Quasars Probing Quasars

Jason X. Prochaska
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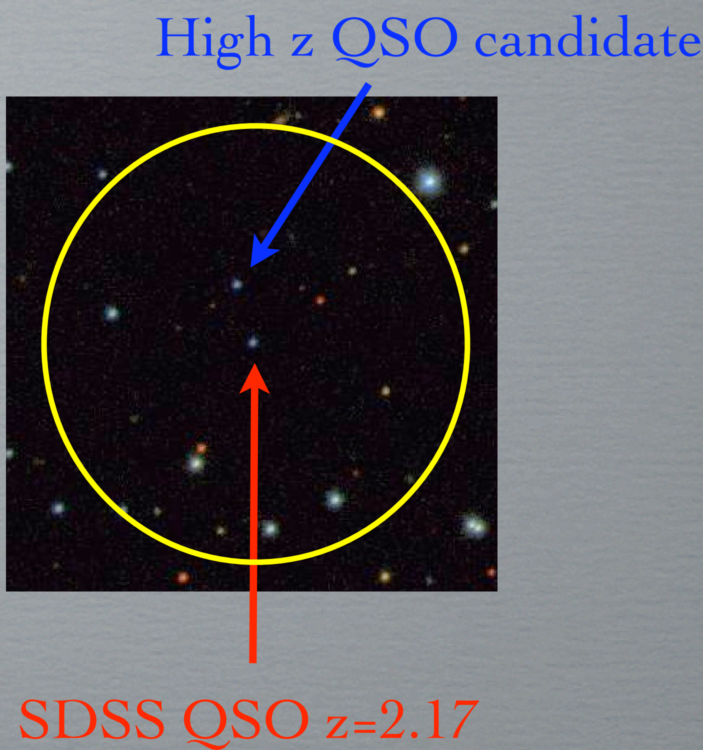
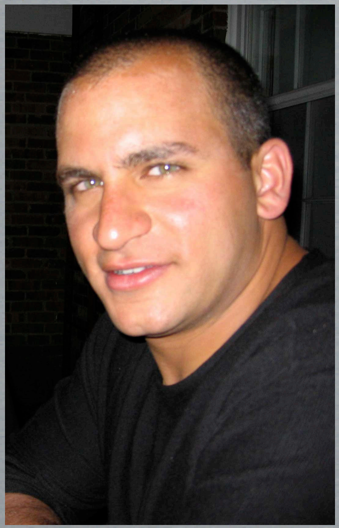
(on behalf of J. Hennawi
and G. Prochter)

Outline of Results

- Intro
  - Traditional QAL studies
  - QSO Pairs
- QSO-MgII Clustering
  - R_0 = 4.55 +/- 0.8 Mpc h^{-1}
    - M ~ 10^{12} Msol
  - Proximity effect for optically thick systems
- MgII toward GRB vs QSO
  - There are 4x more galaxies in front of GRB than QSOs!?
- QSO-LLS Clustering
  - Strong signal at z>2
  - Proximity effect



Where Credit is Due



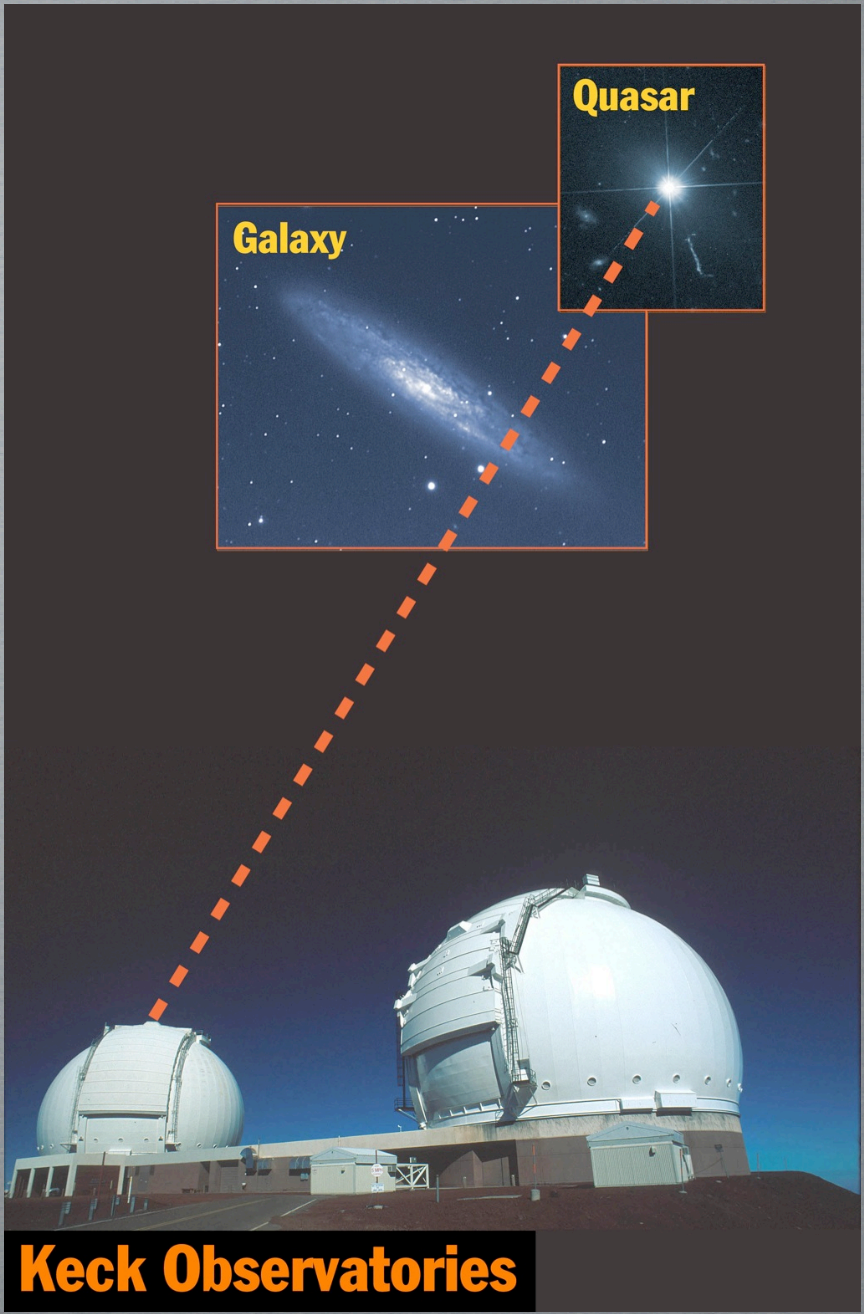
Joe Hennawi
(UCB)
Ideas + Work

Gabe Prochter
(UCSC)
Work + Ideas

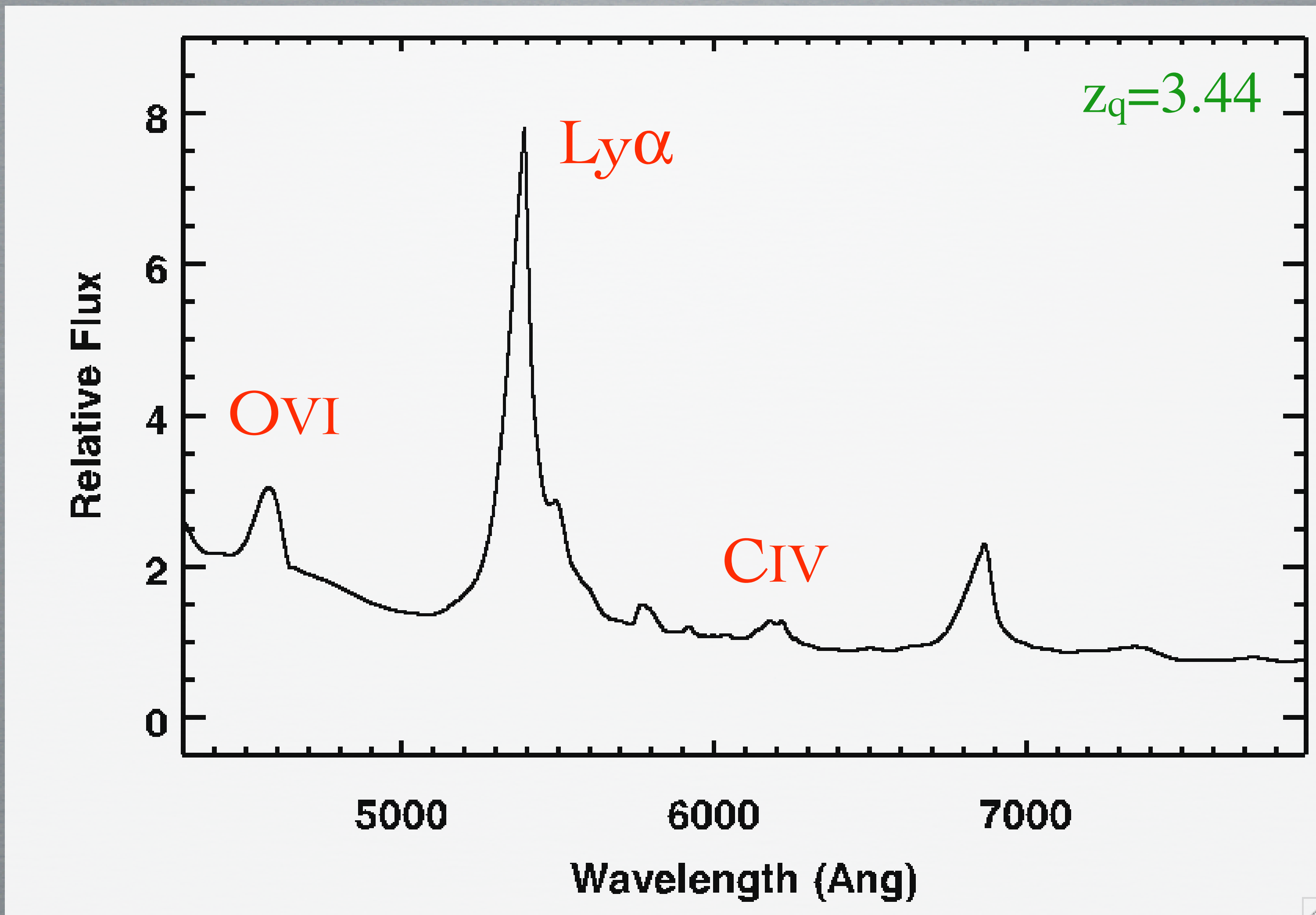
Me
Cheerleading

QAL Experiment

- Observe a quasar
  - typically bright (V<19)
  - Generally z>2
- Study the gas between us and the QSO
  - Properties of the QSO are largely unimportant
  - Absorption-line spectroscopy

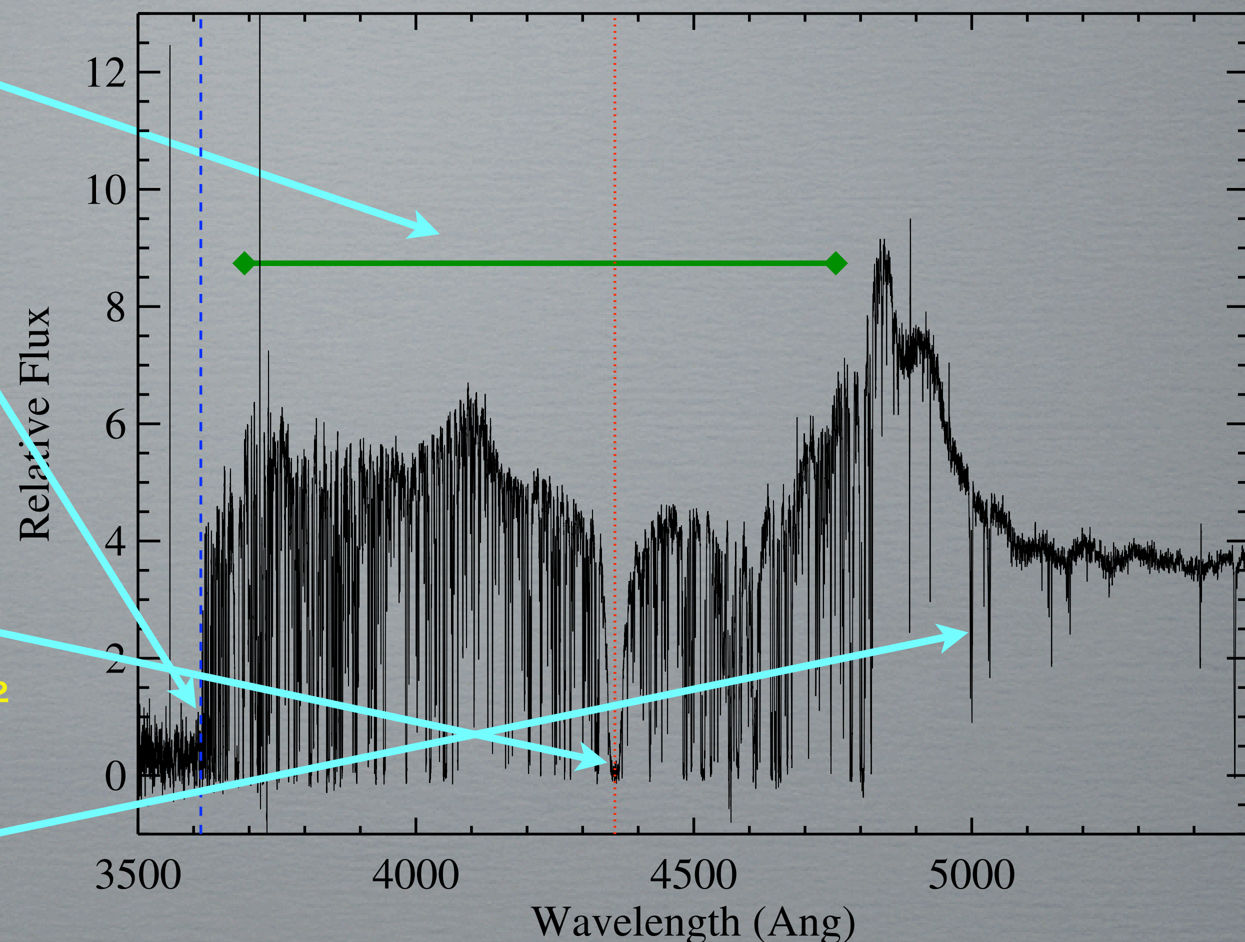


Quasar Continuum

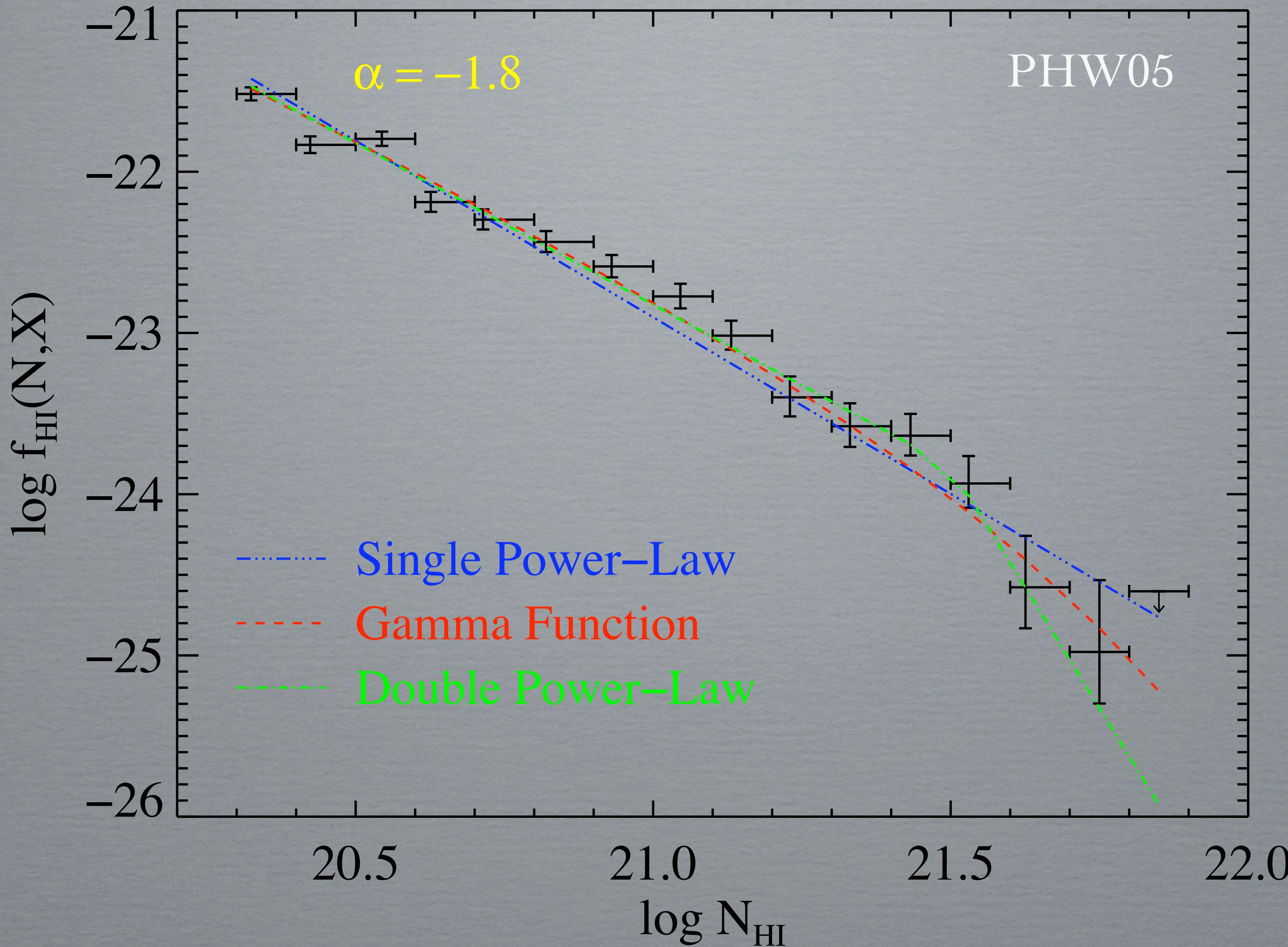


QAL Systems

- Lya forest
  - N(HI) < 10^{17} cm^{-2}
  - $\delta\rho/\rho < 10$
  - Lots o' science
- Lyman Limit Sys
  - N(HI) > 10^{17} cm^{-2}
  - $\delta\rho/\rho \sim 100$
  - Unexplored
- Damped Lyα Sys
  - N(HI) > 2 10^{20} cm^{-2}
  - Galaxies
- Metal-line sys
  - MgII
  - CIV
  - etc.

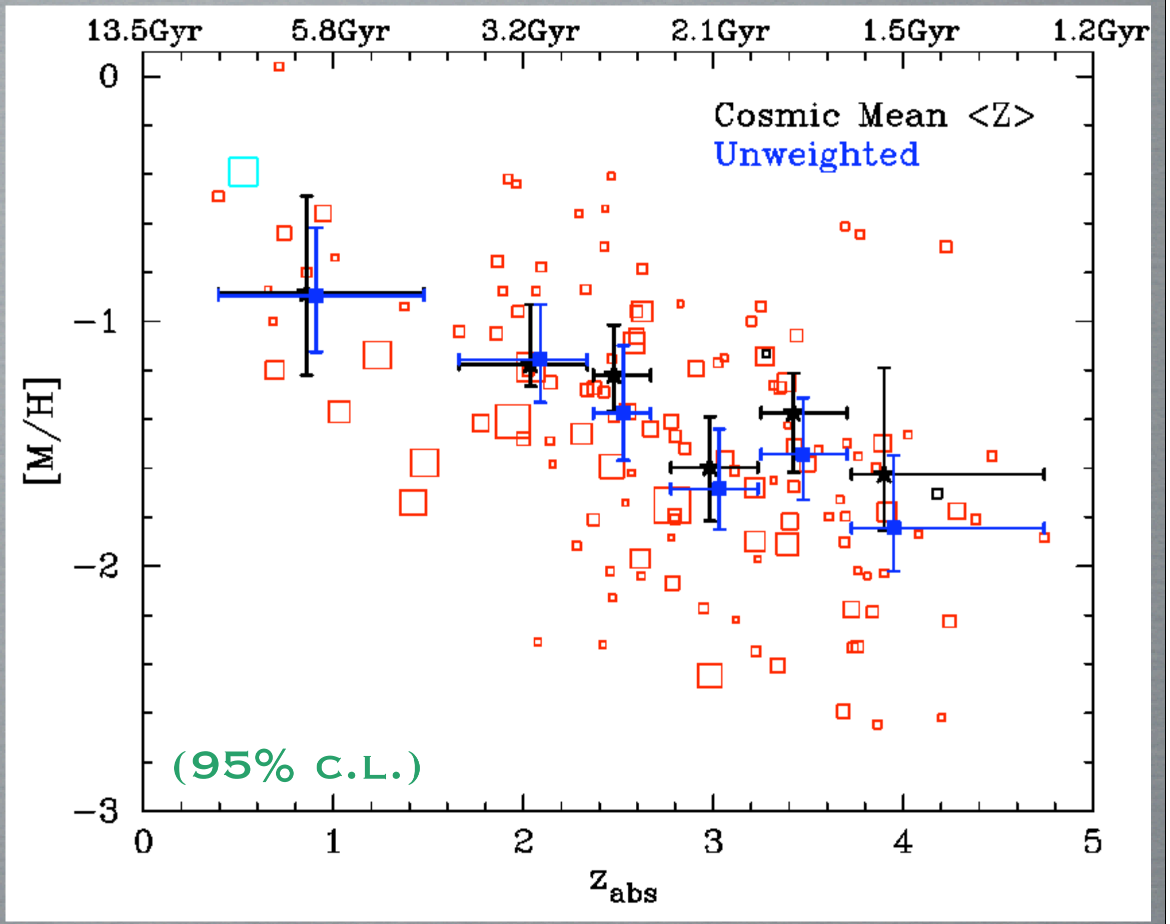


f_{HI}: N_{HI} Frequency distribution



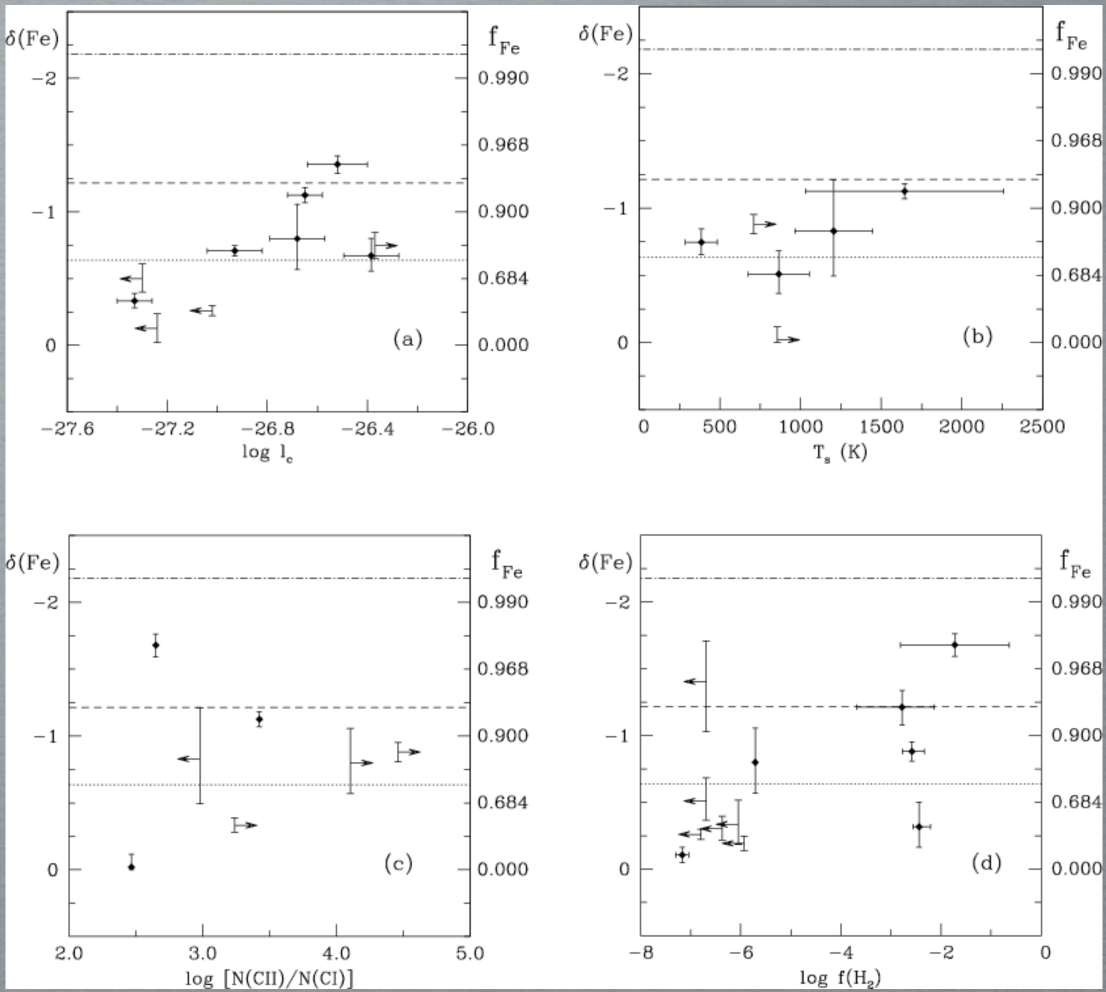
Chemical Evolution

- >120 DLA
  - ✦ Evolution in both unweighted and <Z>
  - ✦ -0.26 dex per Δz
  - ✦ About 2x per Gyr
- Scatter
  - ✦ Roughly constant with z
  - ✦ Uniform population?
- Metallicity floor
  - ✦ [M/H] > -2.6
  - ✦ DLA are linked to current or recent SF



Chemical Abundances

- Dust-to-gas ratio
  - Zn/Fe, Si/Fe
    - Depletion patterns
    - Obscuration implications
  - Molecular content
- Star-formation histories
  - Si/Fe, N/O, z
  - 'Morphology'
    - Dwarf galaxies
    - Outer spiral galaxy



Vladilo (2004)

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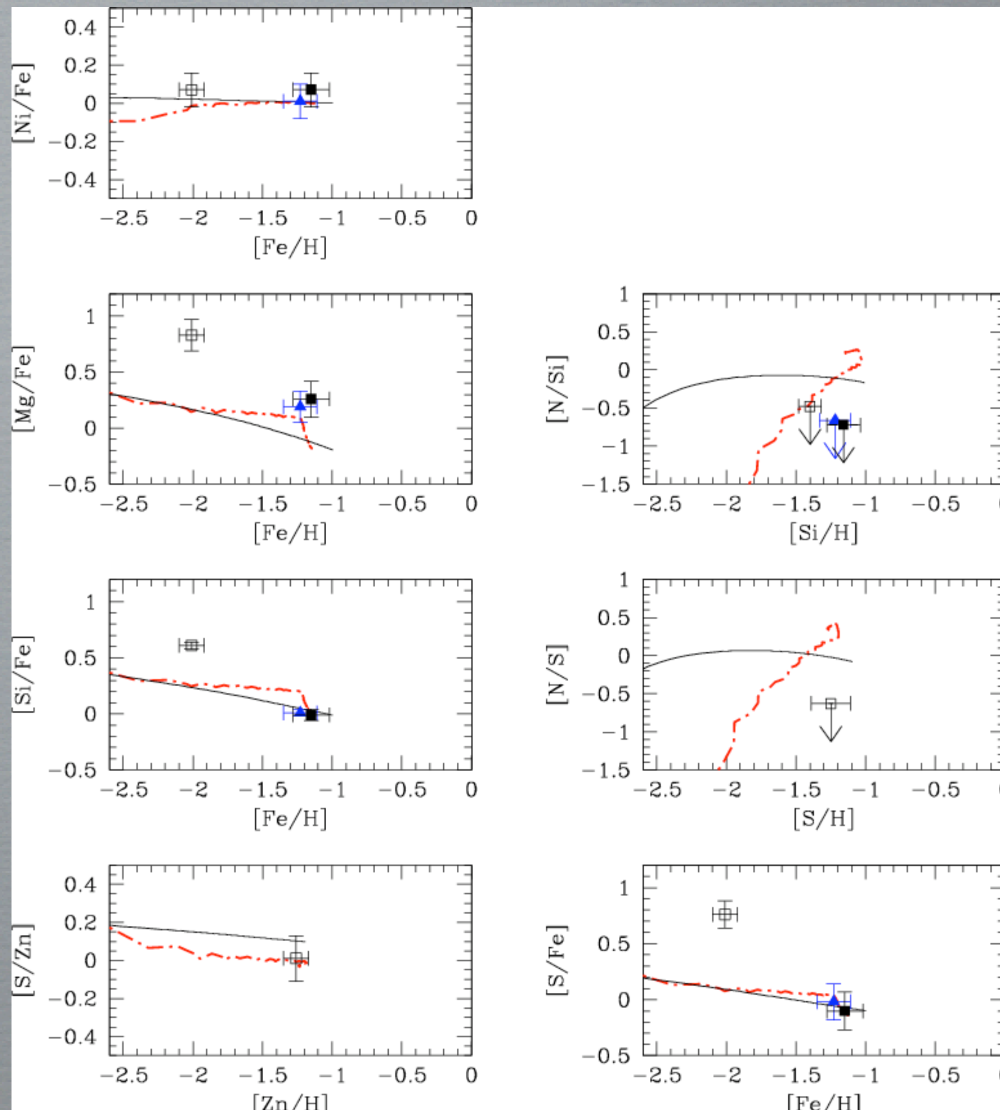


Dessauges-Zavadsky et al. (2004)

QAL Systems

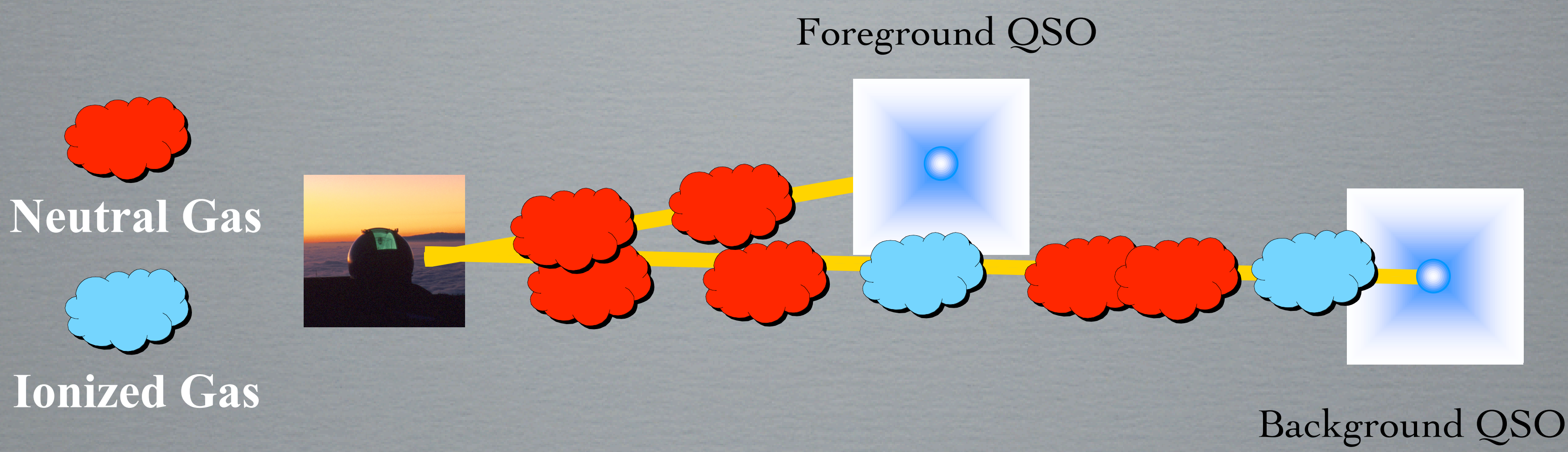
What we (think we) know:

N_{HI}
Metallicity
Dust-to-gas ratio
Velocity field
1D Power spectrum
Chemical abundances

What we don't know:

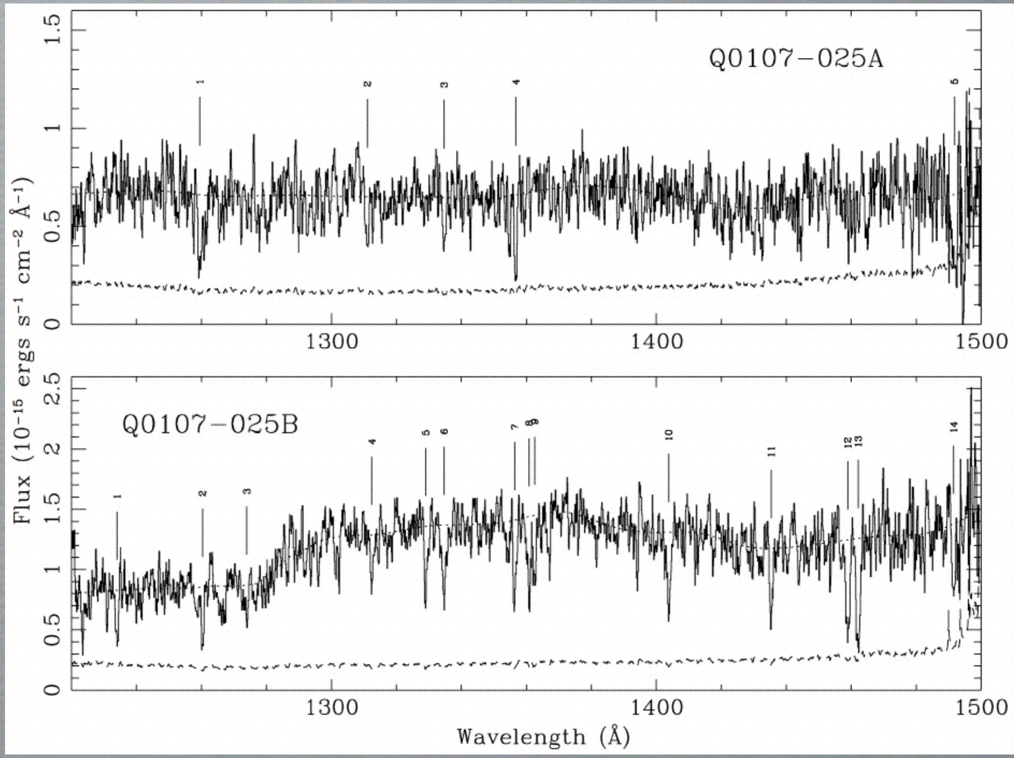
Density
Size
Mass of the host galaxy
Properties of the QSO host
Temperature
Stars associated with the gas

Quasar Pairs



Quasar Pairs: Previous work

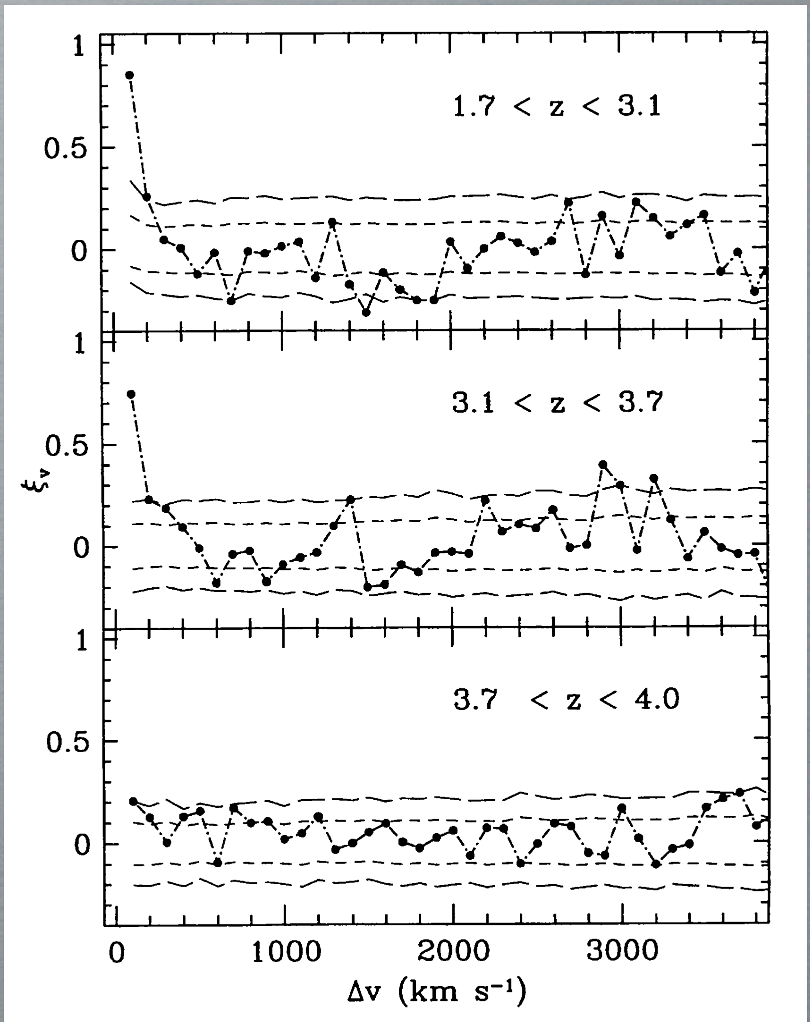
- Low redshift
  - Projected pairs
  - Coherence of Lyα lines
    - ~Mpc scales
    - Suggest these 'clouds' fill large volume
- High redshift
  - Gravitational lenses
    - Small separation
    - Impressive coherence
  - Small sample



Dinshaw et al.

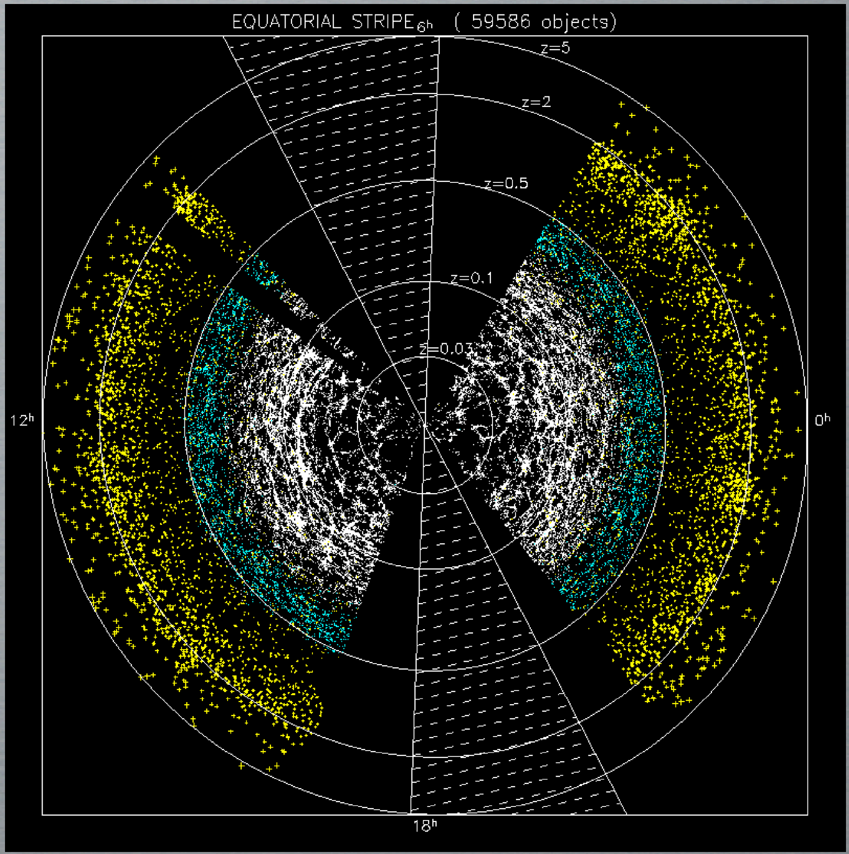
Quasar Pairs: Previous work

- Low redshift
  - Projected pairs
  - Coherence of Lyα lines
    - Mpc scales
    - Suggest these 'clouds' fill large volume
- High redshift
  - Mainly gravitational lenses
    - Small separation
    - Impressive coherence
  - Small sample of projected pairs
    - Mainly >1′ separation



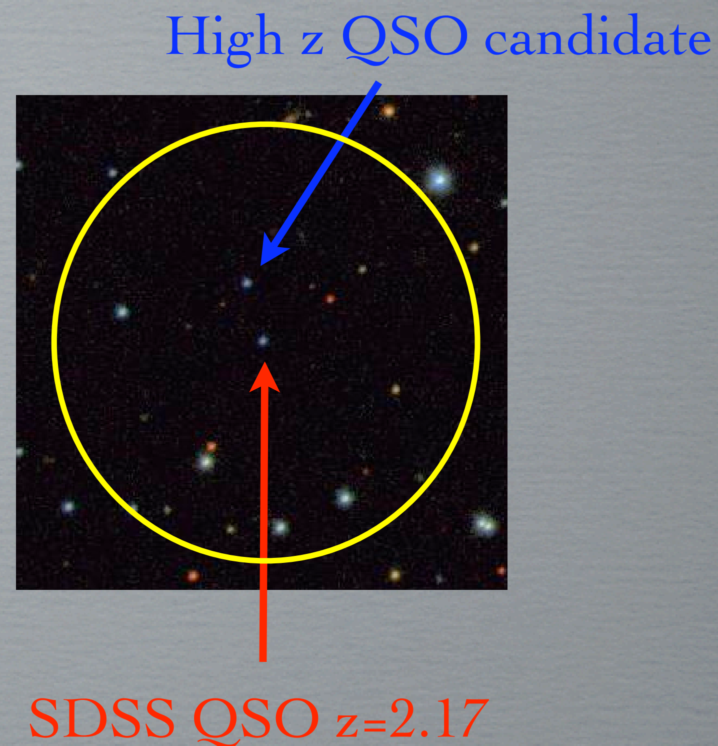
SDSS Survey

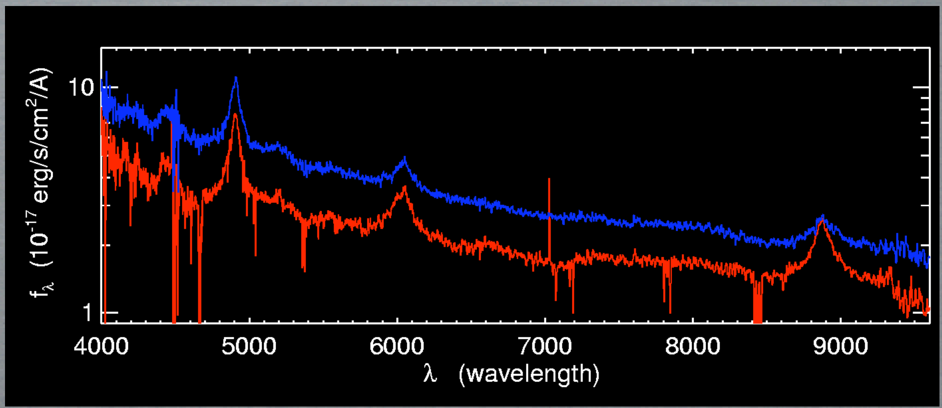
- Data Release 4
  - Over 3000 deg^2
  - Over 40,000 quasars
- Spectral quality
  - R = 2000
  - λ = 3800 - 9200 Ang
- Fiber survey
  - Collisions limit placement to 1′
    - 1′ = 1.5 Mpc h^{-1} at z=2



Close QSO Pairs

- SDSS Photometry
  - Candidate QSOs near known SDSS QSOs
  - Follow-up spectra at APO
    - J. Hennawi thesis
- Terrific success
  - Current sample
    - >50 sub-arcminute pairs
  - Additional follow-up spectra
    - Lyα forest properties
    - QAL clustering
    - etc.





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  - ✦ Proximity effect for optically thick systems
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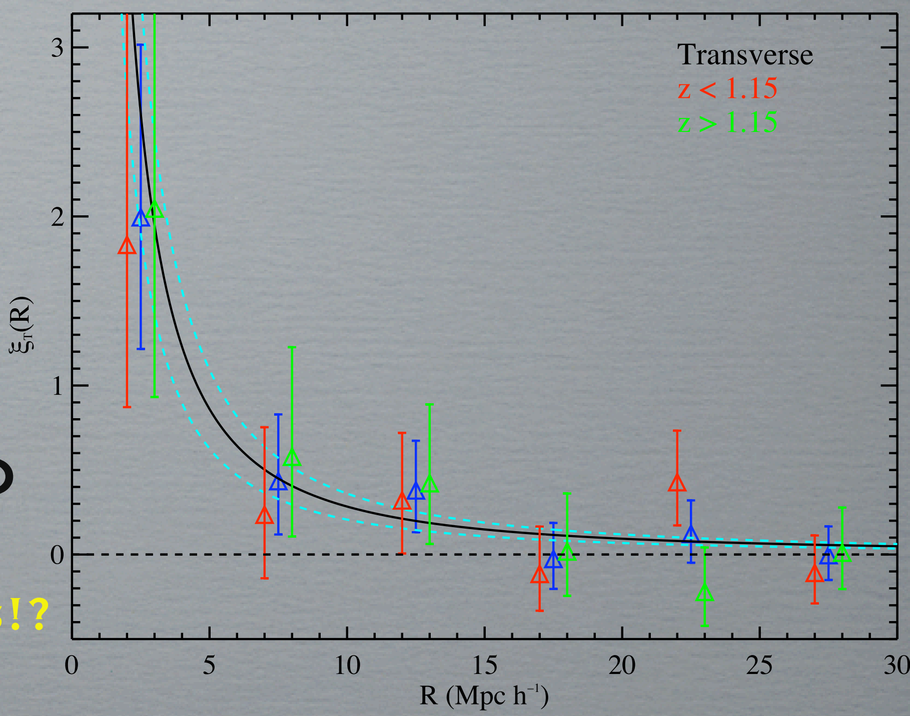
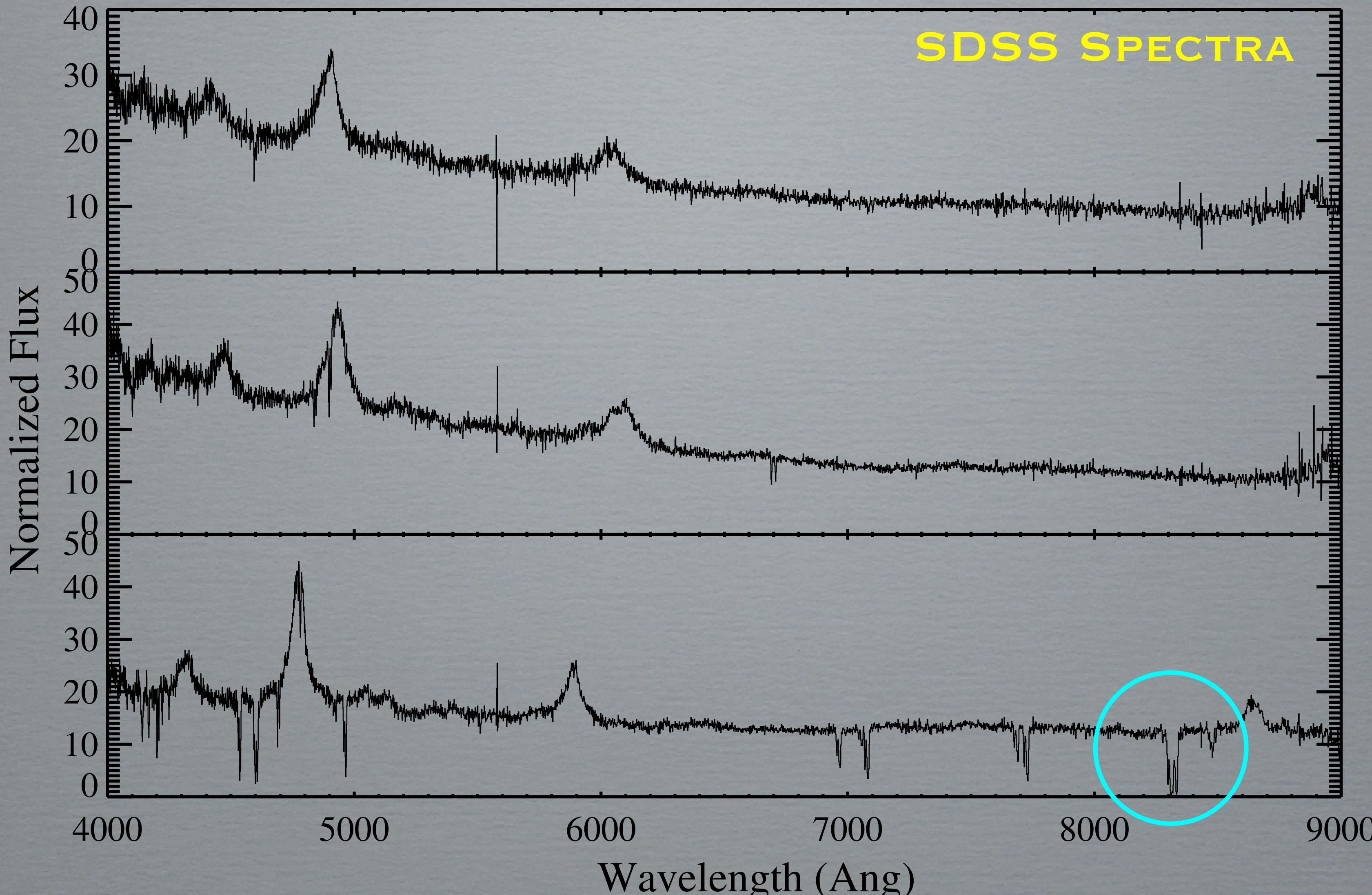


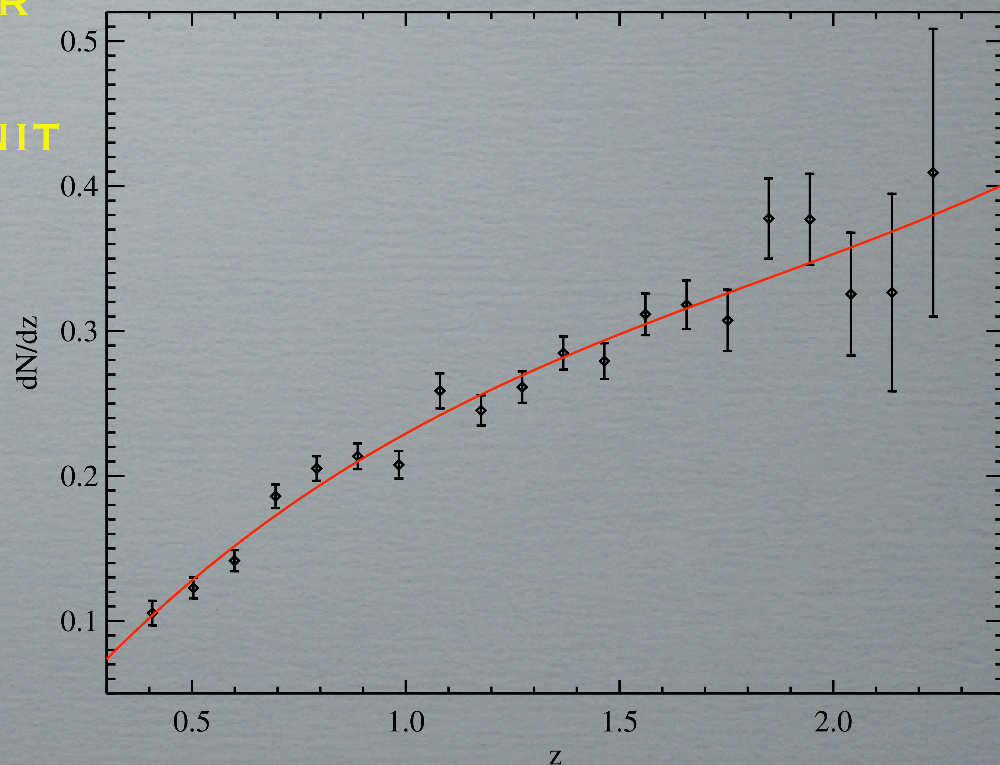
Prochter, Hennawi, Prochaska (2006)

MgII Search in QSO Spectra



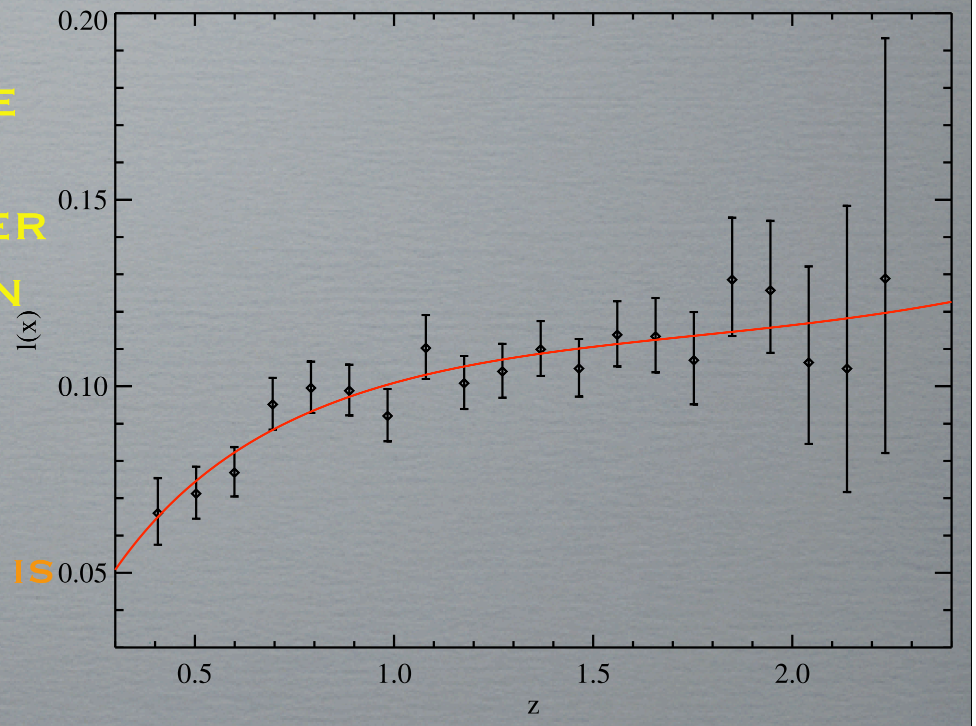
dN/dz of MgII

- *dN/dz*
  - ✦ Number of absorbers per unit redshift
  - ✦ Roughly, 1 QSO has 1 unit of redshift coverage
- SDSS
  - ✦ 20,000 quasars with sufficient SNR
    - Automatically identify 10,000 MgII systems
      - ➡ Each is verified by eye
    - Stat sample is 7000 with Rest EW > 1A



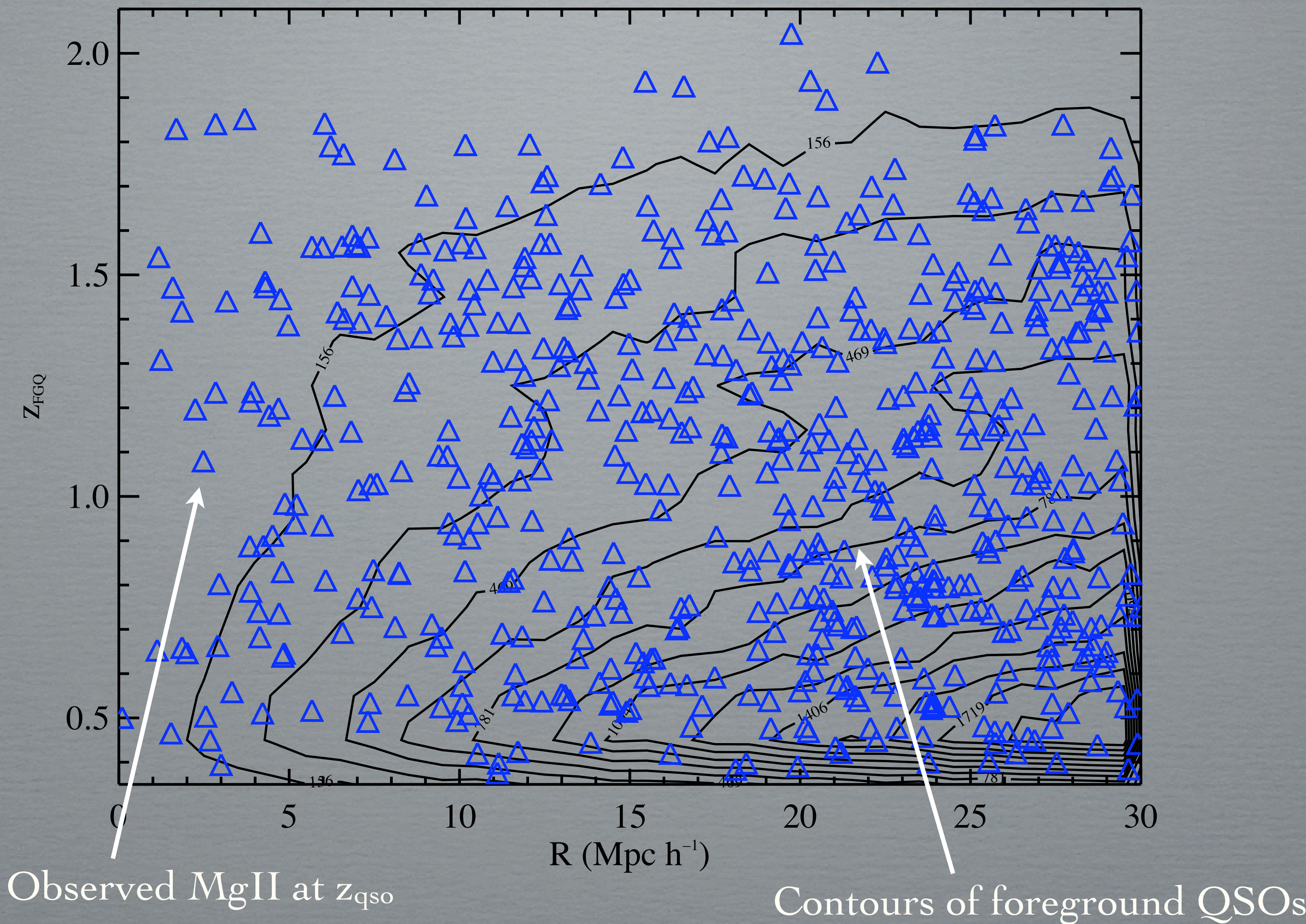
dN/dX of MgII

- *dN/dX*
  - Number of absorbers per unit cosmological distance
    - Assume LCDM
  - Proportional to the number density times cross-section
    - $dN/dX \sim n\,\sigma$
- Result
  - Minimal evolution at z>1
    - Suggests the number density is not significantly evolving
  - M < 10^{12} Msol
    - Press-Schecter argument



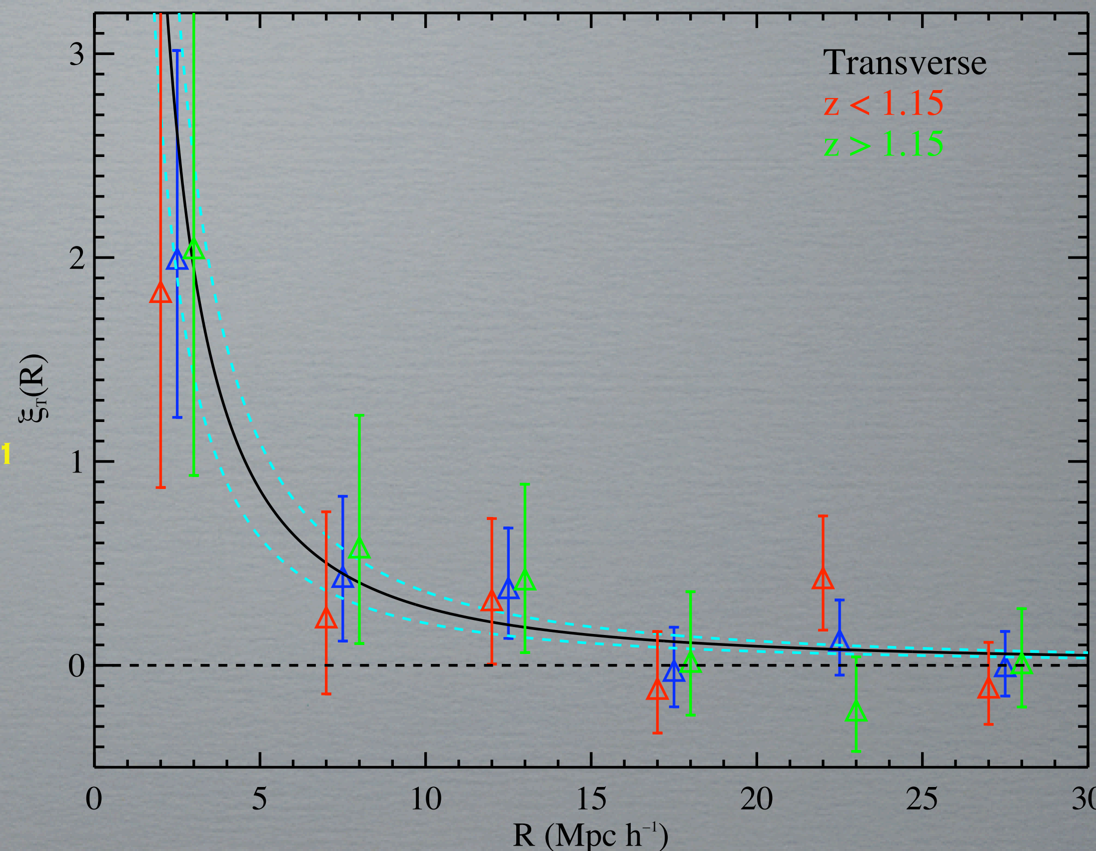
Prochter, Prochaska, & Burles (2006)

MgII-QSO Pairs (Transverse)

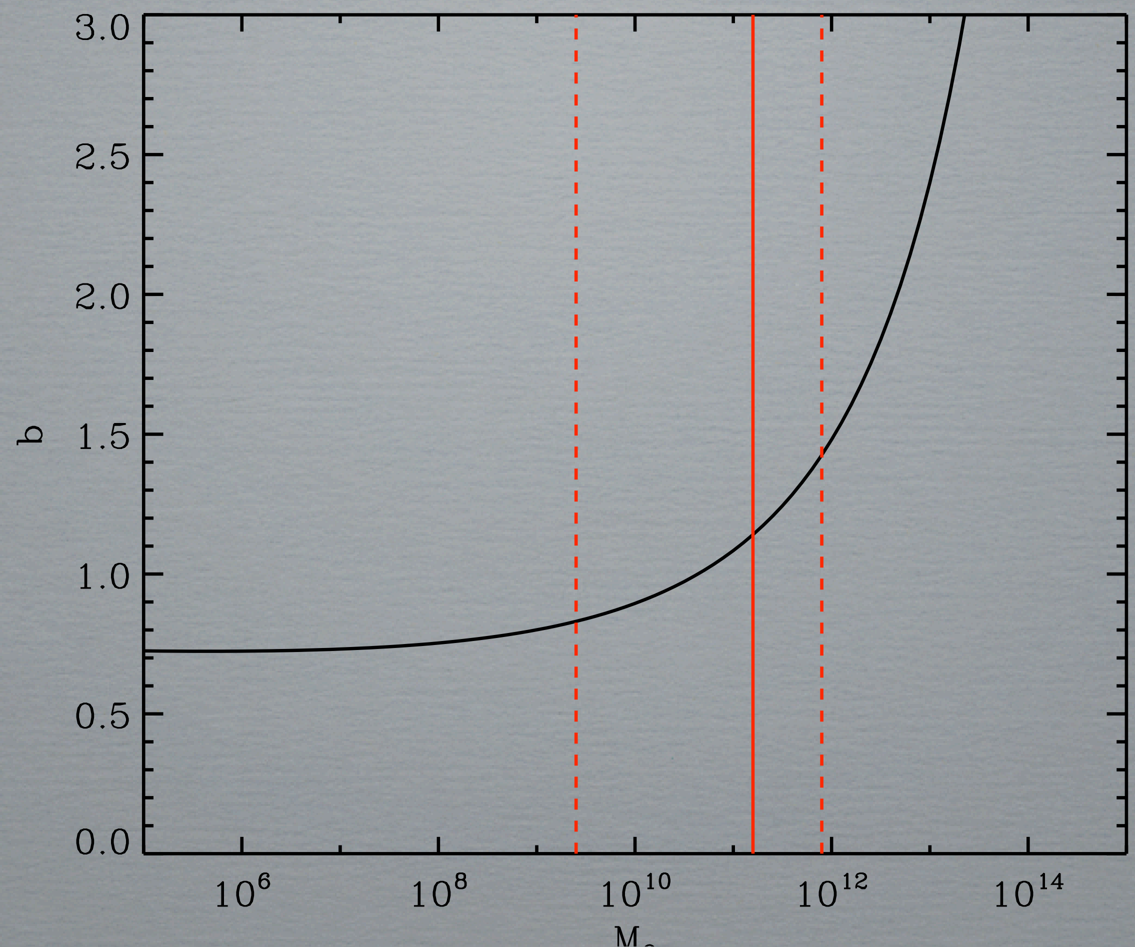


MgII-QSO Clustering (Trans.)

- Correlation func.
  - ✦ $\xi_T = (R/R_0)^\gamma$
  - ✦ Assume $\gamma = -1.6$
- Results
  - ✦ $R_0 = 4.55 \pm 0.8$ Mpc h^{-1}
    - QSO-QSO: $R_0 = 5$ Mpc h^{-1}
    - LBG-LBG: $R_0 = 3$ Mpc h^{-1}
  - ✦ No significant redshift evolution



MgII-QSO Clustering (Mass)

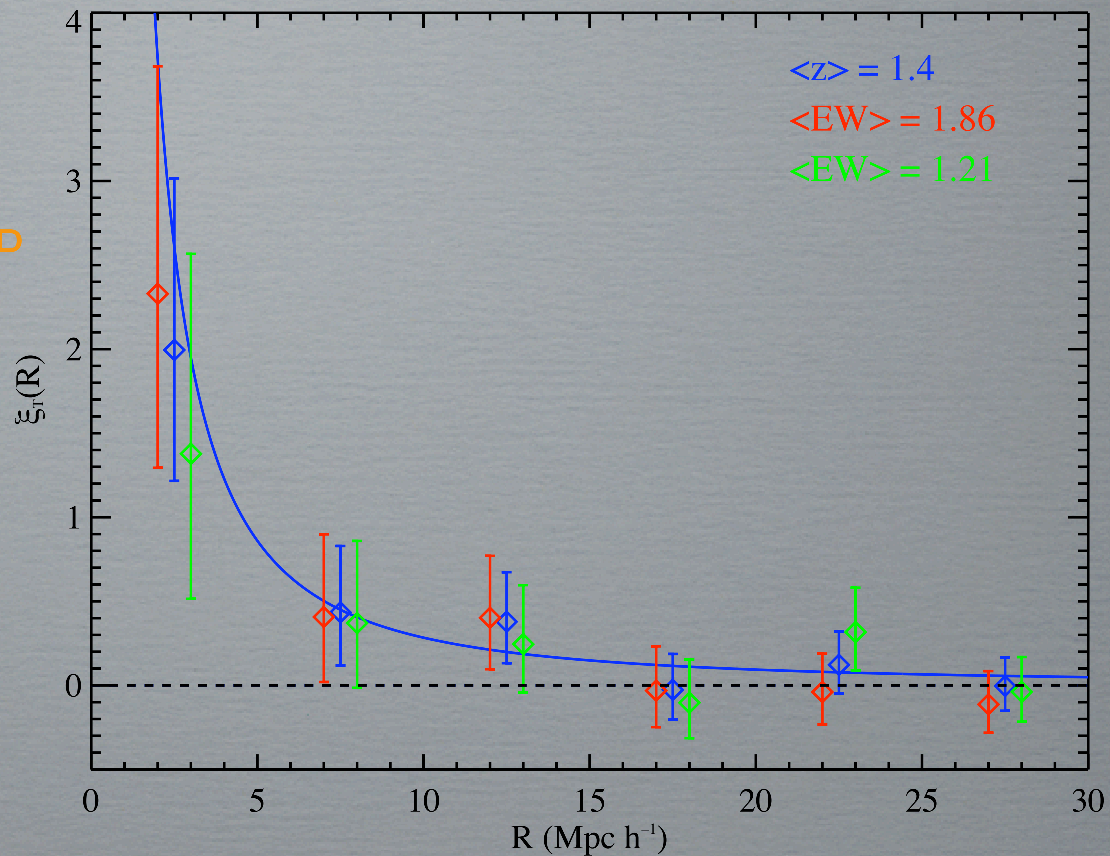


$\xi_T = b_{Mg}\, b_{qso}\, \xi_{DM}$

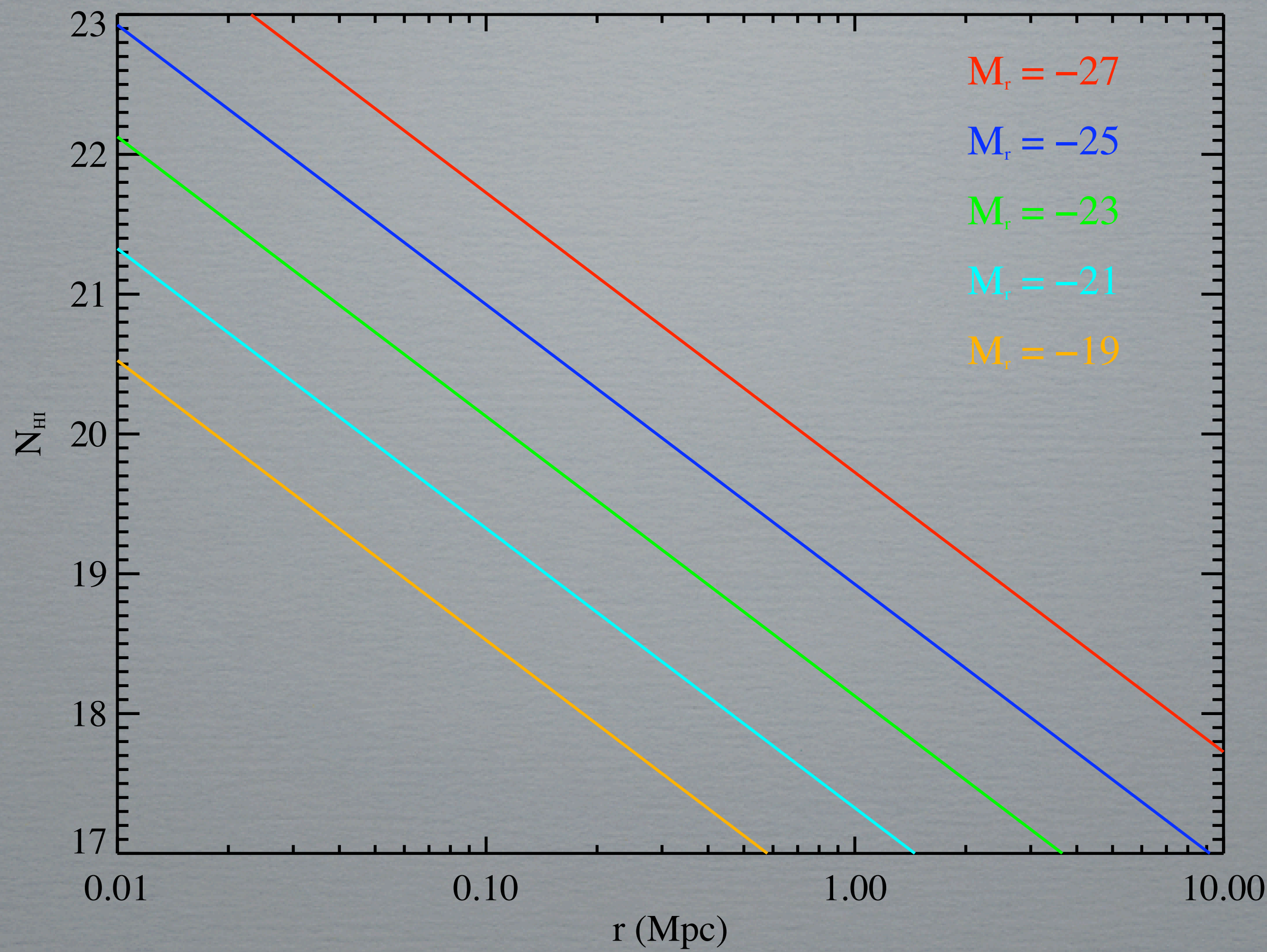
Mo & White formalism

MgII-QSO Clustering (EW)

- Cut on MgII EW
  - Equivalent Width
    - Driven by velocity field of MgII gas
  - Examine mass dependence
- Results
  - No systematic difference
  - Contradicts results from LRG (Bouche)?



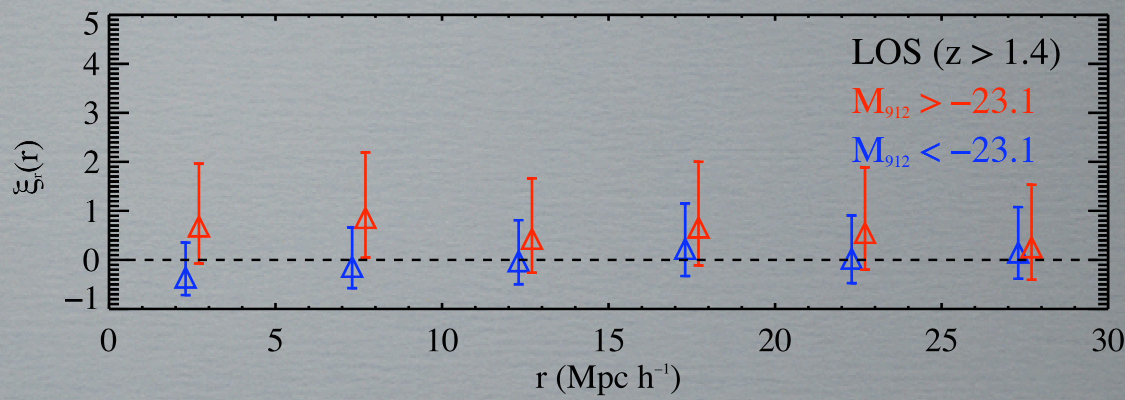
QSO Proximity Effect

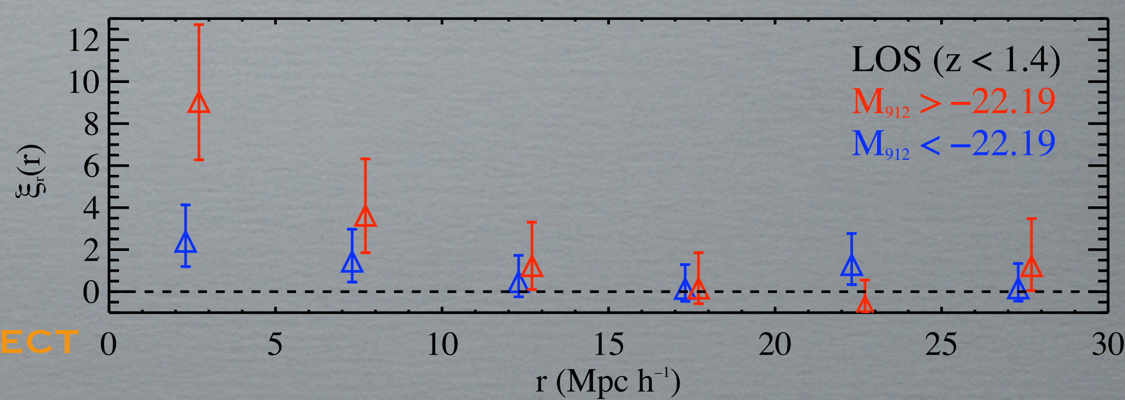


Photoevaporation of clouds (Bertoldi 1989)

MgII-QSO Clustering (Radial)

- Radial clustering
  - Complicated by QSO redshift error
    - Corrected to MgII emission
    - 300 km/s uncertainty
- Results
  - z<1.4
    - Stronger signal in fainter QSOs
    - Clear proximity effect
  - z>1.4
    - Absence of signal indicates proximity effect





MgII-QSO Summary

- SDSS Sample
  - Supplemented by 2QZ
  - Automated MgII search
- Transverse clustering
  - R_0 = 4.55 +/- 0.8 Mpc h^{-1}
    - No redshift dependence
    - No EW dependence
  - Suggests mass of ~ 10^{12} Msol
    - Crude estimate, but one of the best now available
- Line-of-sight clustering
  - Minimal enhancement
    - Less enhancement for brighter QSOs
  - Proximity effect for optically thick absorbers
    - Enhancement of CIV, NV?

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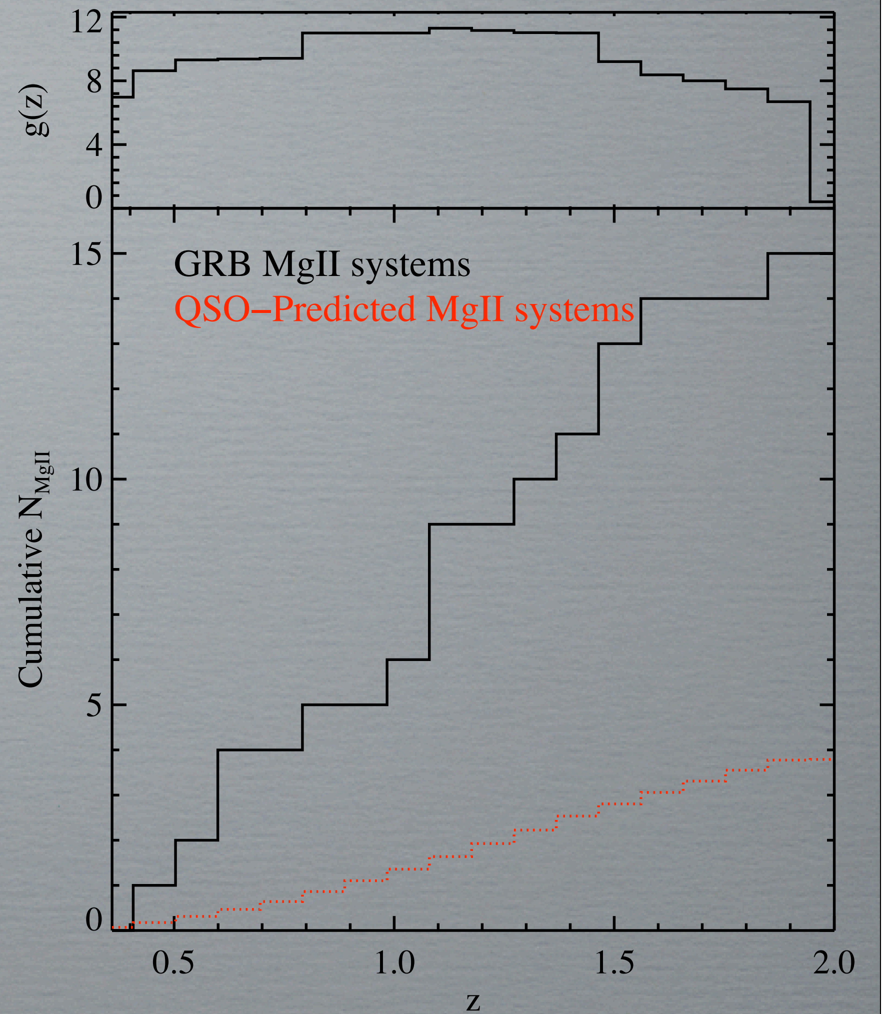


Prochter et al. (2006)

MgII: GRB vs QSO

ON THE INCIDENCE OF STRONG MG II ABSORBERS ALONG GRB SIGHTLINES

G.E. Prochter[1], J.X. Prochaska[1], H.-W. Chen[2], J. S. Bloom[3], M. Dessauges-Zavadsky[4], R. J. Foley[3], M. Pettini[5], A. K. Dupree[6], P. Guhathakurta[1]

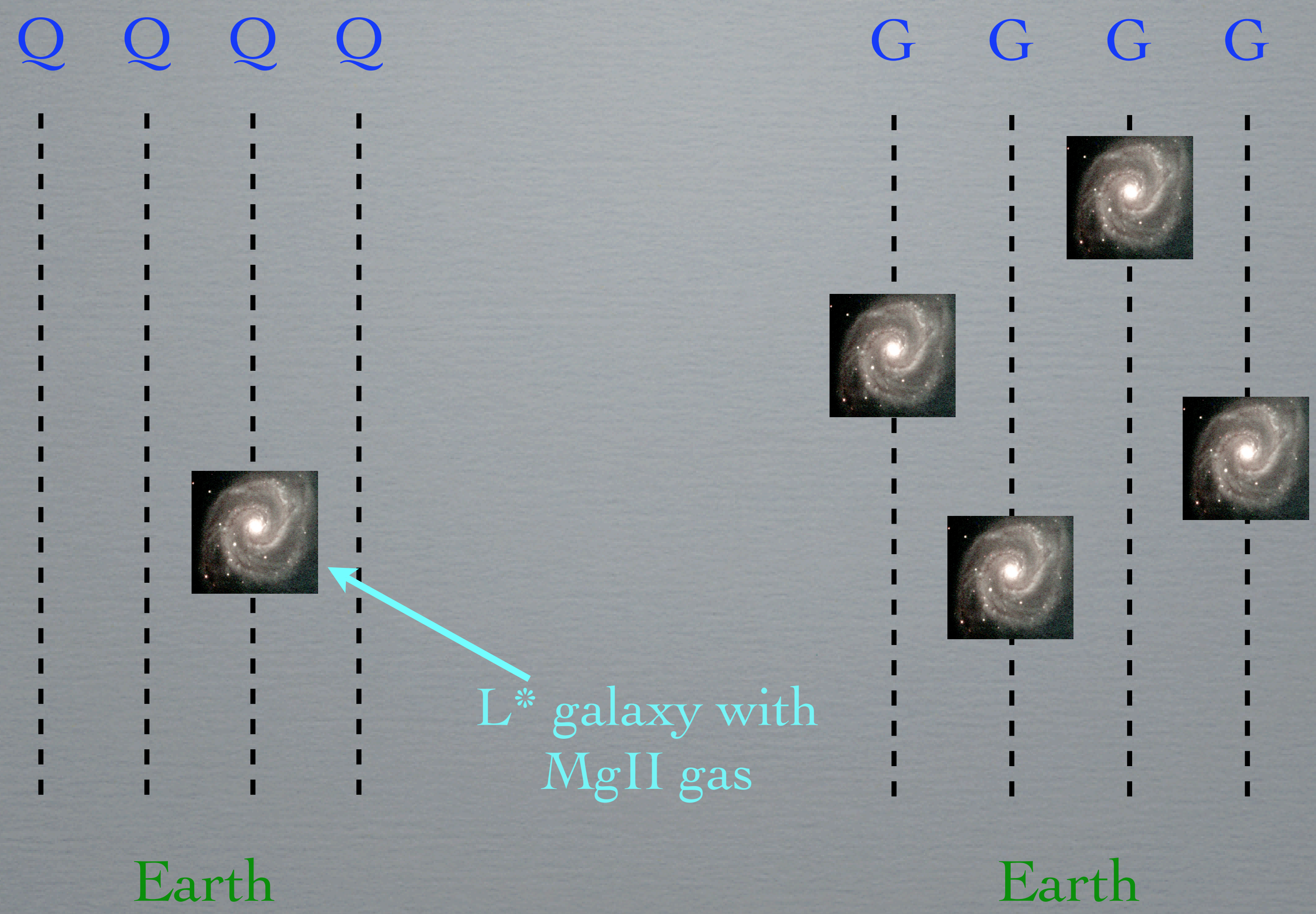
Submitted to ApJL

ABSTRACT

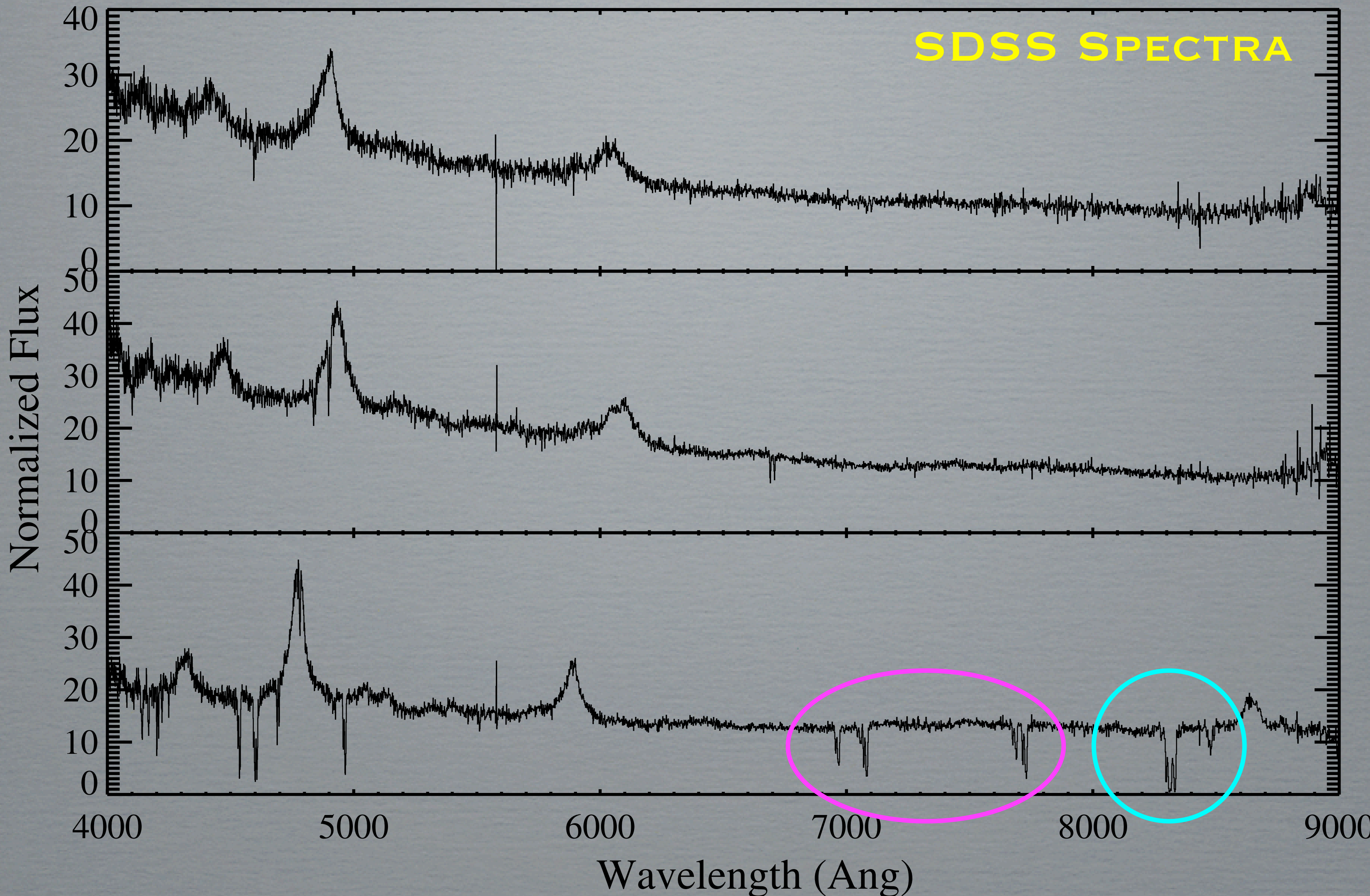
We report on a survey for strong (rest equivalent width $W_r \geq 1$Å), intervening Mg II systems along the sightlines to long-duration gamma-ray bursts (GRBs). The GRB spectra which comprise the survey have a heterogeneous mix of resolution and wavelength coverage, but we implement a strict, uniform set of search criteria to derive a well-defined statistical sample. We identify 15 strong Mg II absorbers along 12 GRB sightlines (nearly every sightline exhibits at least one absorber) with spectra covering a total pathlength $\Delta z = 13.8$ at a mean redshift $\bar{z} = 1.1$. In contrast, the predicted incidence of such absorber systems along the same path length to quasar sightlines is only 3.4. The roughly four times higher incidence along GRB sightlines is inconsistent with a statistical fluctuation at greater than 99.9% c.l. Several effects could explain the result: (i) dust within the Mg II absorbers obscures faint quasars giving a lower observed incidence along quasar sightlines; (ii) the gas is intrinsic to the GRB event; (iii) the GRB are gravitationally lensed by these absorbers. We present strong arguments against the first two effects and also consider lensing to be an unlikely explanation. The results suggest that at least one of our fundamental beliefs on absorption line research is flawed.

Subject headings: gamma rays: bursts

MgII Result for non-QAL Folks



MgII Search in QSO Spectra



dN/dz of MgII

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  - Number of absorbers per unit redshift
  - Roughly, 1 QSO has 1 unit of redshift coverage
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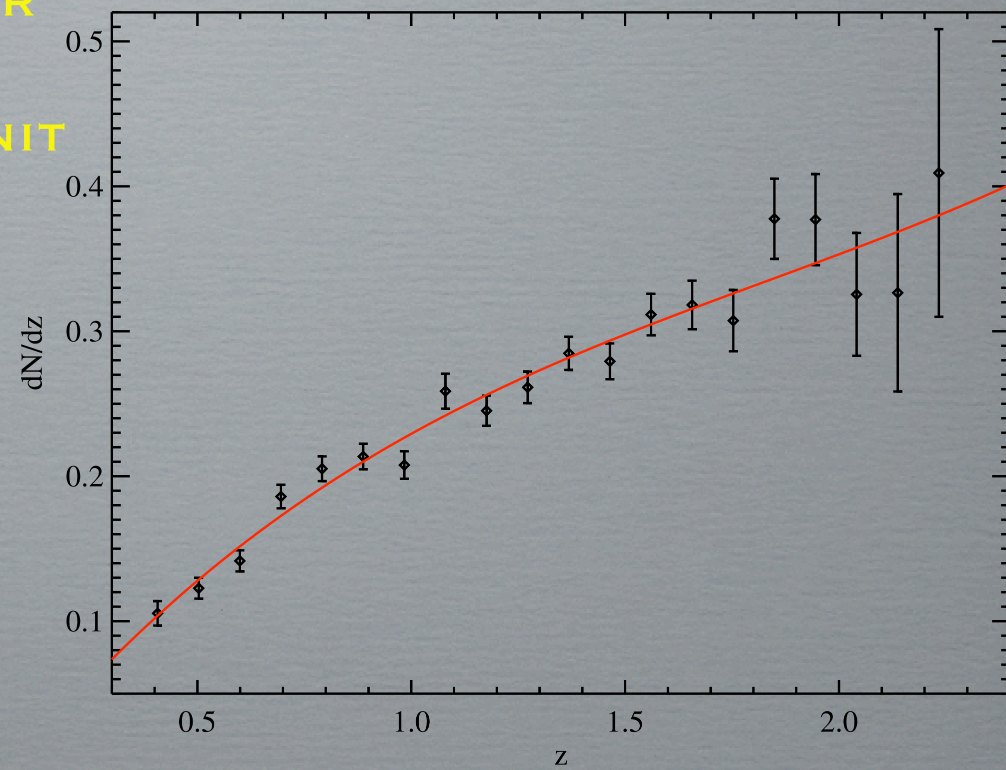
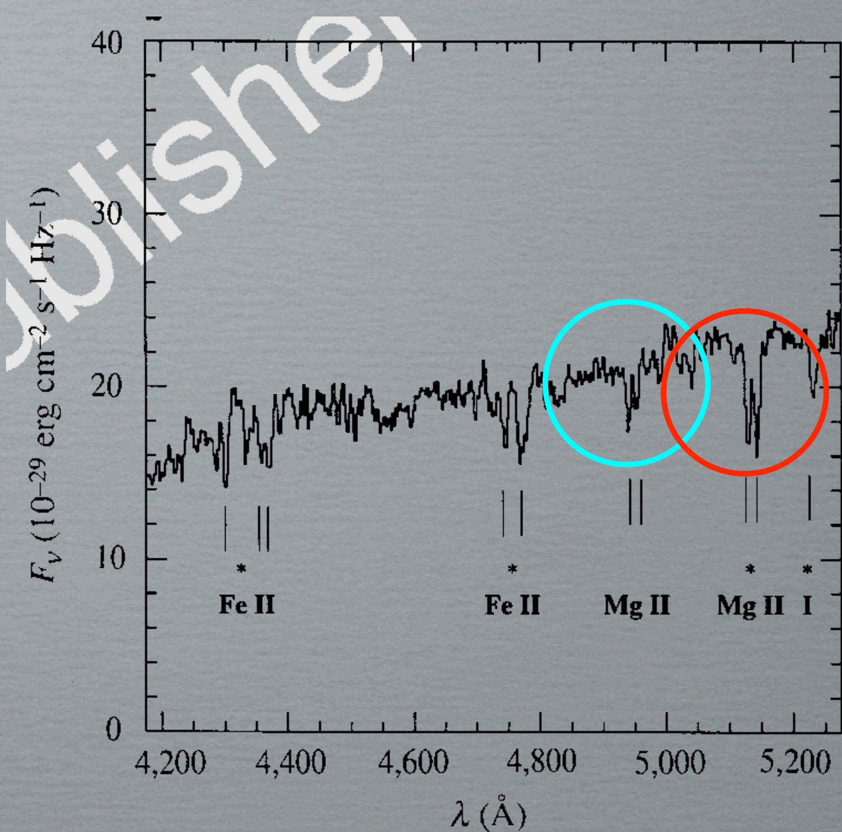
  - 20,000 quasars with sufficient SNR
    - Automatically identify 10,000 MgII systems
    - Stat sample is 7000 with Rest EW > 1A



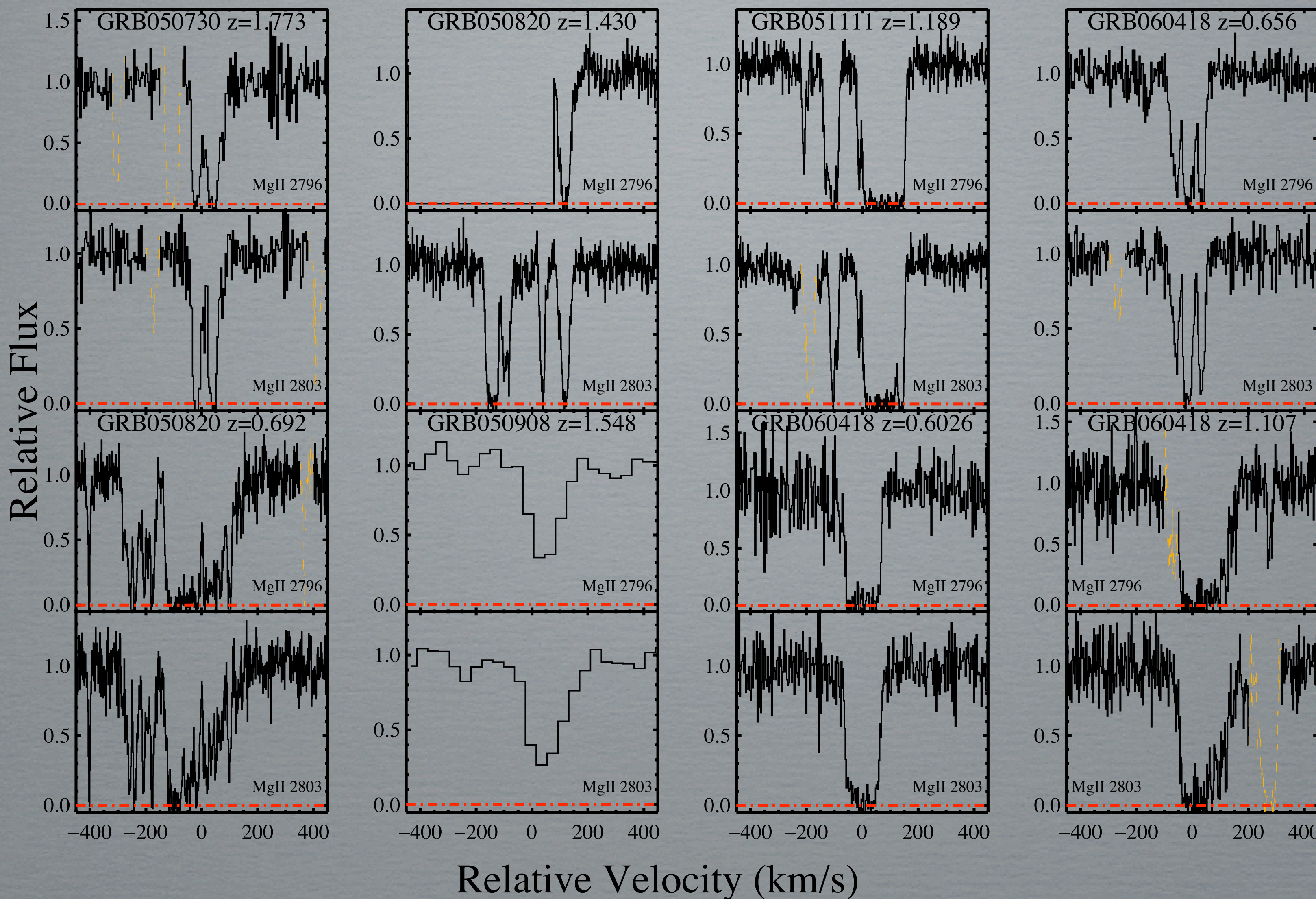
Prochter, Hennawi, Prochaska (submitted)

GRB MgII

- MgII
  - Often establishes the GRB redshift (z<2.5)
    - Rest EW > 2A in most cases
- Intervening MgII
  - Easy to identify
    - Even with low-res data
  - Limited to large EW systems in many cases
- GRB 970508
  - Even an example in the first optical spectrum



GRAASP Swift Sample

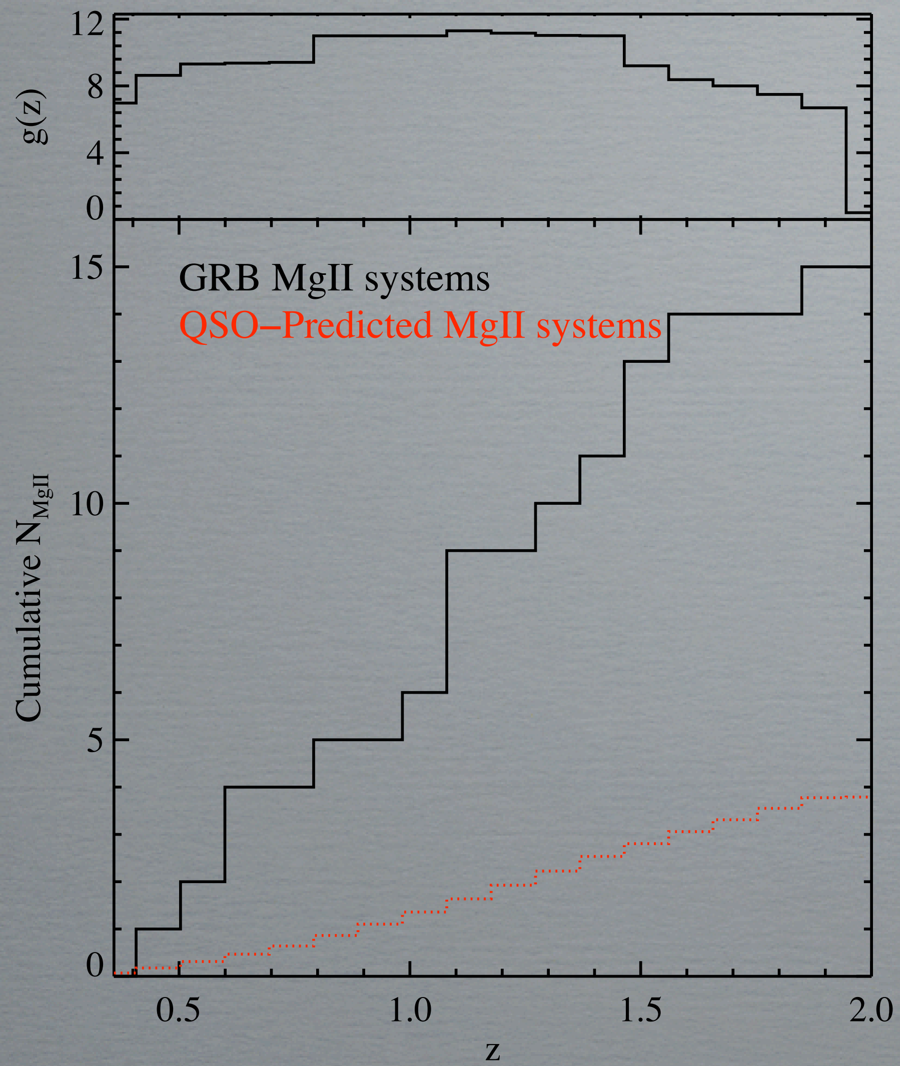


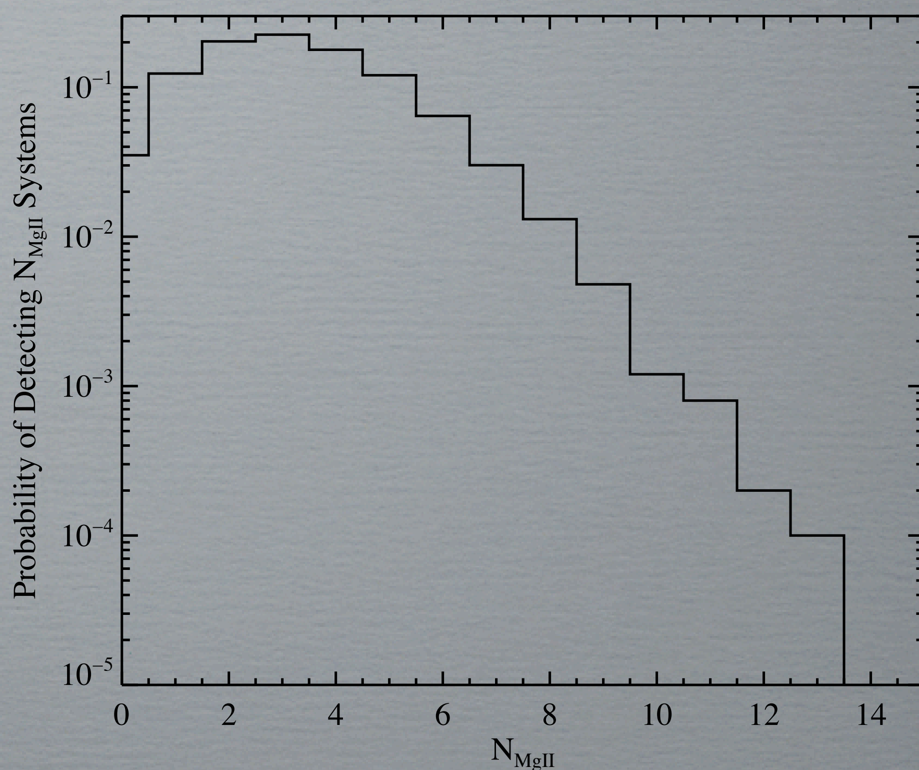
GRB MgII Sample

Table 1. Survey Data for Mg II Absorbers Along GRB Sightlines

GRB	z_{GRB}	z_{start}	z_{end}	z_{abs}	W_r(2796 Å)	Δv (km s^{-1})	Reference
$W_r(2796) \geq 1$ Å Mg II Statistical Sample							
000926	2.038	0.616	2.0				8
010222	1.477	0.430	1.460	0.927	1.00 ± 0.14	74,000	1
				1.156	2.49 ± 0.08	41,000	
011211	2.142	0.359	2.0				2
020405	0.695	0.359	0.684	0.472	1.1 ± 0.3	65,000	11
020813	1.255	0.359	1.240	1.224	1.67 ± 0.02	4,000	3
021004	2.328	0.359	2.0	1.380	1.81 ± 0.3	97,000	4
				1.602	1.53 ± 0.3	72,000	
030226	1.986	0.359	1.966				
030323	3.372	0.824	1.646				7
050505	4.275	1.414	2.0	1.695	1.98	176,000	6
050730	3.97	1.194	2.0				
050820	2.6147	0.359	1.850	0.692	2.877 ± 0.021	192,000	
				1.430	1.222 ± 0.036	113,000	
050908	3.35	0.814	2.0	1.548	1.336 ± 0.107	147,000	
051111	1.55	0.488	1.533	1.190	1.599 ± 0.007	45,000	
060418	1.49	0.359	1.473	0.603	1.251 ± 0.019	124,000	
				0.656	1.036 ± 0.012	116,000	
				1.107	1.876 ± 0.023	50,000	

Statistically Solid Result





Possible Explanations

- Dust obscuration?
  - MgII absorbers contain dust
    - Could remove quasars from a magnitude limited sample
    - Underestimate *dN/dz*
  - But, dust content is low
    - Effect is small
- Gas is Intrinsic to the GRB?
  - v > 100,000 km/s !
  - Galaxies have been identified
- Gravitational lensing?
  - One MgII per sightline
    - Double lens enhancement
  - But, flux counts are flat
    - No GRB pairs?
- Beam size? (Frank et al.)
  - Very unlikely

Bizzare (fundamental?) result

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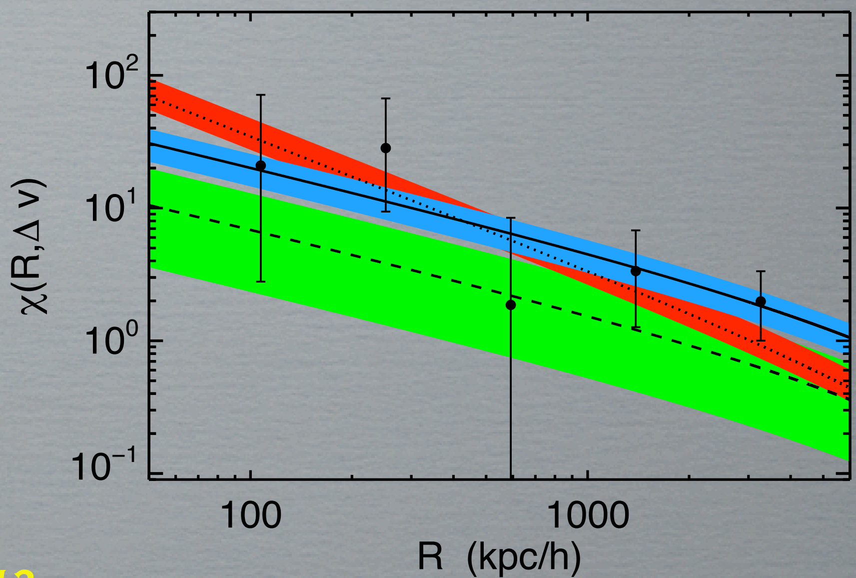
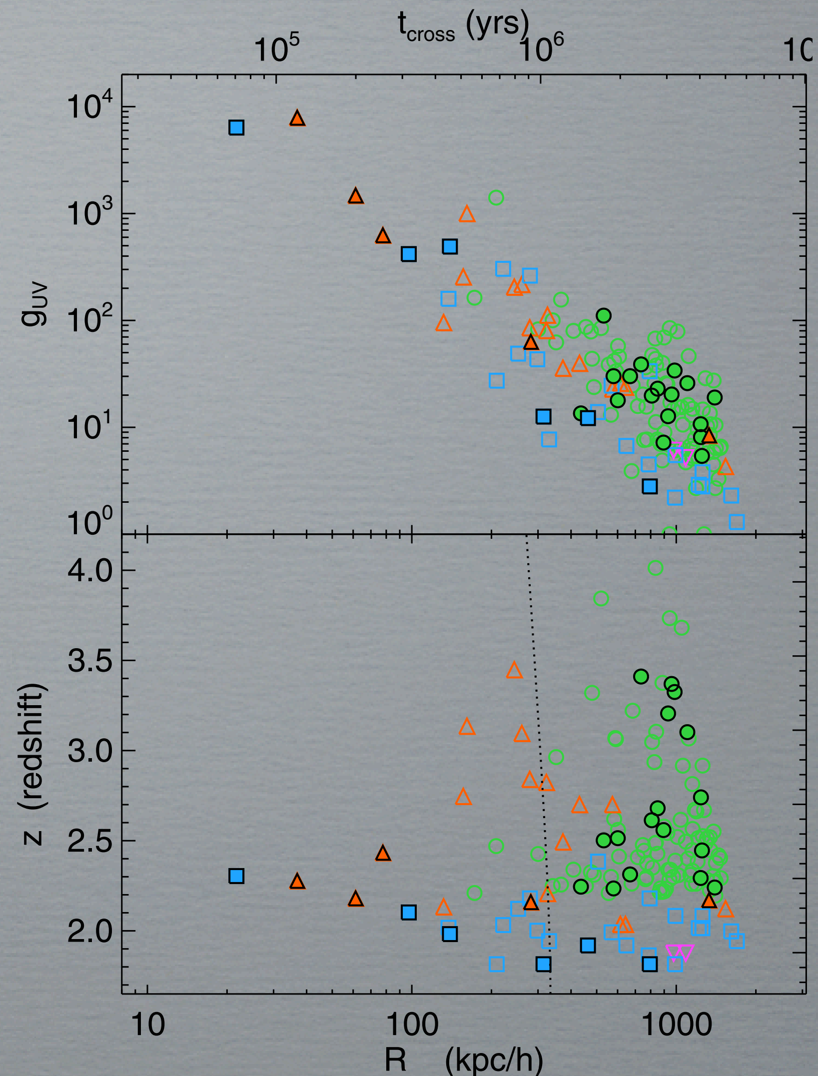


Hennawi & Prochaska (2006)

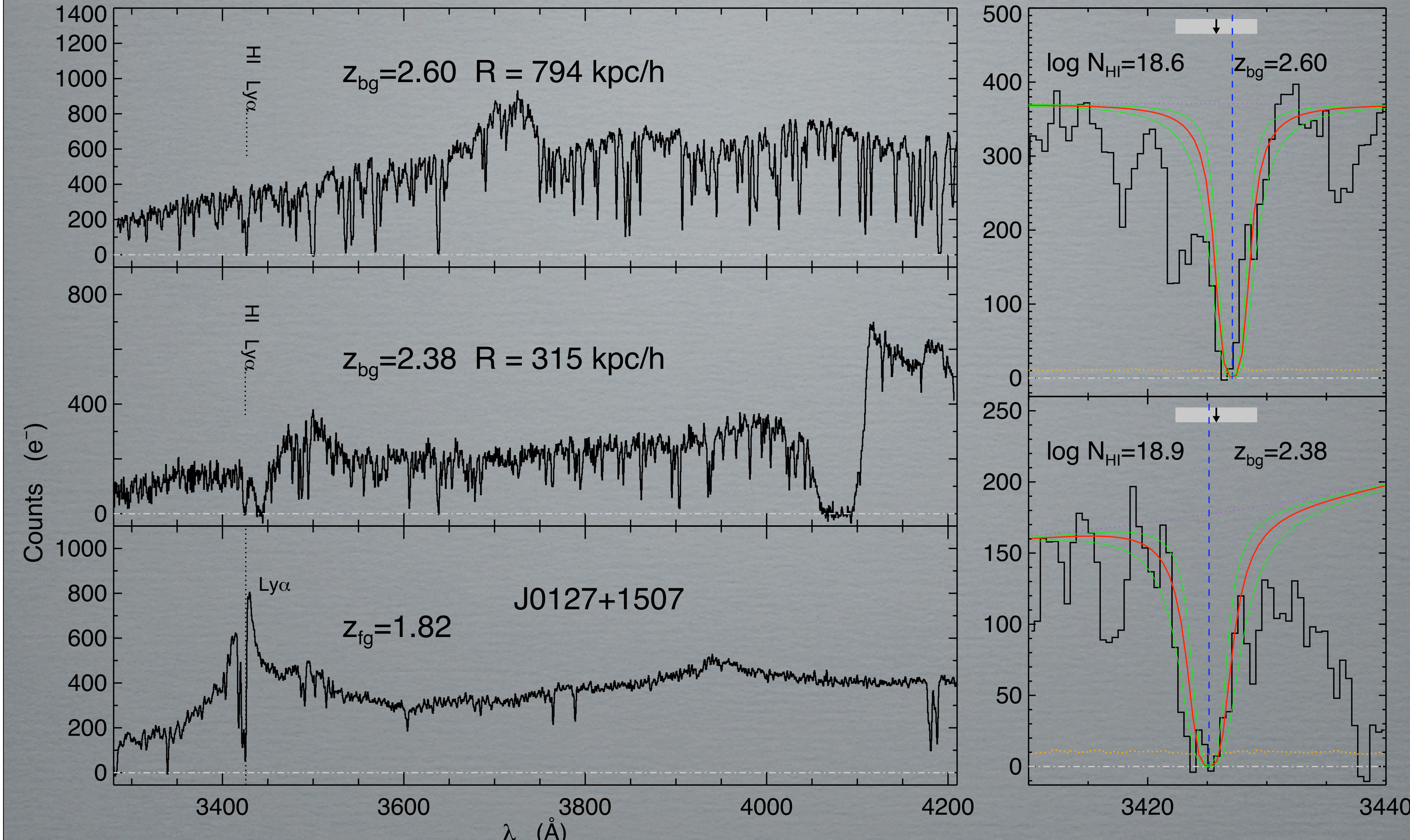
QSO-LLS Pairs

- SDSS Quasars
  - Standard identification
  - FWHM=2A spectra
- QSO Pairs
  - SDSS photomotery
    - APO follow-up
  - 2DF QSO's too
- Follow-up spectra
  - Keck, Gemini
    - FWHM ~ 2A resolution
    - SNR > 5 per pixel
- Identify HI absorbers
  - $N_{HI} > 10^{17}$ cm^{-2}



Hennawi et al. (2006)

Sample Spectra



Hennawi et al. (2006)

$N_{HI} > 10^{19}$ Sample

TABLE 1
Super-LLSs Near Quasars from QPQ1

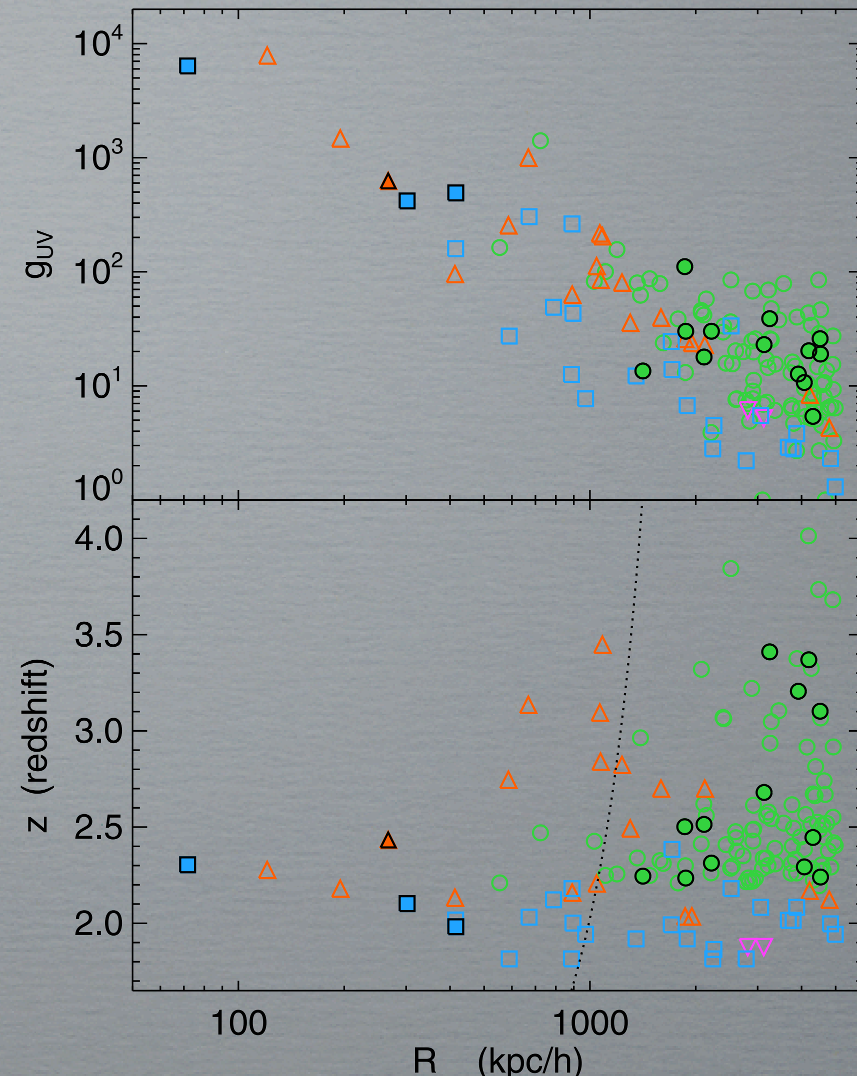
Name	z_{bg}	z_{fg}	$\Delta\theta$ ($''$)	R (h^{-1} kpc)	z_{abs}	$\|\Delta v\|$ (km s^{-1})	Δv_{fg} (km s^{-1})	$\log N_{HI}$ (cm^{-2})	g_{UV}	Telescope
SDSSJ0225−0739	2.99	2.440	214.0	4310	2.4476	690	500	19.55 ± 0.2	5	SDSS
SDSSJ0239−0106	3.14	2.308	3.7	72	2.3025	540	1500	20.45 ± 0.2	6369	Keck
SDSSJ0256+0039	3.55	3.387	179.0	4195	3.387	20	1000	19.25 ± 0.25	20	SDSS
SDSSJ0338−0005	3.05	2.239	73.5	1415	2.2290	960	1500	20.9 ± 0.2	13	SDSS
SDSSJ0800+3542	2.07	1.983	23.1	415	1.9828	40	300	19.0 ± 0.15	488	Keck
SDSSJ0833+0813	3.33	2.516	103.4	2112	2.505	980	1000	19.45 ± 0.3	18	SDSS
SDSSJ0852+2637	3.32	3.203	170.9	3917	3.211	550	1500	19.25 ± 0.4	13	SDSS
SDSSJ1134+3409	3.14	2.291	209.2	4073	2.2879	320	500	19.5 ± 0.3	11	SDSS
SDSSJ1152+4517	2.38	2.312	113.4	2216	2.3158	370	500	19.1 ± 0.3	30	SDSS
SDSSJ1204+0221	2.53	2.436	13.3	267	2.4402	370	1500	19.7 ± 0.15	625	Gemini
SDSSJ1213+1207	3.48	3.411	137.8	3246	3.4105	30	1500	19.25 ± 0.3	39	SDSS
SDSSJ1306+6158	2.17	2.111	16.3	302	2.1084	200	300	20.3 ± 0.15	420	Keck
SDSSJ1312+0002	2.84	2.671	148.5	3129	2.6688	200	500	20.3 ± 0.3	23	SDSS
SDSSJ1426+5002	2.32	2.239	235.6	4529	2.2247	1330	500	20.0 ± 0.15	19	SDSS
SDSSJ1430−0120	3.25	3.102	200.0	4517	3.115	960	1500	20.5 ± 0.2	26	SDSS
SDSSJ1545+5112	2.45	2.240	97.6	1873	2.243	320	500	19.45 ± 0.3	30	SDSS
SDSSJ1635+3013	2.94	2.493	91.4	1861	2.5025	820	500	> 19	111	SDSS

Note. — Optically thick absorption line systems near foreground quasars. The background and foreground quasar redshifts are denoted by z_{bg} and z_{fg}, respectively. The angular separation of the quasar pair sightlines is denoted by $\Delta\theta$, which corresponds to a transverse comoving separation of R at the foreground quasar redshift. Absorber redshift is indicated by z_{abs}, and $|\Delta v|$ is the velocity difference between the absorber redshift and our best estimate of the redshift of the foreground quasar. Our estimated error on the foreground quasar redshift is denoted by Δv_{fg}. Foreground quasar redshifts and redshift errors were estimated according to the detailed procedure described in § 4 of QPQ1. The logarithm of the column density of the absorber from a fit to the H I profile is denoted by $\log N_{HI}$. The column labeled "Telescope" indicates the instrument used to observe the background quasar. The quantity $g_{UV} = 1 + F_{QSO}/F_{UVB}$ is the maximum enhancement of the quasars ionizing photon flux over that of the extragalactic ionizing background at the location of the background quasar sightline, assuming that the quasar emission is isotropic (see Appendix A of QPQ1). We compare to the UV background computed by F. Haardt & P. Madau (2006, in preparation)

Hennawi & Prochaska (2006)

$N_{HI} > 10^{19}$ Sample

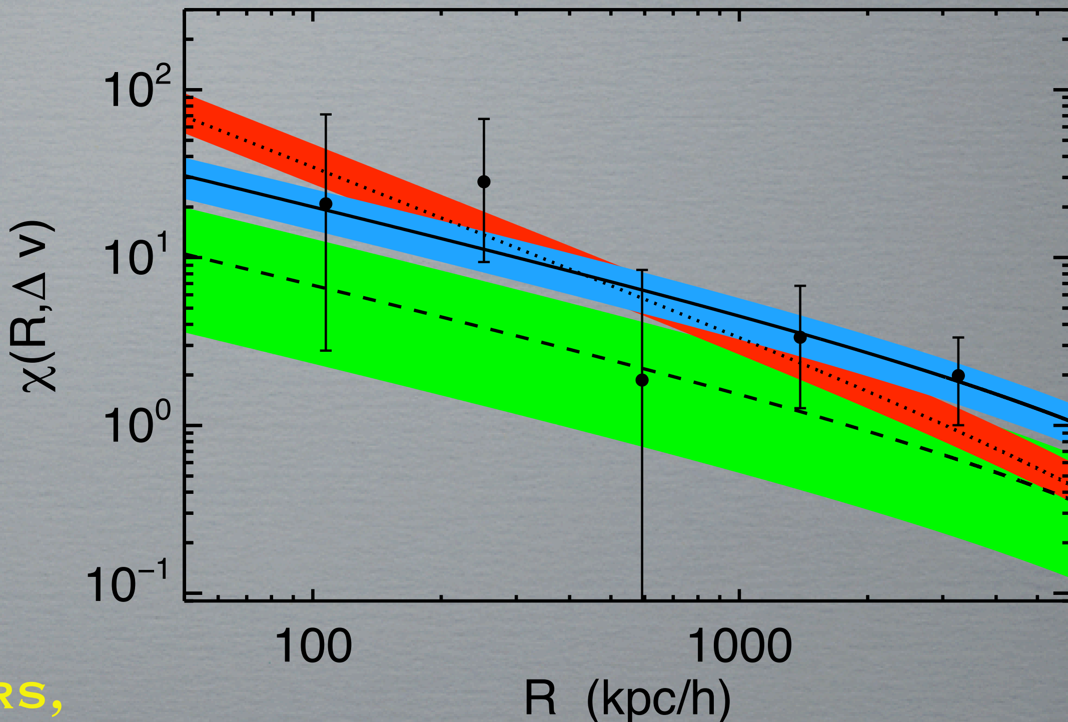
- Absorbers
  - ✦ $N_{HI} > 10^{19}$ cm^{-2}
  - ✦ Malmquist bias may be important
    - Line blending
    - Control by removing systems with $N_{HI} \sim 10^{19}$ cm^{-2}
- Quasars
  - ✦ SDSS
  - ✦ 2QZ
  - ✦ APO sample



Hennawi & Prochaska (2006)

Clustering Result

- Correlation func.
  - $\chi = (R/R_o)^{\gamma}$
  - Assume
    - γ = -1.6 (Blue)
    - γ = -2 (Red)
- Results
  - R_o = 9.2 +/- 1.5 Mpc h^{-1}
    - LBG-LBG: Green
  - R_o = 5 for γ = -2
  - In the transverse direction from quasars, the presence of strong Lya is enhanced

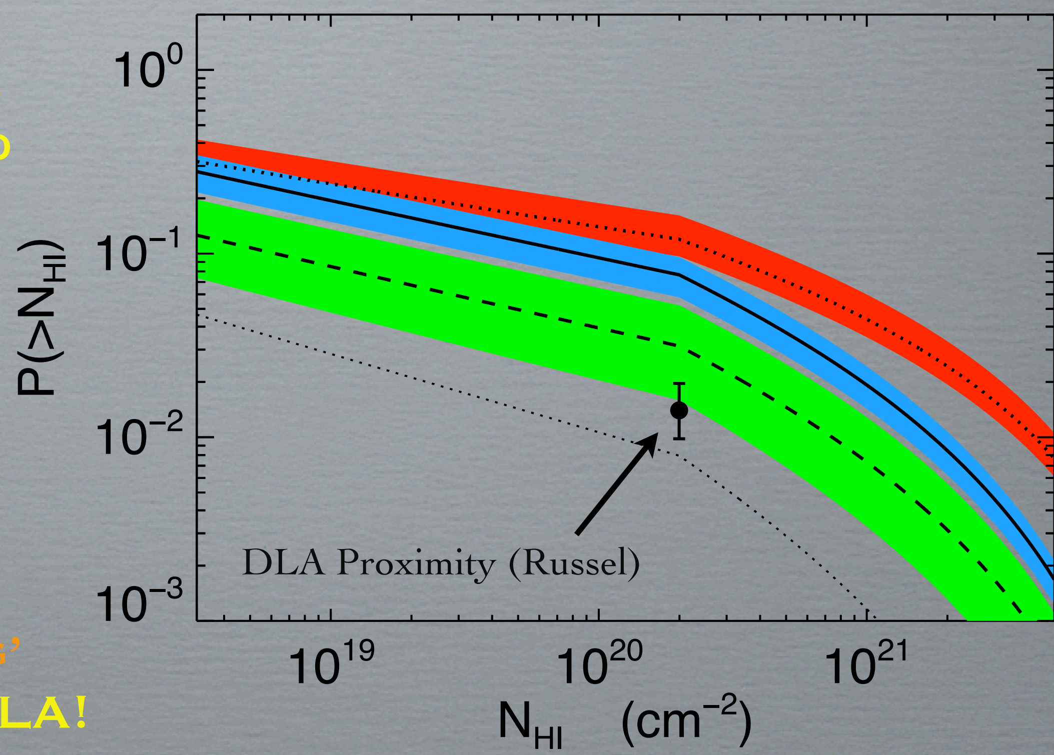


Hennawi & Prochaska (2006)

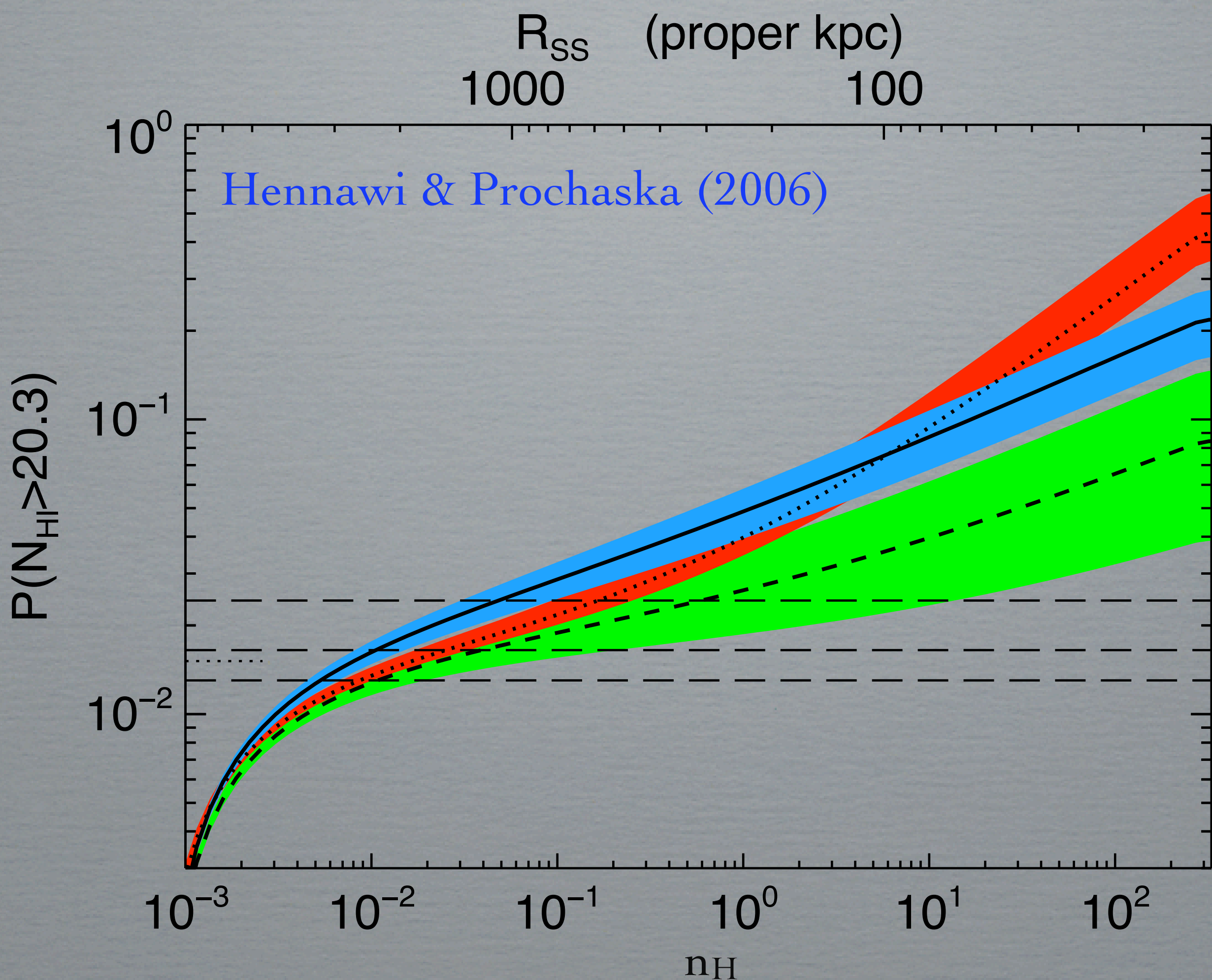
Clustering Anisotropy

- Line-of-sight
  - Probability of intersecting an absorber
    - Dependent on size
    - Project clustering func.
  - Compare with observed rate
- Results
  - Proximate DLAs
    - 2x enhancement
    - Russel et al. (2006)
  - Our prediction
    - >5x enhancement
    - At least 50% are 'missing'
  - Proximity effect for DLA!
    - Implies typical volume density of n_{HI} = 10^{-1} cm^{-3}

Hennawi & Prochaska (2006)

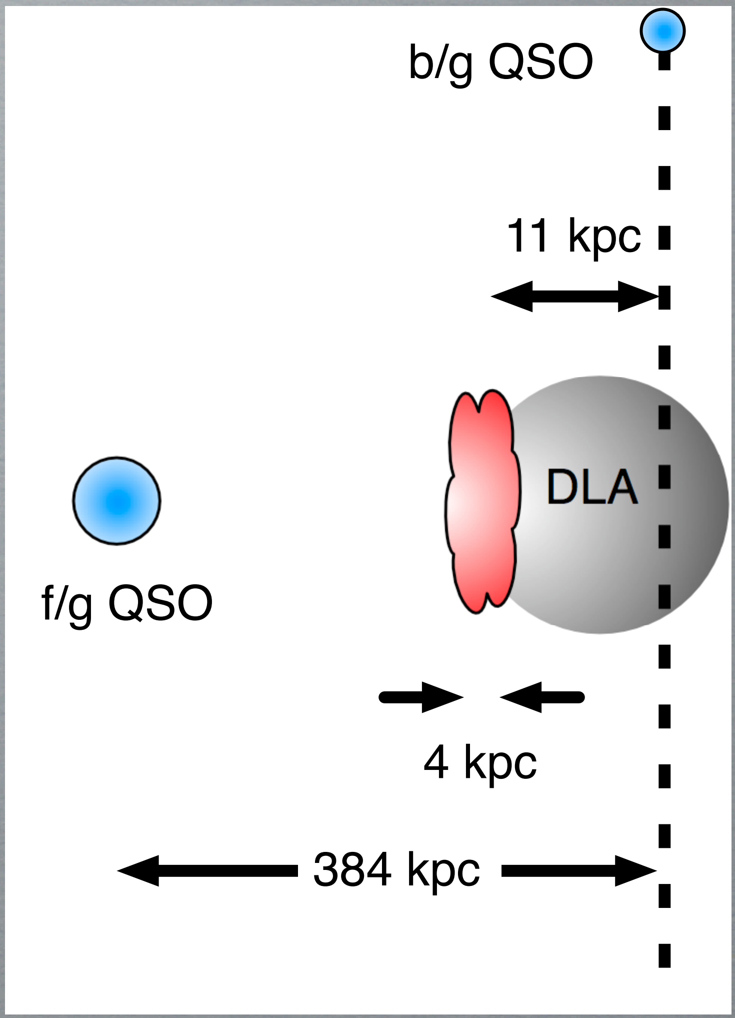


DLA Density Estimate



QSO Flourescence

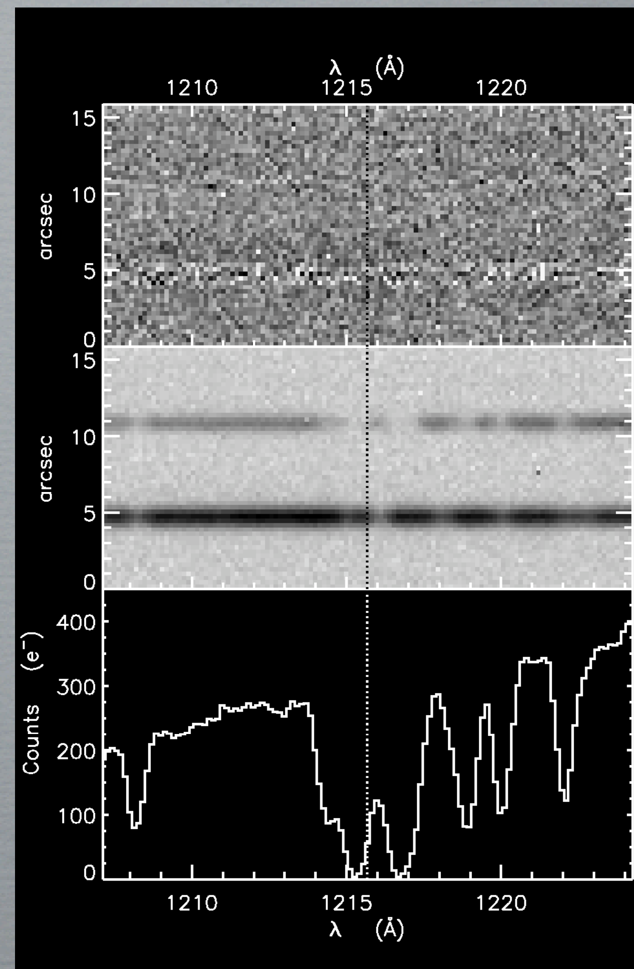
- QSO ionizes outer skin
  - Gas recombines
  - 60% of the QSO radiation is emitted in Lya
    - Relatively high surface brightness
- Investigate
  - QSO emission
    - Anisotropy
    - Lifetime
  - Absorber size
    - Size/Geometry
    - Volume density



Adelberger et al. (2006)

QSO Flourescence

- g_{UV} = 7900 x UVB
  - Expect Lya = 19.5 / sq”
- Observe
  - Gemini (3hr integration)
  - No unresolved emission
    - QSO anistropy?
    - But, note the intriguing feature in the 1D spectrum
- Future
  - Sample of over 10 flourescence candidates
  - Stay tuned...



Hennawi & Prochaska (in prep)

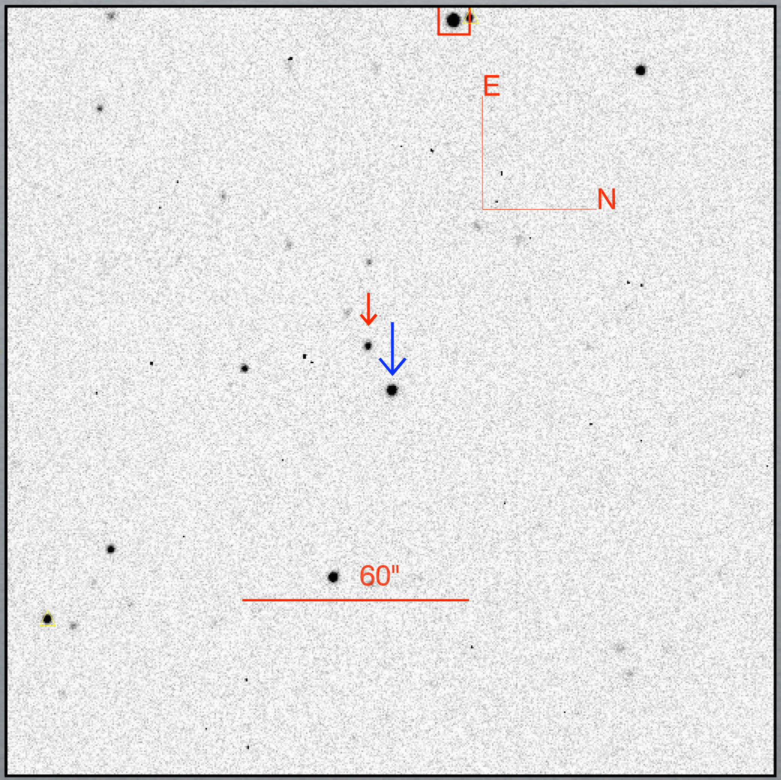
QSO Halo gas

1204+0221

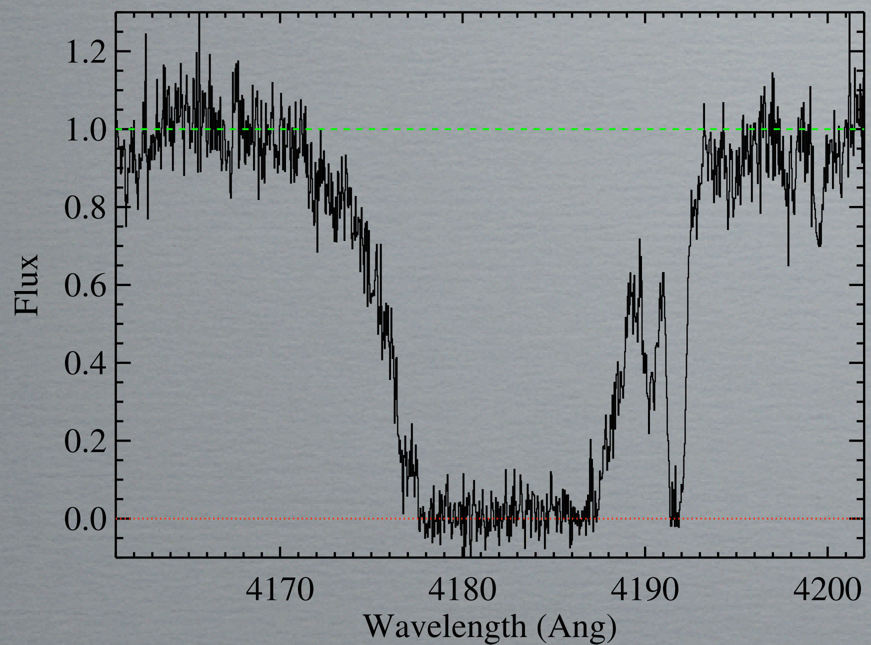
RA=12:04:16.69 DEC=+02:21:11.0

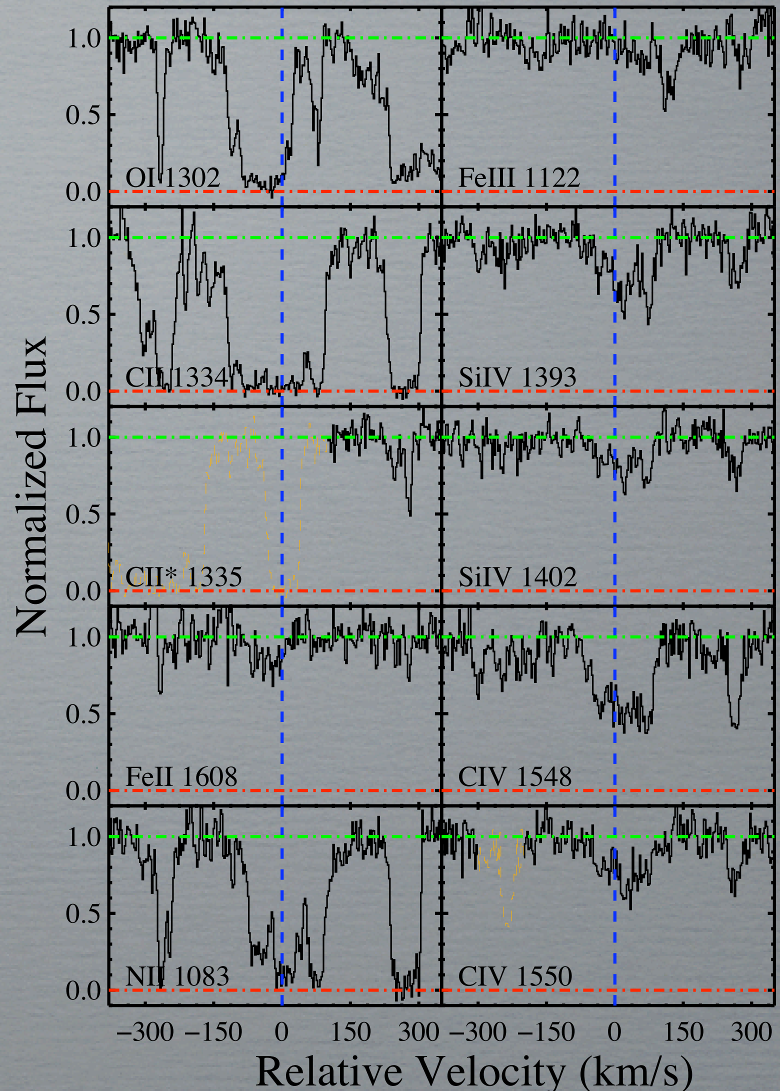
$\Delta\theta$=13.3 α_{pos}=-61.8 Δ_{RA}=-86.0 Δ_{DEC}=-22.8

z=2.53 i_q=19.01 i_p=20.53



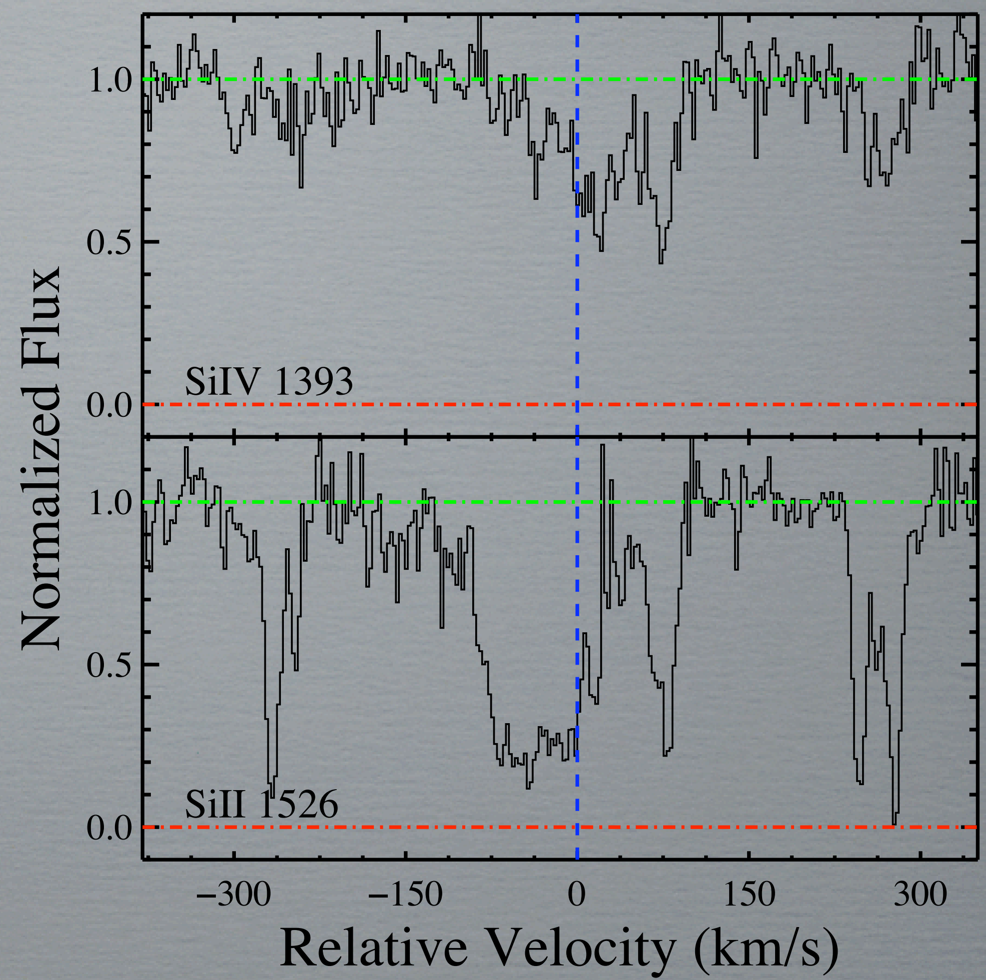
Keck HIRESb Obs.





QSO Halo gas

- **Metallicity**
  - ✦ High: [Si/H] > -0.5
- **Velocity field**
  - ✦ Extreme
  - ✦ Suggestive of outflow
  - ✦ 'Wind' of 100's km/s
- **Ionization state**
  - ✦ Modest: Low SiIV/SiII
  - ✦ But, high NII/NI
  - ✦ Consistent with low UV flux but high X-Ray



QSO-LLS Clustering

- Anistropic clustering
  - Transverse
    - R_0 = 9.2 +/- 1.5 Mpc h^{-1}
  - Proximate prediction
    - Expect one LLS per QSO
    - Observe ~2x increase in DLA
  - Implication: QSO ionization of $N_{HI} > 10^{19}$ absorbers
    - $n_{HI} \sim 10^{-1}$ cm^{-3}
- Other applications
  - Flourescence
    - QSO 'beaming', lifetime
    - Size, geometry
  - High resolution studies
    - Gas kinematics, ionization, metallicity in QSO Halos