Damped Lyman-Alpha Systems (DLAs)

Formation and Evolution of Galaxies, march 2005.

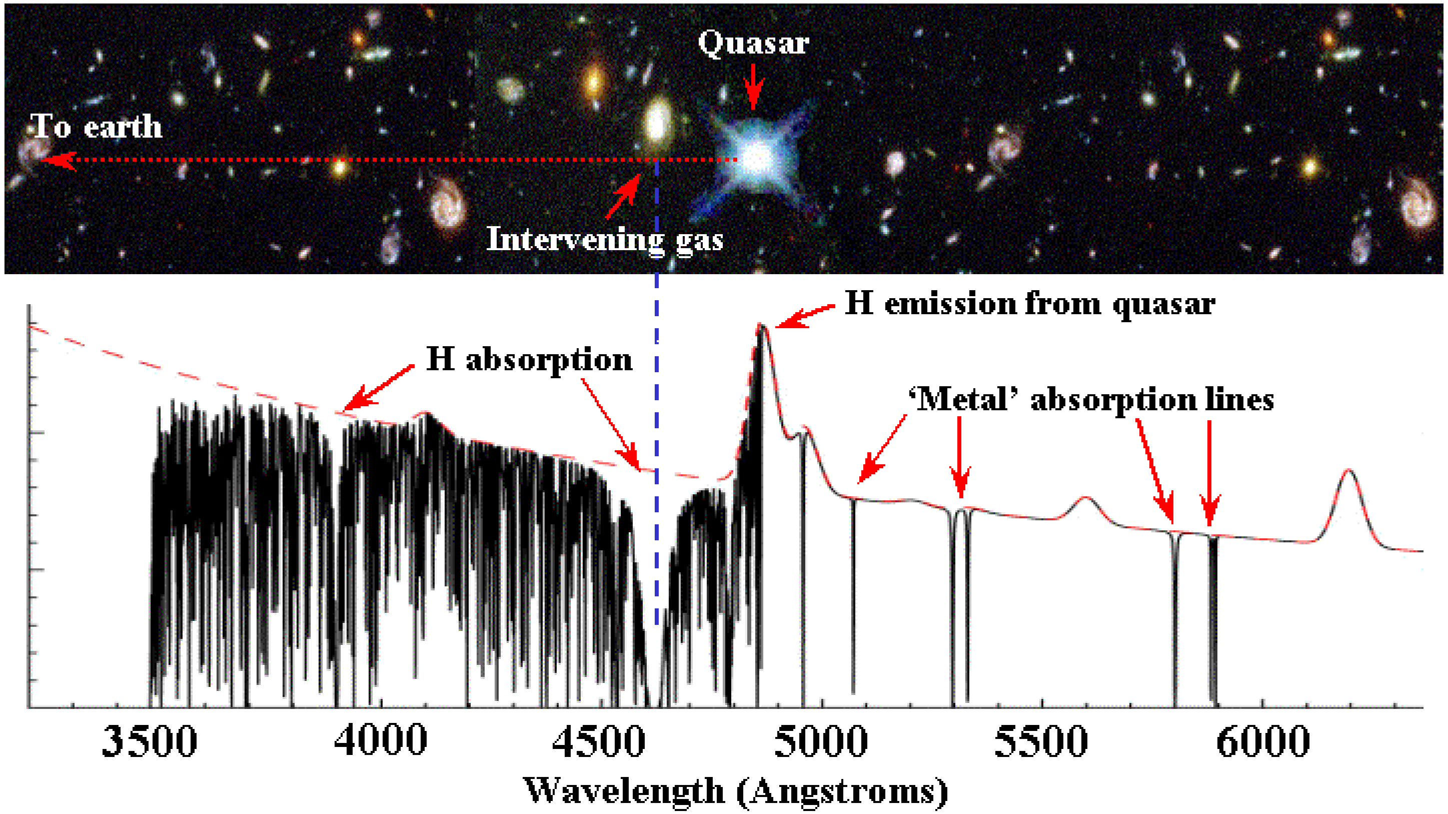
Overview

- What are DLAs?
- What do they look like?
- What are they used for?
- Observational results
- Briefly talk about models

What are DLAs ?

- Gaseous objects with high column density ($N \sim\geq 2x10^{20}$ /cm^2) of Neutral Hydrogen.
- The highest of them has $N \sim 10^{22}$, Normal lines in the Lyman-Alpha Forest are typically between $\sim 10^{13} - 10^{15.}$
- Detected in the spectra of a background Quasar, in the Lyman alpha region (this is a UV resonance line).
- This absorption occurs when the electron of an Hydrogen atoms goes from n=1 to n=2. A photon of the appropriate energy (wavelength) is then “removed” from the continuum; this create the spectral line.

What do they look like?



Curve of Growth

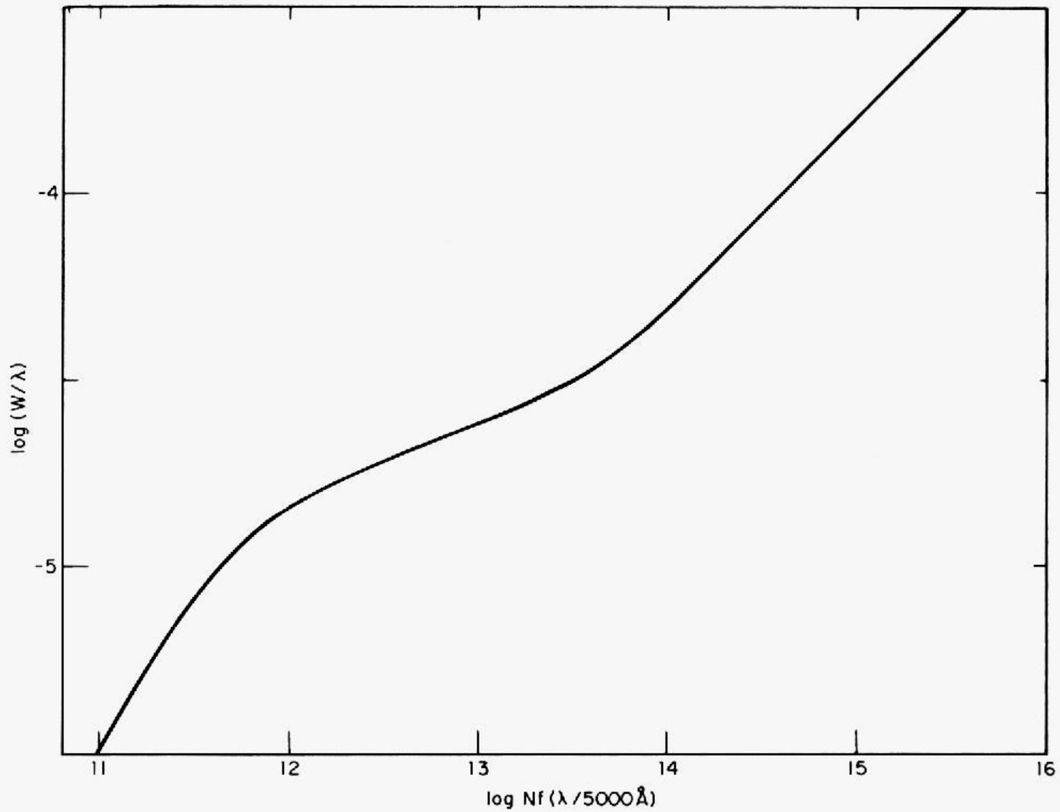


Figure 9.22 A general curve of growth for the Sun. (Figure from Aller, *Atoms, Stars, and Nebulae*, Revised Edition, Harvard University Press, Cambridge, MA, 1971.)

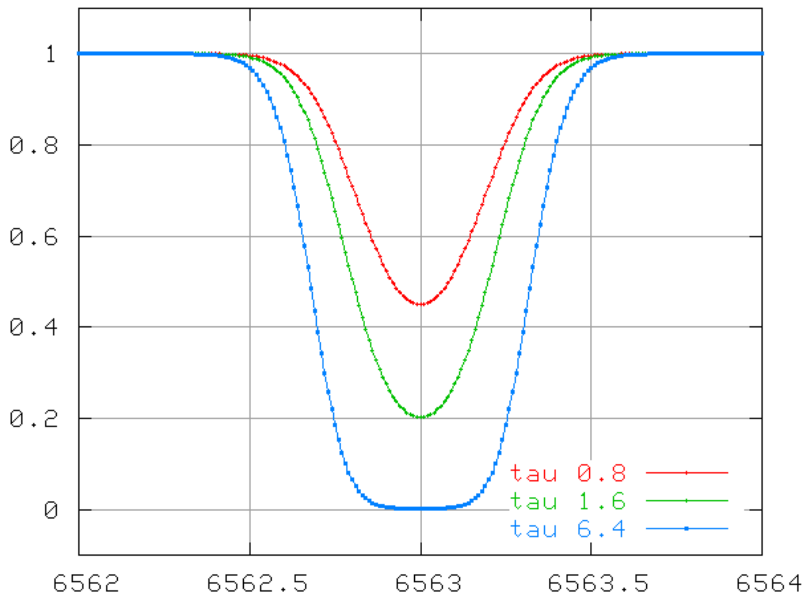
Line shape has two contributions

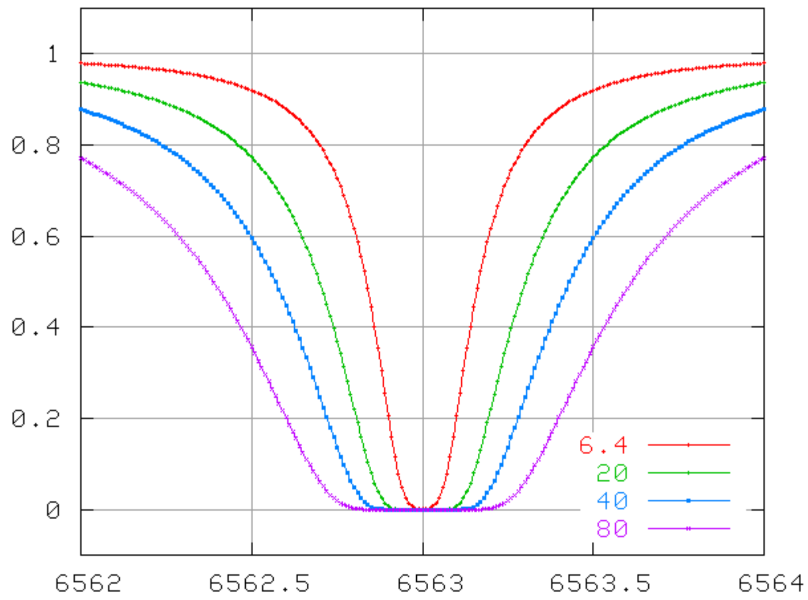
Thermal or Doppler Broadening

(Gaussian)

Pressure and collisional Broadening

(Lorentzian)



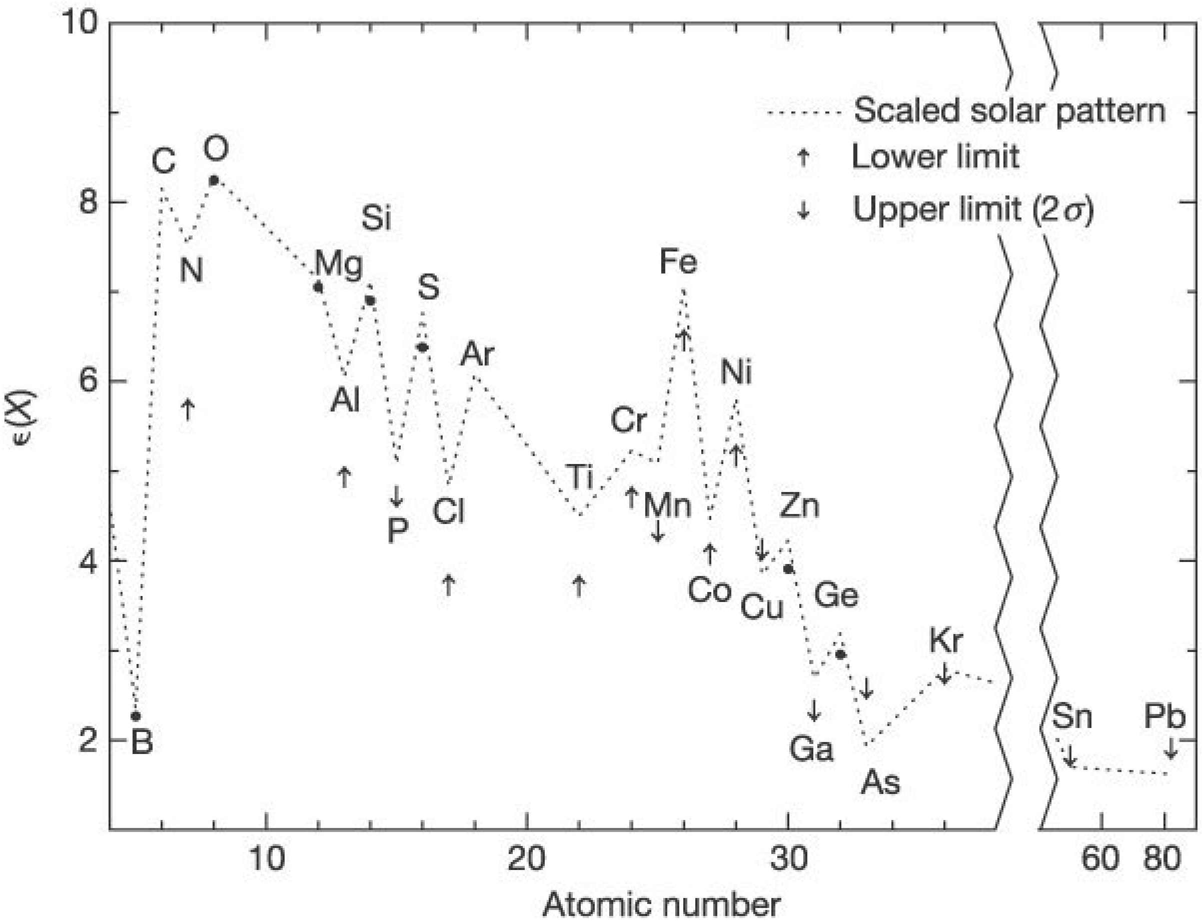


What is their use?

- Interesting to probe at large redshifts. These objects are not luminous enough to be observed otherwise.
- They dominate the mass density of neutral gas in the universe, containing at redshift $z \approx 3\text{-}5$ a comoving mass density of neutral gas equal comparable to the mass density of star in present day galaxies.
- So they are tracers of the available material (neutral gas) at high redshift for star formation.
- It is suggested that this gas is gradually converted into stars in present day galaxies.

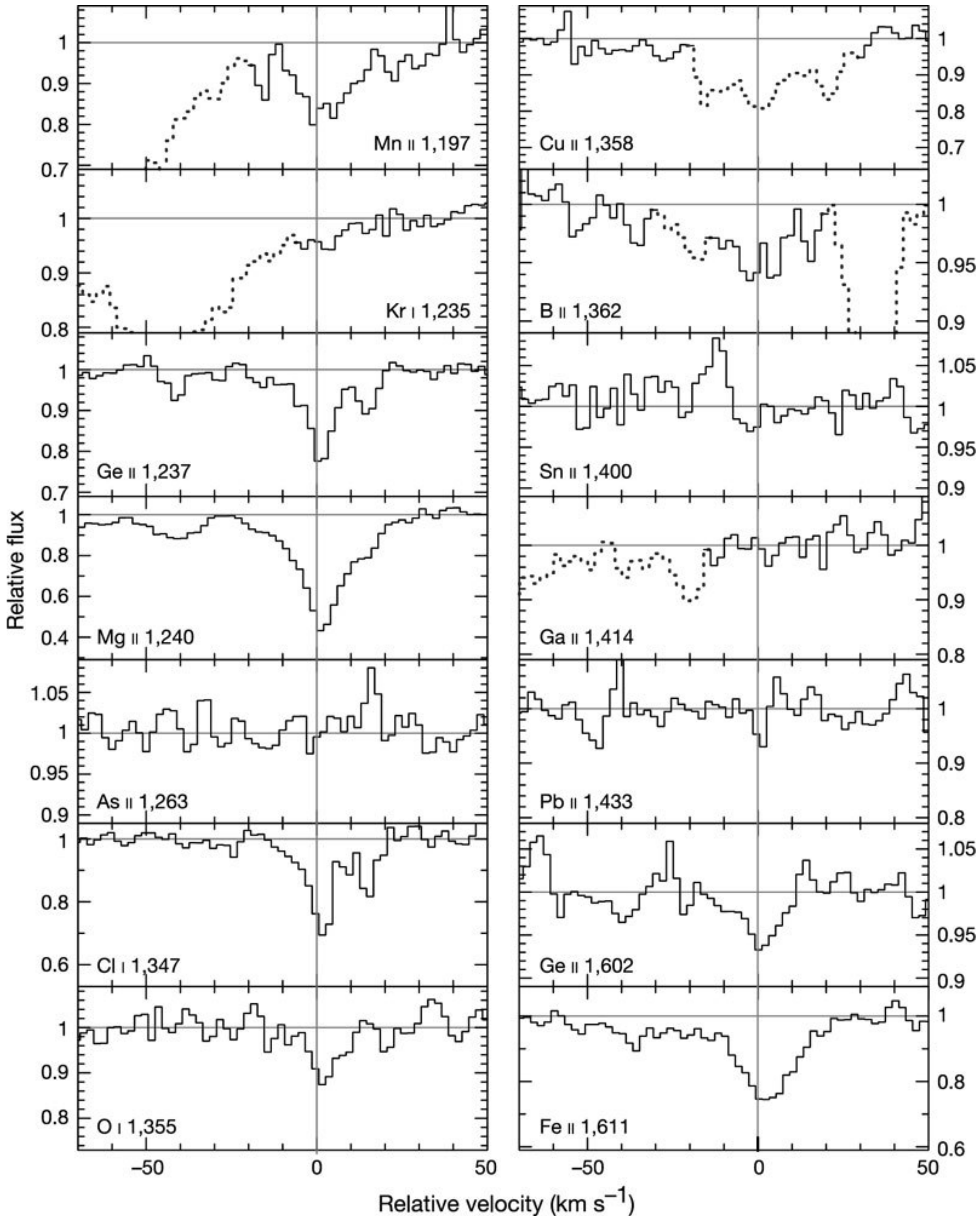
Heavy elements

- They are predominantly neutral, making it easier to measure heavy elements abundance.
- They are neutral because “Self Shielding” prevent the ionization of the gas. UV radiation ionize the gas but at high column density, ionized material quickly recombines becomes neutral again.
- Gas-phase heavy elements abundances (with low ionization potential) are dominant spectral features. You can just divide the column density of the heavy element species by the neutral hydrogen density to get the abundance.



The nucleosynthetic enrichment pattern for a galaxy discovered in the early Universe. Dust-corrected elemental abundances for the protogalaxy at z = 2.626 toward FJ081240.6+320808 on a logarithmic scale where hydrogen is defined to have abundance number (X) = 12. The dust corrections were empirically derived from depletion patterns observed in the local Universe and were applied in a very conservative manner. This explains the lower limits to the Fe, Cr, Al, Co and Ni abundances and similarly the upper limit to Mn. Typical statistical errors are <0.1 dex, that is, the size of the plot symbols (circles). The dotted line traces the solar abundance pattern scaled to match the observed oxygen abundance ([O/H] = -0.44, after dust correction). To zeroth order, the pattern of this high-redshift galaxy resembles that of the Sun; at finer detail, we note several important differences: see text for discussion.

Prochaska, Howk & Wolfe, 2003, Nature, 423, 57.



Sample of previously undetected metal-line transitions. Normalized absorption-line profiles related to the galaxy at z = 2.626 toward FJ081240.6+320808 taken with the HIRES echelle spectrograph on the Keck I 10-m telescope (R ~ 45,000, signal-to-noise ratio ~ 30 per 2 km s^{-1} pixel). With the exception of Fe II 1,611 and Mg II 1,240, none of these transitions have been detected outside of our Galaxy. Line blends with coincident absorption features are designated by dotted lines. The velocity v = 0 km/s was arbitrarily defined to correspond to z = 2.6263. With the exception of Cl I, these transitions correspond to the dominant ion of these elements in neutral hydrogen gas. Therefore, we convert the ionic column densities measured from these transitions into elemental abundances without ionization corrections. Although several transitions provide only upper limits to the elemental abundance (for example, Pb II 1,433, Ga II 1,414), the spectral regions are free from line-blends and future observations will yield detections or important limits.

Prochaska, Howk & Wolfe, 2003, Nature, 423, 57.

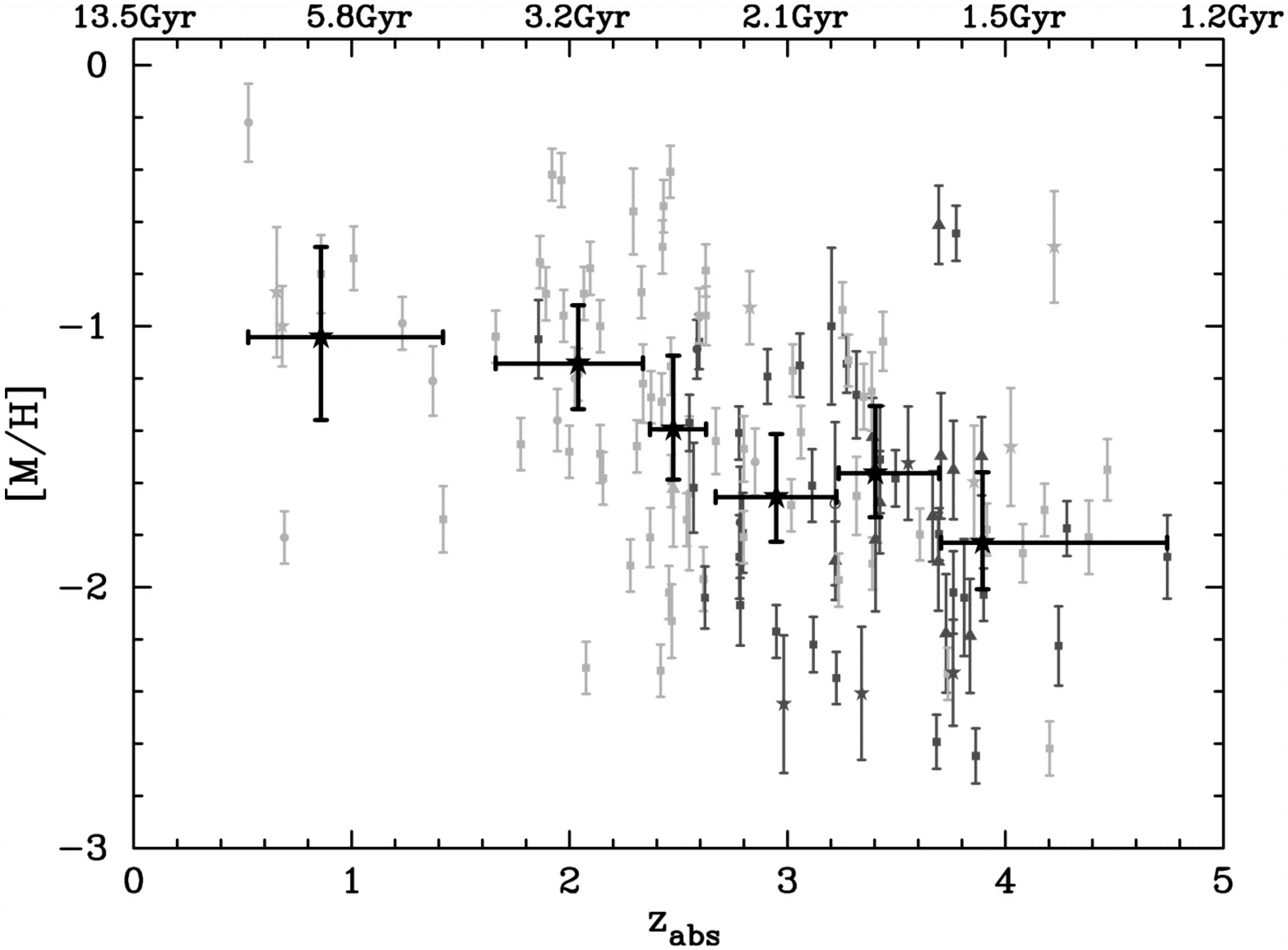
Tracers of Dust

- Typical unsaturated lines are of Ti II, Cr II, Ni II and Zn II.
- In the ISM, Zn in not highly depleted onto dust grains, so it should be a true tracer of the abundance.
- On the other hand, Cr is believed to be highly depleted onto dust grains.
- The ratio between the Zn and Cr values can give us an idea of the dust content of the galaxy at different redshifts.

Age-Metallicity relation if the Universe in Neutral Gas

- Consistent study made by Prochaska et al. 2003 (2^{nd} paper of the list).
- In total, ~300 DLAs have been identified in the literature. Only half of them have a metallicity estimate.
- Build a reliable dataset by filtering to keep only data from ~10m class telescopes and good S/N ratio (15/pixel) and good Resolution (R>5000).
- To that, they added ~ 50 new measurements, for a total on 125 objects in their "good quality uniform" sample.
- From that, they determine the metallicity and redshift of each object.

125 DLAs

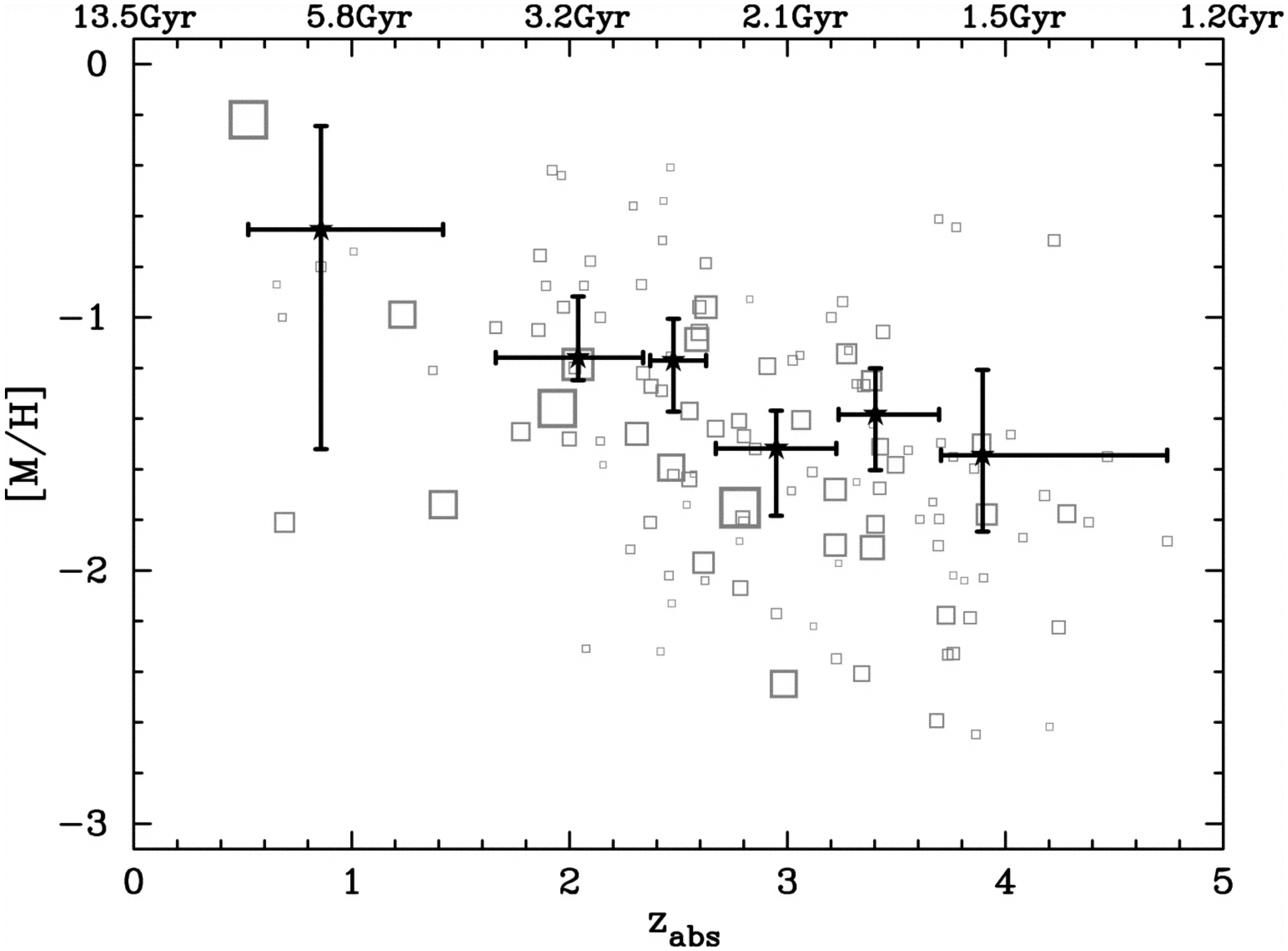


Dark points are the mean their ~50 new points, the light ones are from the ~75 literature reliable sources. The 6 big bold points are the binned, unweighted logarithmic [M/H]. The size of their redshift bin is determine to have the same number of DLAs. The corresponding redshift is the median.

Slope = -0.28 ± 0.05 dex/Δz

The metallicity of an average galaxy is increasing with decreasing redshift. A decrease of 2 times per gigayear at z ~3.

The Cosmological mean metallicity ⟨Z⟩ ($\Omega_{metal}/\Omega_{gas}$)



Same bins as previous figure, but different value computed. This is dominated by the largest N(HI) and [M/H] systems.

The area of each square dot is scale to the N(HI) value of the point, to illustrate which of the point is influencing most the average.

m = -0.26 ± 0.07
(same as previous figure)

So the mean metallicity of neutral gas is roughly doubling every billion year at z ~ 3.

$\langle Z \rangle = \log [\Sigma_i\ 10^{[M/H]_i}\ N(HI)_i\ /\ \Sigma N(HI)_i]$

Conclusions (obs)

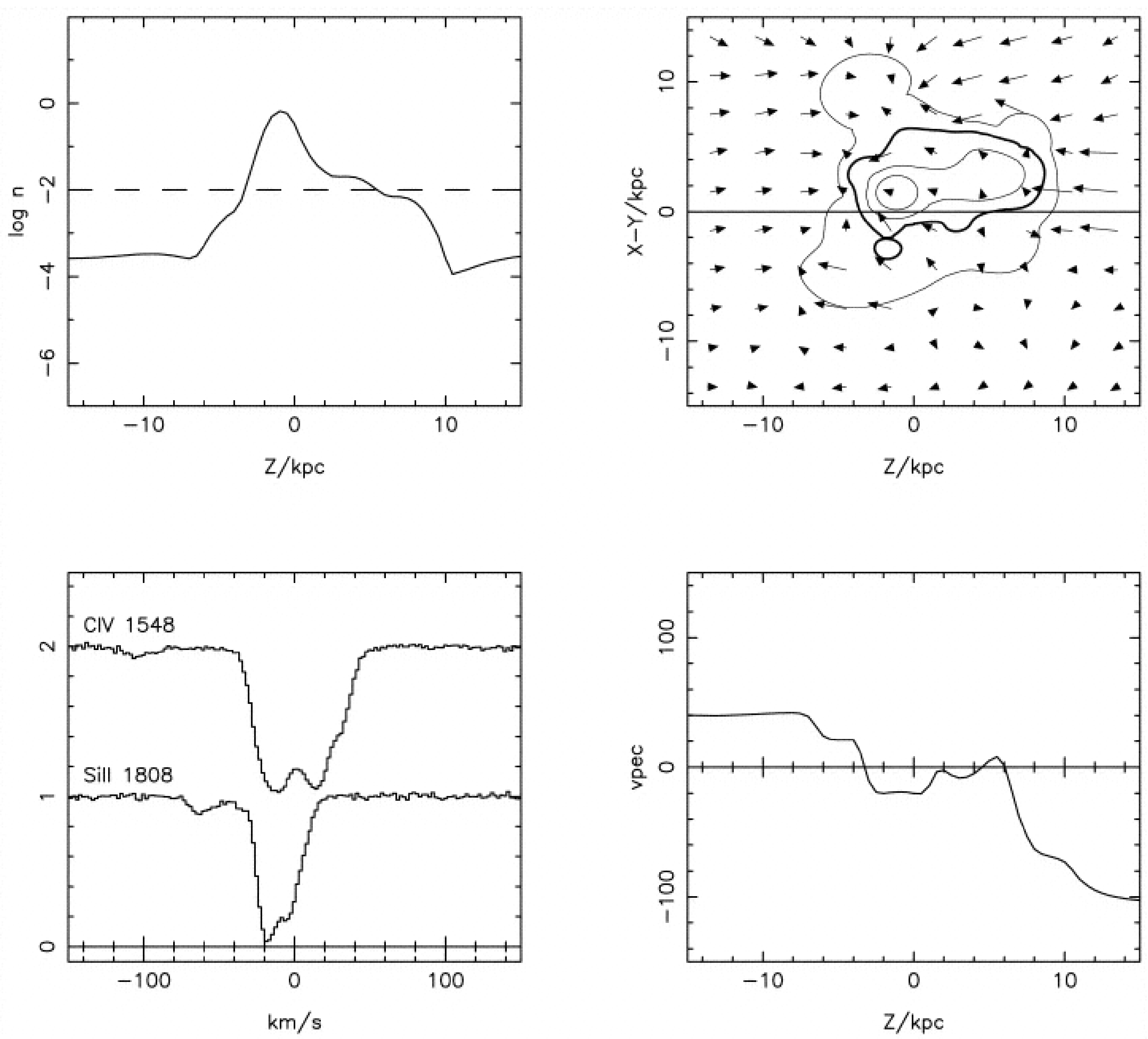
- It is the 1st time such a relation is discovered and it is contradicting previous results. This is mainly due to the quality and size of their sample.
- It provide a constraint on models of galaxy formation on the evolution of metallicity in time.
- It reaffirm the role DLAs plays in formation and evolution of galaxies. They are the likely progenitors of current day galaxies, at least they not completely disconnected from general galactic evolution.
- There is a somewhat constant scatter of the [M/H] points with redshift, which add weight to the previous statement.

Conclusions (obs)

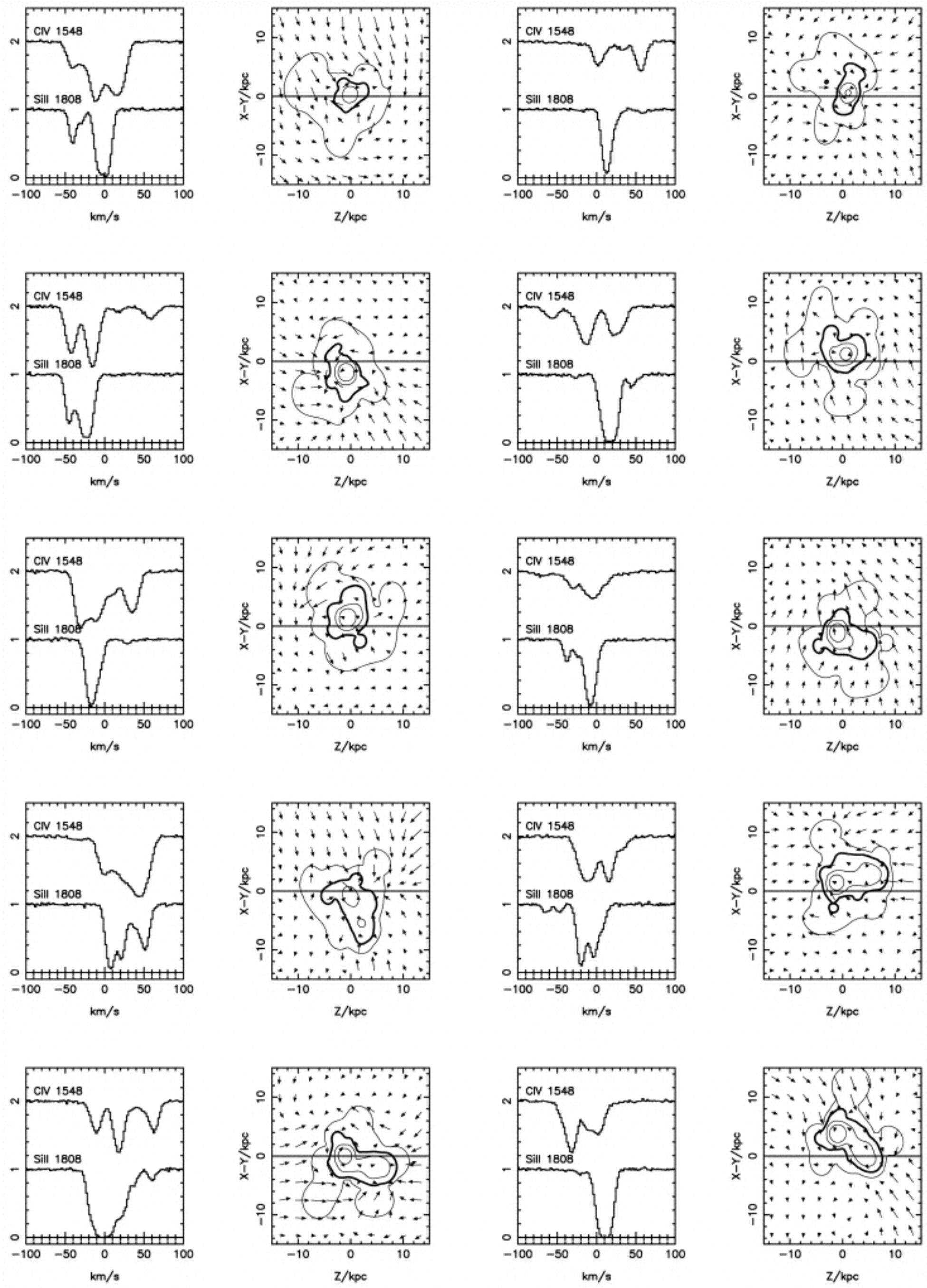
- If DLAs were undergoing transient phase of if they represented a continuously forming population of galaxies, one would expect no evolution of in the mean metallicity with time and/or an increasing scatter in the distribution of the [M/H] values.
- There is no DLAs beyond -3 < [M/H] < 0. A DLA at lower than -3 would exceed the detection limit.
- It also suggest that **DLAs are bounded to a galaxy** (component of), that they are **enriched by metal production** coming from star formation within the galaxy. So DLAs are unlikely overdense regions associated with large scale structures.

Models

- Haehnelt, Steinmetz & Rauch, 1998 ApJ 495, 647. Try to model the observed line profile of low ionization ionic species (LIS) in DLAs.
- Examine the suggestion that only rapidly rotating large disks are the only viable explanation for the observed asymmetry in profiles of low-ionization absorption lines. (Prochasca & Wolfe 1997)
- They conclude that it is not necessary, irregular protogalactic clumps can reproduce the observed velocity and width distribution and asymmetries of the absorption profiles equally well.



Simulated damped Ly alpha absorber at z = 2.1 with log NH I = 21.2, arising from gas in a merging protogalactic clump with v_vir = 70 km/s. *Bottom left*: Absorption spectrum for the Si II 1808 and C IV 1548 transitions. *Top left*: Total hydrogen density along the LOS. *Bottom right*: Peculiar velocity along the LOS. *Top right*: Density and velocity field in a thin slice containing the LOS (*straight solid line*). The density contours have a spacing of 1 dex, and the thick contour marks log n = -2. Velocities are relative to the center-of-mass velocity of a sphere with 30 kpc radius. The normalization of the velocity arrows is such that the length of the longest arrow equals the spacing between arrows. For absolute velocity values, see the bottom right panel.



Ten random LOS producing damped Ly absorbtion in the vicinity of the merging protogalactic clump shown in the previous figure.

Conclusion:
Asymetric profiles of the kind observed in LIS are not necessarily the signature of rotation. They are well reproduced by a mixture of rotation, random motion, infall and merging protogalactic clumps. They are caused by random sampling of irregular density and intrinsic asymmetric configurations arising when two or more clumps collide.

Final slide

- Rapidly evolving field. Authors are contradicting paper they wrote ~5 years ago.
- Still don’t really know really what they are, but we begin to understand what they are not.
- Not really any models based on real physics, they are more toy models.

References

- **The Age-Metallicity Relation of the Universe in Neutral Gas: The First 100 Damped Ly-alpha Systems**, [2003ApJ...595L...9P], Prochaska, Jason X.; Gawiser, Eric; Wolfe, Arthur M.; Castro, Sandra; Djorgovski, S. G., The Astrophysical Journal, Volume 595, Issue 1, pp. L9-L12.
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- **The elemental abundance pattern in a galaxy at z = 2.626**, [2003Natur.423...57P], Prochaska, Jason X.; Howk, J. Christopher; Wolfe, Arthur M., Nature, Volume 423, Issue 6935, pp. 57-59 (2003).
- **Lyman Alpha Absorption: The Damped Systems**, Kenneth M Lanzetta, Encyclopedia of Astronomy and Astrophysics, November 2000, http://eaa.iop.org/full/eaa-pdf/eaa/2141.html
- **Damped Lyman alpha systems and galaxy formation models - I. The radial distribution of cold gas at high z,** [2001MNRAS.326.1475M], Maller, Ariyeh H.; Prochaska, Jason X.; Somerville, Rachel S.; Primack, Joel R., Monthly Notices of the Royal Astronomical Society, Volume 326, Issue 4, pp. 1475-1488, 10/2001.