Cross correlation bwtween Tianlai 21cm survey & DESI galaxy survey

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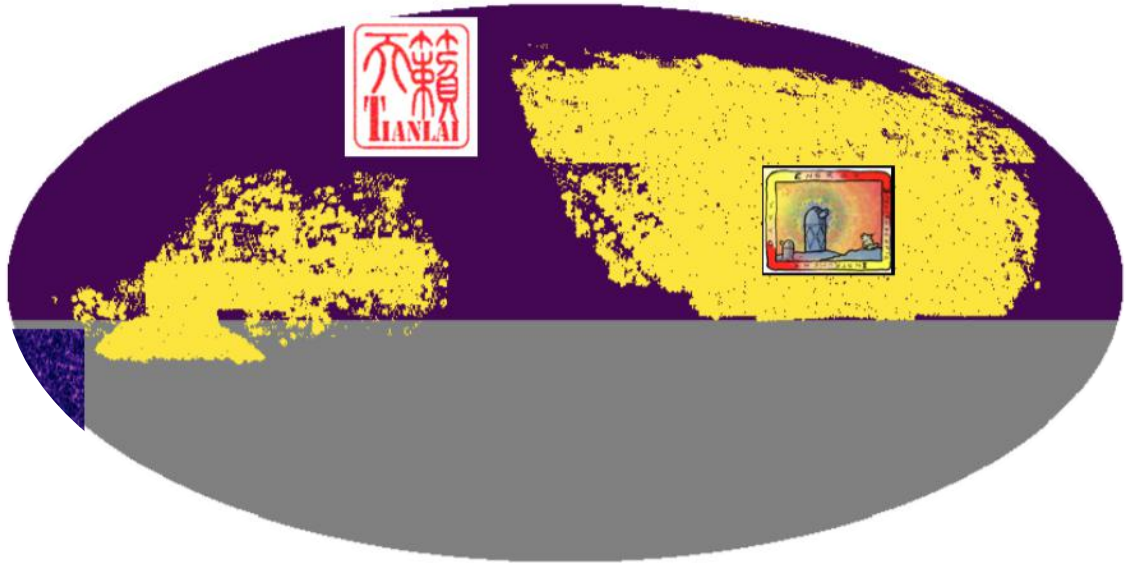
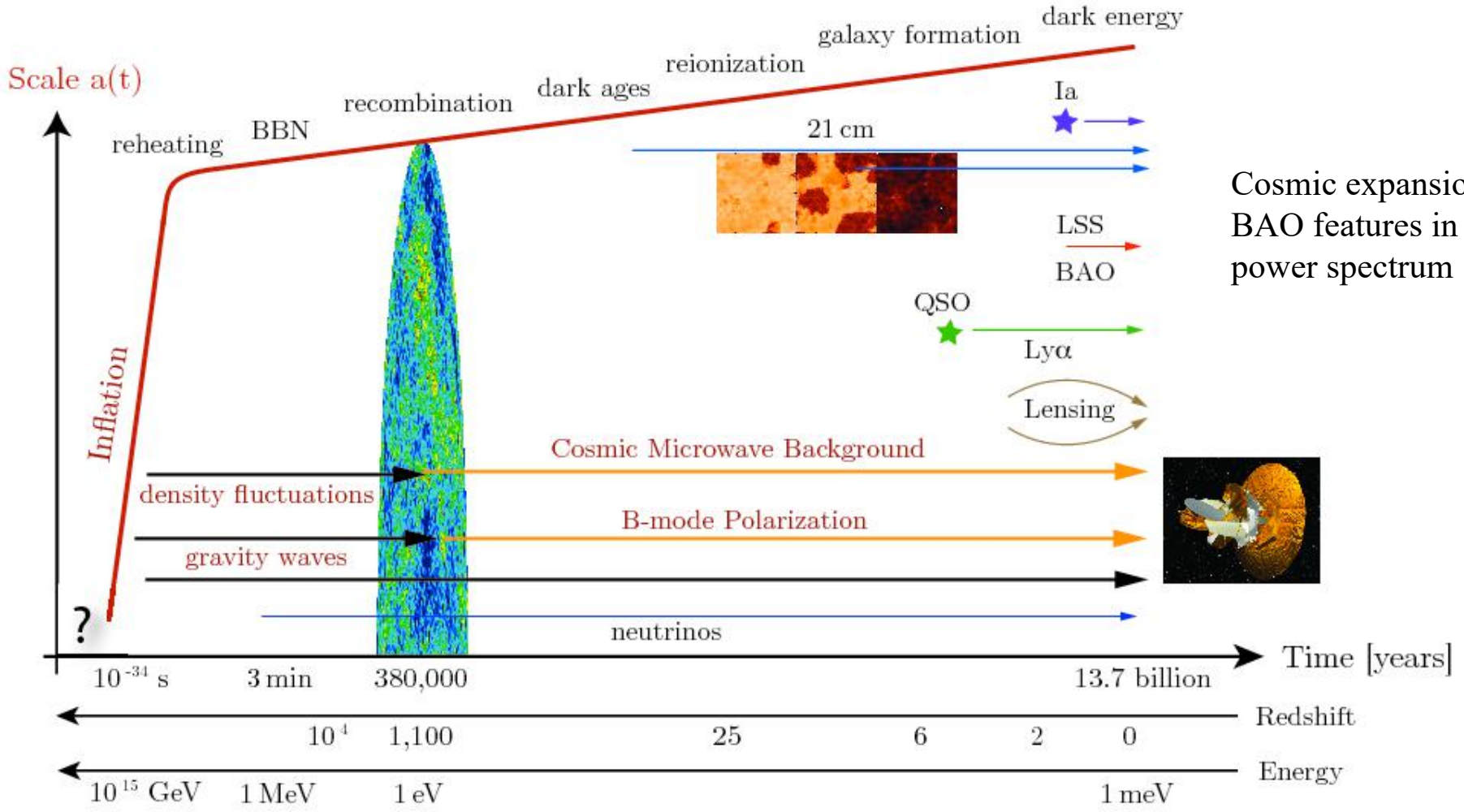


Collaborators: Le Zhang,Y-S Song, J Asorey, D Parkinson, F Shi, K Ahn, SF Zuo

Expansion, Growth and Cross-correlations

- There are many powerful probes to detect different periods, components and structures of the Universe

Inflation theory:
Primordial B mode power spectrum



Cosmic expansion history:
BAO features in the matter power spectrum

D. Baumann, 2009, arXiv:0907.5424

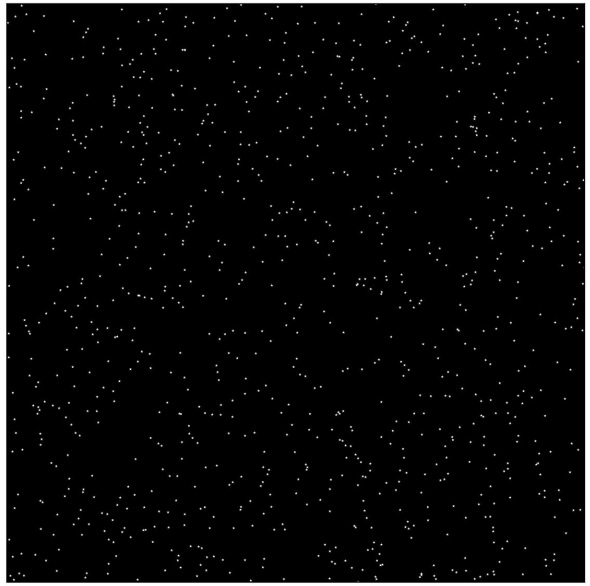
HI - another tracer

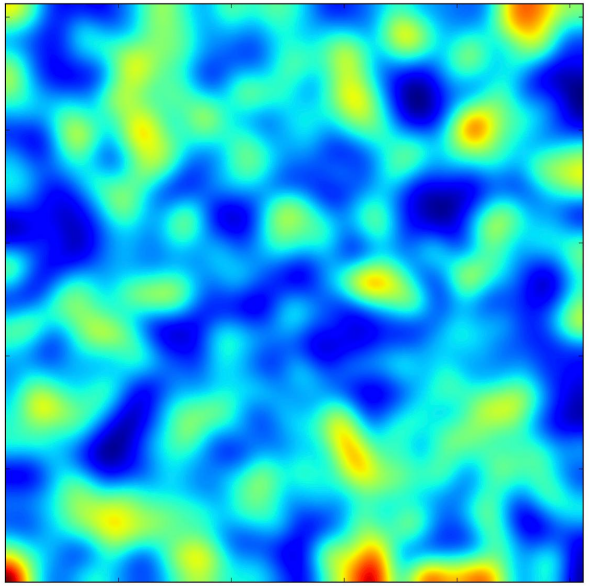
-Neutral hydrogen is another tracer of matter

-Multi-tracer cross-correlation with optical surveys reduces the effect of systematics.
Main: **Radio foregrounds**

-**Intensity mapping** produces 3D maps of LSS with lower angular resolution,faster speed, and larger volume

-In the near future, there will be DESI optical survey, which will overlap with 21cm intensity mapping surveys such as Tianlai and CHIME.





Foreground issue

-The total radiation a radio-telescope receives is the sum of the HI signal and foregrounds.

--synchrotron , free-free ...

--**several orders of magnitude** larger

- Foreground removal methods

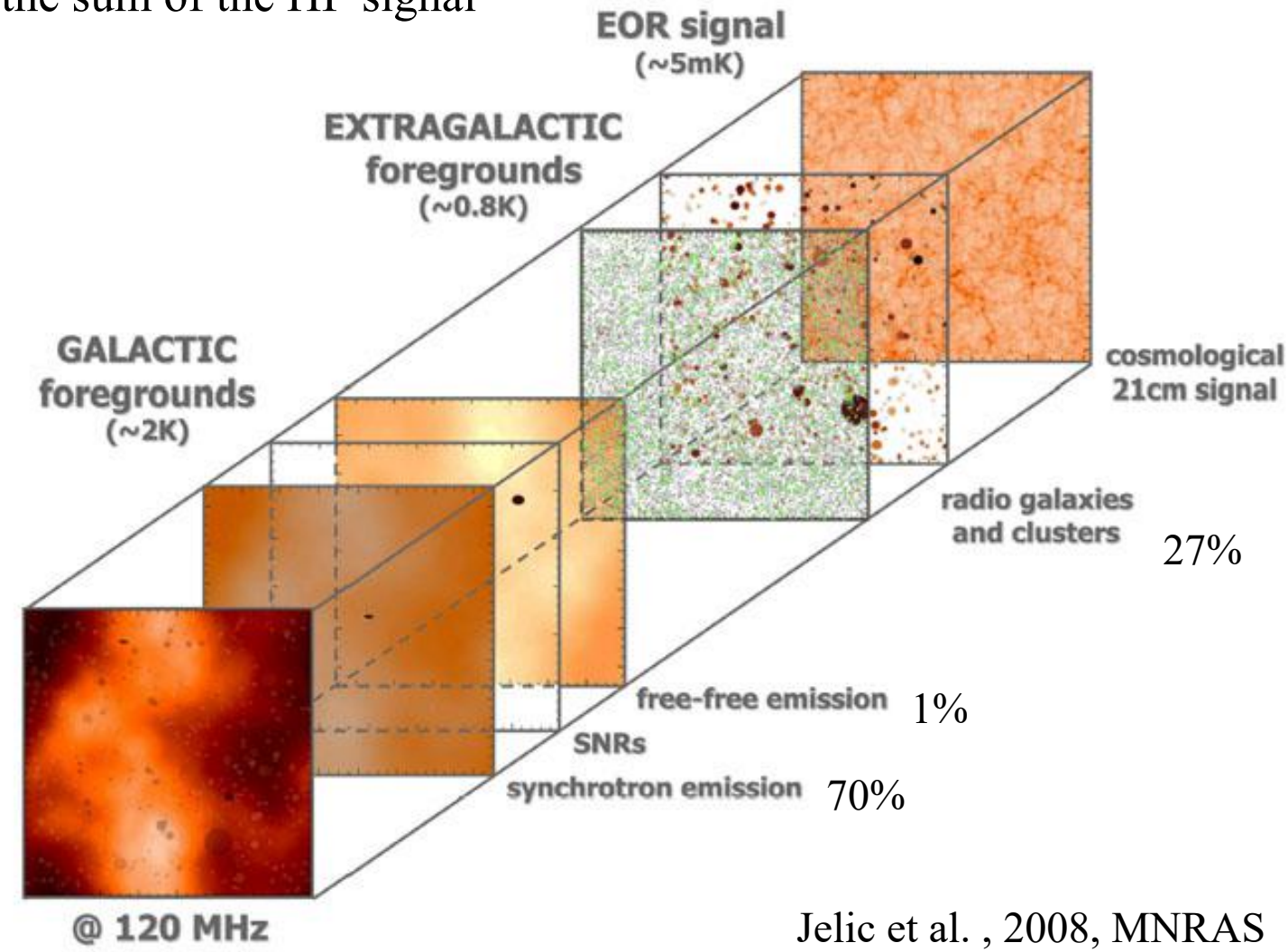
--PCA, FastICA...

--leave **residuals** on the recovered 21cm maps

- To avoid residuals: **cross-correlation**

--Spatial location and amplitude of the residual foregrounds is not correlated with other tracers.

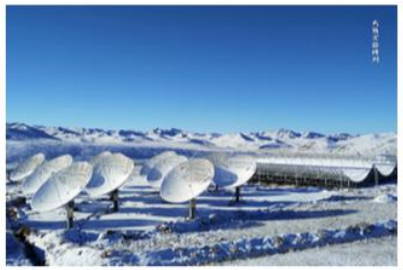
--tighten the constraints on bias parameters, break degeneracies with other parameters



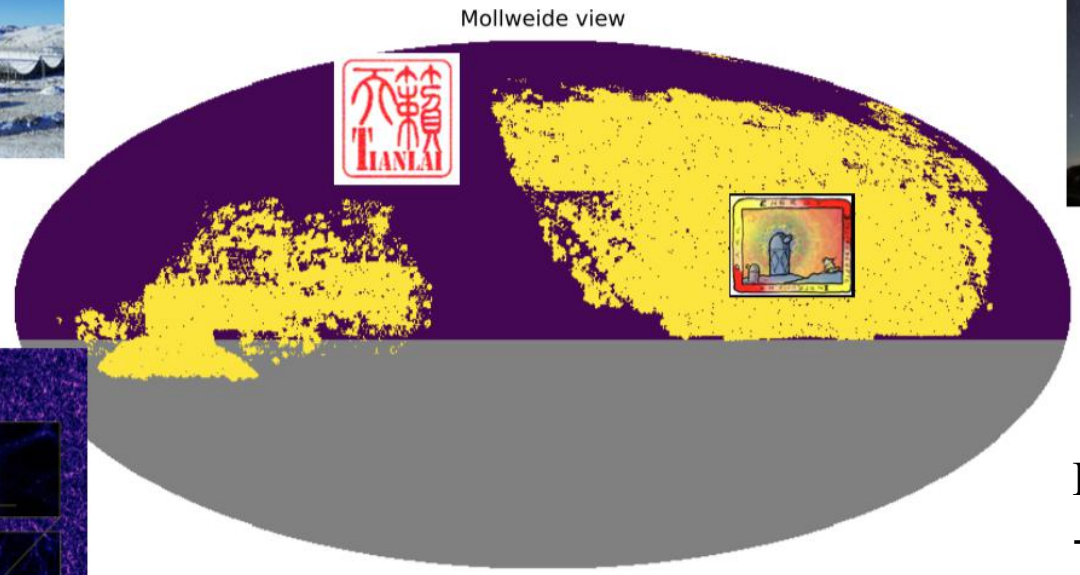
Jelic et al. , 2008, MNRAS

Tianlai x DESI, new opportunity window

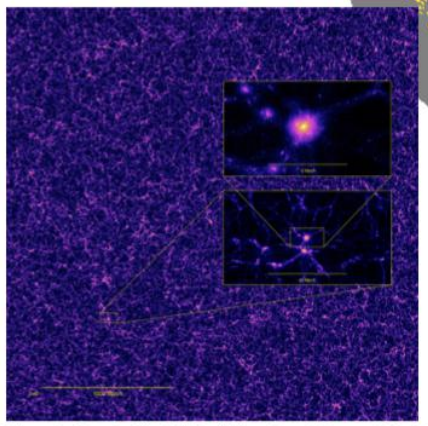
TIANLAI Pathfinder :
- 3 (15x40m) cylinders
- 16 (6m) dishes
- 700-800MHz
- 0.775 < z < 1.03



Credit: NAOC



Credit: R. Lafever



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

Start with simulations!!

Great overlap for cross-correlation!

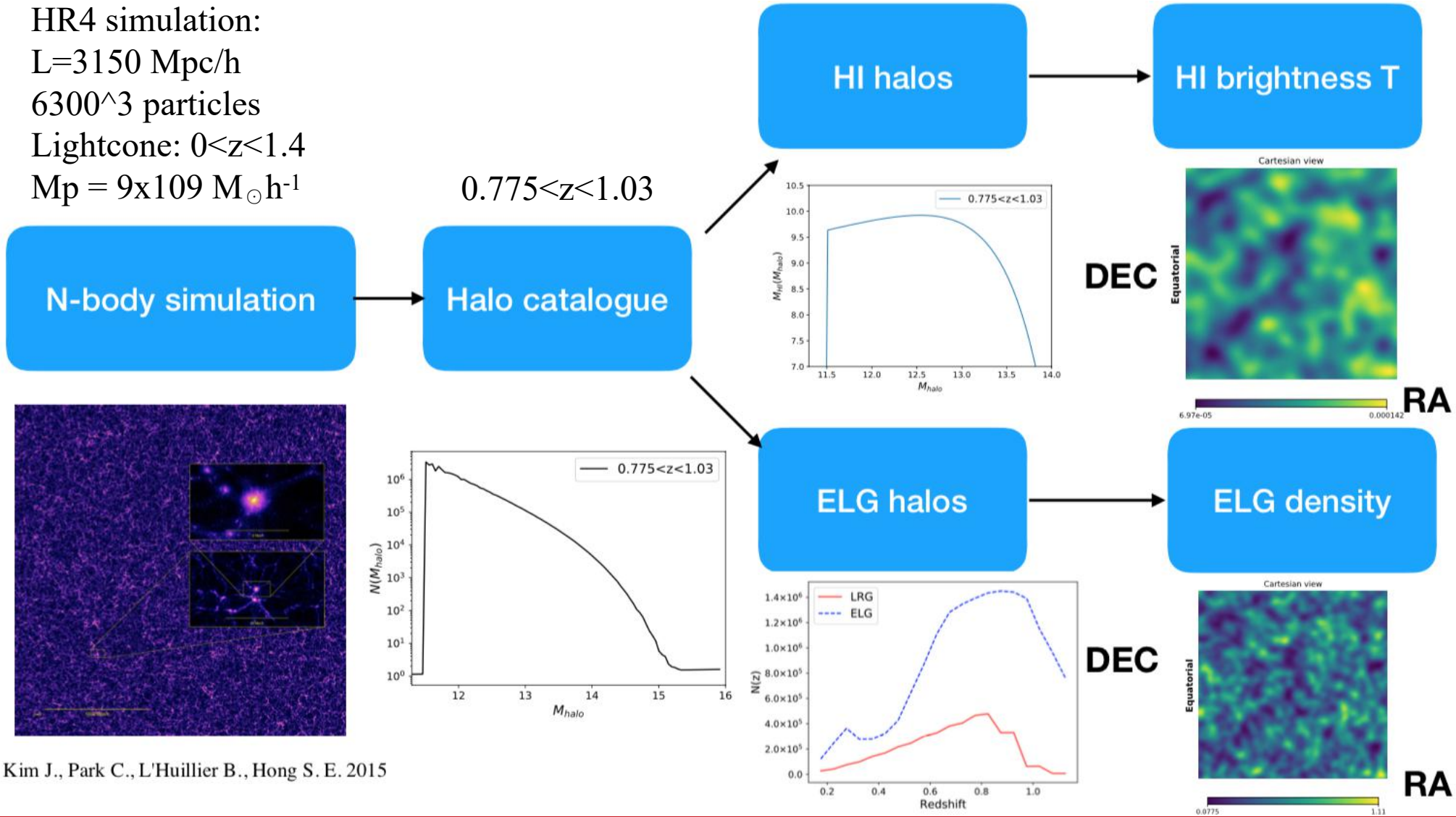
DESI survey :
- 5000 fibre multi-object
- Footprint of 14000 sq. degs:
- 35 million ELGs
- 4 million LRGs
- 2.4 million QSOs

“Painting” neutral hydrogen in the Halo canvas

We start with halo catalogue from Horizon Run4 (HR4) simulation (Kim J et al)

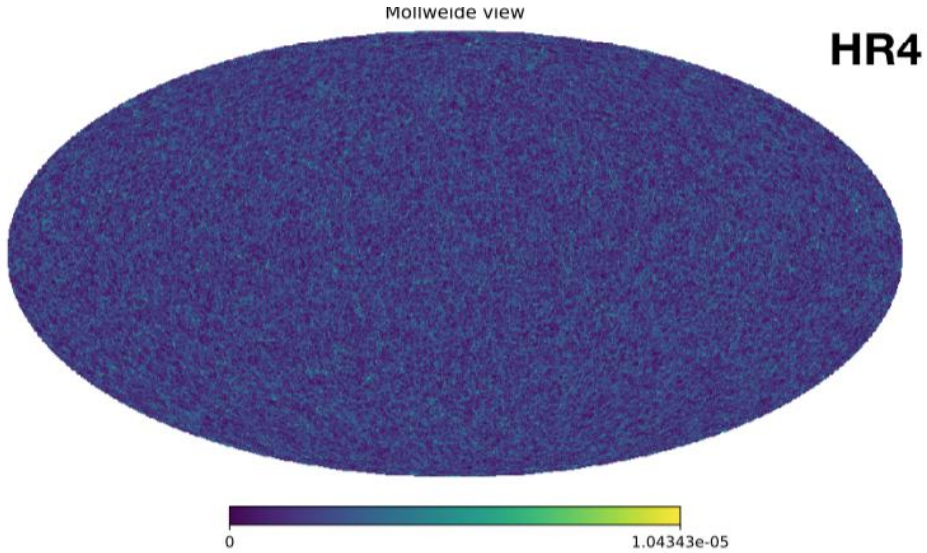
HR4 simulation:
L=3150 Mpc/h
6300^3 particles
Lightcone: 0<z<1.4
Mp = 9x109 $M_{\odot}h^{-1}$

0.775<z<1.03



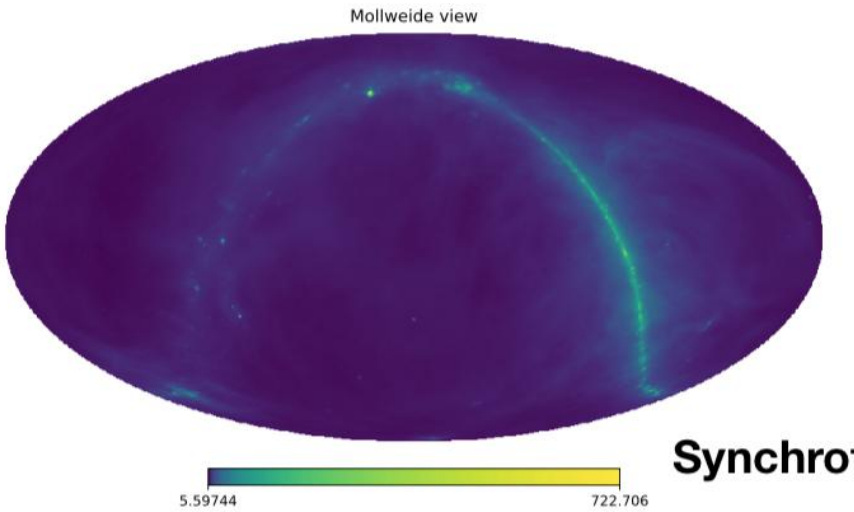
Kim J., Park C., L'Huillier B., Hong S. E. 2015

Hydrogen brightness maps + Foregrounds

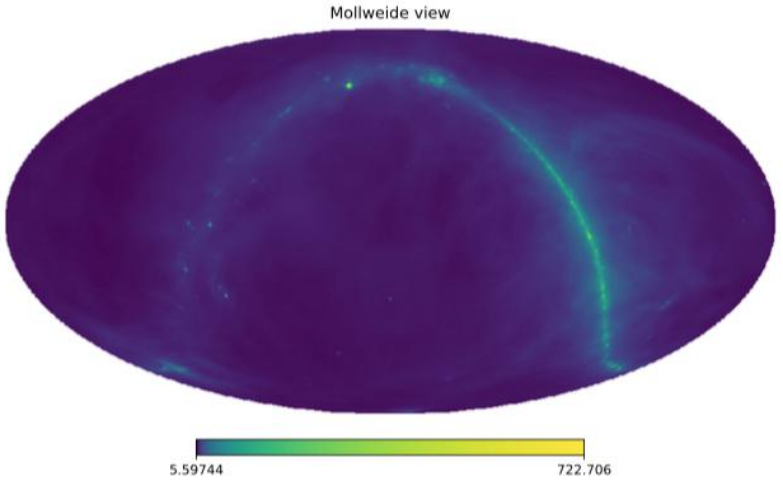


HR4 21cm f=795 MHz

Healpix Nside=256 (0.23 deg)



+

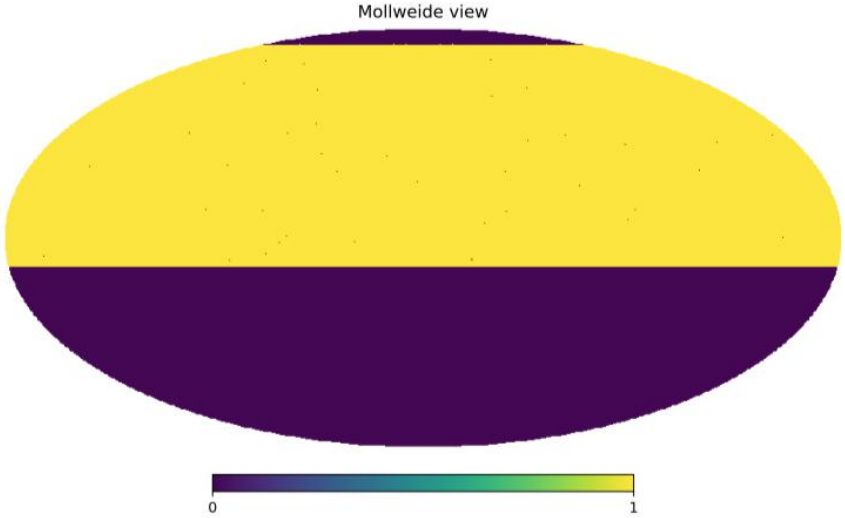


Foreground f=795 MHz

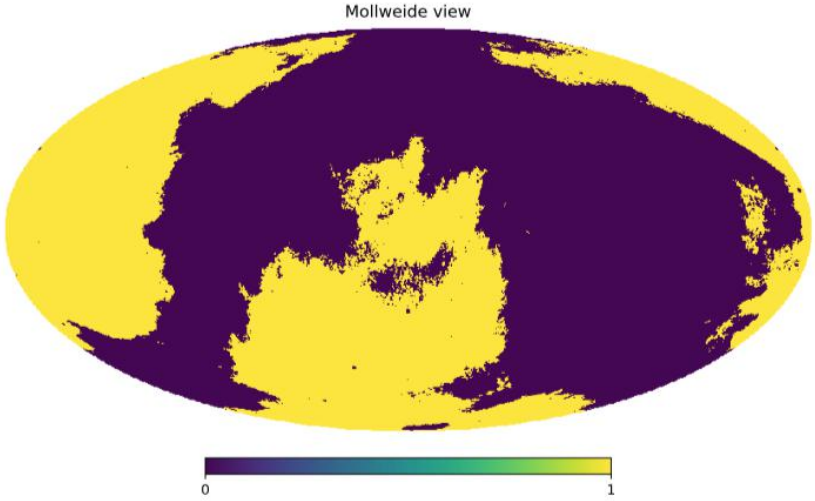
Synchrotron, CMB, HI, Warm & Cold Dust, Free-free

Global Sky model: 1605.04920

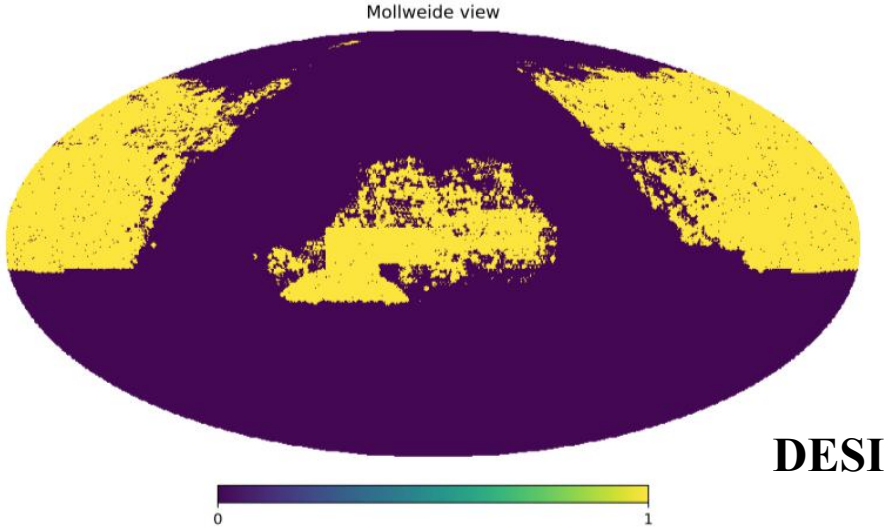
Mask the Milk Way and DESI



Tianlai obseration region

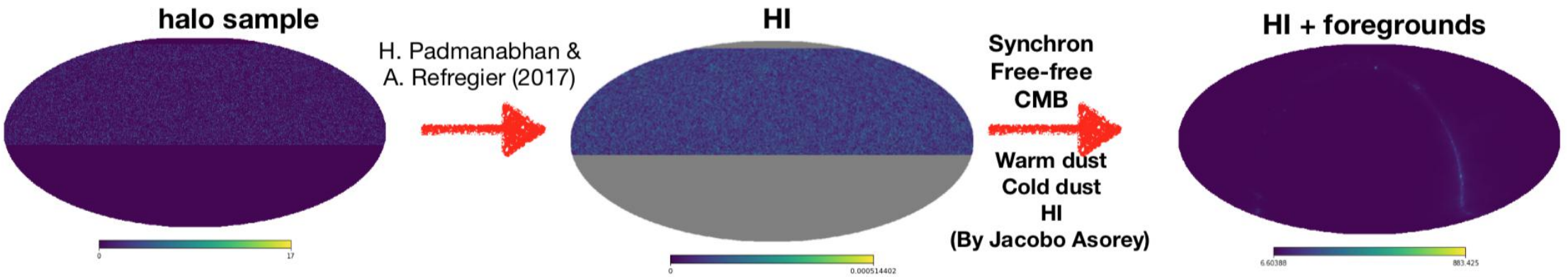


Milk Way foreground cut (>8K)



DESI survey mask

Auto- and Cross-correlation for recovered HI maps



a and b are labeled for the tracer, galaxy or HI Auto- or Cross-correlation

Angular power spectrum in harmonical space

$$C_\ell^{ab} = \frac{1}{2\ell+1} \sum_{m=-\ell}^{\ell} \left| a_{\ell m}^{a} * a_{\ell m}^{b} \right|^2$$

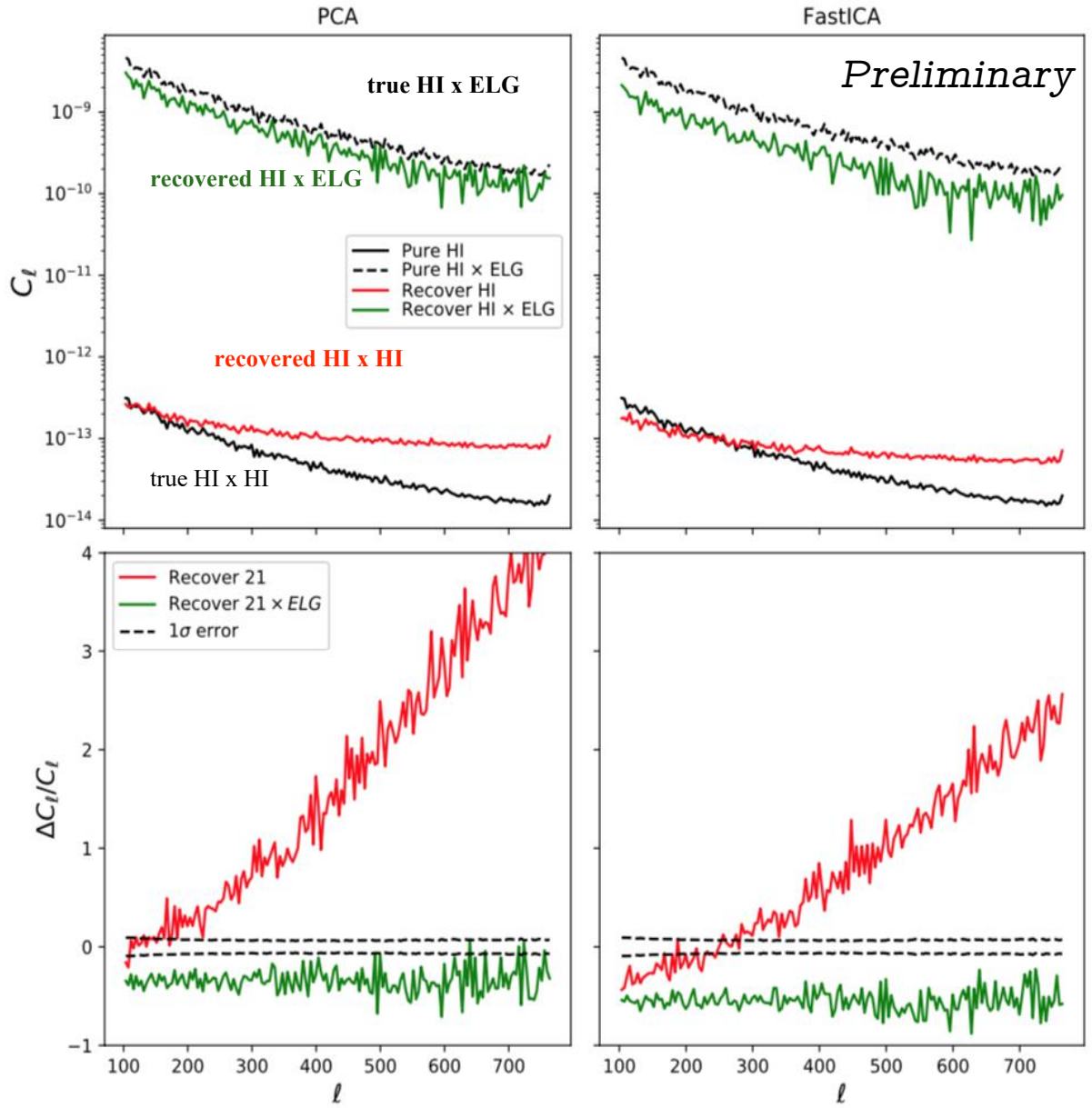
Recovered auto- and cross power spectrum

- Auto-PS: boosted by some orders due to the residual foreground

- Cross-power spectrum have smaller bias than the auto-power spectrum and **underpredicts** systematically at al scales (signal loss in the cleaning procedure);

- The auto-power spectrum is totally **non-linearly** biased

- Deviation from the cross-power spectrum is almost **scale-independent**, easy to be **parameterized** in a future model.



Enhance S/N with cross-correlation

- We put different-level foreground into the HI maps, **without** foreground removal, and test how the **residual foregrounds** affect the clustering measurement.

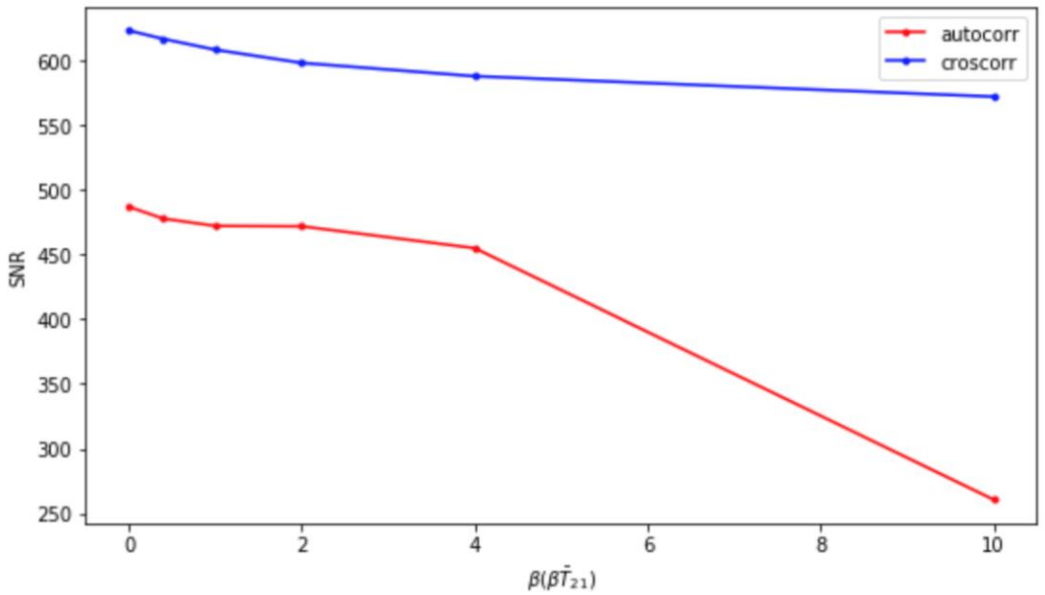
HI map
T_{21}

→

HI map with different-level foreground
$T_{21} + T_{fgrd}$

$$\beta = \frac{< T_{fgrd} >}{< T_{21} >}$$

SNR of angular correlation:



preliminary

$$\Delta C_\ell^{ab} = \sqrt{\frac{1}{(2\ell+1)\Delta\ell f_{sky}}} \left[(C_\ell^{ab})^2 + C_\ell^{aa} C_\ell^{bb} \right]^{1/2}$$

$$S/N(\beta) = \sqrt{\sum_{\ell=0}^{\ell_{max}} \left(\frac{C_\ell(\beta = 0)}{\Delta C_\ell(\beta)} \right)^2}$$

Cross-correlation will keep **more** information when there is residual foreground .

Summary

- **Cross-correlations** between optical surveys and **intensity mapping** surveys can help us deal with the foregrounds and also understand galaxy evolution.

- Tianlai and DESI will **overlap much**, opening a great opportunity for cross-correlations.

- Cross-power spectrum has much **better SNR** and **smaller, linear bias** compared with the auto-power spectrum.

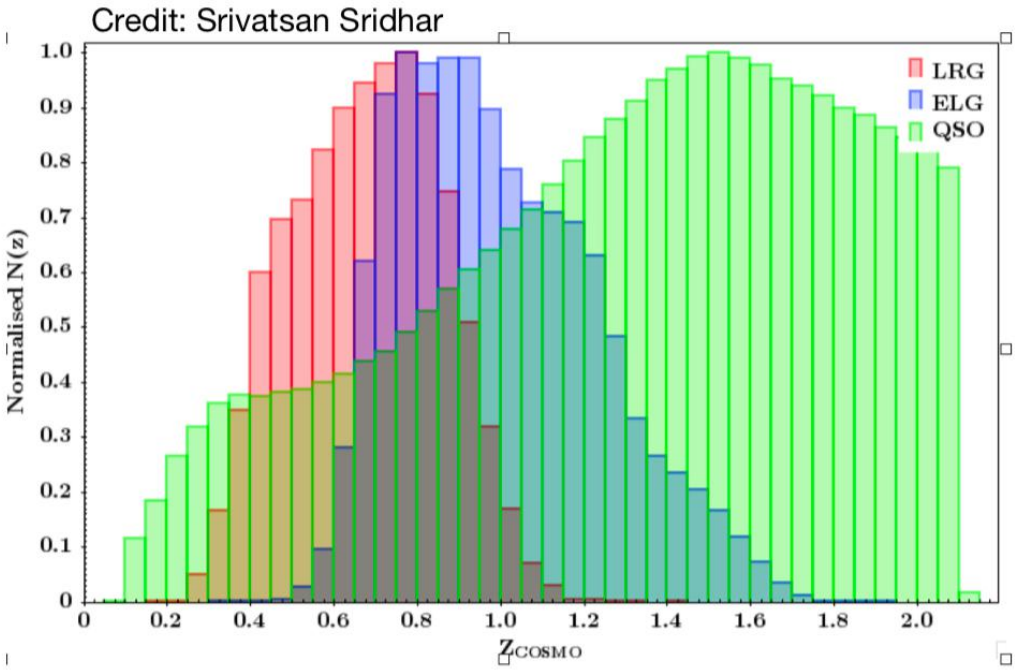
Backup slides

Cross-correlated with LRG or ELG?

	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

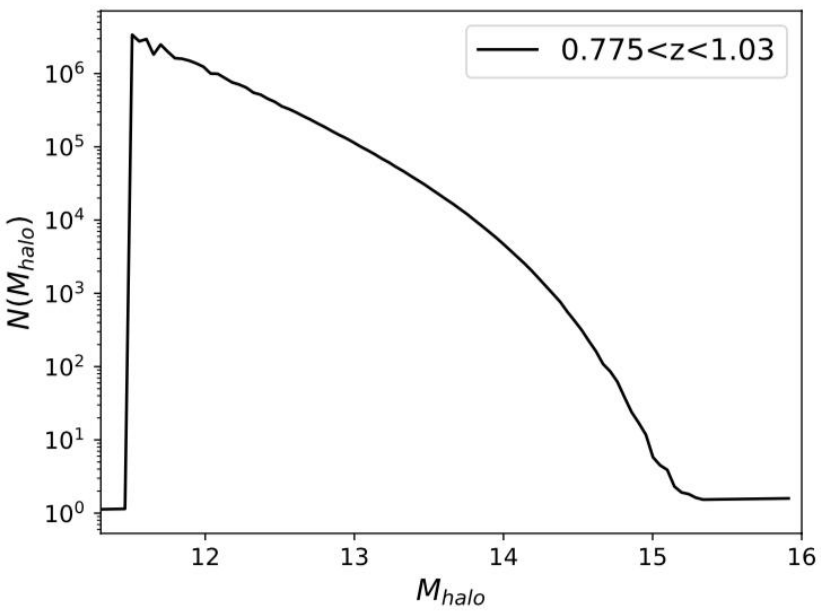
Credit: Srivatsan Sridhar

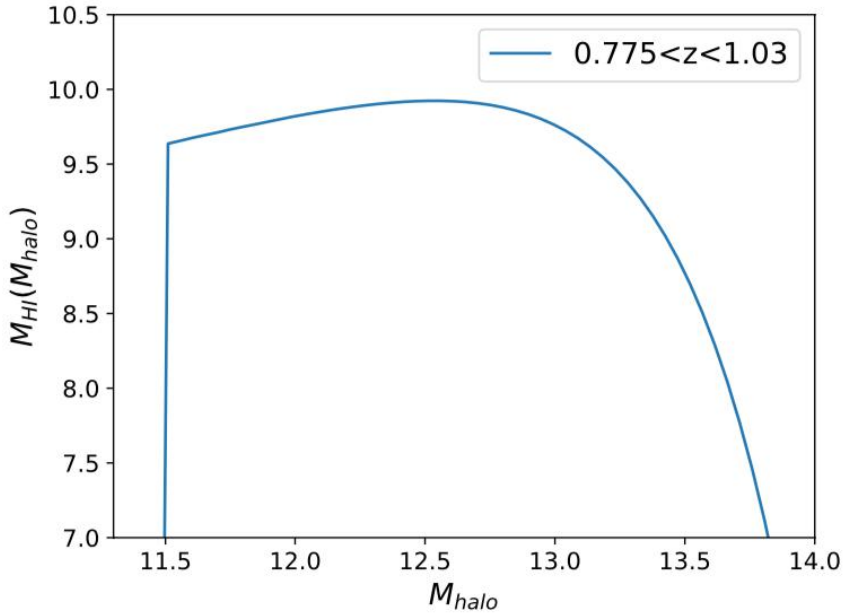


Redshift distribution from DarkSky

LRG is not complete in this redshift range
It's better to use ELG

Populate HR4 with Hydrogen





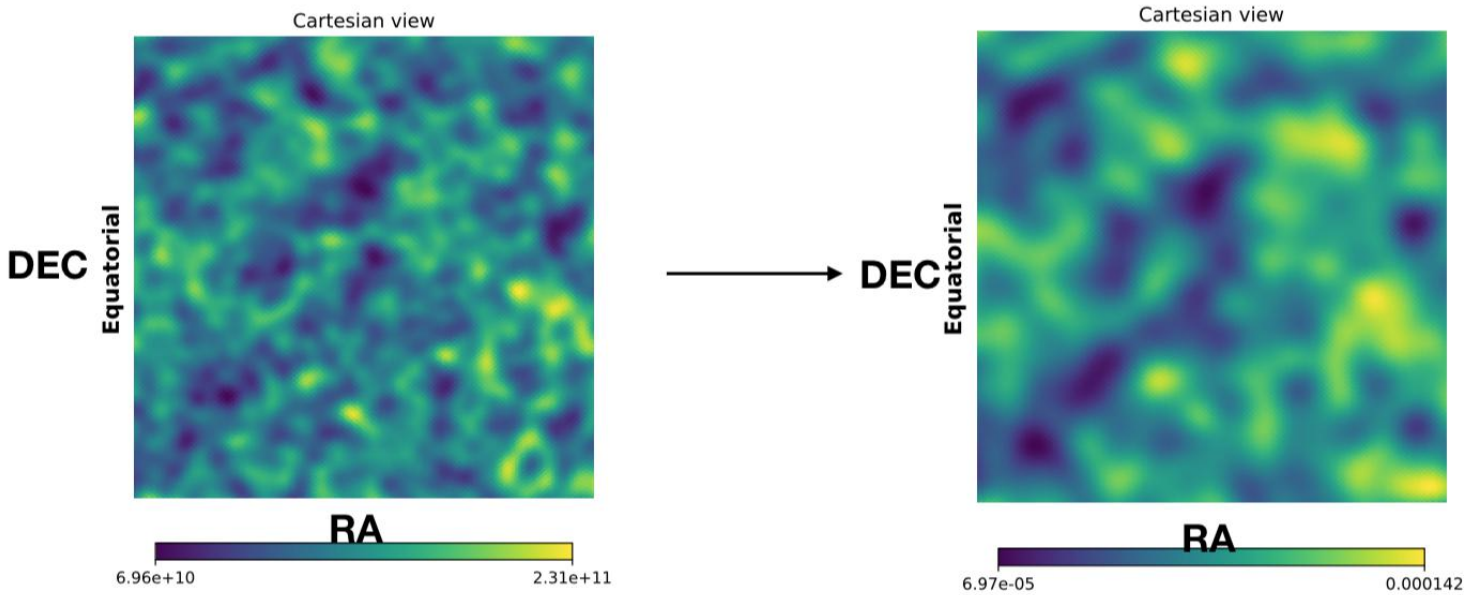
- velocity dispersion
- halo mass

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

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

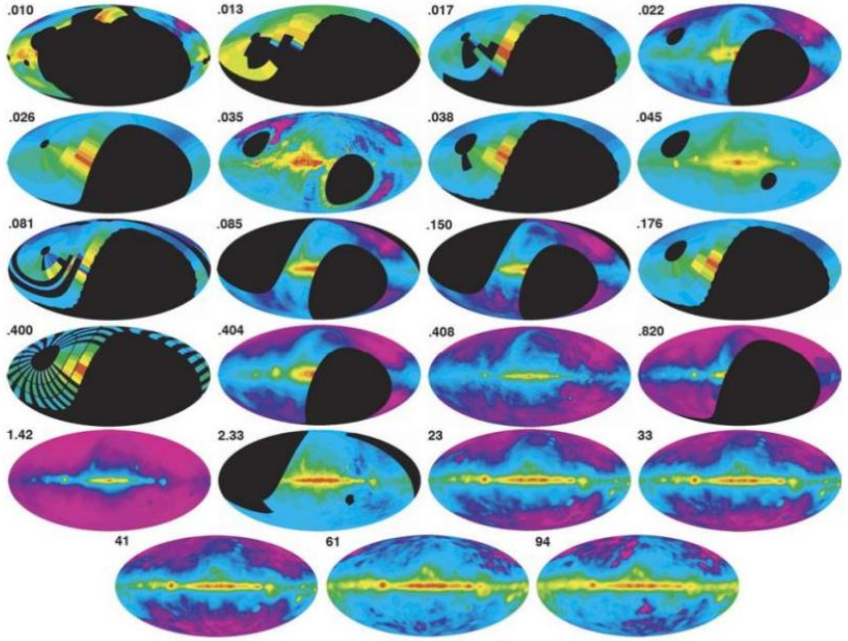


$$T_{21} = \frac{3h_P c^3 A_{12}}{32\pi m_h} \frac{(1+z)^2}{H(z)} \rho_{HI}$$

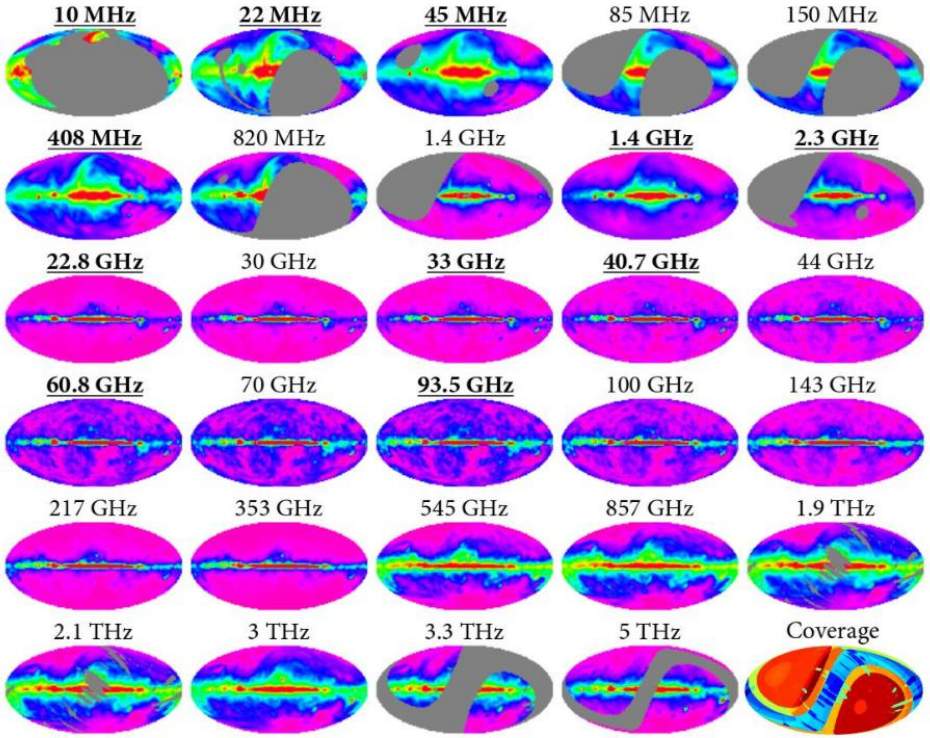
P. Bull & P. G. Ferreira, P. Patel, M. Santos (2015), ApJ, 803, 21

Adding the foregrounds: Global Sky Model

Oliveira-Costa et al. (2008)



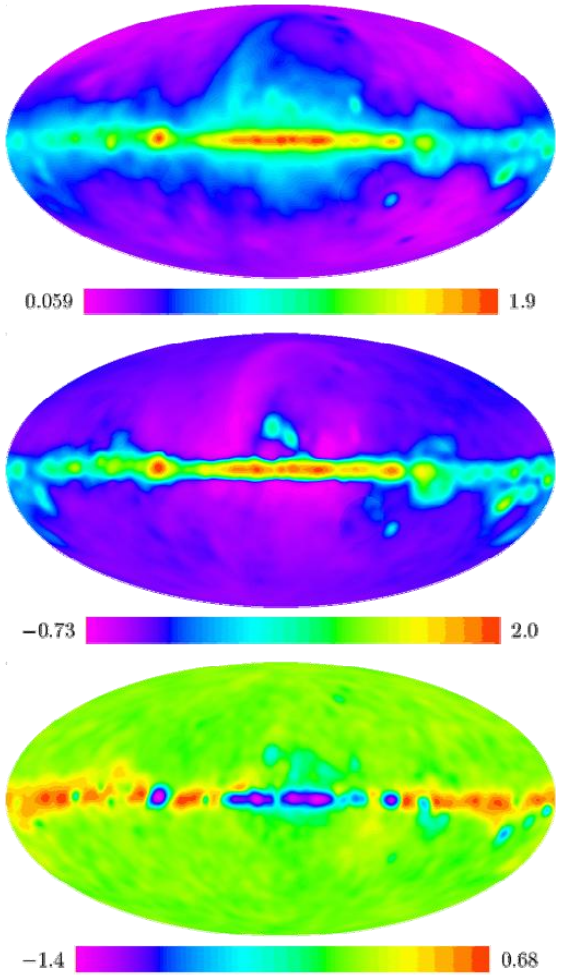
Zheng et al. (2017)

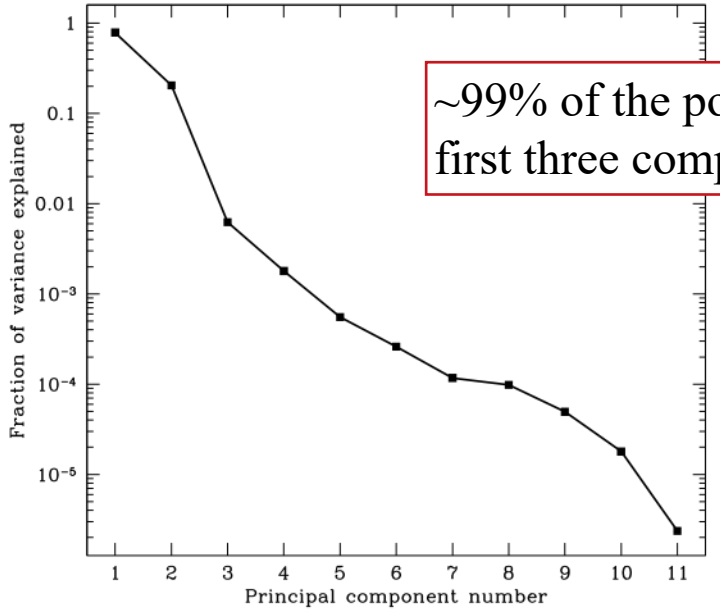


1) **Sky models** from MHz to THz.
2) **Interpolation** requires **up to 5 terms**.
3) **Spectral smoothness** supported by, i.e.:
   - **Theoretical models** (Bernardi et al. 2015)
   - **Measurements from ARCADE- 2** (Kogut et al. 2011; Kogut 2012)

Also:
Sathyanarayana Rao et al. (2016)

Principal Component Analysis (PCA)





~99% of the power is the in first three components

PCA in frequency-frequency covariance matrix from maps

Smooth FG: the first three principal components, which can be crudely interpreted as maps of total “stuff”, synchrotron fraction and thermal dust fraction.