Mock Building: 21cm IM

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Outline

- Overview of 21cm Intensity Mapping Mock
- 21cm IM review
- HI HOD model
- HR4 full-sky mock
- Redshift Space Distortion
- HOD vs HAM
- Frequency Bin Size effect
- Summary

Based on
The BINGO Project VI:
HI Halo Occupation Distribution and Mock Building
Jiajun Zhang et al. in prep
and other BINGO companion papers

Overview

The purpose of mock

- Provide a mock data challenge, test the whole data analysis pipeline
- Construct the covariance matrix

A full mock consist of

- Signal, 21cm from extragalactic HI
- Foreground, contamination from milky way and other astronomical radio source
- Noise, thermal noise, shot noise…
- Mask, telescope survey coverage and galactic influence

Types of simulation

- Hydrodynamic simulation
- N-body simulation + modelling
- Fast simulation + modelling
- Direct tracer field generation

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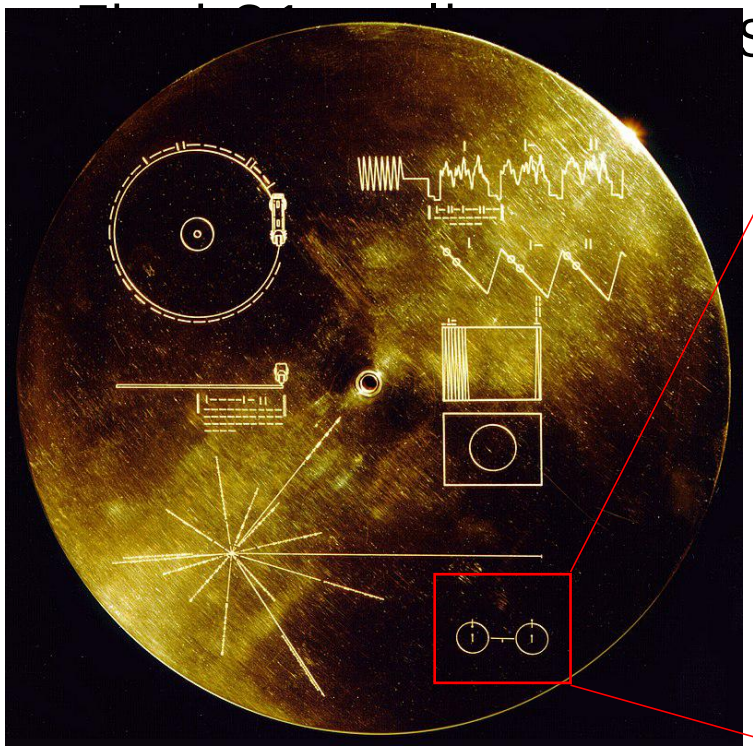
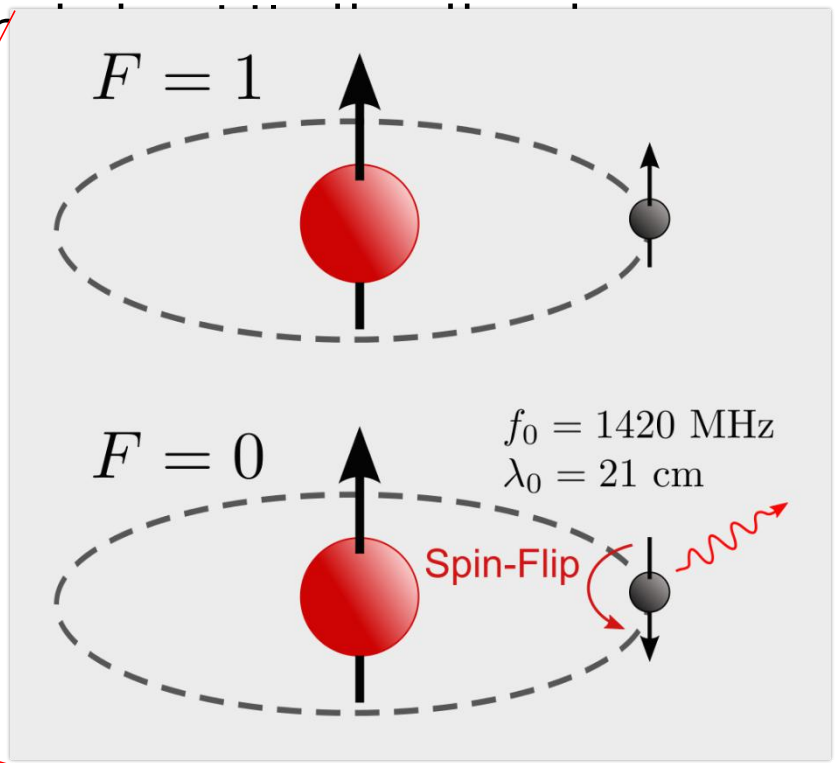
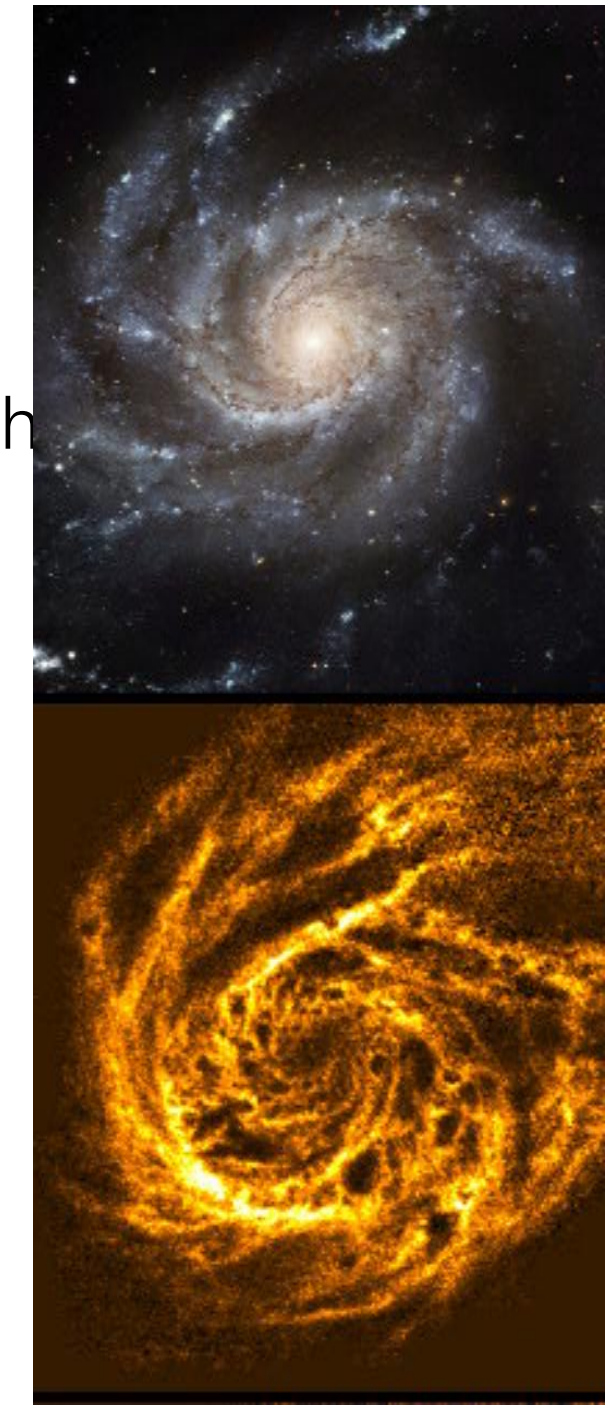
21cm line

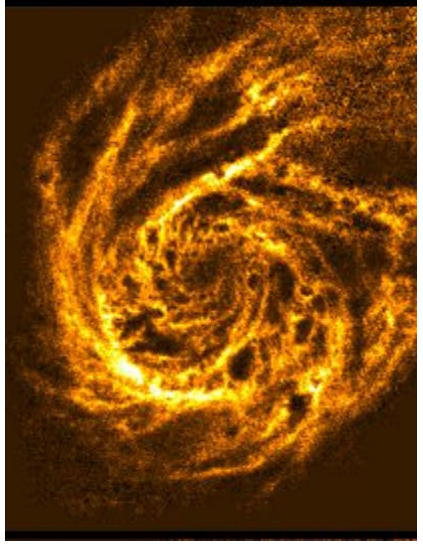
- 21cm line is the transition line of hydrogen atom hyperfin structure, frequency 1420MHz, wavelength 21cm



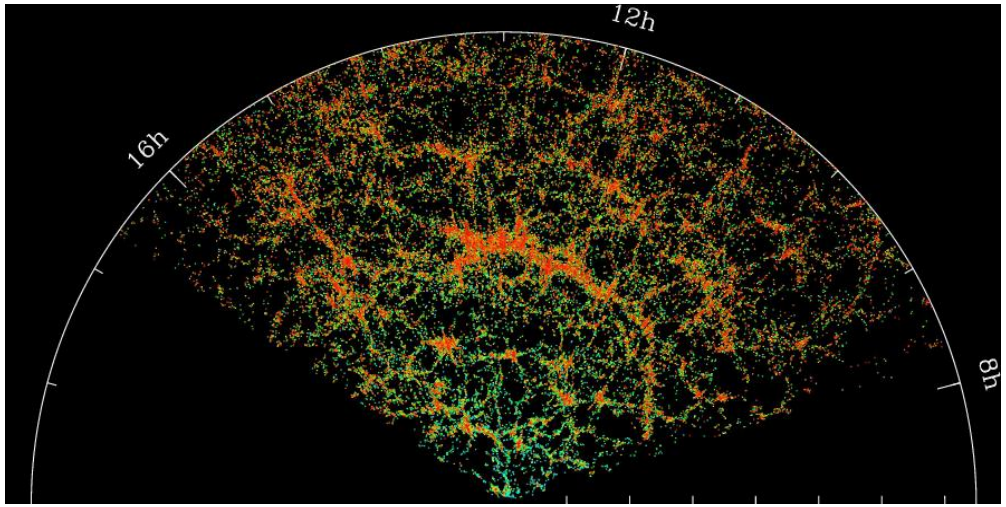


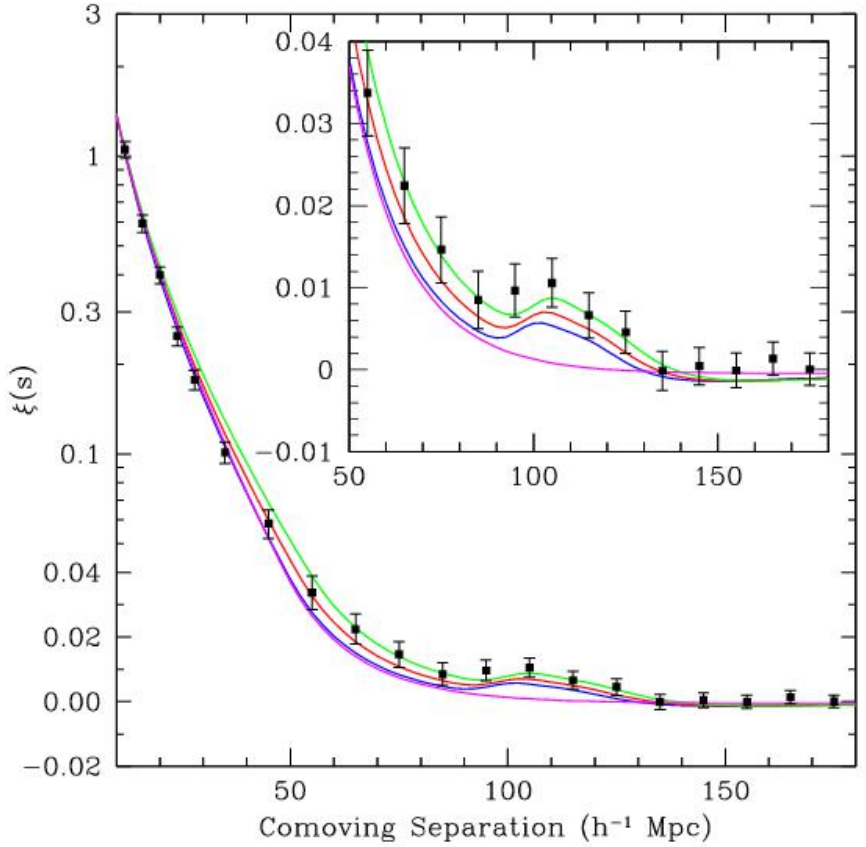


21cm Intensity Map



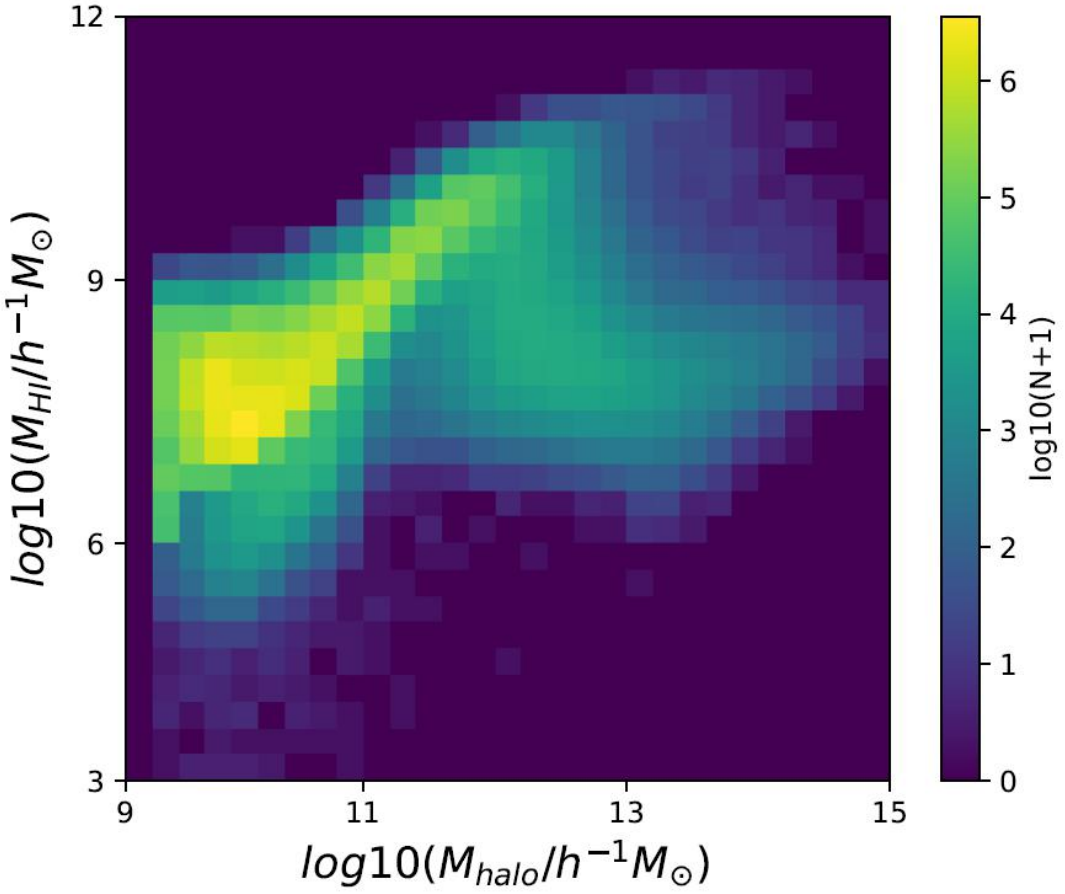
How to detect BAO signal?
1. locate many positions and redshift of galaxies
2. Calculate 2-point correlation function
3. Fit the correlation fucntion with BAO
21cm line can indicate both position and redshift, but cost too much time
BAO ~ 100Mpc, waste of time to identify single galaxy, detect in a integrated way with low resolution? Intensity mapping



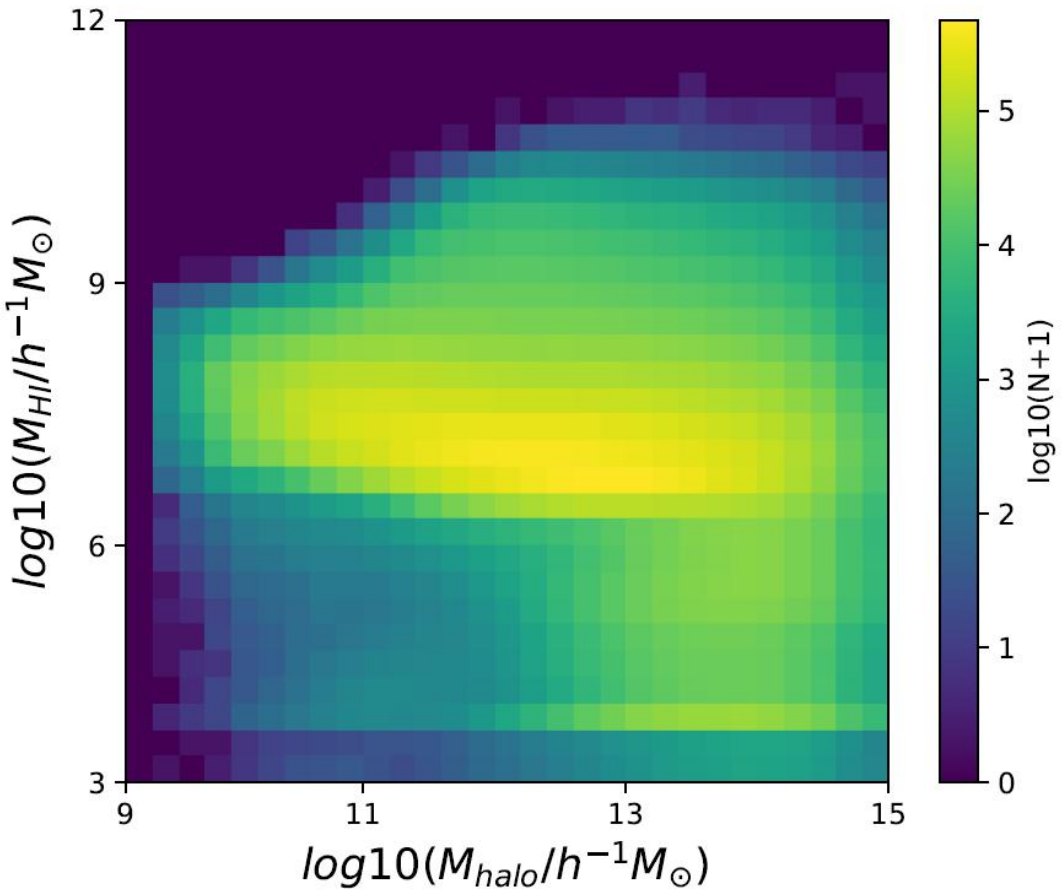


How do HI populate in Halos?

HI HOD model

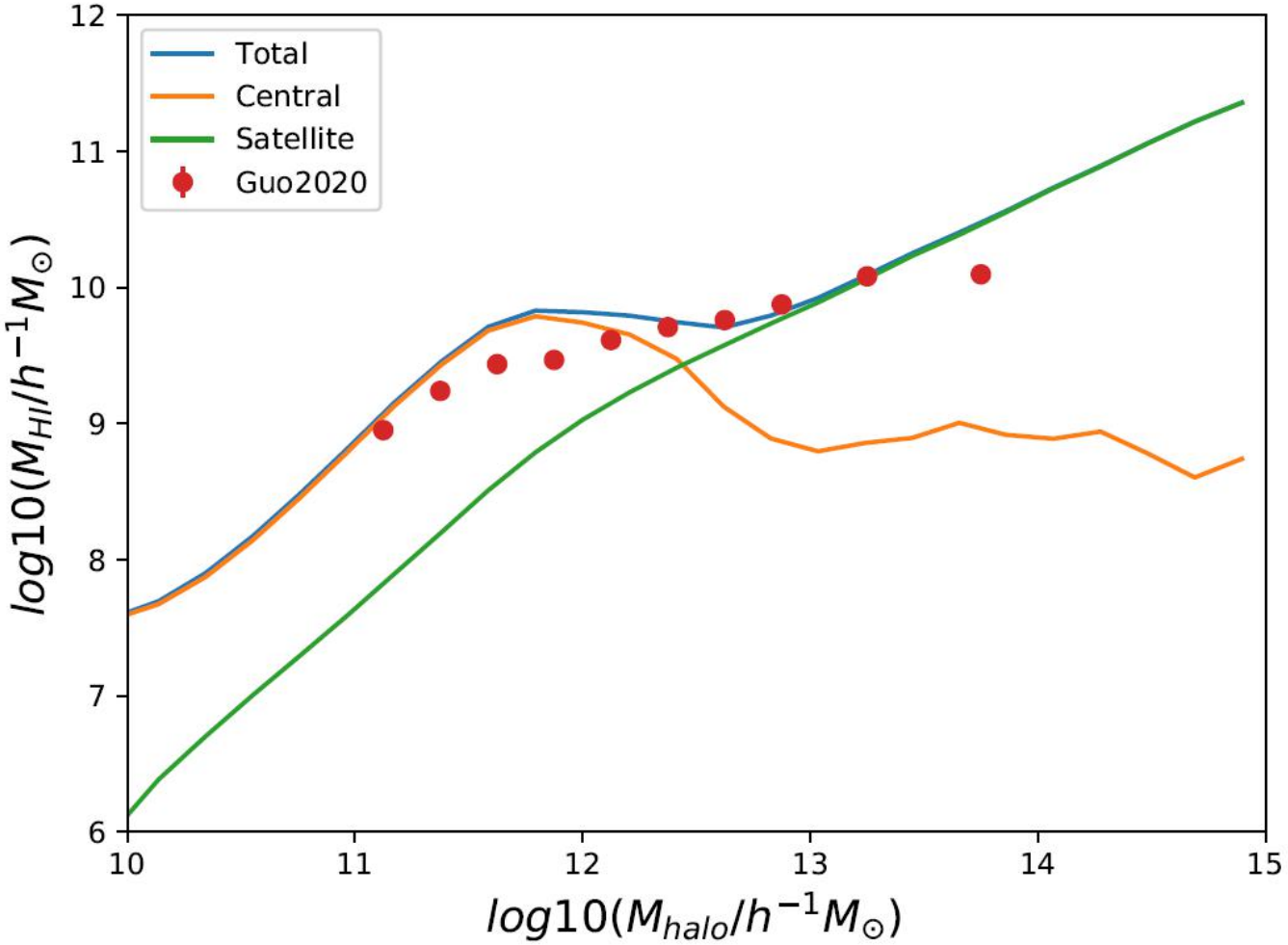


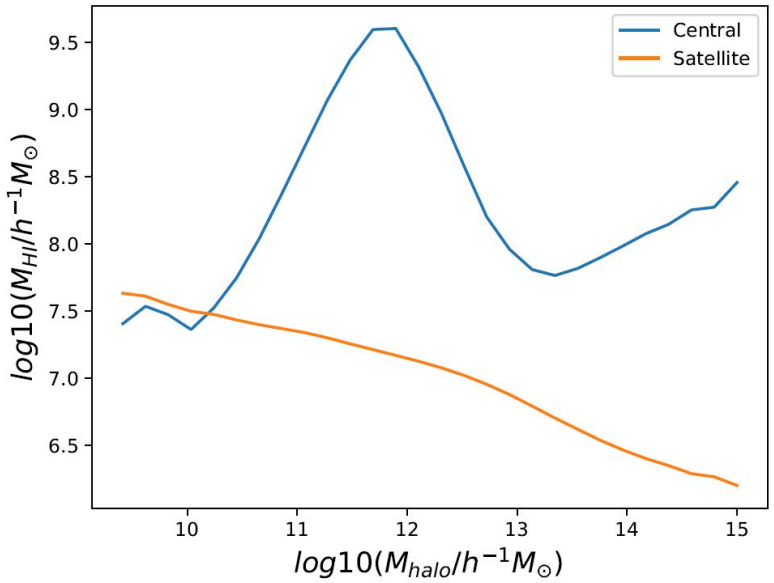
Central Galaxy

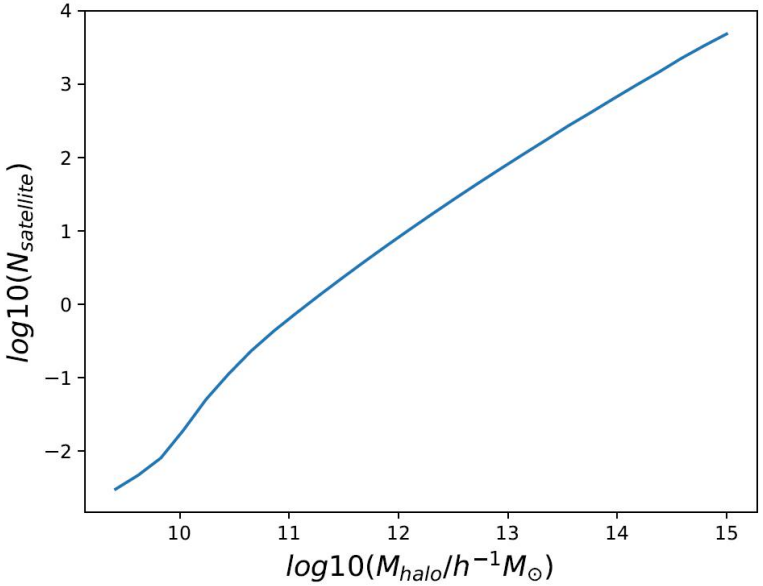


Satellite Galaxy

HI HOD model

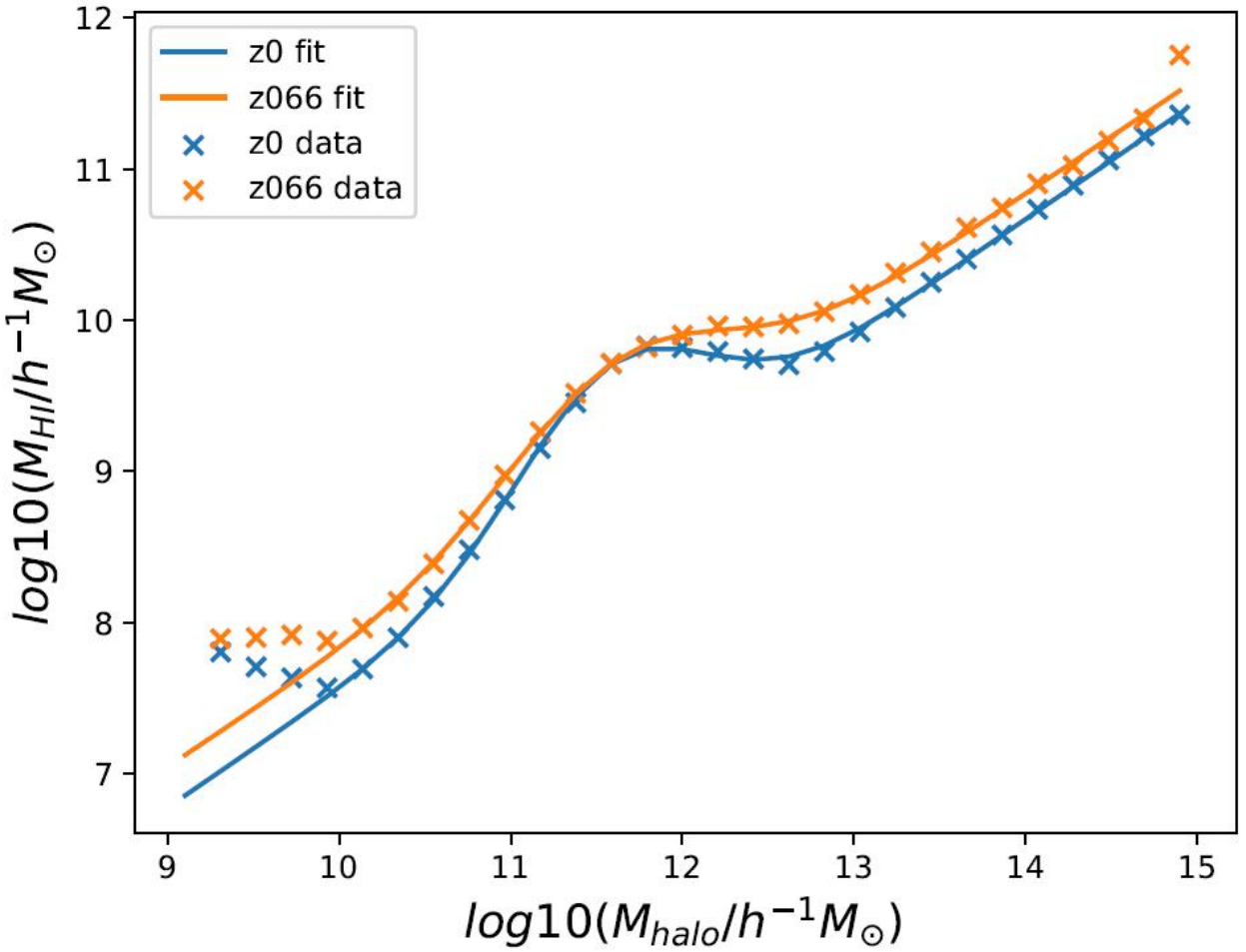






Result from ELUCID SAM model
Comparing to observation Guo2020

HI HOD model



Can be well fitted by
Linear function + gaussian

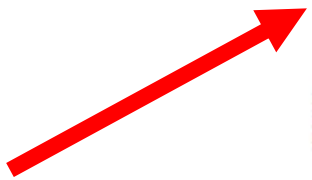
$$log10(m_{HI}) = alog10(m) + b + ce^{-(log10(m)-d)^2/f^2},$$
$$a = 0.7783 - 0.03047z,$$
$$b = -0.2276 + 0.6822z,$$
$$c = 0.9201 - 0.3225z,$$
$$d = 11.58 + 0.03794z,$$
$$f = 0.7892 + 0.1756z,$$

HR4 Full sky mock

Horizen Run 4 (HR4 in short) is a cosmological N-body simulation with cubic box size $3150 Mpc/h$ and 6300^3 number of particles(Kim et al. 2015). HR4 simulation adopted WMAP5 ΛCDM cosmology, where $\Omega_m = 0.26, \Omega_\Lambda = 0.74, h = 0.72, \sigma_8 = 0.79, n_s = 0.96$(Dunkley et al. 2009). The halos are identified by Friend-of-Friend (FoF) algorithm with linking length equal to 0.2 times the particle mean distance in HR4 simulation, at least 30 particles are required for identifying a halo, which means the minimum halo mass is $2.7 \times 10^{11} M_\odot/h$.

HR4 Full sky mock

Key step!



1 Populate HI gas in the galaxy (halo) catalog, calculate the HI density distribution ρ_{HI}, (when considering redshift space distortion, this step is more complicated)
2 Calculate the brightness temperature

$$T_b = 189h\frac{H_0(1+z)^2}{H(z)}\frac{\rho_{HI}}{\rho_c}mK, \tag{5}$$

where ρ_c is the critical density of the universe,
3 Re-scale the map according to required Ω_{HI},
4 Smooth the brightness temperature map with a Gaussian kernel FWHM = 40 arcmin, which is due to the beam of BINGO.

HOD vs HAM

HR4 simulation:

1. FoF halo catalog
2. Galaxy catalog (subhalo)

HOD + FoF halo = HOD HI catalog (halo)

HAM + Galaxy = HAM HI catalog (subhalo)

what is expected?

1. HOD catalog: simple, HI evolution, lack one-halo term
2. HAM catalog: complex, no HI evolution, one-halo term

HR4 Full sky mock

Abundance Matching (HAM), match observed HI mass function (ALFALFA 2010 result, z=0) to HR4 galaxy light cone catalog (with mass “indicator”)

$$\phi(m_{HI})dlog10(m_{HI}) = ln(10)\phi_*(\frac{m_{HI}}{m^*})^{\alpha+1}\exp-\frac{m_{HI}}{m_*}dlog10(m_{HI}),$$

$$\phi_* = 0.0048$$

$$\alpha = -1.33$$

$$m_* = 10^{9.96}(\frac{0.7}{h})^2,$$

HOD model
HI mass-halo mass relation
HR4 FoF light cone halo catalog

$$log10(m_{HI}) = alog10(m) + b + ce^{-(log10(m)-d)^2/f^2},$$

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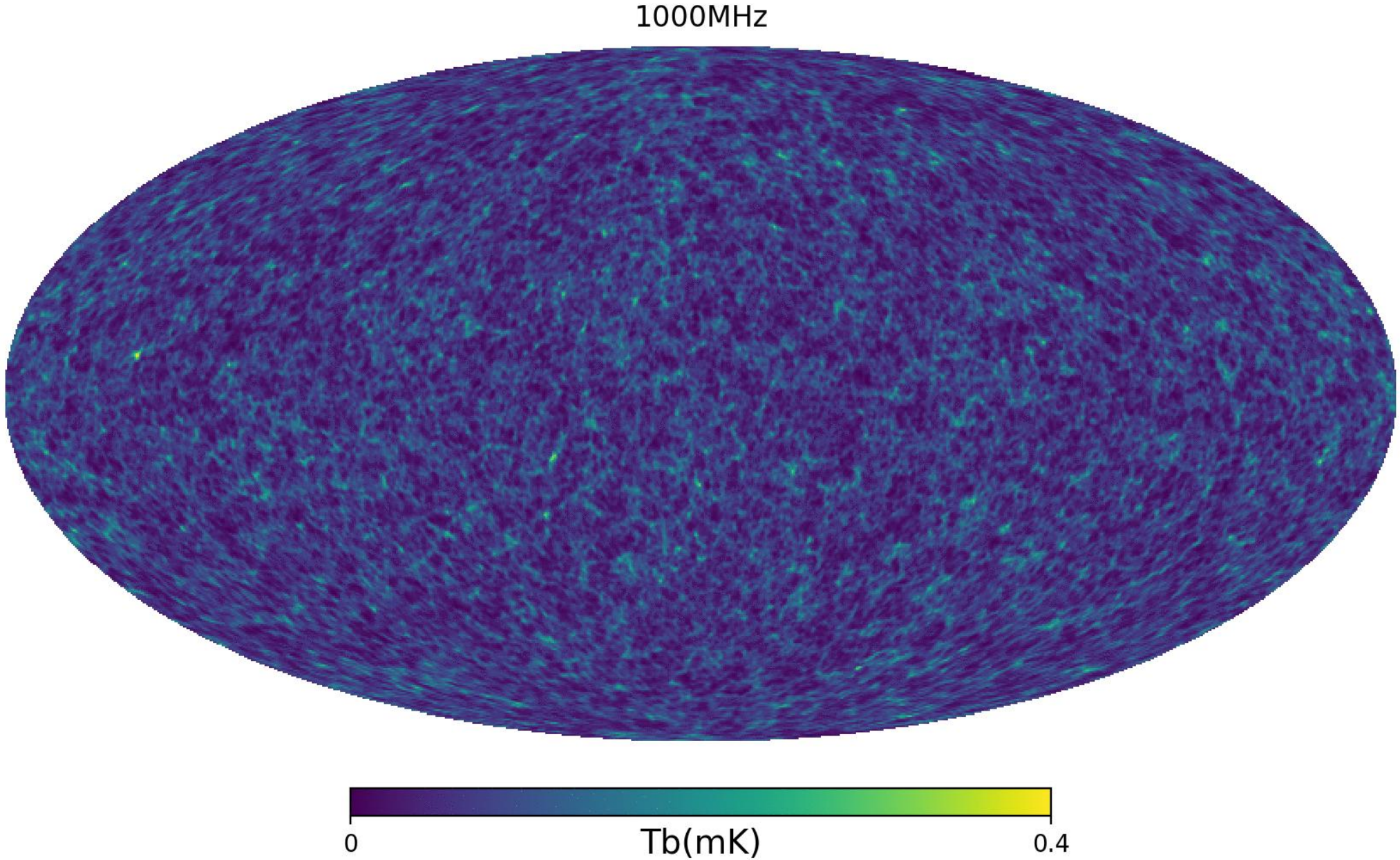
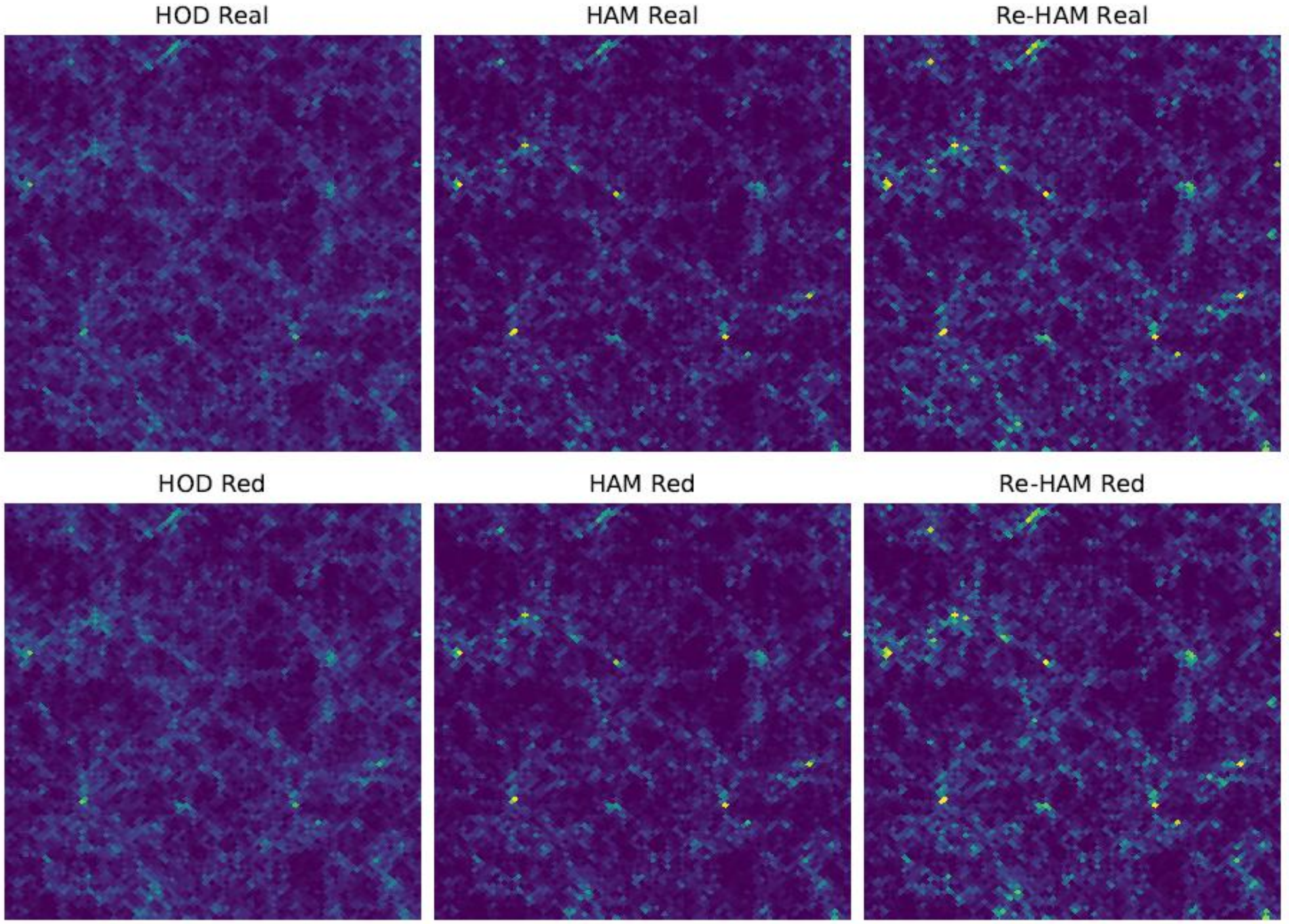

1000MHz
0
Tb(mK)
0.4

HOD vs HAM

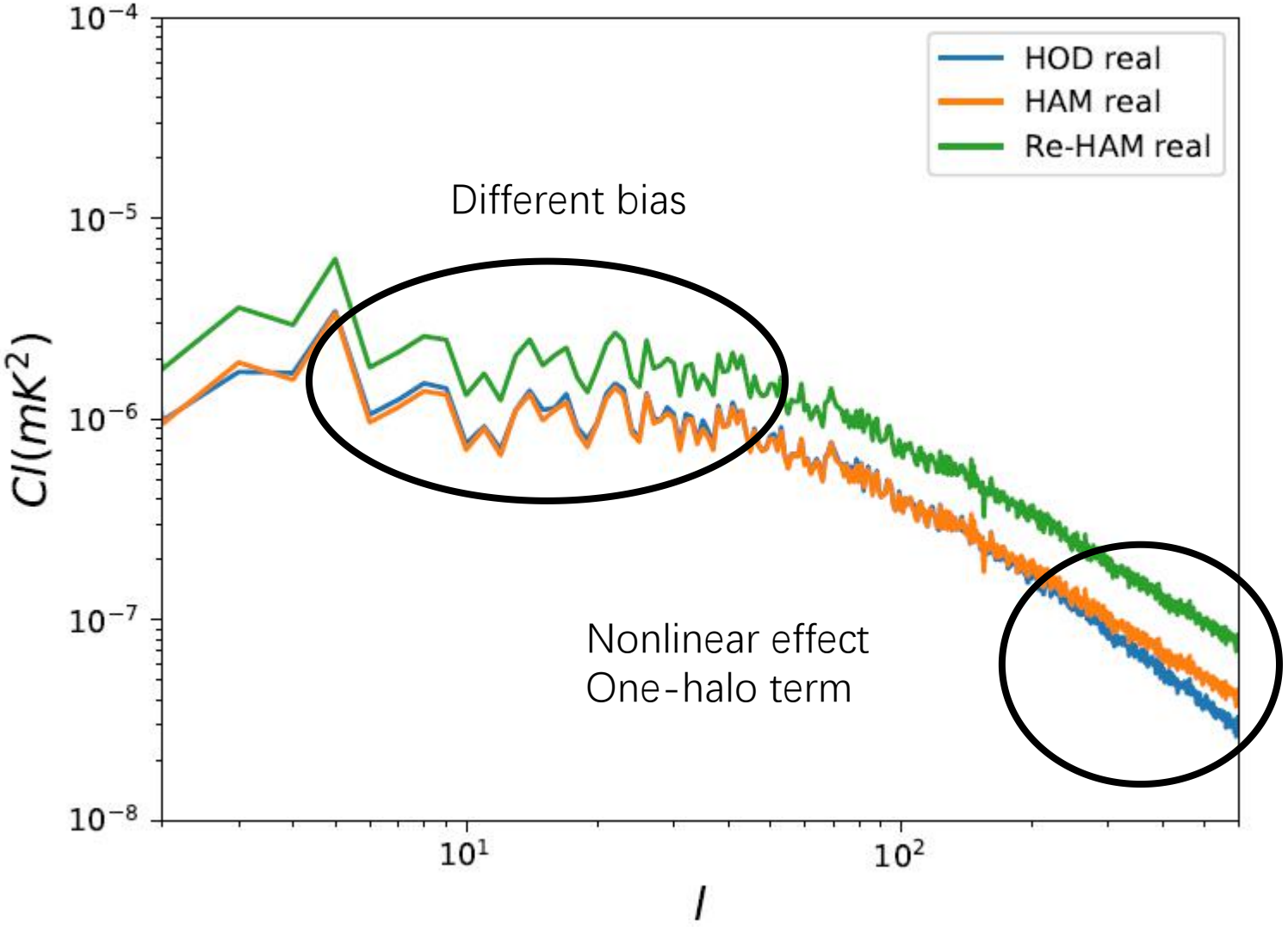


HOD vs HAM

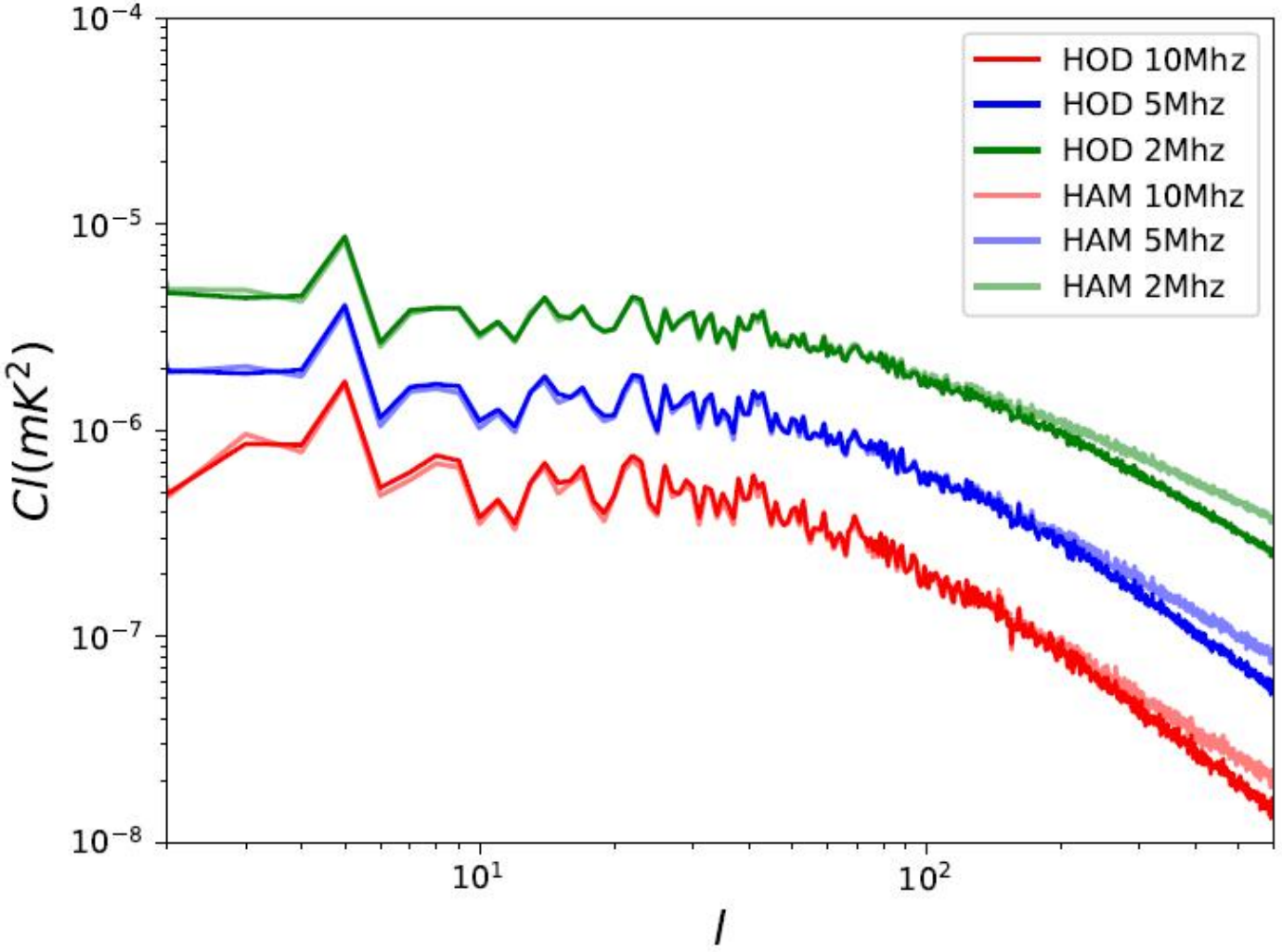
$$\bar{T}_b = 189h\frac{H_0(1+z)^2}{H(z)}\Omega_{HI}mK.$$

$$T'_b = T_b\frac{\Omega'_{HI}}{\Omega_{HI}}.$$

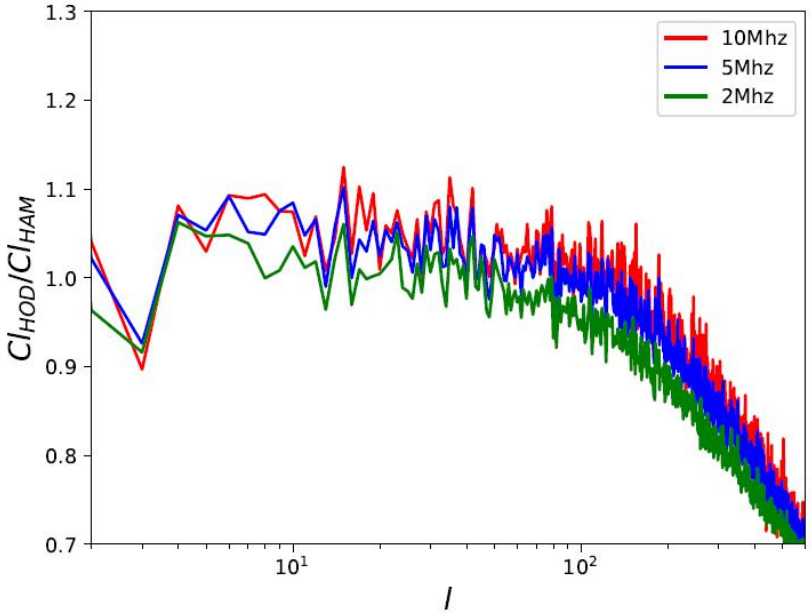
As expected, HAM has satellite galaxies, HOD only has main halo
There are one-halo term in HAM mock, but not in HOD mock



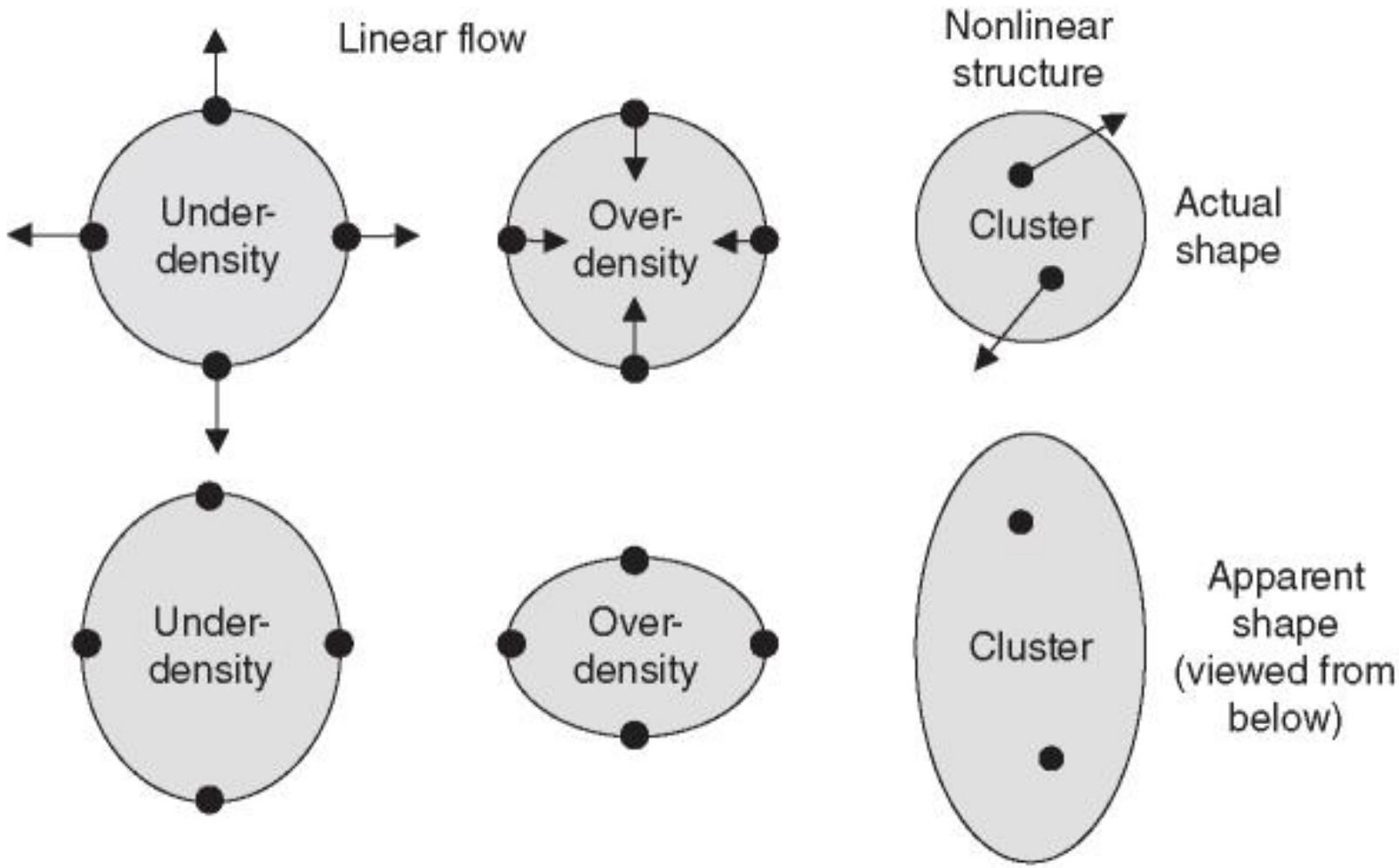
Frequency Bin Size effect



Bin size has little impact on one-halo term, as expected, due to isotropy nature of one-halo term



Redshift Space Distortion



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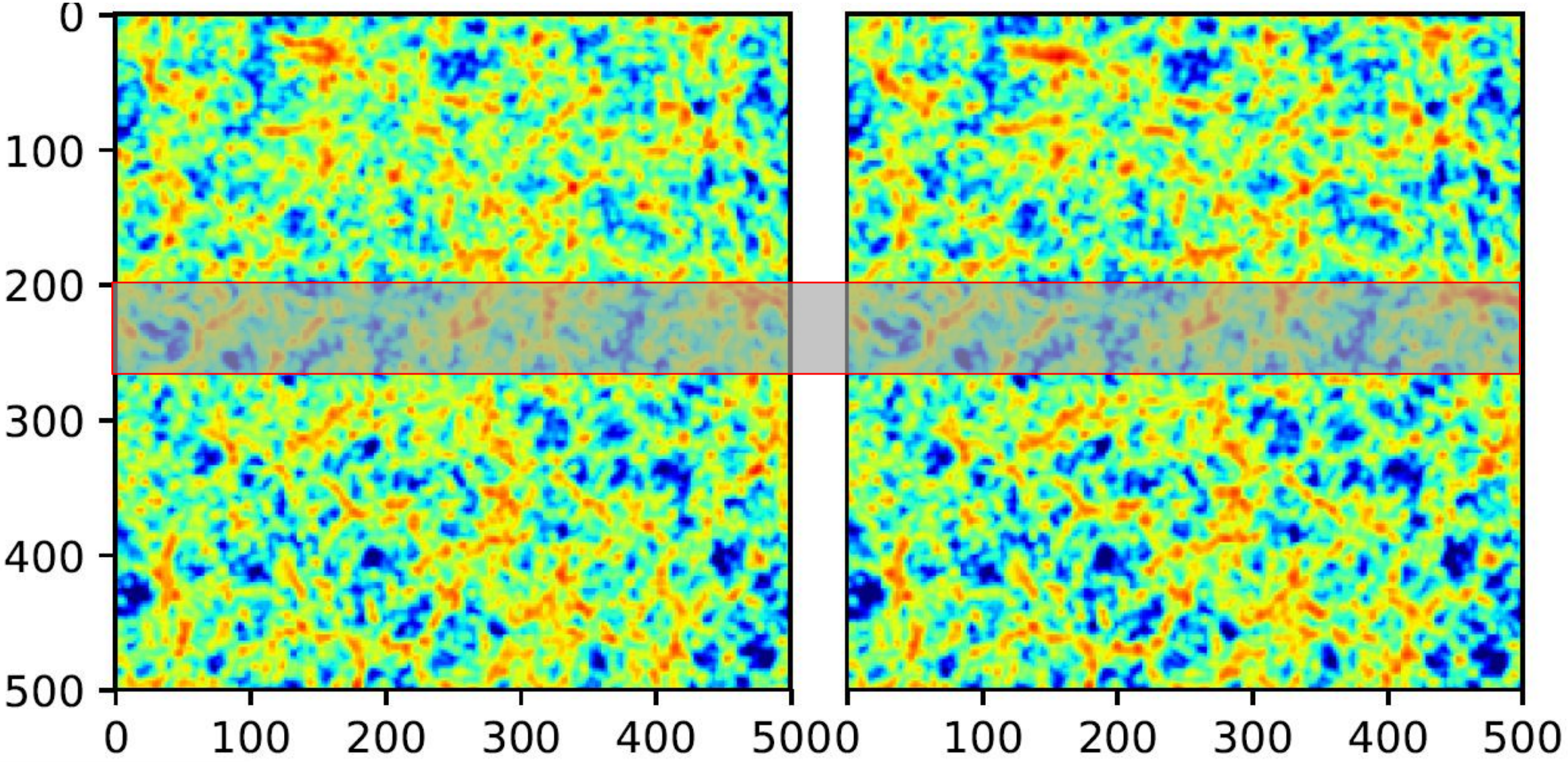
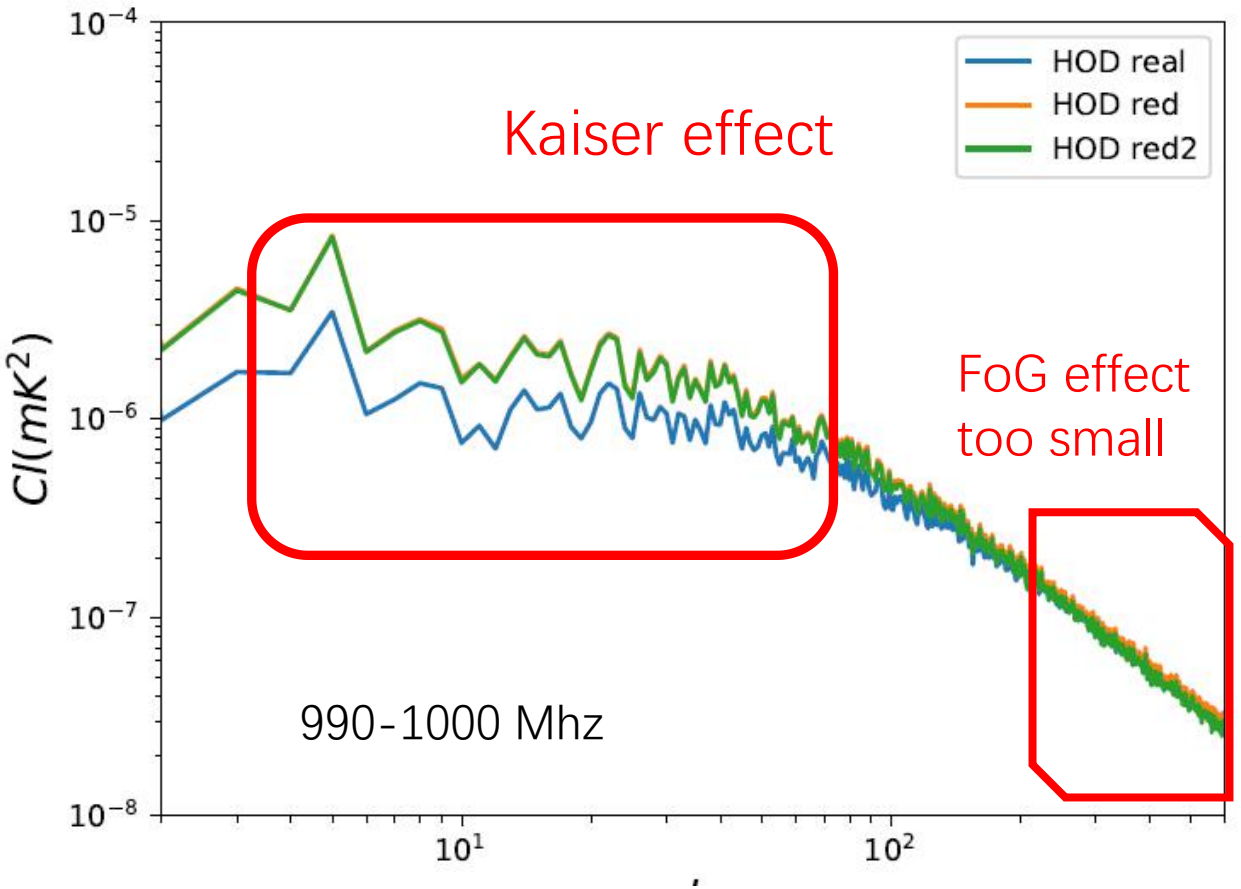
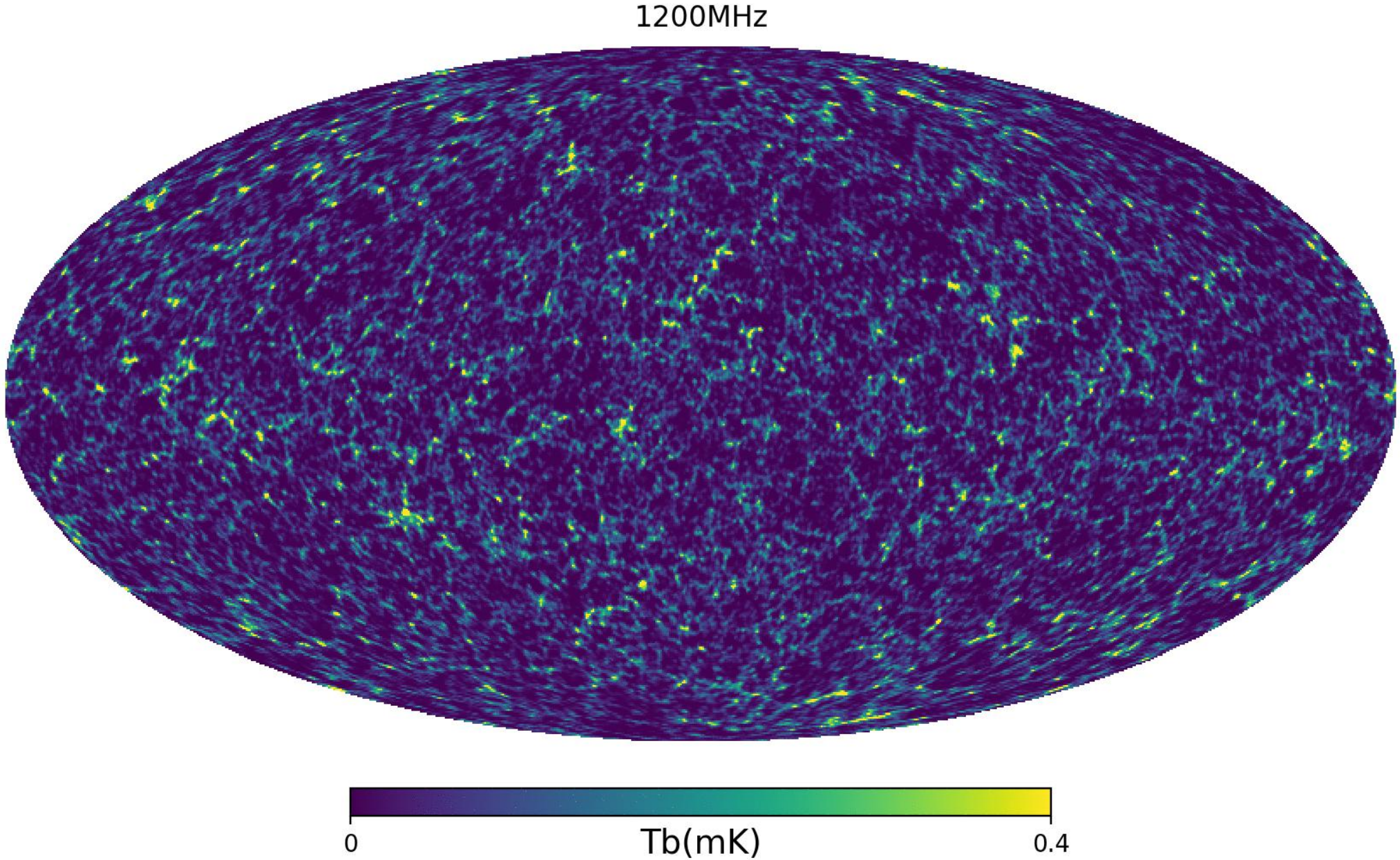


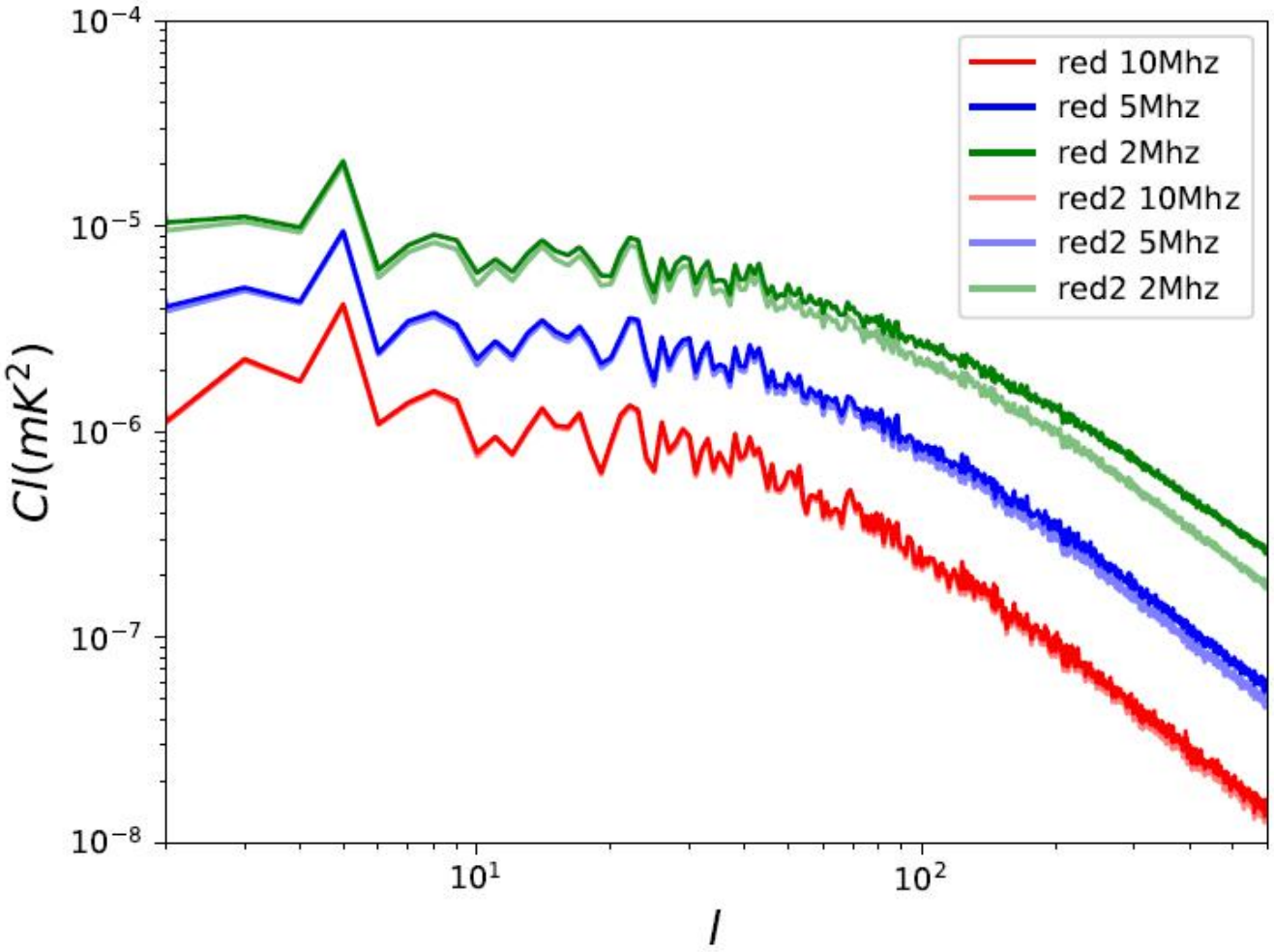
Redshift Space Distortion

- Red: The peculiar velocity of the galaxies (halos) as a point source, which mainly contributes to Kaiser effect
- Red2: The velocity dispersion inside the galaxies (halos), which mainly contributes to FoG effect.
- The mocks in previous works is usually Red (version 1), not Red2 (version 2)




1200MHz
0
Tb(mK)
0.4

Frequency Bin Size effect



Bin size has bit impact on FoG effect

Smaller bin size, larger FoG suppression

As expected, due to the anisotropy nature of FoG

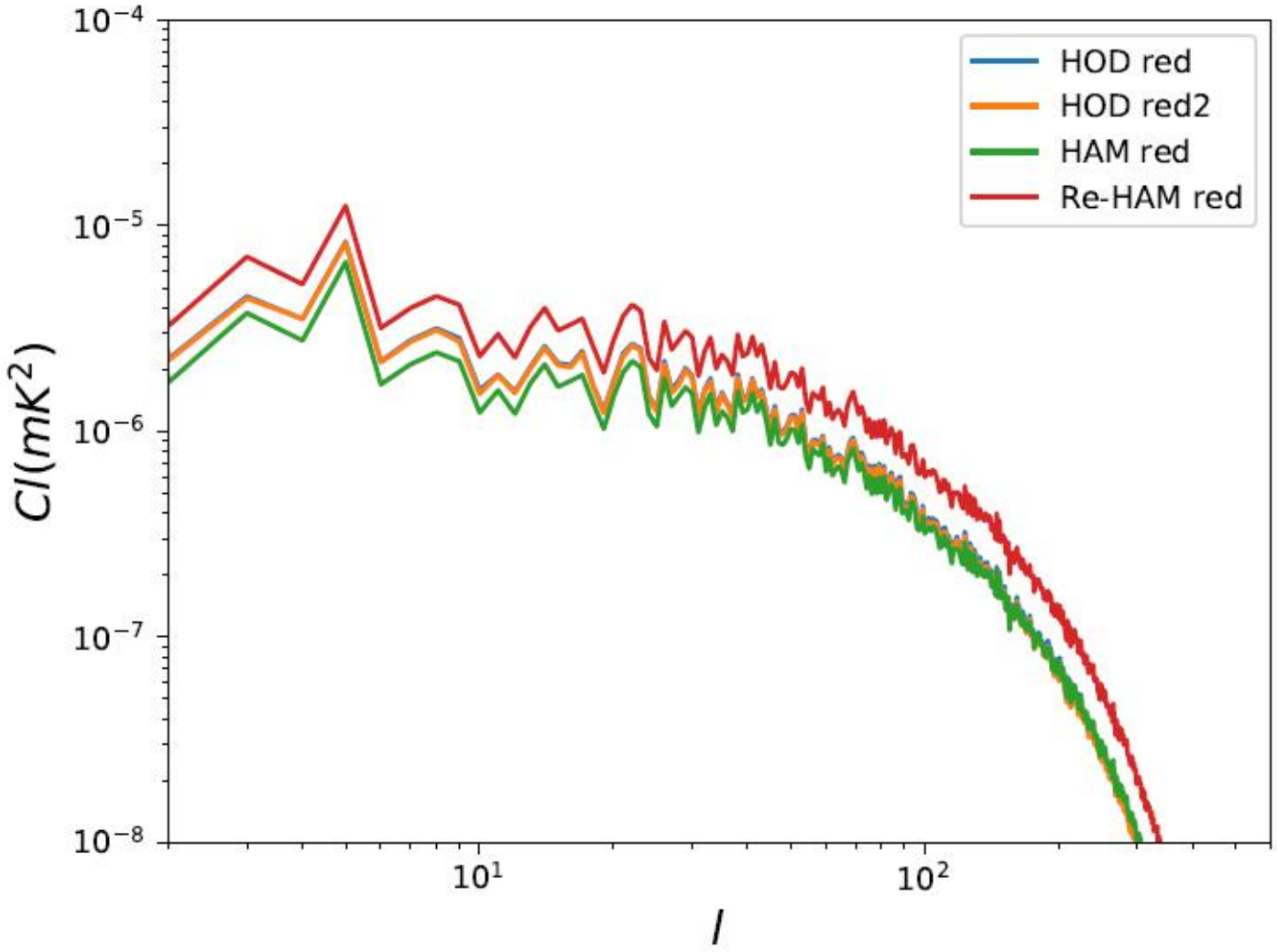
Smoothing

Considering 40 arcmin FWHM Gaussian smoothing

Only large scale difference matters

Kaiser effect in RSD

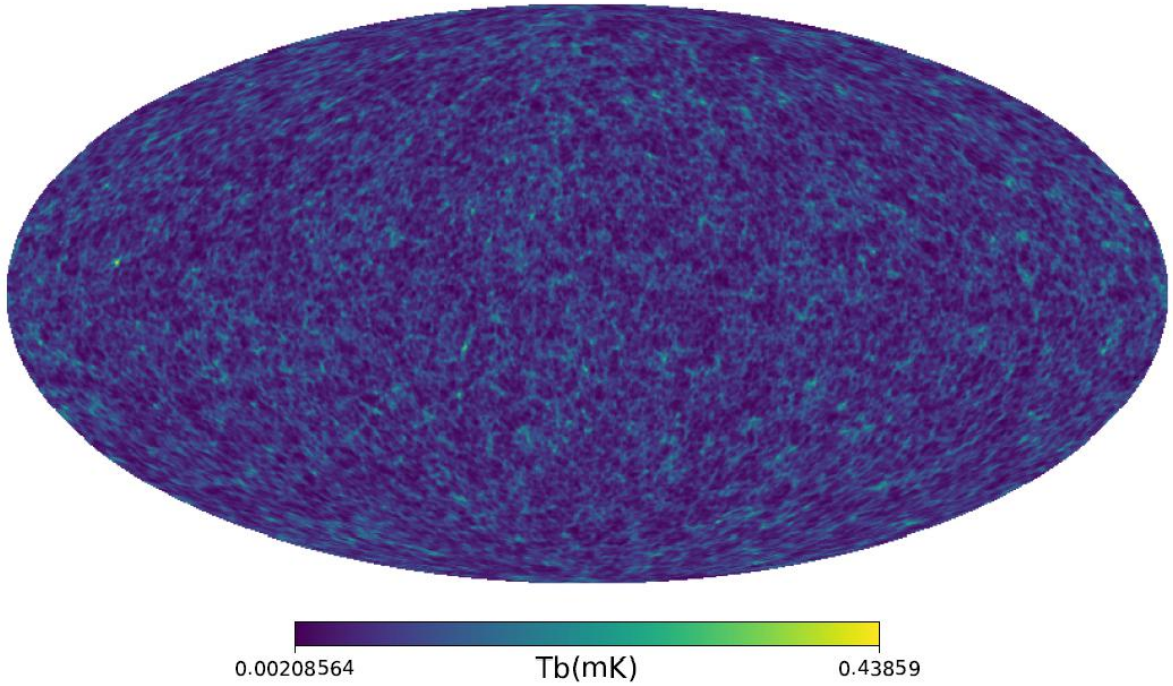
Different linear bias for HAM and HOD

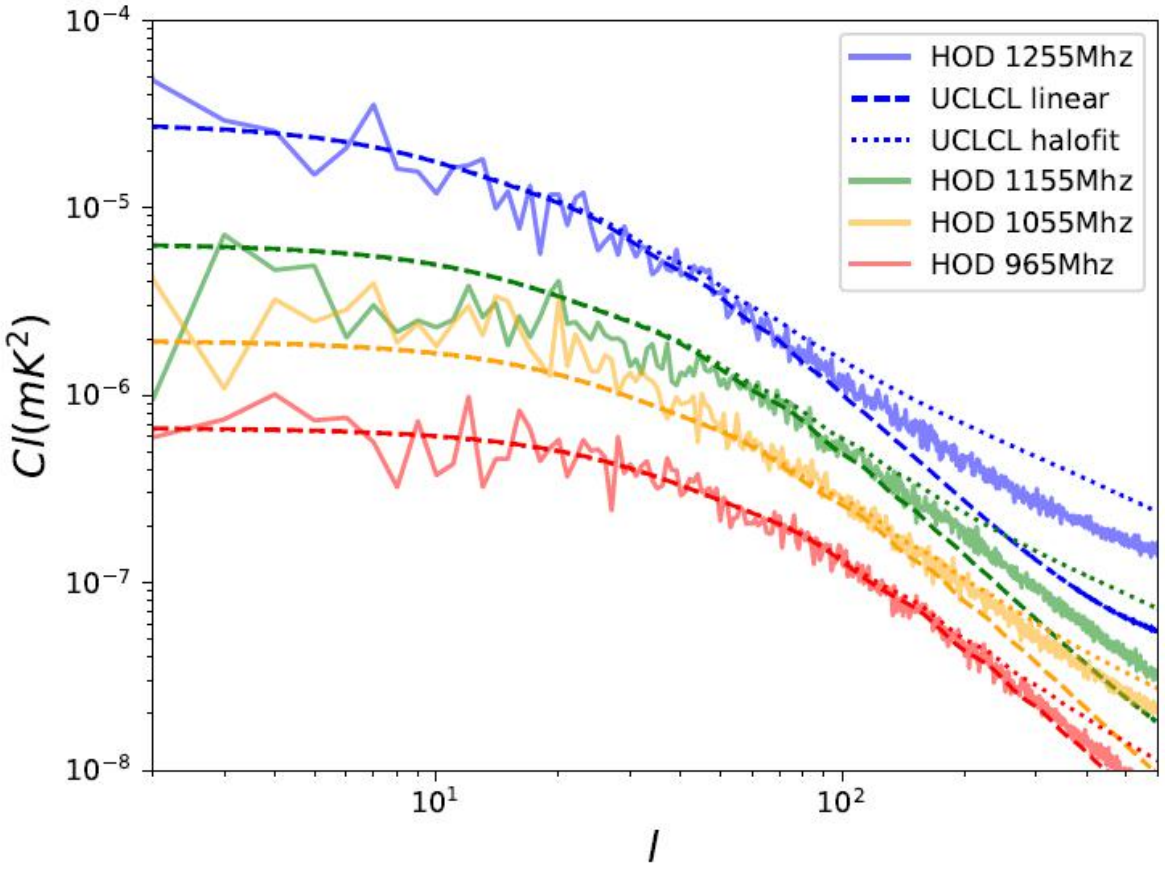


Theory vs Mock

Mock generated from Horizen Run 4

UCLCL calculated theoretical prediction





Summary

1. HI halo occupation studied using ELUCID
2. Fitting formula of HI mass halo mass relation provided
3. Full-sky mock using HR4 built
4. FoG effect considered, Red2 mock provided
5. Cls with Beam smoothing, RSD, and HAM vs HOD studied
6. Frequency bin size effect discussed, important for FoG
7. BINGO will be constructed to detect 21cm IM signal