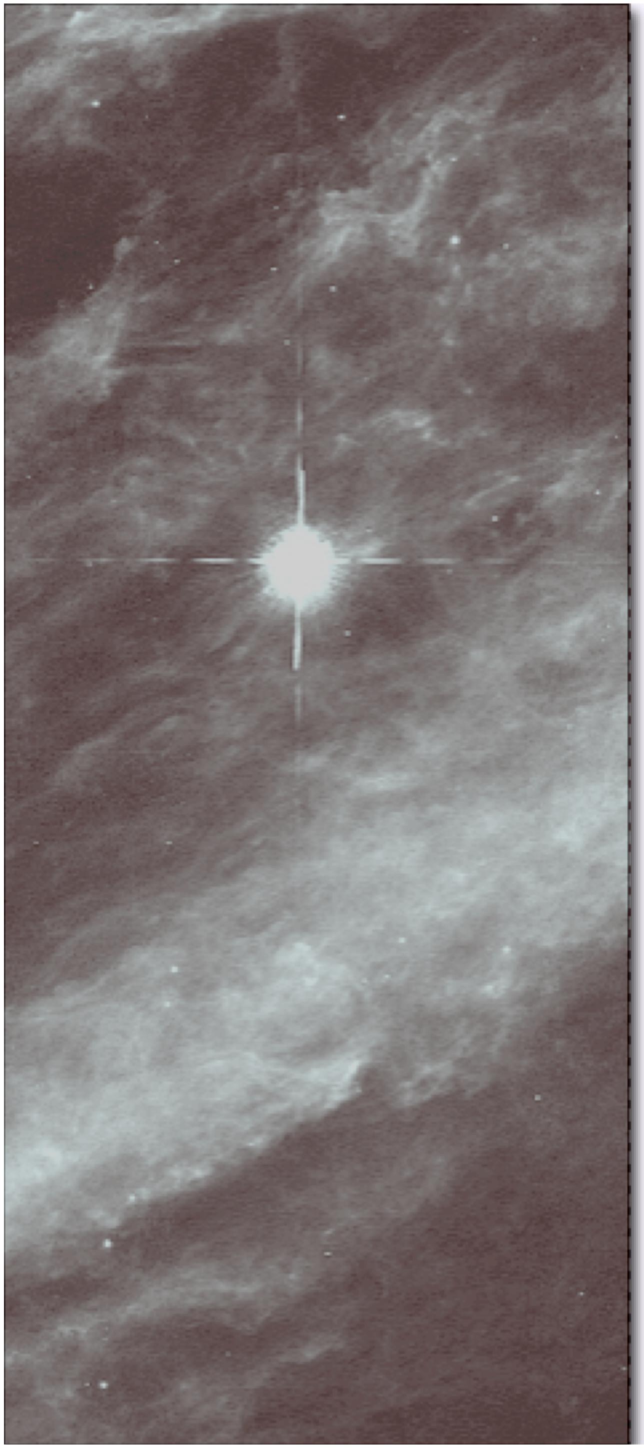
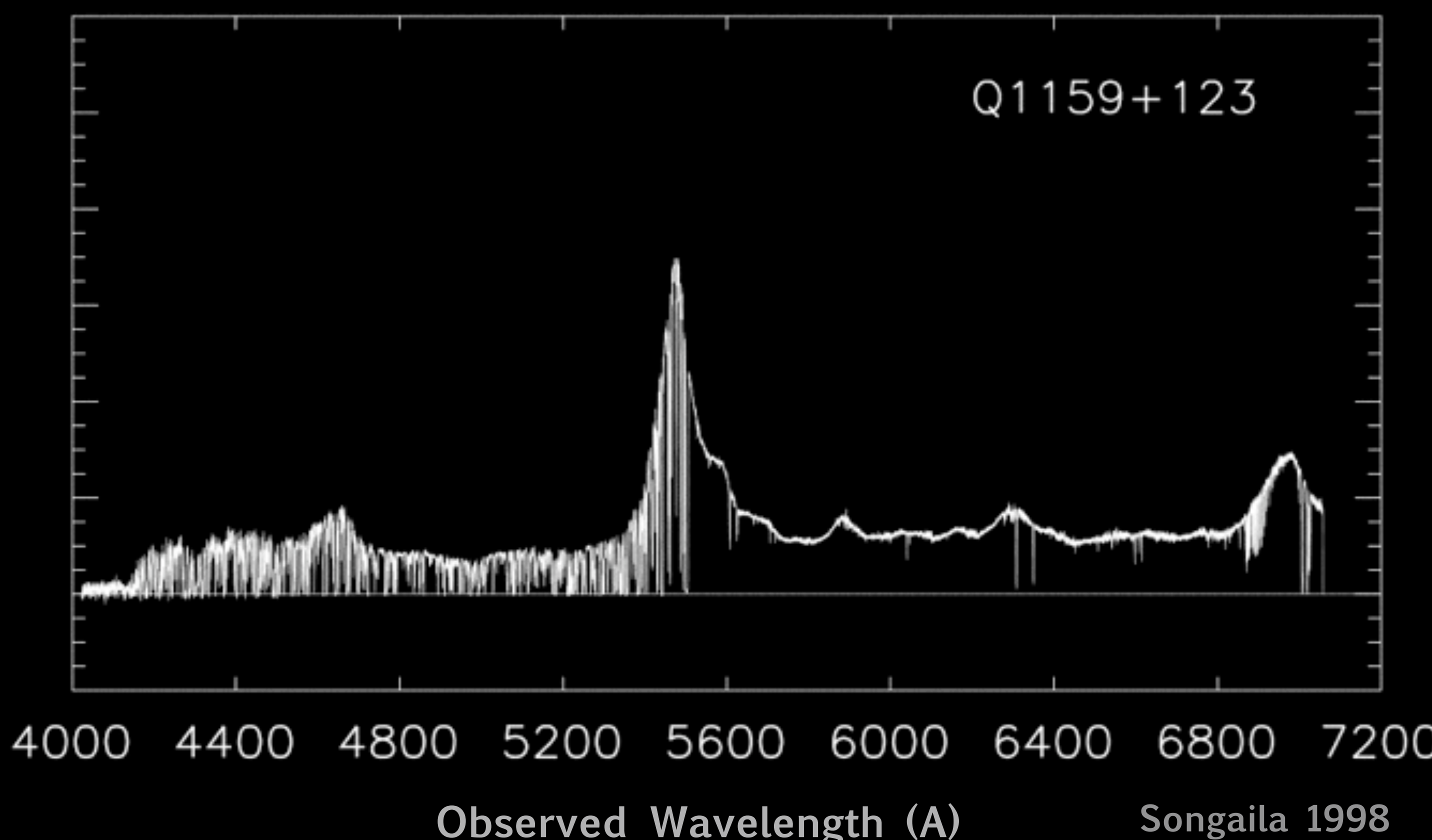


The Origins & Evolution of Weak Low Ionization Quasar Absorption Line Systems

Anand Narayanan

Jane Charlton (PSU), Toru Misawa (PSU), Rajib Ganguly (Wyoming), Tae-Sun Kim (AIP, Potsdam), Ryan Lynch (U. of Virginia)


Q1159+123
4000
4400
4800
5200
5600
6000
6400
6800
7200
Observed Wavelength (A)
Songaila 1998

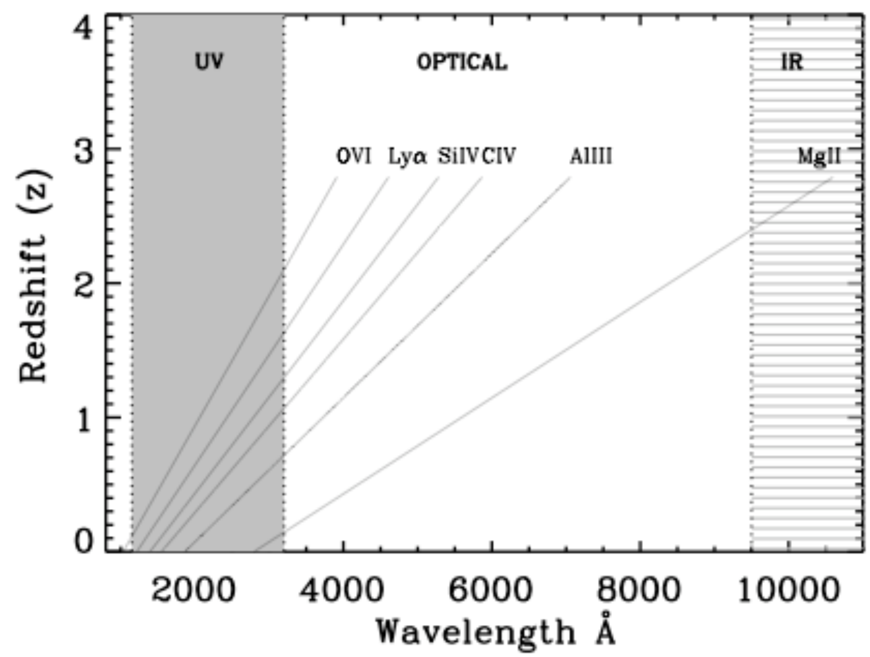
Quasar Absorption Line Spectroscopy

- **Detect galaxies & other gaseous structures unbiased by their luminosity**
  - **galaxies of all morphology, and their gaseous components.**
  - **intergalactic medium**
- **Ly - α in the optical : HI selected galaxies at $z > 1.5$**
- **At $z < 1.5$: Use doublet/multiplet metal lines.**
  - **MgII 2796/2803 Å**

    - strong transition

    - transition in the optical for $z > 0.3$

    - outside of the forest.



Strong MgII - Galaxy Connection

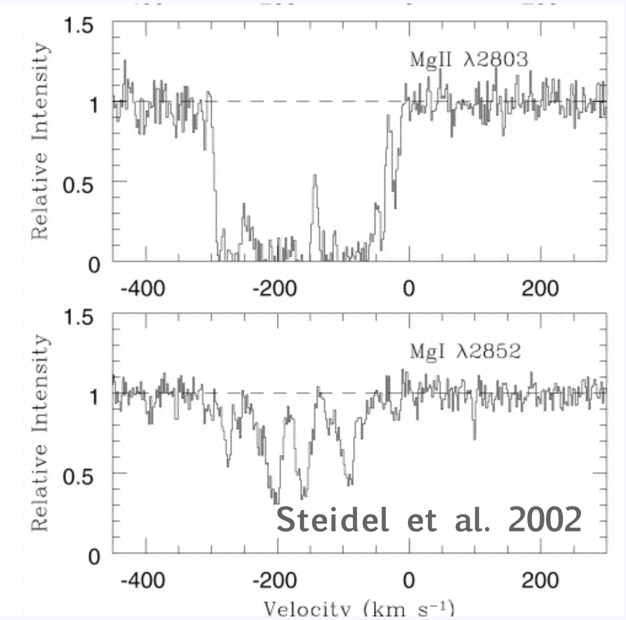
- **Heavy element absorption in QSO spectrum produced by intervening galaxies.**

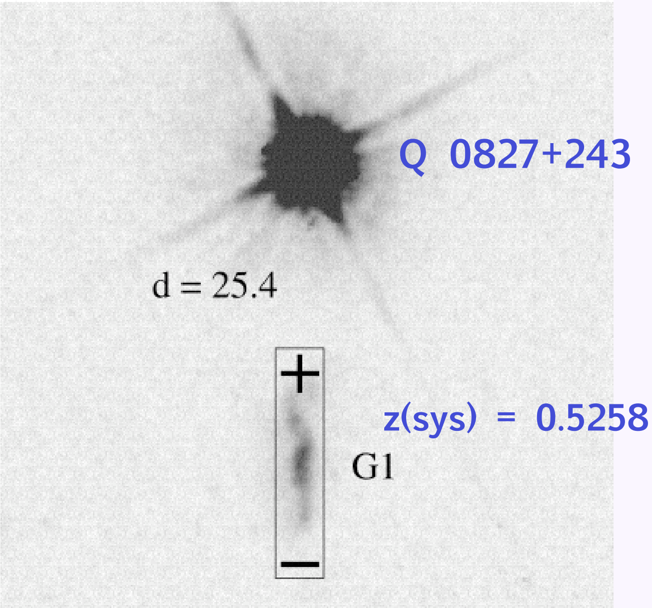
  Bahcall & Spitzer (1969)

- **Galaxies associated with individual absorption systems.**

  Bergeron & Boissé 1991, Steidel et al. 1994, Le Brun et al. 1997

  - $W_r(2796) \geq 0.3$Å (strong MgII)
  - 0.1 L* galaxy found within $50h^{-1}$kpc
    (e.g. Steidel et al. 2002)
  - normal field galaxy population
    (e.g. Dickinson & Steidel 1996)
  - strong MgII selected systems are optically thick in HI, N(HI) > $10^{17.3}$ cm^{-2}. -- Lyman Limit Systems.
  - expected to probe the outer parts of galaxies where HI is more ionized than disk gas (Steidel et al. 2002).



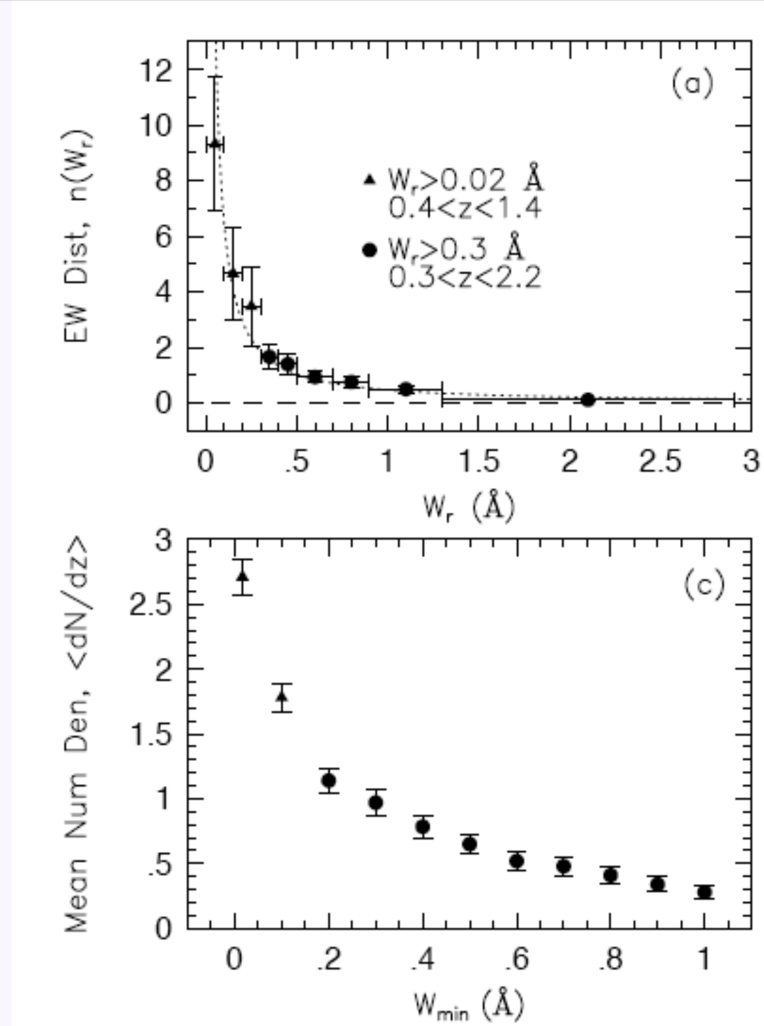


The Population of Weak Absorbers

- **$W_r(2796) \geq 0.3$Å does not provide a full census of MgII absorption gas**

  - **The equivalent width distribution rises steeply for $W_r(2796) < 0.3$Å (Churchill et al. 1999)**

  - **At z ~ 1, 67% of MgII absorbing systems are not "strong"**



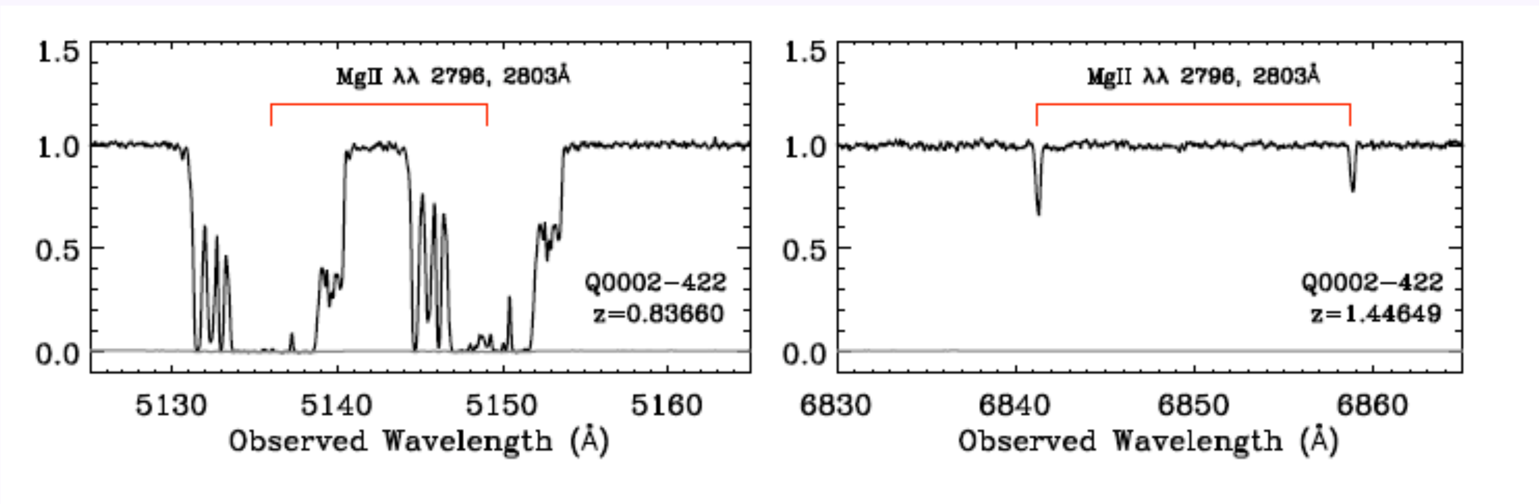
Churchill et al. 1999

Weak MgII Quasar Absorption Line Systems

- **Kinematically simple, narrow and weak**
- **optically thin in HI,** N (HI) < $10^{17.3}$, cm^{-2}
- **at z ~ 1, they outnumber L* galaxies by ~ 3 : 1**
- **Metallicity, Z ≥ $0.1Z_{\odot}$**

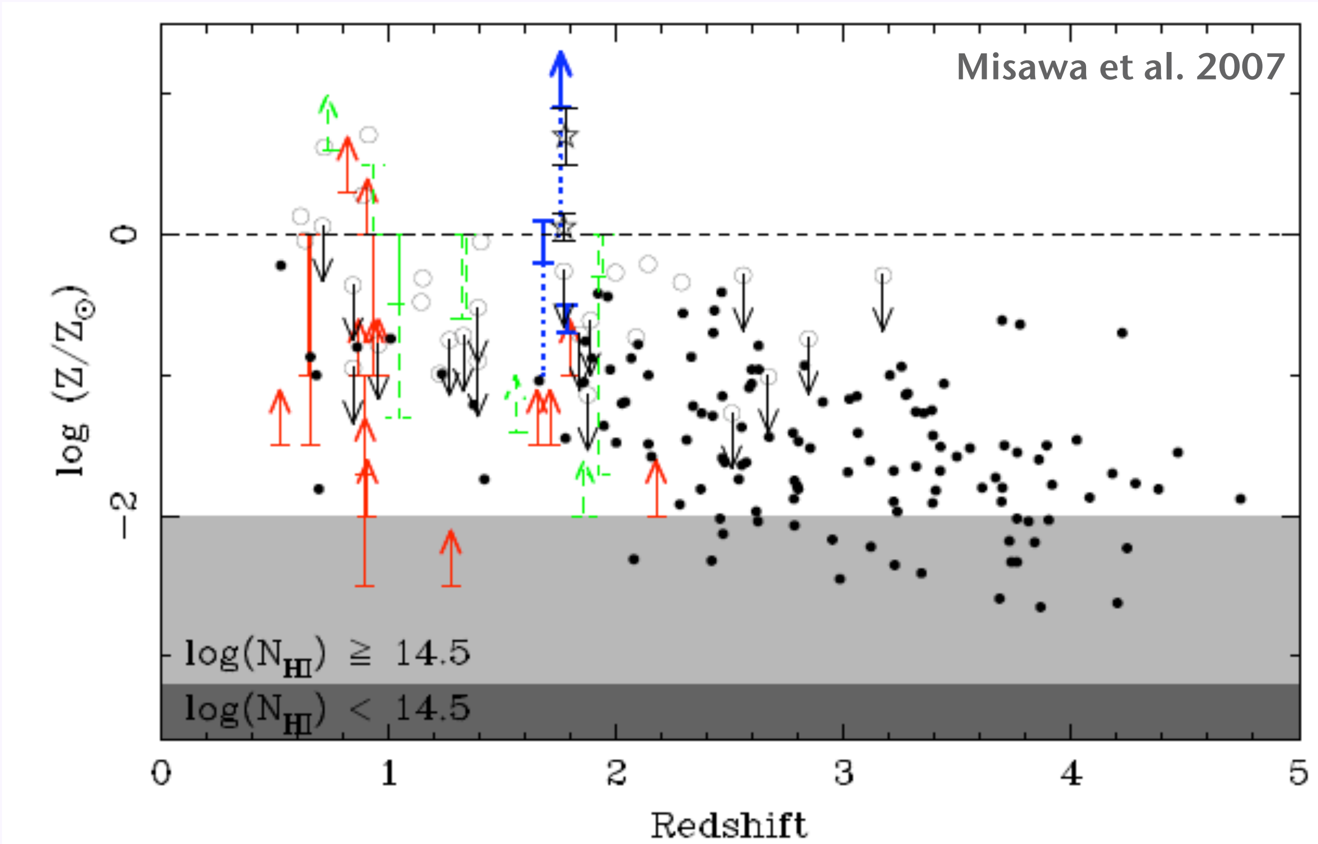
(e.g. Churchill et al. 1999, Rigby et al. 2002, Charlton et al. 2003)

- **Early searches claimed NO optical counterparts out to ~ $50h^{-1}$ kpc from the QSO sight line.** (Steidel 1999, Churchill et al. 1999)



Metallicity in QSO Absorption Systems

- $Z_{weak} > Z_{QSO\text{-}DLAs}$



DLAs - Prochaska et al. 2003

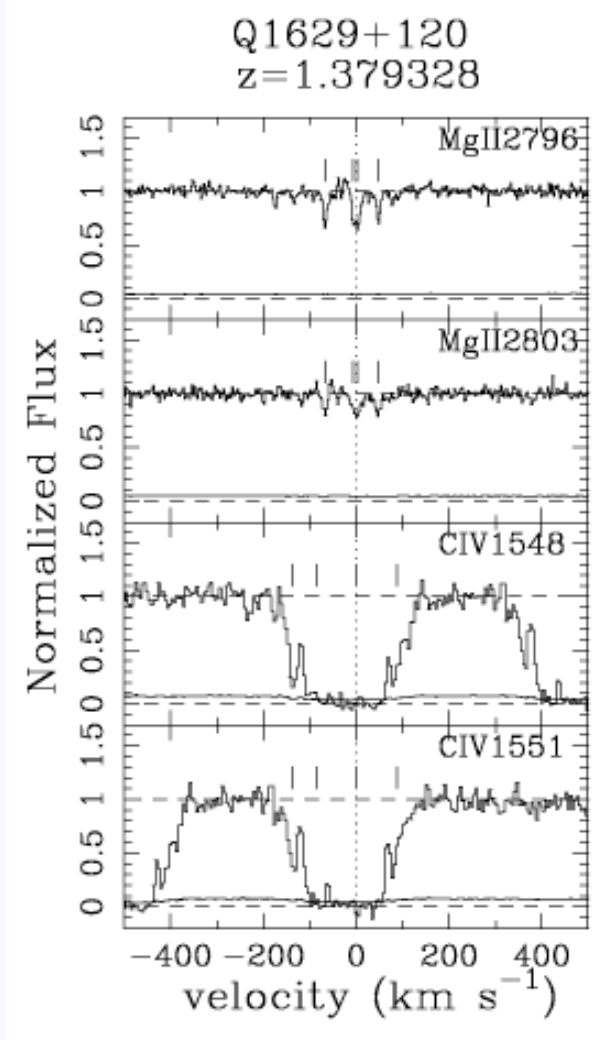
Sub-DLAs - Kulkarni et al. 2007

IGM - Songaila & Cowie 1996, Cowie & Songaila 1998

Physical Conditions in Weak Absorbers

- Dense low ionization gas : traced by MgII (CII, SiII, MgI, FeII)
  - $n_H > 10^{-2}$ cm^{-3}
    N(HI+HII) < 10^{18} cm^{-2}
    cloud thickness < 10 pc

- Diffuse ionized gas, traced by CIV (SiIV. SiIII)
  - $n_H < 10^{-4}$ cm^{-3}
    cloud thickness ~ kpc



Weak MgII Quasar Absorption Line Systems

- Kinematically simple, narrow and weak
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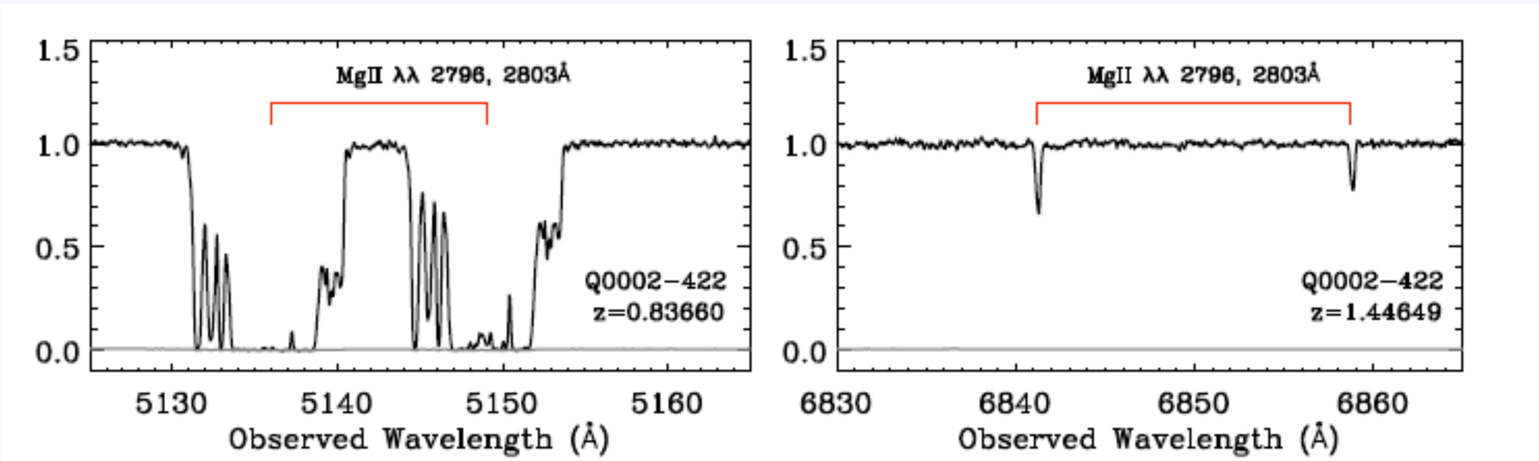
- at z ~ 1, they outnumber L* galaxies by ~ 3 : 1
- Metallicity, $Z \geq 0.1 Z_{\odot}$

(e.g. Churchill et al. 1999, Rigby et al. 2002, Charlton et al. 2003)



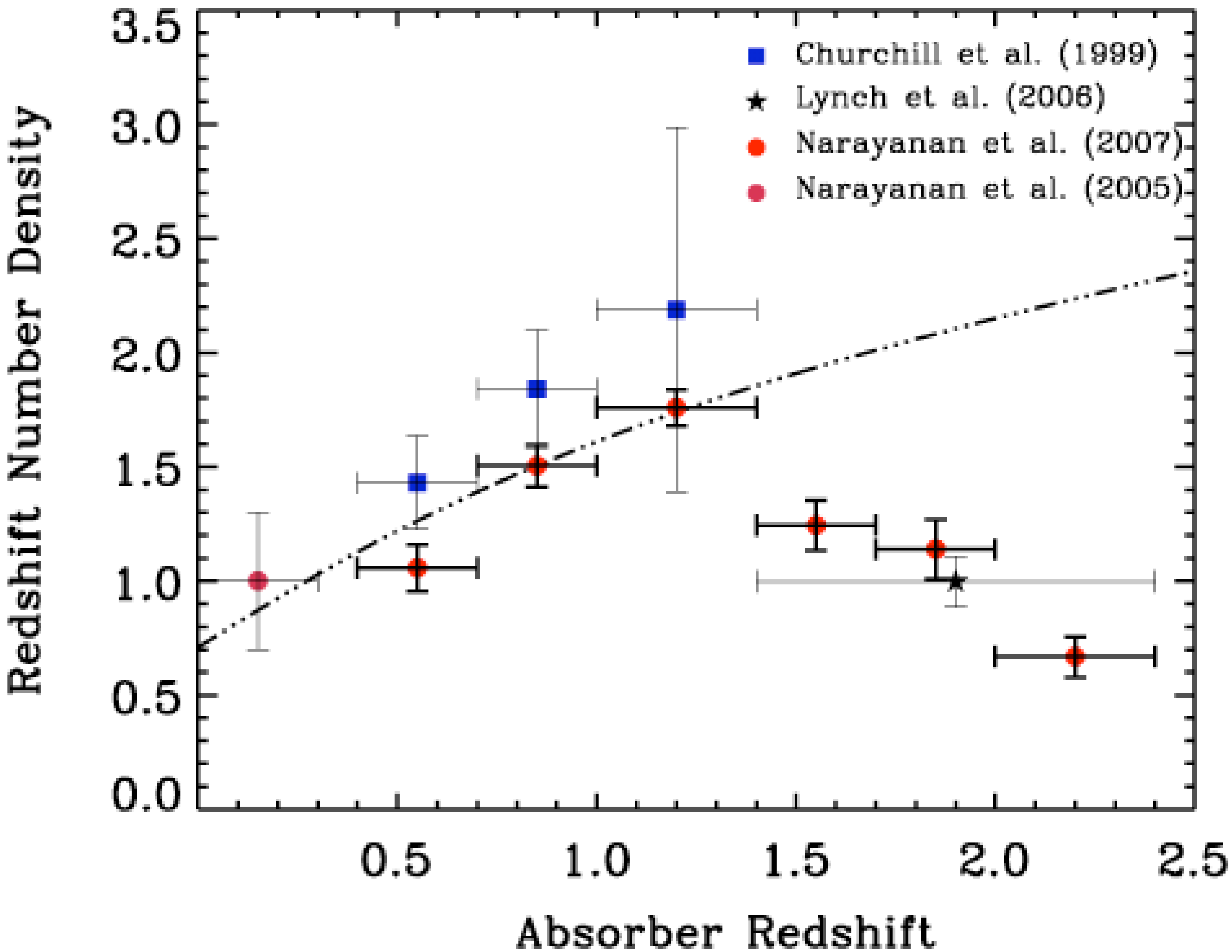
Gaseous structures selected by weak MgII absorption?

Surveys for Weak MgII Absorption Systems

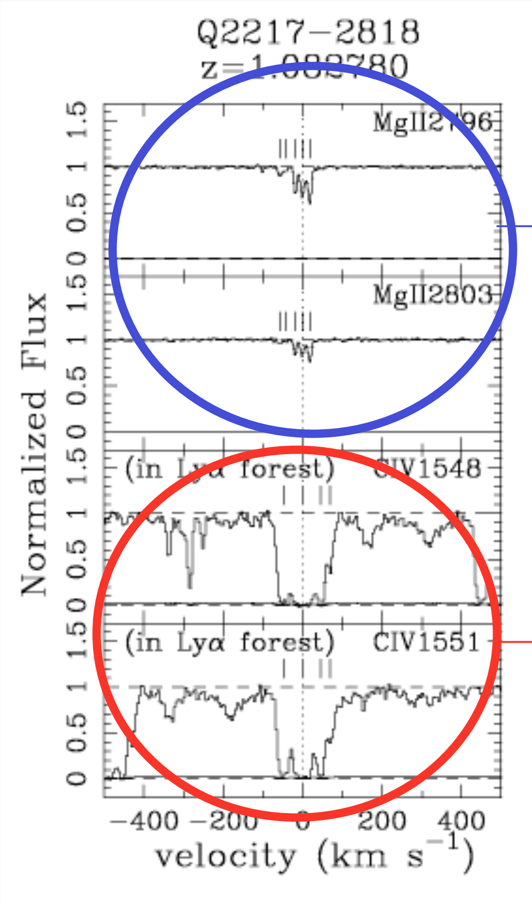
- A VLT/UVES Survey at $0.4 < z < 2.4$
  - 81 high S/N (> 20 $pixel^{-1}$) quasar observations
  - R ~ 45,000   FWHM ~ 7 km s^{-1}
- A HST/STIS Survey in the Present
  - 20 E140M grating archive quasar observations
  - R ~ 45,800

- 112 weak MgII absorbers at $0.4 < z < 2.4$
- 6 weak MgII absorbers at $0 < z < 0.3$

Redshift Number Density



Two Phase Structure - Physical Instability



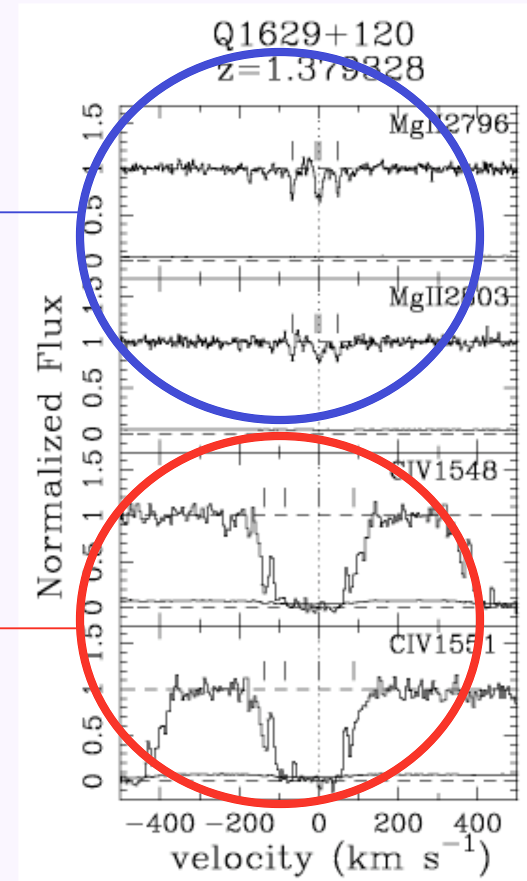
$n_H > 10^{-2}$ cm^{-3}

$T \sim 10^4$ K

Pressure Imbalance

$n_H \sim 10^{-4}$ cm^{-3}

$T \sim 10^4$ K



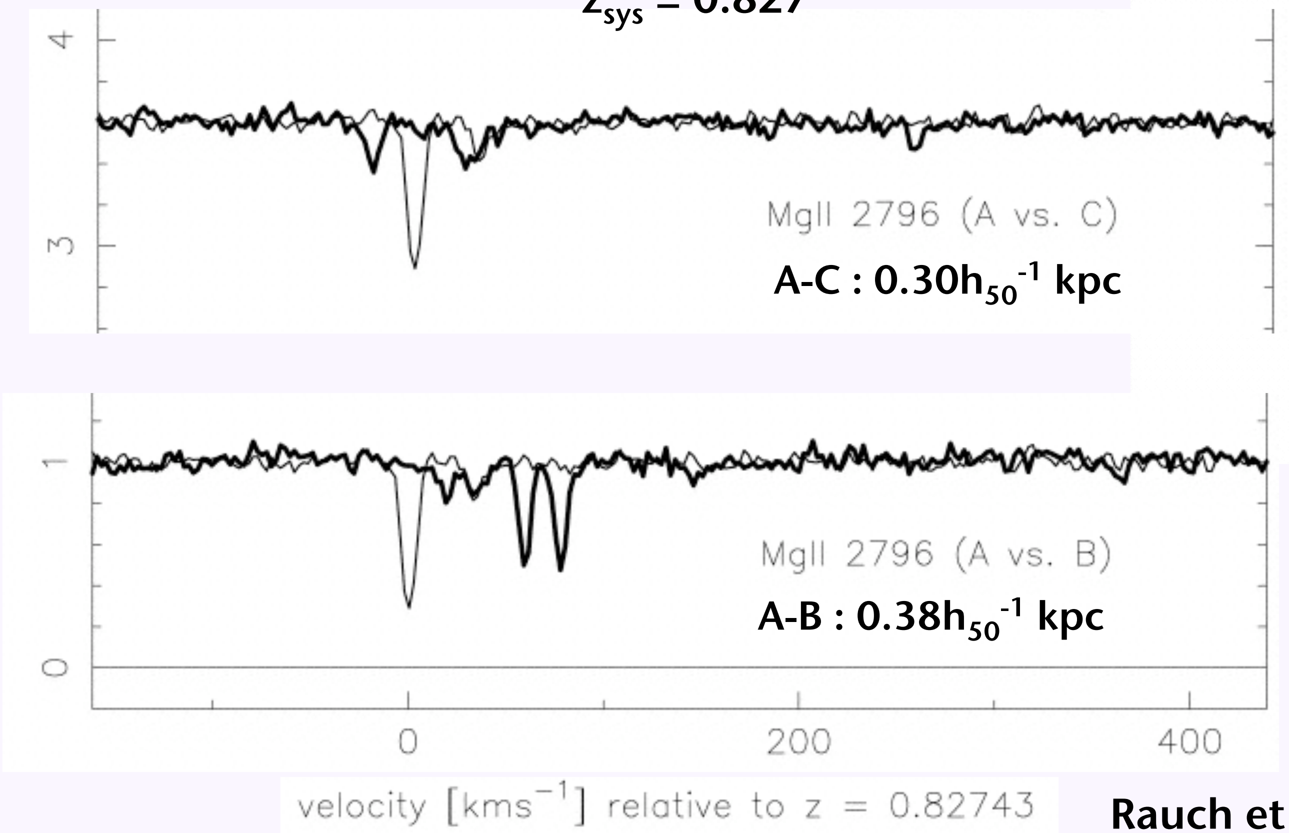
Radial size for a gravitationally bound cloud (Schaye 2001a)

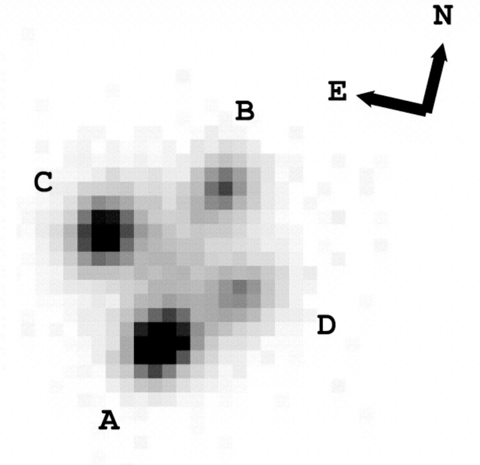
$$L \sim 10^2 \mathrm{kpc} \left(\frac{N_{\mathrm{H\,I}}}{10^{14} cm^{-2}} \right)^{-\frac{1}{3}} T_4^{0.41} \Gamma_{-12}^{-\frac{1}{3}} \left(\frac{f_g}{0.16} \right)^{\frac{2}{3}}$$

L ~ 10 kpc - low ionization gas clouds ?

Physical Size of Absorbers - QSO Multiple Lines of Sight Observations

z_{sys} = 0.827





Q02237+0305

z_{QSO} = 1.69

z_{LENS} = 0.0390

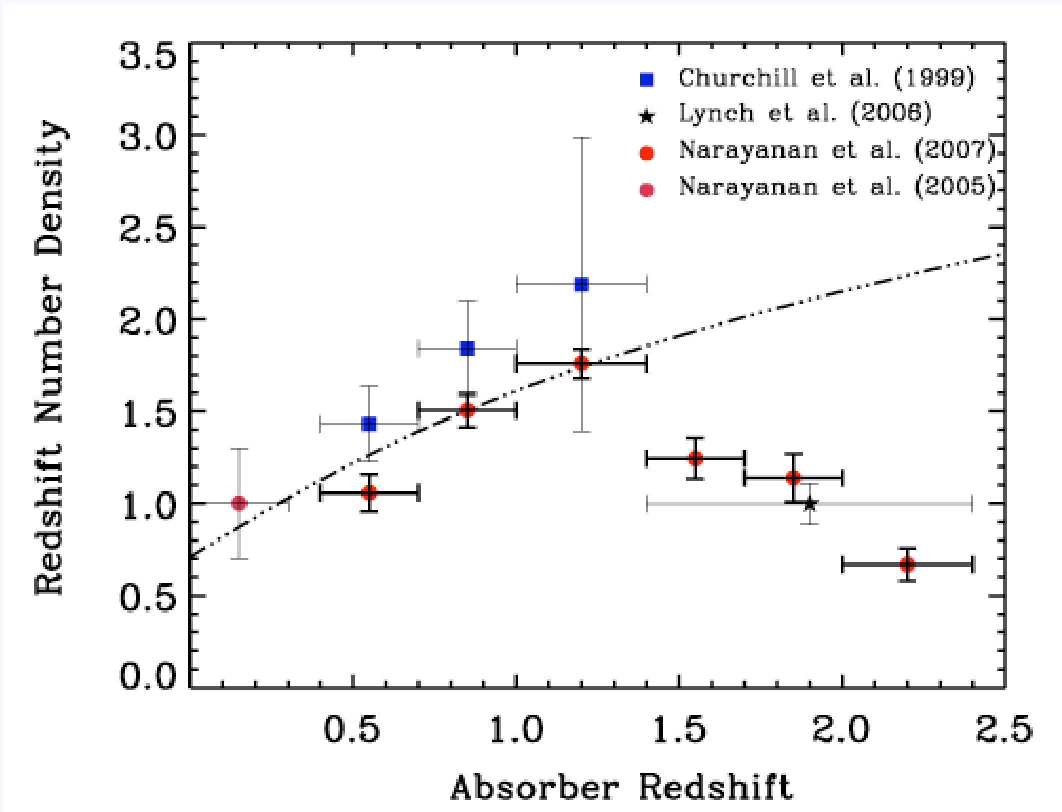
Rauch et al. 2002

Individual low ionization gas clouds (MgII) < kpc (clumpy)

Diffuse, high ionization gas (CIV) > kpc (smoothly distributed and shows little variations along separate lines of sight)

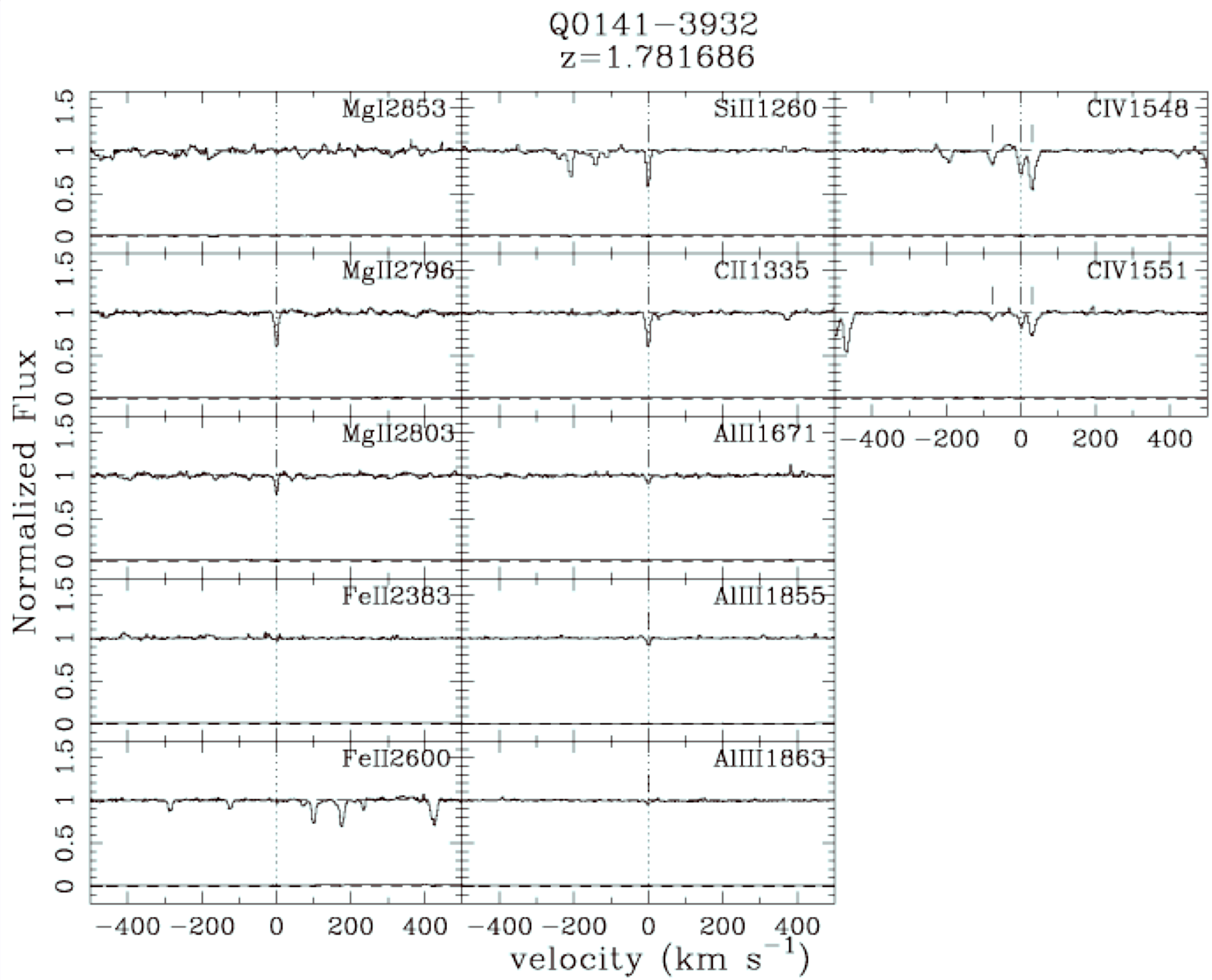
Redshift Number Density

- **Weak absorbers are transient over astronomical timescales.**



- **Absorbers are regenerated at a rate that is consistent with the observed dN/dz.**

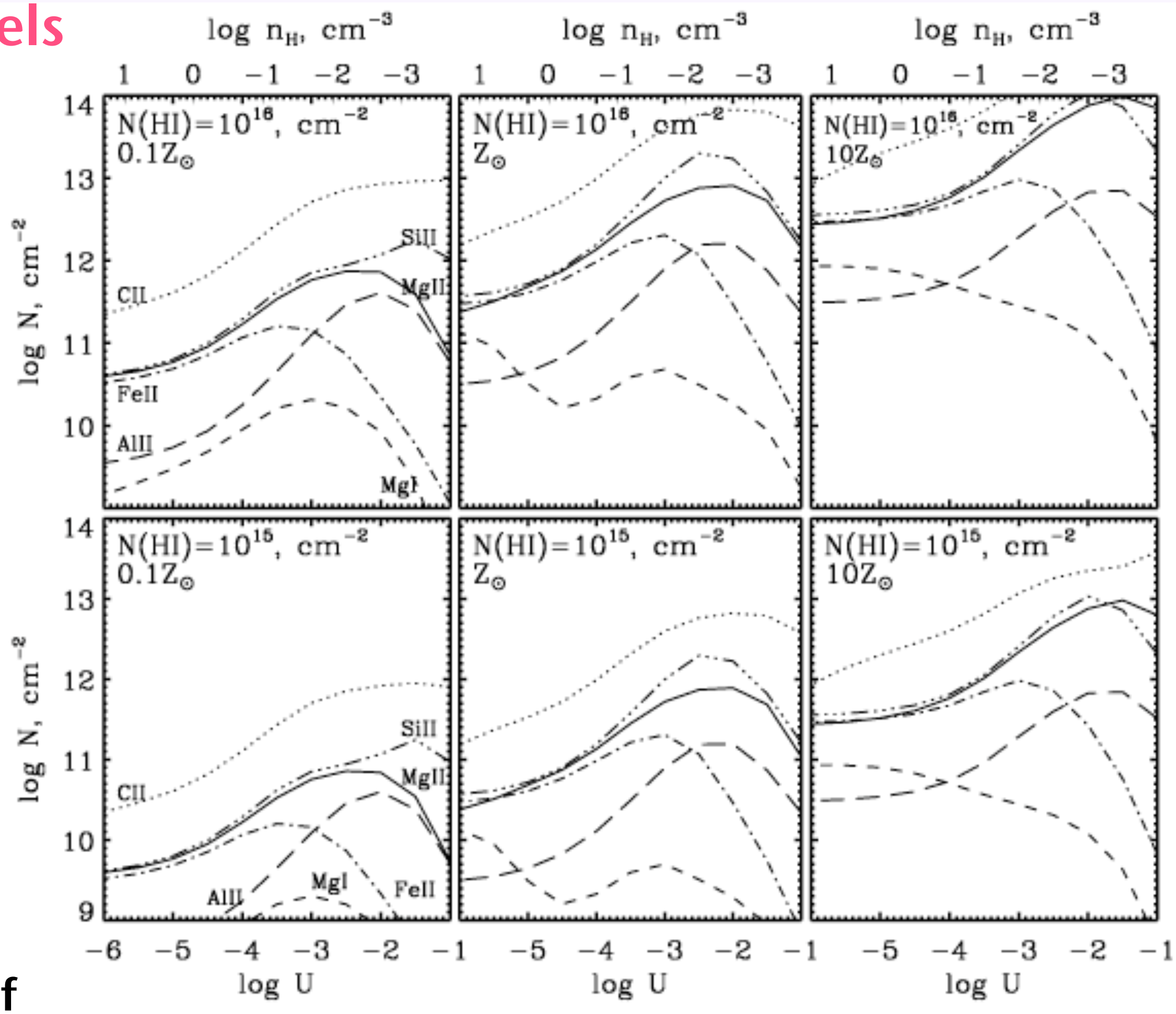
Properties of Weak MgII Absorbers



Chemical & Ionization Conditions - Constraints

Photoionization Models

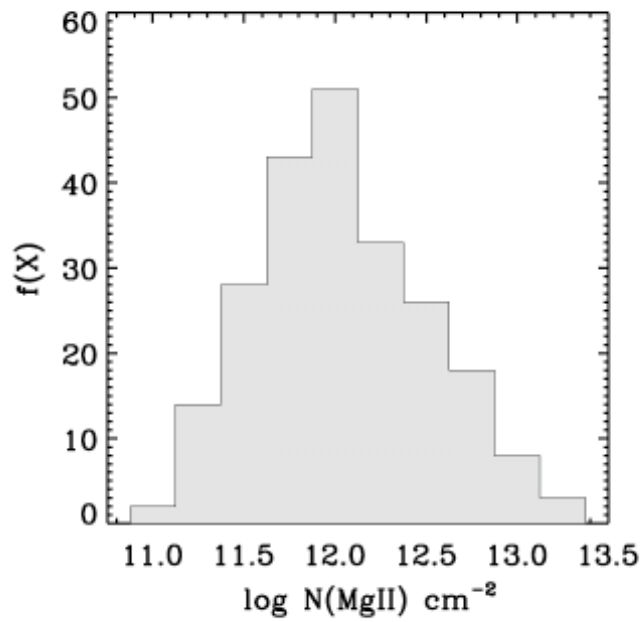
- Inputs to Cloudy
  - N(HI)
  - Metallicity
  - Abundance Pattern
  - $U = n_\gamma / n_H$
  - SED of ionizing radiation
- Output
  - column density of the various atoms & ions.

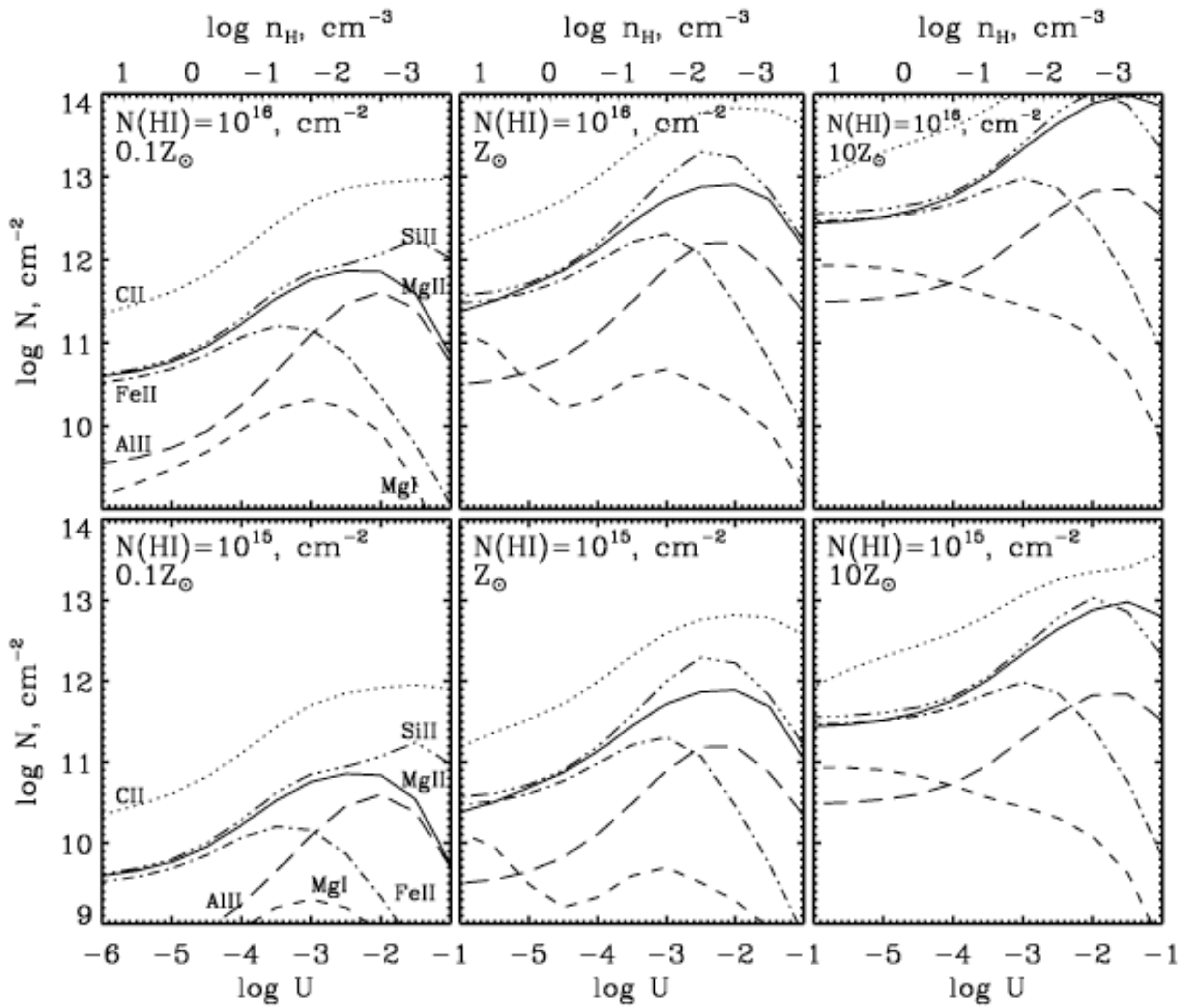


$\log n_H = \log n_\gamma - \log U$,

where $\log n\gamma = -4.70$ for EBR at $z = 2$

Chemical & Ionization Conditions - Constraints





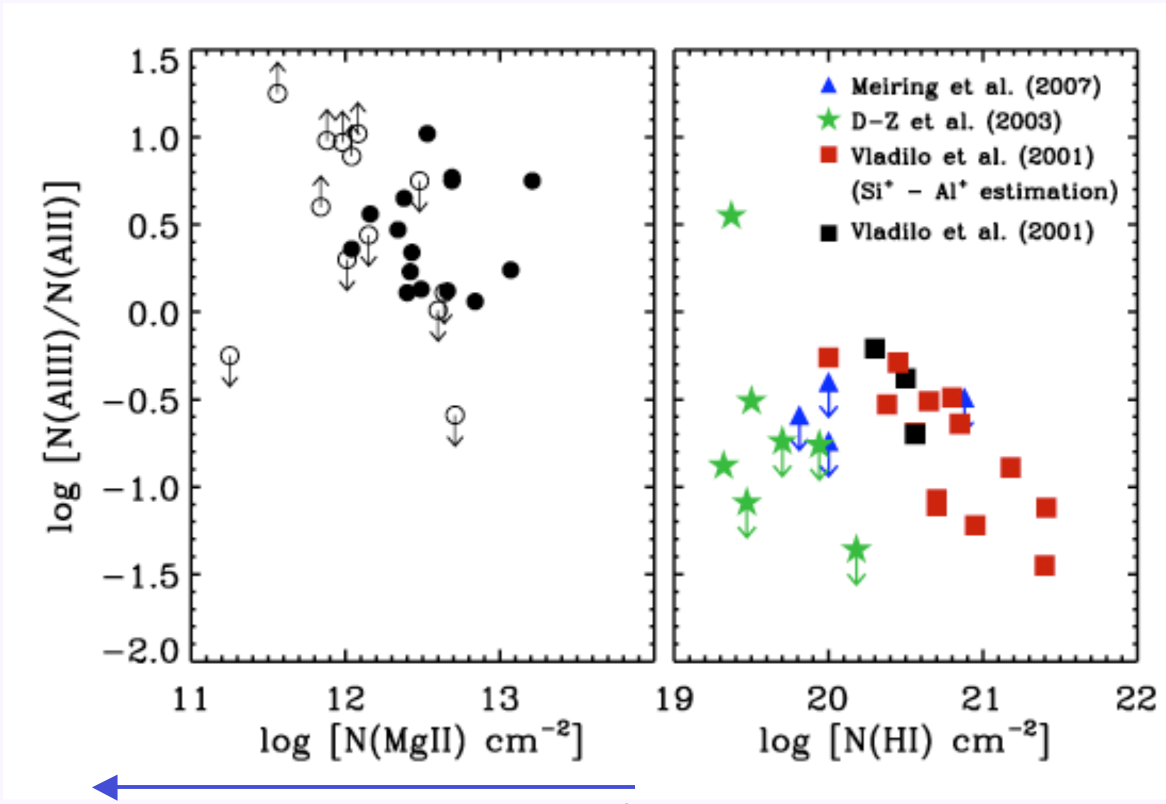
- If clouds are optically thin [N(HI) < 10^{17} cm^{-2}], then $Z \geq 0.1Z_\odot$

$\log n_H = \log n_\gamma - \log U$,
where $\log n_\gamma = -4.70$ for EBR at $z = 2$

N(HI) *in Weak Absorbers*

- **$dN/dz_{LLS} \equiv dN/dz_{strong\ MgII}$**

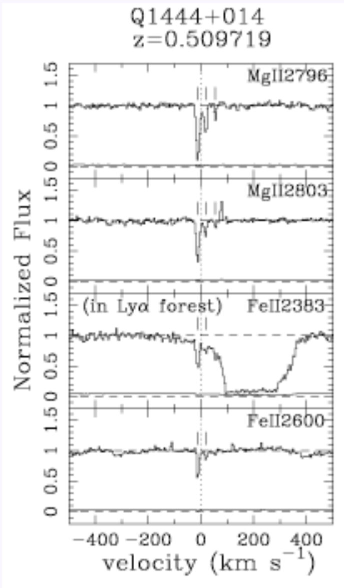
  LLS : N(HI) > $10^{17.3}$ cm-2 , strong MgII $W_r(2796)$ > 0.3A

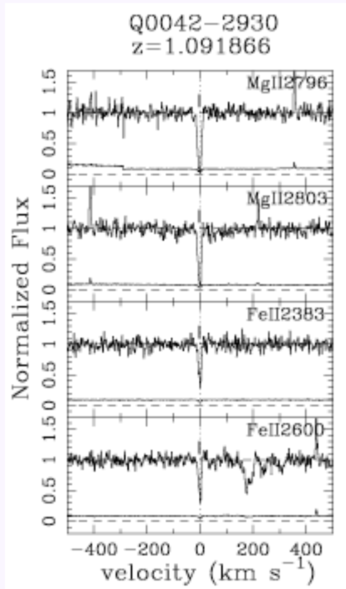


N(HI) < 10^{17} cm^{-2}

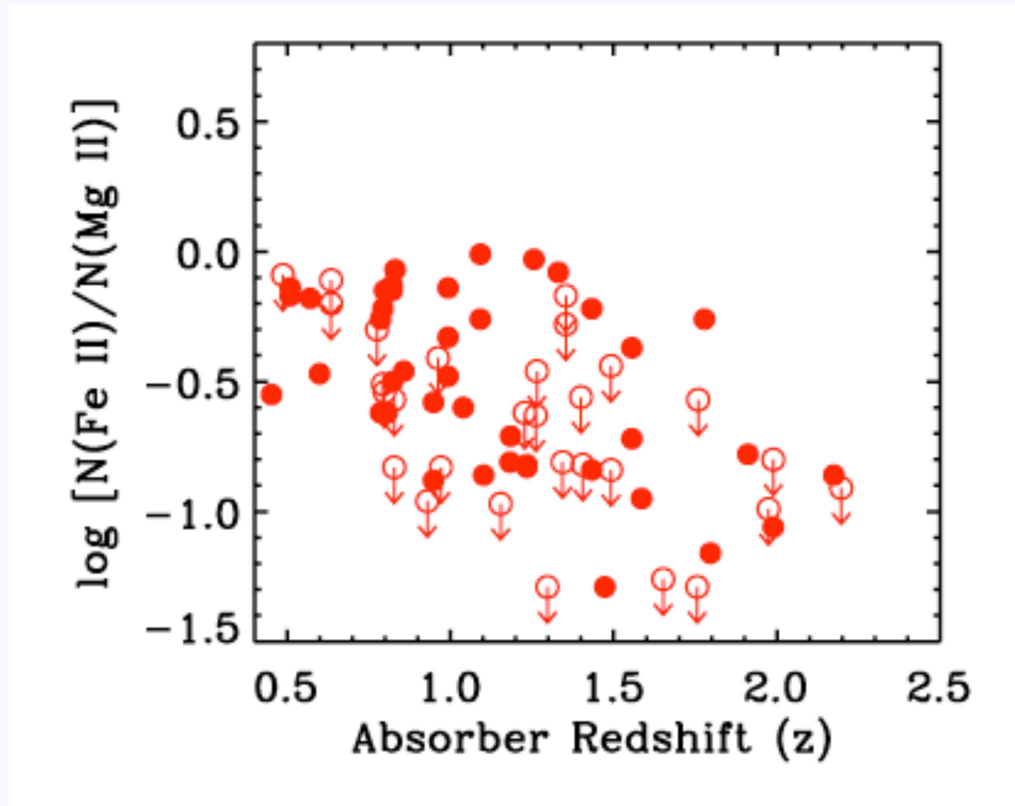
- **Metallicity is $0.1Z_{\odot}$ and higher**

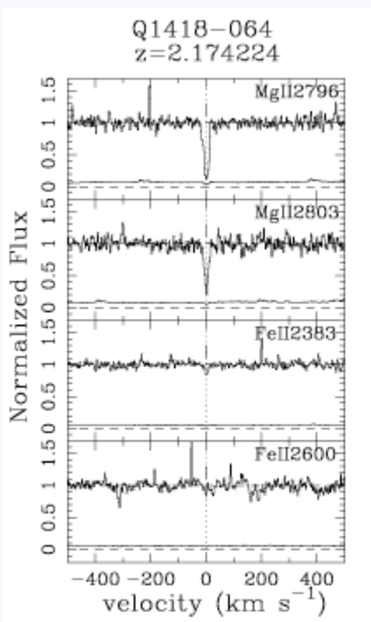
Iron Rich & Alpha Enhanced Populations

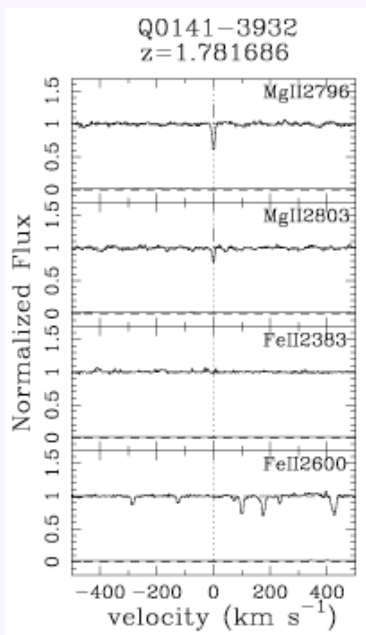




N(FeII) ~ N(MgII)







N(FeII) << N(MgII)

Alpha Enhanced Weak Absorbers

- IGM : Metals detected in the IGM from z ~ 6 to the present.

  Feedback from star-forming galaxies. (e.g. Pettini et al. 2003)

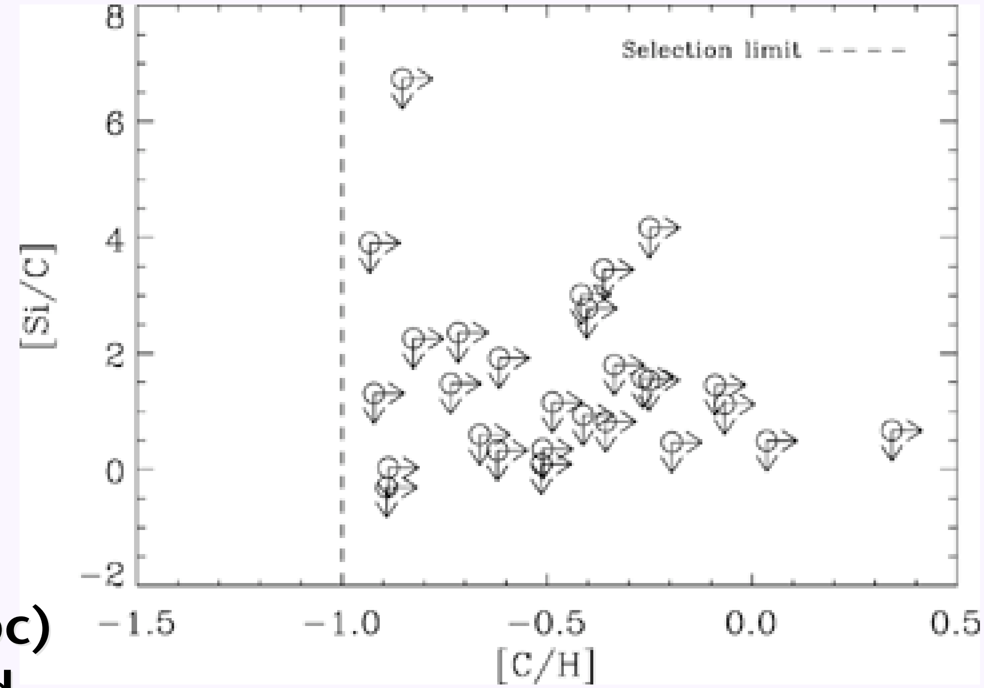
- Metal transport from galaxies to the IGM

  Intermediate Phase?

- Population of weak metal enriched gas clouds (~ $Z_\odot$) at d > 100 kpc from L* galaxies.

  Aracil et al. 2006, Simcoe et al. 2006, Schaye et al. 2007

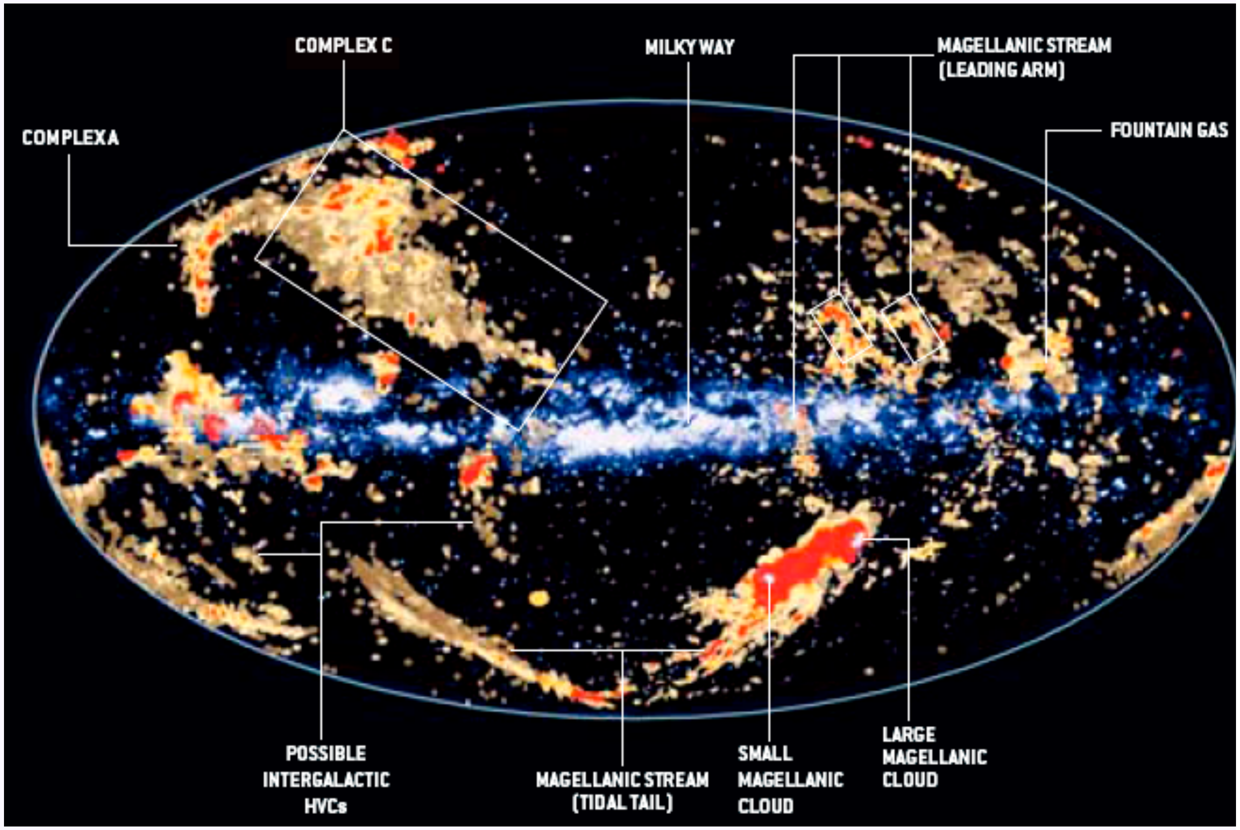
- Strong clustering (< 2.4h^{-1}Mpc) of intergalactic metals around LBGs at z ~ 3 (Adelberger et al. 2003)



Schaye et al. 2007

Galactic High Velocity Clouds

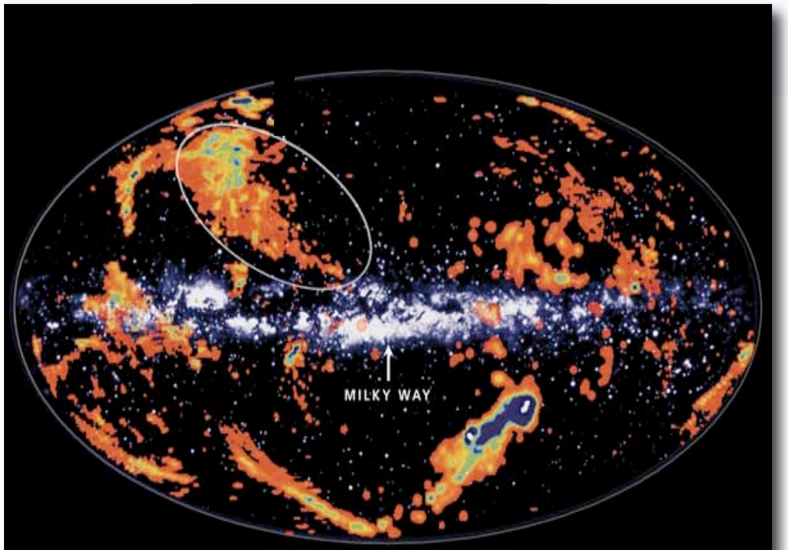
- IVCs and HVCs : gas in the extended halo
- $Z = 0.1 - 1.0\ Z_\odot$
  (e.g. Wakker 1999, Richter et al. 2001, Sembach et al. 2004).
- Galactic fountain
  (e.g. Houck & Bregman 1990)
  +
  Tidal streams
  (e.g. Lu et al. 1998, Sembach et al. 2001)

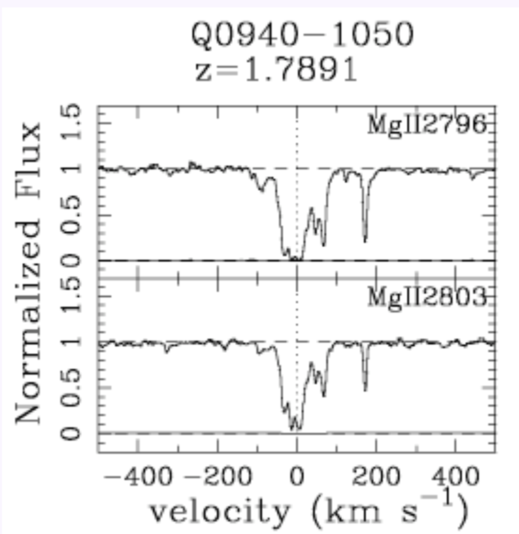


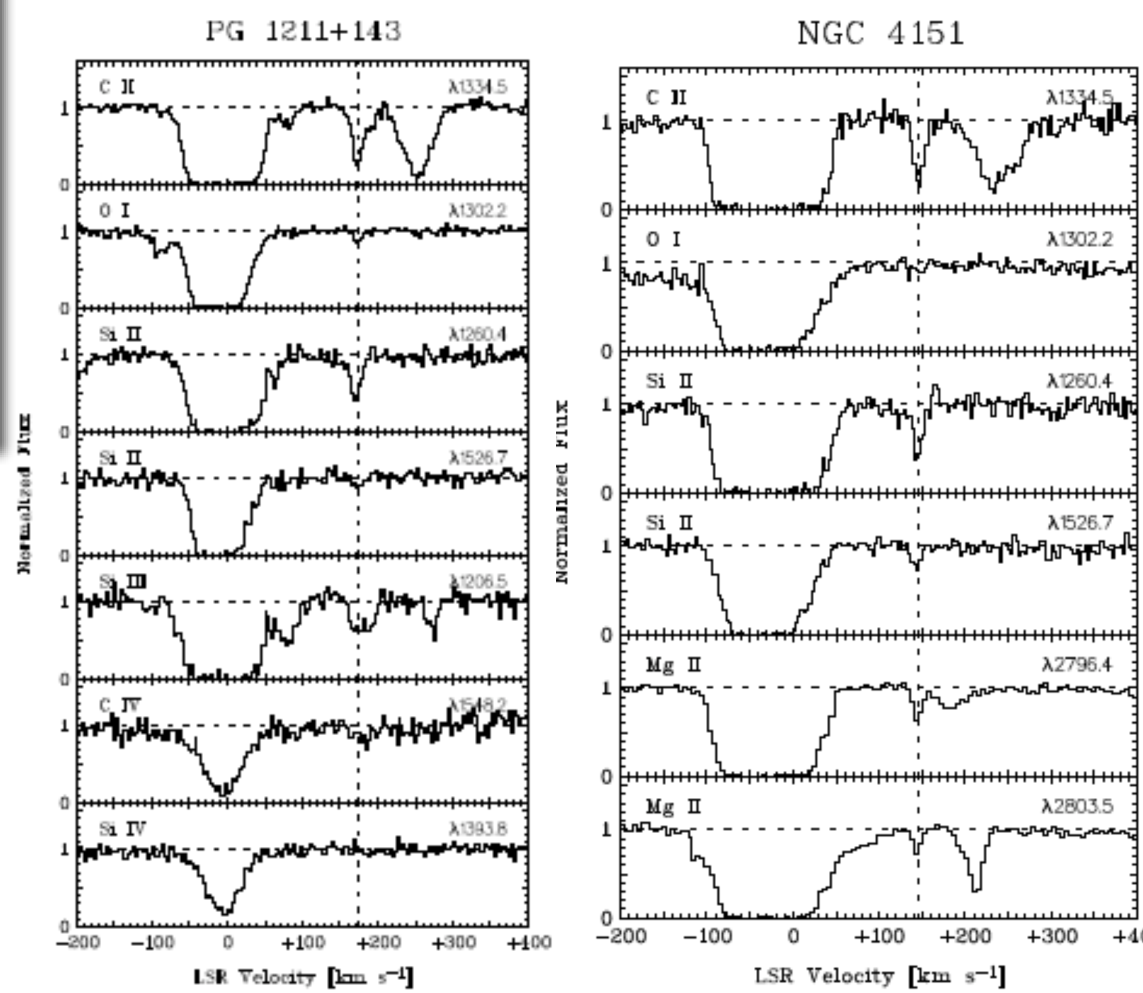
Wakker & Richter Sci.A. 2003

HVCs - Satellites of Strong MgII - Weak

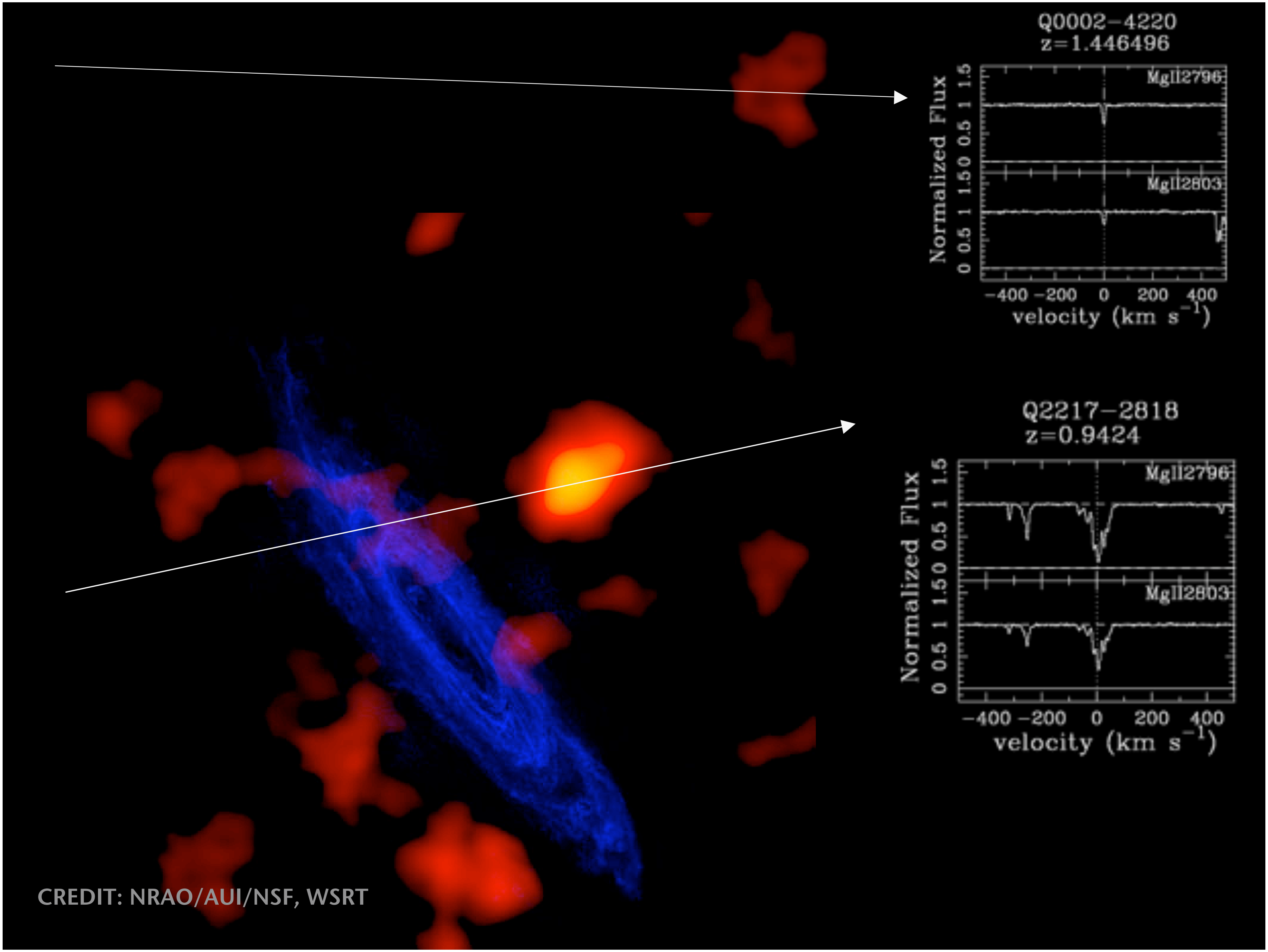
Population of weak absorbers surrounding the Milky Way







Richter et al. in prep


Q0002−4220
z=1.446496
MgII2796
MgII2803
Normalized Flux
velocity (km s^{-1})
Q2217−2818
z=0.9424
MgII2796
MgII2803
Normalized Flux
velocity (km s^{-1})
CREDIT: NRAO/AUI/NSF, WSRT

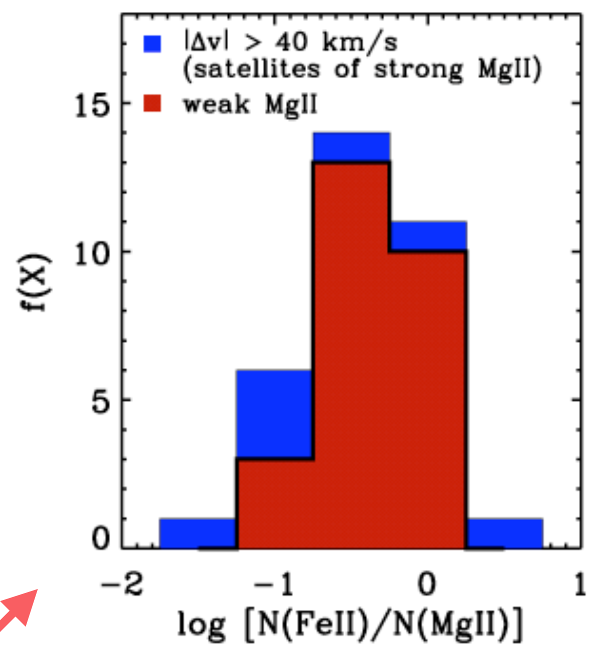
HVCs - Satellites of Strong MgII - Weaks

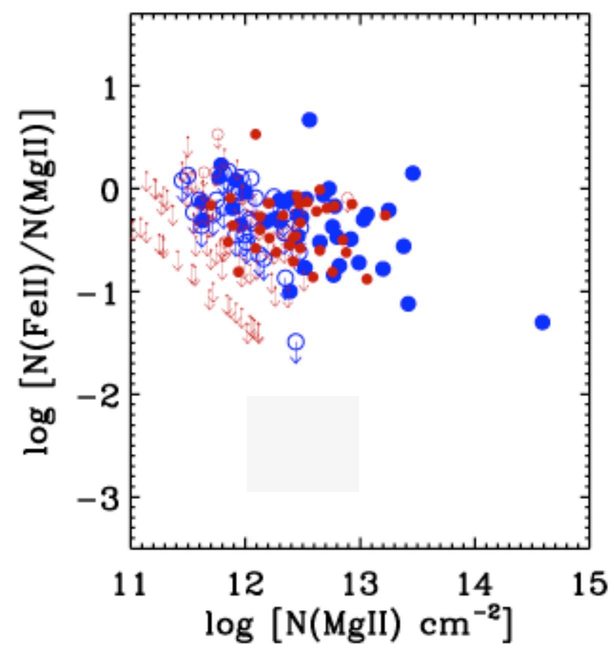
- **Kinematic subsystems in strong MgII ≡ HVCs**

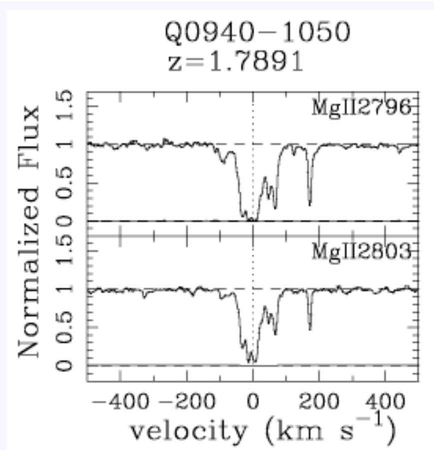
- **Weak MgII clouds ≡ kinematic subsystems in strong MgII** (Churchill & Vogt 2001)

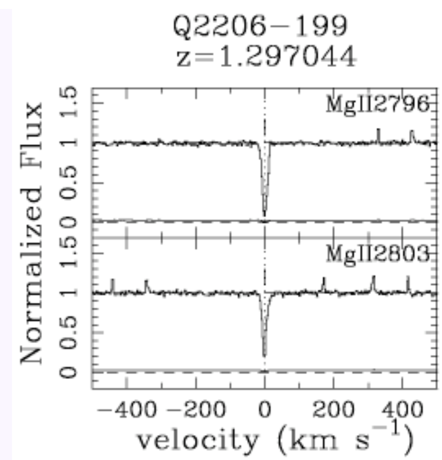
- **The two samples are consistent with being drawn from the same distribution.**

  P(KS) = 0.63 (D=0.196)



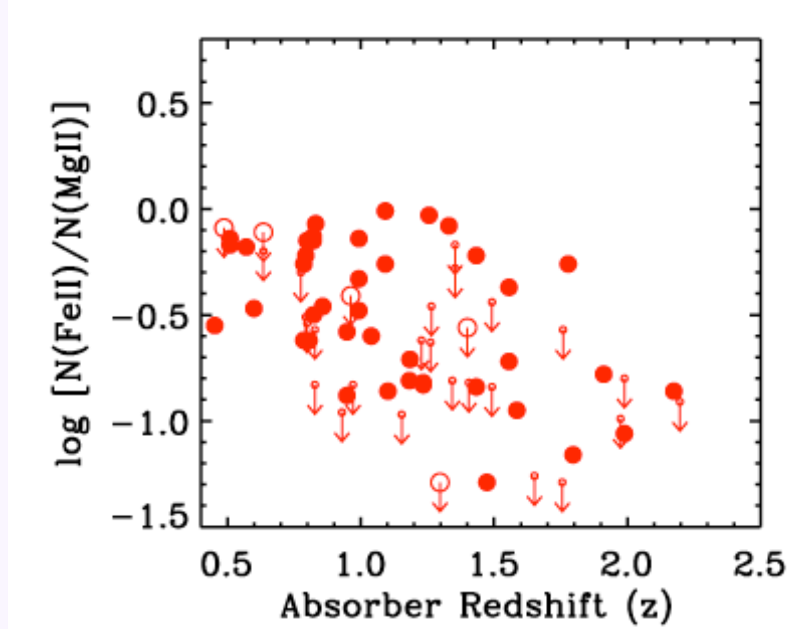


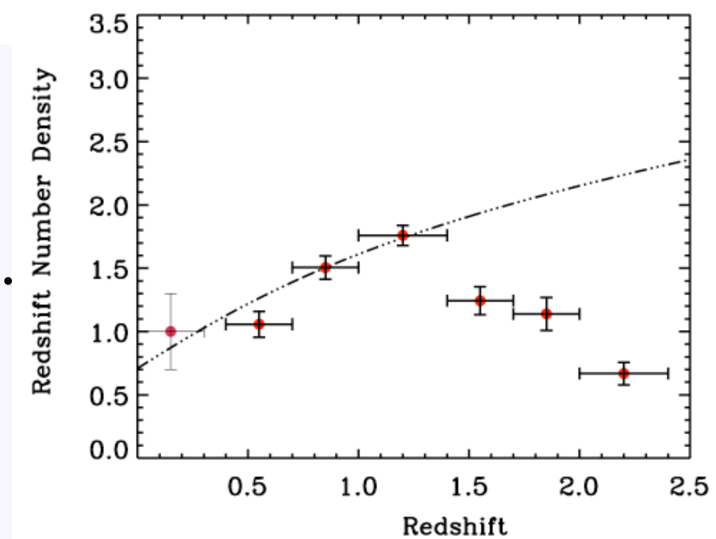




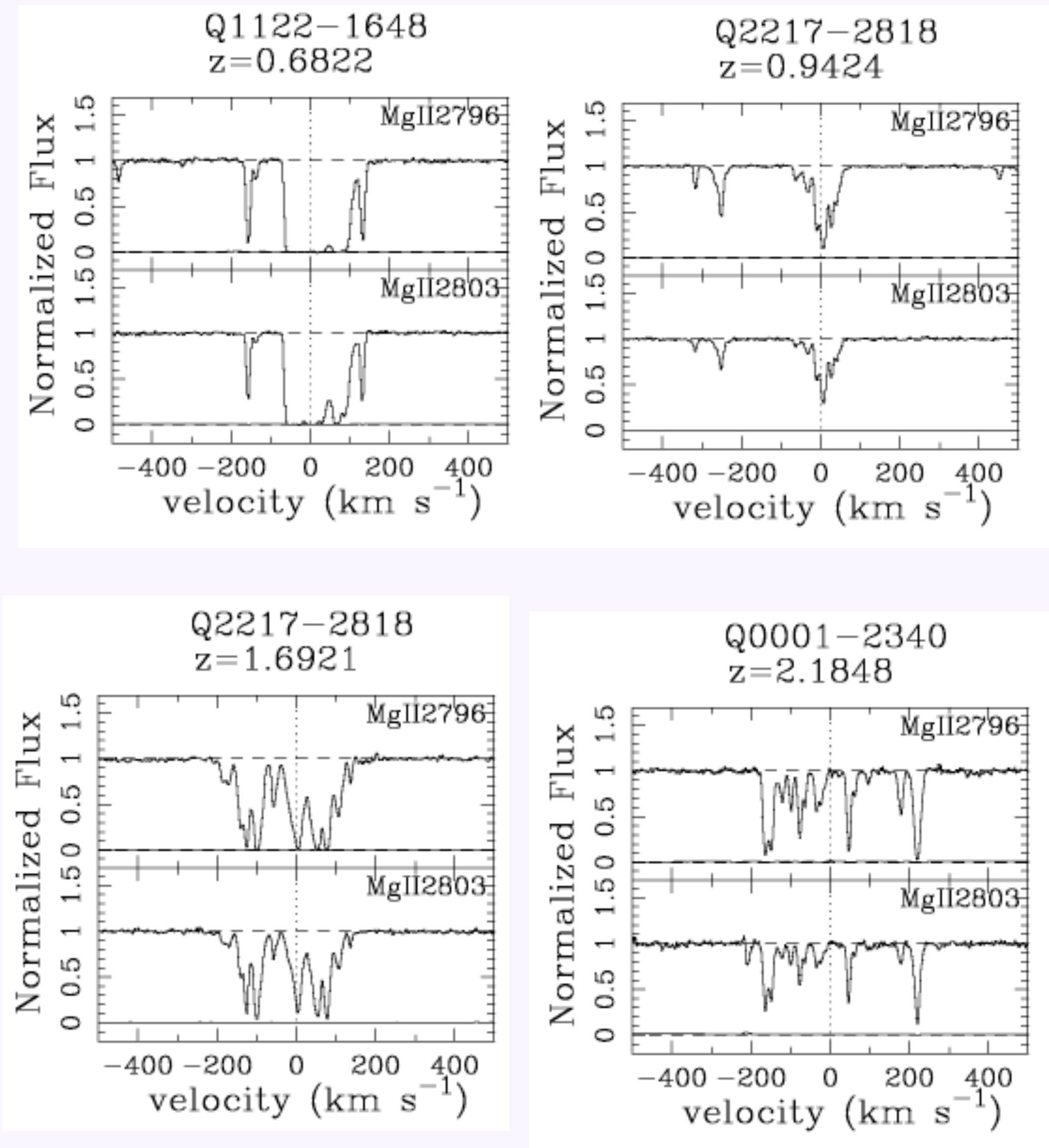
Iron Rich Weak MgII Clouds

- N(FeII) ~ N(MgII)
- Nucleosynthetic yields from Type Ia SNe.
- ~ 1Gyr delay from the onset of star formation - iron enrichment relative to alpha elements
- Potential wells of dwarf galaxies or other intergalactic structures.
- Star formation in dwarfs peak at z ~ 1.5.
  Kauffmann et al. 2004, Bauer et al. 2005

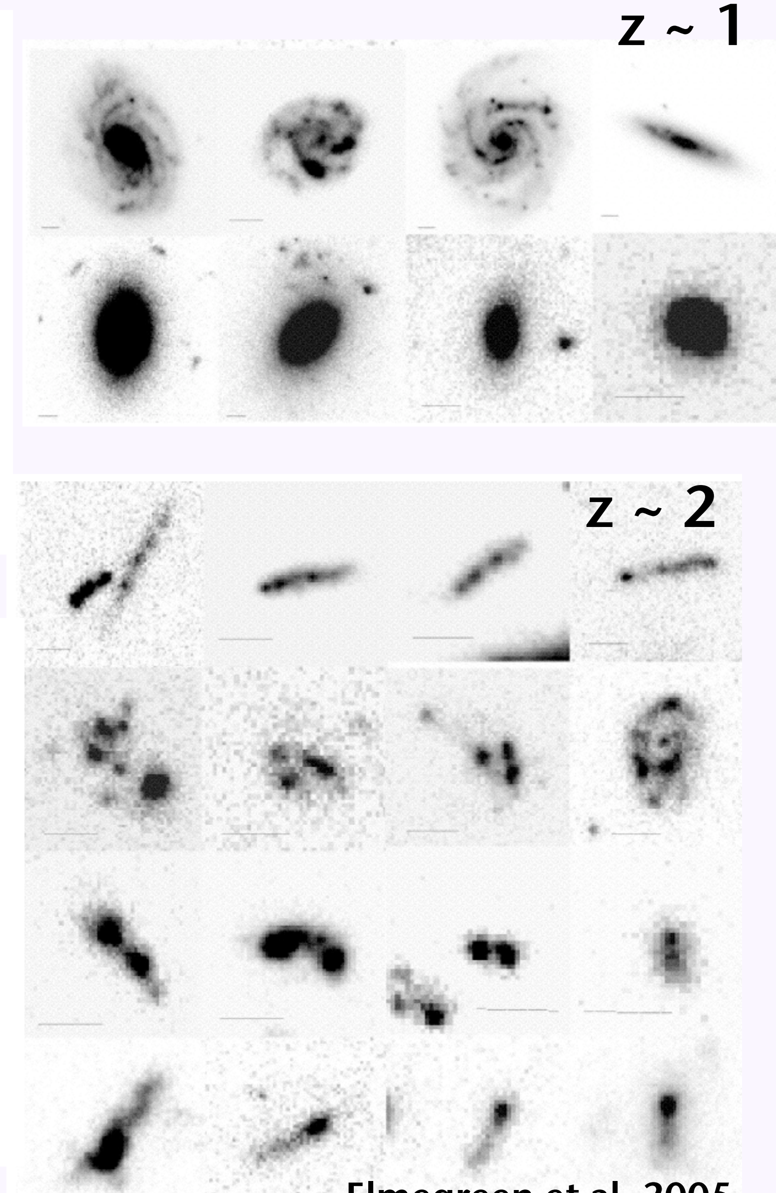




Absorption Signature of Evolution in Galaxy Morphology ?



Mshar et al. 2007



Elmegreen et al. 2005

Summary

- A census of weak MgII absorbers over the last ~ 10 Gyr history of the universe. (Narayanan et al. 2005, 2008)
- The redshift number density peaks at $z \sim 1.2$. At $z > 1.2$, dN/dz declines drastically such that there may not be a separate population of weak MgII clouds at $z \sim 3$. (Narayanan et al. 2007)
- They are sub-Lyman limit systems, i. e., $N(HI) < 10^{17.3}$ cm^{-2} ($\tau_{912Å} < 1$) (Narayanan et al. 2008)
- The low ionization gas clouds are metal rich ($Z \geq 0.1 Z_{\odot}$ in several cases) (Narayanan et al. 2008)
- Population of iron-rich and alpha-enhanced clouds suggestive of different physical origins? (Narayanan et al. 2008)
- Alpha enchanced : Physical origin --> Gas in the extended halos of galaxies (d ~ 30 - 100 kpc) - analogous to Galactic high and intermediate velocity cloud structures. (Narayanan et al. 2007, 2008)