# The Cosmic HI Distribution
# &
# Its connection to galactic ecosystems

Ali Rahmati

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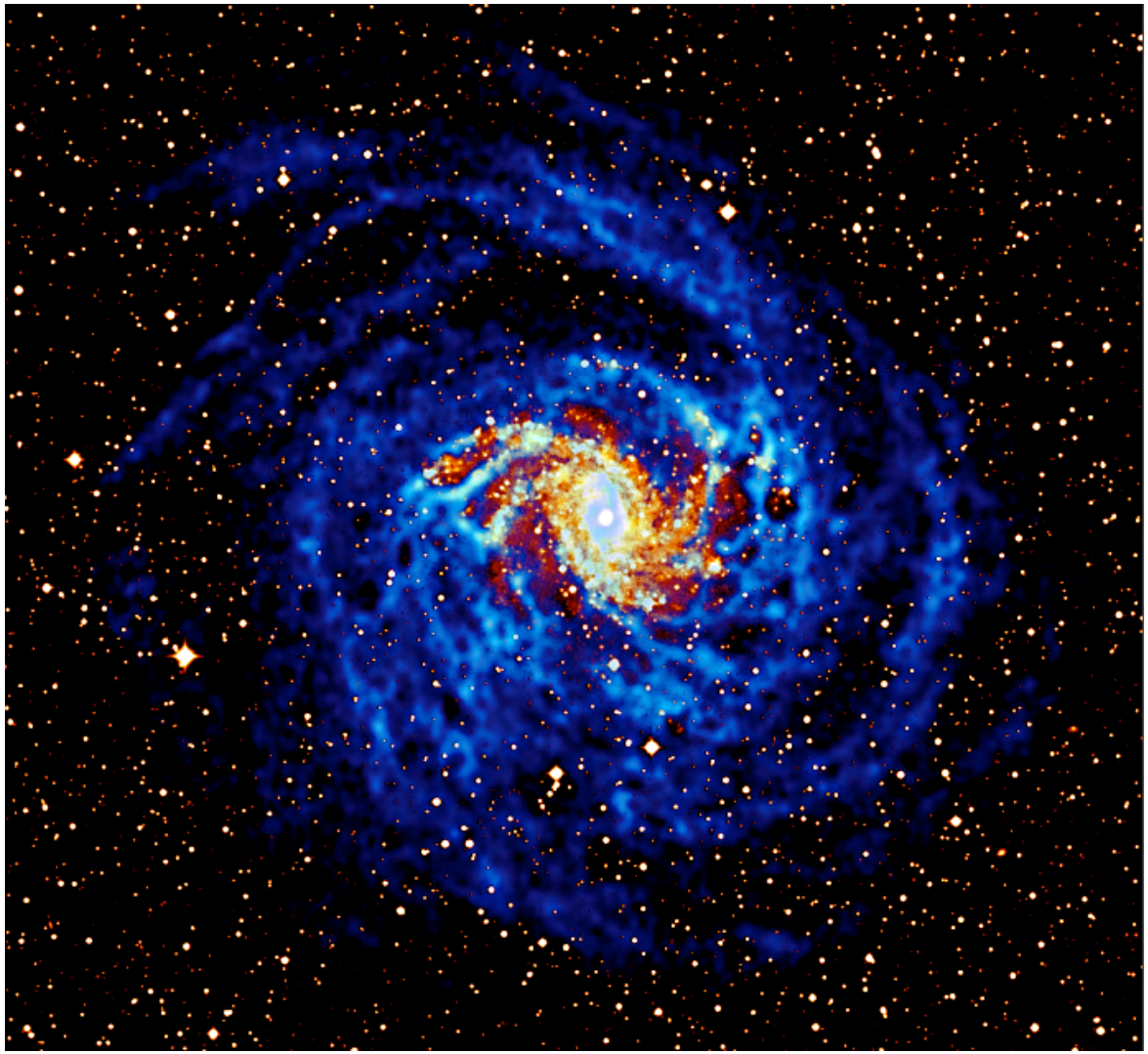
Edinburgh, June 2013

# outline

- $N_{\rm HI} \gtrsim 10^{17}\ {\rm cm}^{-2}$
- post-processing hydro simulations with radiative transfer
- the impact of different ionizing processes
- comparing to observations
- relation between HI absorbers and galaxies

# 21cm emission (z~0)



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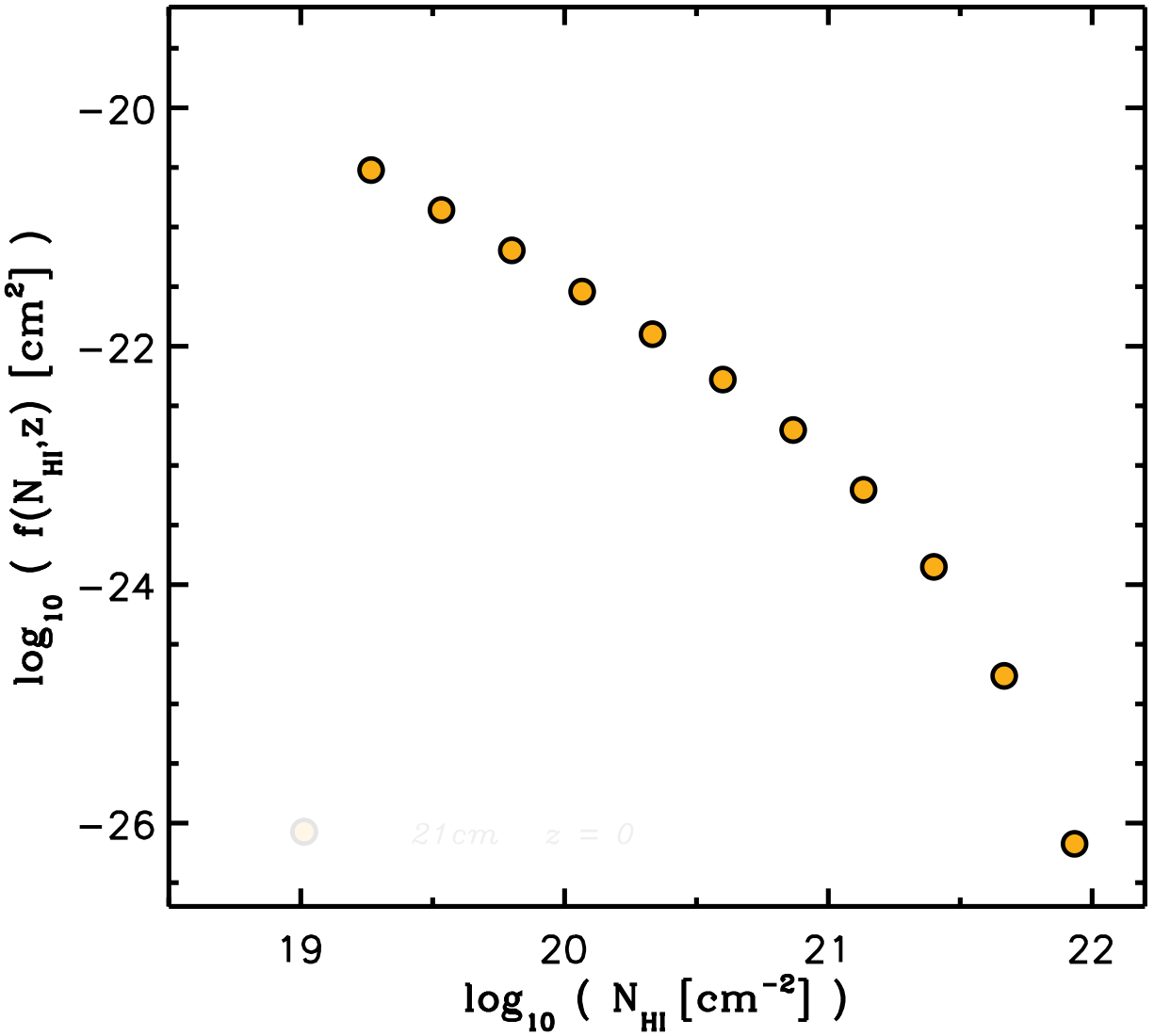
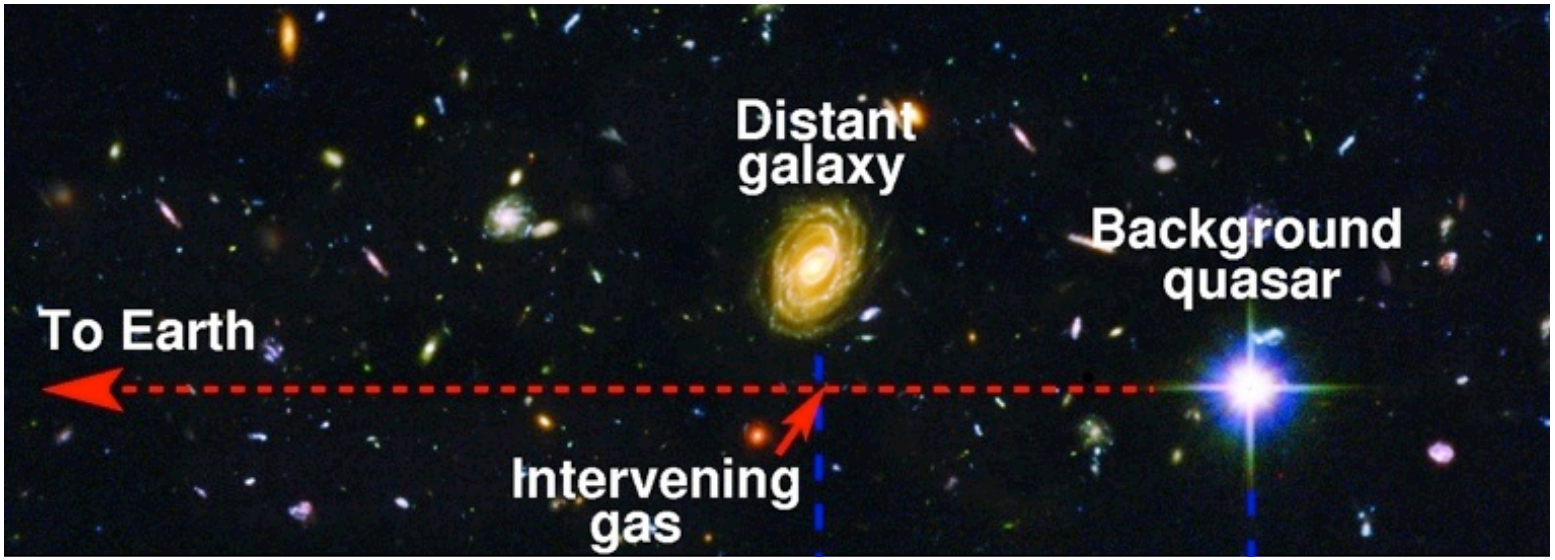



Zwaan et al. 05

# absorption (z > 1.7)



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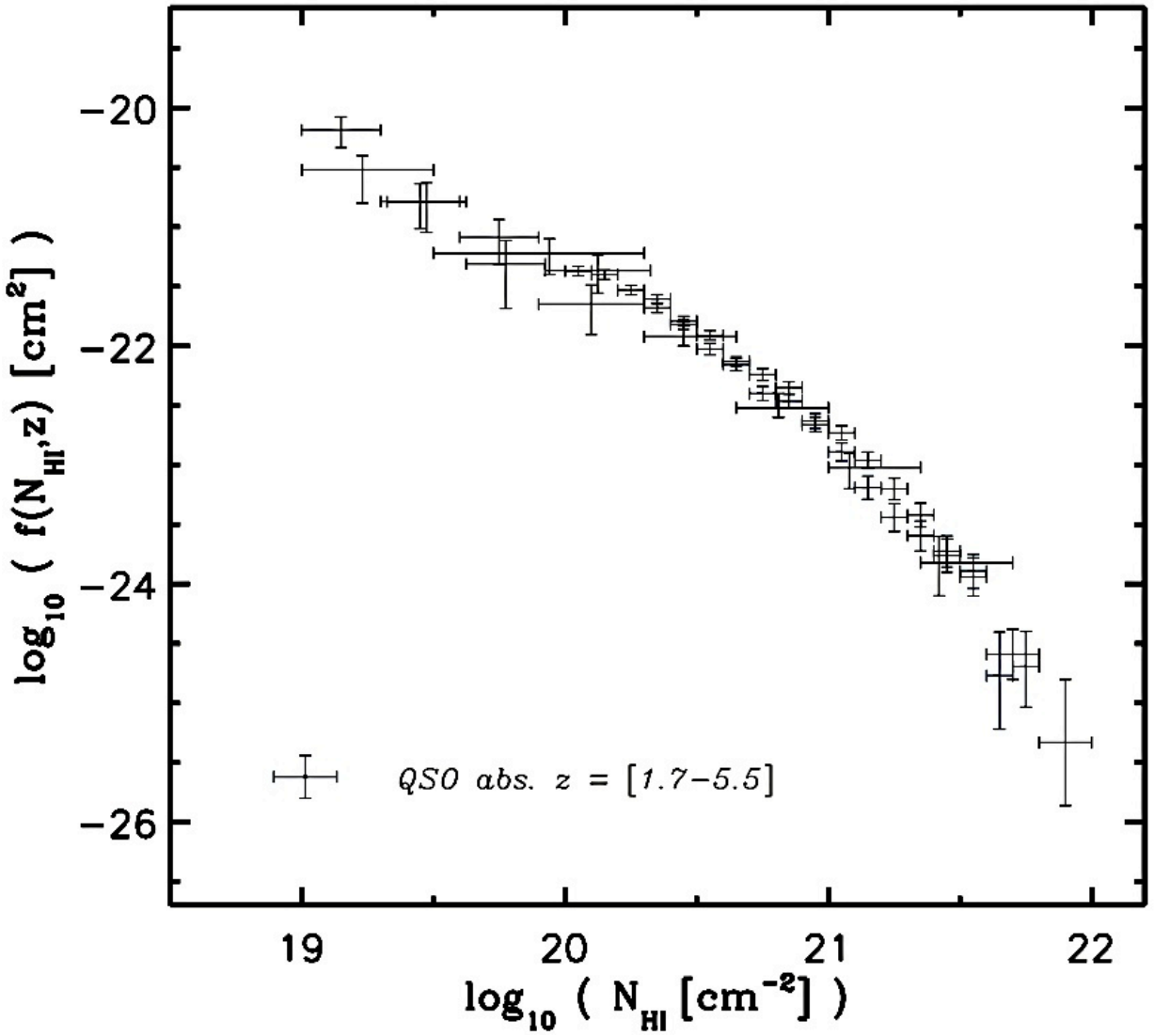
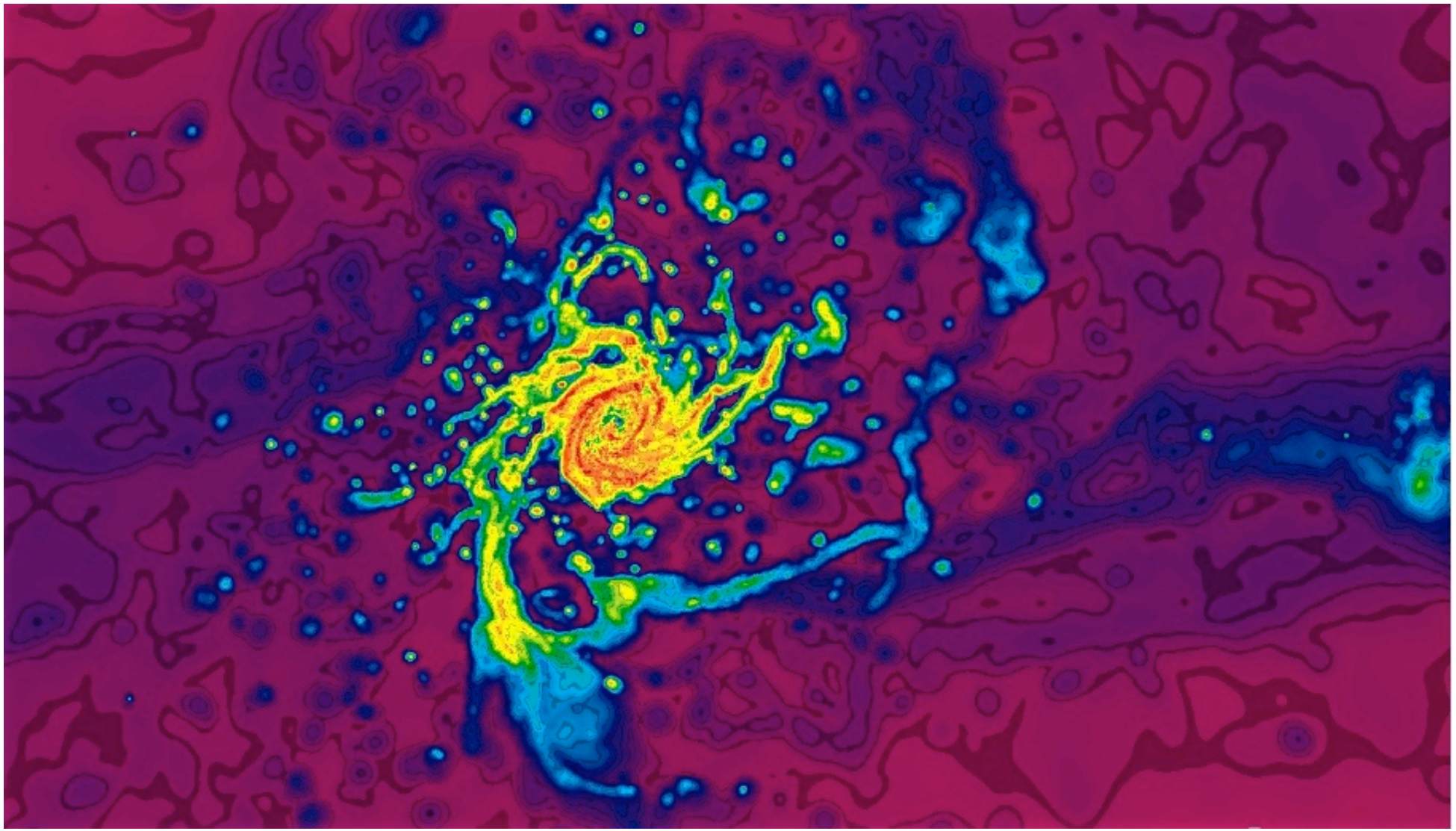



Peroux et al. 05; OMeara et al 07; Noterdaeme et al. 09; Prochaska & Wolfe 09; Kim et al. 02

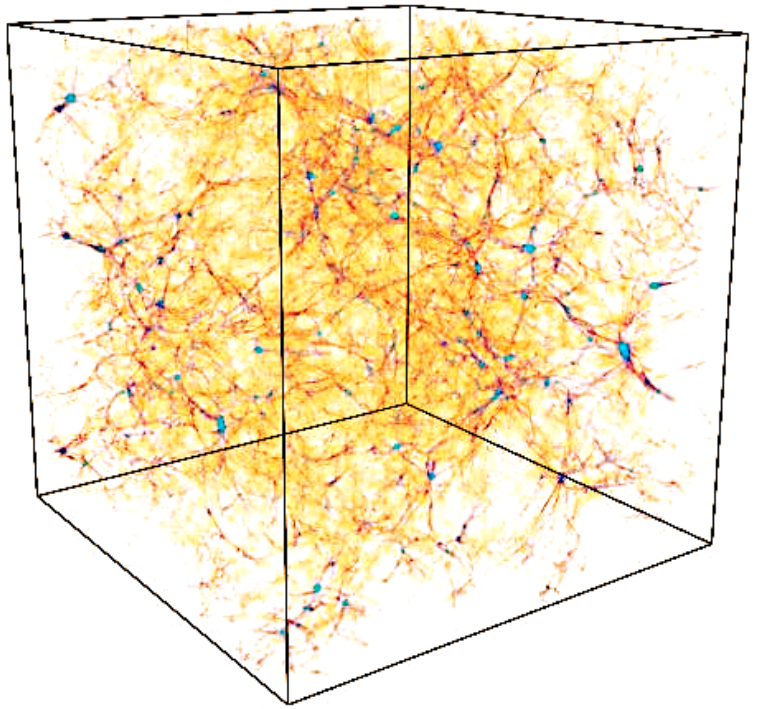
# HI in cosmological simulations



# cosmological simulations

OWLS REFERENCE Model, (Schaye et al. 10)

- gravity+hydrodynamics: GADGET-3
- star formation: subgrid KS
- supernovae feedback: kinetic
- radiative heating/cooling: metals
- chemical evolution
- cosmology : WMAP year 7
- $M_{SPH} = 1.4 \times 10^6 \ M_\odot \ h^{-1}$



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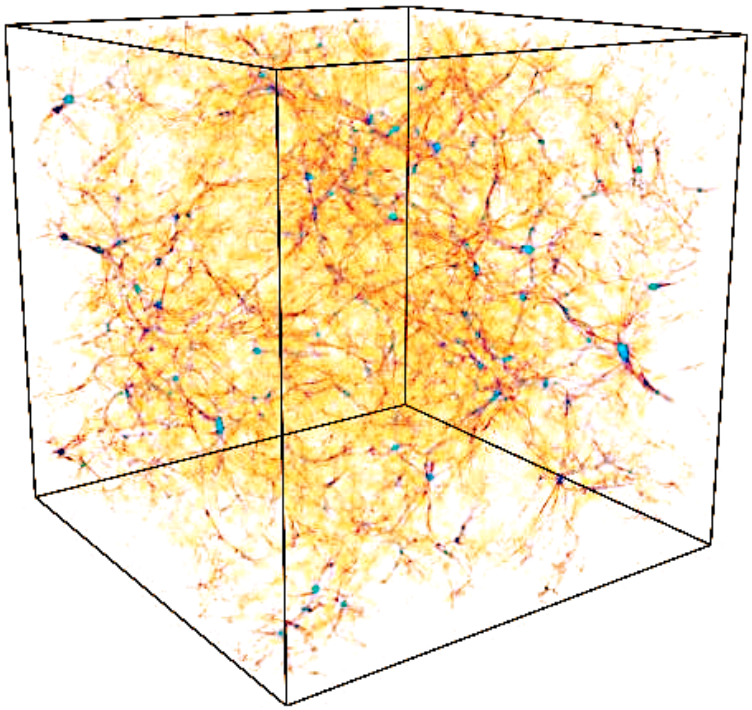

## ioniziation processes

RT using TRAPHIC, (Pawlik & Schaye 08, 11)

## cosmological simulations

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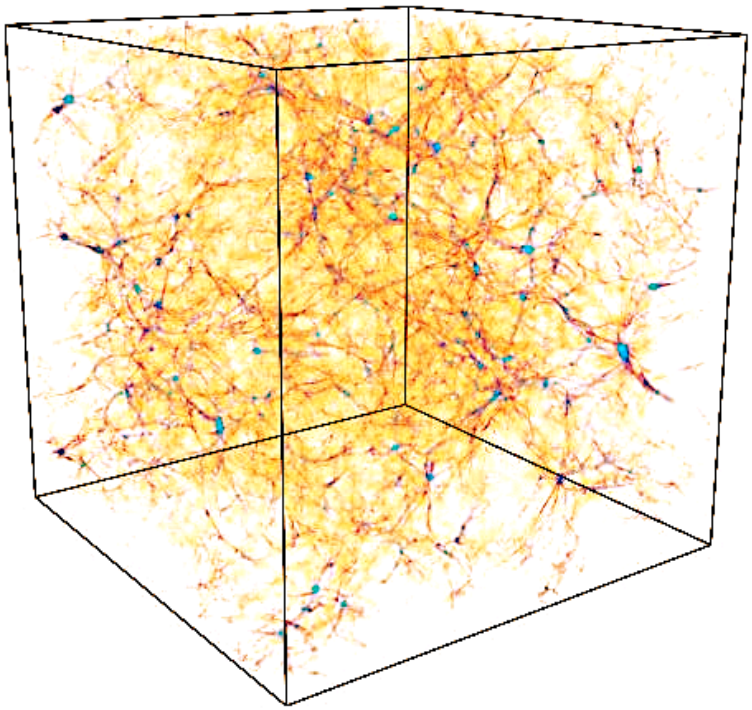

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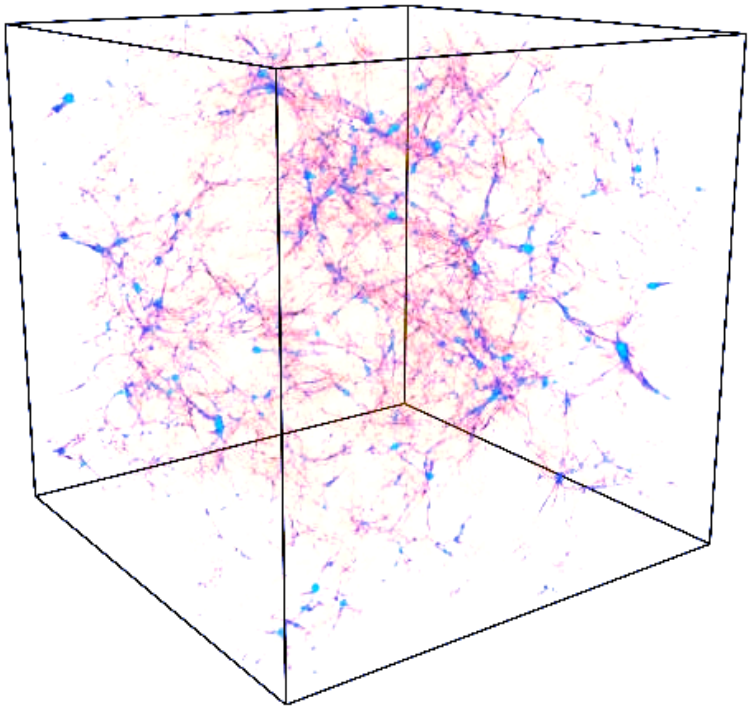
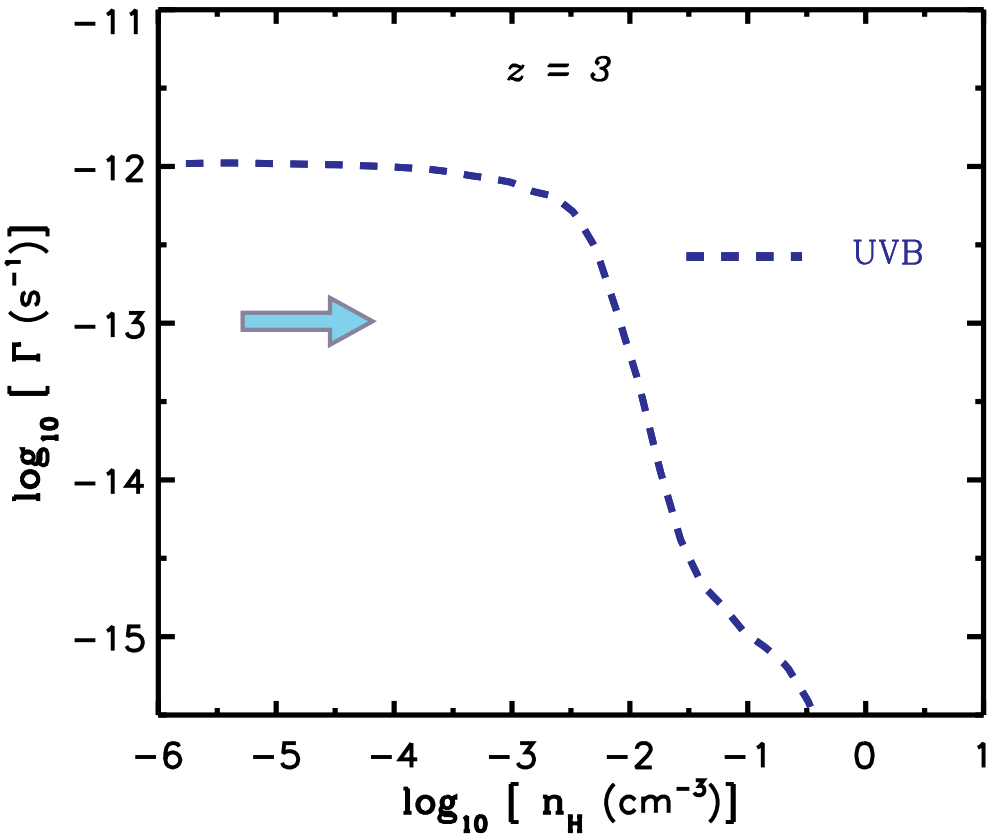


# main ionization processes

✤ Uniform UV Background (UVB)

Haardt & Madau 01

plane parallel
gray approximation




Rahmati et al. 13a

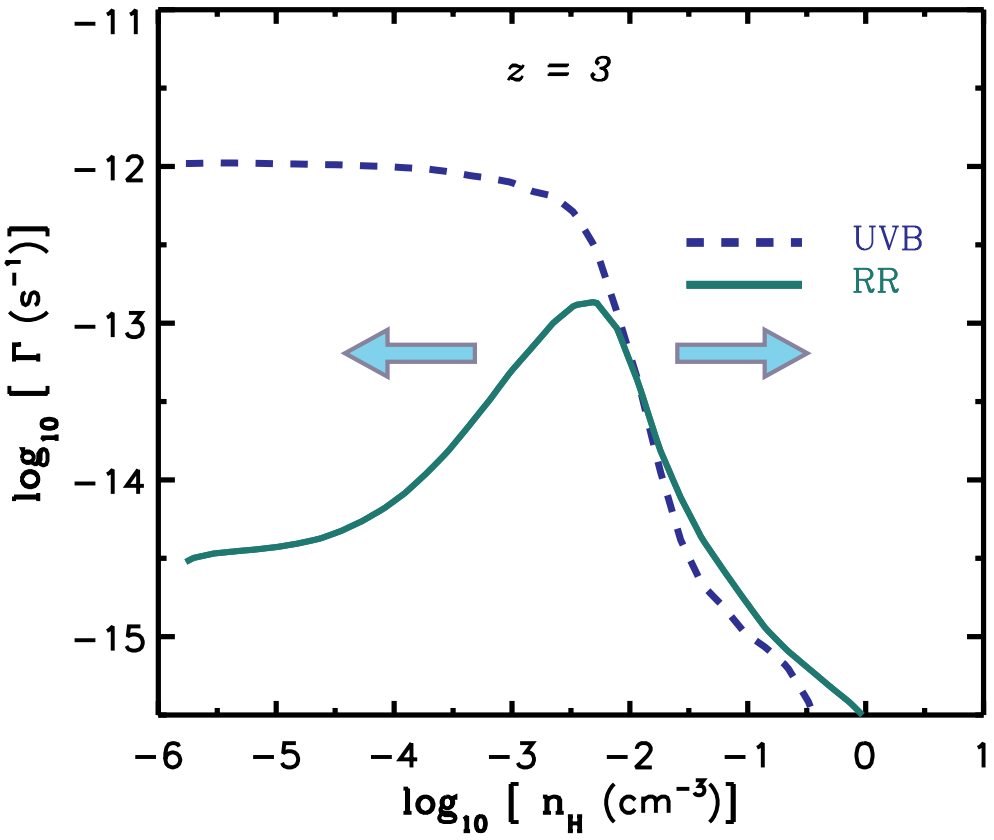
# main ionization processes

- Uniform UV Background (UVB)
- recombination radiation (RR)

peaks at around self-shielding

moves the self-shielding to higher densities

makes the transition smoother

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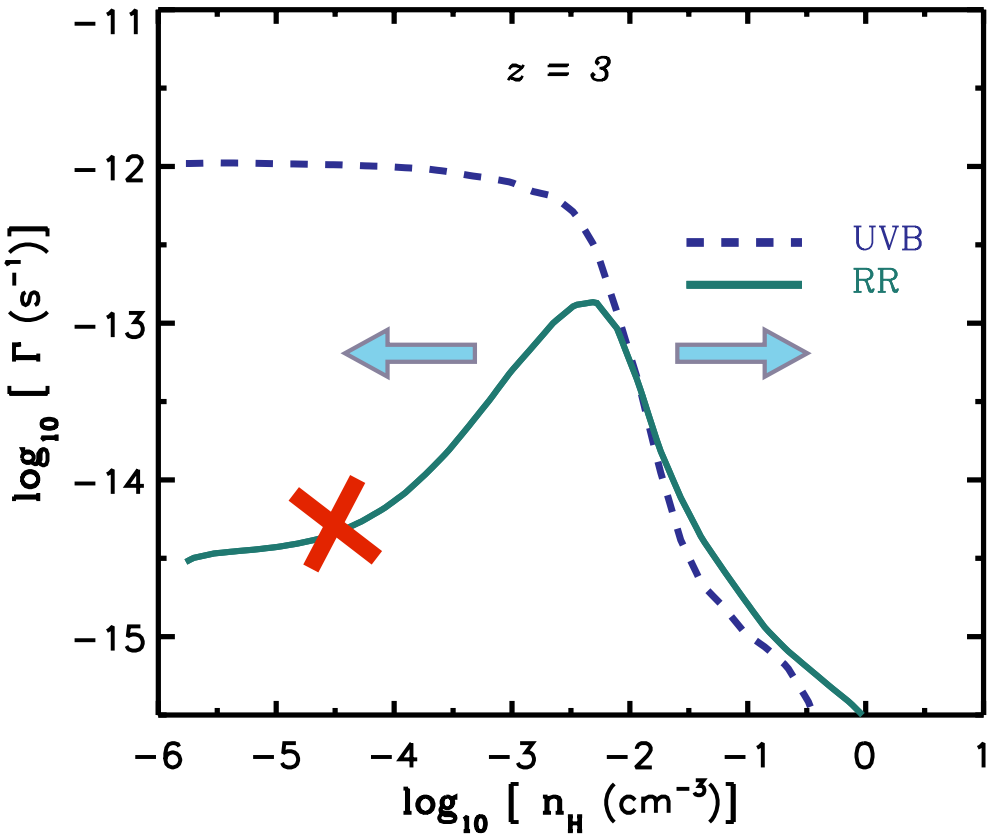


Redshifting

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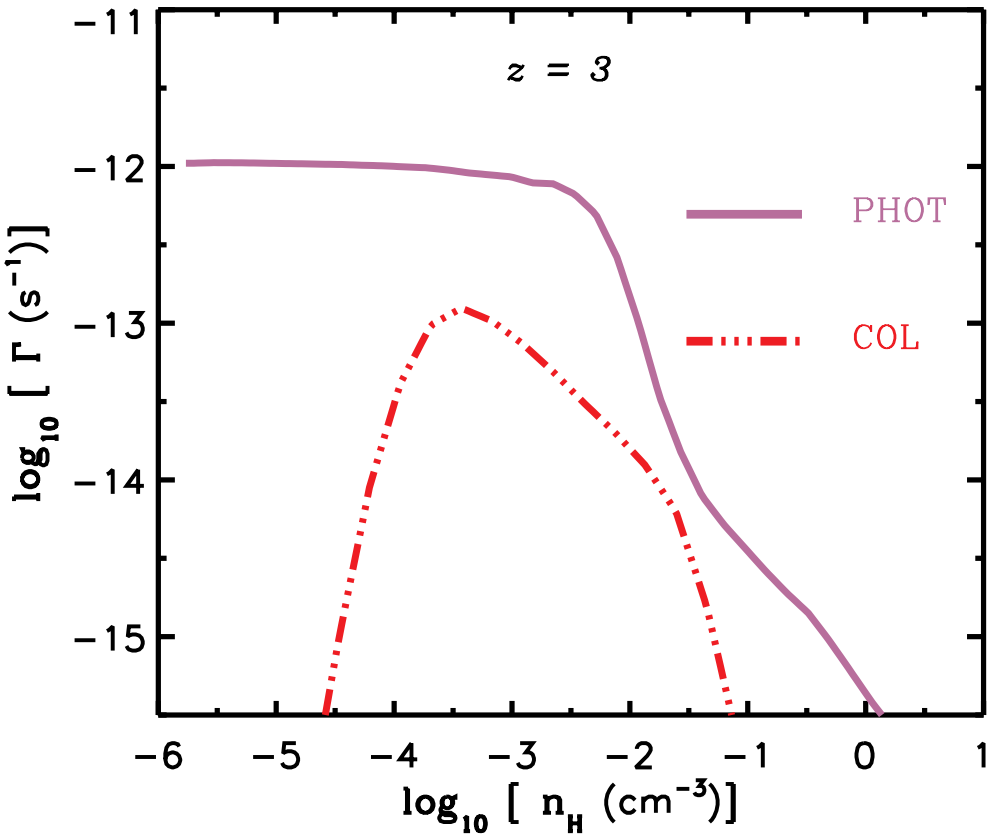
# main ionization processes

- Uniform UV Background (UVB)
- recombination radiation (RR)
- collisional ionization (COL)

  not important at z > 1

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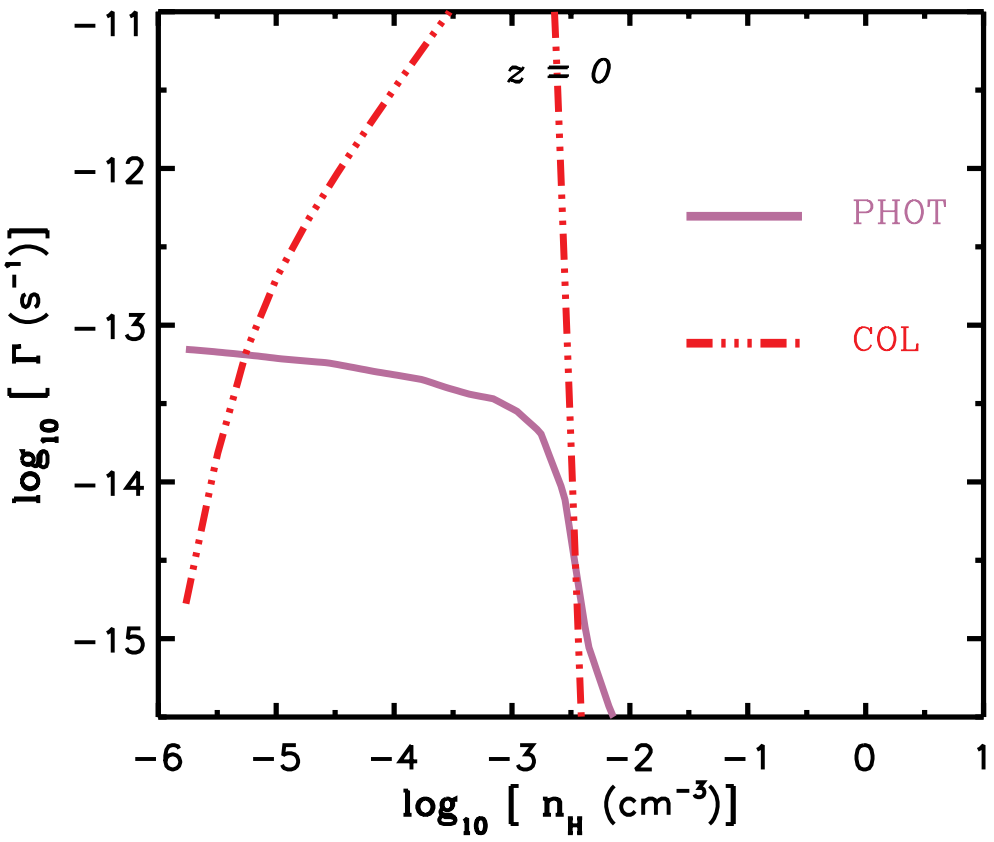


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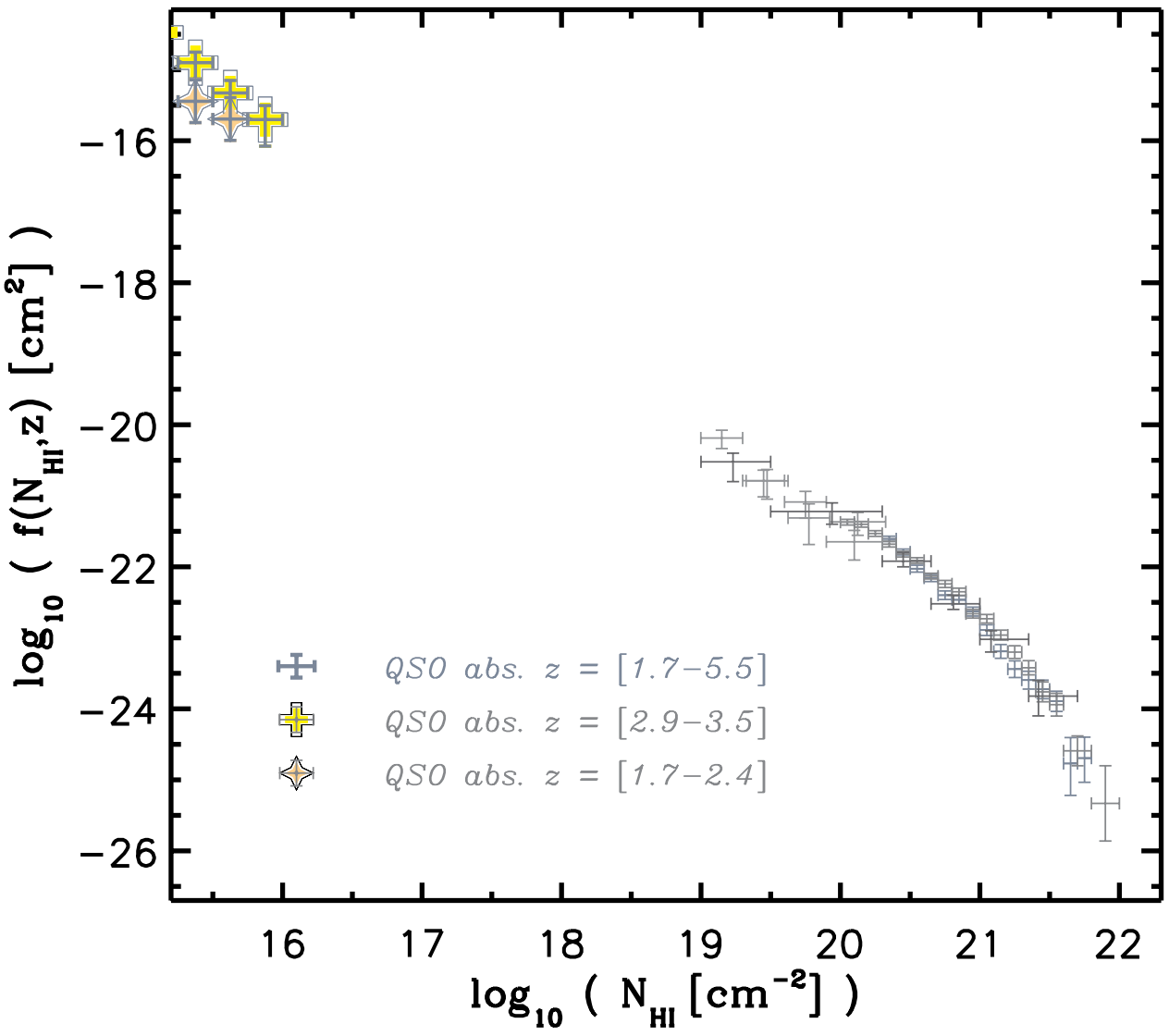
# HI column density distribution function

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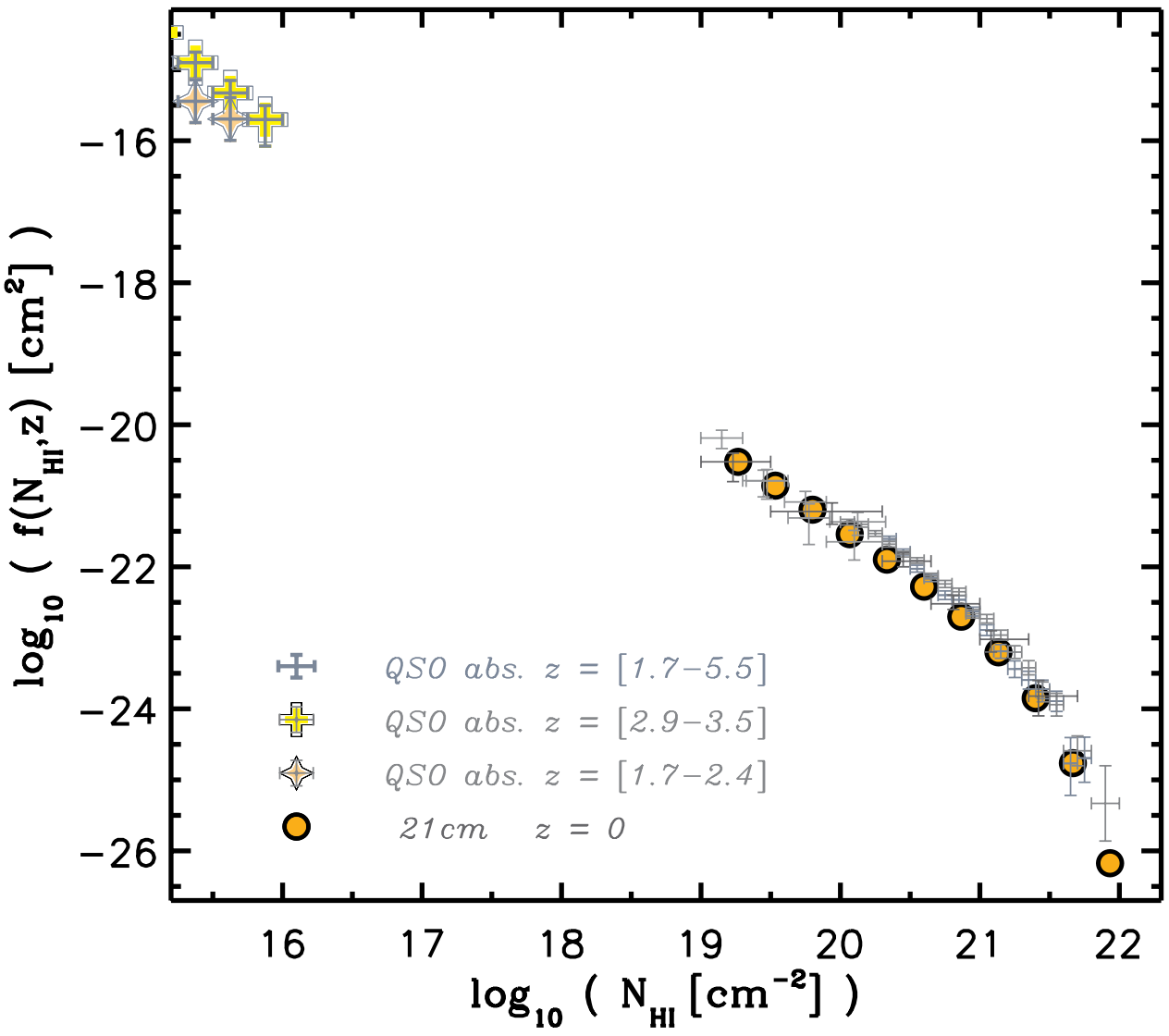


Zwaan et al. 05

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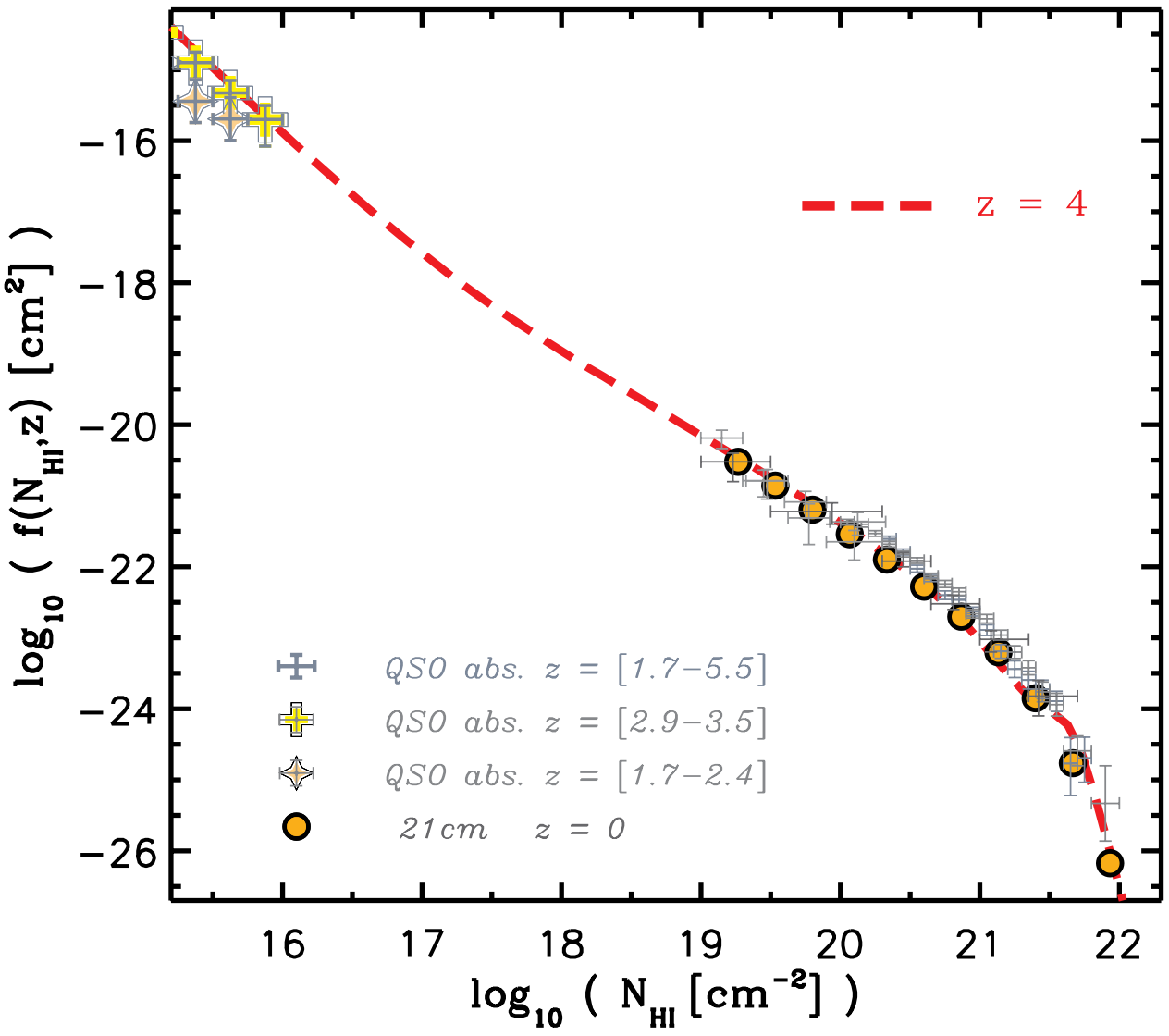


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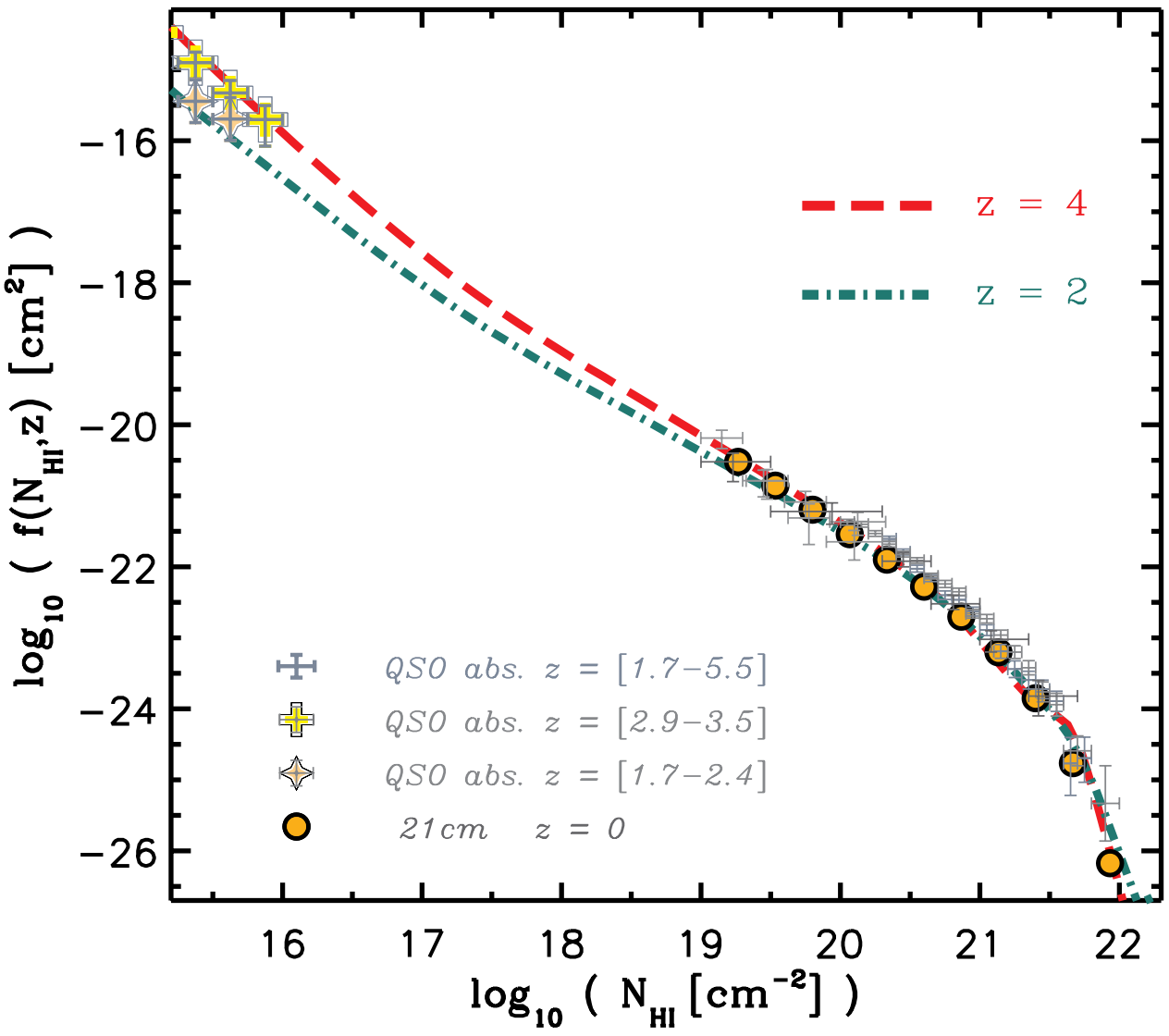


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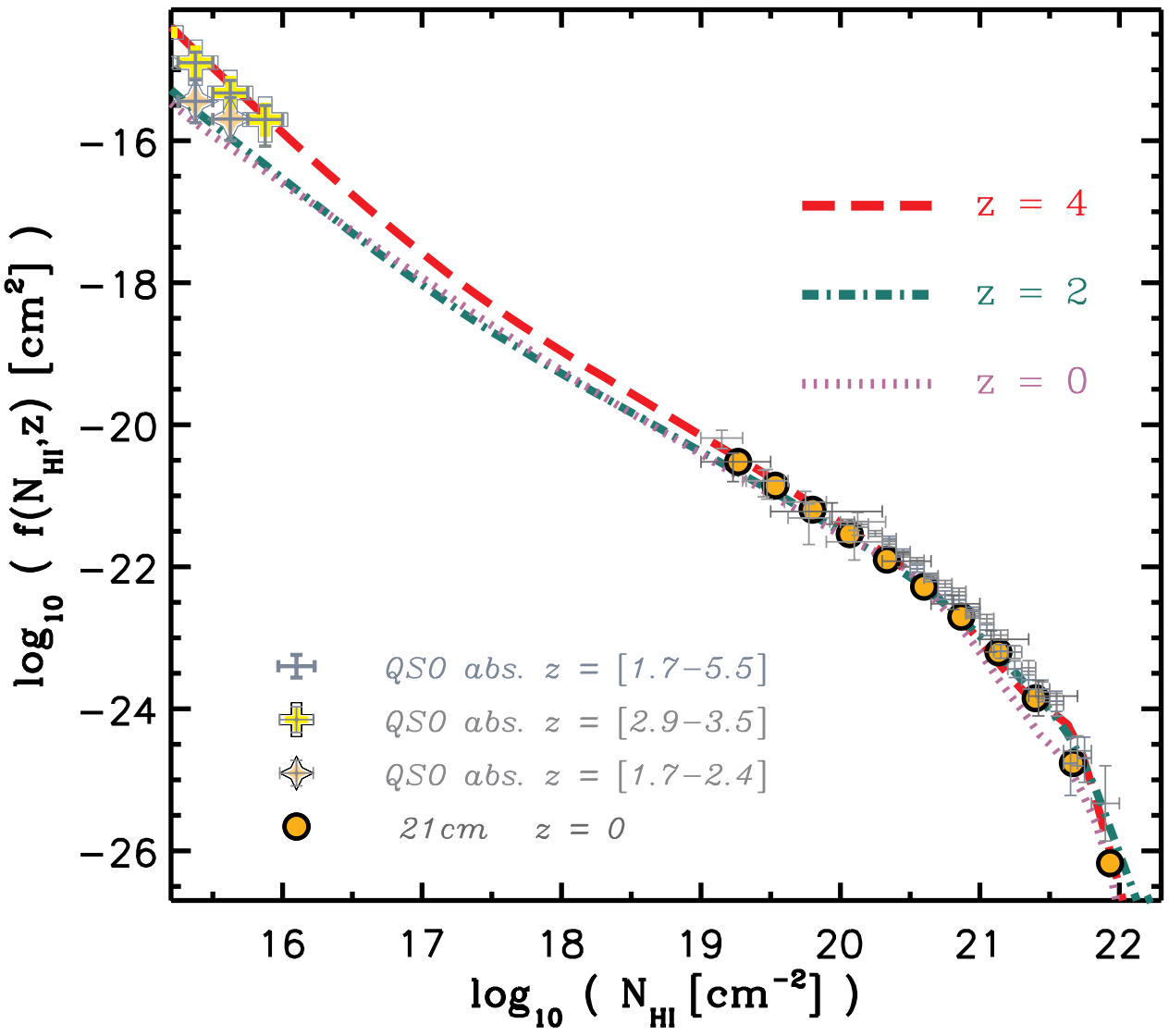


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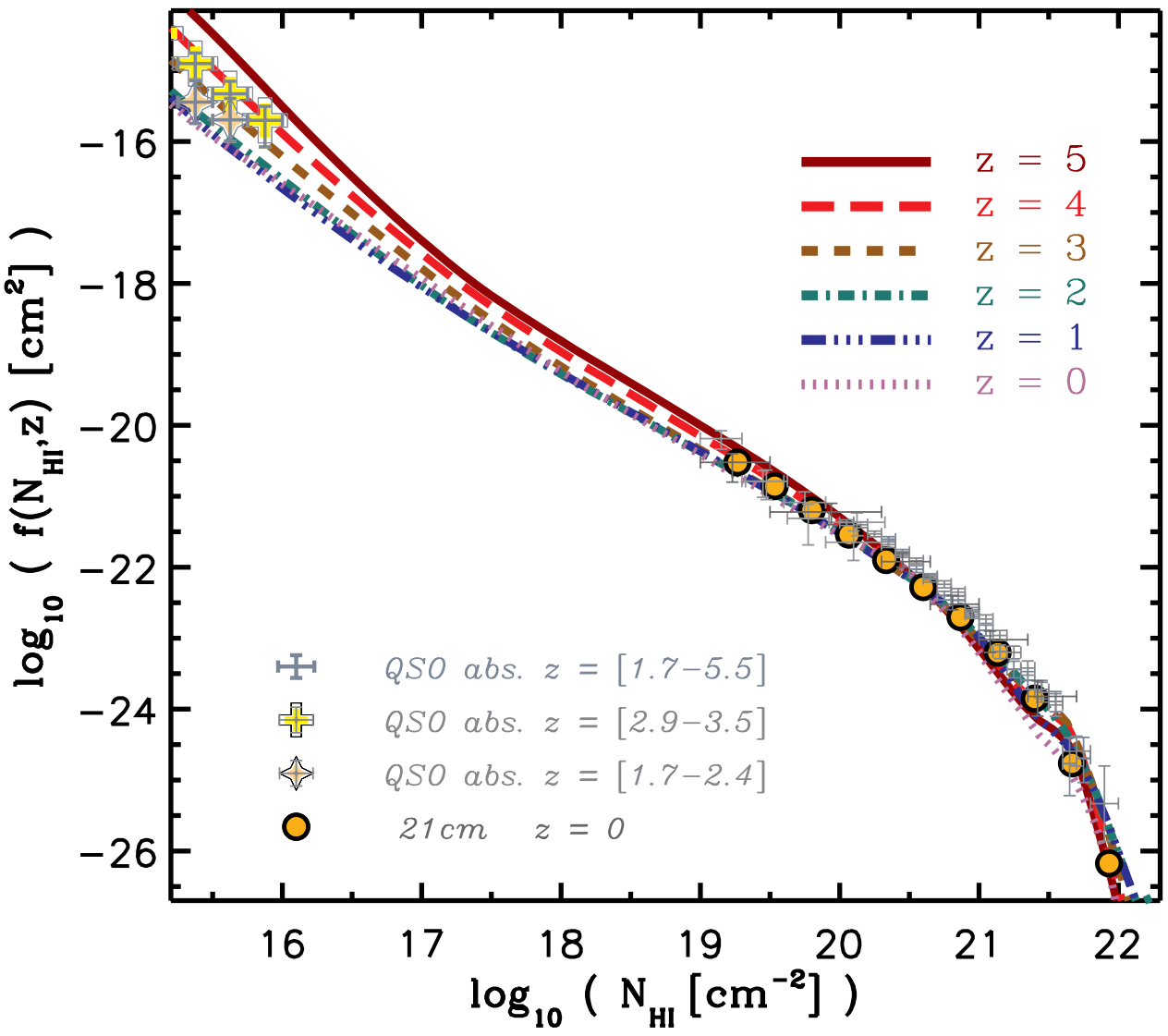


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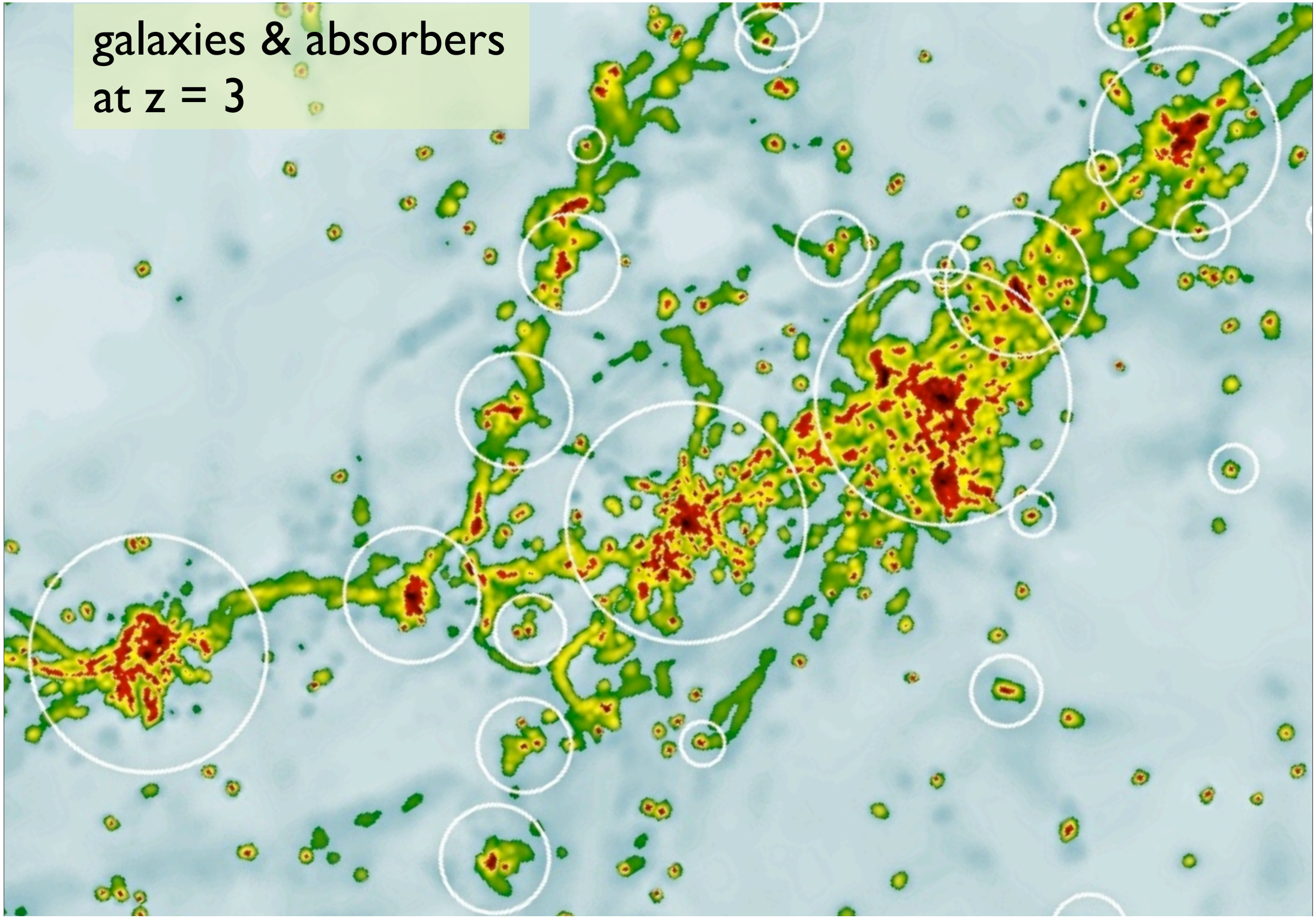
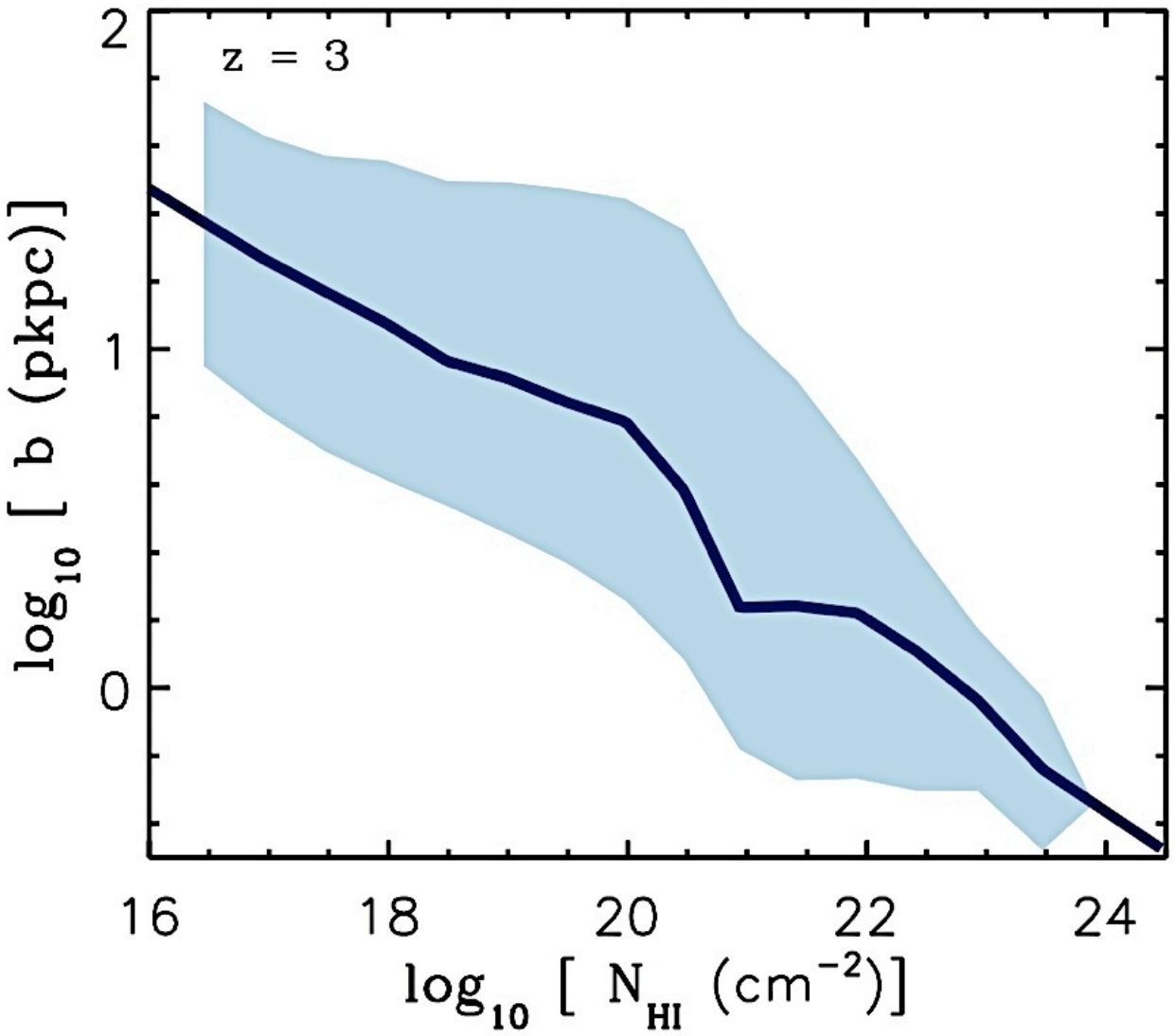

galaxies & absorbers
at z = 3

# anti-correlation between $b$ & $N_{\rm HI}$

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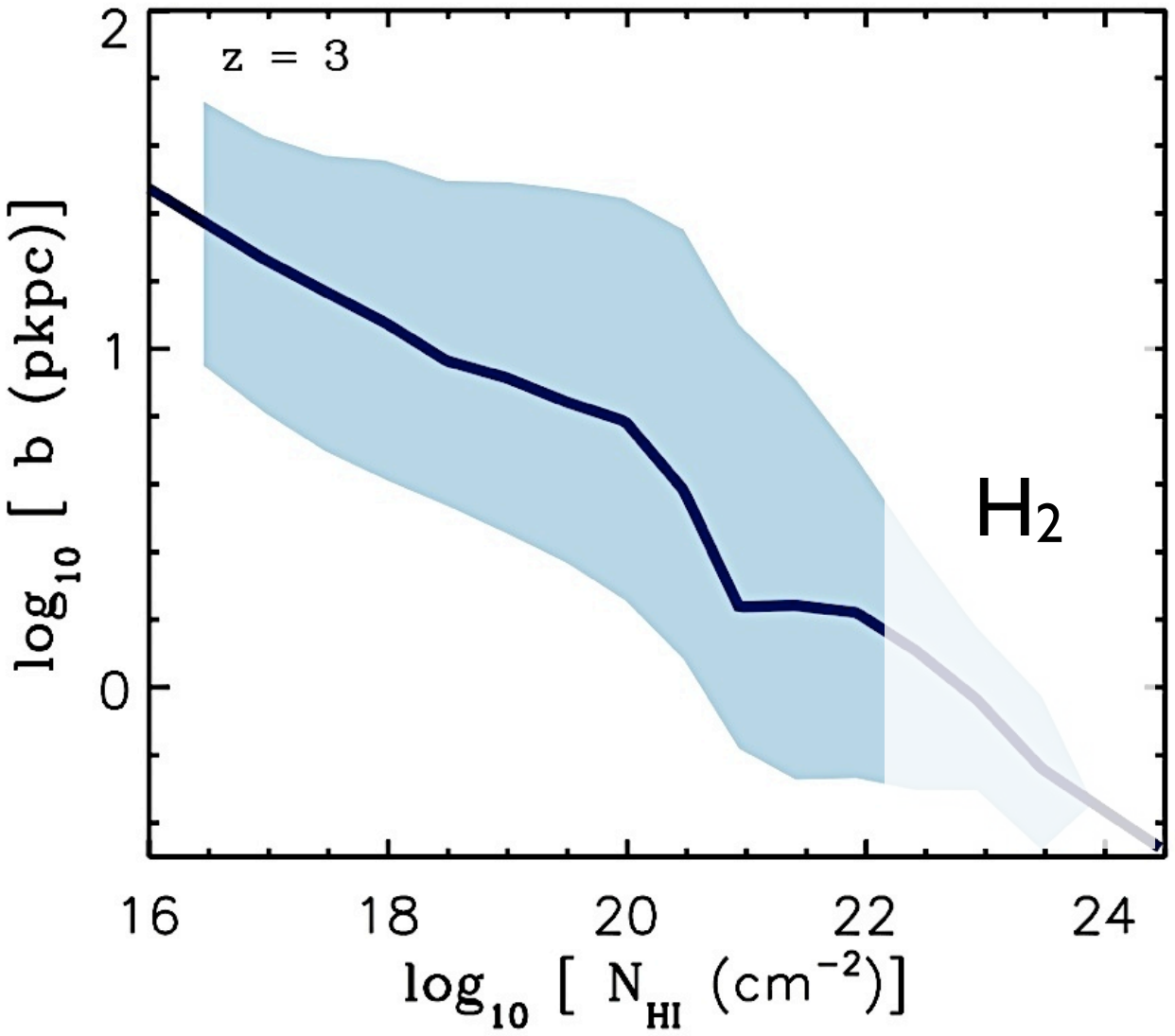


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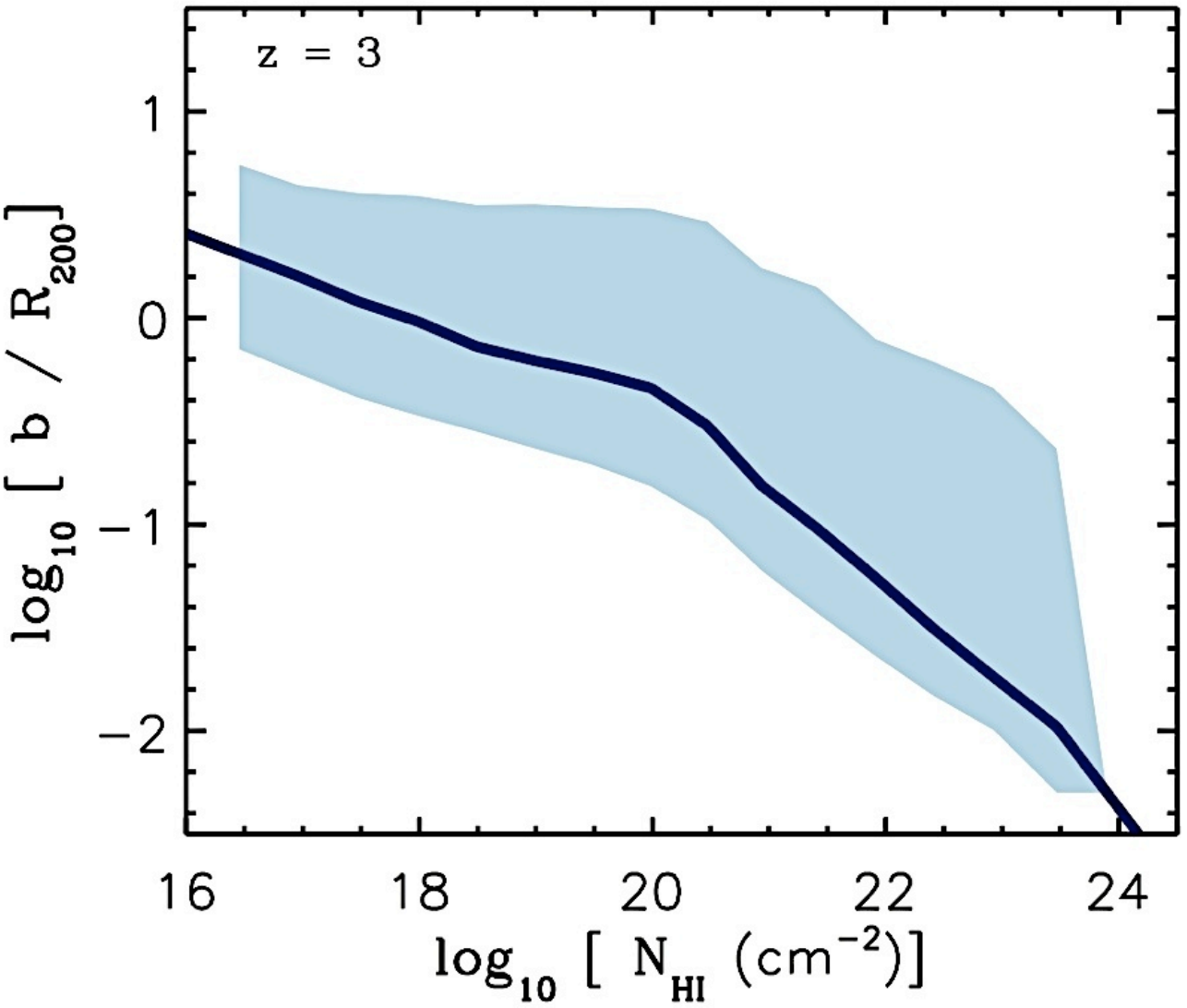
# normalized impact parameter

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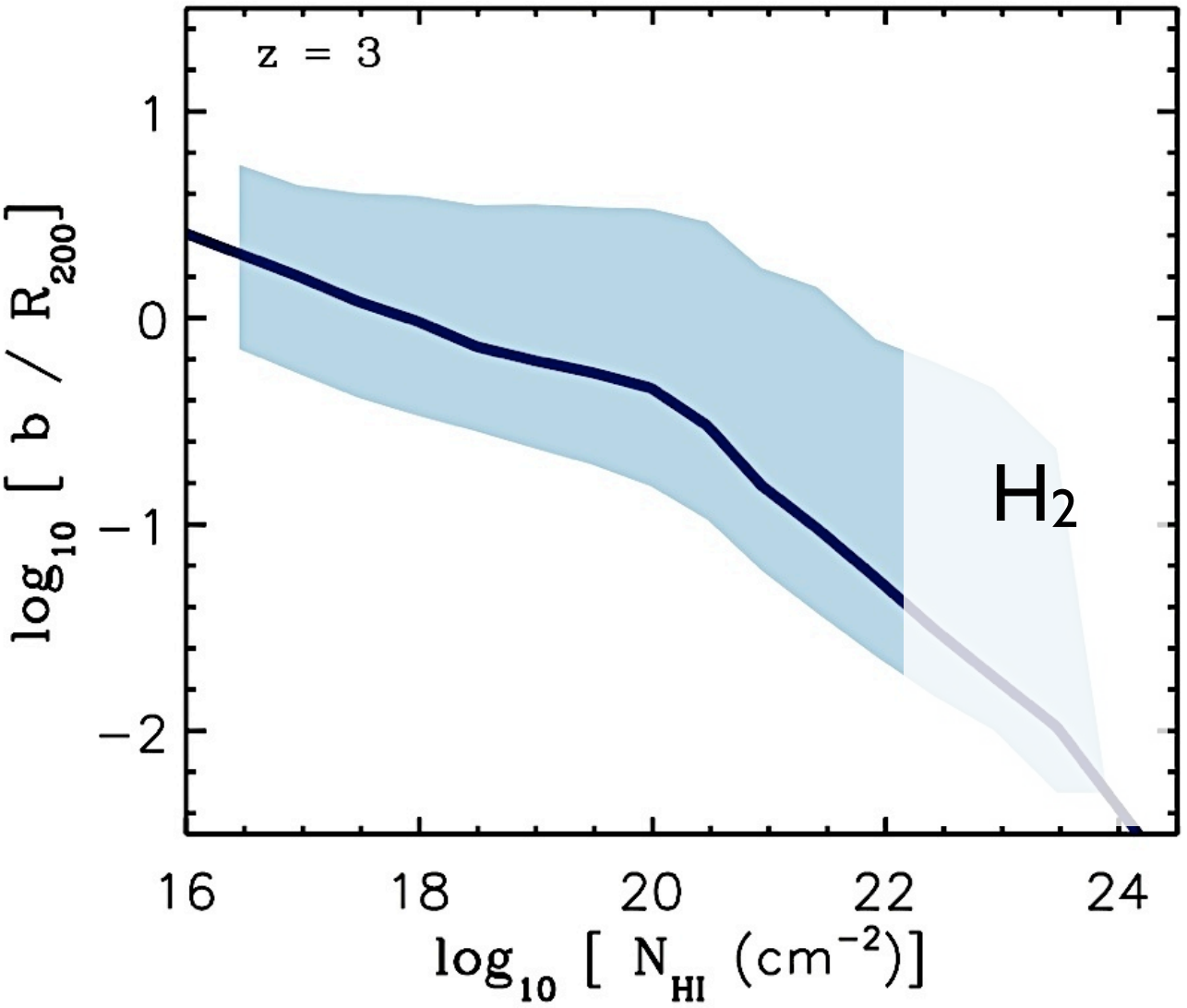


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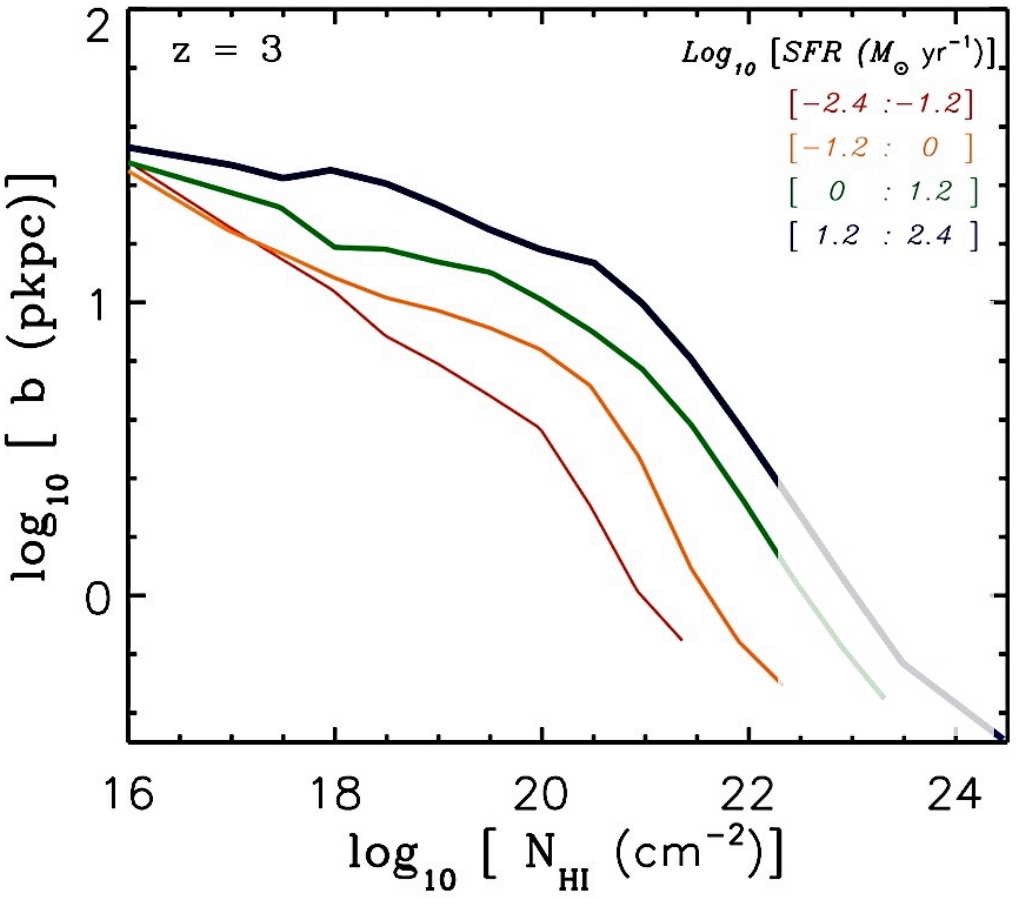
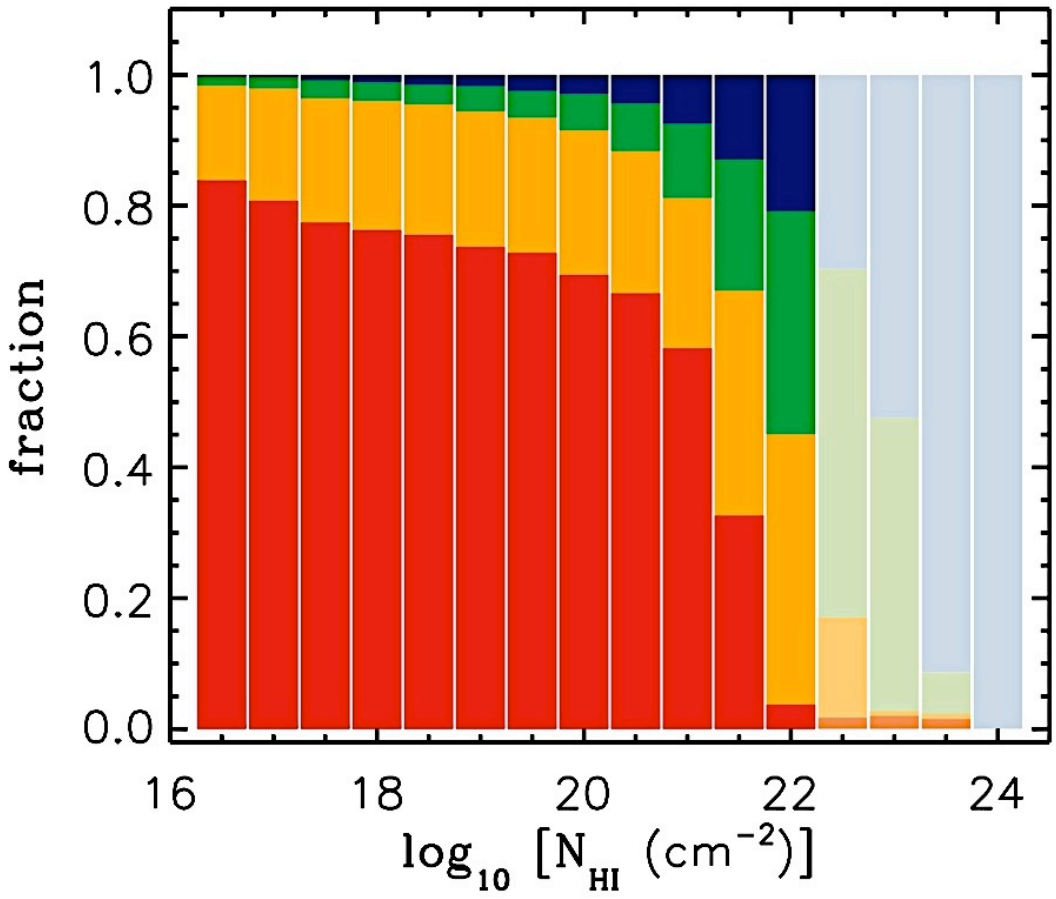
# correlation with galaxy SFRs (masses)

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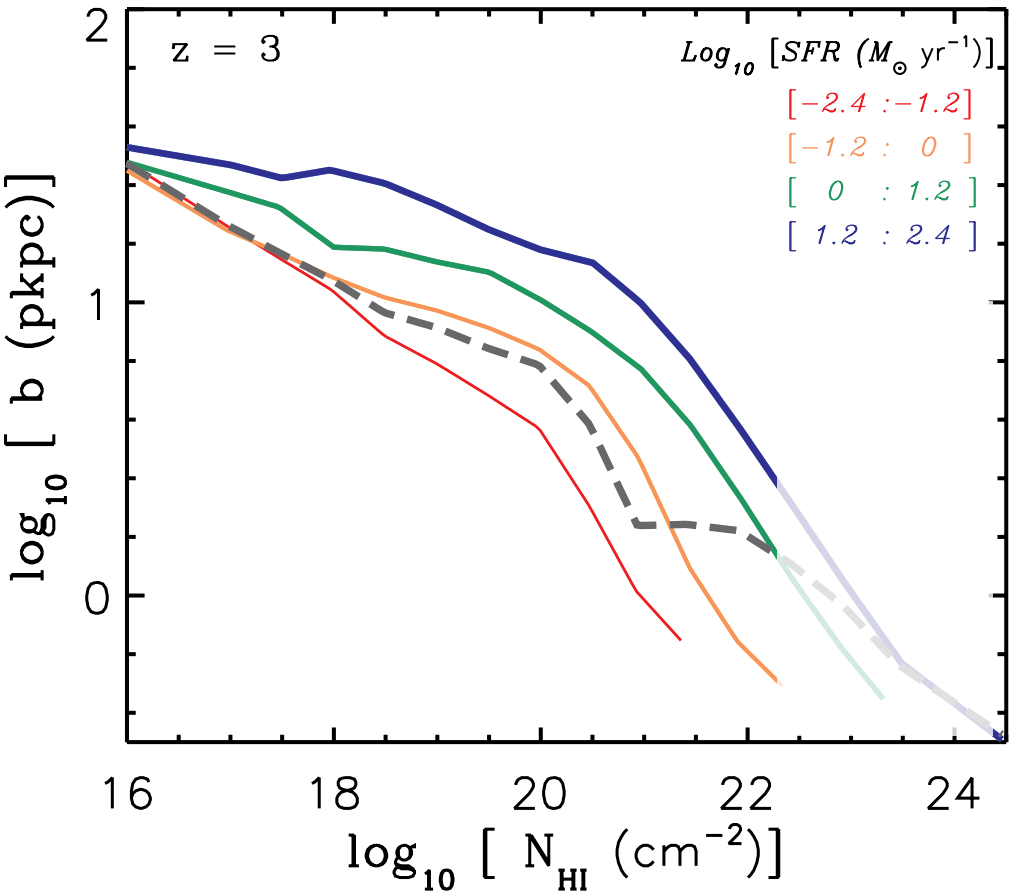


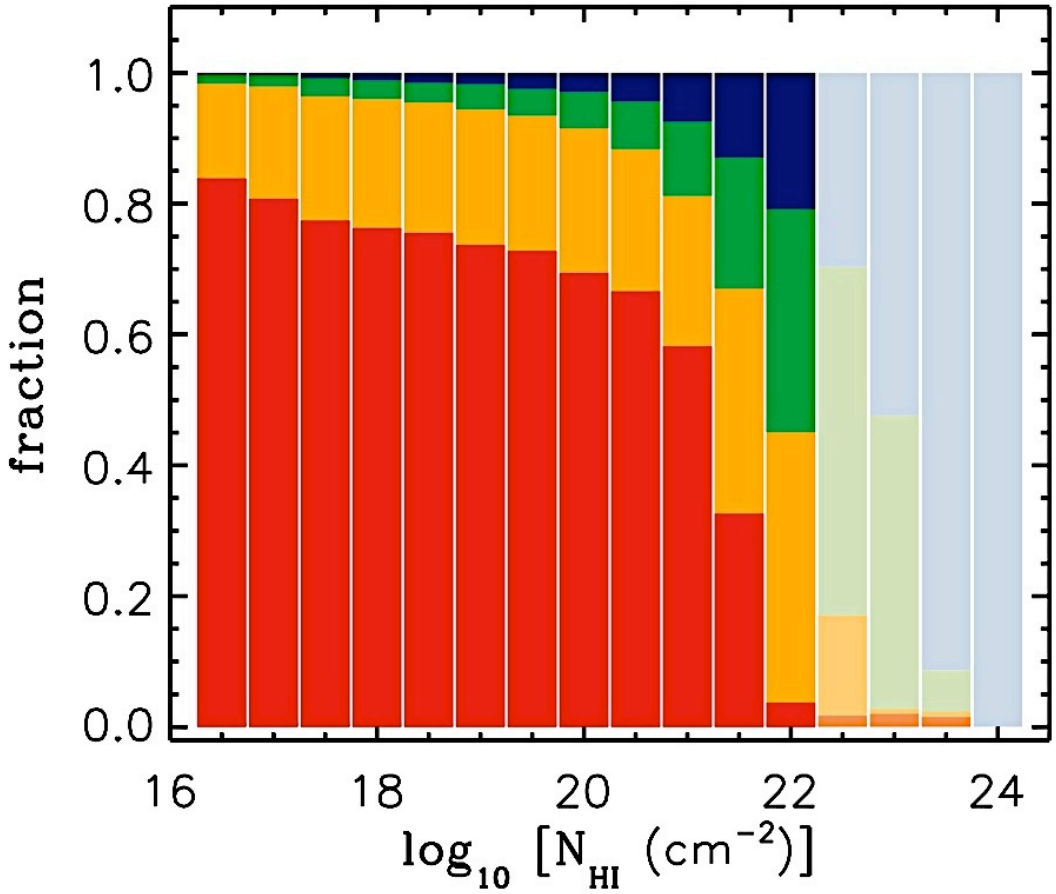


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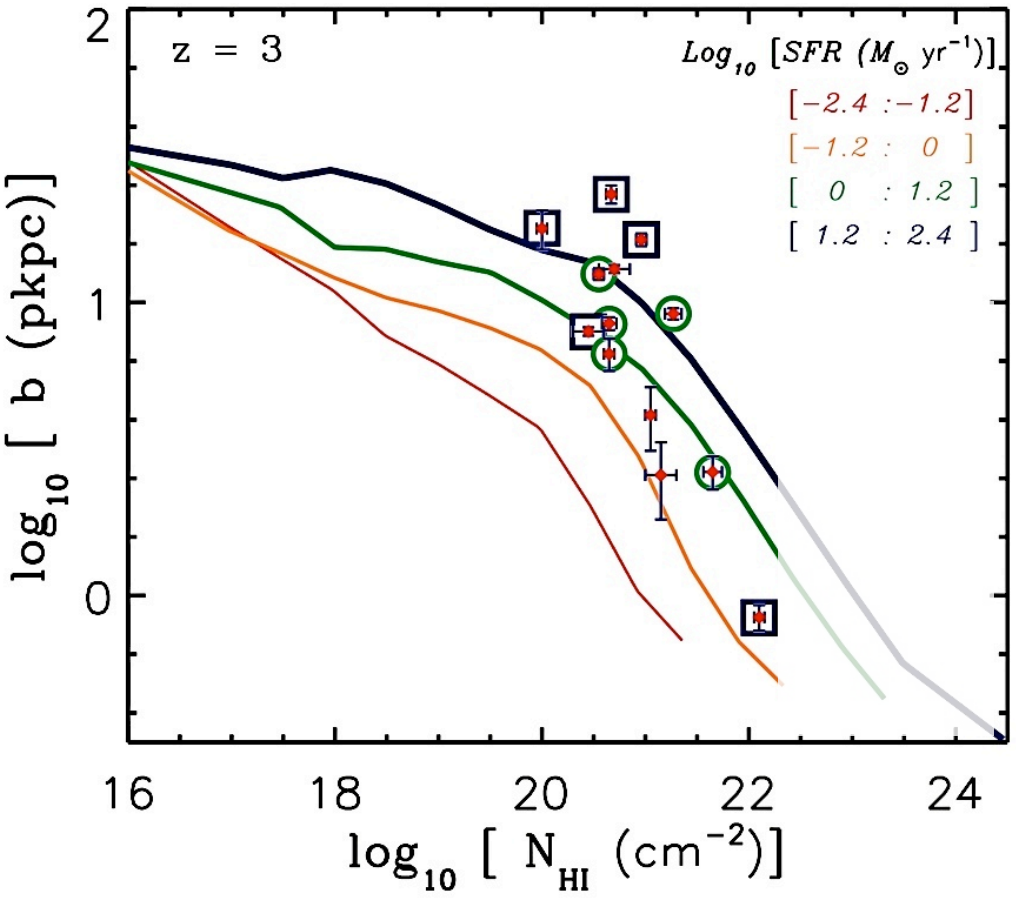


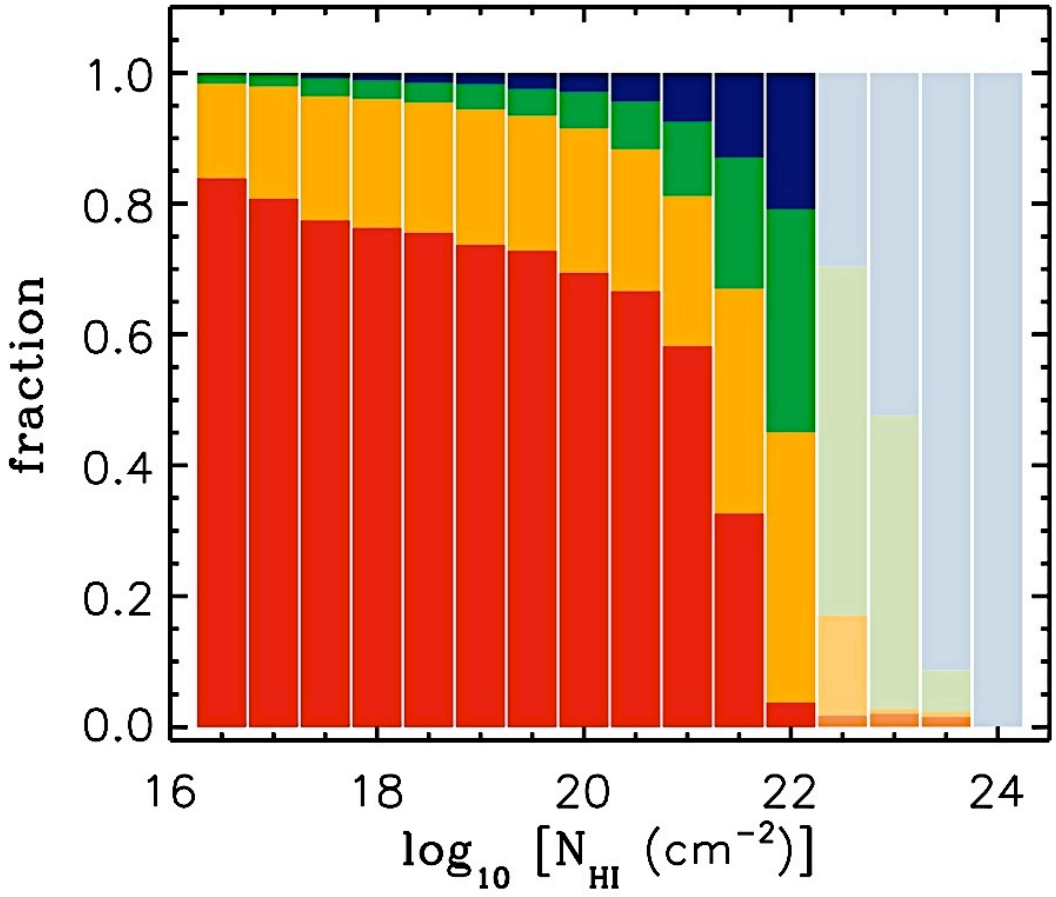


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most absorbers are close to low mass galaxies

$$(\mathrm{M}_\star \lesssim 10^8\ \mathrm{M}_\odot)$$

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most absorbers can be found within 300 kpc of Lyman-Break galaxies

$$(M_\star \gtrsim 10^{10}\ M_\odot)$$

(e.g., Rudie et al. 2012)

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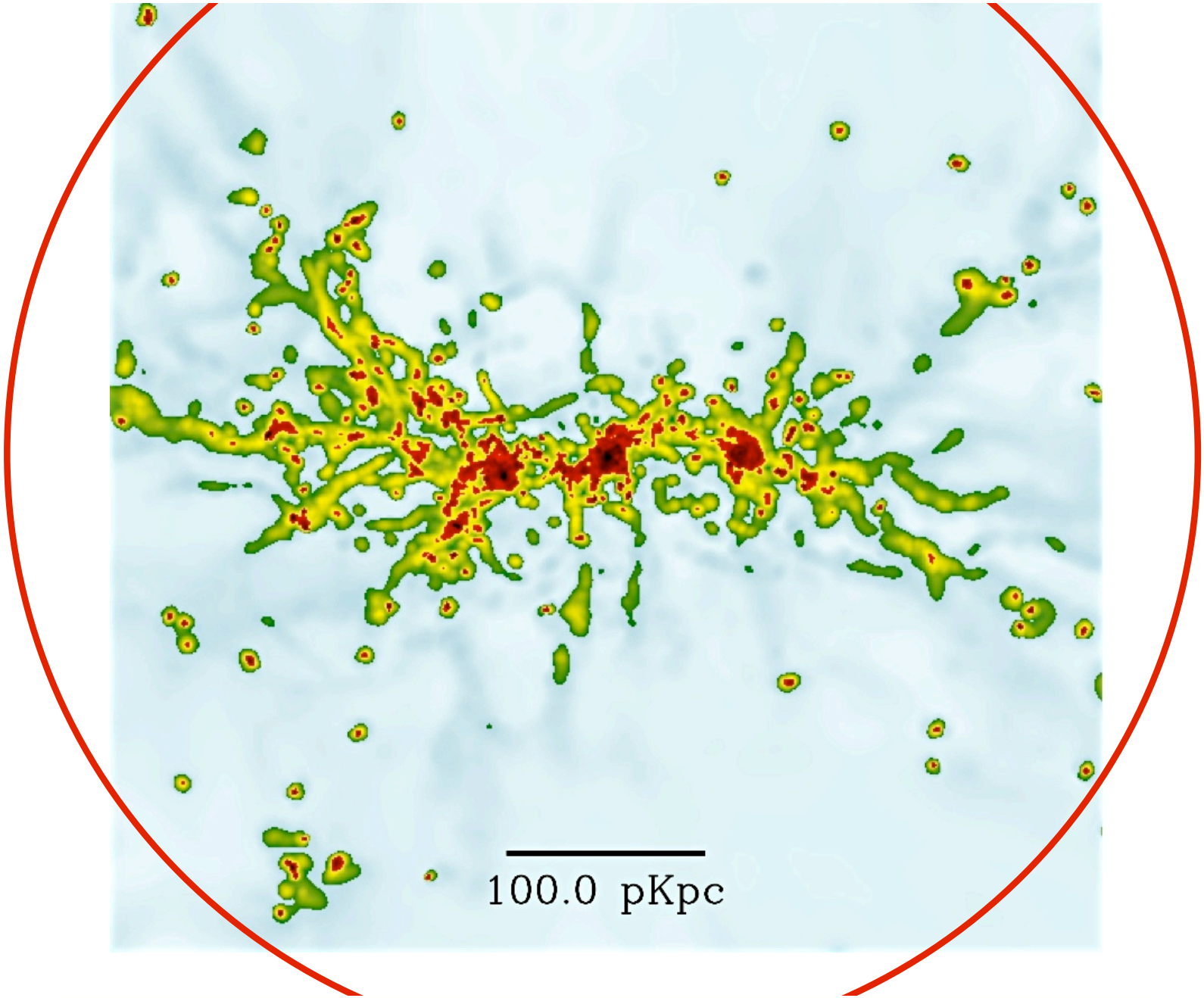
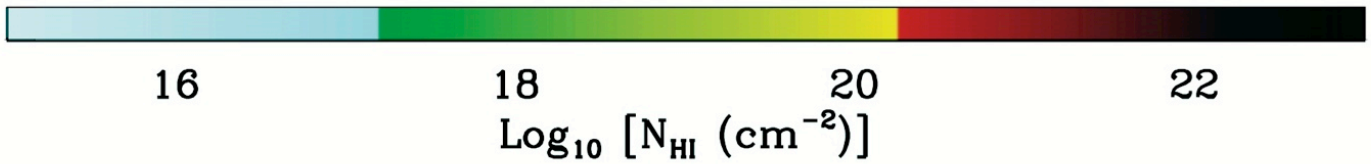
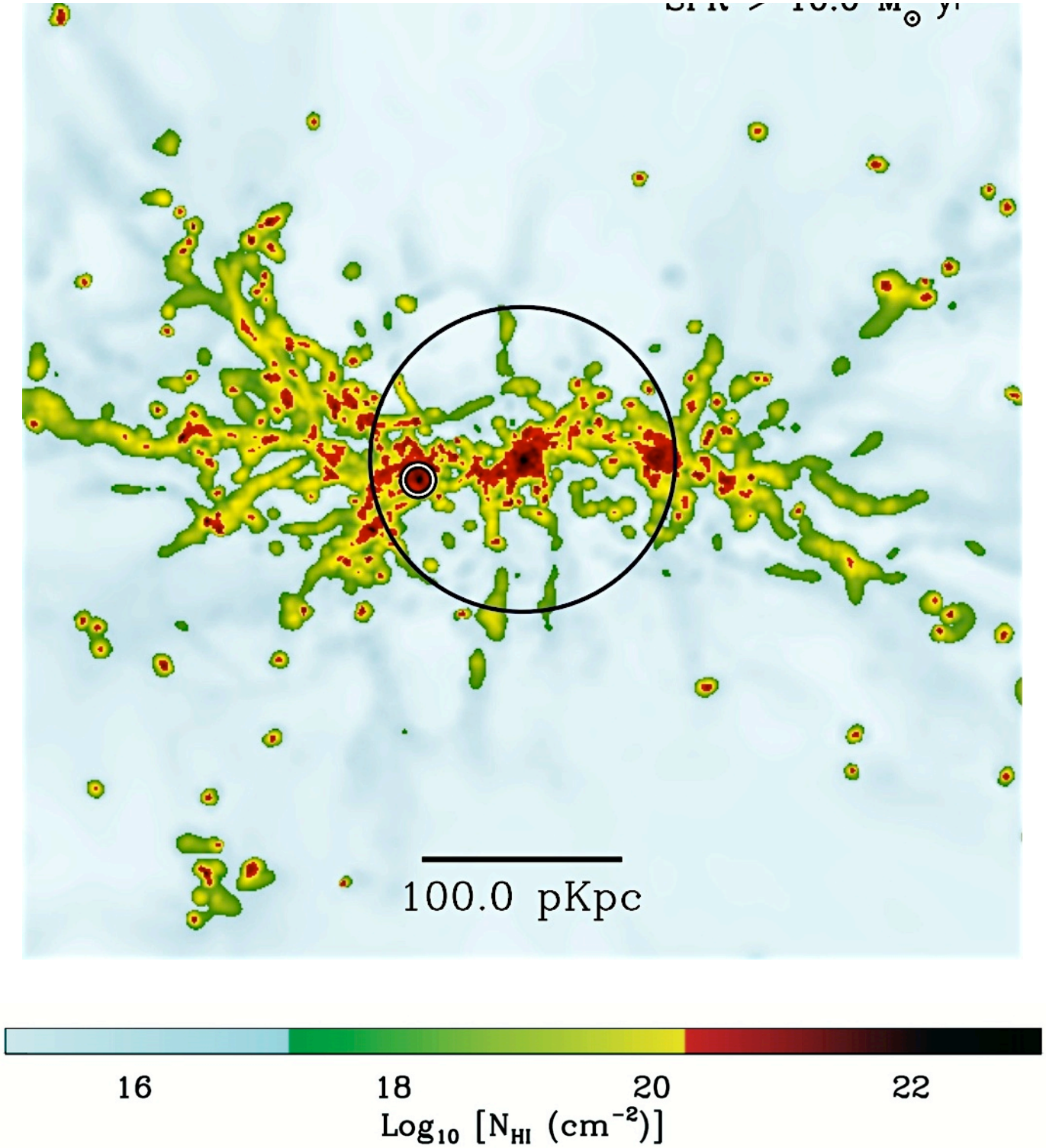
Is this surprising?


100.0 pKpc


16
18
20
22
Log10 [NHI (cm-2)]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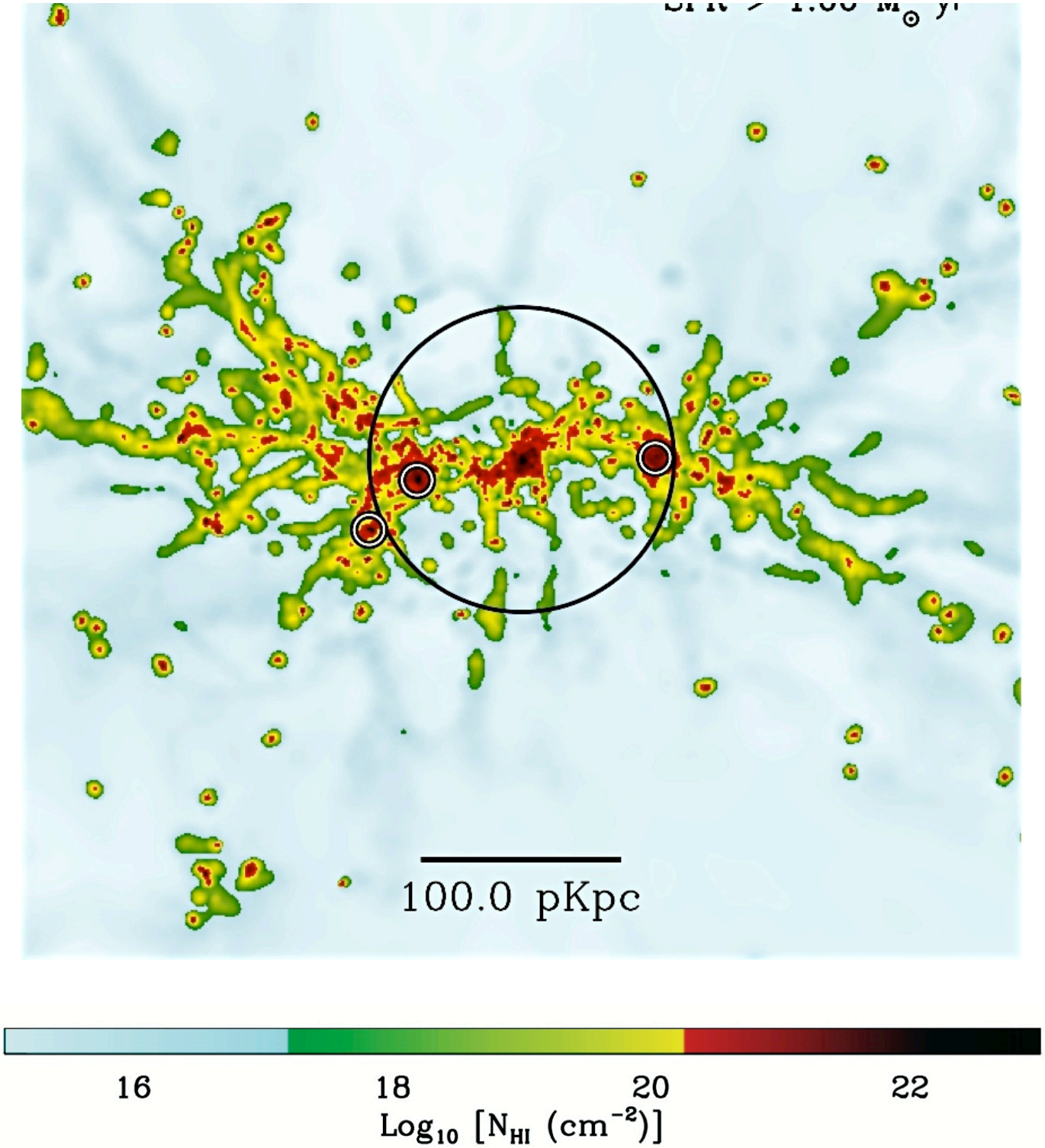
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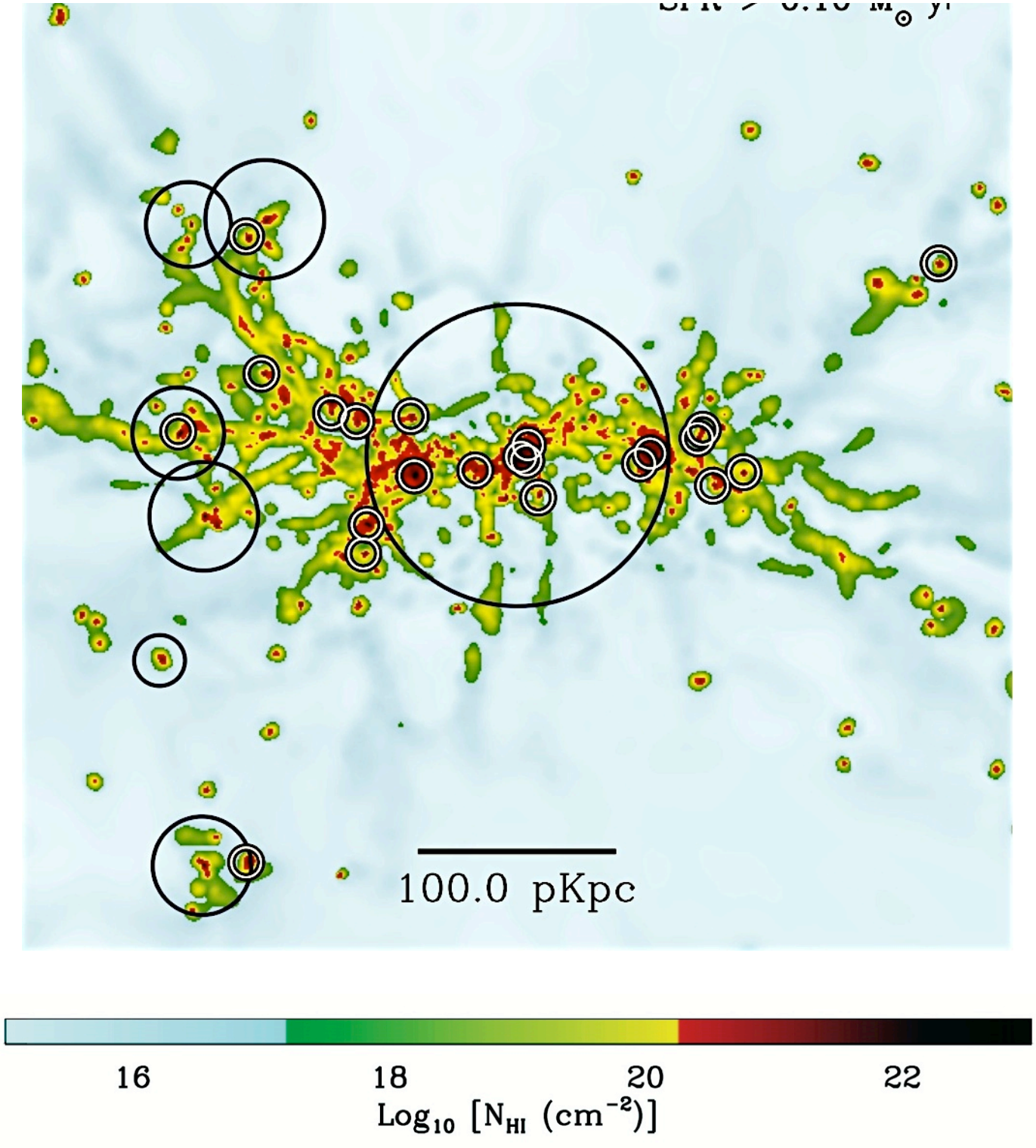
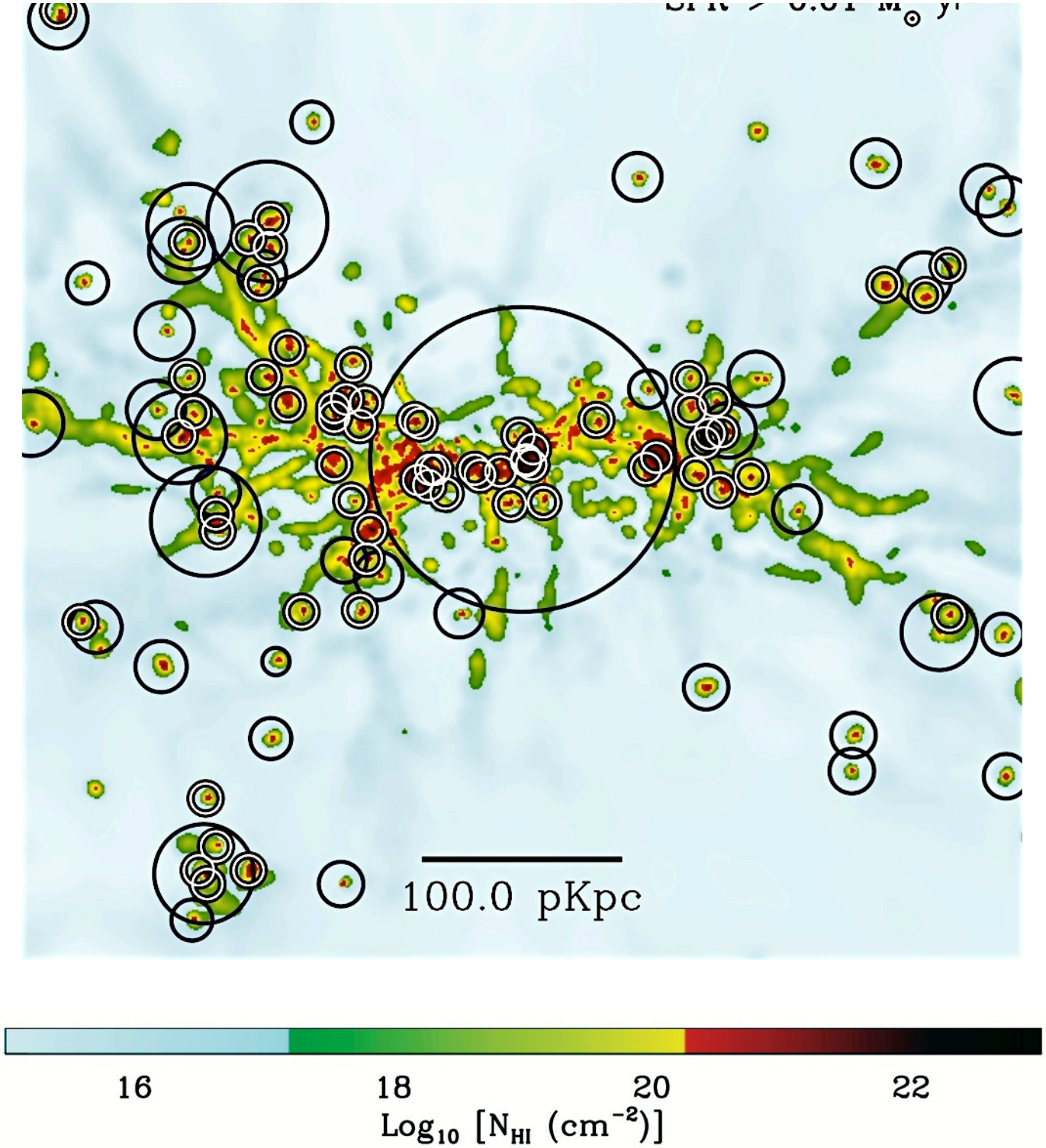
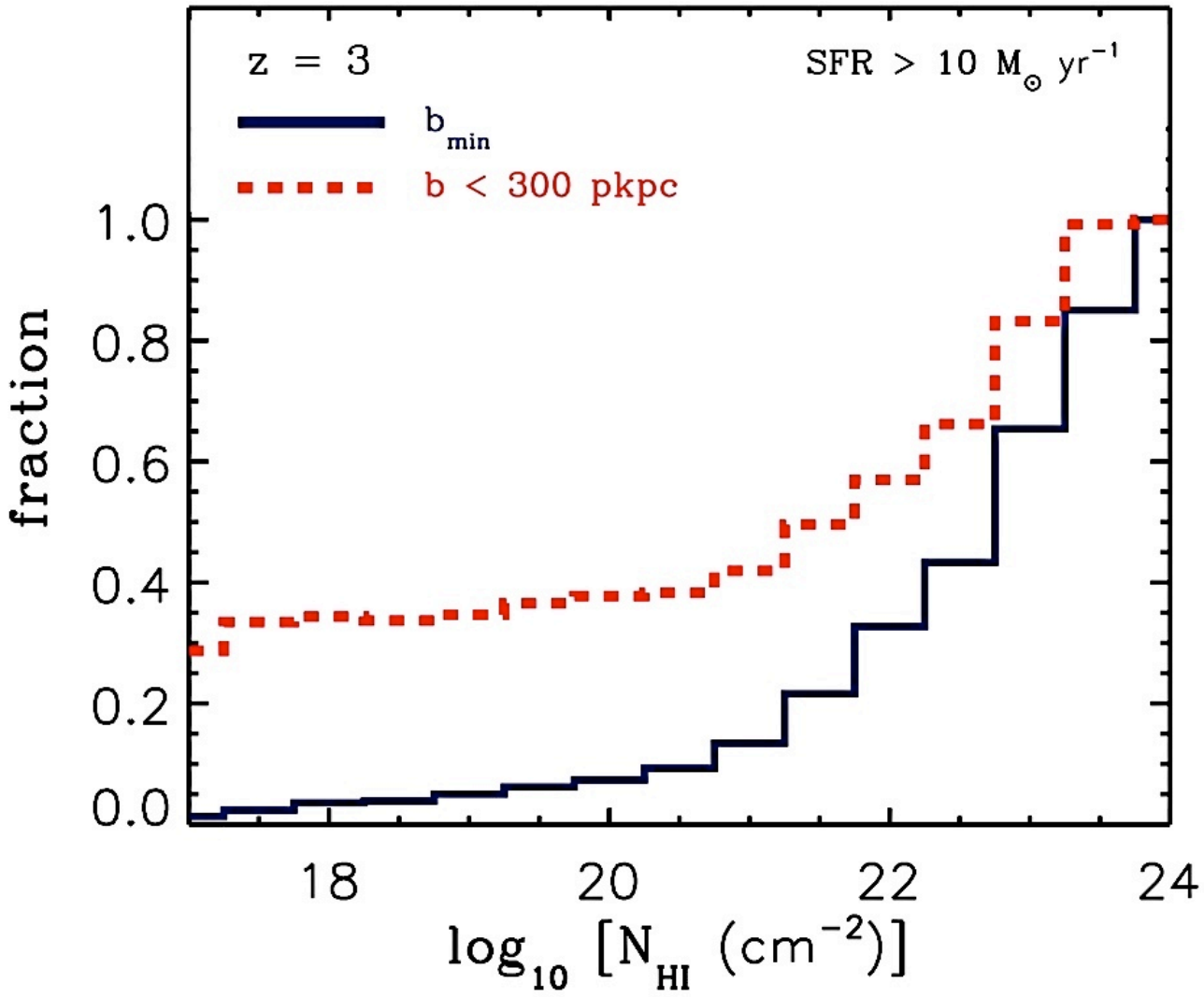

SFR > 0.10 M⊙ yr⁻¹
100.0 pKpc
16
18
20
22
Log10 [NHI (cm−2)]


SFR > 0.01 M⊙ yr⁻¹
100.0 pKpc
16
18
20
22
Log10 [NHI (cm−2)]

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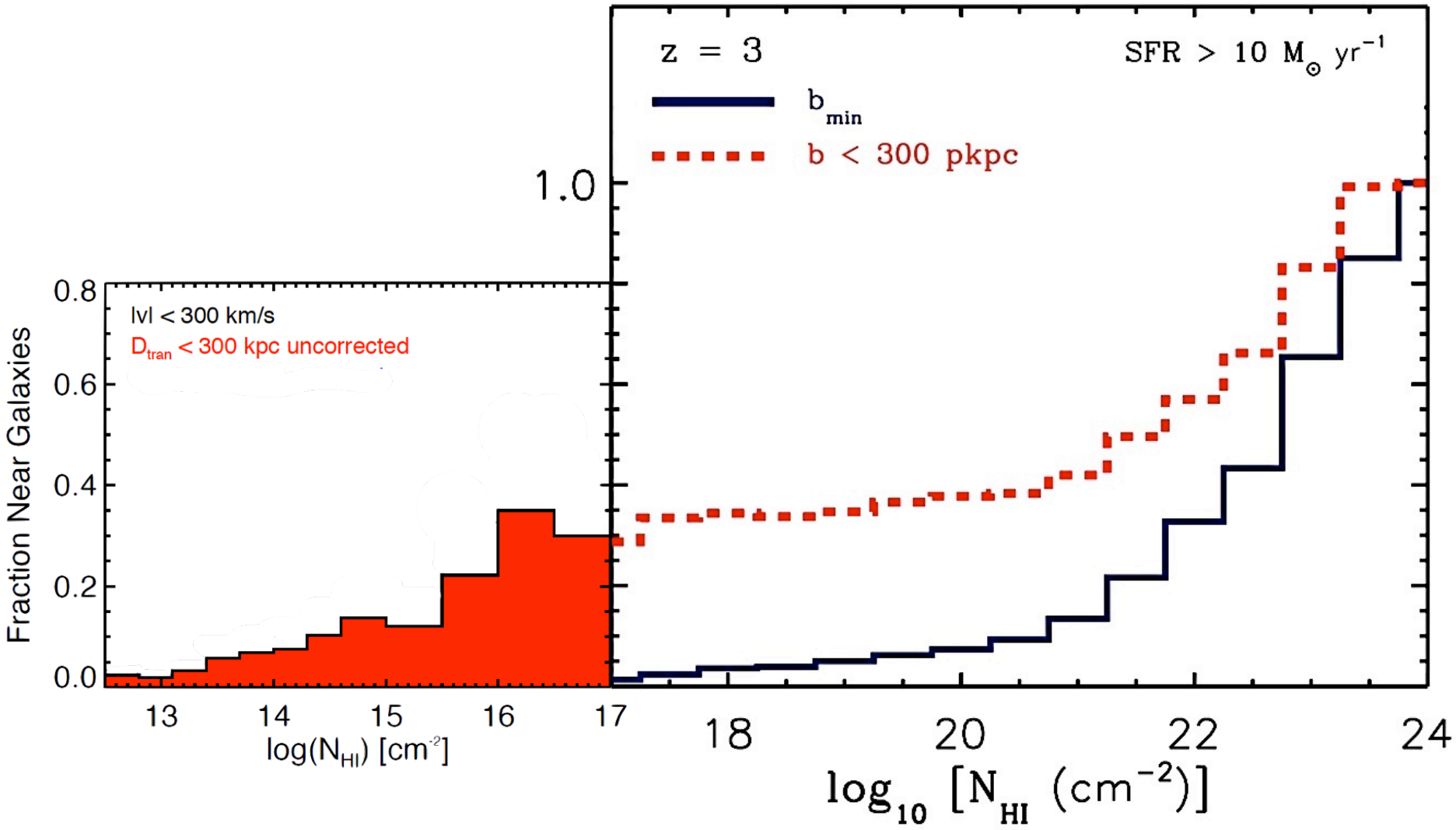


Rudie et al. 12

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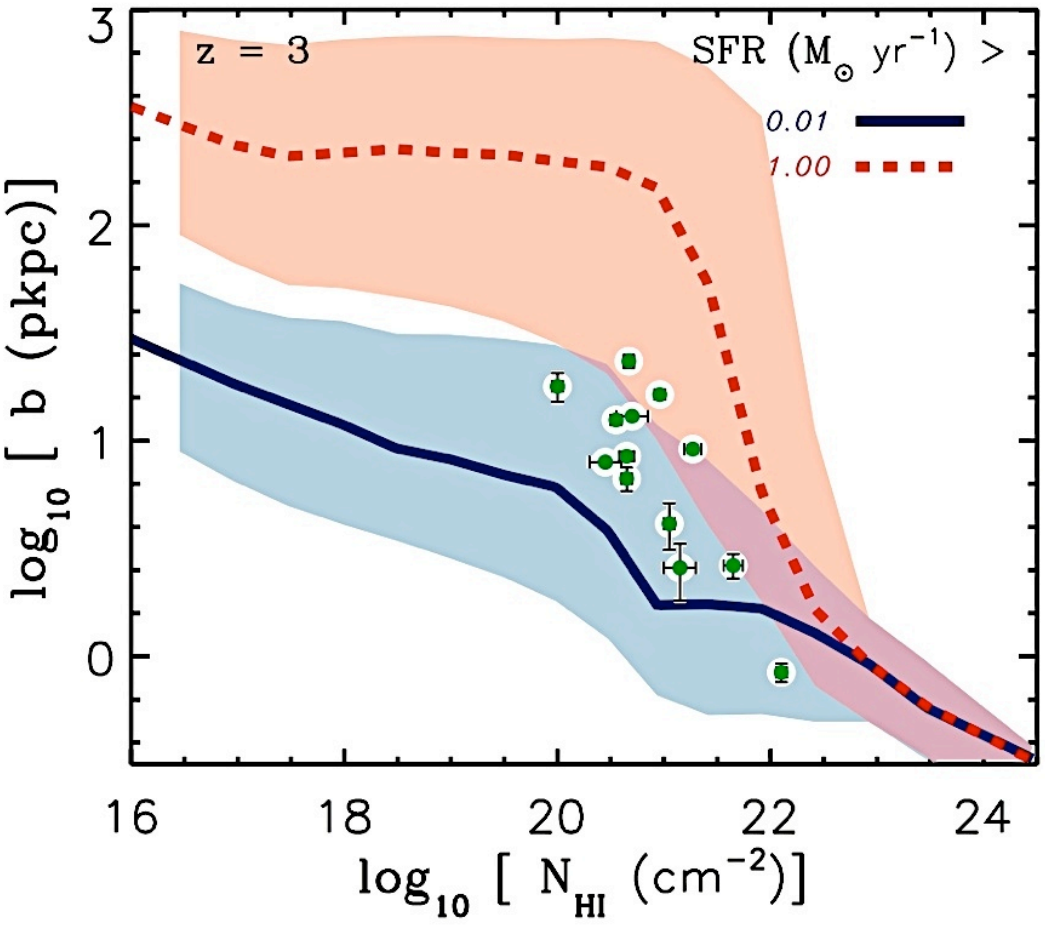
# comparison with observations




detection threshold at z = 3 is

$$1 - 10\ \mathrm{M}_\odot\ \mathrm{yr}^{-1}$$

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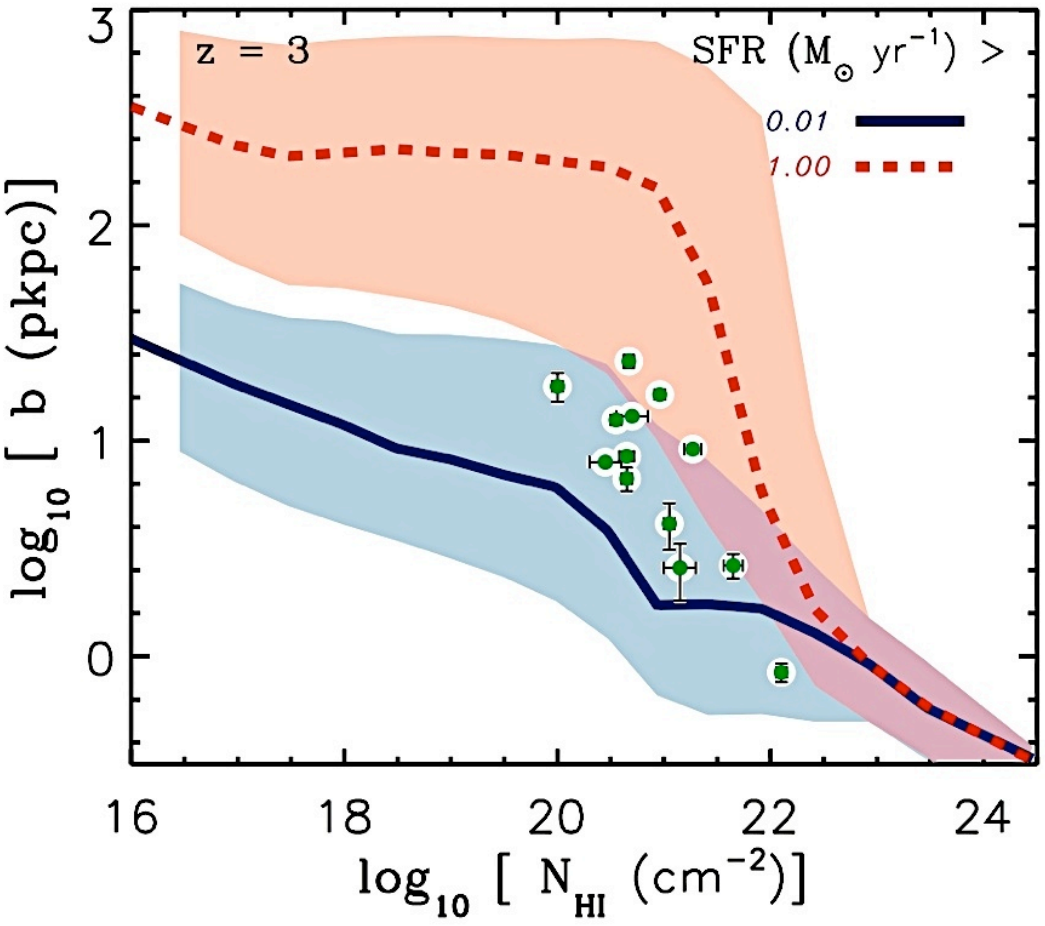


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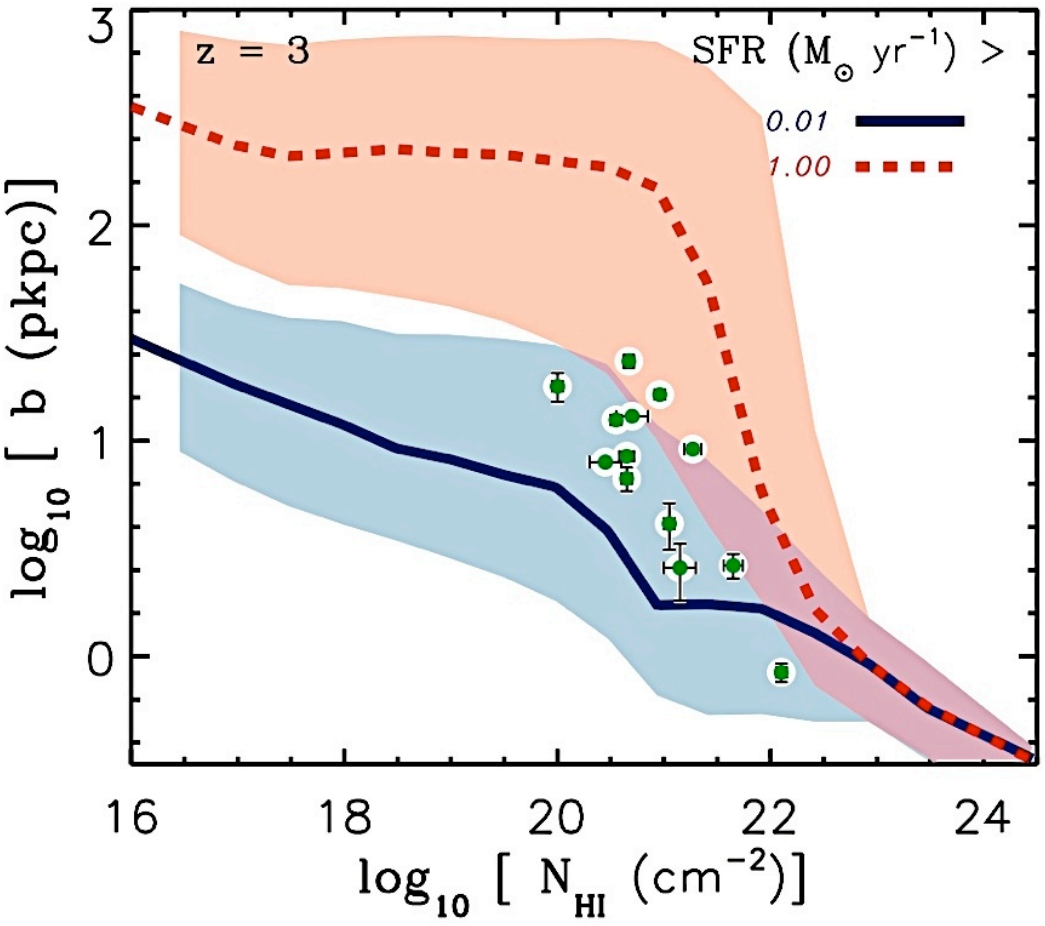


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Galaxies far away from DLAs

(e.g., Teplitz et al. 98, Mannucci et al. 98)

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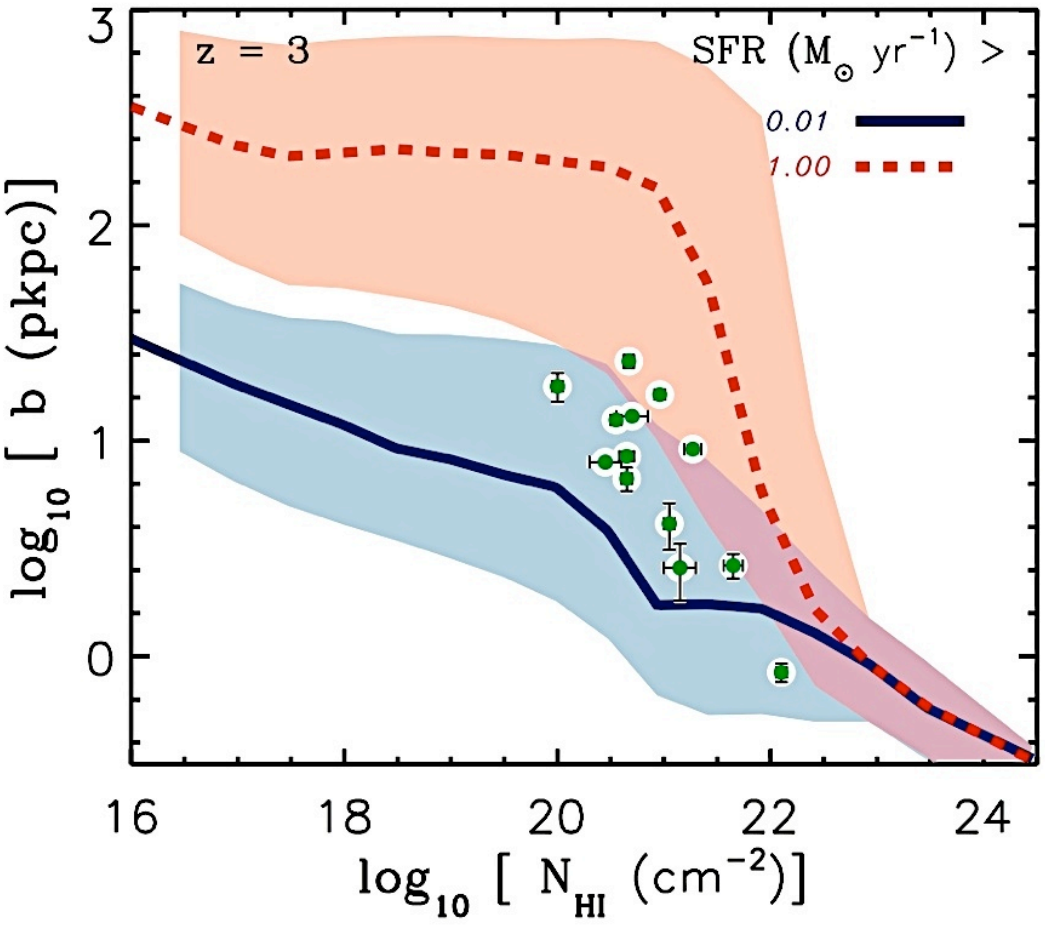


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Large number of non-detections

(e.g., Foltz et al. 86, Smith et al. 89, Lowenthal et al. 95, Bunker et al. 99, Prochaska et al. 02, Kulkarni et al. 06, Rahmani et al.10, Bouche et al. 12)

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# What about local stellar radiation?

**Analytic arguments**

(Miralda-Escude 05; Schaye 06)

dominant source of ionization
for lyman limit systems and
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## Analytic arguments

(Miralda-Escude 05; Schaye 06)

dominant source of ionization for lyman limit systems and DLAs

## Simulations

(Nagamine 10; Yajima 12)

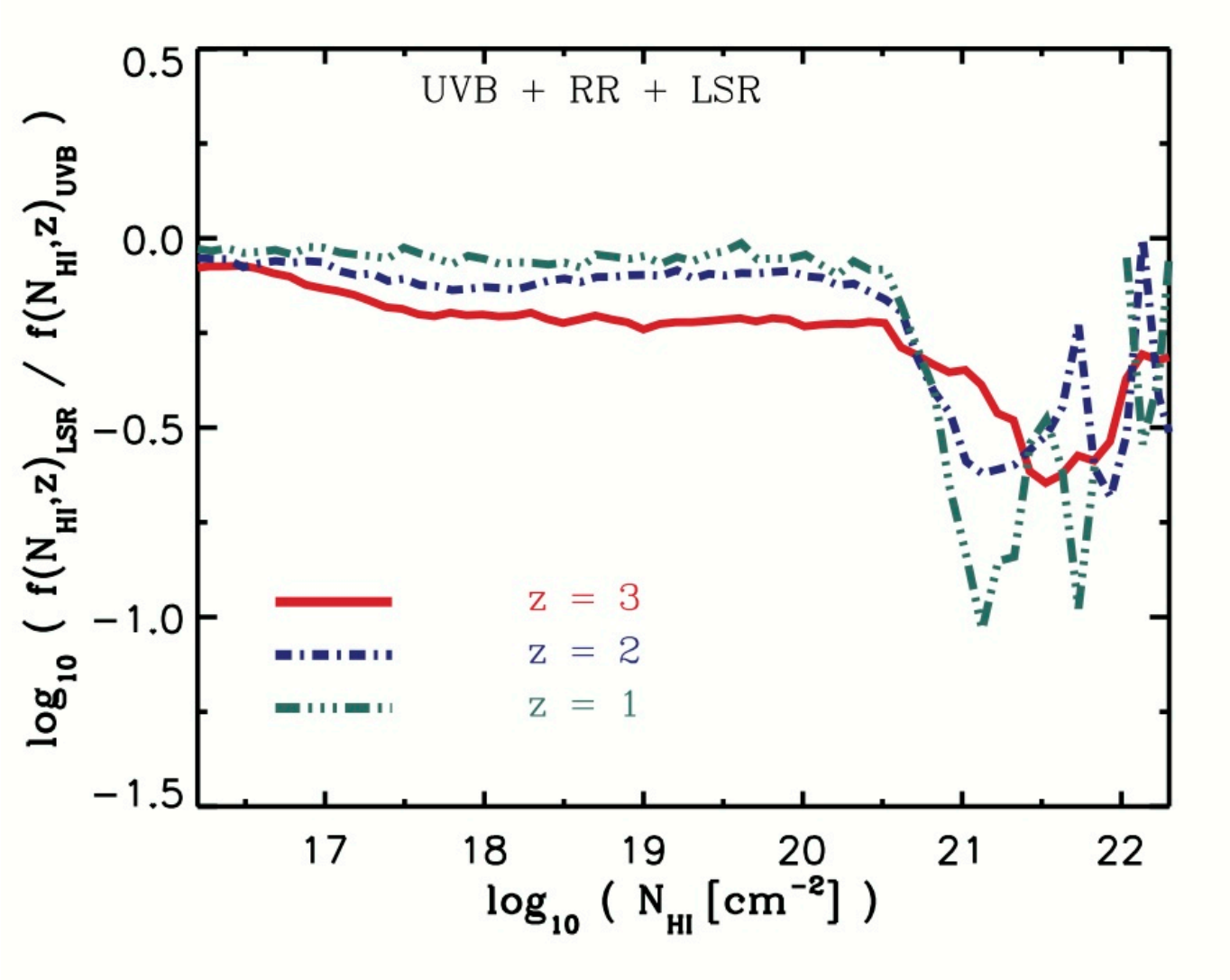
Negligible effect

but

(Fumagalli 11)

High HI column densities are affected

# impact of local stellar radiation on the HI distribution

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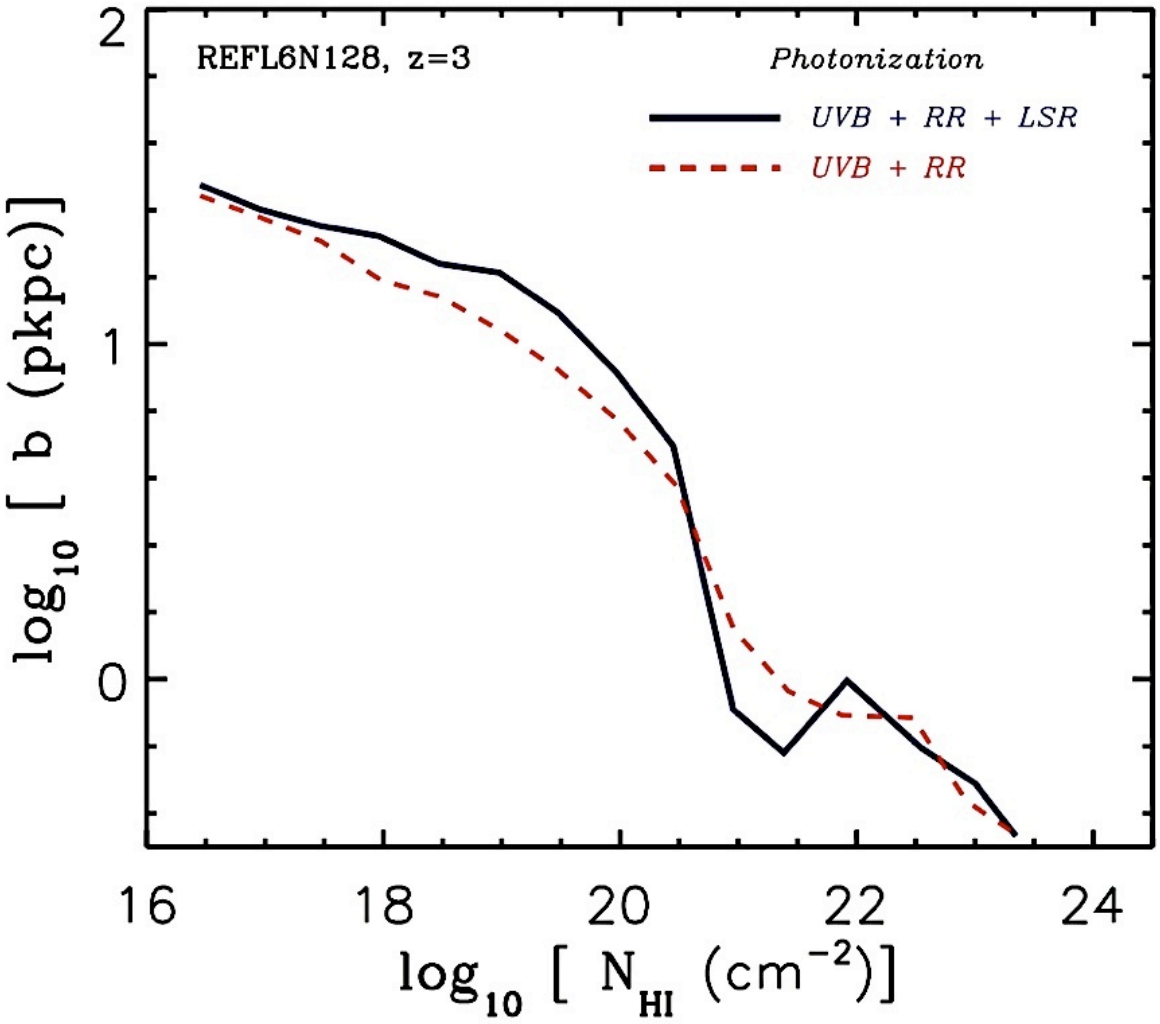
# The impact of local sources on the impact parameters

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# Summary and Conclusions

- excellent agreement with observed HI column density distribution
- HI column density distribution function weakly evolves
- HI column density increases with mass (at a fixed impact parameter)
- impact parameter decreases strongly with HI column density
- most absorbers are near galaxies that are too faint to be detected (in current observations)
- Local sources significantly affect strong DLAs (but not their impact parameters)