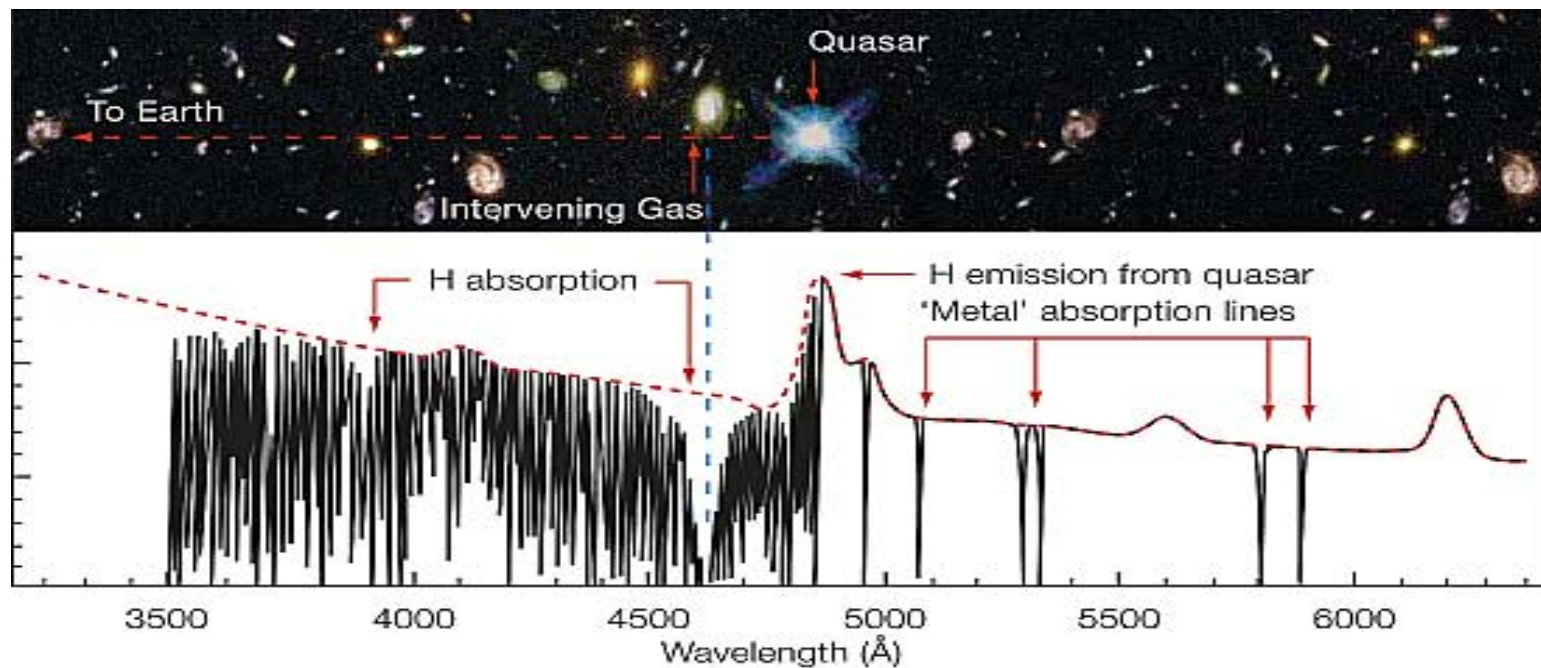


Dust and Molecules at high-z



Seeing Metal From Invisible Galaxies

ESO PR Photo 08/06 (15 February 2006)



R. Srianand, IUCAA, PUNE

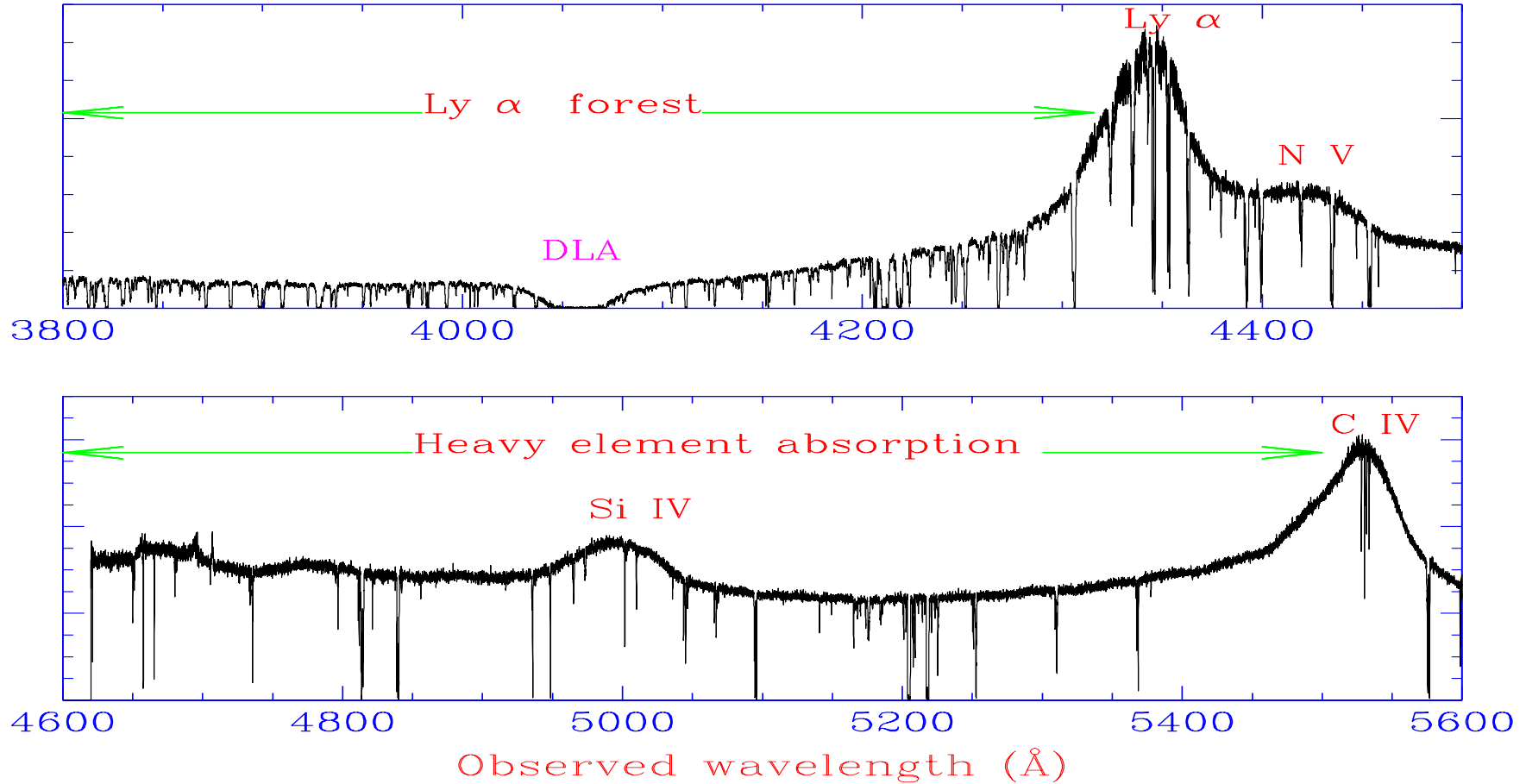
COLLABORATORS:

- Patrick Petitjean, IAP, France
- Neeraj Gupta, ASTRON, Netherlands
- Pasquier Noterdaeme, IAP, France
- Cedric Ledoux, ESO, Chile
- Sebastian Lopez, Universidad de Chile, Chile
- Hadi Rahmani, IUCAA
- Sowgat Muzahid, IUCAA

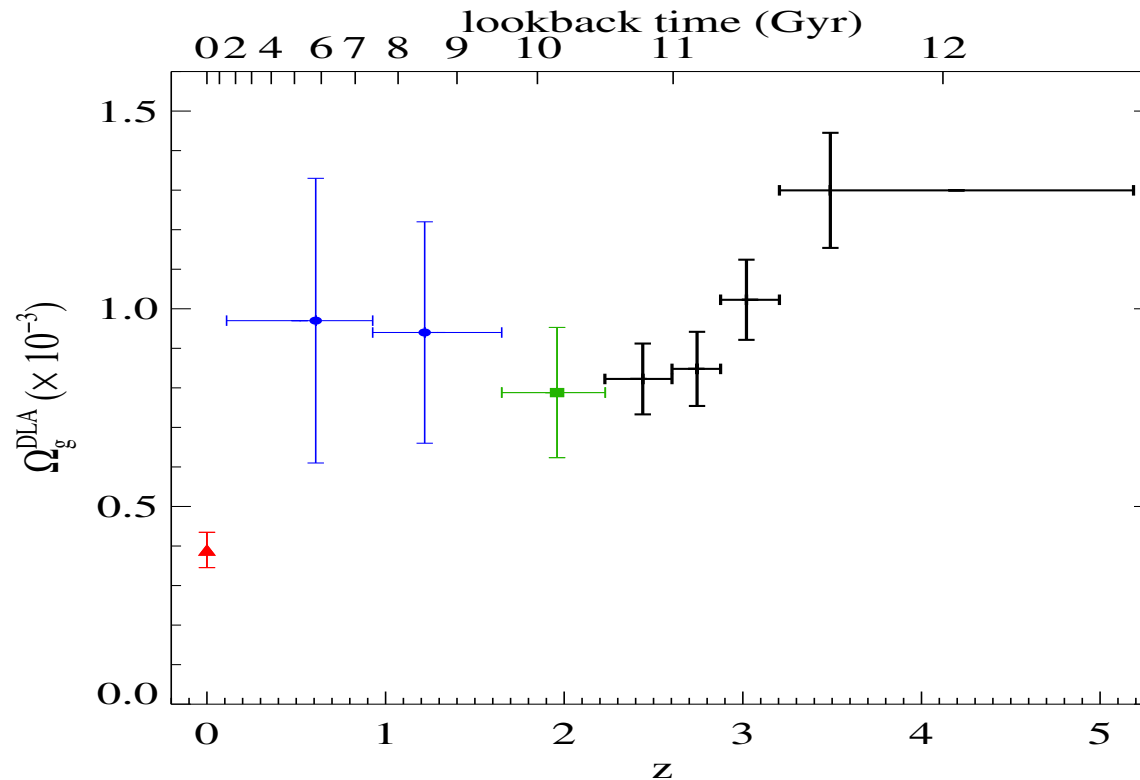
PLAN OF THE TALK:

- Basic introduction to damped Lyman- α systems (DLAs)
- Search in DLAs for
 - H₂ and HD absorption
 - CO molecule
 - 2175 Å bump
 - DIBs
- Summary

QSO SPECTRUM: ABSORPTION LINES



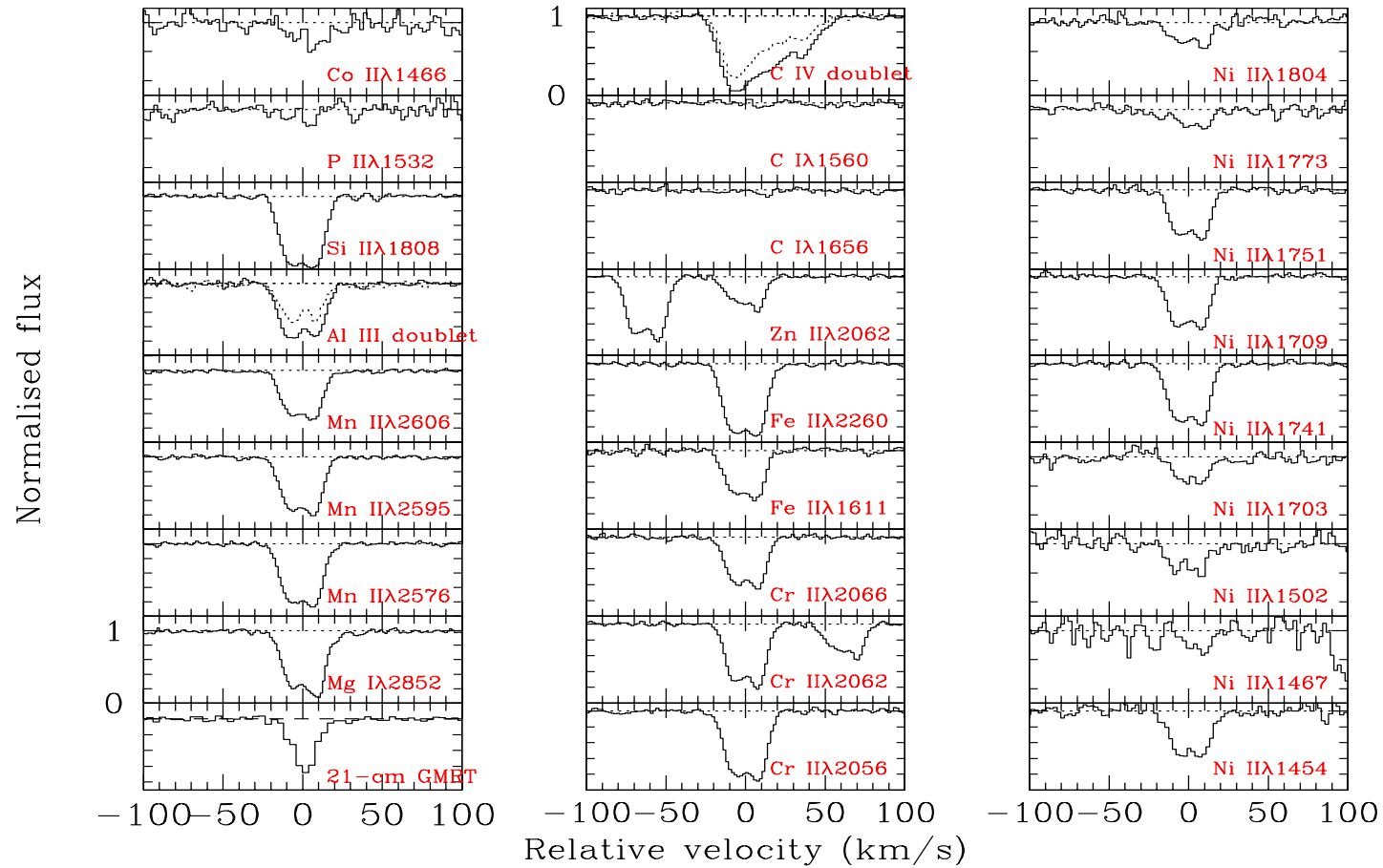
DLAs CONTAIN GOOD AMOUNT OF Ω_g :



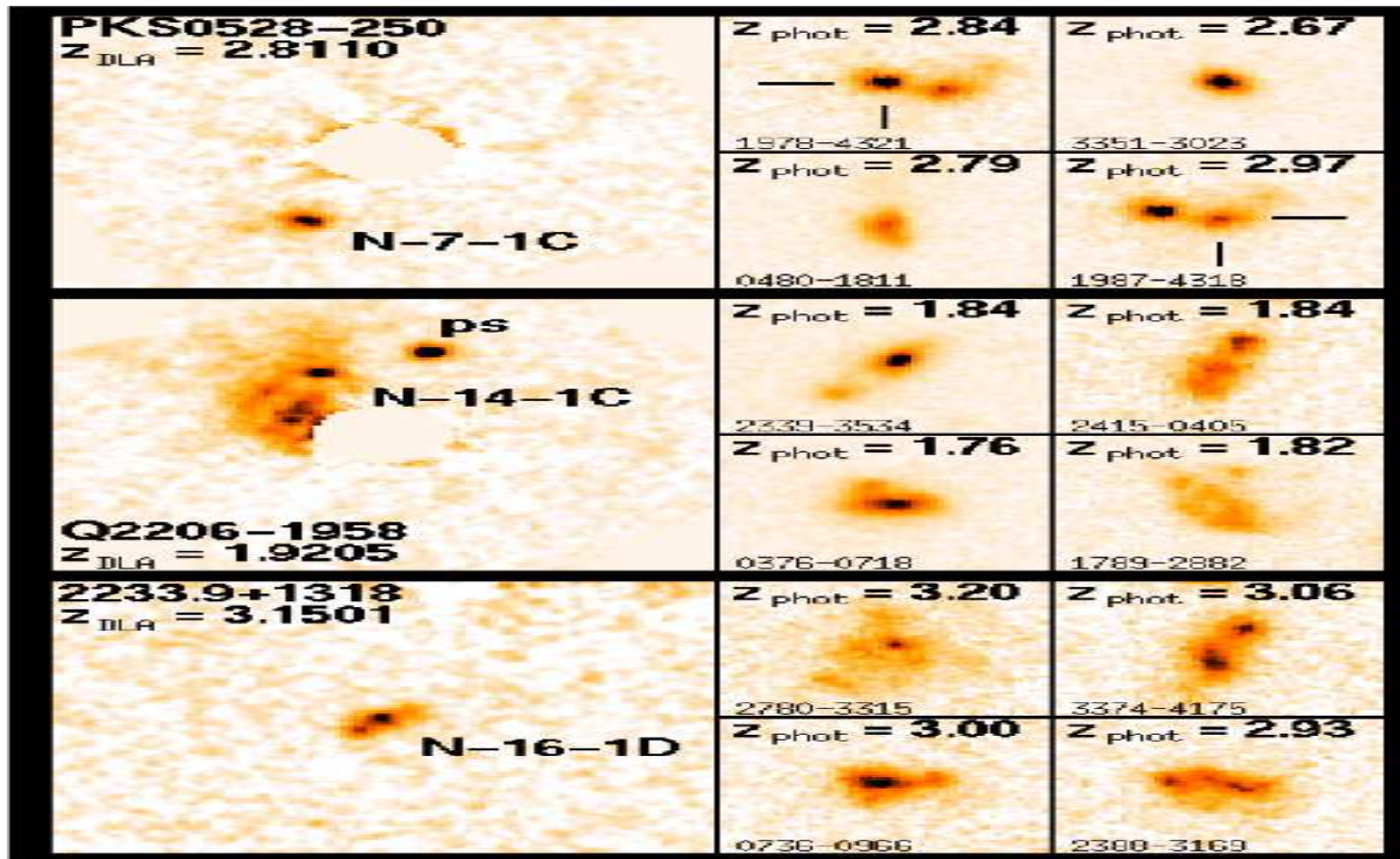
Noterdaeme et al. 2009, A&A, 505, 1087

WIDE RANGE OF HEAVY ELEMENTS

$z = 1.3710$ system towards J0108-0037

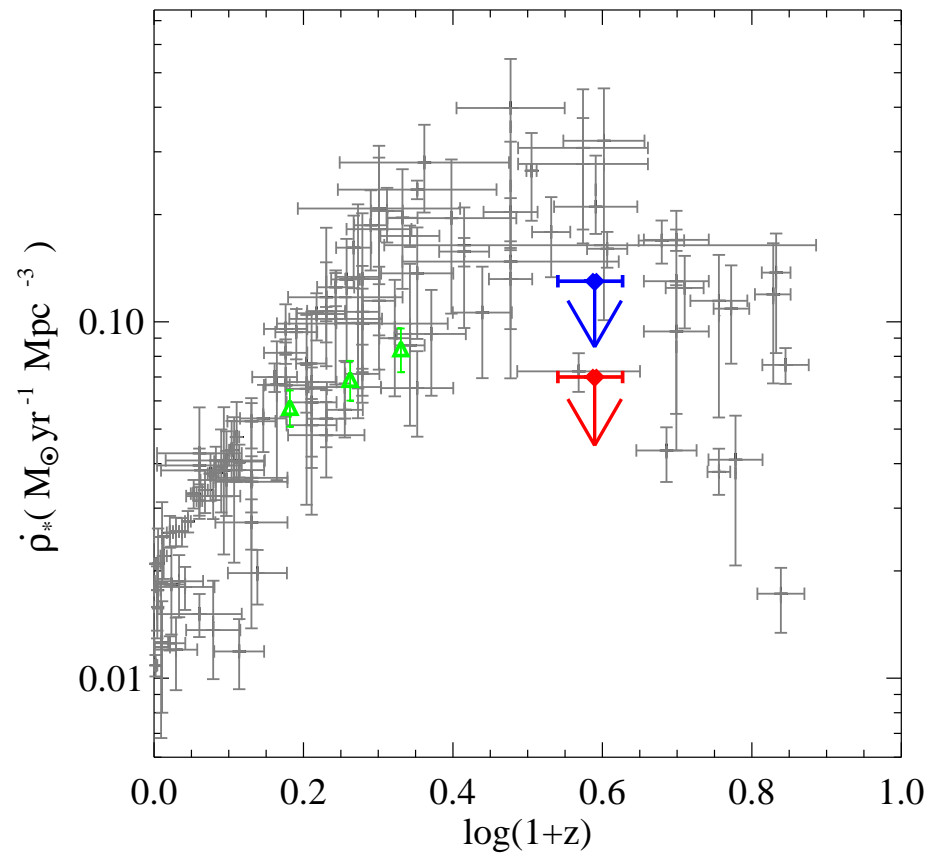
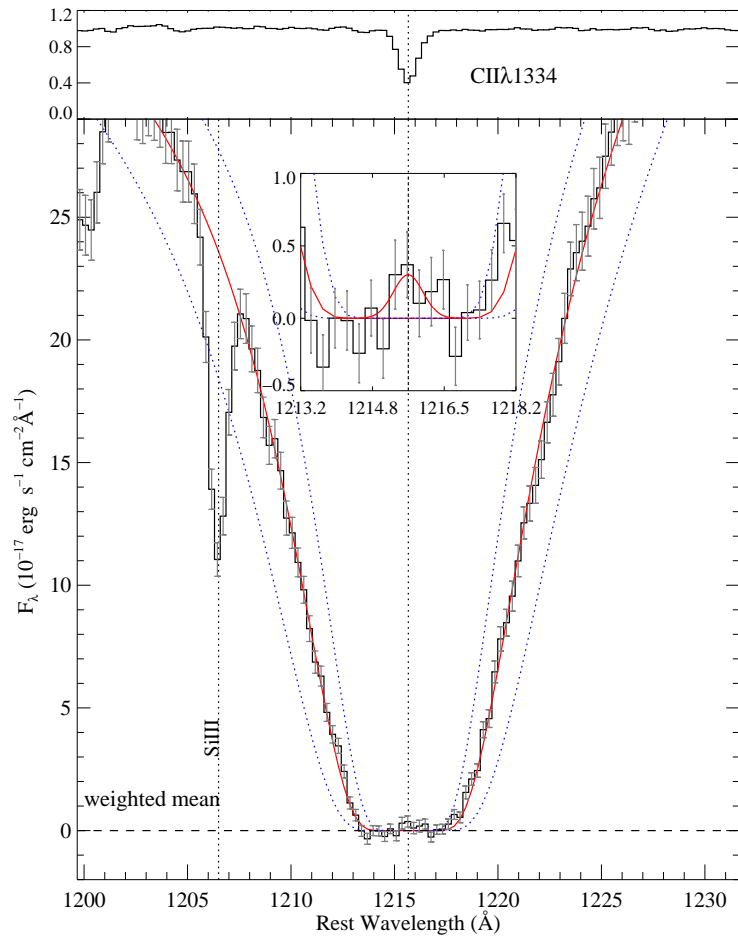


PROPERTIES OF DLAS: HIGH Z DLAS AND LBGs



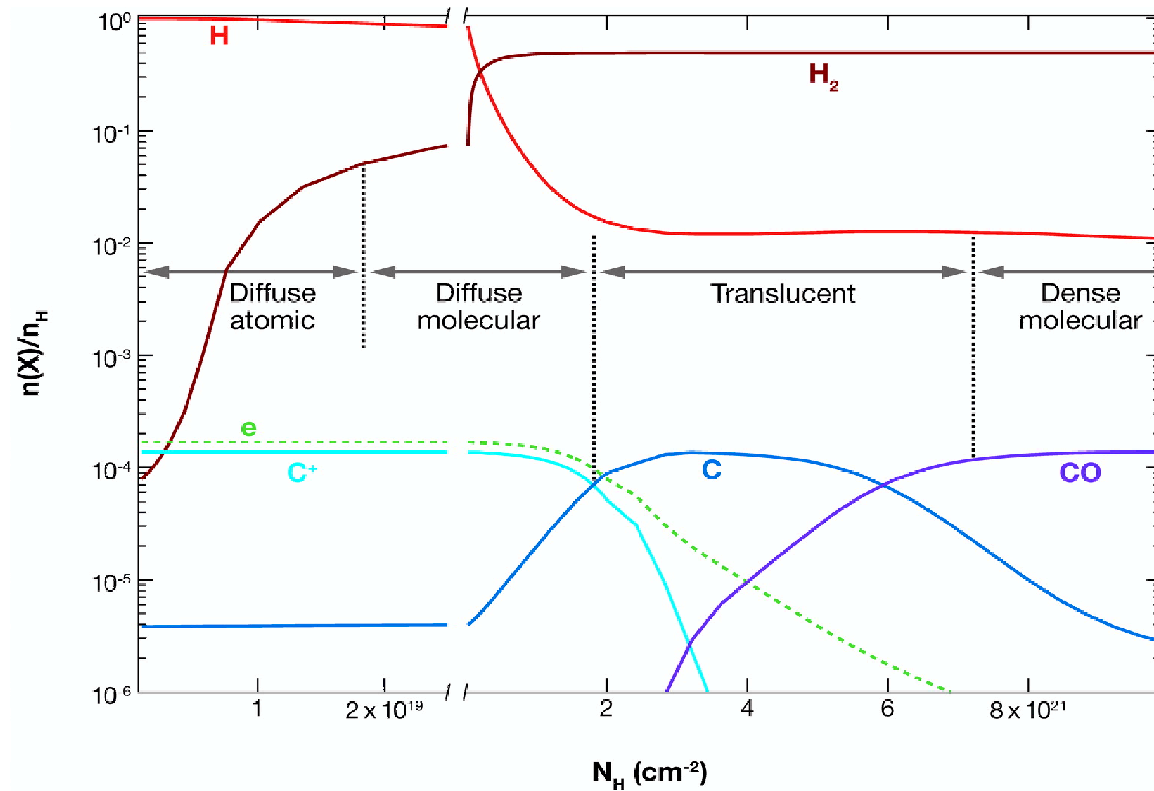
Most of these have high metallicity absorbers—Moller et al., 2002


INSITU STAR-FORMATION IN HIGH-Z DLAs



Rahmani et al. 2010

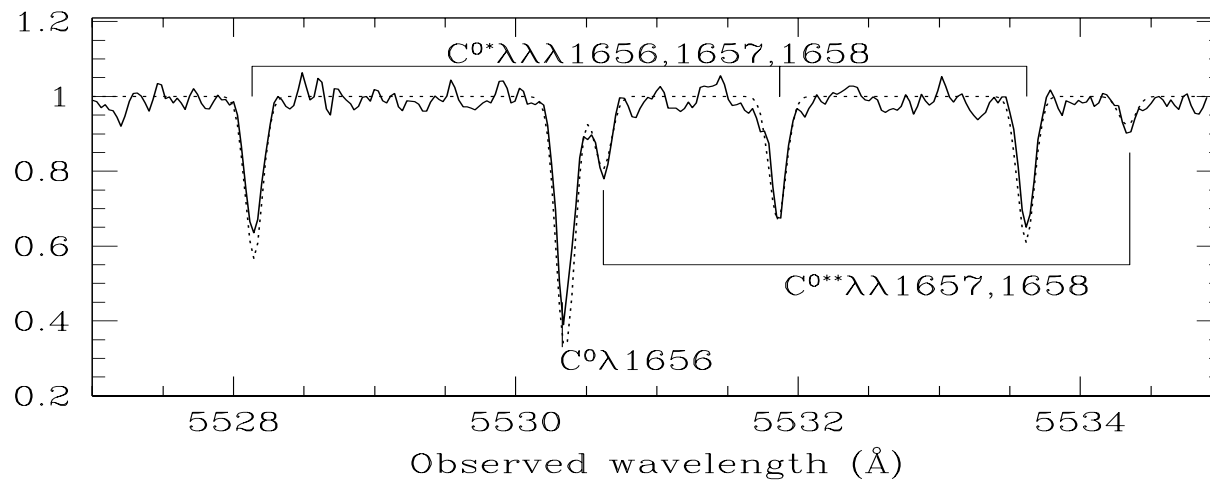
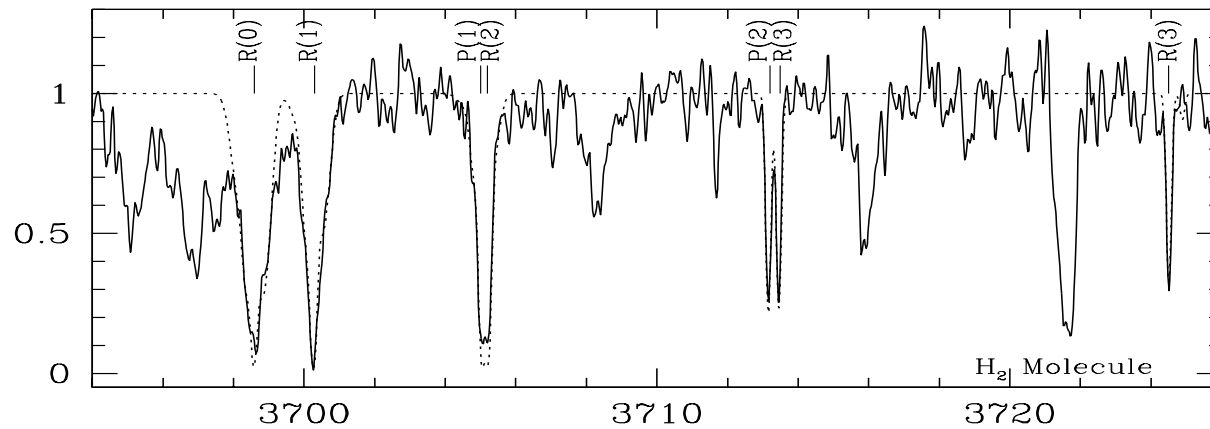
PHOTO-DISSOCIATION REGIONS:



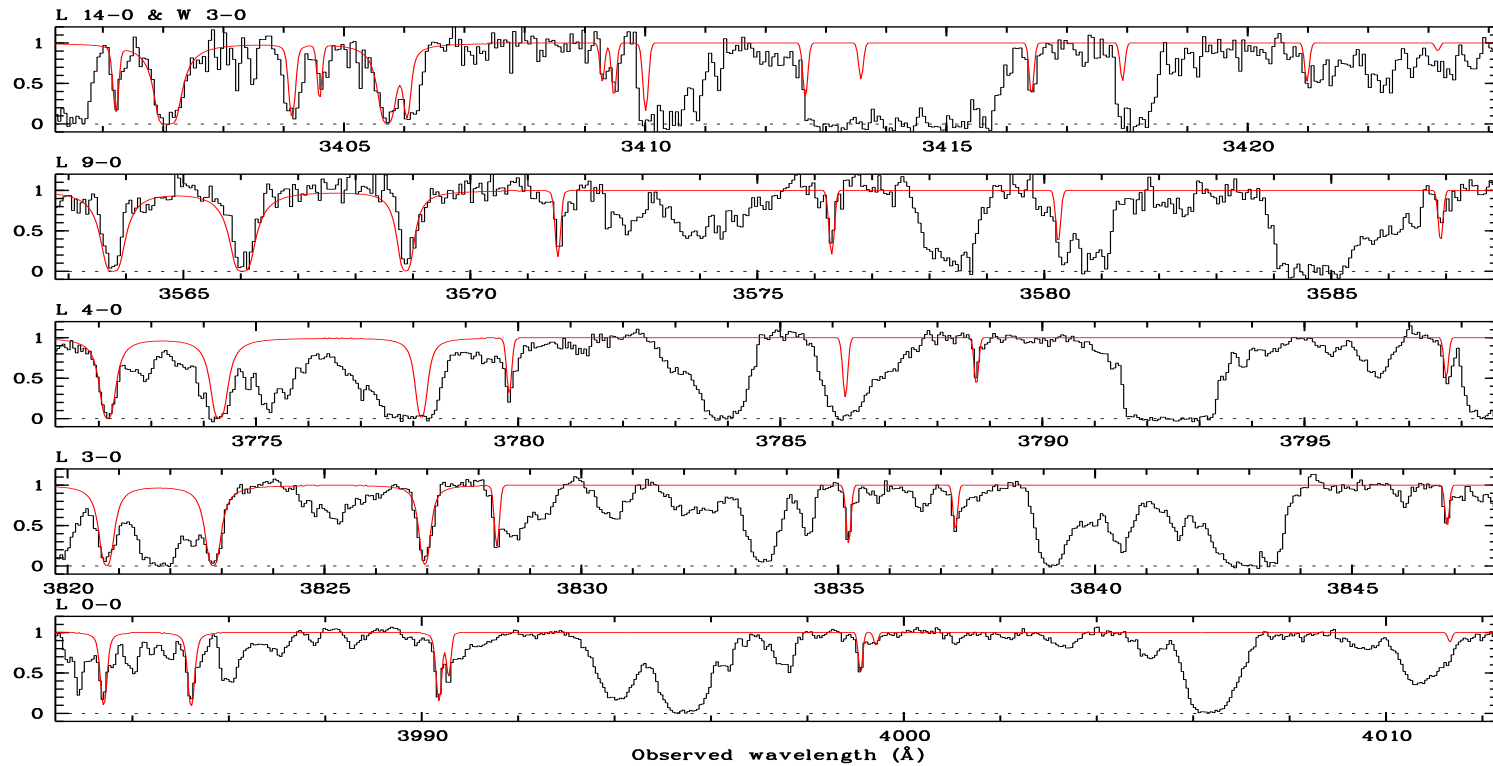
 Snow TP, McCall BJ. 2006.
Annu. Rev. Astron. Astrophys. 44:367–414

H₂ MOLECULES:

H₂ AND C I IN DLAs:



SEARCH FOR H₂ IN DLAs: UVES SURVEY



Petitjean et al. 2000; Ledoux et al. 2003; Srianand et al. 2005; Noterdaeme et al. 2008 & Srianand et al. 2011

MOTIVATION: UVES SURVEY

- Quantify the H₂ fraction in DLAs
- Use the rotational level population to infer the physical state of the gas
- Establish the connection between C I and H₂ and get additional constraints on physical state of the gas.
- Constraining the variation of fundamental constants.
- Probing the thermal evolution of CMBR.
- Obtaining HD/H₂ and providing independent constraints on Ω_b

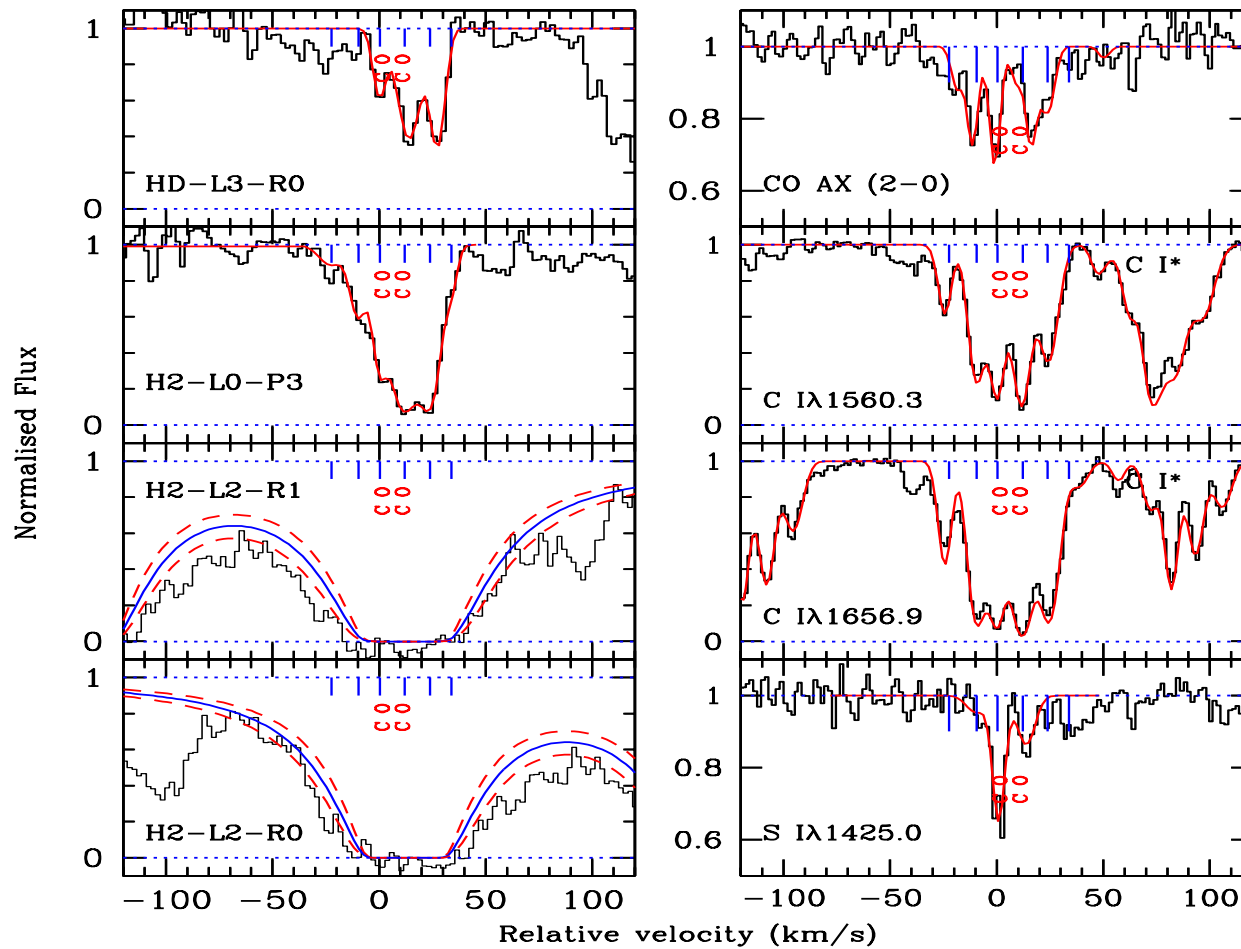
RESULTS OF OUR UVES SURVEY:

- Out of 77 DLAs at $z \geq 1.8$ only 13 show H₂ detection.
- Molecular fraction: 5×10^{-7} and 0.1. (Diffuse gas!).
- Molecular fraction: $\leq 10^{-5}$ in non-detections
- H₂ detection is independent of H I column density
- H₂ detection is more frequent in high metallicity and dusty DLAs.
- $T = 100\text{-}300$ K, $n_{\text{H}} = 10 - 200 \text{ cm}^{-3}$ and $G = \text{few } G_0$.
- Good candidates for constraining $\Delta\mu/\mu$.
- HD is detected in one case. D/H is consistent with WMAP constraints.
- **Photoionization models**: most of the DLAs originate from low density hot gas.
- **21-cm survey**: The H₂ gas contains very small amount of $N(\text{H I})$. The extent of this component is less than 10 pc.

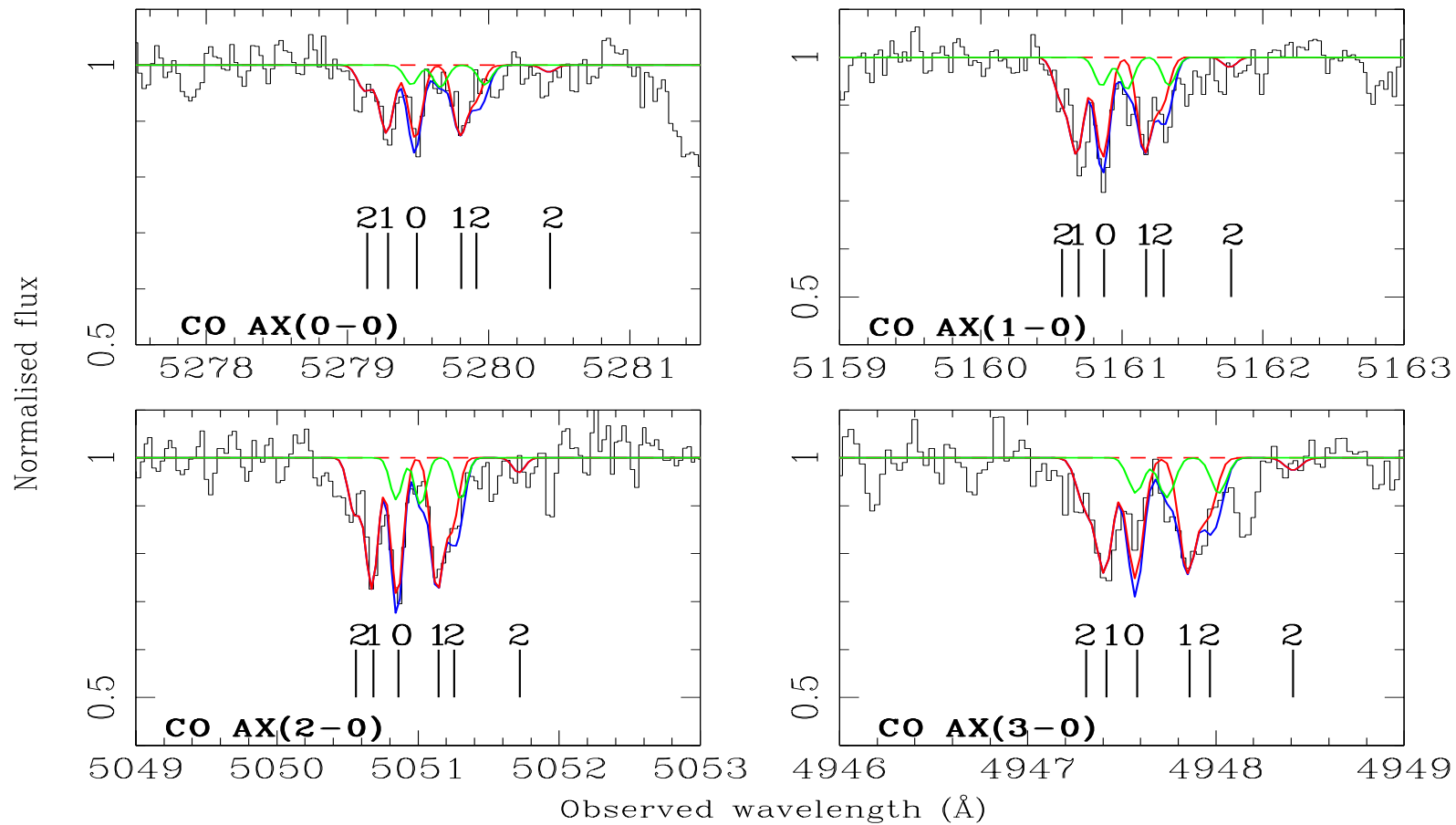
SEARCH FOR CO IN DLAs:

- To detect translucent and molecular gas.
- Automatic search for very strong C I absorption in the SDSS spectrum of QSOs. 45 strong systems found.
- The expected CO bands are in high wavelength side of the Lyman- α emission from the QSOs so one can search for them at $z \geq 1.5$.
- Detection of CO at $z \geq 2$ will allow one to measure CO/H₂ directly at different environments.

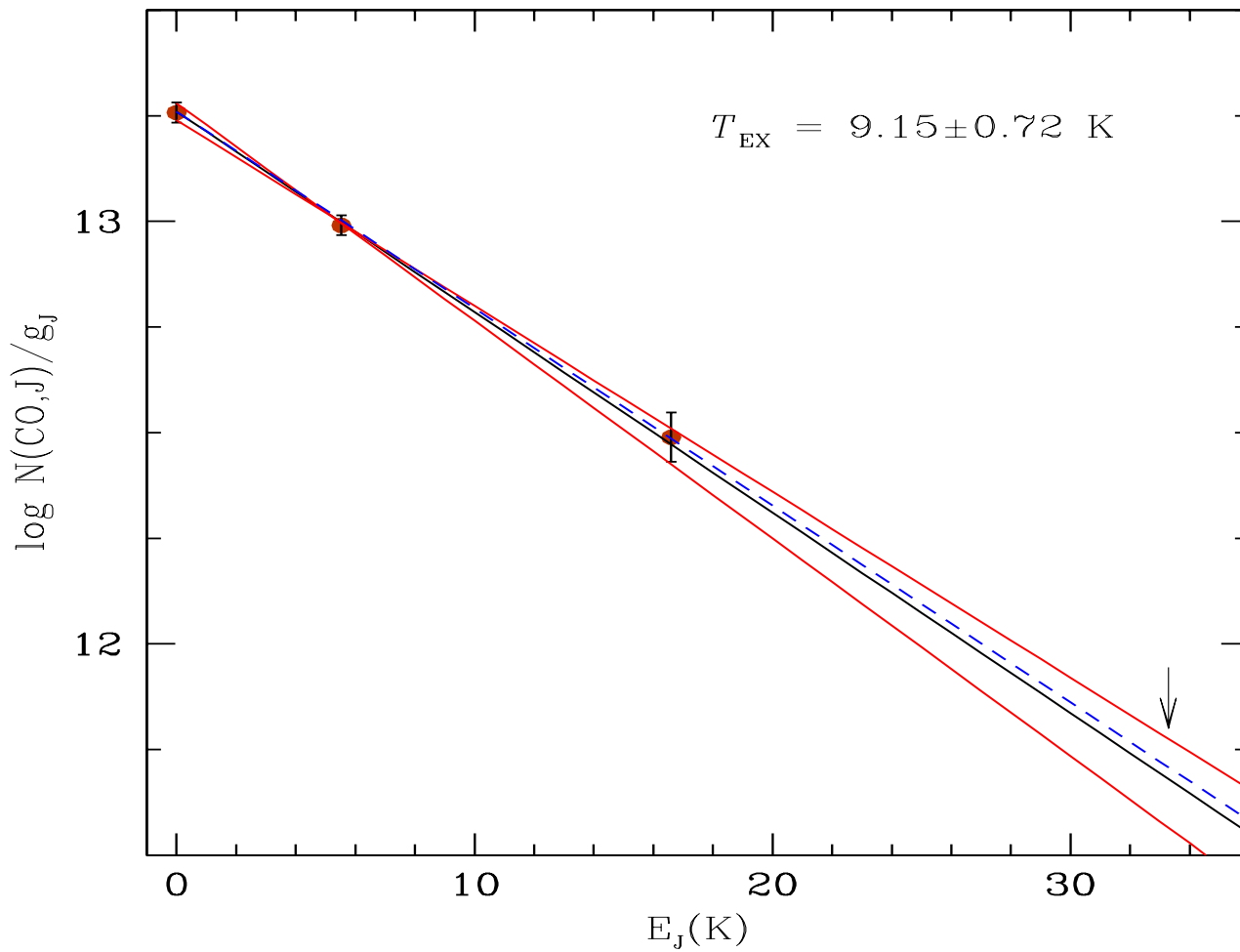
FIRST DETECTION OF CO IN A DLA AT HIGH-Z



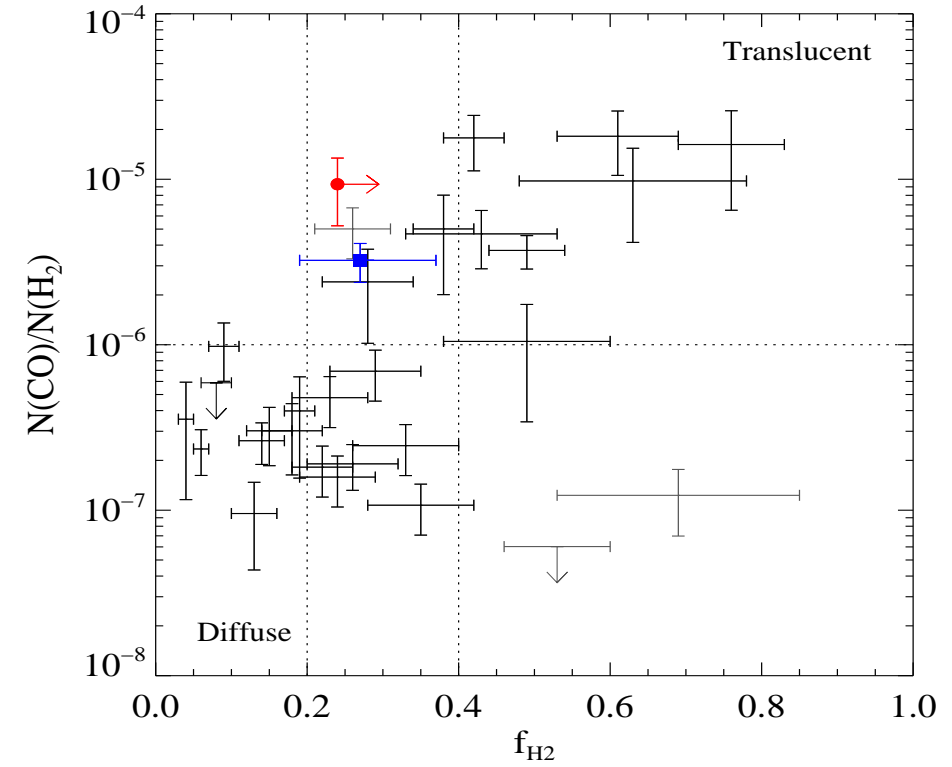
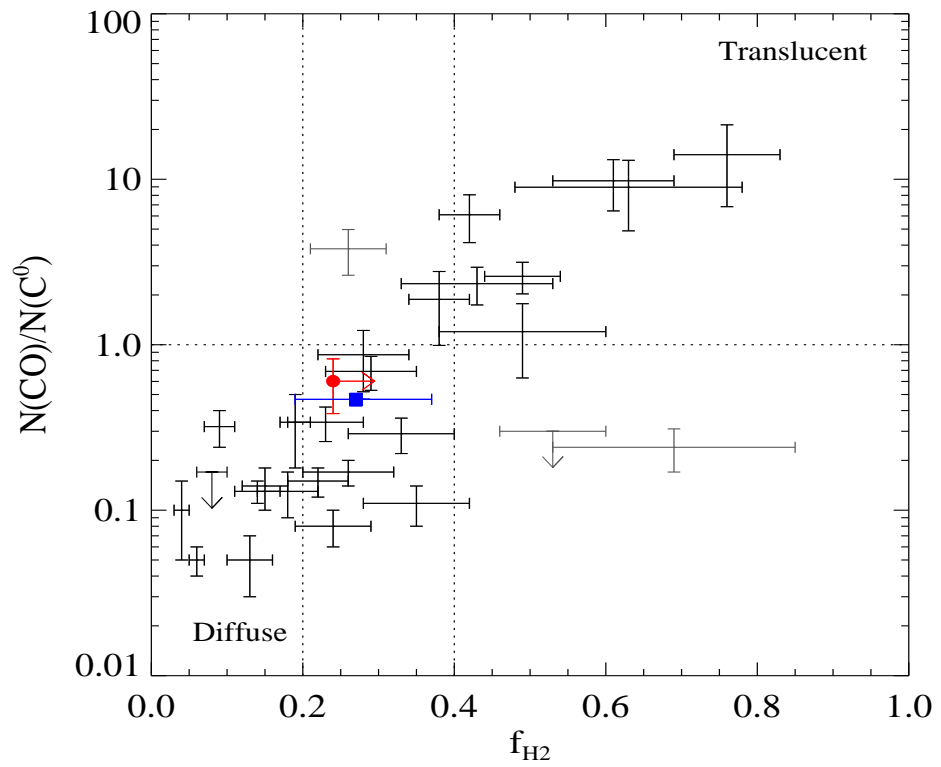
VOIGT PROFILE FITTING OF DIFFERENT J LEVELS:



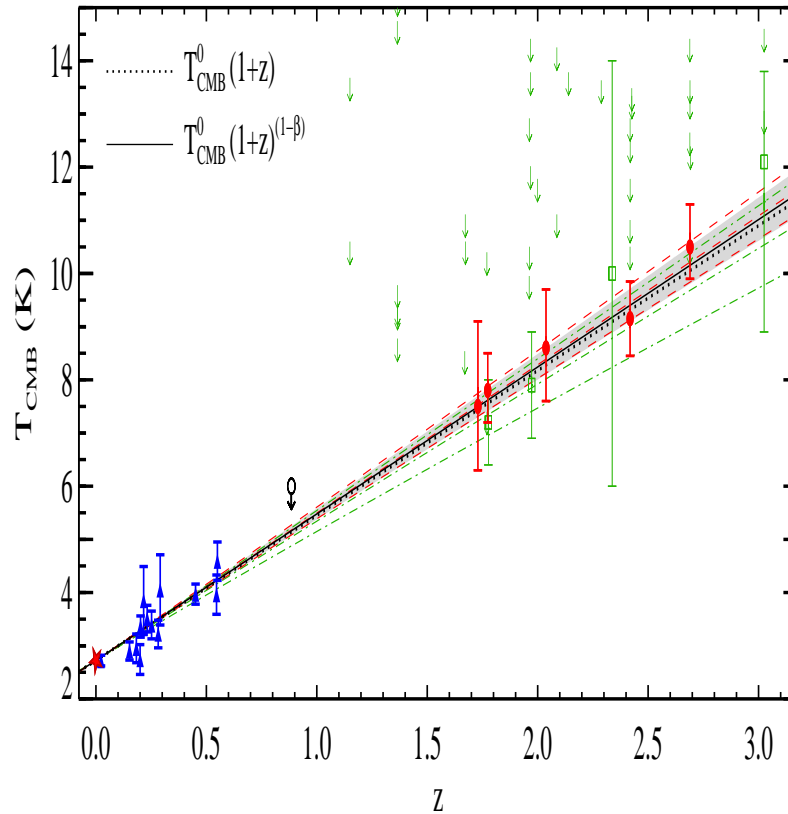
CO EXCITATION DIAGRAM



CO/H₂ RATIO



T(CMBR) vs. z



- $T_{\text{CMB}}(z) = (2.725 \pm 0.002) \times (1+z)^{1-\beta}$ with $\beta = -0.007 \pm 0.027$.
- Following decaying dark energy models of Jetzer et al. 2010,

$$T_{\text{CMB}}(z) = T_{\text{CMB}}(z=0) \times (1+z)^{3\gamma-1} \left(\frac{(m-3\Omega_m) + x(1+z)^{m-3}(\Omega_m-1)}{(m-3)\Omega_m} \right)$$

Where, $\gamma = 4/3$, $\Omega_m = 0.275 \pm 0.015$ and $m=3(w_{eff} + 1)$ with $w_{eff} = p/\rho$. The best fitted value is $w_{eff} = -0.996 \pm 0.025$.

Noterdaeme et al. 2011, A&AL, 526, L7

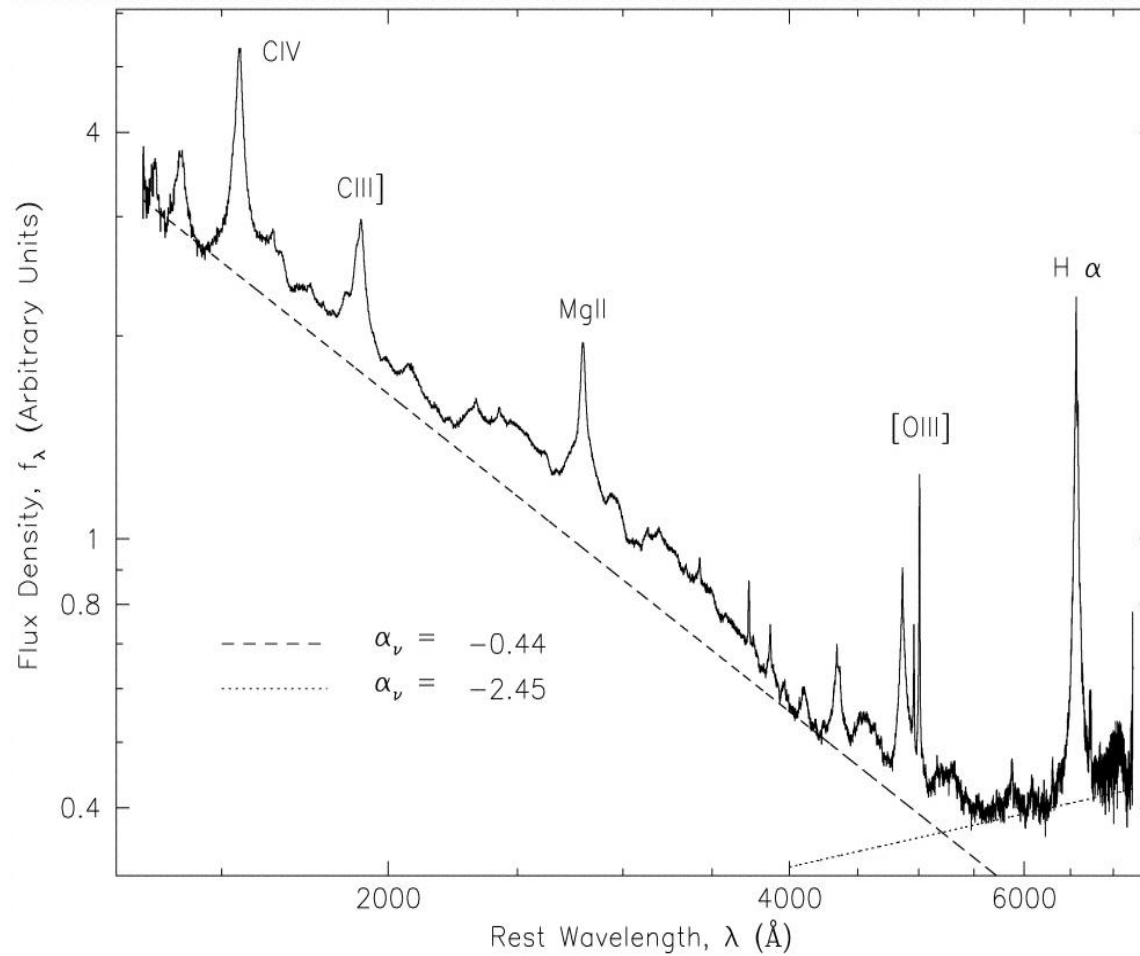
CO SURVEY: STATUS

- 16 bright candidates were observed with UVES and about 20 is being observed with X-SHOOTER.
- Till now there are 7 CO detections. Whenever $z \geq 2$ we are detecting very strong H₂ and HD molecules.
- Typical detection limit of N(CO) is few times 10^{13} cm^{-2} .
- 50% of the data yet to be analysed.
- CO detections are all towards red objects not in SDSS because of color selection but for other reasons.
- Strong C I absorbers allow us to probe the translucent gas at high-z.
- X-SHOOTER spectra also allow us to search for associated emission from the absorbers.

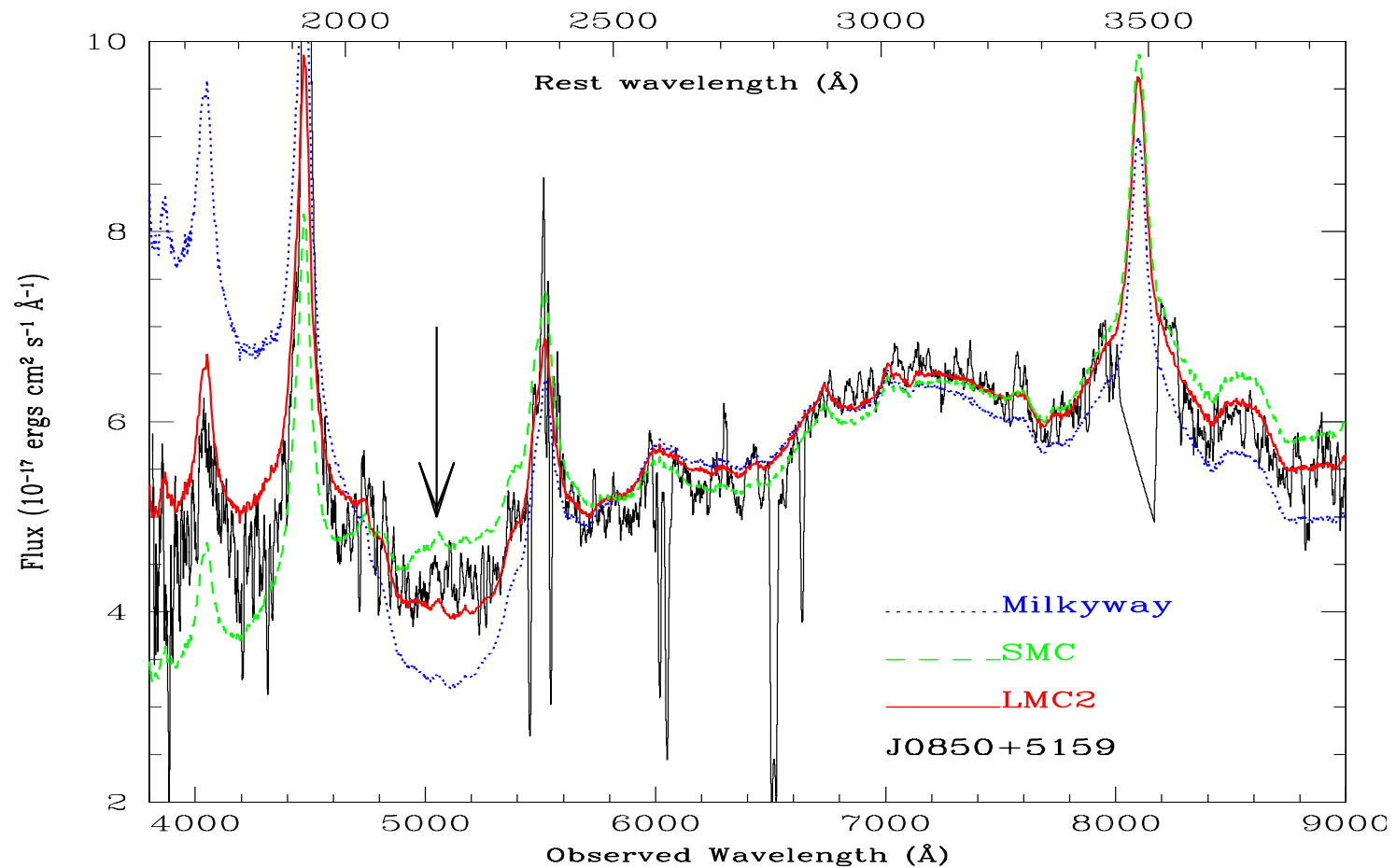
Srianand et al. 2008; Noterdaeme et al., 2009; 2010; 2011

2175 Å FEATURES:

QSO COMPOSITE SPECTRUM:

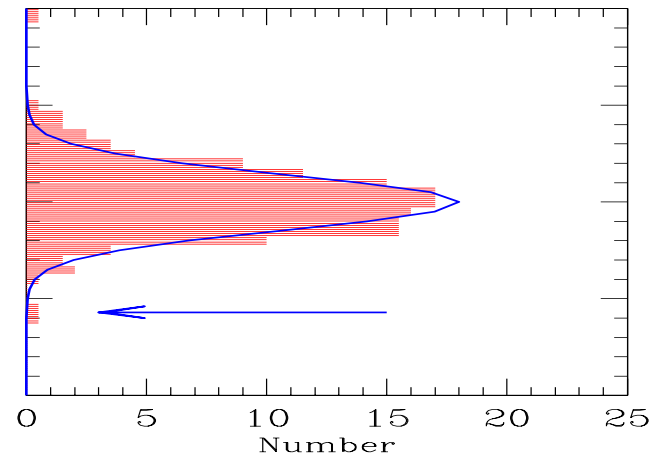
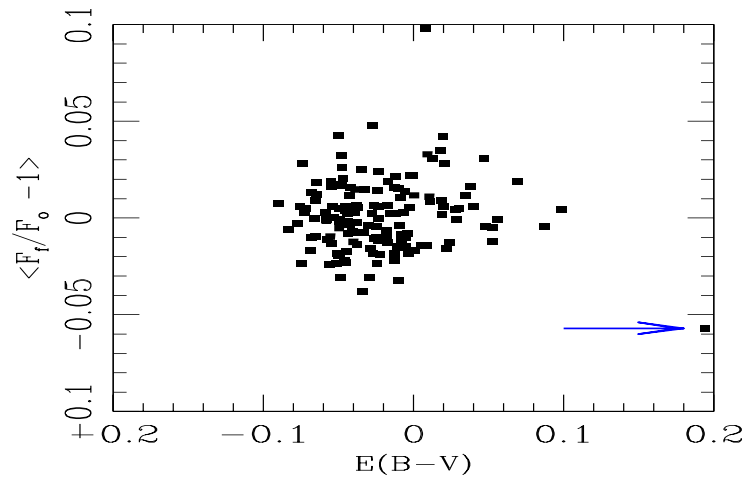
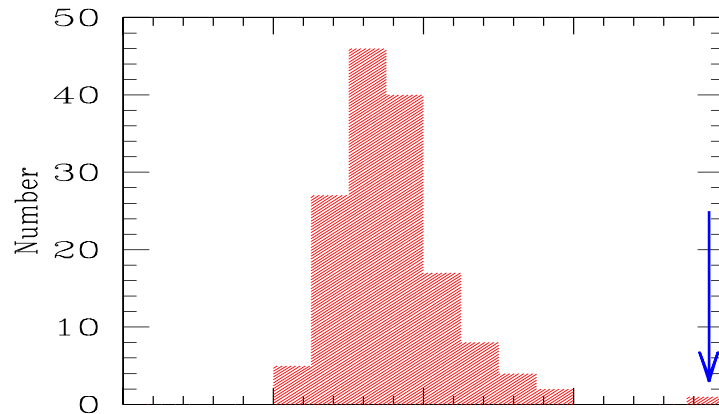


2170Å DUST FEATURE TOWARDS J0850+5159

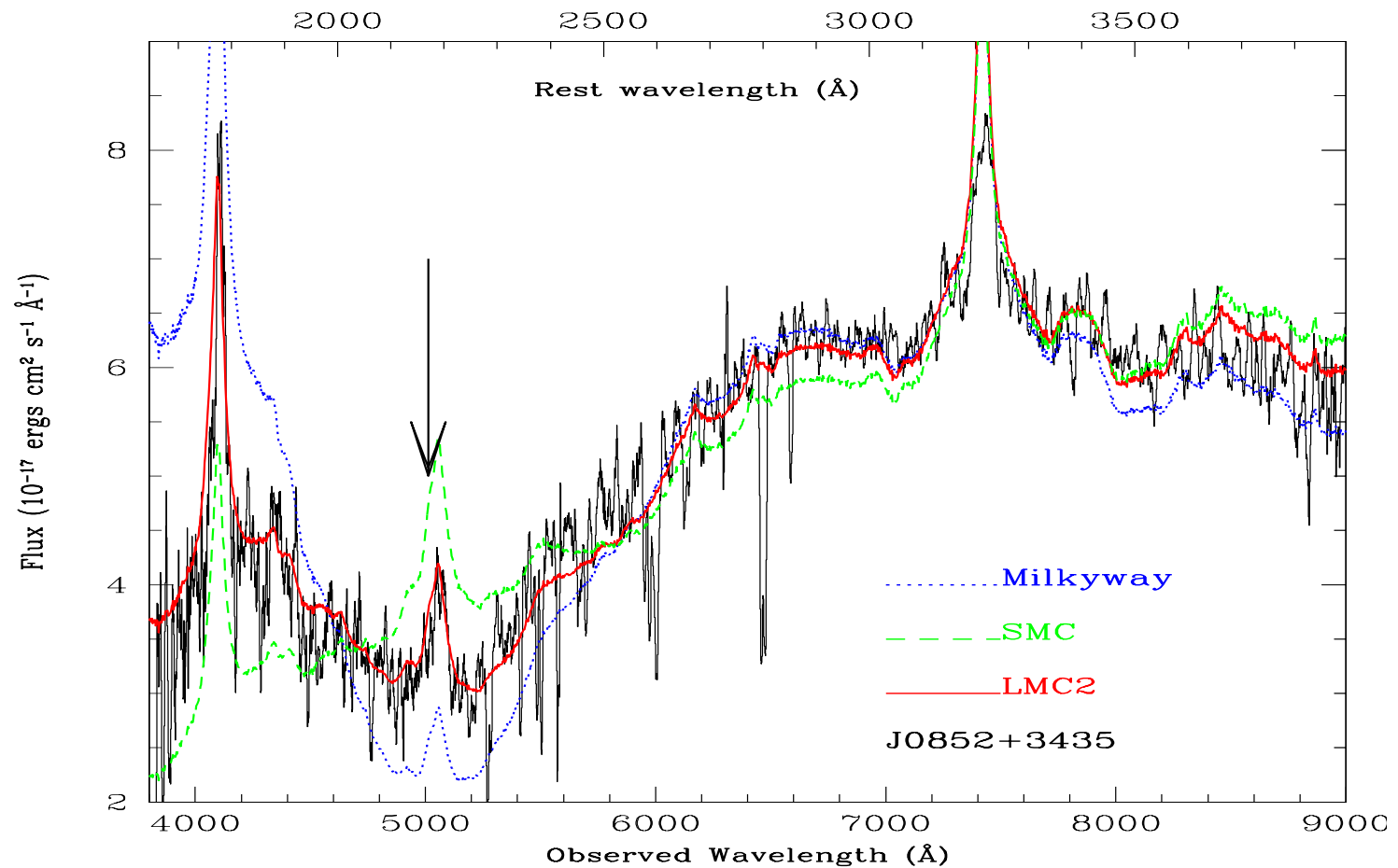


SIGNIFICANCE OF THE FEATURE:

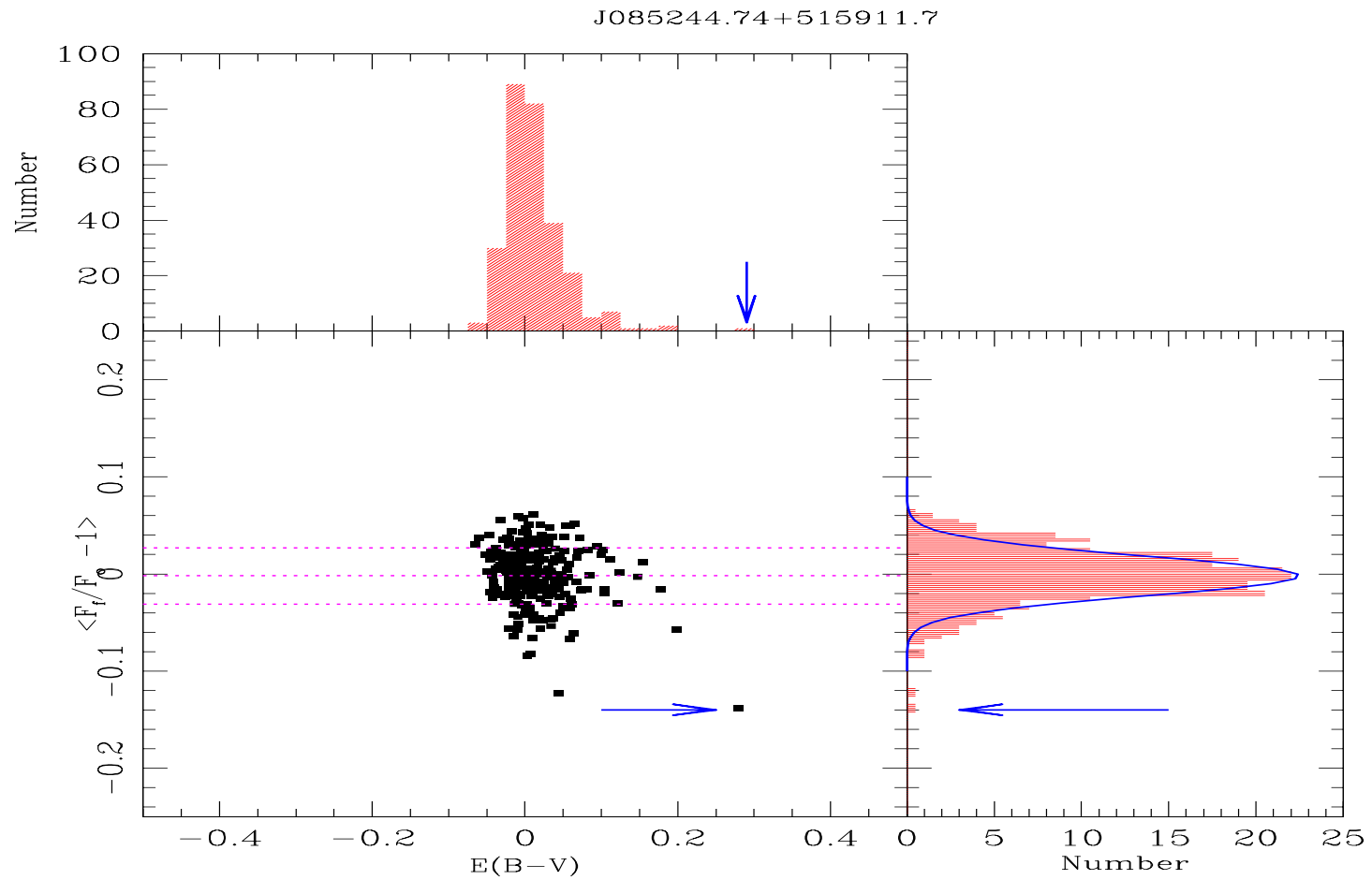
J085042.21+515911.7



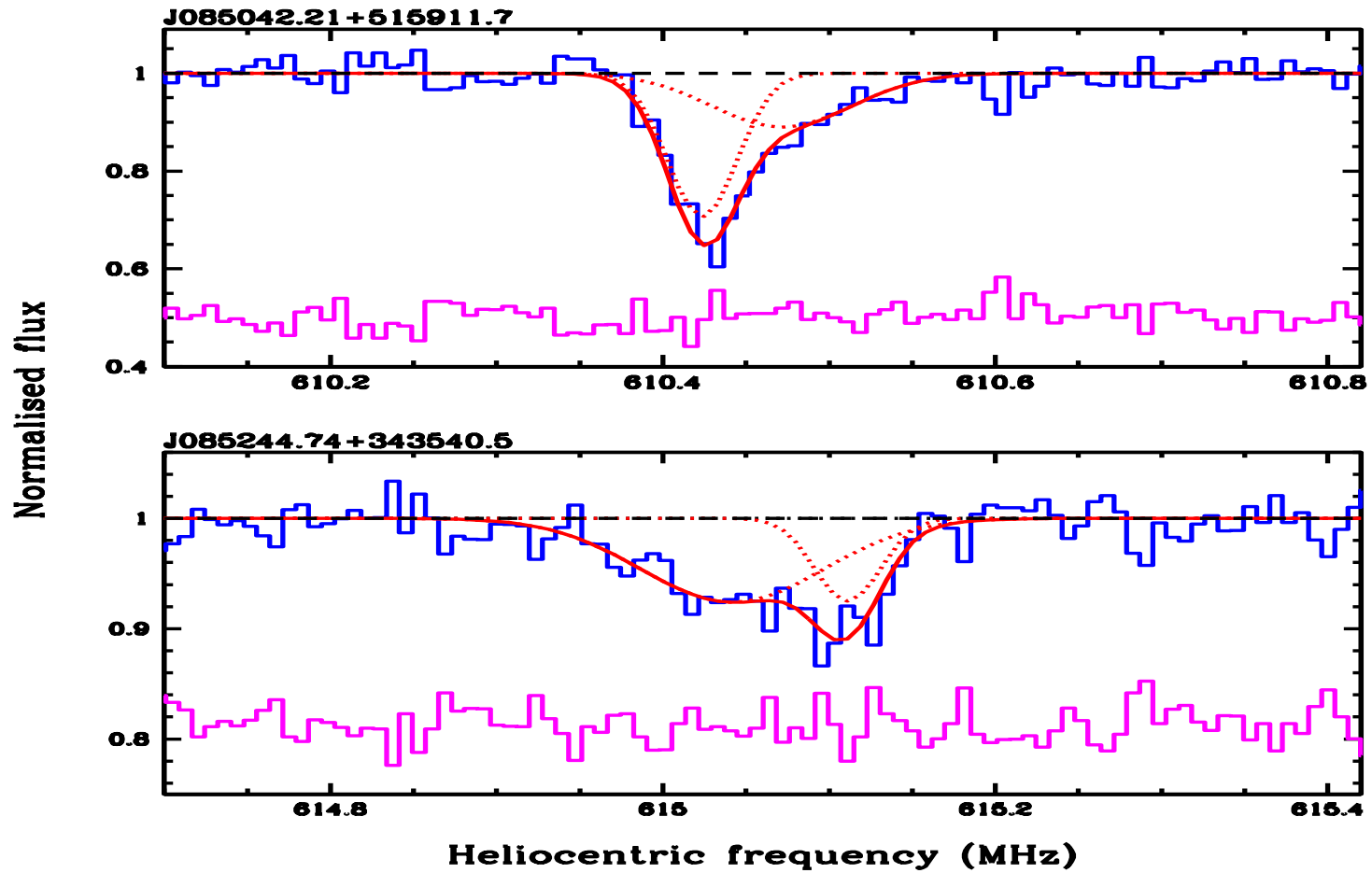
2170Å DUST FEATURE TOWARDS J0852+3432



SIGNIFICANCE OF THE FEATURE:



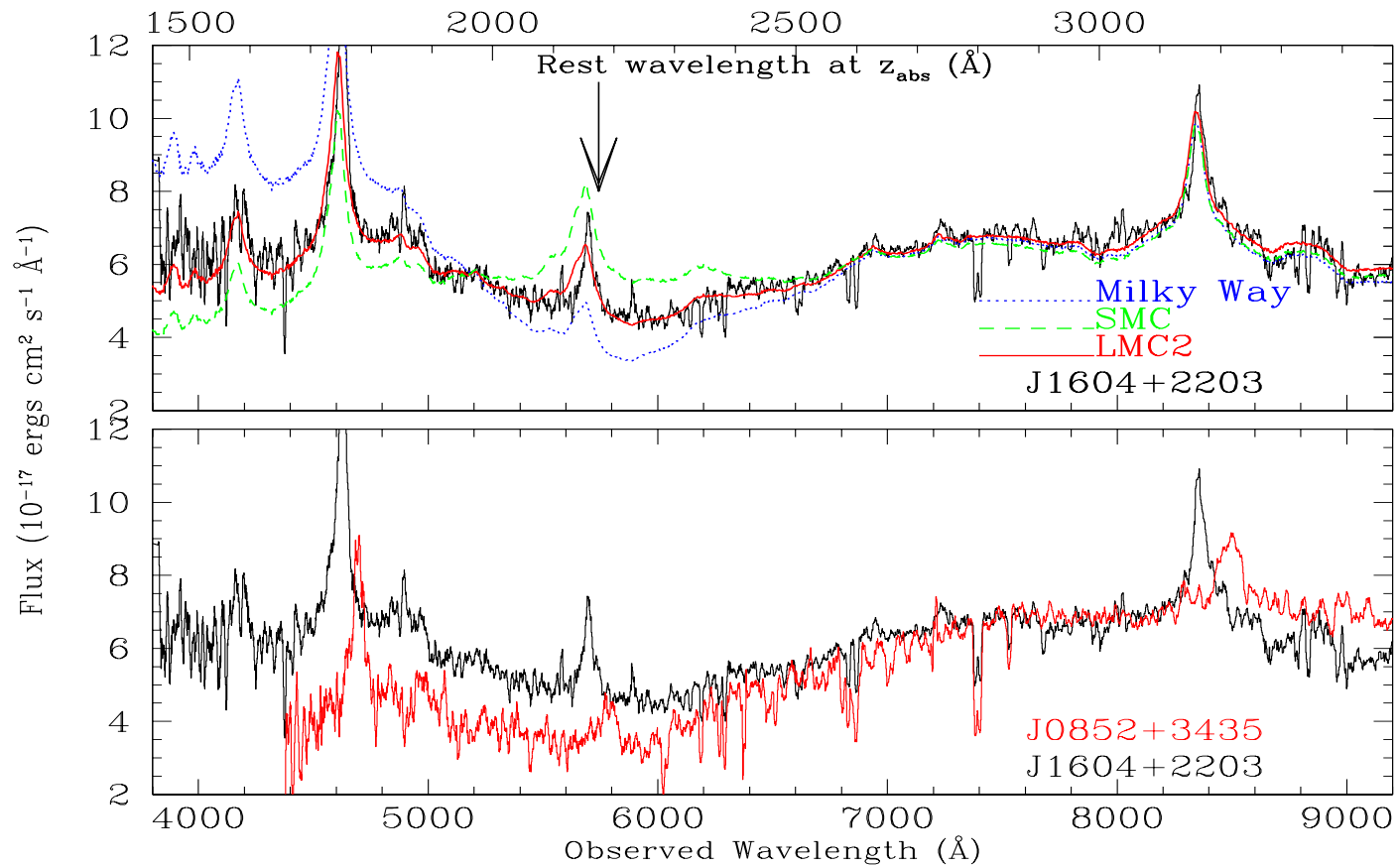
GMRT SPECTRA:



SED FITTING: RESULTS

- For J0850+5159 :
 - $N(\text{H I}) = (5.73 \pm 1.10) \times 10^{21} \text{ cm}^{-2}$
 - $T_s \sim 190_{-69}^{+124} \text{ K}$
- For J0852+3435 :
 - $N(\text{H I}) = 6.97 \pm 1.30 \times 10^{21} \text{ cm}^{-2}$
 - $T_s/f_c = 536_{-88}^{+234} \text{ K}$.

CO AND UV BUMP

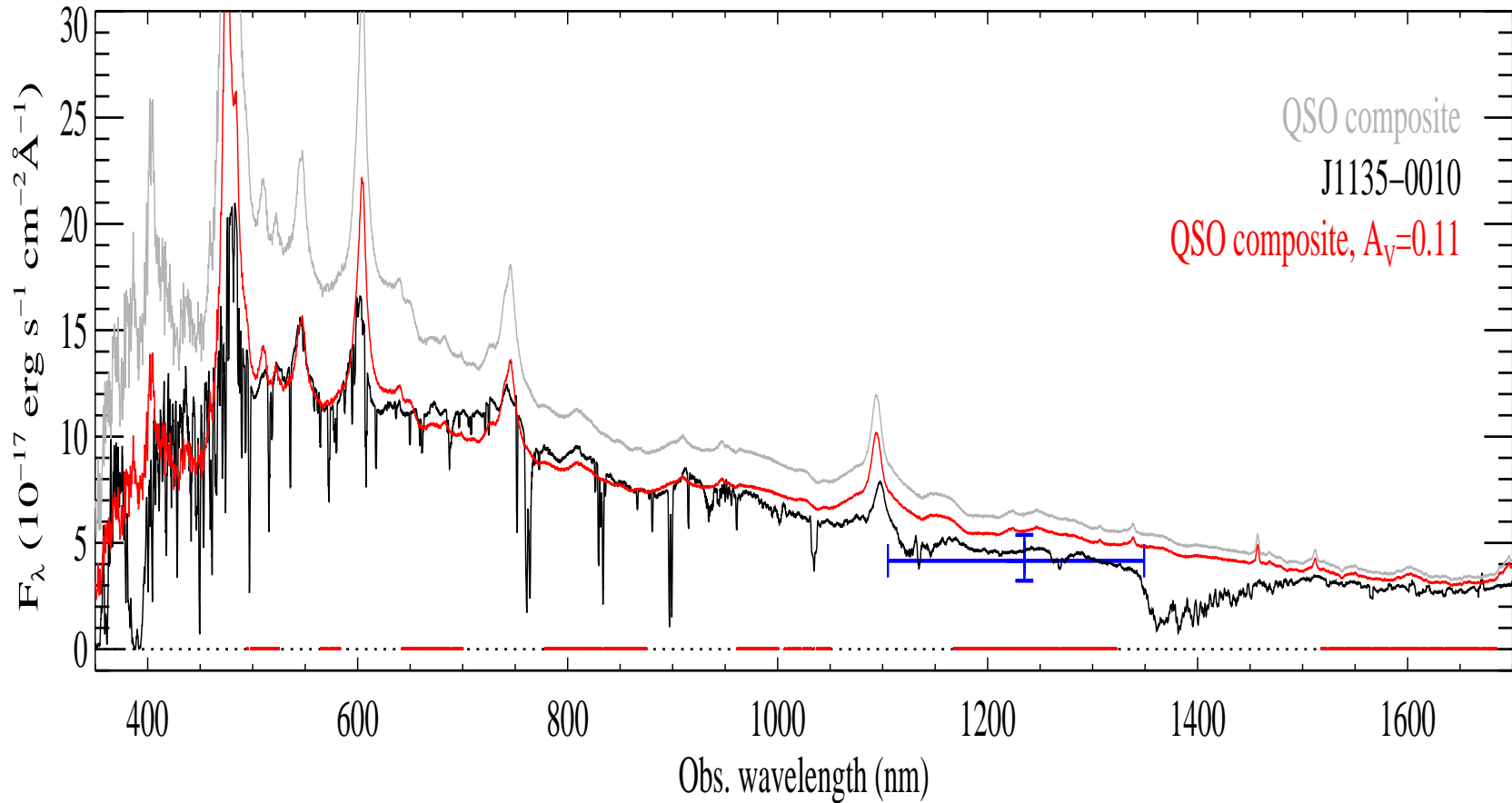


SDSS SAMPLE:

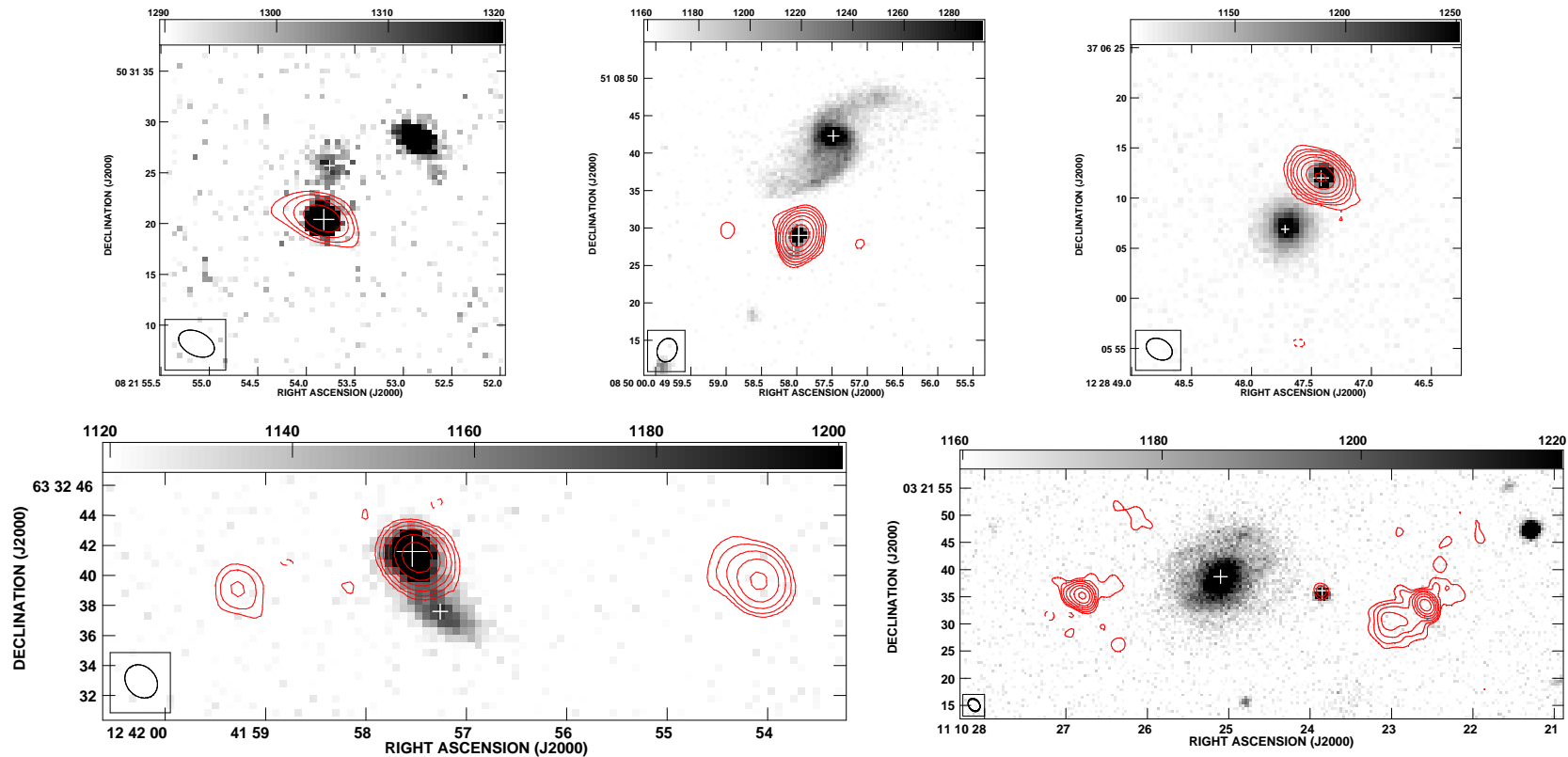
- 9.7 μm silicate feature is seen in the systems that show UV bump. (Kulkarni et al. 2011, ApJ, 726, 14)
- ~ 15 UV bump candidates. Most of them will be searched for CO using VLT.
- 39 Mg II systems with bump are reported by Jiang et al. 2011, ApJ, 732, 110.
- Estimation of redshift path length for dusty absorbers.

DIBS AT HIGH-Z:

DIBs IN DLAs: X-SHOOTER SPECTRA



QSO-GALAXY PAIRS: GMRT MINI-SURVEY



Gupta et al. 2010

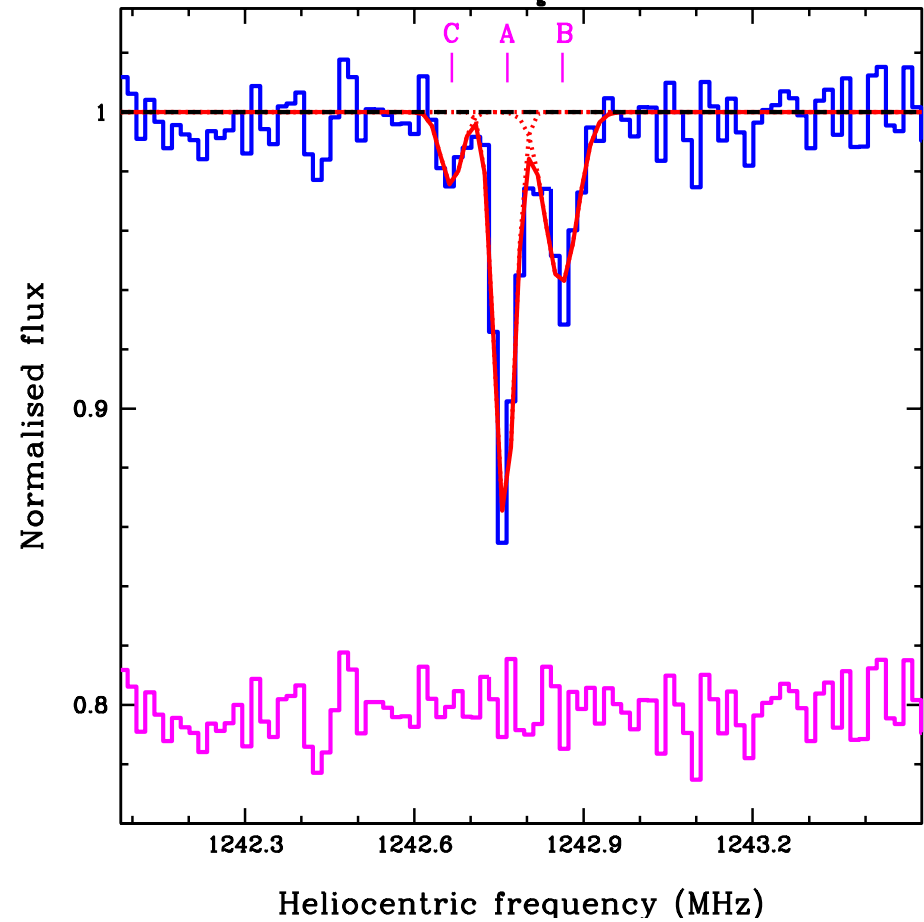
QSO-GALAXY PAIRS: J124157.54+633241.6

J124157.54+633241.6

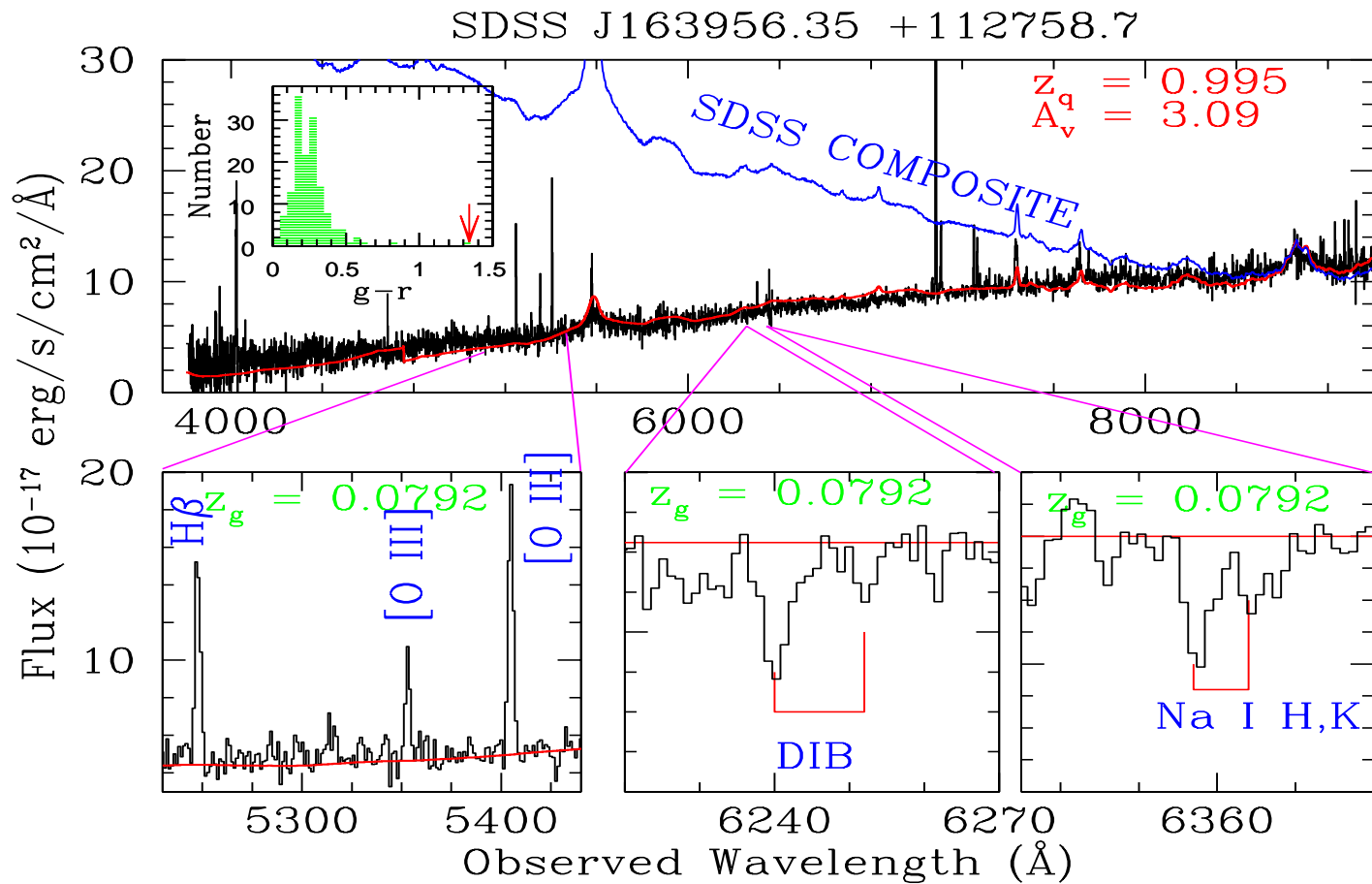


J124157.26+633237.6, $z=0.143$

SDSS J124157.54+633241.6 $z_g=0.144$



QSO-GALAXY PAIRS: DIBs



SUMMARY:

- We are successful in detecting the basic molecules in DLAs under normal interstellar medium conditions.
- Complex molecules are still elusive. May be due to colour selection of QSOs. New selection is needed.
- 2175Å feature is detected at high-z. DIBs are still elusive for $z \geq 0.5$.
- Blind radio survey will be helpful.