Fast Radio Bursts as Probes of the Intergalactic Medium and Galaxy Feedback

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ASTRO 3D

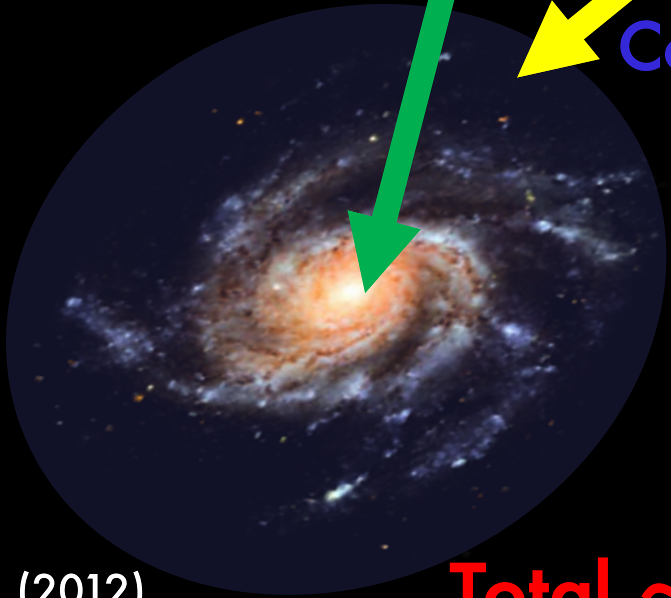
SWINBURNE Centre for Astrophysics and Supercomputing

Why Do We Care About the Intergalactic Medium?

Galaxies ~ 7%

CGM ~ 5%

IGM ~ 82%



Cold Gas ~ 2%

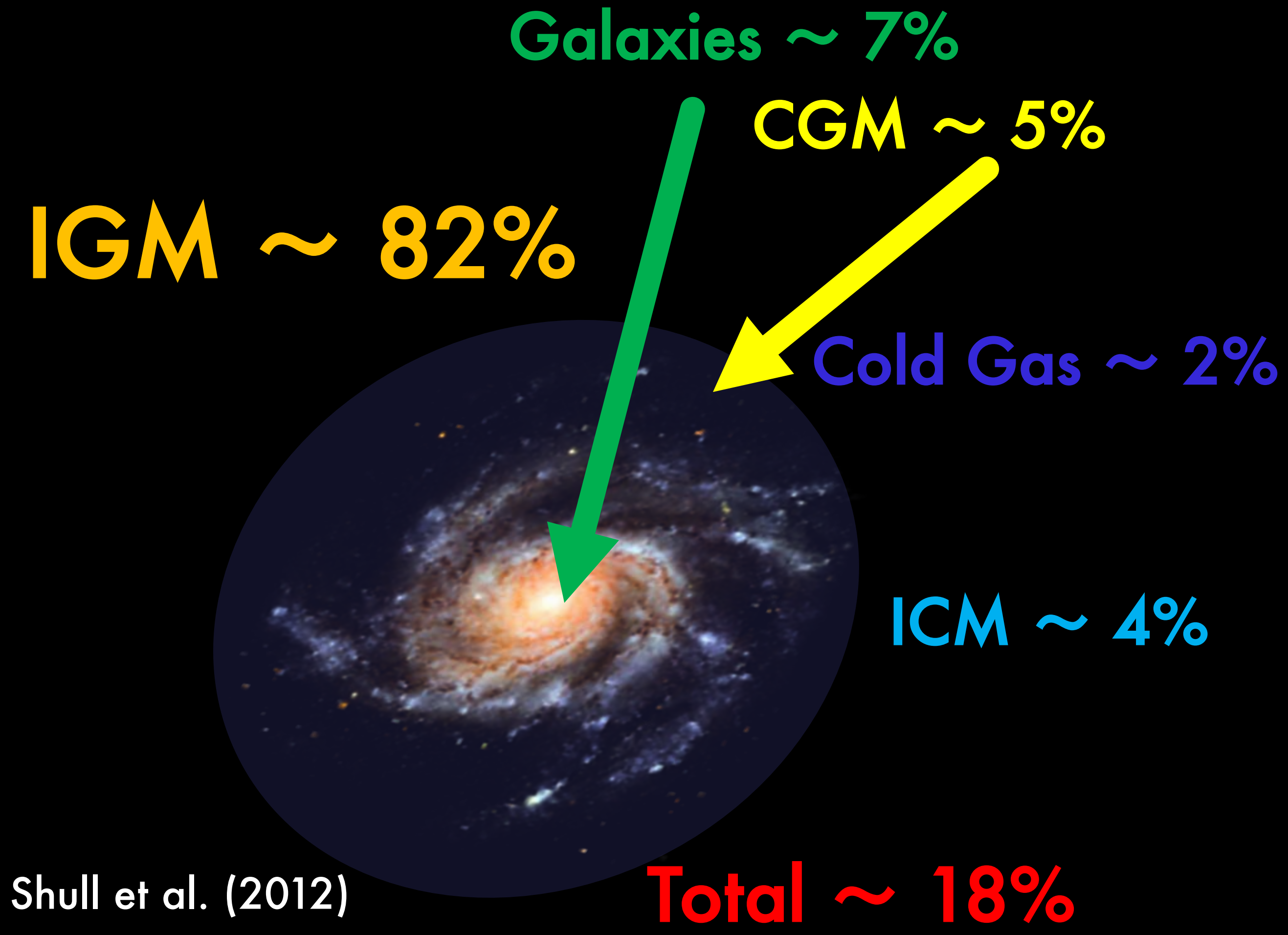
ICM ~ 4%

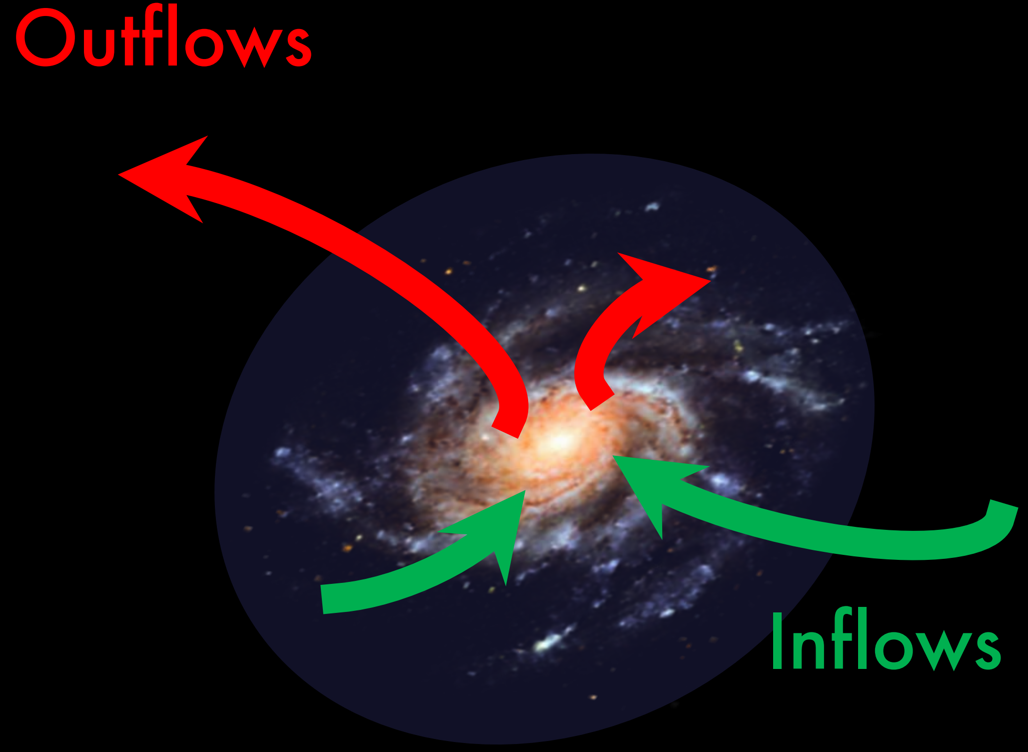
Total ~ 18%

Shull et al. (2012)

1. The IGM contains most of the baryonic matter

Why Do We Care About the Intergalactic Medium?





1. The IGM contains most of the baryonic matter

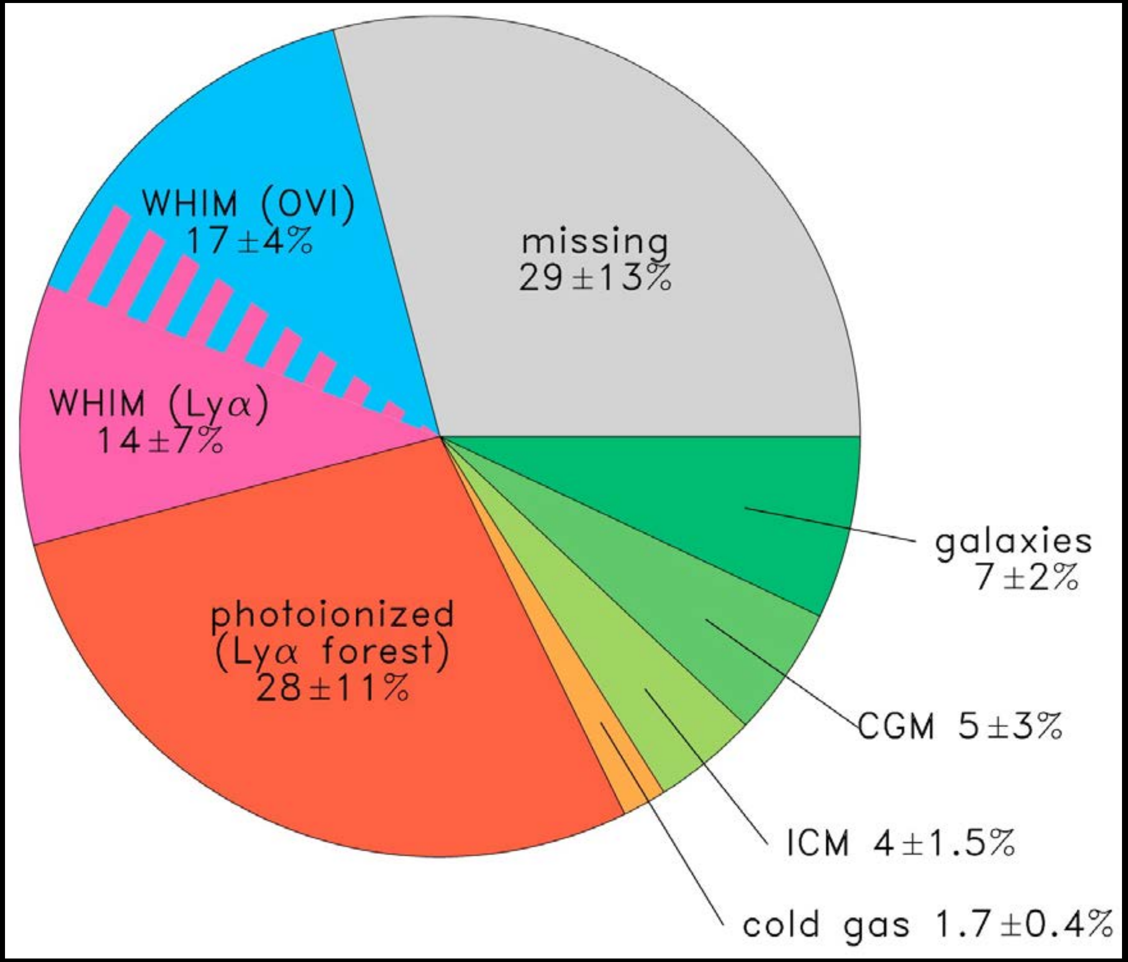
2. Galaxies and the IGM evolve together

Problems Observing the Intergalactic Medium

- Density ~ 1 particle per cubic meter
- Temperature $\sim 1 \times 10^6$ K

➽ Lack of favourable UV/Optical transition lines. Hard to observe!!!

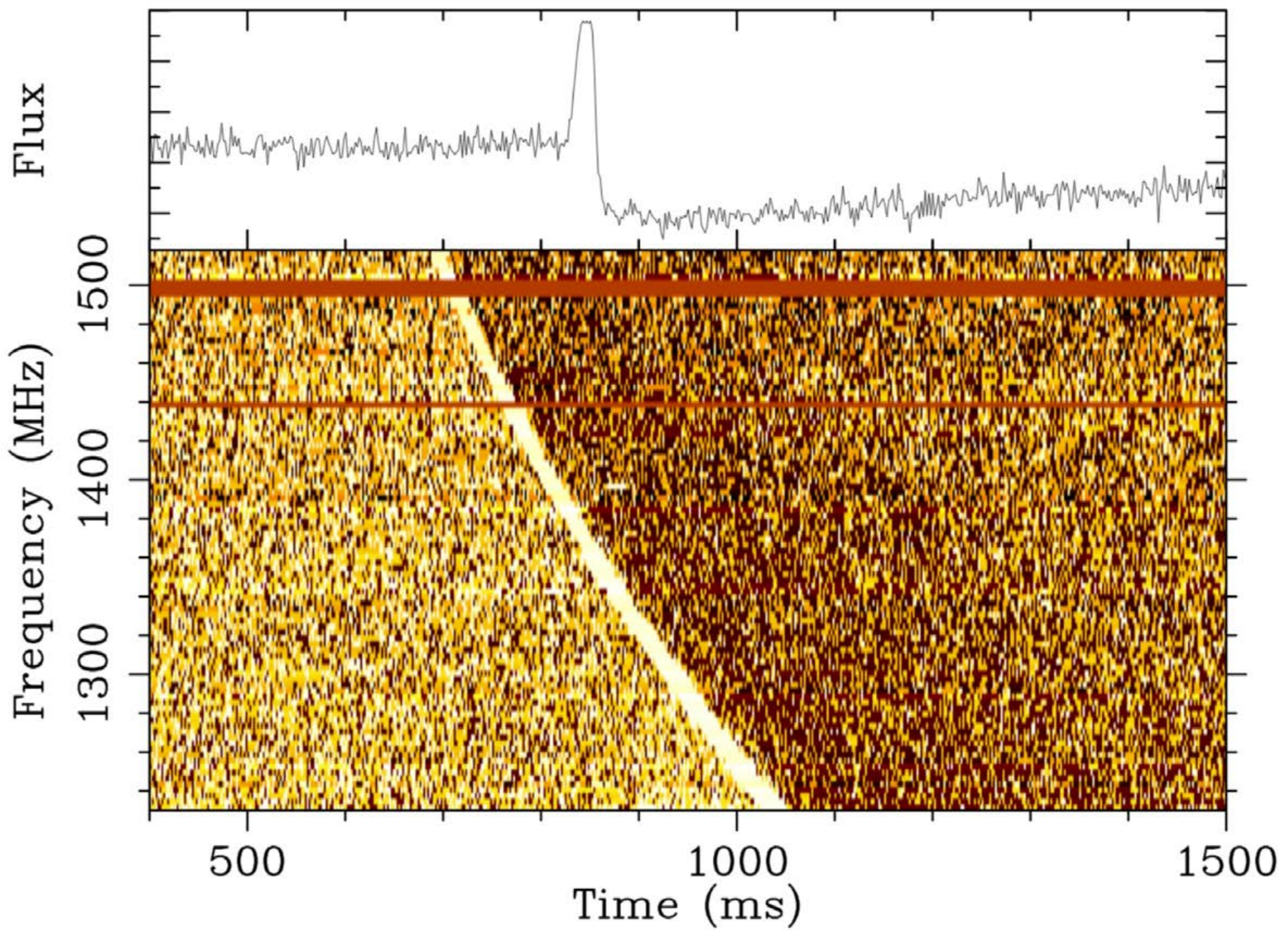
The Missing Baryon Problem:
~ 30% of baryons at low redshift appear to be missing!



Shull et al. (2012)

How do Fast Radio Bursts (FRBs) help?

Lorimer et al. (2007)
Petroff et al. (2019)



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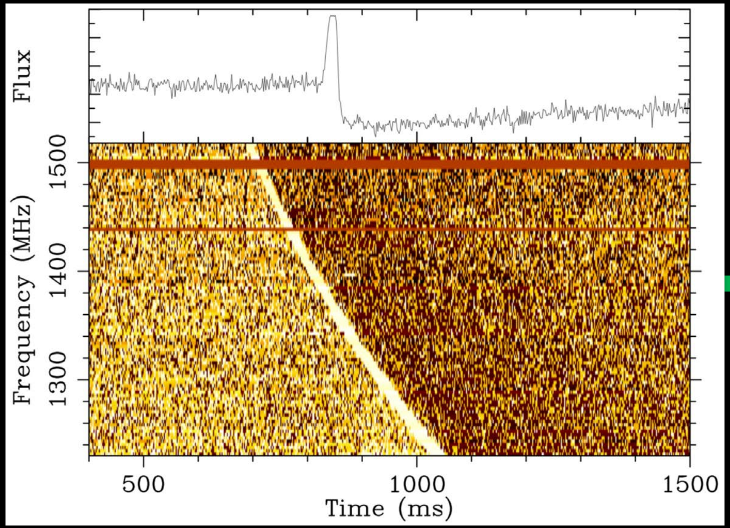
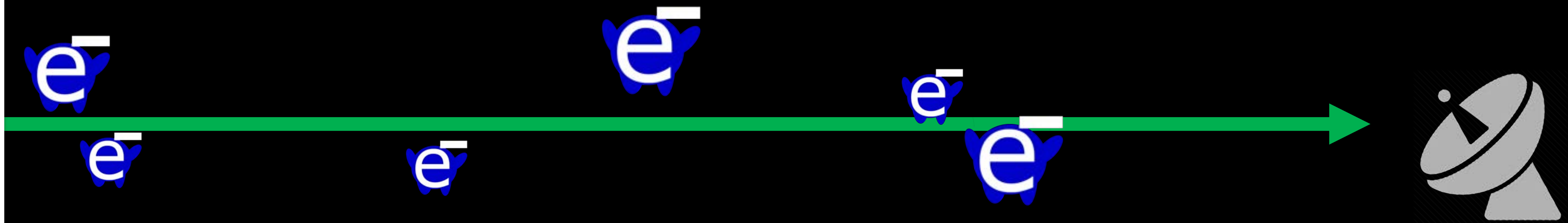




Constant

Frequency

Electron number density

$$t = k\nu^{-2} \int_0^d n_e \, dl$$

$$\mathrm{DM} = \int_0^d \frac{n_e}{1+z} \, dl$$

DM = Dispersion Measure

Not Dark Matter

$$\mathrm{DM} = \mathrm{DM}_{\mathrm{MW}} + \mathrm{DM}_{\mathrm{cosmic}}(\mathrm{z}) + \frac{\mathrm{DM}_{\mathrm{Host}}}{1 + \mathrm{z}}$$

Milky Way

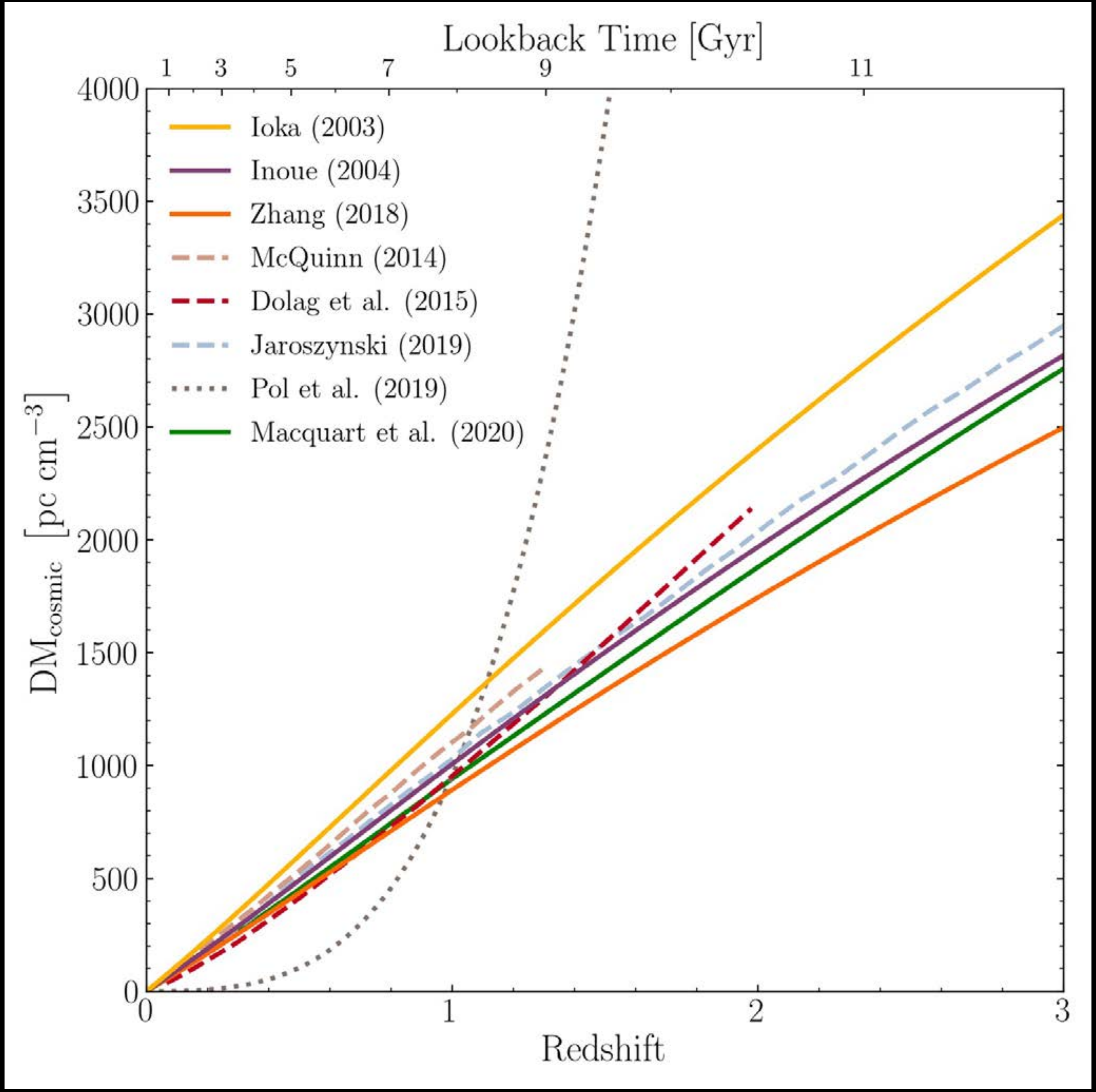
Host Galaxy/Local Environment

$$\mathrm{DM} = \mathrm{DM}_{\mathrm{MW}} + \mathrm{DM}_{\mathrm{cosmic}}(z) + \frac{\mathrm{DM}_{\mathrm{Host}}}{1+z}$$

$$\mathrm{DM}_{\mathrm{cosmic}}(z) = \mathrm{DM}_{\mathrm{IGM}}(z) + \mathrm{DM}_{\mathrm{CGM,Interlopers}}$$

Intergalactic Medium

The CGM of Galaxies along the line-of-sight



Ioka (2003) [Analytic]

Inoue (2004) [Analytic]

Zhang (2018) [Analytic]

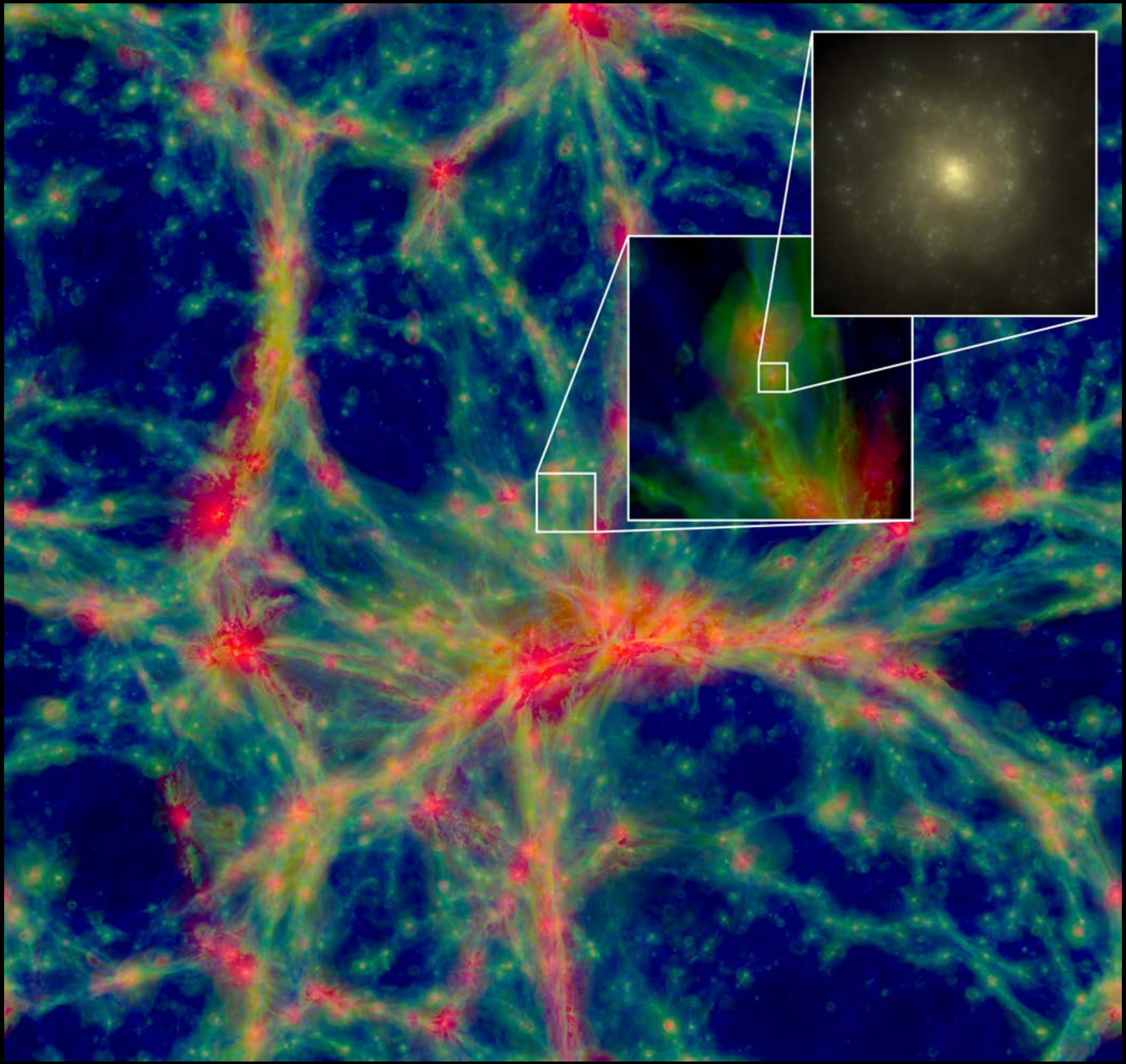
McQuinn (2014) [Analytic+Hydro]

Dolag+(2015) [Hydro; Magneticum]

Jaroszynski (2019) [Hydro; Illustris]

Pol+(2019) ["Semi-Analytic"; MICE]

Macquart+(2020) [Analytic]



EAGLE Simulations

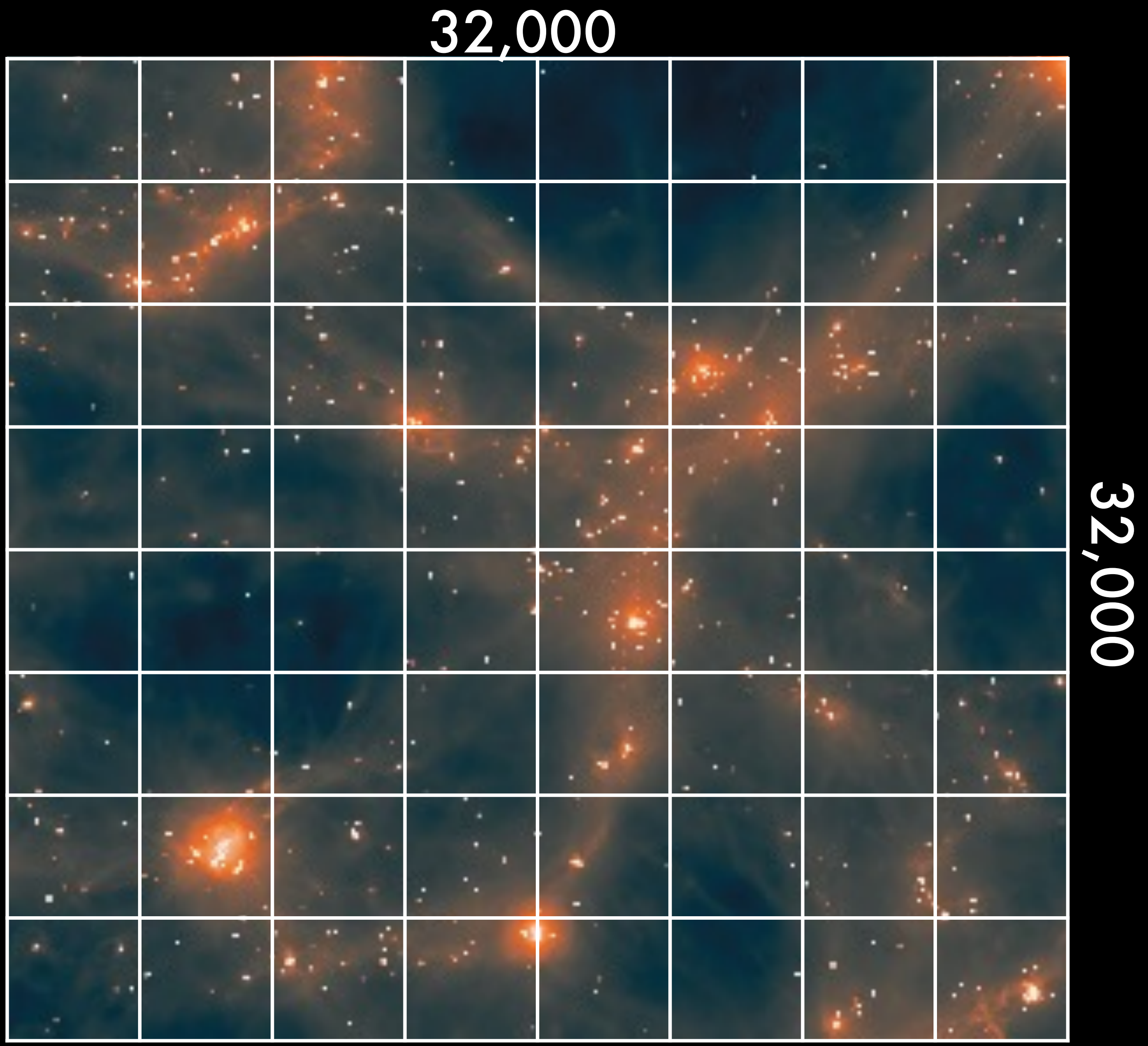
Schaye et al. (2015), Crain et al (2015)

- Hydrodynamics + Nbody
- Large cosmological volume (100 cMpc)
- Redshift range ($z \sim 127$ to $z = 0$)

- Abundances for 11 different elements.
- HM12 UV Ionising Background
- Galactic Winds: Star formation & AGN

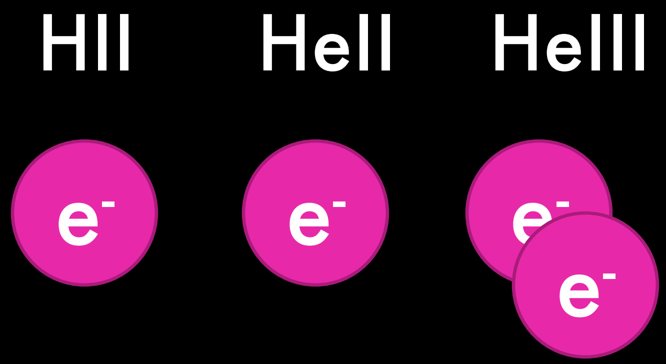
- Resolution: $\sim$ 0.7 ckpc
- Particle Masses: $\sim 10^6 M_\odot$

Batten et al. (2021)



EAGLE Simulations

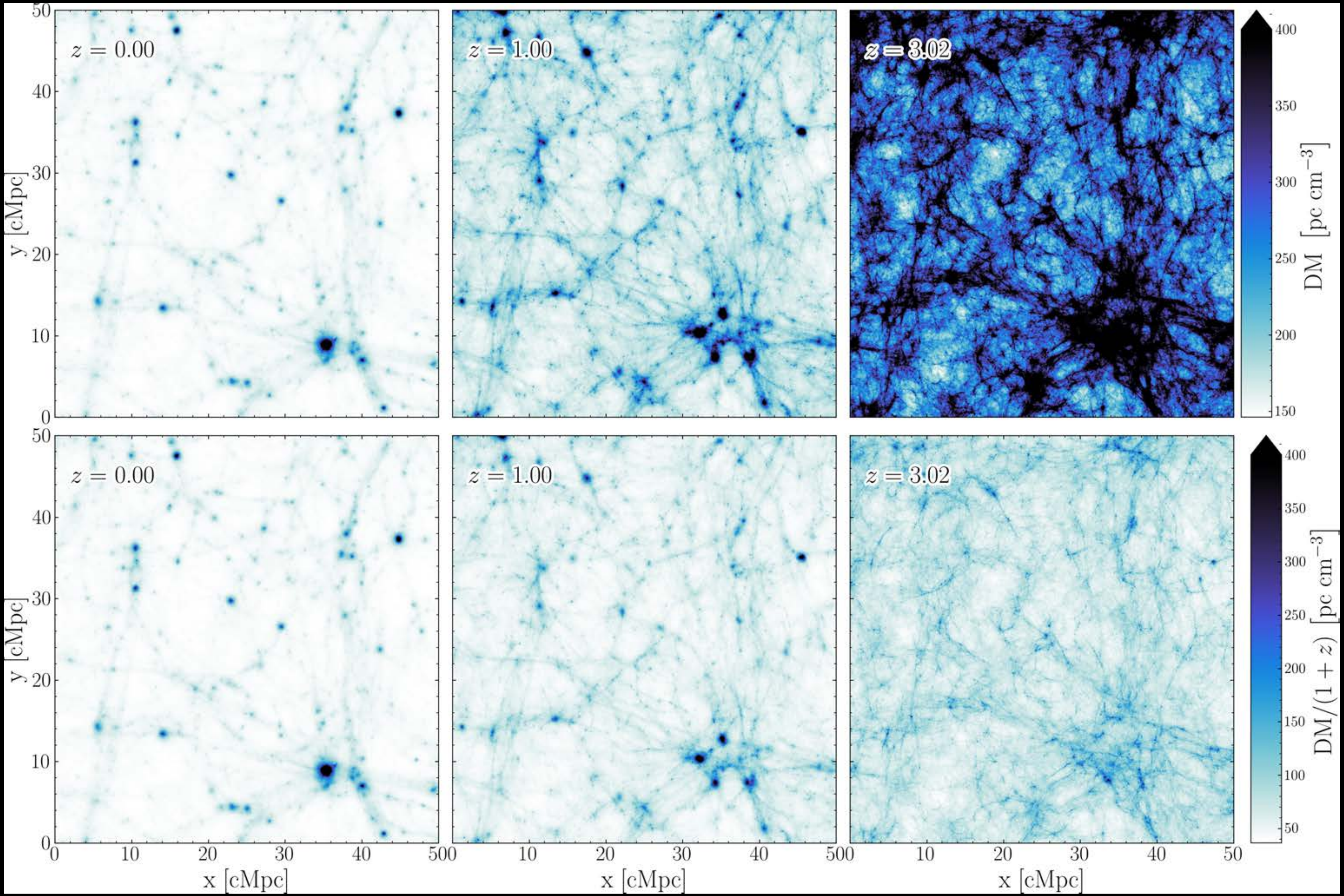
- Divide cube into columns
- Calculate column densities
  - Rahmati et al. (2013) (SS)
  - Wijers et al. (2019)
- Convert column densities to units of pc cm^{-3}



Batten et al. (2021)

Local Observer

$z = 0$ Observer



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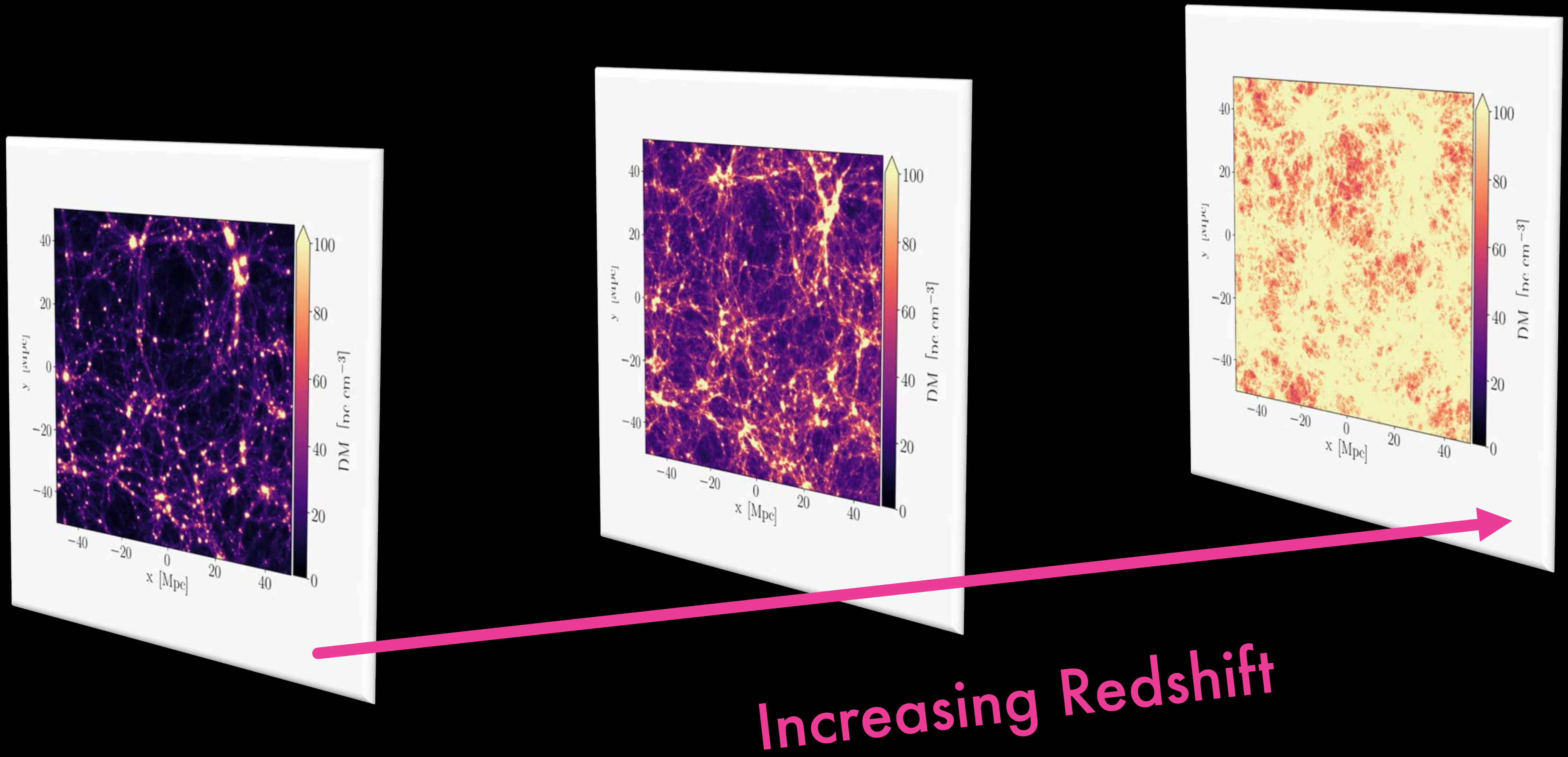

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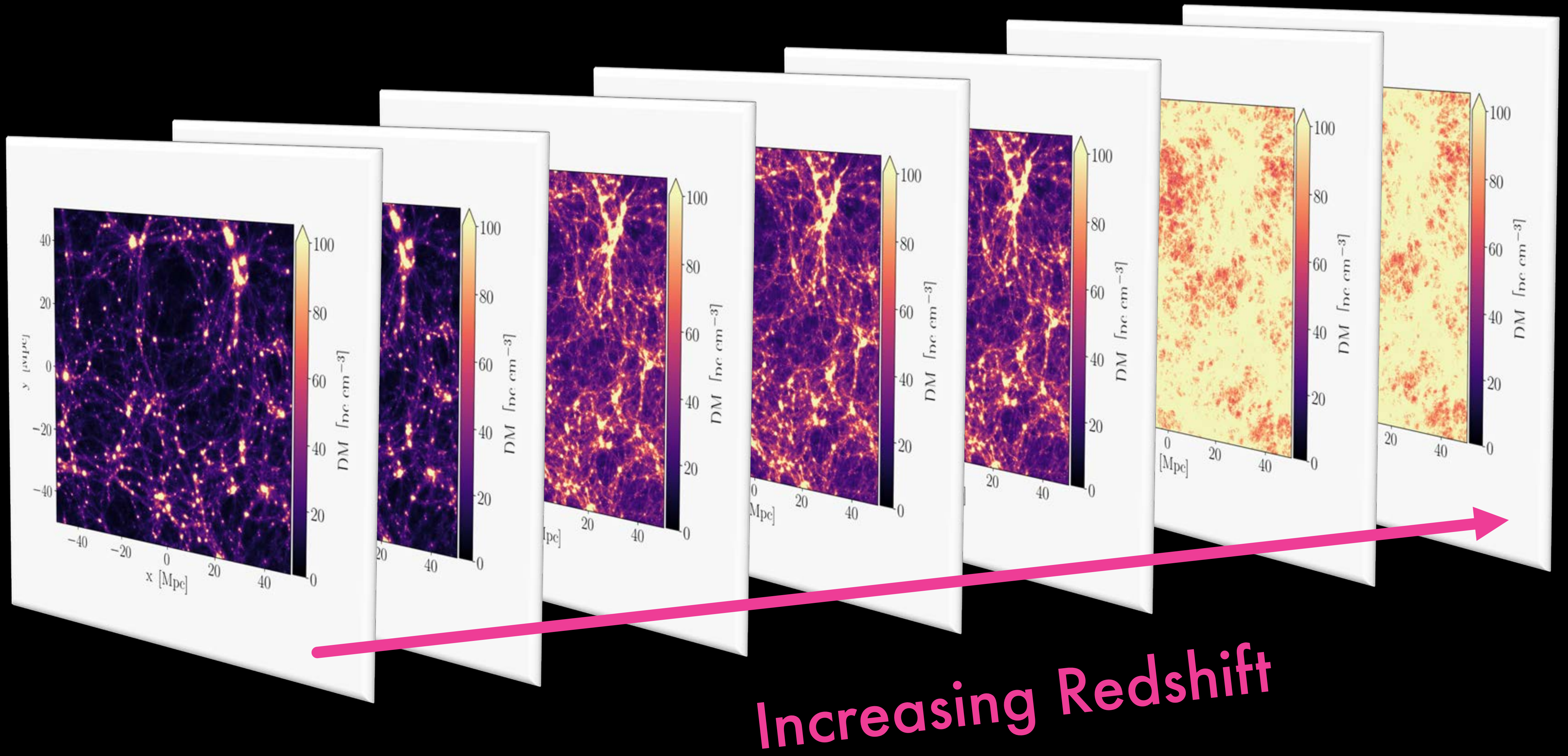

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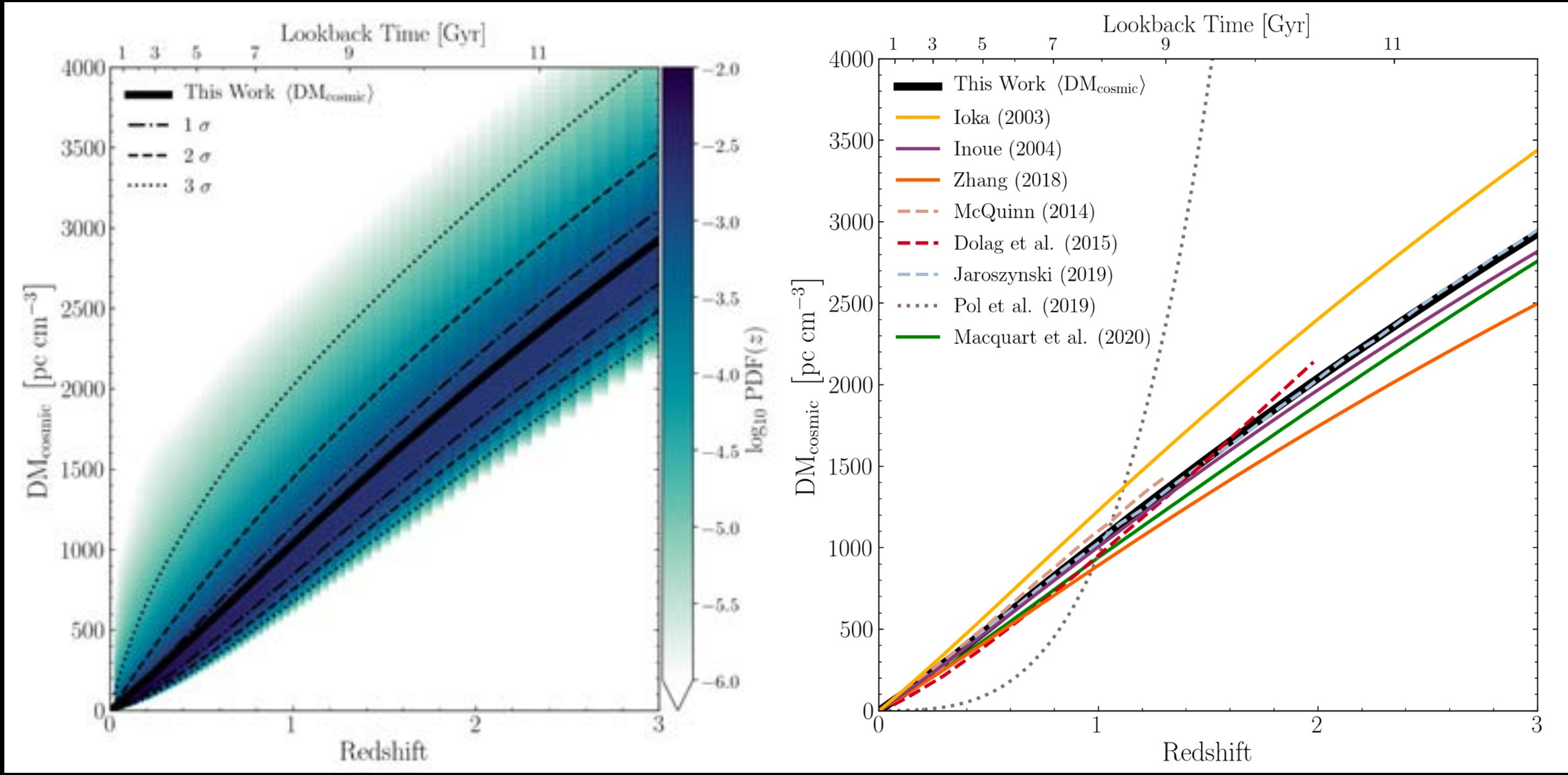

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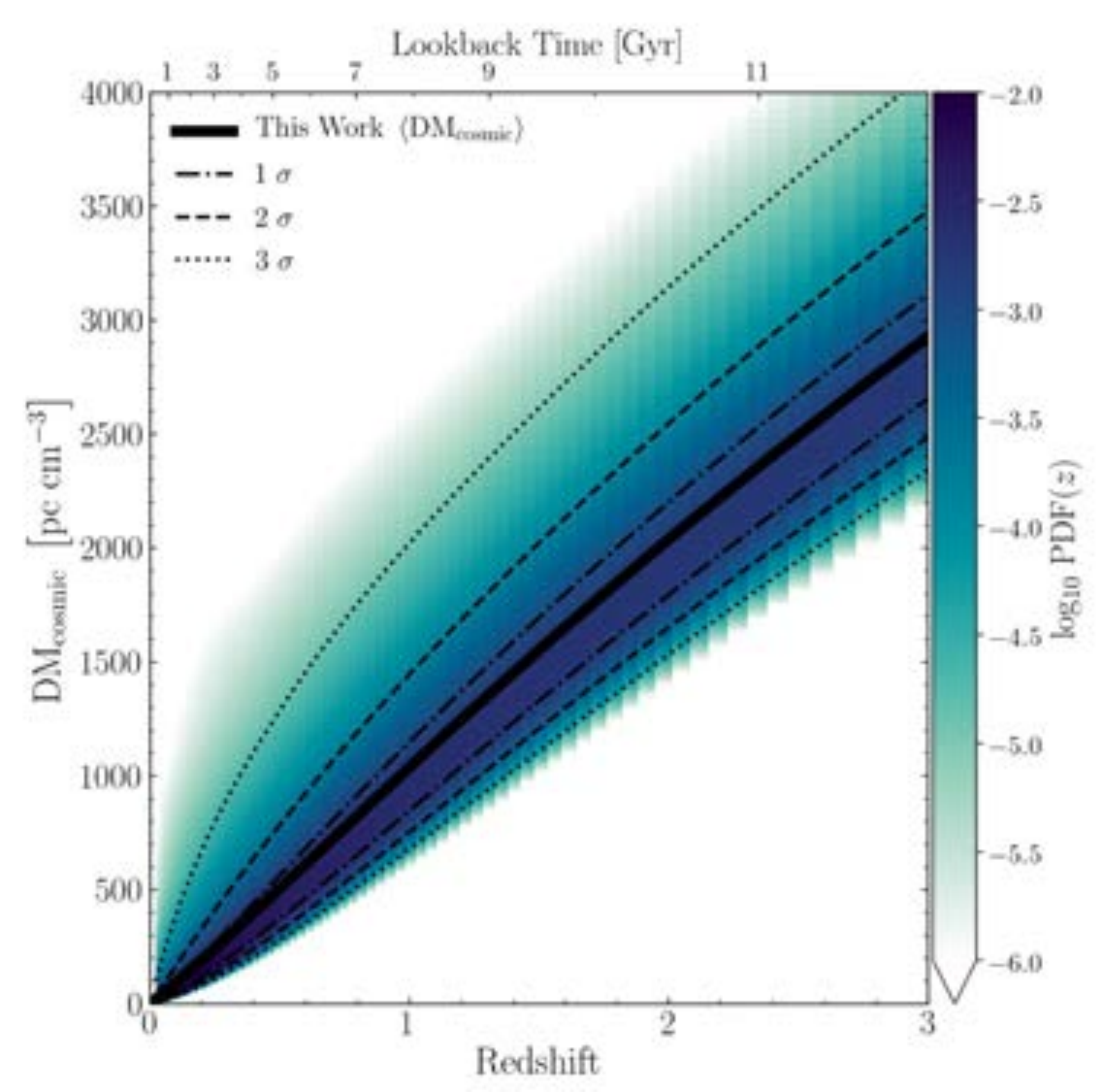

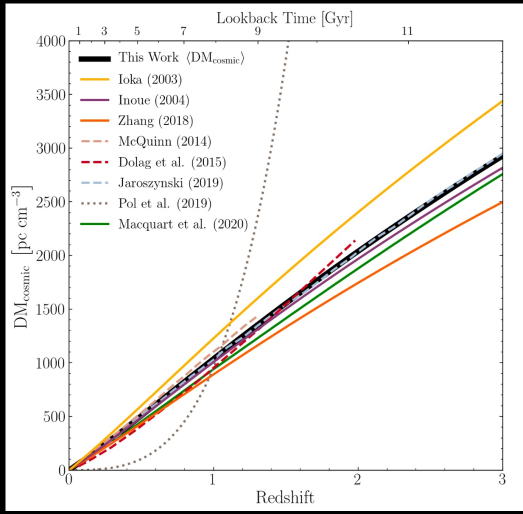

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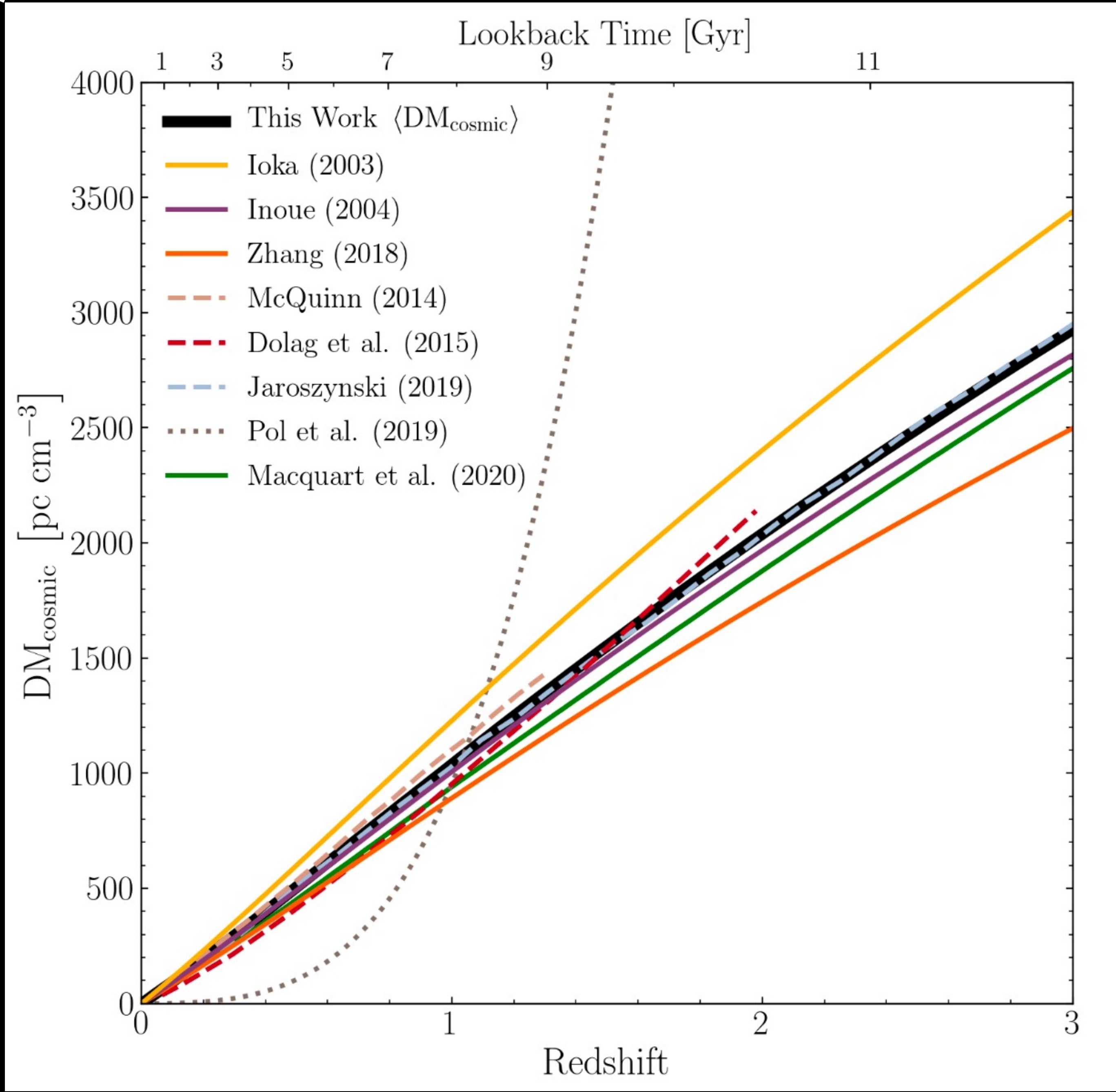
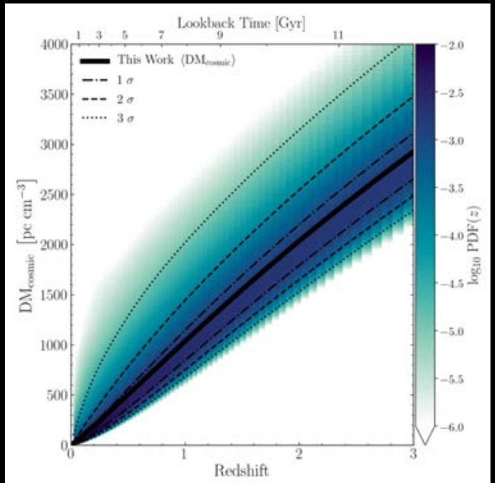


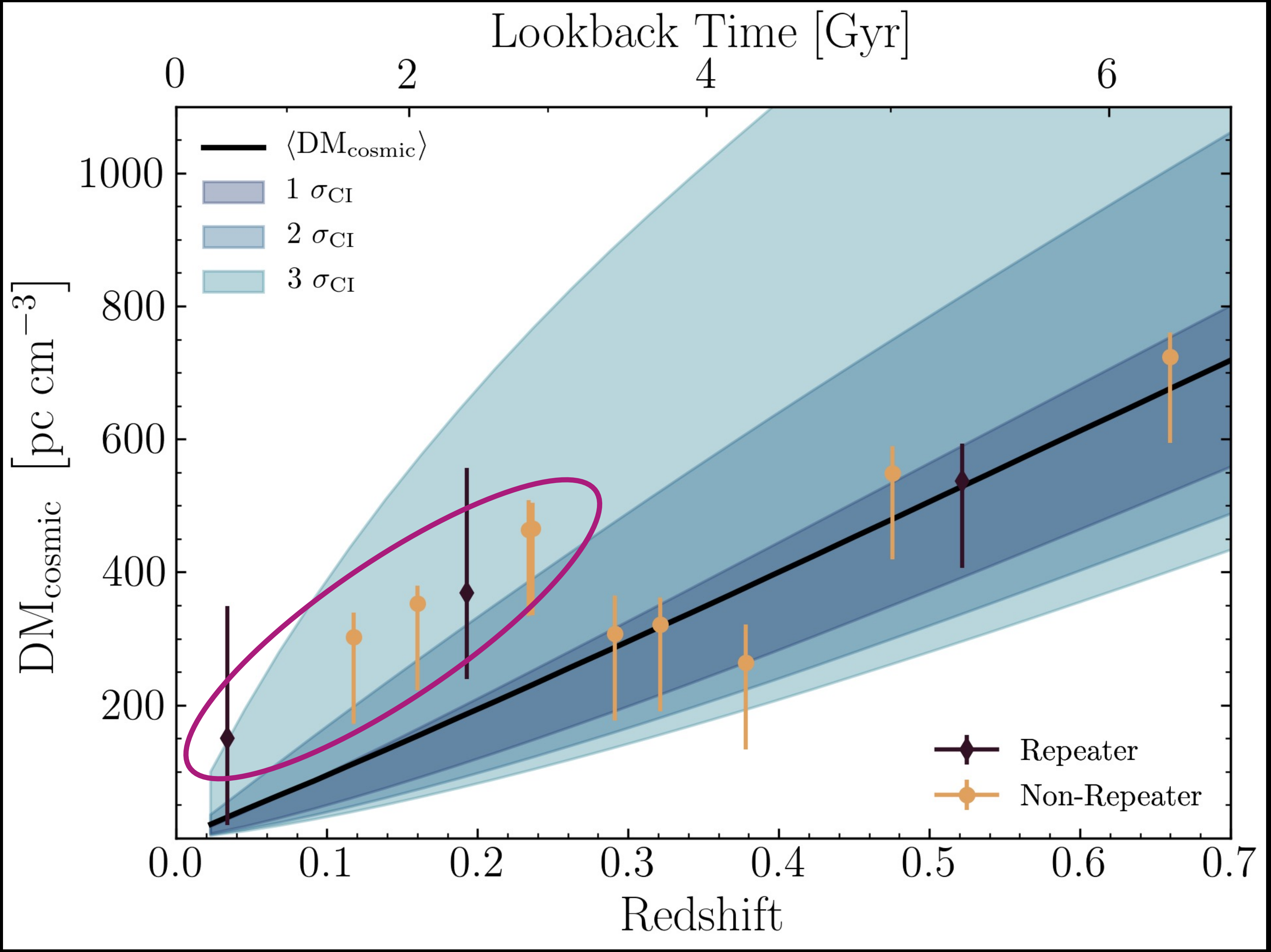


Batten et al. (2021)

The $\mathbf{DM_{cosmic}}$ of most FRBs at low redshift appear to be $2 - 3\sigma$ sigma above the mean.

FRBs with High DM:

- FRB 190608
- FRB 200430
- FRB 191001
- FRB 190714



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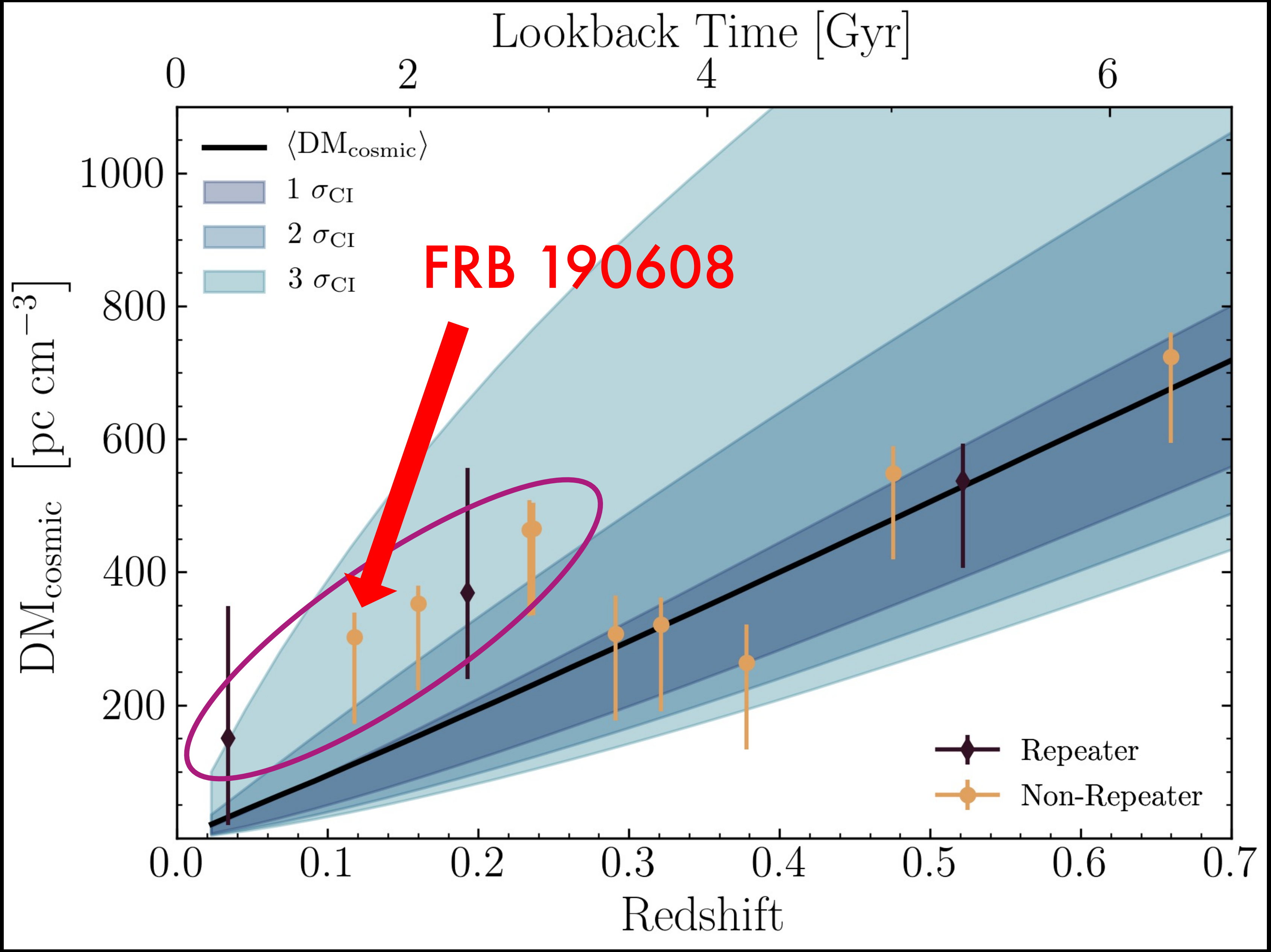
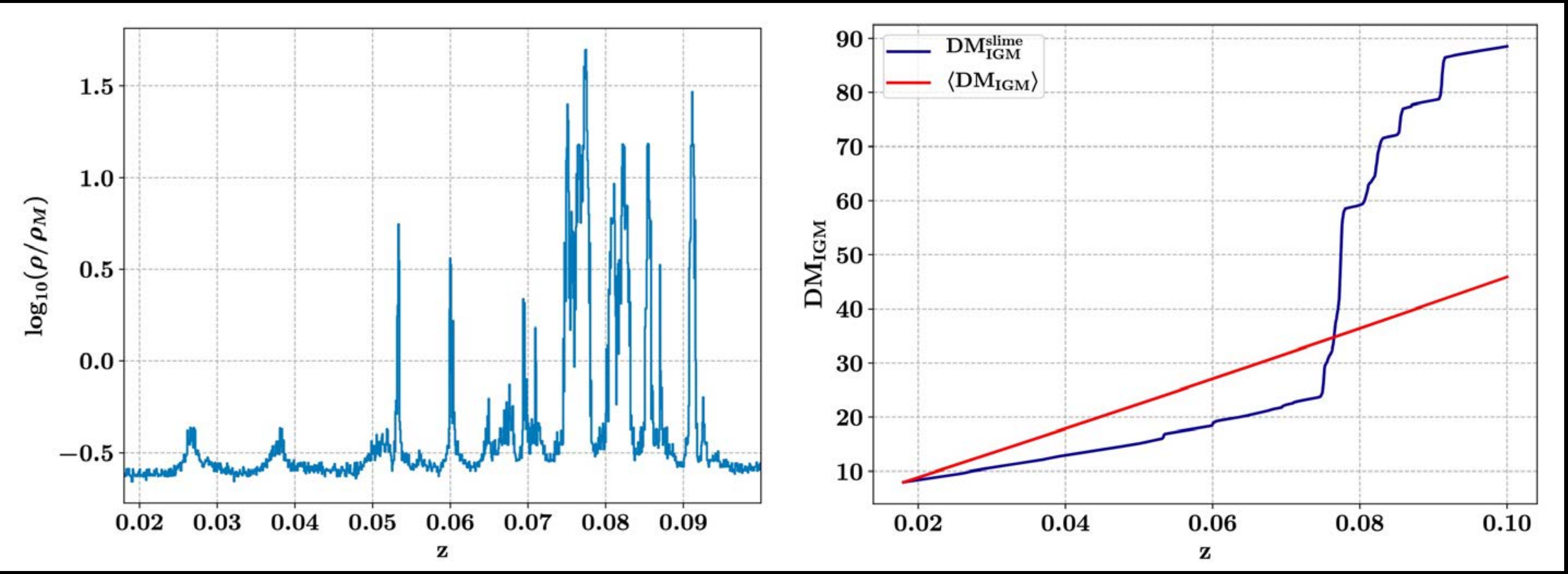
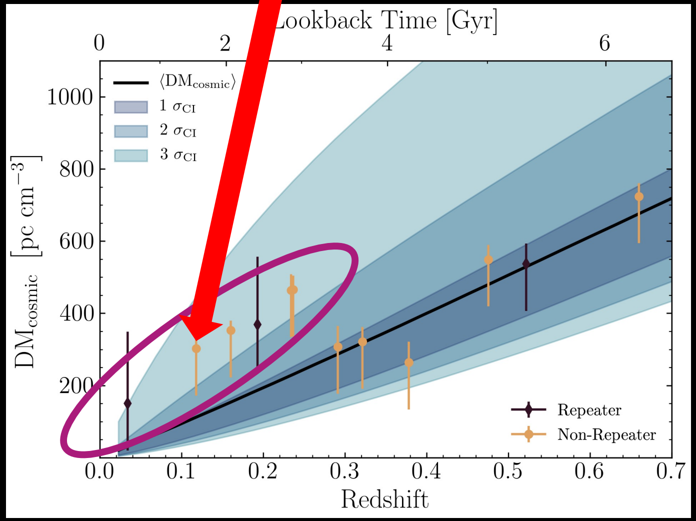


Batten et al. (2021)

IGM Density Reconstruction Towards FRB 190608



FRB 190608



Simha et. al (2020)

FRB 190608 intersects overdense IGM filaments along the line of sight!

Batten et al. (2021)

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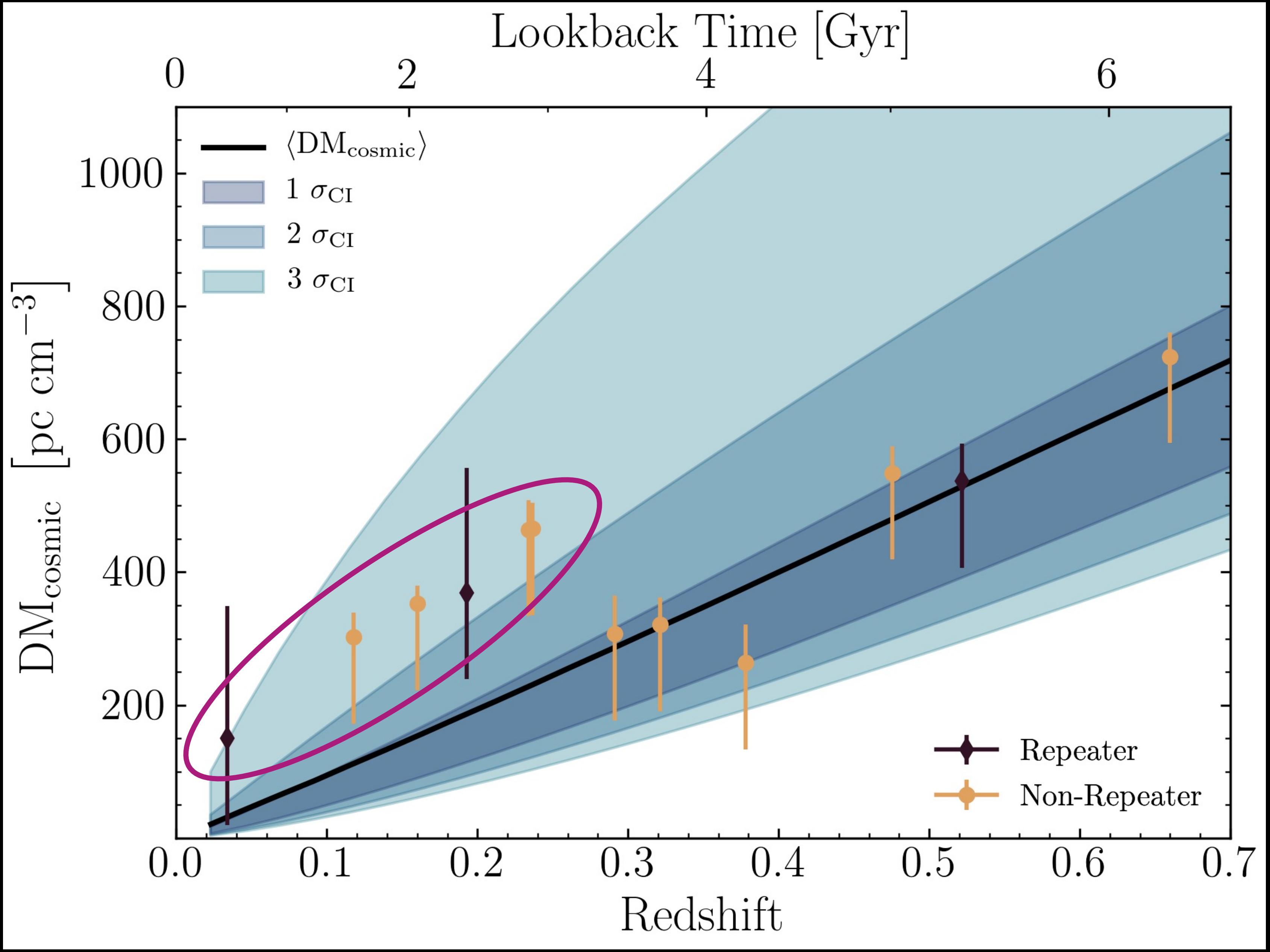


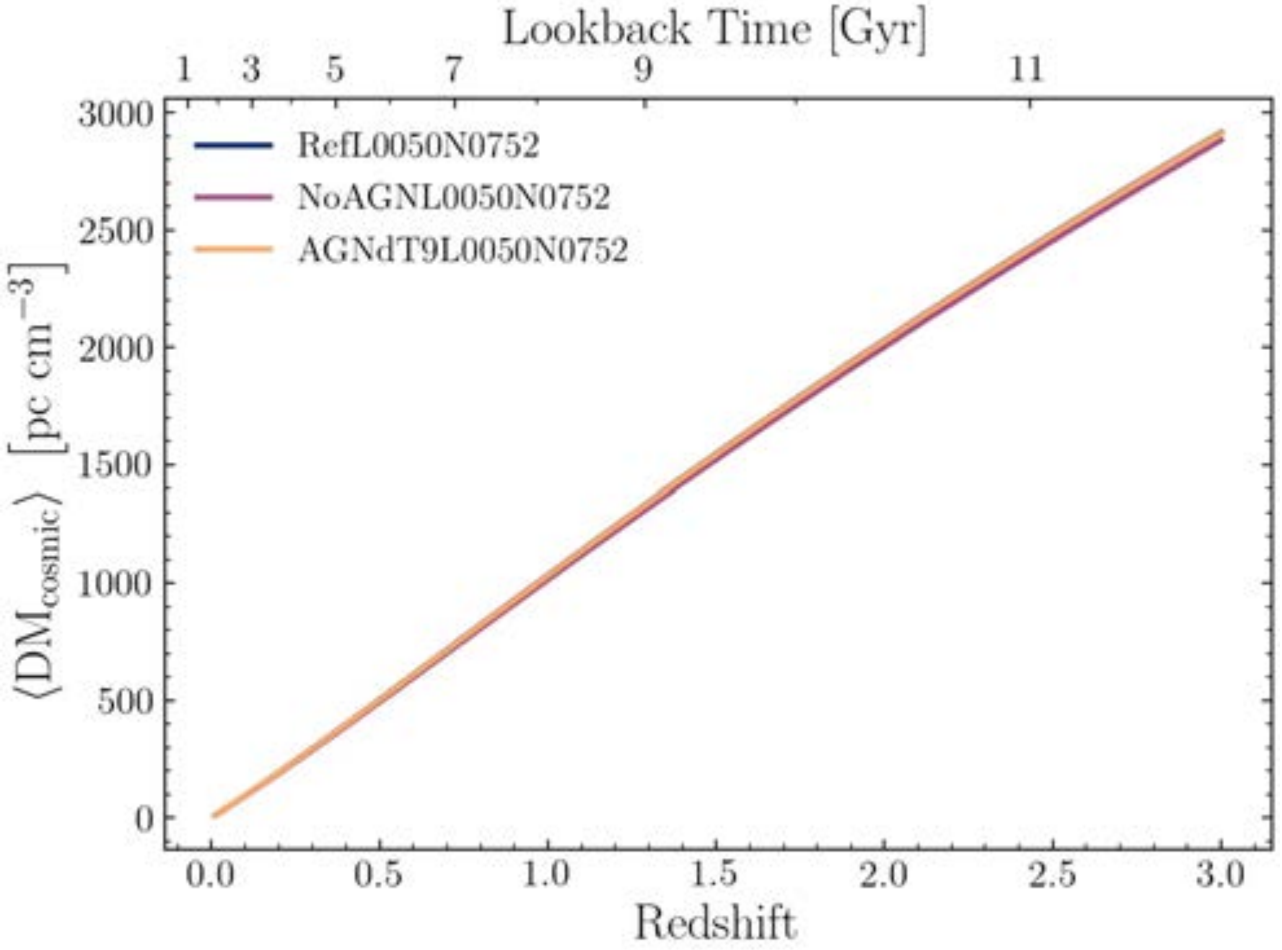
Batten et al. *in prep.*

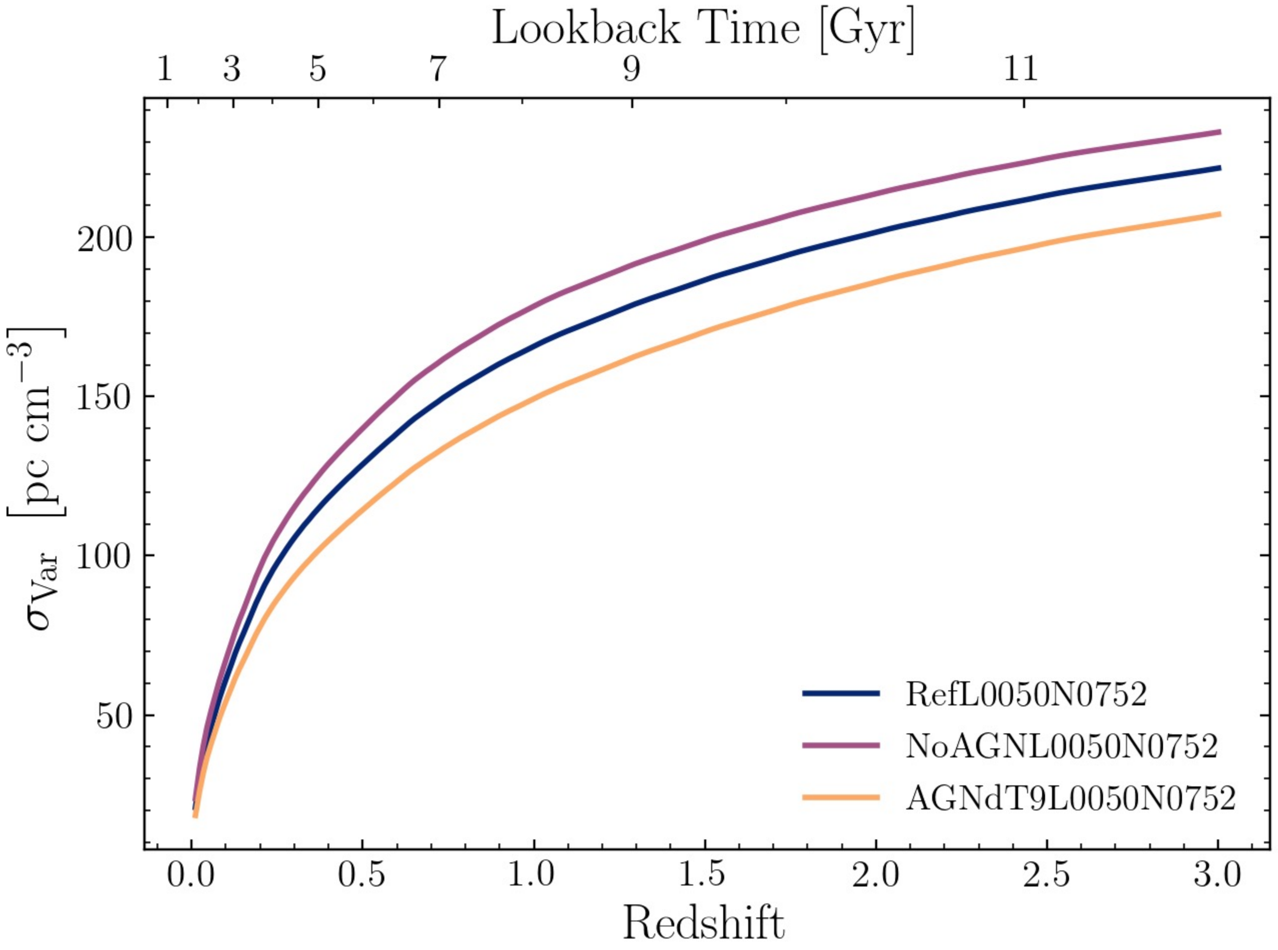
EAGLE Simulations varying AGN feedback

- RefL0050N0752 Reference Simulation
- NoAGN No Active Galactic Nuclei
- AGNdT9 More Efficient AGN Feedback

Batten et al. *in prep.*

FRBs as Probes of Galaxy Feedback





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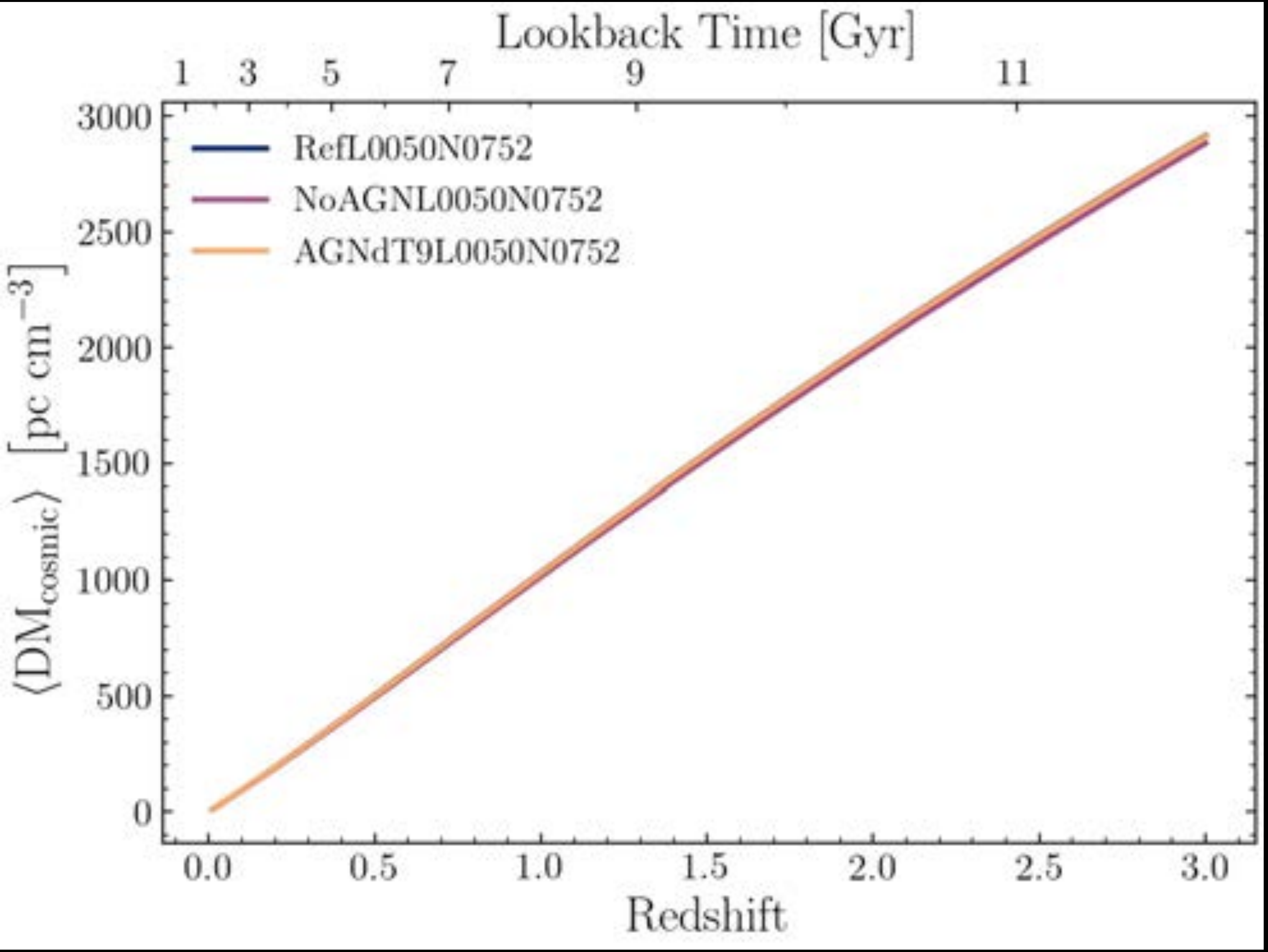
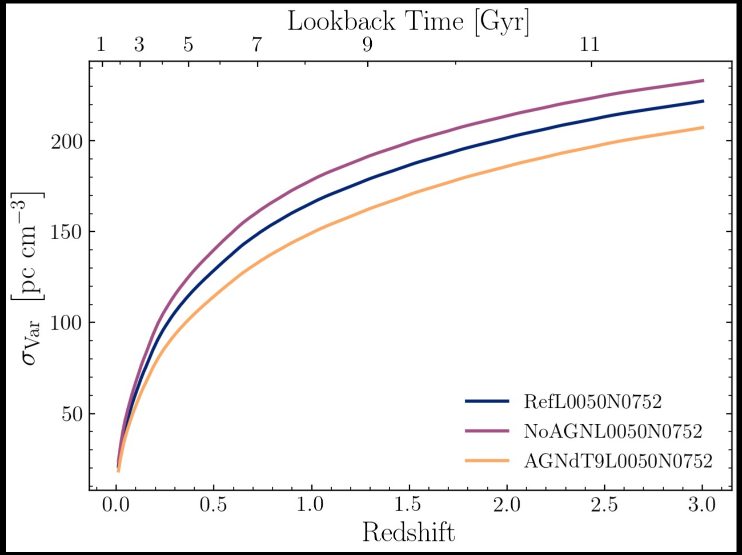
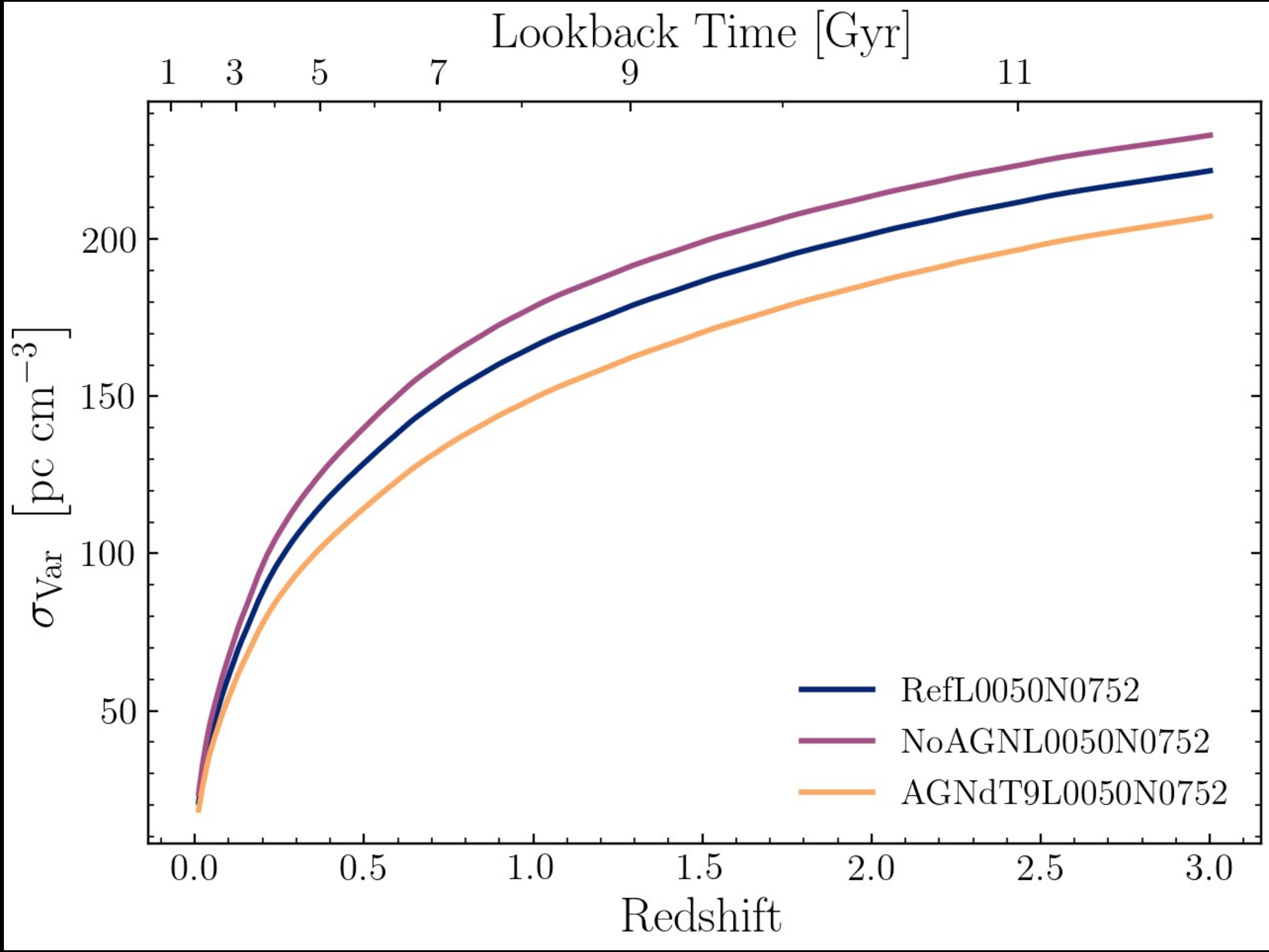


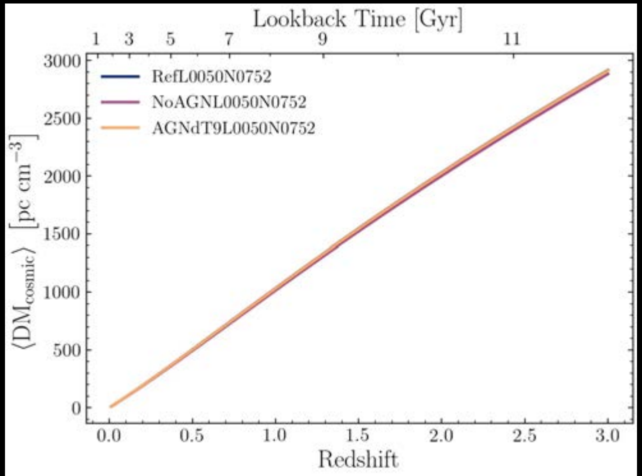
Mean DM-z Relation is extremely robust to changes in galaxy feedback!



Batten et al. *in prep.*

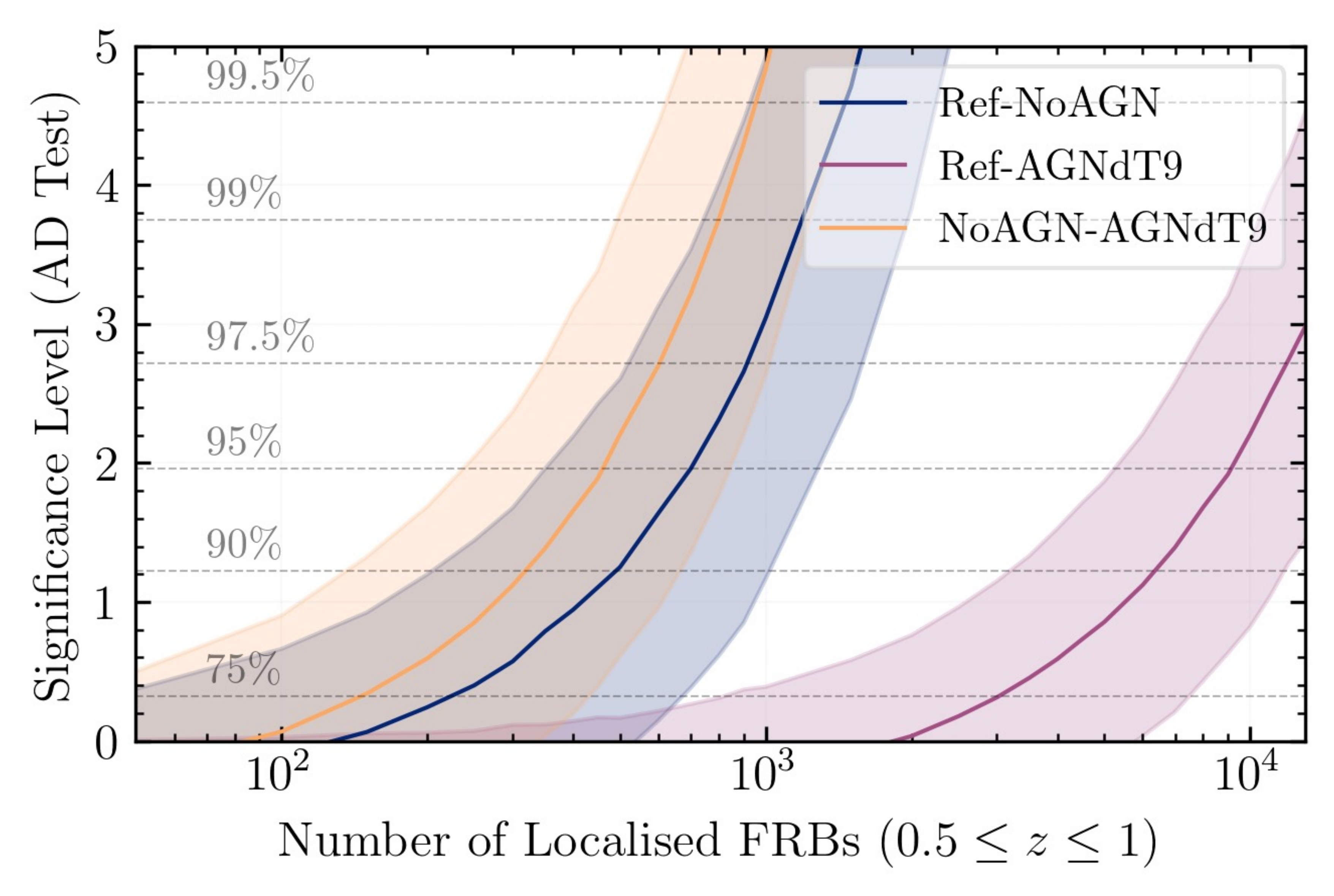
Main difference between models is in the standard deviation around the mean!





Batten et al. *in prep.*

How many localised FRBs do we need?



Summary:

- Fast Radio Bursts provide a new way to probe the electron/baryon distribution in the IGM.
- Batten+2021: *The Cosmic Dispersion Measure in EAGLE (MNRAS, Volume 505, Issue 4)*
  - ➥ I used the EAGLE simulations to calculate DM-z relation and the scatter around it.
  - ➥ Large scatter around relation, with extremely skewed PDFs at low redshifts.
  - ➥ Most low redshift FRBs lie in the 2 – 3σ confidence intervals.
  - ➥ Indicates intersection with IGM filaments, or possibly high host/source contributions.
- Batten+ *in prep.: The Dispersion Measure of FRBs as probes of AGN feedback*
  - ➥ The mean DM-z relation is very robust against different AGN feedback.
  - ➥ It appears that the scatter around the DM-z relation might be able to probe galaxy feedback.
  - ➥ Approx. 9000 localised FRBs are needed between z = 0.5 – 1 to constrain AGN feedback.
  - ➥ Need more large box simulations required with different galaxy feedback prescriptions.

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