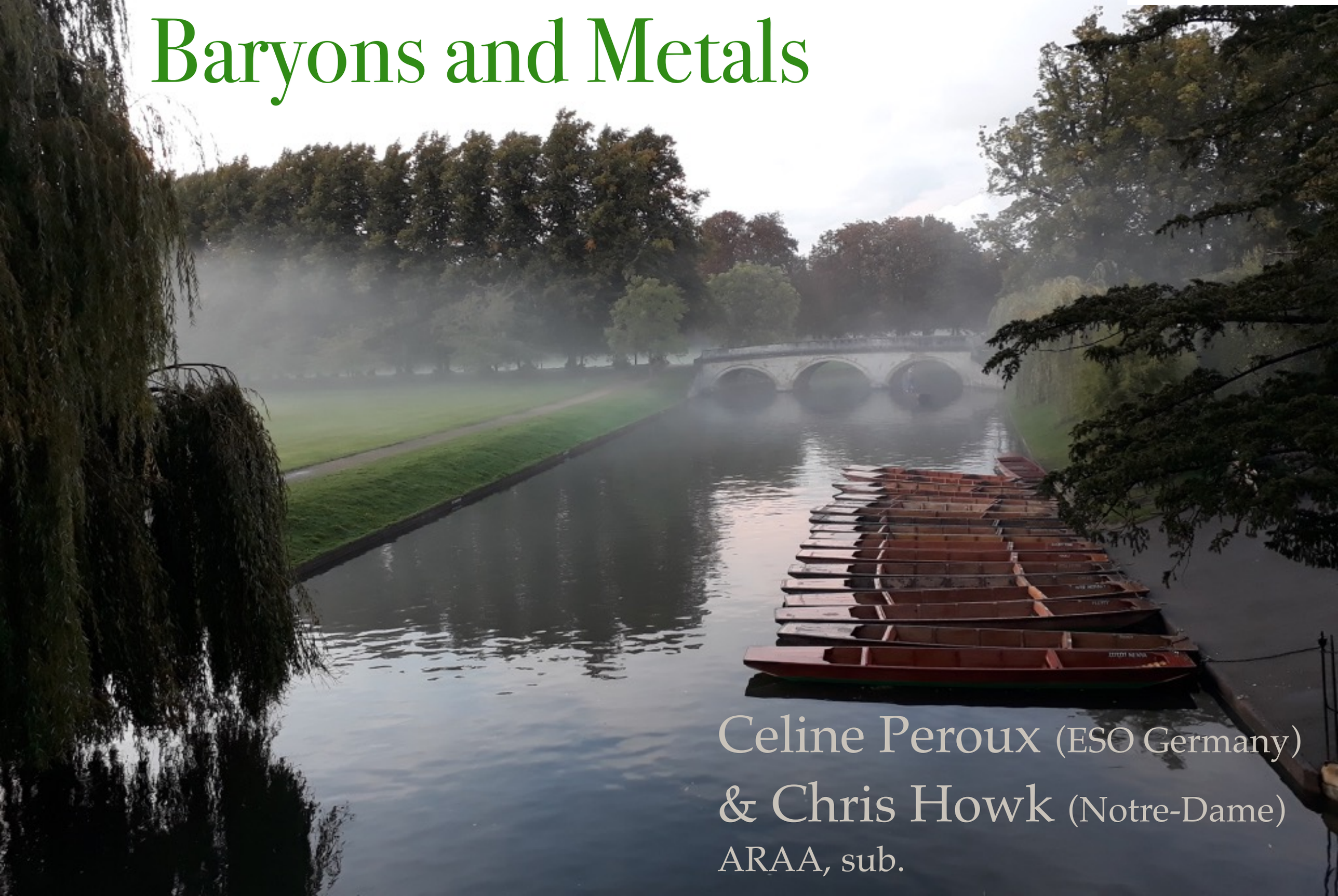
Cosmic Evolution of Baryons and Metals

Alexander von Humboldt
Stiftung/Foundation

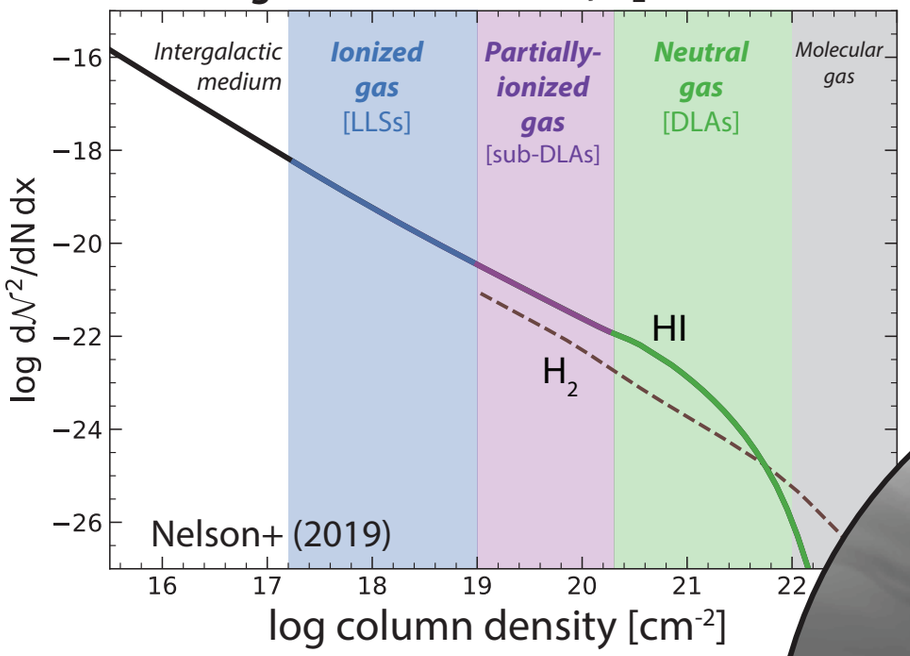


Celine Peroux (ESO Germany)
& Chris Howk (Notre-Dame)

ARAA, sub.

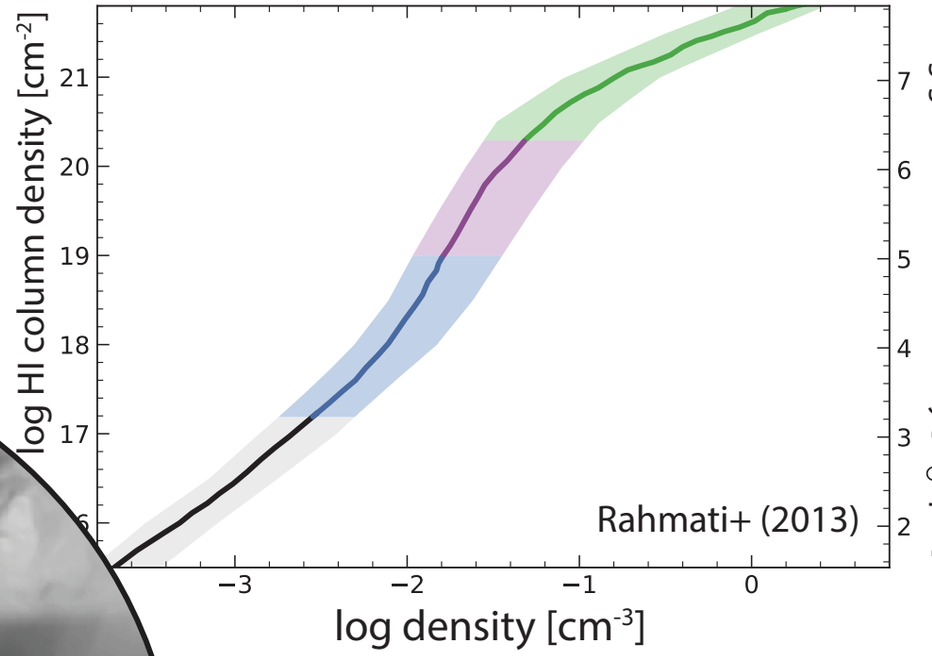
(b)

Cosmological incidence of HI, H_2

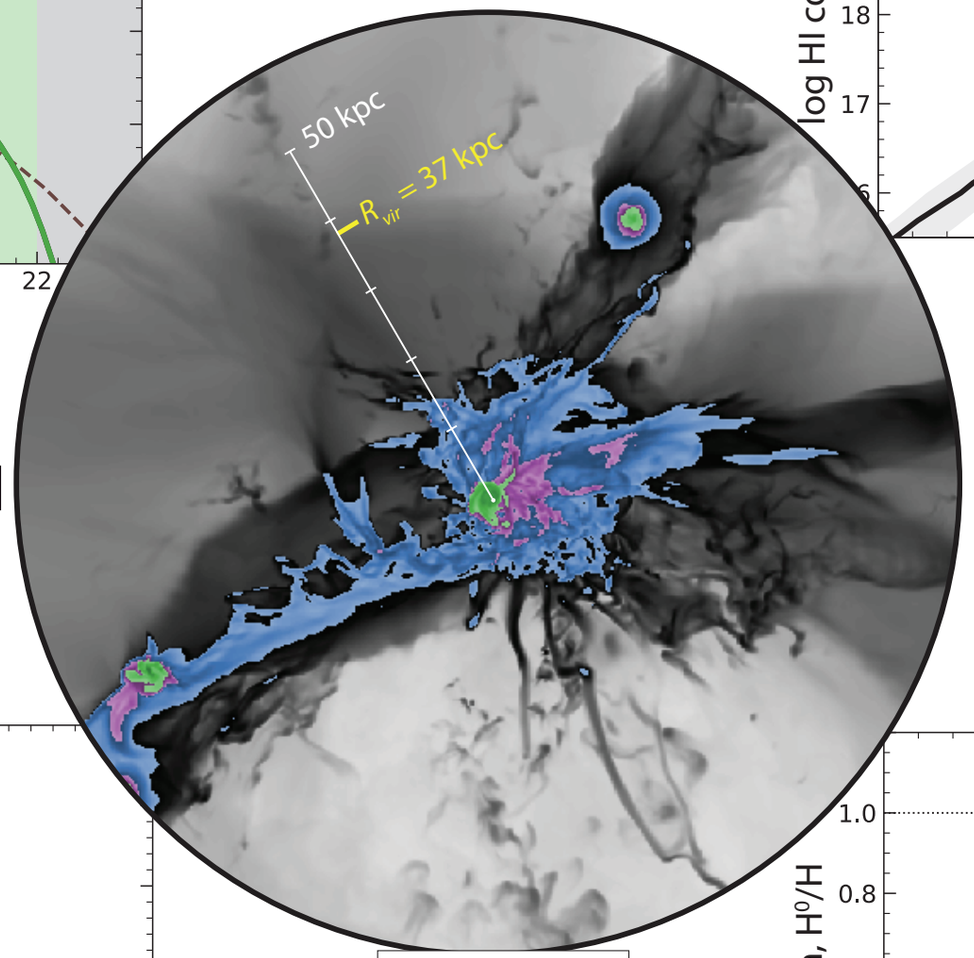


(c)

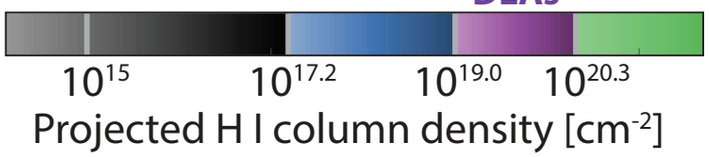
Typical density probed with HI column



(a)



Peeples+ 2019

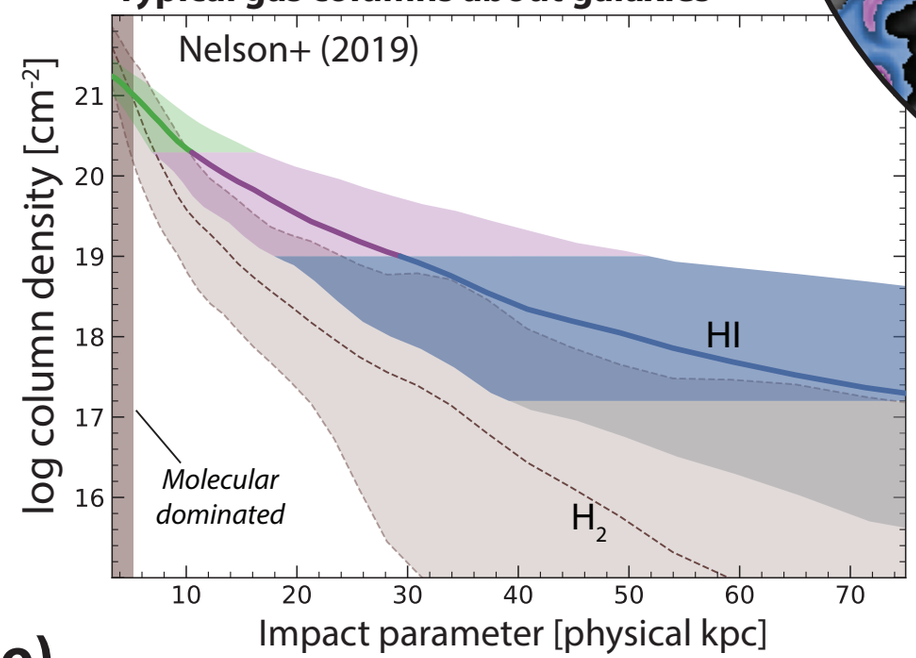


Neutral gas [DLAs]

Partially-ionized gas [sub-DLAs]

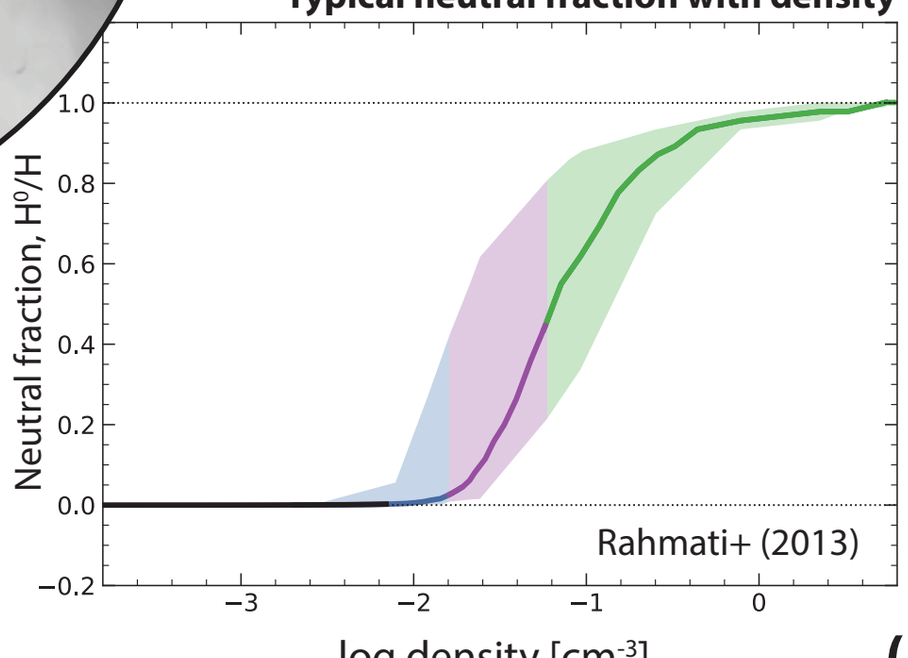
Ionized gas [LLSs]

Typical gas columns about galaxies



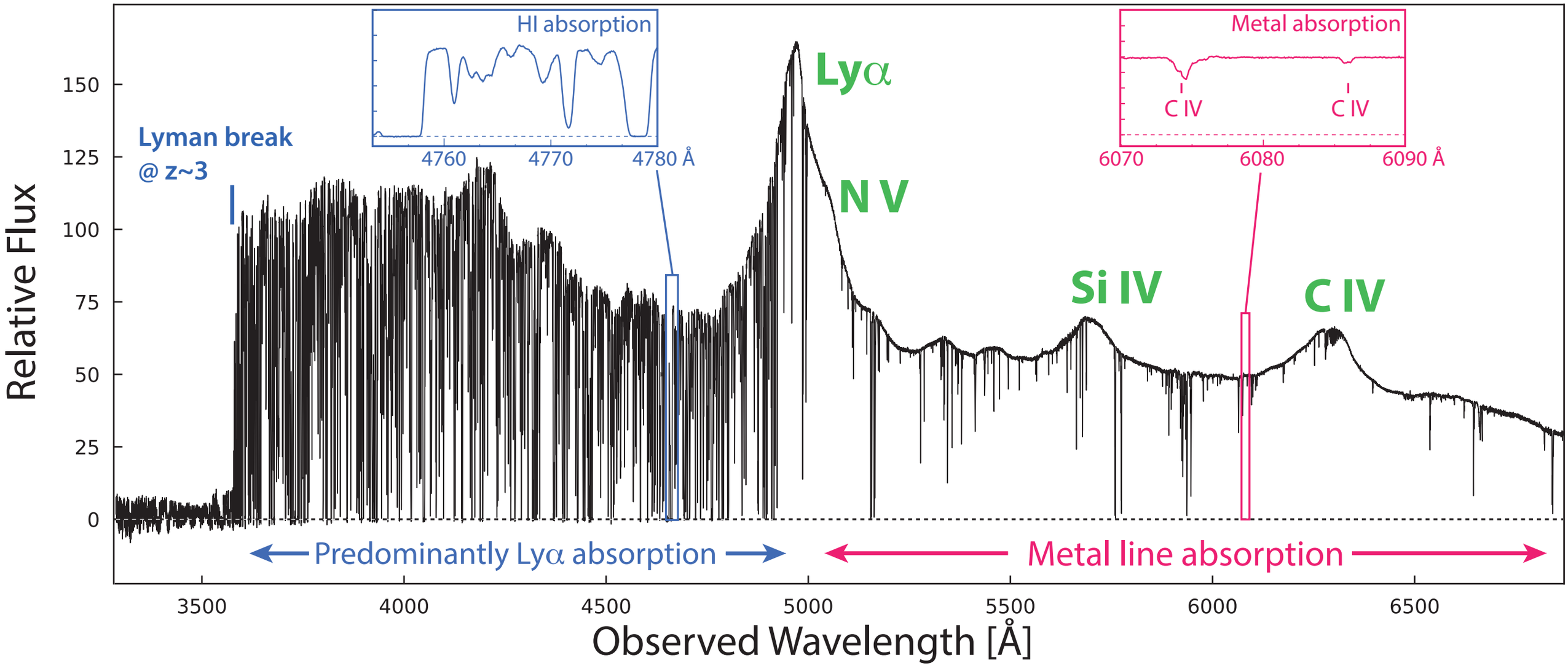
(e)

Typical neutral fraction with density



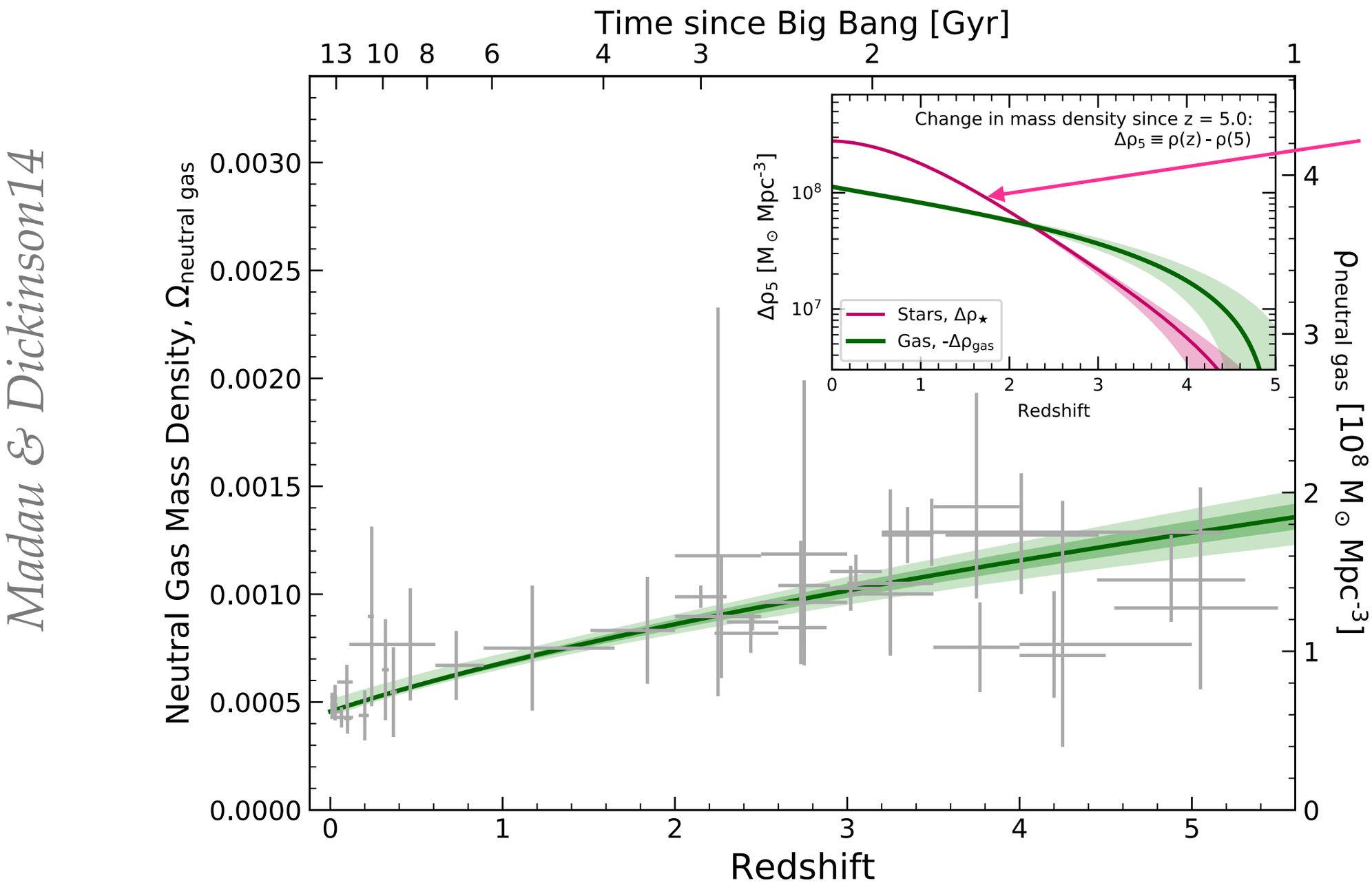
(d)

Absorption lines are powerful



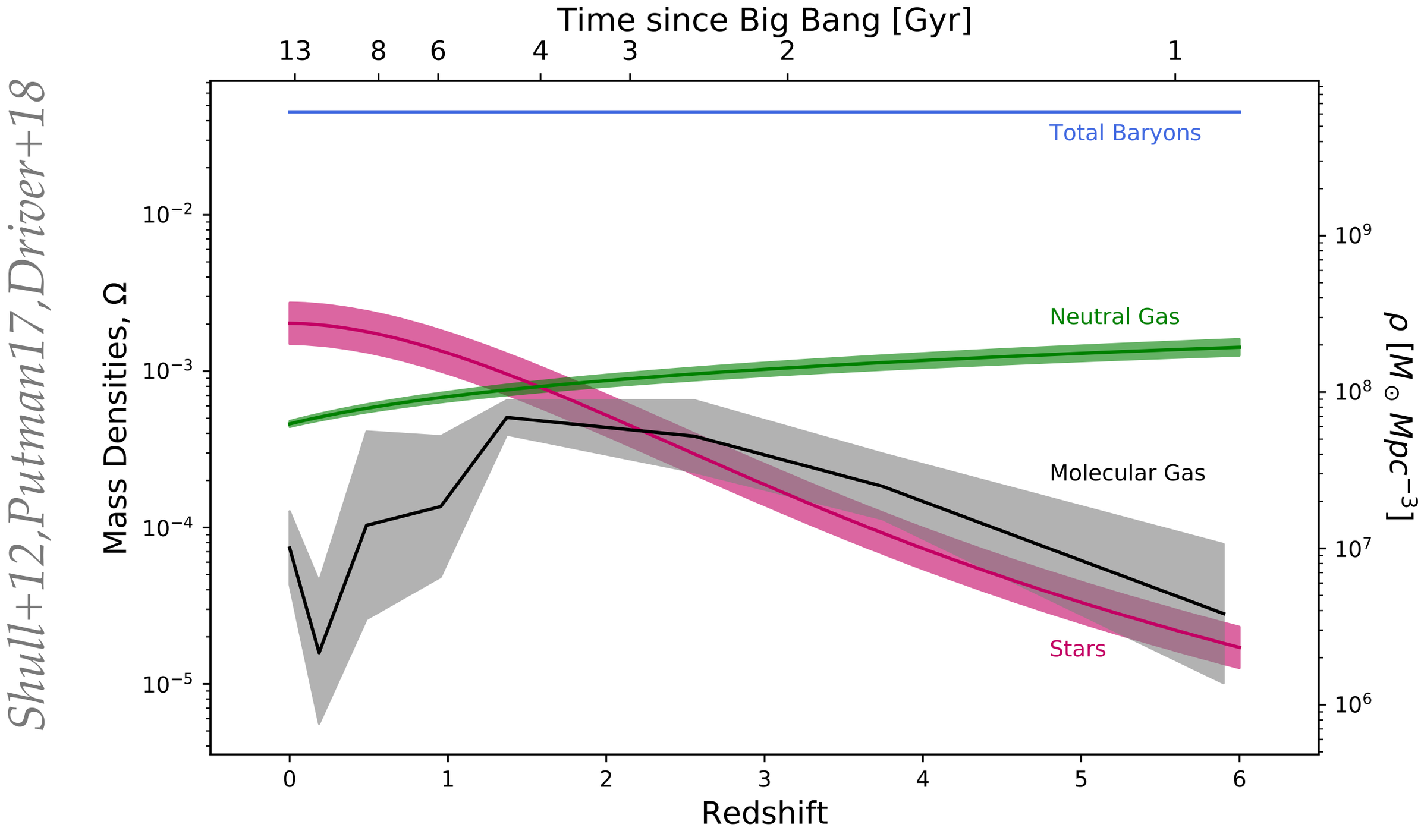
How does the gas reservoir which fuels star formation evolve?

Evolution neutral gas mass shallower than stellar density

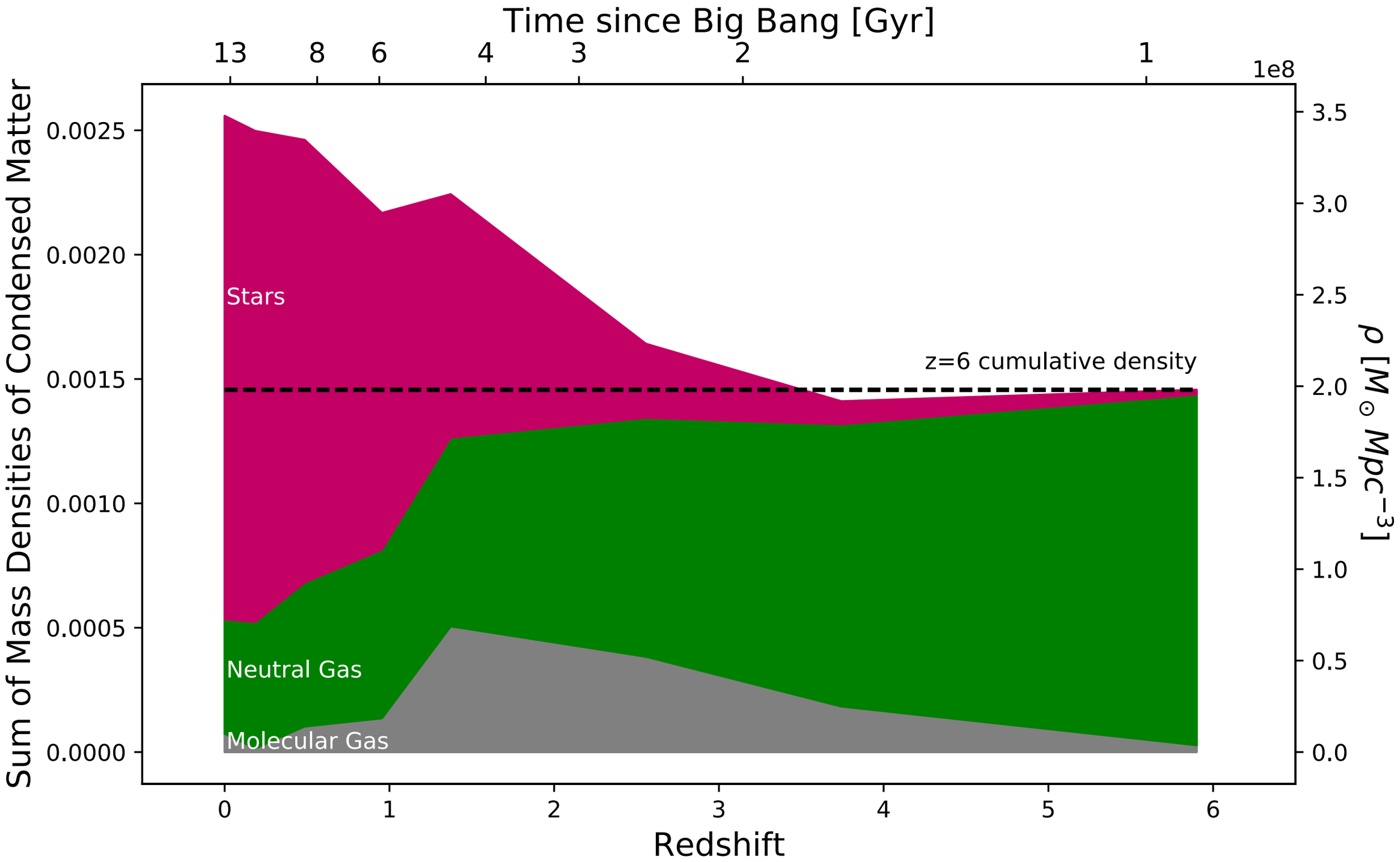


$$\Omega_{\mathrm{neutral\ gas}}(z) = [(4.6 \pm 0.2) \times 10^{-4}](1+z)^{0.58 \pm 0.04}$$

Molecular gas mirrors SFR history

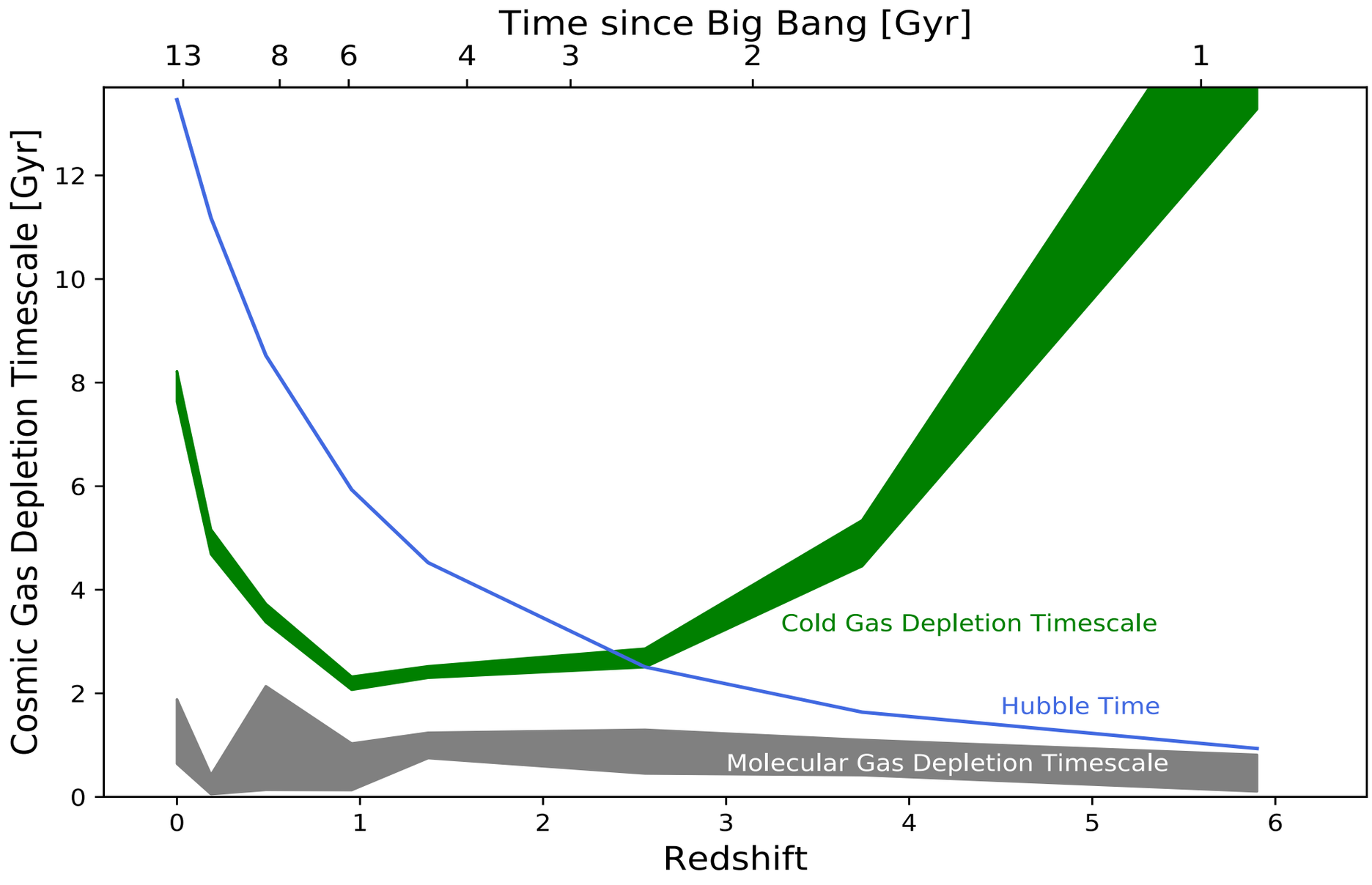


Gas is depleted faster than it can be made at z<3



H2 gas depletion timescale universal

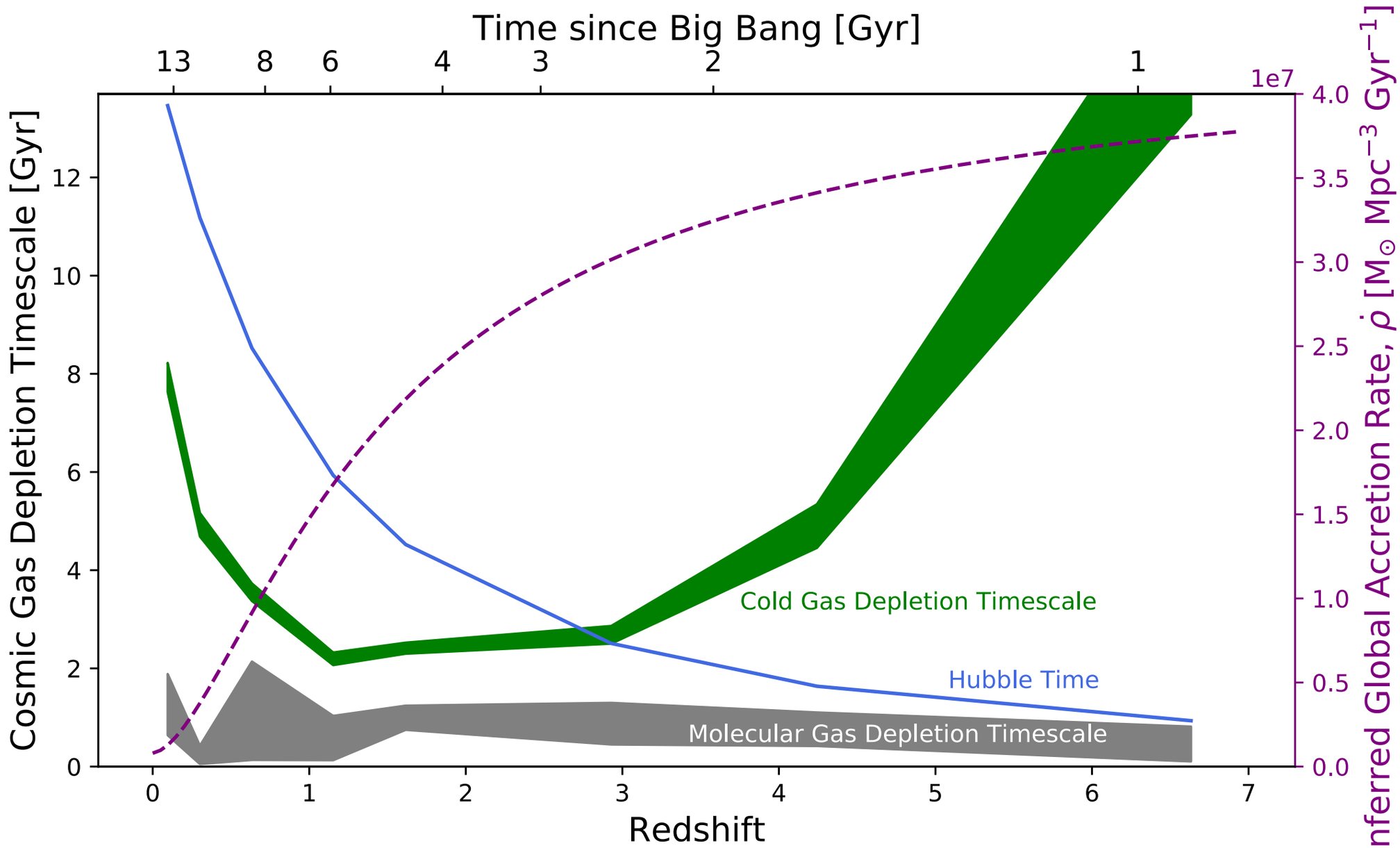
Genzel+15,Freundlich+19



$$\tau_{\rm dep} = \rho_{\rm gas} / \dot{\rho}_{\star},$$

Need for accretion of cold gas from IGM

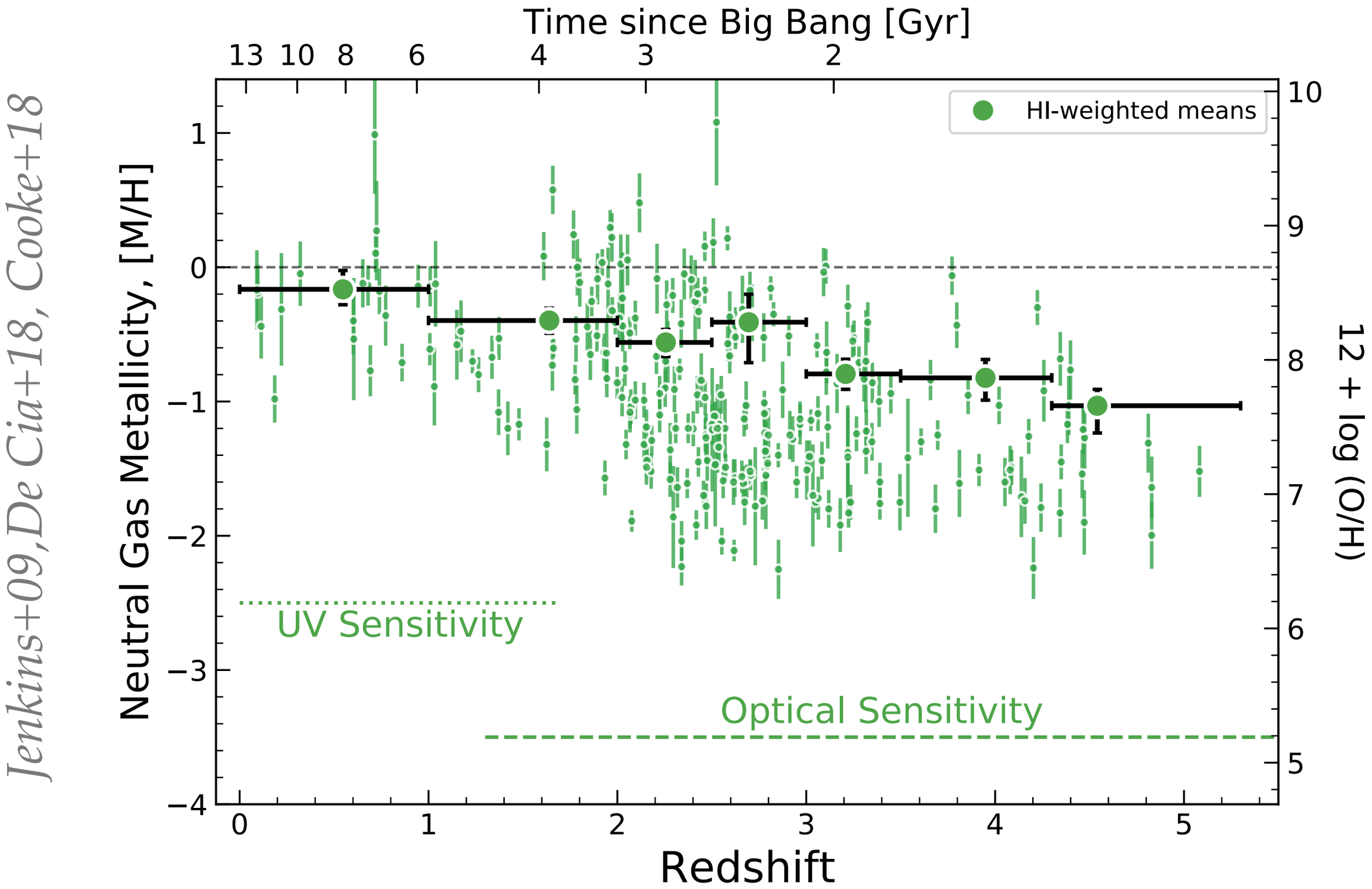
Bouche+10,Lilly+13,Dekel+14



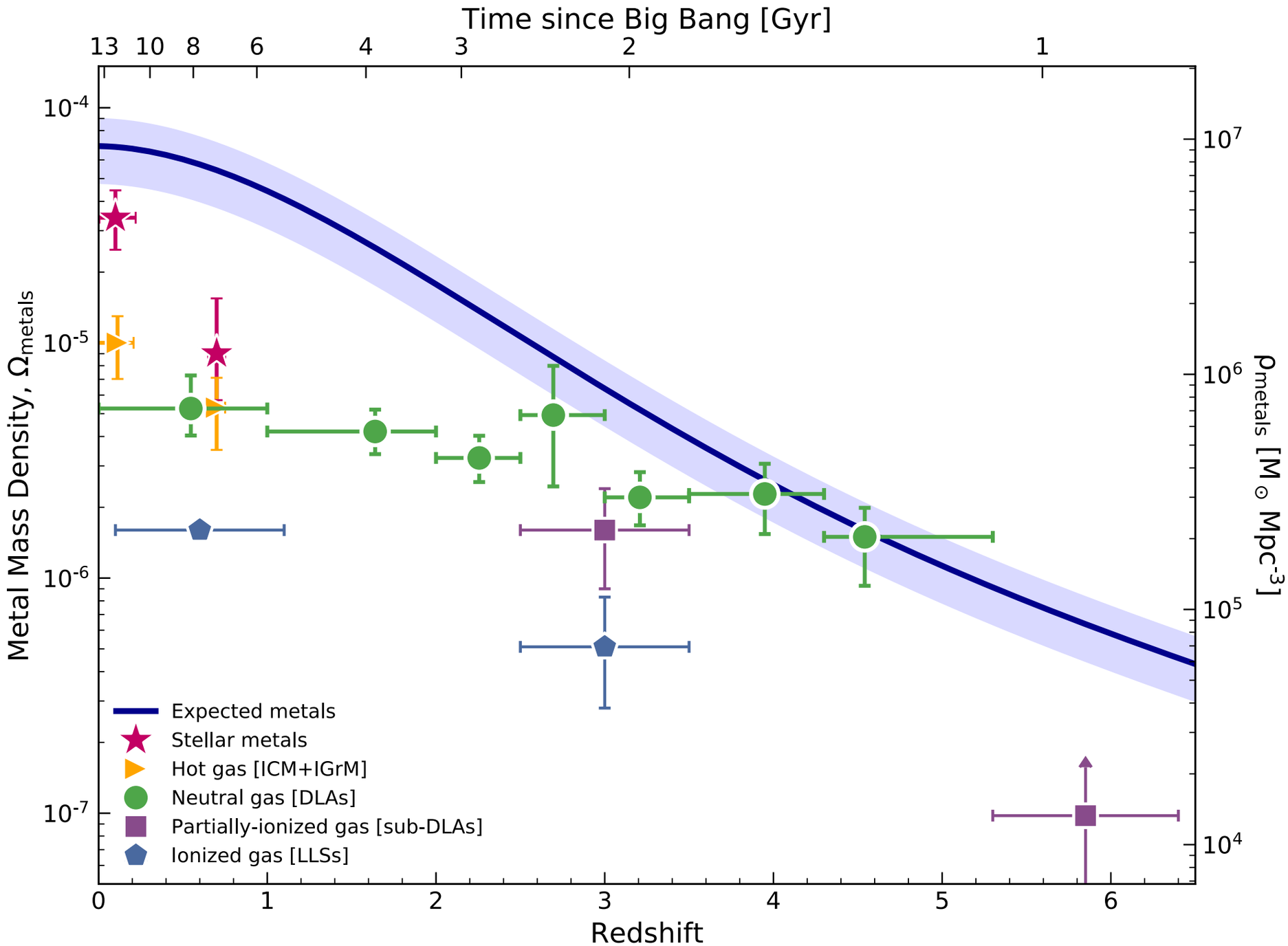
➥ *bathtube/regulator model*

Where are the metals in the Universe?

Mild cosmic evolution of metallicity



Where are the metals in the universe?

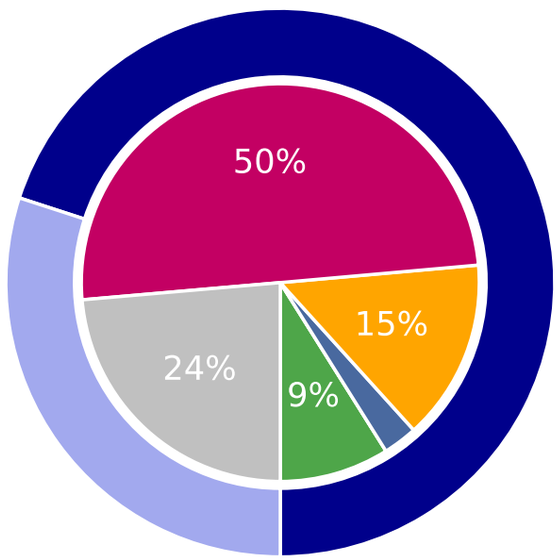


$$\rho_\star(z) = (1-R)\int_0^{t(z)} \psi(z)\frac{dz}{dt}dt.$$

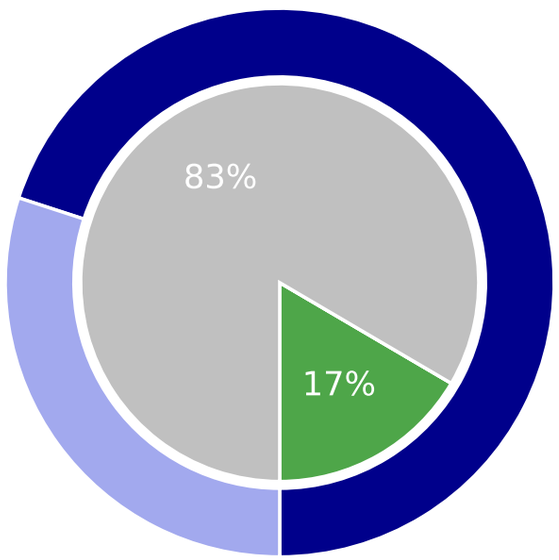
Is there a missing metals problem?

Pettini99, Ferrara+05, Bouche+07

z ~ 0.1
12.2 Gyr post-Big Bang

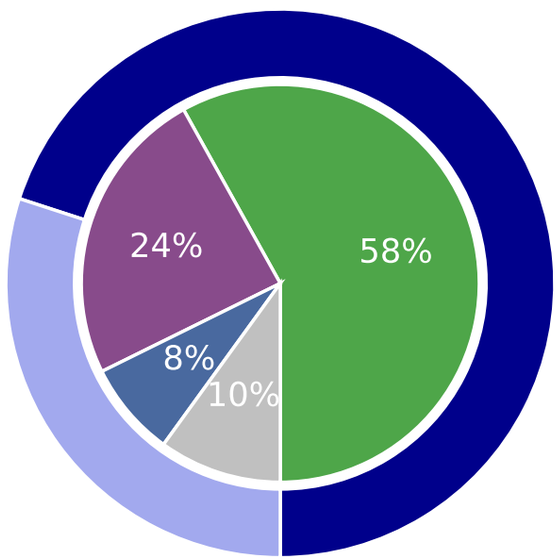


z ~ 1.6
4.0 Gyr post-Big Bang

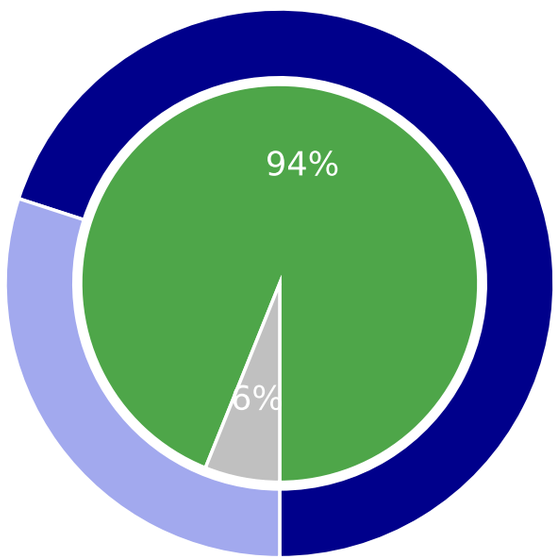


Observed Metals
- Neutral gas [DLAs]
- Partially-ionized gas [sub-DLAs]
- Ionized gas [LLSs]
- Hot gas [ICM+IGrM]
- Stars
- Not cataloged

z ~ 3.0
2.1 Gyr post-Big Bang



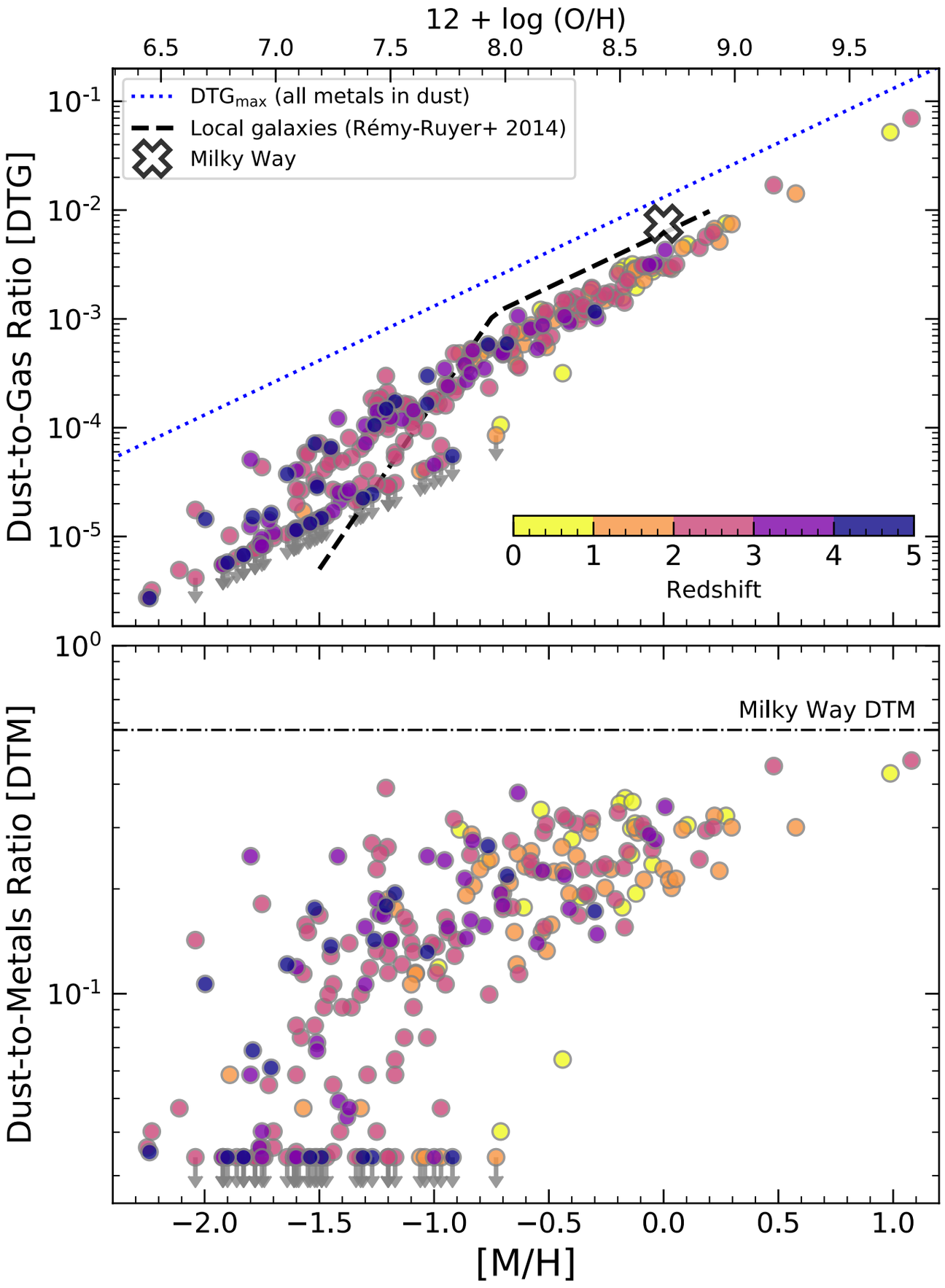
z ~ 4.5
1.3 Gyr post-Big Bang



Expected Metals
- Expected metals - 1σ
- 1σ expected metals

What is the cosmic evolution of dust mass?

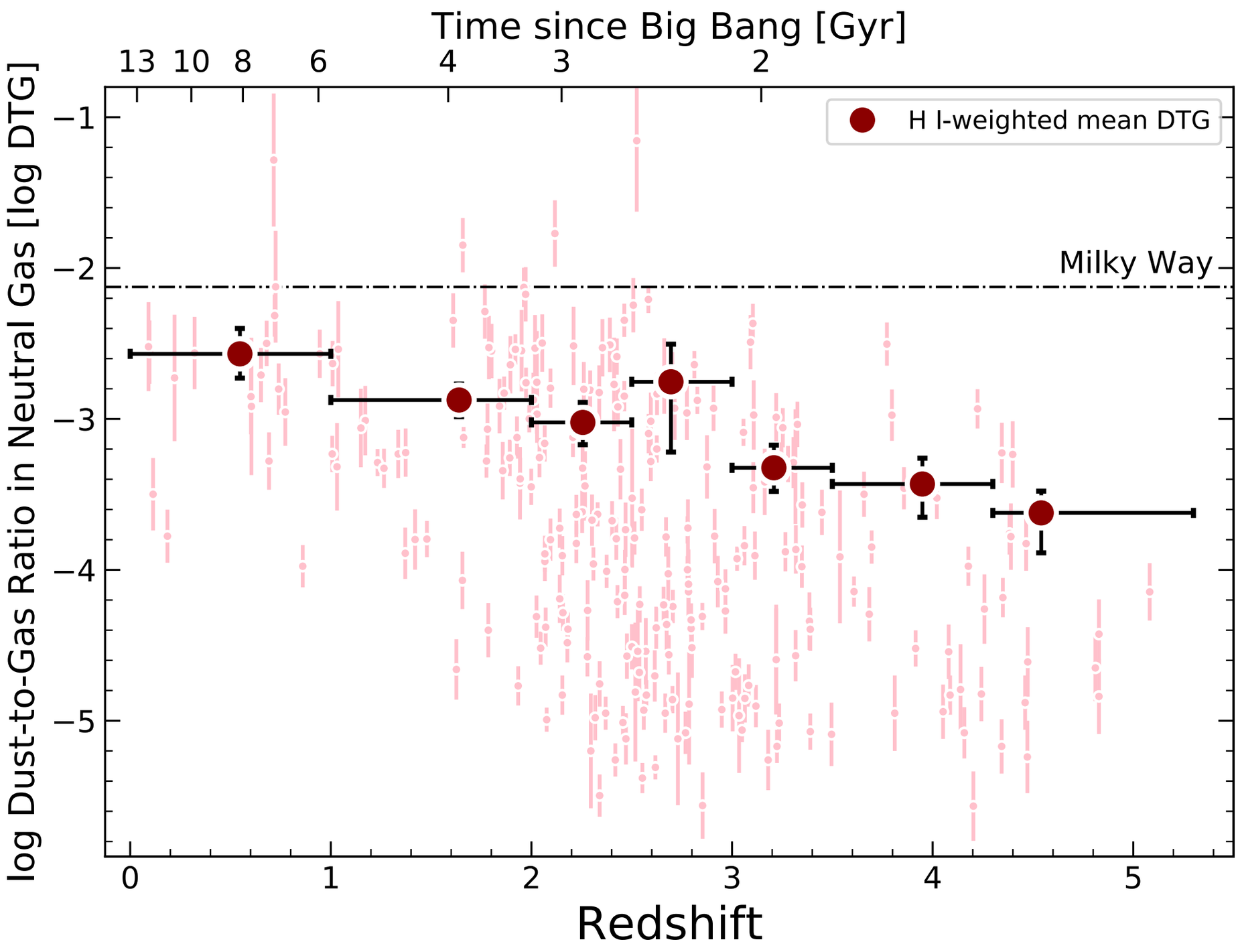
$$\delta_X = \log N(X)/N(\mathrm{H}) - \log Z^X_{\mathrm{abs}}/Z^X_{\odot}\,.$$



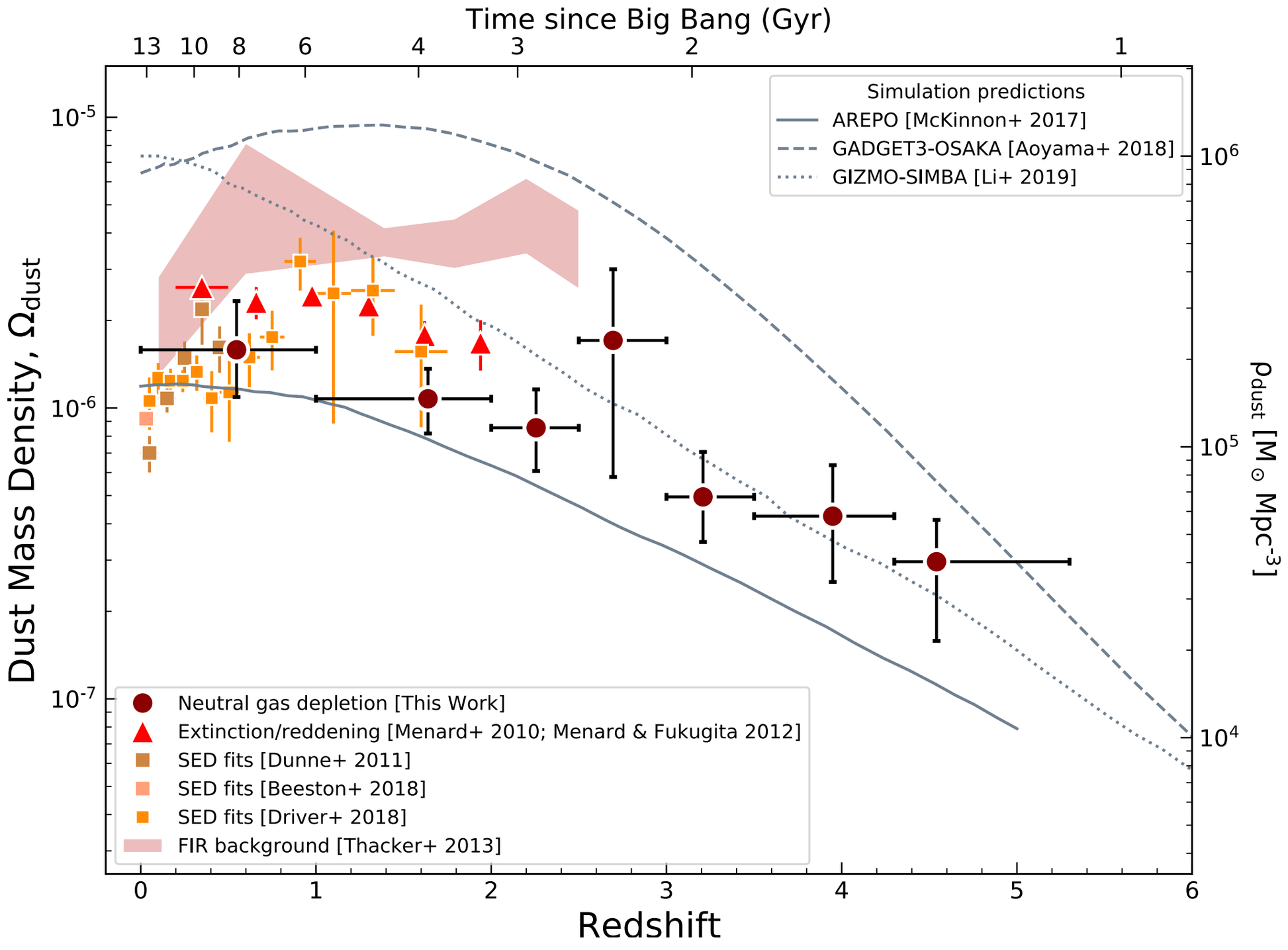
$$\mathrm{DTG}_X = (1 - 10^{\delta X})\,(10^{[\mathrm{M/H}]}\,10^{[X/\mathrm{M}]}\,Z^X_{\odot})$$

$$\mathrm{DTM}_X = 1 - 10^{\delta X}$$

Mild evolution of dust-to-gas ratio

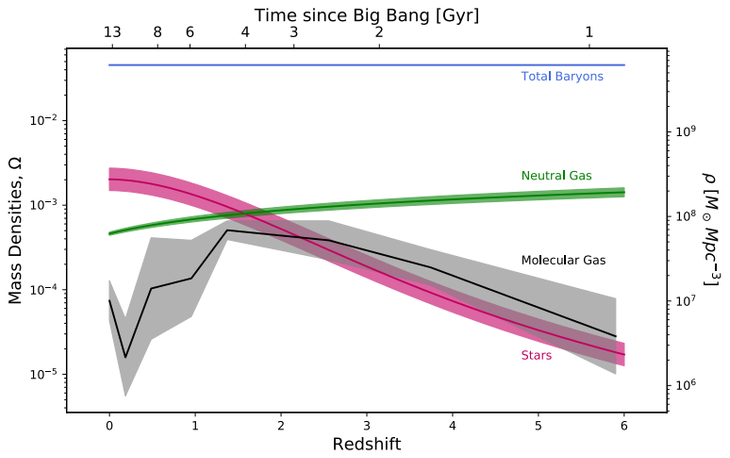


Probing the evolution of dust to z=5.5



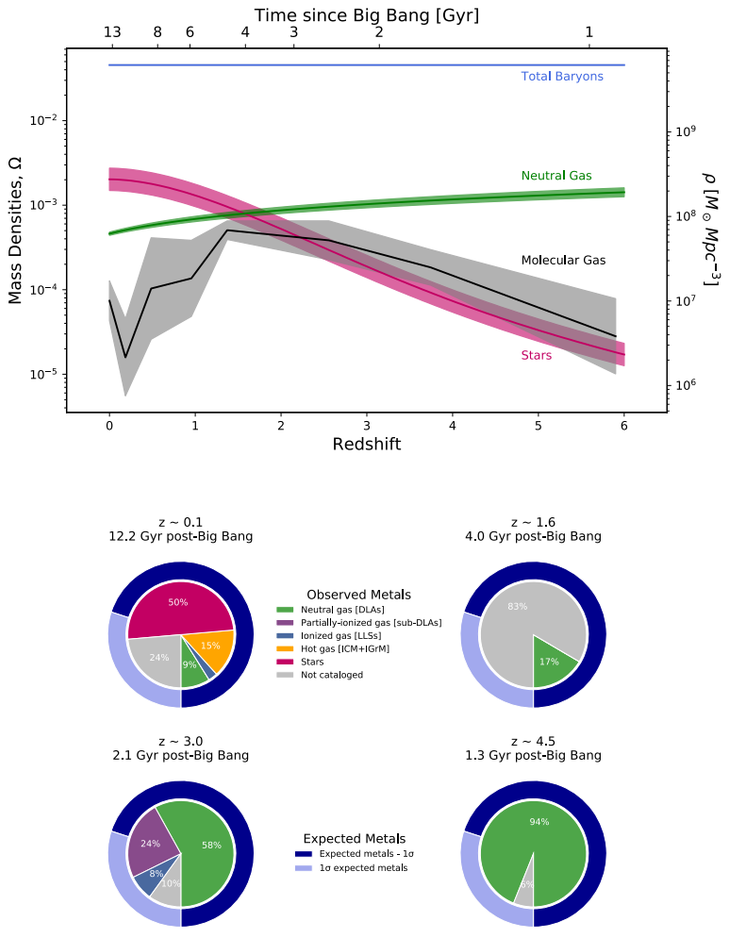
$$\Omega_{\rm dust} \equiv \rho_{\rm dust} / \rho_{\rm crit,0} = \langle {\rm DTG} \rangle \, \Omega_{\rm gas},$$

Take home Messages



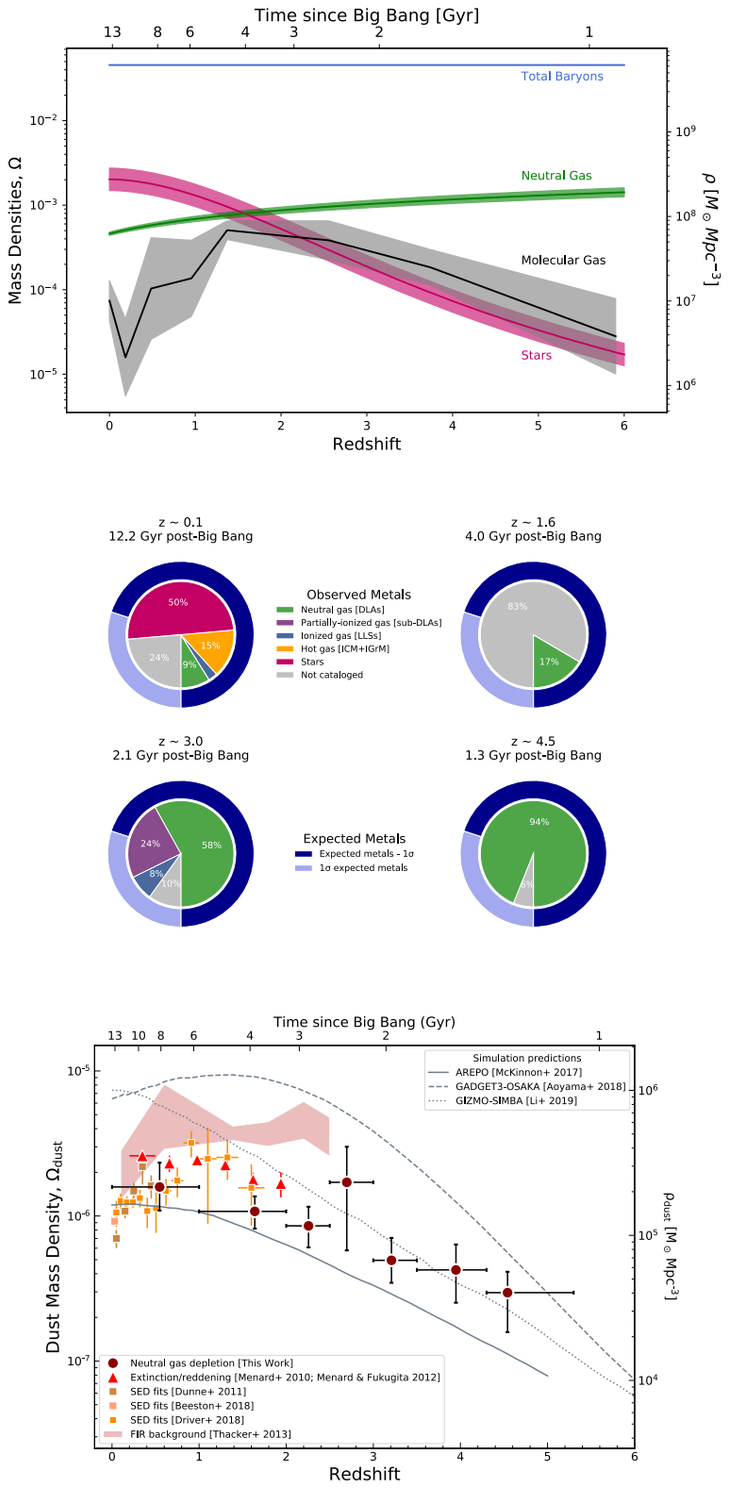
- Evolution of “condensed” matter calls for accretion from the IGM

Take home Messages



- Evolution of "condensed" matter calls for accretion from the IGM
- Little evidence for "missing metals problem" in modern censuses

Take home Messages



- Evolution of “condensed” matter calls for accretion from the IGM
- Little evidence for “missing metals problem” in modern censuses
- New calculations of dust mass density uniformly up to z=5.5