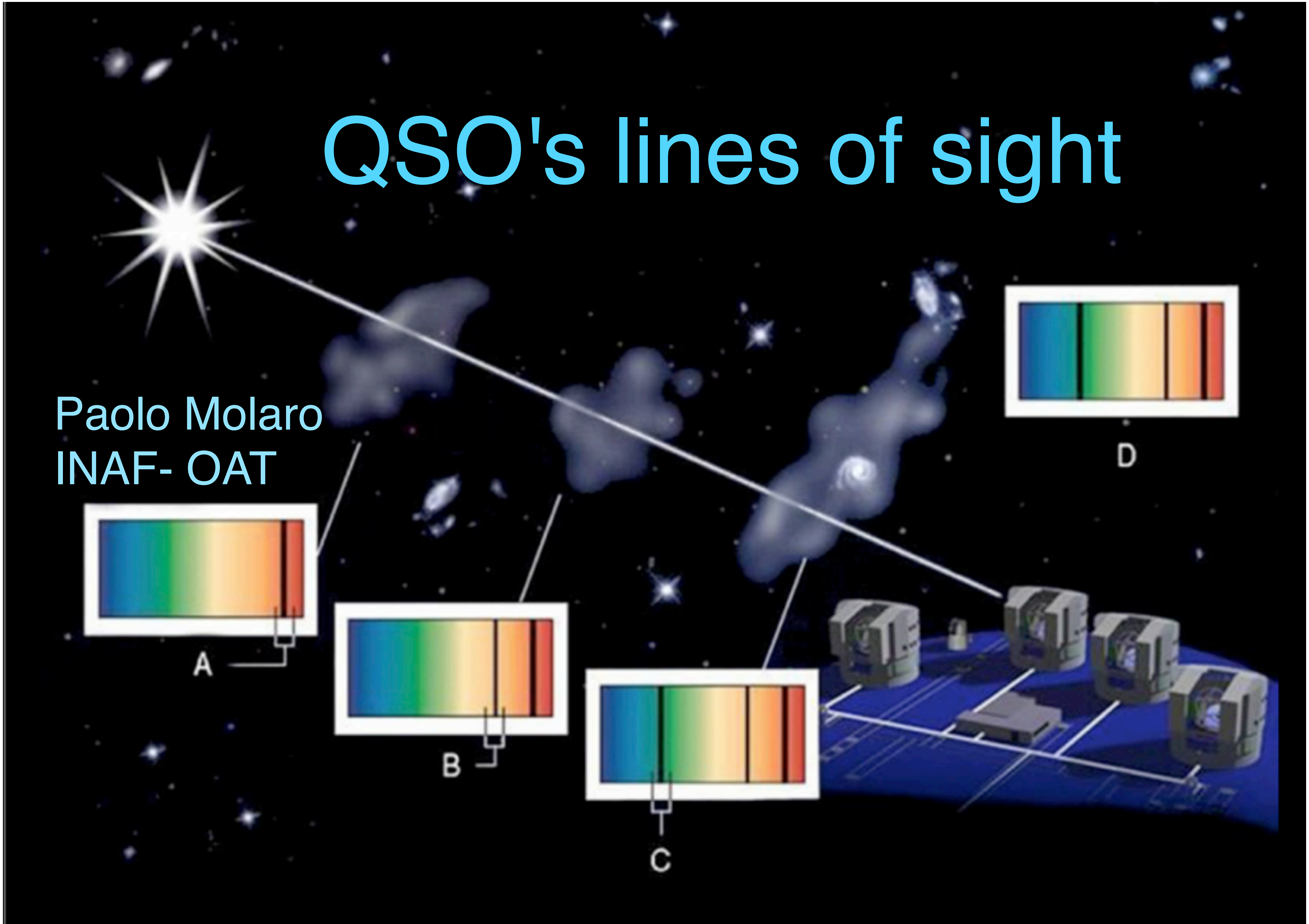
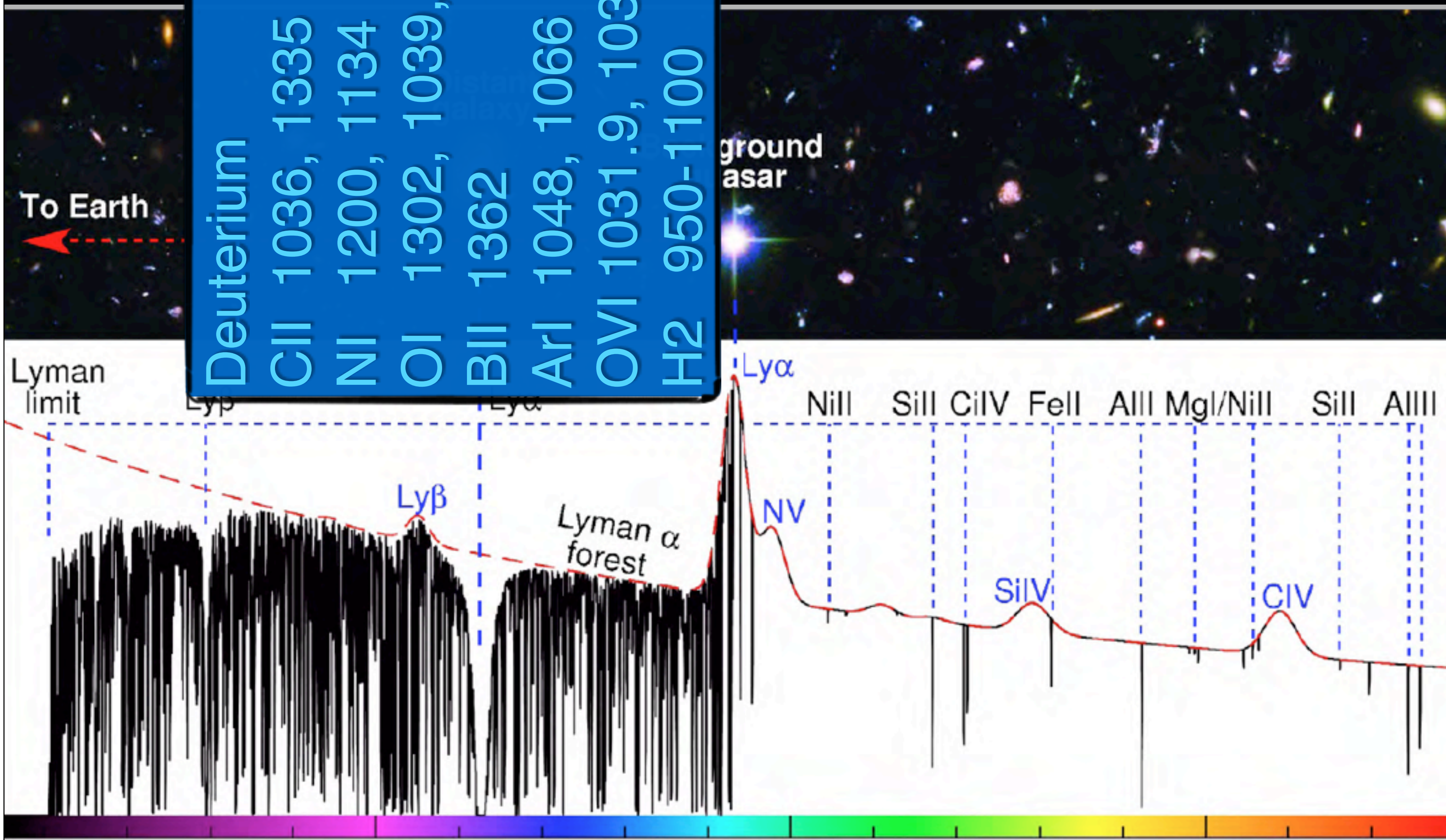
QSO's lines of sight

Paolo Molaro
INAF- OAT

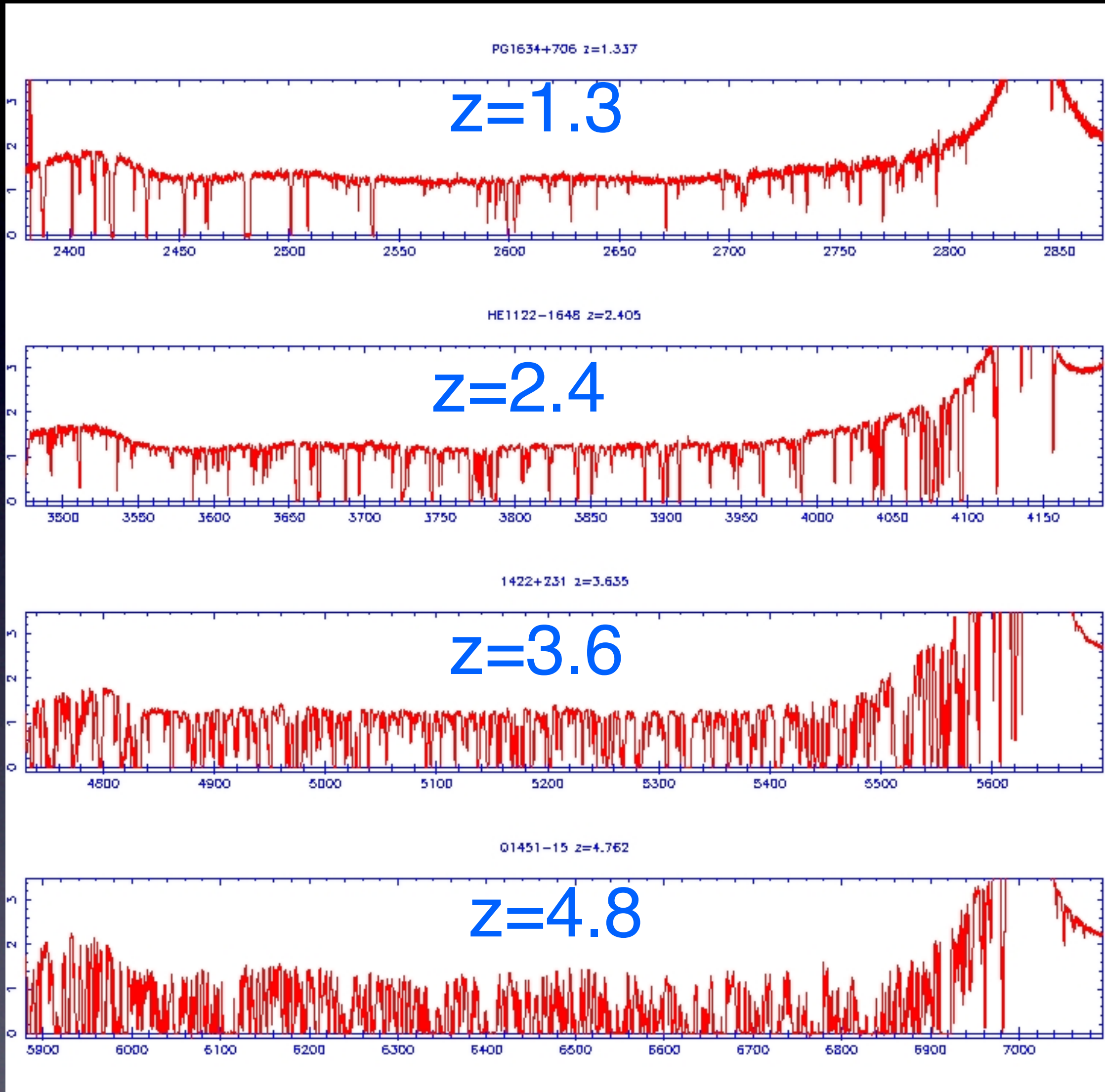


game for all wavelengths

Deuterium
CII 1036, 1335
NI 1200, 1134
OI 1302, 1039, 988, 976,
BII 1362
ArI 1048, 1066
OVI 1031.9, 1037.6
H2 950-1100



Digging inside the Ly α forest



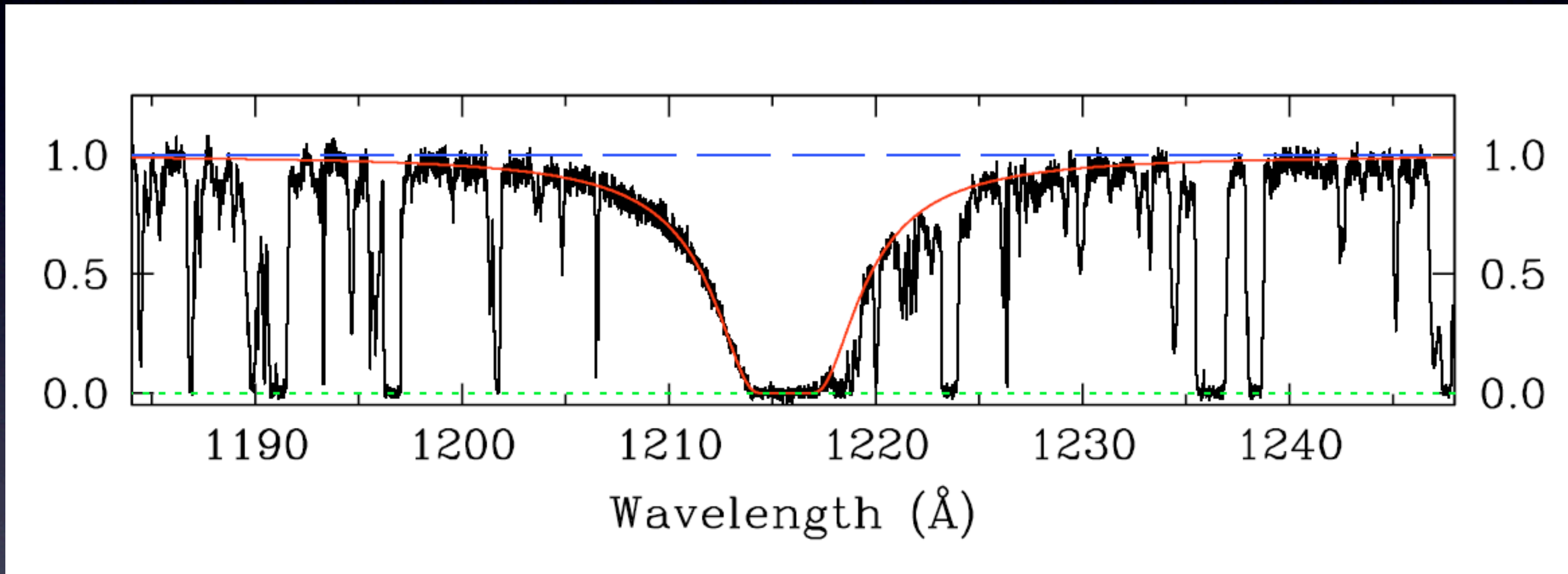
for elements with transitions in the Ly-α forest better go at the lower redshift: ~ 2.5

Why the 3000-4000 Å region si important?

- Deuterium
- CNO
- Other interesting elements (S, B, Ar, OVI)
- Molecular gas: H_2, HD, CO

Damped galaxies

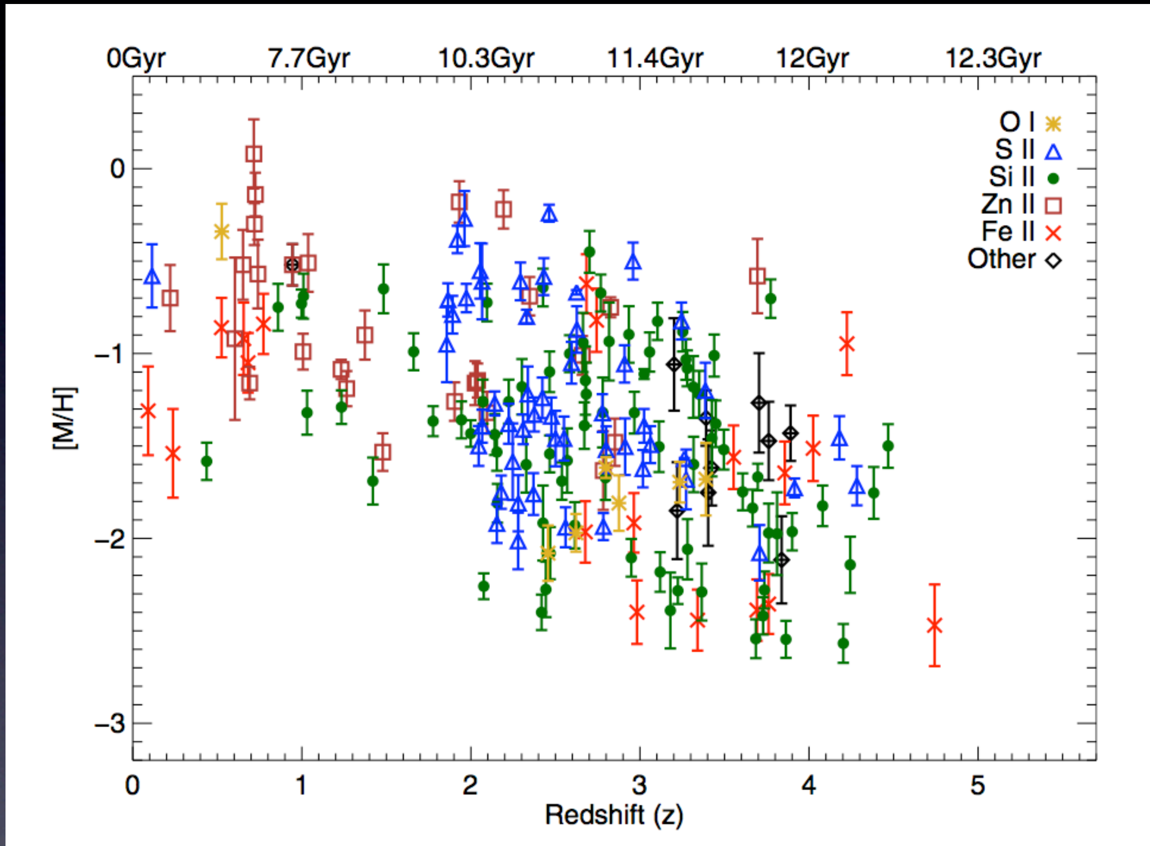
Definition: N(HI) > $10^{20.3}$ atoms cm^{-2}



Ly α absorption profile with damping wings

Optically thick to ionizing radiation

Accurate abundances throughout the whole universe (unbiased with respect to Luminosity or Mass)

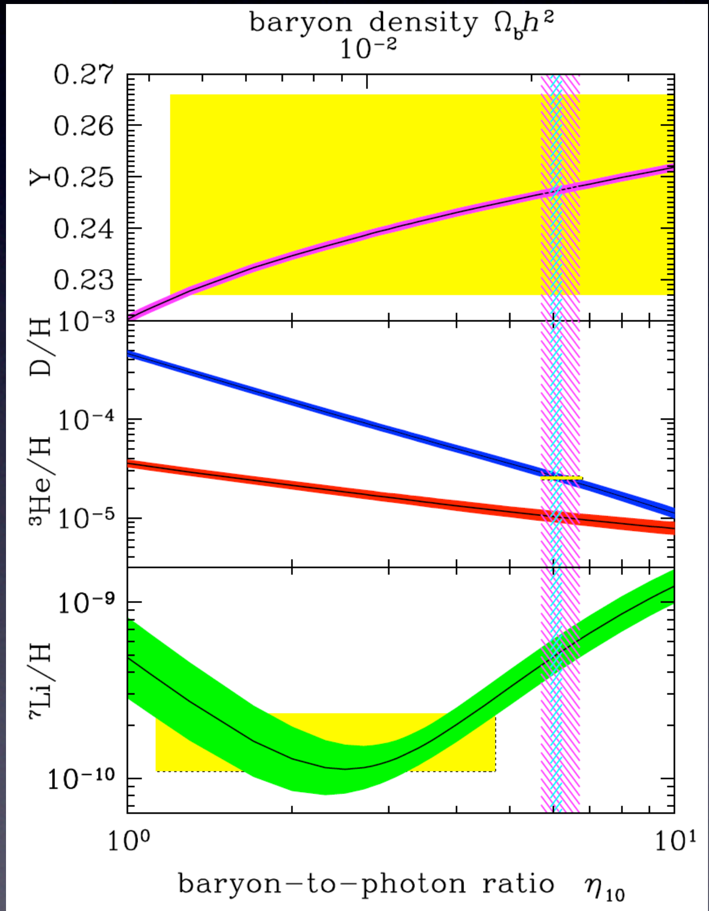


Rafelski et al 2002

metal-poor DLAs as probes of early stellar nucleosynthesis

Deuterium: the best "baryometer"

BBN

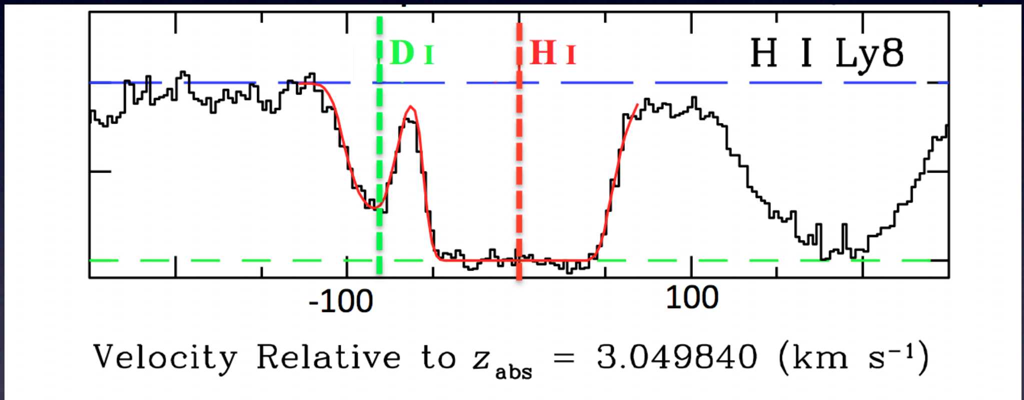


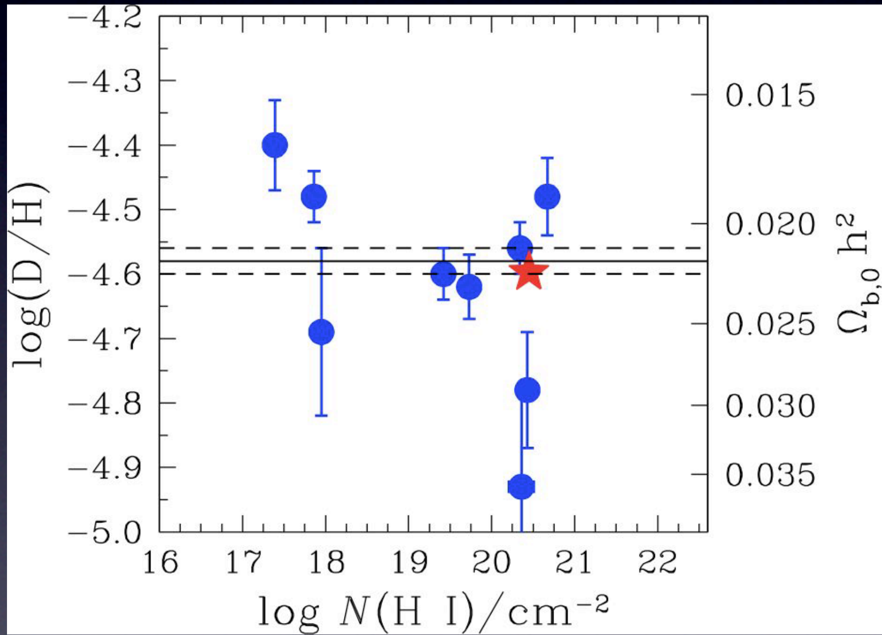
D not sensitive to expansion rate

BB only astronomical source

Brian et al 2013

~ 12 measurements with Keck-HIRES and VLT-UVES





Why is there an excess dispersion in D/H measures?

D/H in DLA

J1358+6522

z= 3.067, [Fe/H] = -2.84

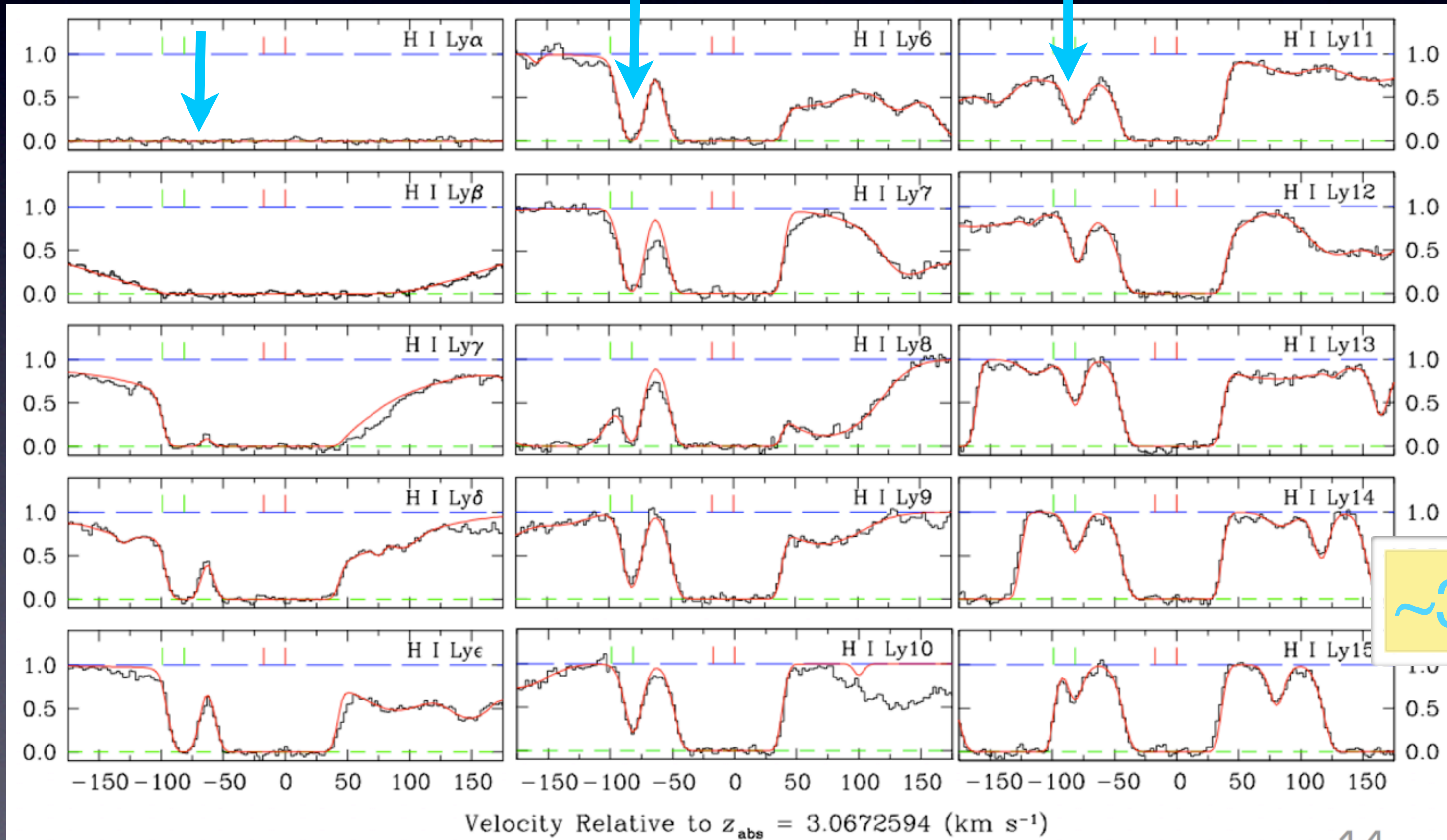
keck-HIRES

13 resolved DI absorption lines!

Cooke et al (2013) arxiv 1308.3240

Two components b=8-9 km/s

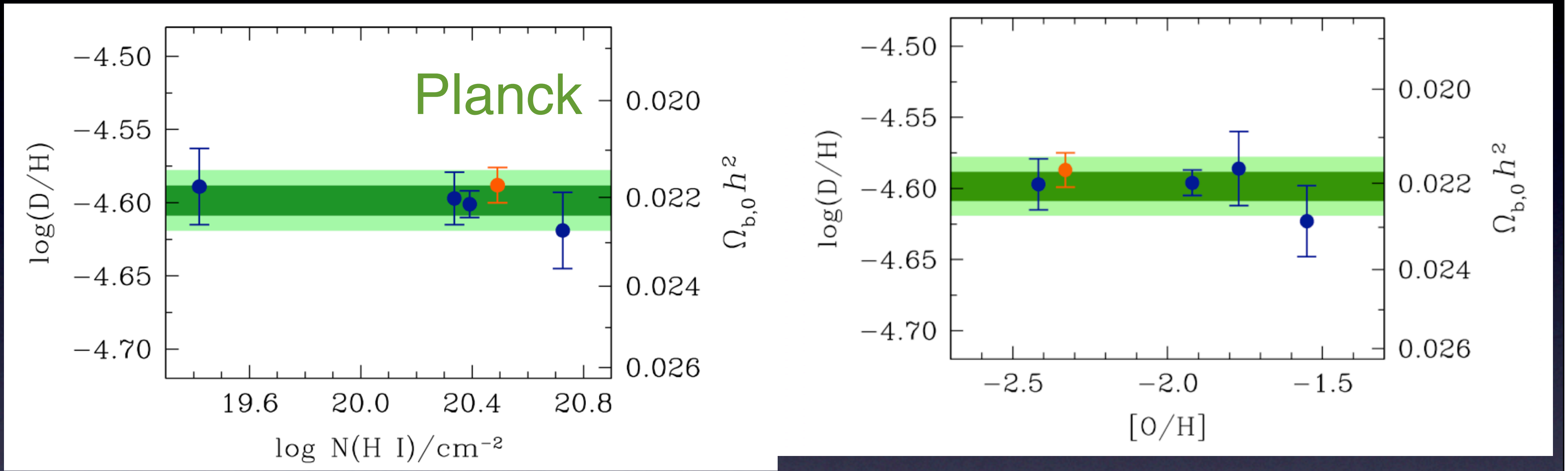
-82 km/s



~3600A

Precision sample of D/H

sub-sample of the best 5 systems with several DI resolved
i.e. less contamination by lyman-α forest



Cooke et al (2013)
arxiv 1308.3240

coherent analysis

Blind analysis

→ No dispersion!

$(D/H)_{DLA} = (25.3 \pm 0.4)$ ppm

1.6%!

BBN & CMB

BBN

$$(D/H)_p = 2.55 \times 10^{-5} (6/\eta_D)^{1.6} \times (1 \pm 0.03)$$
$$\eta_D = \eta_{10} - 6(S-1) + 5\xi/4$$

$$\eta_{10} = 273.9\,\Omega_{b,0}\,h^2,$$

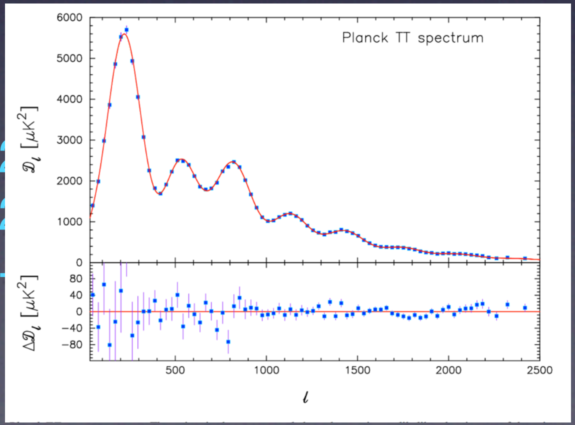
$$S = [1 + 7(N_{\rm eff} - 3.046)/43]^{1/2}$$

$$100\,\Omega_{b,o}h^2 = 2.202 \pm 0.019_{ran} \pm 0.041_{sys}$$

sys comes from nuclear cross sections

CMB

$$100\,\Omega_{b,o}h^2 = 2.218 \pm 0.026$$



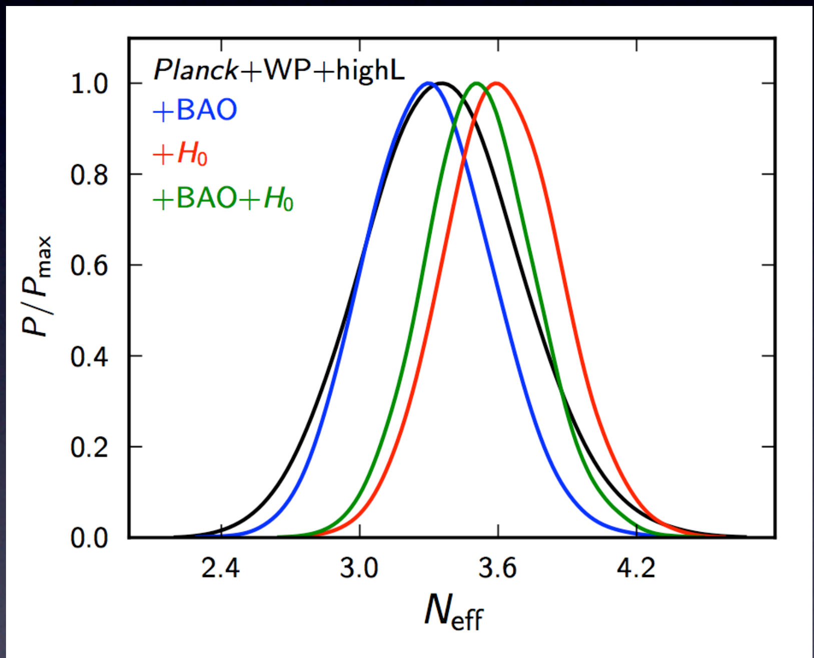
Planck collaboration XVI arXiv:1303.5076

D/H +BBN agrees with CMB-Planck

N_{eff} = νe, νμ, ντ, +.....?

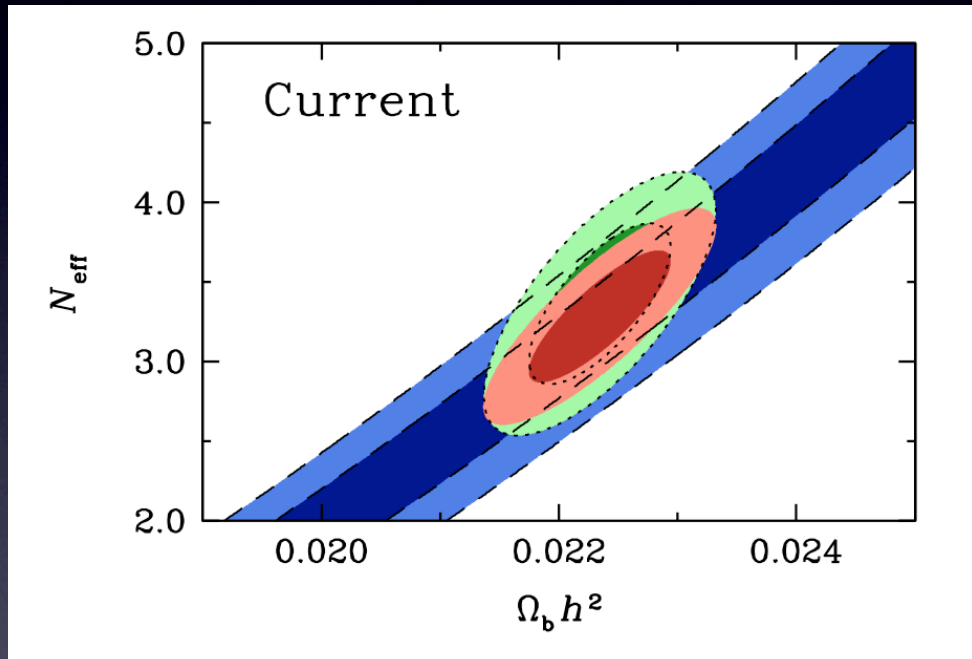
(assuming consistency)

CMB



Planck: N_{eff} = 3.36 ± 0.34
(Planck +WP+ highL)

joint CMB + BBN



N_{eff} = 3.28 ± 0.28

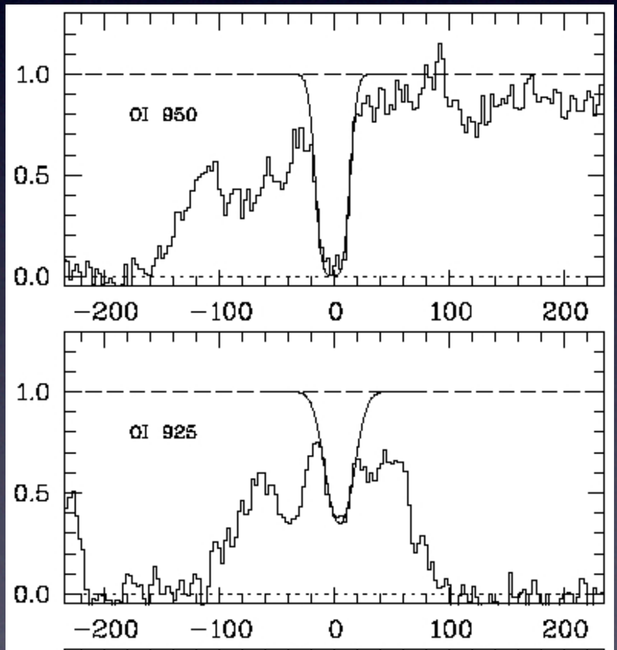
no evidence for new physics beyond the SM!

C,N,O abundances in the UV-Optical region

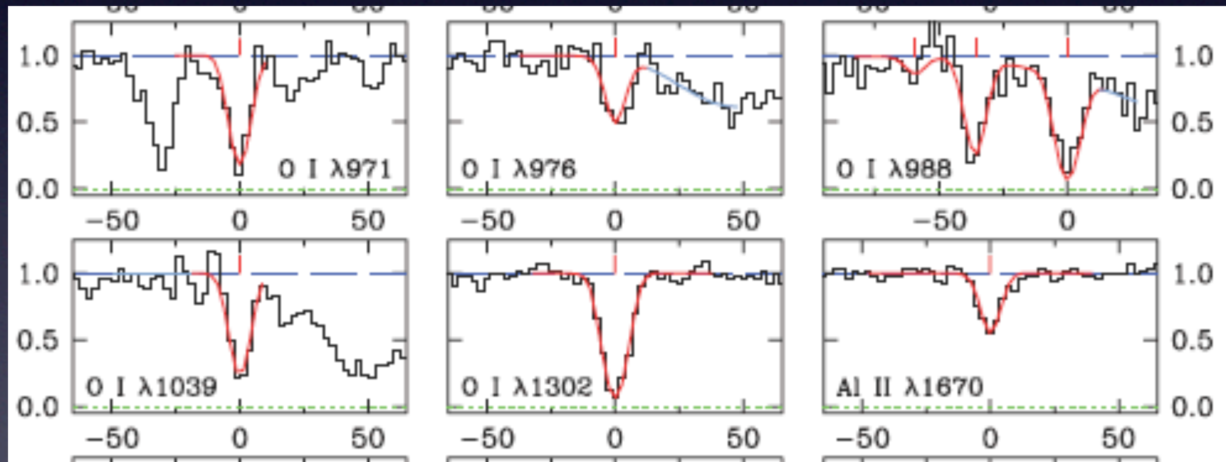
OXYGEN

Outside the Lyα forest: OI 1302 A: saturated (1355 A: too weak) ➔ metal poor DLA
Inside the Lyα forest: OI 1039, 988, 976, 971, 948, 925 A

[O/H]=-1.7

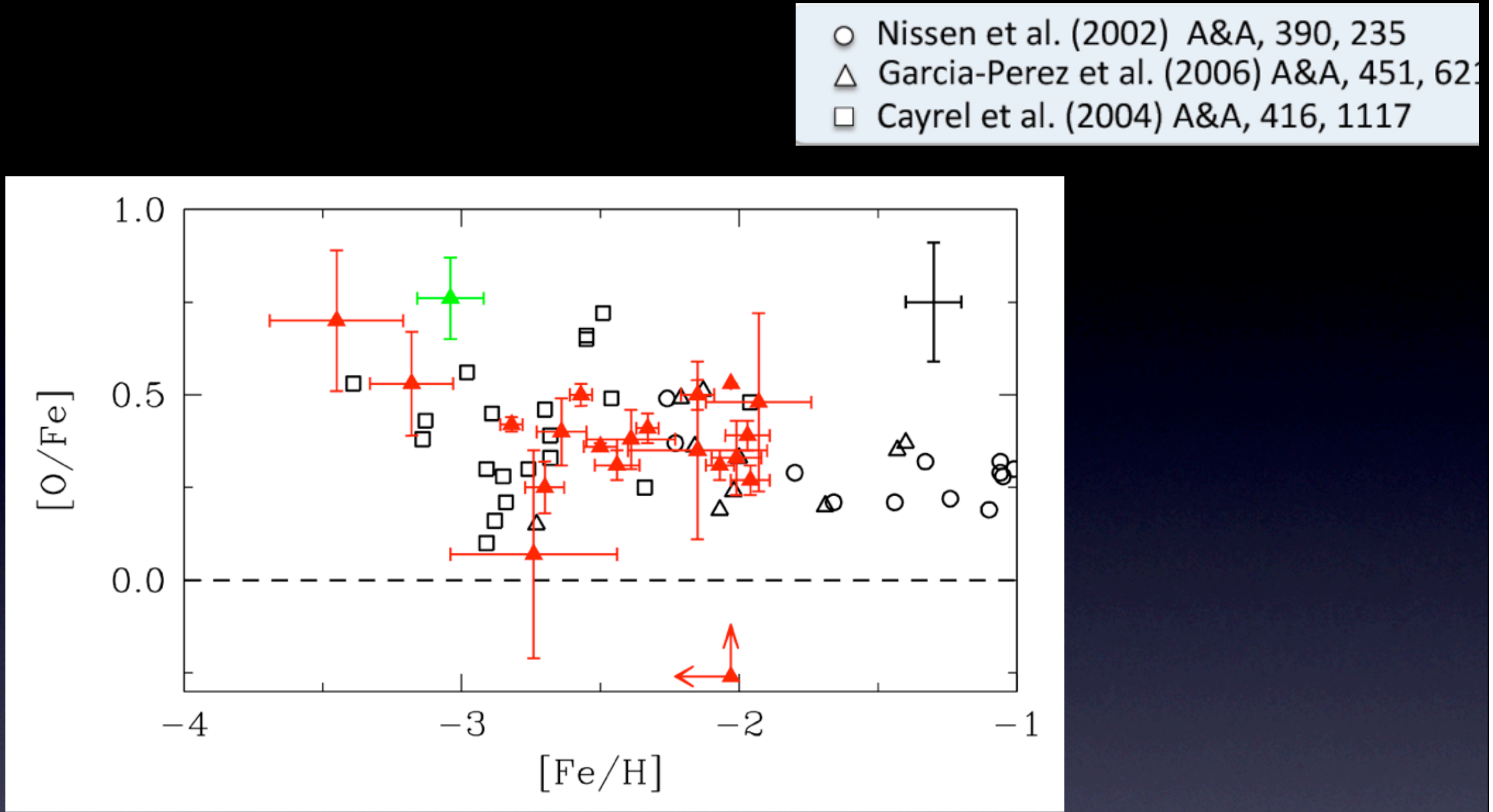


[O/H]=-2.3



Cooke et al 2011, 2012

First measurements of O/H in the DLA
z=3.39 Q0000-26 PM et al. 2000



DLA ~ HALO STARS ??

But what is [O/Fe] in halo stars?

cfr talk of Bonifacio

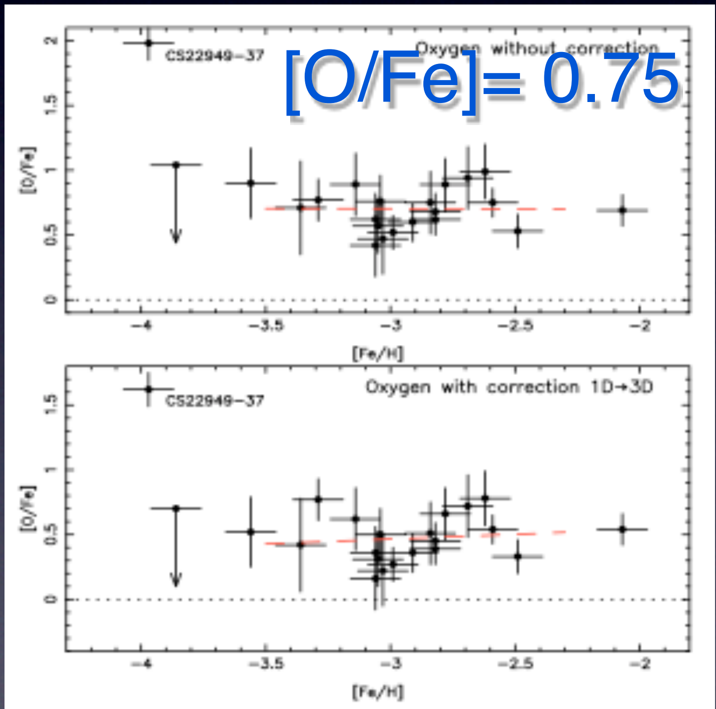
The Oxygen problem

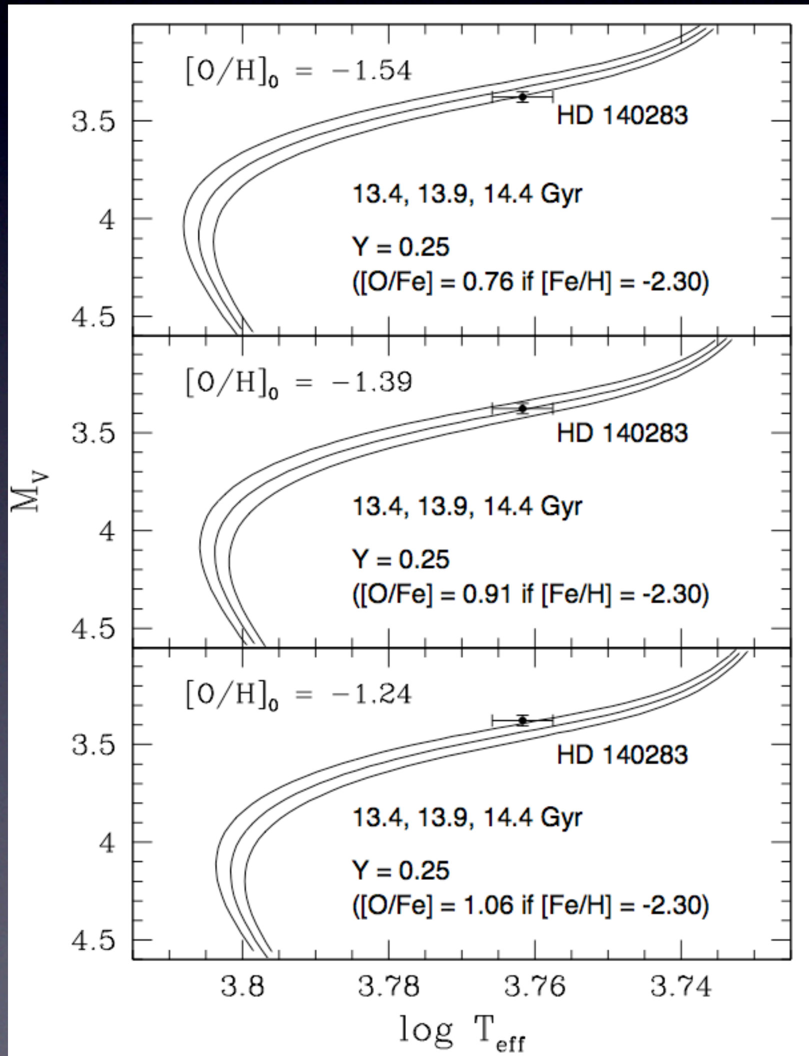
Bond et al 2013

OH UV 3D (+ non-LTE?)
OI 7770Å 3D + nonLTE
OH IR 3D (+ non-LTE?)
[OI]6300Å 3D?

Trigonometric paralax with FGS of HST

[O/Fe]> 0.8

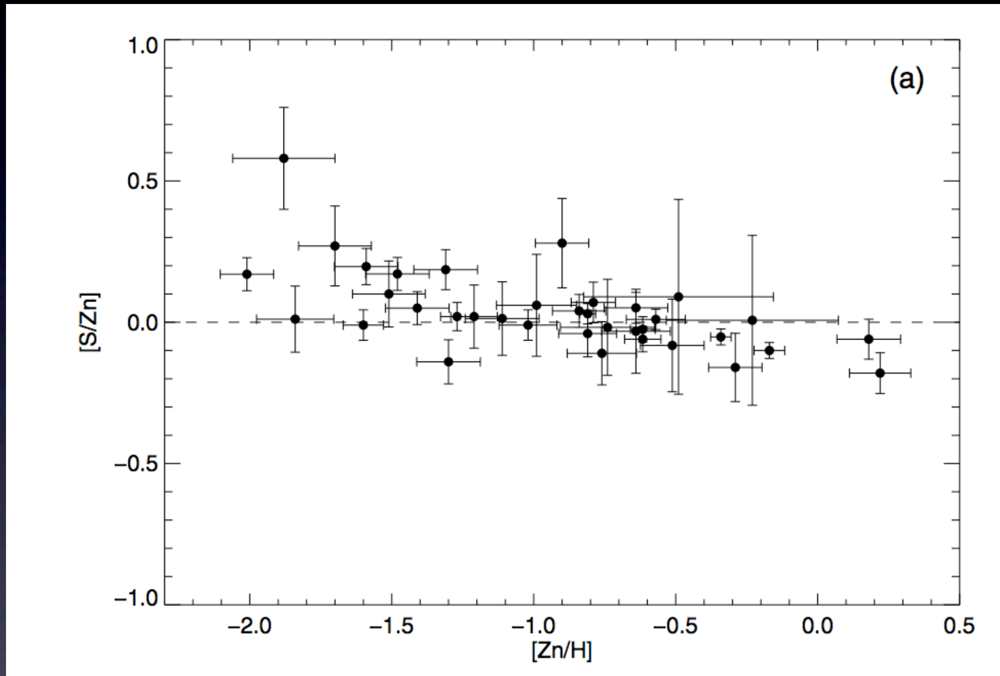




Sulphur

Proxy of O (non-refractory, α-element)

SII 1250.584, 1253.811, 1259.519 A



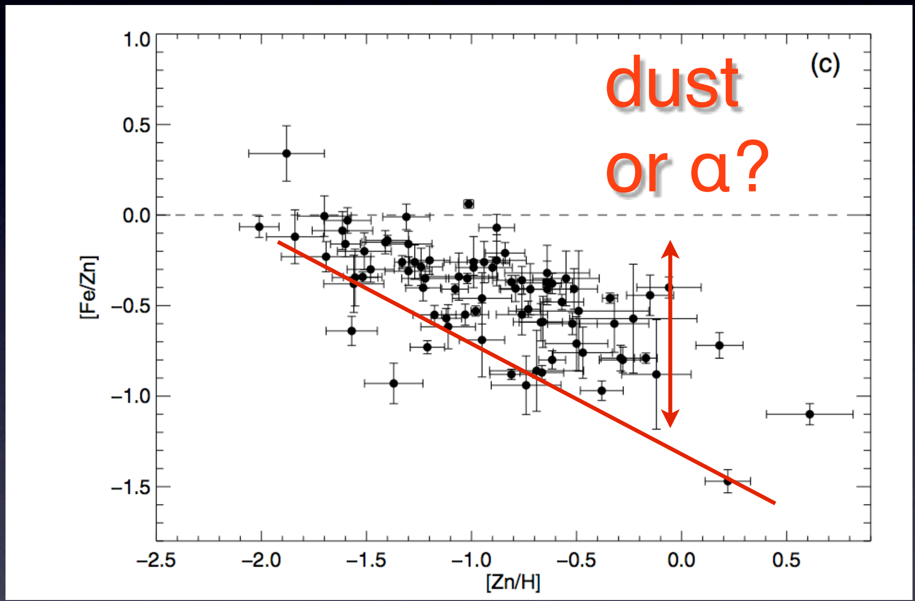
Rafelski et al 2012

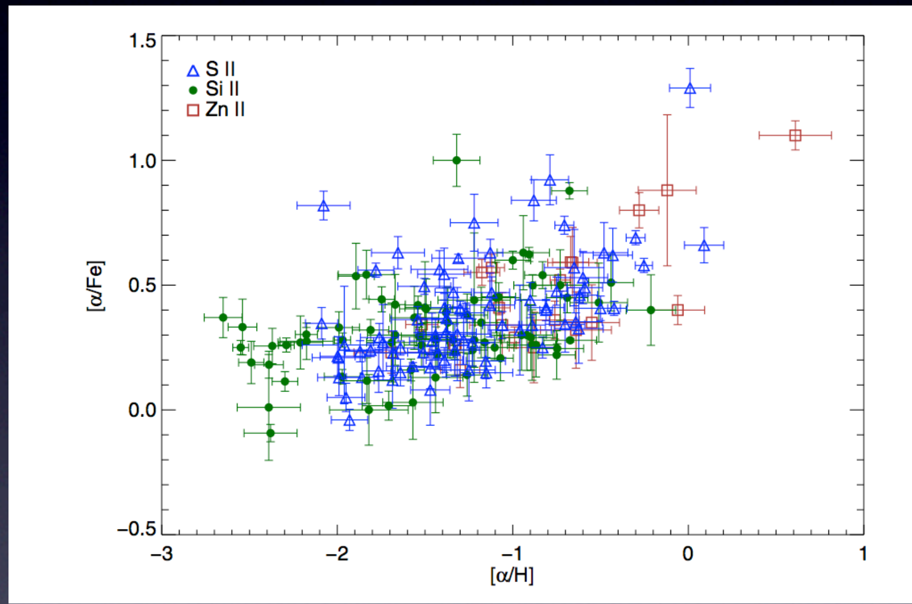
What is the behavior of Zn?

Zn behaves as an α-element → DLA are α-enhanced.

Zn traces Fe (as in stars) → DLA are not α-enhanced

What is the behavior of Zn?





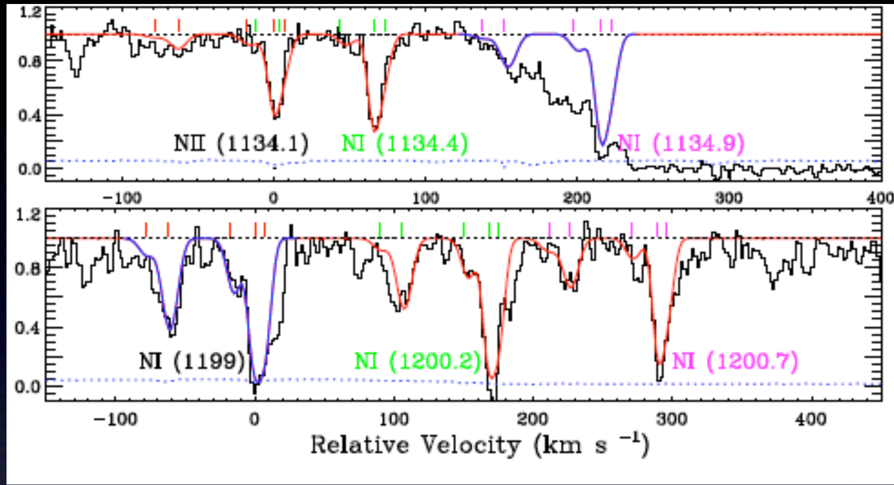
at low metallicity several [α/Fe] ~ 0, i.e. solar α-enhancement of ~ 0.3

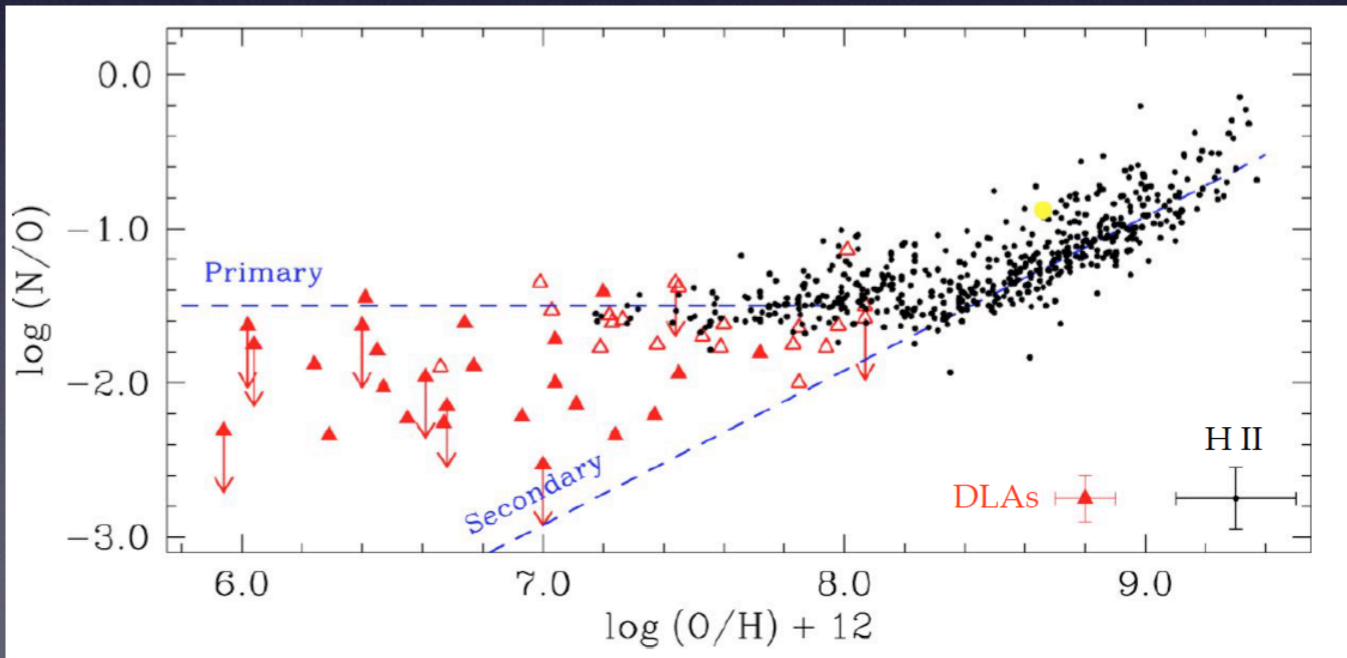
Nitrogen

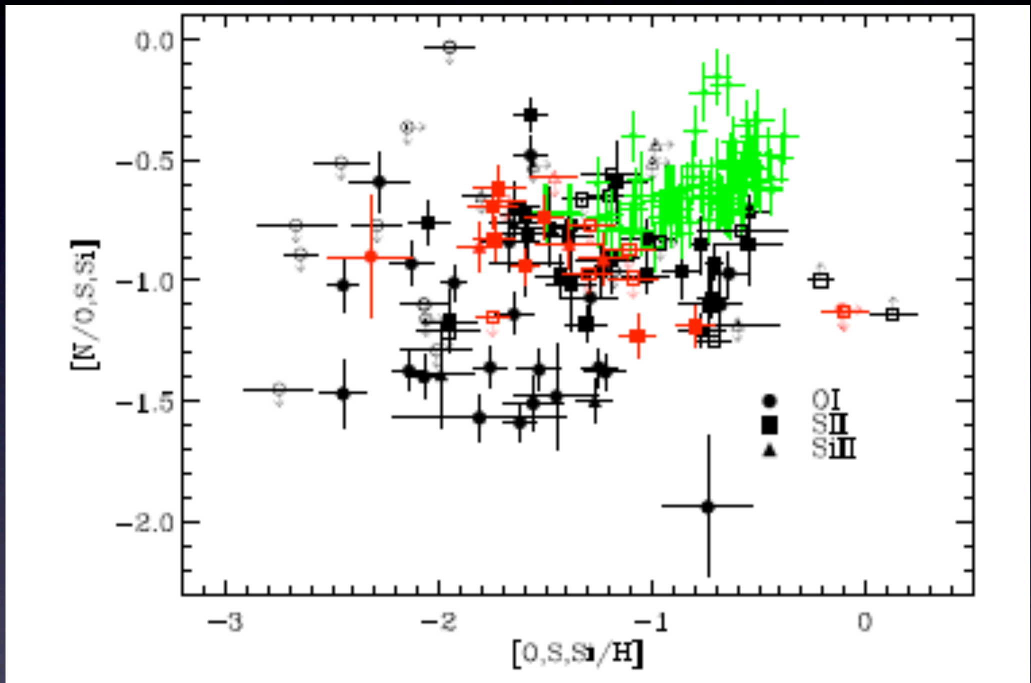
6 NI transitions in the forest:

NiI 1134.1 1134.4 1134.9 Å

NI 1199.0 1200.2 1200.7 Å







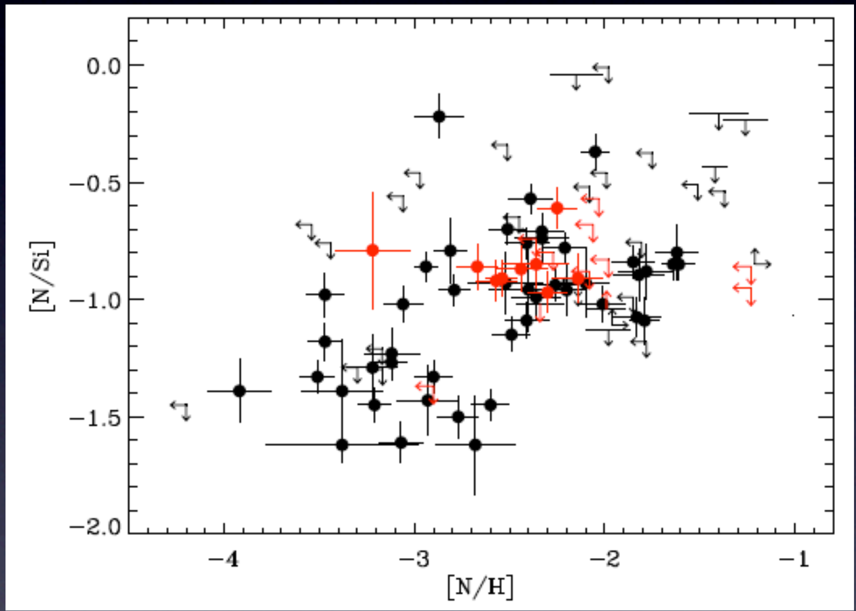
- Large spread

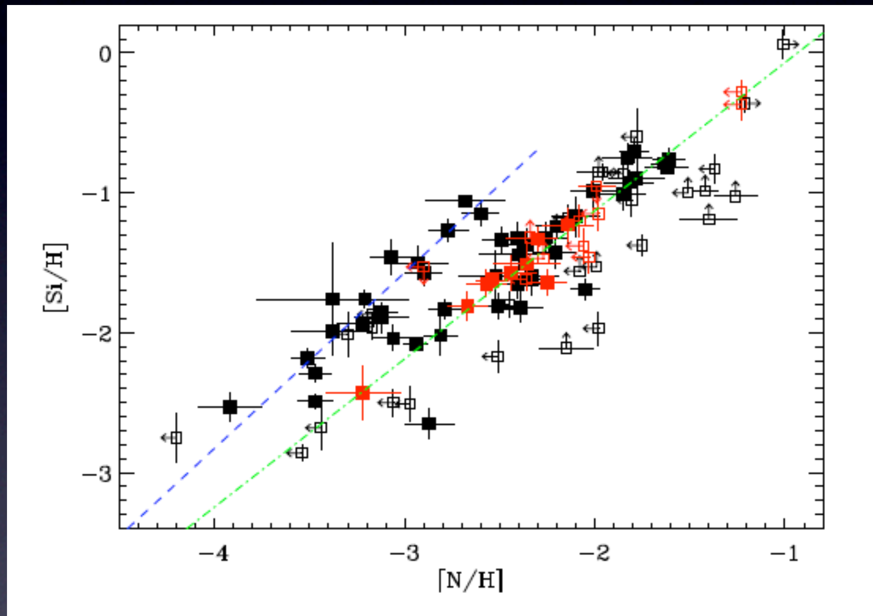
- [N/α] << than HII (and Galactic stars)

- Bimodal?

Tayyaba et al 2013 in prep

Bimodal distribution of N?





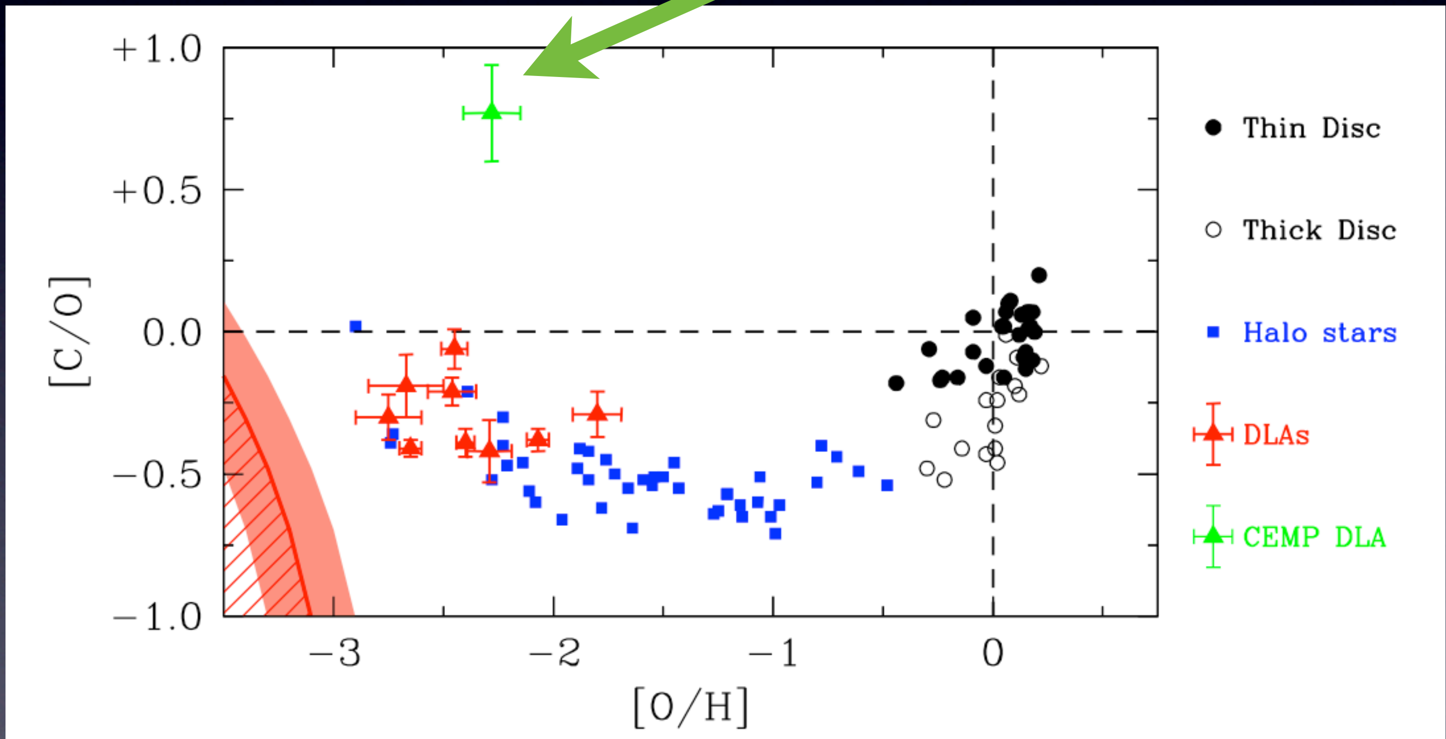
different nucleosynthesis processes for N at low [Fe/H]?

Tayyaba et al 2013 in prep

Carbon

CII 1036 and 1334 A lines are strongly saturated
➡ very metal poor DLA (~ [Fe/H]<-2.5)

C-rich DLA Cooke et al 2011, 2012



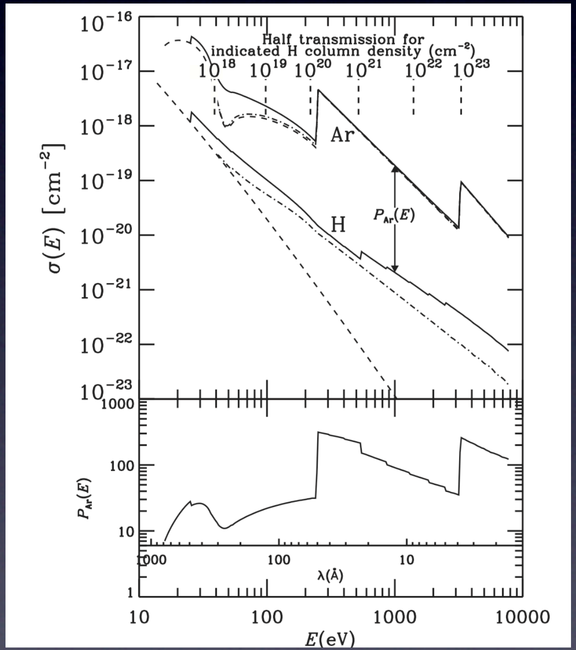
- CEMP: stars [Fe/H]<-2 with [C/Fe]>+1.0, fraction > 30%
- 1 (2?) DLA ~ CEMP [C/Fe]=1.5 and [C/Fe]=0.6 Why?

Argon

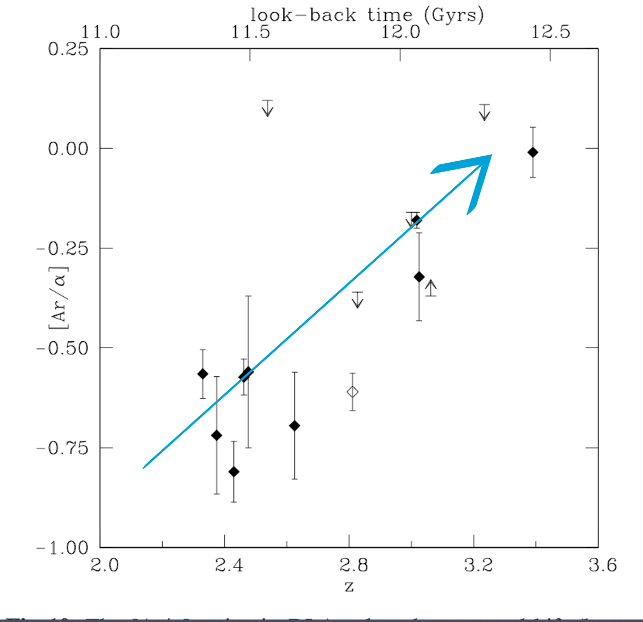
- ➡ ArI 1048, 1066 Å
- ➡ α-element (not measured in stars)
- ➡ non-refractory
- ➡ IP= 15.76 eV,
- ➡ photoionization cross section >> HI

MW: [ArI/OI] = -0.43 ± 0.11
Jenkins 2013

DLA: [Ar/α] ~ -0.8 -0



is varying with z?

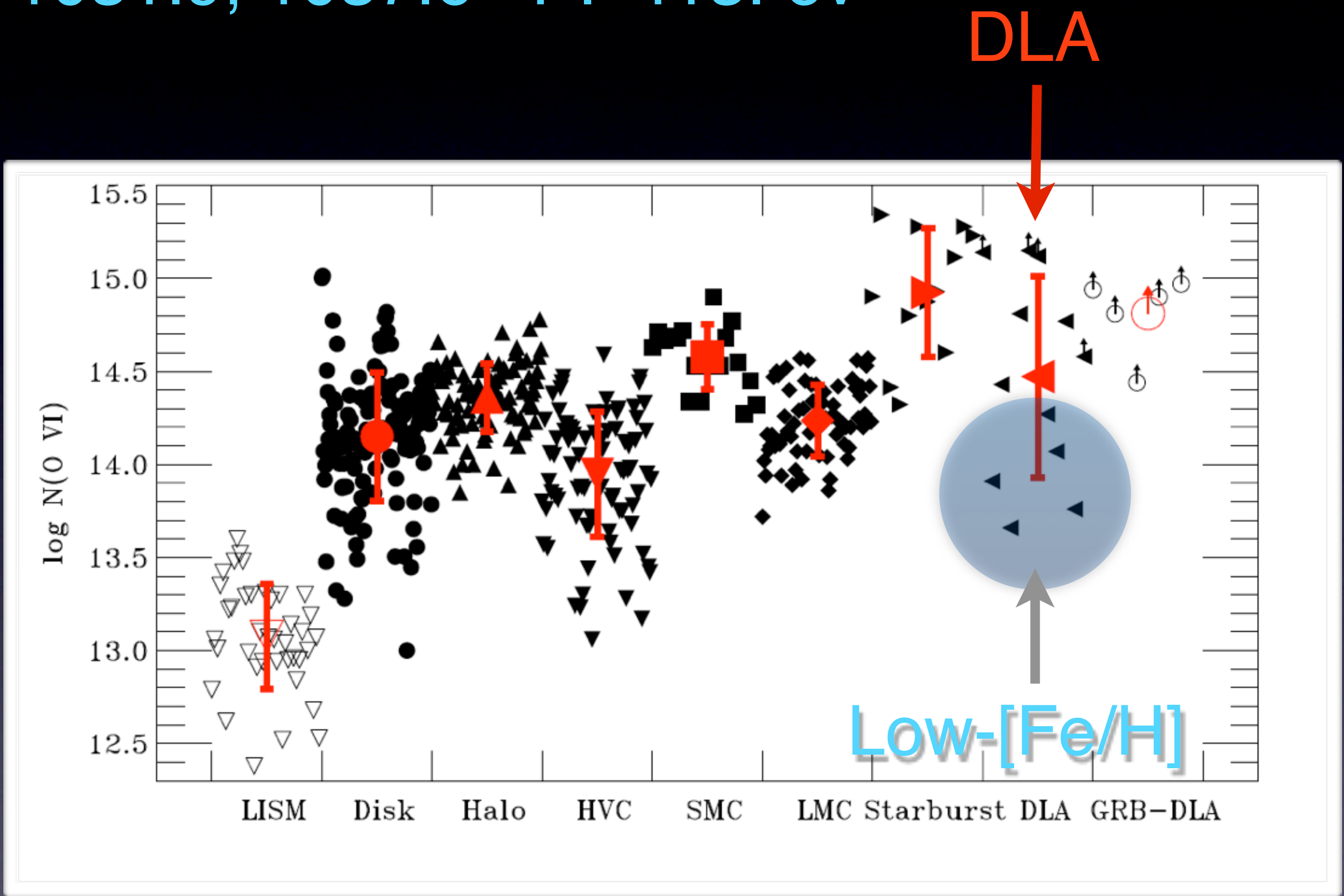


Vladilo et al 2003

photoionized by local soft Xrays or UV background (z<3?)

OVI

OVI 1031.9, 1037.6   PI=113. ev



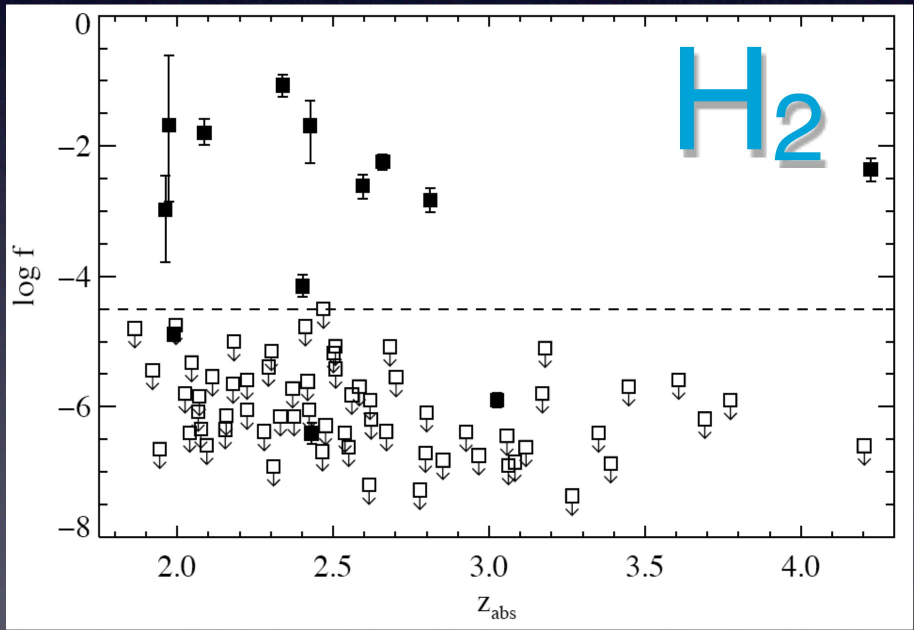
Fox 2011

Collisional ionization in cooling coronal plasma ~10^5 - 10^6K

Different velocities from the cool gas

Molecular gas

- H_2 (~ 20 detections); HD (6 detections)

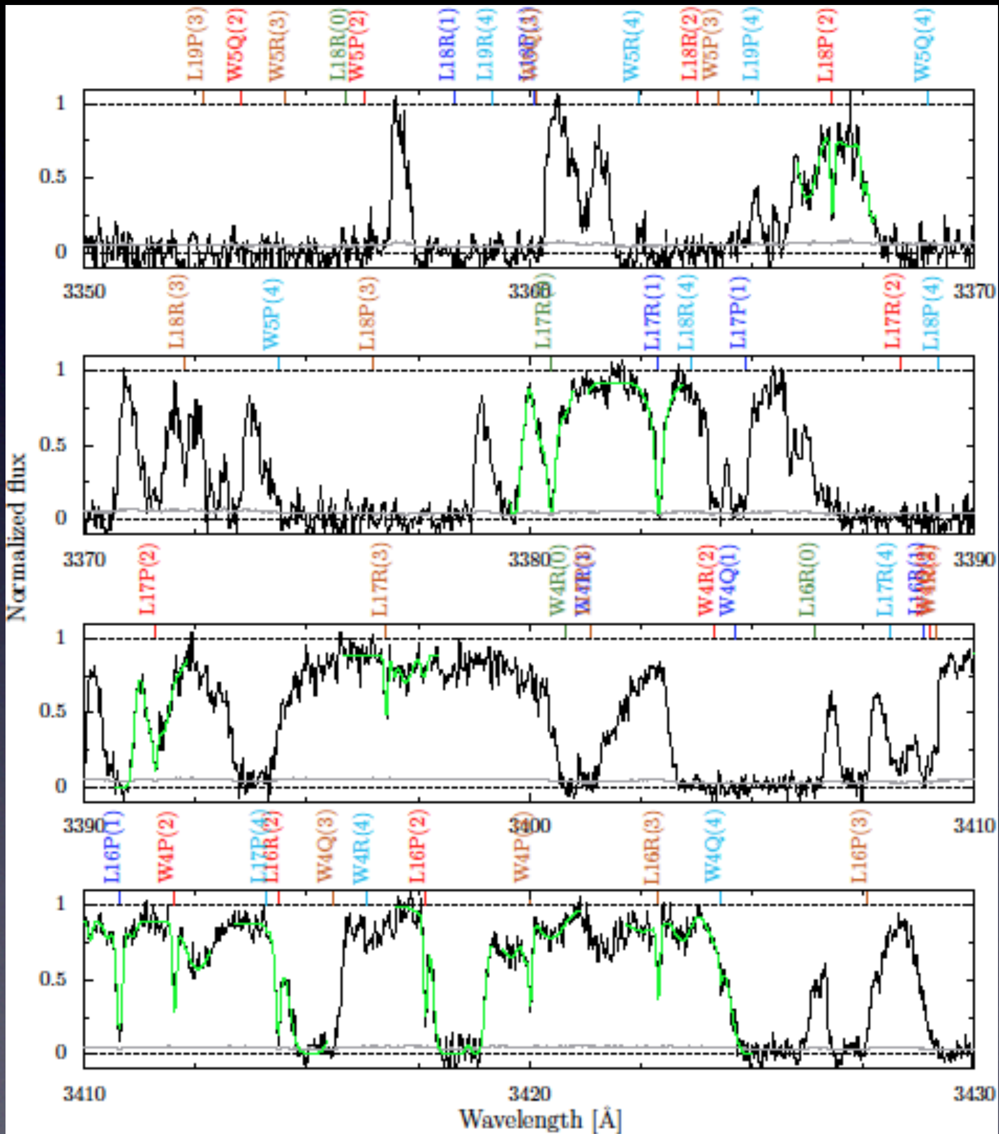


Noterdaeme et al 2008

peak of systems at z~ 2.5 (related to dust)

H_2 at z~2.66

B 0642-5038



Bagdonaite (2013)

Lyman Werner rovibronic transitions 950-1100 A

~ 10% DLA

correlated with dust

Importance of molecules

Constrain the physical state of the gas

- ➡ Temperature: ~ 100 K
- ➡ density: n(H) ~ 50-60 cm-3
- ➡ sizes: ~ pc
- ➡ Radiation fields: MW or lower

Models of primeval galaxies

➡filling factor of molecular gas
➡connection between dust and molecules

Cosmology & Fundamental Physics

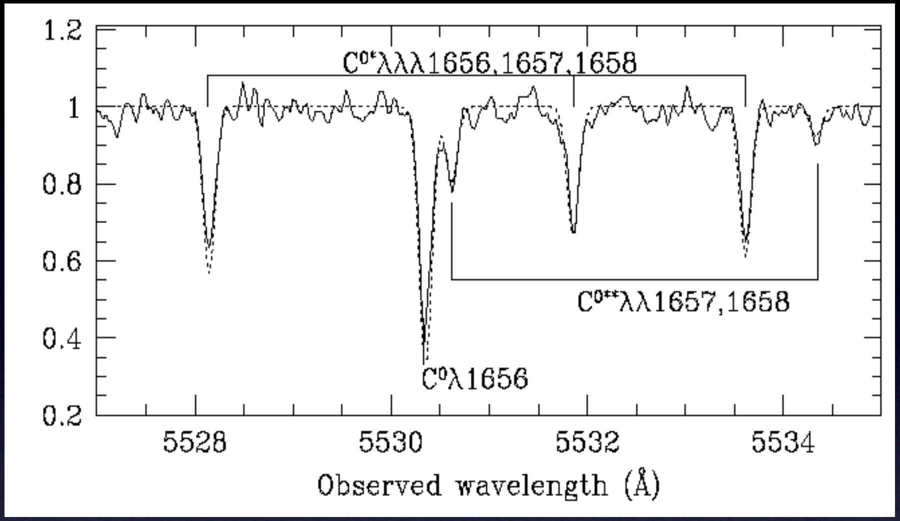
➡Variability of Mp/Me
➡ Measure of T (z)

Probing T_{CMB} (z)

In the cool gas C I* or C II* are observed

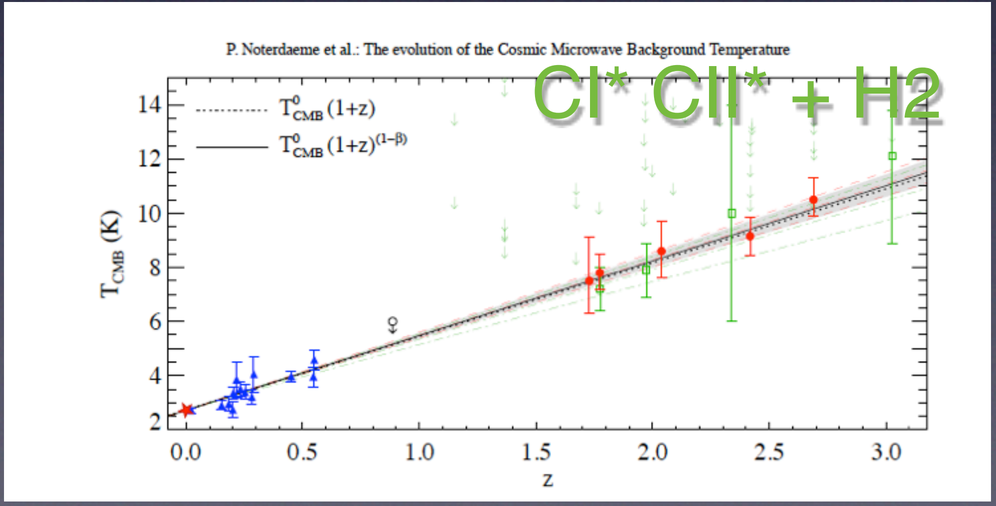
The population of fine-structure levels of the ground state of C I* or C II* depends on (Bachall Wolfe 1968):

-Collisional excitation
-UV pumping plus cascades
-CMB radiation



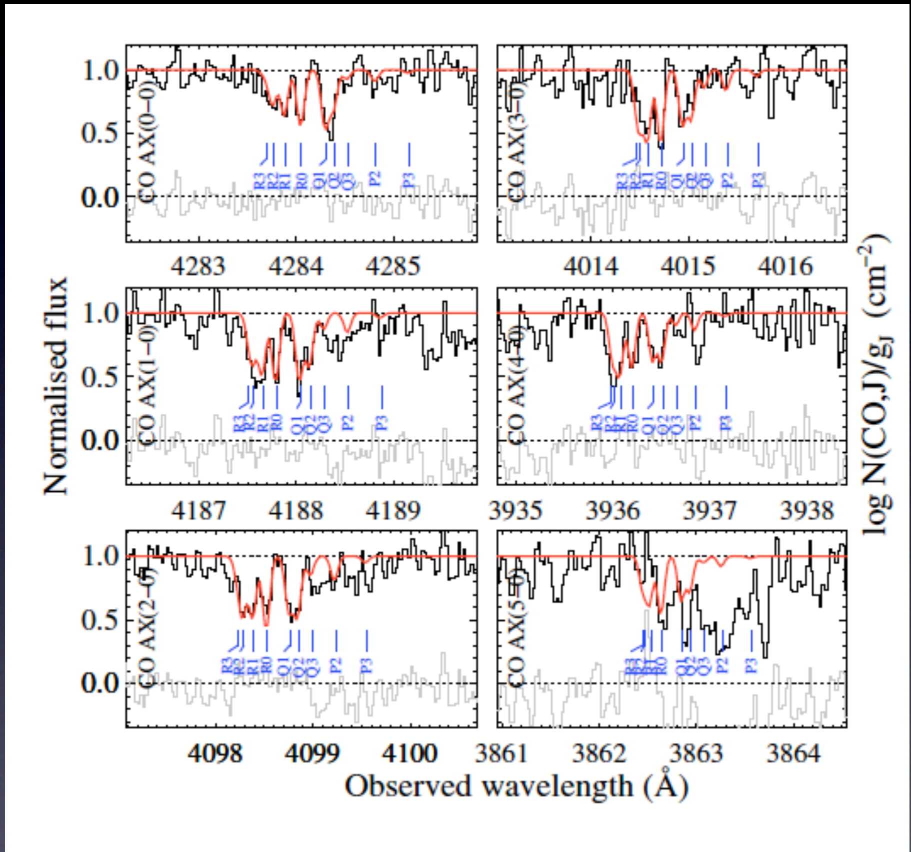
H2 provides simultaneous determination of local density, kinetic temperature and UV radiation

=> determination of T_{CMB}
Srianand et al. 2001, Nature, 408, 931,
PM et al 2002



CO

J1705+354



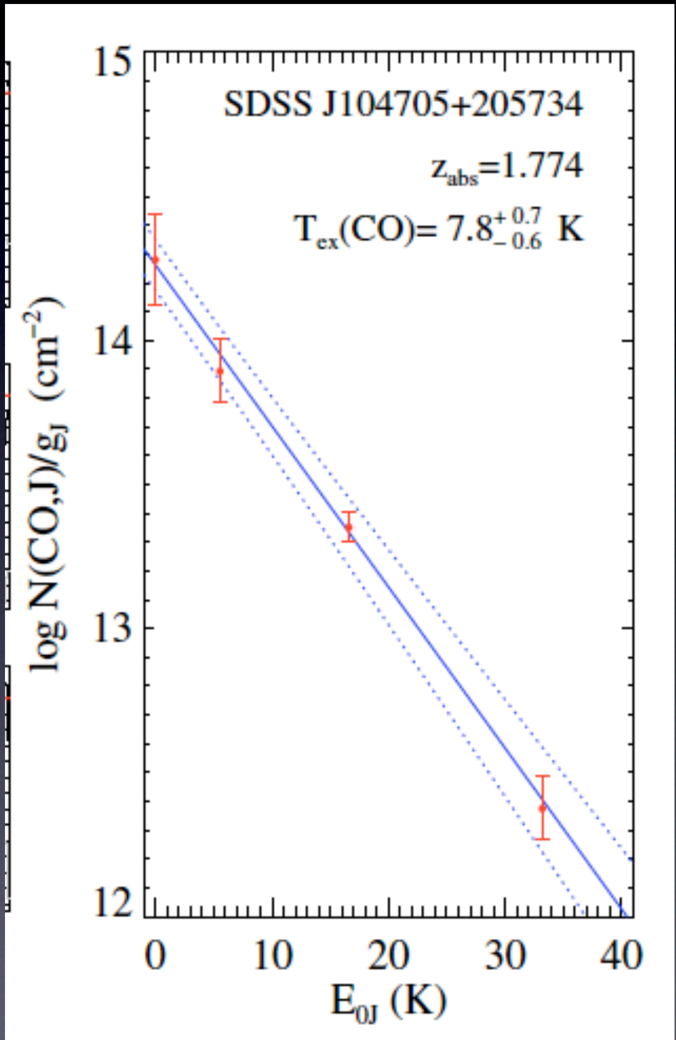
CO 2nd molecule more abundant in the universe A-X band at ~1300-500 Å

Q1439+113	at z = 2.42
Q1604+220	at z = 1.64
J1237+064	at z = 2.69
J0857+18	at z = 1.73
J1047+205	at z = 1.77
J1705+354	at z = 2.04

Srianand et al 2008, Noterdaeme et al 2010, 2011

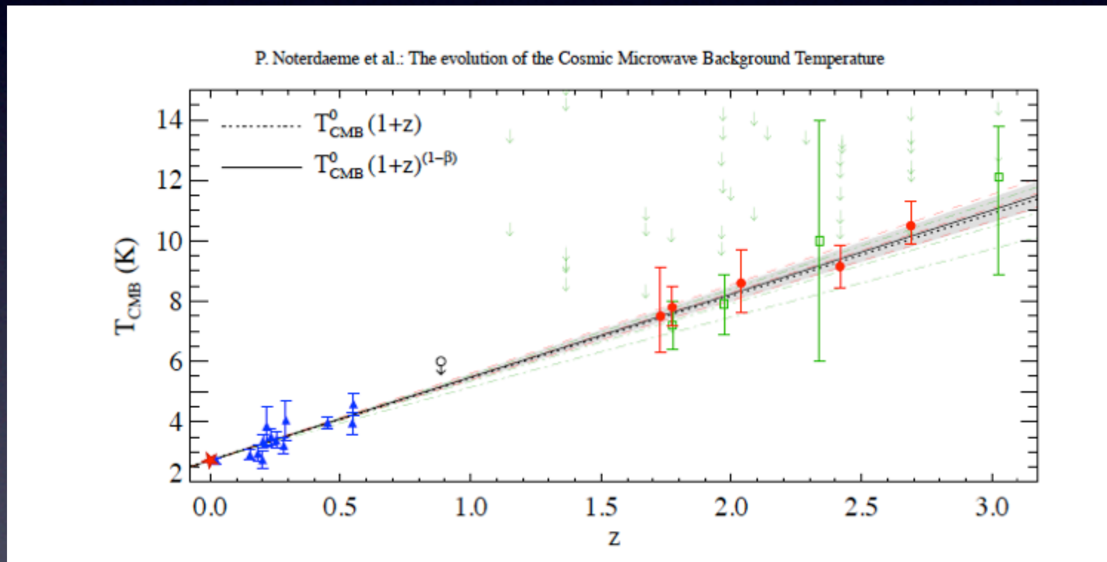
CO levels depend uniquely from CMB photons

AX(0-0)-AX(4-0) band



Noterdaeme et al 2010

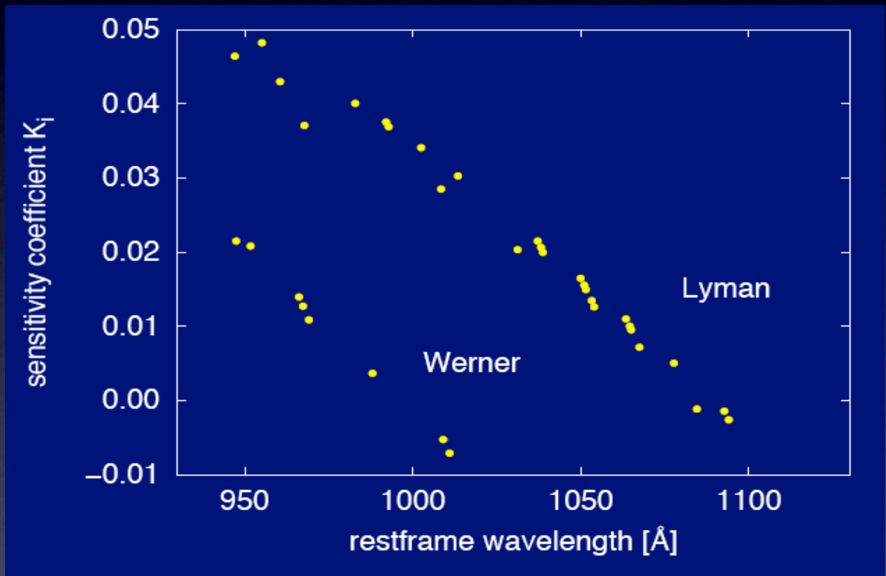
CO

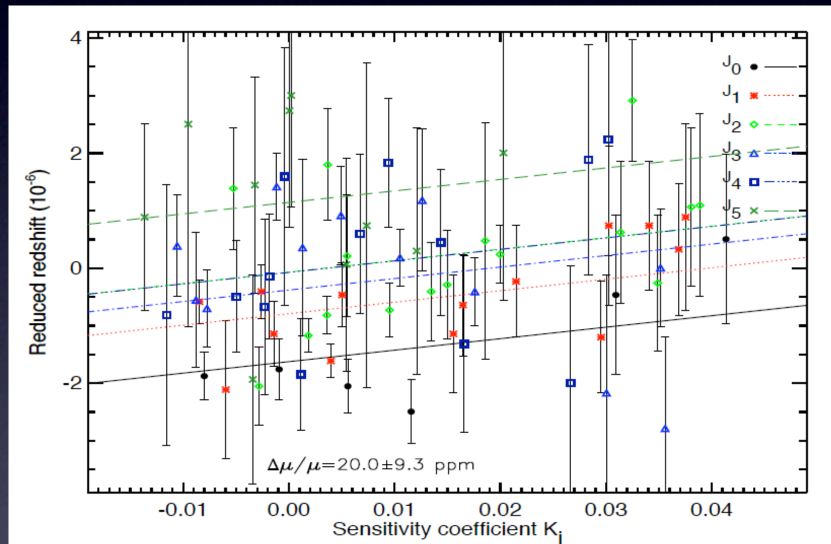


Constraint to non adiabatic expansion (.e. decaying DE)

μ =Mp/Me

- electron-vibro-rotational transitions have different dependence from the reduced mass.



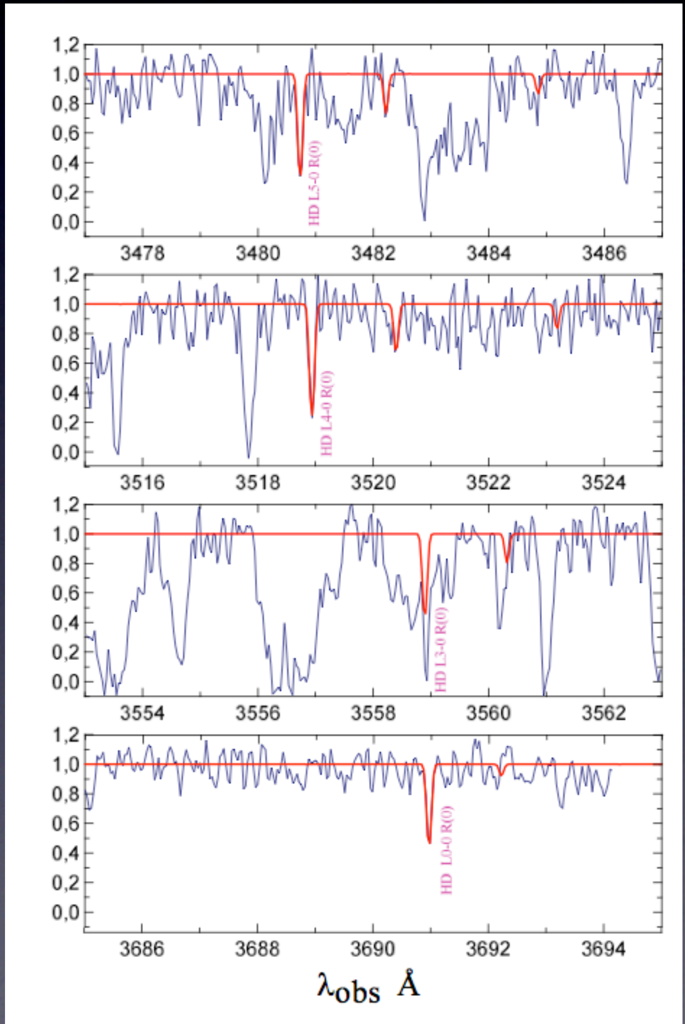


$$\lambda_{obs} = \lambda_{rest}\,(1+z_{abs})(1+K_i\,\Delta\mu/\mu)$$

weighted mean of 7 H_2 : $\langle\Delta\mu/\mu\rangle$ = 3.4 **± 2.7 ppm**

Deuterate Hydrogen

Q1232+082 zabs=2.3



6 detections

Q1232+082 Varshalovich et al 2001
J1439+1117 Srianand et al 2008
J2123-0500 Tumlison et al 2010
0812+32 Balashev et al 2010
Q1331+170 Balashev et al 2010
J1237+064 Noterdaeme et al 2010

N(HD)/2(N(H2) ~ 10-80 ppm

in the MK ~ 1 ppm

(D/H)p= 25 ppm

puzzling behaviour-unexplained!

Conclusions

3000-4000 Å: the last frontier for QSO's absorption line systems (DLA with $2 < z < 3$)

- ➡ D/H to follow the highest members of the Ly series to compute the baryonic density; constrain Nv families; probe new physics.
- ➡ C/H in DLAs to understand why only few DLAs are CEMP (relics of first stars)
- ➡ N/H to confirm its unique behaviour and possibly a new nucleosynthetic process
- ➡ O/H to understand if DLA are as $\alpha-$ enhanced as the halo stars
- ➡ Ar/O to study the local and EGB soft-X (<4-5 Ry) components
- ➡ H_2 to study the molecular gas within DLAs, to put bounds to the variability of fundamental constants (Mp/Me), CO to measure the CMBT (z) (but R~ 100000 is desirable).