



TRACING GAS ENRICHMENT IN QUASAR ABSORPTION LINES: EVOLUTION OF CIV AND IMPLICATIONS FOR GALAXY EVOLUTION

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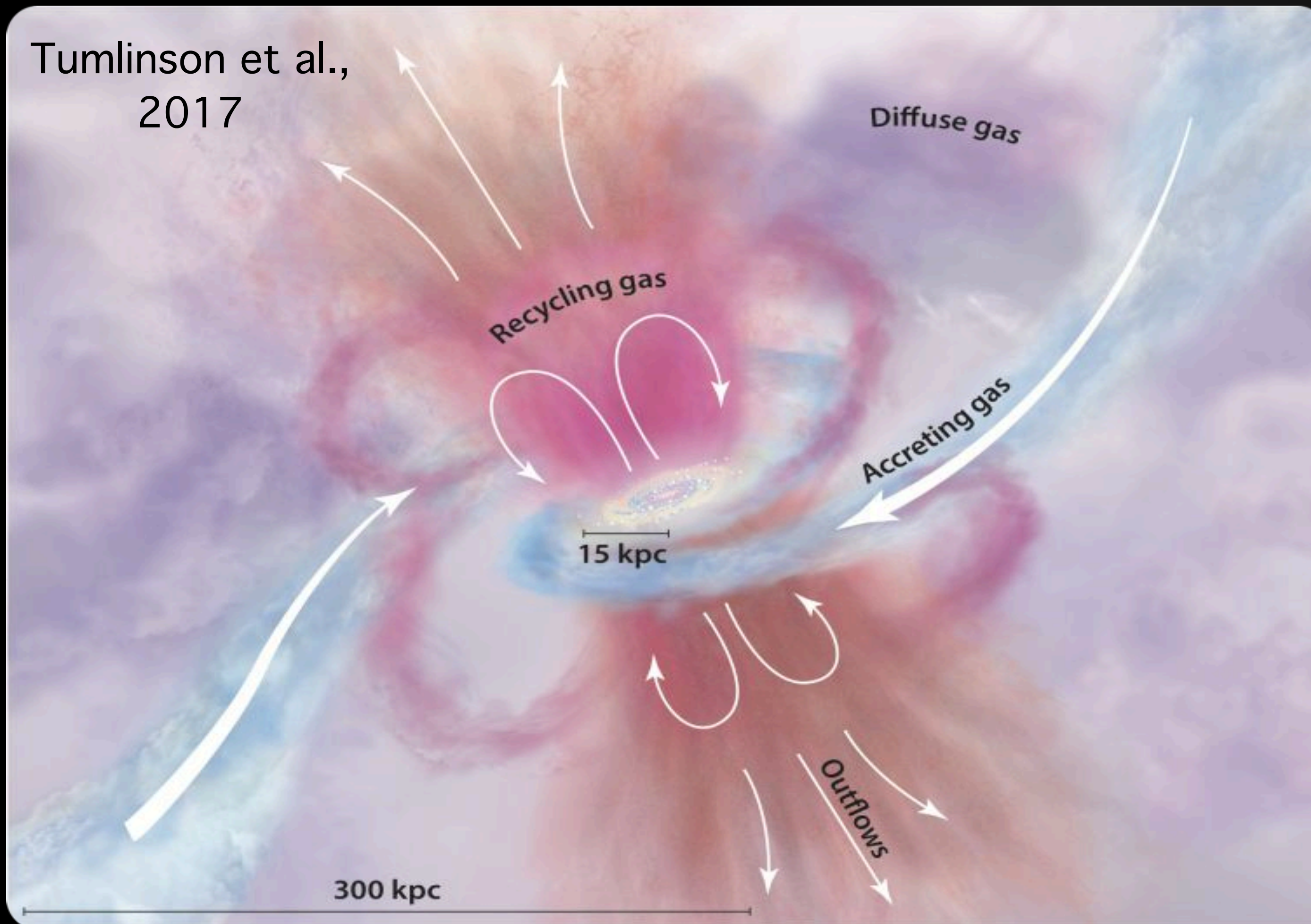
Sameer
Penn State



GALAXY ECOSYSTEMS AND THE BARYON CYCLE



Tumlinson et al.,
2017



More than 90% of baryons exist in
gaseous form

The majority resides in the
Circumgalactic medium (CGM) and
Intergalactic medium (IGM)

They record the history of metal
enrichment and ionization of the universe

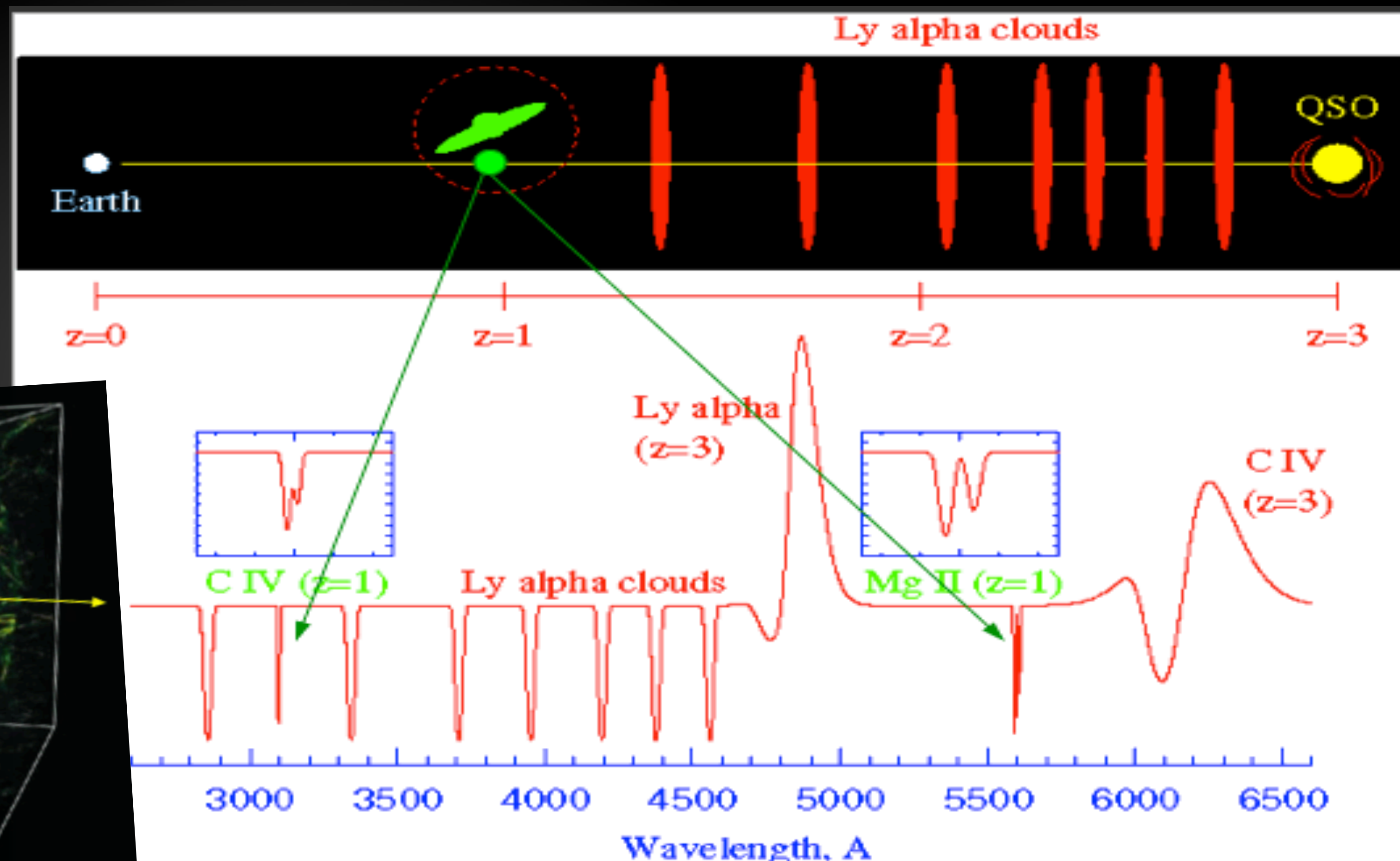
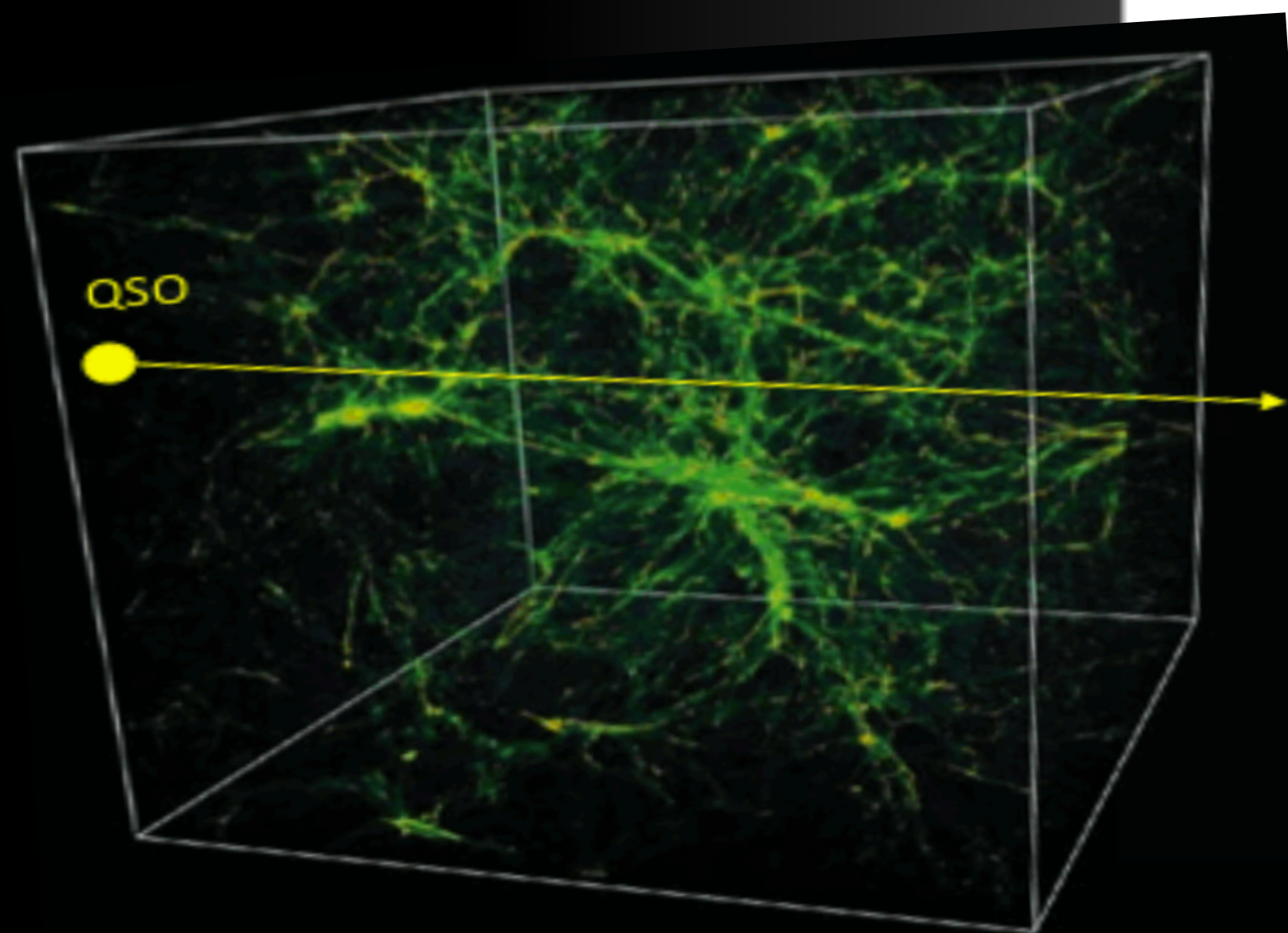
Galaxy evolution is dictated by cycling of
baryons into and out of galaxies

QUASAR ABSORPTION LINES



Absorption lines + atomic physics =
properties of gas around galaxies

Equivalent Width (EW) = strength
of absorber



Credits: C. Churchill

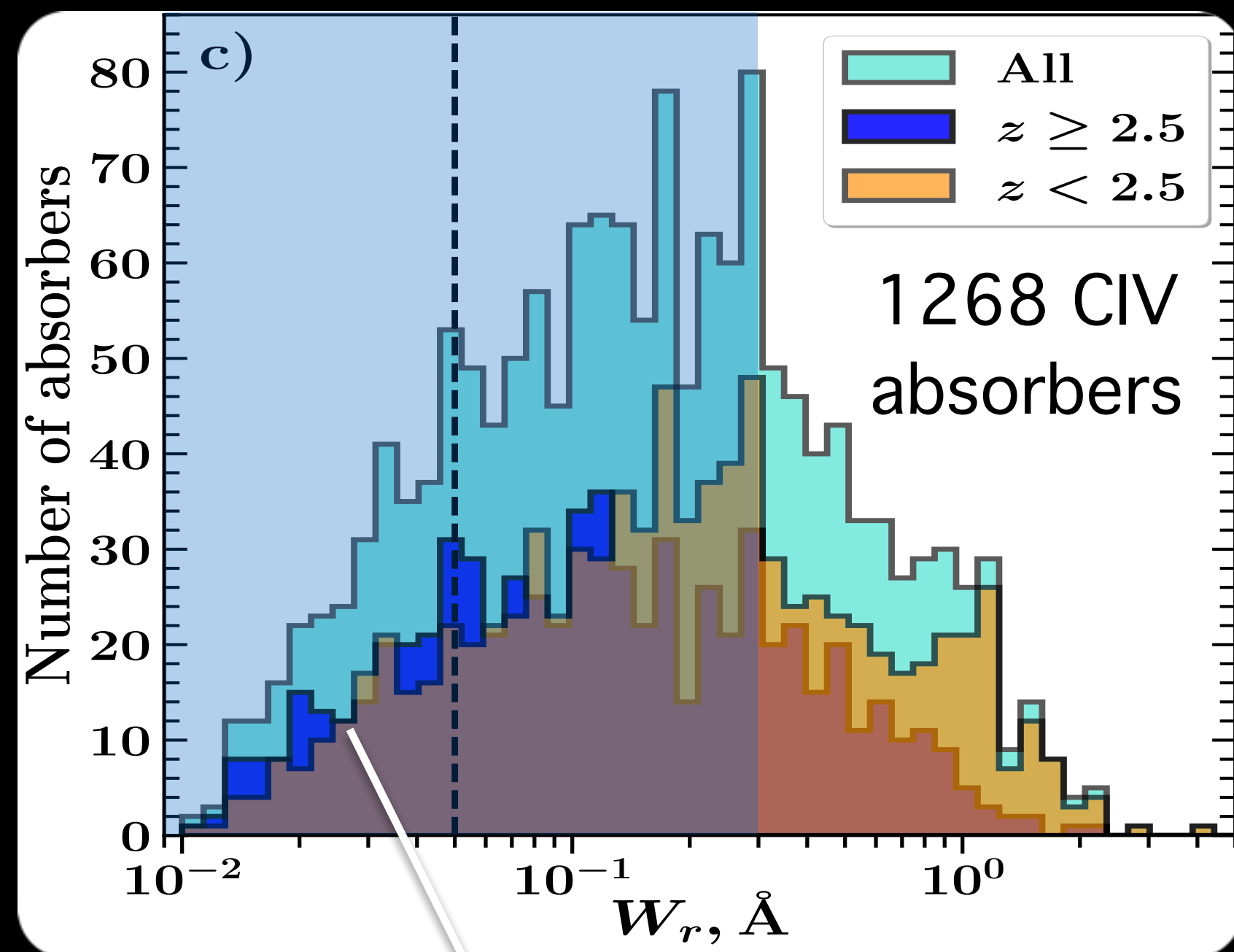


HIGH-RES SURVEY FOR CIV 1548, 1550

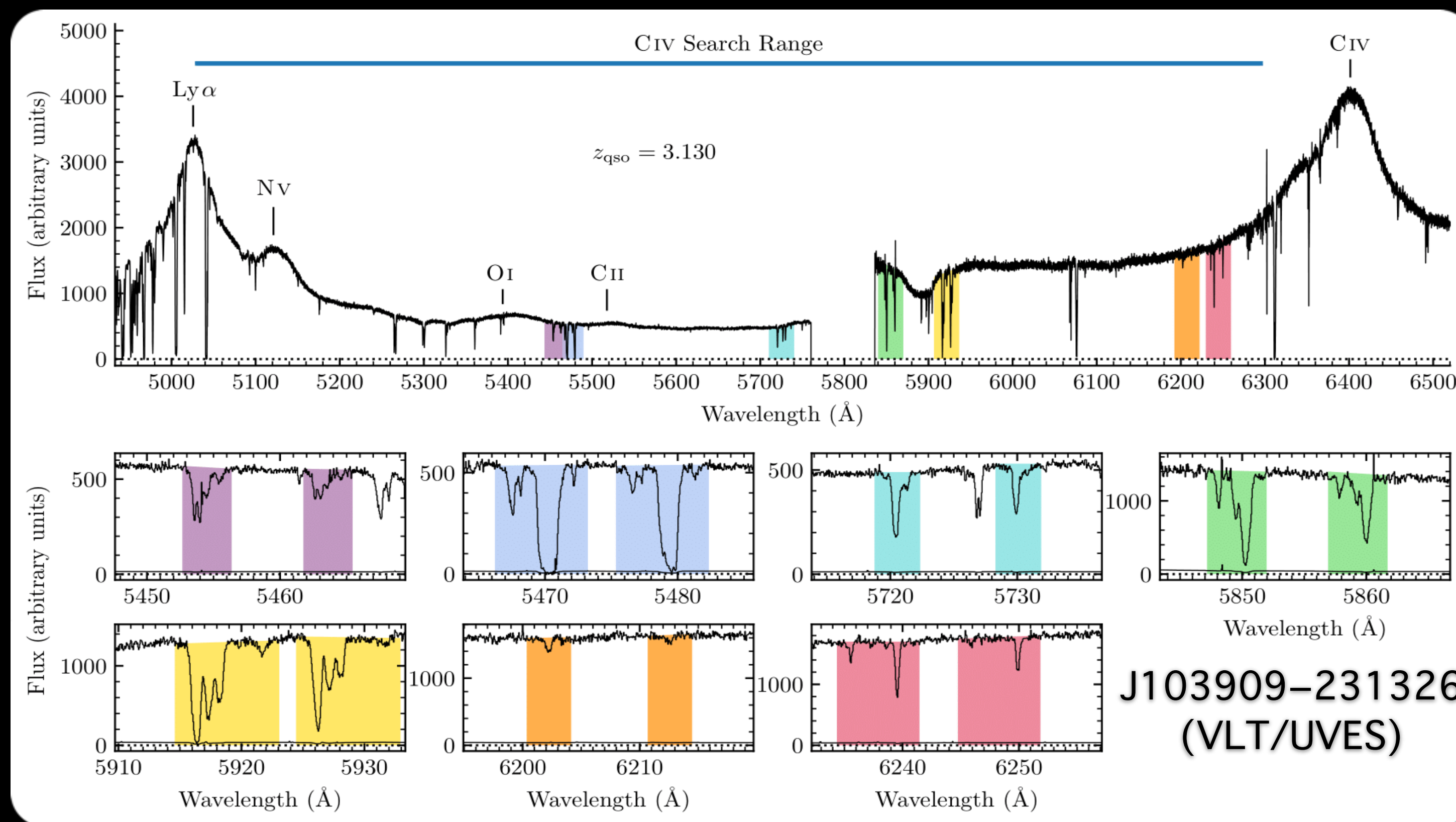


369 QSO spectra ($R \sim 45000$) from
Keck/HIRES (Vogt et al., 1994)
VLT/UVES (Dekker et al., 2000)

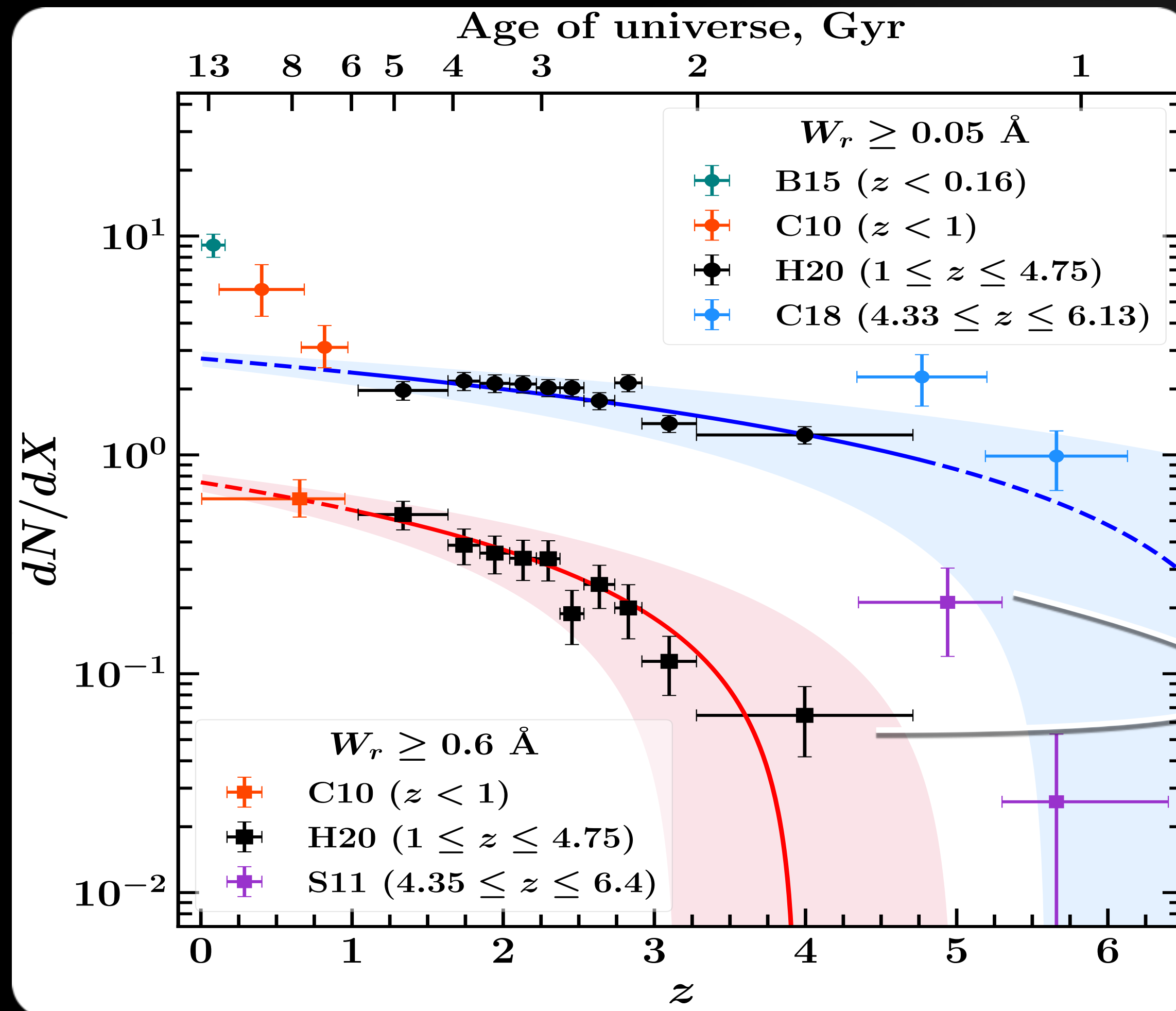
Hasan et al., 2020



EW < 0.3 Å Not well characterized



WHAT IS THE COSMIC INCIDENCE OF CIV?



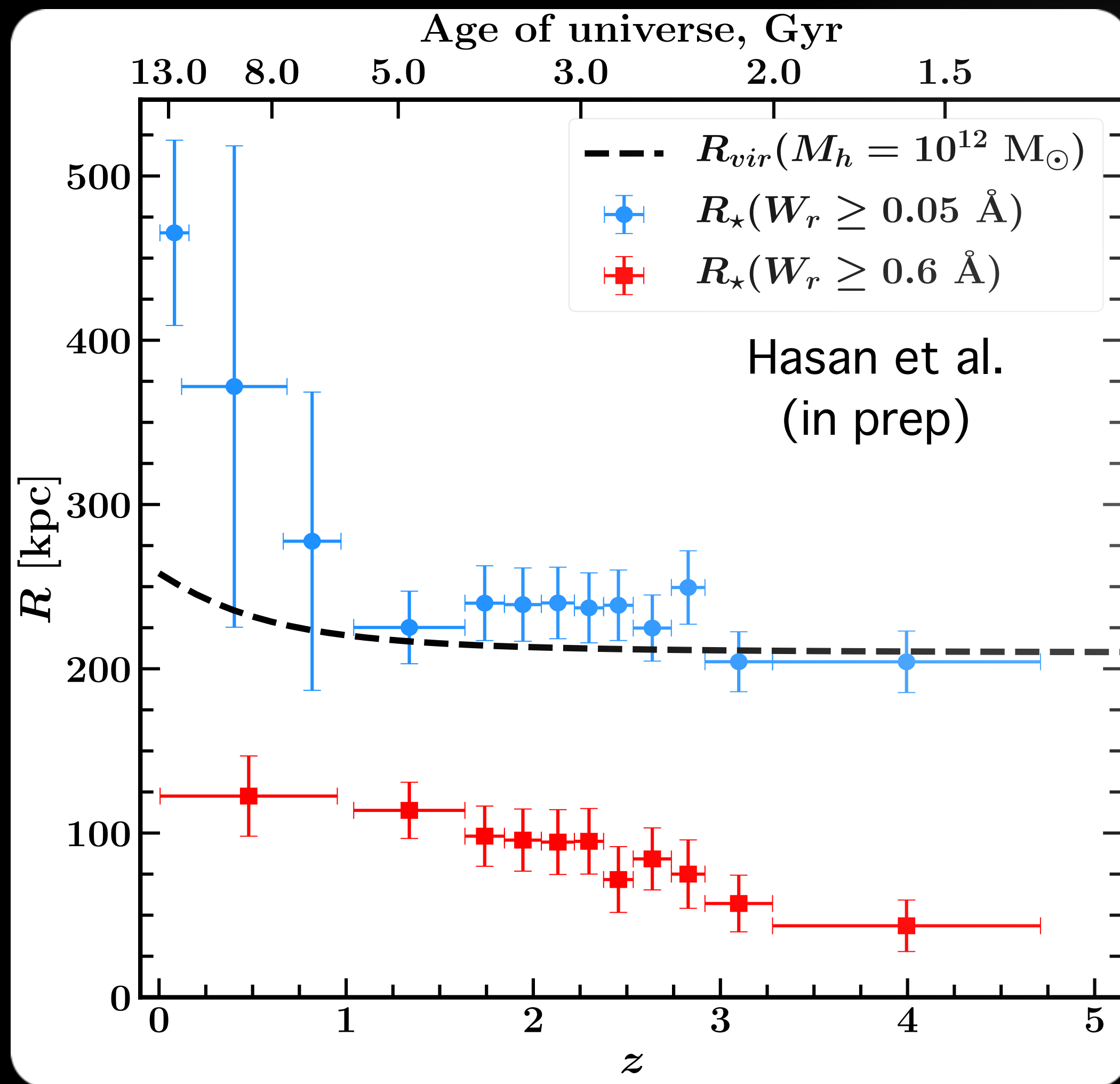
~10x increase in incidence of $EW > 0.05 \text{ Å}$ and $EW > 0.6 \text{ Å}$ CIV over ~13 Gyr

Rise in CIV due to increased metal enrichment and harder ionizing background with time

CIV evolution Does NOT trace star formation rate density (Madau & Dickinson, 2014)

model of linear decrease in dN/dX with redshift

WHERE DOES CIV LIVE?



$$\frac{dN}{dX}(z) = \frac{c}{H_0} n(z) \sigma(z)$$

$R_*(dN/dX, z)$

Characteristic absorption radius of CIV
around L^* galaxies

$R^* \geq$ virial radius at lower redshift

Lots of weak CIV may reside in the IGM!



PROJECT CHIMERA: DESIGN



Cosmic **H**istory In **M**etal **E**nriched **R**edshifted **A**bsorption

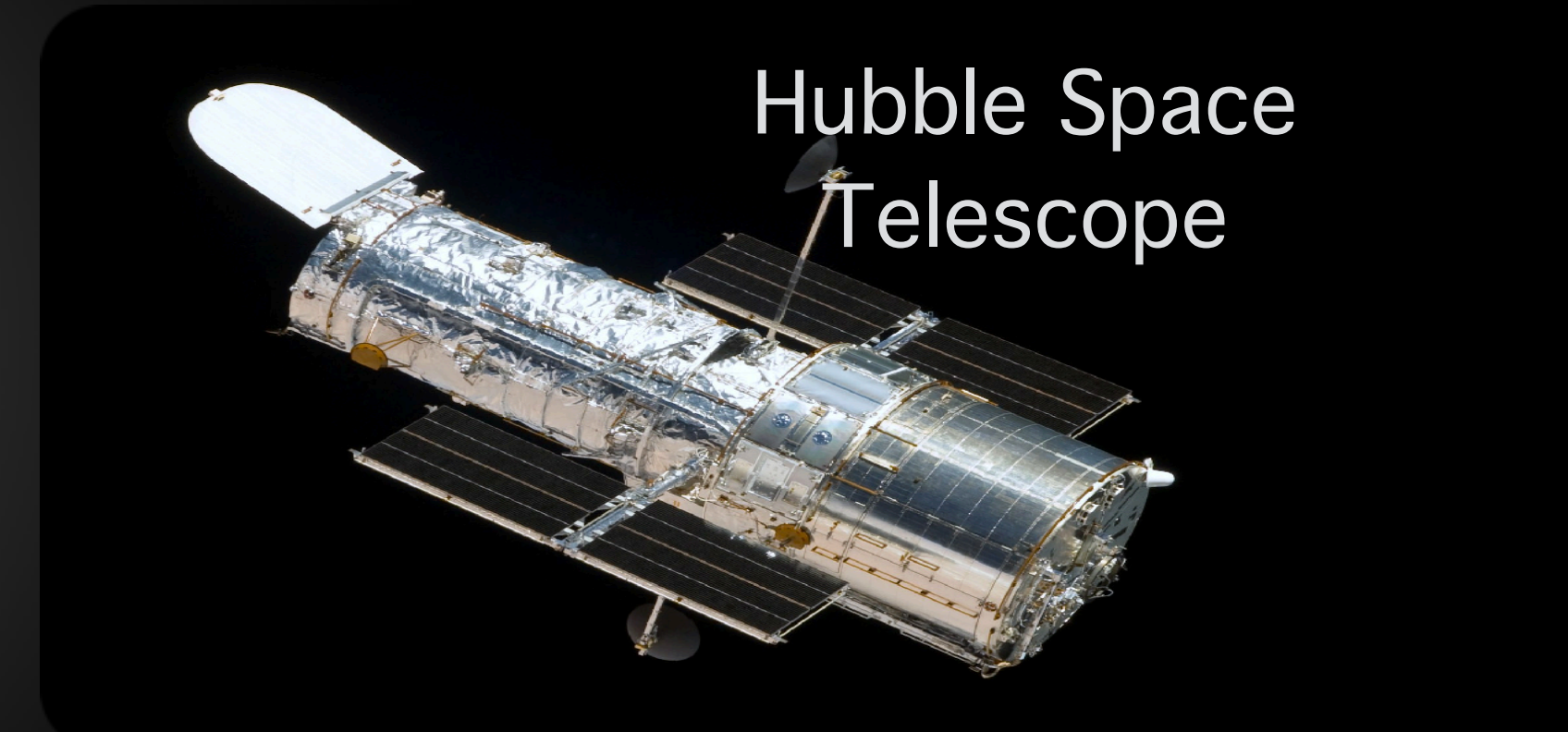
1. Assemble definitive high-res database of ~ 1000 quasars: including KODIAQ (O'Meara et al., 2015, 2017), UVES SQUAD (Murphy et al., 2019), HST Science Legacy Archive (Peeples et al., 2017)



W.M. Keck Observatory (Hawaii)



ESO Very Large Telescopes
(Chile)



Hubble Space
Telescope

2. Find hydrogen and metal absorbers across cosmic time and analyze their absorption properties (e.g., Churchill et al., 2020; Hasan et al., 2020)
3. Perform novel cloud-by-cloud Multiphase Bayesian modeling to uncover ionization properties across cosmic time (Sameer et al., 2020)



PROJECT CHIMERA: DECODING THE COSMIC ERAS

How did the chemistry, kinematics, and ionization conditions in galaxy ecosystems change across the cosmic eras?

Cosmic Afternoon ($z < 1.5$)

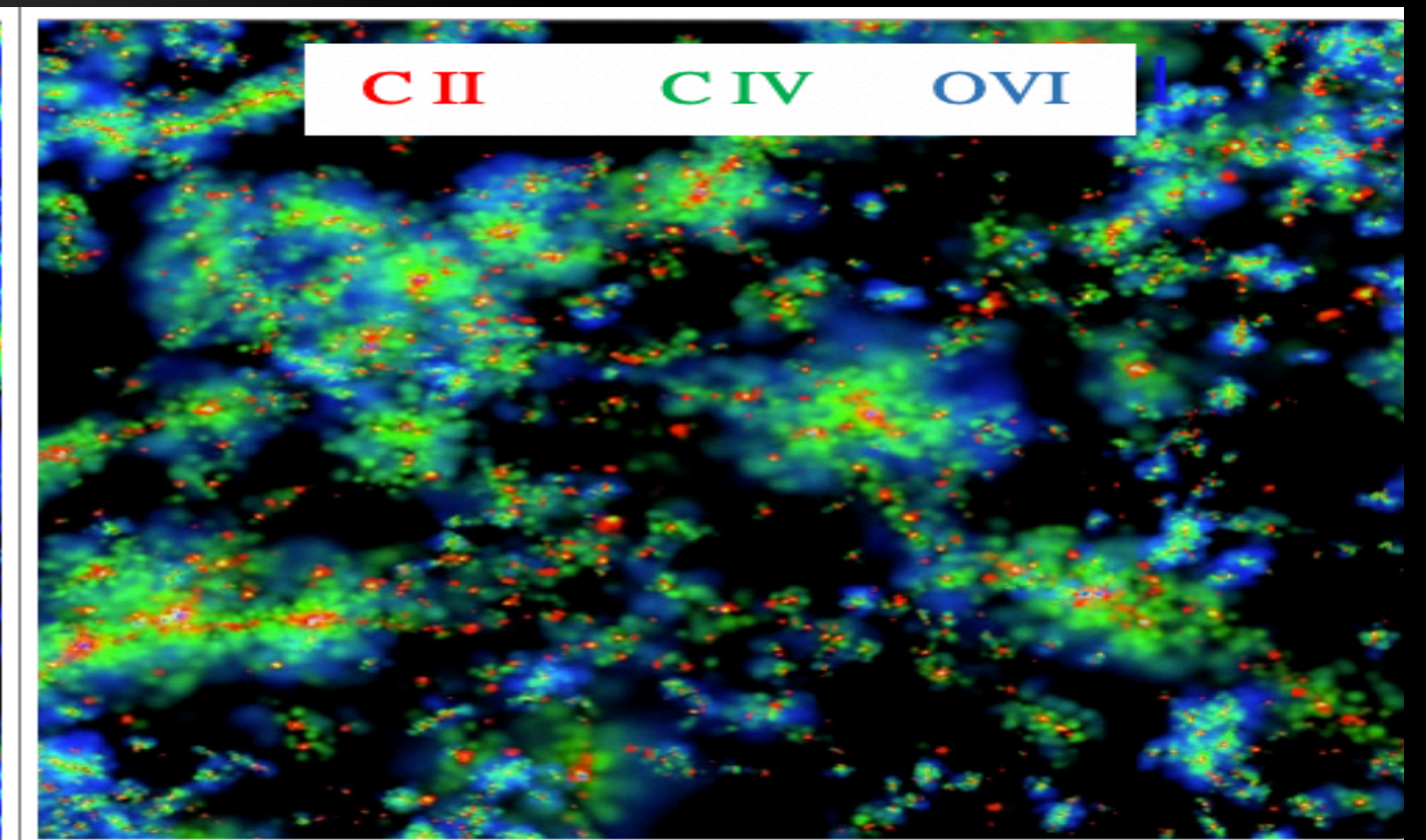
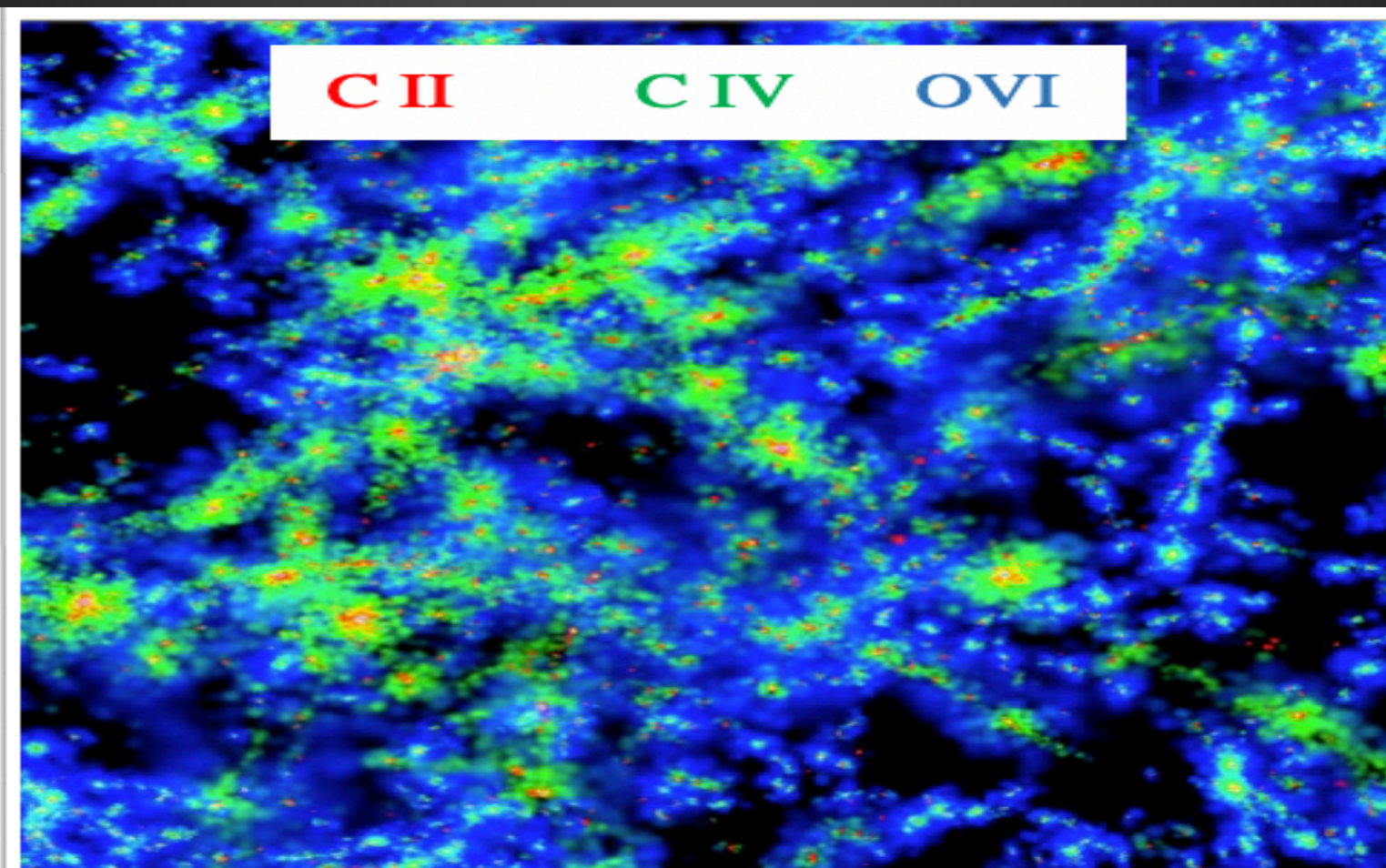
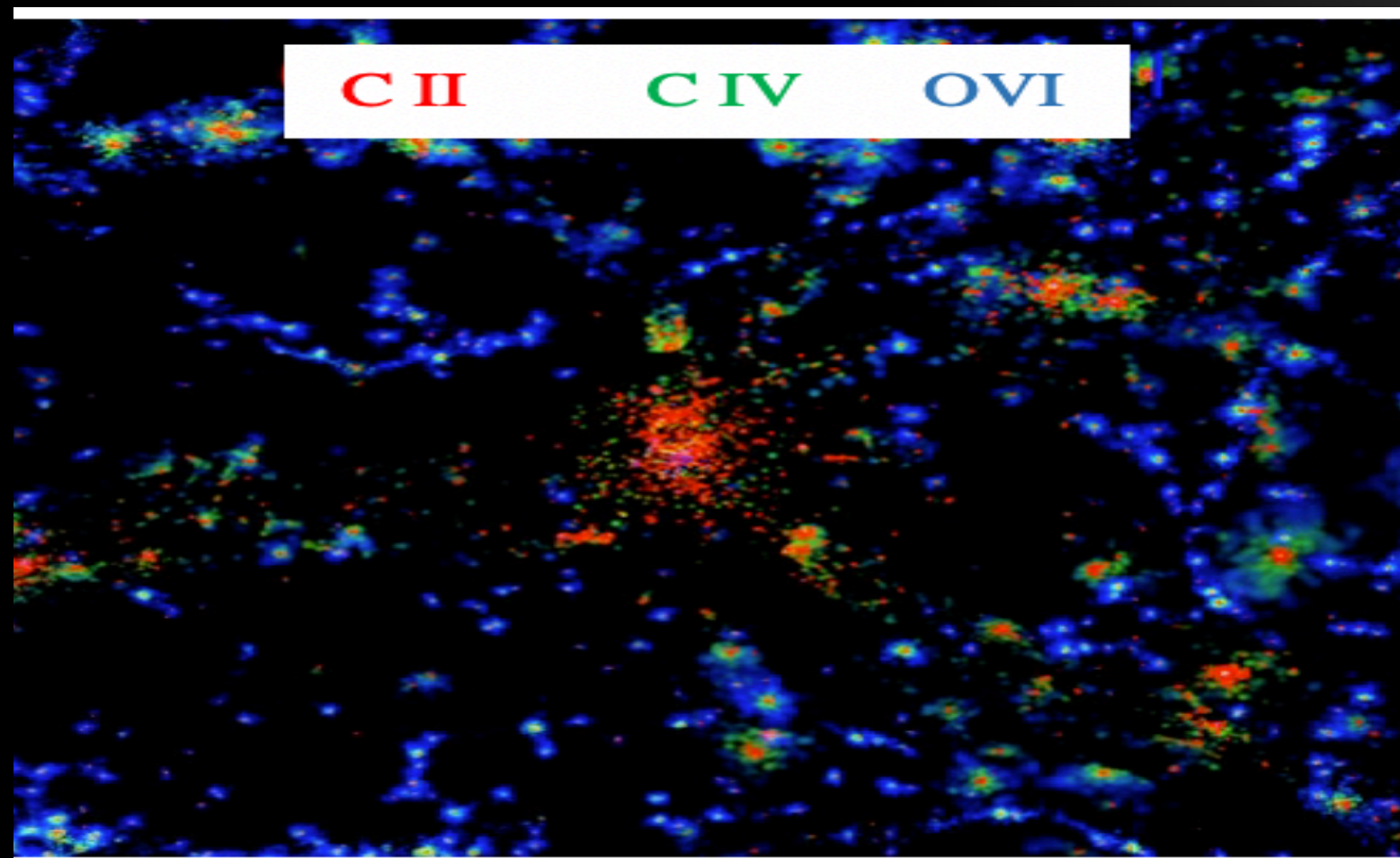
Decline in star formation + BH accretion

Cosmic High Noon ($1.5 < z < 3$)

Peak in star formation + BH accretion

Cosmic Late Morning ($3 < z < 5$)

First QSOs, ionized metals



Credits: B. Oppenheimer



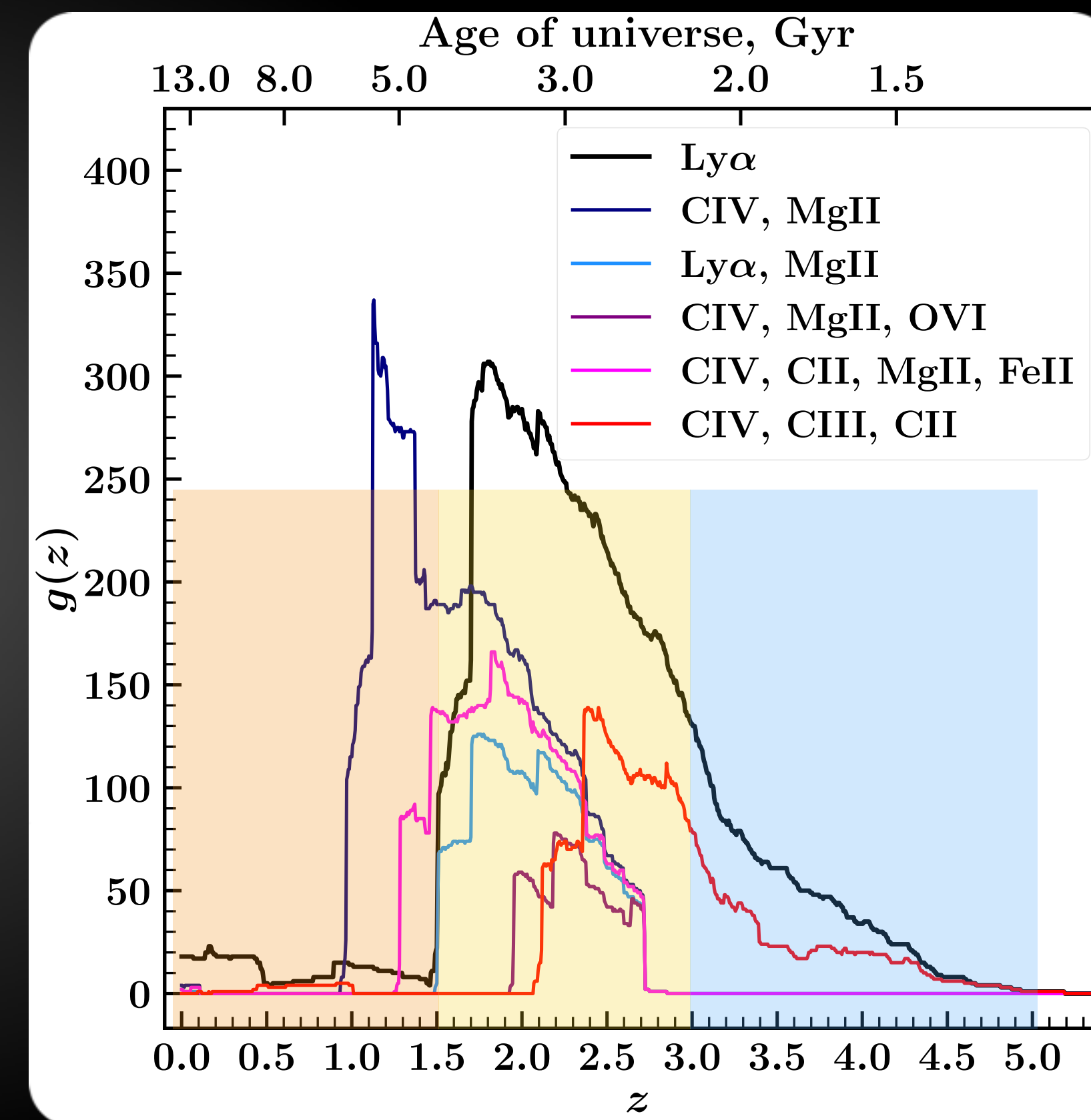
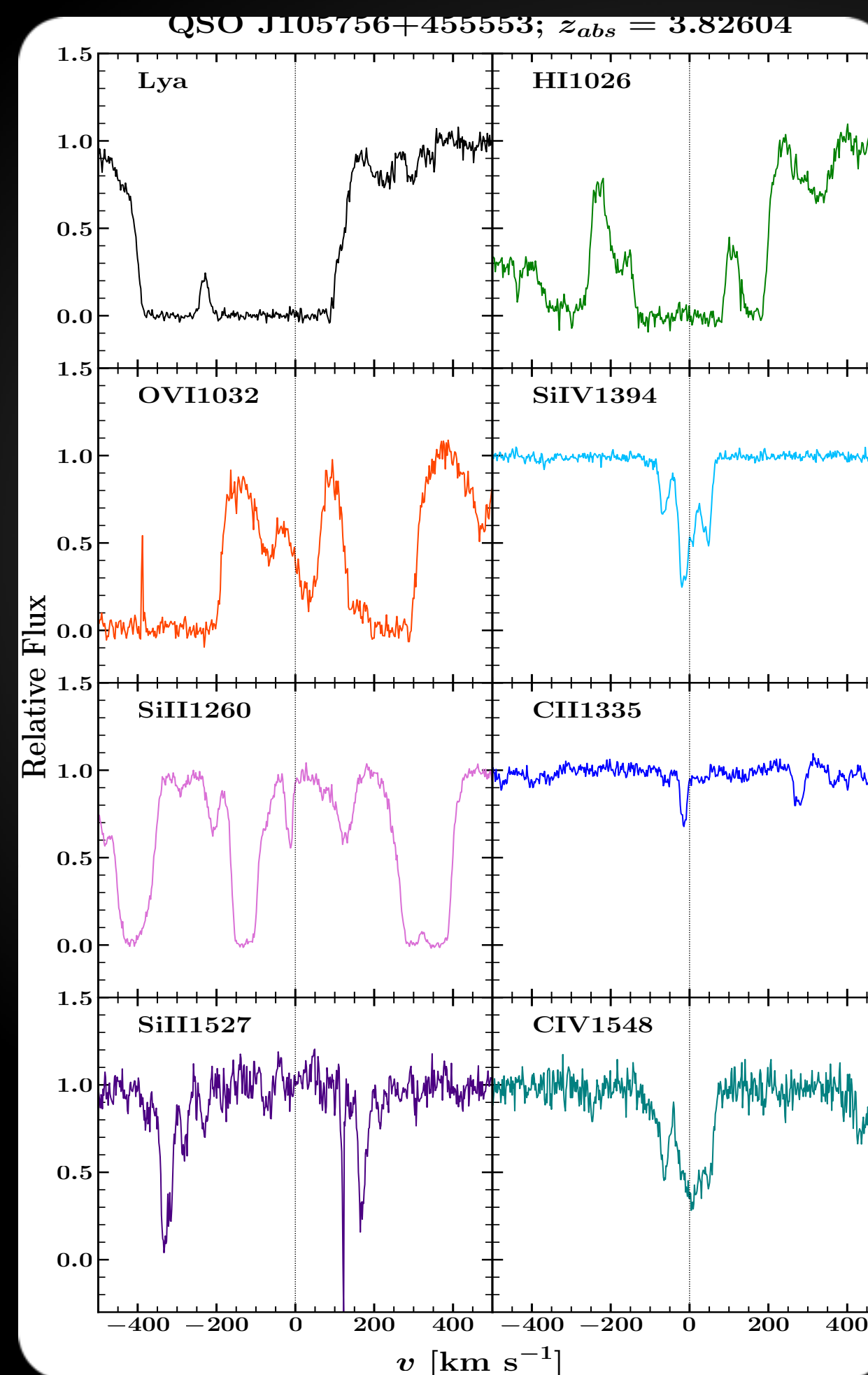
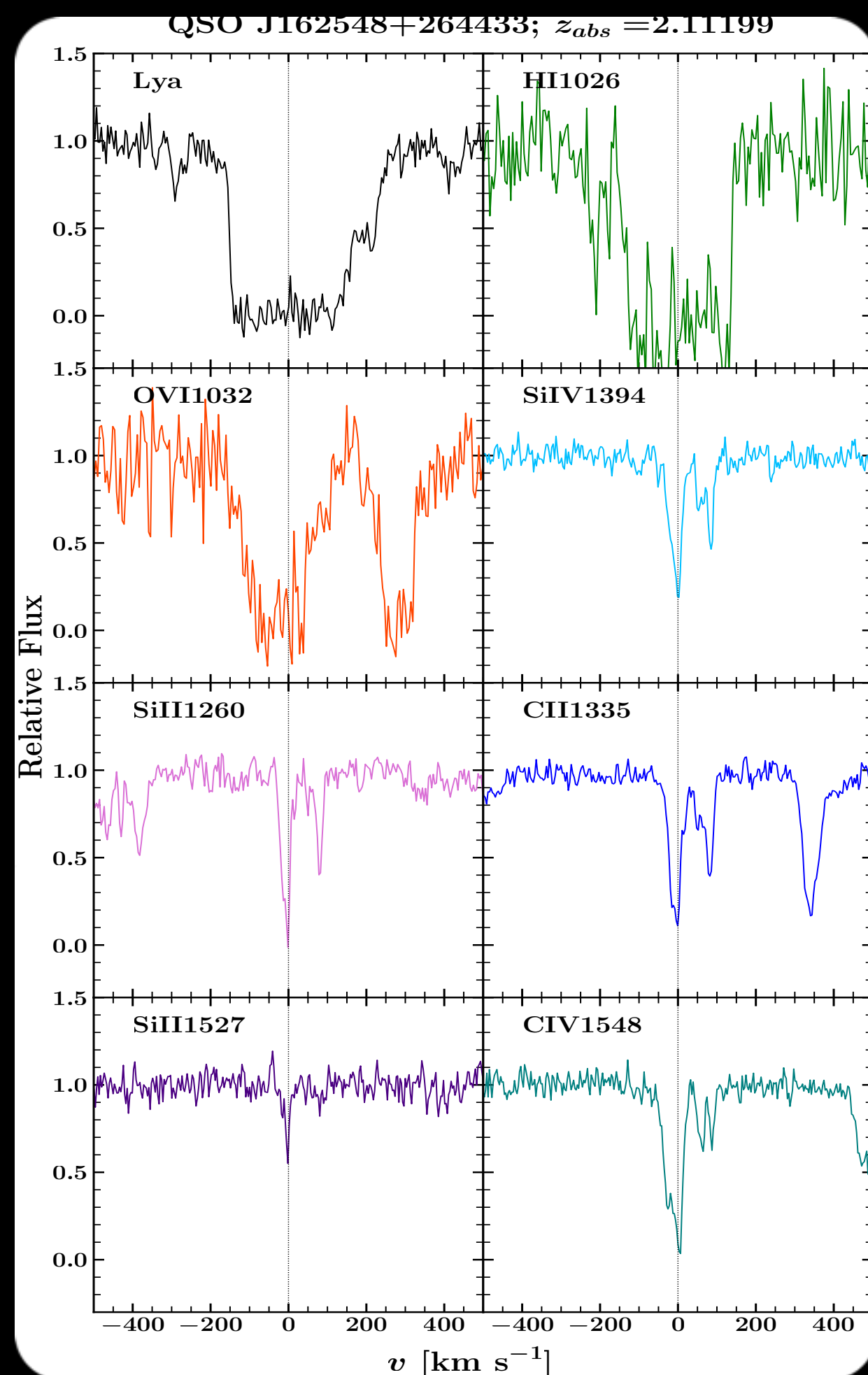
PROJECT CHIMERA: POTENTIAL



High Noon

Late Morning

We have high redshift coverage



Afternoon High Noon Late Morning



SUMMARY



High-res survey of CIV quasar absorption lines using Keck and VLT reveals huge population of weak ($EW < 0.3 \text{ \AA}$) absorbers

Cosmic incidence of CIV increases ~ 1 dex in last ~ 13 Gyr, for both weak and strong CIV

Simulations produce too much weak CIV

Significant fraction of CIV could exist in the IGM

Project CHIMERA will help understand chemical, kinematic, ionization conditions across cosmic late morning, high noon and afternoon



REFERENCES



Churchill et al. 2020, arXiv:2008.08487 (ApJ, in press)

Cooksey et al. 2013, [2013ApJ...763...37C](#)

Dekker et al. 2000, [2000SPIE.4008..534D](#)

Finlator et al. 2018, [2018MNRAS.480.2628F](#)

Finlator et al. 2020, [2020MNRAS.493.3223F](#)

Hasan et al. 2020, arXiv:2007.11751 (ApJ, in press)

Madau & Dickinson 2014, [2014ARA&A..52..415M](#)

Murphy et al. 2019, [2019MNRAS.482.3458M](#)

O'Meara et al. 2015, [2015AJ....150..111O](#)

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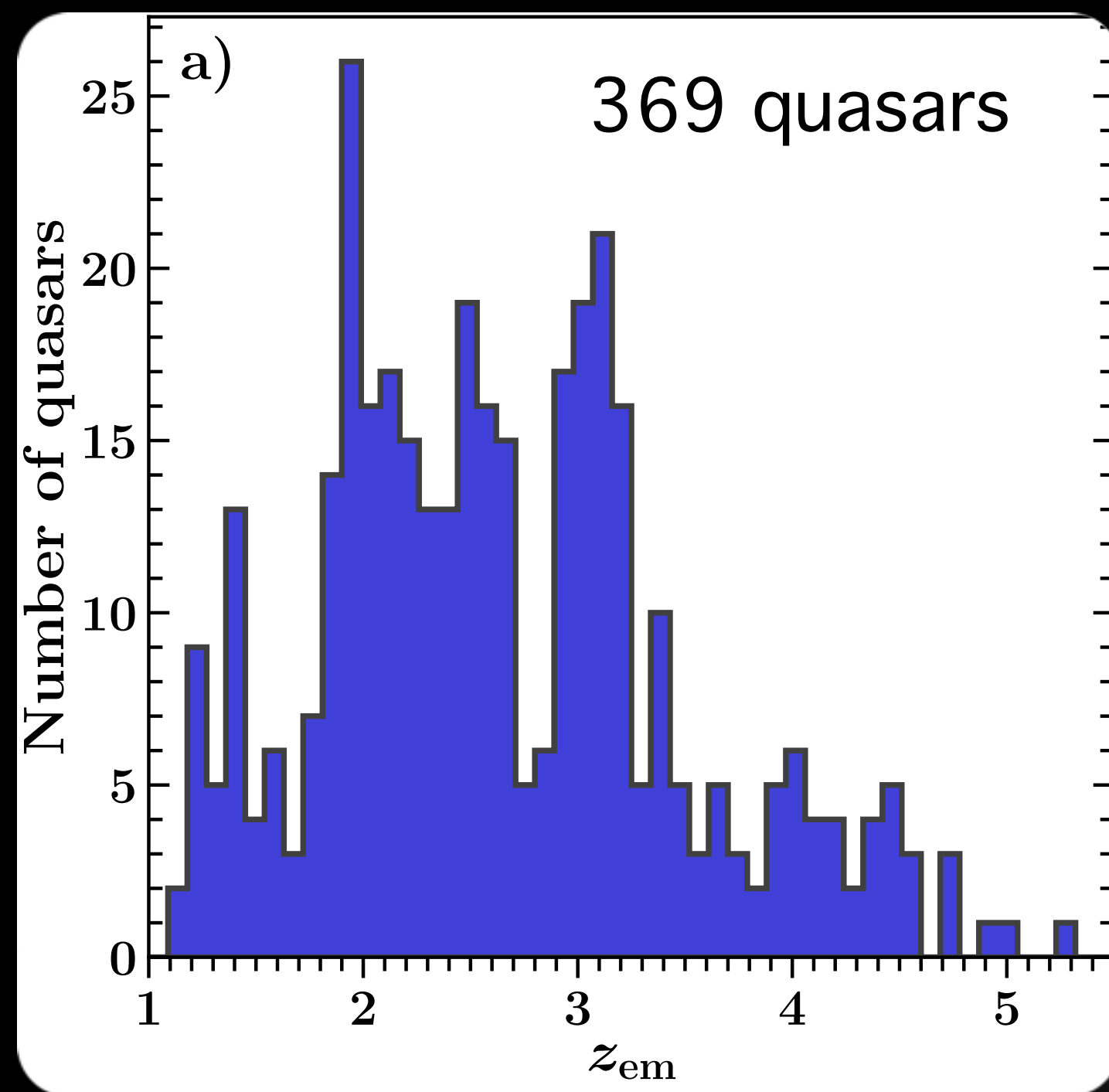
Peeples et al. 2017, [2017cos..rept....4P](#)

Sameer et al. 2020, submitted to MNRAS

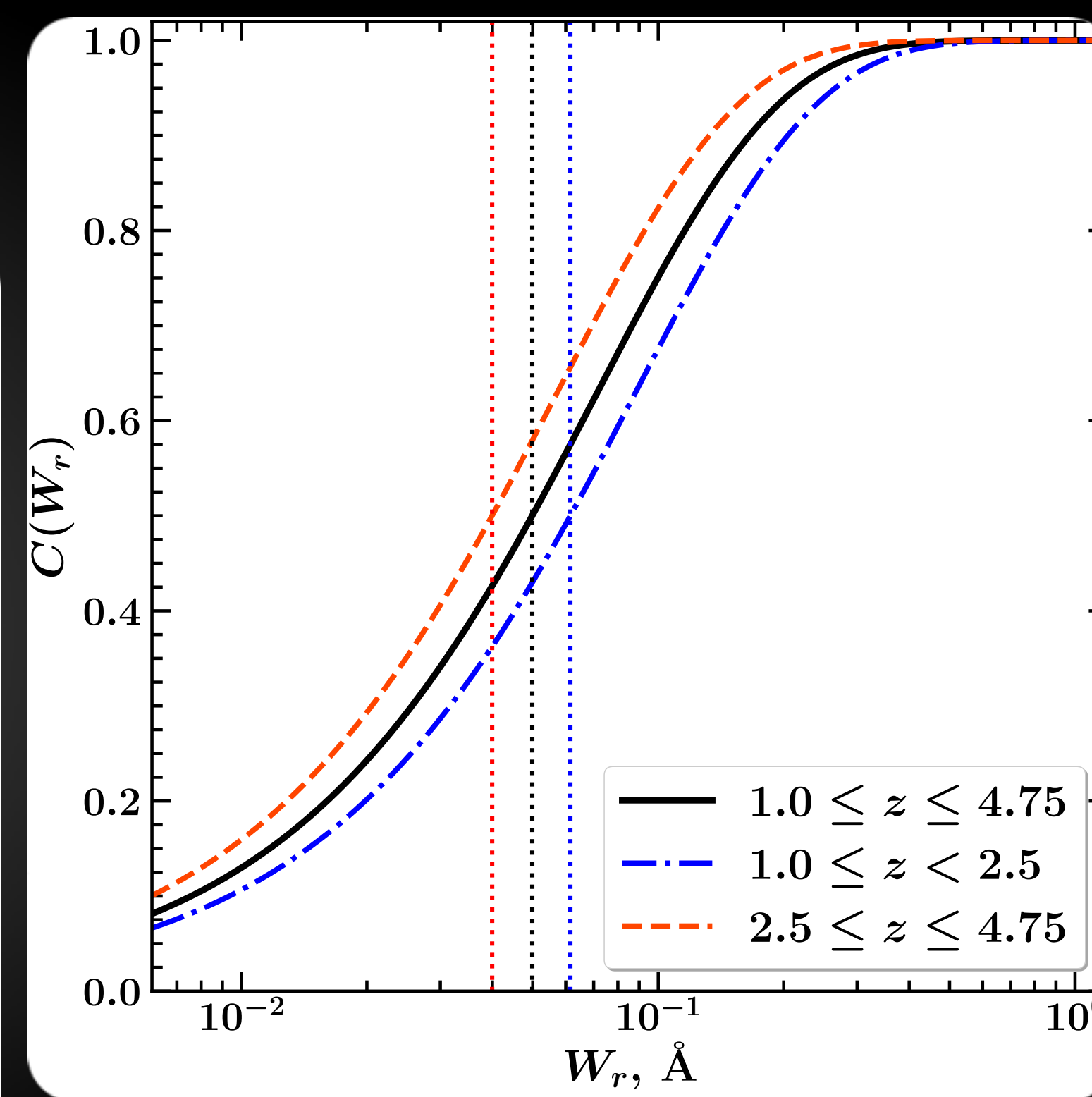
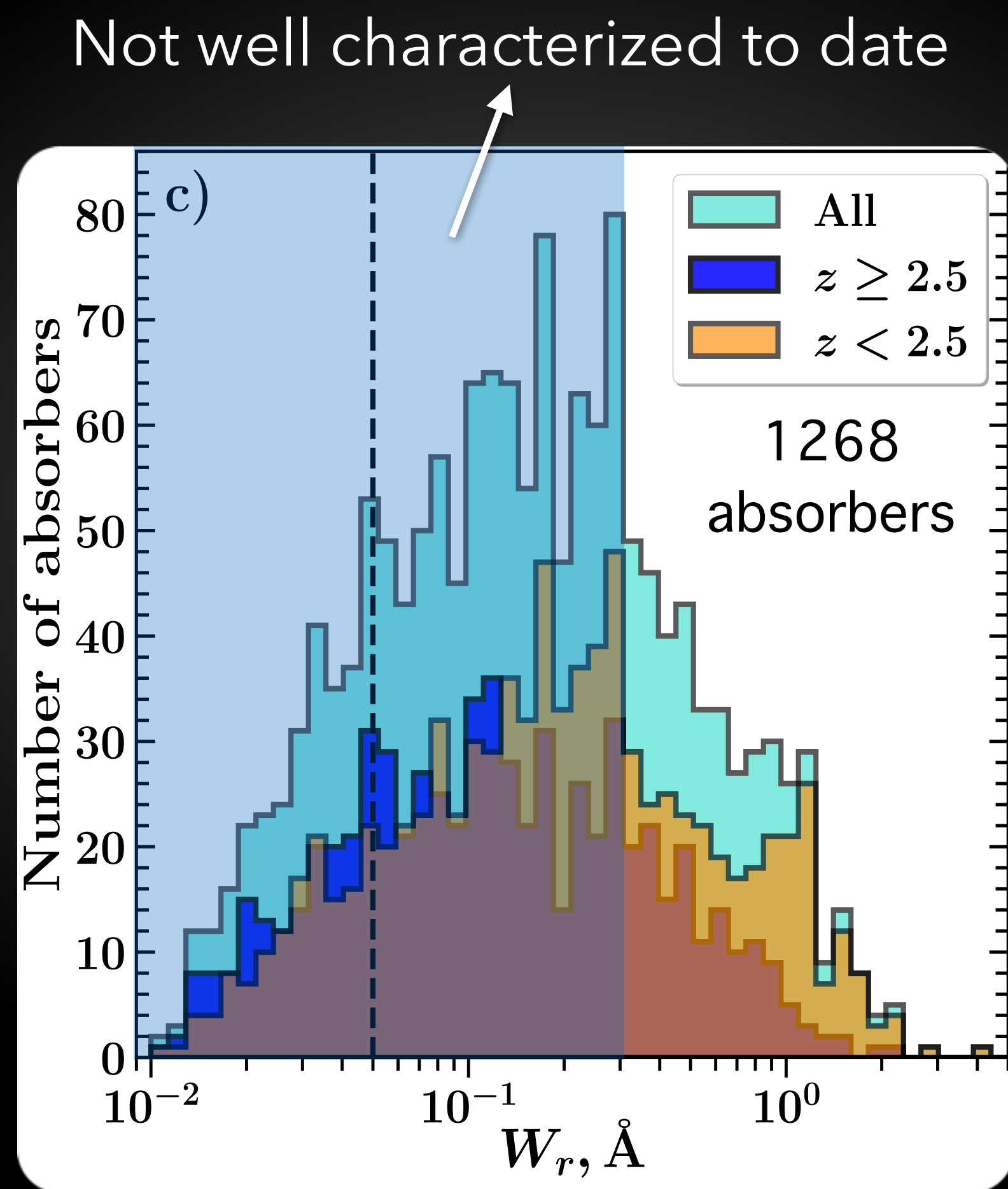
Tumlinson et al. 2017, [2017ARA&A..55..389T](#)

Vogt et al. 1994, [1994SPIE.2198..362V](#)

APP: HISTOGRAMS AND COMPLETENESS

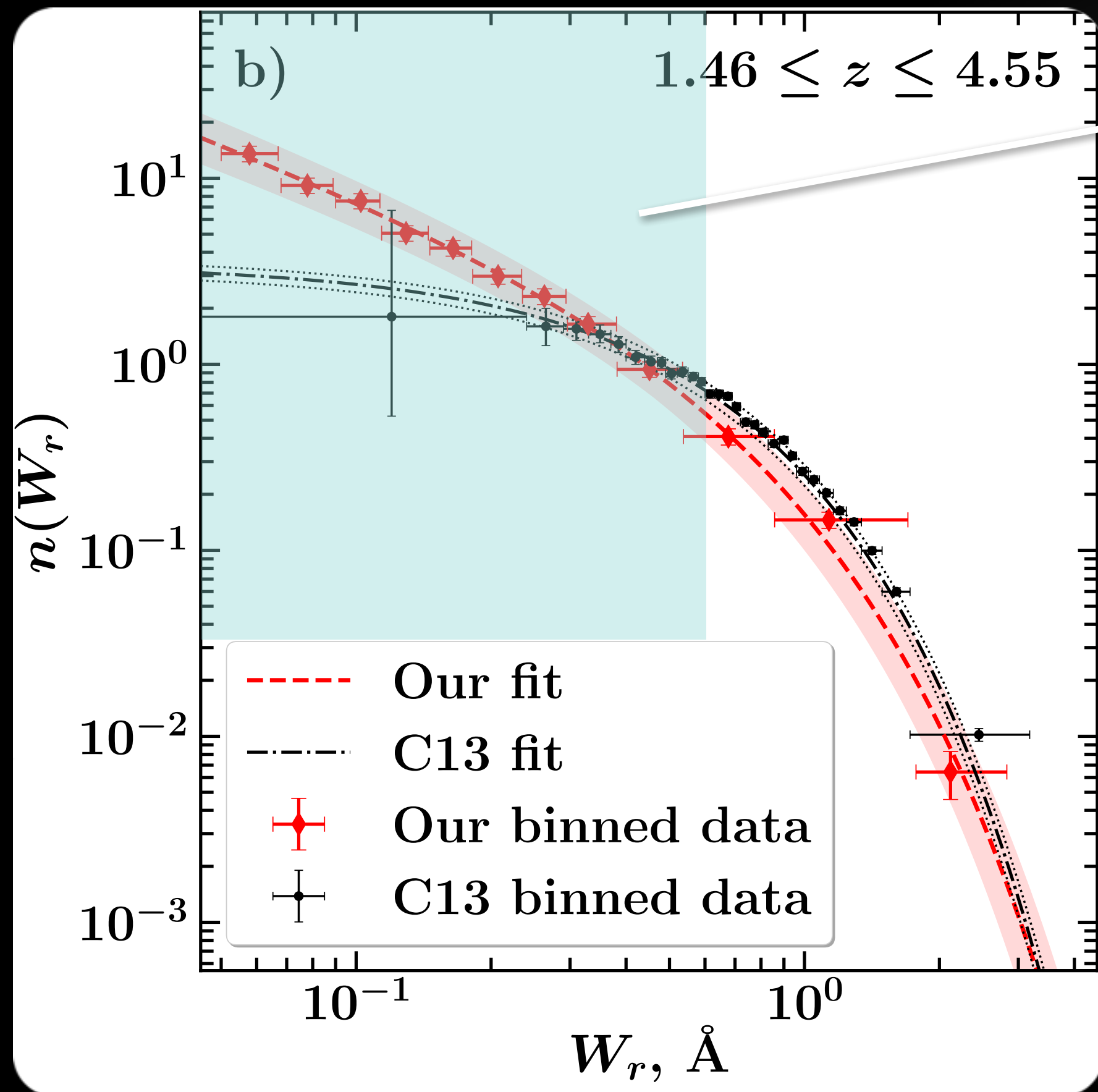


R~45000 spectra from
Keck/HIRES (Vogt et al., 1994)
VLT/UVES (Dekker et al., 2000)



50% complete at $EW \sim 0.05 \text{ Å}$

APP: CIV FREQUENCY DISTRIBUTION

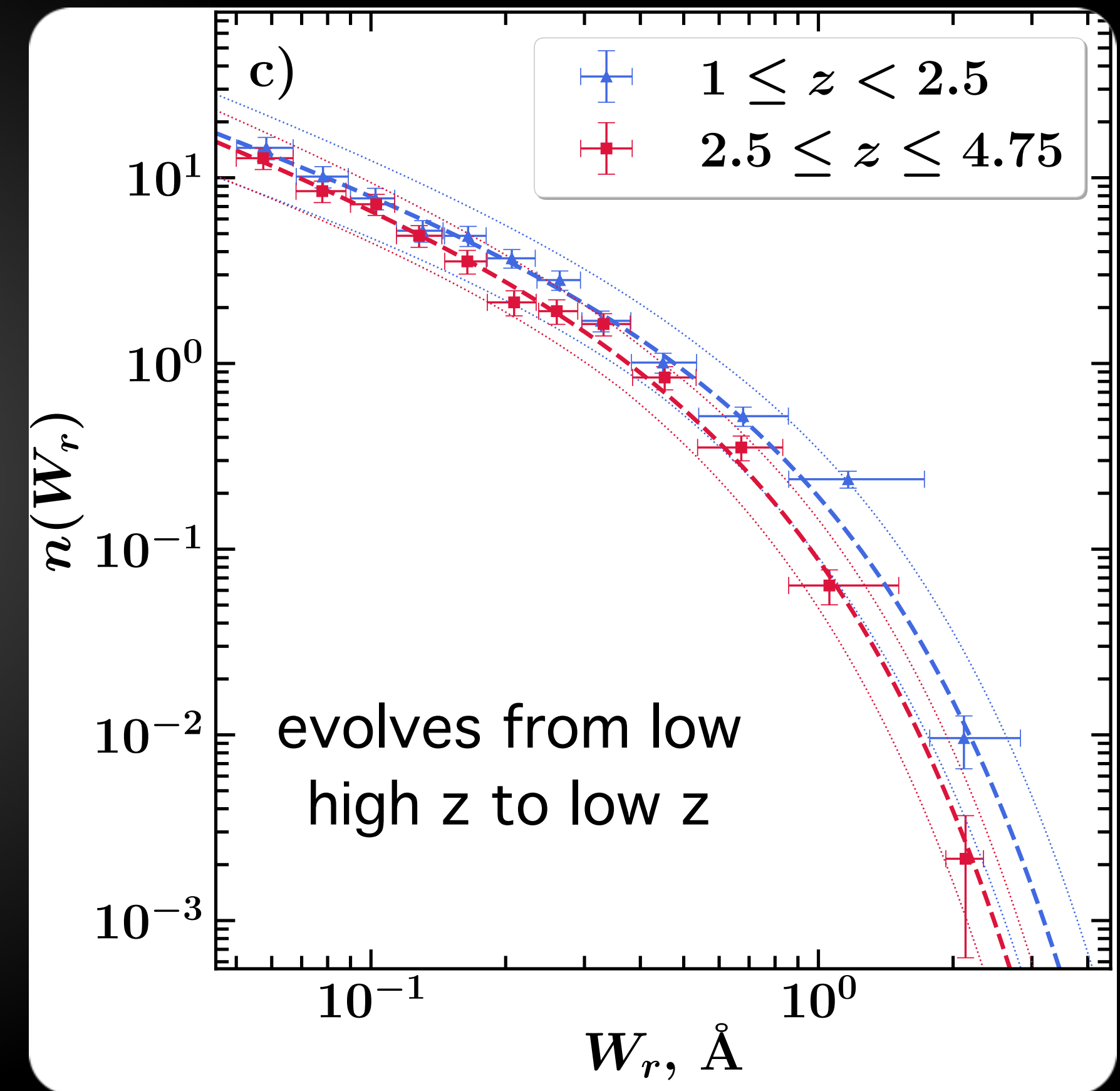


Cooksey et al., 2013
incomplete

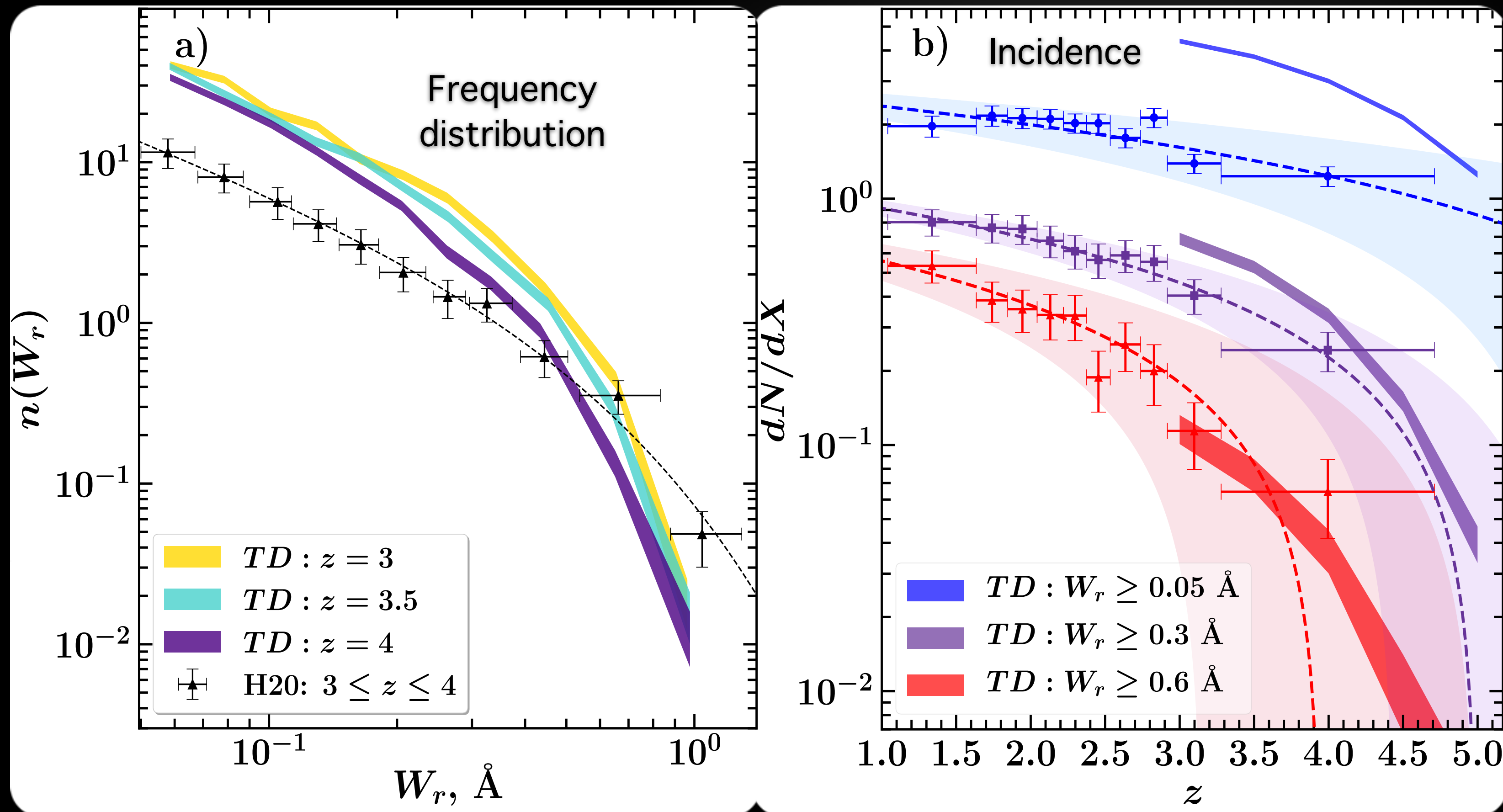
Schechter function

Lots of weak absorbers
($W < 0.3 \text{ Å}$)

Few strong absorbers
($W > 1 \text{ Å}$)



APP: OBSERVATIONS VS. SIMULATIONS



Technicolor Dawn (Finlator et al., 2018) overproduces weak absorbers at $z=3-5$

Better match with stronger absorbers

At $z > 5$, *TD* underproduces strong CIV (Finlator et al., 2020)

Need to refine feedback model, ionizing background, etc.