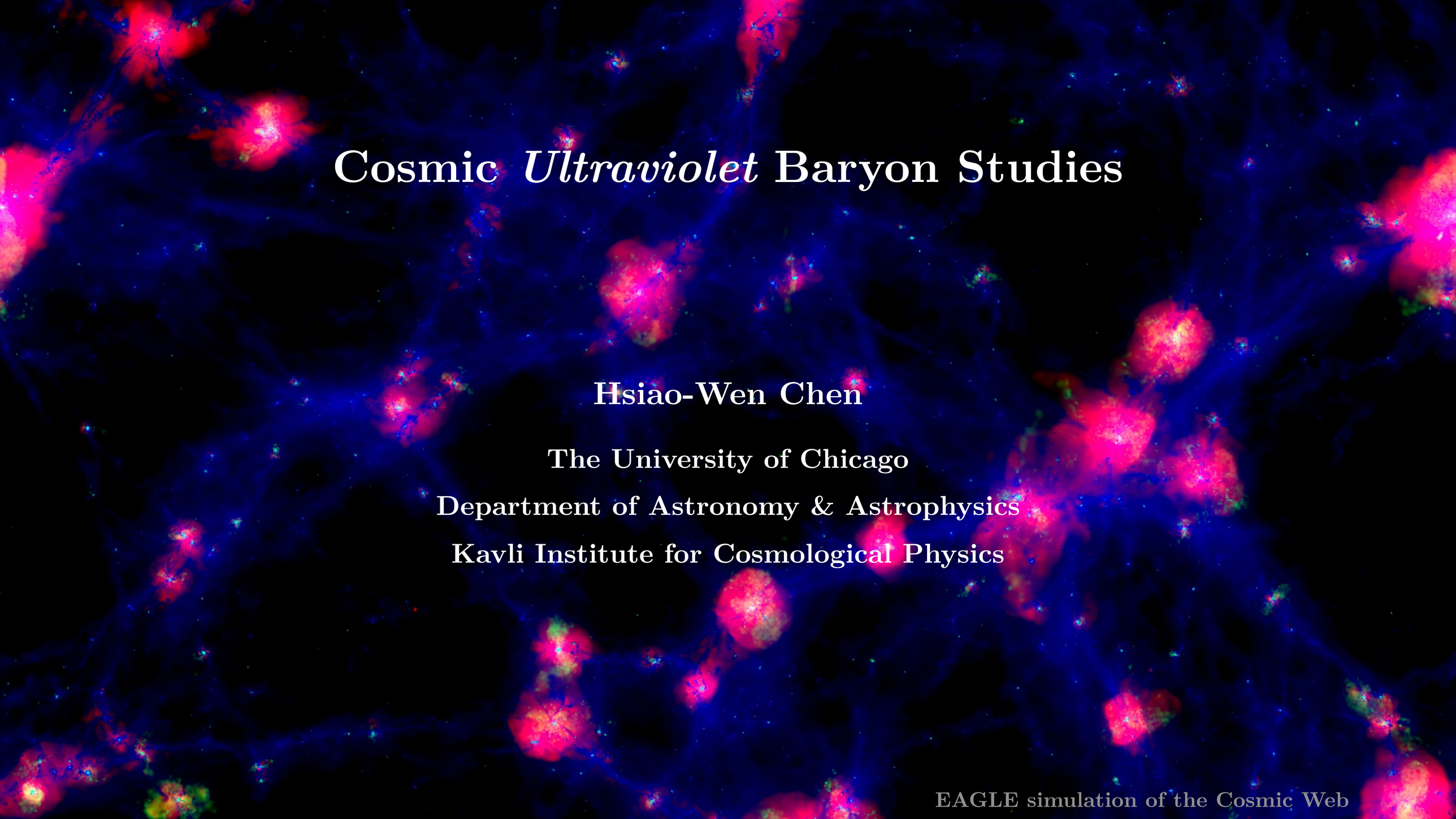
Cosmic *Ultraviolet* Baryon Studies

Hsiao-Wen Chen

The University of Chicago

Department of Astronomy & Astrophysics

Kavli Institute for Cosmological Physics



EAGLE simulation of the Cosmic Web

Cosmic *Ultraviolet* Baryon Studies

a focus on the circumgalactic space

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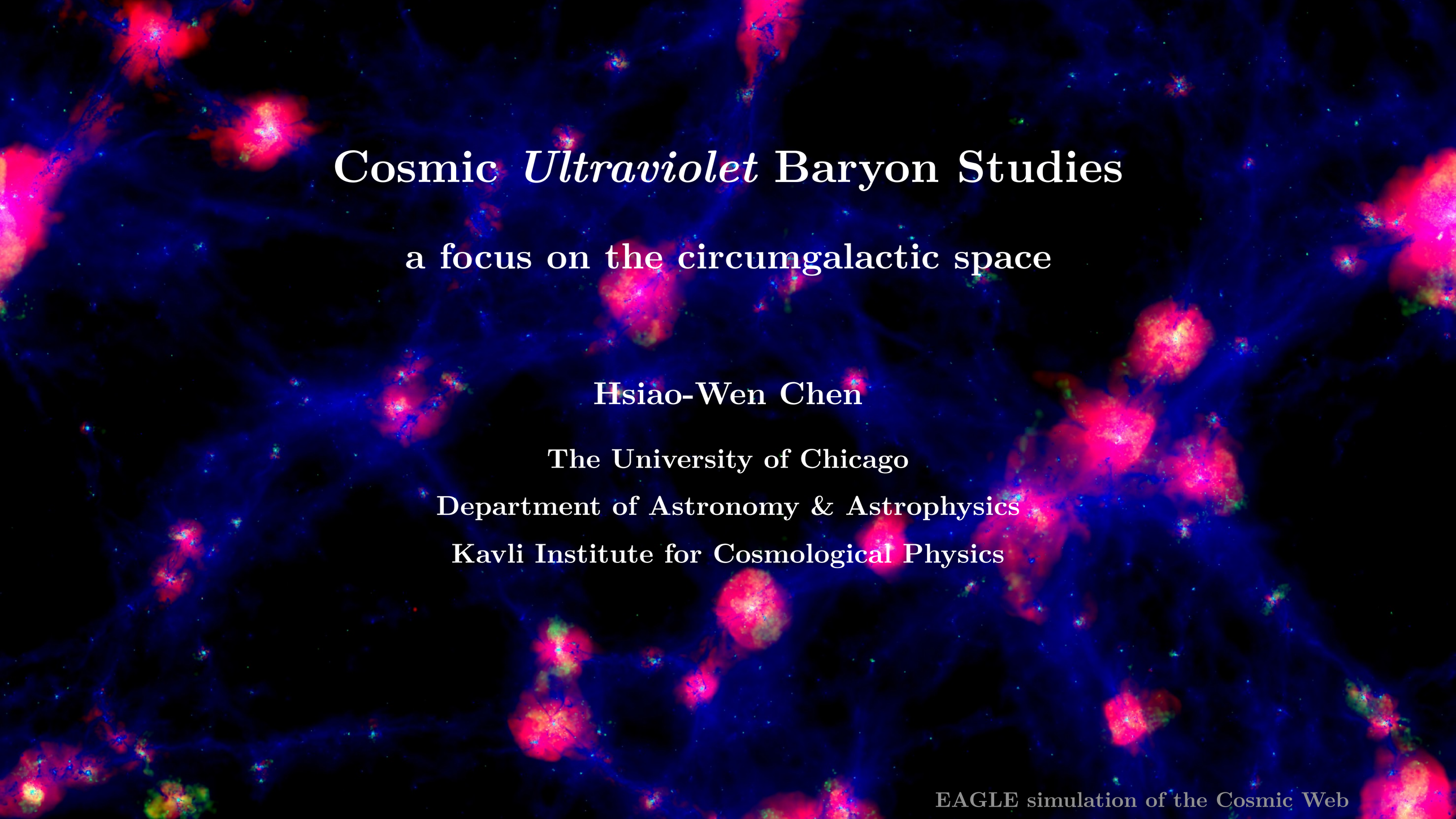
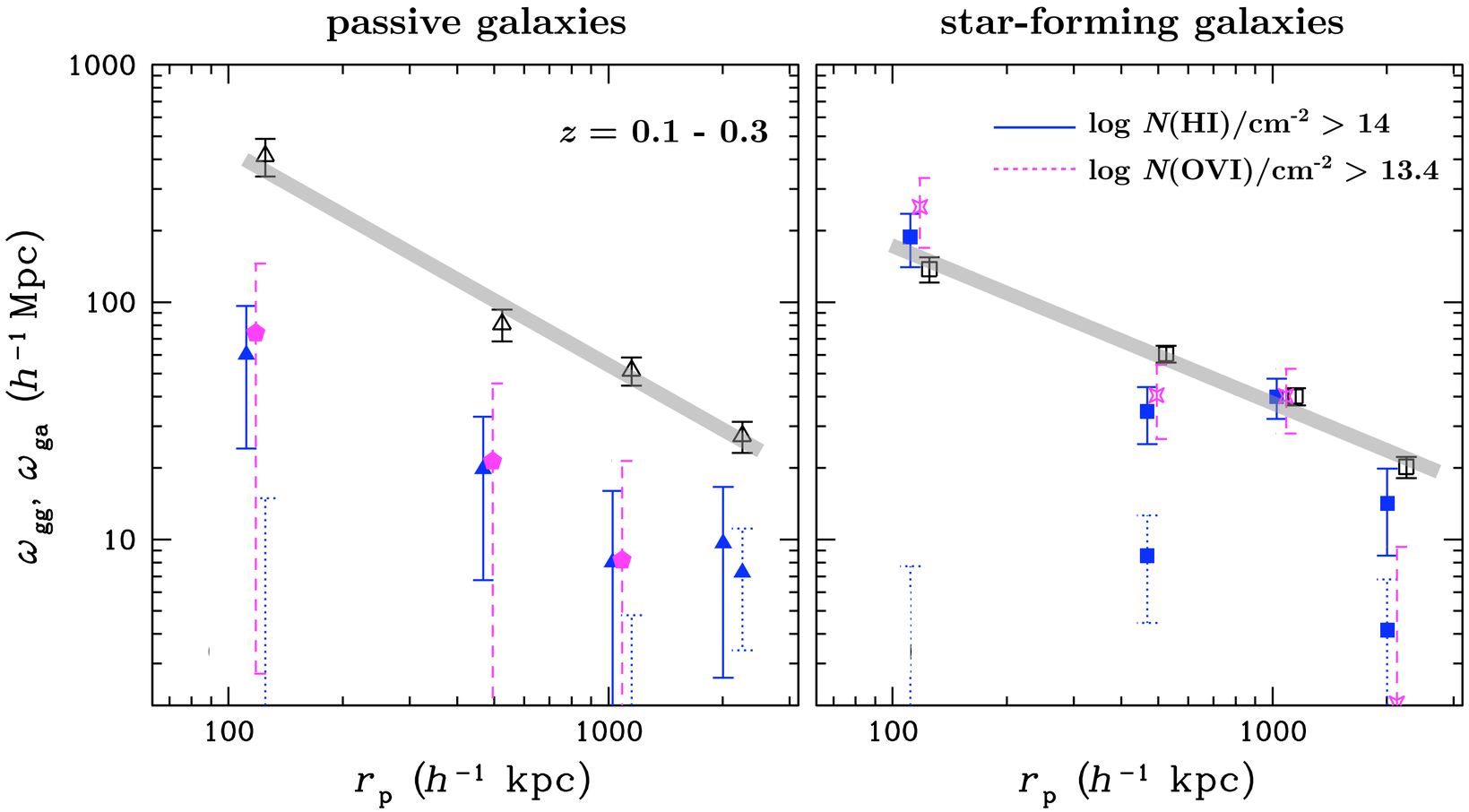


EAGLE simulation of the Cosmic Web

OVI absorbers are strongly correlated with galaxies

OVI absorbers and star-forming galaxies share a comparable clustering amplitude



Chen & Mulchaey (2009)

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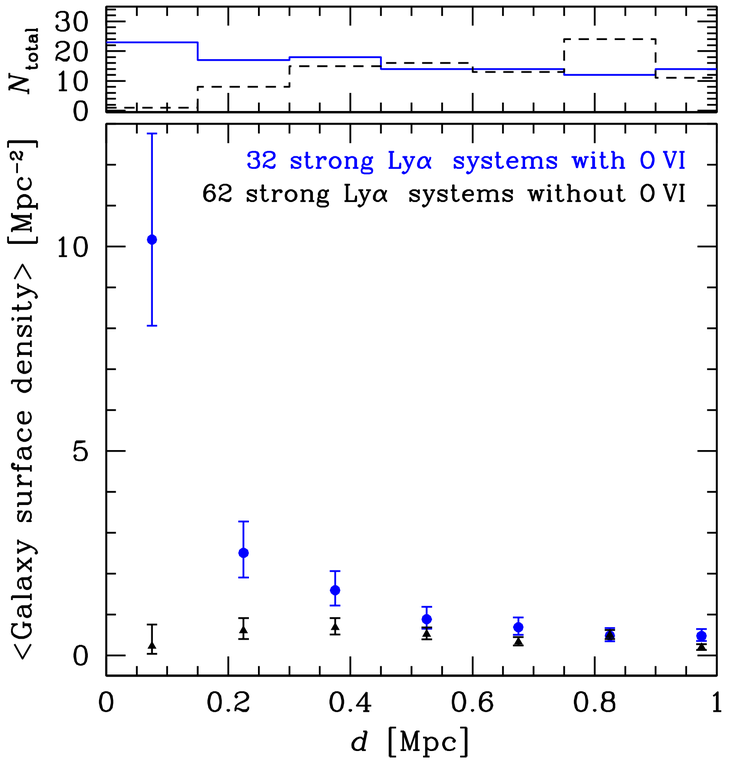
OVI absorbers are found in regions of high mean surface density over $d \lesssim 500$ kpc



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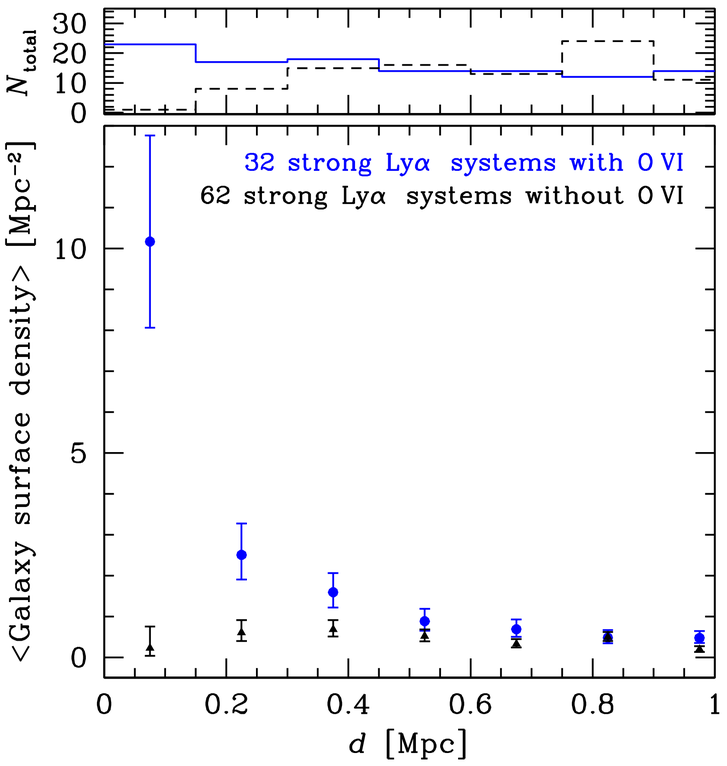

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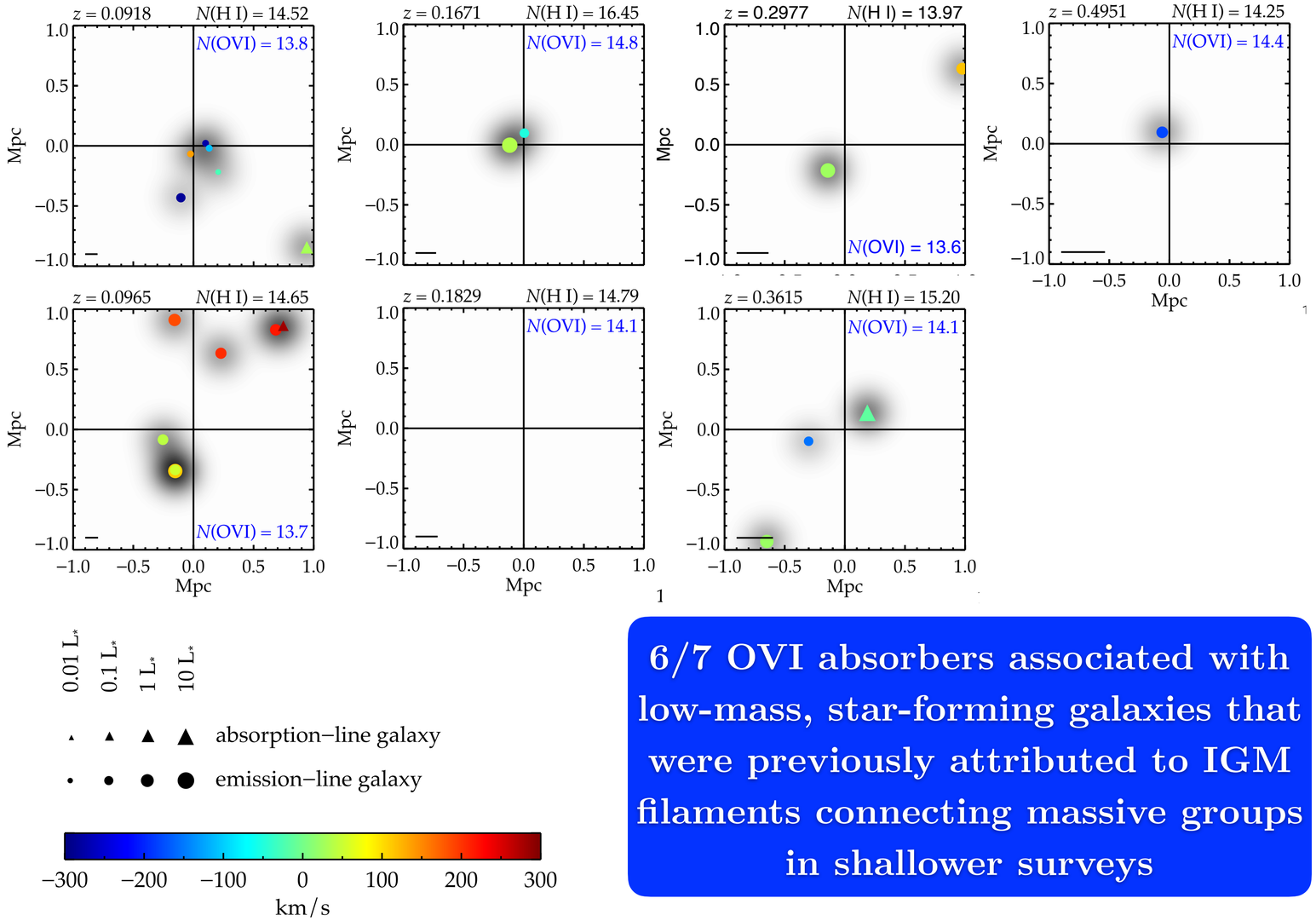
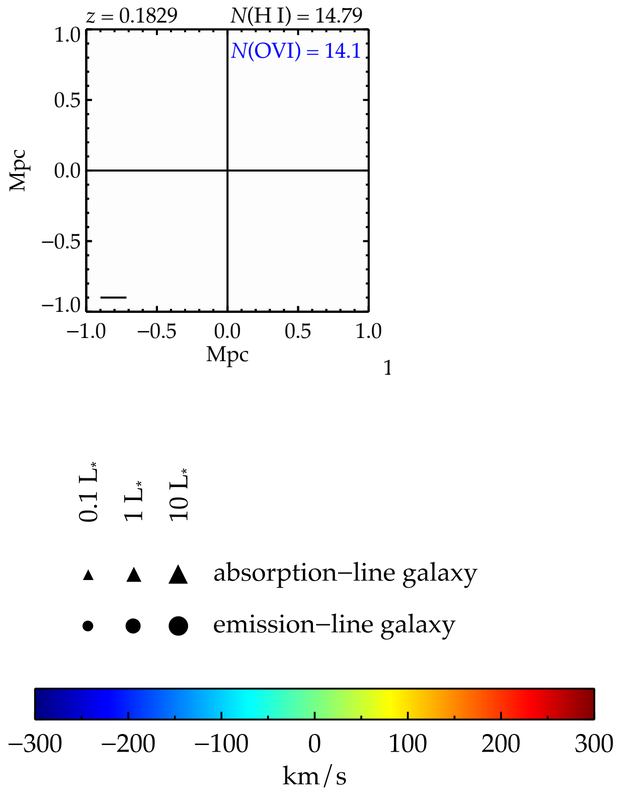


6/7 OVI absorbers associated with low-mass, star-forming galaxies that were previously attributed to IGM filaments connecting massive groups in shallower surveys

OVI absorbers are strongly correlated with galaxies

As the galaxy survey goes deeper, we continue to uncover low-mass dwarfs in the vicinities of OVI



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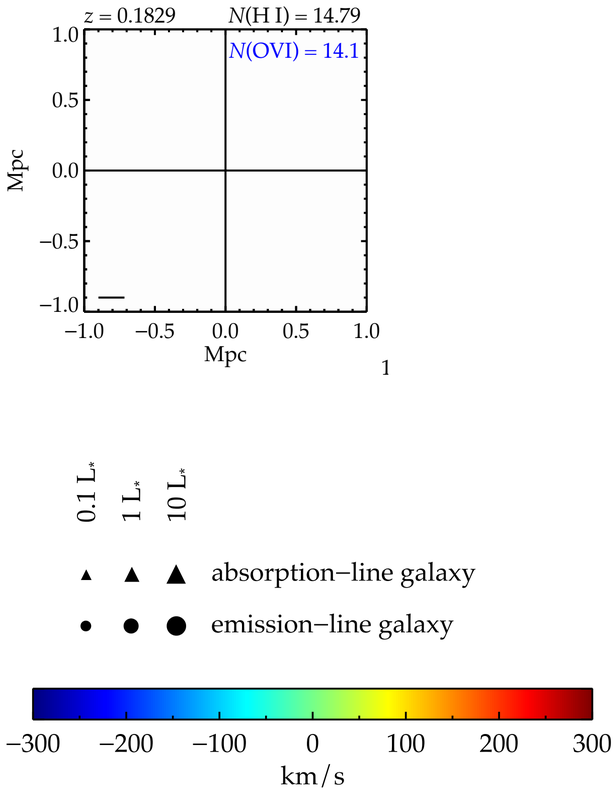

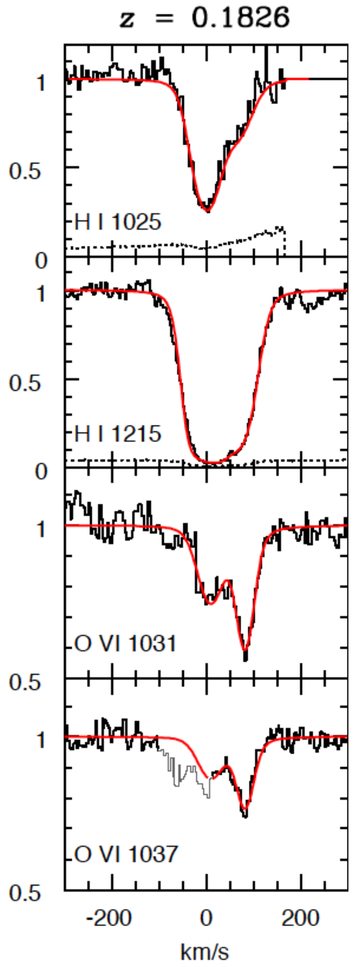

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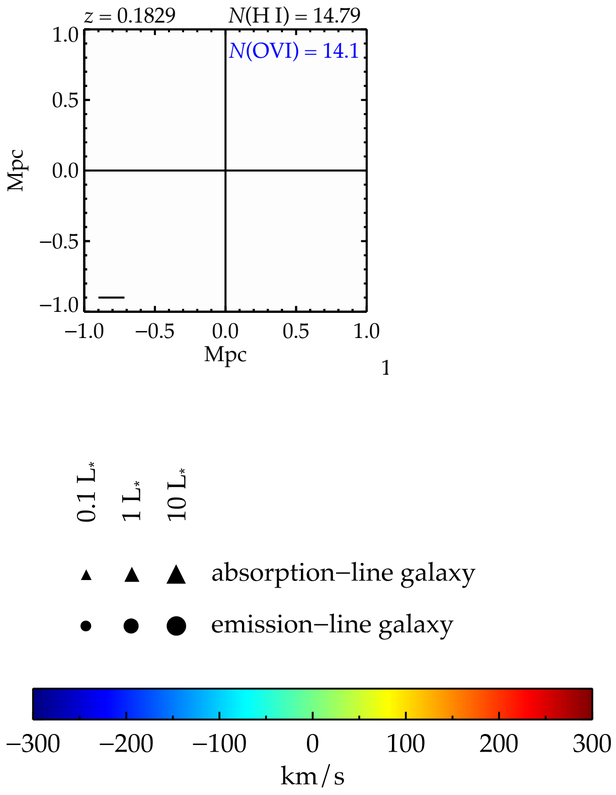

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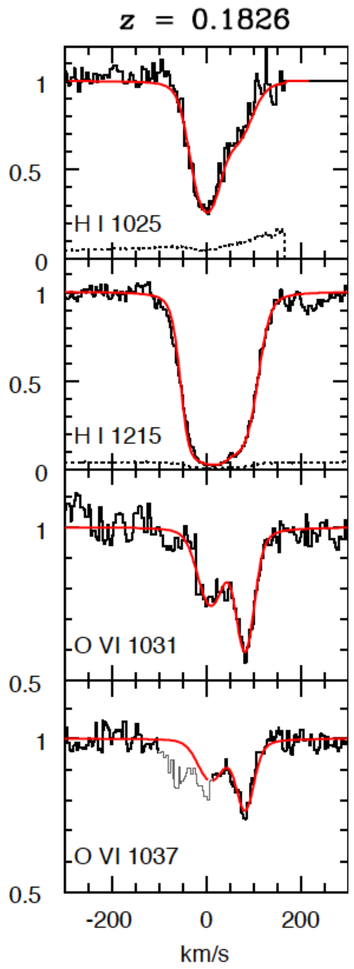
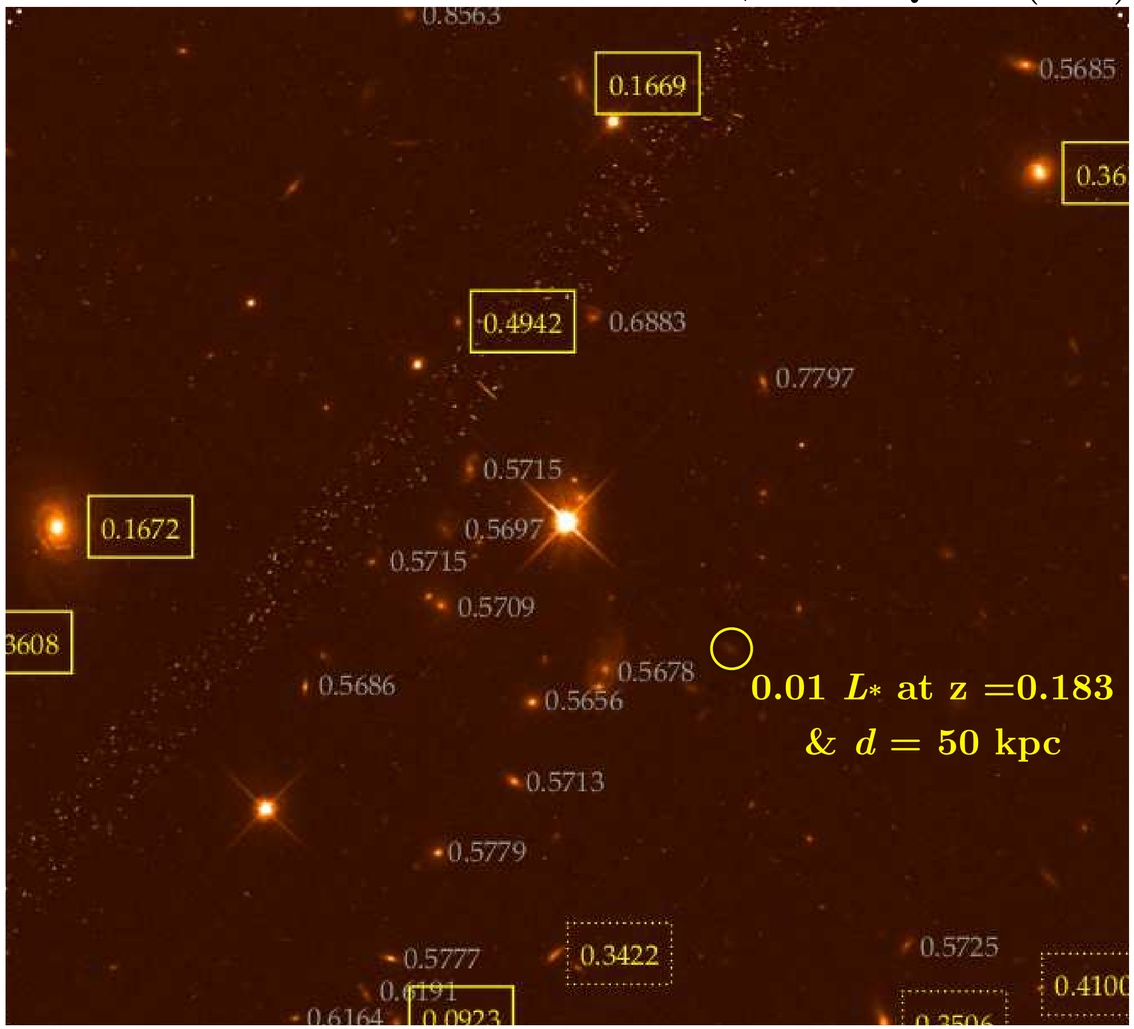


Straka + MUSE-QuBES (2018)



The Baryon Content of Low-mass Dwarf Galaxies

Johnson, Chen, Mulchaey, Schaye, & Straka (2017)

- **A sample of 18 star-forming dwarfs with stellar masses log $M_{\rm star}/{\rm M}_{\odot} = 7.7$ - 9.2 at z $= 0.09$ - 0.3 that have a UV luminous background QSO at $d < 3\ R_{\rm vir}$**

- **No luminous galaxies of $> 0.1\ L_{*}$ are known at $d < 500$ kpc and $|\Delta v| < 300$ km/s of these dwarfs**

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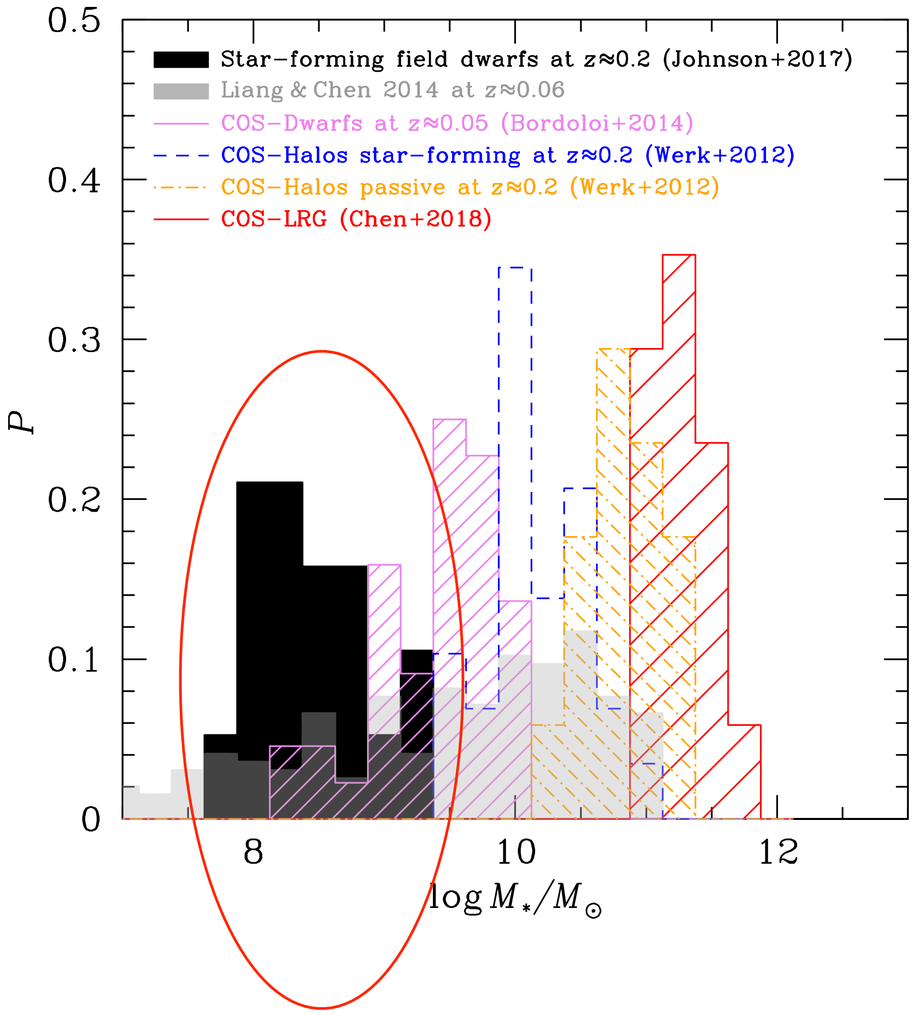

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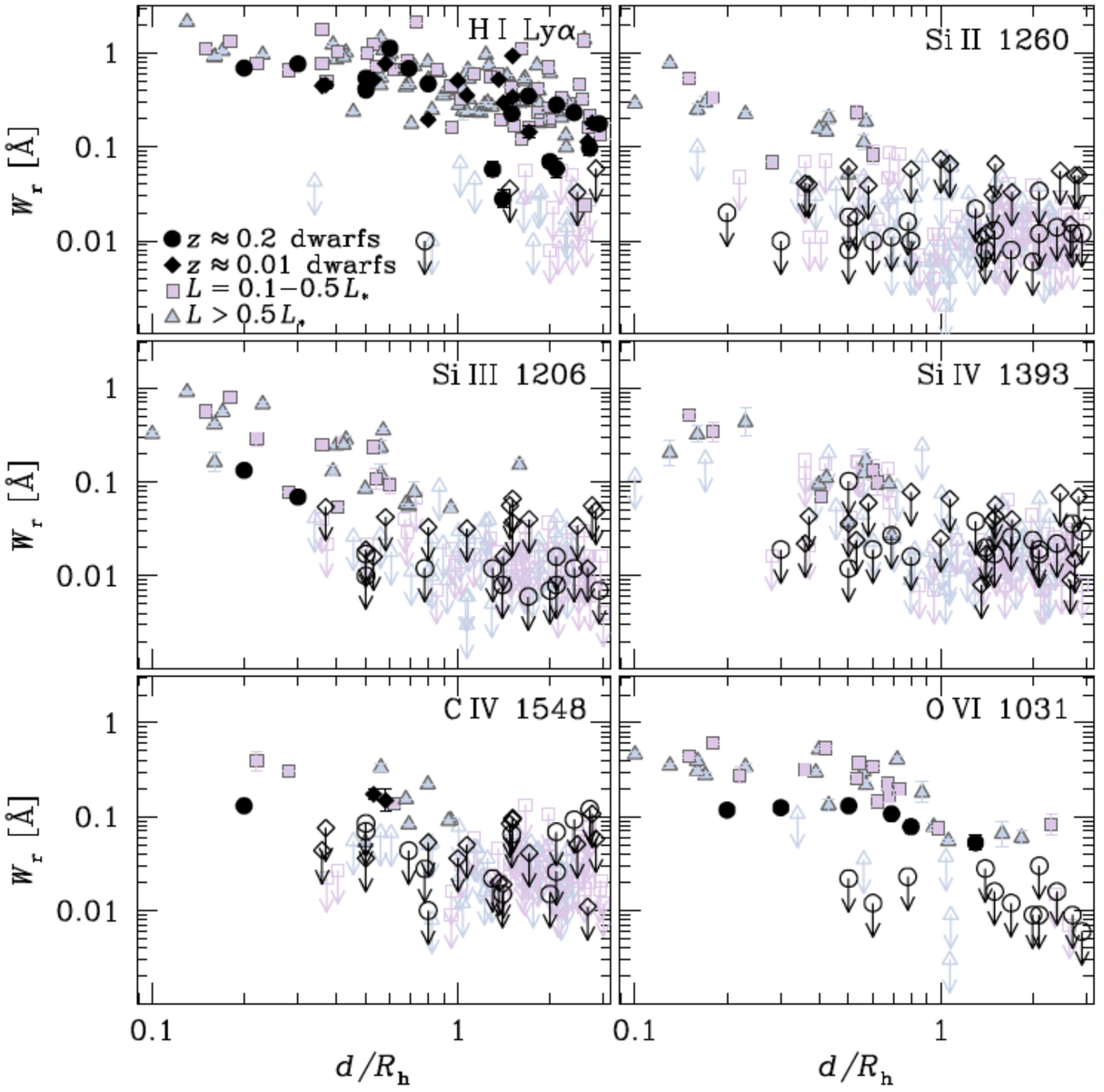

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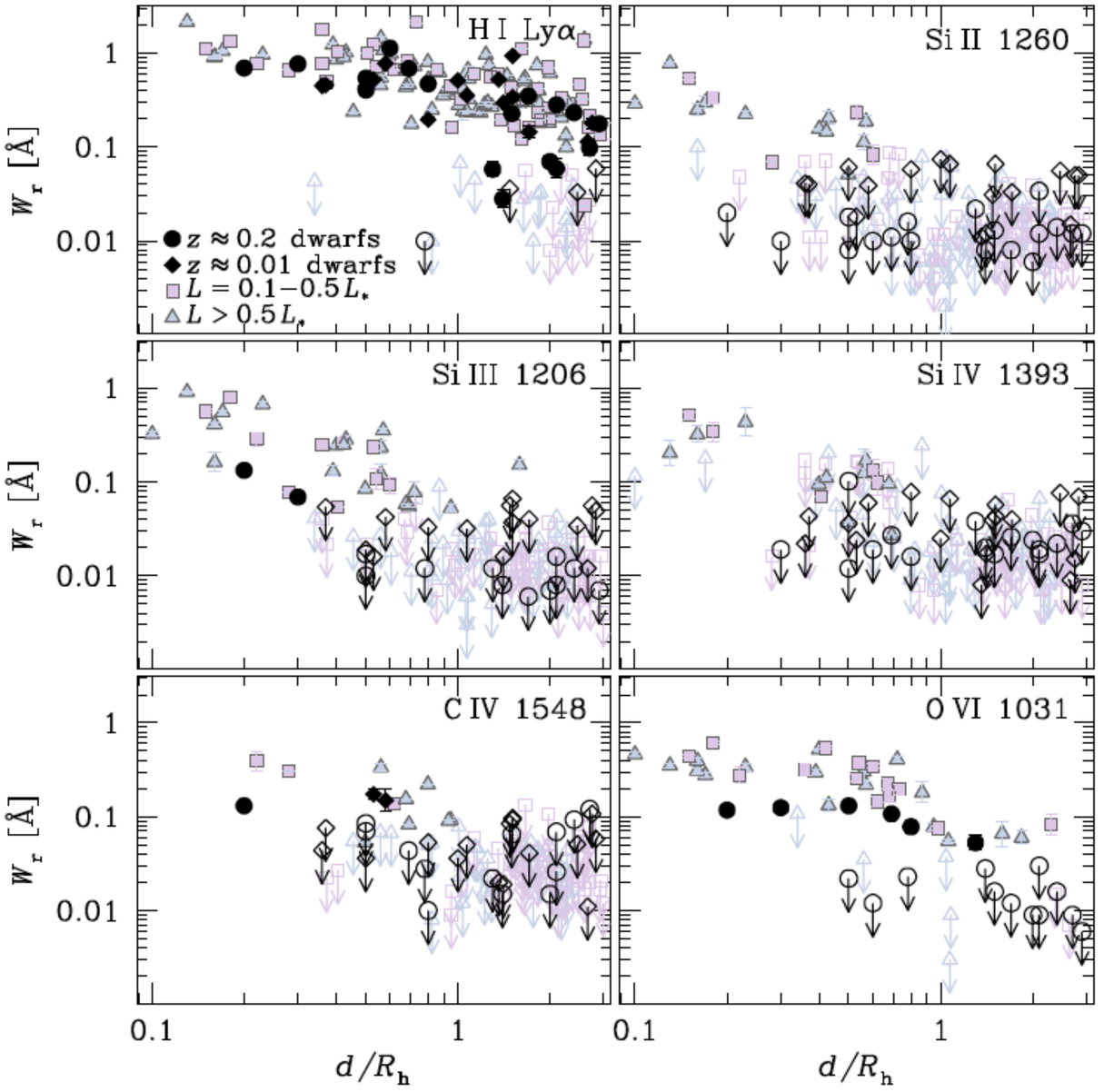

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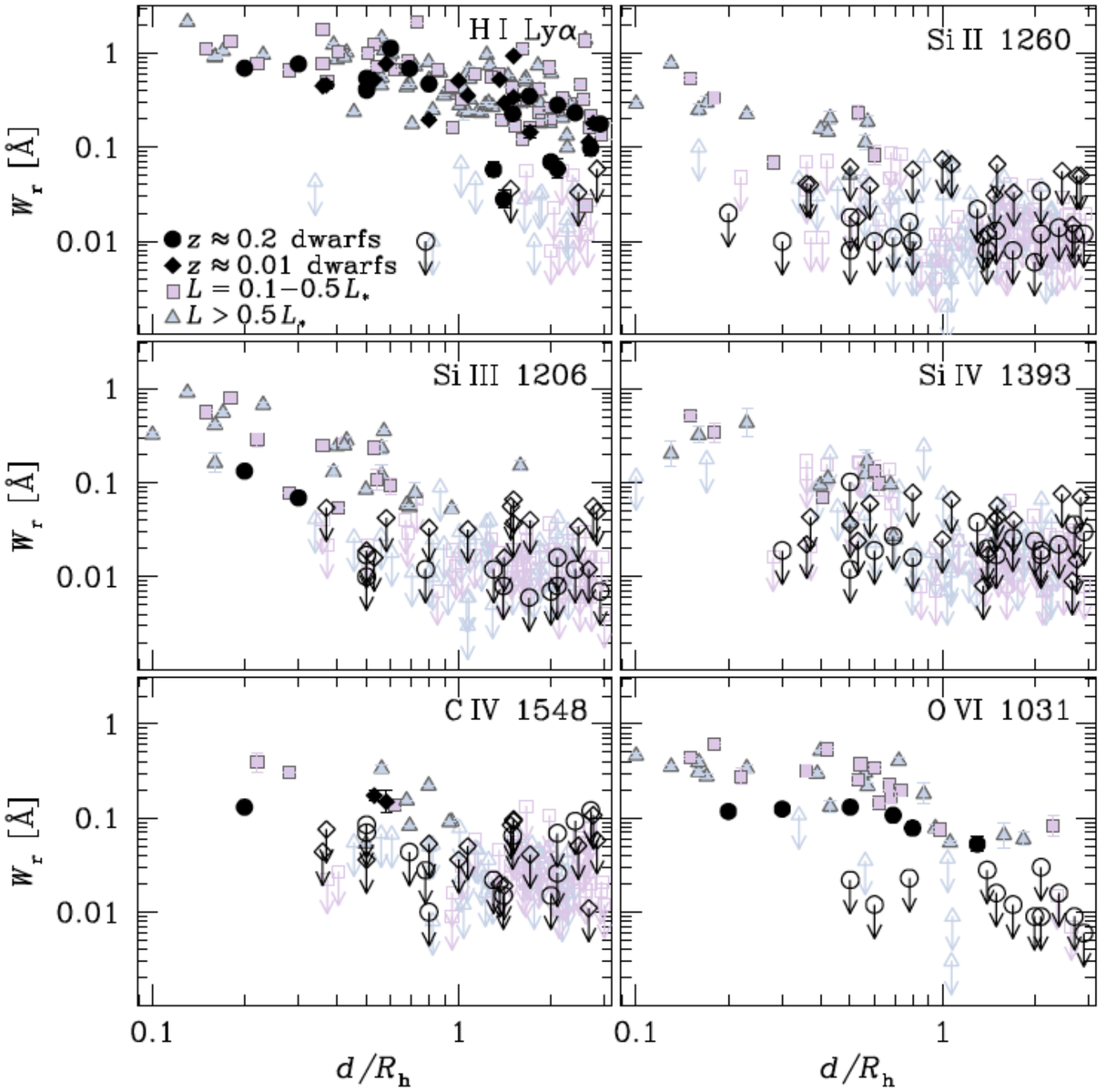

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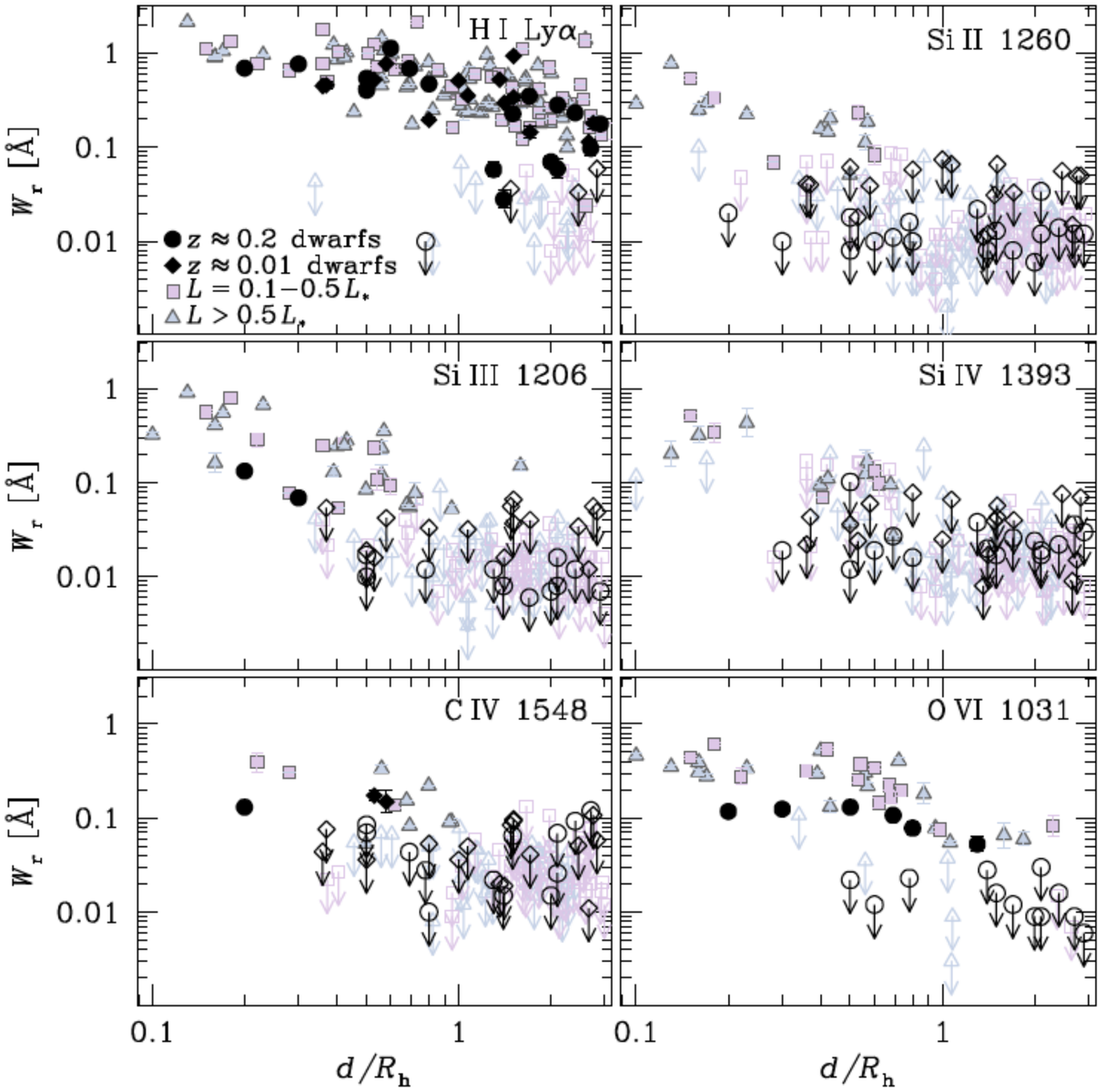
- As OVI traces an ion with expected equilibrium fraction of < 0.2, the highly-ionized CGM around dwarfs represents a significant reservoir for heavy elements

Johnson et al. (2017)



The Baryon Content of Massive Quiescent Galaxies

a Cycle 23 HST COS program to study the CGM of luminous red galaxies (LRGs) at $z \sim 0.4$

Chen, Zahedy, Johnson, Gauthier, Huang, & Weiner

- A sample of 16 SDSS LRGs of $M_{\rm r} < -22$ and stellar masses $M_{\rm star} \approx 10^{11}$ $M_\odot$, that occur at $d < 160$ kpc of a UV luminous background QSO; no prior knowledge of the presence of any absorption features.
- Selecting those at $z > 0.26$, so that accurate and precise constraints for N(HI) is possible based on COS observations of higher order Lyman series lines and the Lyman limit transition
- The primary goal is to determine N(HI), which enables detailed studies of the ionization state and metallicity of the gas

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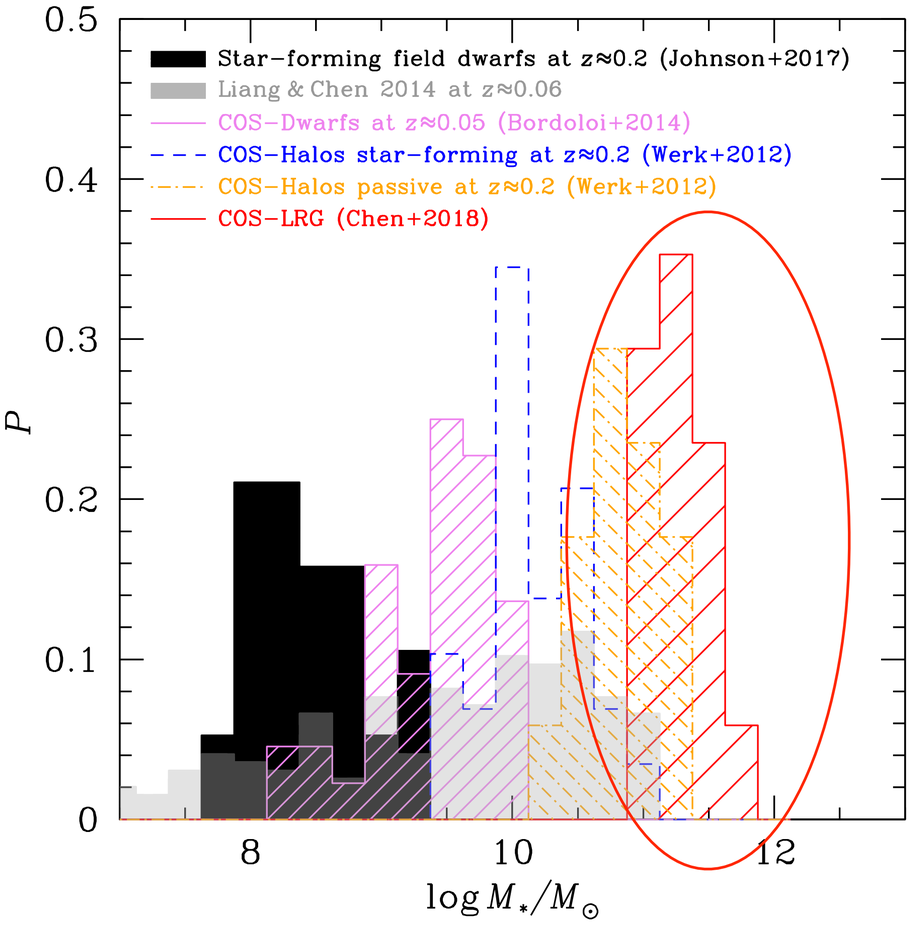

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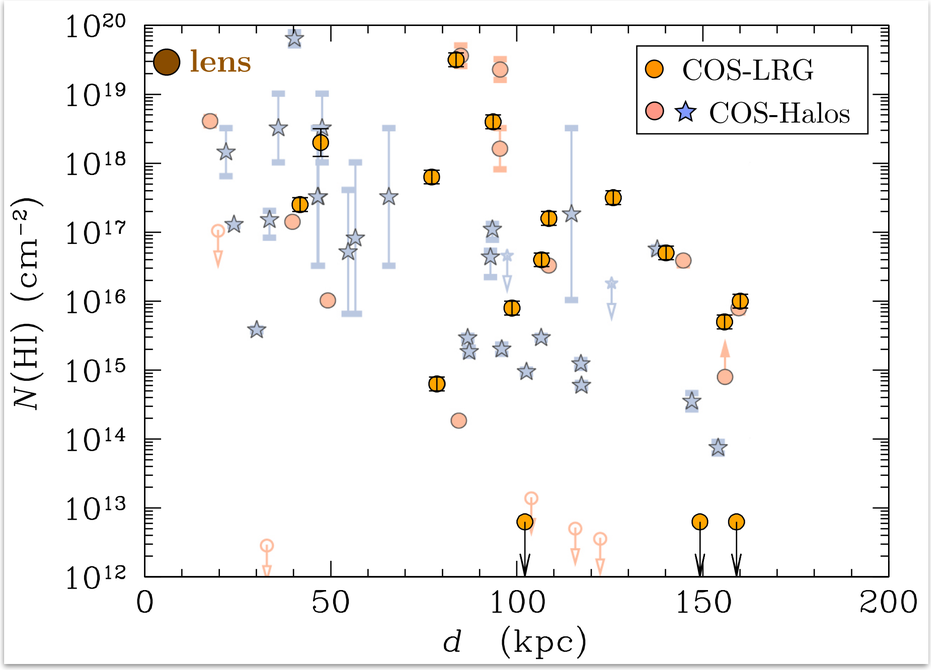
Chen et al. (2018)

Radial profile of N(HI) in quiescent halos



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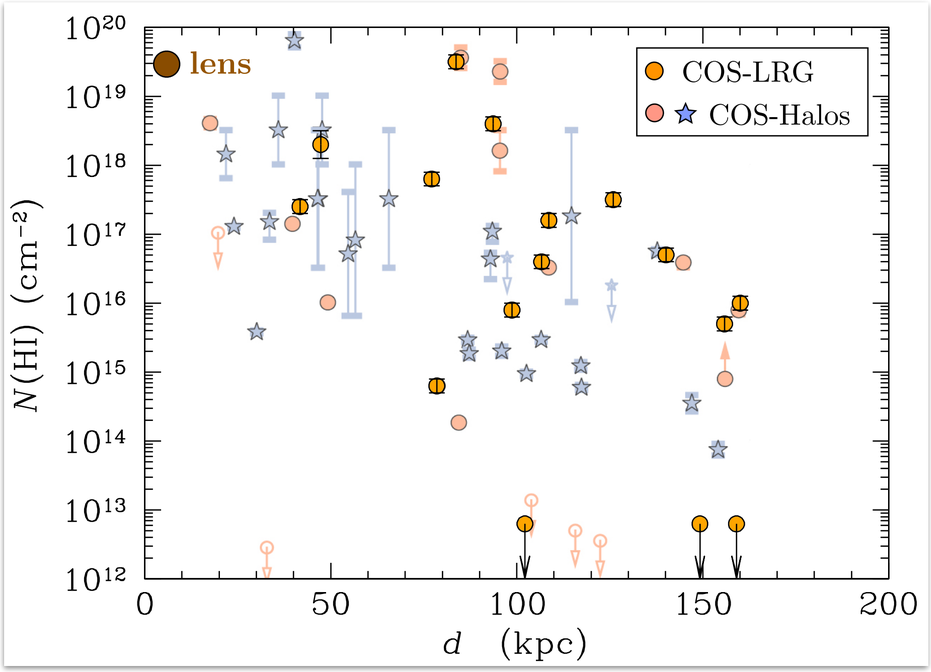

44% covering fraction of optically-thick ($\tau_{LL}>1$) gas at $d < 160$ kpc in massive ($M_h = 10^{12.6\text{-}13.4}$ $M_\odot$) quiescent halos.

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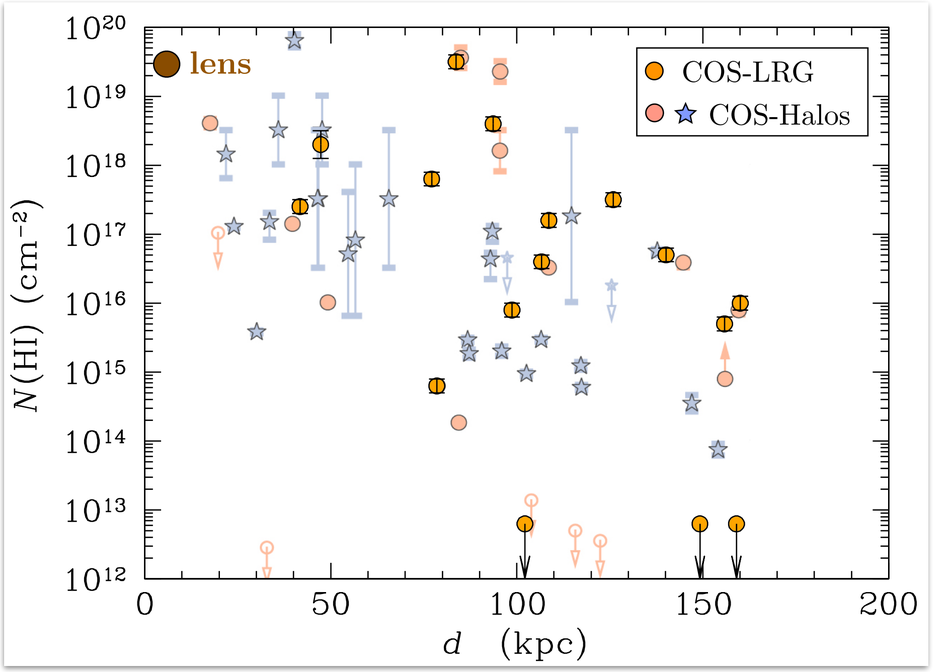

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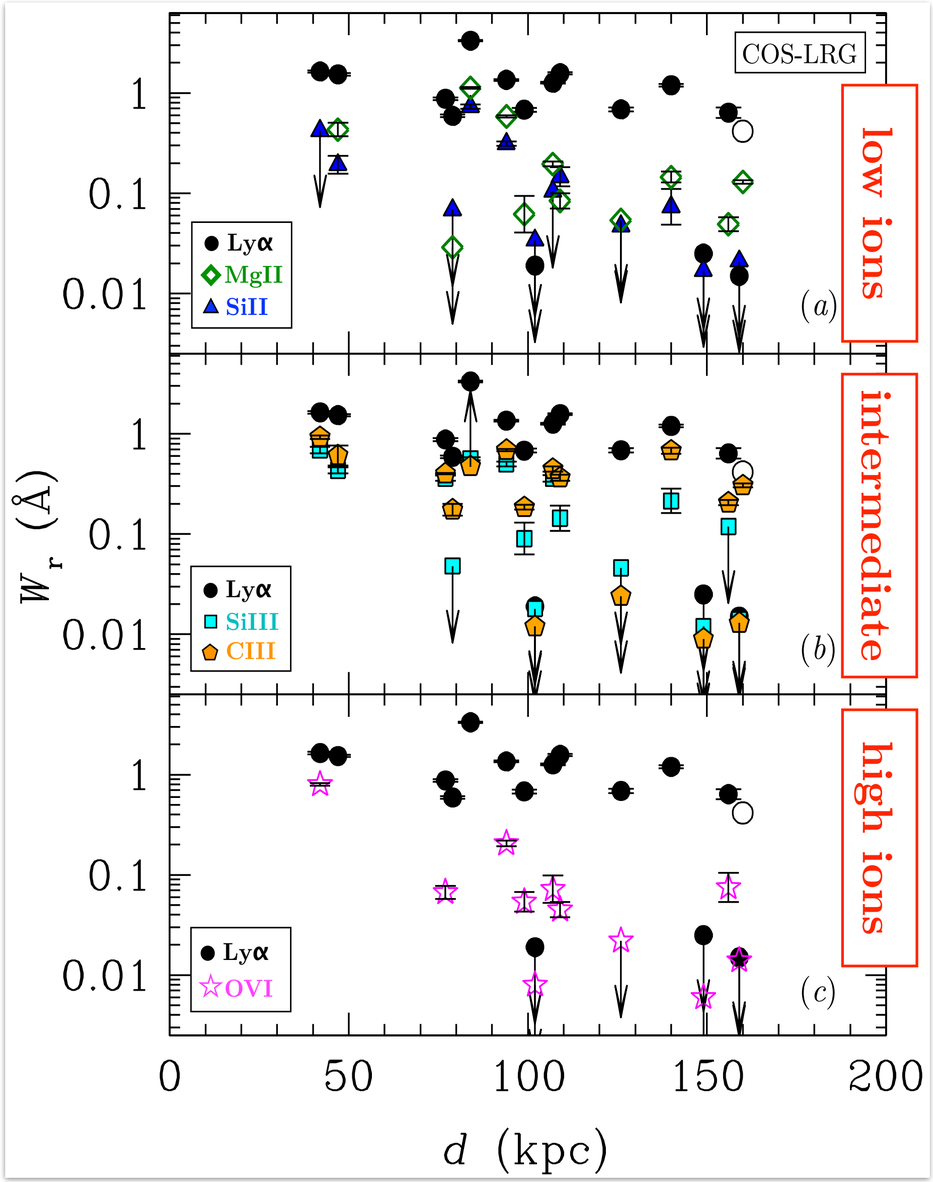
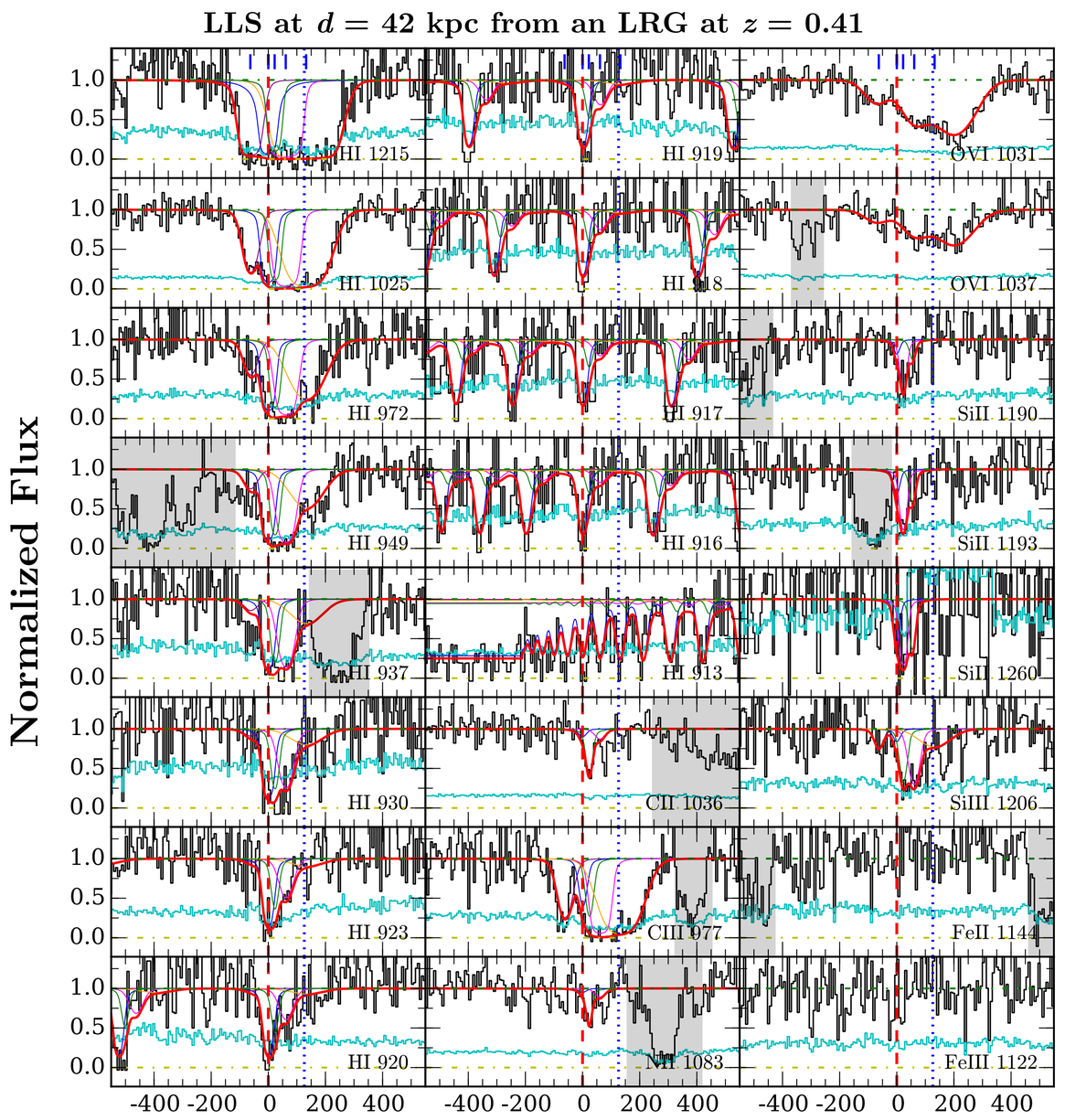
75% (50%) covering fraction of C^{2+} (Mg^{+}) at $d < 160$ kpc in quiescent halos.



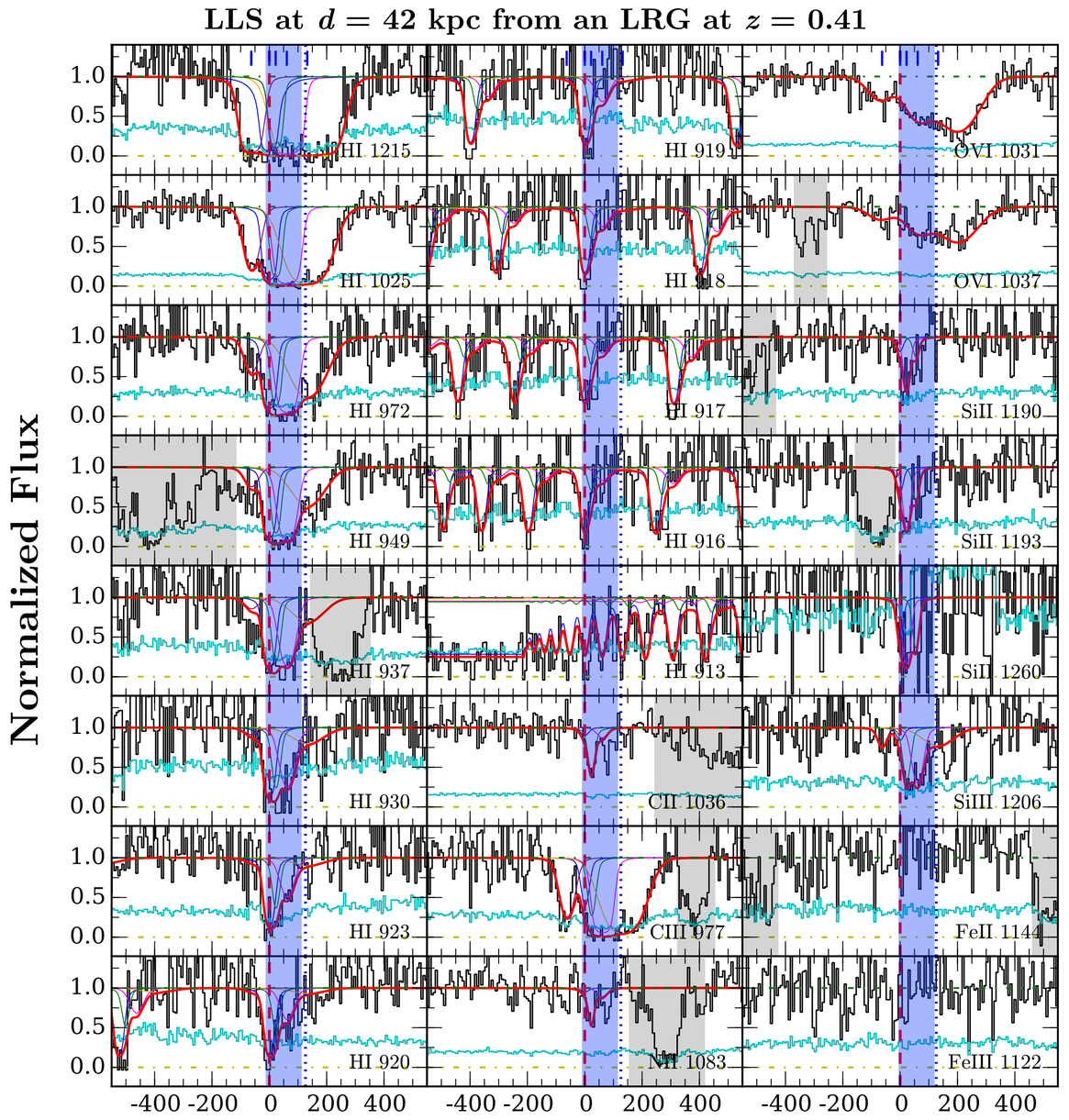
distinct from dwarfs

Resolved component structures between low and high ions



Resolved component structures between low and high ions

Matched low-ionization transitions, enabling component-by-component ionization modeling



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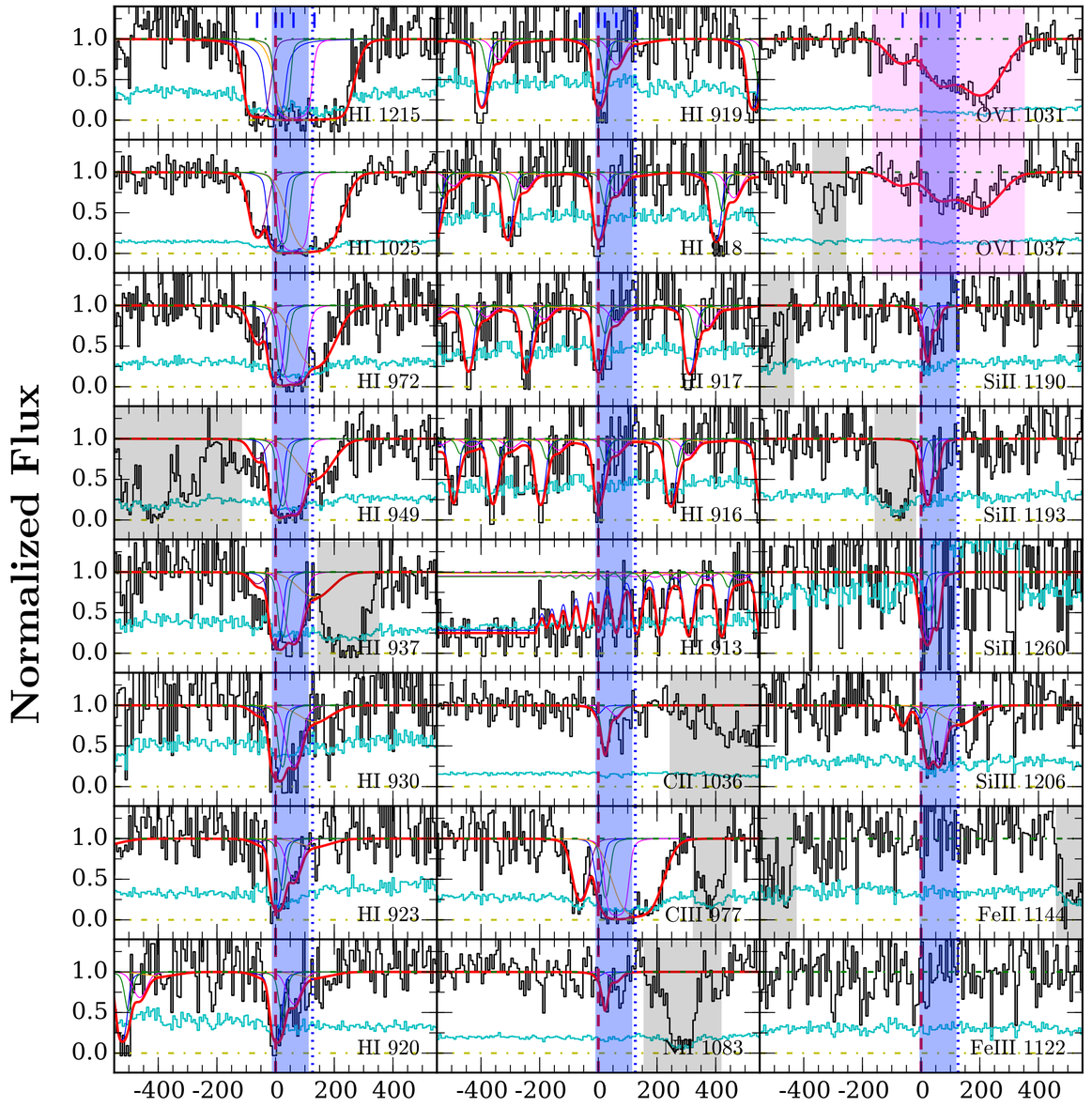
LLS at $d = 42$ kpc from an LRG at $z = 0.41$

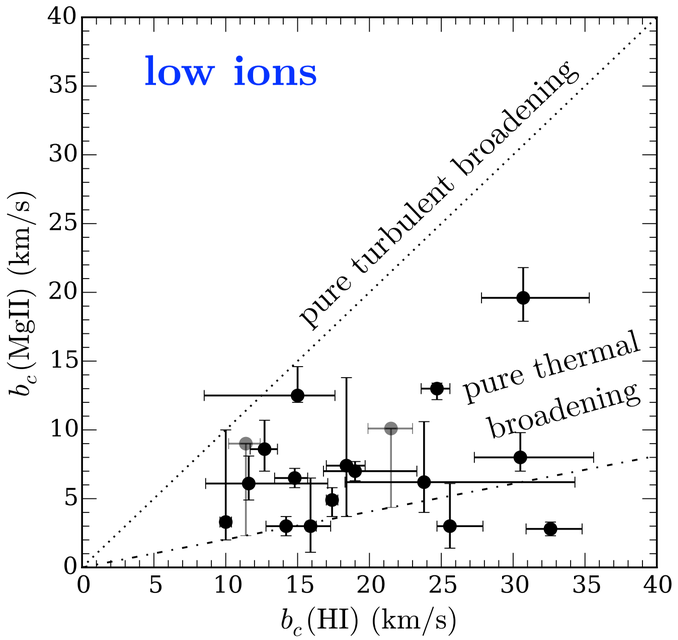
Zahedy et al. (2018)



OVI displays kinematically distinct profiles

Thermal State of the CGM around LRGs

Zahedy et al. (2018)



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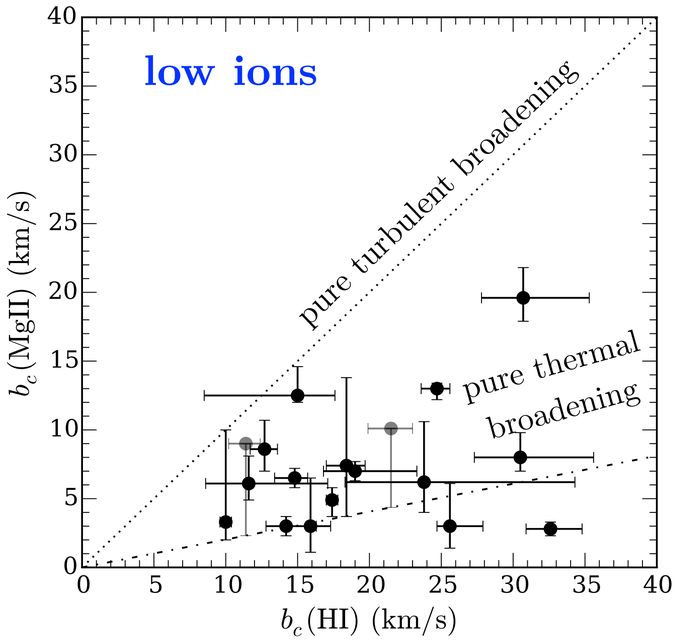

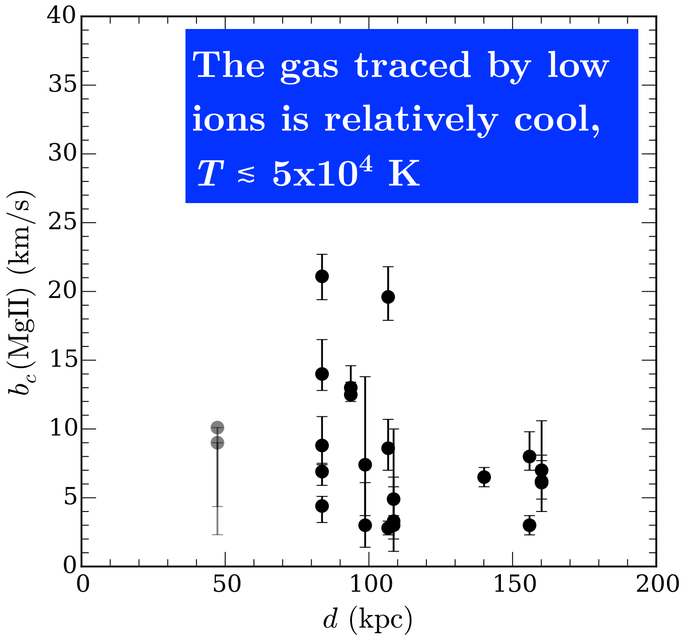

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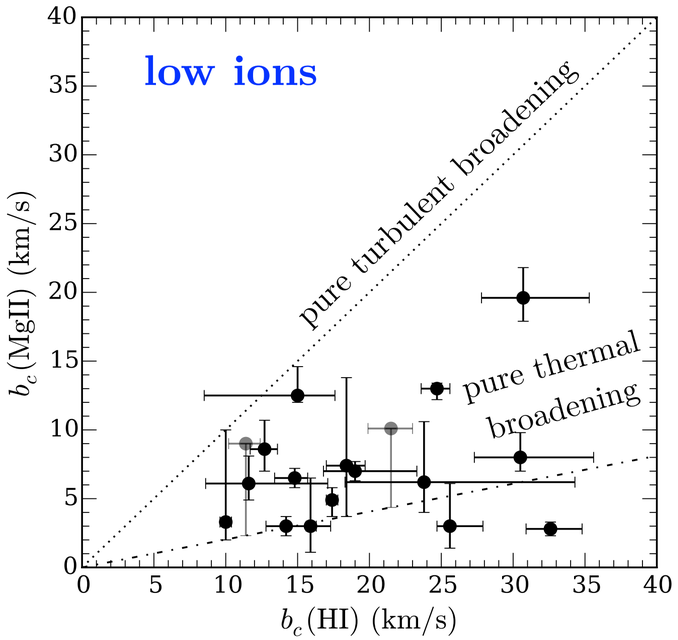

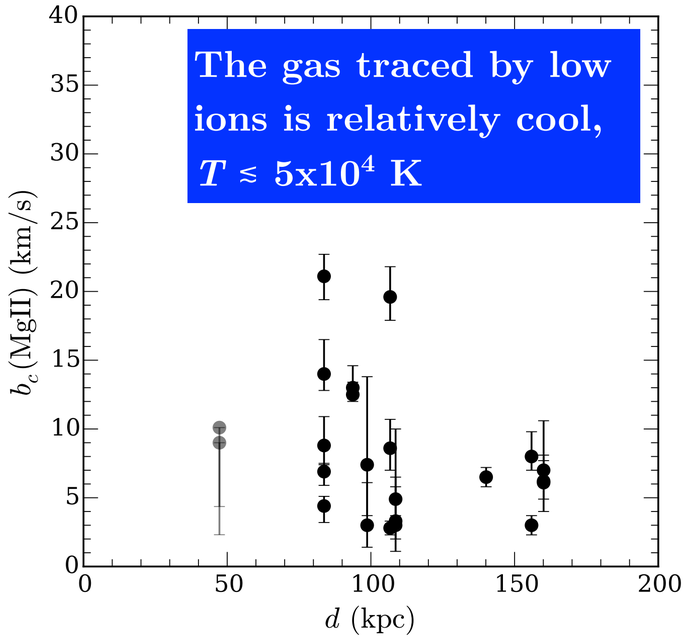

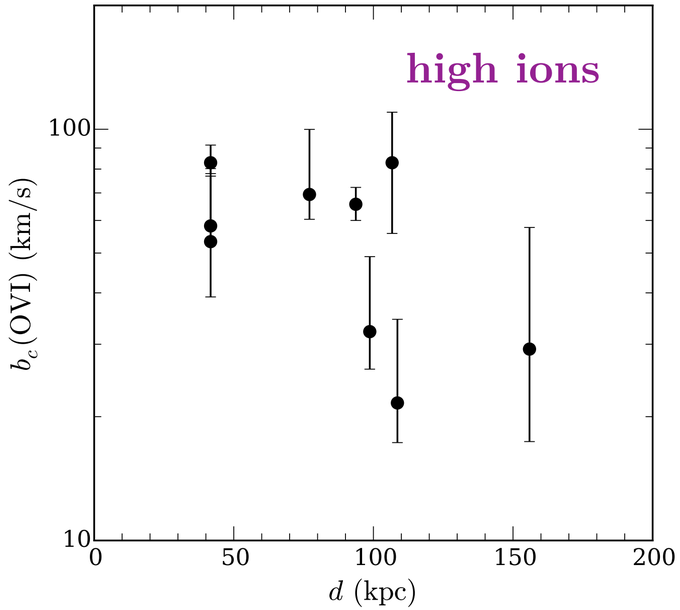

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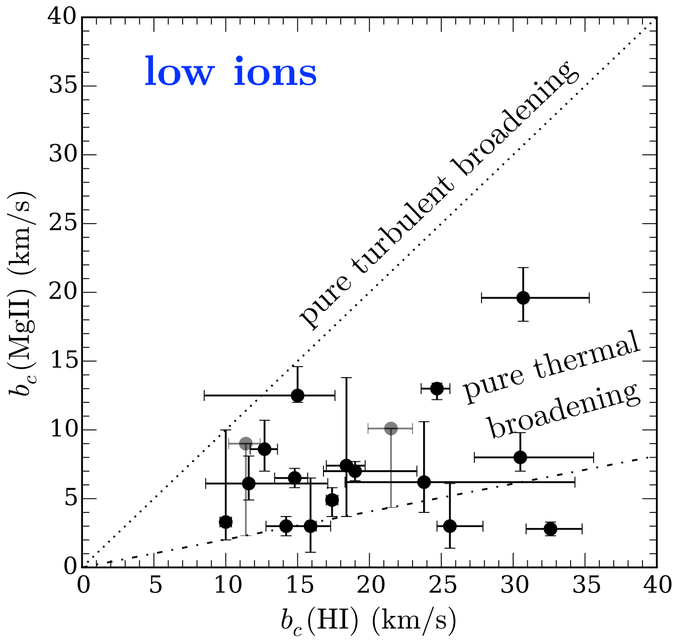
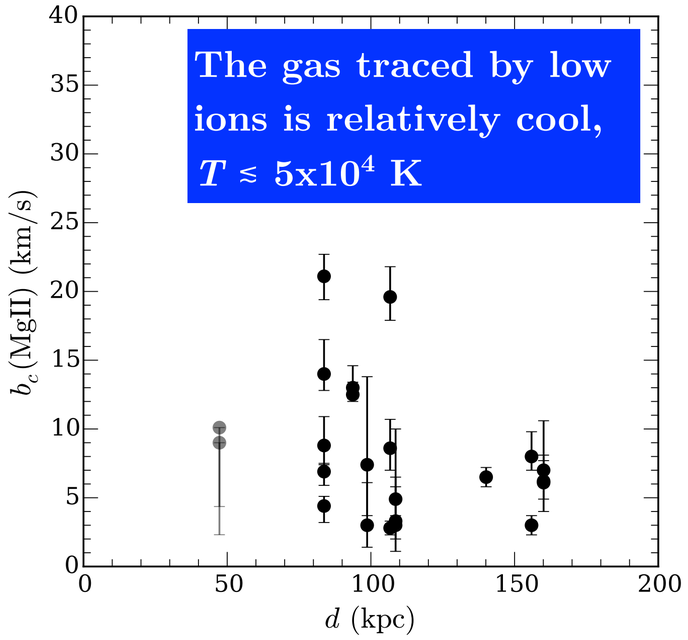
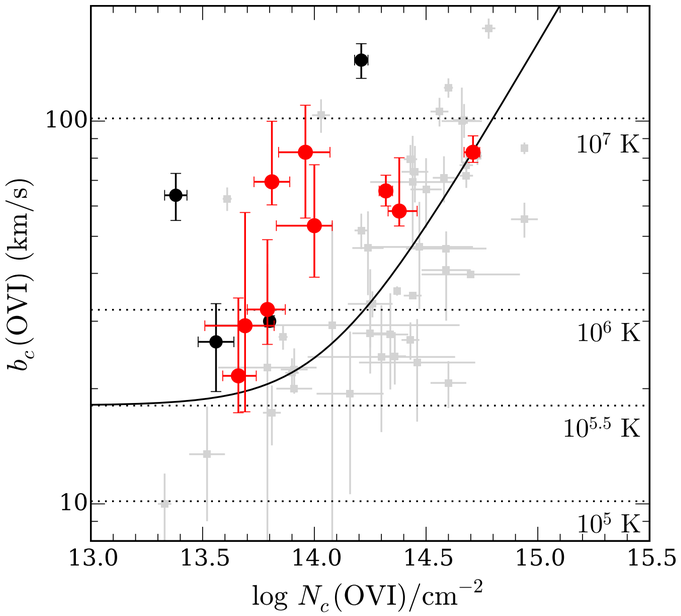
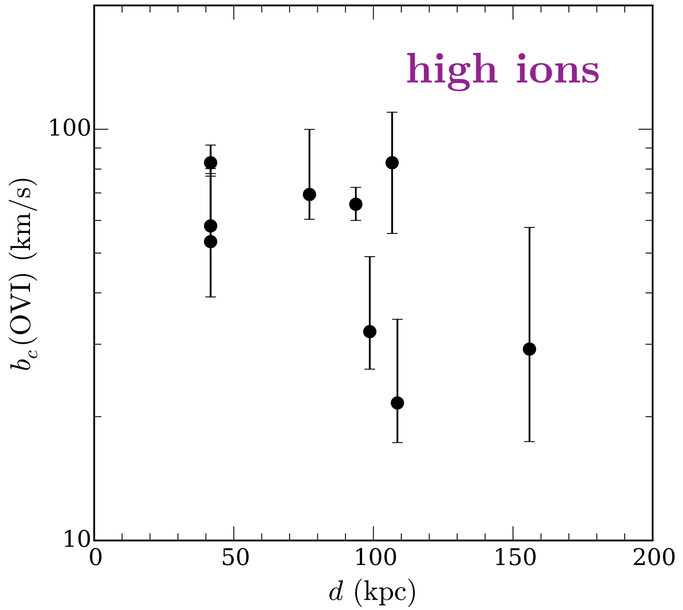


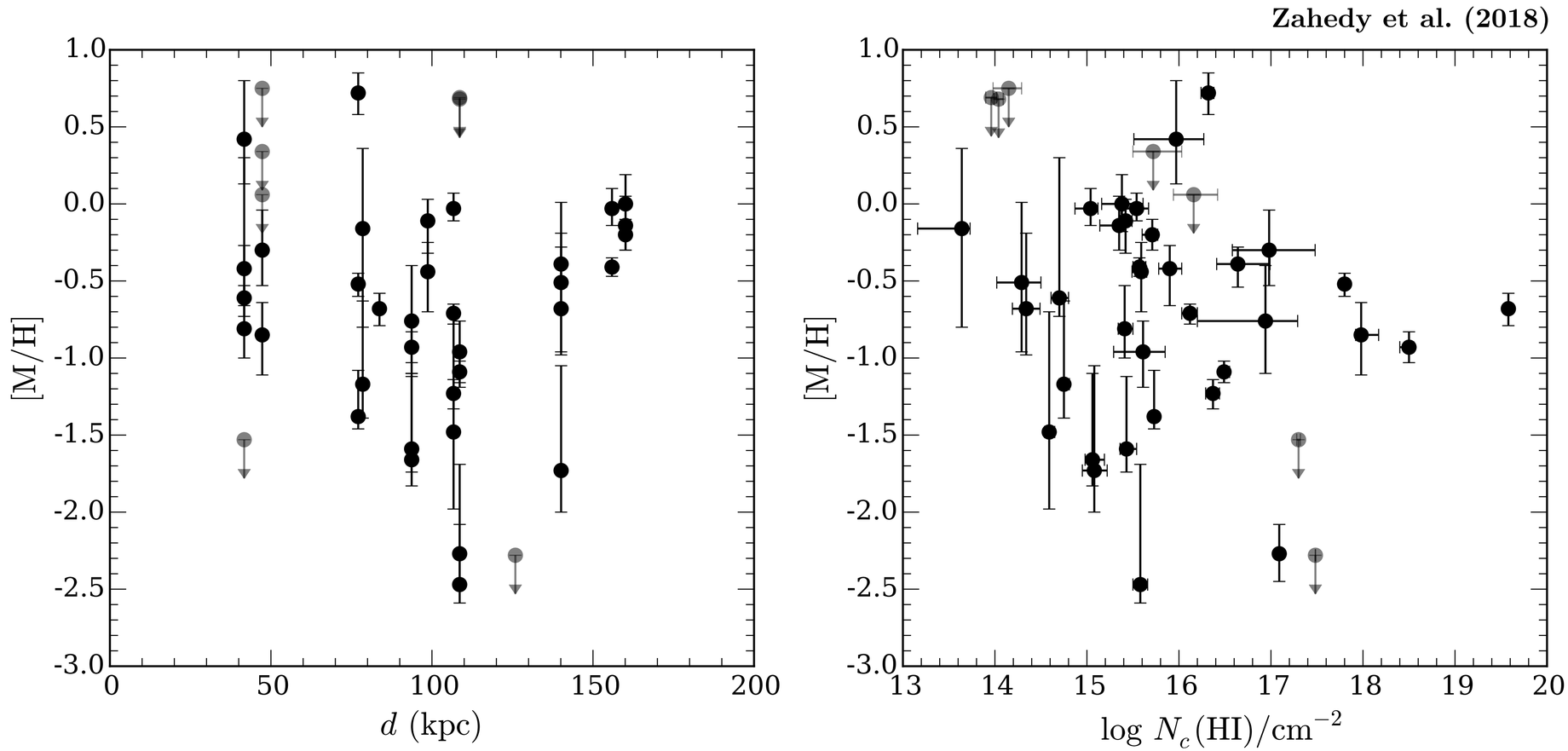


The observed broad OVI line width is difficult to be explained by simple models.





Metallicity of Cool Circumgalatic Gas



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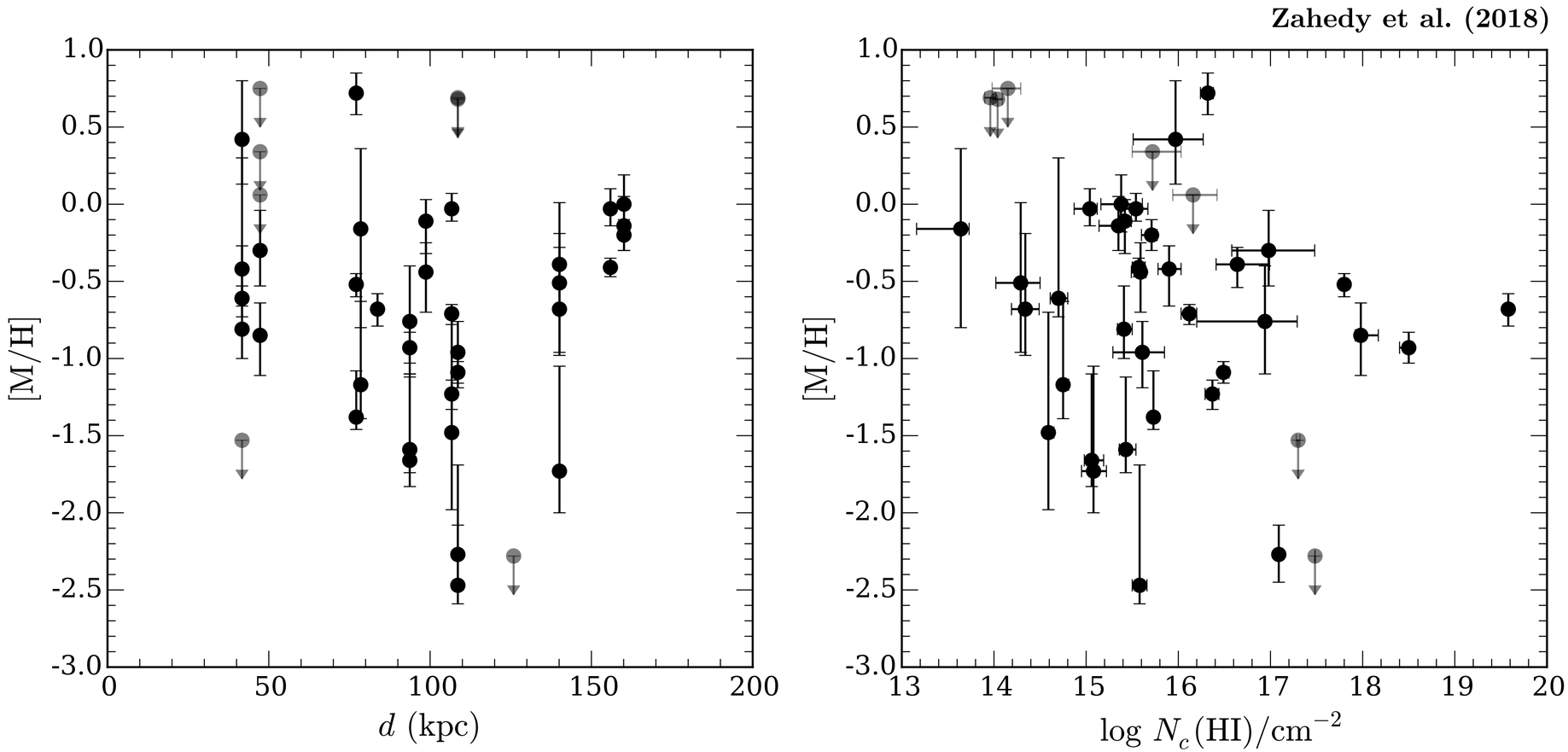

large scatter in [M/H] between individual components -> chemical mixing is inefficient

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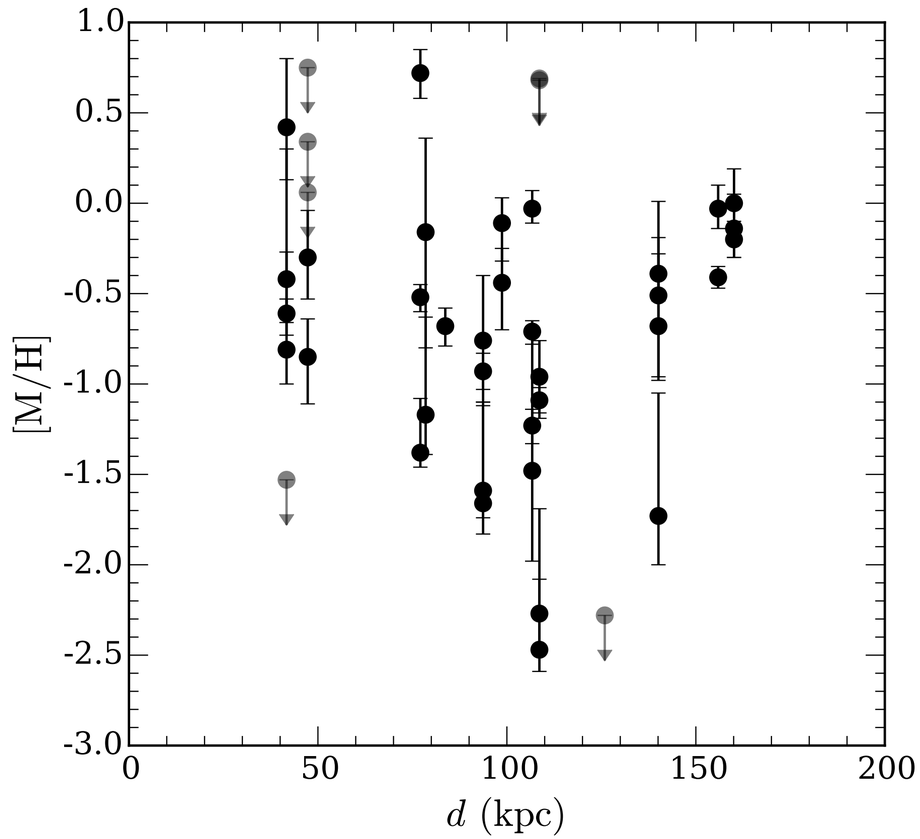

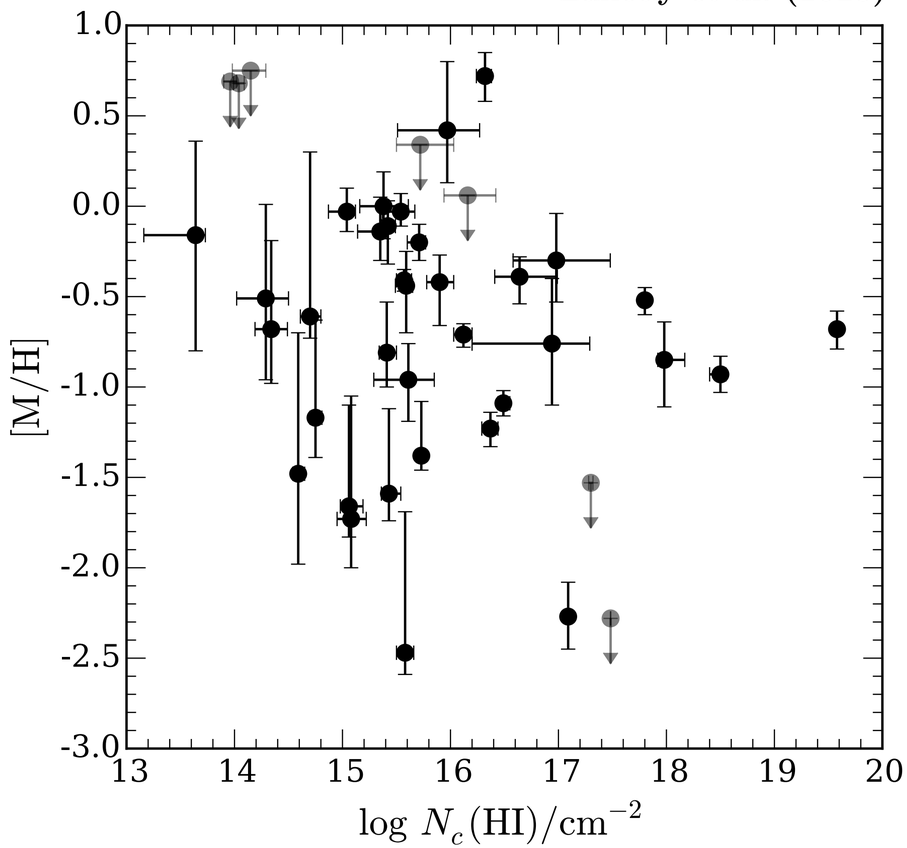

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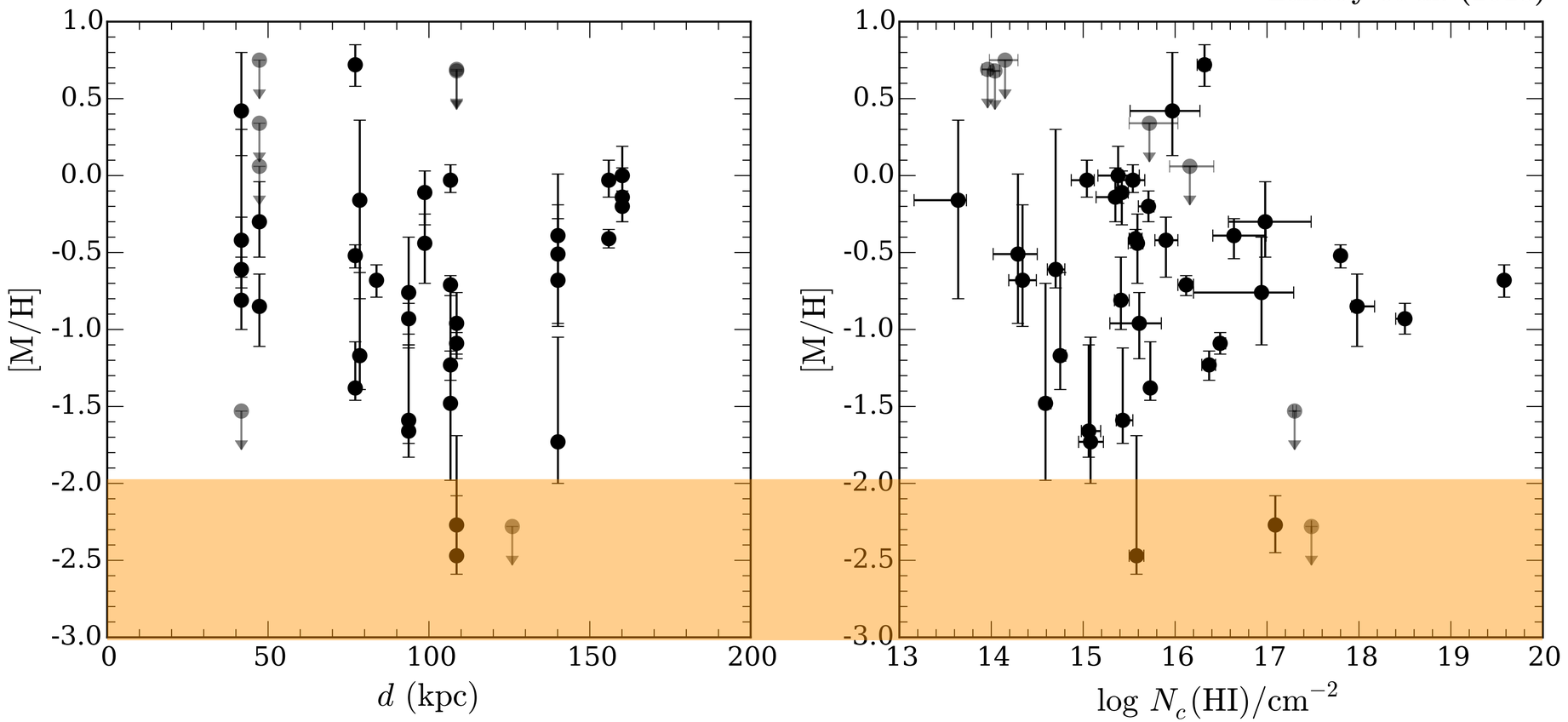
no correlation between [M/H] and N(HI)

Metallicity of Cool Circumgalatic Gas

Some fraction of the CGM around massive quiescent halos can remain metal poor

Zahedy et al. (2018)



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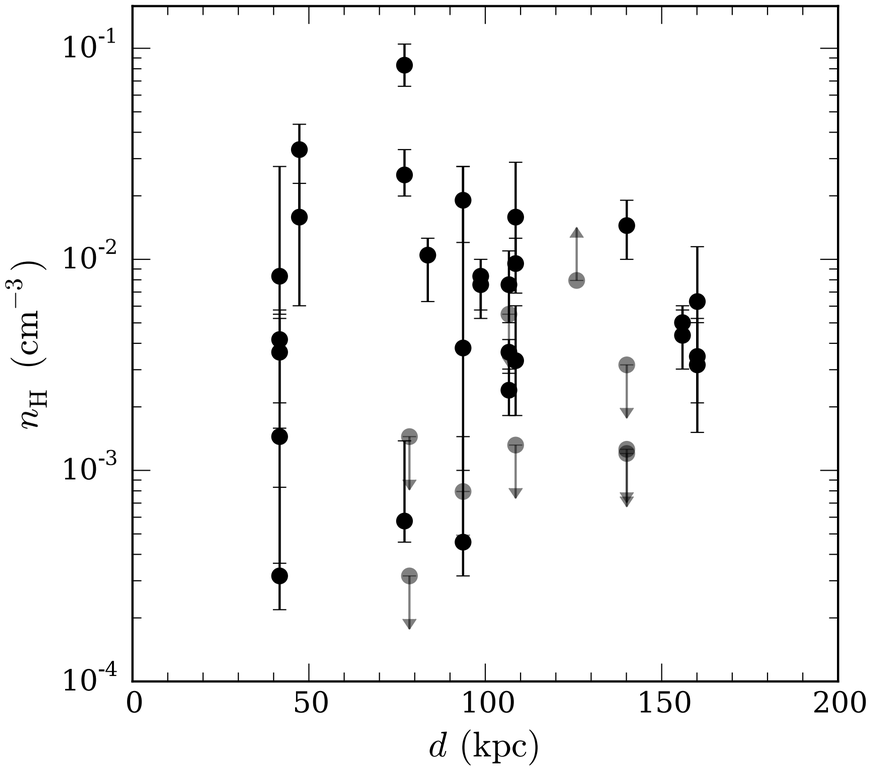
Density of Cool Circumgalactic Gas



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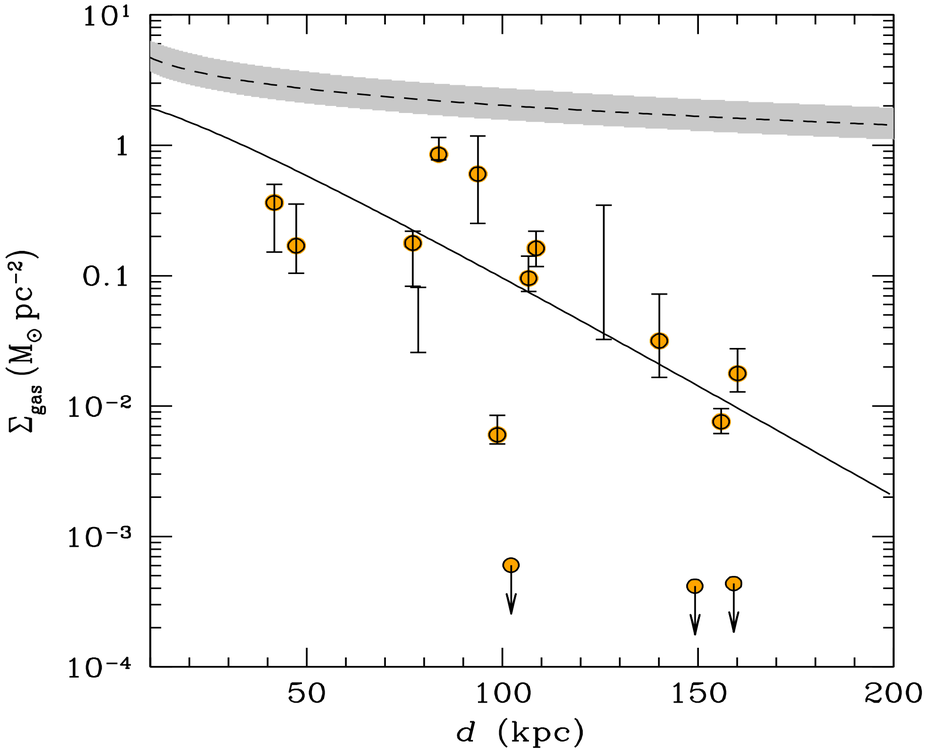

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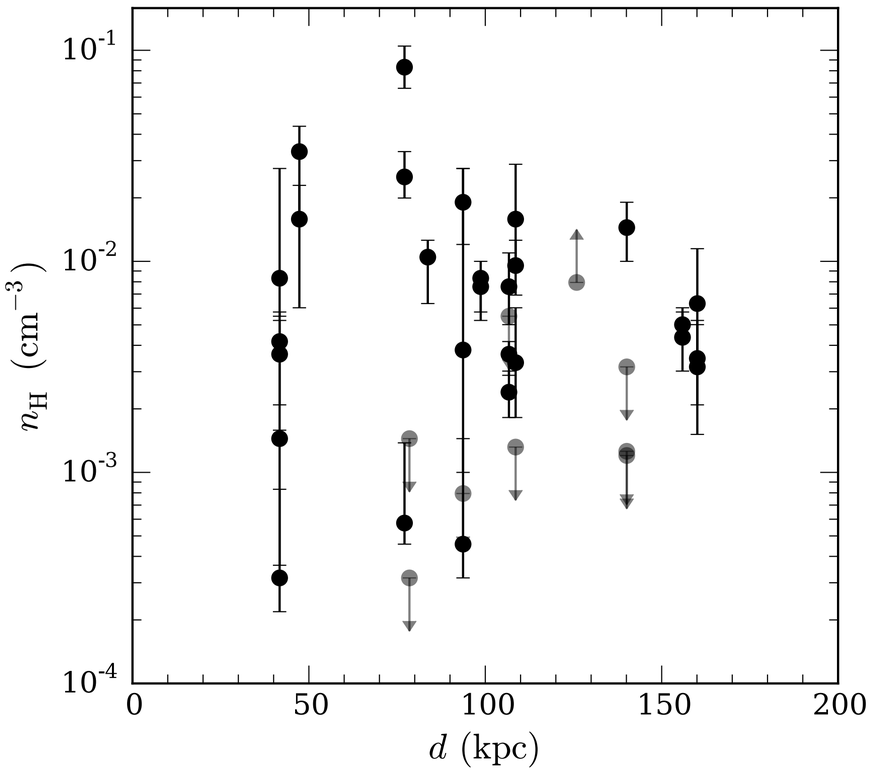
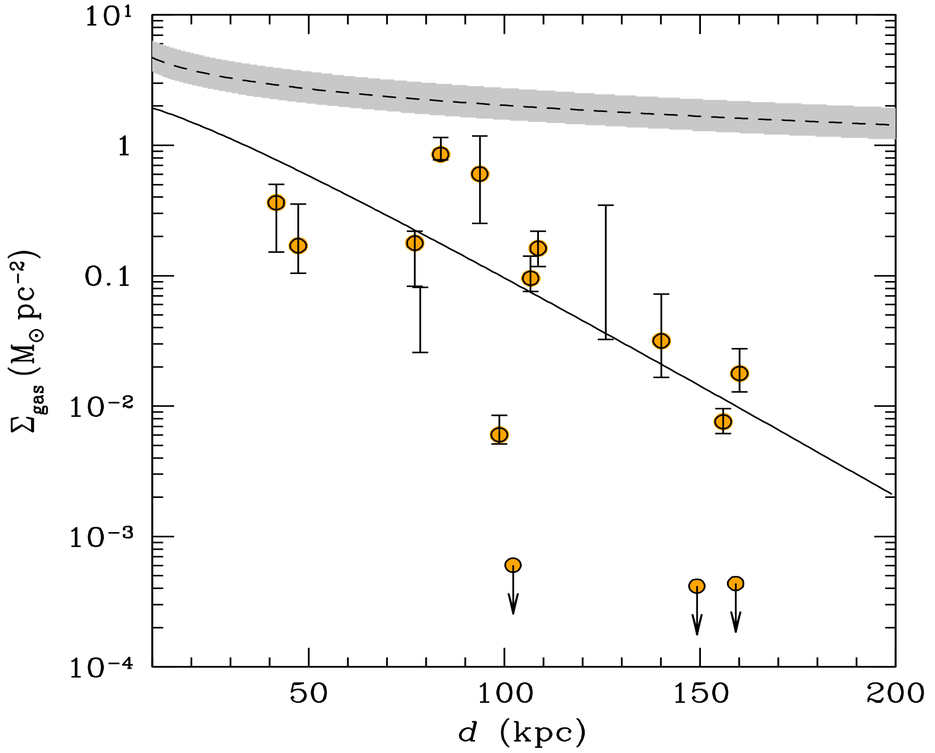
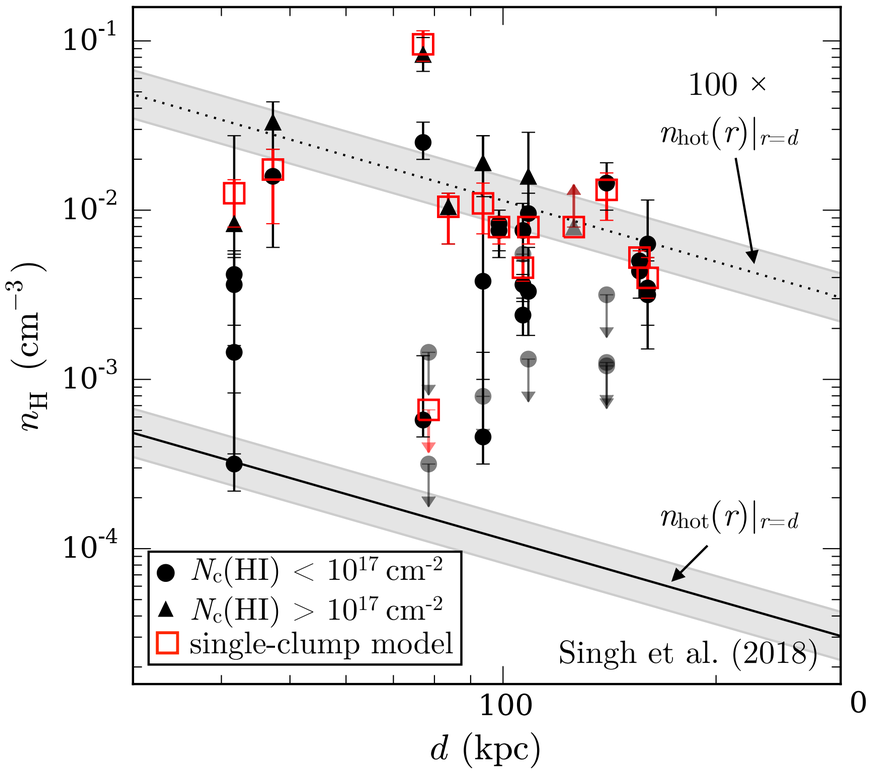


Zahedy et al. (2018)

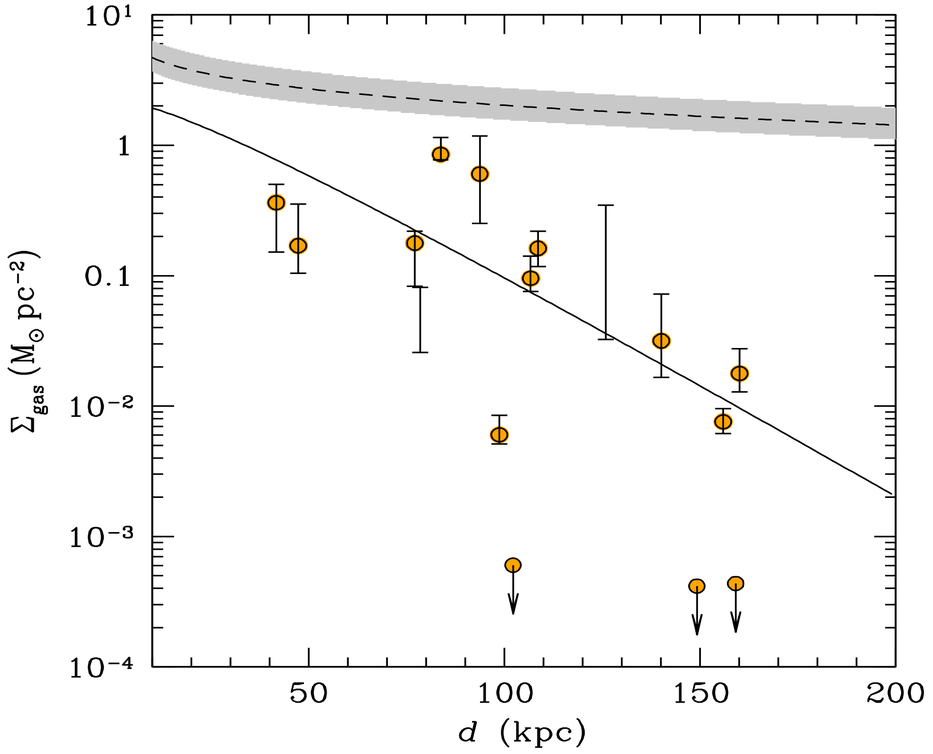


large scatter in $n_{\rm H}$ between individual components -> different ionization states

Density of Cool Circumgalactic Gas

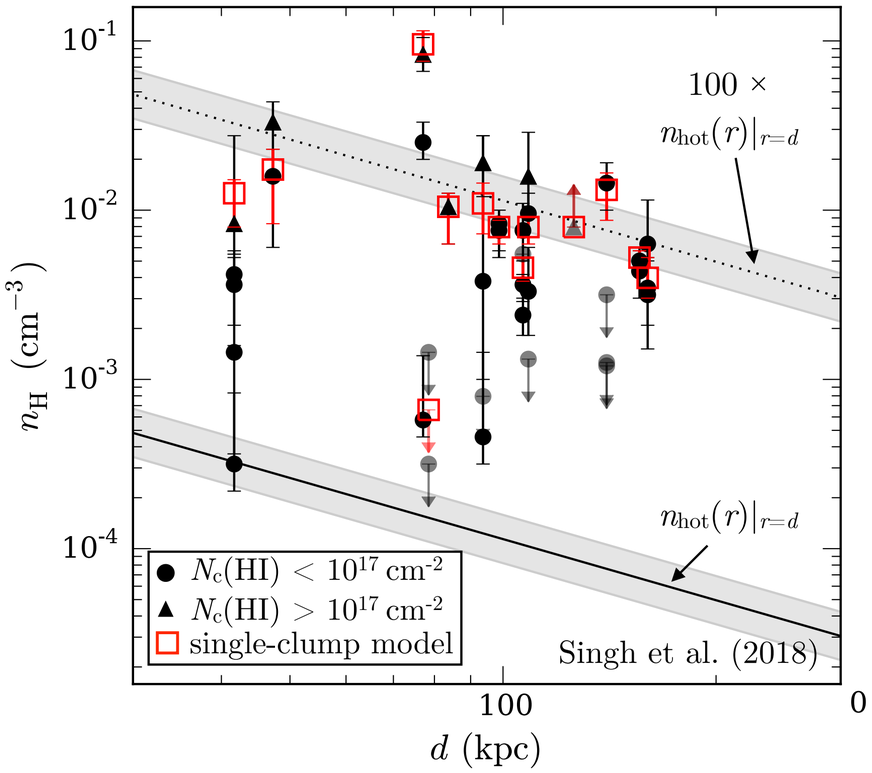


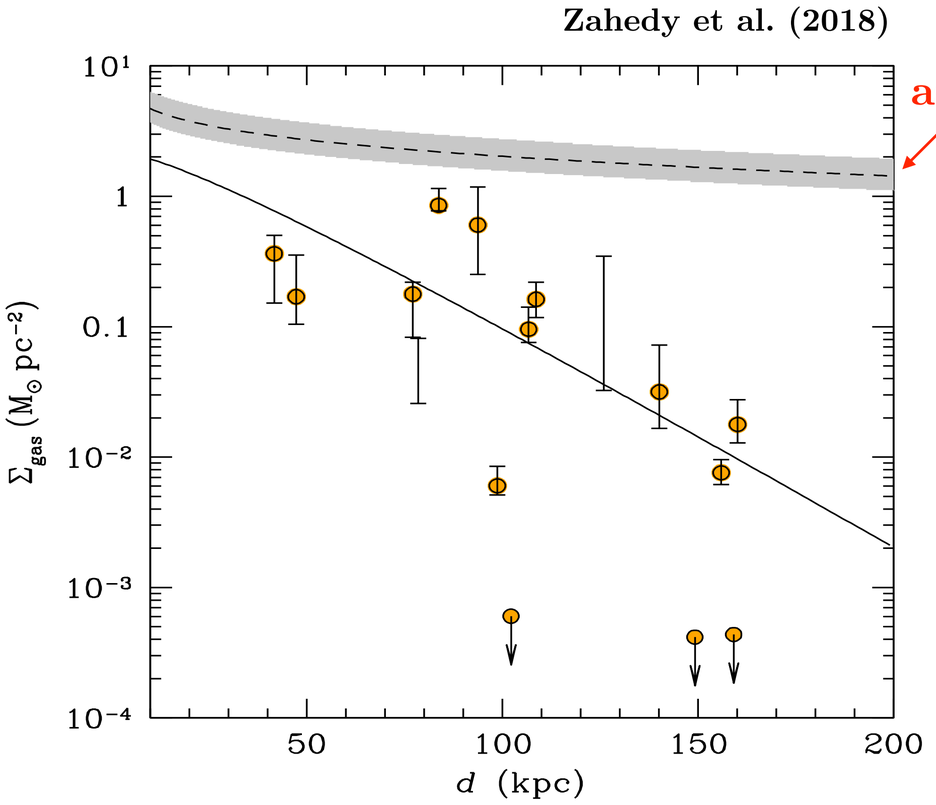
Zahedy et al. (2018)



large scatter in $n_{\rm H}$ between individual components -> different ionization states

Density of Cool Circumgalactic Gas





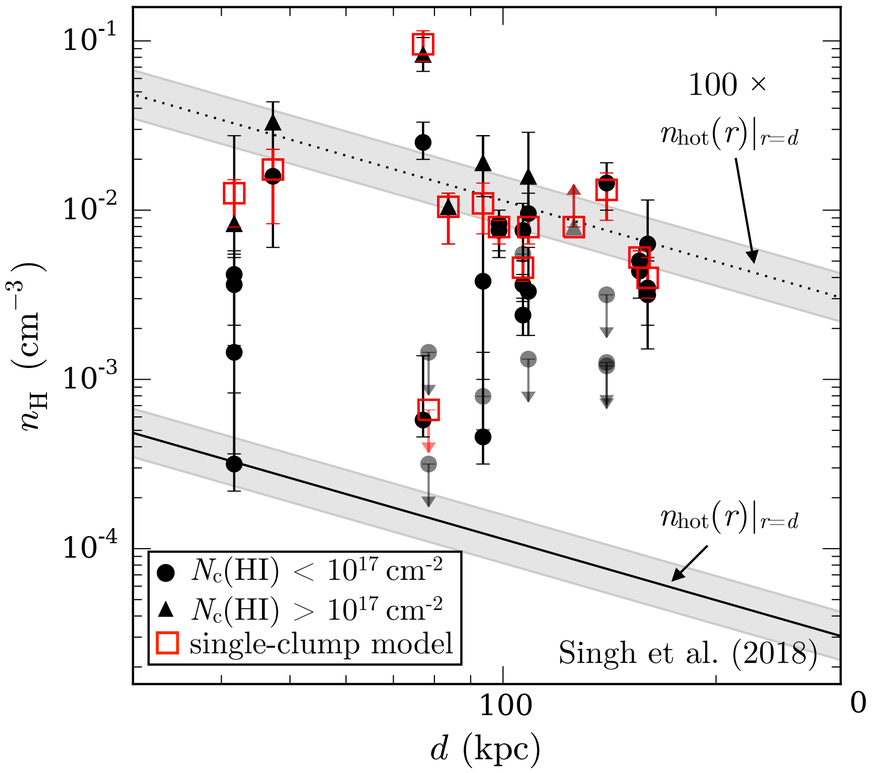
large scatter in $n_{\rm H}$ between individual components -> different ionization states

$M_{\rm cool}$ (d<160 kpc) ~ 1.5e10 M$_\odot$

$X_{\rm cool} \equiv M_{\rm cool}/M_{\rm hot} \approx 6-12\%$

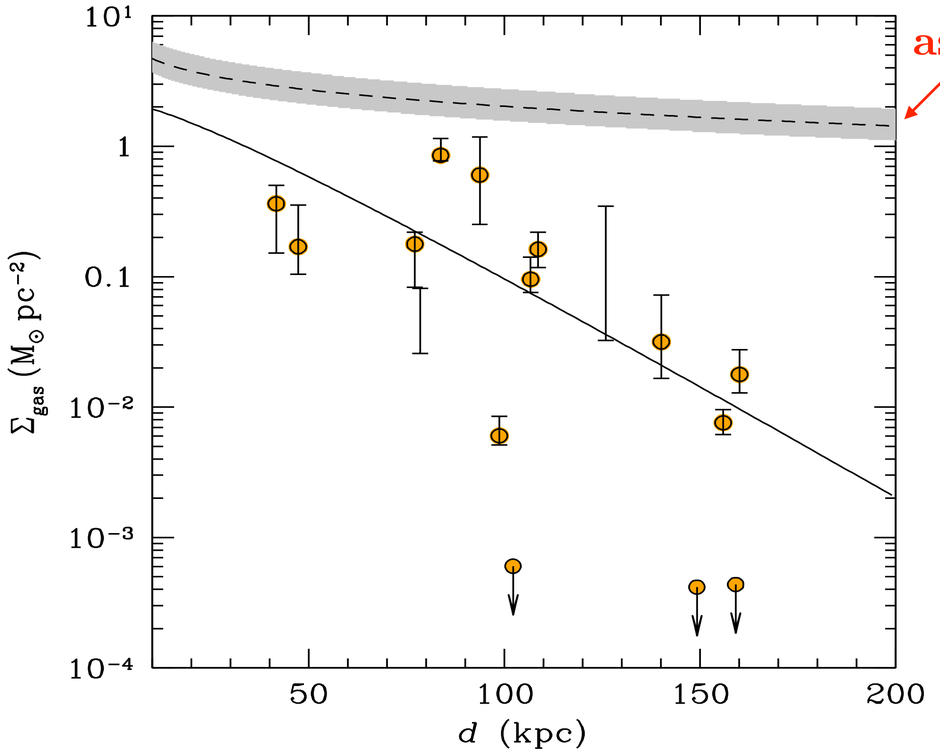
Density of Cool Circumgalactic Gas

In LRG halos of ~10^{13} $M_\odot$, the total gas mass in cool phase is ~ 4 x 10^{10} $M_\odot$ and ~ (2 - 6) x 10^{11} $M_\odot$ in the hot phase, while the OVI phase remains unconstrained



Zahedy et al. (2018)

hot phase assuming 0.2 $Z_\odot$



large scatter in $n_{\rm H}$ between individual components -> different ionization states

$M_{\rm cool}$ (d<160 kpc) ~ 1.5e10 $M_\odot$

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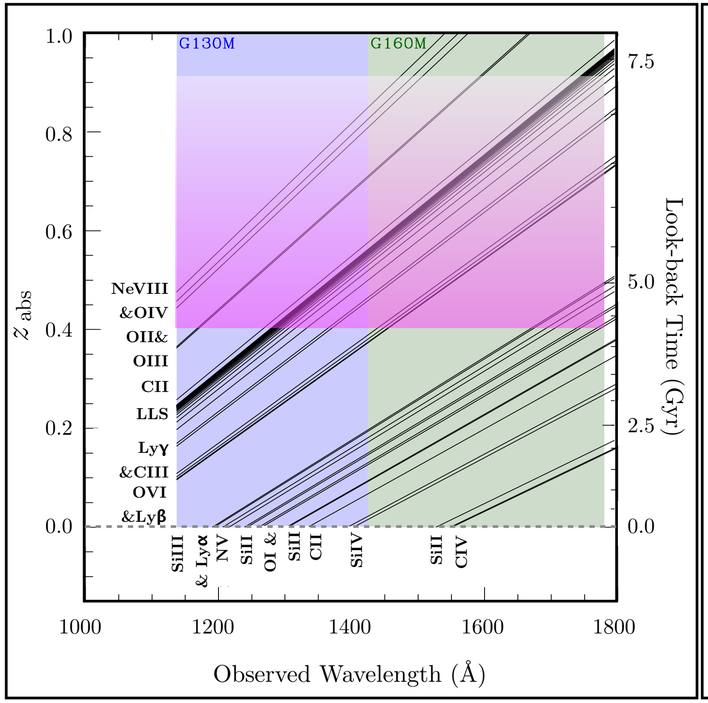
The Cosmic Ultraviolet Baryon Survey (GO-CUBS)

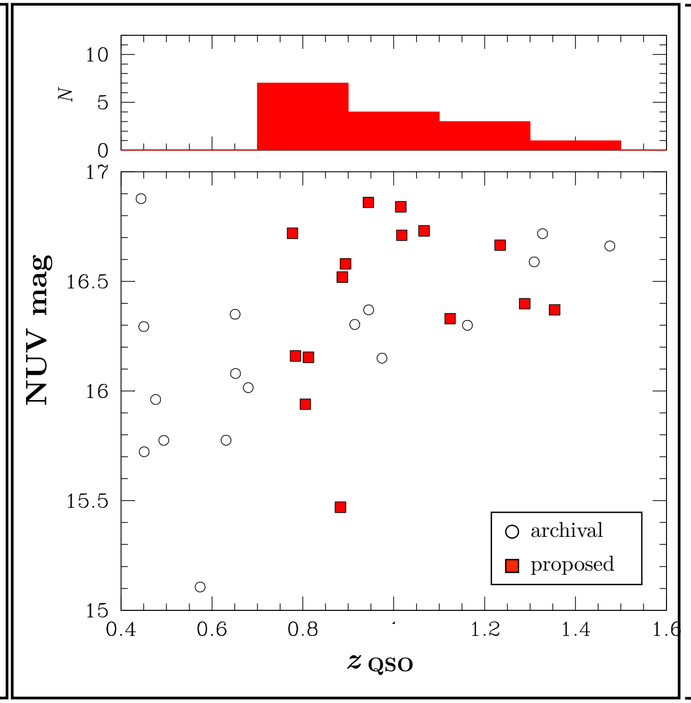
HST Cycle 25 large GO program, 169 x 2 orbits

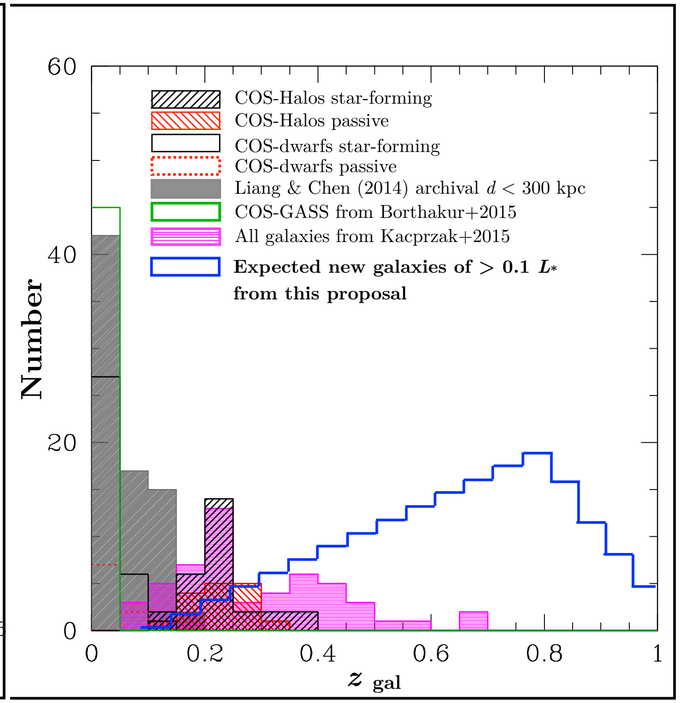
Chen (UChicago), Johnson (Princeton), Rudie (Carnegie), Simcoe (MIT), Mulchaey (Carnegie), Boettcher (UW Madison->UChicago), Cooper (MIT-> Carnegie), Penton (STScI), Cantalupo (ETH), Cooksey (UH Hilo), Faucher-Giguère (Northwestern), Greene (Princeton), Lopez (UChile), Petitjean (IAP), Putman (Columbia), Rafelski (STScI), Rauch (Carnegie), Schaye (Leiden), Weiner (Steward), Zahedy (UChicago)

https://cubs.uchicago.edu

CUBS is designed to map 'dark' baryonic structures in the crucial but unconstrained epoch between redshift z = 0.4 and z ~ 2, by combining absorption-line spectroscopy of 15 UV-bright QSOs at z > 0.8 with matching deep galaxy survey data (25 nights of Magellan time).







Summary

- **OVI absorbers are strongly correlated with galaxies**
- **The CGM is multi-phase and diverse in origin, with large scatters in both gas density and metallicity**
- **The CGM of low-mass dwarfs is dominated by a highly-ionized phase traced by OVI, while the CGM of massive elliptical is dominated by intermediate-state ions traced by CIII and SiIII**
- **Chemical mixing is inefficient (at least some part of the low-redshift IGM remains pristine)**
- **In LRG halos of $\sim 10^{13}$ $M_\odot$, the cool phase contributes up to 2.5% of the expected cosmic baryon mass fraction, while the OVI phase remains unconstrained**
- **Stay tuned for results from the GO-CUBS program**