Reconstructing HI power spectrum using the dark matter distribution beyond haloes

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RA[1], A. J. Nishizawa[1], I. Shimizu[2], K. Nagamine[3] 2011.13165

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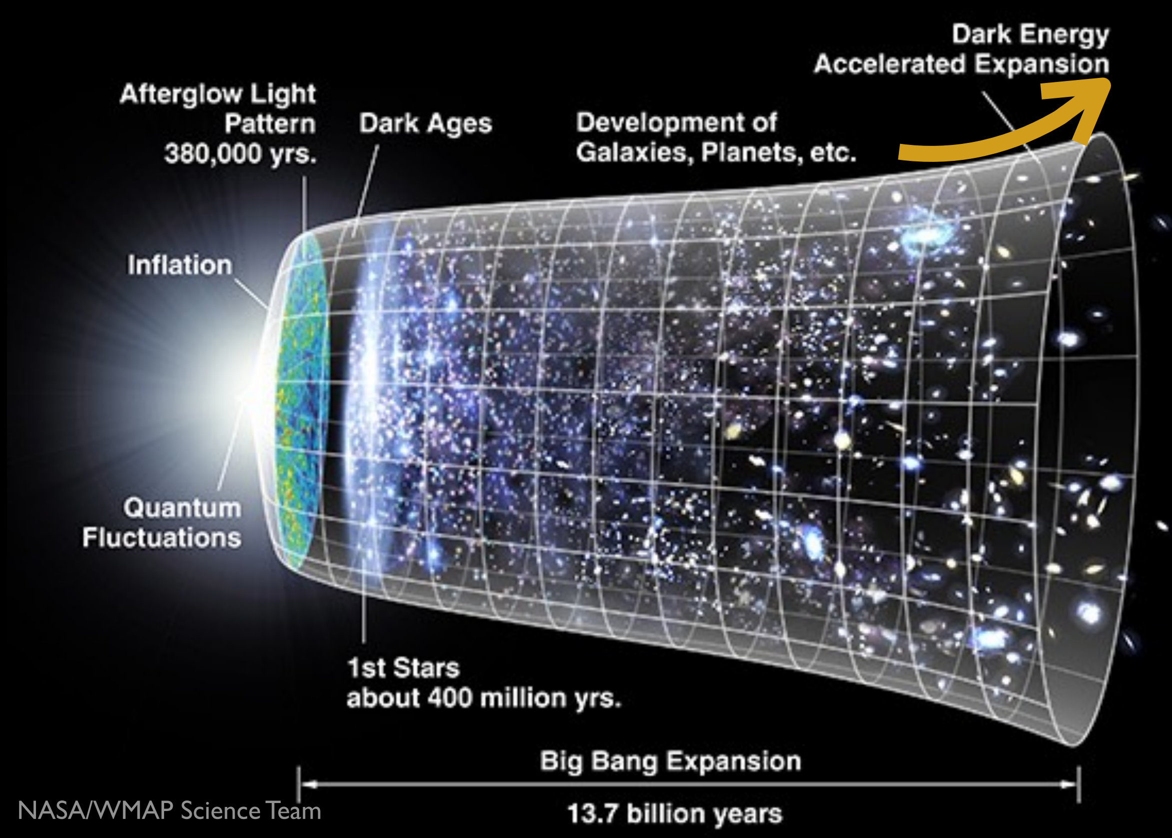
Accelerating universe and large scale structure



The origin of the accelerating expansion

- Dark energy
- Modified gravity

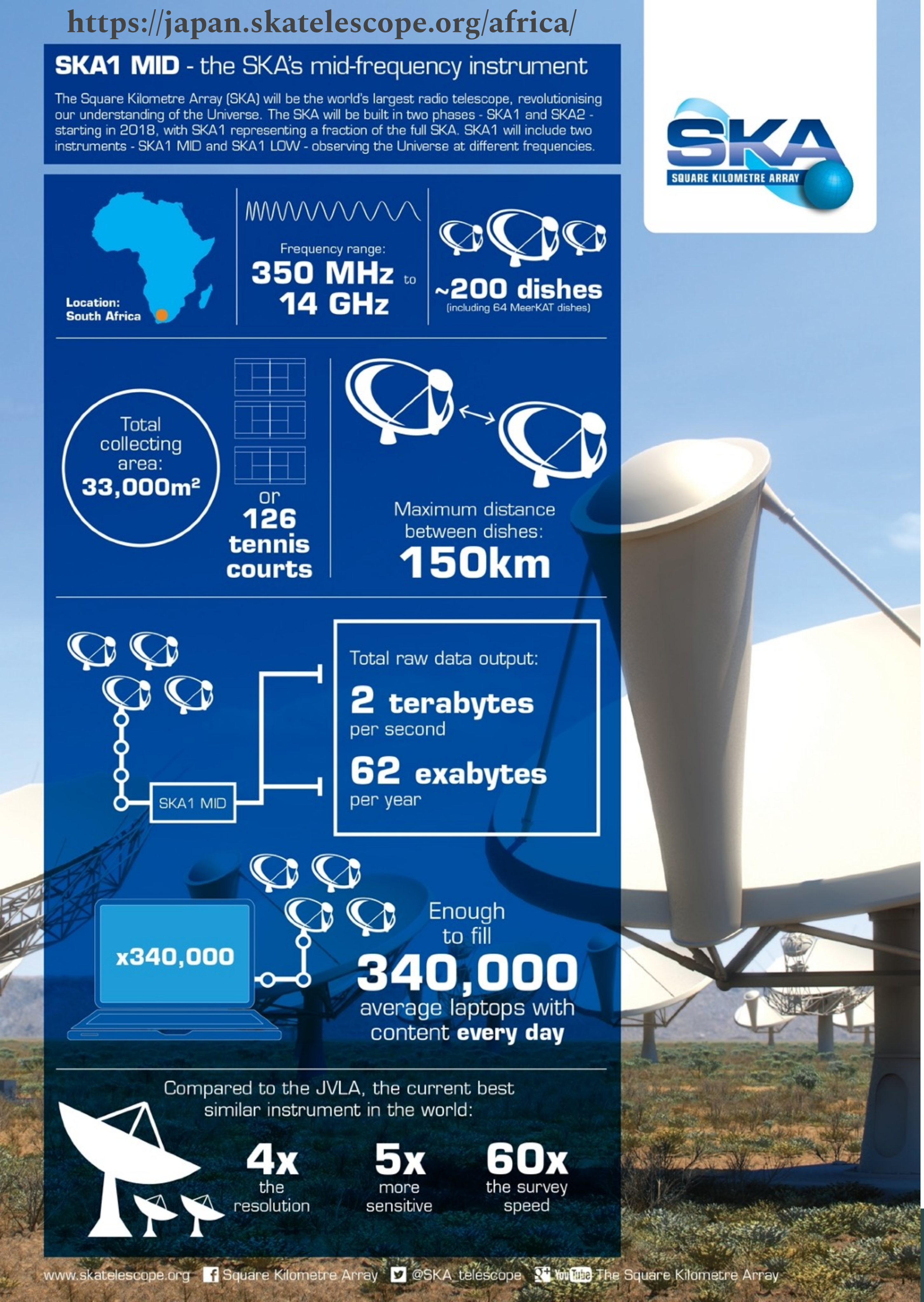
$w = p/\rho$

$$\frac{\ddot{a}}{a} = -\frac{4\pi G}{3}(1+3w)\,\rho \quad > 0$$

- Expansion history $H(z)$
- Growth of the density fluctuation $\dot{\delta}$, $f\sigma_8$

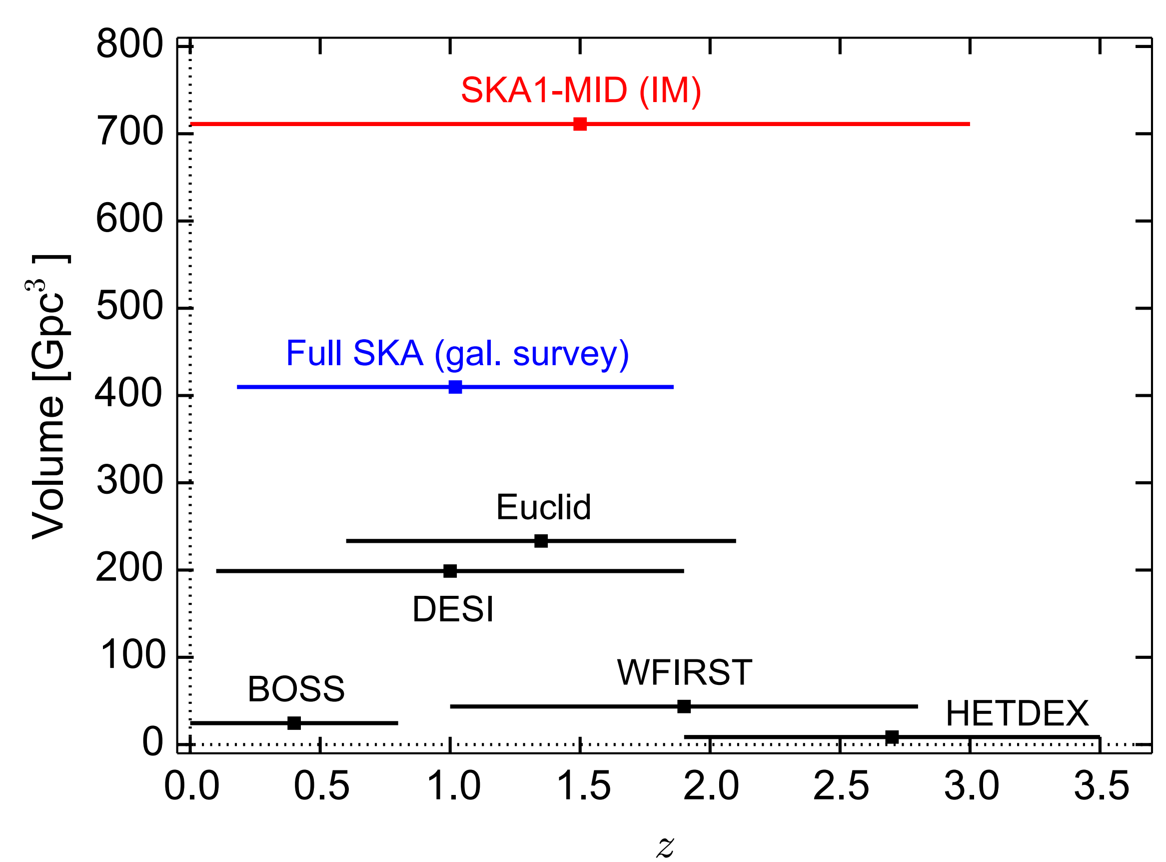
the probe is the *large-scale structure* of the universe

such as P(k), BAO, RSD



21-cm line

Explore the large scale structure with 21-cm line intensity mapping



Santos et al. 2015

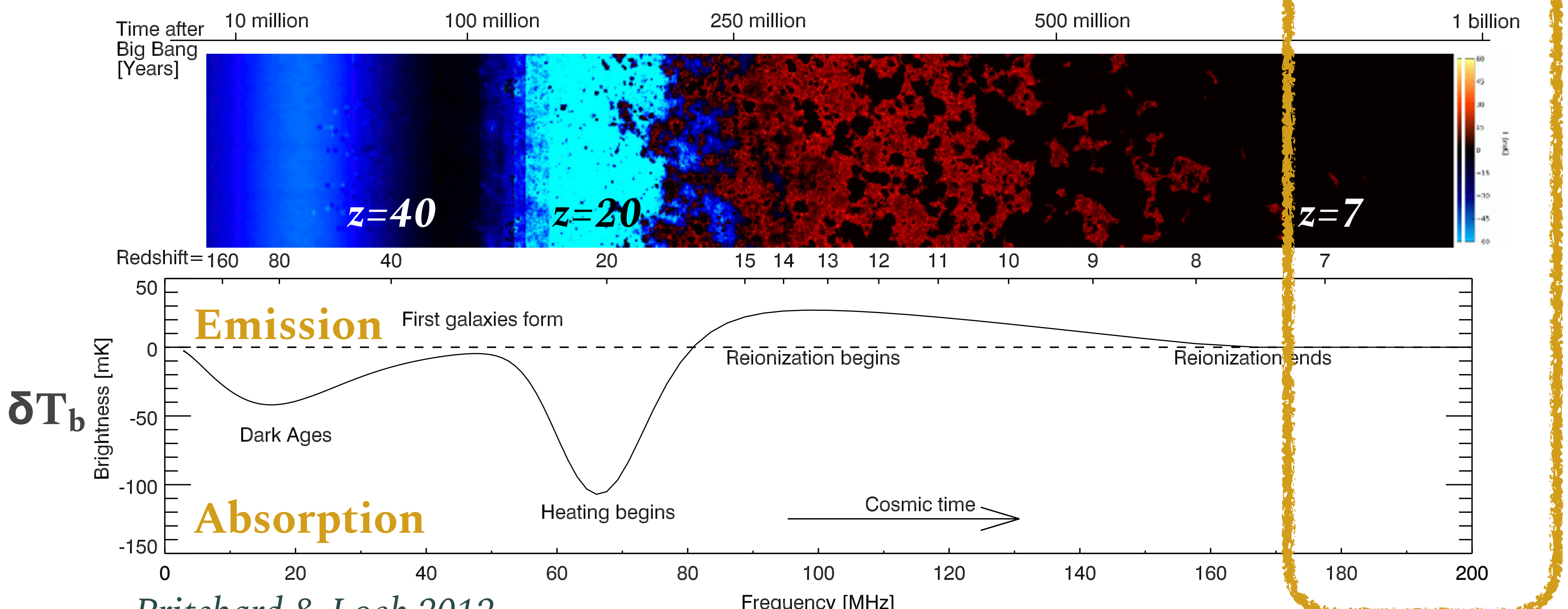
Evolution of 21-cm signal

Focus on the spatial fluctuations at the epoch of post-reionization

$$\delta T_b(\nu) = 9\, x_{\rm HI}\,(1+\delta)(1+z)^{1/2} \left[1 - \frac{T_{\rm CMB}(z)}{T_{\rm S}}\right] \left[\frac{H(z)/(1+z)}{dv_{\parallel}/dr_{\parallel}}\right]$$

$T_{\rm CMB}/T_{\rm S} \ll 1$ @ post-reionization

spin temp ($\sim T_{\rm K}$)

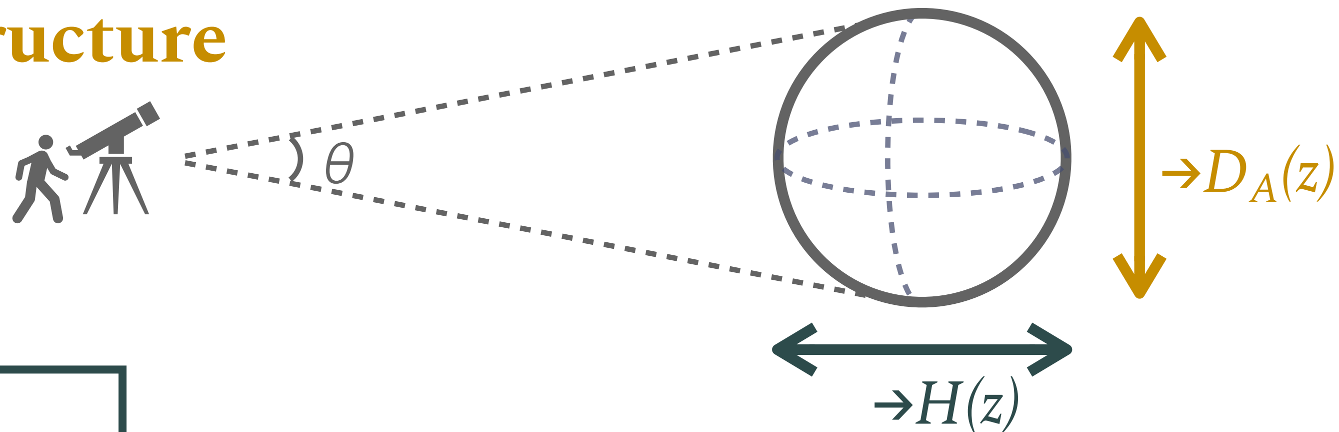


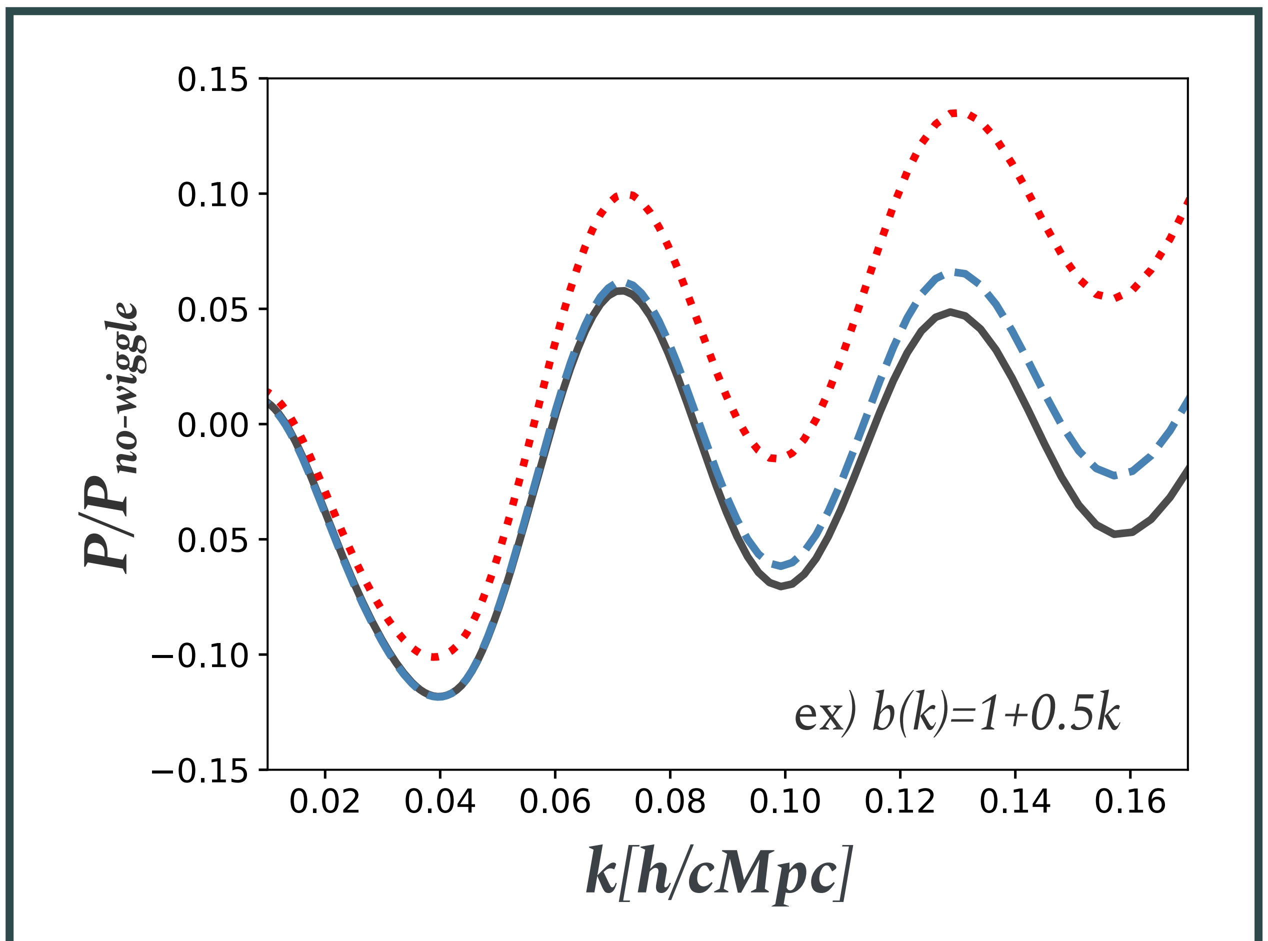
Pritchard & Loeb 2012

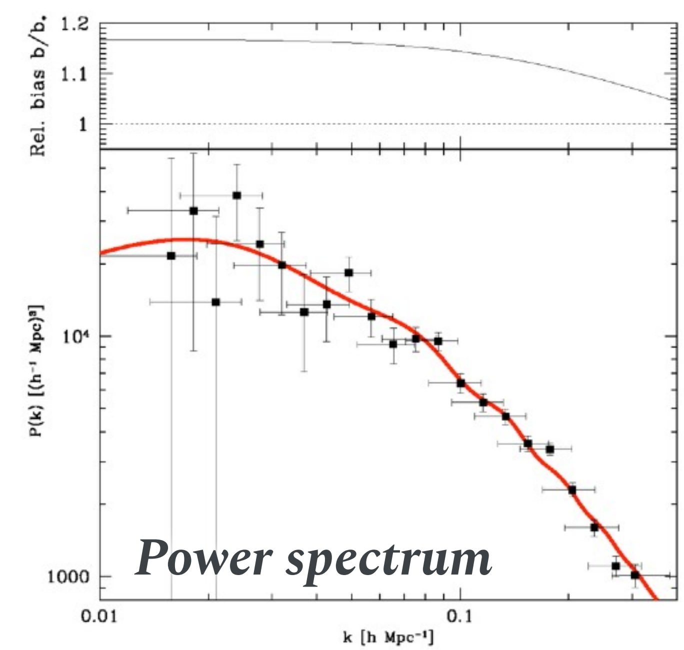
Theoretical framework for cosmological analysis

BAO peak scales in $P_{\mathrm{HI}}(k)$ deviate from theoretical prediction

- **Non-linear evolution of the structure**
- **Scale-dependent HI bias**







Tegmark et al. 2004

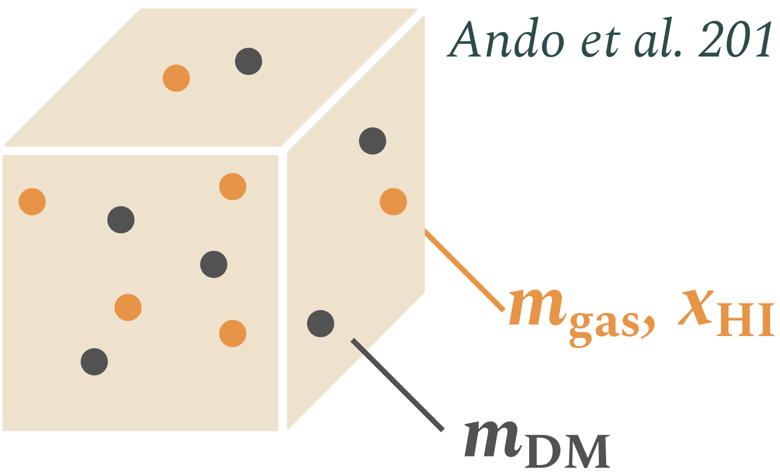
Linear mater
Non-linear matter
Non-linear biased tracer

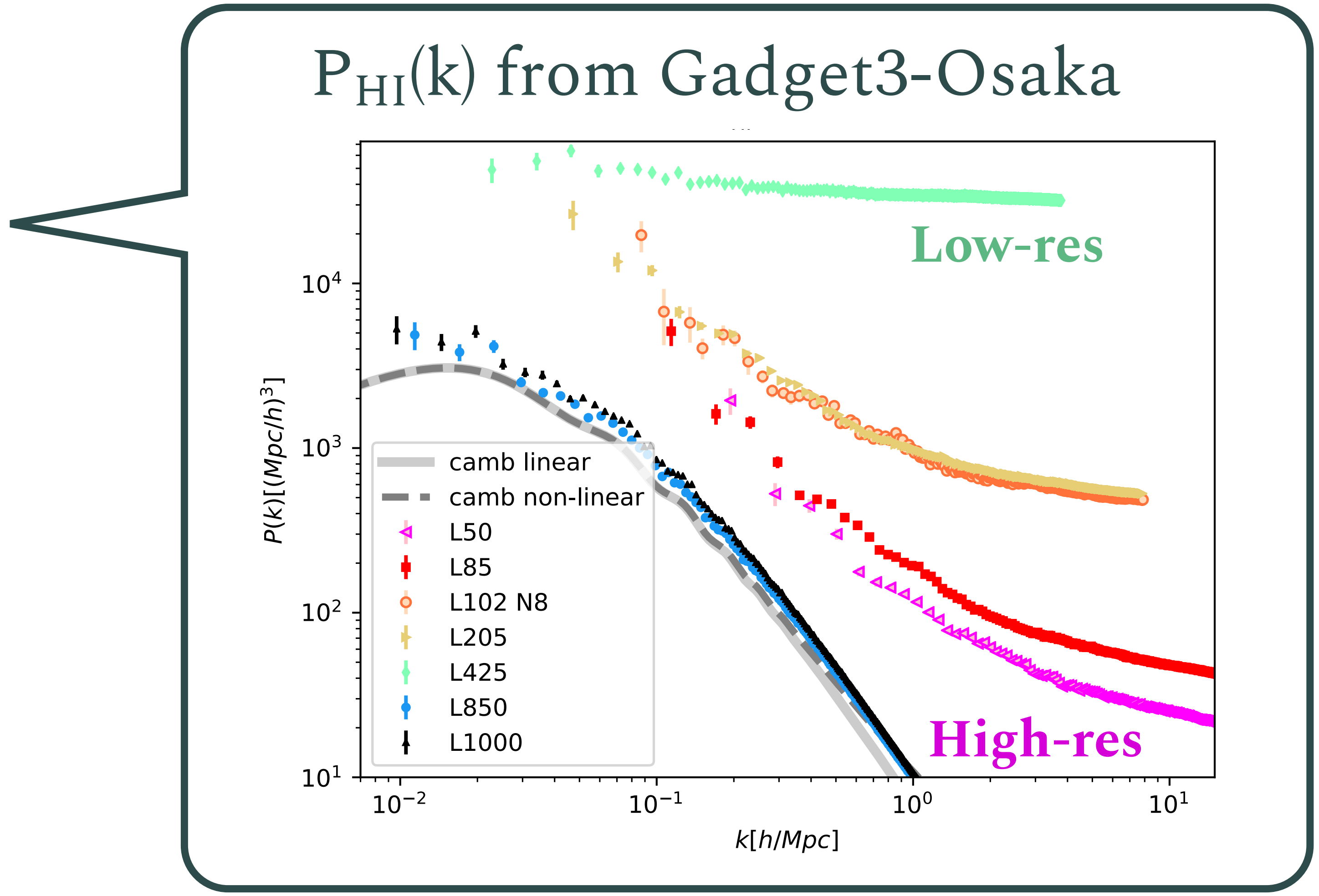
How to obtain HI distribution

Aoyama et al. 2017
Shimizu et al. 2019

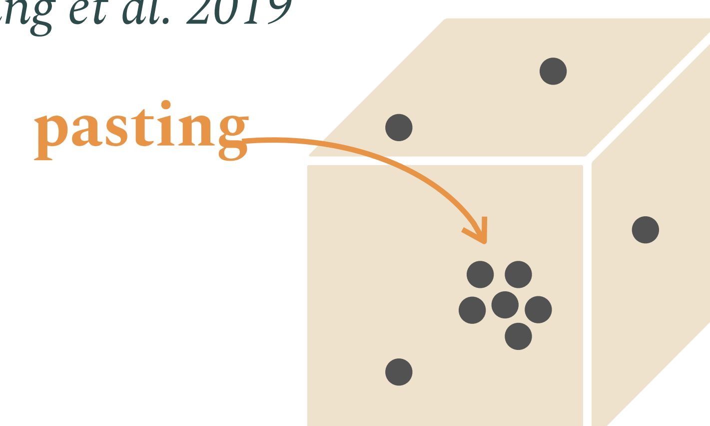
- Hydrodynamic simulation
  - depends on resolutions
  - high computational costs

Villaescusa-Navarro et al. 2018
Ando et al. 2019





- Assign HI on the DM *Sarkar et al. 2016, Modi et al. 2019, Wang et al. 2019*
  - Pasting HI on the DM halos

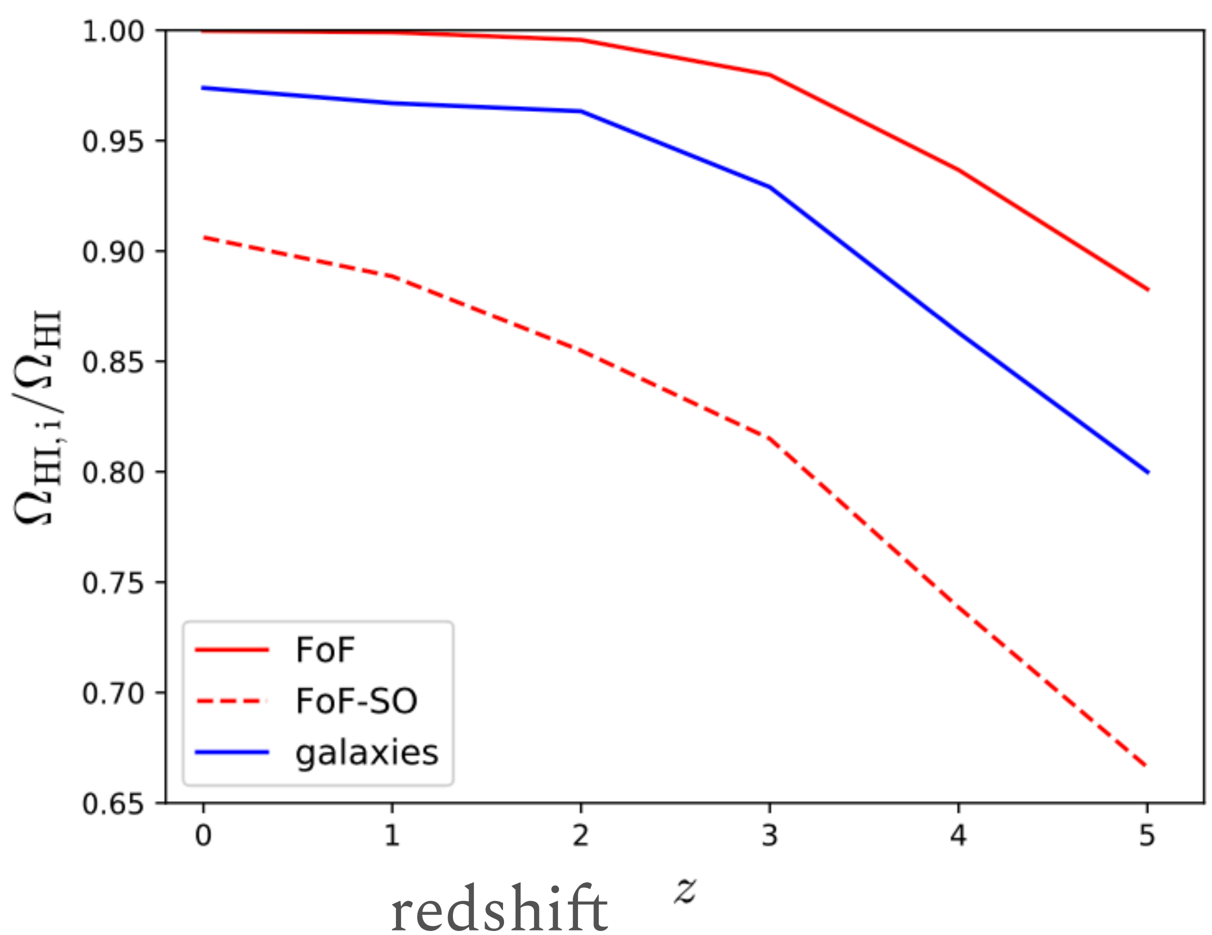


- Deep learning
  - Generative Adversarial Nets (GAN)) *Zamudio-Fernandez et al. 2019*

Previous work: M_{halo}-M_{HI} relation

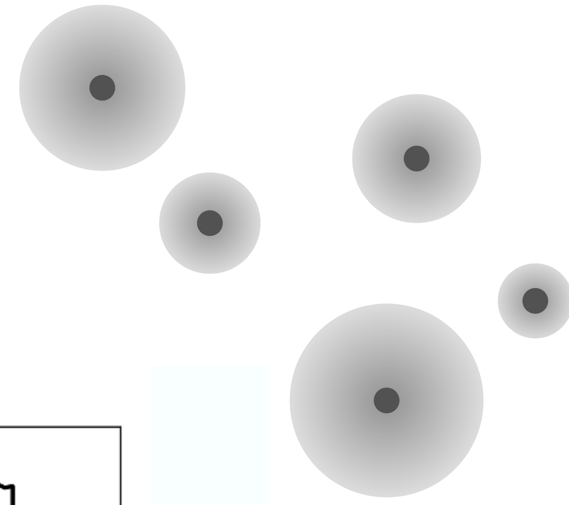
pasting HI on the center of DM halo assuming M_{halo}-M_{HI} relation

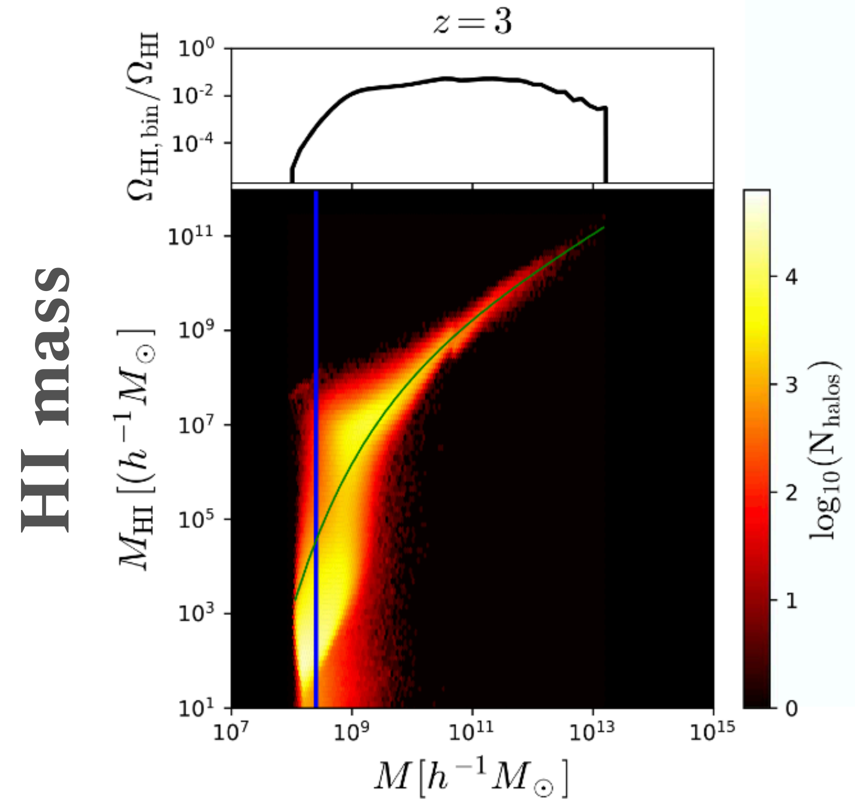
The ratio of the HI mass inside the halos



Villaescusa-Navarro et al. 2018

Halo

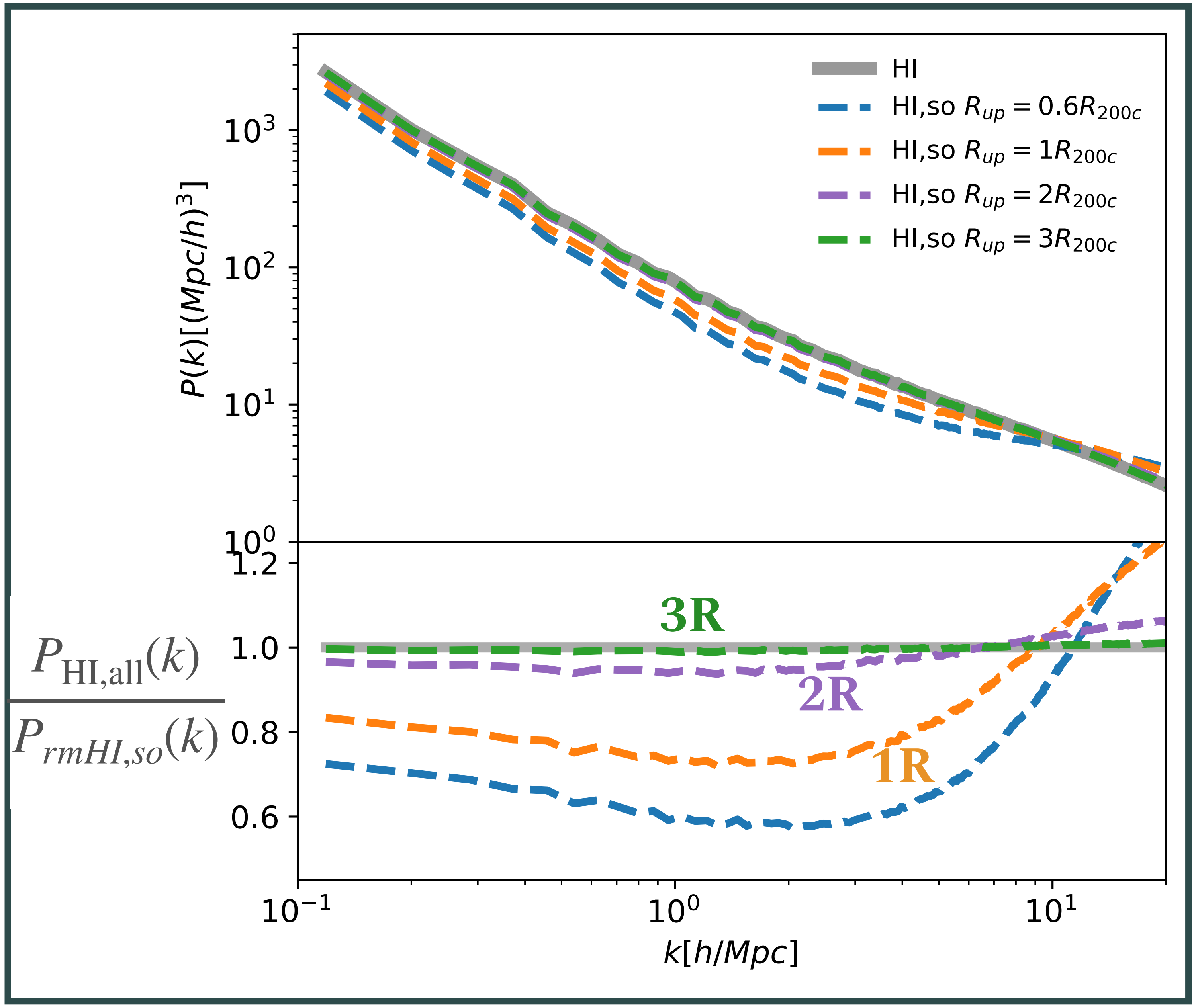


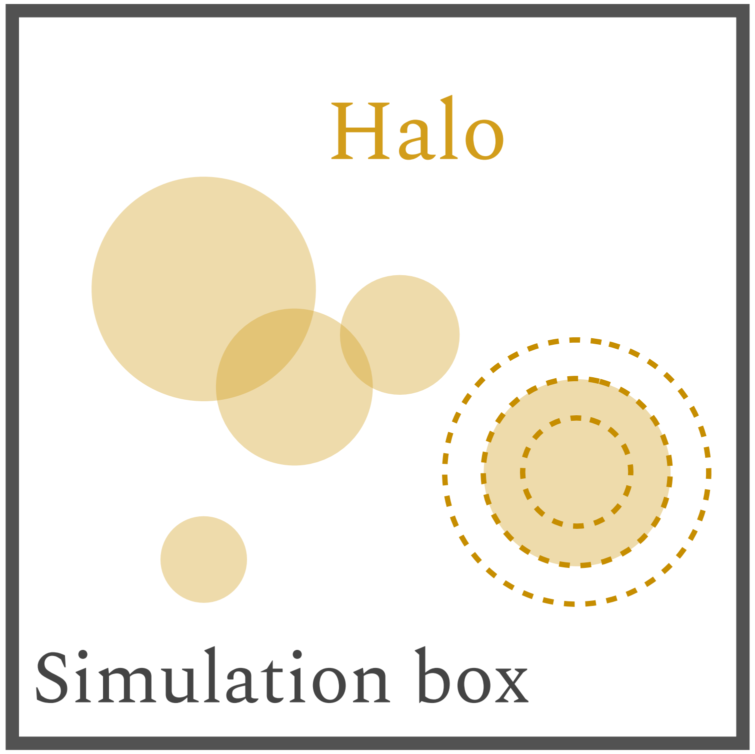


Halo mass

HI around the halo and $P_{HI}(k)$

$P_{HI}(k)$ is mainly composed of HI that exists within $3R_{200c}$ of the halo center.



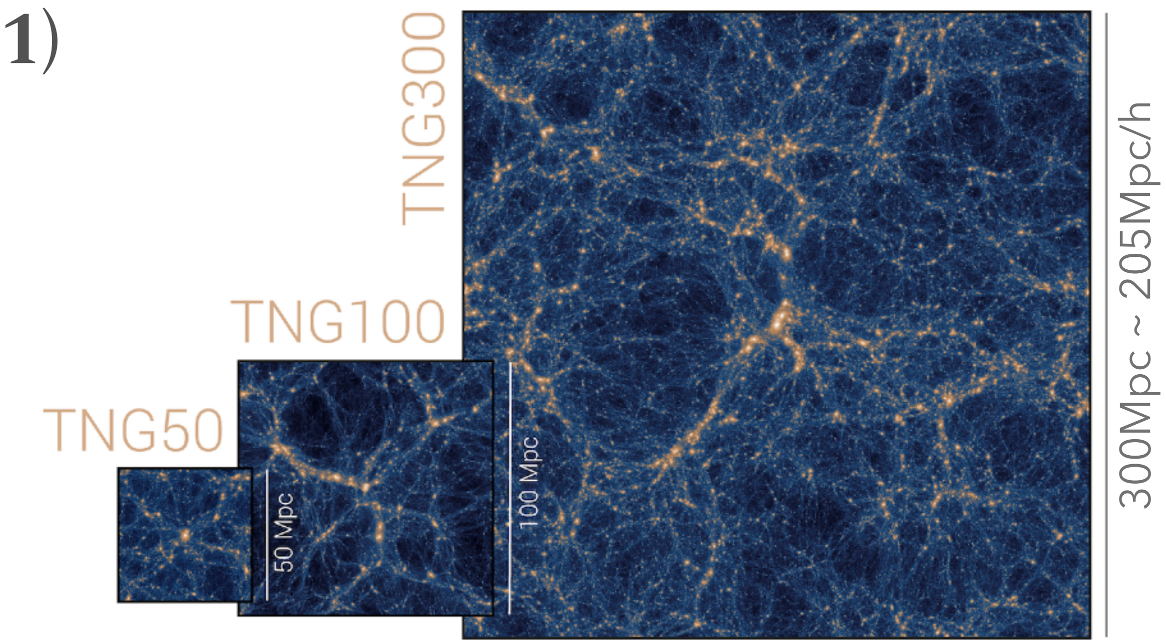


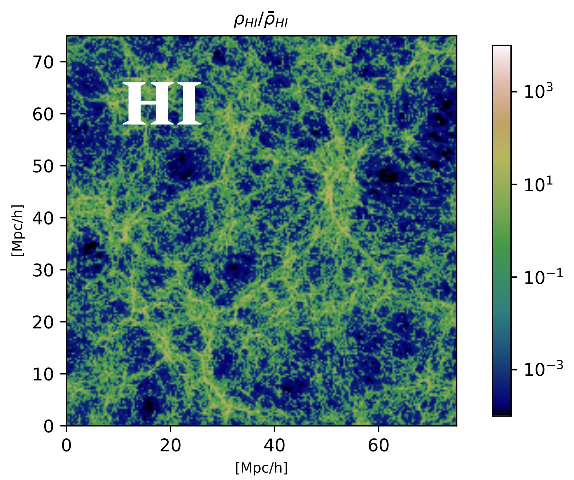
Aim: propose new method and test it

Nelson et al. 2019, Villaescusa-Navarro et al. 2018

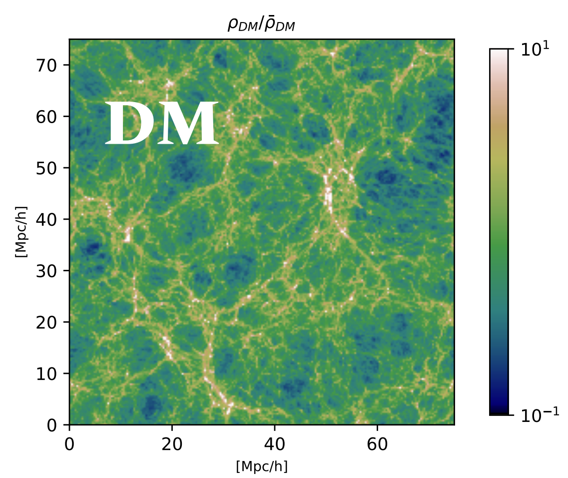
IllustrisTNG simulation (TNG100-1)

- L_{box}=75Mpc/h, N_p=2*1820^3
- $M_{halo} > 10^7\ M_{sun}$/h

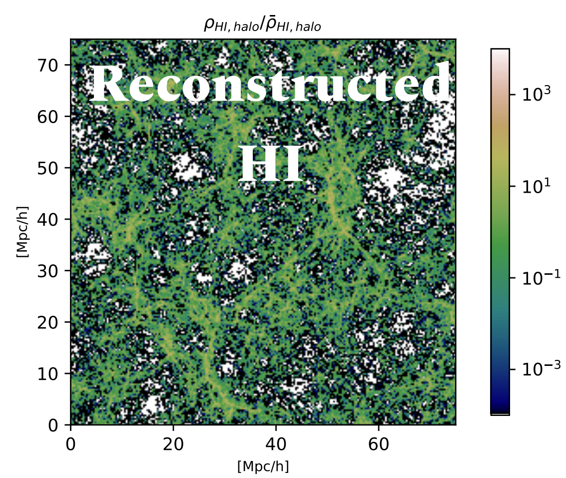




$\longrightarrow$ $P_{HI,true}$



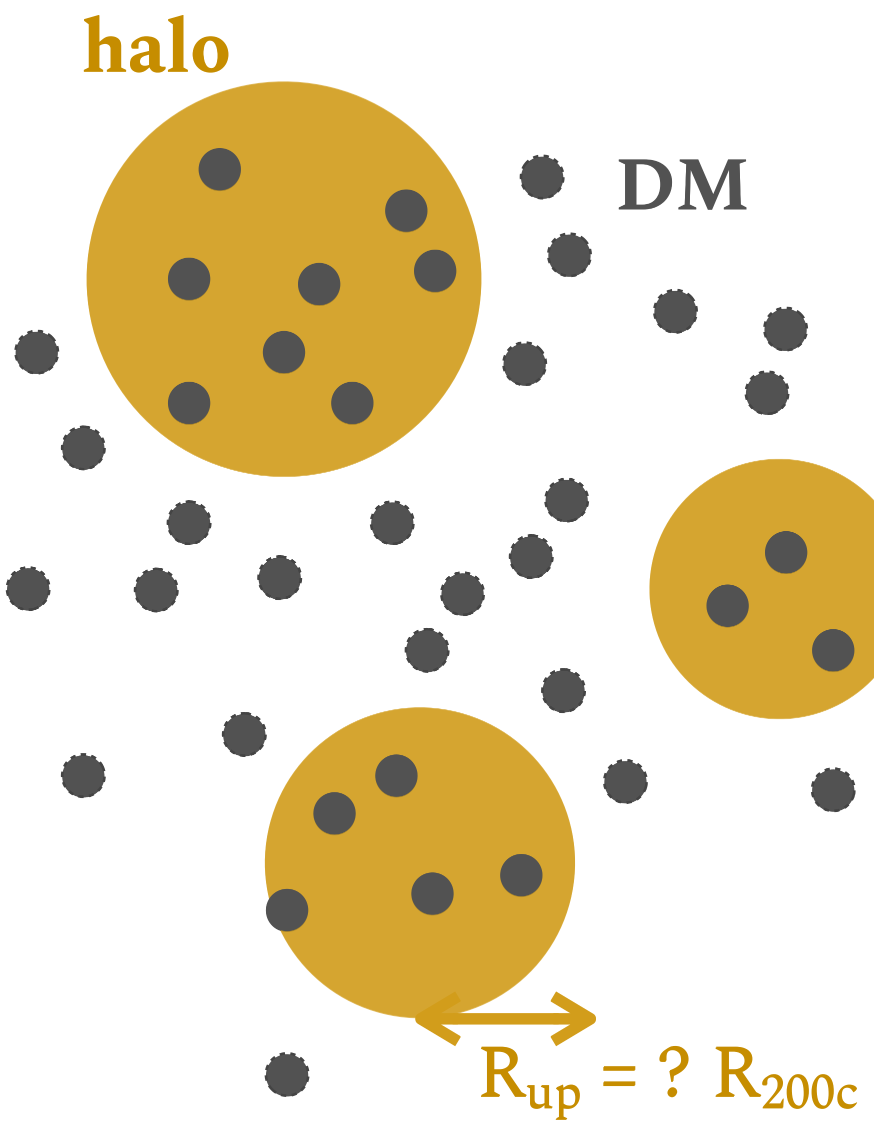
halo $\longrightarrow$



$\longrightarrow$ $P_{HI,halo}$

This work: Spherical Overdensity

To create a HI map that reproduces the slope of $P_{HI}(k)$



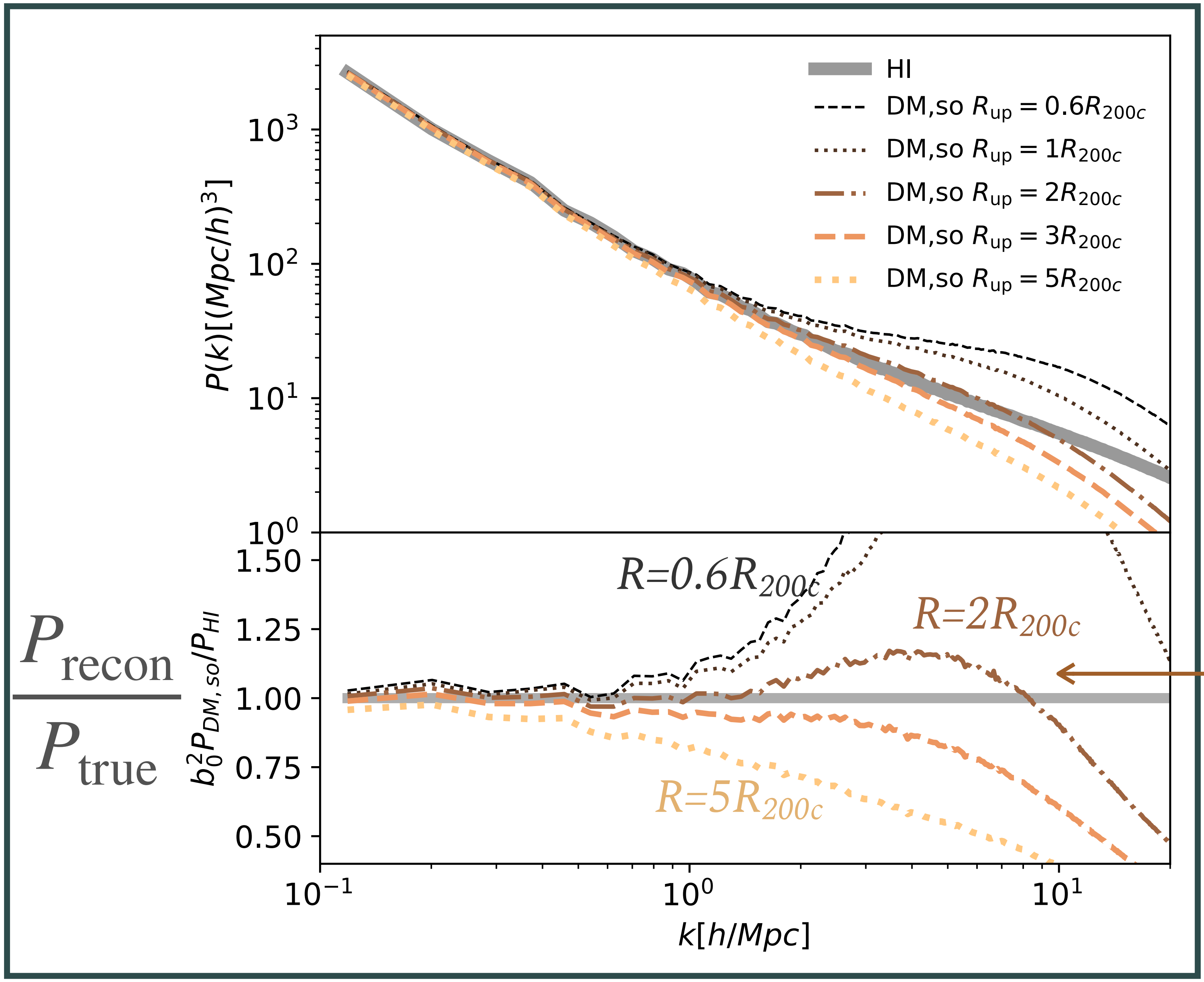
Generate density fields with DM particles only inside $R<?R_{200c}$ from halo center

$$\delta_{\mathrm{DM,so}}(\vec{x}) = \delta_{DM}(\vec{x})\ \Theta\left[\sum_i W_{R_{\mathrm{up}}}(\vec{x}_i)\right]$$

R_{200c}: Radius of a sphere whose mean density is 200 times the critical density

Result: $P_{\mathrm{DM,so}}(k)$ with various SO radius

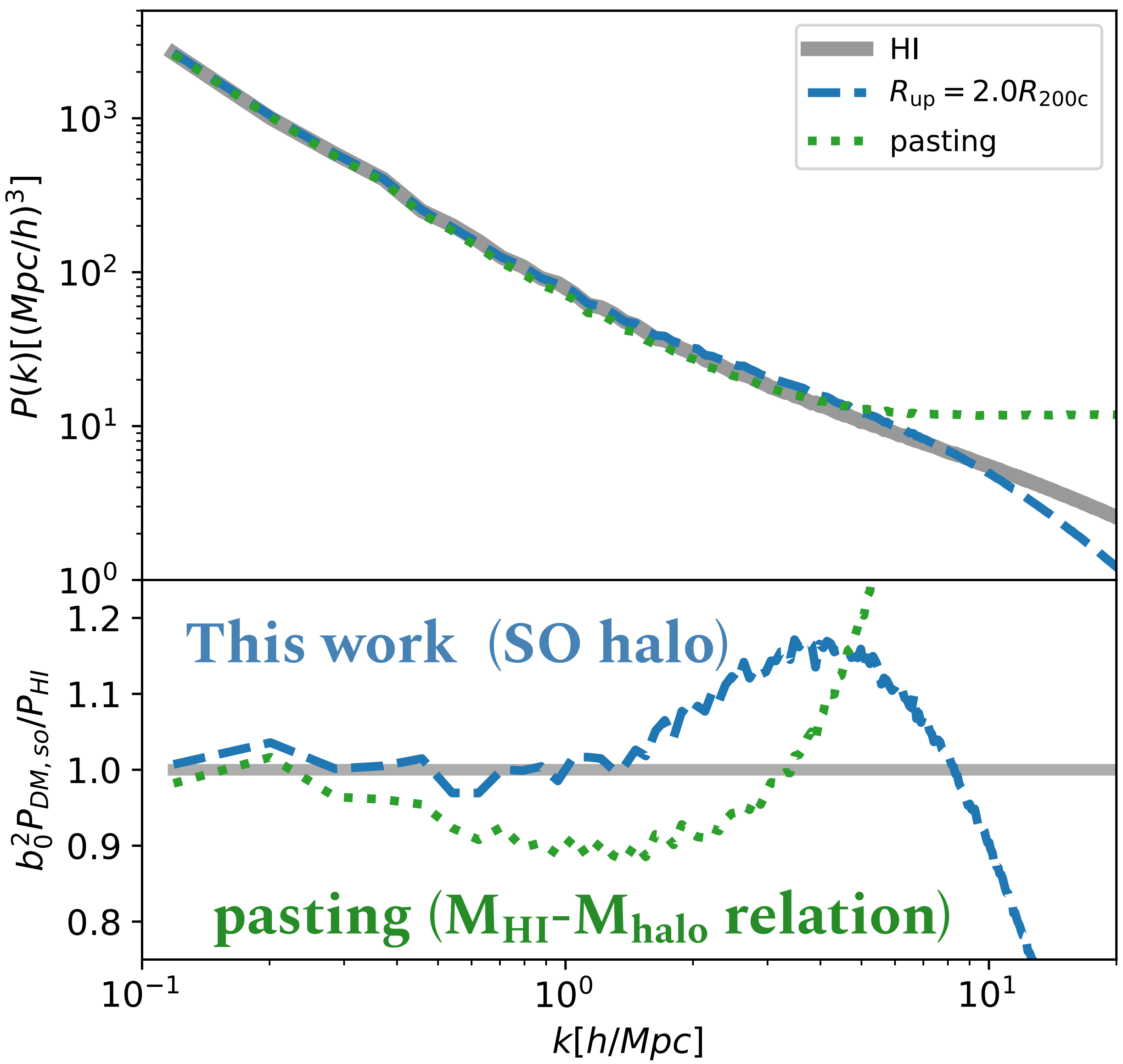
Compare the slope with $\mathrm{P_{HI,true}(k)}$ to find the optimal R



Reproduce the slope well when $R=2R_{200c}$

Result: comparison of the reconstructed $P_{\mathrm{HI}}(k)$

Reconstructed HI power spectrum



$$M_{\mathrm{HI}}(M,z) = M_0 \left(\frac{M}{M_{\mathrm{min}}}\right)^{\alpha} \exp\left(-(M_{\mathrm{min}}/M)^{0.35}\right)$$

Good point

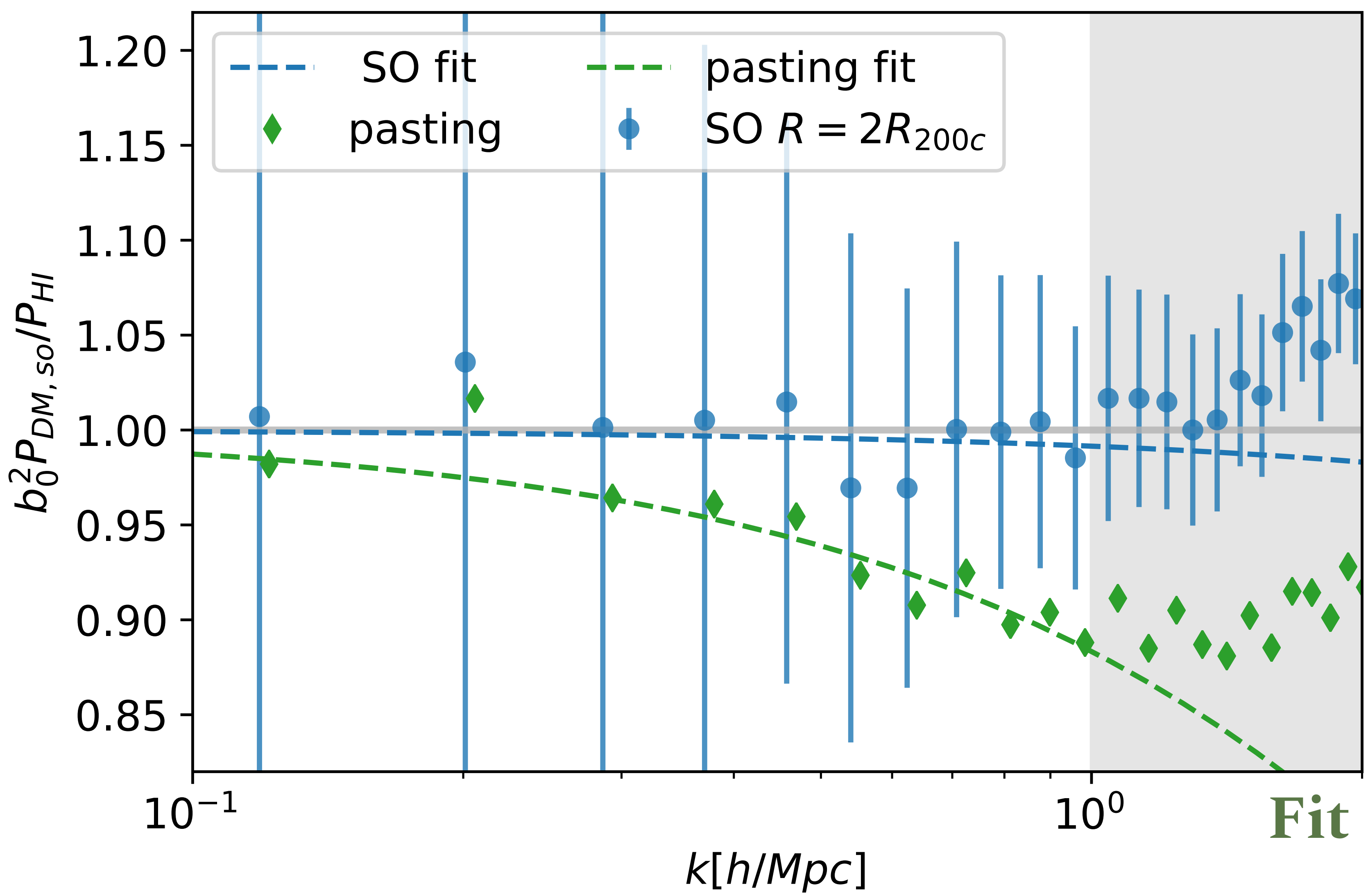
- Use only single parameter R_{up}

Bad point

- there are cases in which it cannot reproduce $P_{\mathrm{HI}}(k)$ depending on the treatment of HI

How well is it reproduced? Fitting with linear function

We fit the ratio $\sqrt{\dfrac{P_{\mathrm{HI}}(k)}{P_{\mathrm{DM,so}}(k)}}$ with $\mathrm{Res(k)} = b_0 + b_1 k$



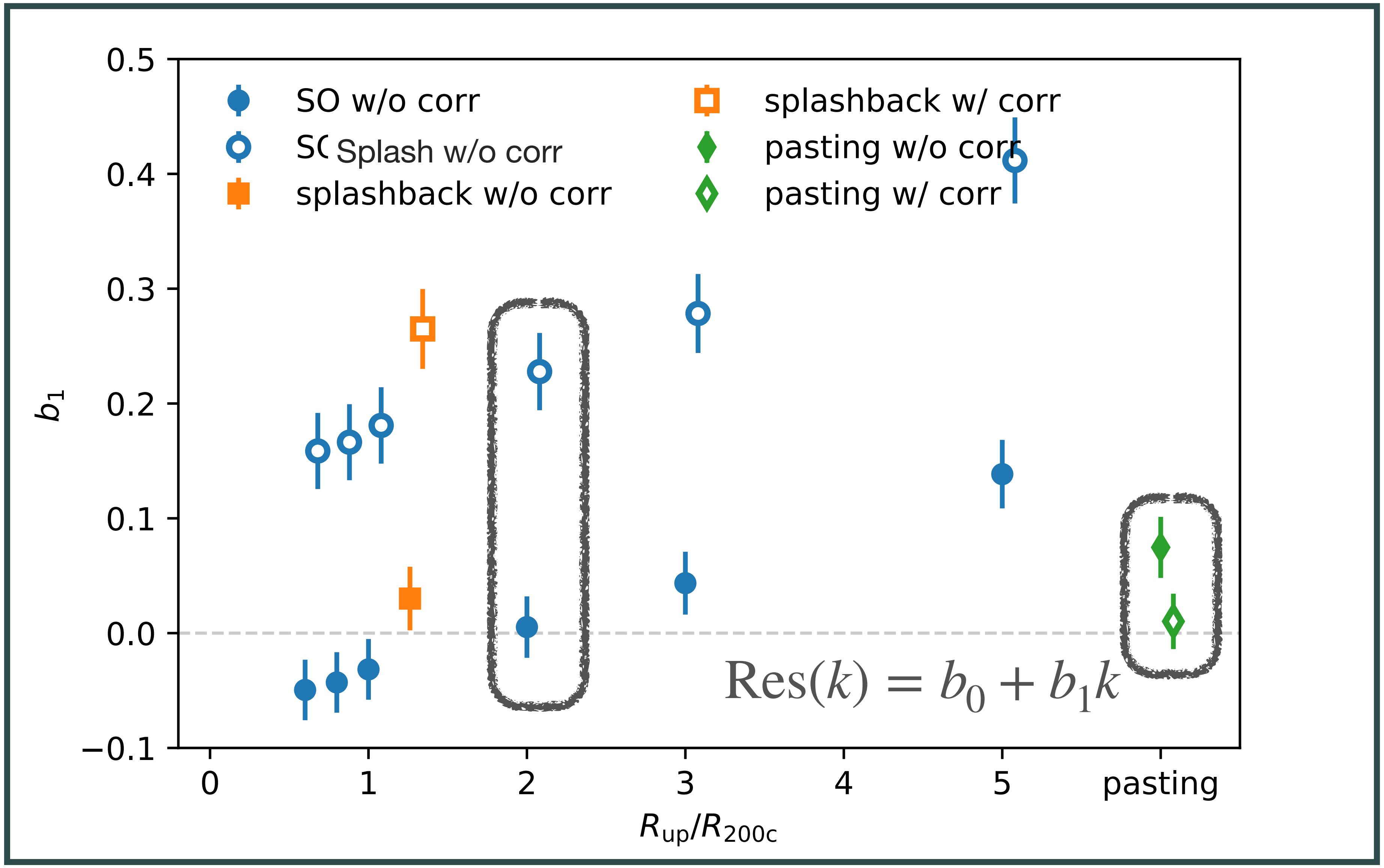
Our method (SO halo)

Fit

M_{halo}-M_{HI} relation (Pasting)

How well is it reproduced? Scale dependence

In SO method, $R=2R_{200c}$ best reproduces the slope



Summary

We proposed a new method to reproduce the $P_{\mathrm{HI}}(k)$

By using the dark matter distribution truncated at specific scales ($\sim 2R_{200c}$) from the halo centre

This method

- uses only single parameter
- reproduces the scale dependence
- some limitation on the slope