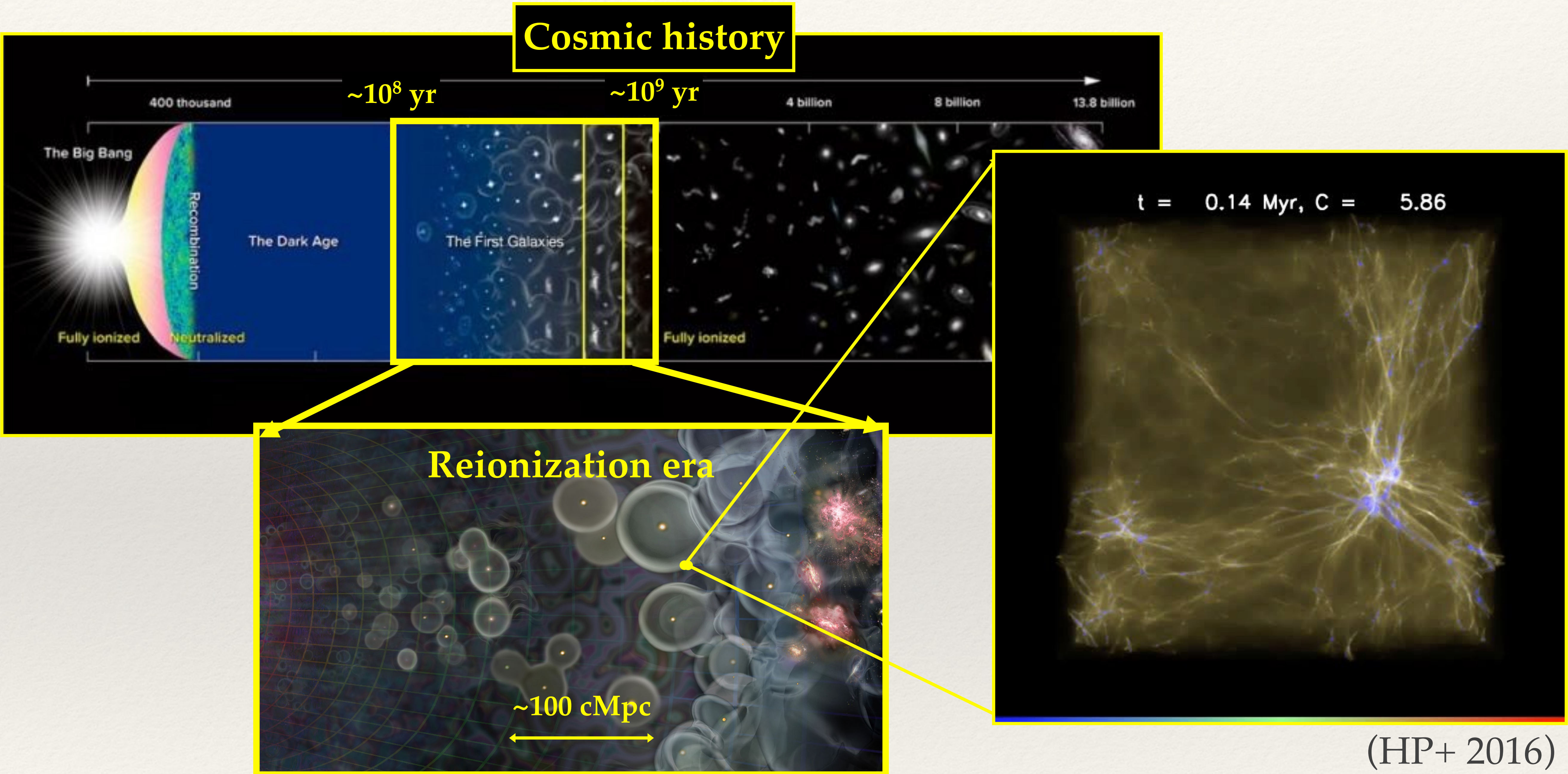
Cosmic Dawn at High Latitude (June 2024)

Impact of Minihalos on Lyα Opacity of the Intergalactic Medium

Hyunbae Park
(Tsukuba University)

ArXiv: 2309.04129v2

Self-shielding Minihalos during Reionization

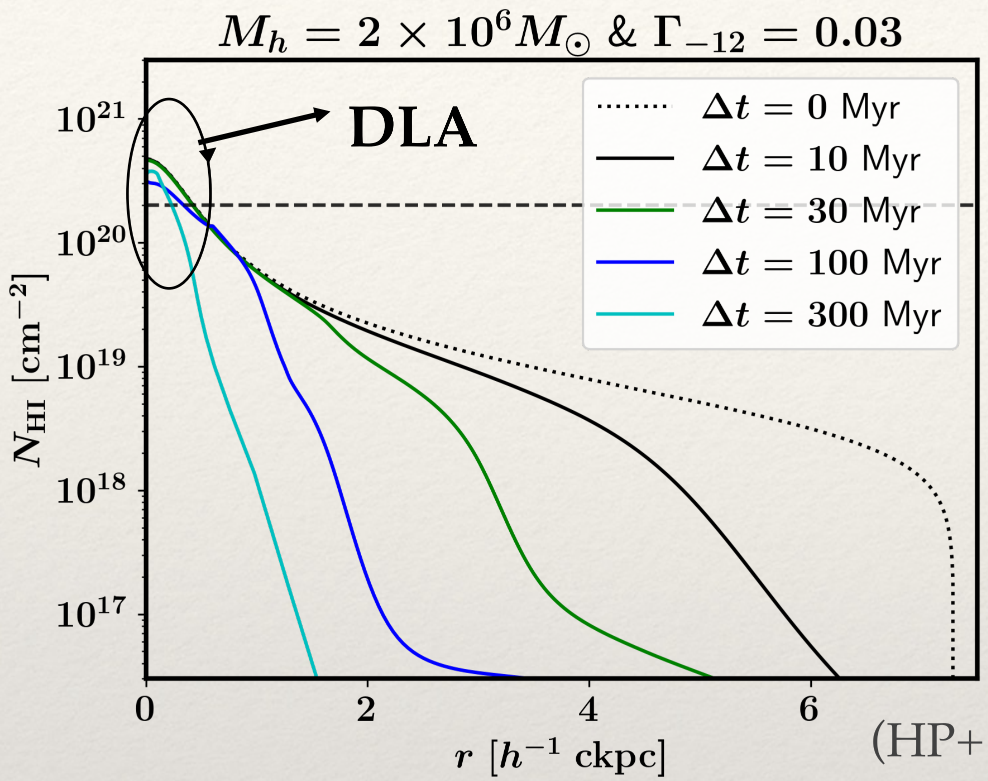


(HP+ 2016)

During reionization, minihalos can shield themselves from ionizing background radiation for > 100 Myrs.

(See also Iliev+ 2005; Shapiro+ 2006)

Minihalos as Damped Lyα Absorber



(HP+ 2024)

- $\Gamma_{-12} \equiv$ [Ionizing rate]/[10^{-12} s^{-1}]

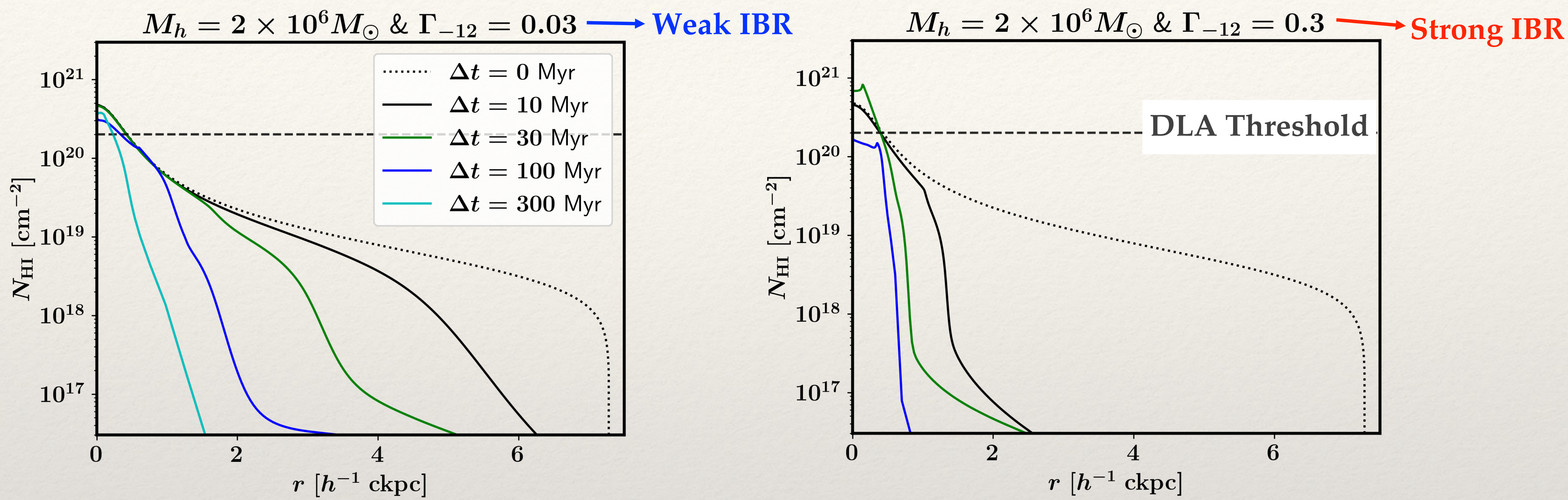
from 1D rad-hydro code introduced by Ahn+ (2008) and updated by HP+ (2016)

(See also Nakatani+ 2020.)

MH cores can manifest as DLAs for >100 Myrs.

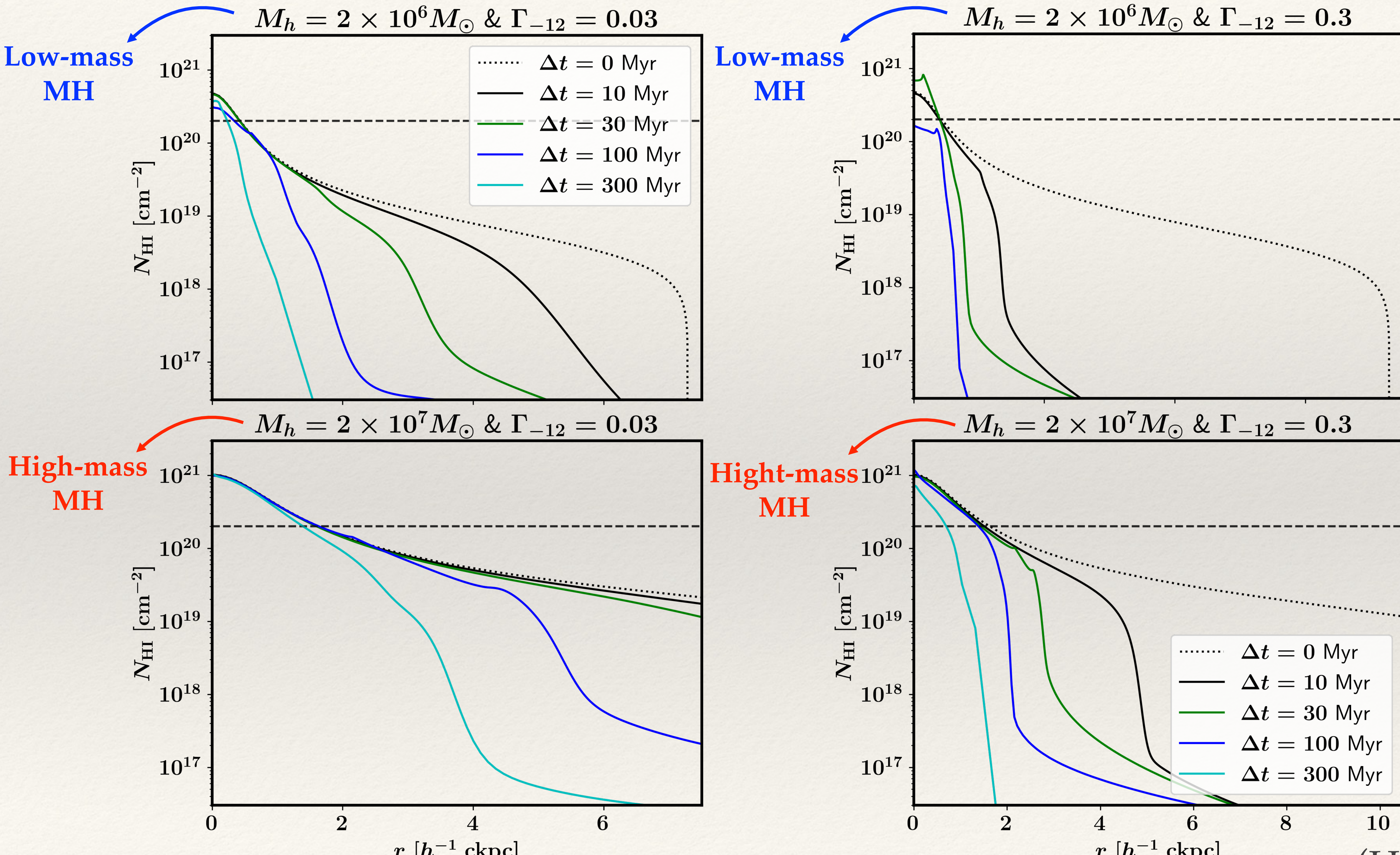
How will that affect (1) the Lyα forest and (2) Lyα emission lines from $z > 5$?

MHs as DLA: IBR Dependence



The lifetime as a DLA depends on the IBR intensity, of course.

MHs as DLA: Mass Dependence

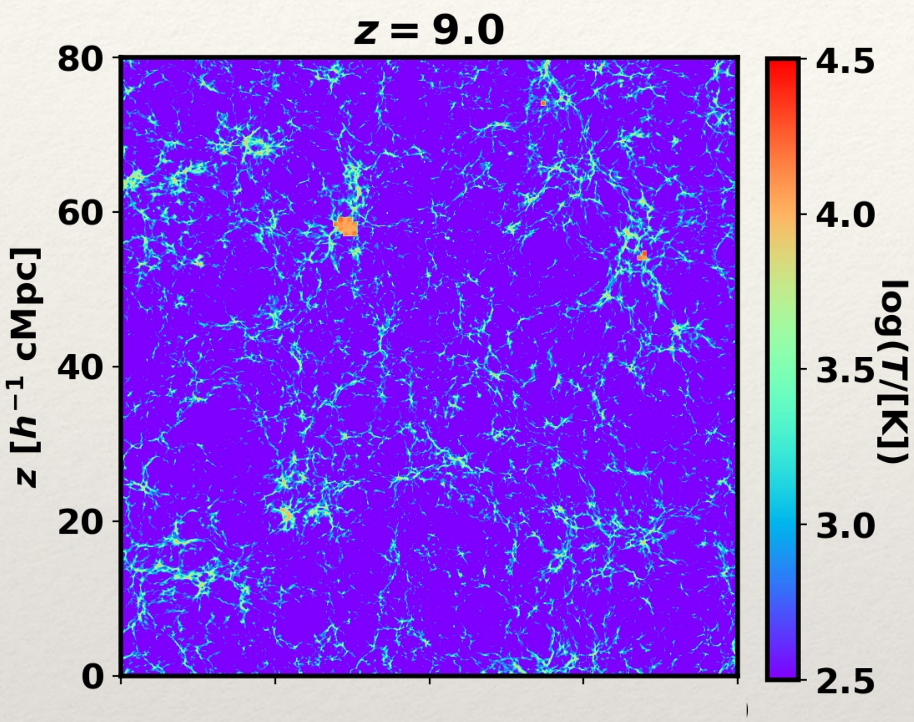


(HP+ 2024)

High-mass (>10^7 M$_\odot$) MHs host larger DLAs, but are fewer.

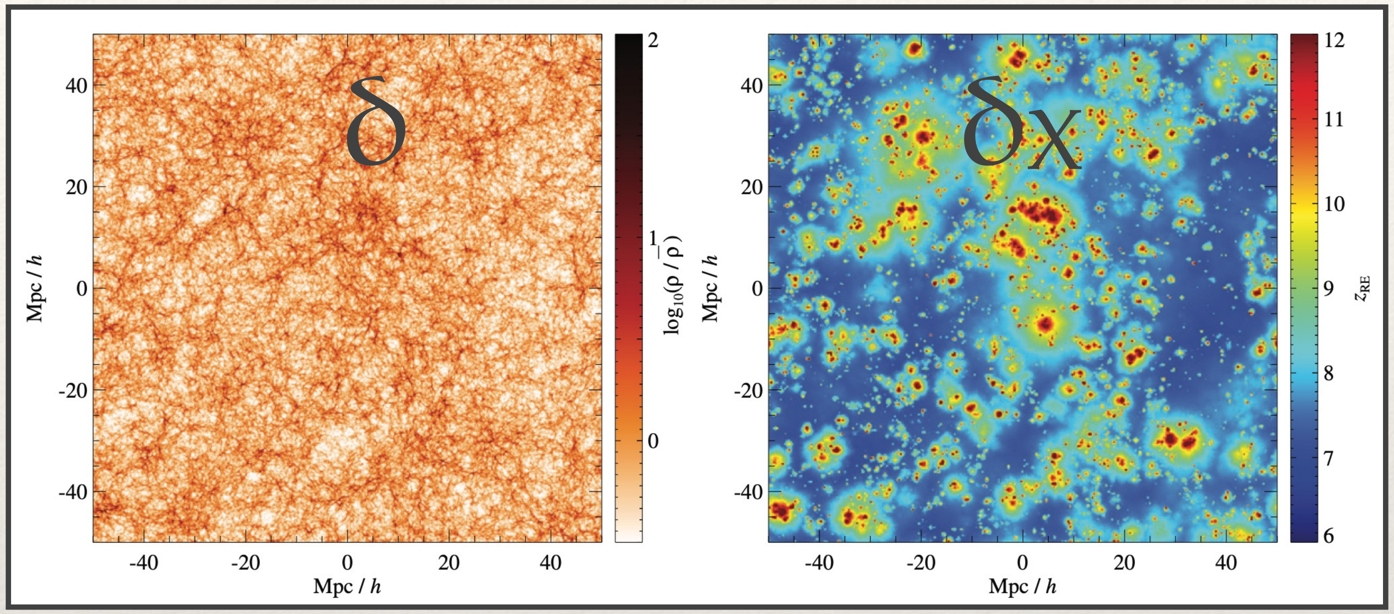
(For more dependences, see Ahn+ (2008) & Nakatani+2020)

Simulation of Lyα forest



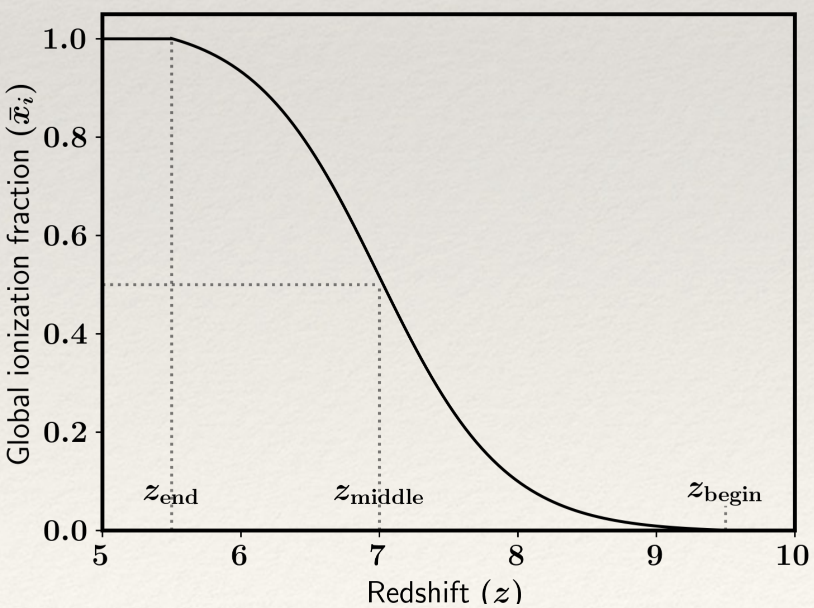
Code: Nyx
Box size: 80 h^{-1} Mpc
Resolution: 4096^3
$m_{\rm DM} = 8\times10^5\, M_\odot$

Reionization field from smoothed density



(Battaglia+ 2013)

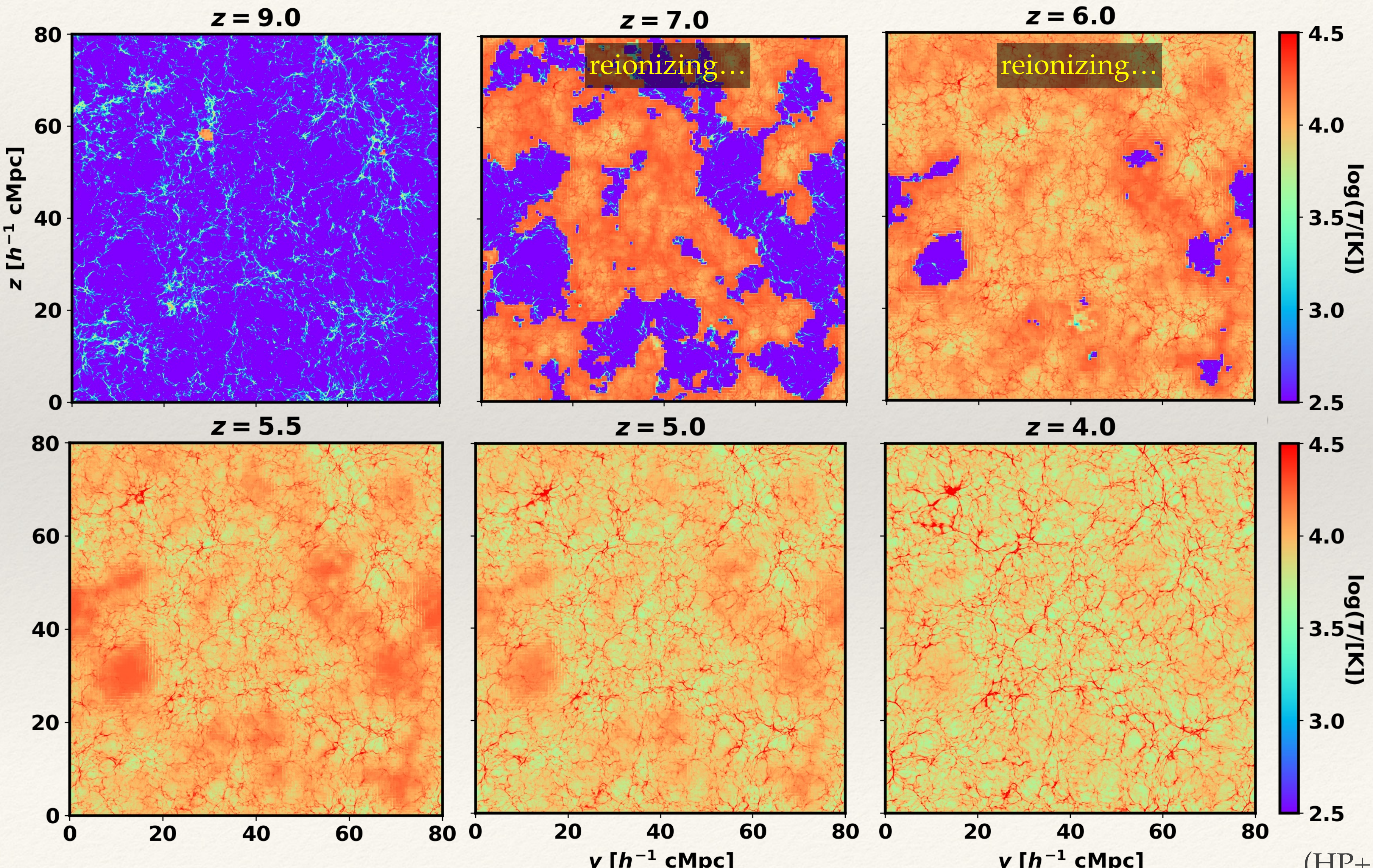
Assumed reionization history



Ionization redshift field obtained from smoothed density and assumed reionization history

Simulation of Lyα forest

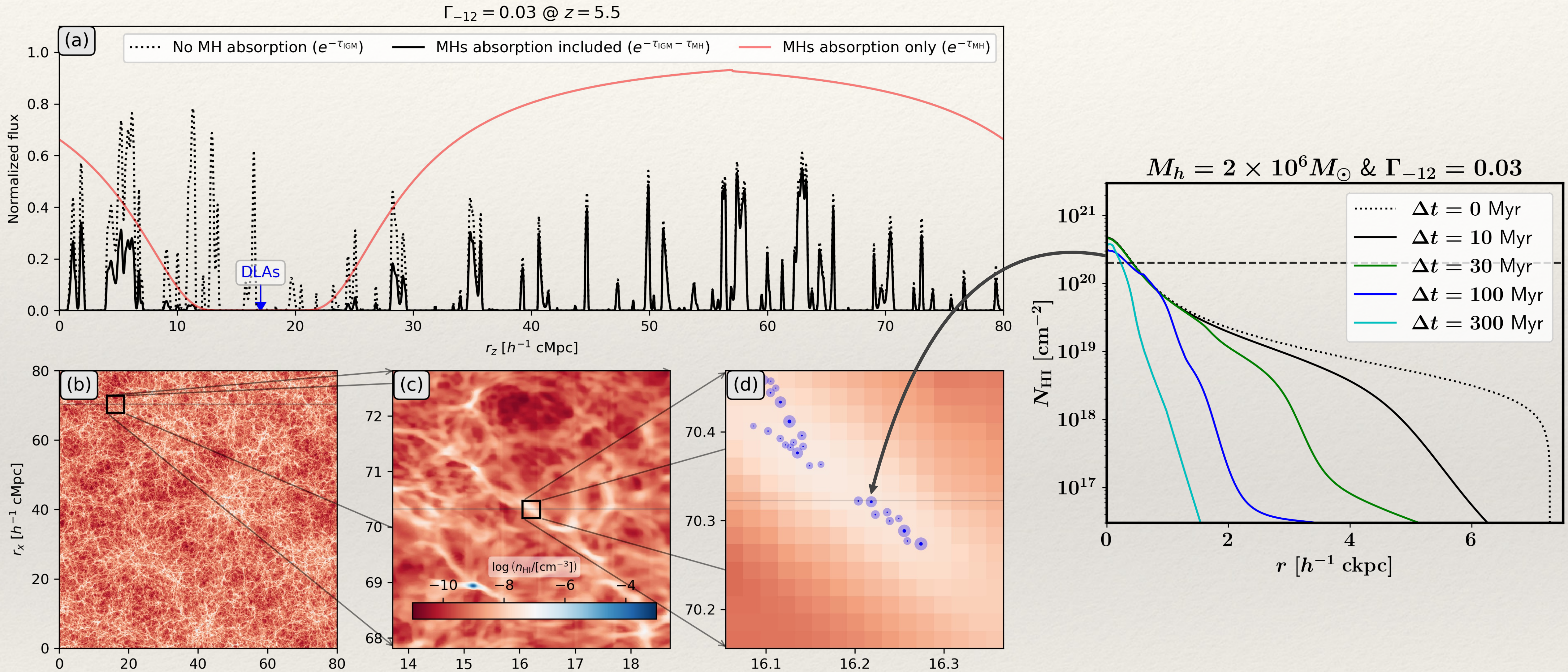
Inhomogneously reionized IGM



(HP+ 2024)

Impact of MHs on Lyα Forests

Sight line affected by MH DLAs



Global mean Lyα flux

z	5.5	5	4.5
No MHs	0.1048	0.2010	0.2976
$\Gamma_{-12} = 0.3$	0.1043 (−0.47%)	**0.2006 (−0.31%)**	**0.2974 (−0.12%)**
$\Gamma_{-12} = 0.03$	**0.1011 (−3.2%)**	0.1965 (−2.6%)	0.2935 (−2.1%)

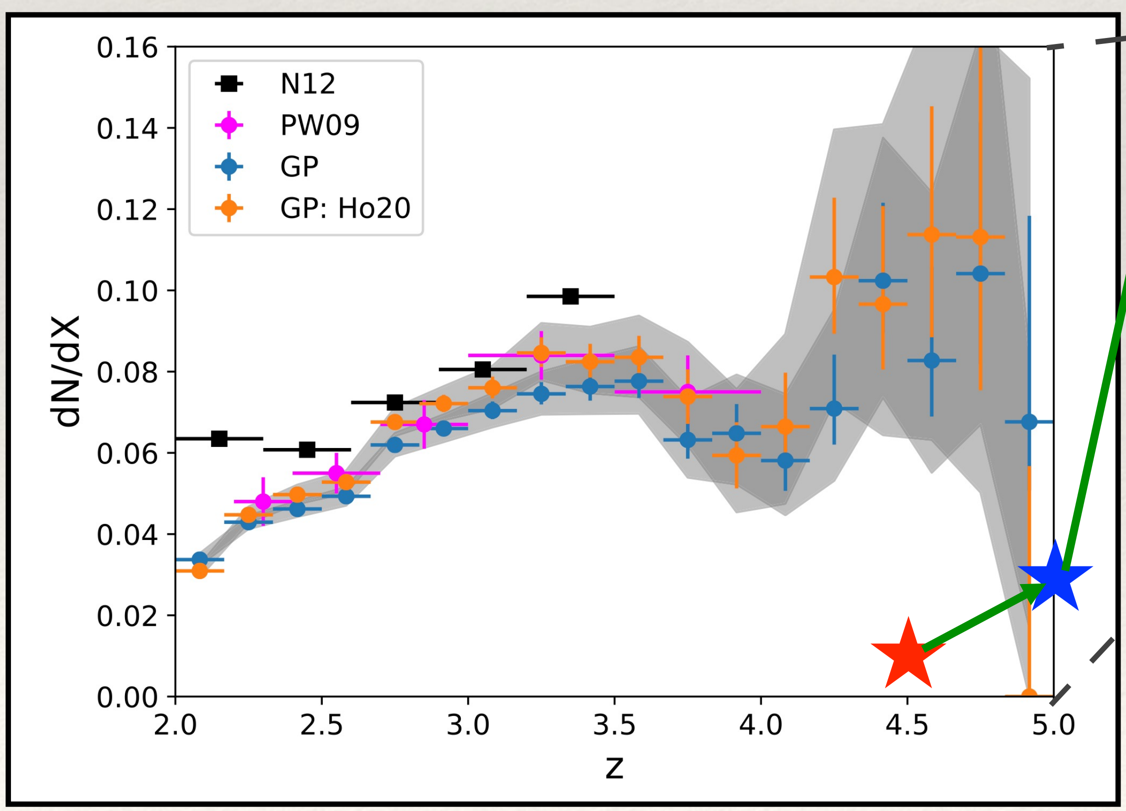
Up to 3% suppression in the global Lyα flux

(HP+ 2024)

DLA Incidence Rate

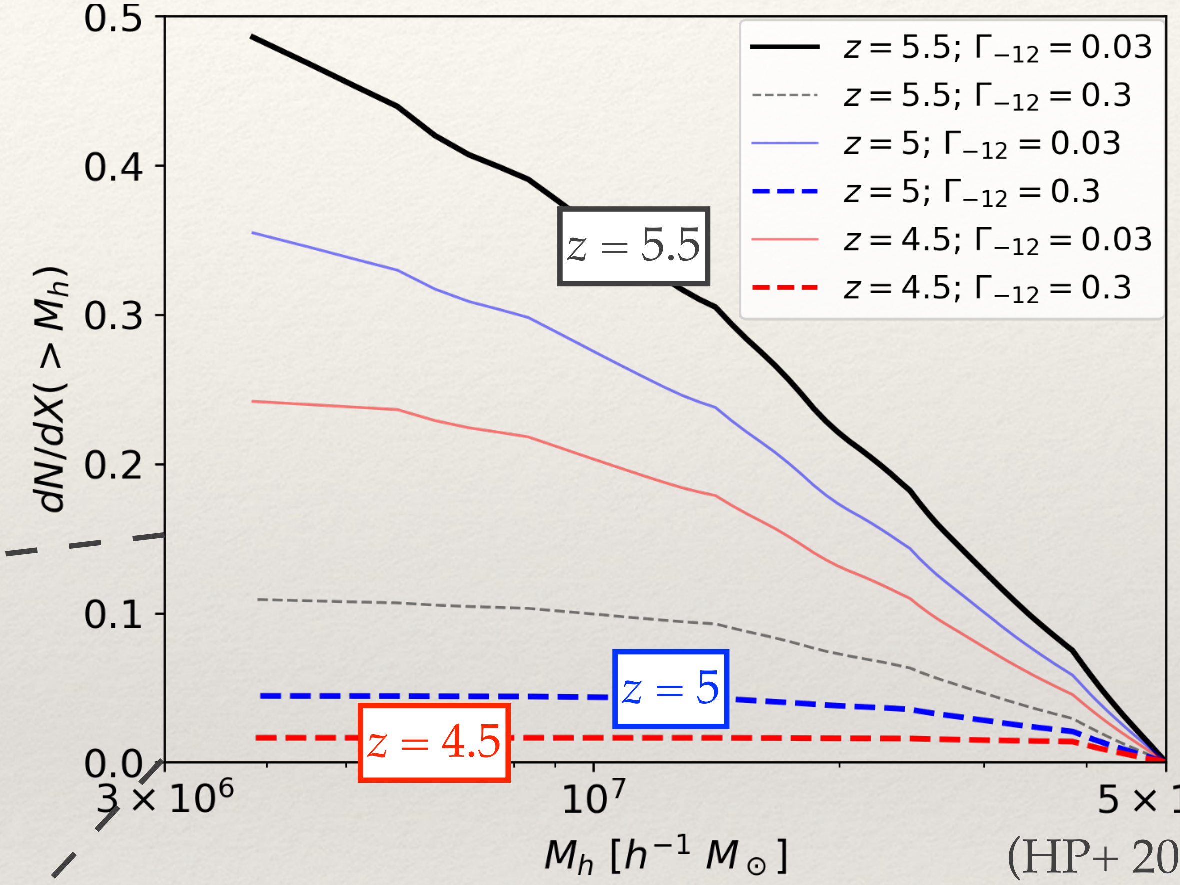
DLAs at $z < 5$ are thought to be associated with galactic disks.
The DLA incident rate rises steeply at $z > 4.5$.

Observed DLA incidence rate



(Ho et al. 2021)

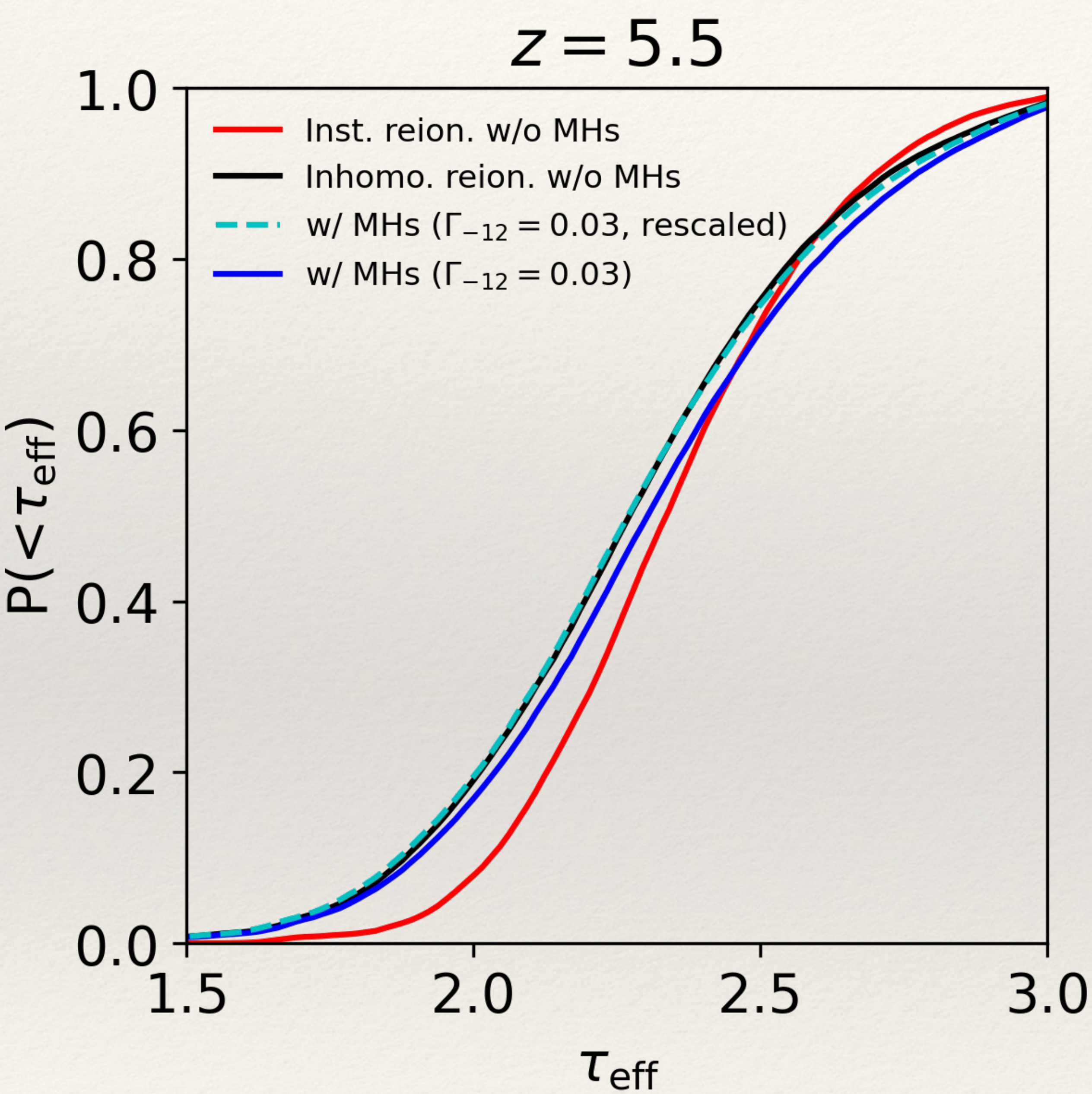
MH DLA incidence rate



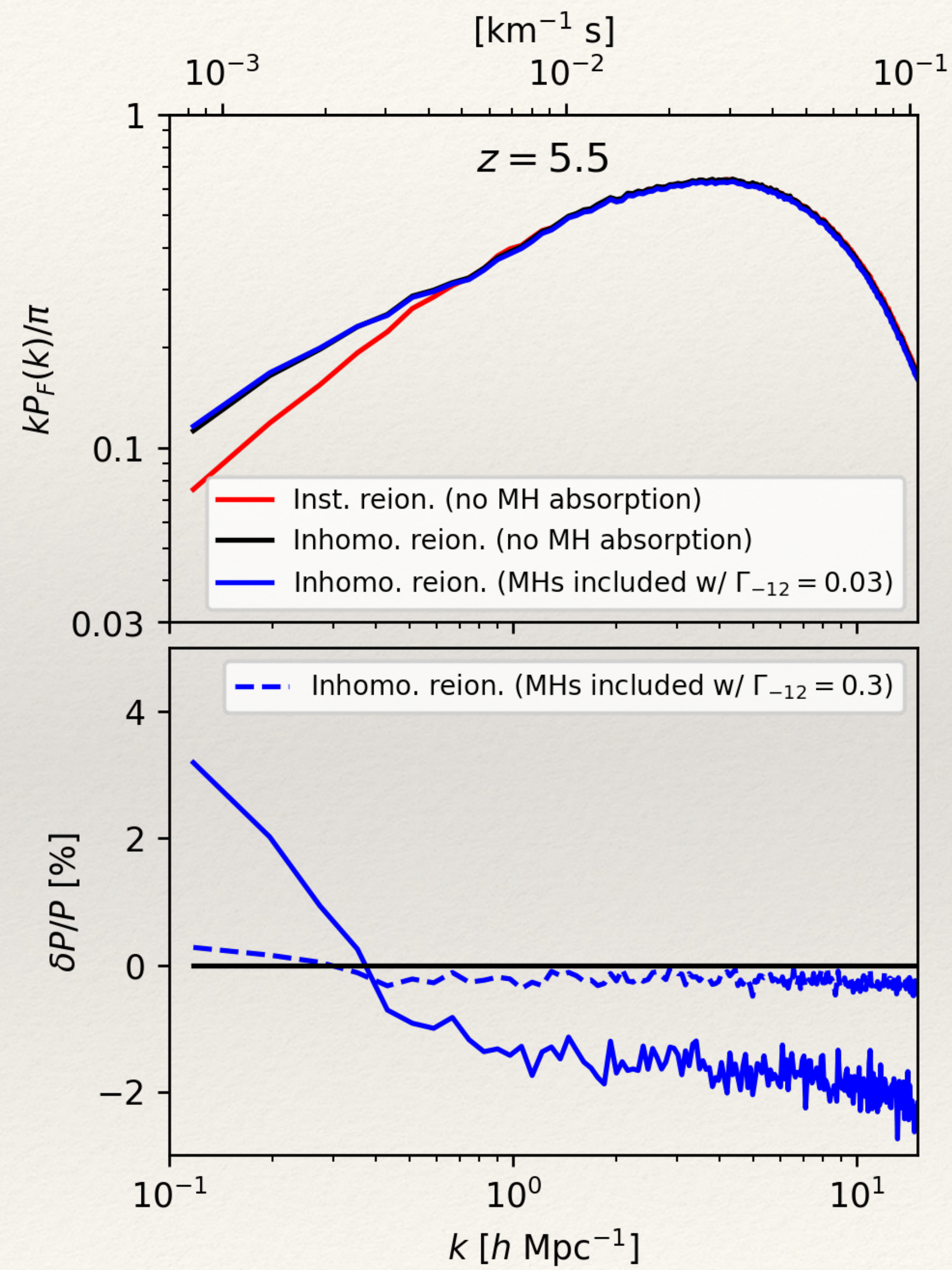
(HP+ 2024)

MHs may dominate the DLA population at $z > 5$.

Flux Statistics



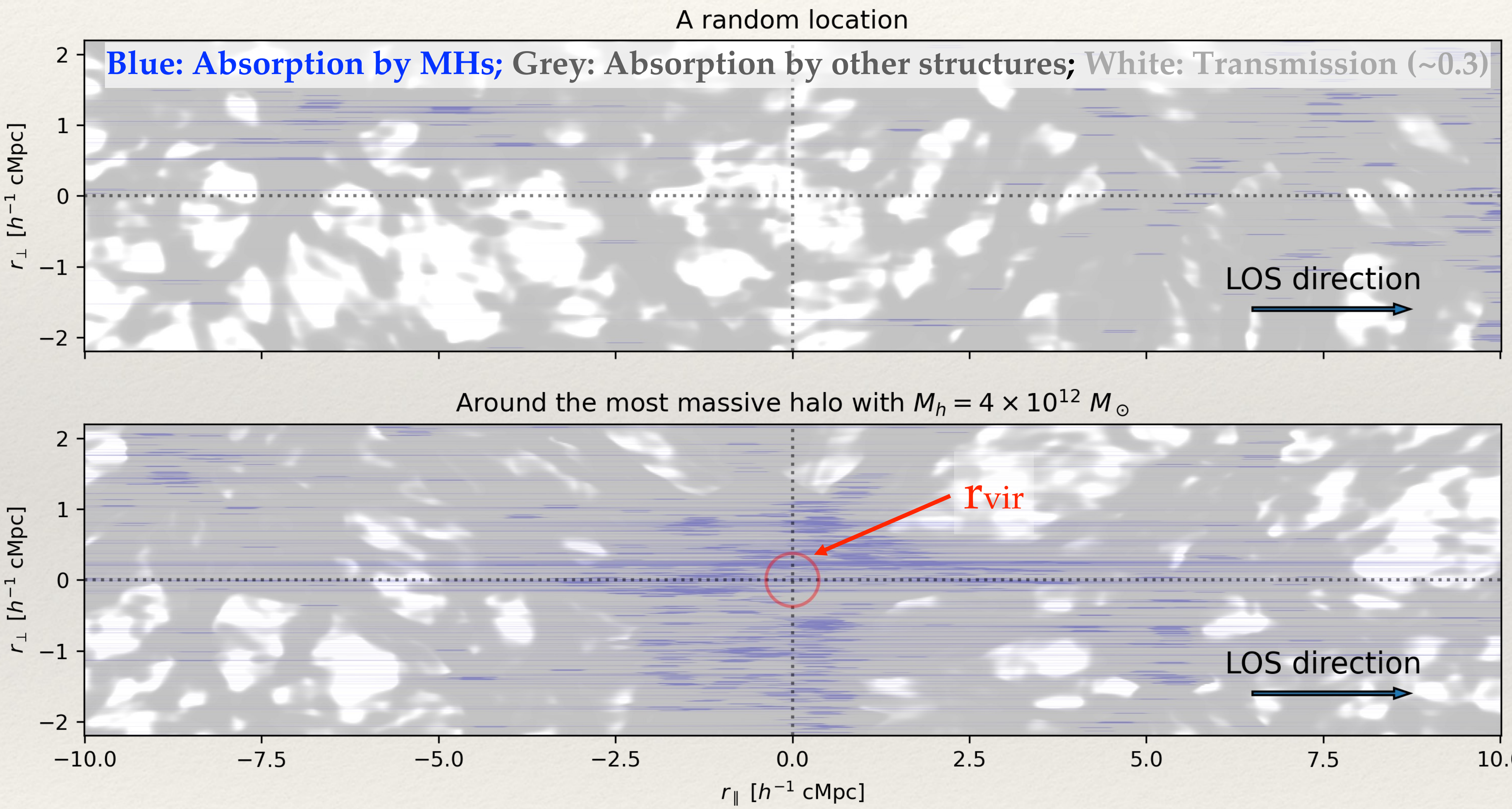
Negligible impact,
if rescaled to match the mean flux.

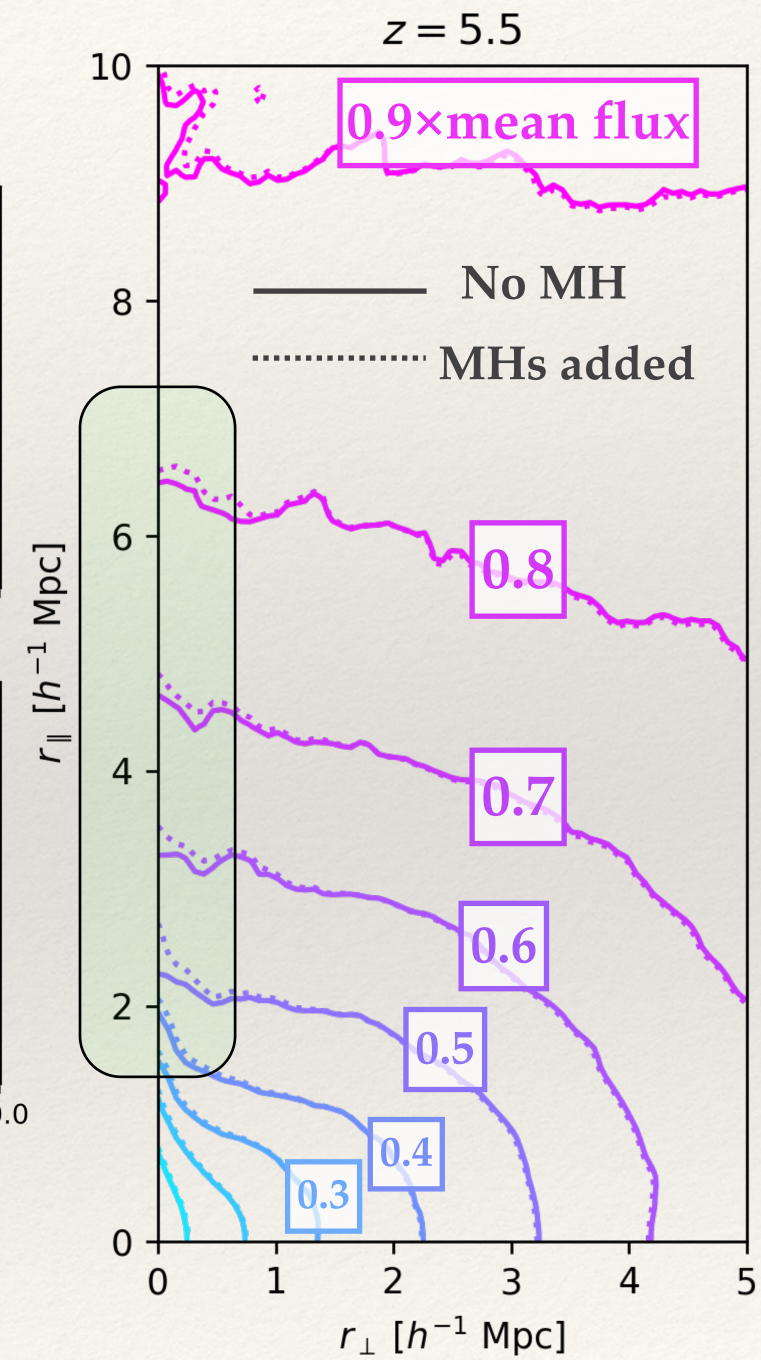


~3% impact on the 1D flux power spectrum.

Galaxy-Flux Correlation

At z=5.5 assuming $\Gamma_{-12} = 0.03$,



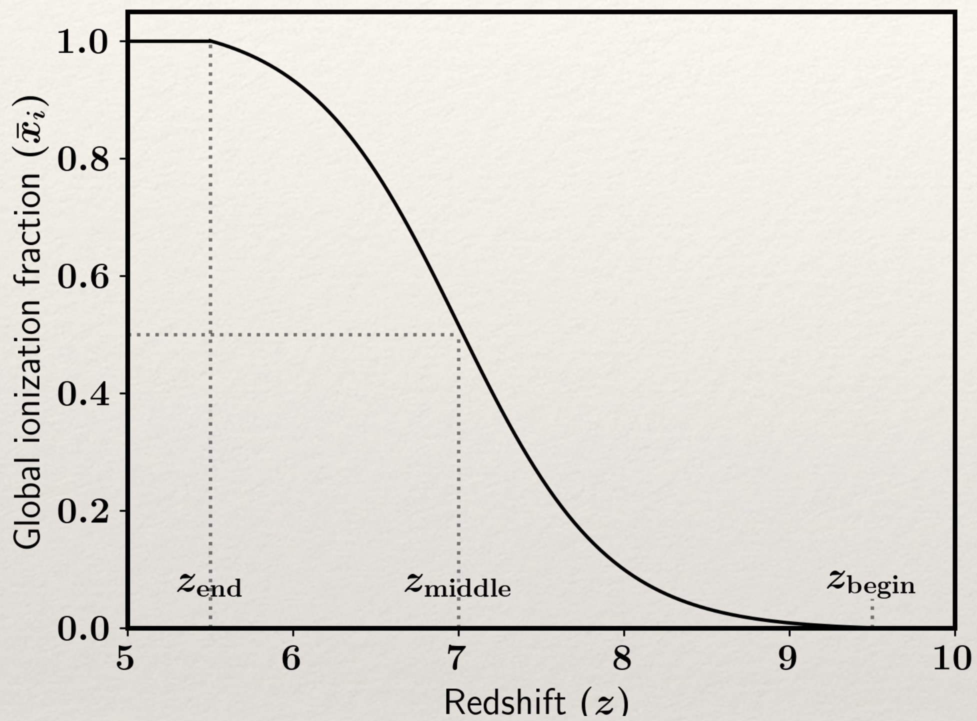


(HP+ 2024)

Reduced flux up to ~10 cMpc in the LOS direction for small impact parameters (< 1 cMpc).

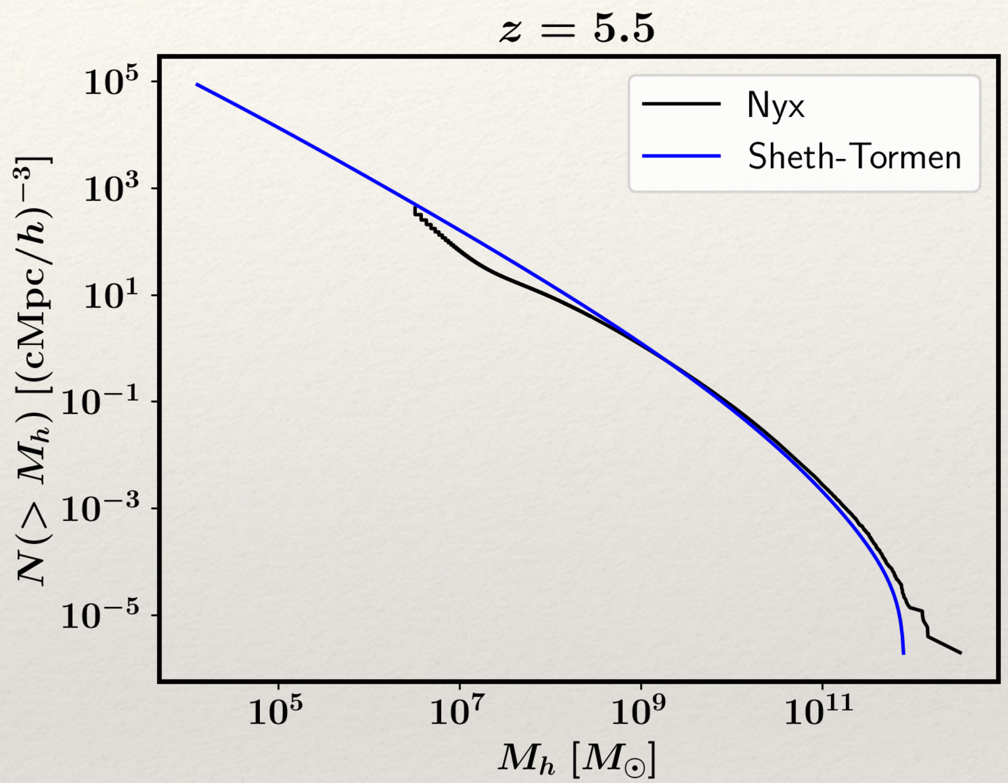
Uncertainties from Assumptions/Approximations

Reionization history



Stronger impact for later/quicker reionization

MH mass function

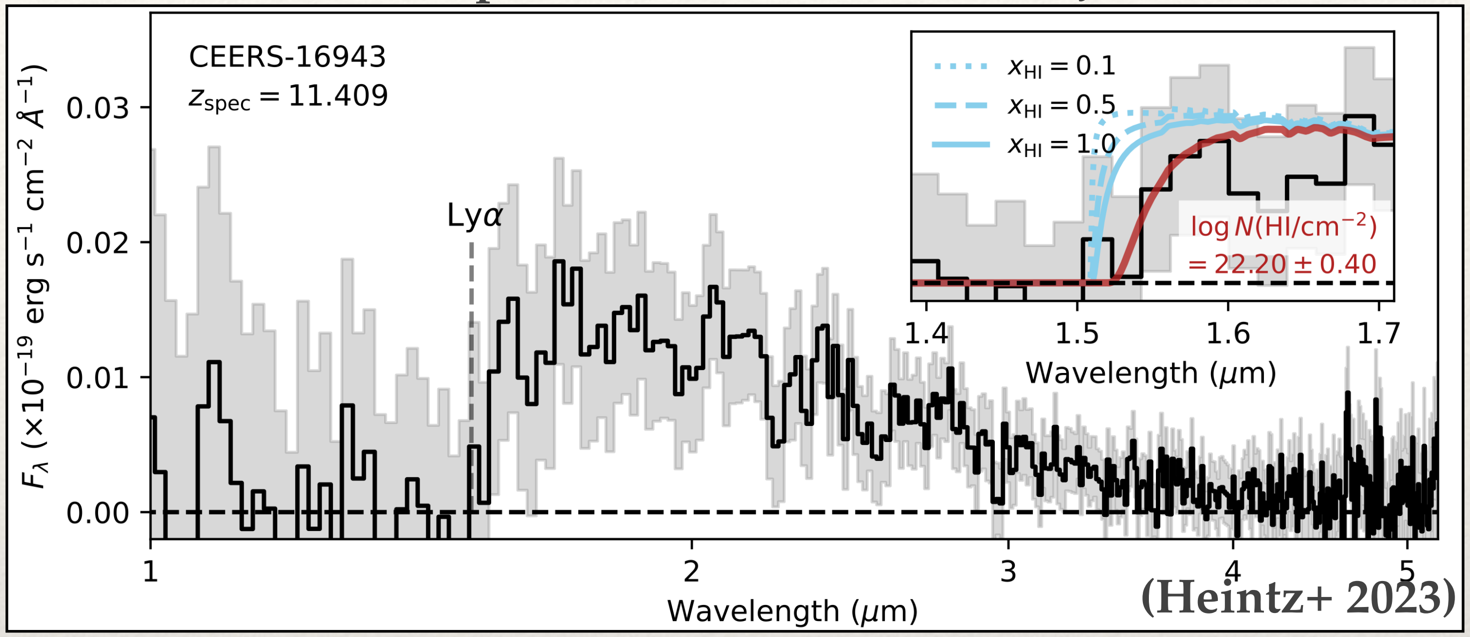


We produced a bit less MHs than in the theoretical models.

Uniform IBR assumed in Nyx simulation
Uniform & constant IBR assumed for the 1D simulation
Evolution of MHs; $N_{\rm HI}$ profile of MHs
and etc…

DLAs from High-z Galaxies?

Galactic spectrum from $z = 11.4$ from JWST

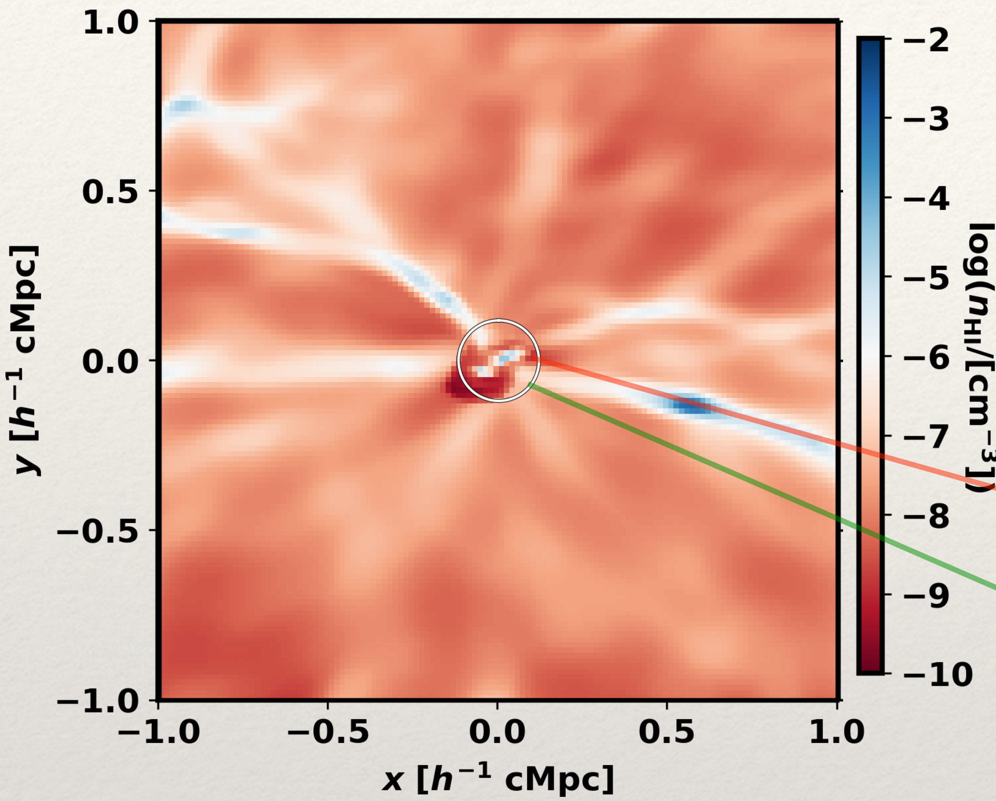


(Heintz+ 2023)

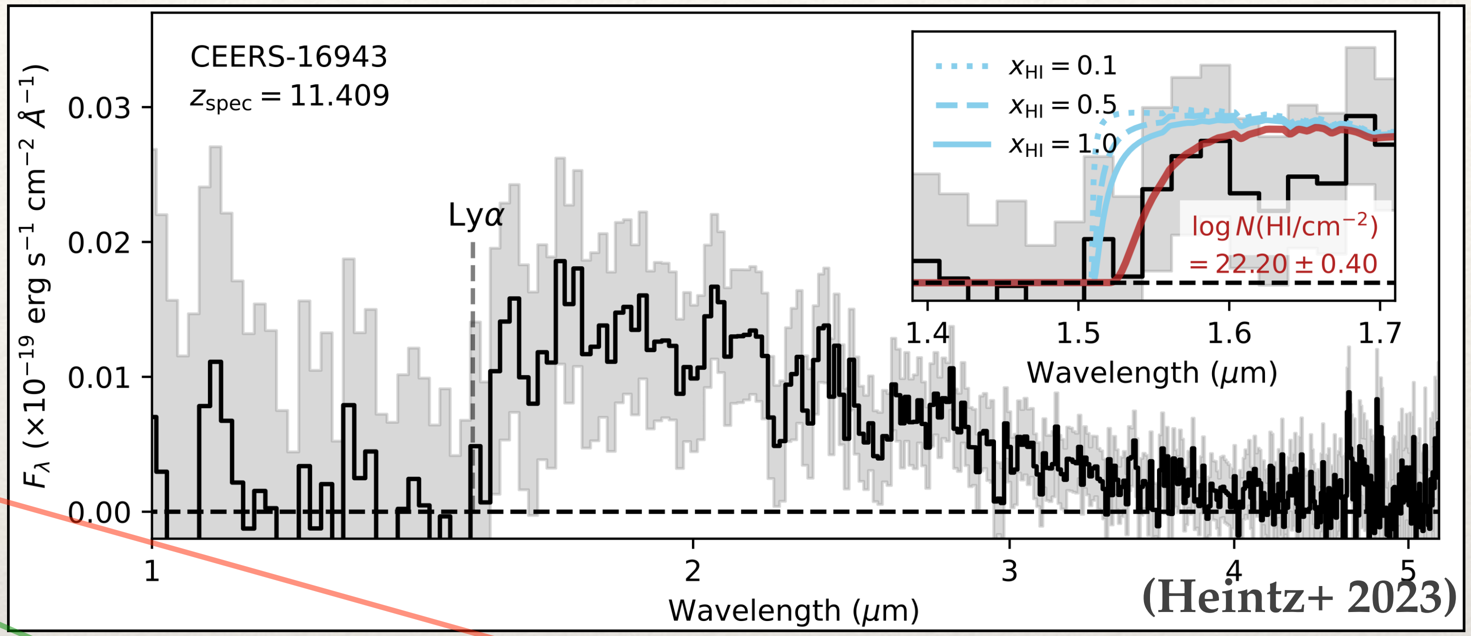
(see also Umeda+2023; Hsiao+ 2023; Curtis-Lake+ 2023; Keating+ 2023)

>50% of galaxies at $z > 6$ show damping-wing feature in the spectrum.
ISM and CGM are the prime suspects of the DLAs.
Can MHs explain DLAs from high-z galaxies?

SED from High-z Galaxies

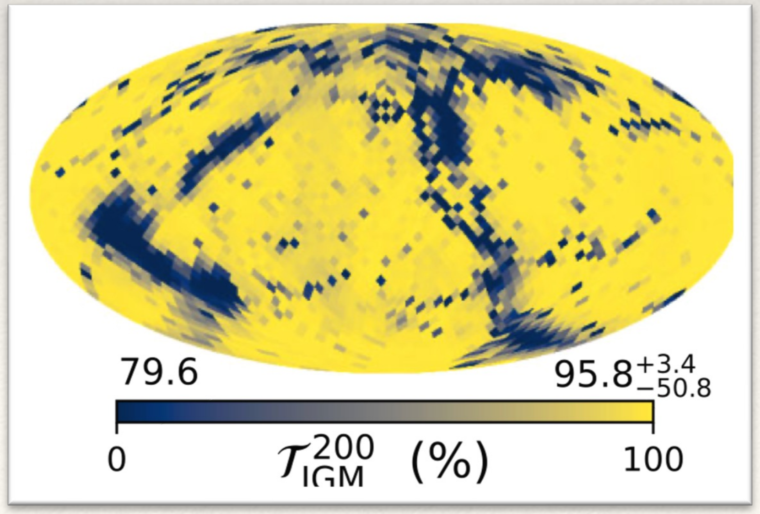


JWST Observation at $z = 11.4$

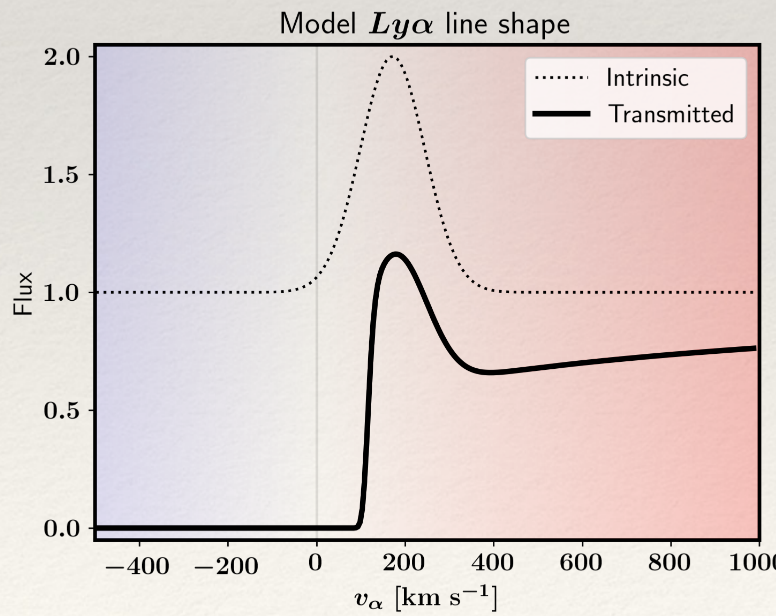


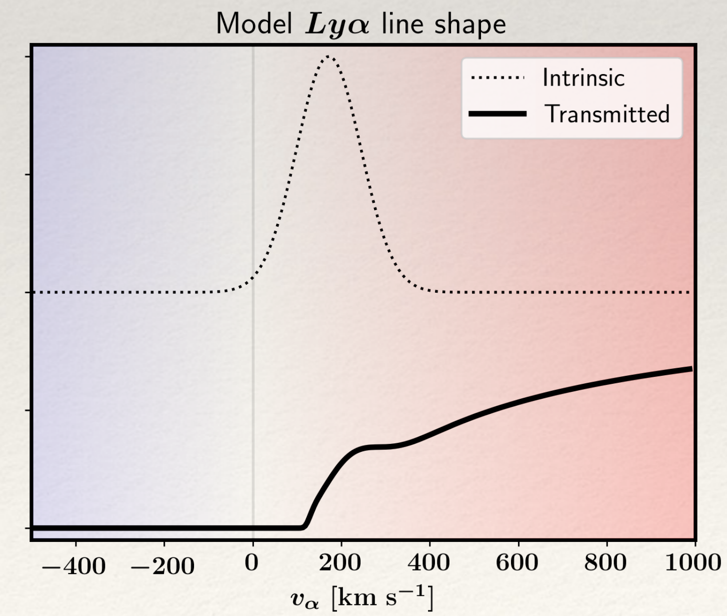
(Heintz+ 2023)

Self-shielded systems strongly attenuates Lyα for ~ 1% of the sightlines. (HP+ 2021)

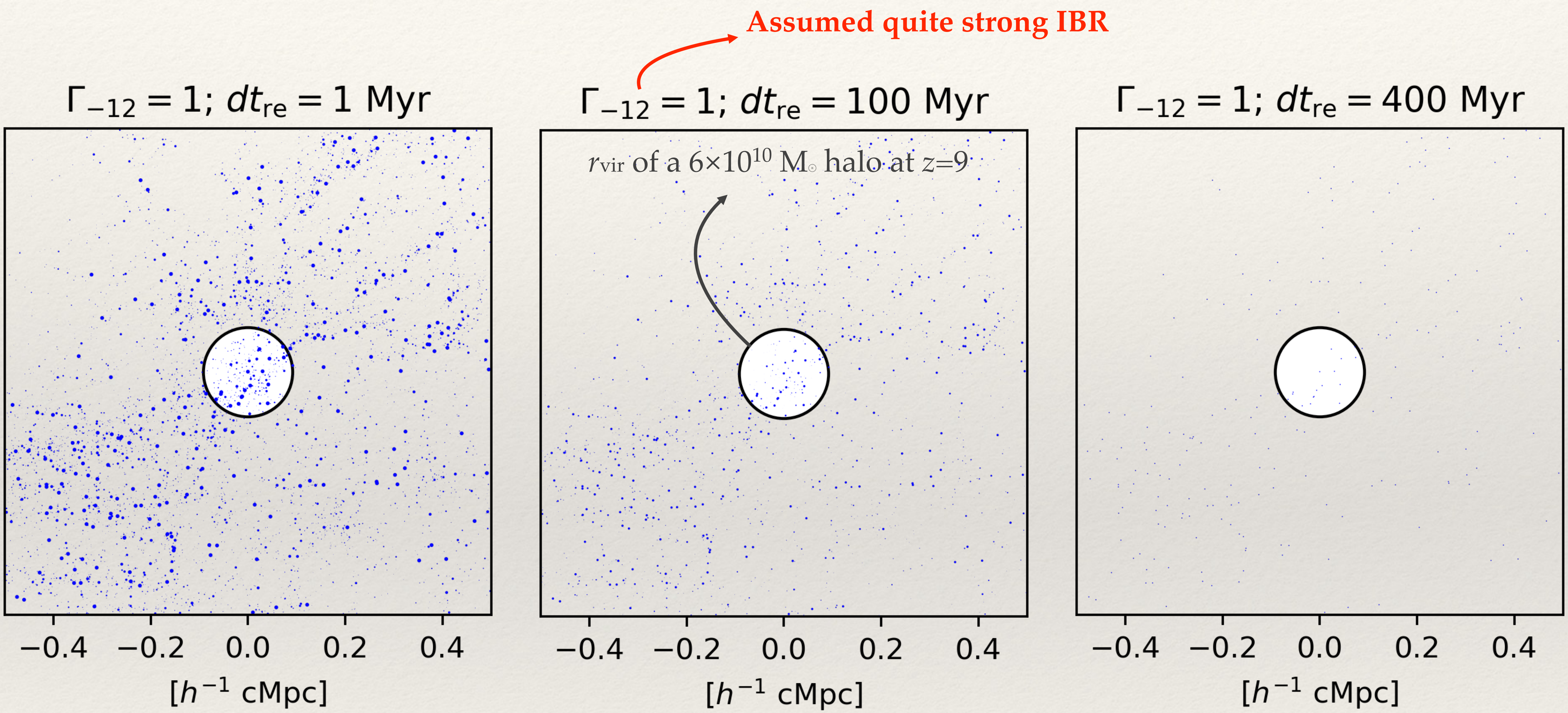


(Smith, A. + 2022)





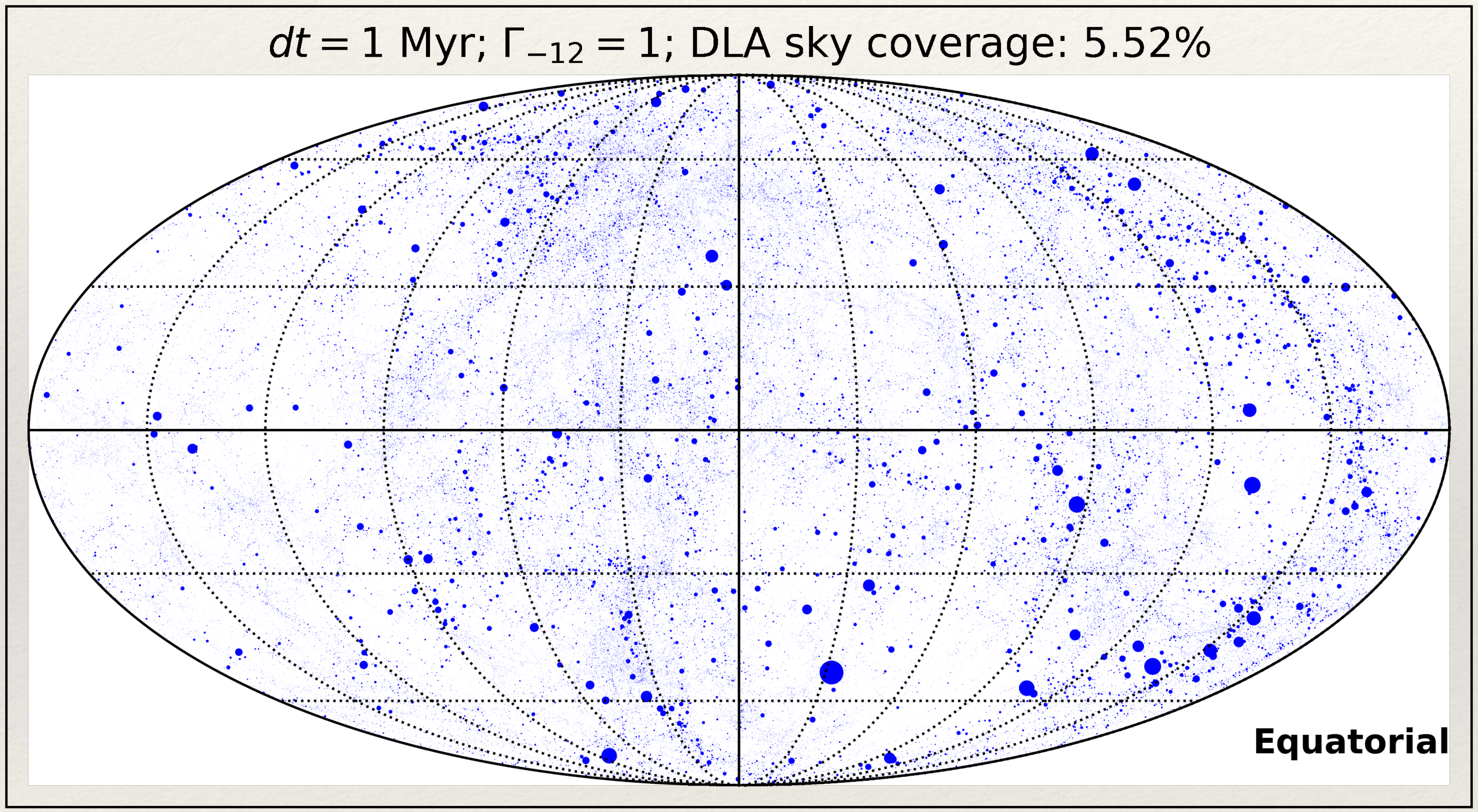
MHs in a High-res Simulation

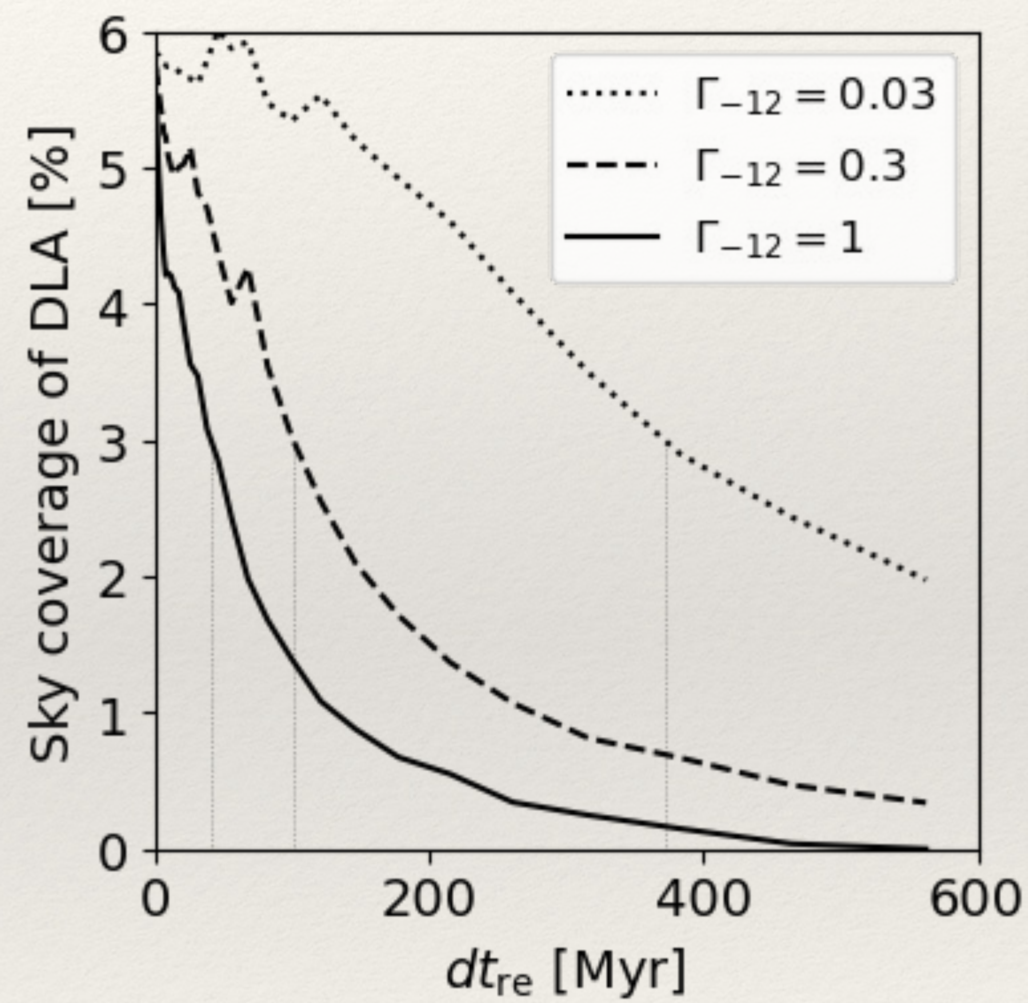


Code: Nyx
Box size: 10 h^{-1} Mpc
Resolution: 4096^3
$m_{\rm DM} = 1.5\times10^3\ M_\odot$

DLA Sky Coverage

DLA sky map of a $6 \times 10^{10}\ M_\odot$ halo at $z = 9$





~5% of the viewing angles blocked by DLAs (more for higher mass?)

Photo-evaporation time scale ~ 100 Myrs / $(\Gamma_{-12} / 0.3)^{0.5}$

Not enough to account for ~50% of galaxies having very strong ($>10^{22}$ cm^{-2}) DLAs.

Summary

Looked into Lyα opacity due to MHs at $z \geq 5$.
The findings are …

- MHs can survive $\Gamma_{-12} = 0.03$ for >100 Myrs and affect the Lyα forest at $z \sim 5.5$.
  - a steep increase in DLA incidence rate
  - ~3% higher flux power-spectrum at $k \sim 0.1$ h/Mpc
  - distorted galaxy-flux correlation.

- MHs survive $\Gamma_{-12} \geq 0.3$ for $\lesssim$ 100 Myrs and can strongly attenuate Lyα flux from galaxies at $z > 7$ for ~5% of the sight lines.