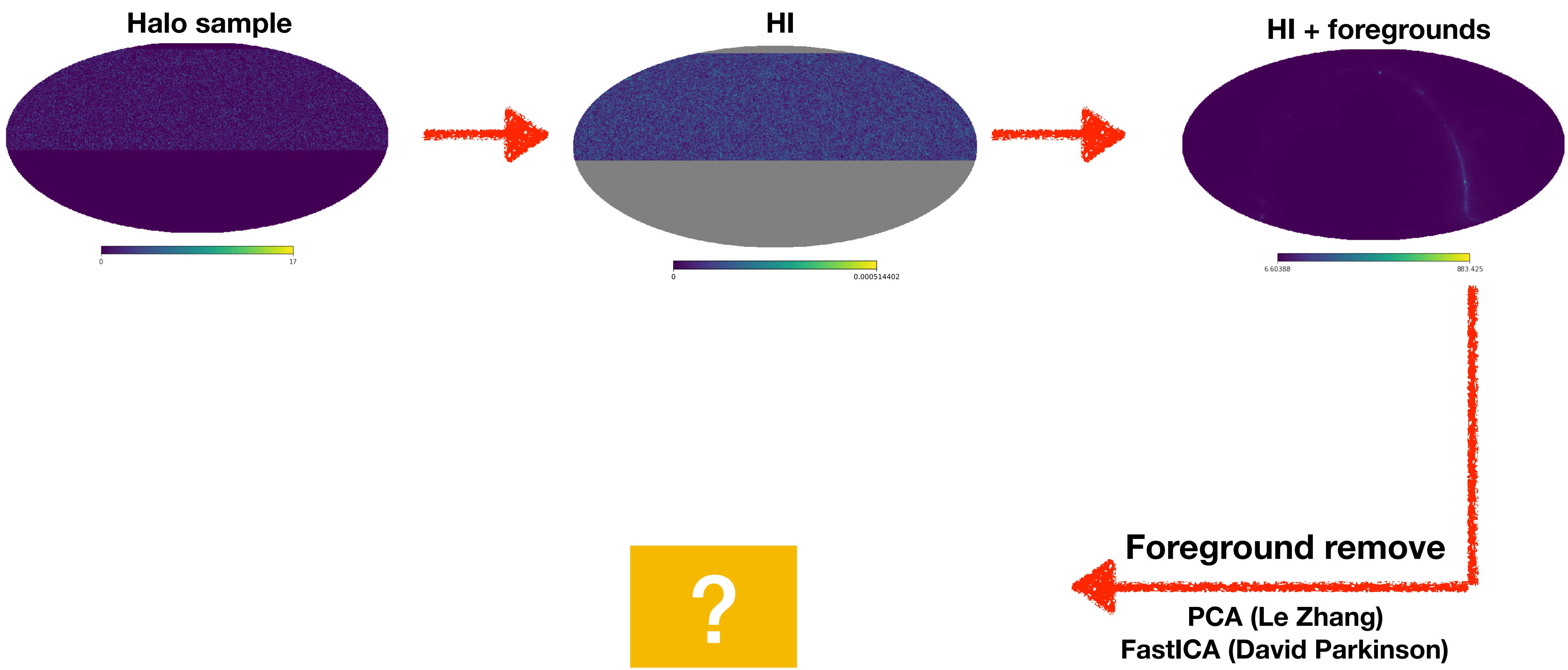


Milky Way cut



DESI survey mask

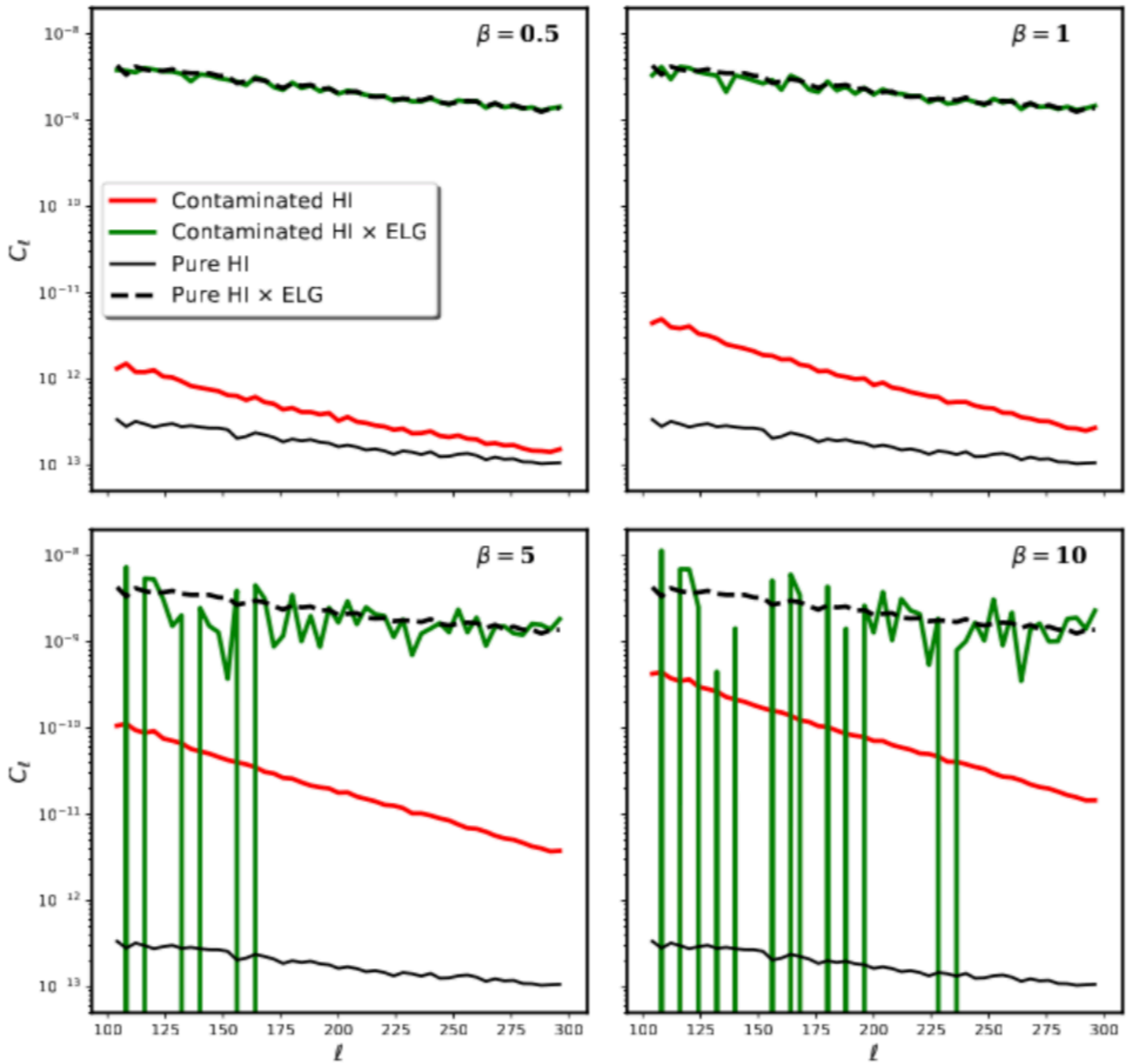
Verification based on simulation data



Toy model : how the different-level foregrounds affect the clustering measurement

We then put different-level foreground into the HI map $\beta = \frac{< T_{fgrd} >}{< T_{21} >}$

Angular power spectrum



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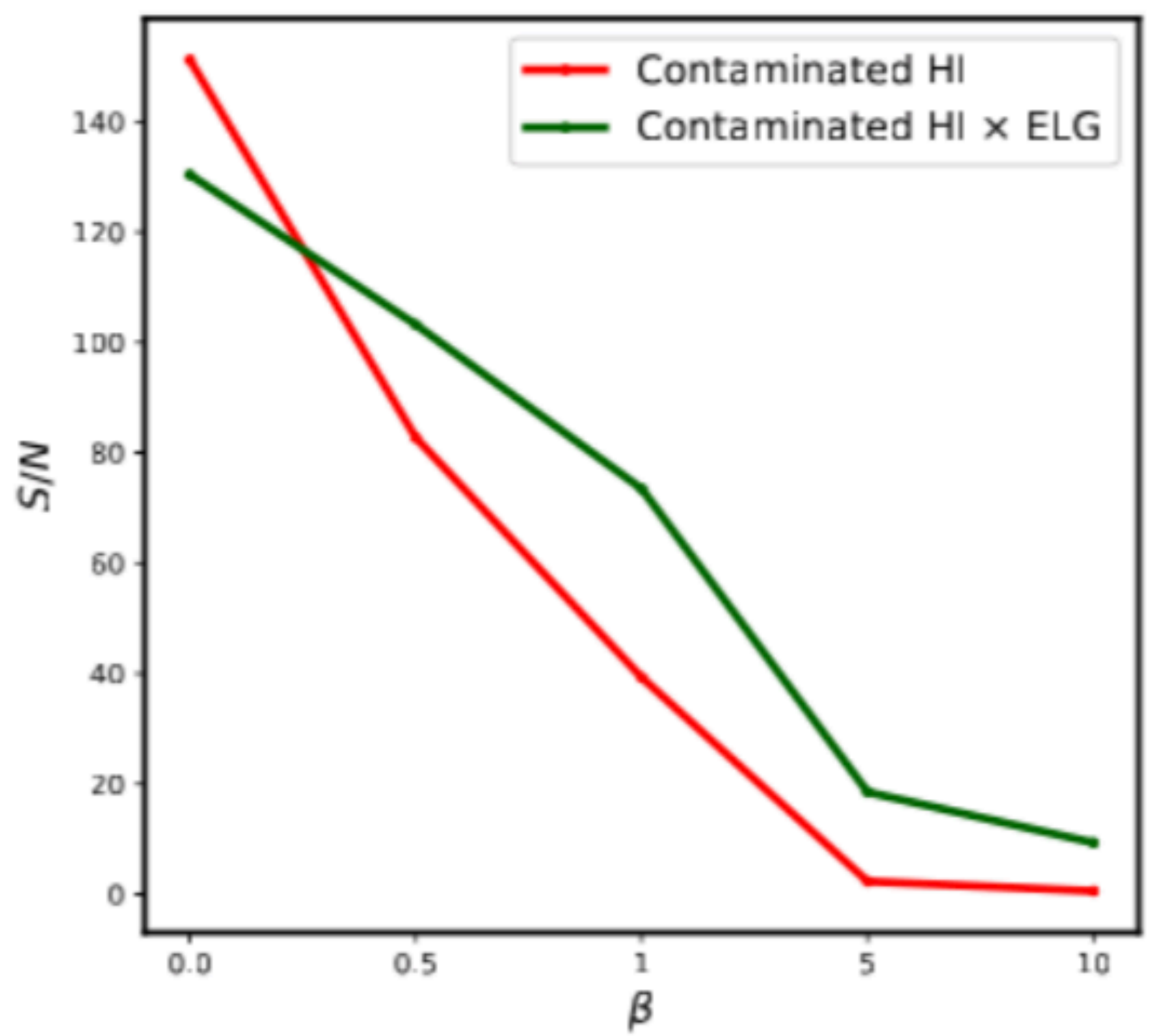
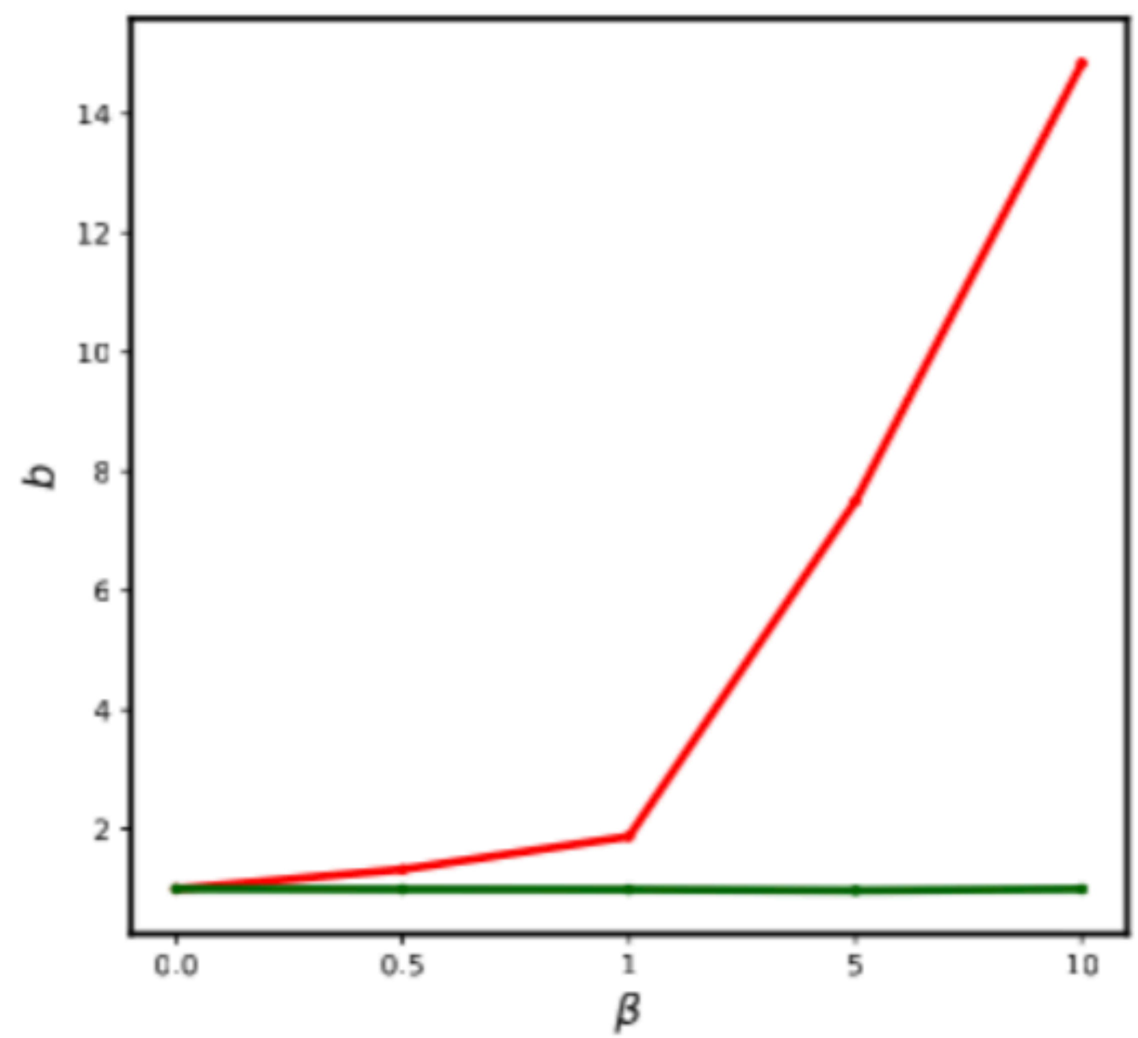
S/N

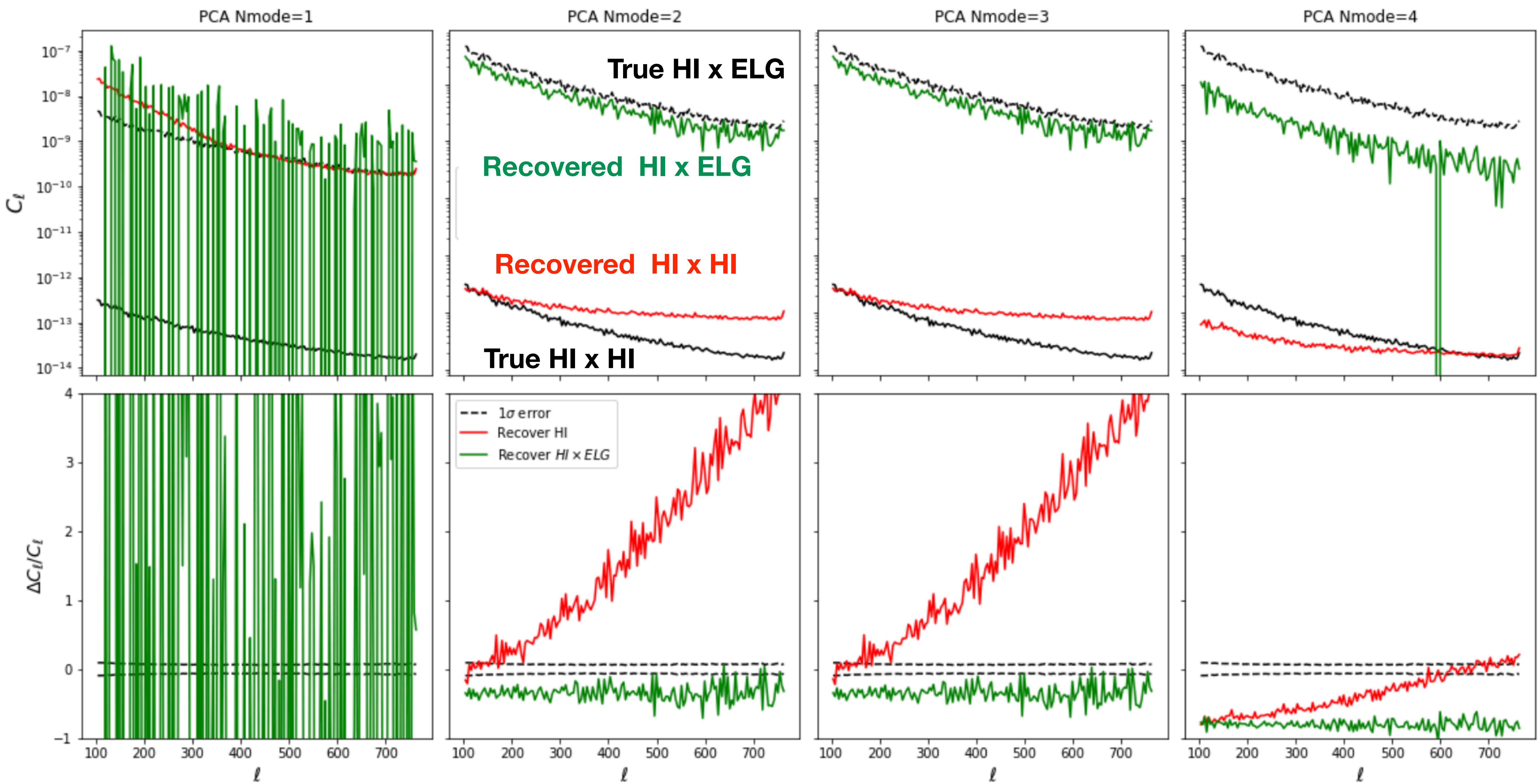


Bias



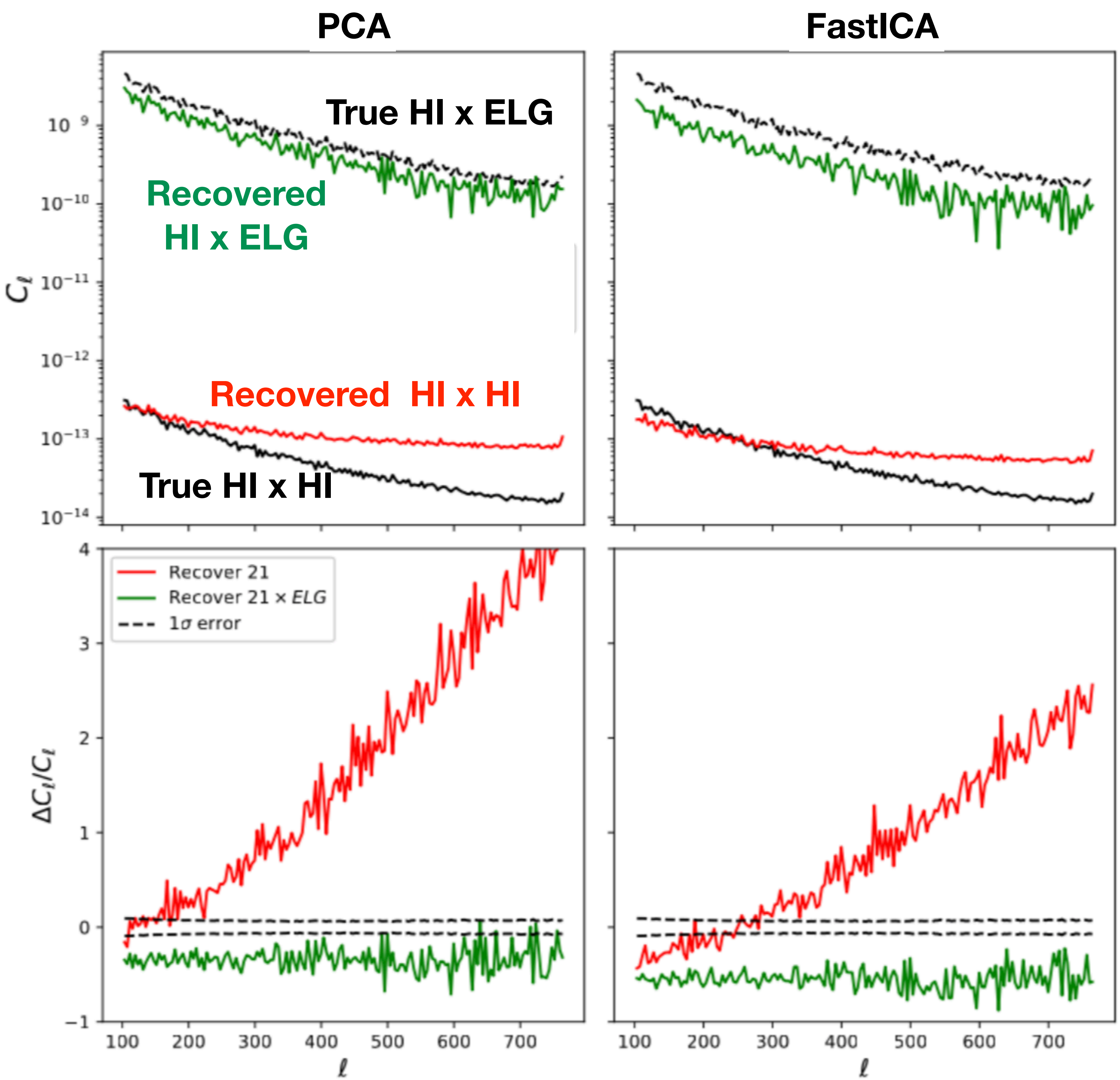
Validation in foreground-cleaned map

PCA approach



In real case, the foreground cleaning method will also make signal loss.

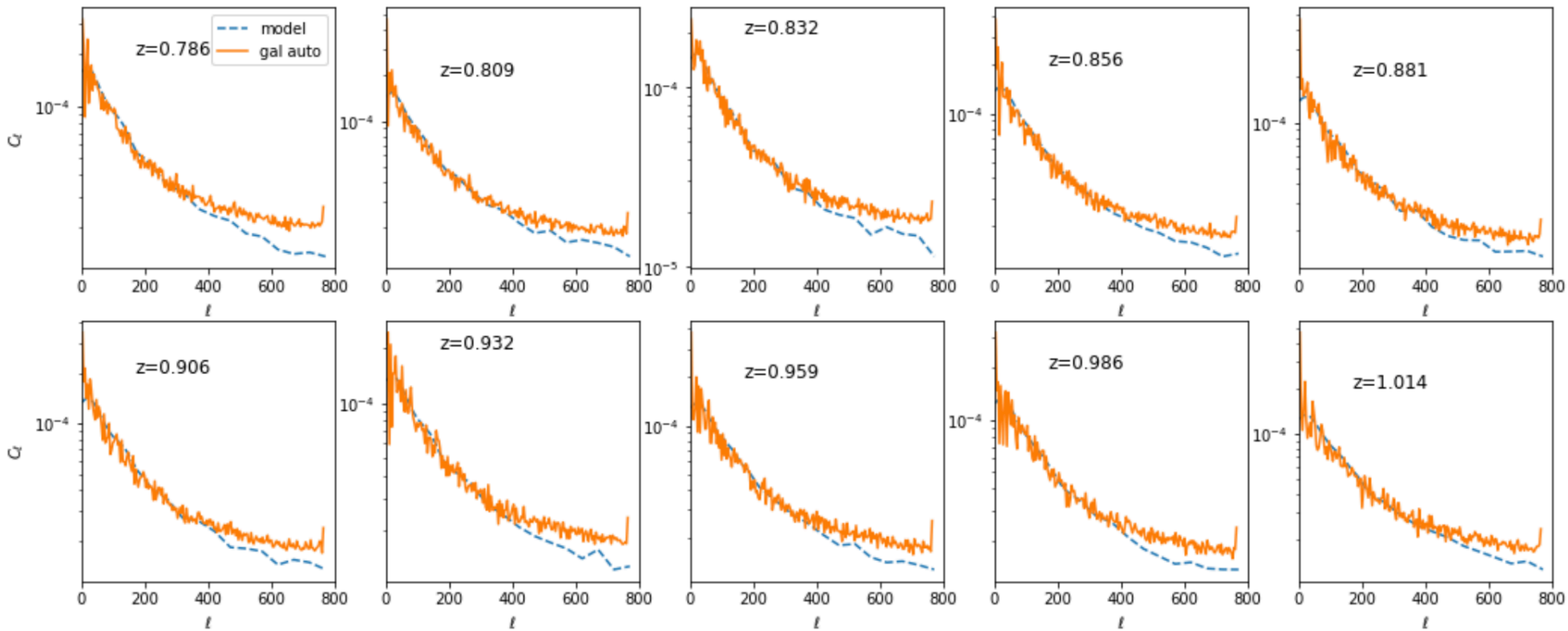
Validation in foreground-cleaned map



Modeling the angular power spectrum of galaxies

$$C_\ell = \frac{2}{\pi} \int k^2 dk P_0(k) W^2(k) \qquad W(k) = \int dz n(z) b(z) D(z) j_\ell(kr(z))$$

0.775<z<1.03 in 10 bins



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$$\delta_h(\boldsymbol{x}) = b_1\delta(\boldsymbol{x}) + \frac{1}{2}b_2[\delta(\boldsymbol{x})^2 - \sigma_2] + \frac{1}{2}b_{s2}[s(\boldsymbol{x})^2 - \langle s^2\rangle]$$
$$+ \text{ higher order terms}\,.$$

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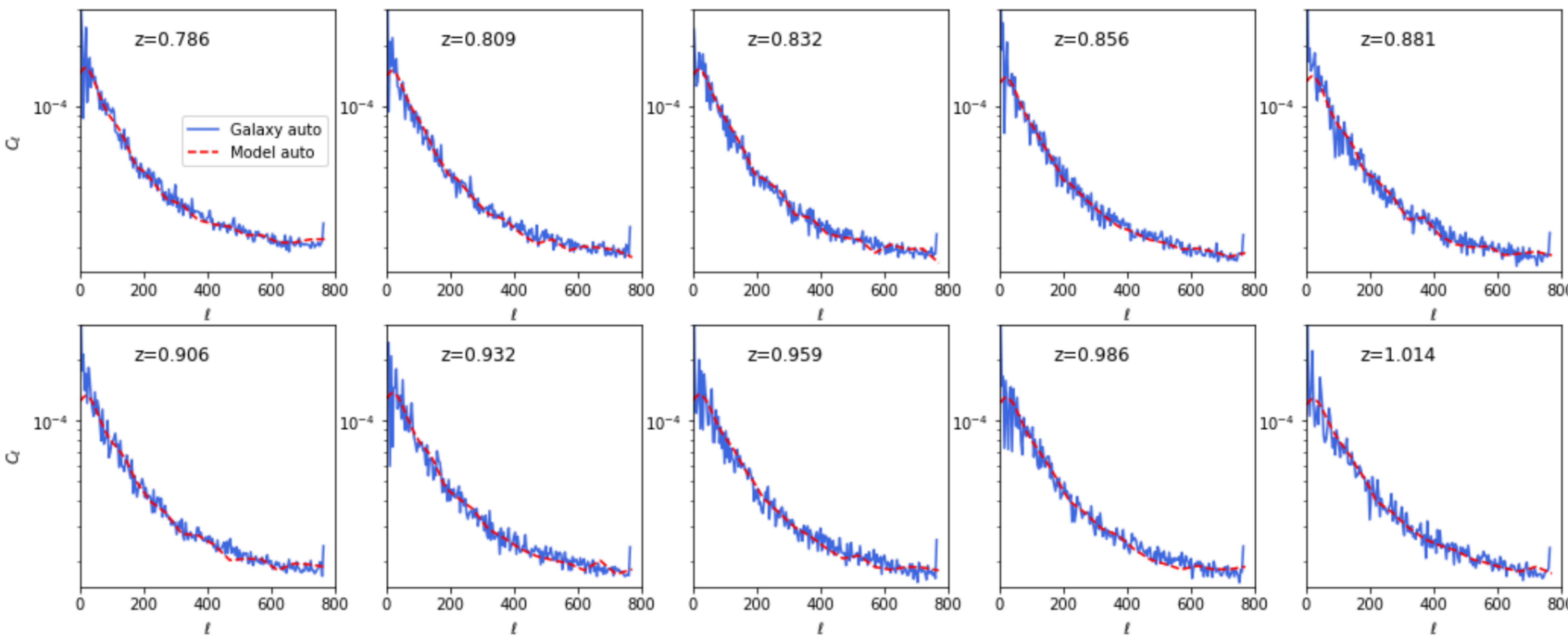


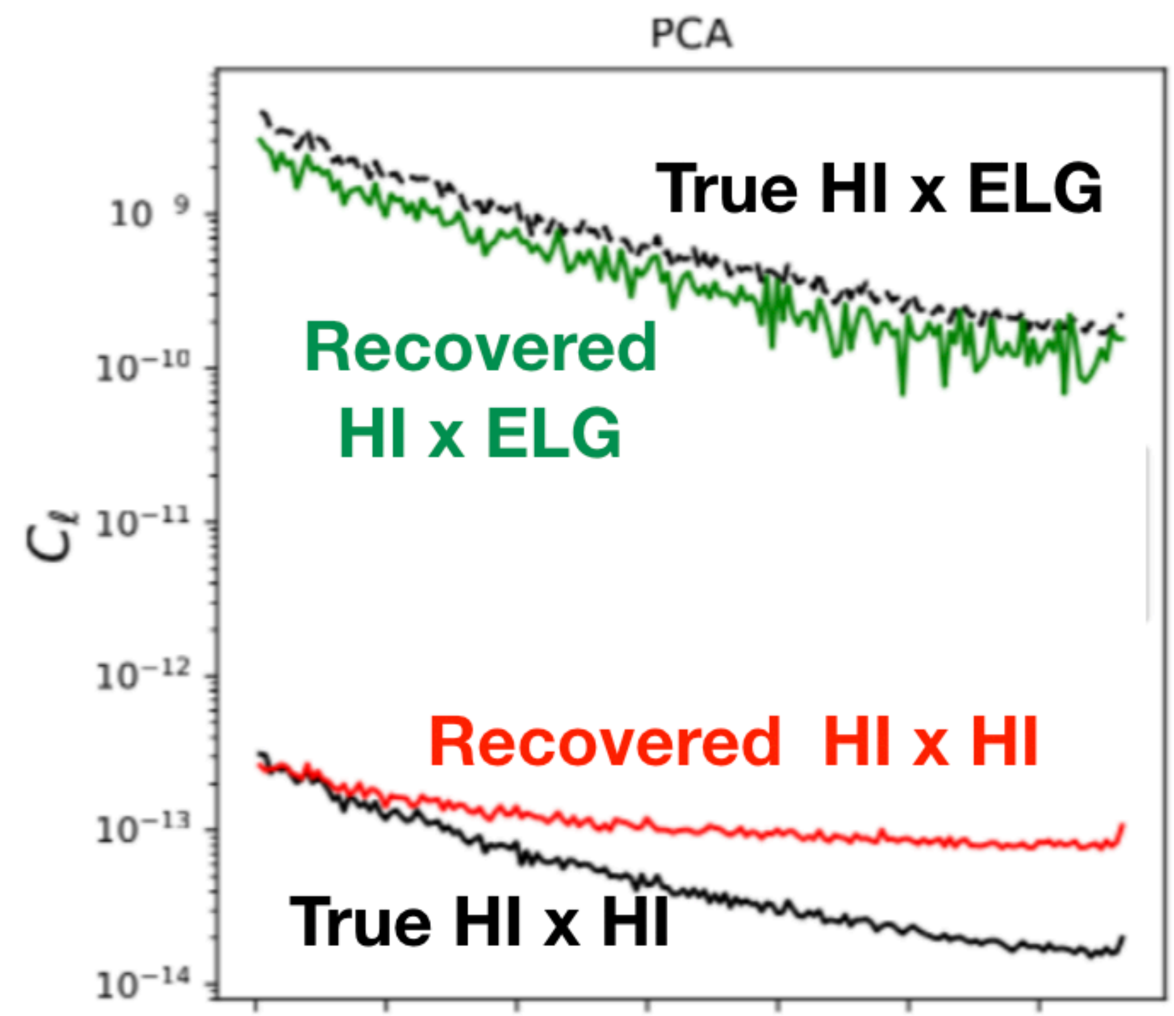
Discussion: bias in the modeling

Angular power spectrum:

For galaxies: (b_1, b_2)

For HI: (b_1, b_2, b_f)

For their cross: (b_1, b_2)



Modeling the angular cross-power spectrum

$$C_\ell = \frac{2}{\pi}\int k^2 dk P_0(k) W^2(k)$$

$$W(k) = \int dz n(z) b(z) D(z) j_\ell(kr(z))$$

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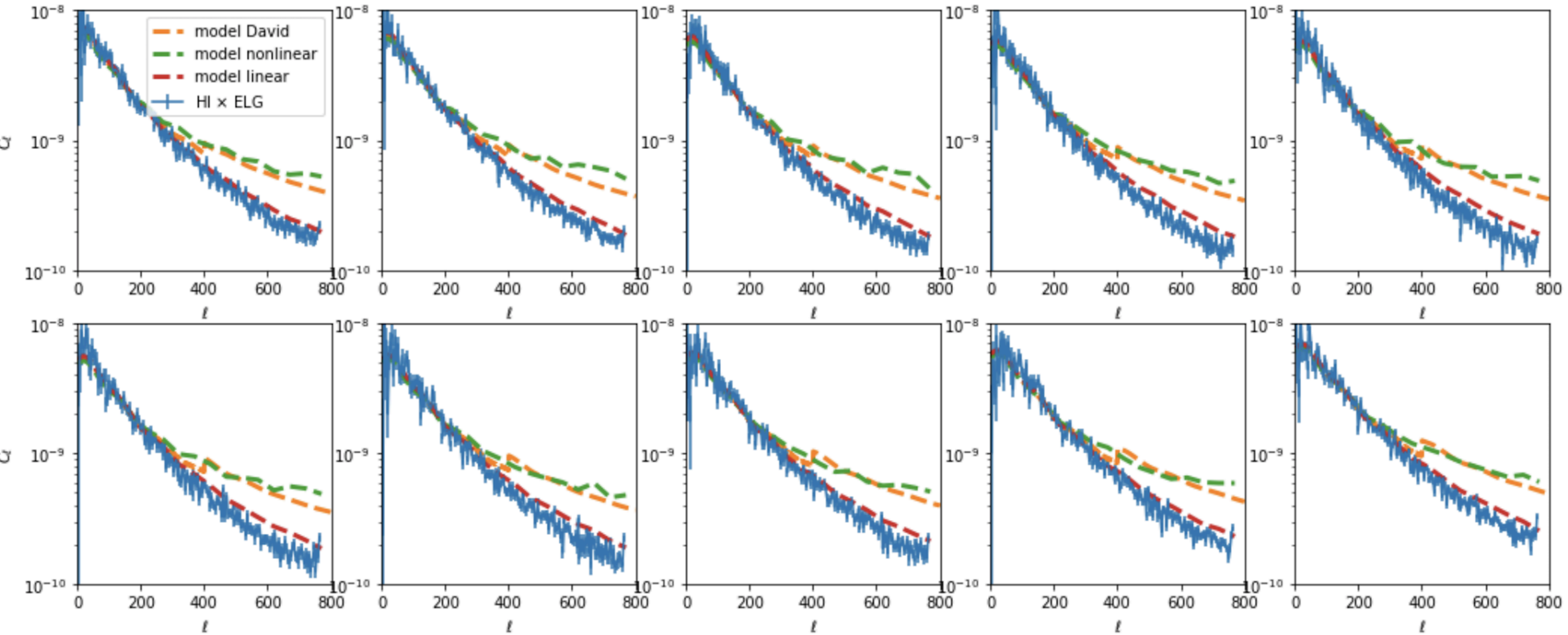

Another problem: the measurement is even smaller than the linear power spectrum!

Modeling the angular cross-power spectrum

$$C_\ell = \frac{2}{\pi}\int k^2 dk P_0(k) W^2(k) W^2(kR) \qquad W(kR) = exp\left[-\frac{(kR)^2}{2}\right]$$

$$W(k) = \int dz n(z) b(z) D(z) j_\ell(kr(z)) \qquad \delta_h(\boldsymbol{x}) = b_1\delta(\boldsymbol{x}) + \frac{1}{2}b_2[\delta(\boldsymbol{x})^2 - \sigma_2] + \frac{1}{2}b_{s2}[s(\boldsymbol{x})^2 - \langle s^2\rangle]$$
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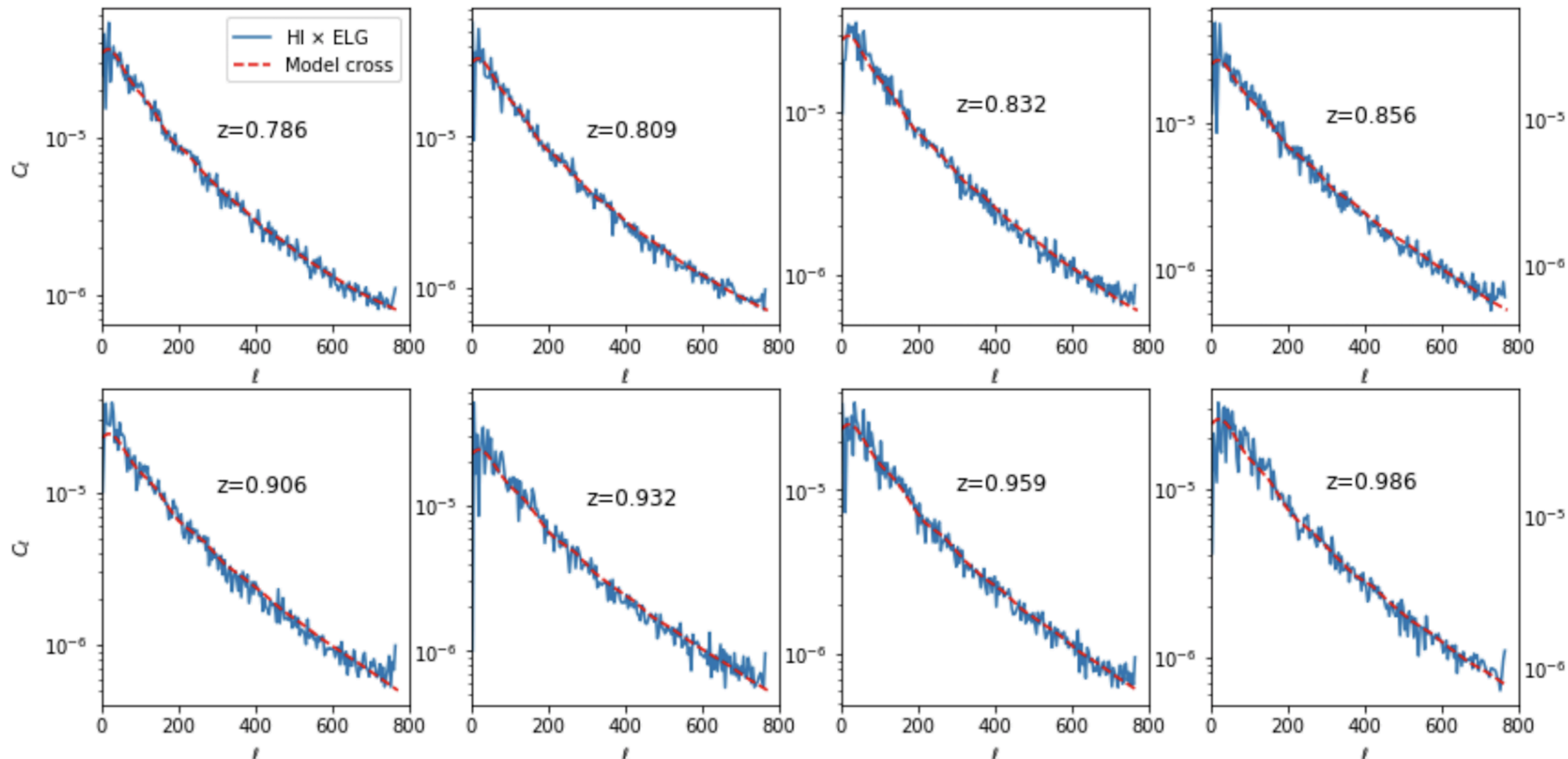
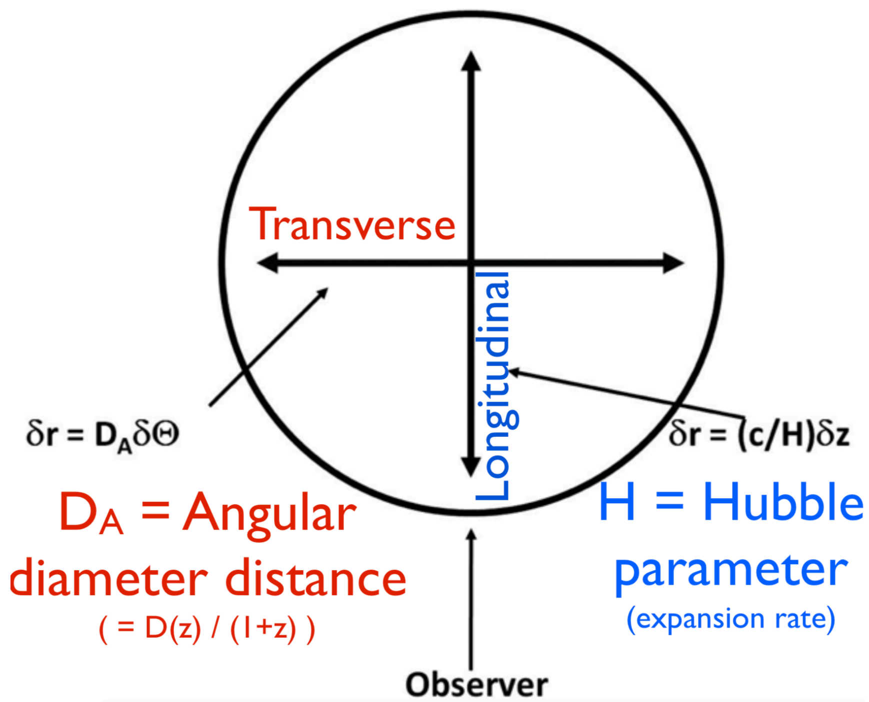


Fitting the BAO feature in broadband shape of power spectrum



$$\ell \propto \frac{1}{\Delta\theta} = \frac{(1+z)D_{\rm A}(z)}{r_{\rm s}(z_{\rm drag})}$$

$$(1+\Delta\alpha)\ell \propto D_{\rm A}(z)(1+\Delta\alpha)$$

0.775<z<1.03 in 10 bins

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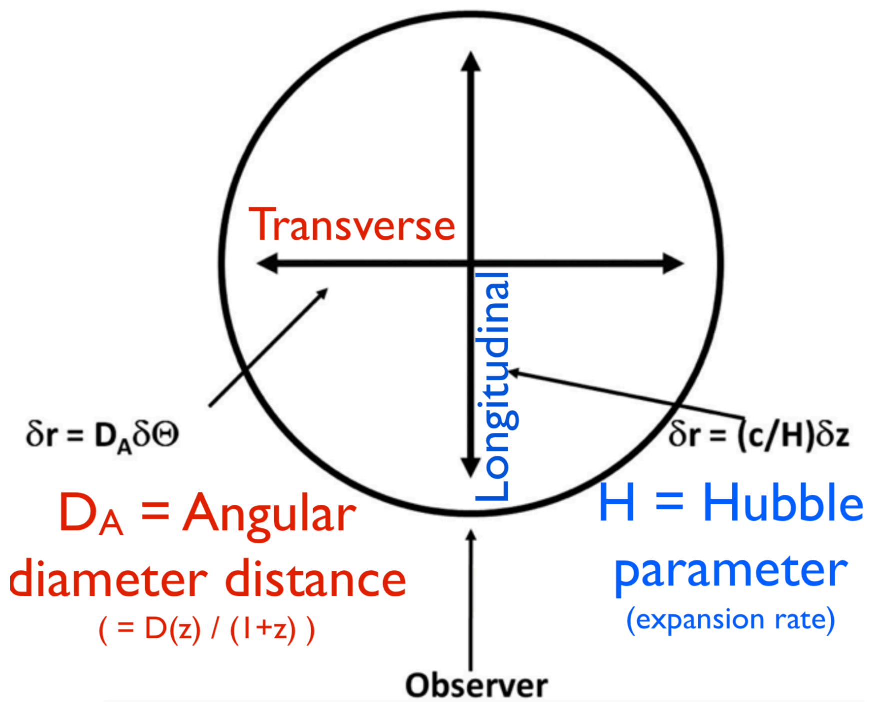

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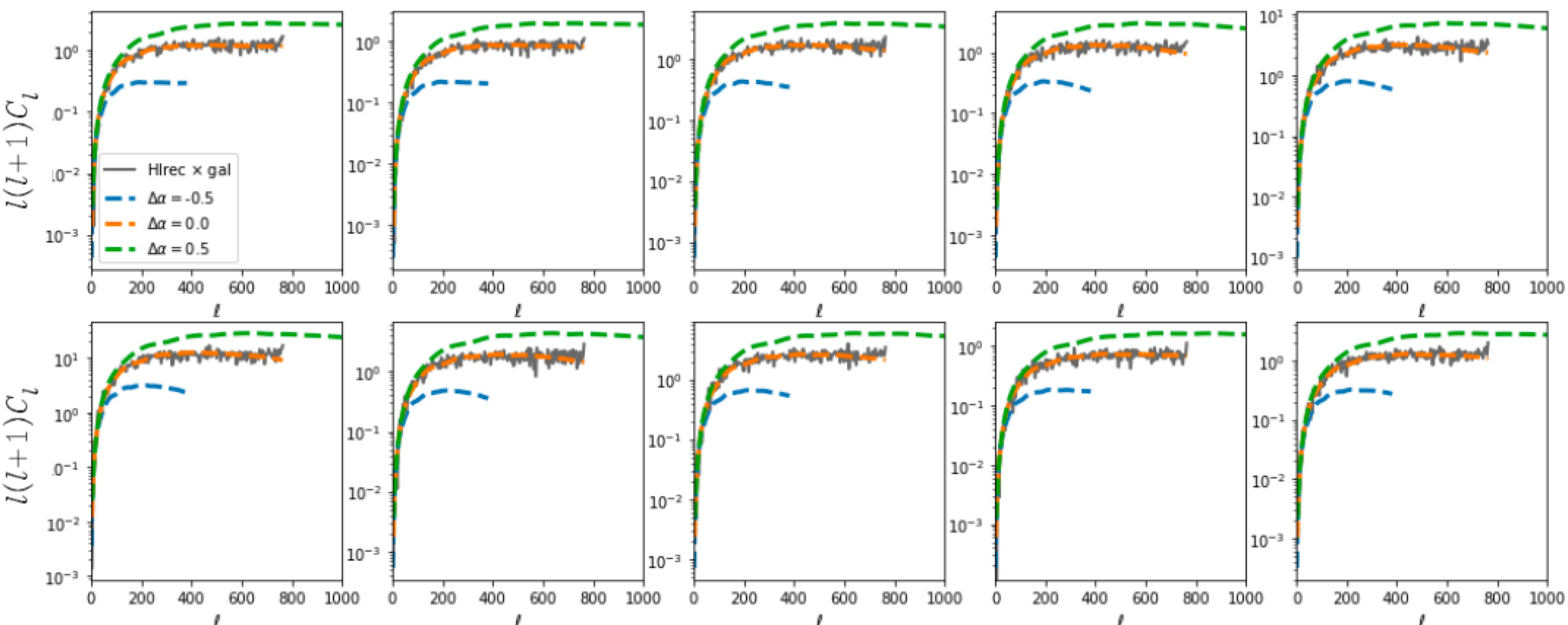

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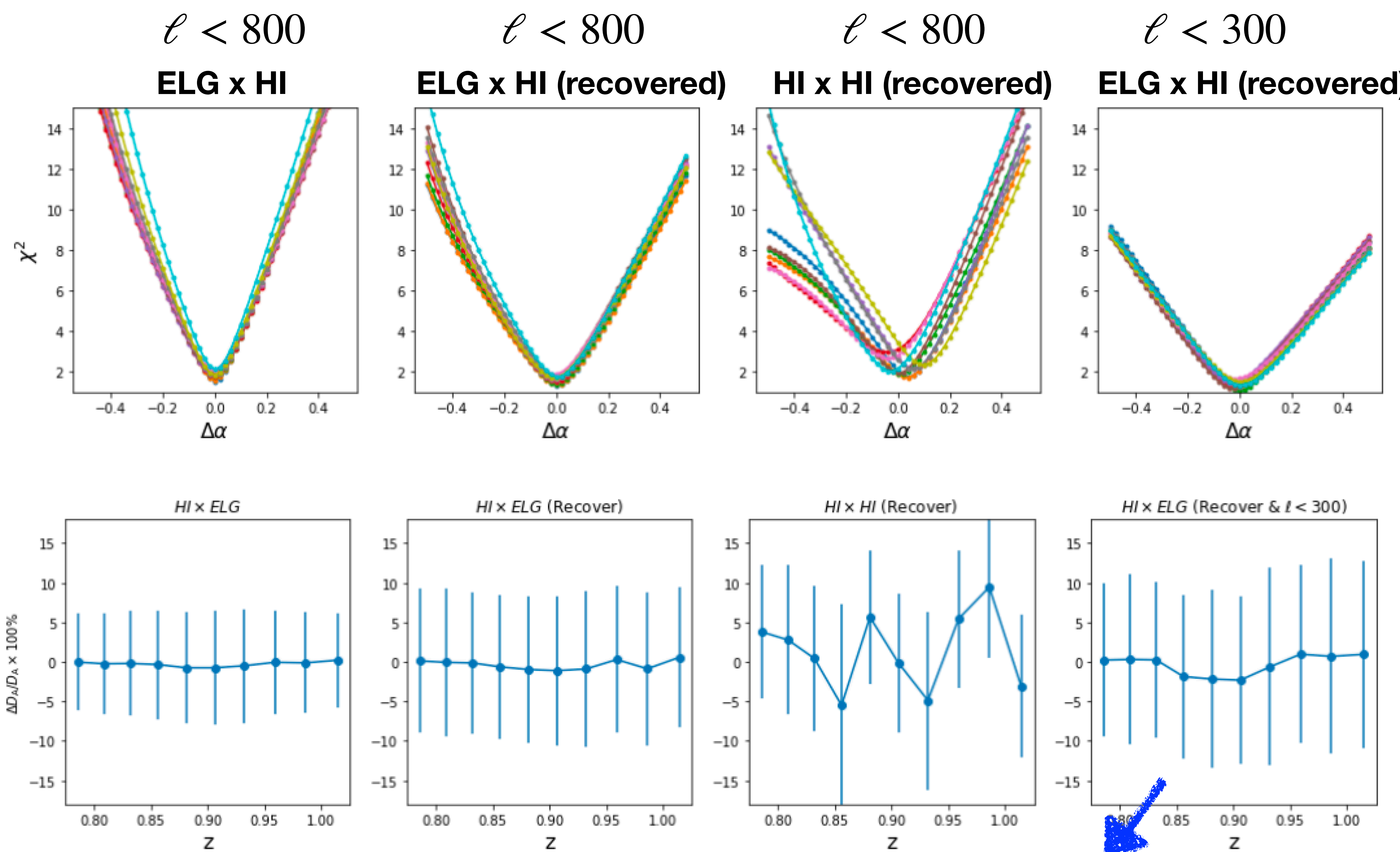

Averaged error in the whole bin
is at ~3% level

Summary

- The HI IM can increase our knowledge about the nature of the Universe.

- We have created a **full-sky mock 21cm intensity mapping** maps using HR4 N-body simulation. Focus on precursors (e. g. Tianlai) but relevant for SKA. Focus on potential cross-correlations with optical surveys.

- Cross-power spectrum has much **better S/R and smaller bias** than the auto-power spectrum.

- Deviation from cross-power spectrum is **scale-independent,** which is easy to be parameterized, while it's totally non-linear biased in auto case.

- Developed a model of angular cross-power spectrum, recovering well the BAO feature in the broadband shape of power spectrum.

Thank You!