Damped Lyman-alpha systems in absorption

Pasquier Noterdaeme

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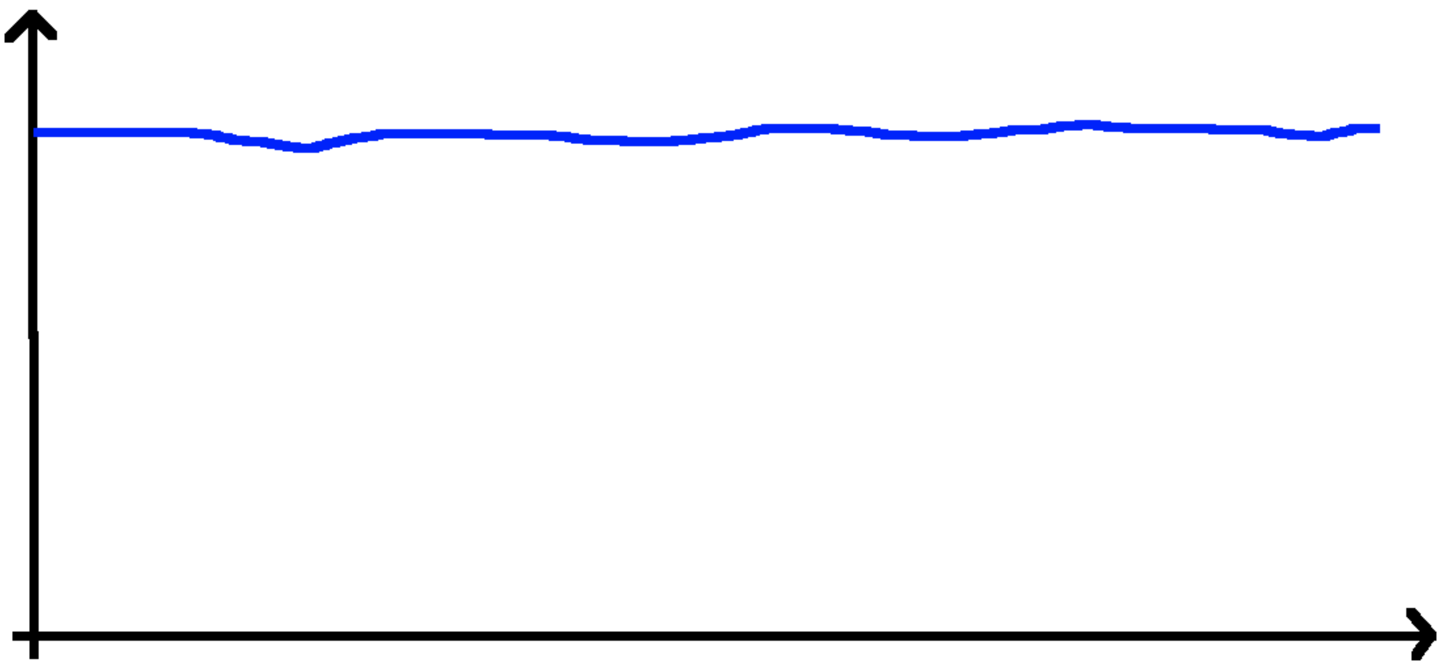

Pasquier Noterdaeme

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in absorption

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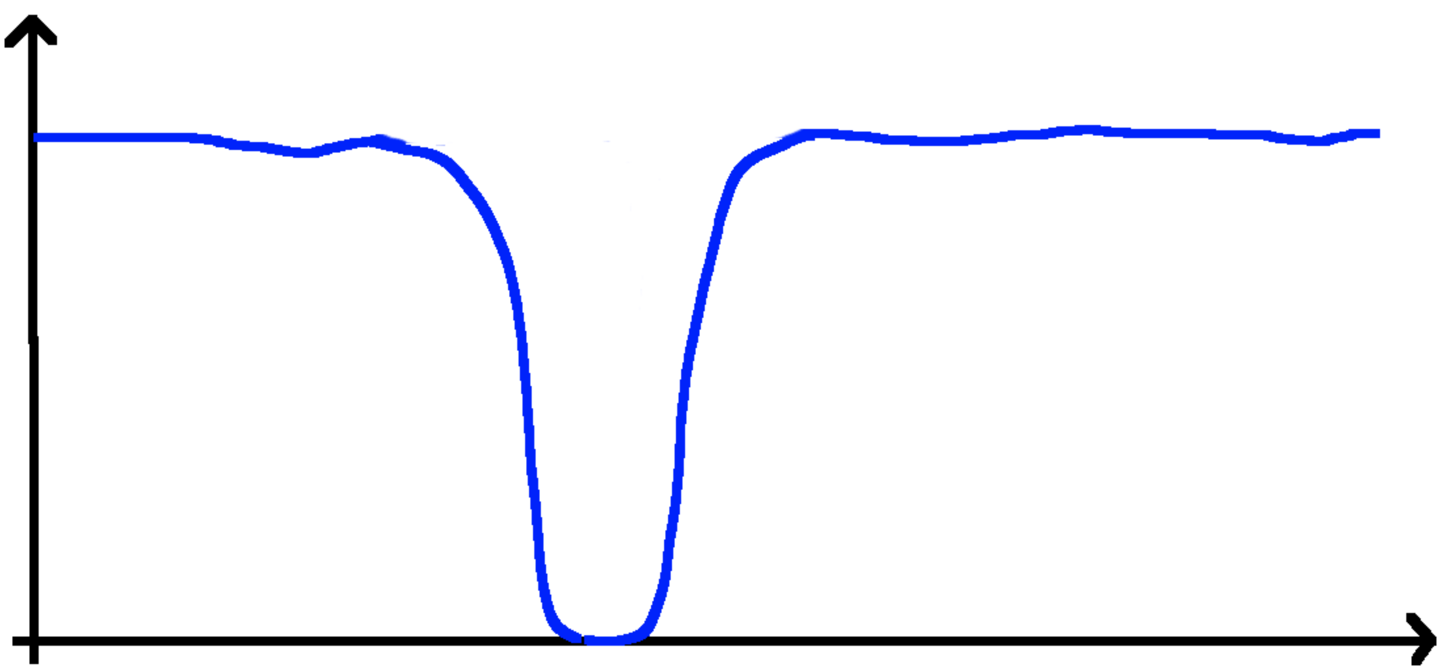
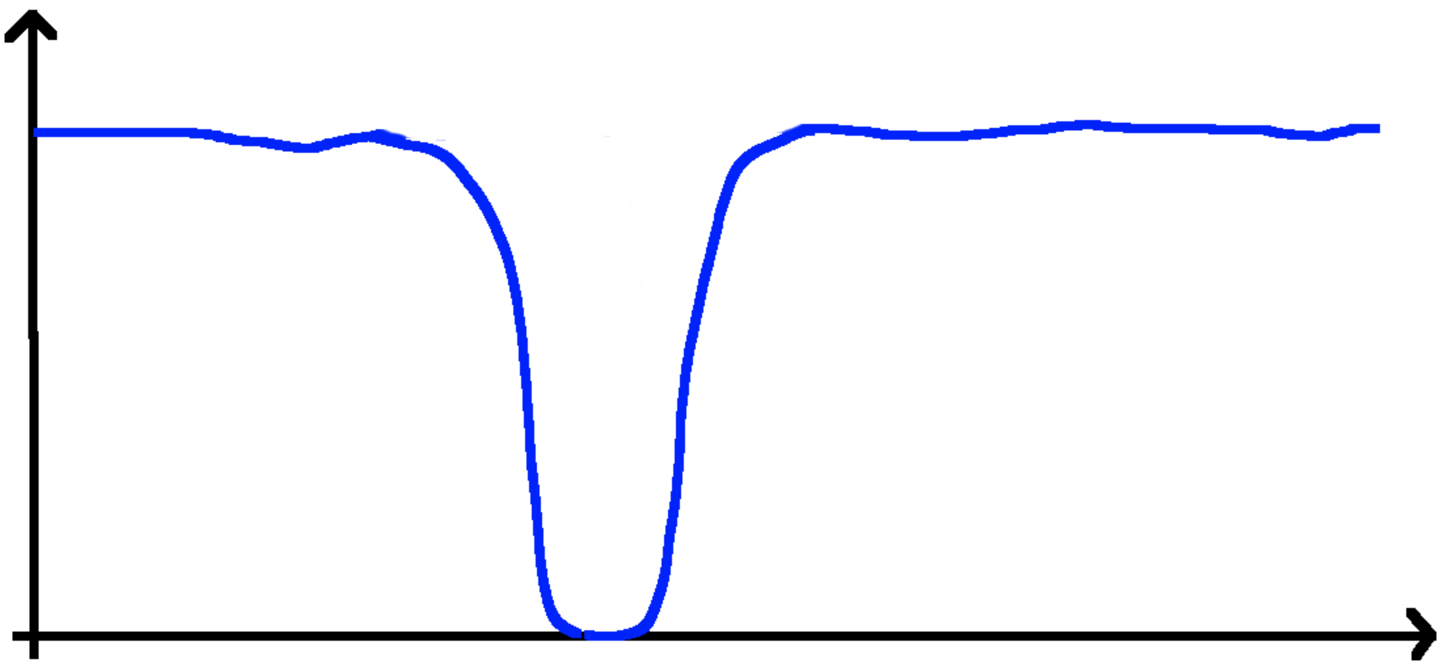


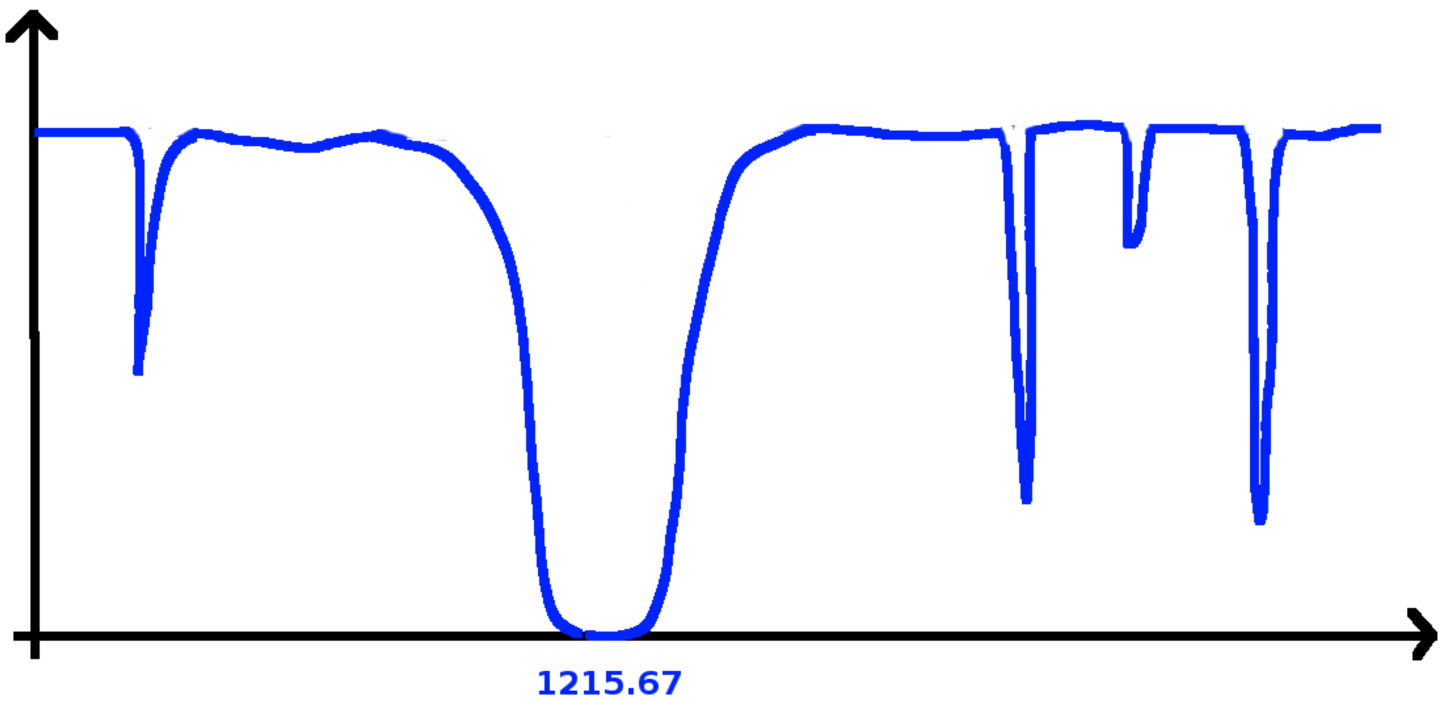
Pasquier Noterdaeme

Damped Lyman-alpha systems
in absorption



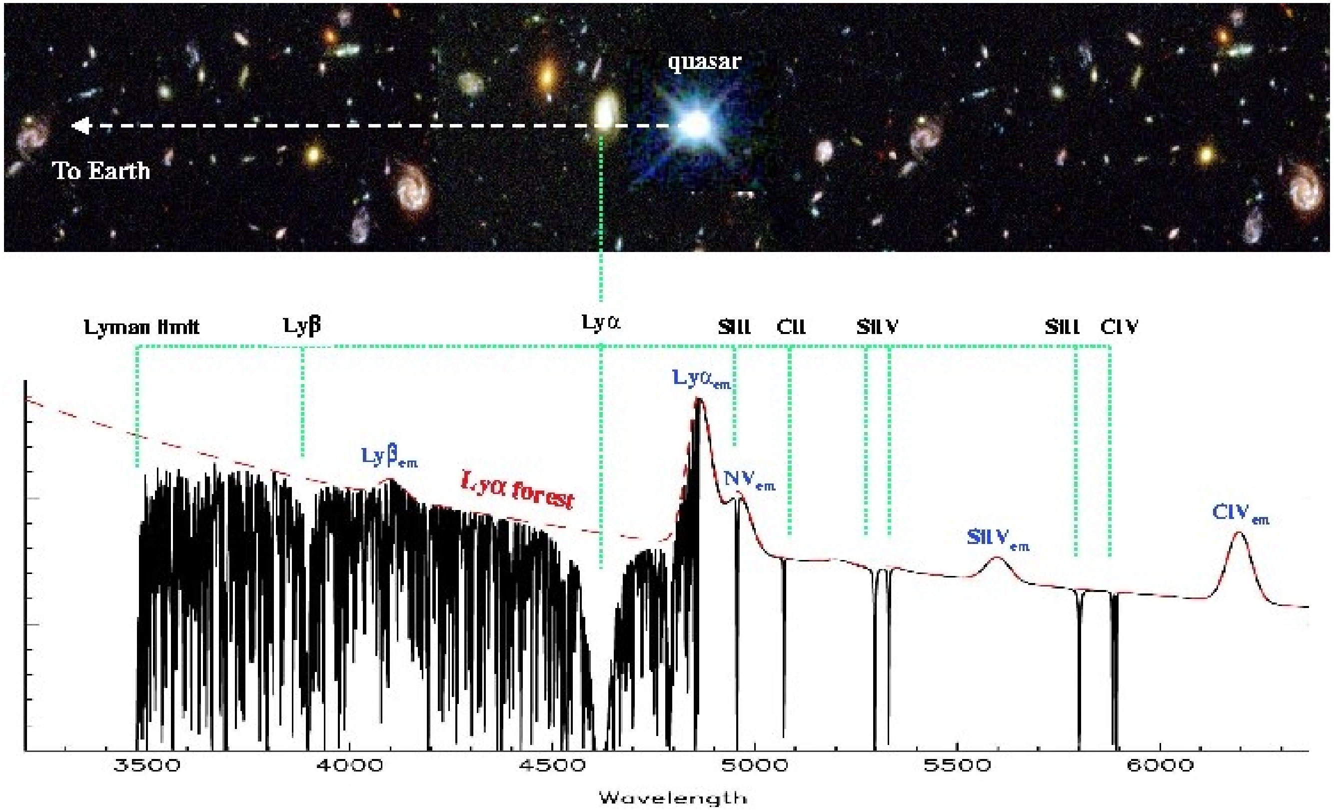
Pasquier Noterdaeme

Damped Lyman-alpha systems in absorption



Pasquier Noterdaeme

BASICS



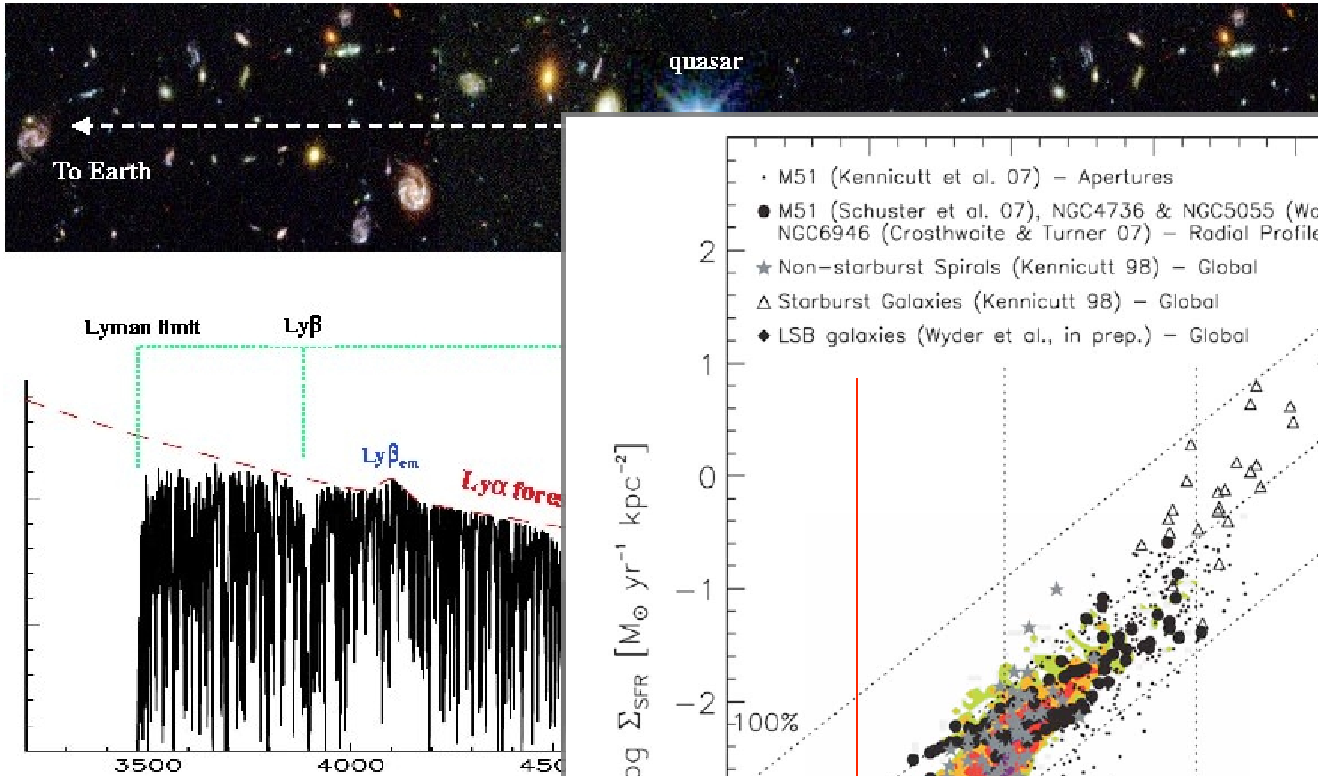
⇒ z_{abs}

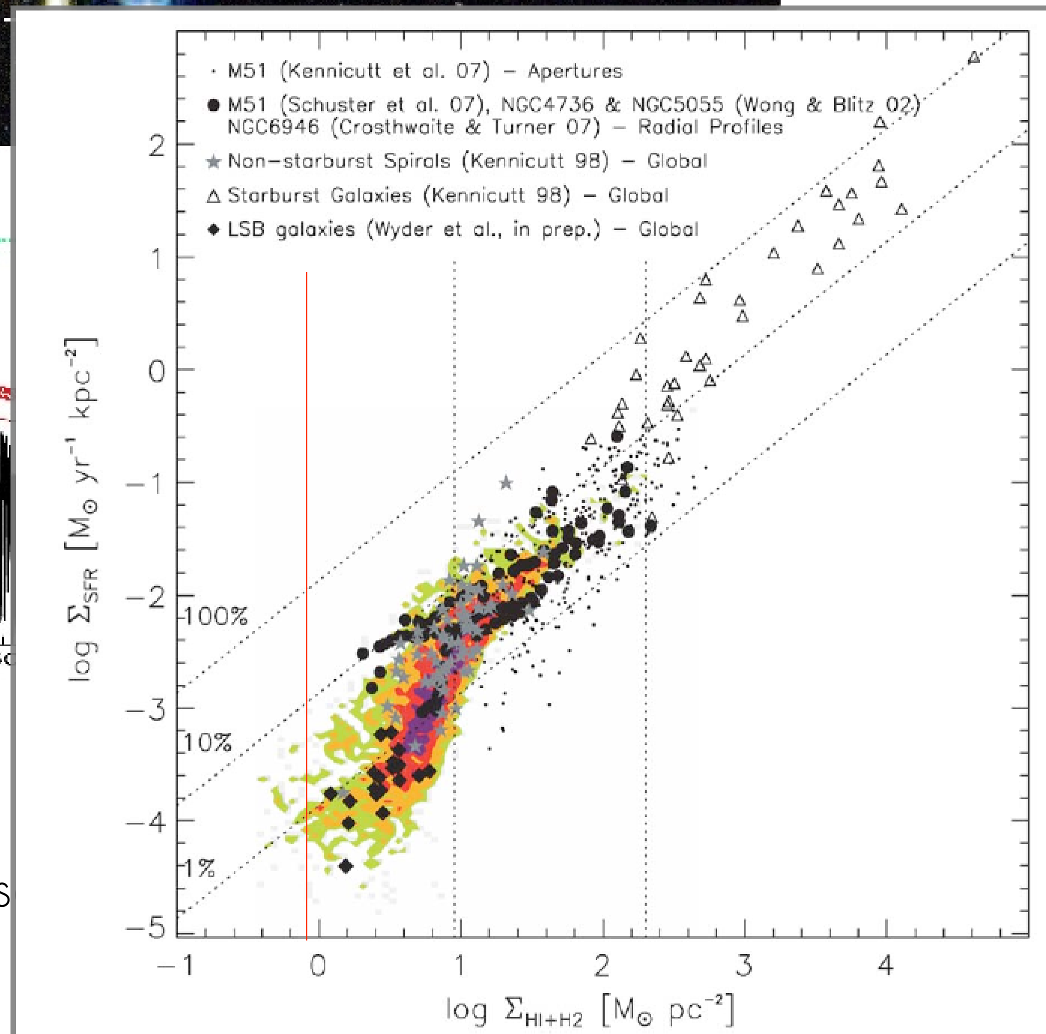
- Observable from ground at z>1.6
- **Def.** : intervening / proximate / associated / GRB-DLAs

⇒ N(HI) > 2×10^{20} cm^{-2}

- The gas is self-shielded and neutral
- Similar to what is seen in local galaxies through 21cm emission

BASICS





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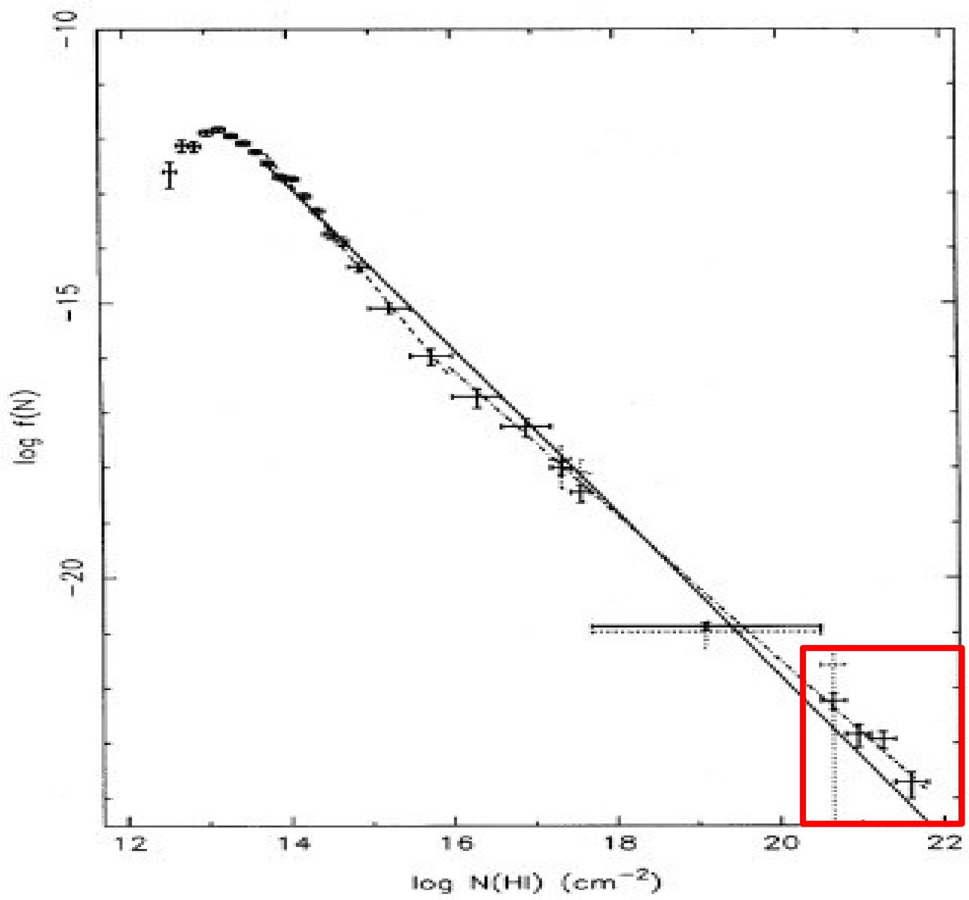
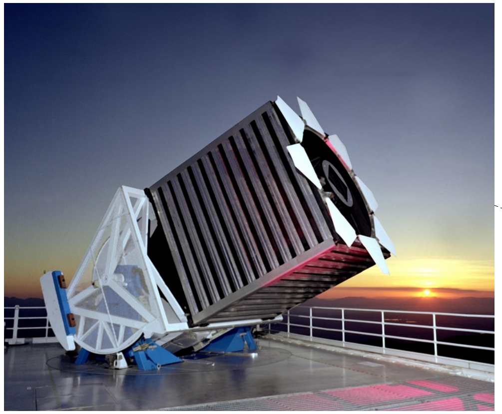
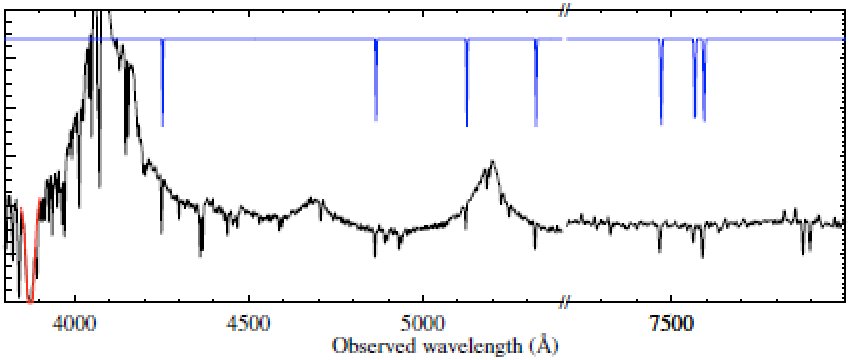
1. Counting Lyman-alpha absorbers

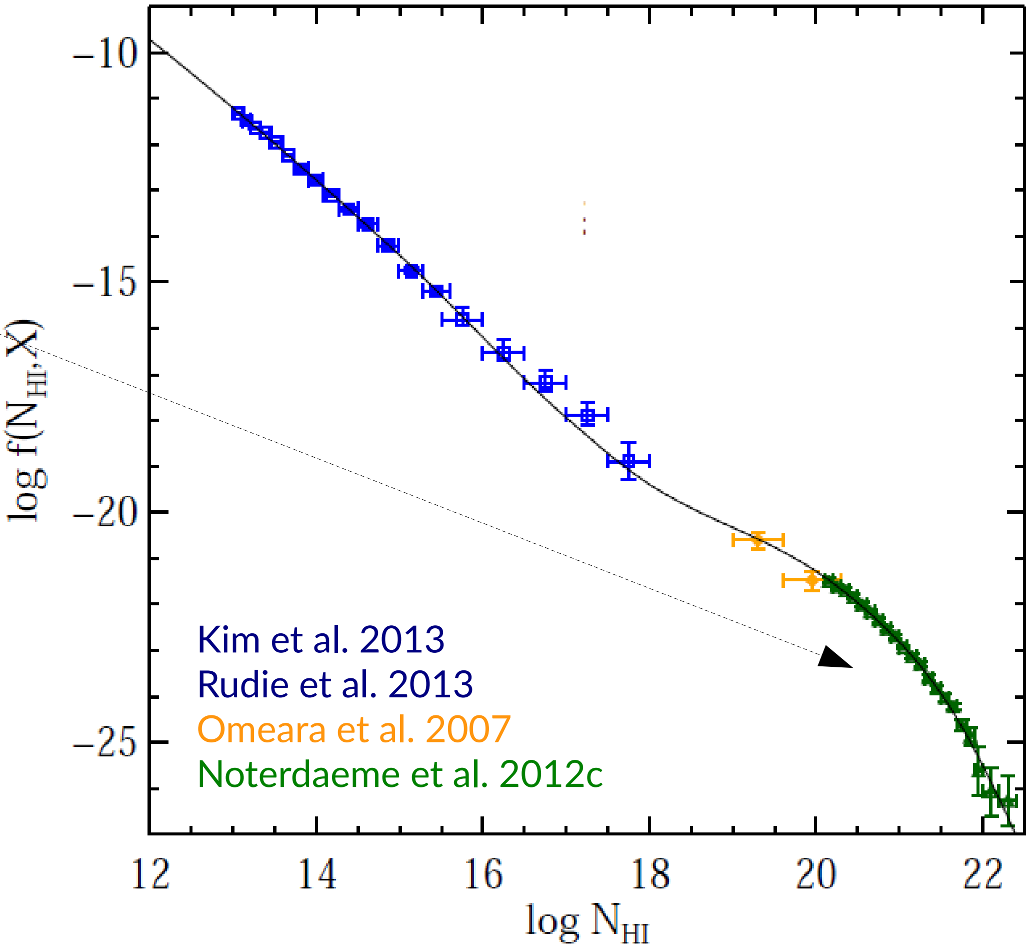
Petitjean et al. 1993



1. Counting DLAs







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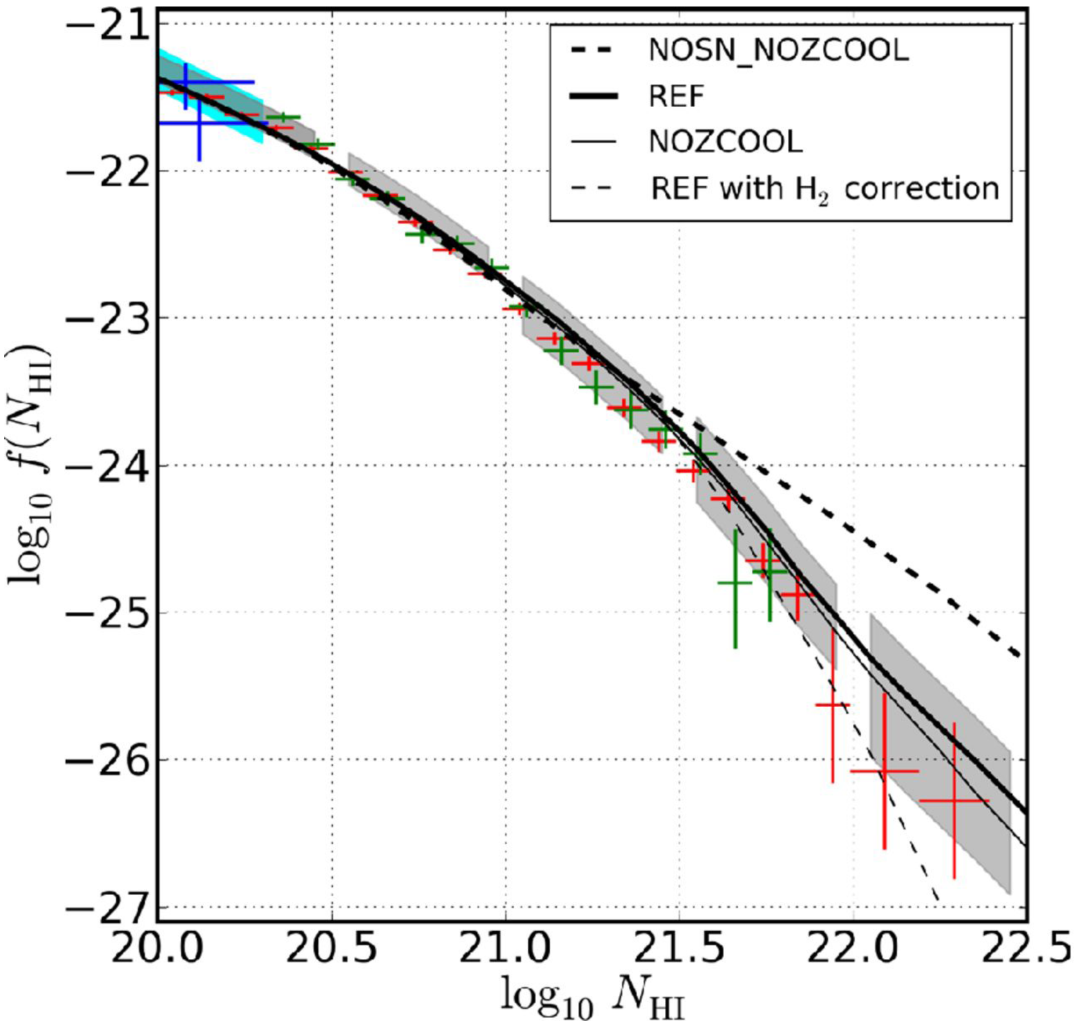
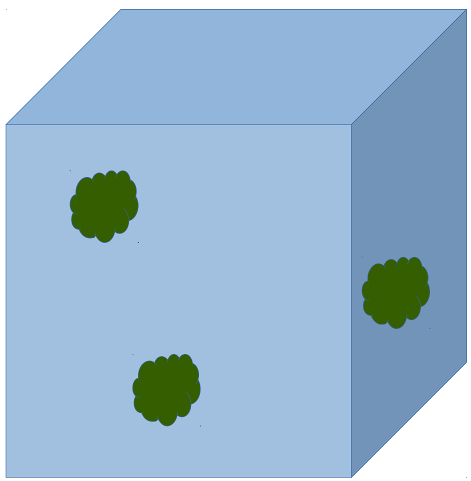


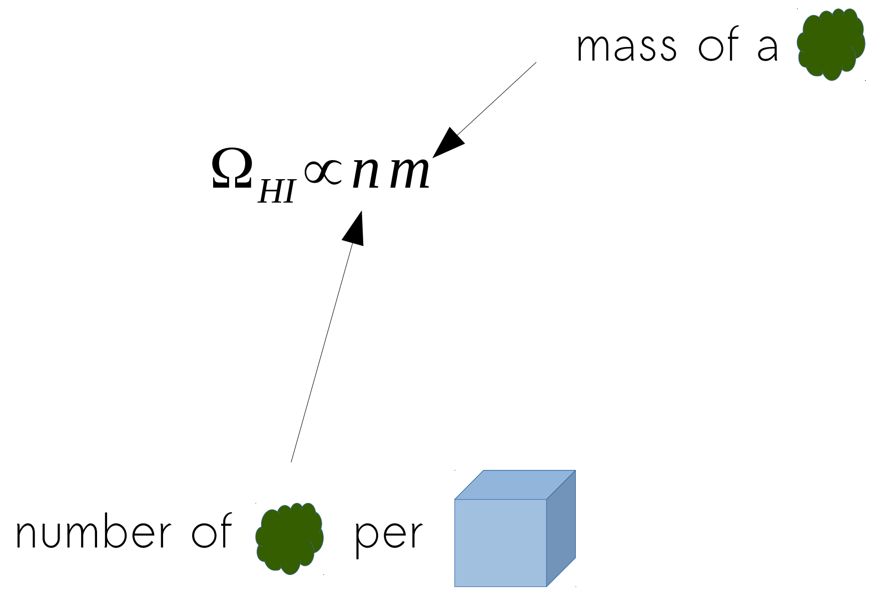
⇒ The high-column density end of the distribution is sensitive to SF feedback/conversion into molecules

Altay+13

1. Counting DLAs

How much neutral gas in the Universe ?





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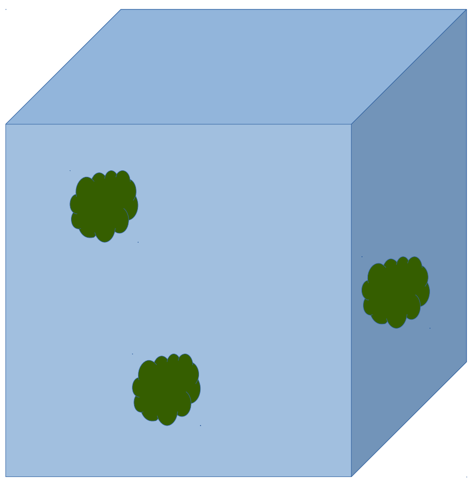
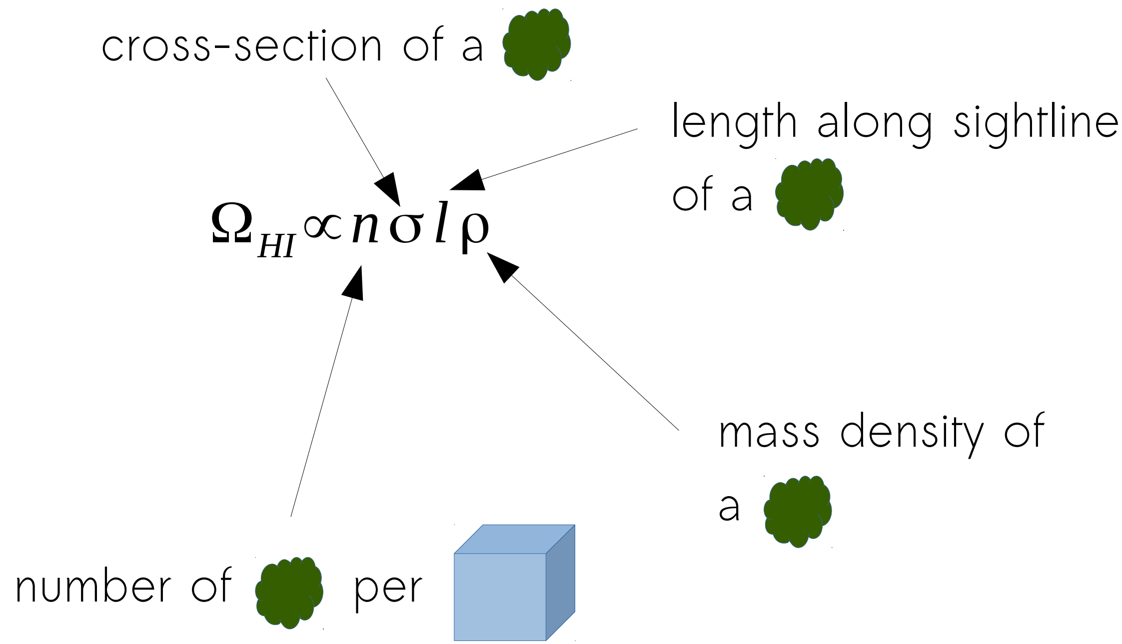
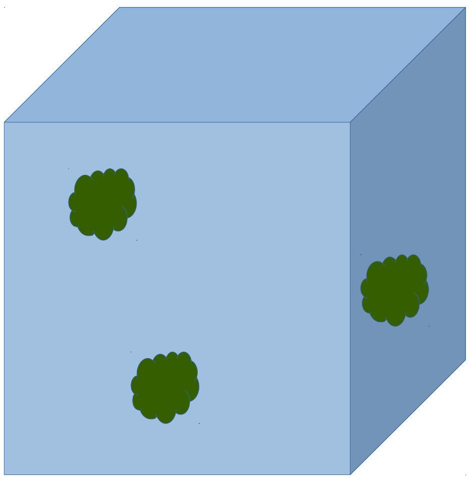




1. Counting DLAs

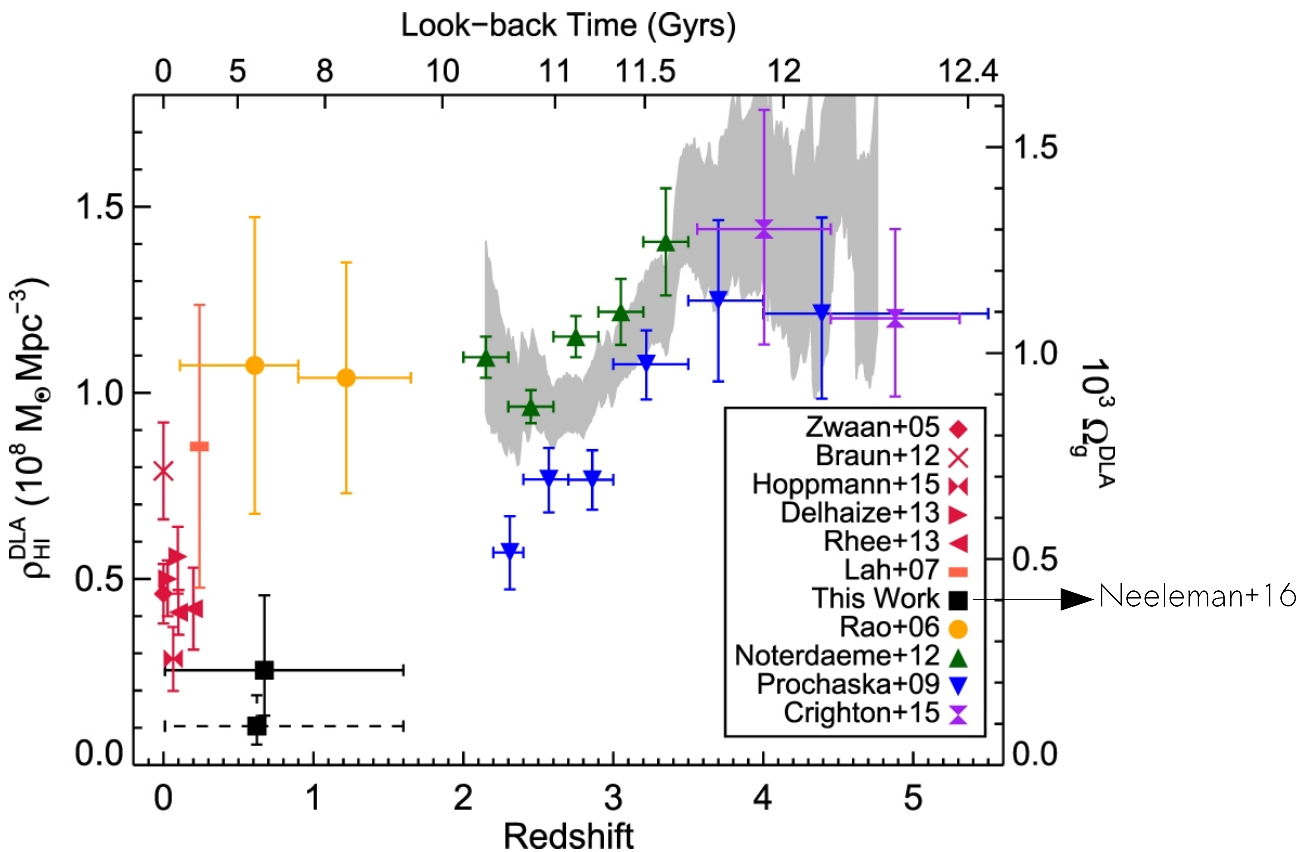
How much neutral gas in the Universe ?



$$\Omega_{HI} \propto \underbrace{n\,\sigma}_{dN/dz}\, \underbrace{l\,\rho}_{N(HI)}$$

$$\Omega_{\rm g}^{\rm DLA} = \frac{\mu m_{\rm H} H_0}{c\rho_{\rm c}} \frac{\Sigma N(\textrm{H\,I})}{\Delta X}$$

1. Counting DLAs (at different epochs)

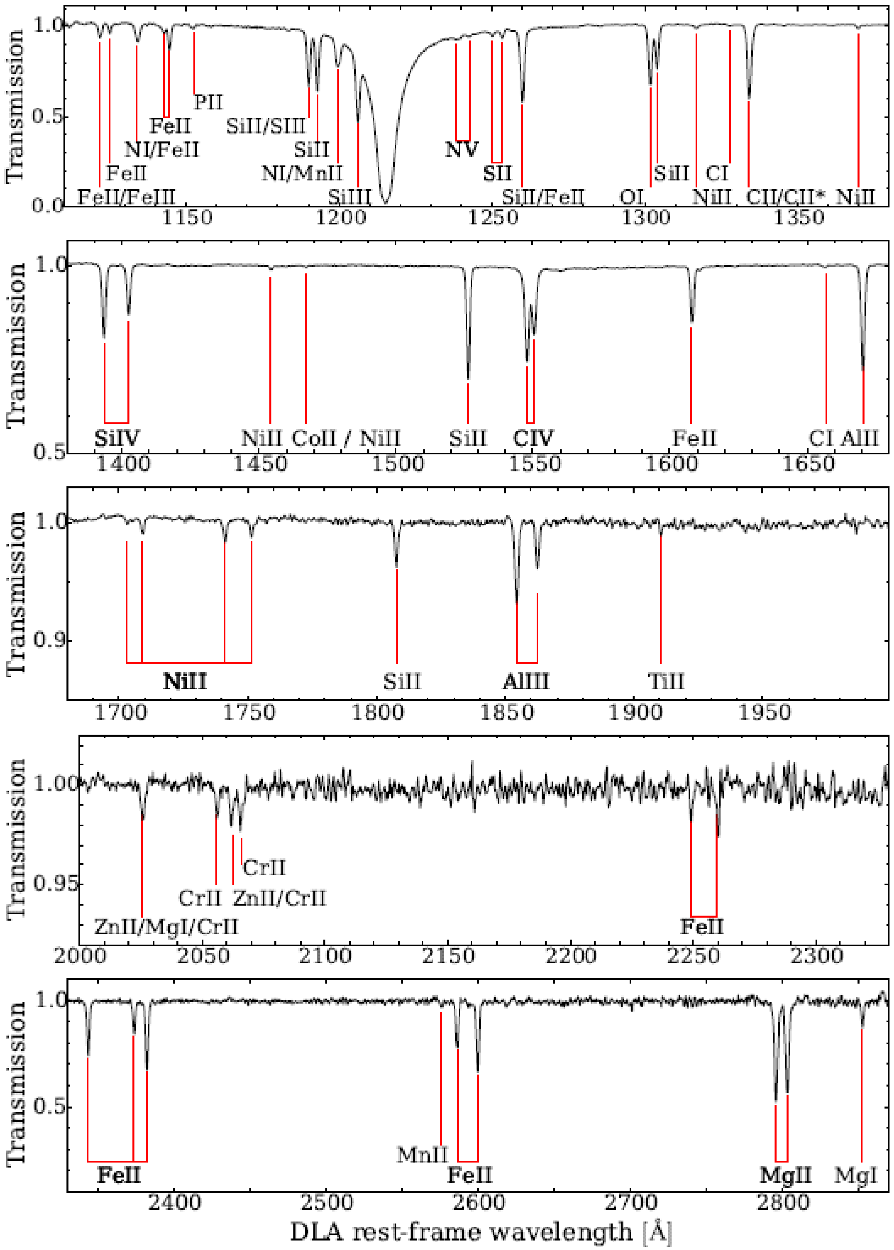


- Some evolution (but not that much)
- Not enough gas in DLAs to acount for baryons in present day stars

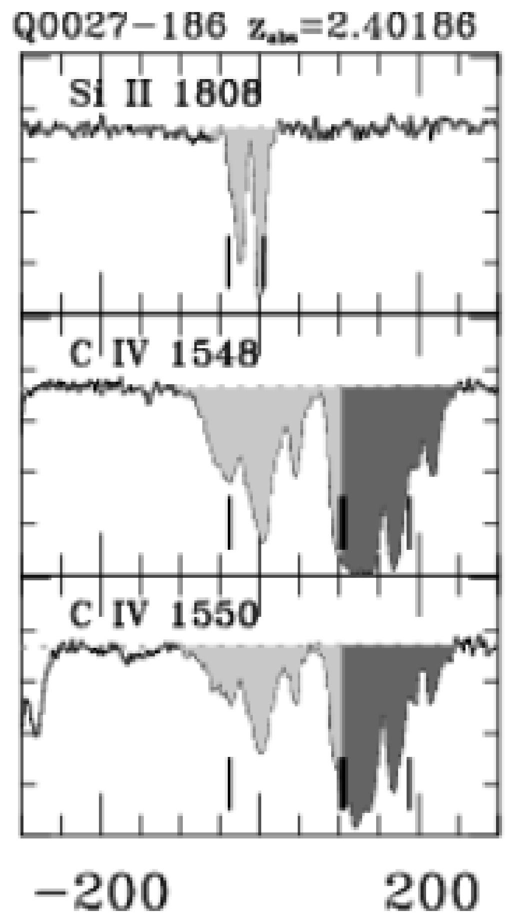
⇒ DLAs must continuously resplenish gas (closed-box model rejected).

2. Looking at metal lines

BOSS stack : Mas-Ribas+16



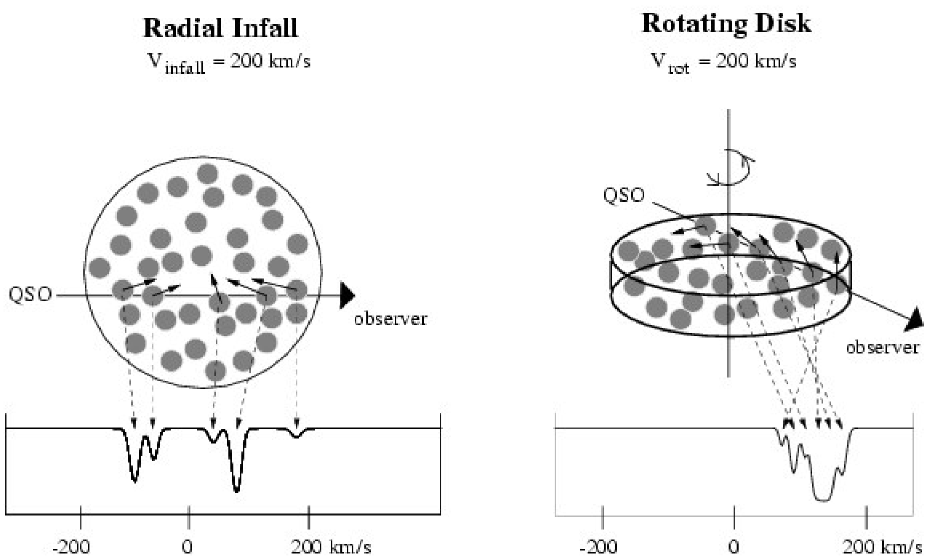
- Various ionisation stages

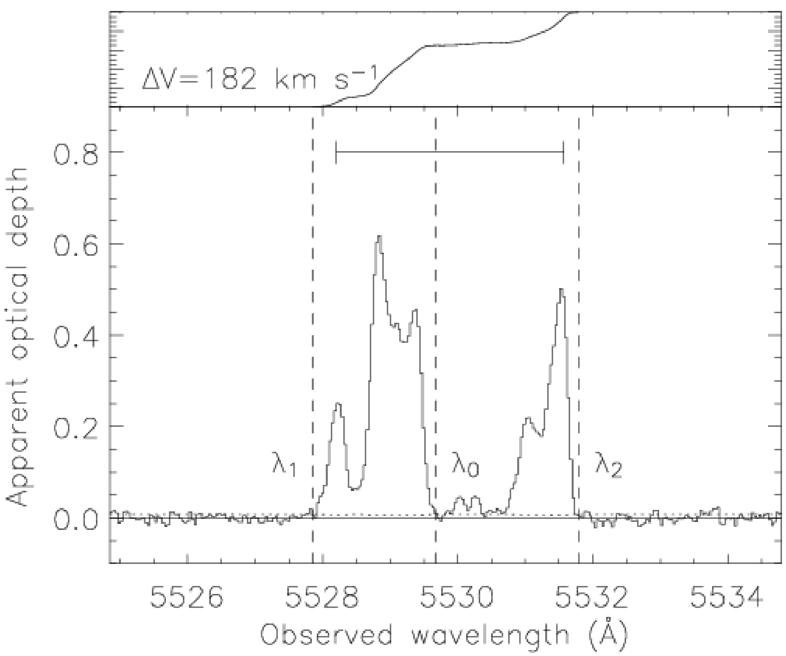


Fox et al. 2007

⇒ Flows of ionised gas

2. Low-ionisation metals : neutral gas kinematics

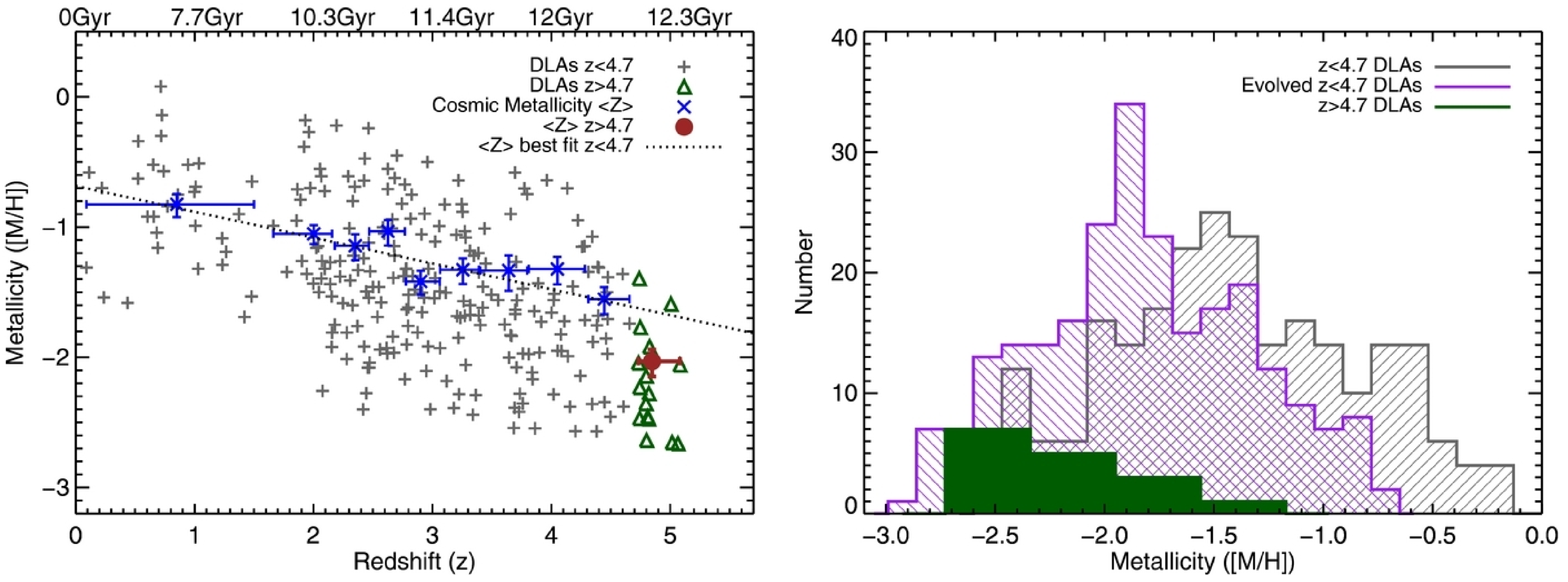




Interpretation in terms of galaxy properties is not easy (e.g. Prochaska & Wolfe 1997, Haenelt et al. 1998)

Quantitative measurement : Δv_{90}

3. Metallicity



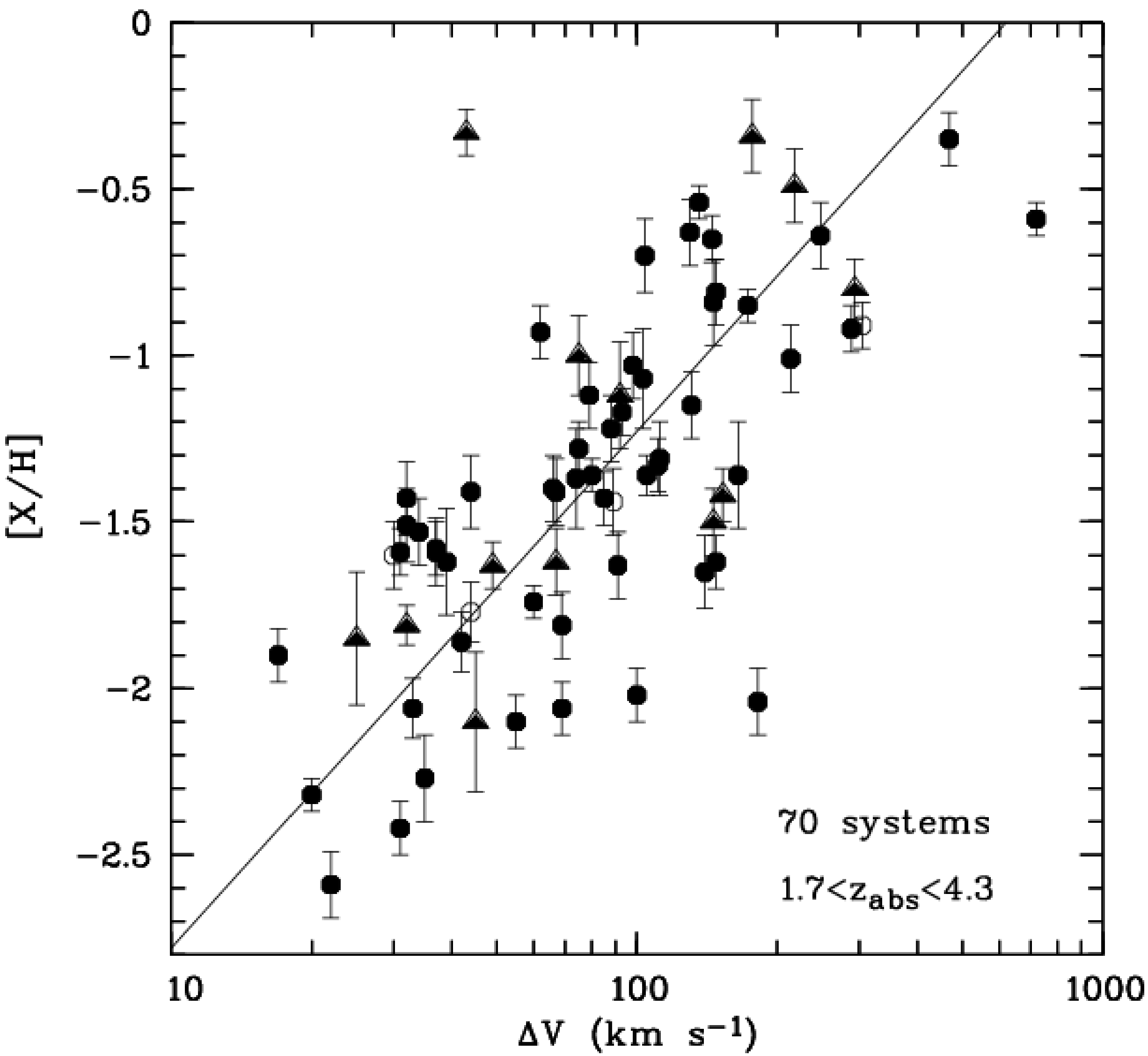
⇒ Z increases with decreasing redshift

⇒ Floor in metallicity around 1/1000th solar

⇒ Dispersion ~1dex

Rafelski+14

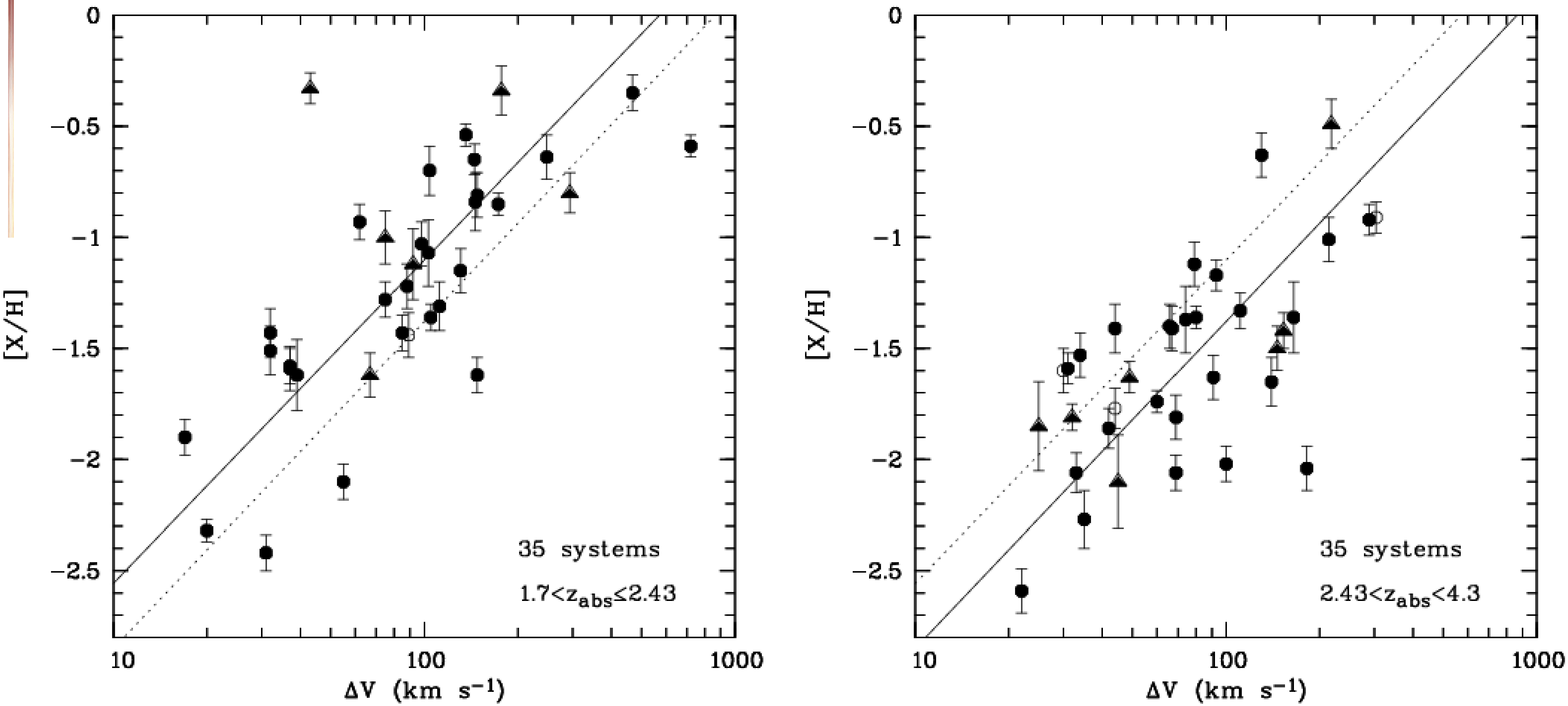
4. Metallicity vs kinematics



mass ?

Ledoux+06

Z vs Δv_{90} vs z



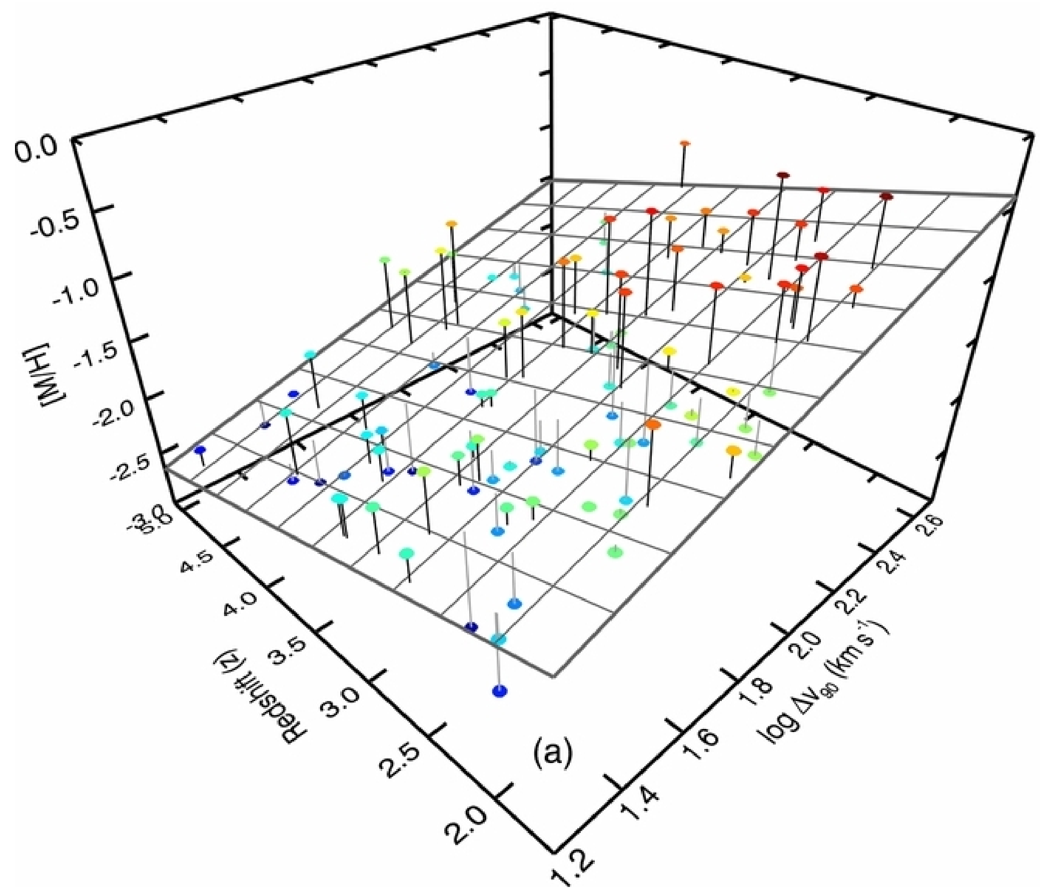
Ledoux+06

Z vs Δv_{90} vs z

Scatter at all redshifts can be explained by:

→ mass-metallicity relation (Ledoux et al. 2006)

→ difference in history of structure formation (overdense vs underdense) Dvorkin et al. (2015)



Neeleman+13

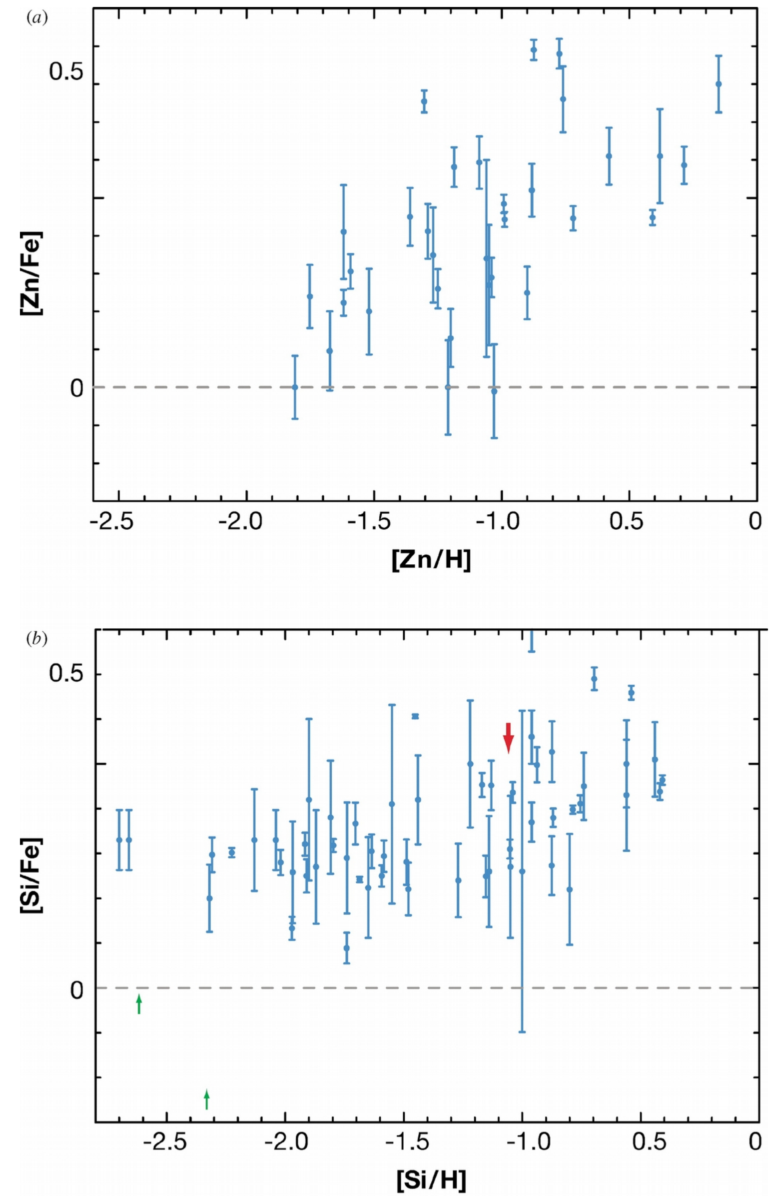
4. Abundance ratios

Observations of non-Solar ratios

$$X_{obs} = X_{gas} = X_{int} - X_{dust}$$

⇒ Intrinsic non-Solar enrichment ?

⇒ Depletion onto dust grains ?



Wolfe, AM et al. 2005
Annu. Rev. Astron. Astrophys. 43: 861–918

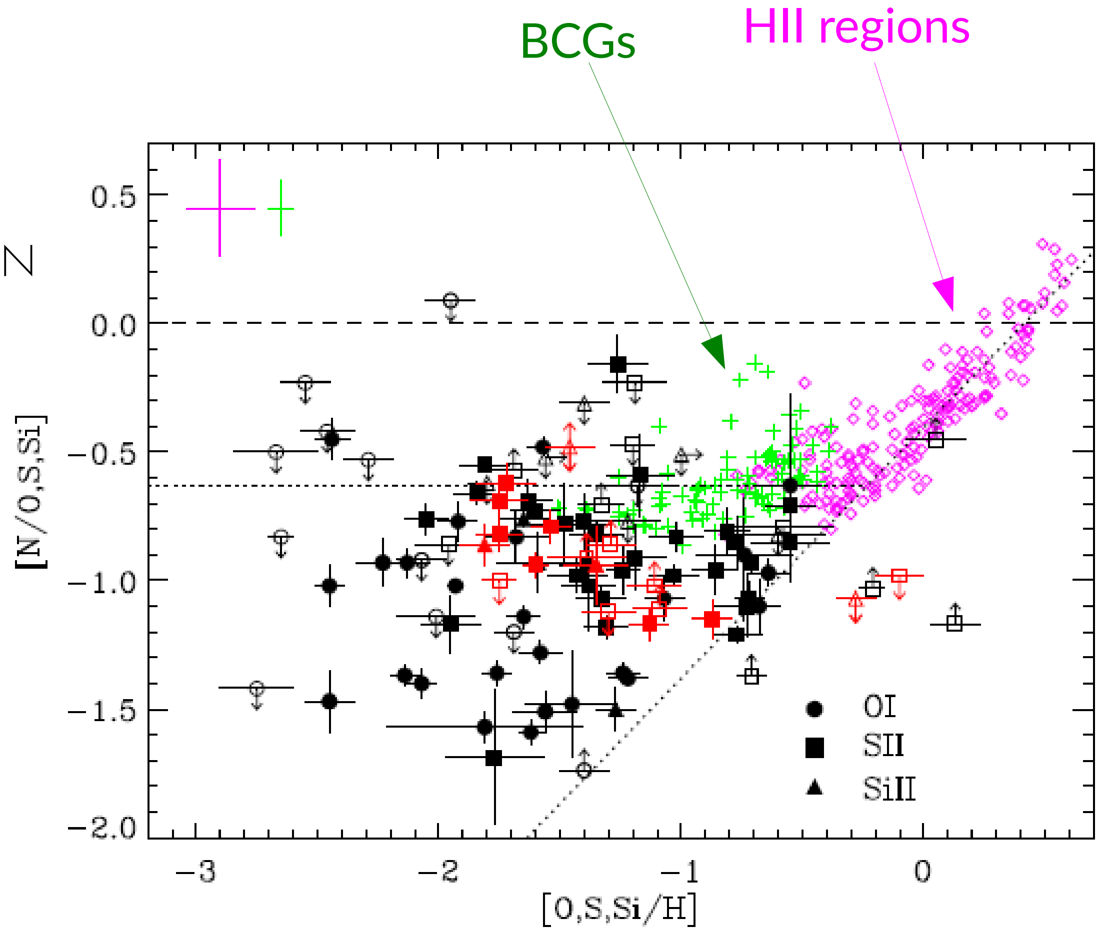
4. Abundance ratios

SN type II enrichment:

- overabundance of O compared to N
- overabundance of alpha elements compared to iron-peak

Burst of star-formation :

O first, then N some 0.25 Gyr later

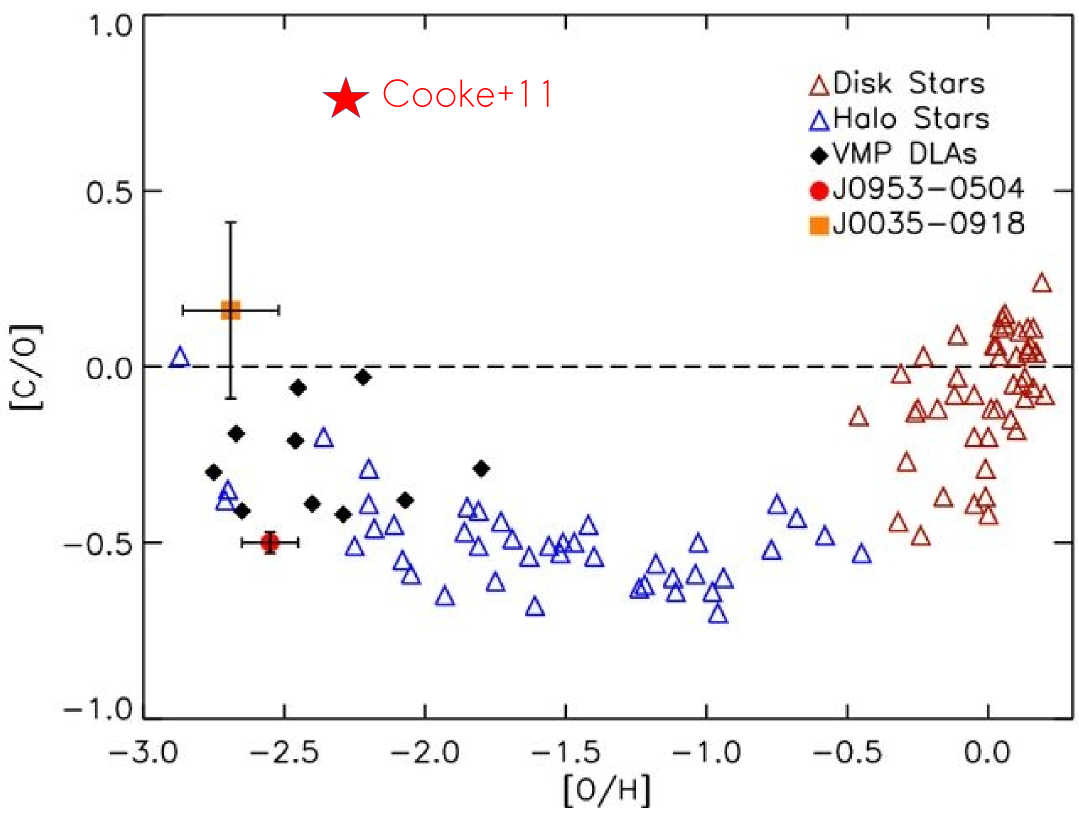


Petitjean et al. 2008, Pettini et al. 2008, Zafar et al. 2014

5. Low metallicity DLAs

Low metallicity regime : carbon enhancement at low-metallicity ?

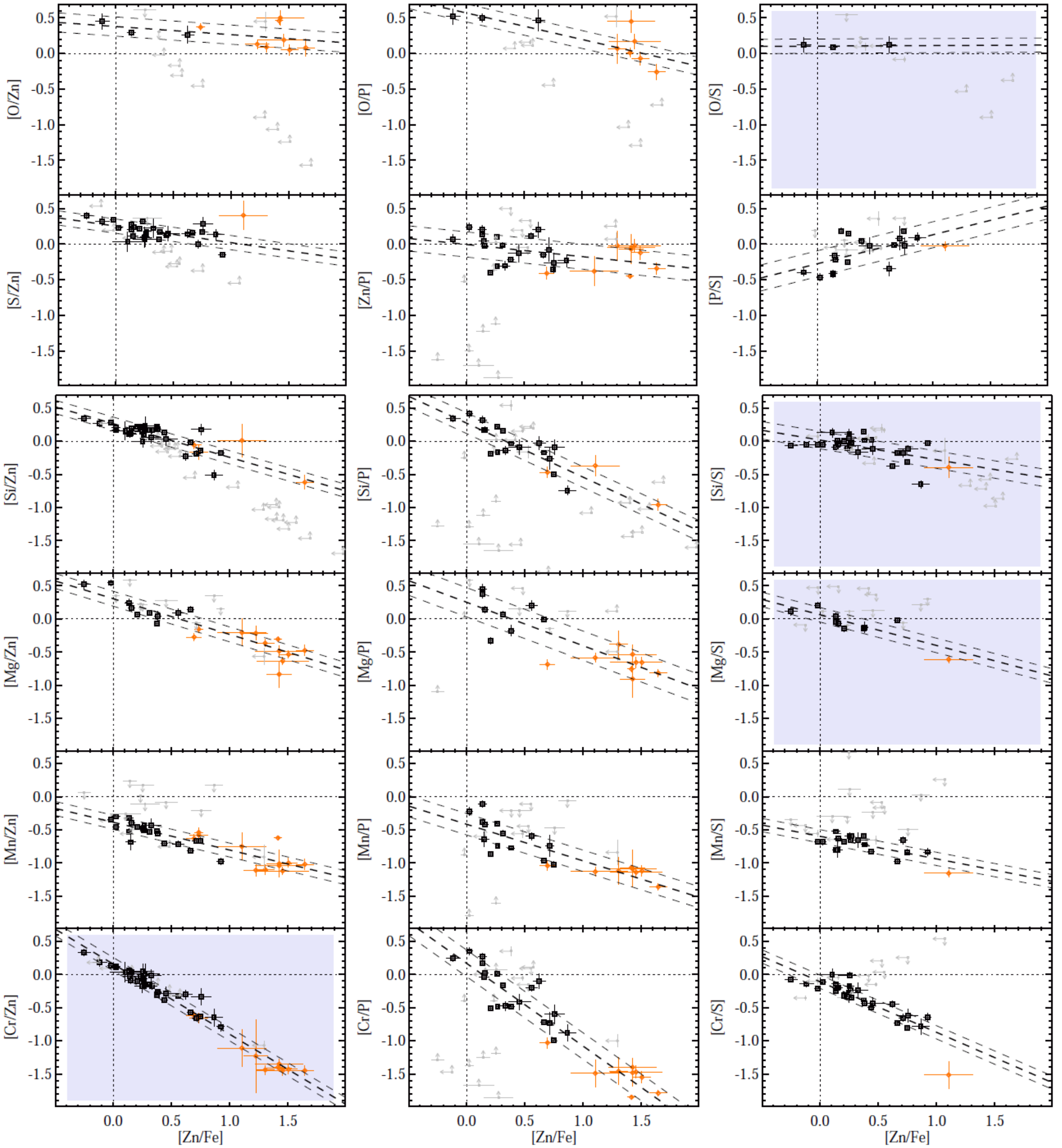
⇒ probing Pop III ?



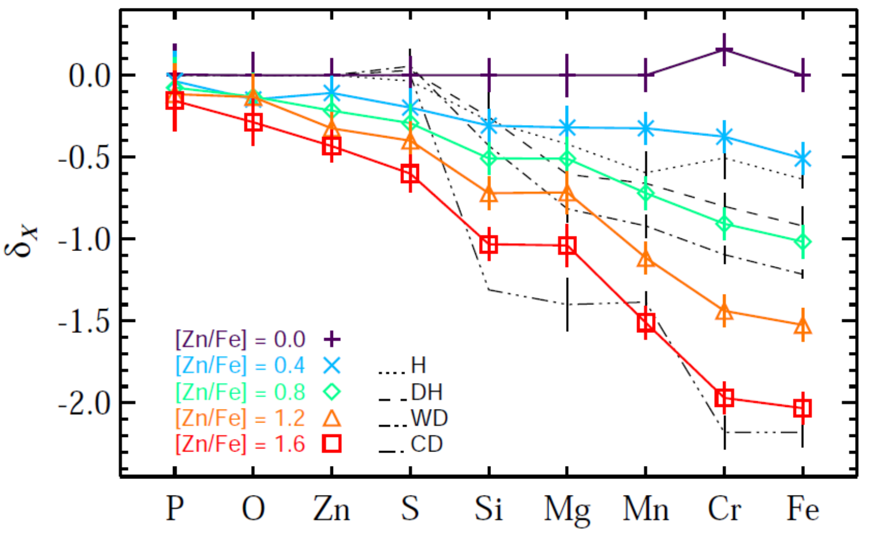
Dutta+14

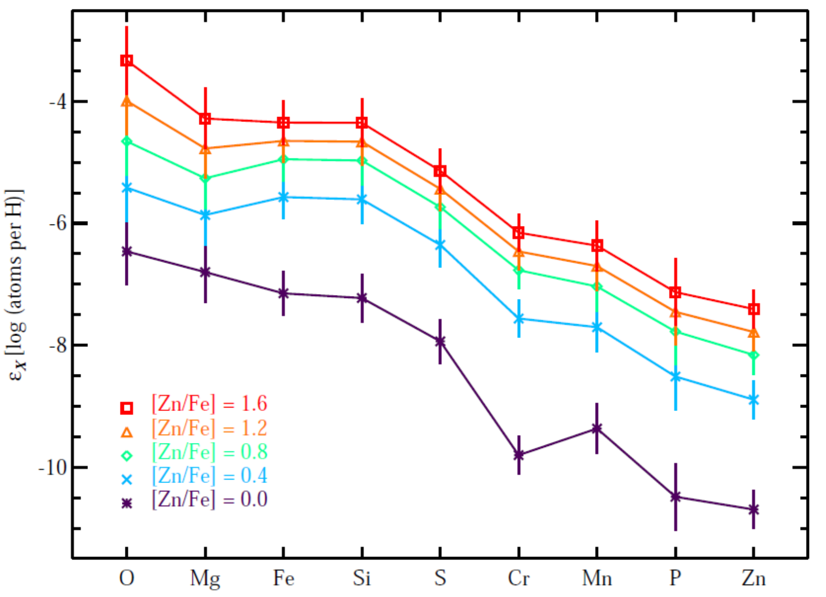
⇒ Measuring carbon abundance is delicate : themal broadening is important !

6. Dust - A. from depletion



De Cia+16



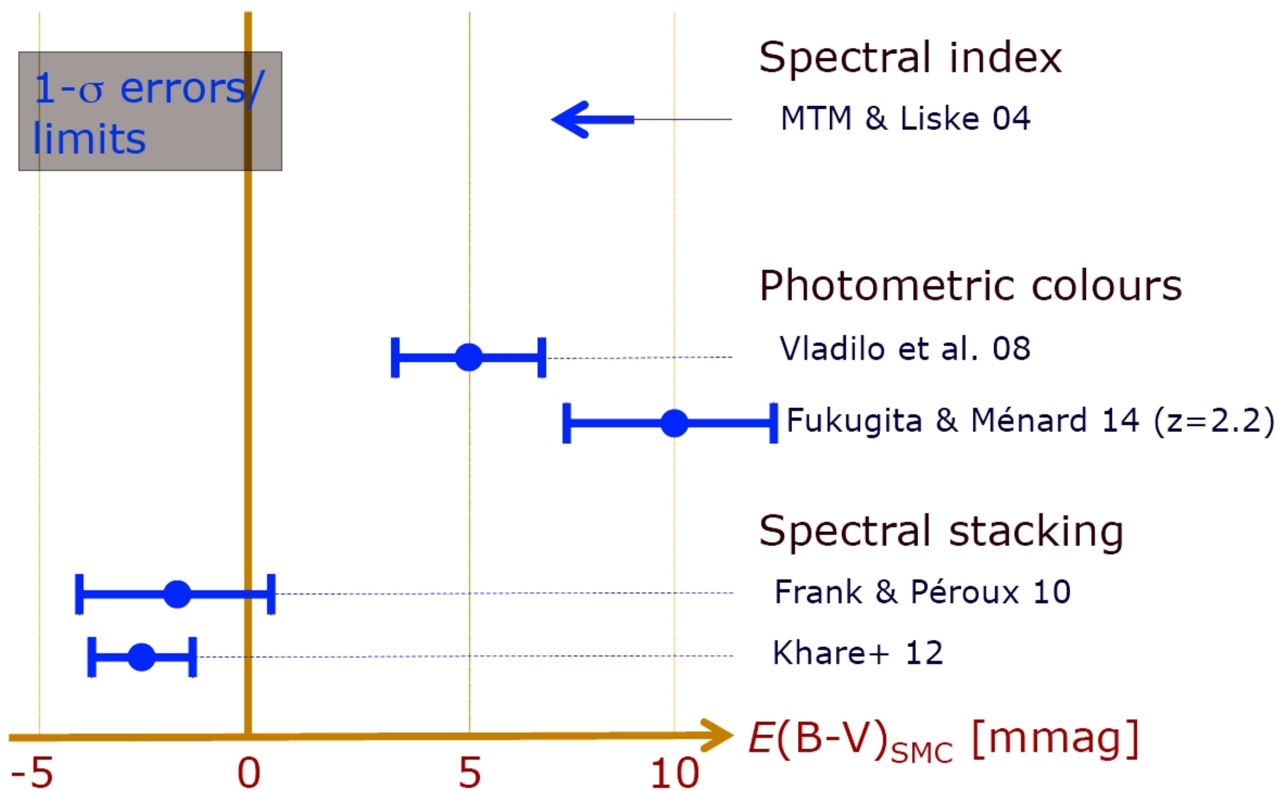


6. Dust - B. from extinction

Bias in the DLA samples ?

⇒ Radio-selection (Ellison et al. 2005) : no effect on HI stats

⇒ Little extinction



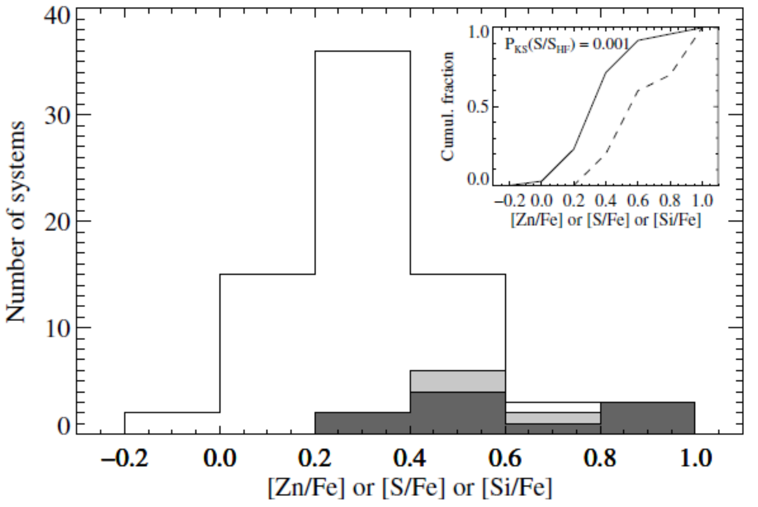
6. Dust - C. from H_2

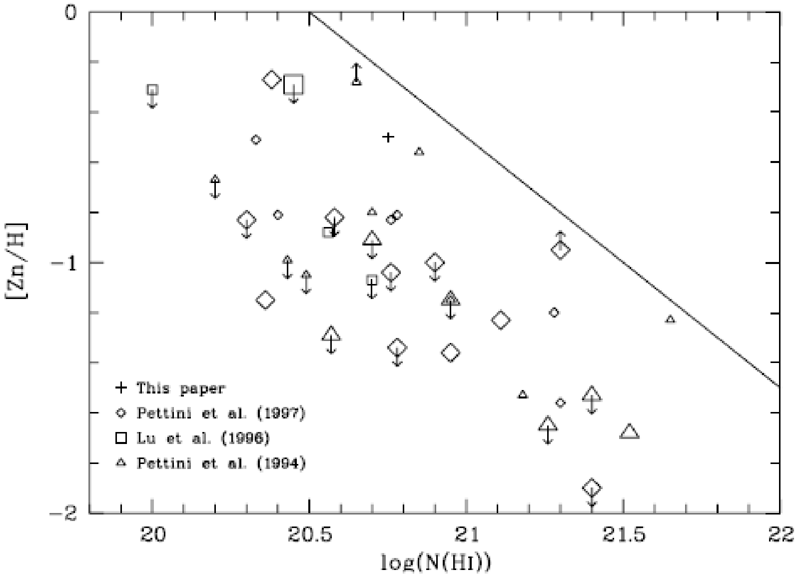
Dust in DLAs ?

⇒ Depletion of refractory metals

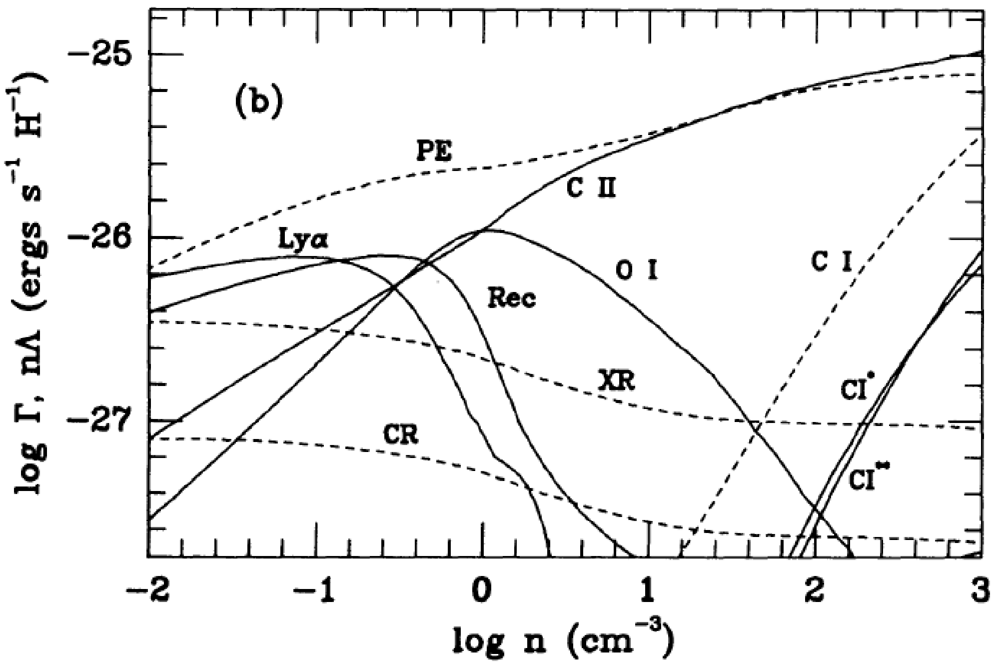
⇒ Presence of H_2 molecules (Ledoux+03, Noterdaeme+08)

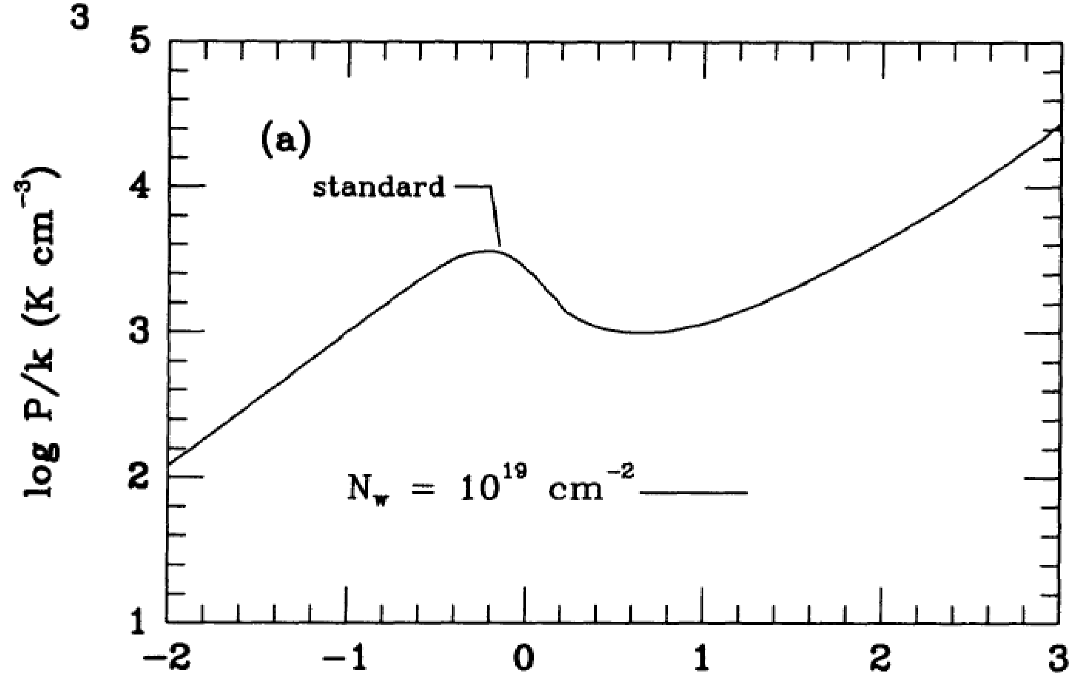
⇒ Absence of systems with high-metallicity and high NHI ? (Boissé+98)





7. Physical conditions



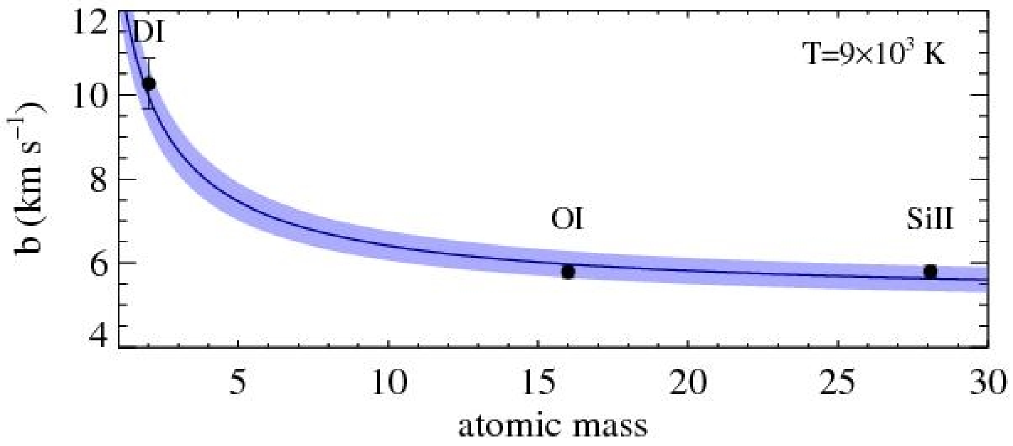


⇒ At typical ISM pressure : both Cold Neutral Medium and Warm Neutral Medium can coexist

7. Main question : WNM/CNM

a) Line broadening : $b^2 = b_{turb}{}^2 + b_{th}{}^2$

⇒ Thermal broadening $b_{th} = \sqrt{2 K_b T / m}$



e.g. Carswell+10,12, Noterdaeme+12b, Cooke+14, Dutta+14

7. Main question : WNM/CNM

b) 21-cm

$$N(\mathrm{HI}) = 1.823 \times 10^{18}\, T_s \int \tau dv$$

⇒ together with N(HI) (and covreing fraction), we get the average Ts.

⇒ ~ 10 % DLAs have CNM fractions > 20 %.

e.g. Curran+, Kanekar+, Srianand+, Gupta+

7. Main question : WNM/CNM

c) Excitation of fine-structure levels

- CI, CI*, CI** : excited levels mostly populated by collisions (e.g. Srianand+05, Jorgenson+10). ⇒ physical conditions in the CNM.

- CII* (e.g. Wolfe+03,04) :

$$l_c = \frac{N(\mathrm{C\,II}^*) h\nu_{ul} A_{ul}}{N(\mathrm{H\,I})} \mathrm{erg\,s^{-1}} \text{ per H atom,}$$

  Cooling from [CII]158 emission

  Heating from photo-electric effect on dust grains : F_{UV} x dust

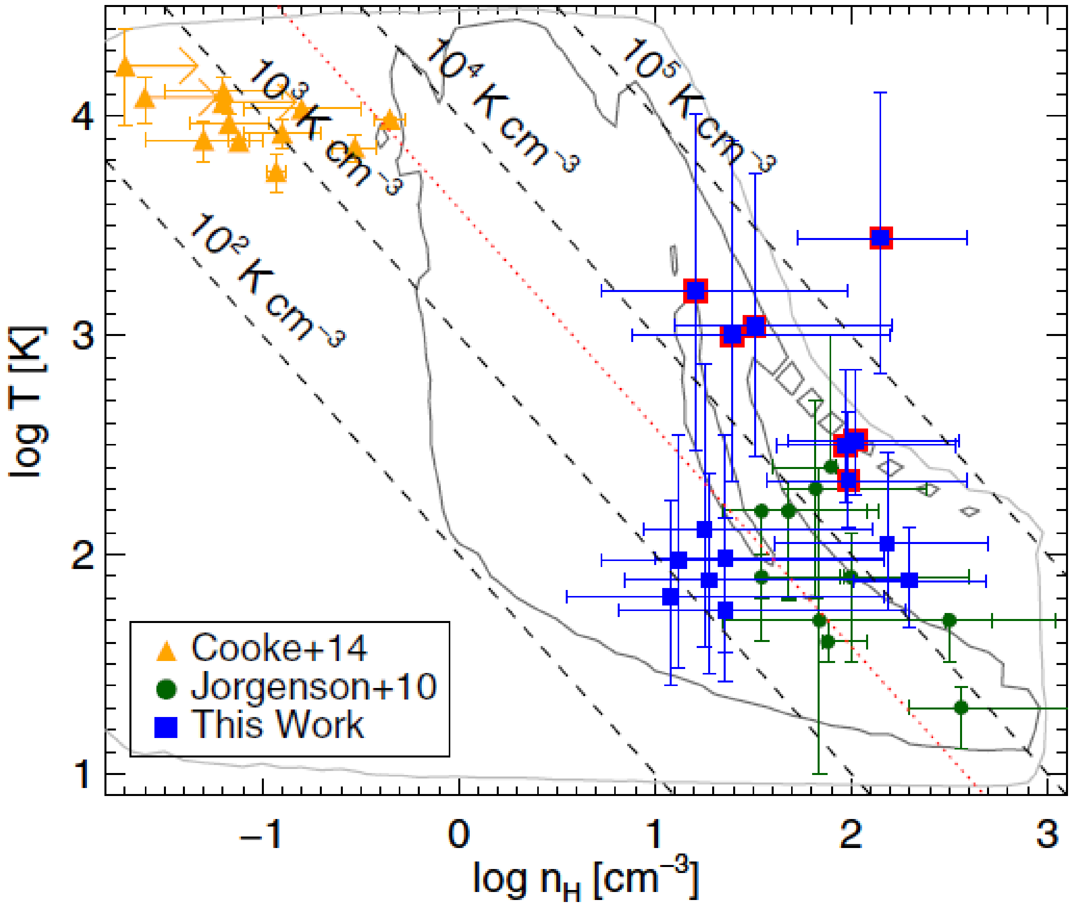
  ⇒ SFR too large is only WNM : must have CNM

7. Main question : WNM/CNM

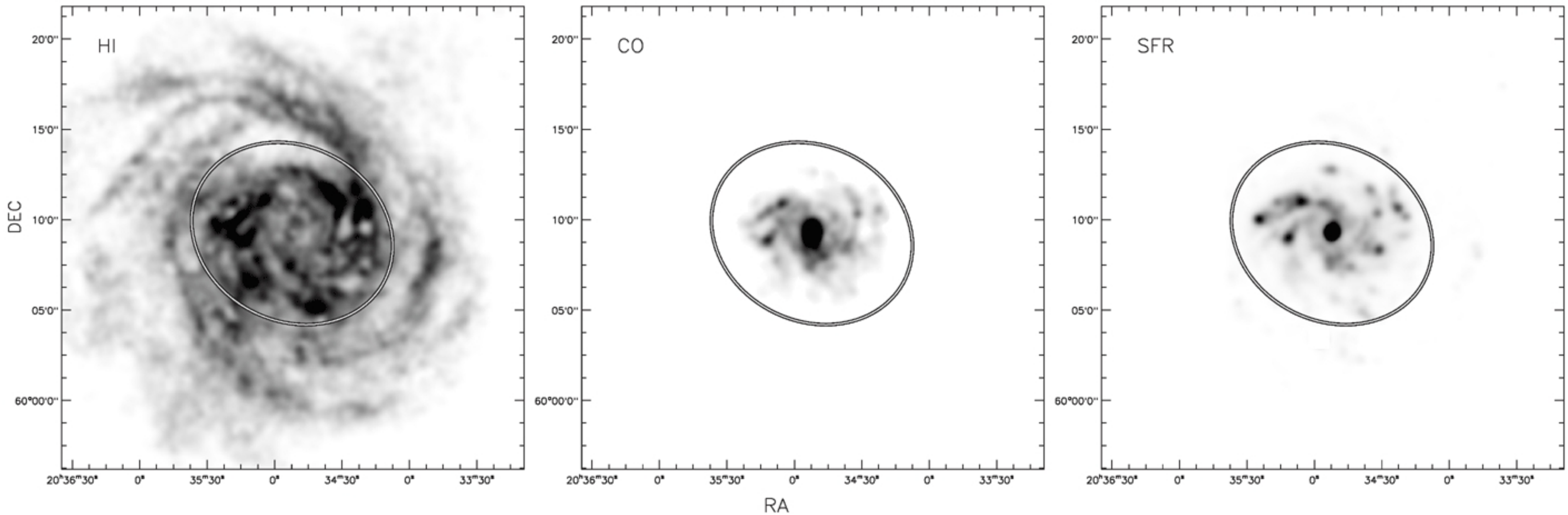
c) Excitation of fine-structure levels

- CII*, SiII* (Neeleman+15)

  ⇒ Like CI, but dominant ionisation stage in DLAs.



8. From atomic to molecular gas



Bigiel+08

8. From atomic to molecular gas

⇒ is the molecular phase essential for star-formation or only a tracer of the cold, dense phase ? In other words, why do we care about the *chemical* state ?

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⇒ is the molecular phase essential for star-formation or only a tracer of the cold, dense phase ? In other words, why do we care about the *chemical* state ?

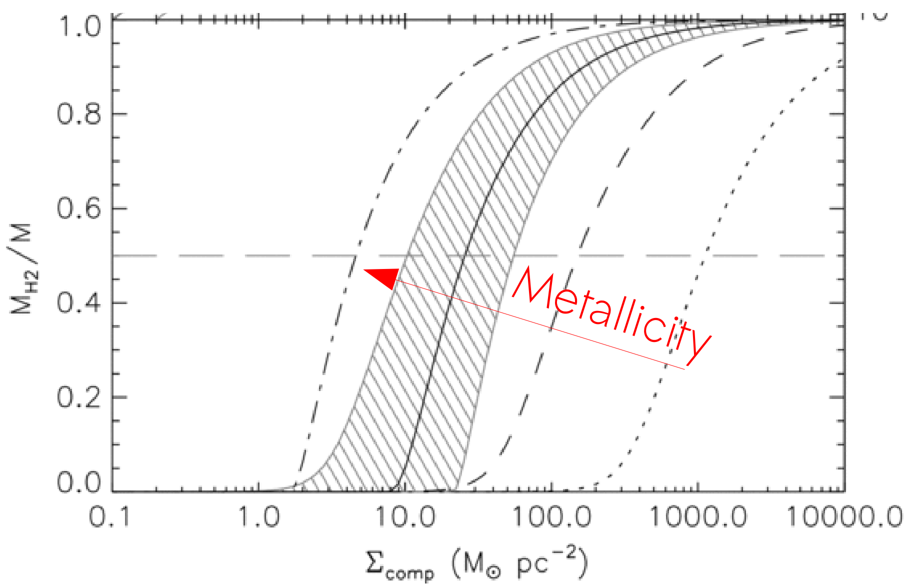
- H_2 forms on dust grains
  ⇒ $\sim n \times n_{dust} \sim n^2Z$
- Cooling of the gas through atomic lines
  ⇒ $n \times n_{CII} \sim n^2Z$
- H_2 dissociation
  ⇒ $\sim F_{UV}$
- Heating : photoelectric effect
  ⇒ $\sim F_{UV}$

The conditions that favour the onset of star-formation also favor the production of H_2.

⇒ $\Sigma_{SFR} \propto \Sigma_{H2}$

DLAs - from atomic to molecular gas

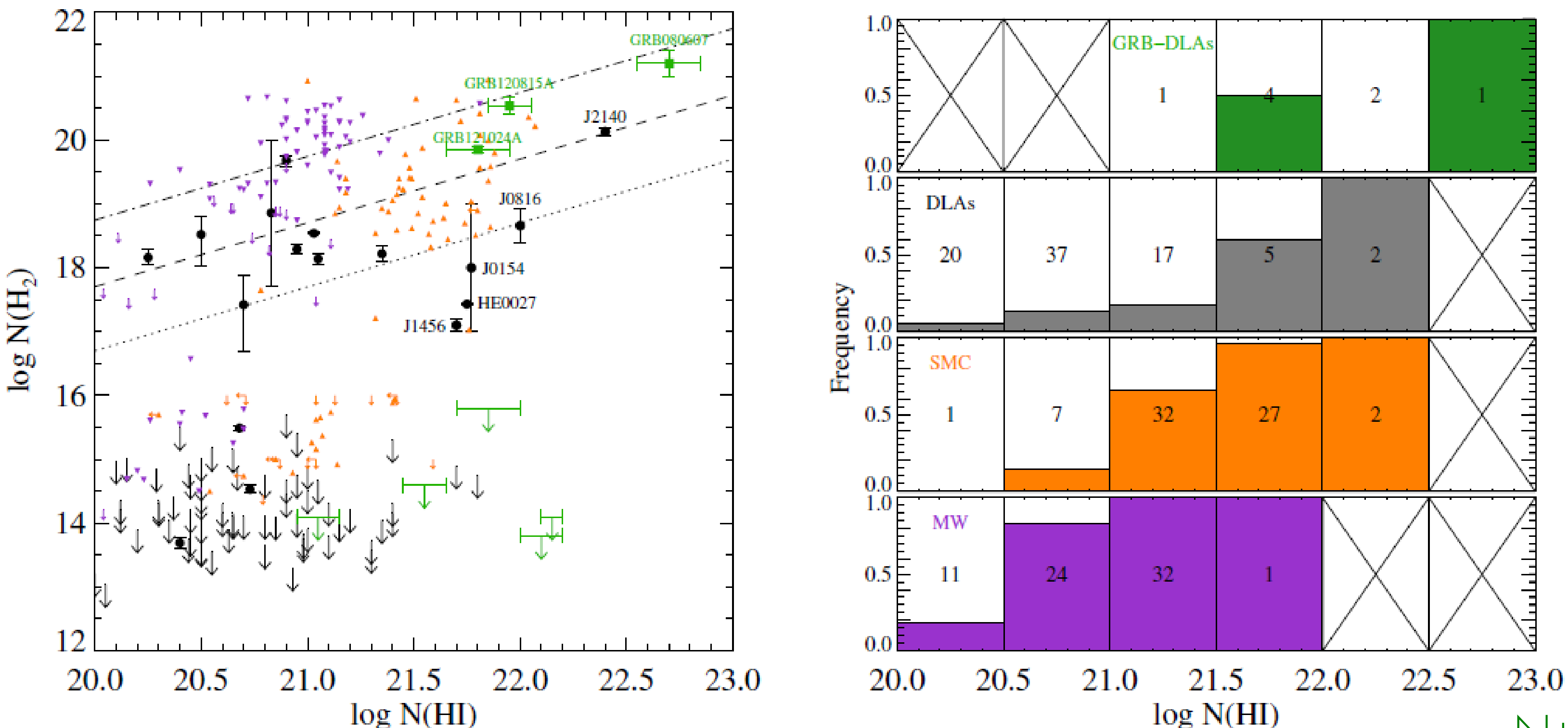
Sharp atomic to molecular transition that depends on metallicity



Krumholz+09

$\Sigma_{HI-H2} \sim 10/Z \;\; M_\odot \; yr^{-1}$

DLAs - from atomic to molecular gas

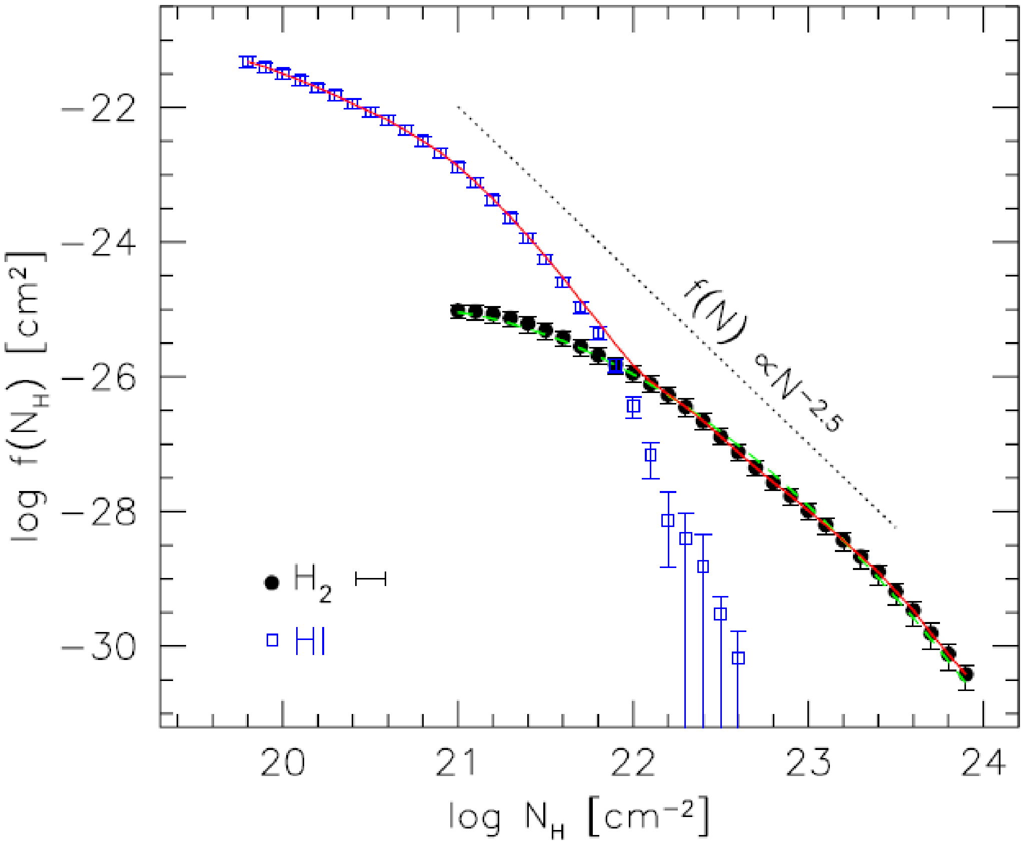


N+15b

Sharp transition not seen in DLAs :

- Range of physical (n, T) and chemical (Z) conditions
- Atomic gas unrelated to H_2 enveloppe

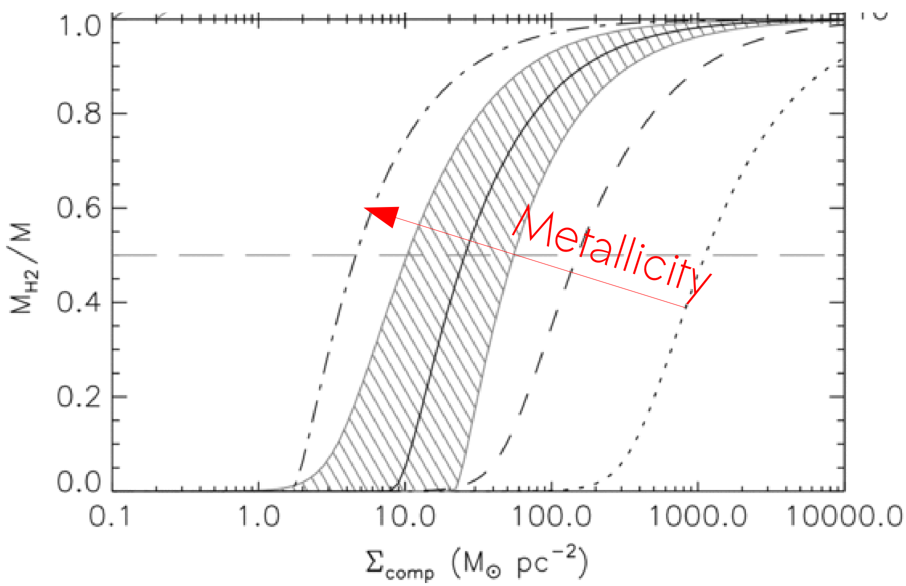
Does trully molecular gas escape detection ?



Zwaan & Prochaska 2006

⇒ More efficient searches

Does trully molecular gas escape detection ?



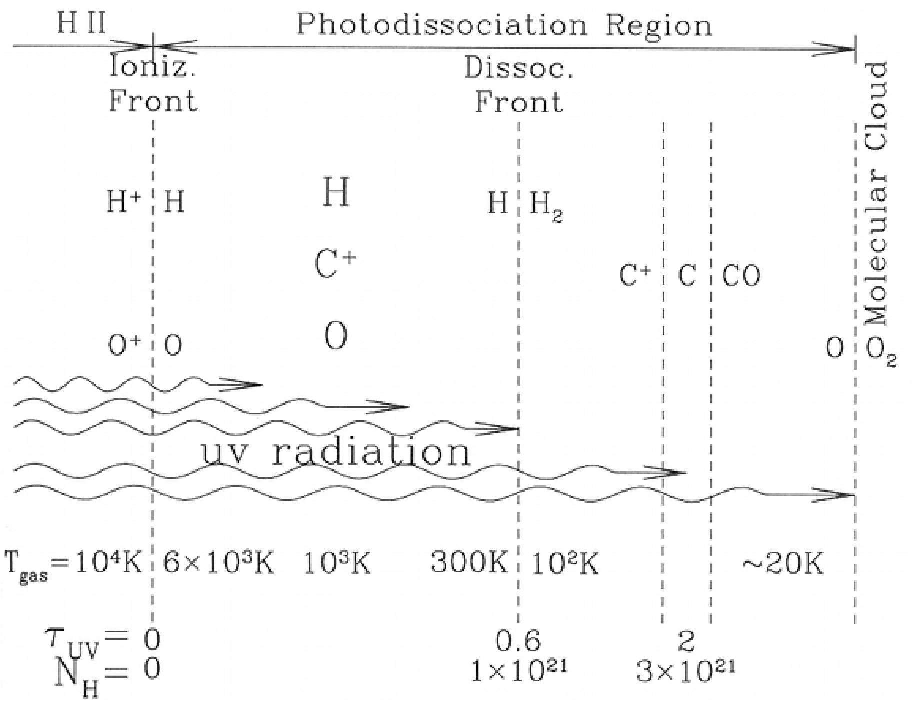
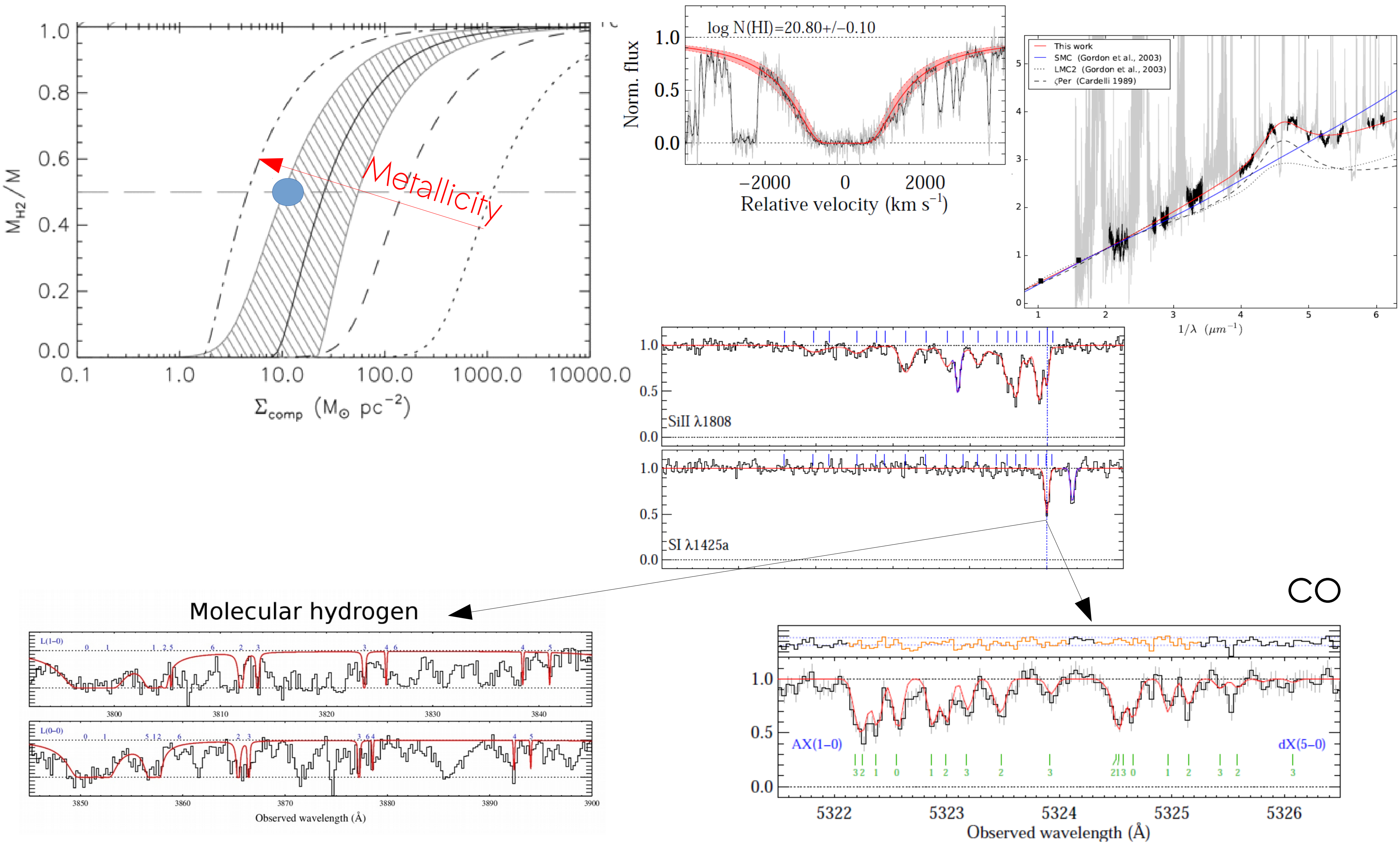


Figure 31.2 Structure of a PDR at the interface between an H II region and a dense molecular cloud.

Does trully molecular gas escape detection ?



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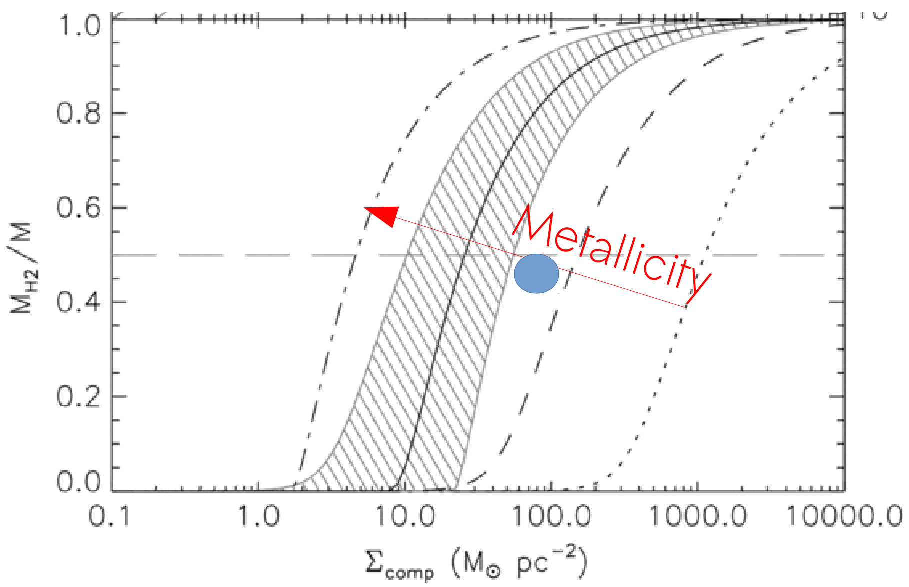
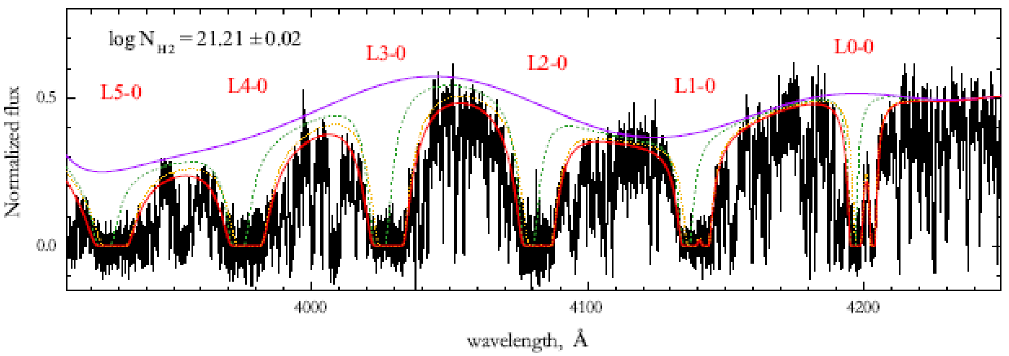
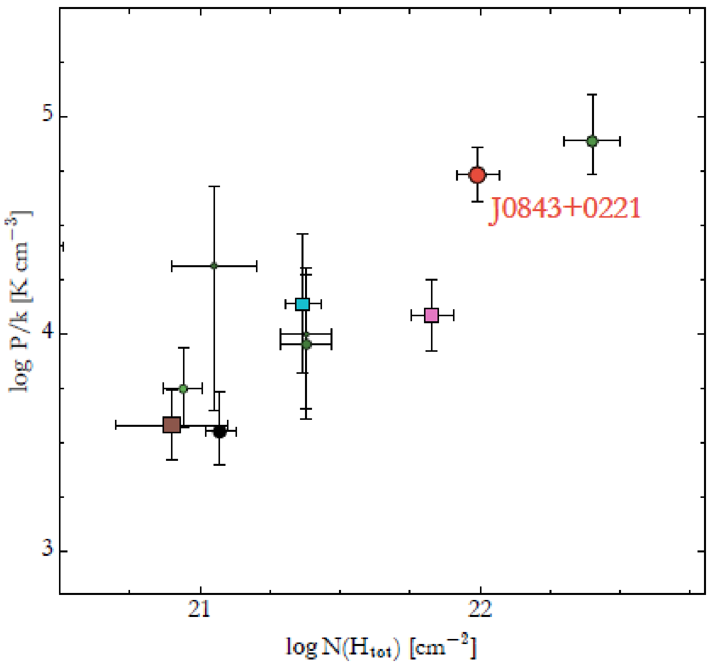
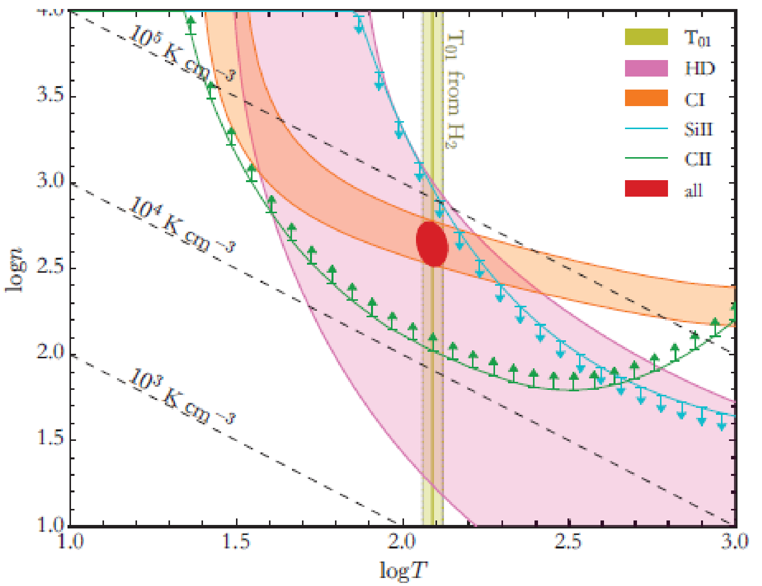


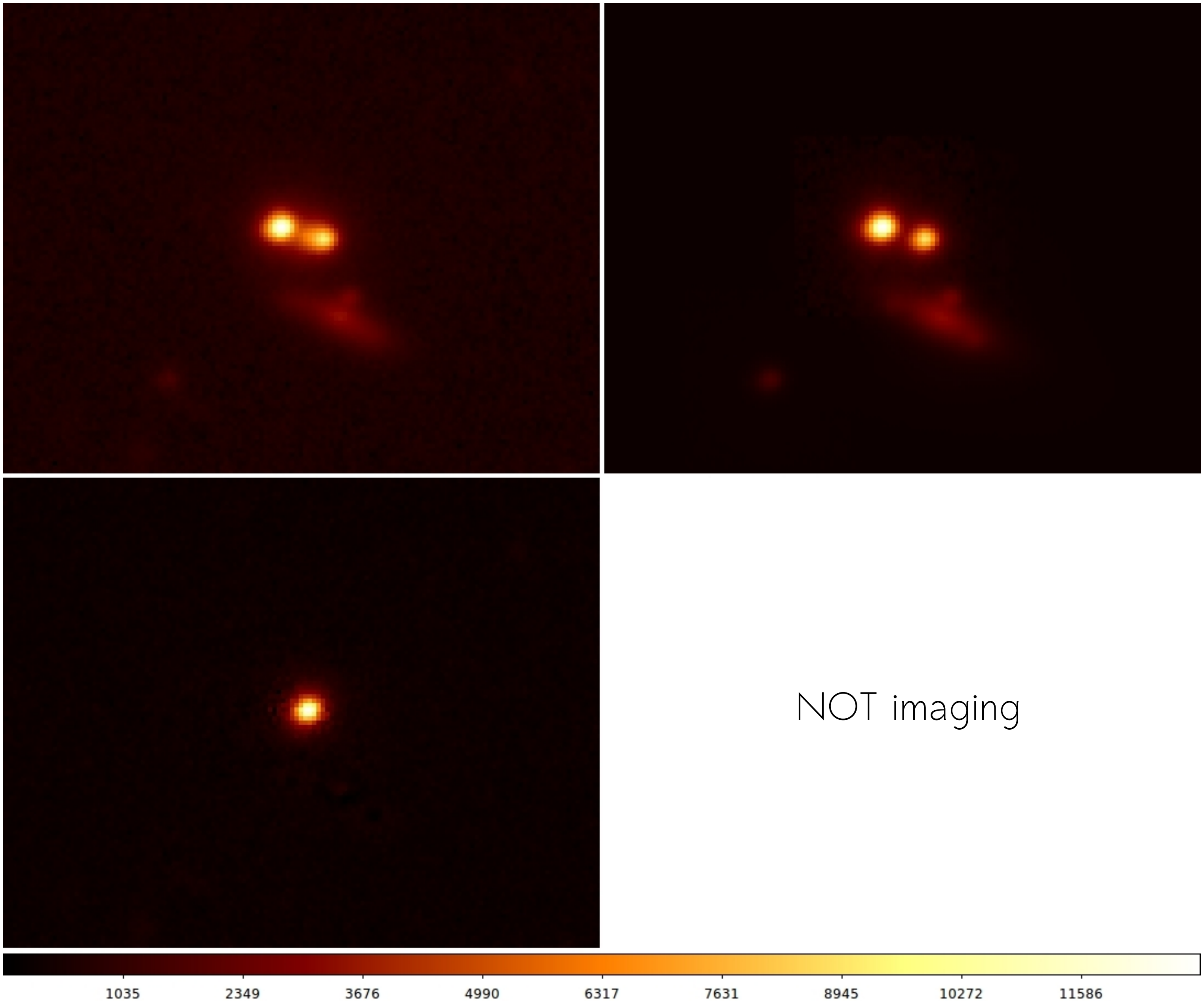






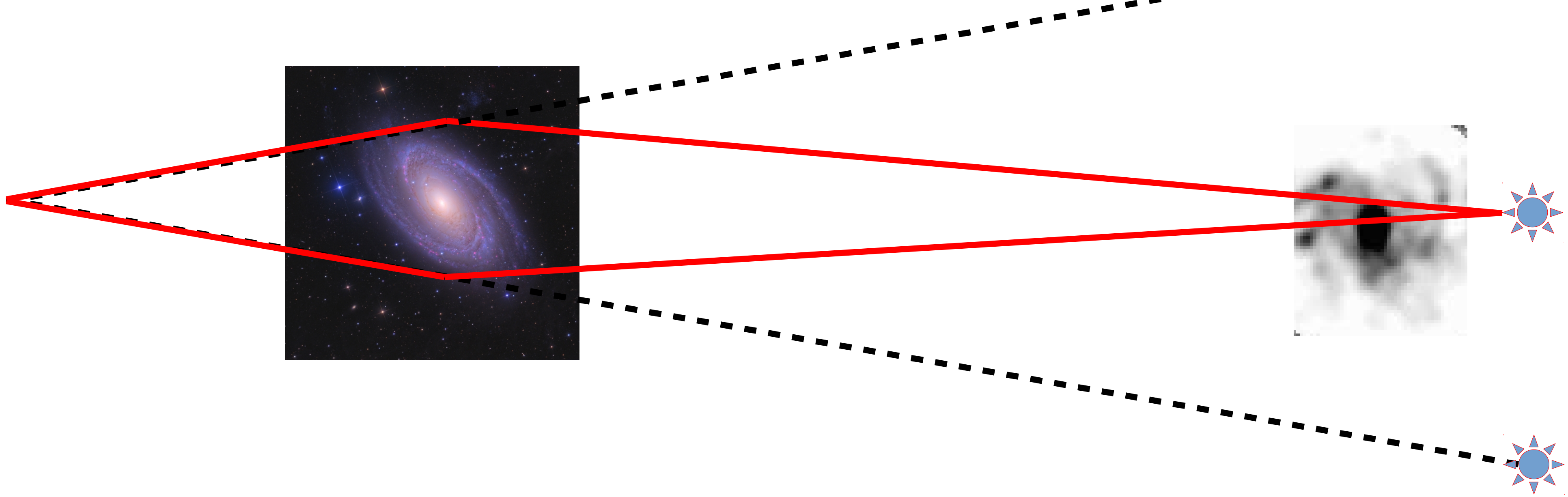
High pressure can lead to large N(H_2) even at low metallicity in prep !

Hitting central (molecular-rich) region of galaxies ?

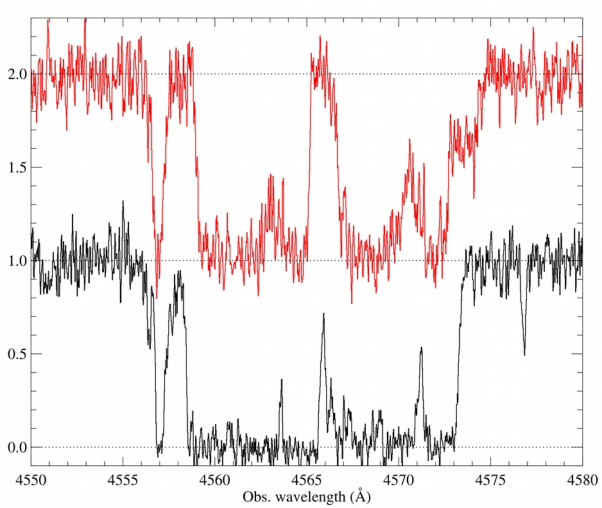


in prep !

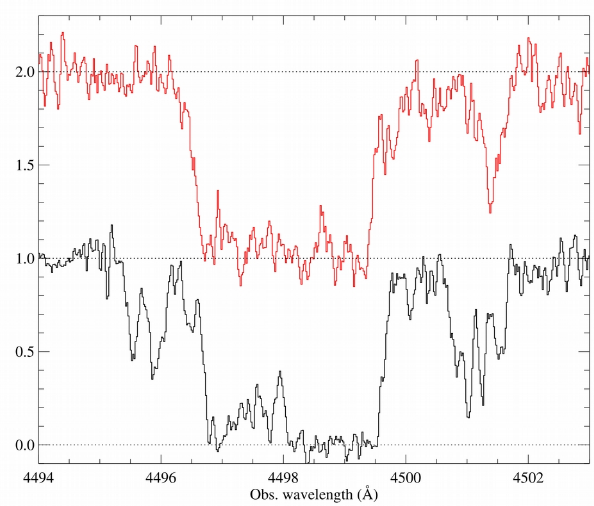
Hitting central (molecular-rich) region of galaxies ?



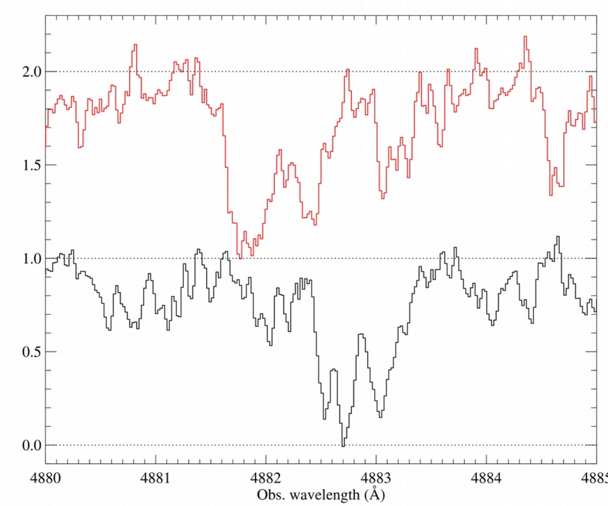
C IV



Si II



C I



Hitting central (molecular-rich) region of galaxies ?

in prep !