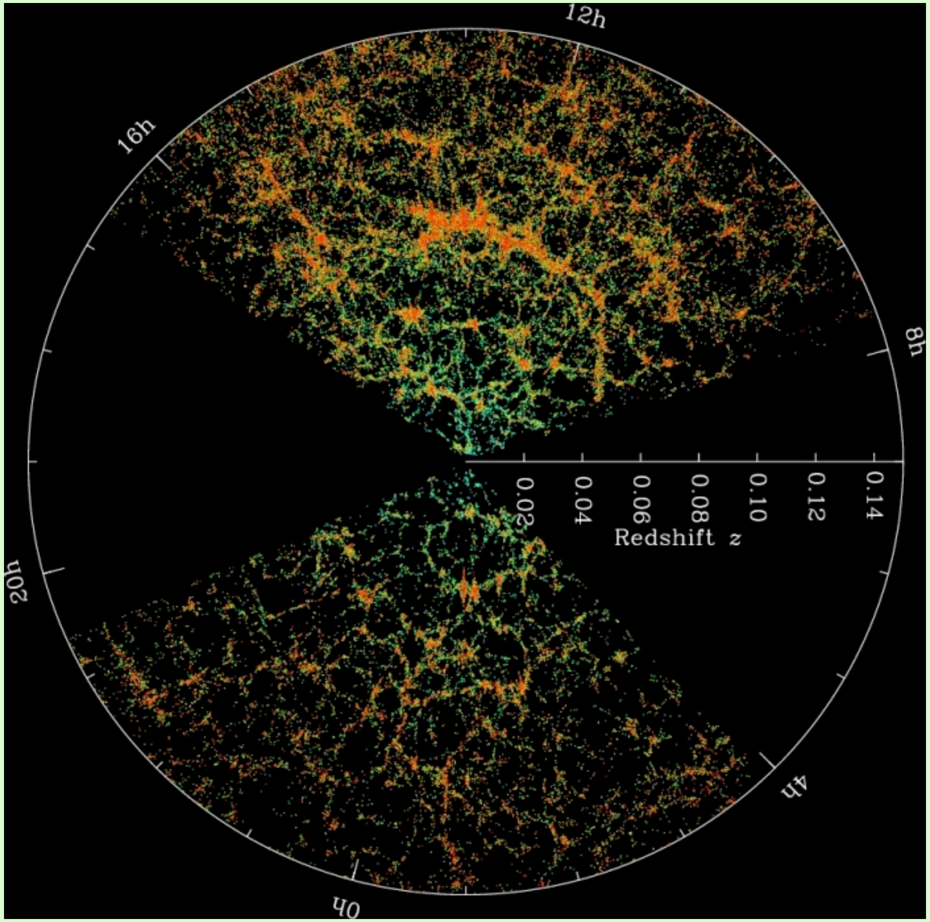
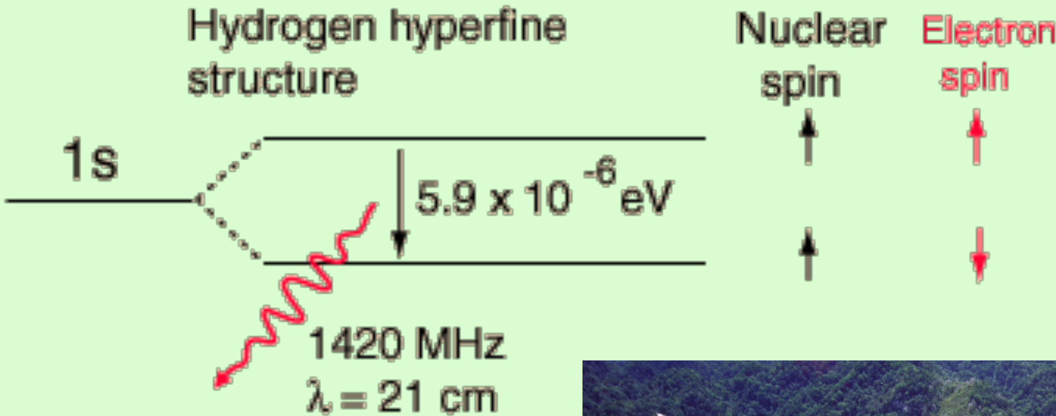
Precision cosmology with 21cm intensity mapping in the post-reionization era

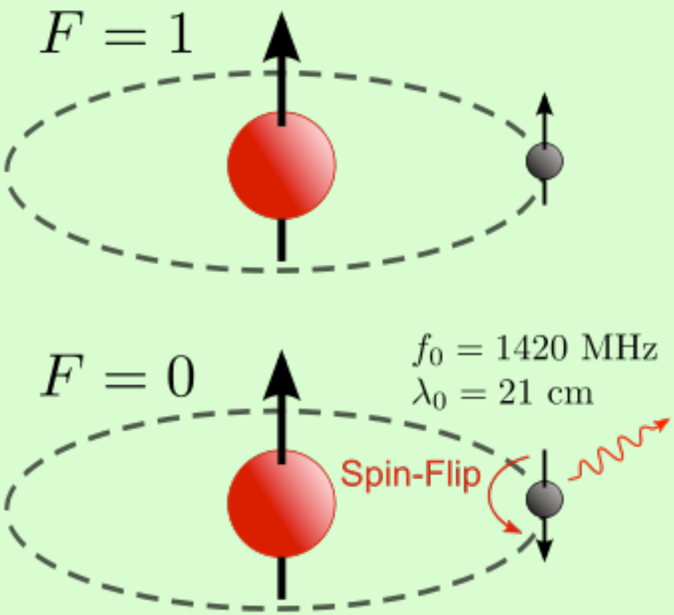


Francisco Villaescusa-Navarro --- INAF/INFN Trieste

ICTP, Trieste, Italy – 13/05/2015

MOTIVATION

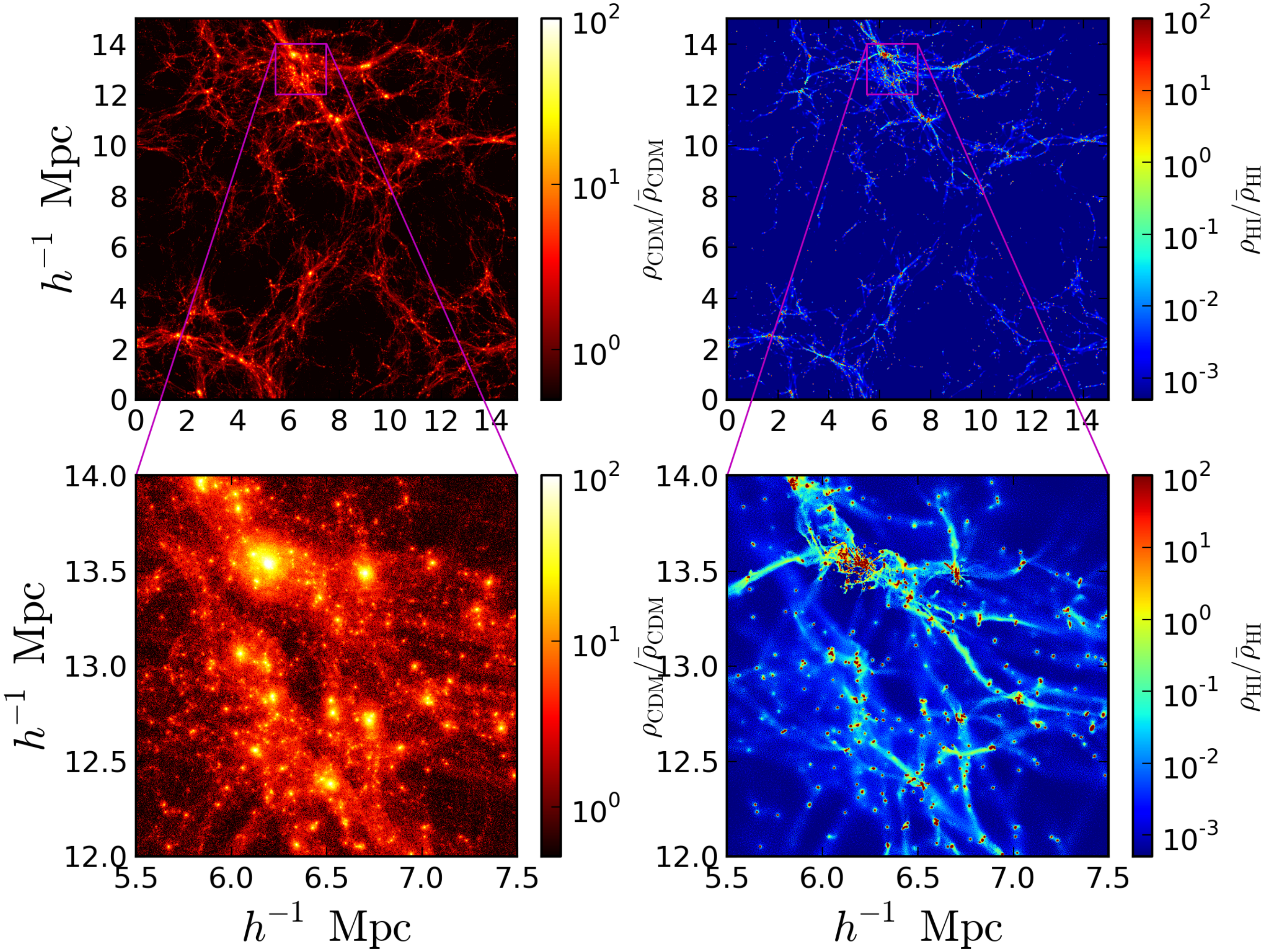

Hydrogen hyperfine structure
Nuclear spin
Electron spin
1s
5.9 x 10 -6 eV
1420 MHz
λ = 21 cm


$F = 1$
$F = 0$
$f_0 = 1420$ MHz
$\lambda_0 = 21$ cm
Spin-Flip

MOTIVATION

- Study the Epoch Of Reionization (EOR).
- Fundamental to understand galaxy formation/evolution.
- Constrains the cosmological parameters.

$$P_{21cm}(k,z) = b_{21cm}^2(k,z)P_m(k,z)$$

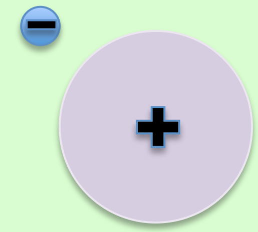
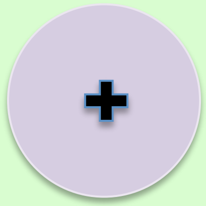
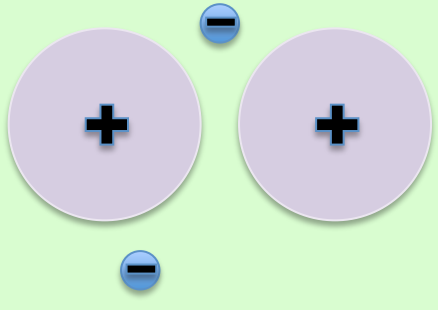


Need to model the HI distribution as best as possible to retrieve the maximum information from surveys

$$z \sim [2-5]$$

MODELING THE HI DISTRIBUTION

Hydrogen phases

HI	
HII	
H_2	

NEUTRAL HYDROGEN: PROPERTIES

Hydrogen phases	HII	HI	H_2

Photo-ionization with UVB

1) Low density environments (Lyman-alpha forest)	HII	HI	

HI self-shielding
formation of molecular hydrogen

2) High density environments (galaxies)	HII	HI	H_2
	HII	HI	H_2

N-body simulations

GADGET-III

Name	Box (h^{-1}Mpc)	$m_{\rm CDM}$ ($h^{-1}M_\odot$)	$m_{\rm b}$ ($h^{-1}M_\odot$)	wind model	$z_{\rm end}$
$\mathscr{B}120$	120	8.16×10^8	1.64×10^8	no winds	2.4
$\mathscr{B}60W$	60	1.02×10^8	2.05×10^7	constant velocity winds	3.0
$\mathscr{B}60$	60	1.02×10^8	2.05×10^7	no winds	2.4
$\mathscr{B}30$	30	1.28×10^7	2.56×10^6	no winds	2.4
$\mathscr{B}15$	15	1.59×10^6	3.20×10^5	no winds	2.4

Table 1. Summary of the simulations. The value of the cosmological parameters is the same for all simulations: $\Omega_{\rm m} = \Omega_{\rm cdm} + \Omega_{\rm b} = 0.2742$, $\Omega_{\rm b} = 0.046$, $\Omega_\Lambda = 0.7258$, $h = 0.7$, $n_s = 0.968$ and $\sigma_8 = 0.816$. Each simulation contains 512^3 CDM and 512^3 baryon particles.

- Radiative cooling by H and He
- Heating by uniform UV background
- Star formation
- Feedback (galactic winds)

✔ Photo-ionization equilibrium

✗ HI self-shielding

✗ Presence of H_2

MODELING THE HI DISTRIBUTION

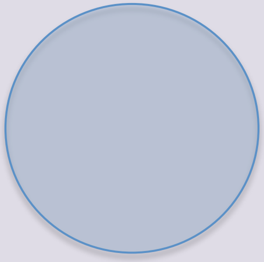
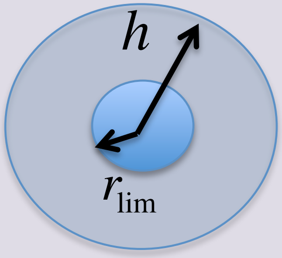
Pseudo-RT post-processing

1. Photo-ionization equilibrium
2. HI self-shielding
3. Presence of H_2

- *Dave et al. 2013*
- *Rahmati et al. 2013*

MODELING THE HI DISTRIBUTION

Pseudo-RT post-processing

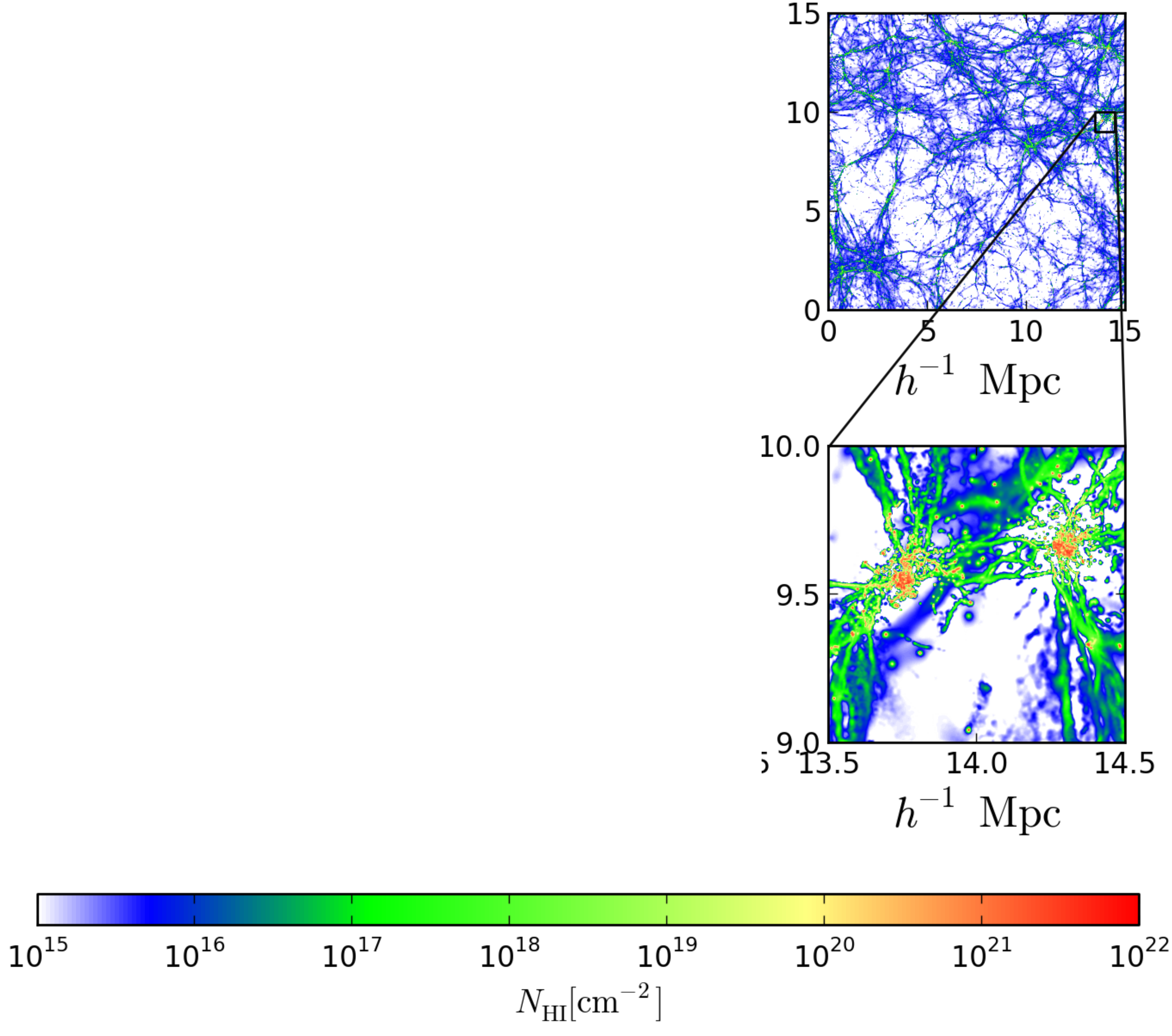
Method	Photo-ionization equilibrium	HI self-shielding
Dave et al. 2013	 $HI/H \rightarrow \rho, T, \Gamma_{HI}$ Tuned to reproduce the <F> of the Lya forest	 $N_{HI} = \frac{0.76m\left(\frac{HI}{H}\right)}{m_H}\int_{r_{\lim}}^{h} W(r,h)\,dr = 10^{17.2}\,cm^{-2}$
Rahmati et al. 2013		$HI/H \rightarrow \rho, T, \Gamma_{HI}$ $\frac{\Gamma_{phot}}{\Gamma_{UVB}} = (1-f)\left[1+\left(\frac{n_H}{n_0}\right)^{\beta}\right]^{\alpha_1} + f\left[1+\frac{n_H}{n_0}\right]^{\alpha_2}$

MODELING THE HI DISTRIBUTION

Pseudo-RT post-processing

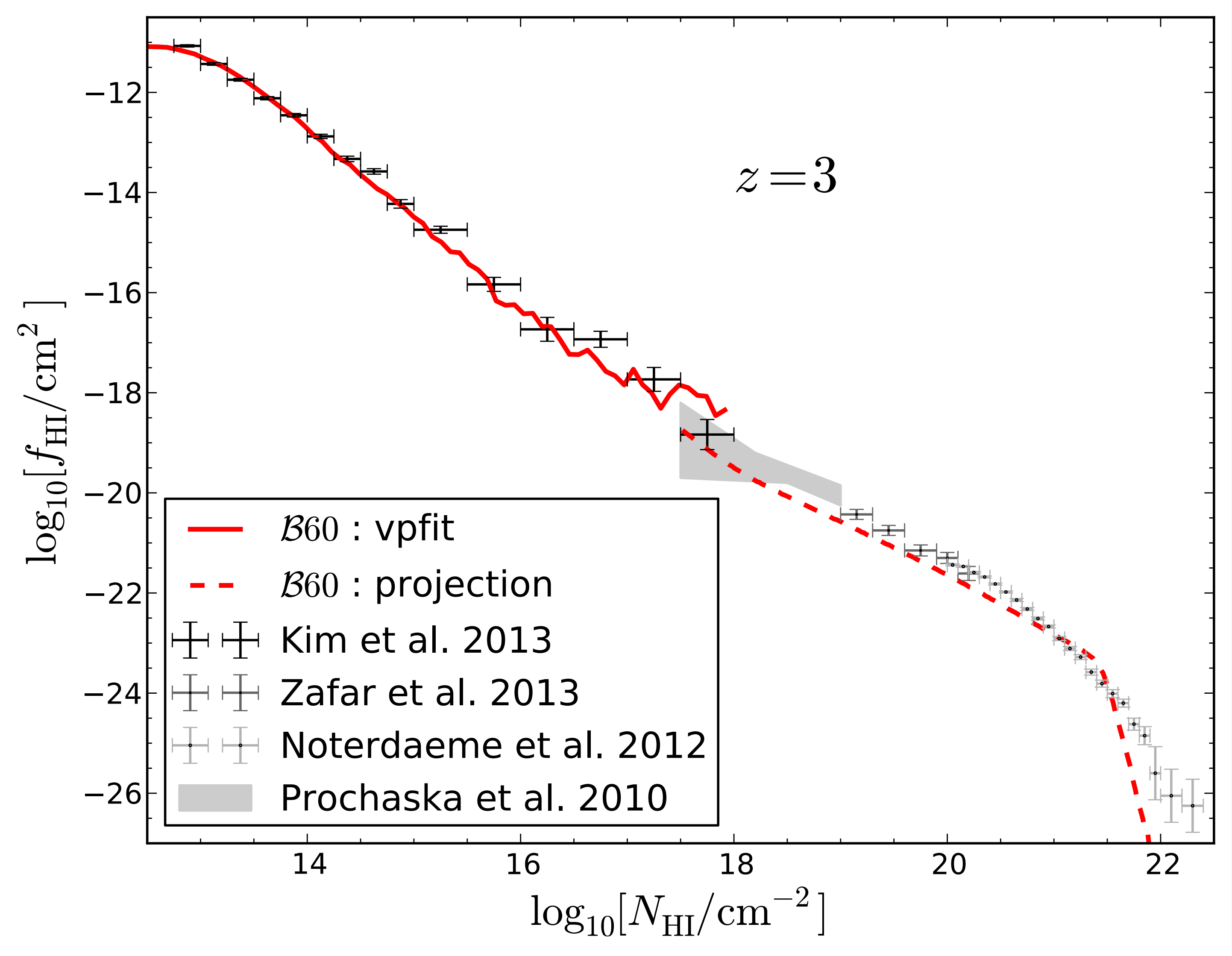
Method	Presence of H_2
Dave & Rahmati	$$R_{mol} = \frac{\Sigma_{H_2}}{\Sigma_{HI}} = \left(\frac{P / k_B}{1.7 \times 10^4 cm^{-3} K} \right)^{0.8}$$ Blitz & Rosolowsky 2006 THINGS: Leroy et al. 2008
	$$f_{H_2} = 1 - \frac{0.75s}{1 + 0.25s} \qquad s = \frac{\ln(1 + 0.6\chi + 0.01\chi^2)}{0.6\tau_c}$$ $$\chi = 0.756(1 + 3.1Z^{0.365}) \qquad \tau_c = \Sigma\sigma_d / \mu_H$$ Krumholz & Gnedin 2011

MODELING THE HI DISTRIBUTION



MODELING THE HI DISTRIBUTION

Pseudo-RT post-processing



$b_{DLA}(z = 2.4) = 1.48$

FVN, Viel, Datta, Choudhury, 2014

MODELING THE HI DISTRIBUTION

Pseudo-RT post-processing: problems

- Computationally very expensive
- Limited to relatively small volumes

HOD/Halo model approach

$$n(M,z) \qquad M_{HI}(M,z)$$

$$b(M,z) \qquad \rho_{HI}(r\,|\,M,z)$$

$$P_L(k)$$

Hydrodynamical simulations

↓

Pure CDM simulations

↓

Pinocchio

↓

Halo model

MODELING THE HI DISTRIBUTION

Semi-analytic model

No HI outside halos!!!

$M_{HI}(M)$

$$M_{\rm HI}(M) = \begin{cases} f_3 \frac{M}{1+\left(\frac{M}{M_{\rm max}}\right)} & \text{if } M_{\rm min} \leqslant M \\ 0 & \text{otherwise} \end{cases}$$

Bagla et al. 2010

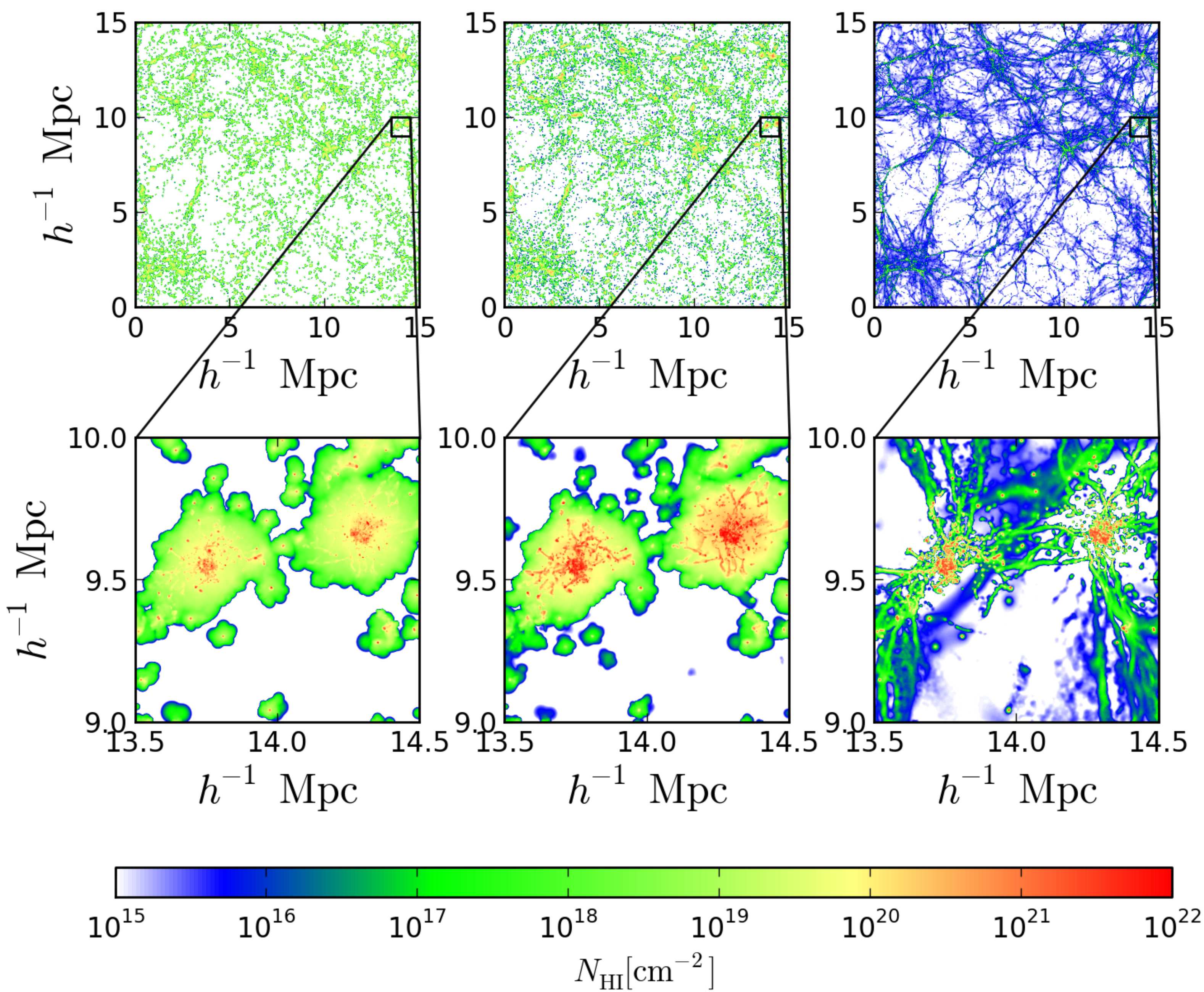
$$M_{\rm HI}(M) = \alpha f_{\rm H,c} \exp\left[-\left(\frac{v_c^0}{v_c}\right)^{\beta}\right] M \ ,$$

Barnes & Haehnelt 2014

$\rho_{HI}(r)$ → Tuned to fit the HI CDDF

Find DM halos → Compute $M_{HI}(M)$ → Distribute according to $\rho_{HI}(r)$

MODELING THE HI DISTRIBUTION



MODELING THE HI DISTRIBUTION

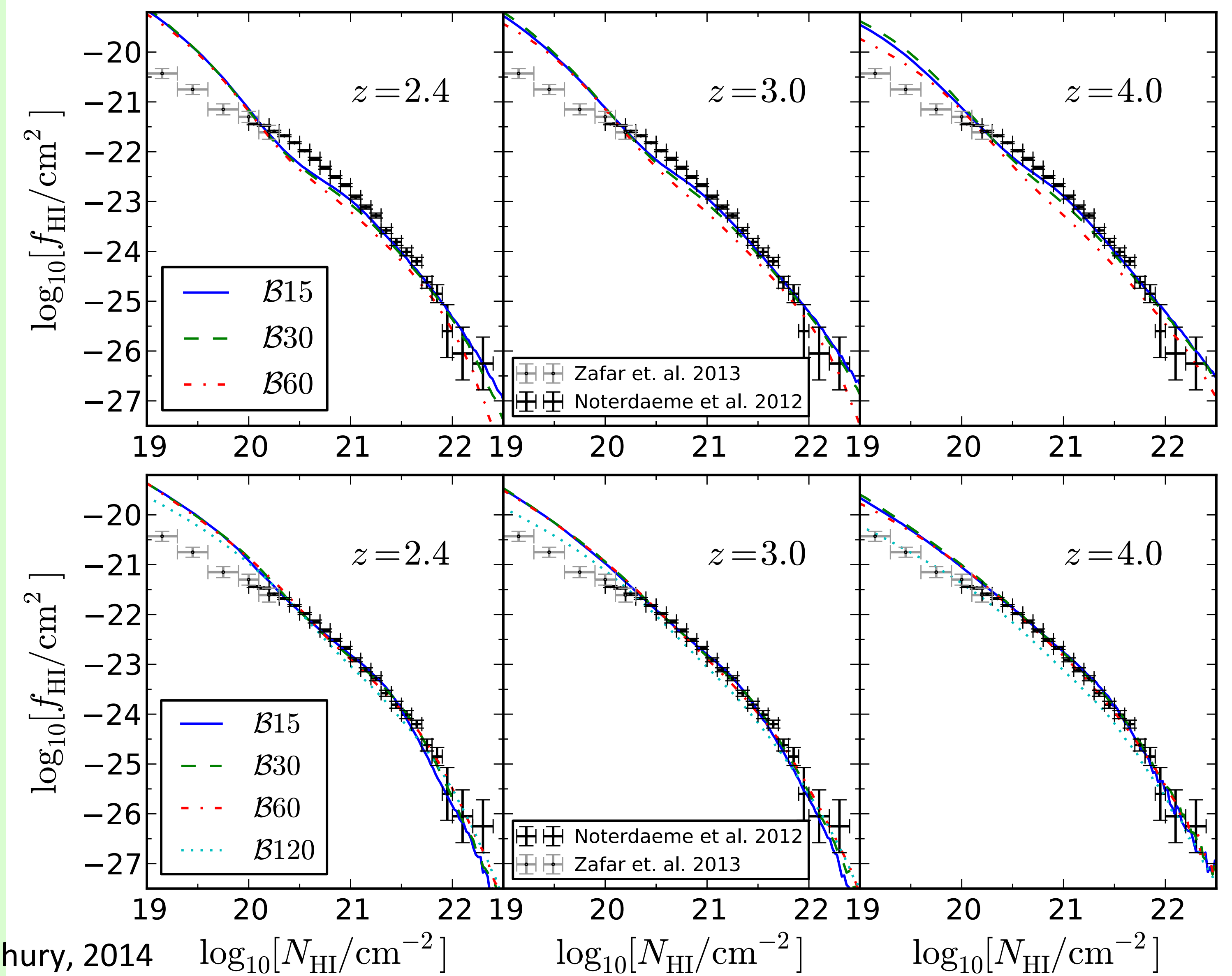
Semi-analytic model

Model 1

$b_{DLA}(z=2.4)=1.47$

Model 2

$b_{DLA}(z=2.4)=2.17$



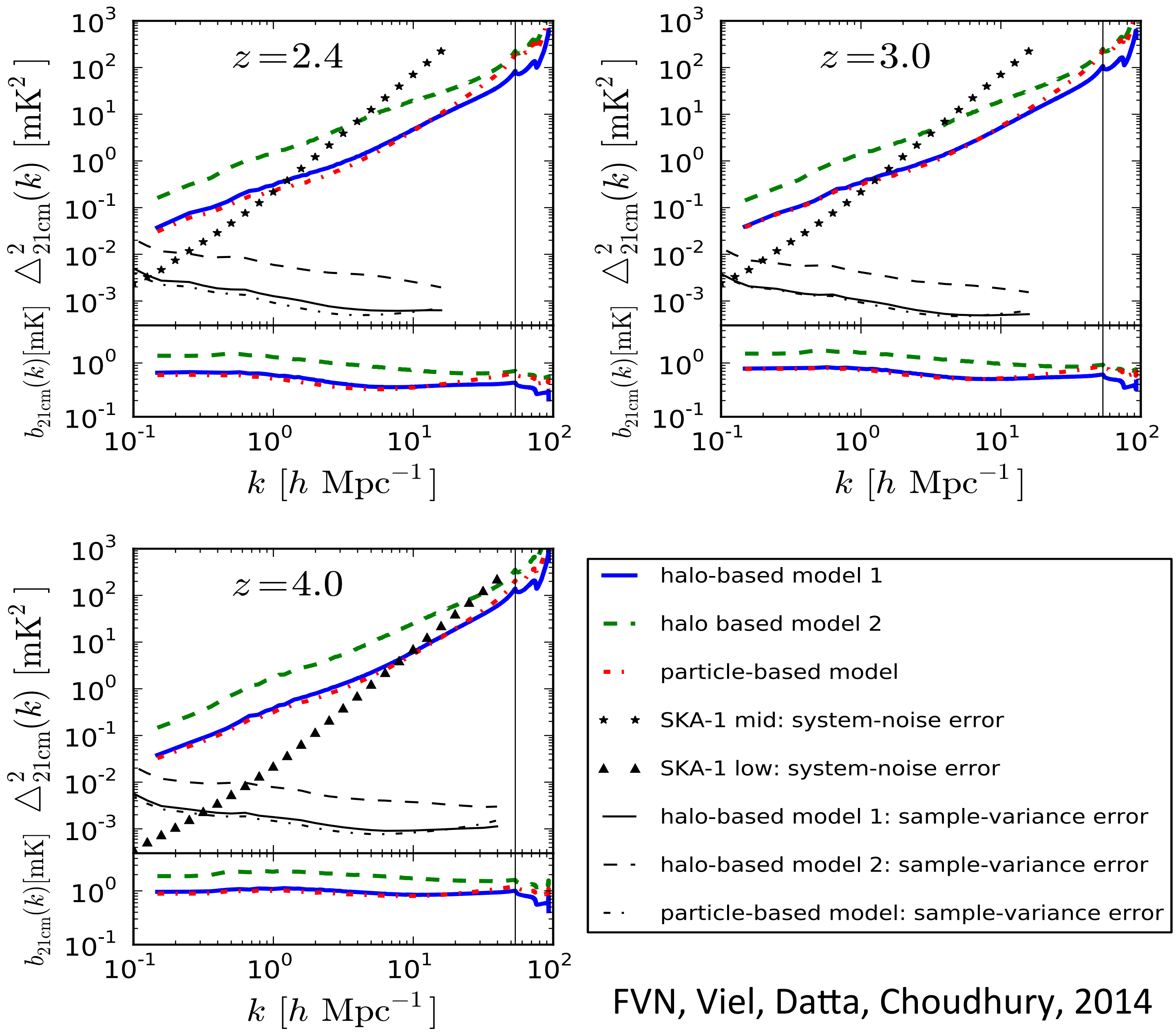
FVN, Viel, Datta, Choudhury, 2014

21 cm signal: detectability & imaging

SKA1-MID:
250 antennae, 15 m

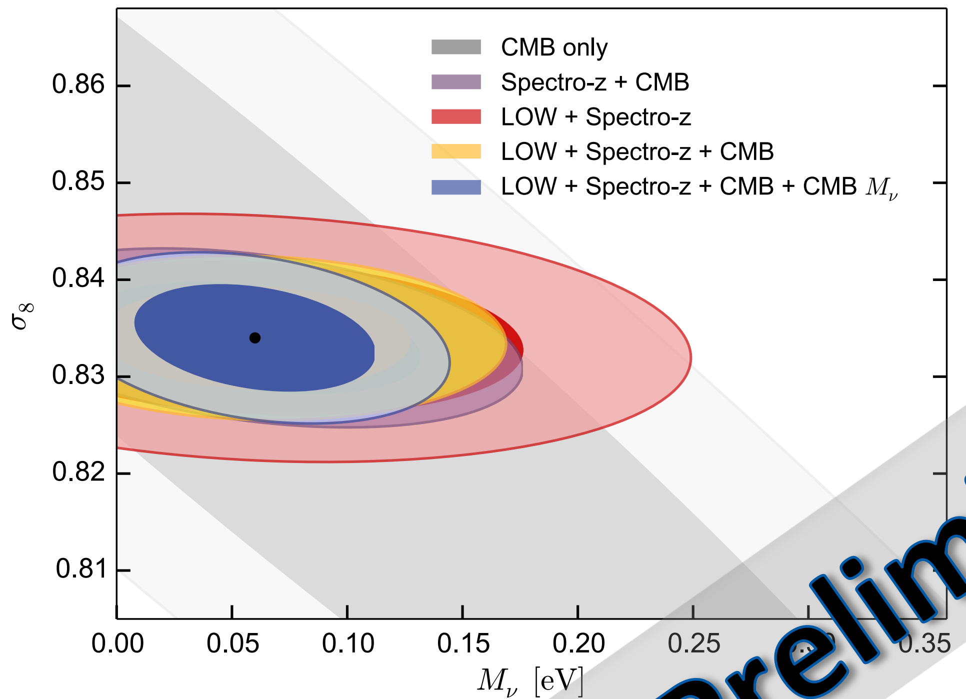
100 hours

SKA1 LOW:
911 antennae, 35 m

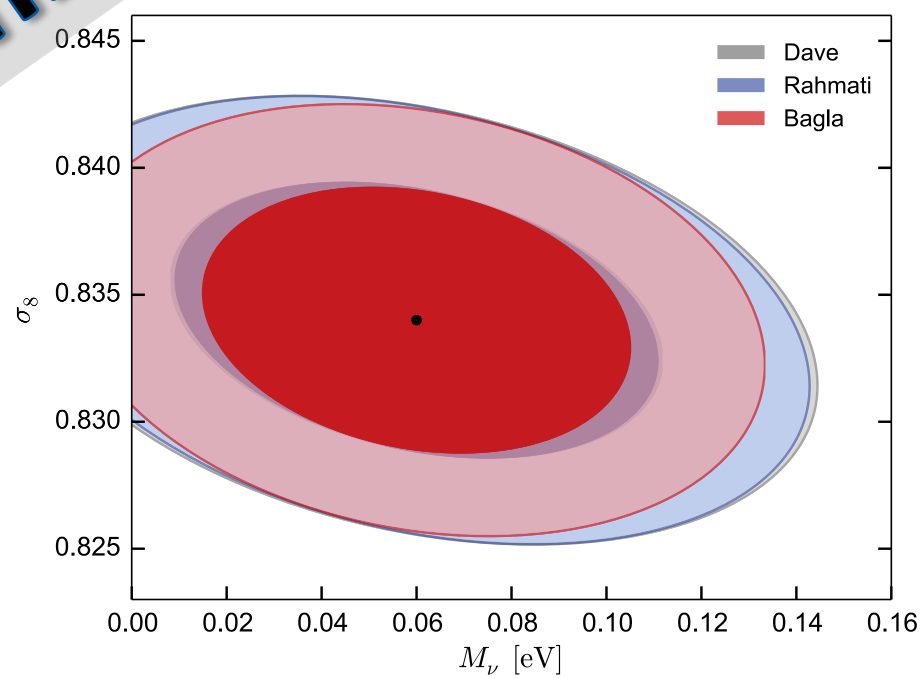


FVN, Viel, Datta, Choudhury, 2014

Precision cosmology with SKA

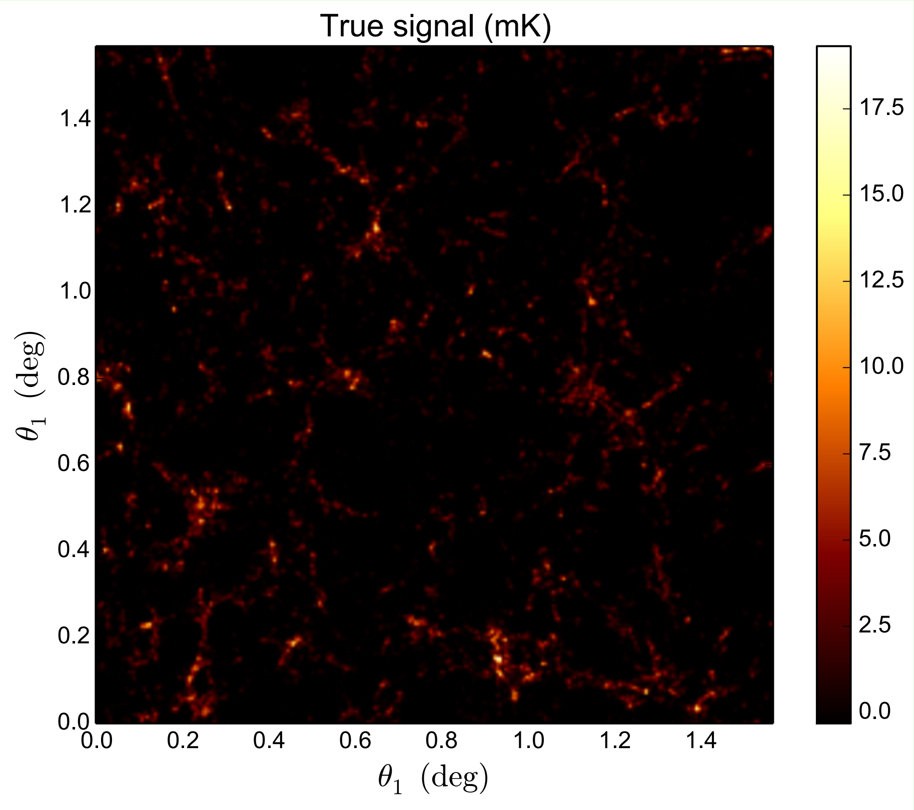


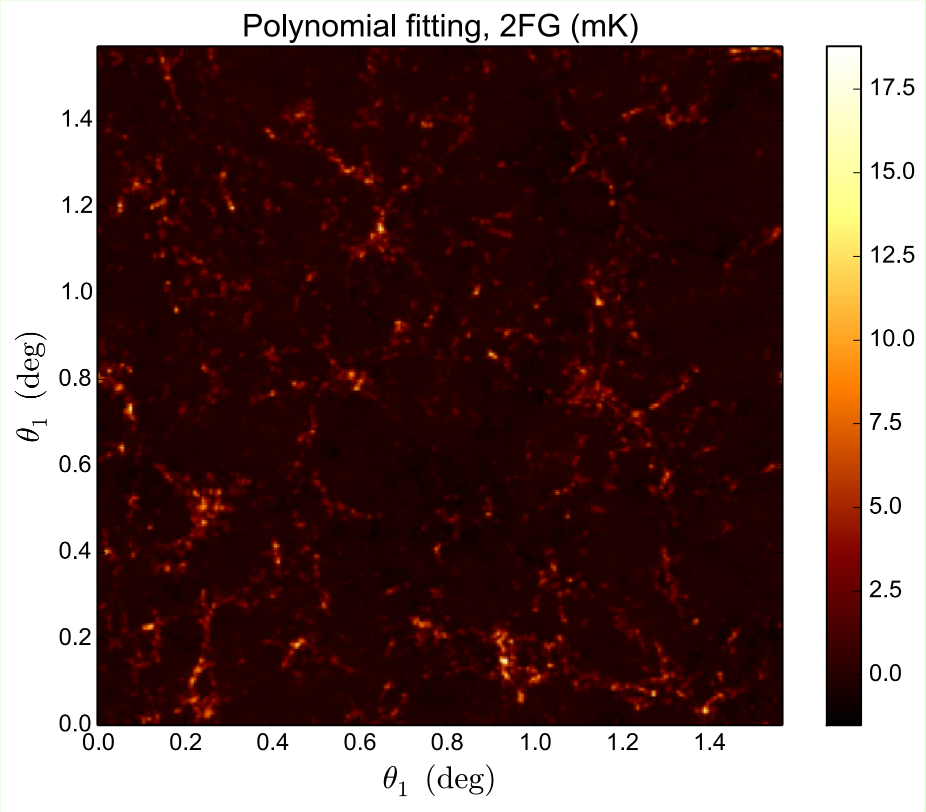
Preliminary



With Philip Bull and Matteo Viel

Cross-correlating 21cm intensity maps with Lyman Break Galaxies in the post-reionization era





FVN, Viel, Alonso, Datta, Bull, Santos, 2014

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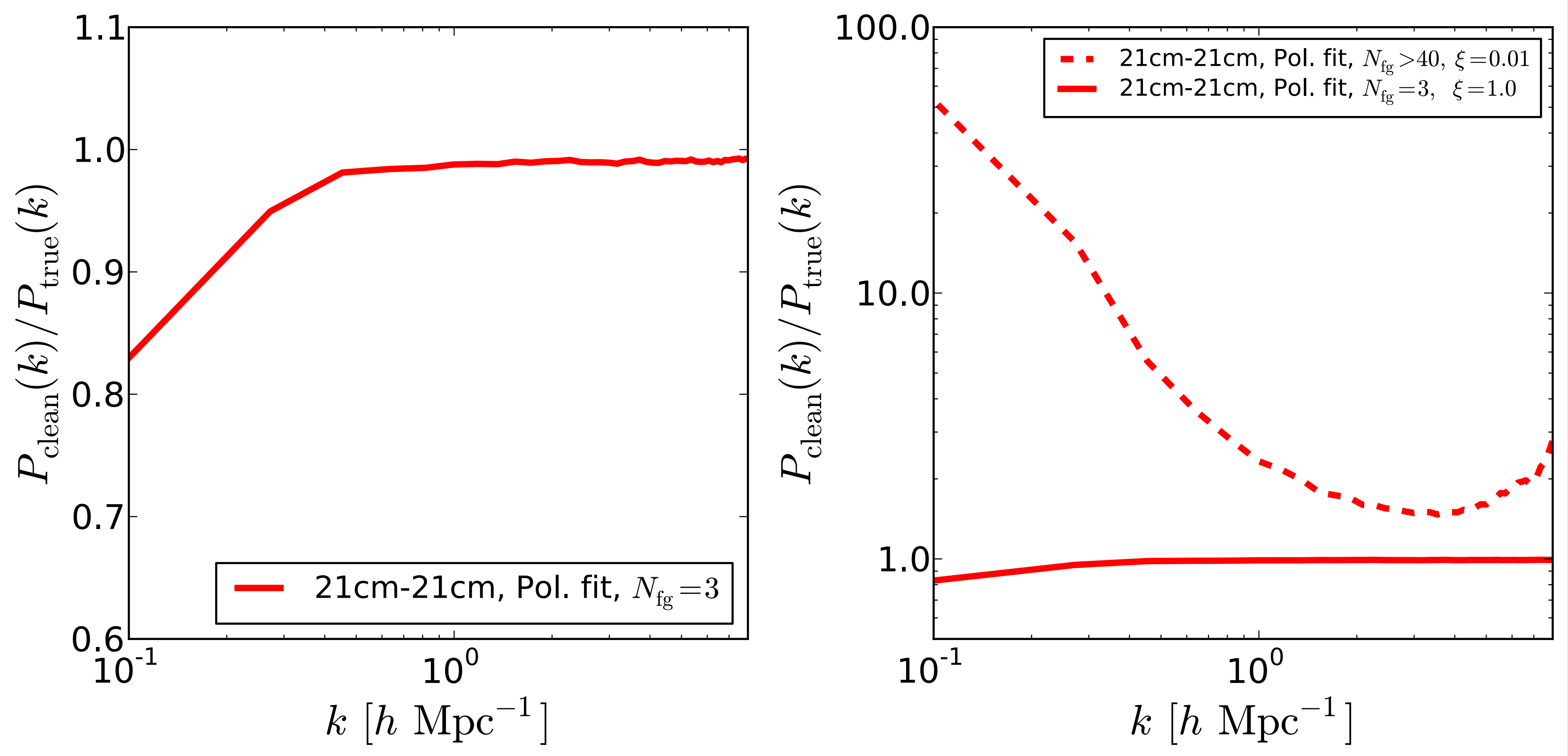


FVN, Viel, Alonso, Datta, Bull, Santos, 2014

Cross-correlating 21cm intensity maps with Lyman Break Galaxies in the post-reionization era

Neutral hydrogen

All HI resides in halos

$$M_{HI}(M) \longrightarrow b_{DLA}$$

$$\rho_{HI}(r) \downarrow$$

$$\text{HI CDDF} \longrightarrow \Omega_{HI} = \frac{\rho_{HI}}{\rho_c}$$

Bagla et al. 2010

$$M_{\rm HI}(M) = \begin{cases} f_3 \dfrac{M}{1+\left(\frac{M}{M_{\rm max}}\right)} & \text{if } M_{\rm min} \leqslant M \\ 0 & \text{otherwise} \end{cases}$$

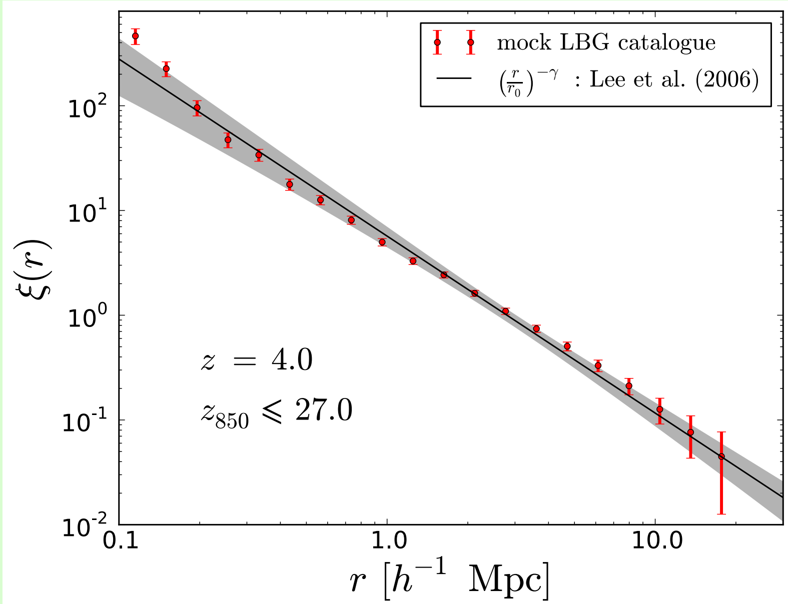
Barnes & Haehnelt 2014

$$M_{\rm HI}(M) = \alpha f_{\rm H,c} \exp\left[-\left(\frac{v_c^0}{v_c}\right)^{\beta}\right] M \ ,$$

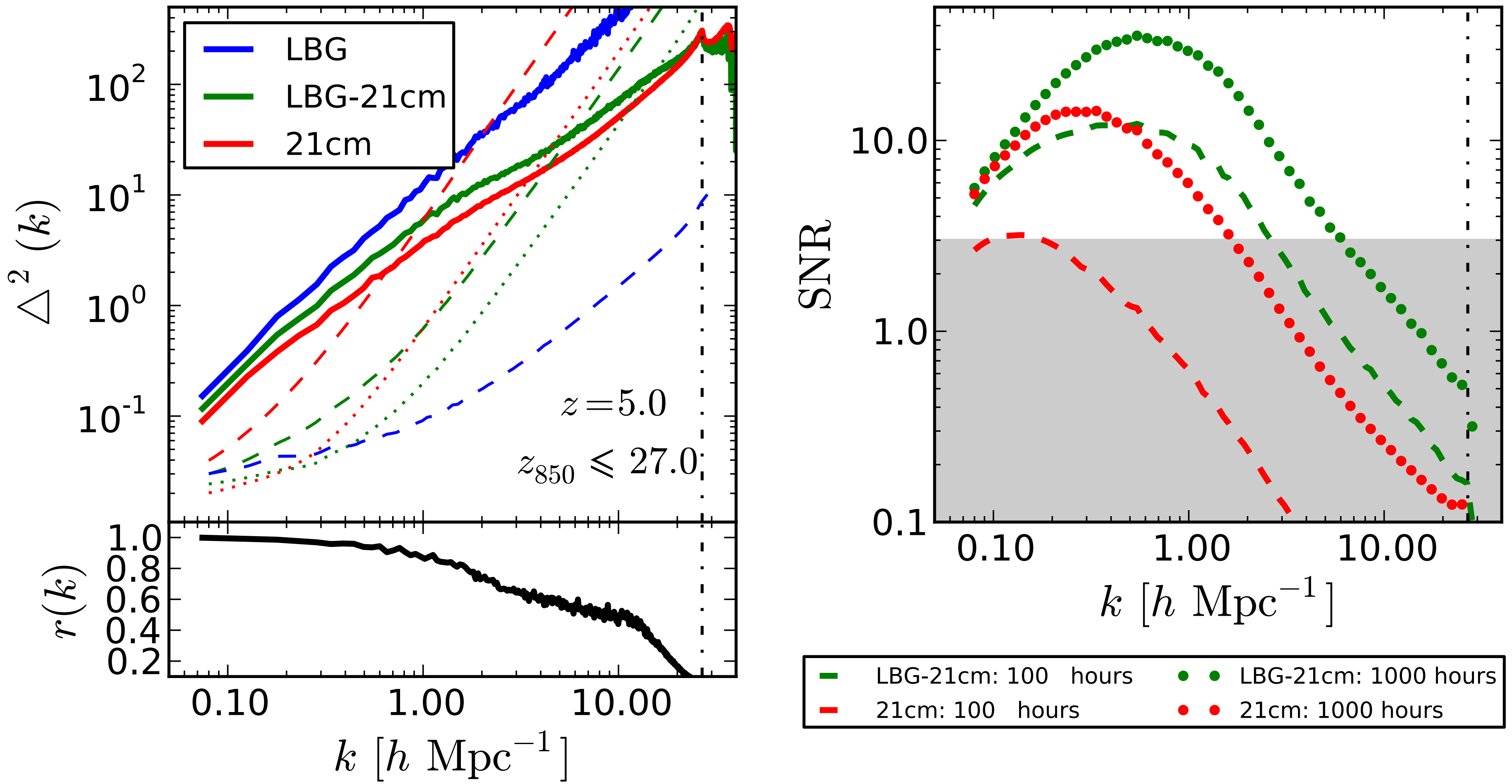
Lyman Break Galaxies

Halo Occupation Distribution (HOD)

$$\langle N \rangle_M = \begin{cases} \left(\dfrac{M}{M_1}\right)^{\alpha} & \text{if } M > M_{\min} \\ 0 & \text{if } M \le M_{\min} \end{cases}$$



Cross-correlating 21cm intensity maps with Lyman Break Galaxies in the post-reionization era



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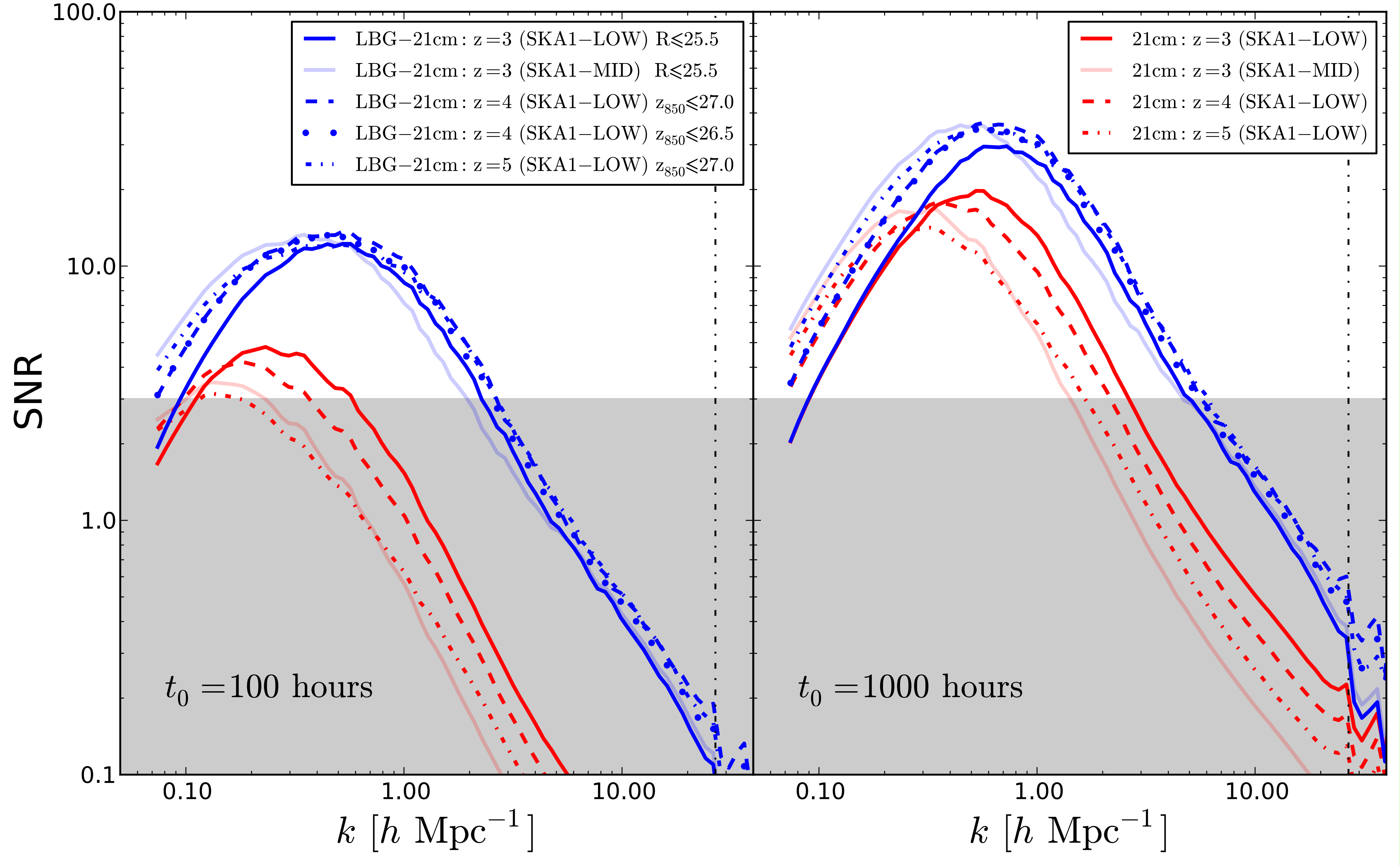

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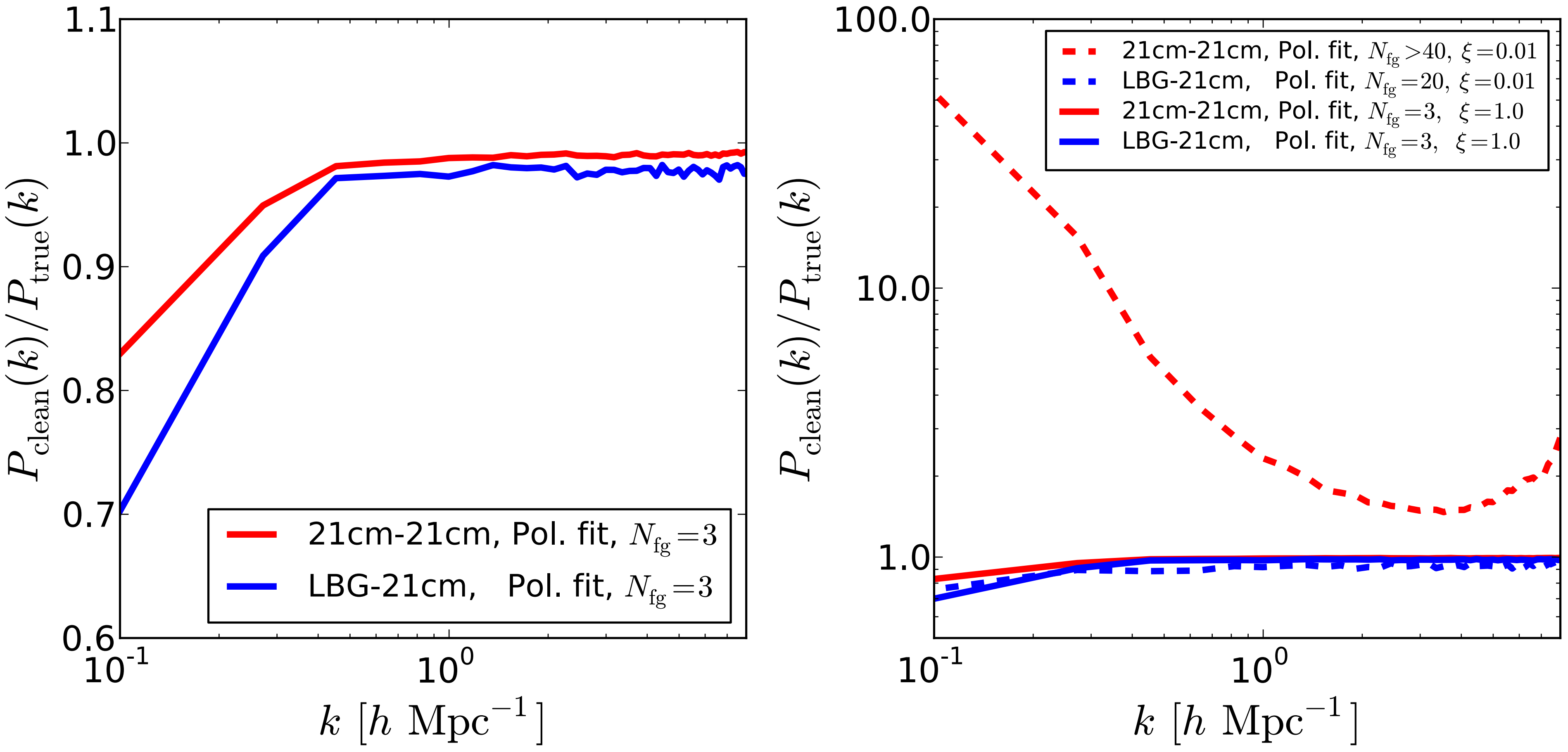
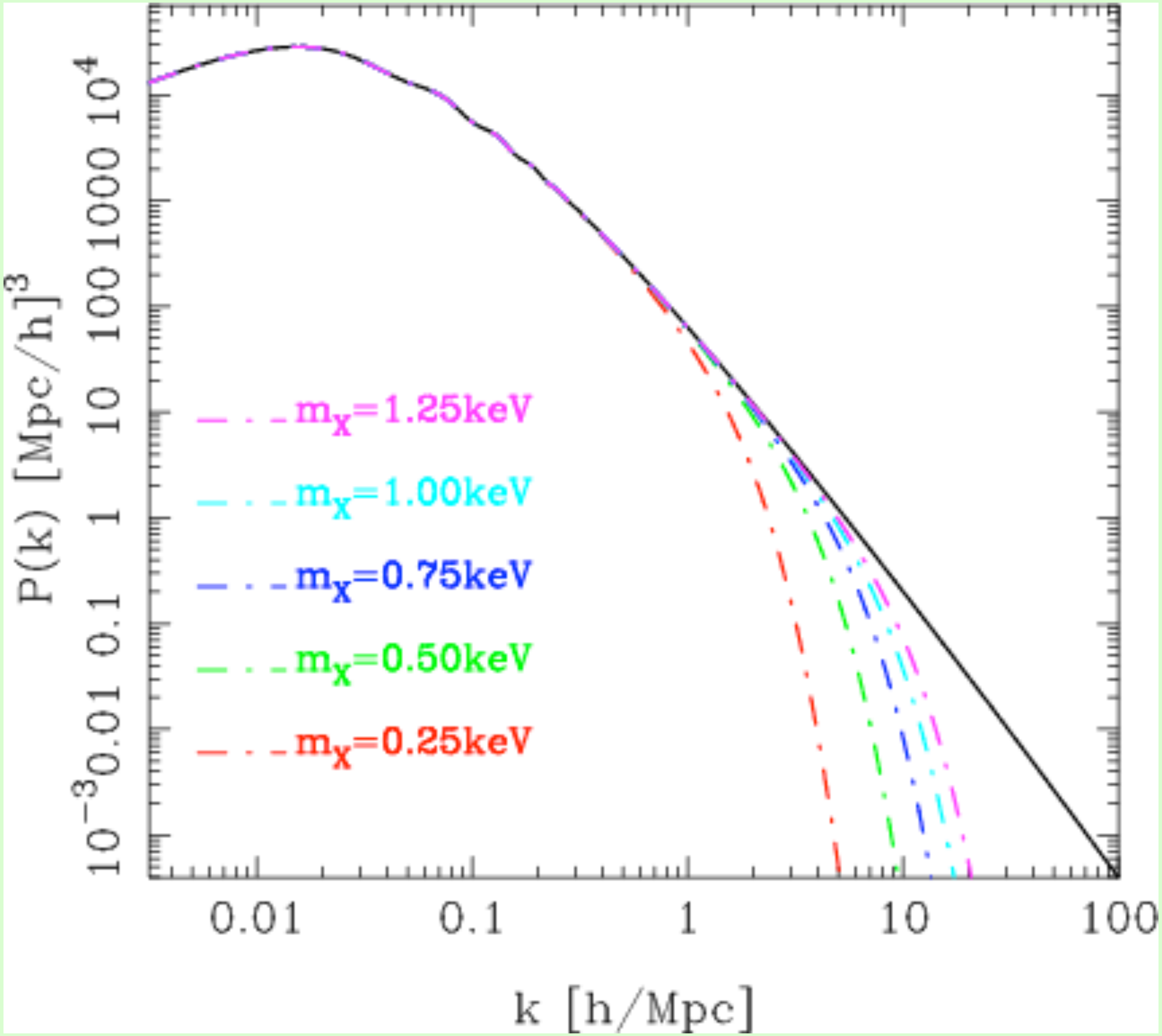
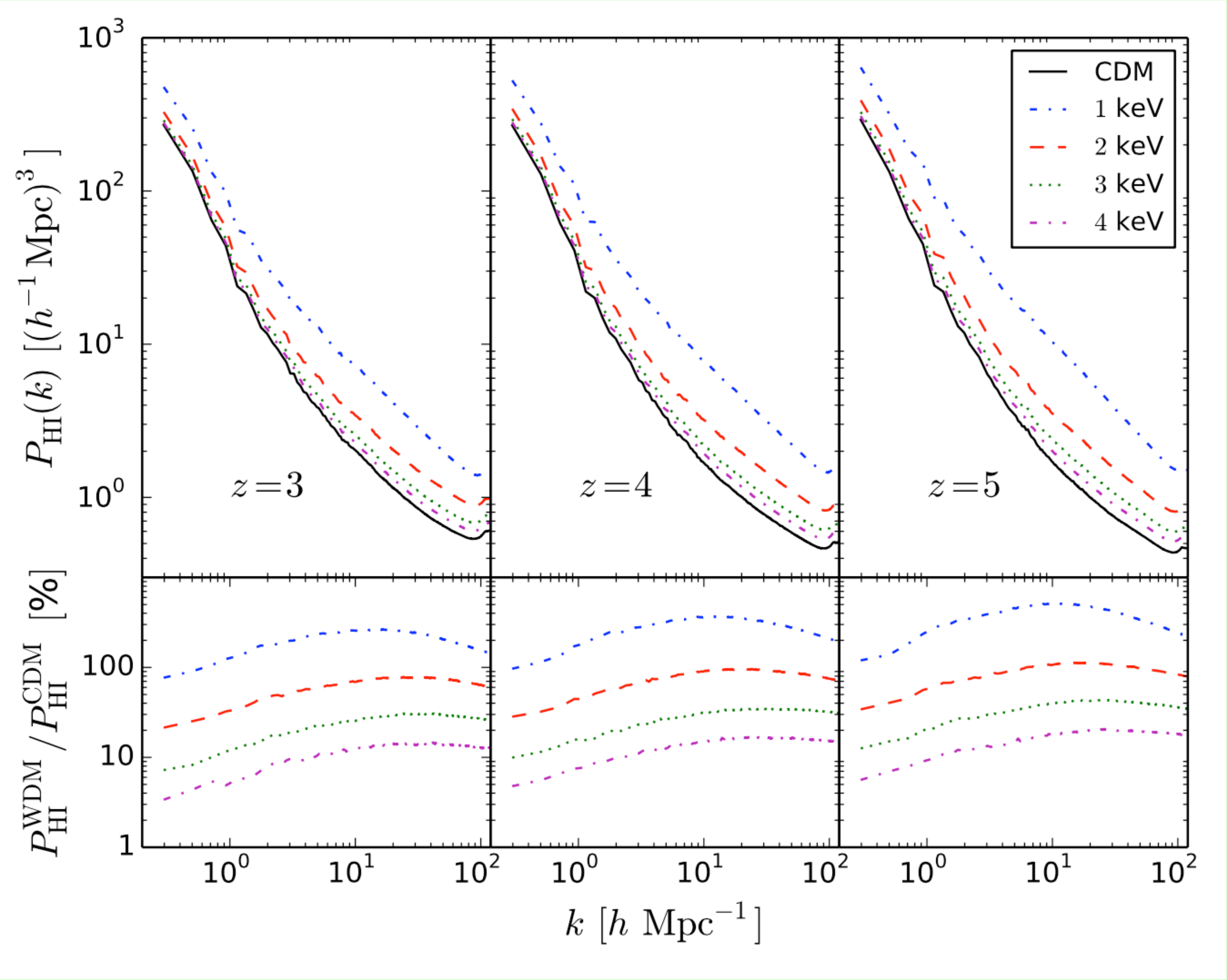


FVN, Viel, Alonso, Datta, Bull, Santos, 2014

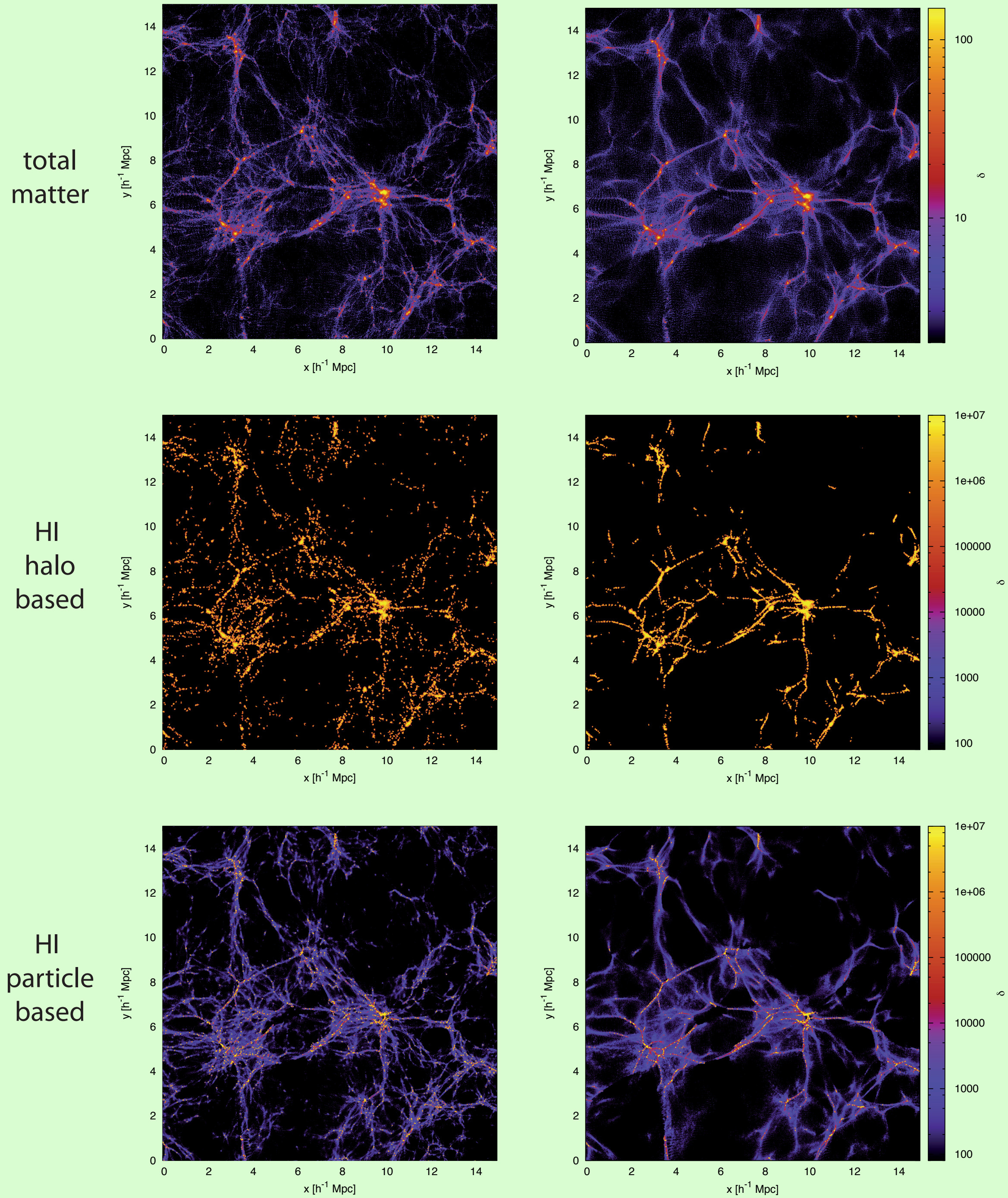
WDM signatures on the 21cm power spectrum



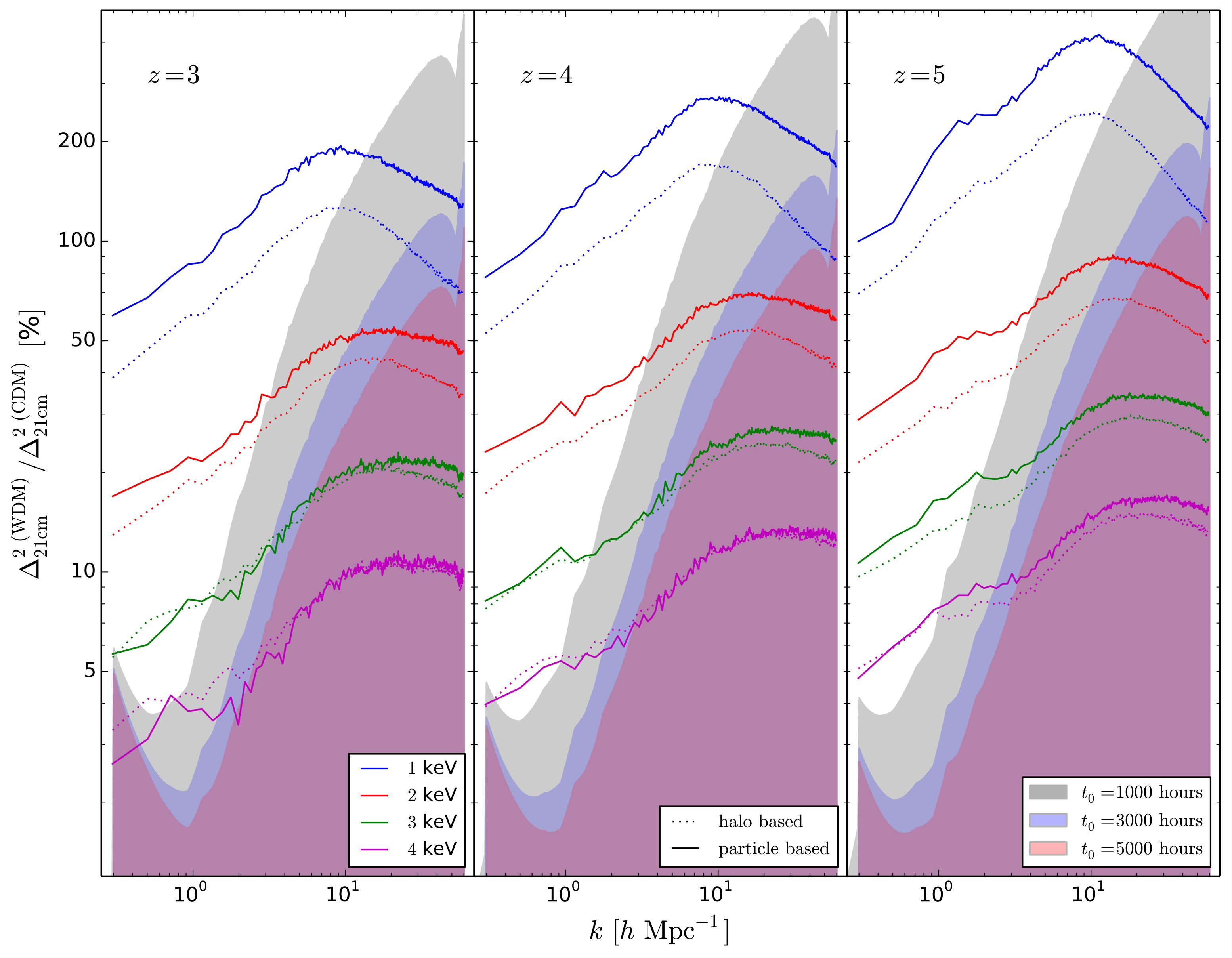
WDM signatures on the 21cm power spectrum



Carucci, FVN, Viel & Lapi 2015


total matter
HI halo based
HI particle based
y [h^-1 Mpc]
x [h^-1 Mpc]
δ
100
10
1e+07
1e+06
100000
10000
1000
100

WDM signatures on the 21cm power spectrum



Carucci, FVN, Viel & Lapi 2015

SUMMARY

1. Crucial to model the HI distribution from the theory side
2. Three different models to simulate the HI distribution:
   - Pseudo-RT codes: HI assigned to gas particles individually
   - Semi-analytic methods: HI assigned to gas within DM halos
3. SKA will detect the 21cm P(k) up to k 1-5 h/Mpc depending on redshift and model
4. Cross-correlations very useful for foregrounds
5. WDM signatures in the amplitude of the 21cm power spectrum