The local PNG bias of neutral Hydrogen, HI

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Speaker: Siyi Zhao **@ Student seminar 2021.12.17**

Take-home message

- The previous forecast studies of f_{NL} using HI data should be revised.

An important cosmology parameter,
which can rule out some of the inflation models

- due the over-prediction of the popular universality expressions for the local PNG bias.
- found in simulations.

Background

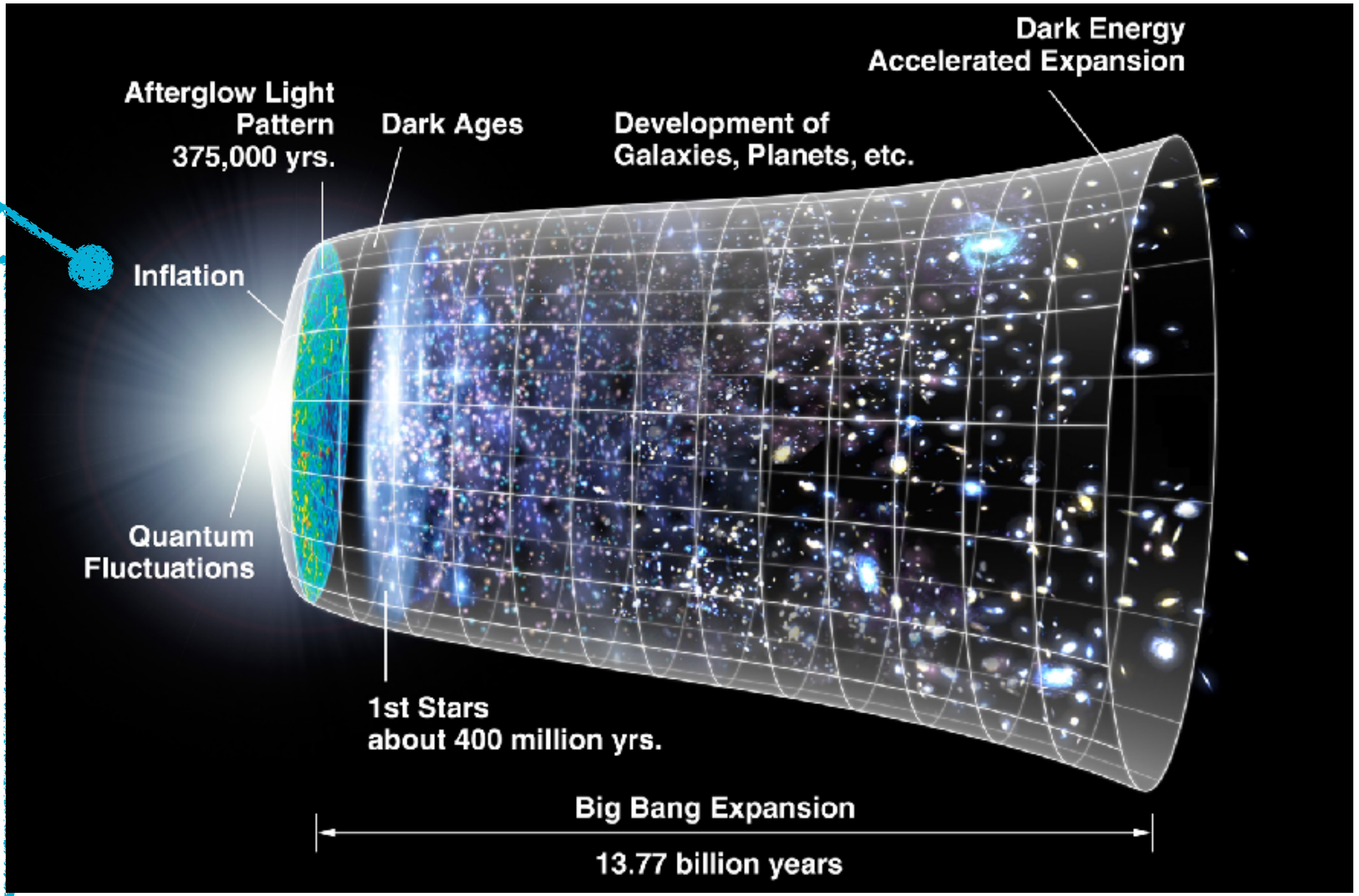
Primordial non-Gaussianity (PNG)

Inflation predicts nearly Gaussian primordial potential field.

local Primodial Non-Gaussianity

$$\phi(\boldsymbol{x}) = \phi_G(\boldsymbol{x}) + f_{\rm NL}\left[\phi_G^2(\boldsymbol{x}) - \langle \phi_G^2(\boldsymbol{x}) \rangle\right]$$

- Different inflation models -> different fNL
  - Slow-roll single field : very small
  - Multi-field : much larger
    - eg: the spectator field -> order 1



Constrain PNG with HI

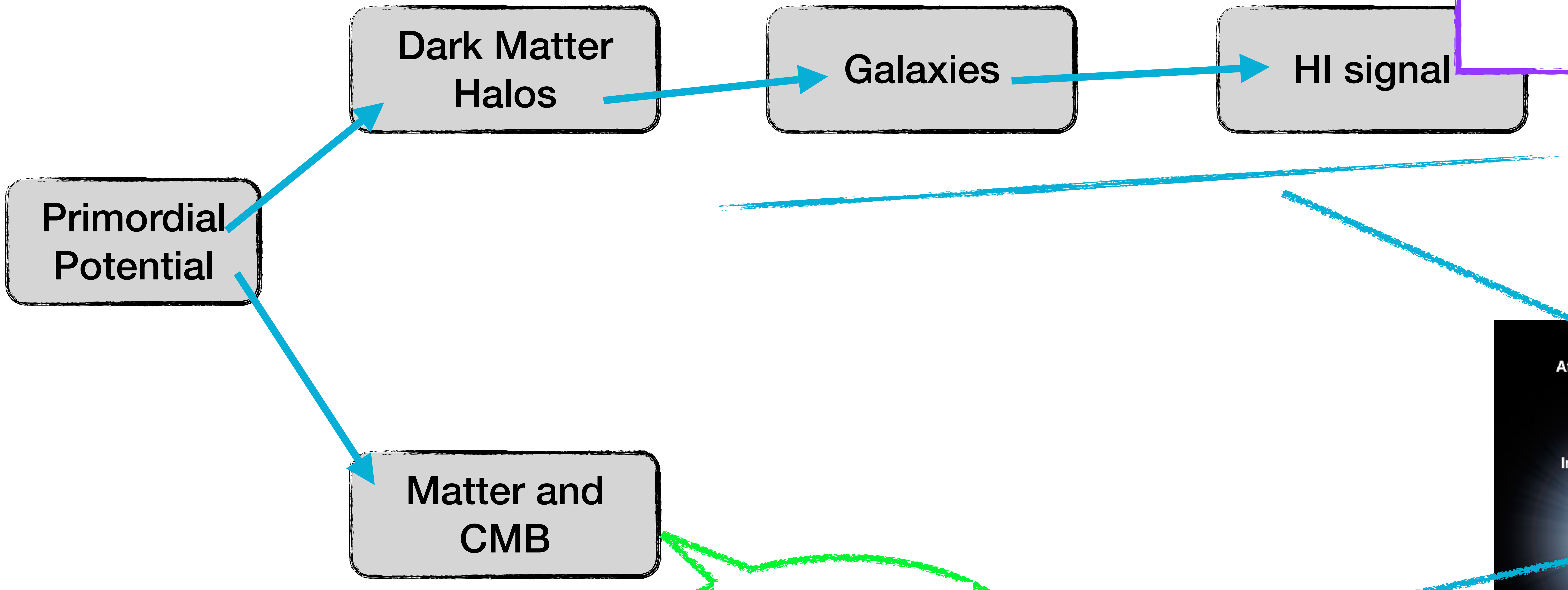
PNG affects the distribution of HI.

The Predicted 1σ Errors of f_{NL} Using the H I Ppower Spectrum Measured by Tianlai

	Pathfinder	Pathfinder+	Full Scale
N_{feed} per cylinder	32	72	256
$\sigma_{f_{NL}}^{local}$	1504	161	14.1

The Marginalized 1σ Errors of f_{NL} Using the H I Bispectrum Measured by Tianlai

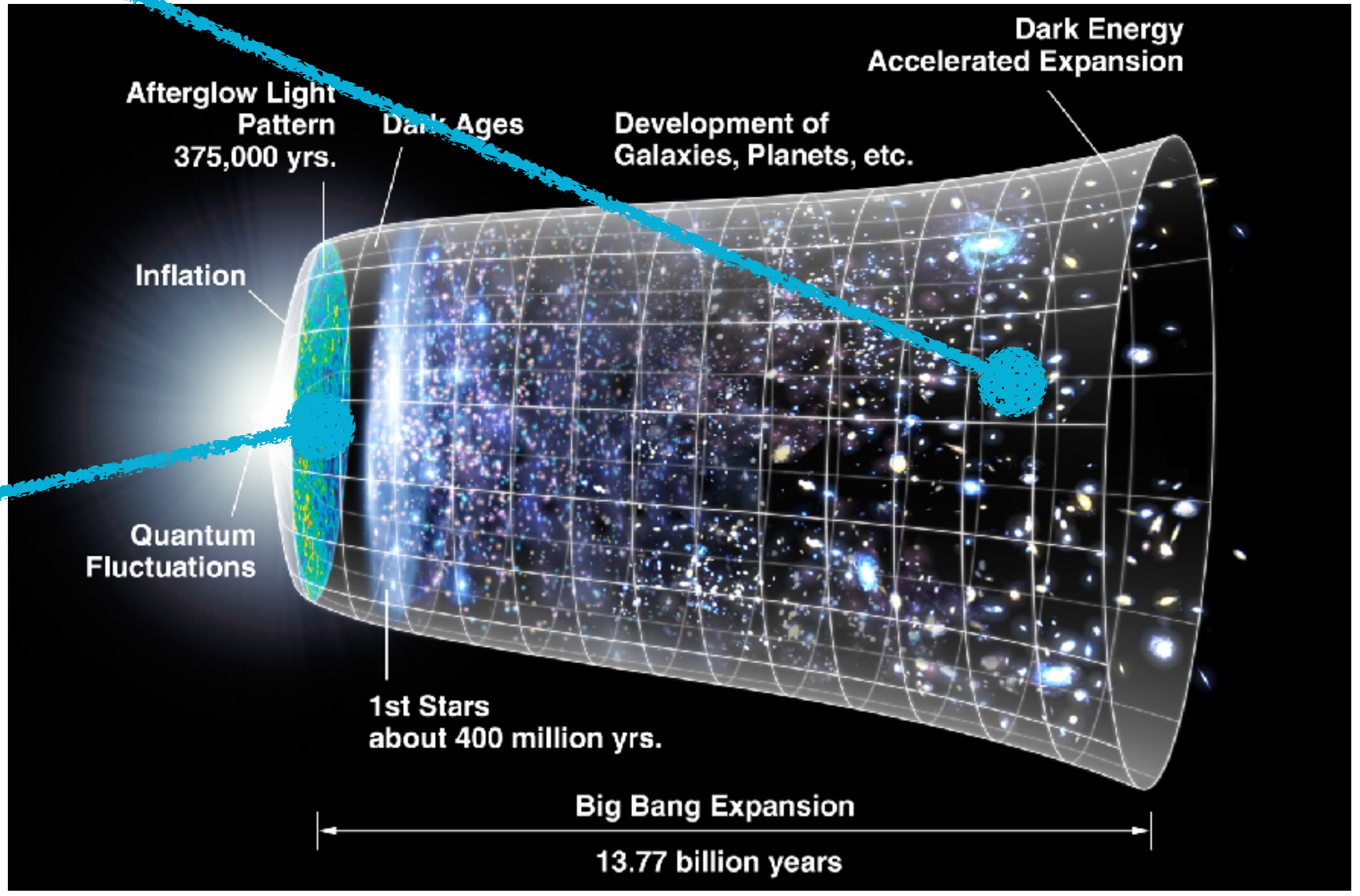
	Pathfinder	Pathfinder+	Full Scale
N_{feed} per cylinder	32	72	256
$\sigma_{f_{NL}}^{local}$	70814	2272	21.7



$f_{NL} = -0.9 \pm 5.1$

Planck18

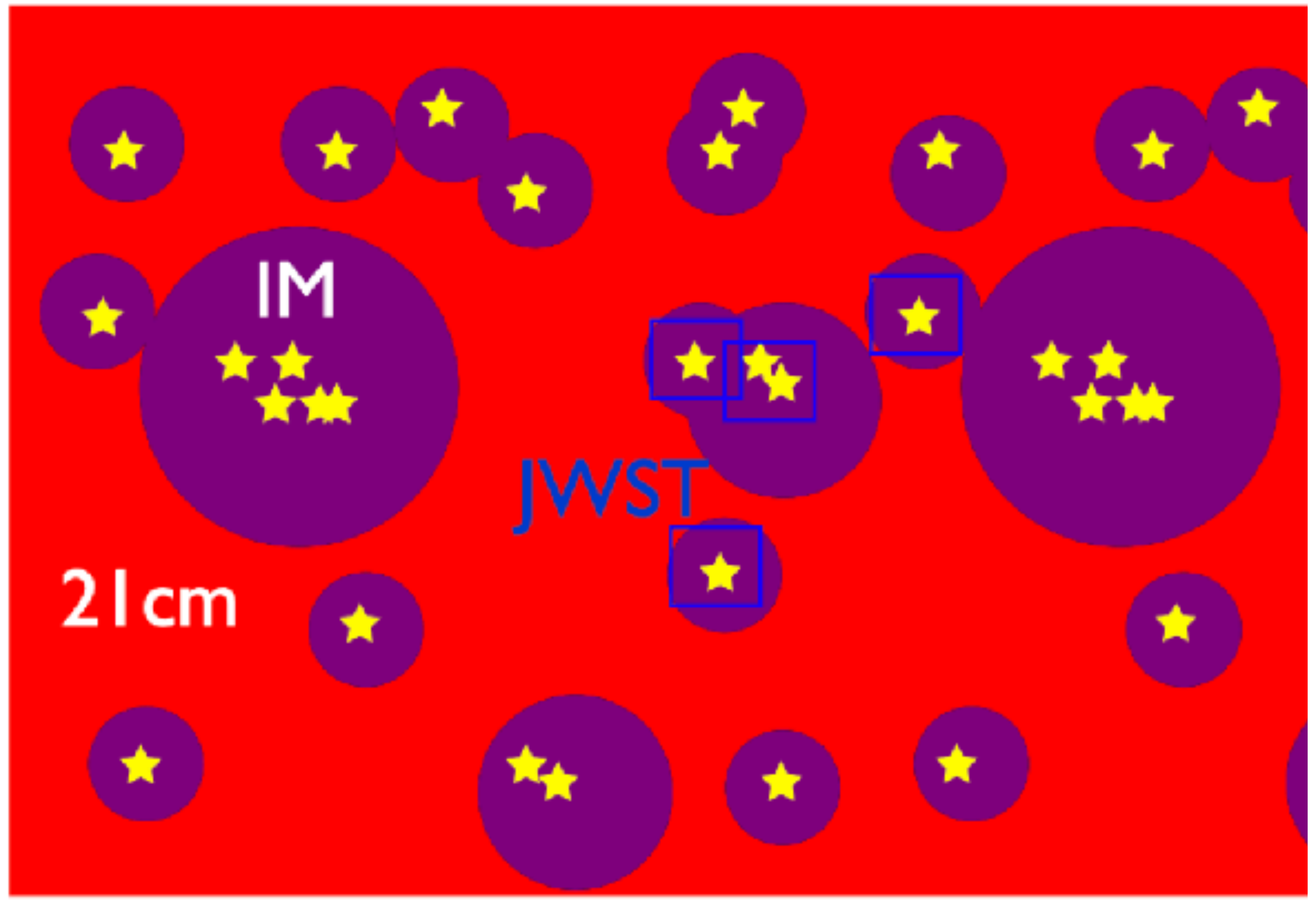
$\Delta f_{NL} \gtrsim 1.6$



21 cm line-intensity mapping (IM)

IM provides a powerful synergy to galaxy surveys.

- Galaxy surveys
- resolve individual galaxies
  - bright (sensitivity threshold)
  - highly biased



Pritchard & Loeb, RPP (2012)

- 21 cm IM :
- the integrated emission
  - all sources (resolved or not)
  - less biased

Bias theory

Bias describe the relation between tracers and perturbations.

$$\rho_{\mathrm{H_I}}(\boldsymbol{x}, z) \supset \bar{\rho}_{\mathrm{H_I}}(z)\left[1 + b_1(z)\delta_m(\boldsymbol{x}, z) + b_\phi(z) f_{\mathrm{NL}}\phi(\boldsymbol{q}) + b_{\phi\delta}(z) f_{\mathrm{NL}}\phi(\boldsymbol{q})\delta_m(\boldsymbol{x}, z)\right],$$

The local PNG bias

- the observational signatures of fNL are effectively degenerate with the bias parameters.
- So it's important to predict the PNG bias theoretically.
  - their relation to b1

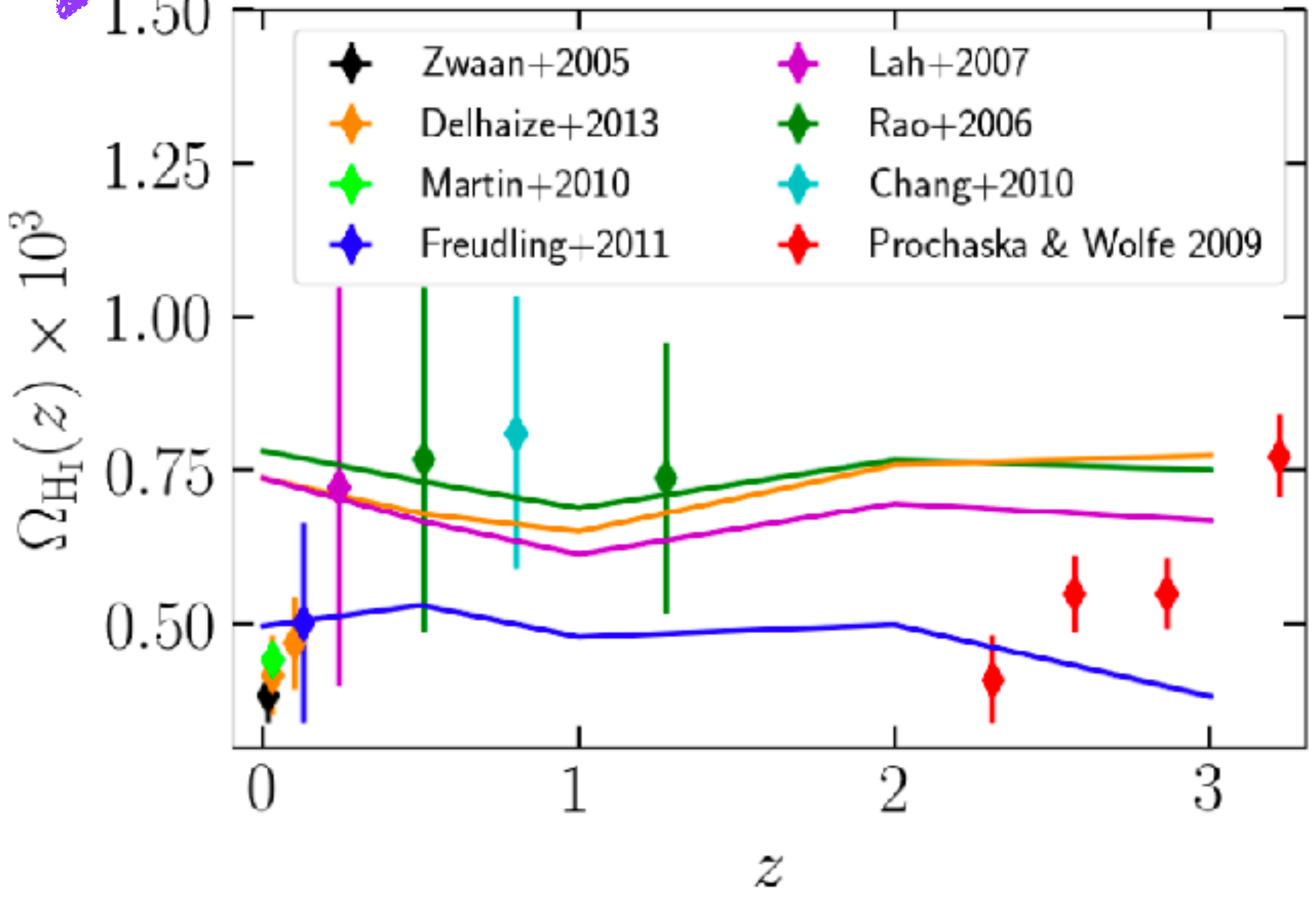
Methodology

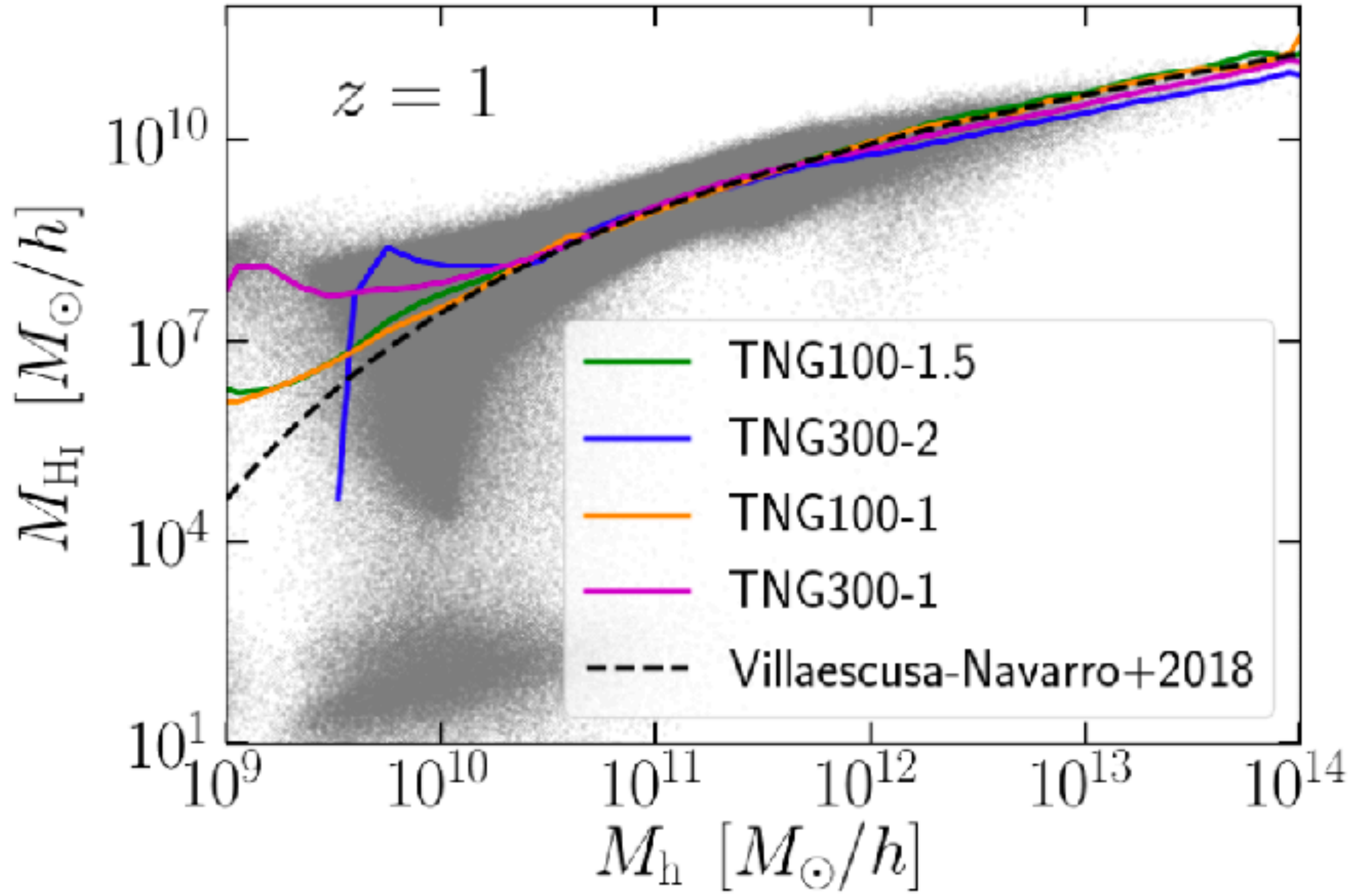
N-body simulations

- the galaxy formation model : AREPO, IllustrisTNG
- 2 resolution
    - TNG300-2 : L = 205 Mpc/h, Np = 2* 1250^3 (dark matter + gas)
    - TNG100-1.5 : L=75 Mpc/h, Np = 2* 1250^3
- z = 0, 0.5, 1, 2, 3

Modeling of HI

- m_Hydrogen -> neutral H + ionized H
- neutral H -> atomic H + molecular H : McKee-Tumlinson (KMT) model.
- numerical resolution





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Bias parameters measurement

- fit $b_1(z)$ at a scale dependent k-range: $b_1 + Ak^2$
- for b_ϕ, they use an **equivalent** to global structure formation in a cosmology with the primordial scalar power spectrum amplitude.
  - $\delta_{\mathcal{A}_s} = 4 f_{\rm NL}\phi_{\rm L},$
  - so they 'simulate' PNG with the primordial scalar power spectrum amplitude, A_s
- use their ($b_\phi^{\mathrm{High}A_s}$ and $b_\phi^{\mathrm{Low}A_s}$) difference as a rough estimate of the error in our measurements

$$b_\phi(z) = \frac{\partial \ln \rho_{\rm H_I}(z)}{\partial (f_{\rm NL}\phi_L)} \equiv 4\frac{\partial \ln \rho_{\rm H_I}(z)}{\partial \delta_{\mathcal{A}_s}}.$$

ıen be estimated by finite diferencing us:

$$b_\phi(z) = \frac{b_\phi^{{\rm High}\mathcal{A}_s} + b_\phi^{{\rm Low}\mathcal{A}_s}}{2},$$

$$b_\phi^{{\rm High}\mathcal{A}_s} = \frac{4}{+|\delta_{\mathcal{A}_s}|}\left[\frac{\rho_{\rm H_I}^{{\rm High}\mathcal{A}_s}(z)}{\rho_{\rm H_I}^{\rm Fiducial}(z)} - 1\right],$$

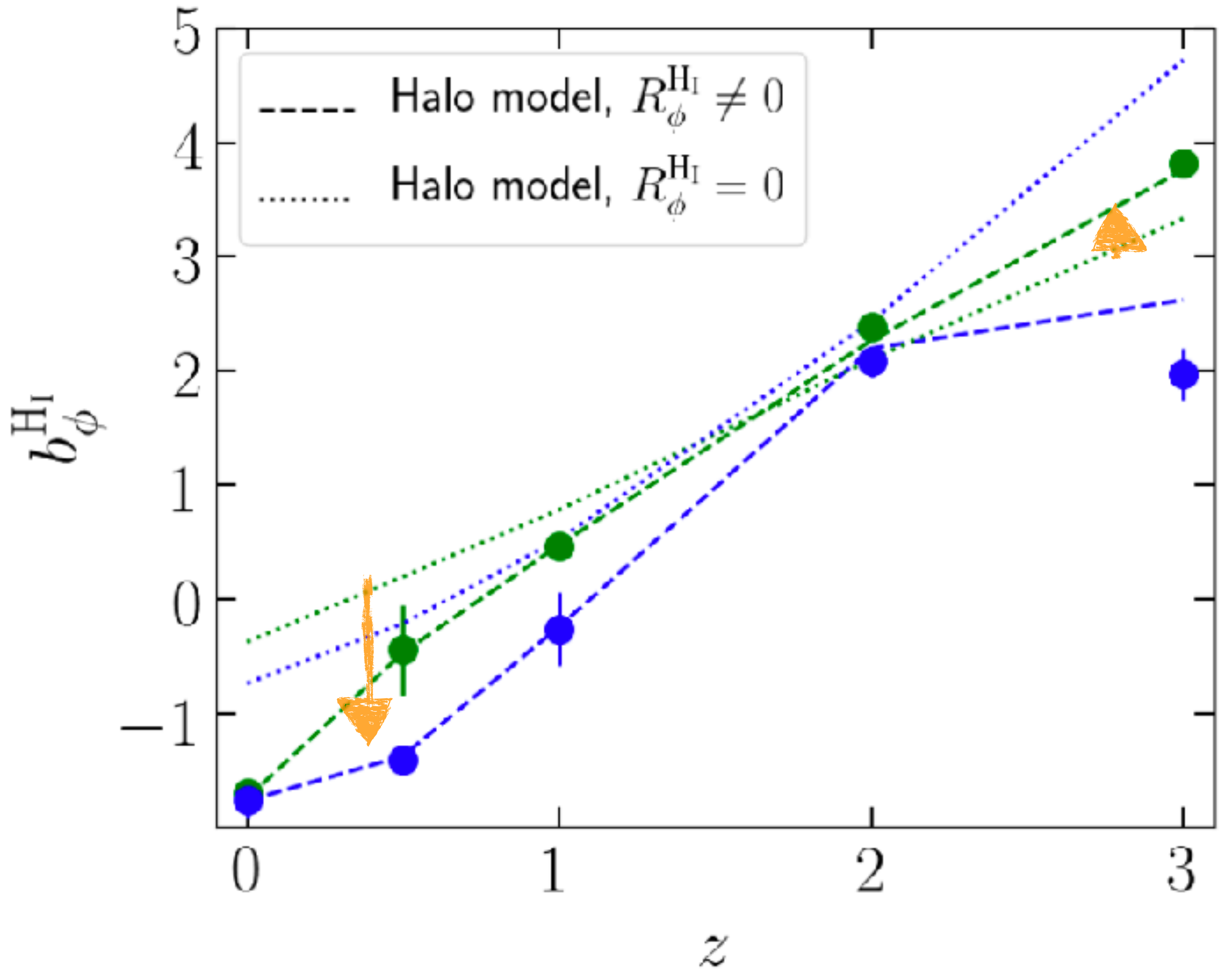
$$b_\phi^{{\rm Low}\mathcal{A}_s} = \frac{4}{-|\delta_{\mathcal{A}_s}|}\left[\frac{\rho_{\rm H_I}^{{\rm Low}\mathcal{A}_s}(z)}{\rho_{\rm H_I}^{\rm Fiducia}(z)} - 1\right],$$

$$b_{\phi\delta}(z) = \left[\frac{\partial \ln b_1(z)}{\partial (f_{\rm NL}\phi)} + b_\phi(z)\right] b_1(z) \equiv \left[4\frac{\partial \ln b_1(z)}{\partial \delta_{\mathcal{A}_s}} + b_\phi(z)\right] b_1(z),$$

Results

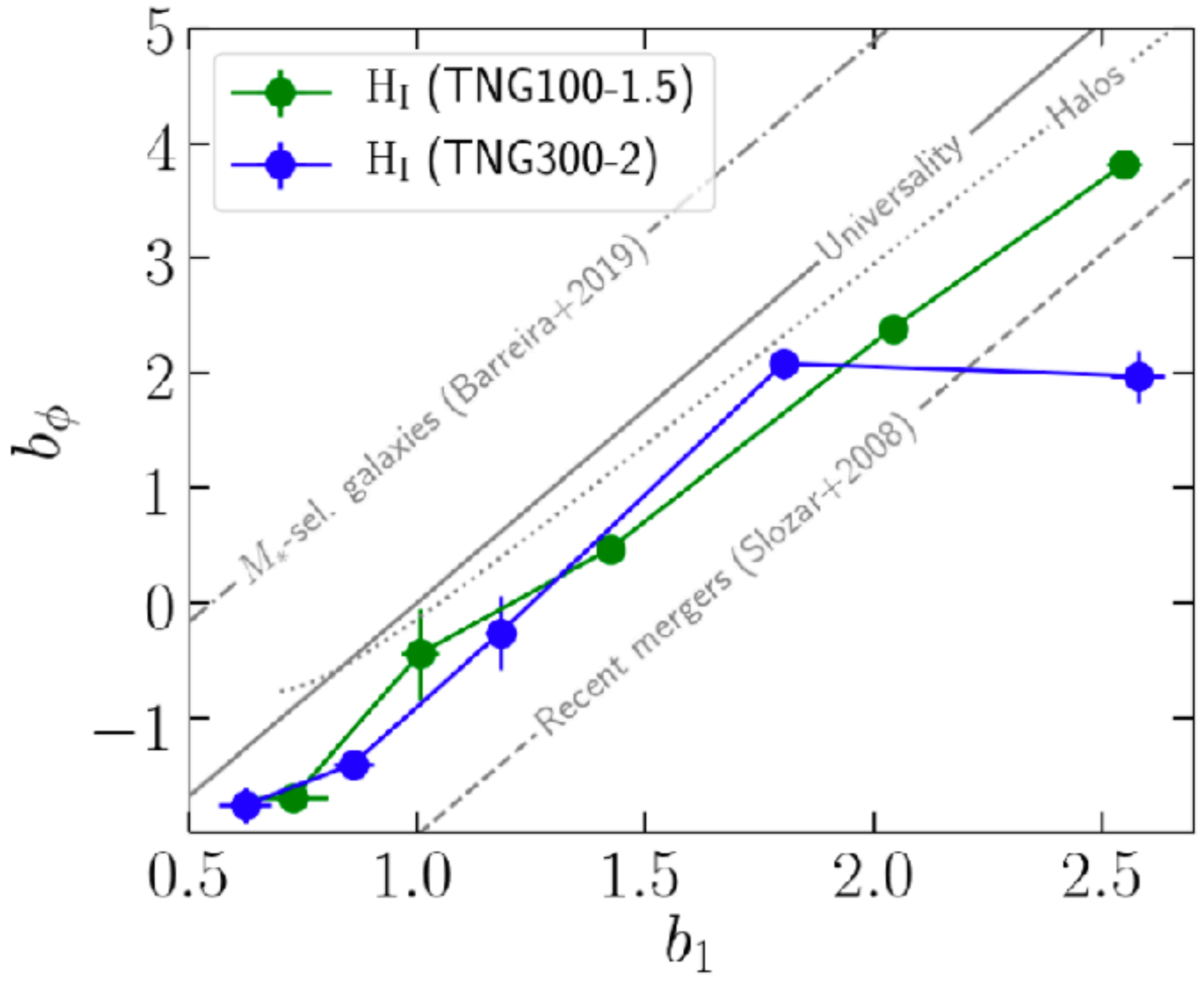
b_ϕ measured

- $R_\phi^{H_I}$ is important.



$$R_\phi^{\mathrm{H_I}}(M_\mathrm{h}) = \frac{\partial \ln M_{\mathrm{H_I}}(M_\mathrm{h})}{\partial (f_\mathrm{NL}\phi)}$$

- Disagree with the universality relation



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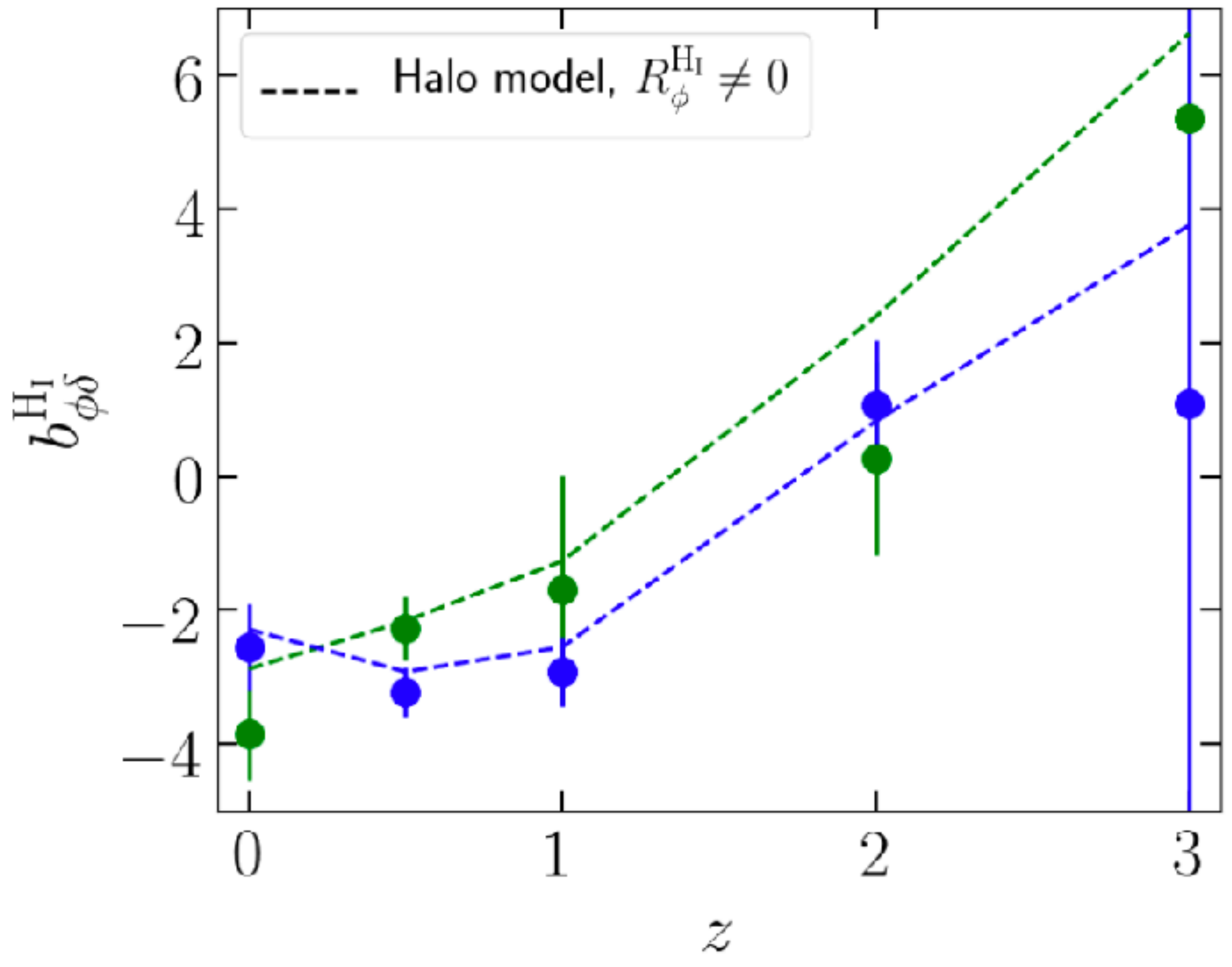
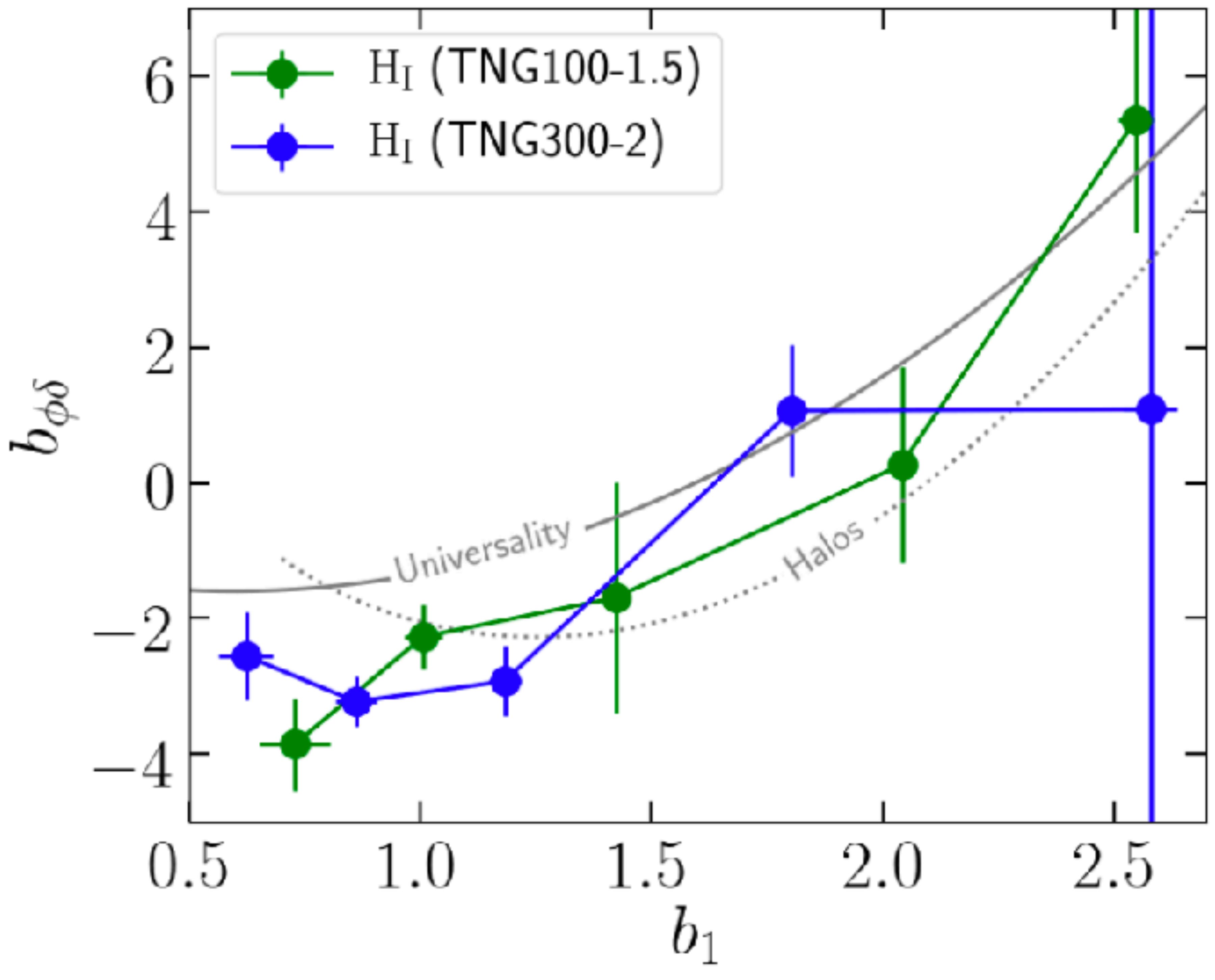
$b_{\phi\delta}$ measured

- noisier (second-order)



$$R_\phi^{\rm H_I}(M_{\rm h}) = \frac{\partial \ln M_{\rm H_I}(M_{\rm h})}{\partial (f_{\rm NL}\phi)}$$

- Disagree with the universality relation



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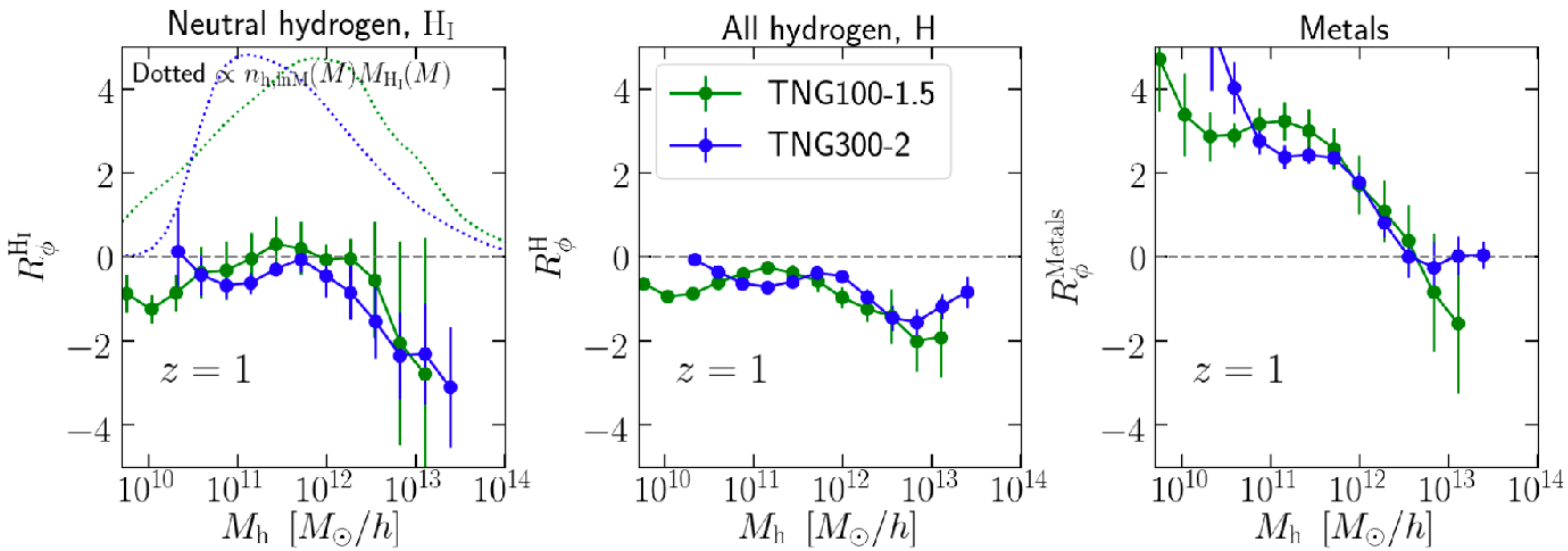
Interpretations $z \lesssim 1$

- $f_{\rm NL}\phi$ perturbations **enhance star formation**, accelerates the transformation of the hydrogen into stars and heavier metals.



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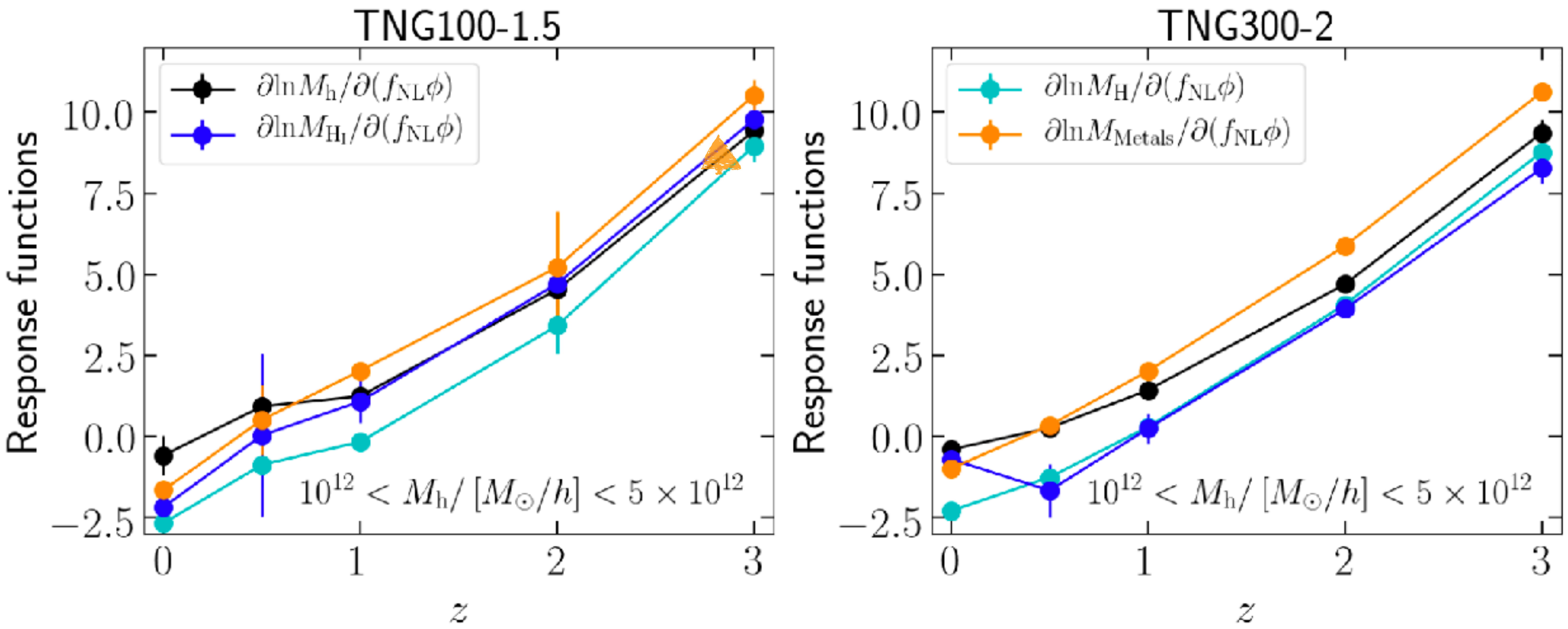
Interpretations $z \gtrsim 2$

- $f_{\rm NL}\phi$ perturbations **promote the formation of denser gas clouds.**



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Summary

- PNG affects the distribution of HI. By detecting 21 cm IM, we can constraint PNG, finally distinguish inflation models.
- The author measured the local PNG bias parameters from simulations.
- They find that
    - The values of b_ϕ and $b_{\phi\delta}$ grow with redshift and are negative at $z \lesssim 1$ and $z \lesssim 2$, respectively.
    - The popular universality expressions for the $b_\phi(b_1)$ and $b_{\phi\delta}(b_1)$ relations over-predict the simulation measurements.
    - The physical explanations would be perturbations enhance the formation of stars and dense gas clouds.
- So they argue that there is strong motivation to revisit the impact of $b_\phi(b_1)$ assumptions in existing forecast studies of $f_{\rm NL}$ using HI data.

Comments

- The results on high redshift may not be credible.
- The response function of metals could not tell us whether the $f_{\rm NL}\phi$ perturbations **enhance star formation** in high-mass halo or not.
- Does the enhancement of star formation appear in first stars and then let reionization begin earlier? Currently reionization model (ESMR) does NOT think so…

Questions

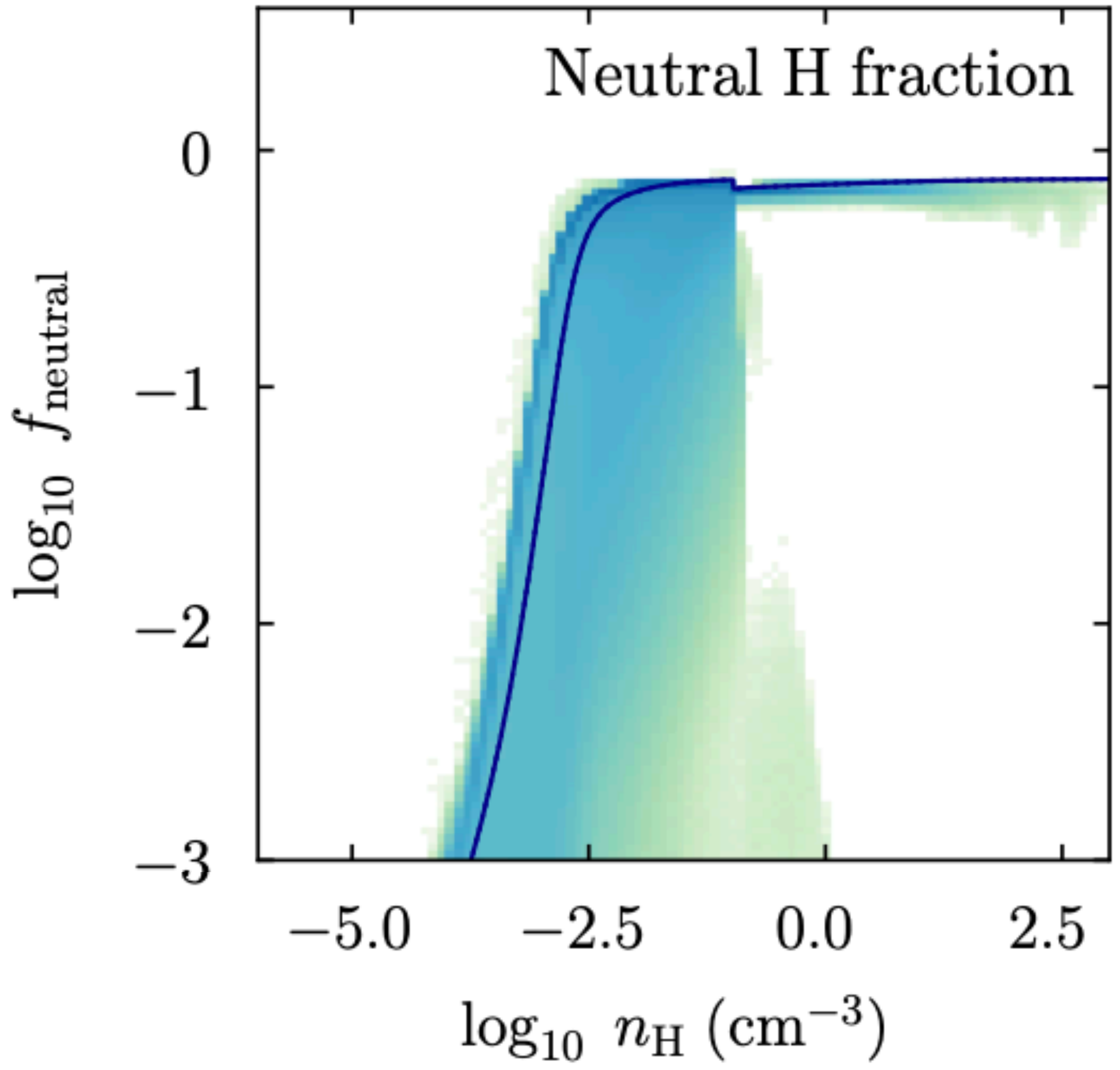
- Why didn't the author consider the second order bias b2?
- Why can we 'produce' PNG by change the value of A_s?
- What are the physical interpretations of the changes in result due to the numerical resolution?

Backup

Modeling of neutral H

to neutral and ionized

- 'non-star-forming gas' in IllustrisTNG: self-consistently
    - neutral
    - ionized
  - UV radiation background
  - self-shielding in high-density gas regions
  - ionizing radiation by local AGN
- consider all hydrogen of 'star forming cells' to be neutral.

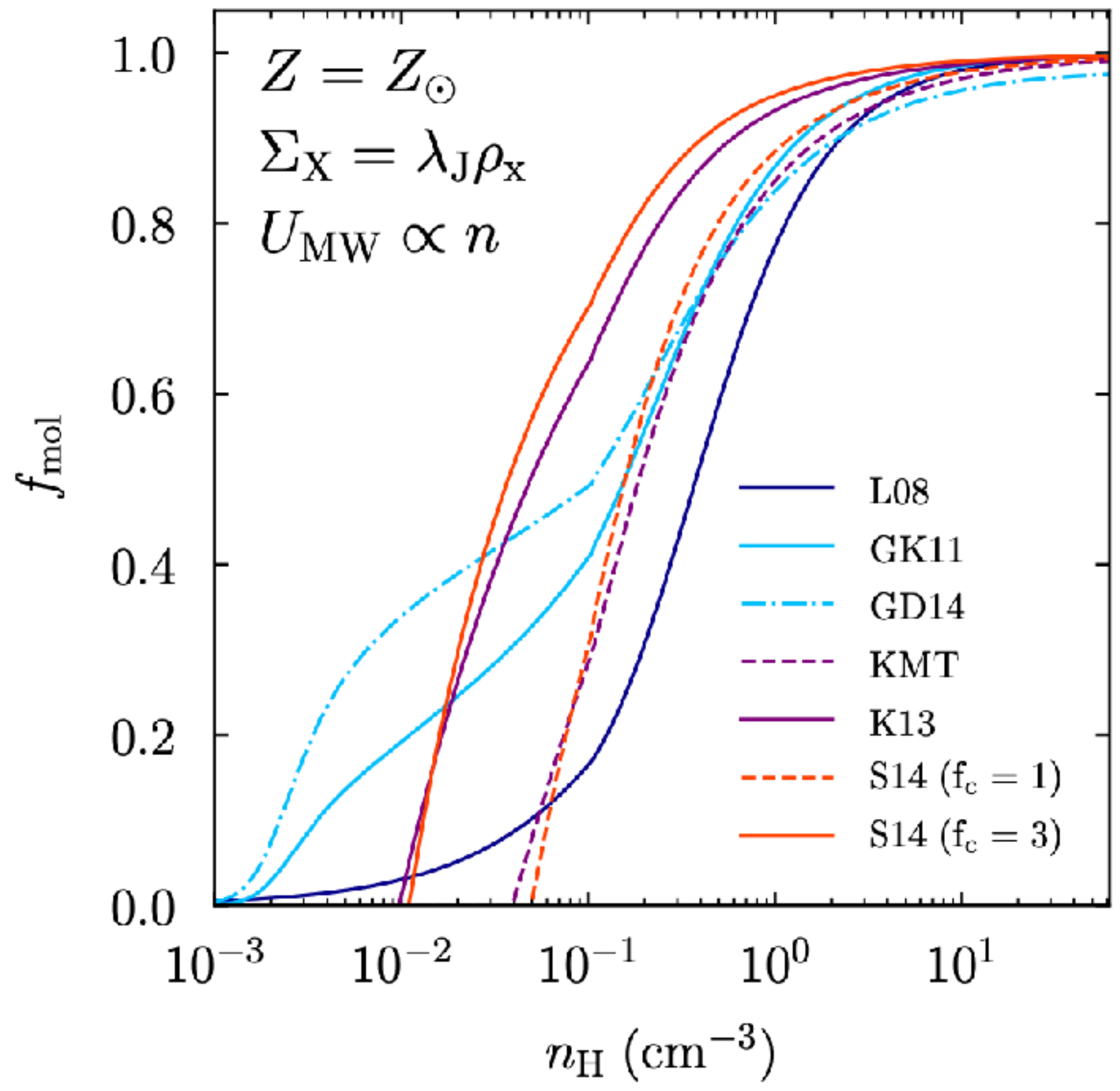


Diemer et al. (2018)
1806.02341

Modeling of atomic H

to atomic HI and molecular H2

- atomic fraction: McKee-Tumlinson (KMT) model



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Measurement values of bias

Redshift	$z=0$	$z=0.5$	$z=1$	$z=2$	$z=3$
b_1 (TNG100-1.5)	0.73 ± 0.07	1.01 ± 0.04	1.42 ± 0.02	2.04 ± 0.02	2.5 ± 0.04
b_1 (TNG300-2)	0.62 ± 0.06	0.86 ± 0.04	1.18 ± 0.03	1.80 ± 0.02	2.58 ± 0.06
b_ϕ (TNG100-1.5)	-1.70 ± 0.05	-0.44 ± 0.39	0.47 ± 0.12	2.39 ± 0.12	3.82 ± 0.06
b_ϕ (TNG300-2)	-1.76 ± 0.16	-1.40 ± 0.11	-0.26 ± 0.32	2.08 ± 0.14	1.98 ± 0.22
$b_{\phi\delta}$ (TNG100-1.5)	-3.86 ± 0.68	-2.27 ± 0.47	-1.70 ± 1.71	0.27 ± 1.44	5.37 ± 1.66
$b_{\phi\delta}$ (TNG300-2)	-2.55 ± 0.65	-3.23 ± 0.36	-2.93 ± 0.52	1.06 ± 0.97	1.09 ± 14.5

Table 1. Values of the bias parameters b_1, b_ϕ and $b_{\phi\delta}$ of the H_I distribution measured in this work.

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