Using Quasar Absorption Lines to Probe Cold Gas at High-z Galaxies

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MOTIVATION

- What are the gas properties to form stars at high redsfhit?
- How to trace this kind of gas efficiently?

WHAT IS A QUASAR

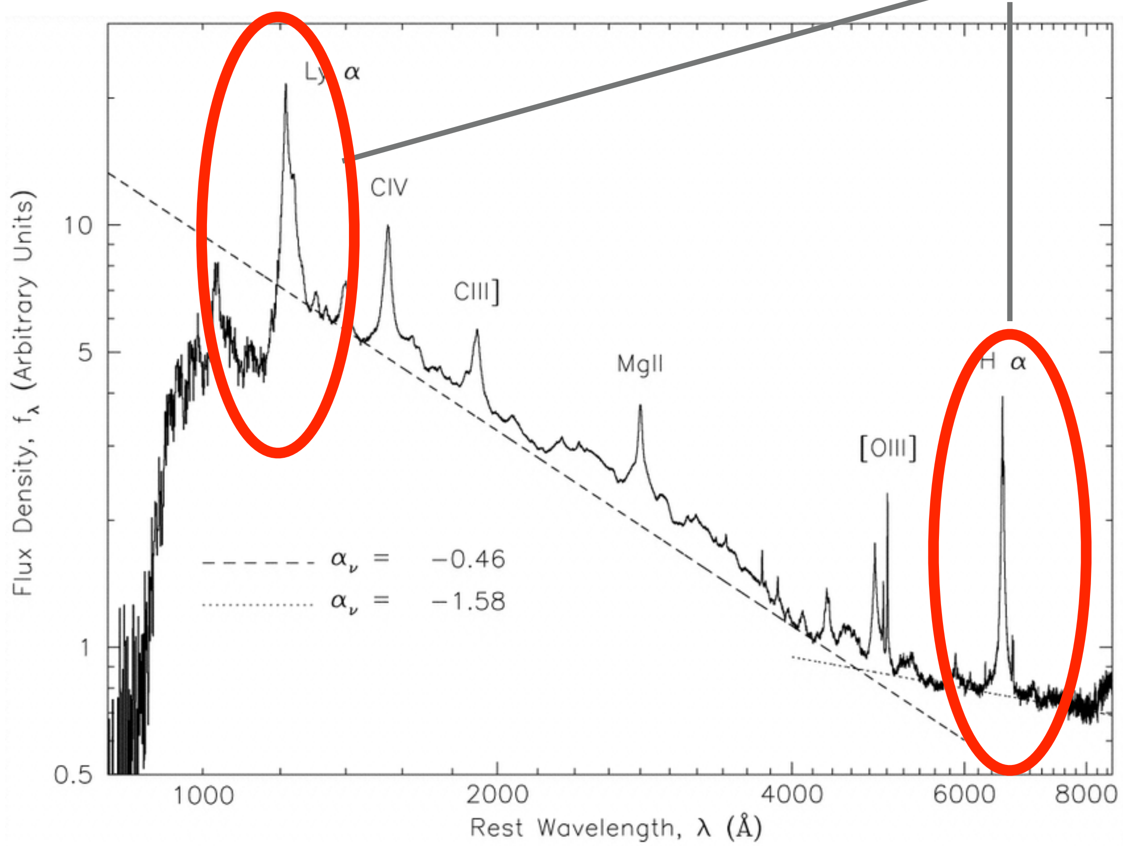
- **VERY BRIGHT** point source
- **Structure:**

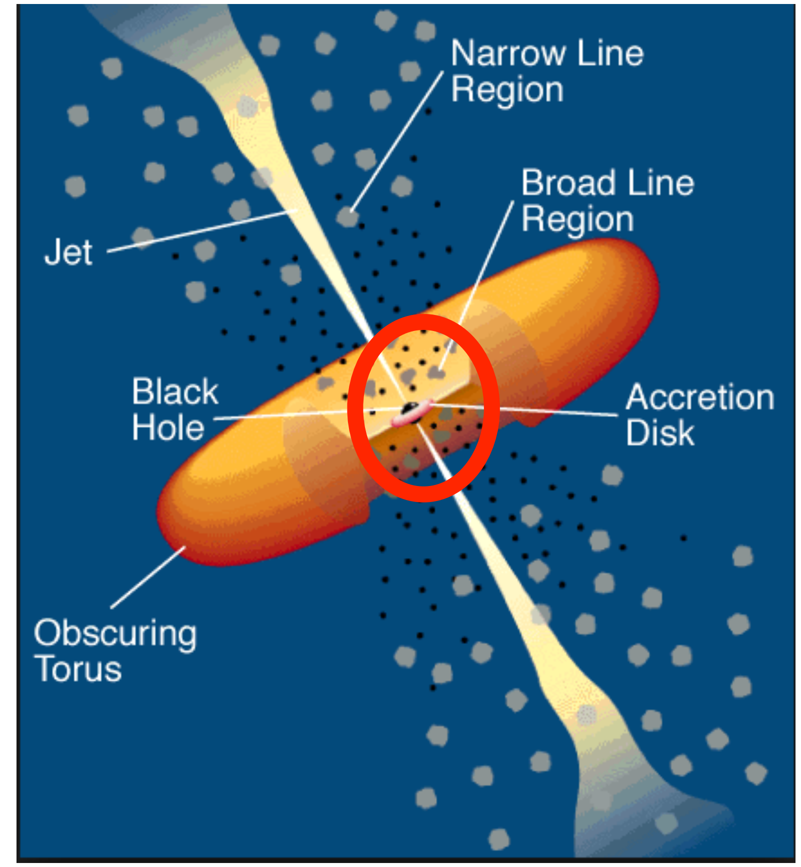
- SMBH and its accretion disk

- Broad-line-region ~1 pc

- Narrow-line-region >10 pc

Broad emission lines





credit: NASA

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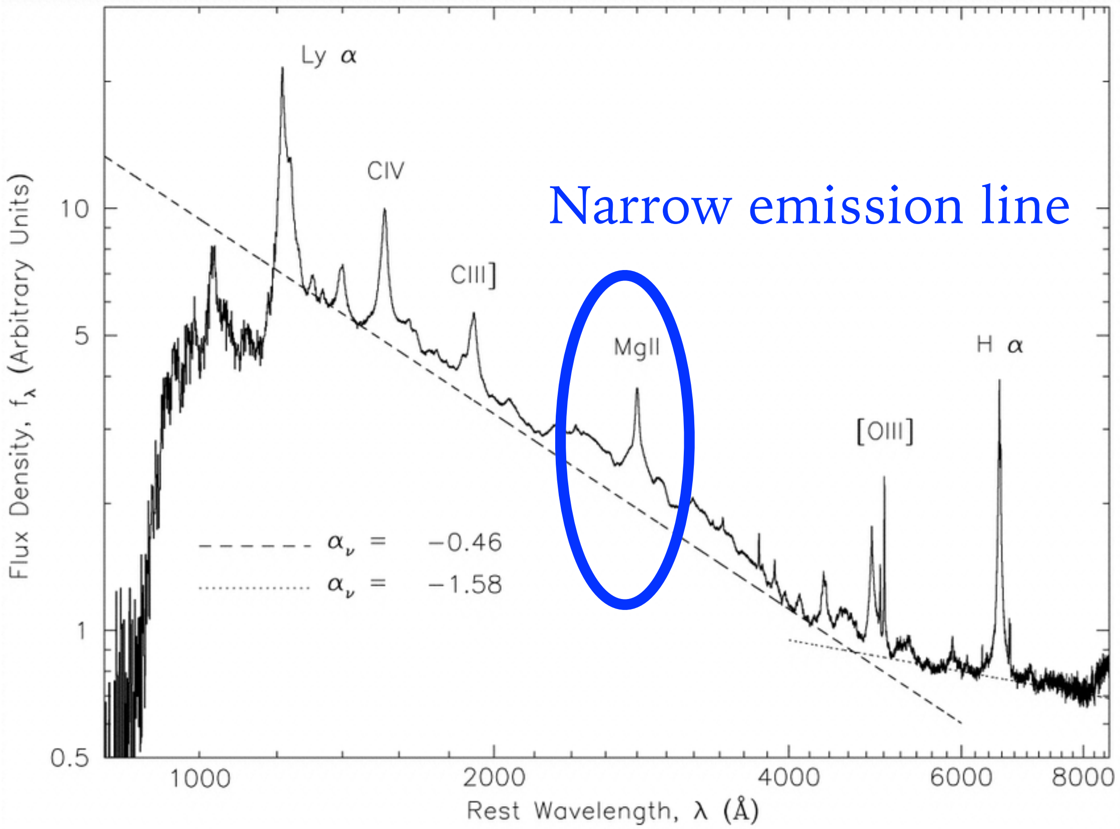
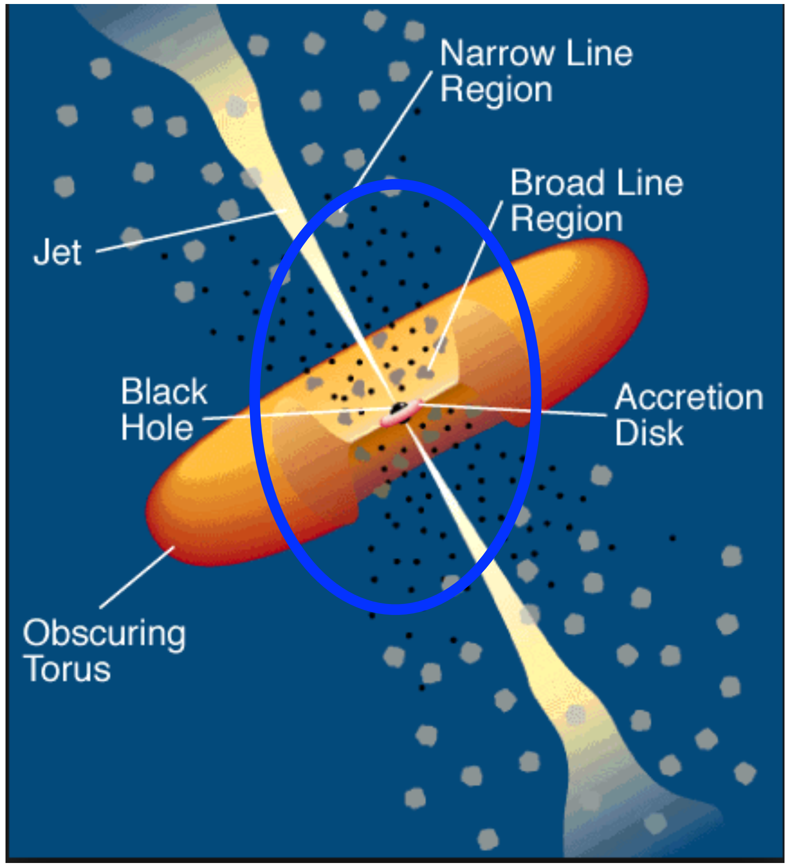


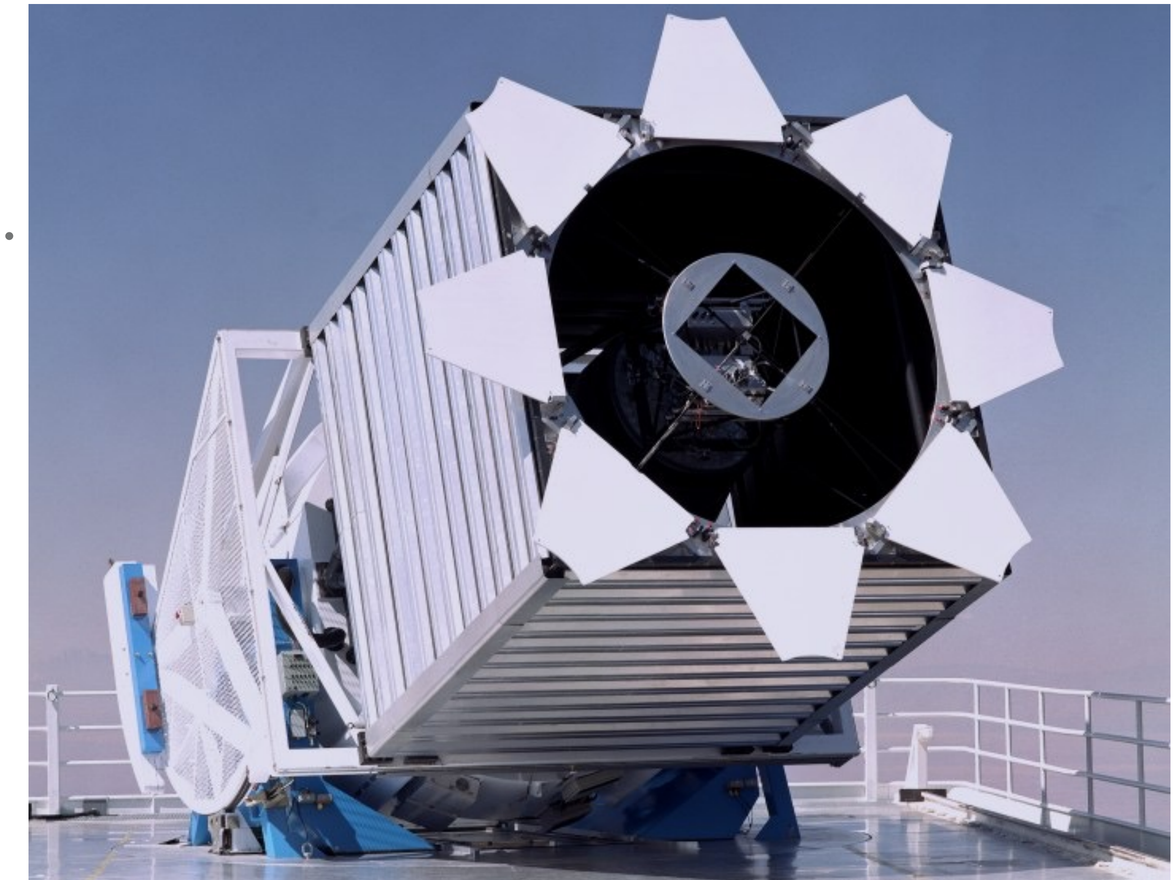


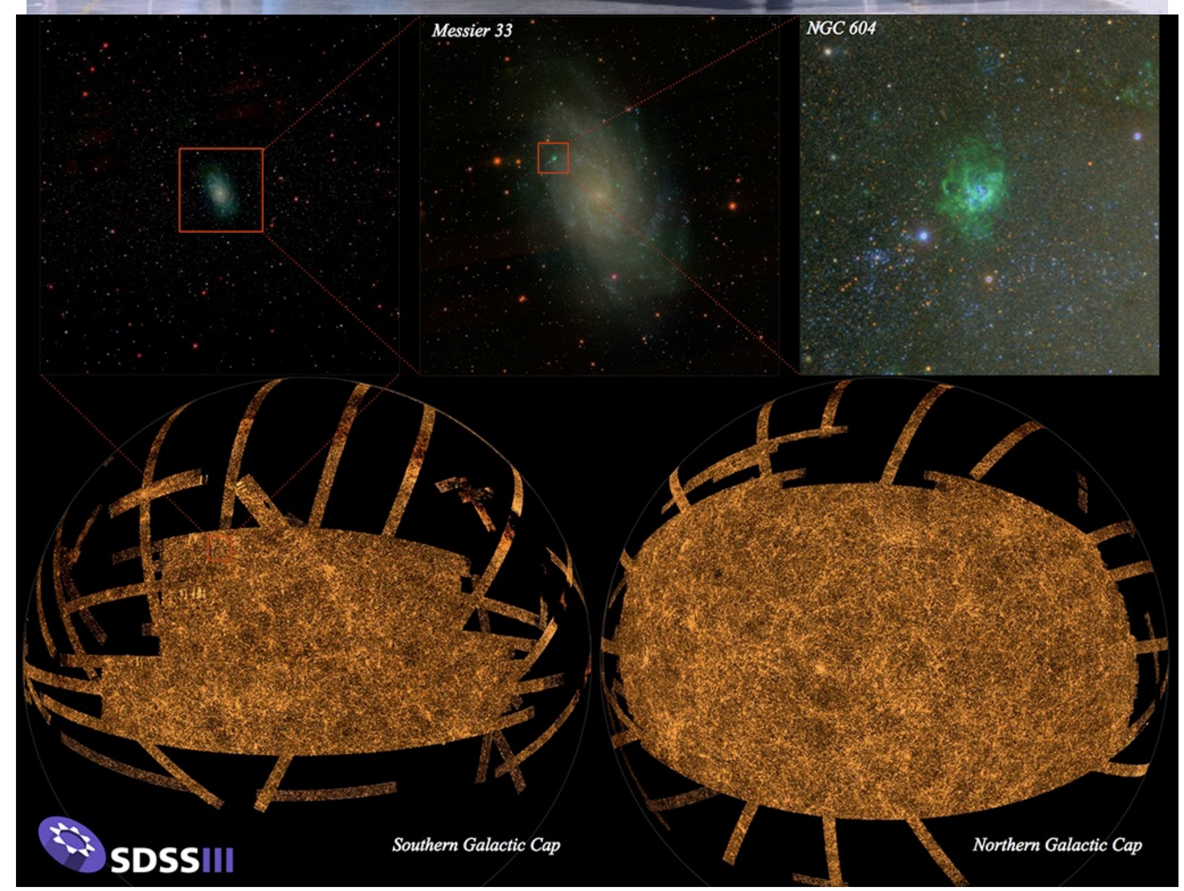
credit: NASA

DETECTION

➤ **Sloan Digital Sky Survey**

- 2.5-m telescope at Apache Point Observatory in south east New Mexico.
- The survey starts in 2000.
- Deep color images covers 1/3 sky
- Spectra of more than 3000,000 astronomical objects





www.sdss.org

DETECTION

- Sloan Digital Sky Survey for quasars survey
- Baryon Oscillation Spectroscopic Survey (BOSS)

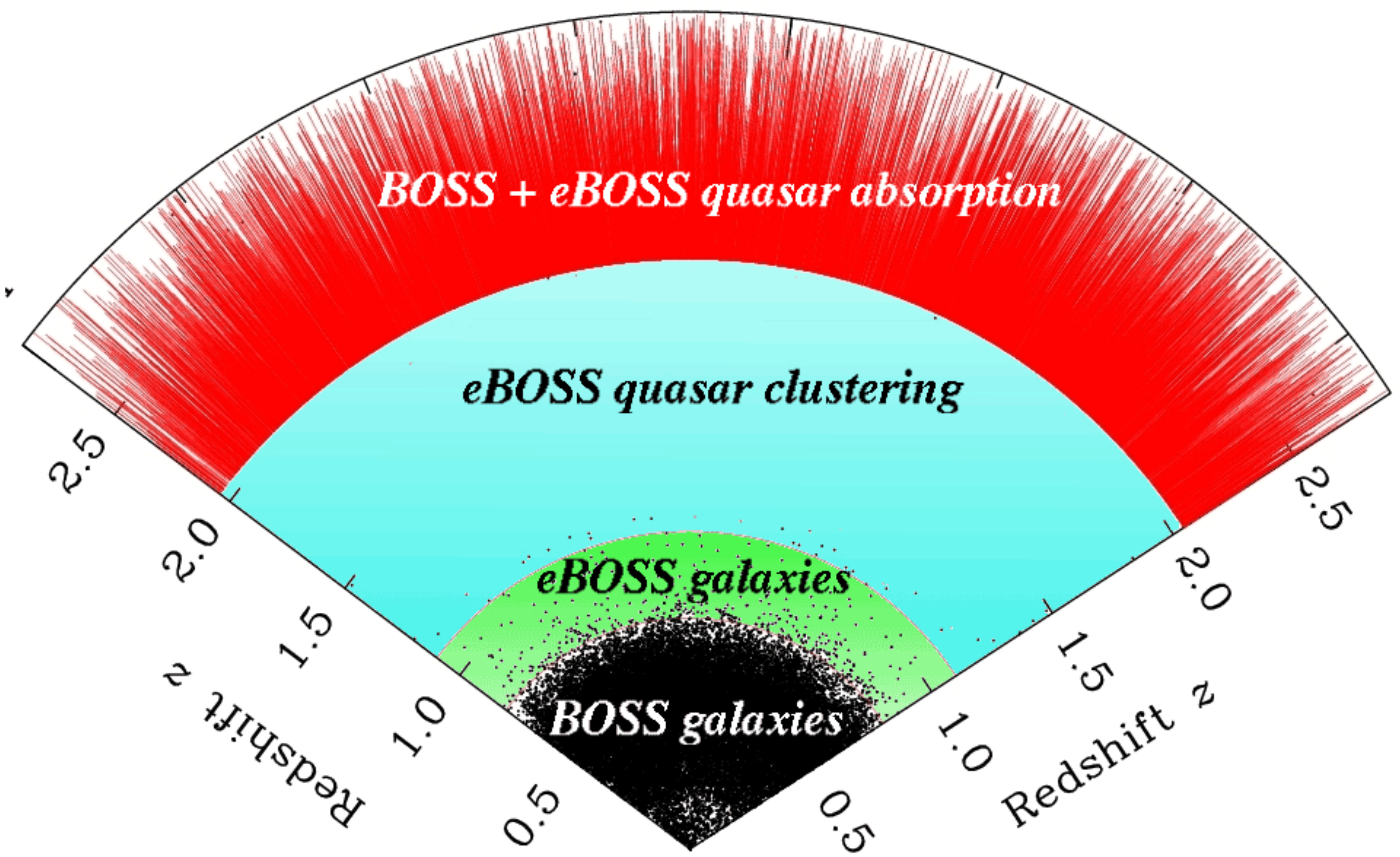
Lyman-α forest spectra of 160,000 quasars at redshifts $2.2 < z < 3$

- eBOSS

What is the evolution of bright quasars of all luminosities out to redshift $z = 3$?

Pâris et al, 2017 (DR14)

573,000 quasars



www.sdss.org

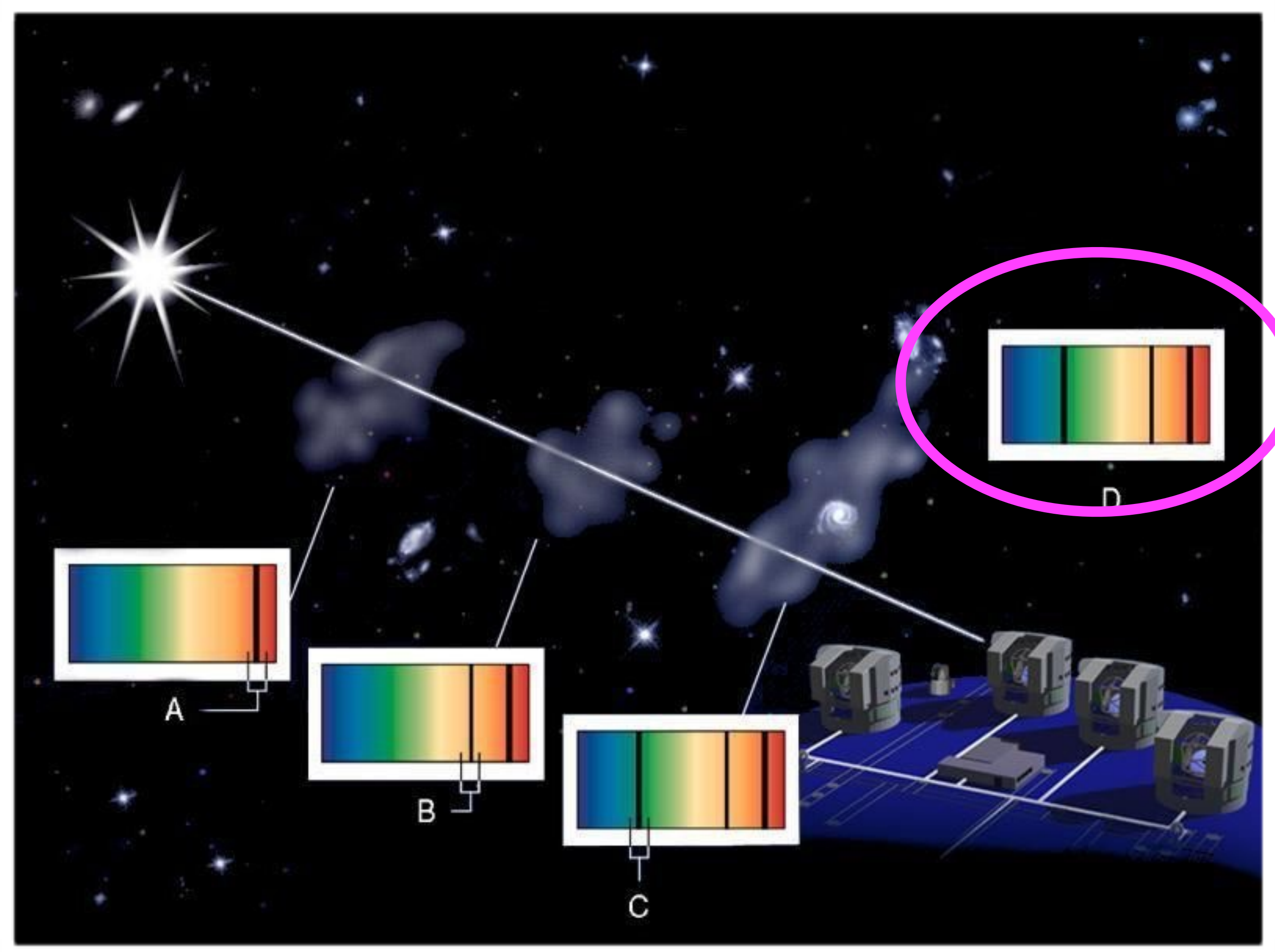
ABSORPTION LINES

- **Intrinsic Absorption lines:**
  Provide information of the quasar and the host galaxy
- **Intervening Absorption lines**

  - The primeval hydrogen generate different colors

  - Intervening gas absorbed the emission at different redshift

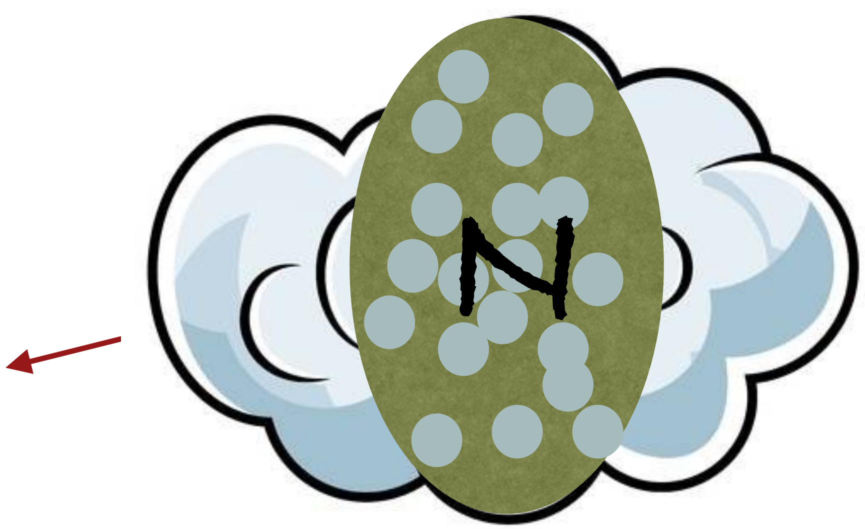
  —> The final cumulative absorption spectrum

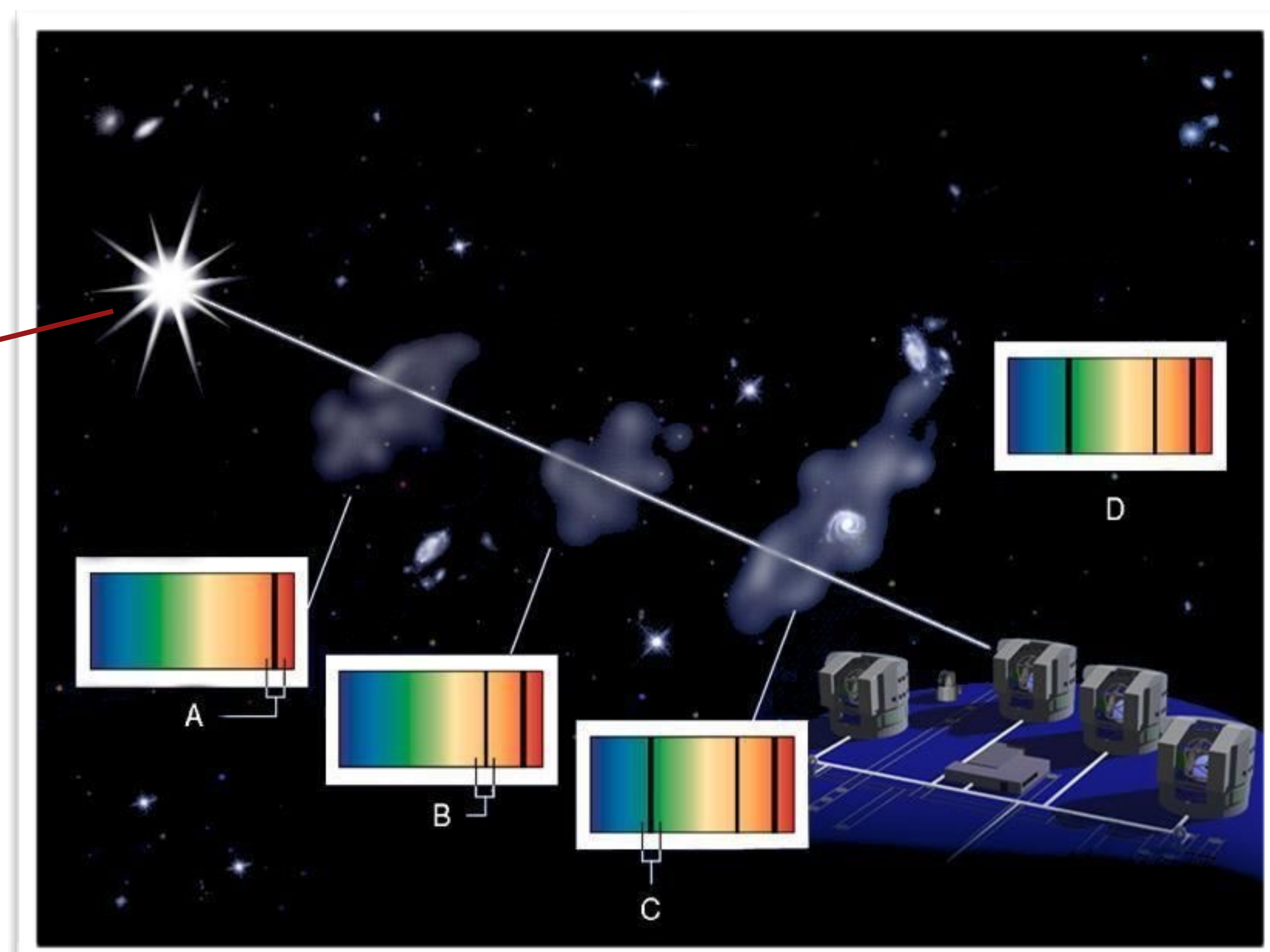


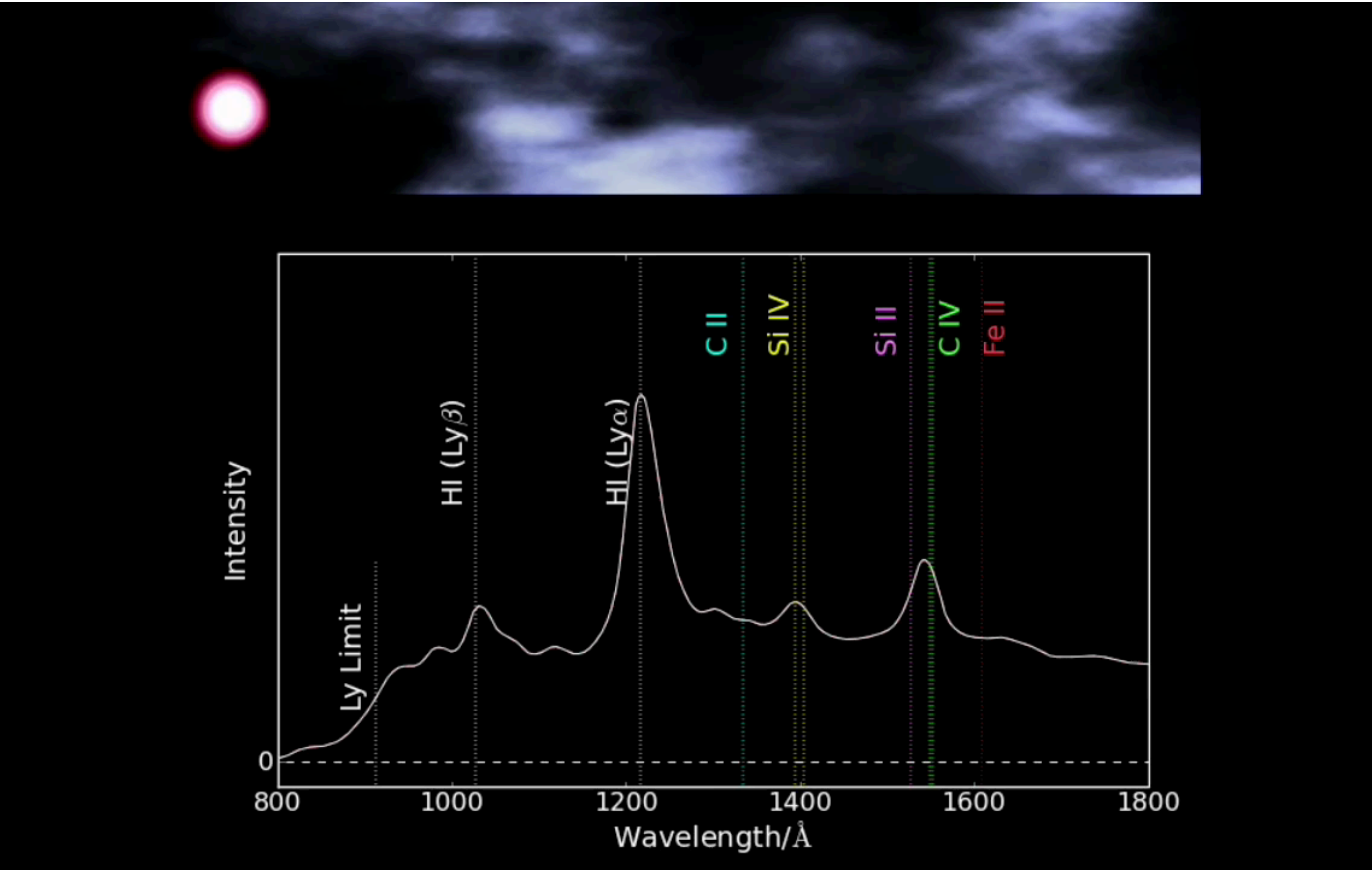
ABSORPTION LINES

- **Intrinsic Absorption lines:**
  Provide information of the quasar and the host galaxy
- **Intervening Absorption lines**
  - **column density**

    N = atoms cm^{-2}

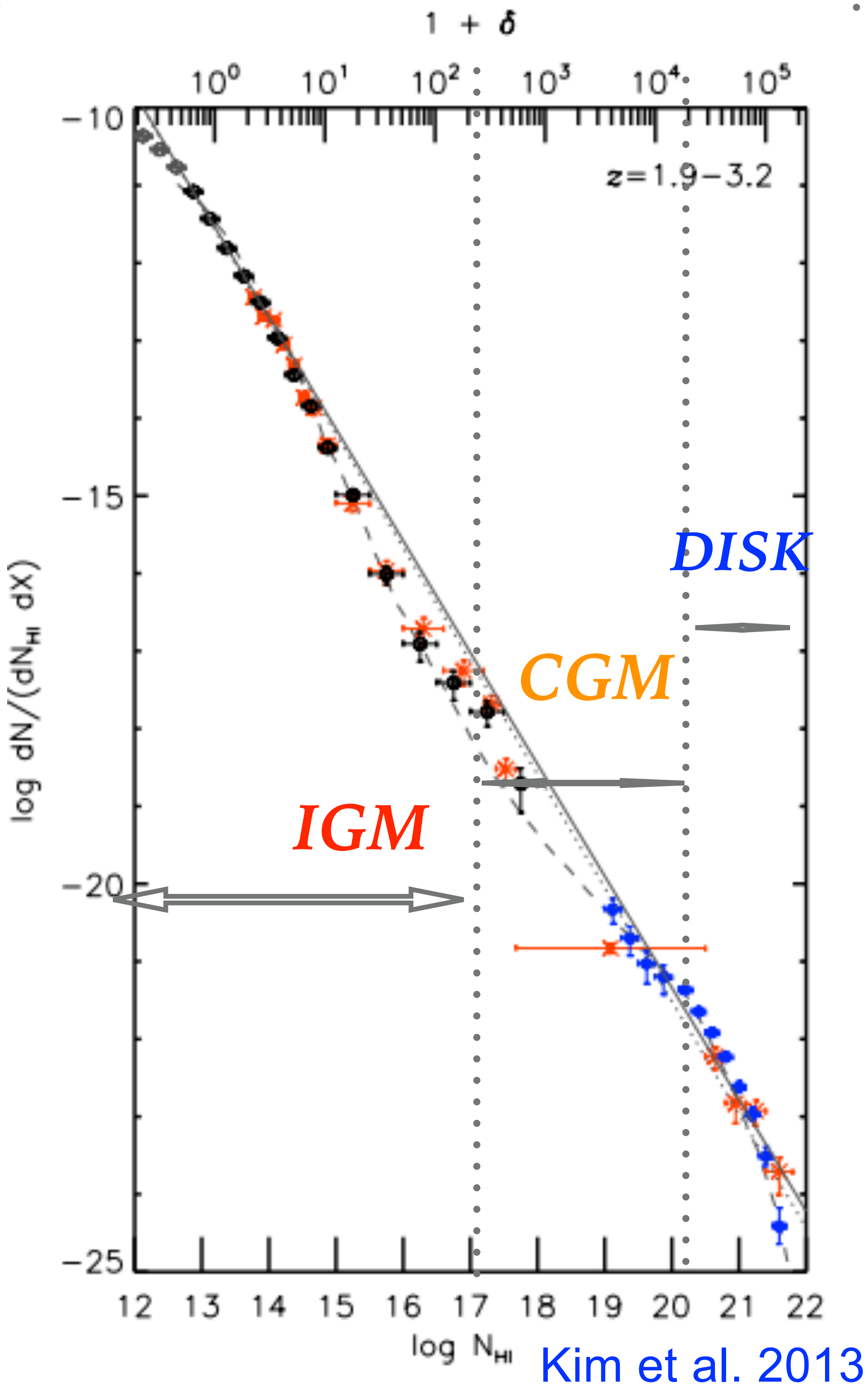


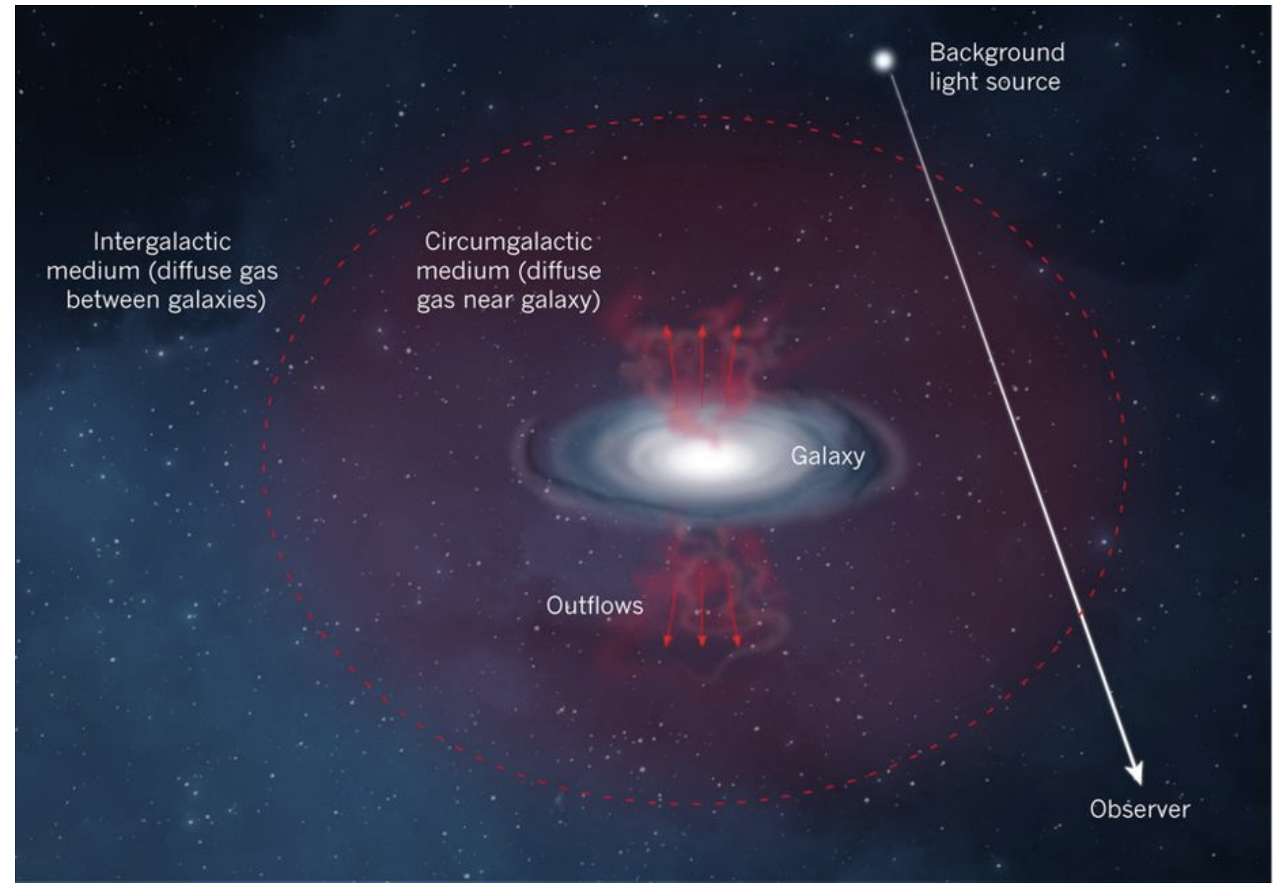




INTRODUCTION

LY-A ABSORBERS





Ly-α forest: $\log N(HI) < 17.2$

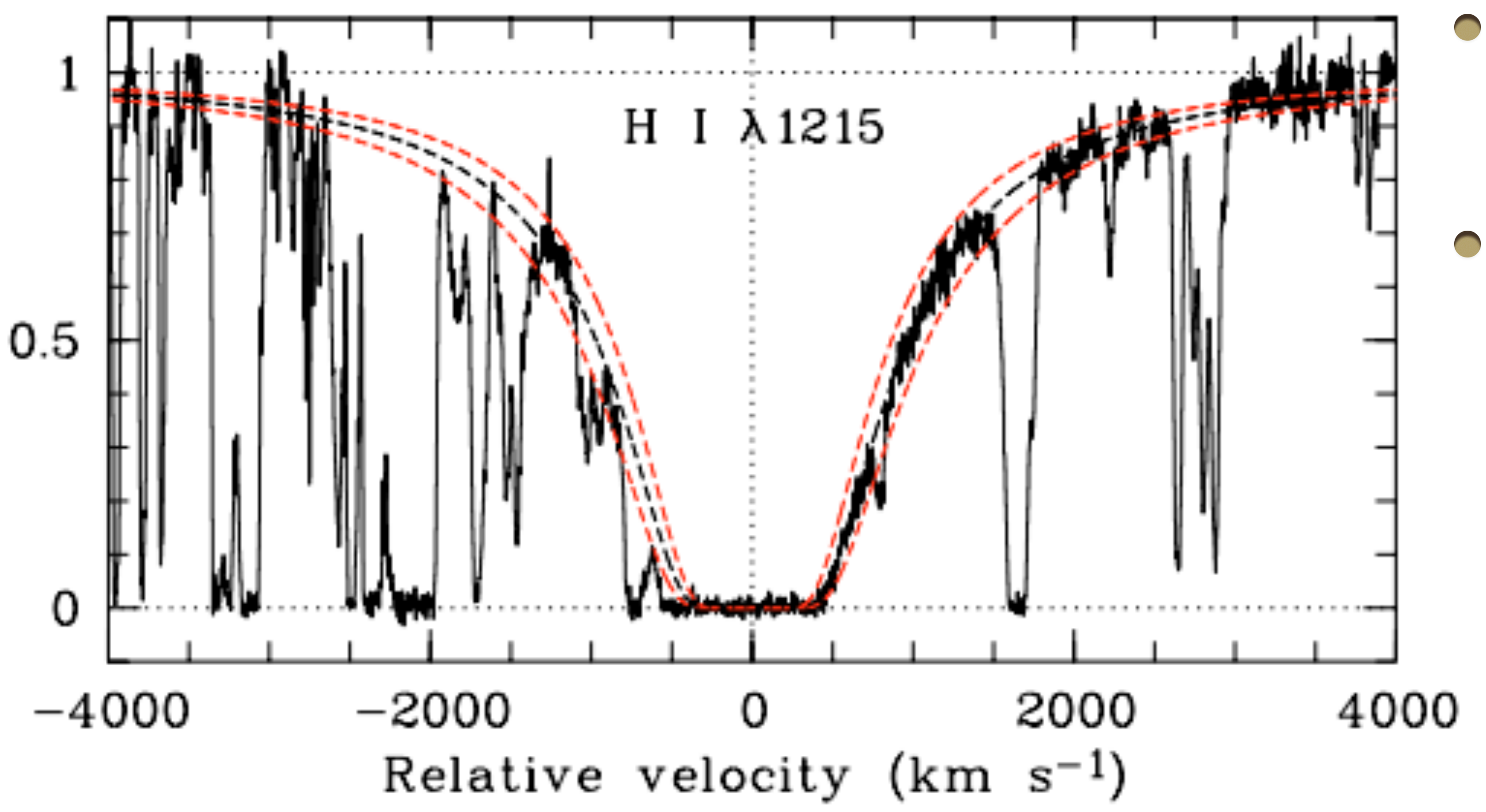
Lyman Limit Systems:

$17.2 < \log N(HI) < 20.3$

Damped Ly-α systems: $\log N(HI) > 20.3$

LY-A SYSTEMS

- Disk
- Damped Ly-α systems (DLA) log N(HI) > 20.3

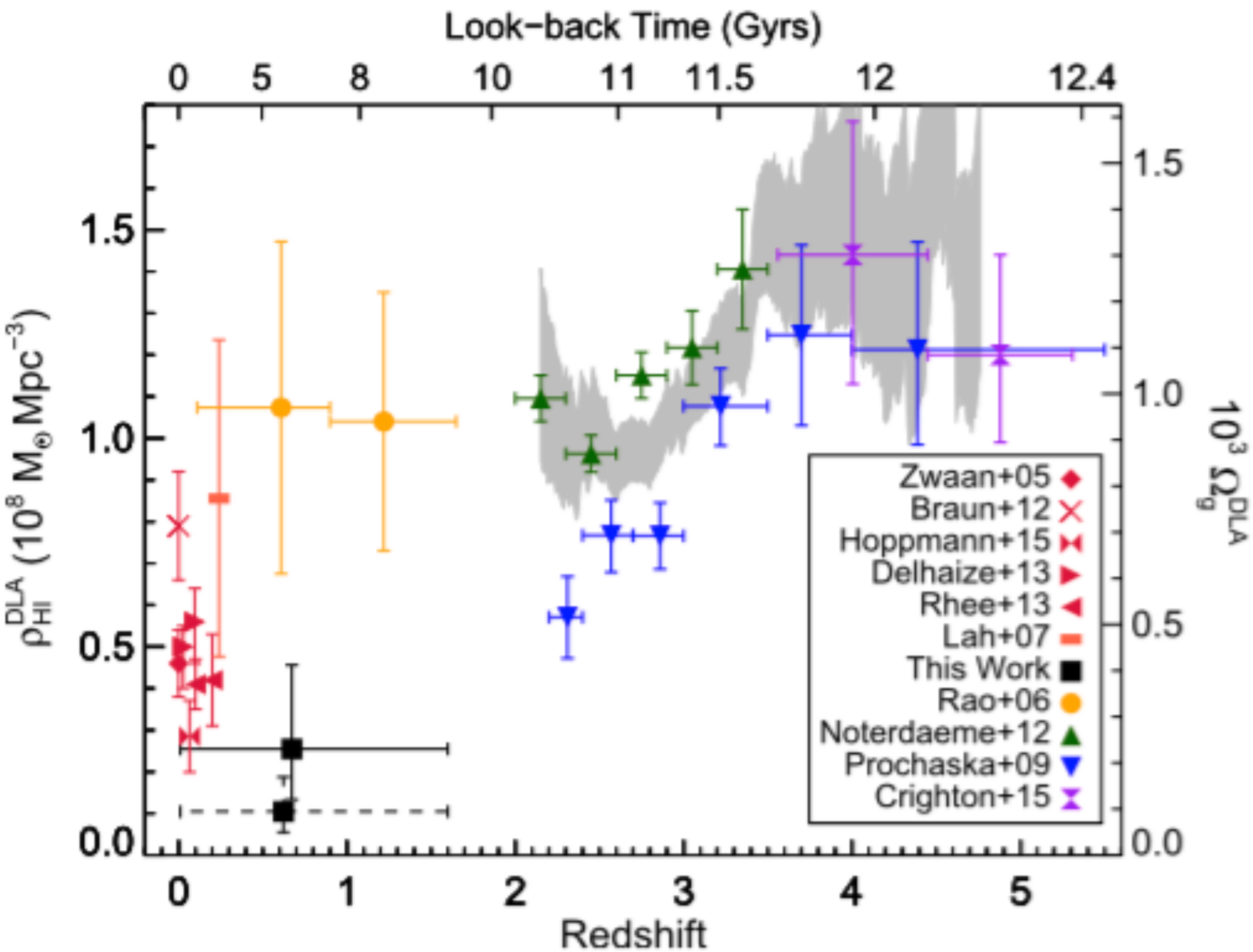


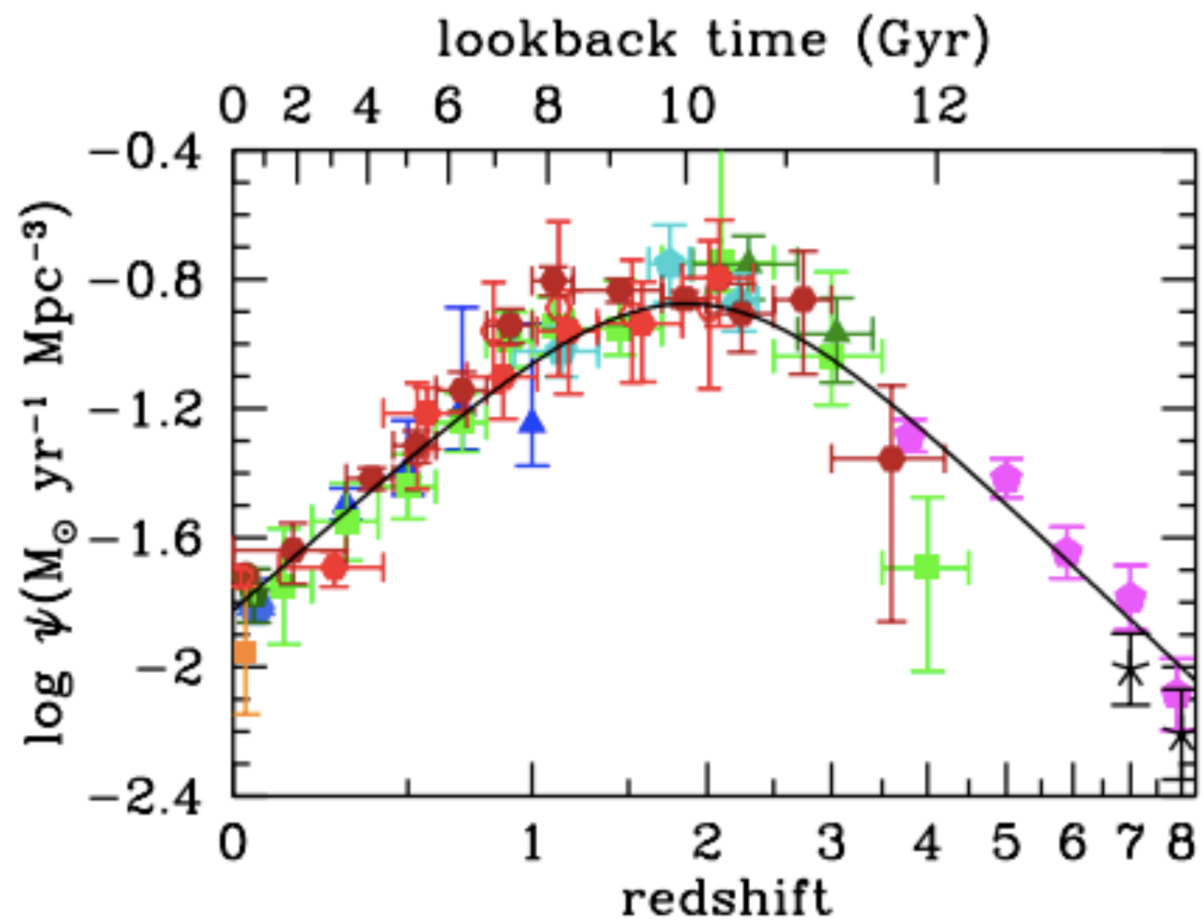
- contains most of the neutral hydrogen in the Universe
- easy to recognize

Noterdaeme et al. 2007

DLA

➤ HI mass density



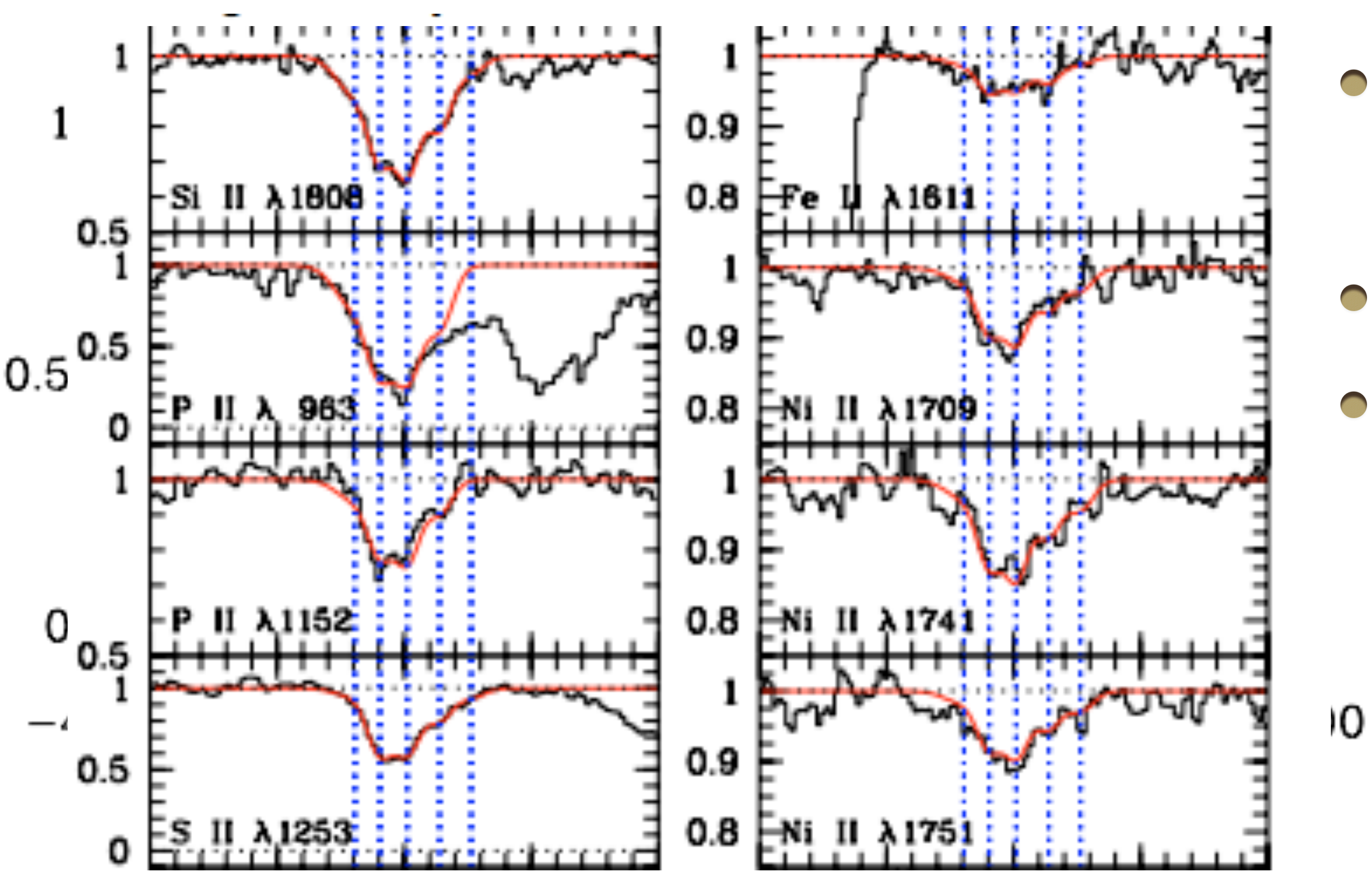


Neeleman et al. 2016

Madau & Dickinson 2014

LY-A SYSTEMS

- Disk
- Damped Ly-a systems (DLA) log N(HI) > 20.3



- contains most of the neutral hydrogen in the Universe
- easy to recognize
- associated with metal lines

Noterdaeme et al. 2007

DLA

- Metallicities

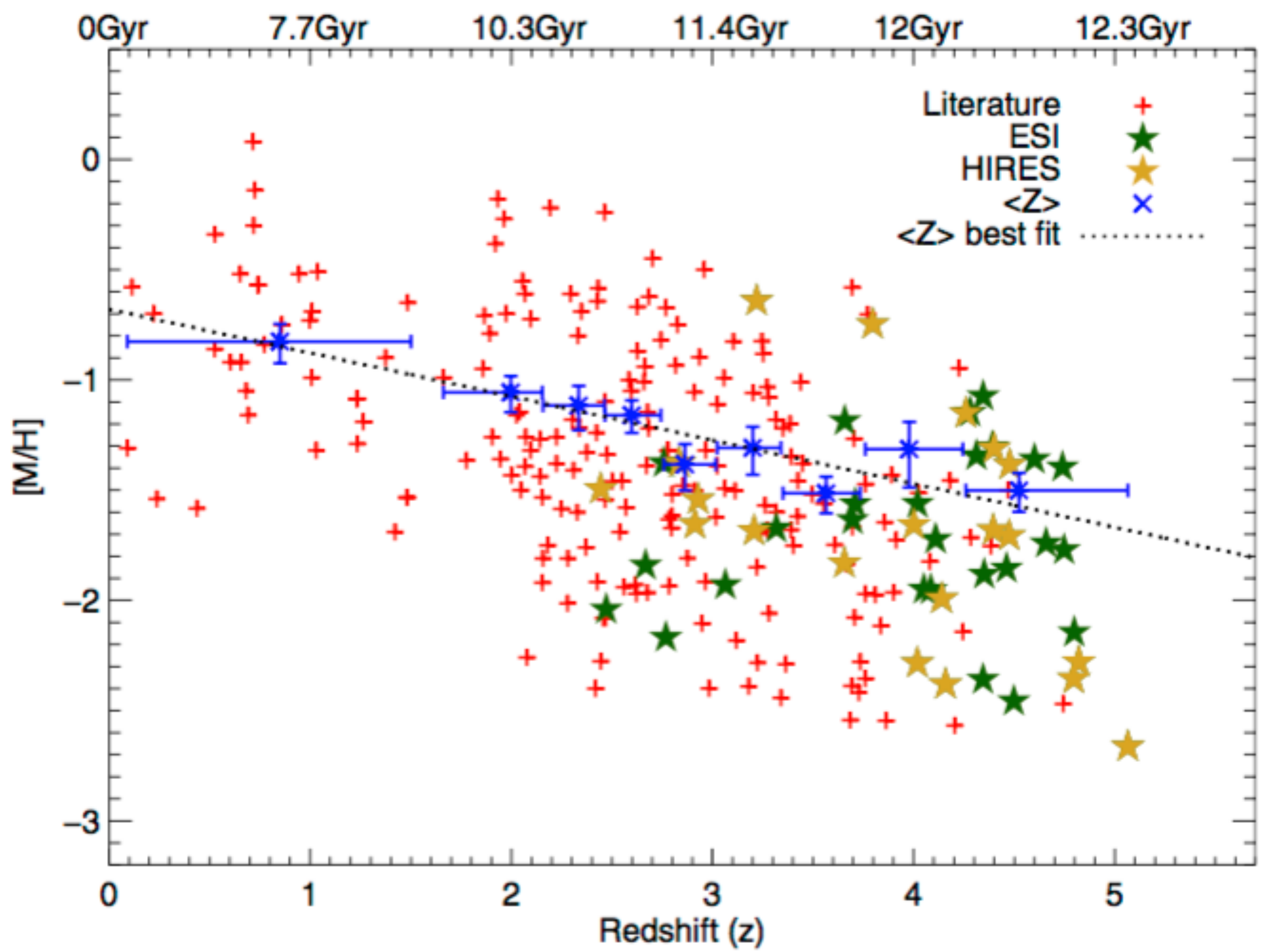
  Z =log ($N(X)/N(H)$)

  - log $(N(X)/N(H))_\odot$

- Mean metallicity evolution

$Z = (-0.26 \pm 0.07) \times z - (0.59 \pm 0.18)$

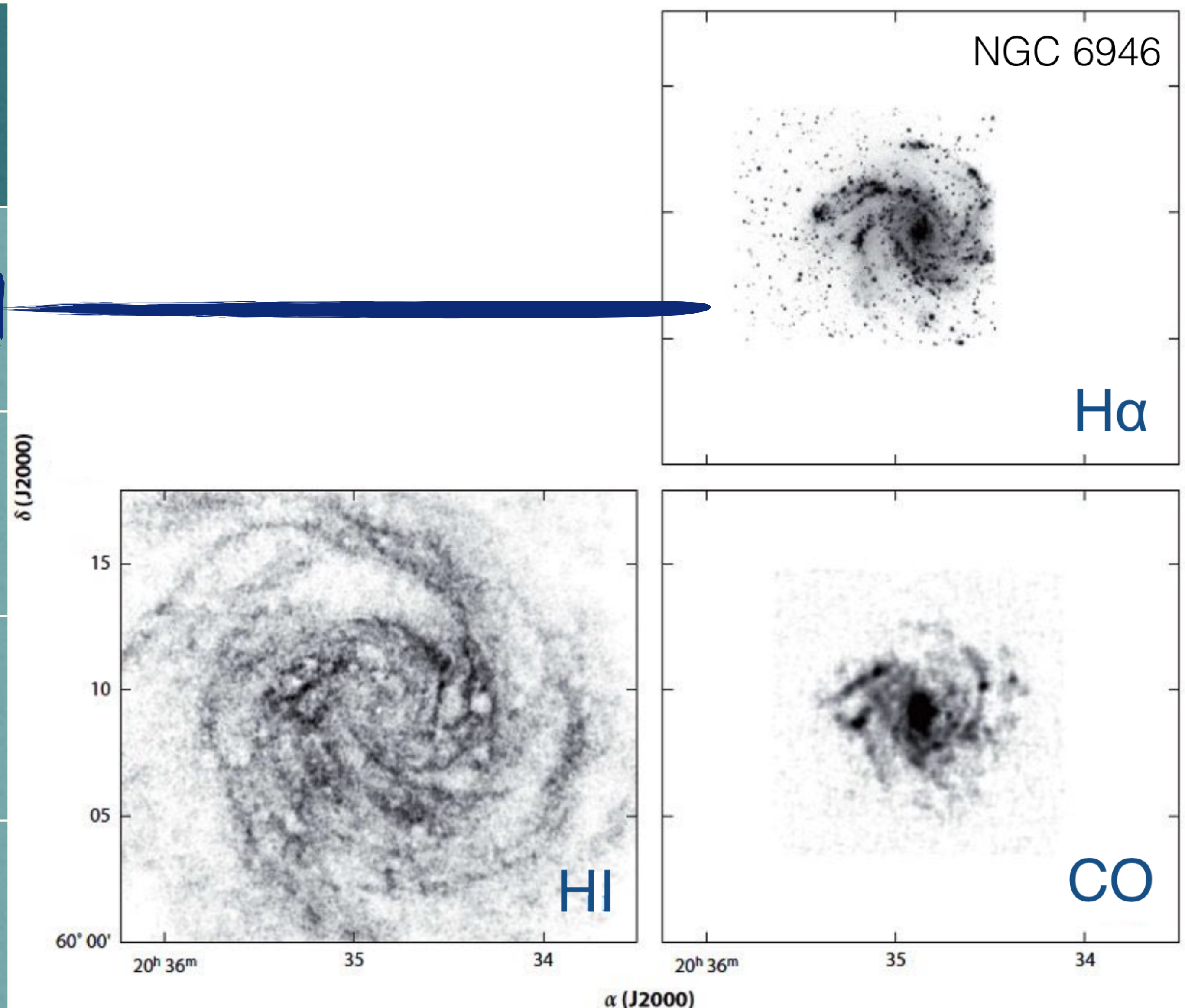
—> Metallicity measurements are **robust** in absorption



Rafelski et al. 2015

PROJECT I: COLD GAS IN CI SAMPLE

	ISM phases
warm ionized	T ~8000 K, n~0.3 cm-3 f > 15%
warm neutral	T > 6000 K, n ~ 0.3 cm-3, f > 30%
cold neutral	T ~ 100 K, n ~ 20 cm-3 f ~ 2 - 4%
molecular	T~ 20 K, n > 1000 cm-3 f < 1%



Data from: Walter et al. 2008 (HI + CO), Knapen et al. 2004, Kennicutt et al. 2011

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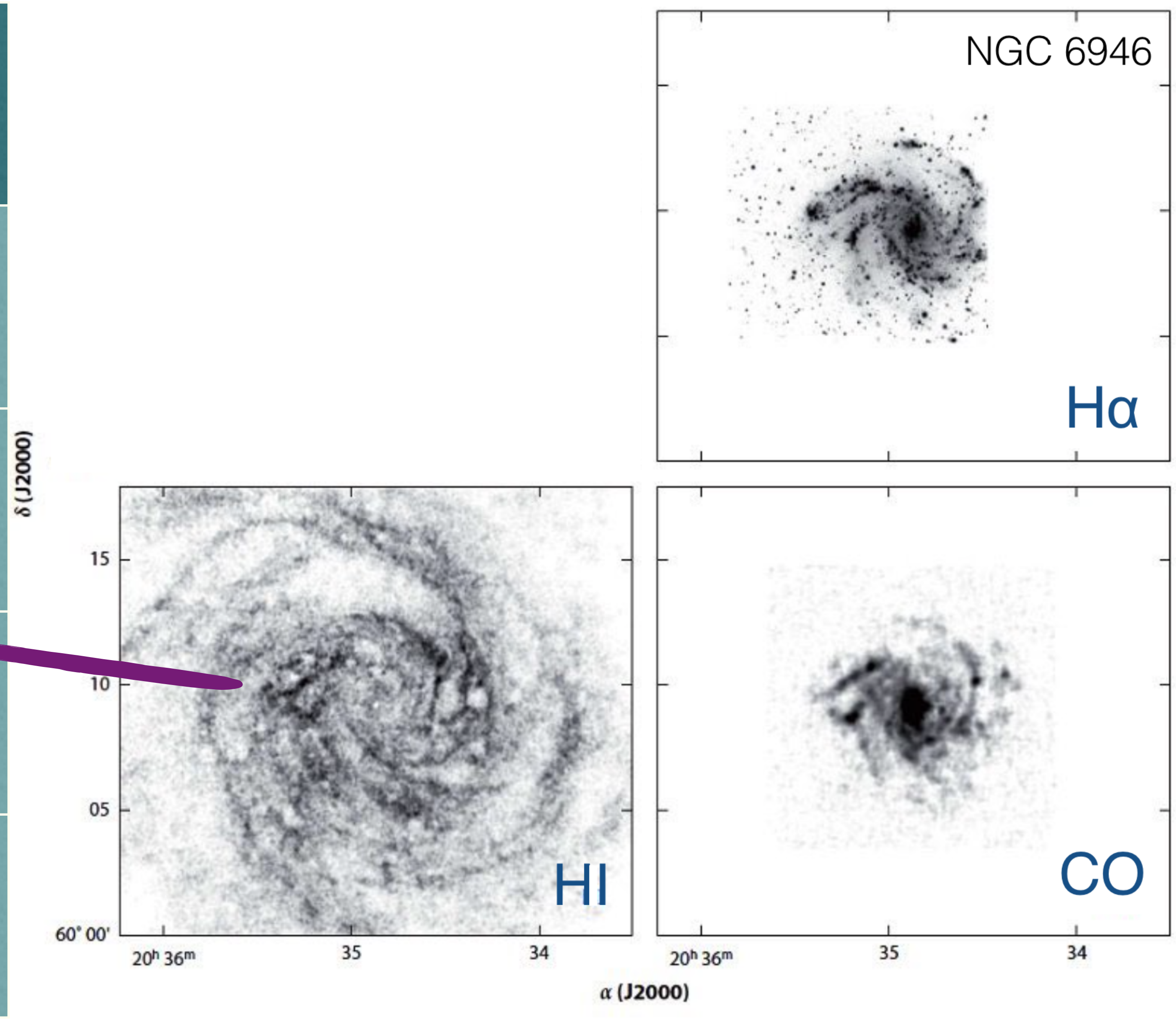

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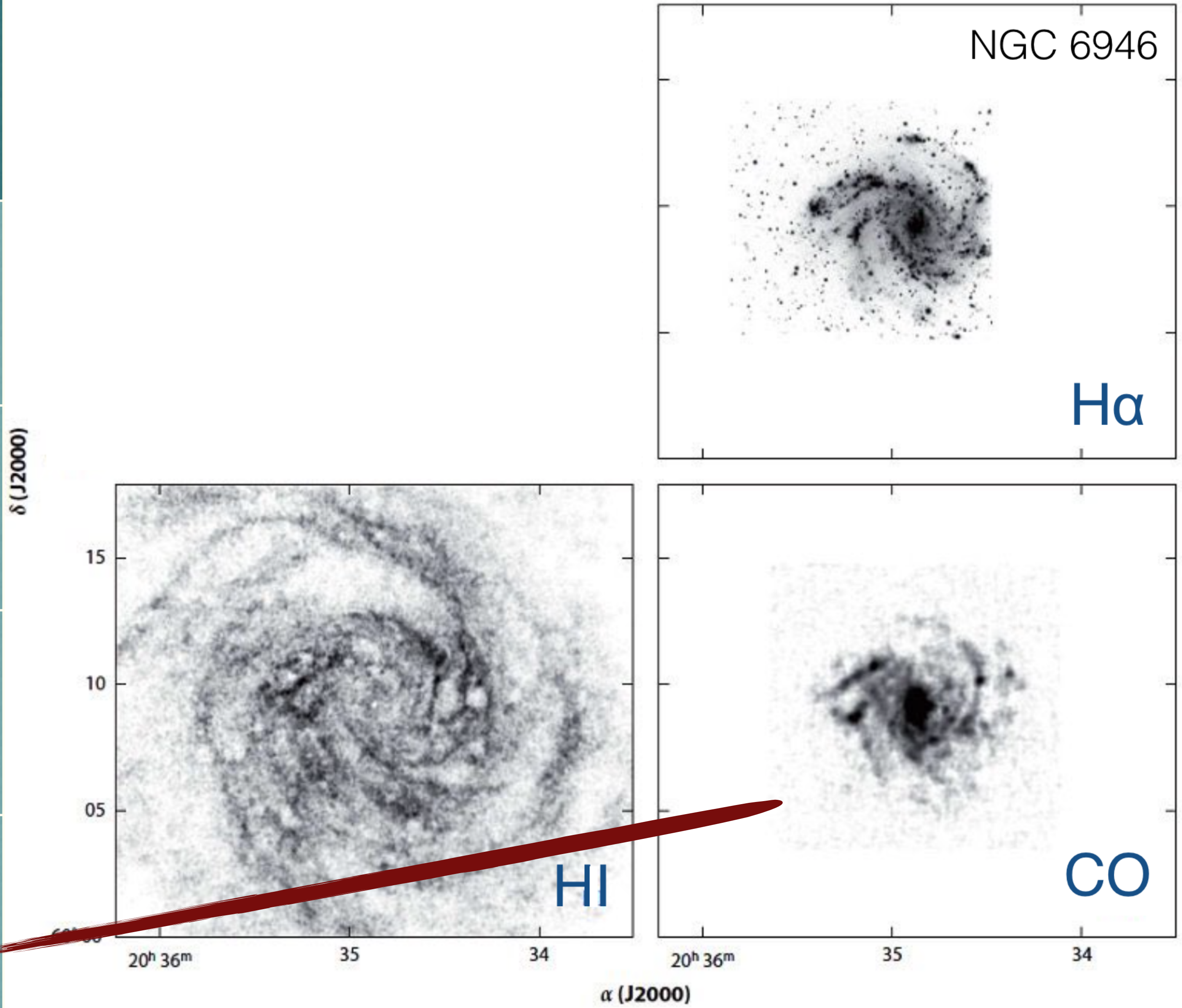

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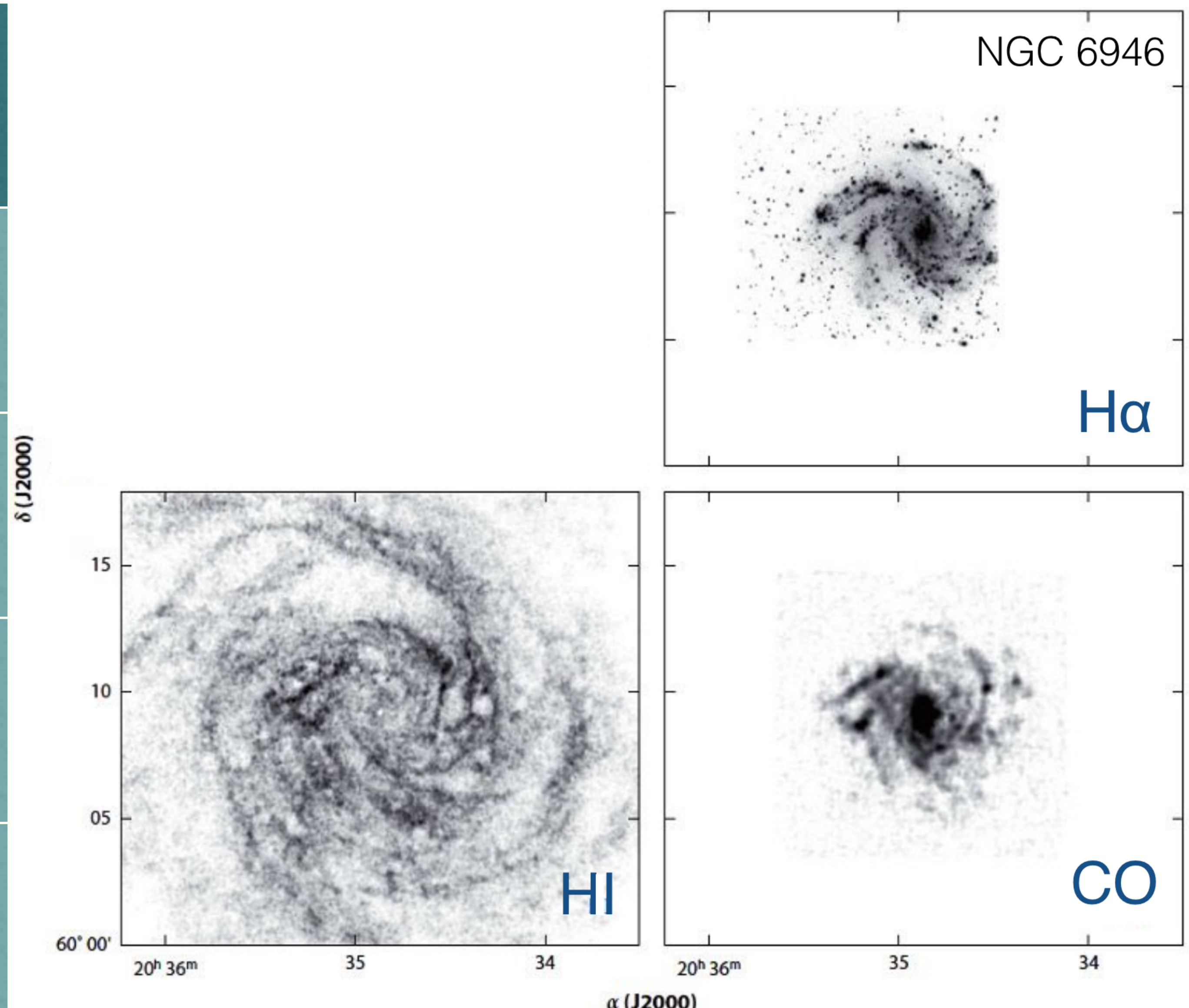


Data from: Walter et al. 2008 (HI + CO), Knapen et al. 2004, Kennicutt et al. 2011

PROJECT I: COLD GAS IN CI SAMPLE

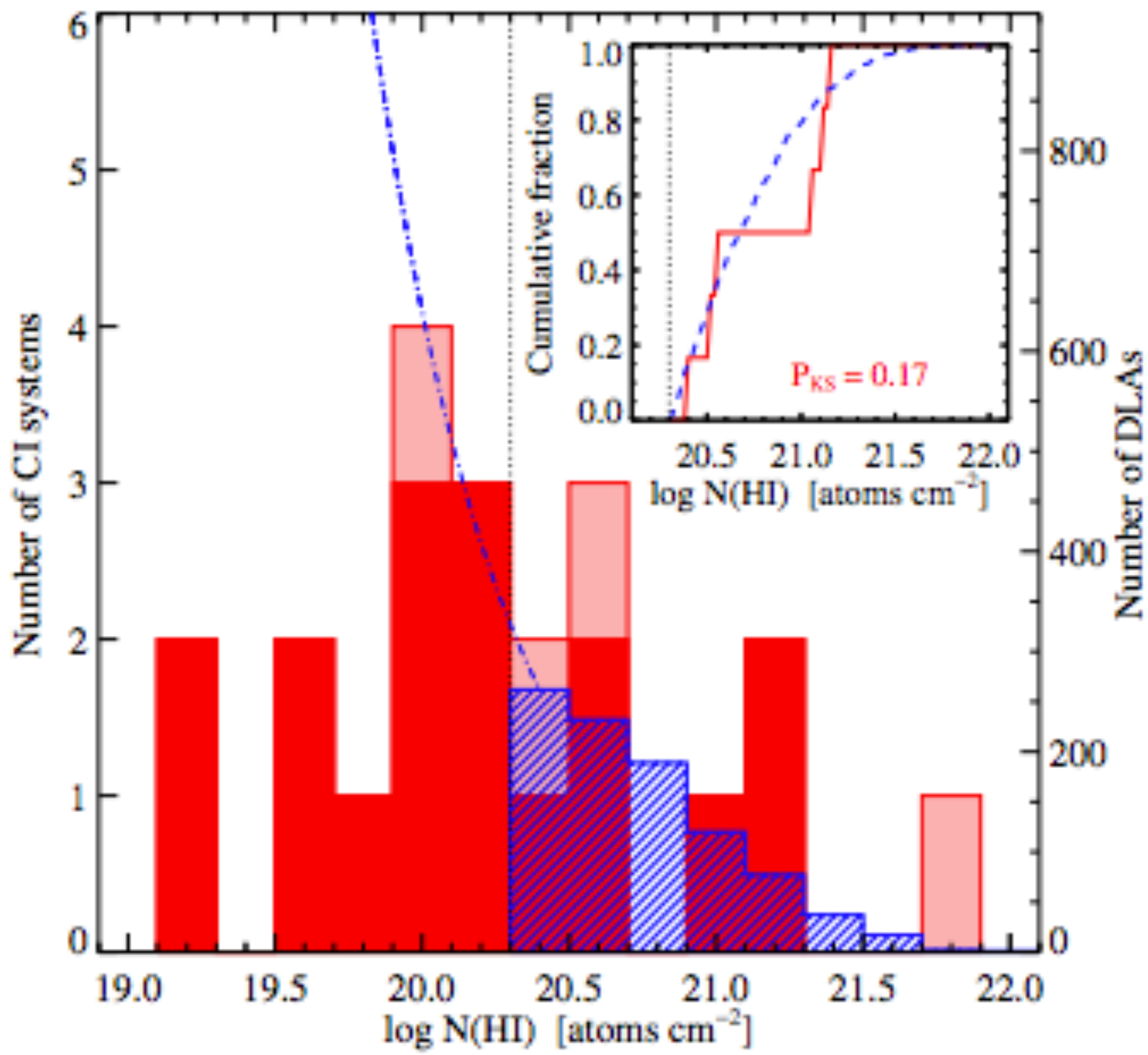
- Stars are formed in **cold, shielded** gas, which is dusty and molecular rich.
- In order to understand the evolution of **star-formation**, we also need to study the evolution **of cold gas**.
- The neutral gas, as probed by most **DLAs** is found to be very **diffuse**.
- Much more difficult to observe cold gas at **high-z** which normally lies in the disk of galaxies — a **new tracer** is needed,

WHY CI?

- New tracer —*C I*, which is directly connected to cold gas
- Indeed, C I only survives in shielded gas. The ionization energy of C I (11.26 ev) is below the neutral hydrogen ionization energy (13.6 ev).
- Since there are very few samples using C I as the tracer of cold gas in the previous studies, therefore a large database is needed.

SAMPLE

- Large database **SDSS –DR7 (Abazajian et al. 2009)**,
- Redshift range **1.5 < z_{abs} < 3.1**
- C I λ λ **1560,1656** doublets are used in selection.
- The completeness limit of our survey is *W*r_lim (λ1560) ≈ 0.4 Å.
- A complete sample of **66** C I absorbers are selected from 41696 QSOs, see details in **Ledoux et al. 2015 (A&A, 580,8)**.



Ledoux et al. 2015

Red histograms: CI systems

Blue-hased histograms: Normal DLAs in Noterdaeme et al. 2009b

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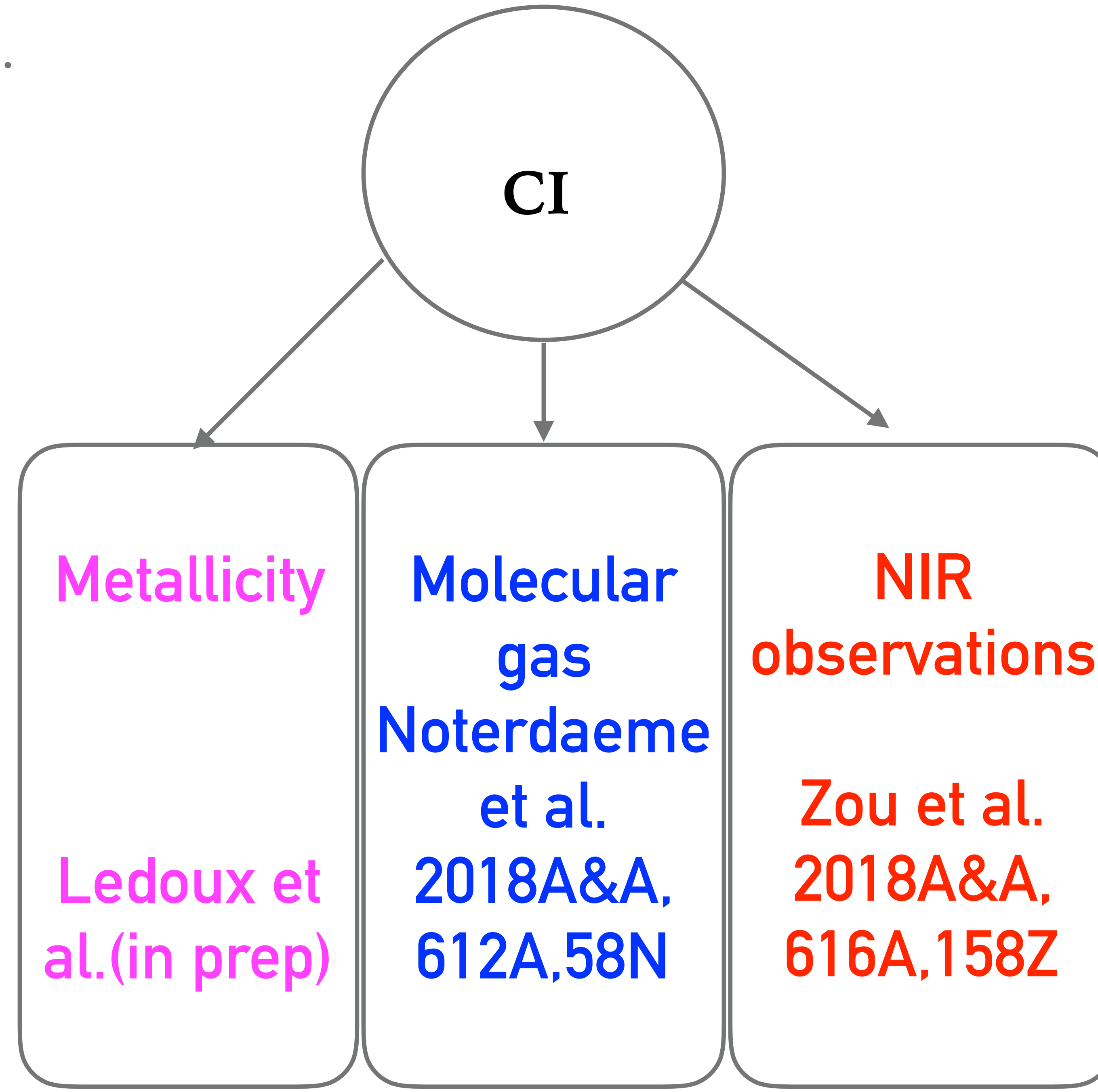


SUBSAMPLE

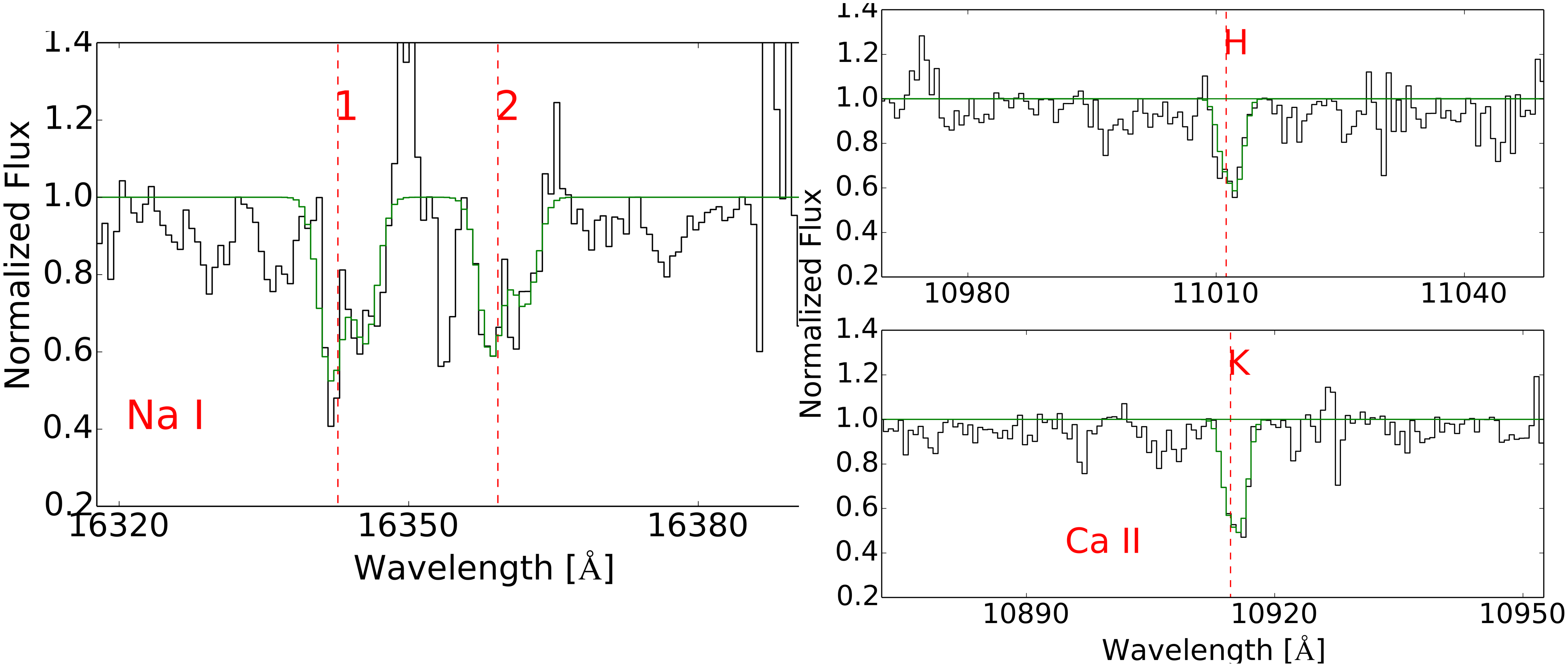
- We re-observed 17 QSOs using VLT-Xshooter

- VLT-Xshooter is a multi-wavelength (3000-20000 Å) medium resolution spectrograph which has three arms covering the UVB(3000-5595 Å), VIS (5595- 10240 Å) and NIR (10240-24800 Å) wavelength ranges.

- Due to the absorption redshift range, NaI ($\lambda\lambda$ ***5891,5897***), CaII ($\lambda\lambda$ ***3934, 3969***) can be detected. (draw the difficulties)

NAI AND CAII

- **First** systematic study of **Na I and CaII** at high-redshift: NaIλλ5891,5897 and CaII λλ3934,3969 can be detected with X-shooter in the NIR wavelength range.

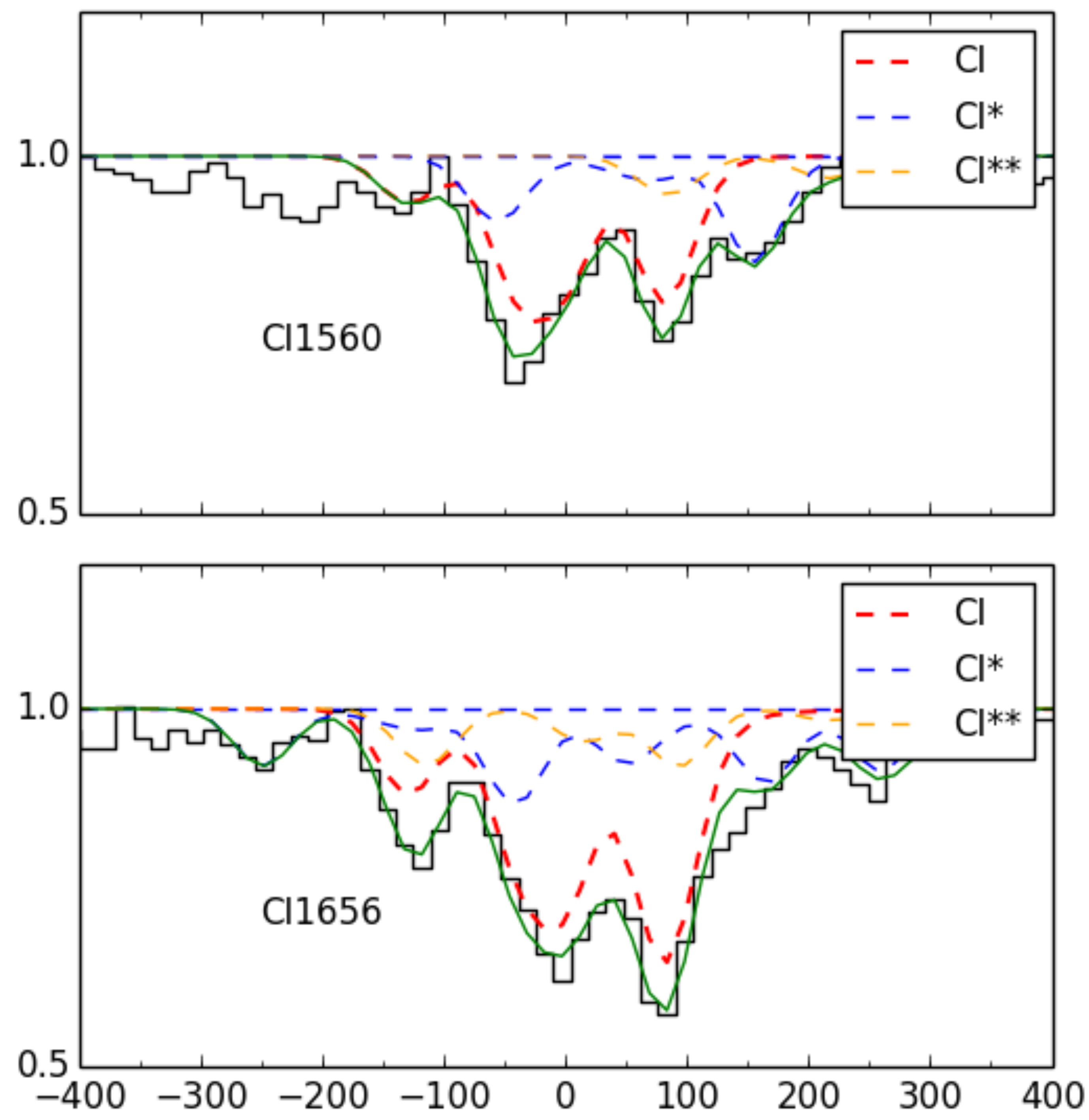


MEASUREMENTS

- Decomposition of C I absorption (show a
- figure of CI, CI* and CI** —>measurements of

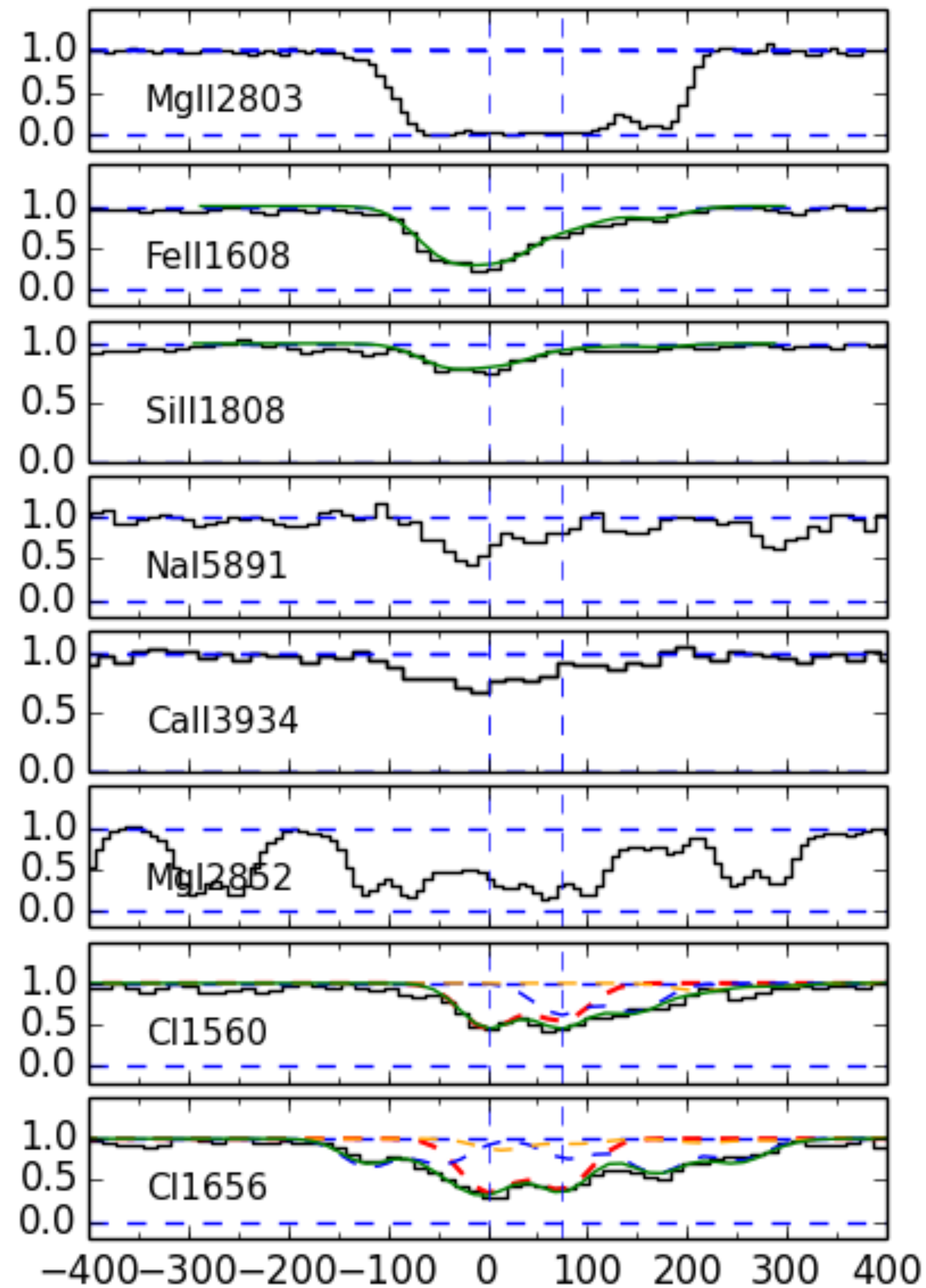
  $^3P_0$, $^3P_1$, and $^3P_2$

volume density ~ 10-100 cm-3



MEASUREMENTS

- Decomposition of C I absorption
- EW of C I, NaI and CaII, MgII and MgI
- Metal Column densities.



RESULTS

- **Metallicity**

left panel :

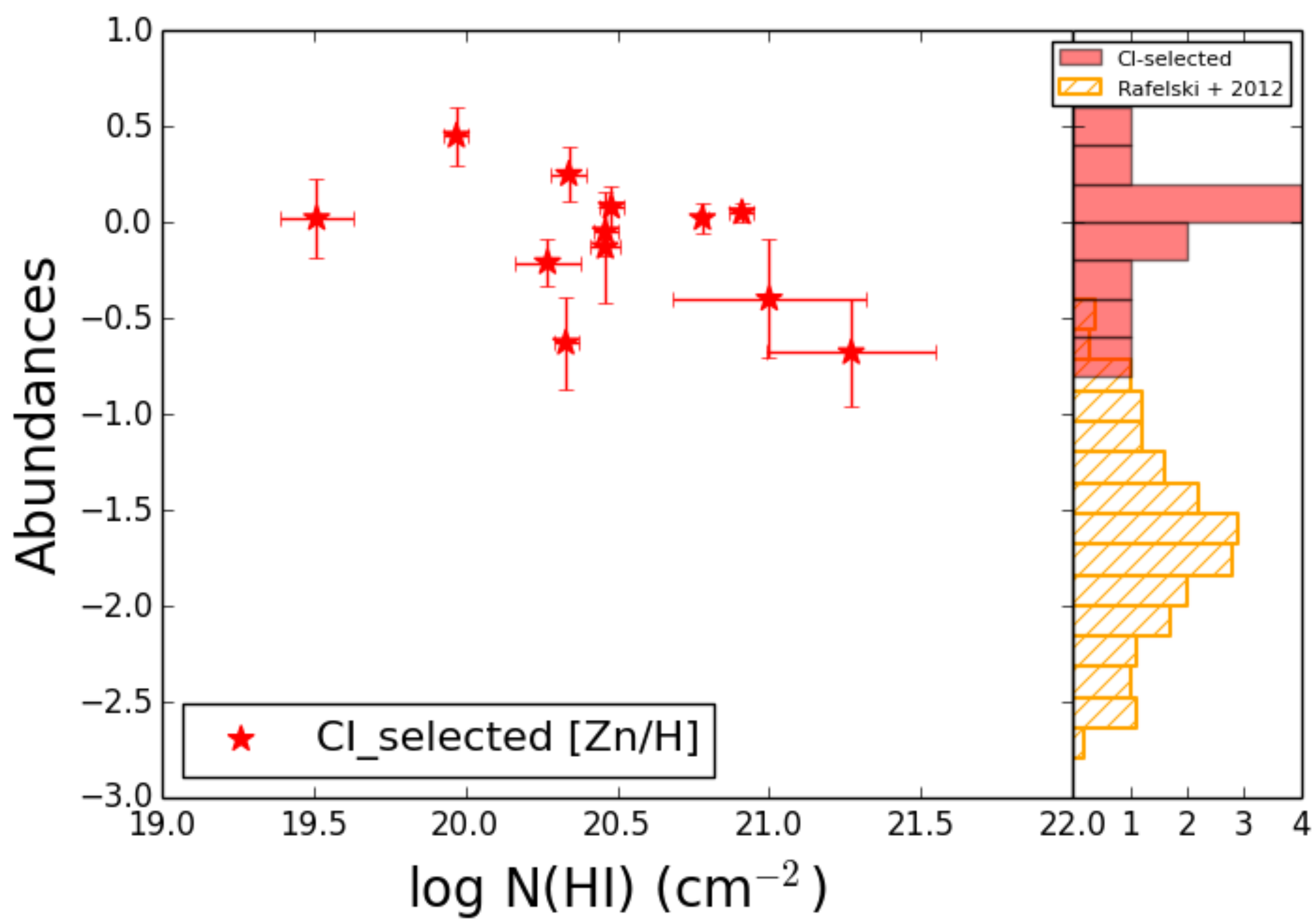
red stars: CI-selected [Zn/H]

right panel:

Metallicity distribution function

orange histogram: Metallicity distribution in Rafelski+ 2012

red histogram: CI-selected metallicity



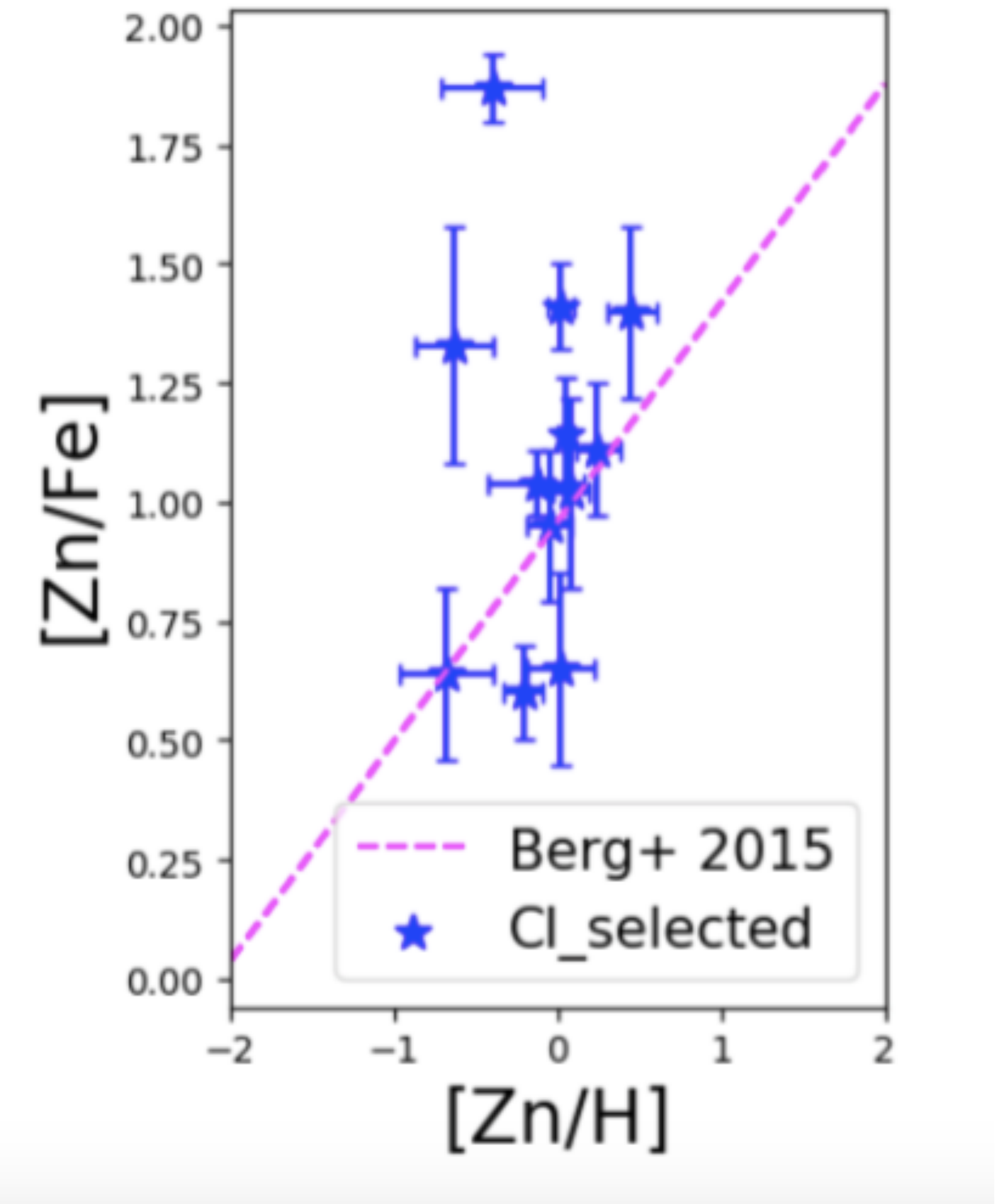
Zou et al. 2018

MEASUREMENTS

- Decomposition of C I absorption
- EW of C I, NaI and CaII, MgII and MgI
- Metal Column densities.
- Depletion

  - highly depleted: FeII, CrII

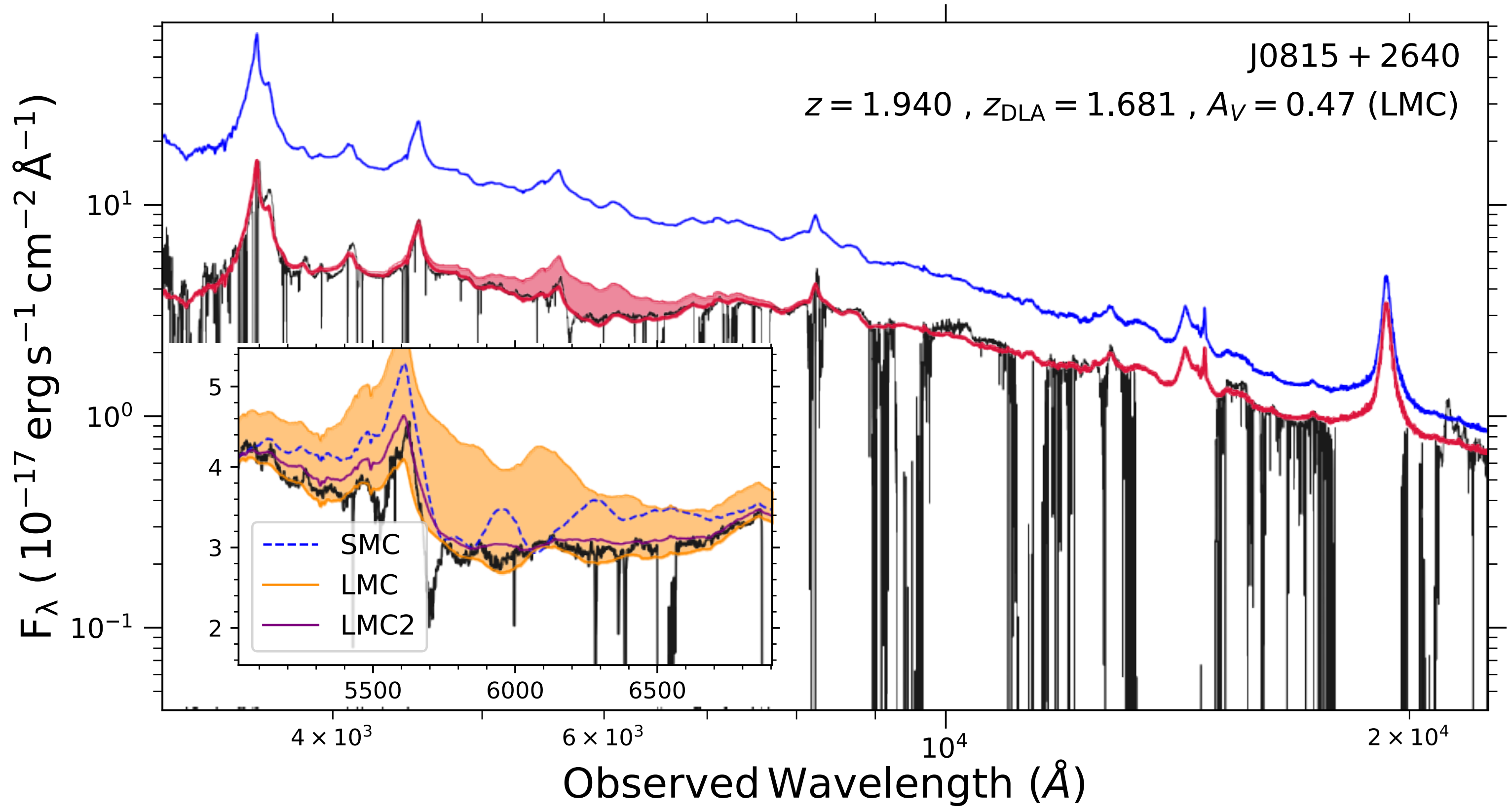
  - less depleted: ZnII



Zou et al. 2018

MEASUREMENTS

- Decomposition of C I absorption
- EW of C I, NaI and CaII, MgII and MgI
- Metal Column densities.
- Extinction
- upper: the extinction model without the 2175 bump, and lower one is the the model with the bump, which means there is the 2175 bump in this absorber
- 4 systems in the subsample with 2175 bump.



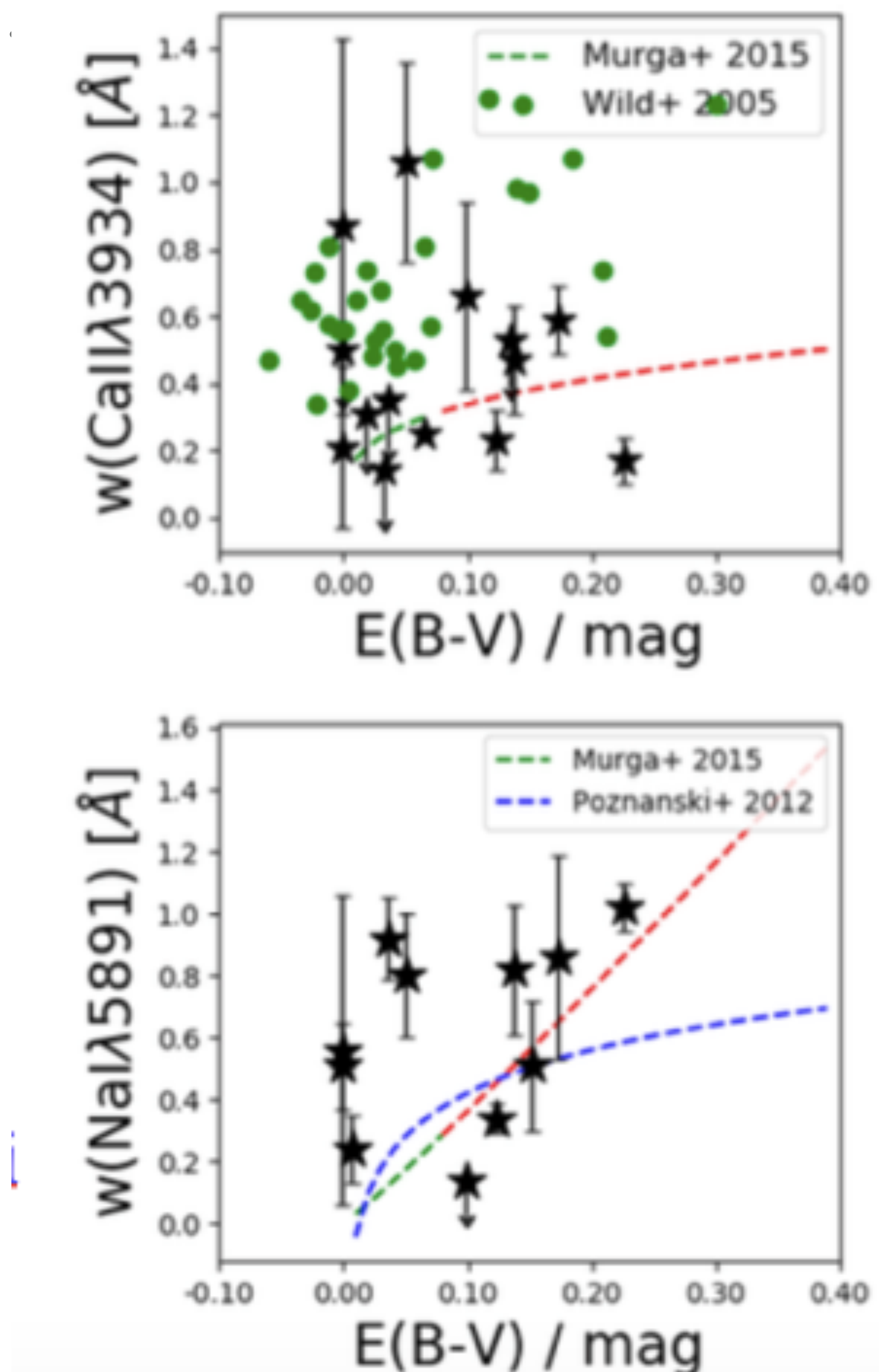
Zou et al. 2018

RESULTS

- NaI and CaII

Green line: Murga+ 2015, CaII and NaI study in the local universe , red line is the extrapolation at higher reddening

Blue line: W(NaI)- E(B-V) empirical relation in Poznanski et al. (2012)



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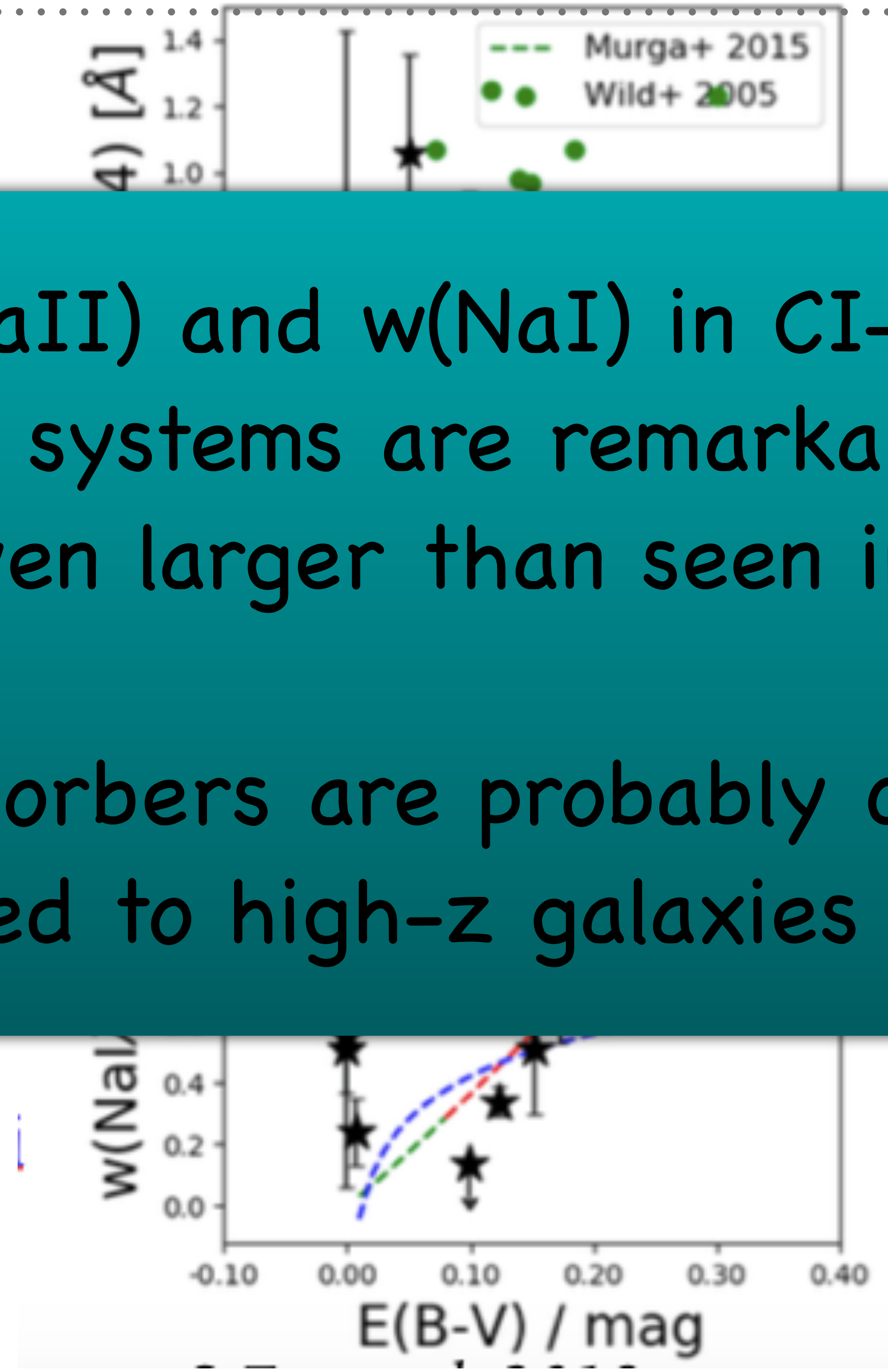
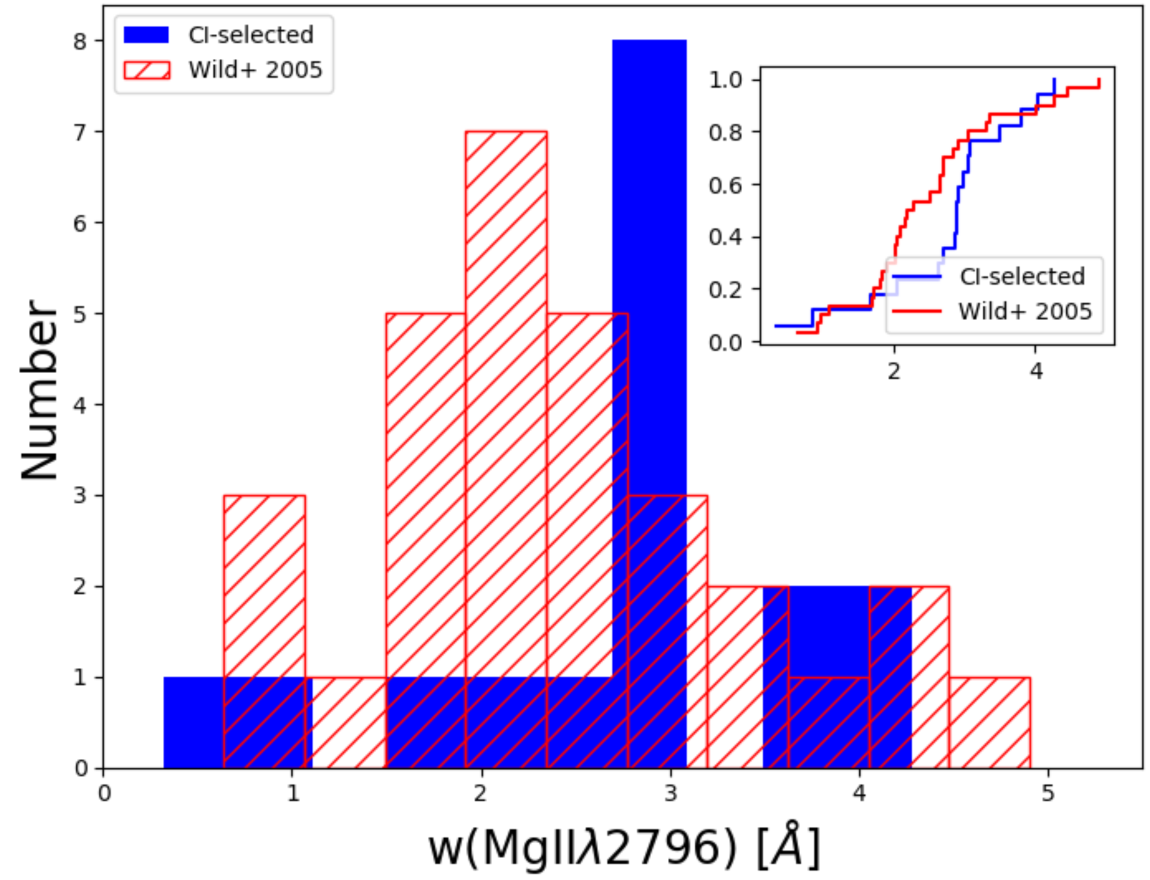


The w(CaII) and w(NaI) in CI-selected systems are remarkably large, even larger than seen in our Galaxy
- CI absorbers are probably closely associated to high-z galaxies

Zou et al. 2018

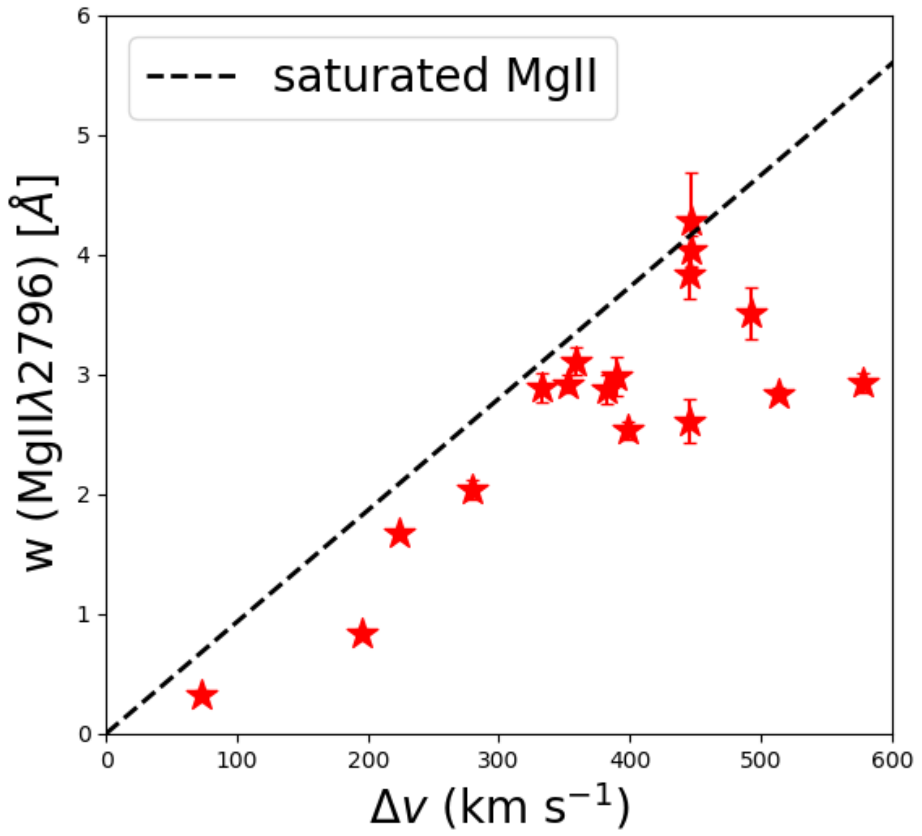
RESULTS

➤ **MgII**



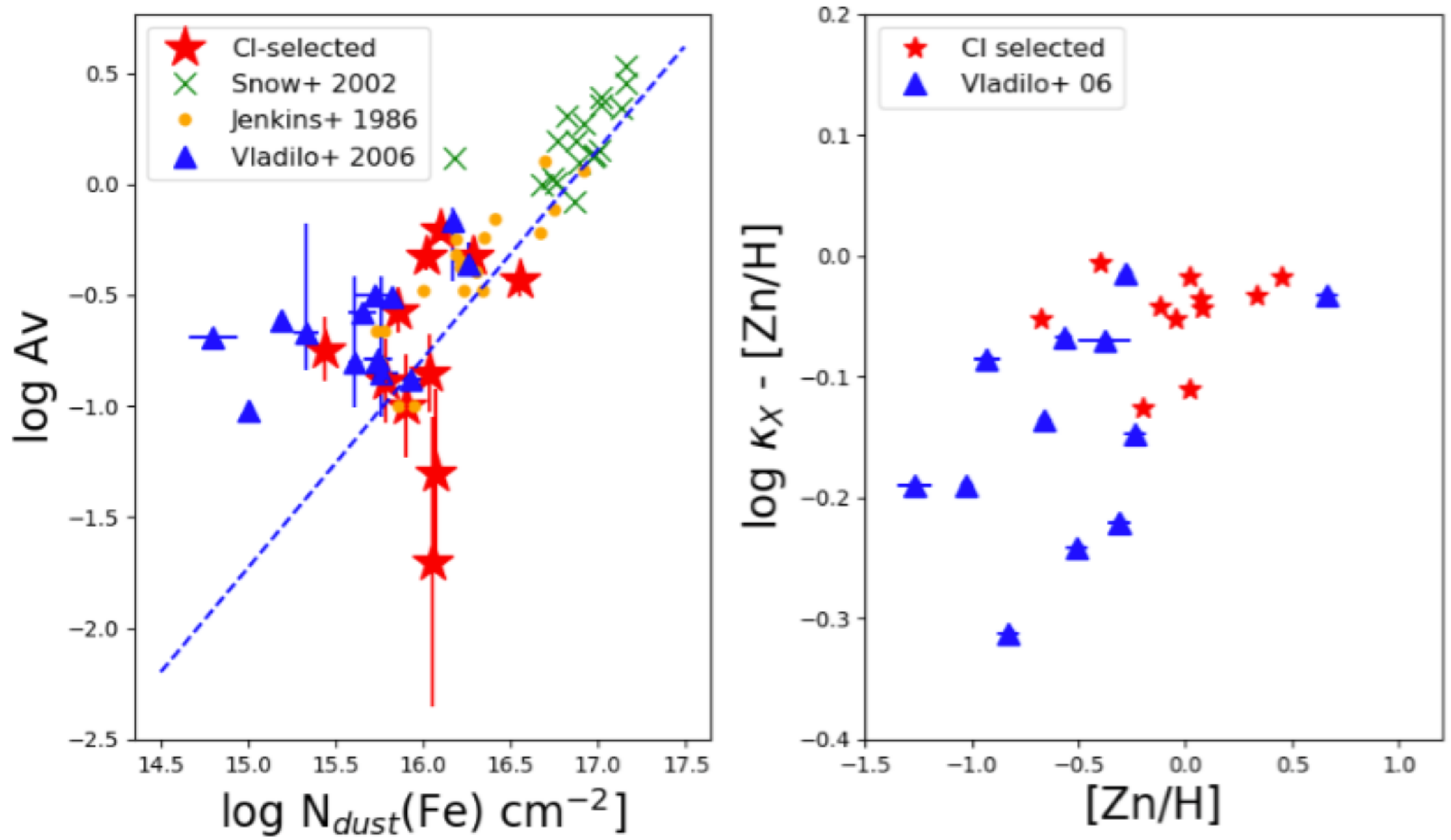
Red histogram: Wild et al. 2005

$0.84 < z_{abs} < 1.3$



Black dashed line: the expected line when MgII is totally saturated

DUST ATTENUATION



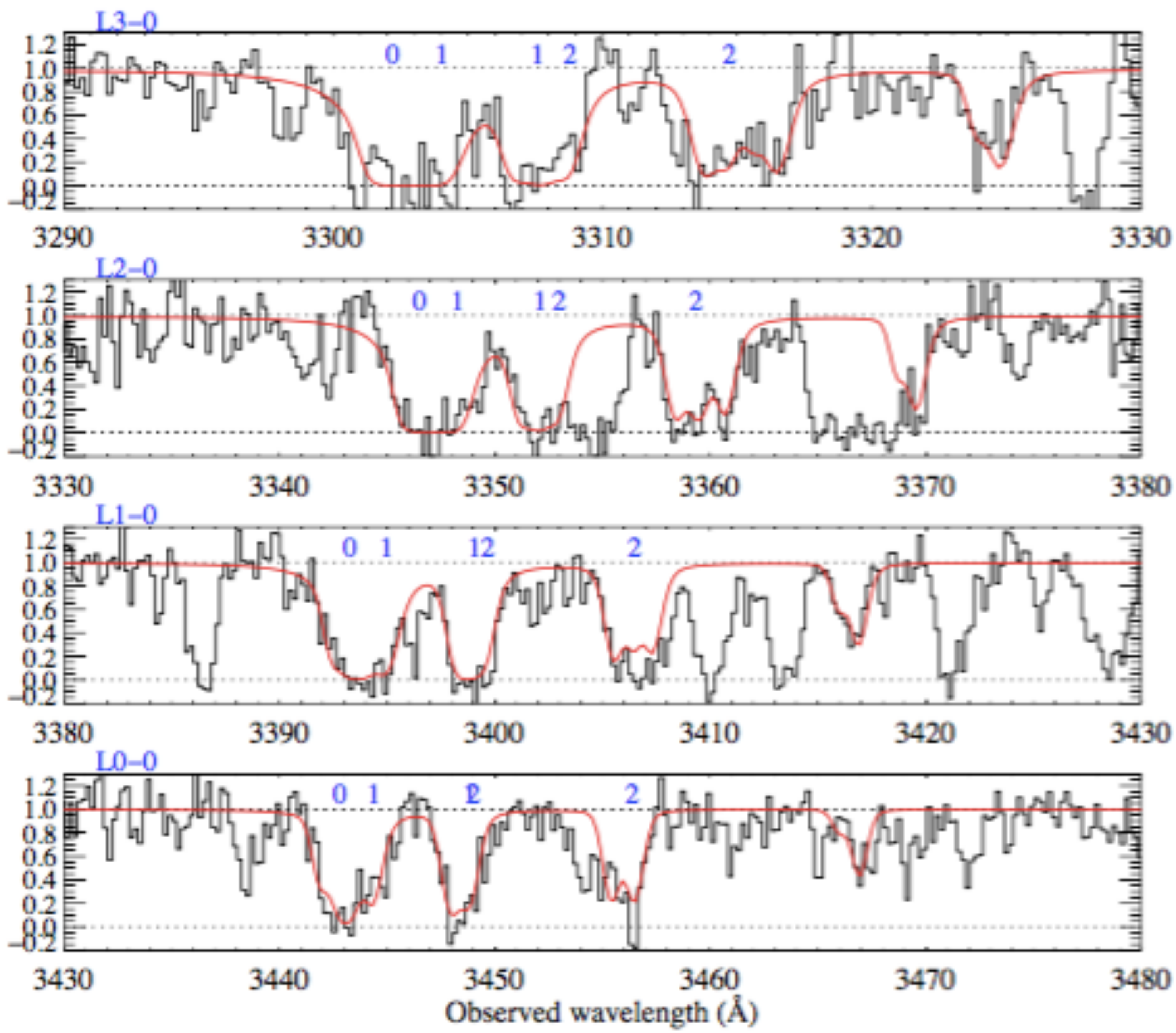
$$\kappa_X = 10^{[X/H]}(1 - 10^{[Fe/X]}).$$

Red: FeII in the dust of CI-selected sample
Blue: FeII in the dust in Vladilo et al. 2006

Zou et al. 2018

PROJECT II: MOLECULAR GAS

P. Noterdaeme, C. Ledoux, **S. Zou,** P. Petitjean, R. Srianand, S. Balashev, S. López 2018



PROJECT II: MOLECULAR GAS

P. Noterdaeme, C. Ledoux, **S. Zou,** P. Petitjean, R. Srianand, S. Balashev, S. López 2018

All the systems in this sample have H2 detection!

PRE-SUMMARY

- What are the gas properties to form stars at high redsfhit?

  - Higher metallicity compared to normal DLA

  - nH in the range of 10-100 cm^{-3}

  - High dust content

  - Larger W(CaII) and W(NaI) than that in the Galaxy, which probably indicates that CI systems are closely associated to high-z galaxies

  - Extremely large W(MgII)

  - High dust-to-gas ratio

- How to trace this kind of gas efficiently?

  - CI traces molecular gas very efficiently

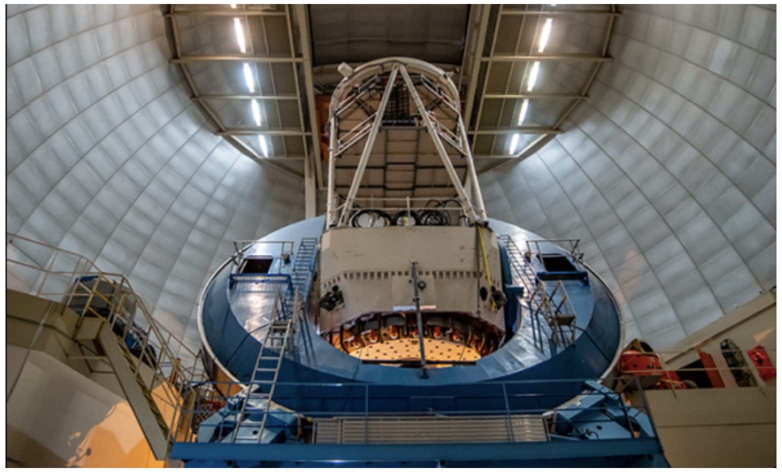
CONCLUSION

- I have analyzed the properties of a unique sample of **CI-selected** absorbers at high-redshift using the X-shooter spectrograph on the VLT.
- The metallicity of the C I-selected systems are **close to solar**, which is **10** times higher than that in the typical DLAs. The metallicity and dust-depletion are in turn more similar to what is seen in our Galaxy, despite CI-systems being observed when the Universe was about 10 Gyr younger.
- We detected 9/17 CaII H&K doublets and 10/17 NaID lines. We showed that dust attenuation is strongly correlated with w(CaII), similar to what is seen locally.
- CI absorbers are probably more closely associated to galaxies than other classes of absorption systems.
- These systems are not quiet! The observed kinematics of MgII lines in our sample are larger than that of regular DLAs, around **400** km/s. This implies that CI systems are **strongly disturbed**. This could be the signature of **star formation activity** within the associated galaxies.
- Since the dust content is remarkably high in the CI-selected sample, we predicted and then verified that H2 should be detected in every CI-system. This supports again our proposal that CI traces the cold gas efficiently.

ON-GOING PROJECTS

with Prof. Jiang Linhua in KIAA

- CI at z ~ 5 - 6
- High-z star forming galaxies (Ly-alpha emitters and Lyman Break Galaxies) at z > 5



- Subaru Prime Focus Spectrograph (PSF) —> sensitive to galaxies at all redshift even to the galaxies formed at the billions years of the Big Bang

  - inflows and outflows circle

Seeking for simulation collaboration !

PROSPECTS