

Mg II Absorption through Galaxies at Intermediate Redshift

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Mg II Absorption Studies...

- 1) Spectroscopic Surveys
- 2) Connection to Galaxies

Spectroscopic

UV ($z < 0.1$)

Churchill (2001)

OPTICAL ($0.1 < z < 2.2$)

Lanzetta+ (1987, LTW)

Tytler+ (1987)

Steidel+ (1988, SBS88)

Caulet (1989)

Petitjean & Bergeron (1990, PB90)

Boisse'+ (1992)

Steidel & Sargent (1992, SS92)

Churchill+ (1999)

Churchill & Vogt (2001)

Churchill+ (2003)

Nestor+ (2005)

Procter+ (2005)

IR ($2.2 < z < 4.5$)

Elston+ (1994)

Kobayashi+ (in prep, IRCS/Subaru)

Connection to Galaxies

ESTABLISHMENT

Yanny & York (1990)

Lanzetta & Bowen (1990)

Bergeron & Blosse' (1991, BB91)

Steidel+ (1994, SDP94)

Bowen+ (1995, BBP94)

Steidel (1995, S95)

Guillemin & Bergeron (1997)

Rao & Turnshek (1999)

GAS KINEMATICS

Lanzetta & Bowen (1992)

Churchill+ (1996, CSV96)

Churchill+ (2000a,b)

GALAXY MORPHOLOGES

Steidel+ (1997)

Kacprzak+ (talk today)

GAS/GALAXY KINEMATICS

Steidel+ (2002)

Ellison+ (2003)

Multiphase Ionization and Kinematics

Ding+ (2003)

Charlton+ (2003)

Zonak+ (2004)

Ding+ (2005)



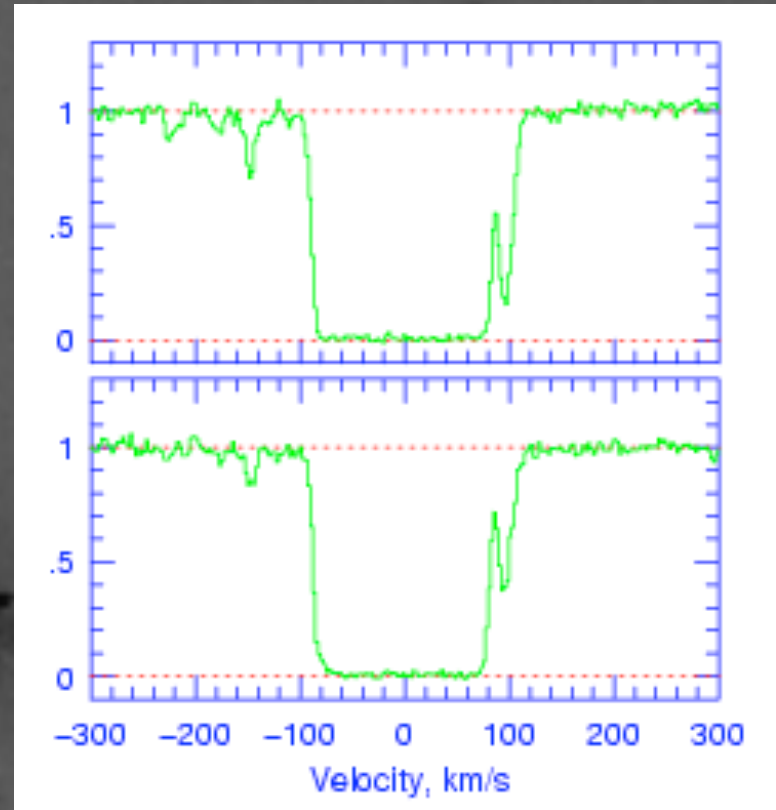
Mg II Absorption Selects...

DLAs: $N(\text{HI}) > 2 \times 10^{20} \text{ cm}^{-2}$

(eg. Le Brun+ 1997; Rao & Tumshak 2000; Churchill+ 2000)

- 0.1 L^* galaxies and LSB galaxies
- Wide range of galaxy morphologies
- Mg II: black-bottom profiles; $\Delta v \sim 200 \text{ km s}^{-1}$
- C IV: average absorption strengths

If you observe...



Mg II Selects Galactic Environments...

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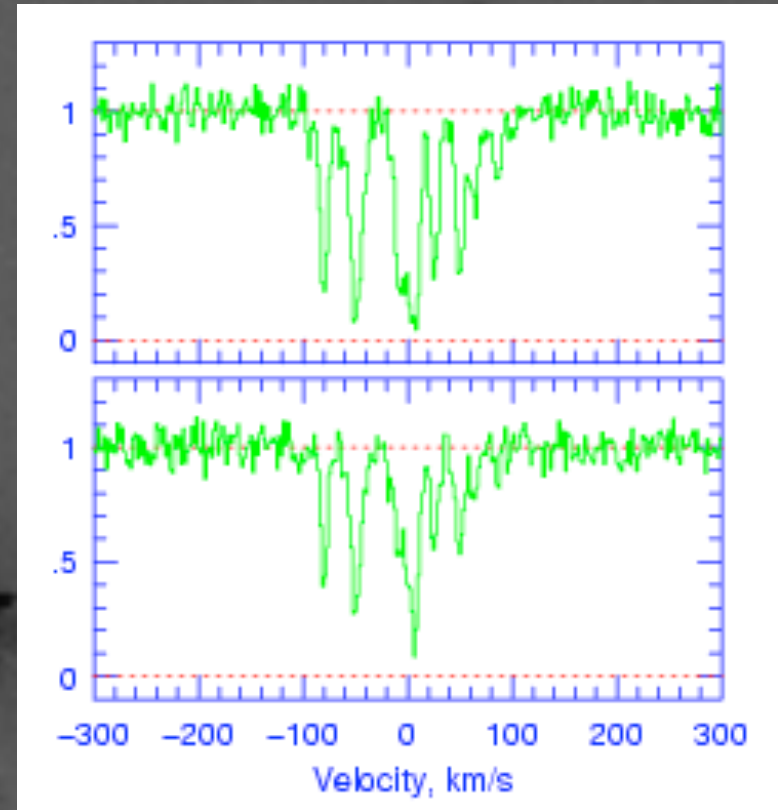
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LLSs: $N(\text{HI}) > 2 \times 10^{17} \text{ cm}^{-2}$

(eg. Steidel et al 1994; Churchill+ 1996; Churchill & Vogt 2001)

- Normal, bright galaxies; $L > 0.1 L^* - 3 L^*$
- Mg II: complex kinematics; $\Delta v \sim 100 - 400 \text{ km s}^{-1}$; $C_f \sim 1$
- Mg II: Weak narrow “high vel components”
- C IV: absorption strengths vary
- C IV: correlates with Mg II kinematic spread



Mg II Selects Galactic Environments...

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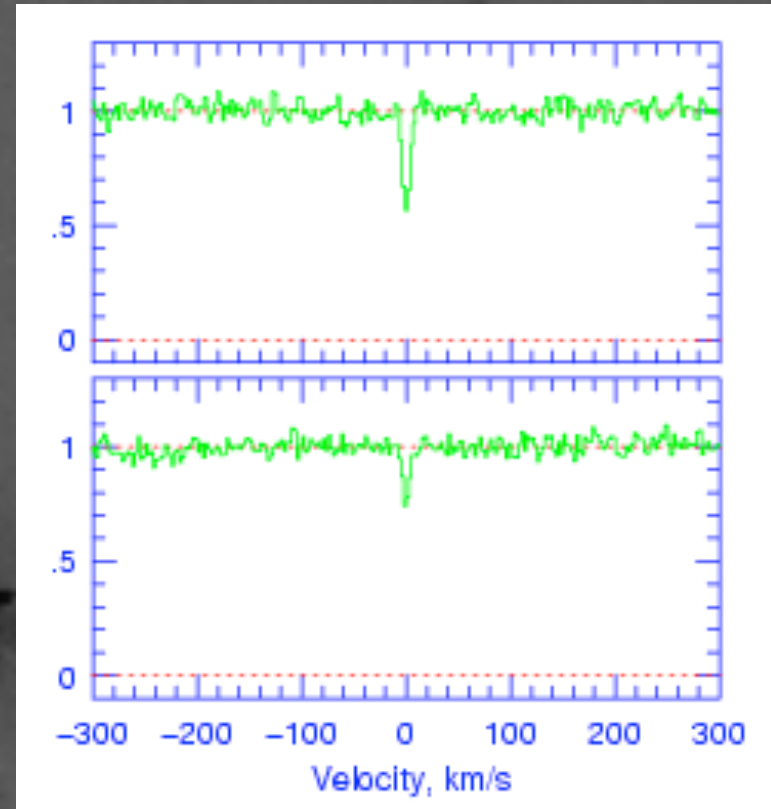
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- C IV: correlates with Mg II kinematic spread

sub-LLSs: $N(\text{HI}) < 6 \times 10^{16} \text{ cm}^{-2}$

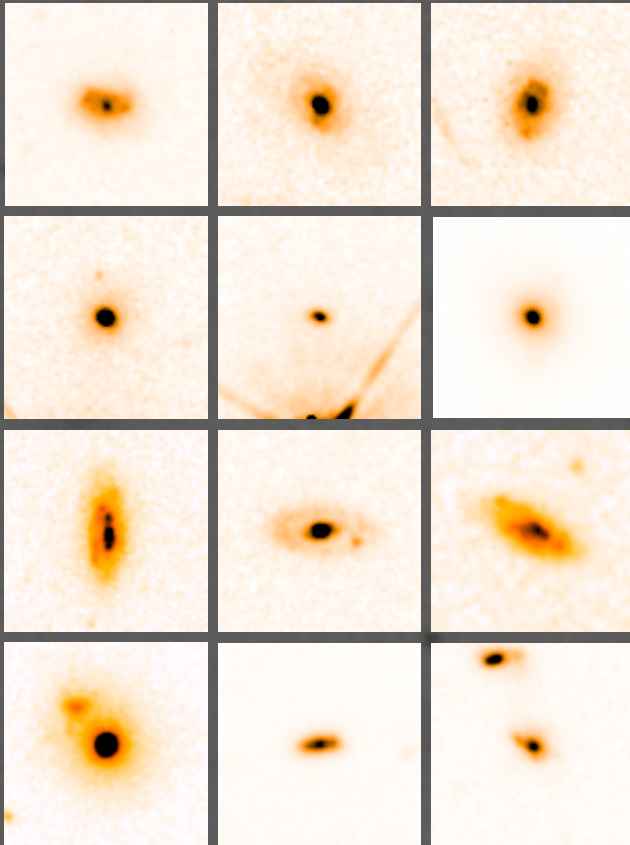
(eg. Churchill+ 1999 ; Churchill & Charlton 1999; Rigby + 2001)

- Normal bright galaxies (some), dwarf galaxies?
- Mg II: cloud sizes $\sim 10 \text{ pc}$ to $\sim 10 \text{ kpc}$
- $Z > 0.1$ solar; $0 < [a/\text{Fe}] < +0.5$; $C_f \sim 0.15$?
- C IV: range of absorption strengths
- many multiphase ionization



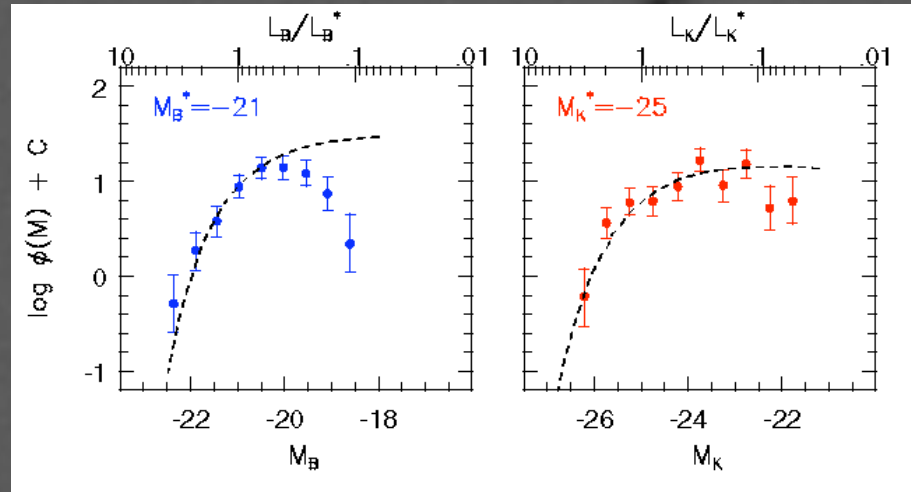
...ranging over five decades of $N(\text{HI})$

What Galaxy Types are Selected by Mg II Absorbers?



Population of normal morphology, bright galaxies are selected by Mg II absorbing gas cross section...

Steidel (1998); Kacprzak+ (2005)



Little to no evolution in luminosity function except for a paucity of faint blue galaxies

Steidel+ (1994)

$$F = F^*(L/L^*)^{-a} \exp(-L/L^*) h^3 \text{ Mpc}^{-3}$$

$$F^* = 0.03 h^3 \text{ Mpc}^{-3}$$

$$a = -1$$

Mg II Absorption Cross Sections...

Statistical sizes based upon Redshift Path Densities..

Sargent, Steidel, & Boksenberg 1988
Steidel & Sargent 1992
Steidel 1993
HST KP 1995
Churchill 2001
Churchill & Vogt 2001
Nestor+ 2005

$$dN/dz = D_H ns(1+z)^2 H_0/H(z)$$

$$ns = F(L)pR(L)^2 \text{ (integrated)}$$

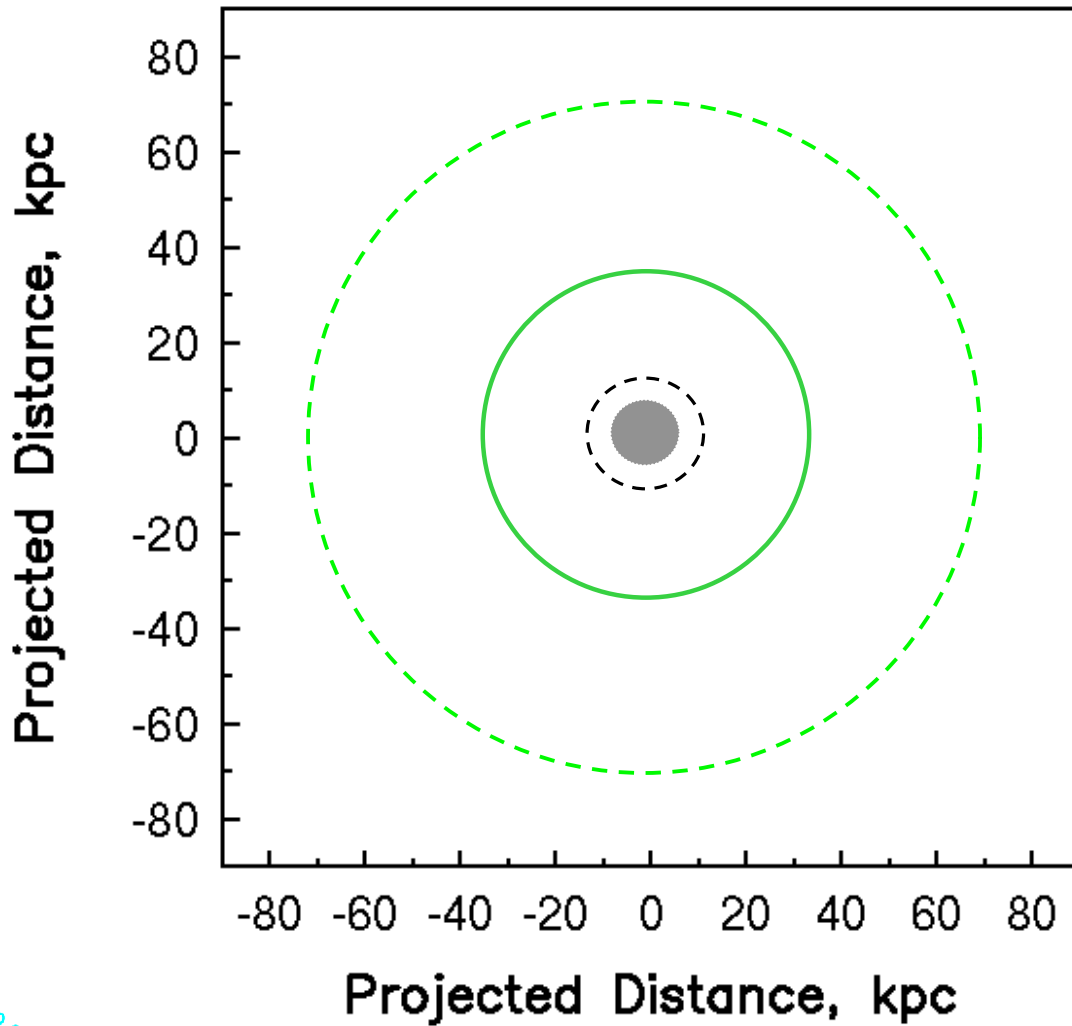
$$F(L) = 0.03(L/L^*)^{-1} \exp(-L/L^*) h^3 \text{ Mpc}^{-3}$$

$$R(L) = R^*(L/L^*)^{-b} h^{-1} \text{ kpc}$$

Mg II Absorption Cross Sections...

Statistical sizes based upon Redshift Path Densities..

Sargent, Steidel, & Boksenberg 1988
Steidel & Sargent 1992
Steidel 1993
HST KP 1995
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Nestor+ 2005



● $6h^{-1}$ kpc
DLA: LSB included
 $F^*=0.08 h^3 \text{ Mpc}^{-3}$

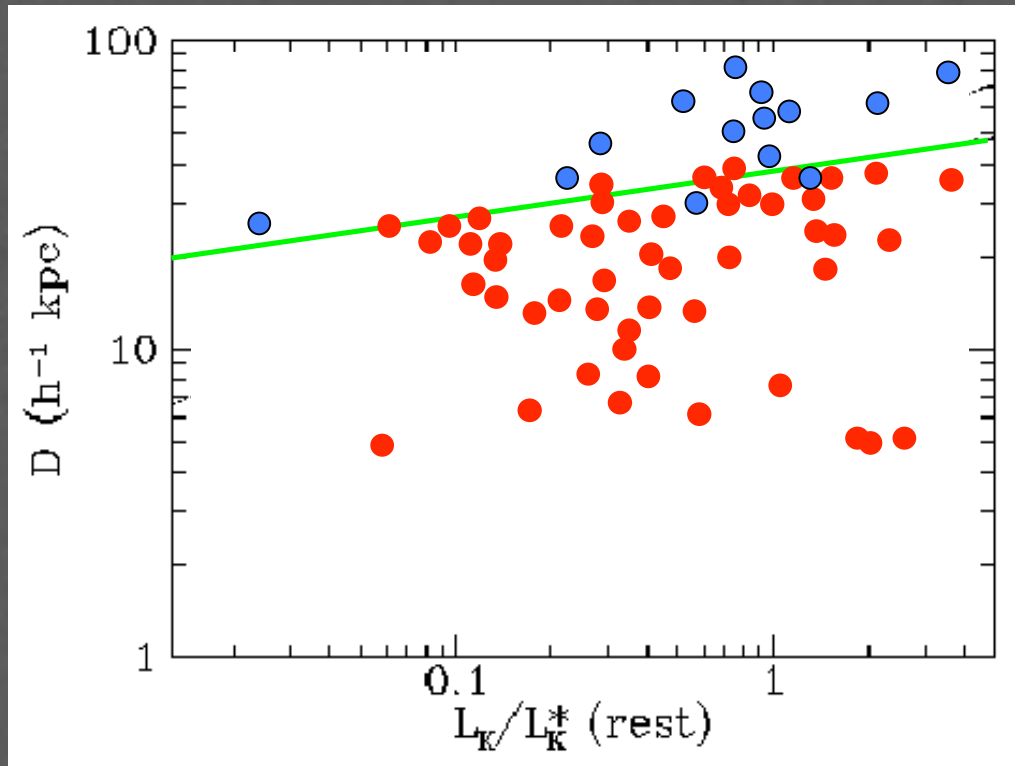
----- $15h^{-1}$ kpc
DLA: LSB excluded
 $F^*=0.03 h^3 \text{ Mpc}^{-3}$

————— $40h^{-1}$ kpc
Mg II: $W(2796)>0.3 \text{ \AA}$
LLS : $F^*=0.03 h^3 \text{ Mpc}^{-3}$

- - - - - $70h^{-1}$ kpc
Mg II: $W(2796)<0.3 \text{ \AA}$
C IV : $W(1548)>0.3 \text{ \AA}$



Is There a Halo Size - Mass/Luminosity Relationship? Does the Gas Follow a Smooth Radial Dependence?



Steidel (1995)

The “R(L) Relation”

Minimize number of non-absorbers below the line

Minimize number of absorbers above the line

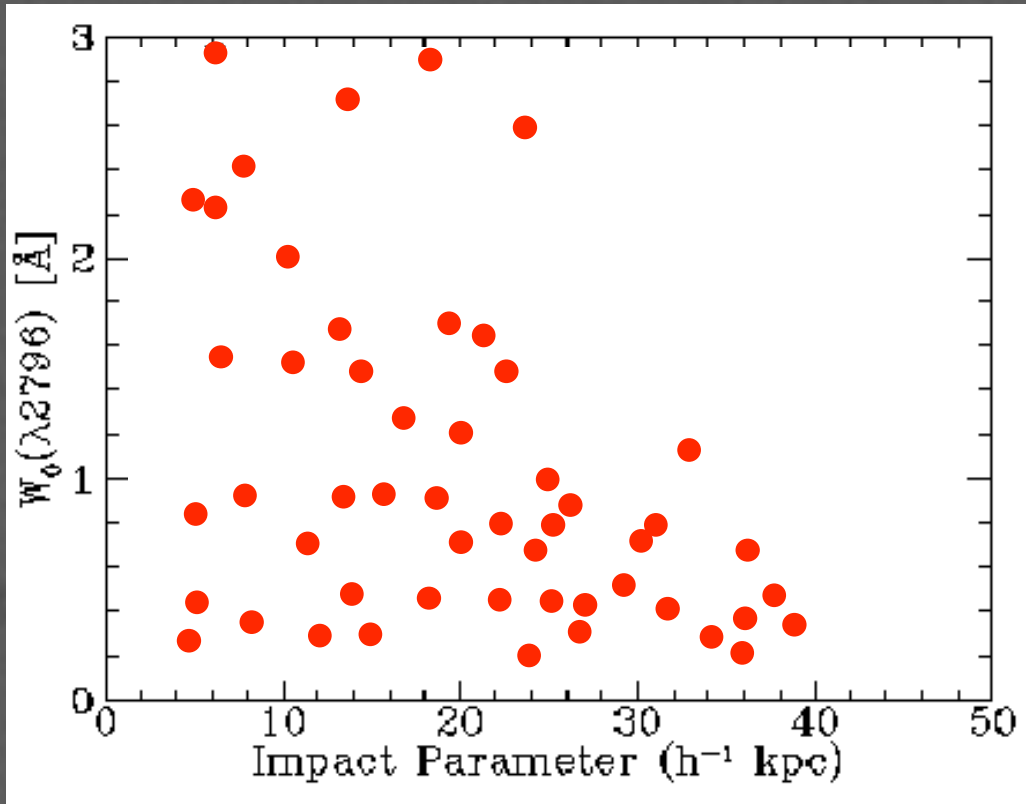
$$R = R^*(L/L^*)^{-b}$$

$$b=0.15$$

$$R^* = 40h^{-1} \text{ kpc}$$

Spherical; $C_f=1$

Does the Gas Follow a Smooth Radial Dependence?



Steidel (1995)

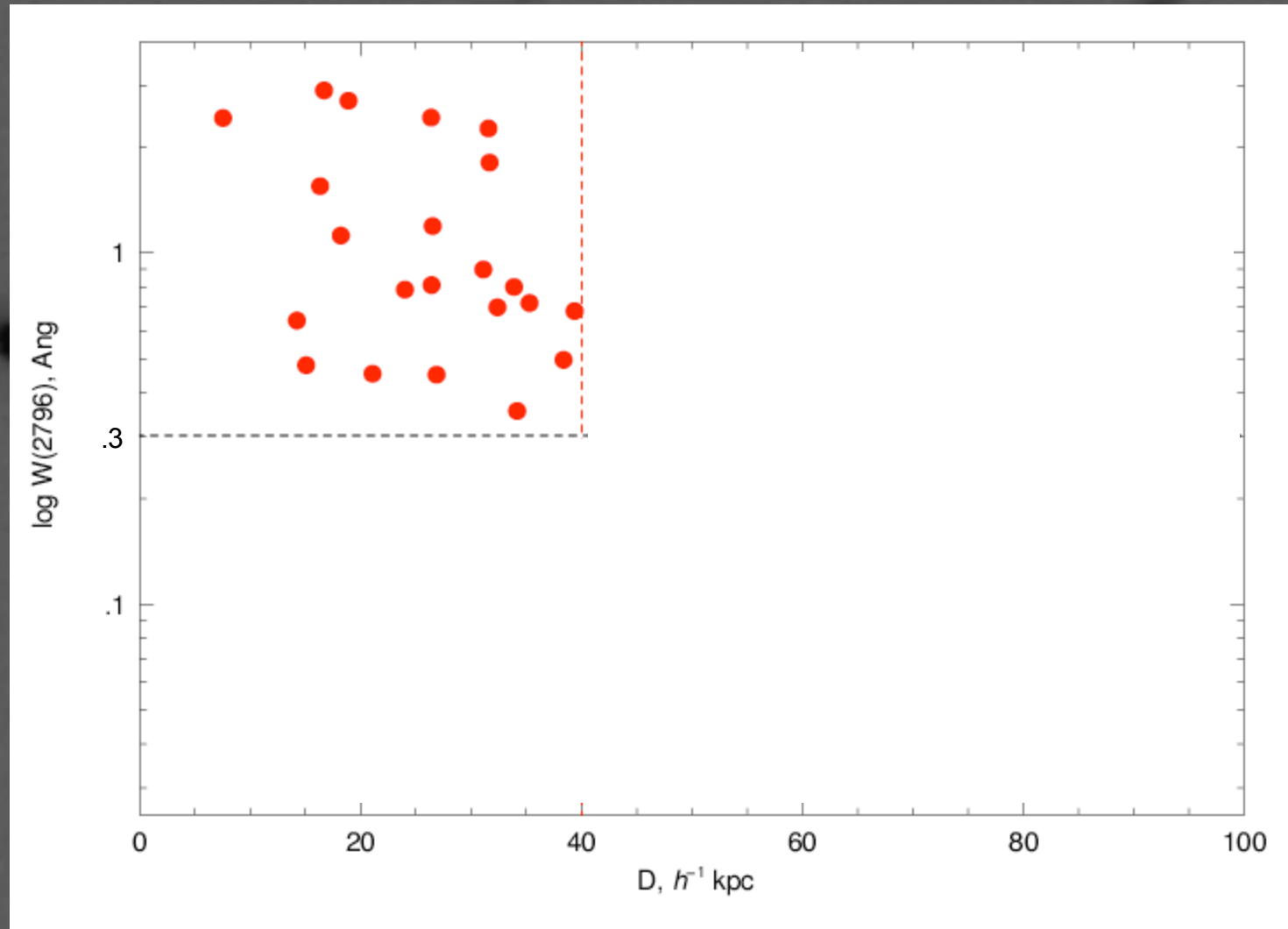
The 3.1 s anti-correlation between equivalent width and impact parameter.

Halos are “patchy” (as seen in the scatter), but appear to obey overall trend...

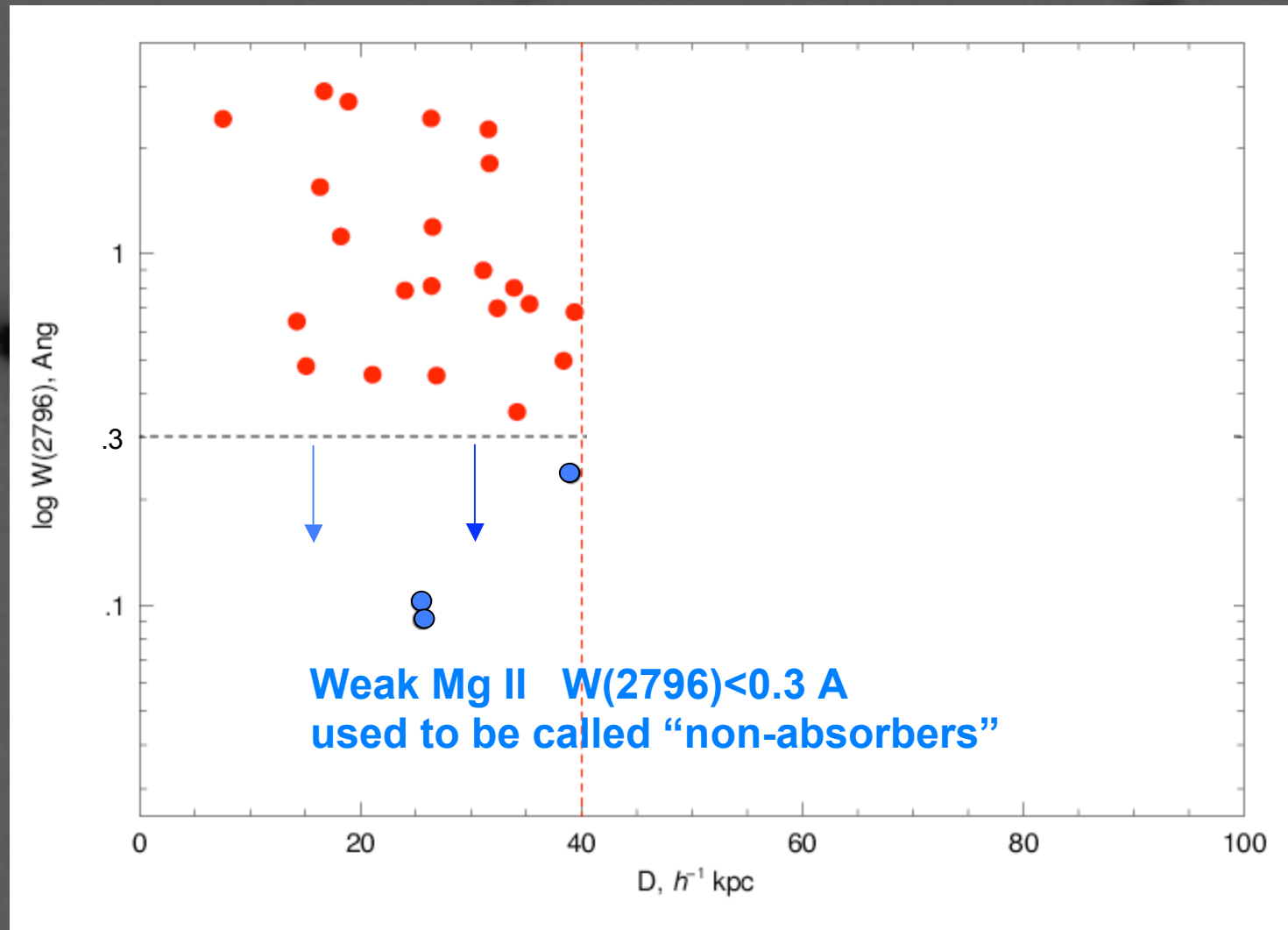
Is there a maximum equivalent width at each impact parameter?

EW is strongly dependent upon the velocity spread and number of clouds intercepted by the quasar sightline, so the scatter speaks to the velocity spreads variations or “additional” parameters

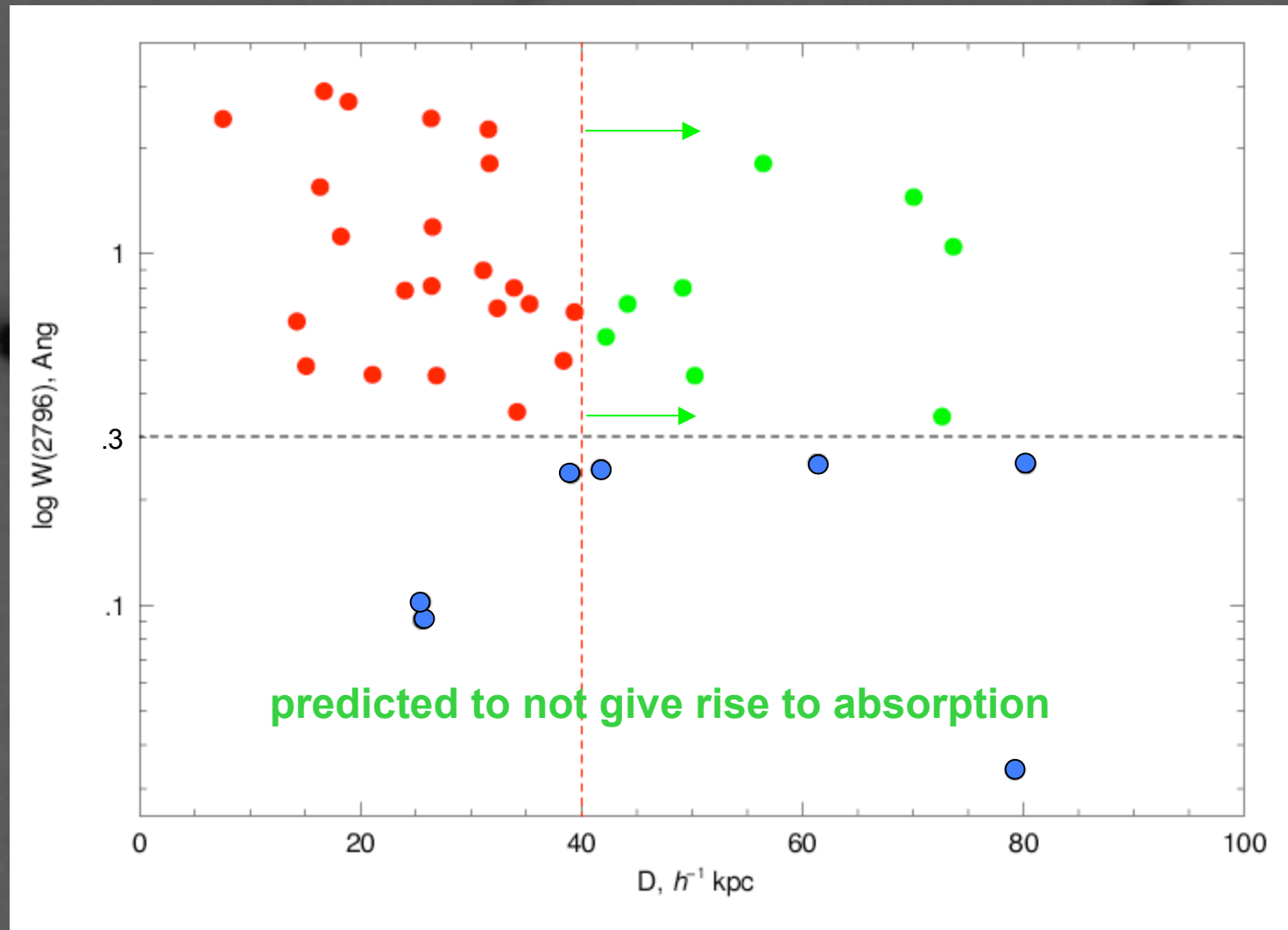
Sample: Equivalent Width vs. Impact Parameter



Sample: Equivalent Width vs. Impact Parameter



Sample: Equivalent Width vs. Impact Parameter

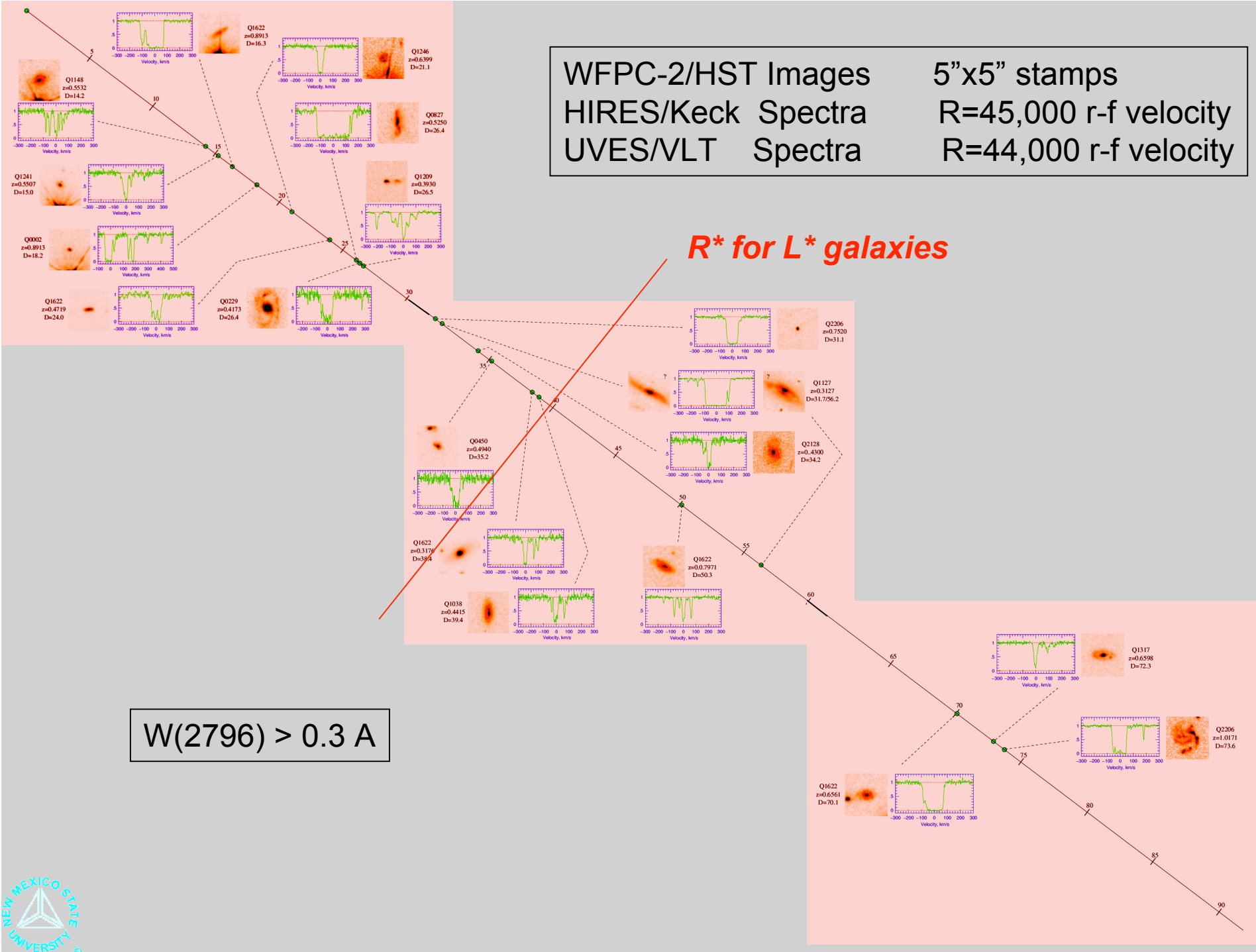


WFPC-2/HST Images
 HIRES/Keck Spectra
 UVES/MLT Spectra

5"x5" stamps
 R=45,000 r-f velocity
 R=44,000 r-f velocity

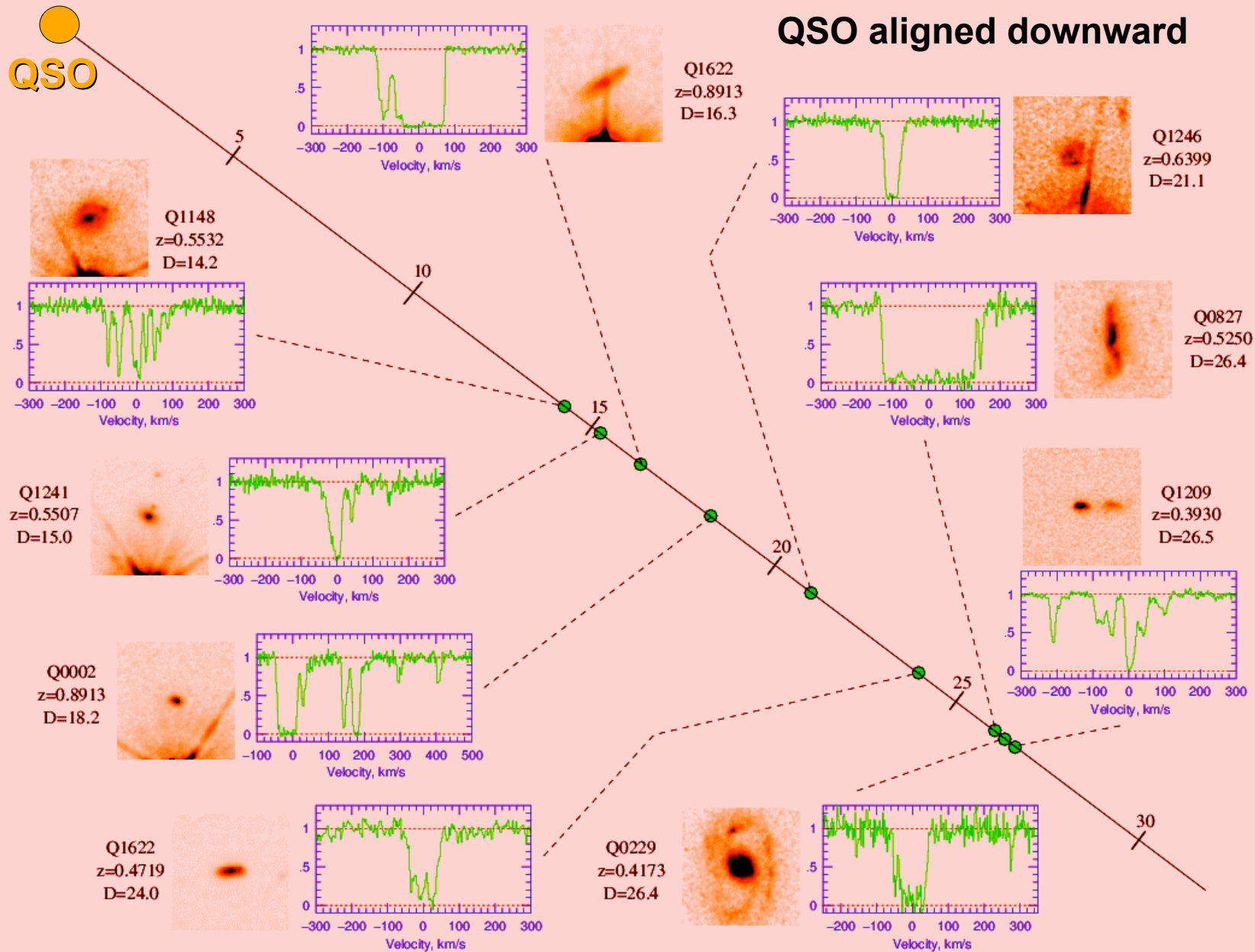
R for L* galaxies*

$W(2796) > 0.3 \text{ \AA}$

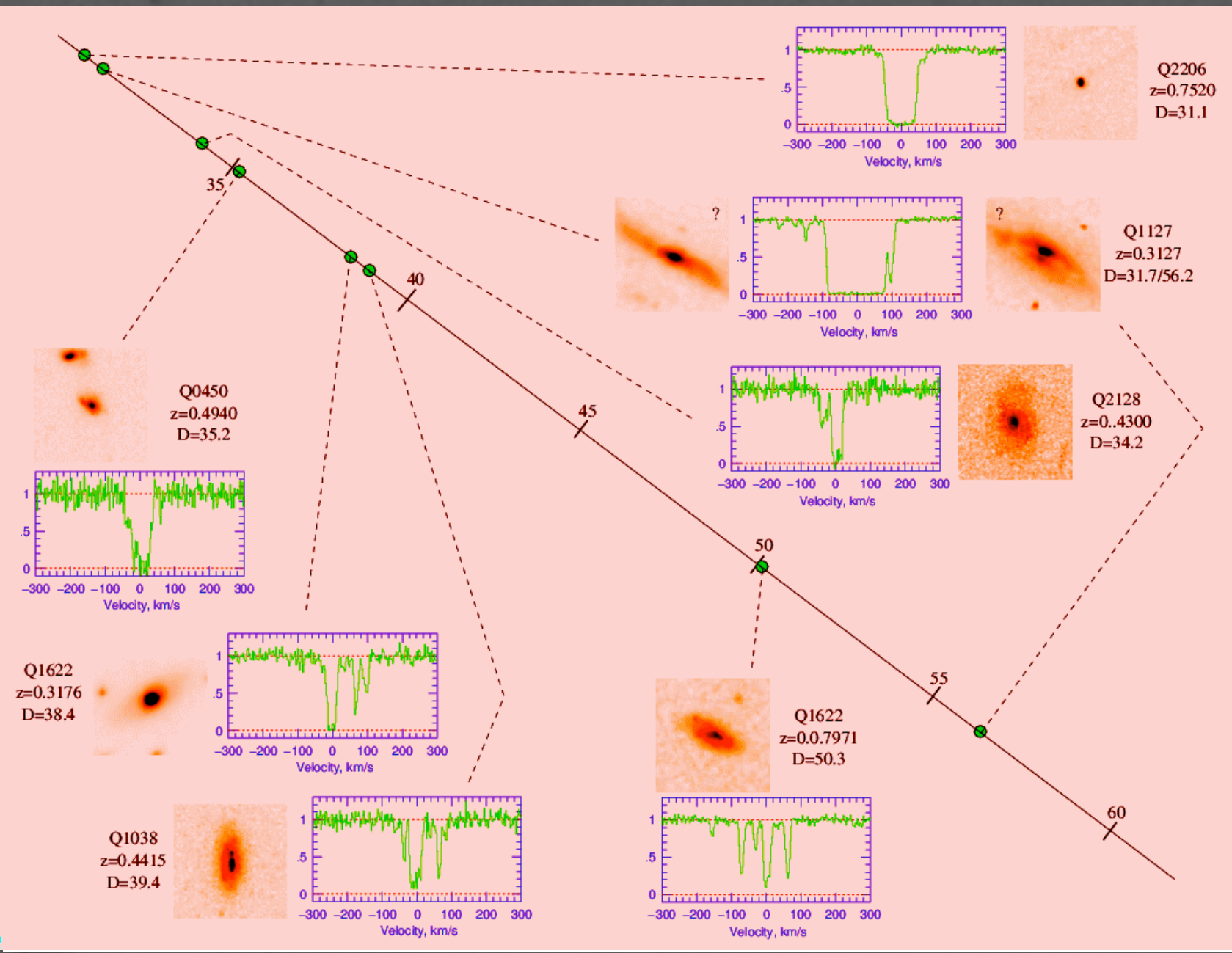


PANEL 1. $D < 30 h^{-1} \text{ kpc}$

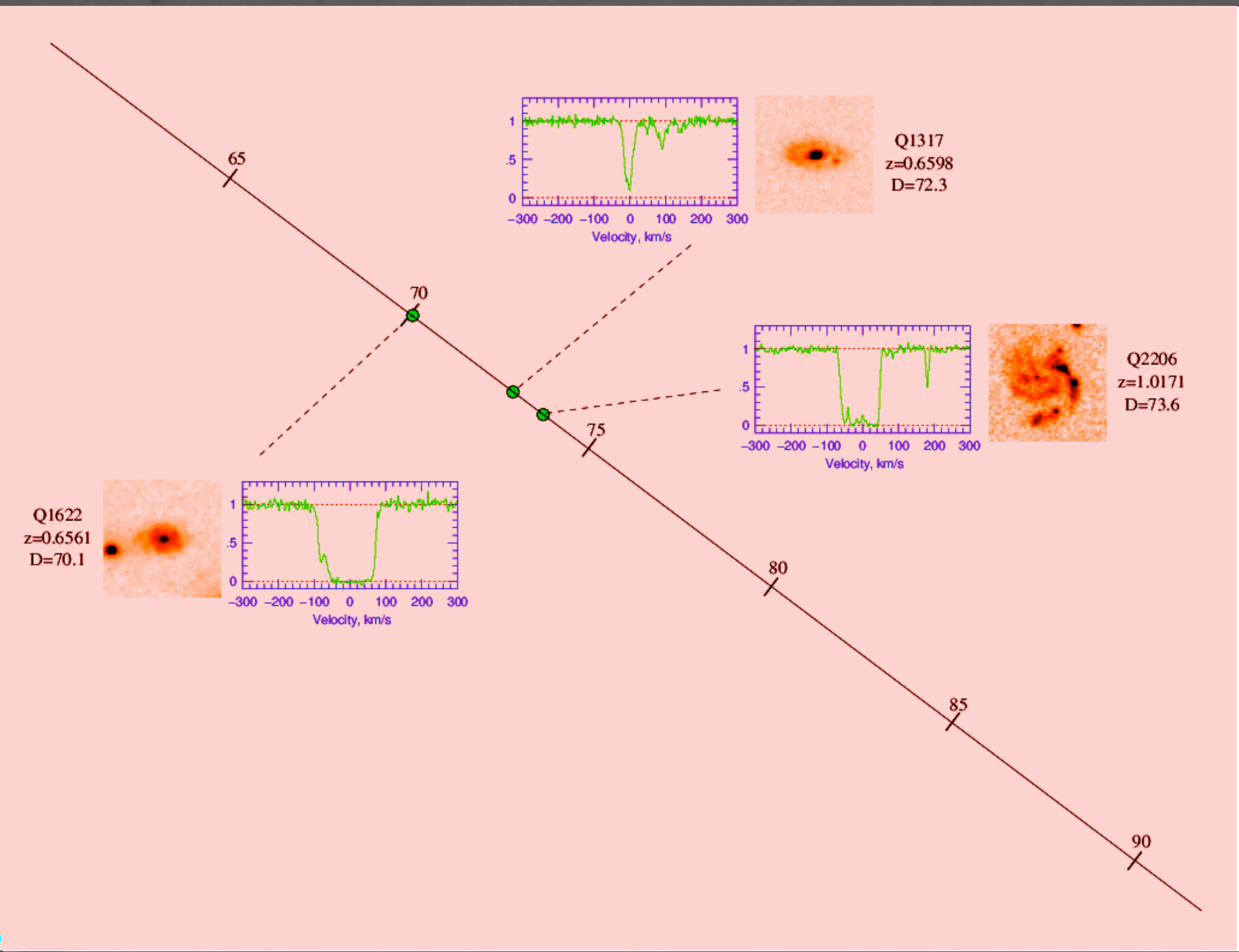
QSO aligned downward



PANEL 2. $30 < D < 60 h^{-1} \text{ kpc}$



PANEL 3. $D > 60 h^{-1} \text{ kpc}$



A Few Case Studies...

SDP Galaxy sample/survey incomplete...

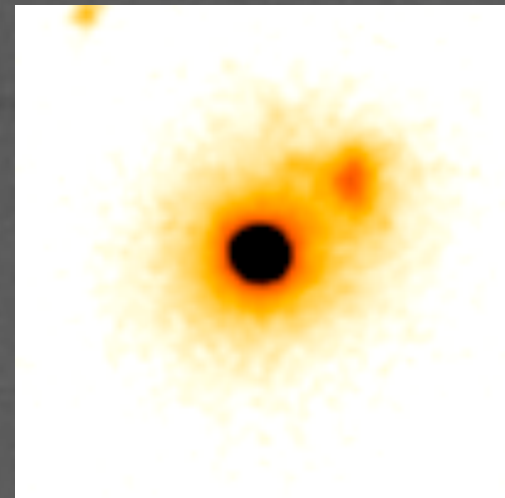
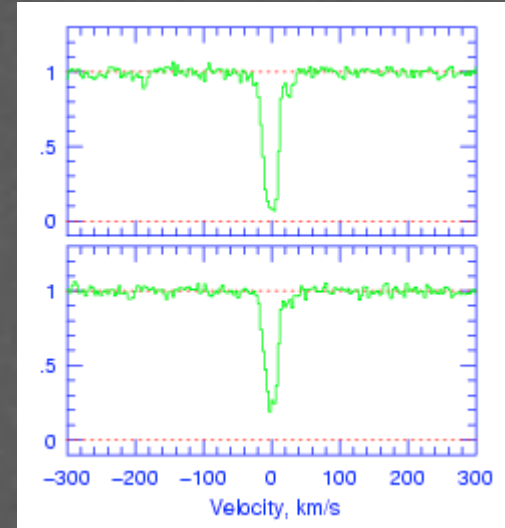
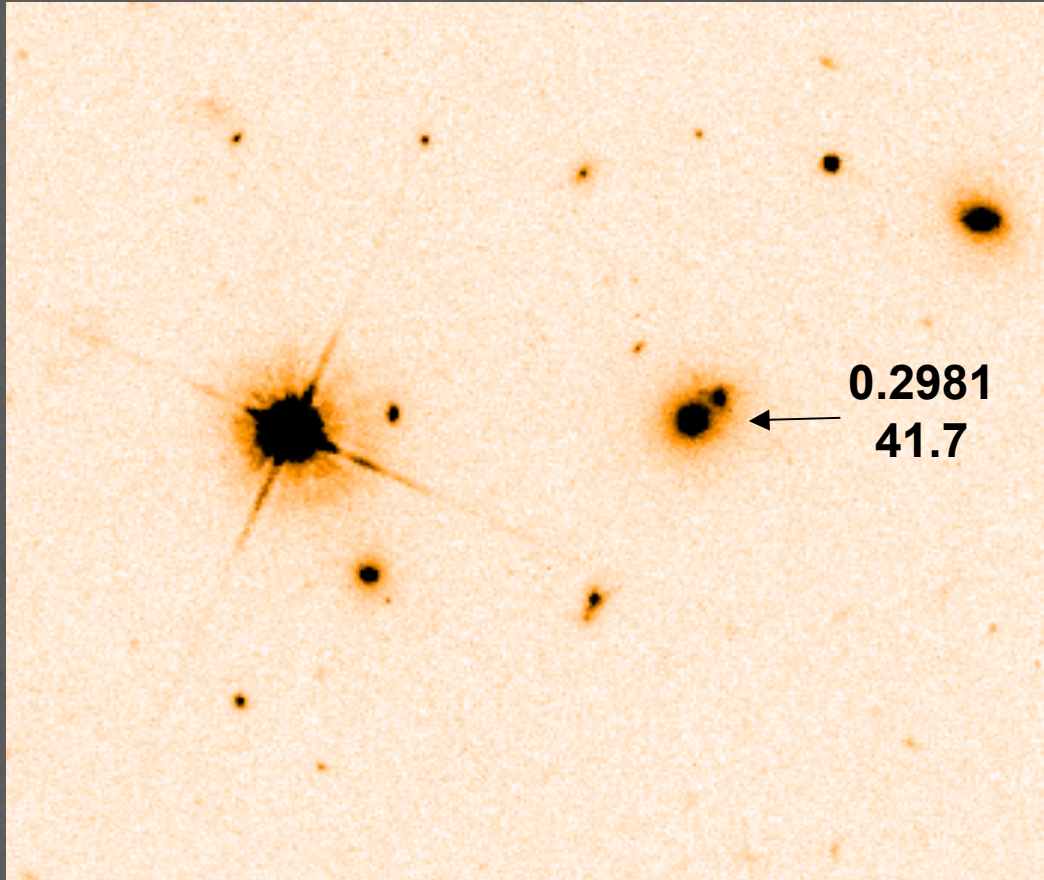
- 70% spectroscopic redshifts
- 30% remain candidates
- search pattern biased toward most likely galaxy (nearest quasar), stopped after confirmation

General Picture is essentially correct, but there is much to be learned in detail...

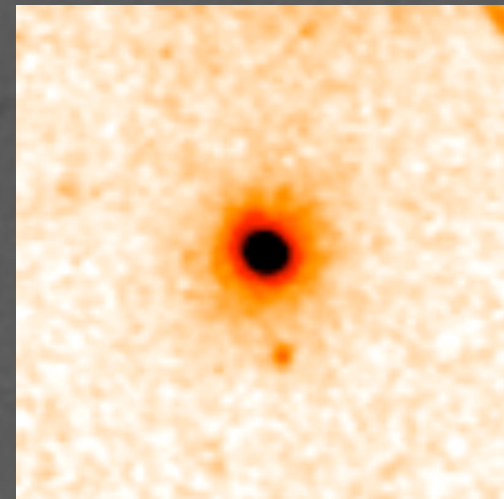
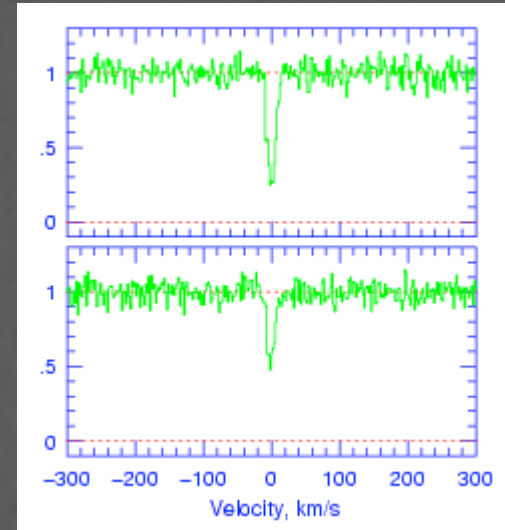
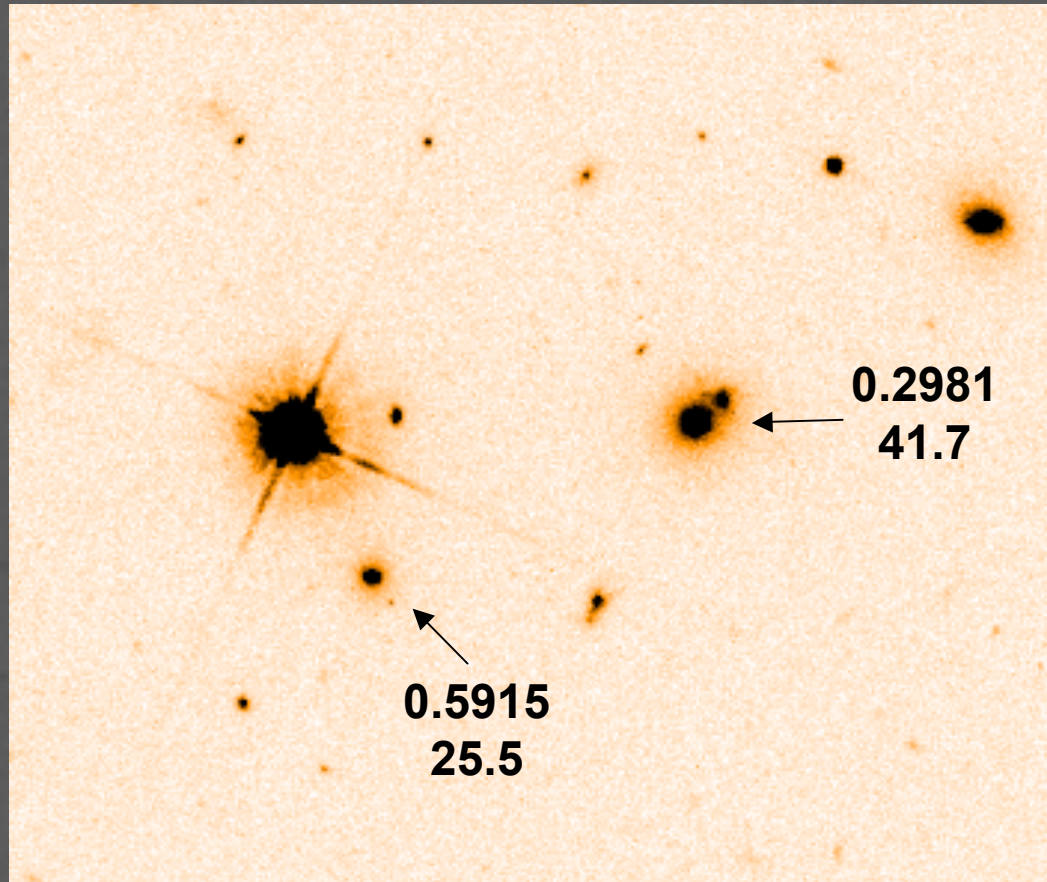
- in patch-work follow-up studies, several absorber hosts found to be
 - misidentified
 - unidentified
 - “double” galaxies or ambiguous identity

What are Implications?

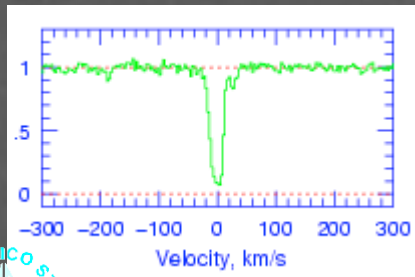
The Q0002+051 Field



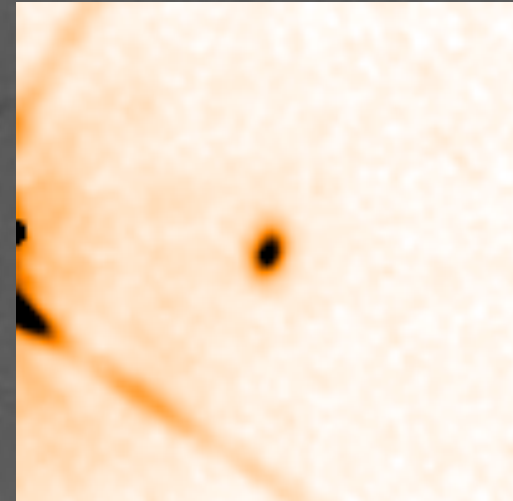
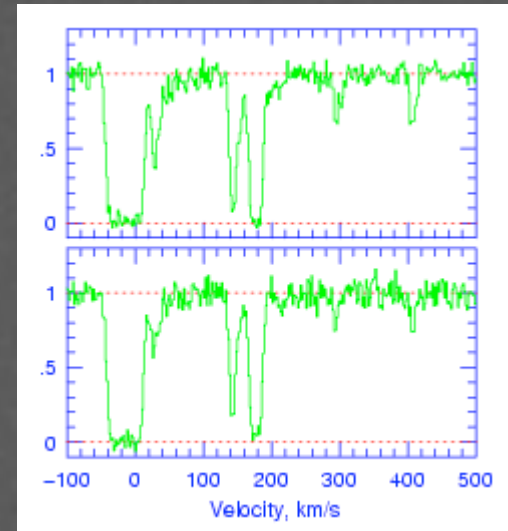
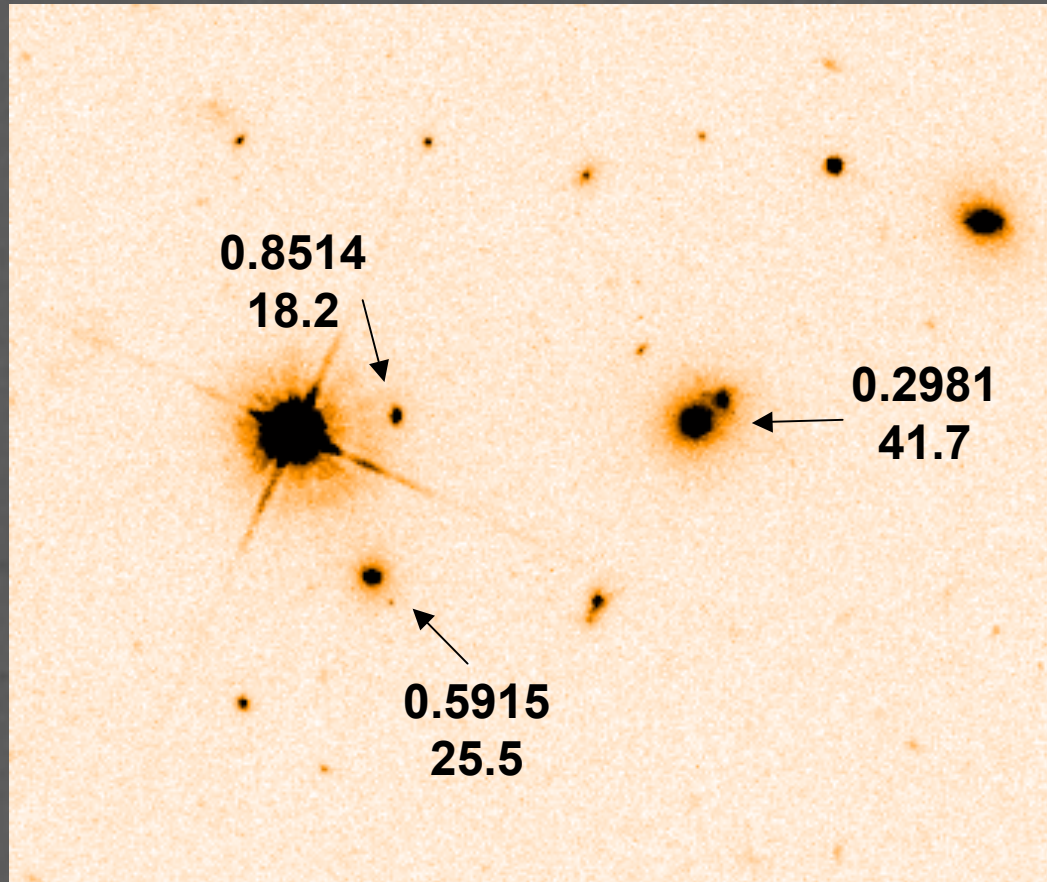
The Q0002+051 Field



$z=0.2981$

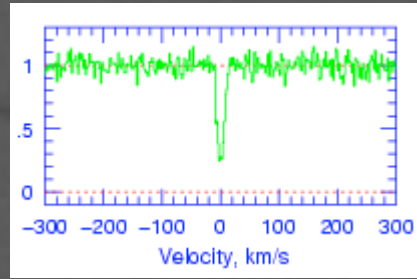
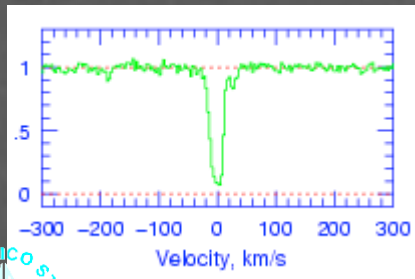


The Q0002+051 Field

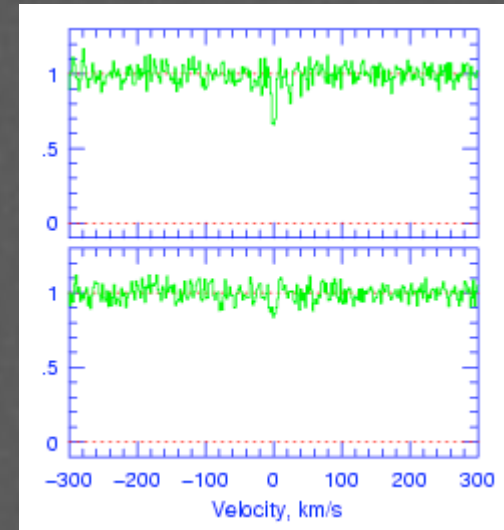
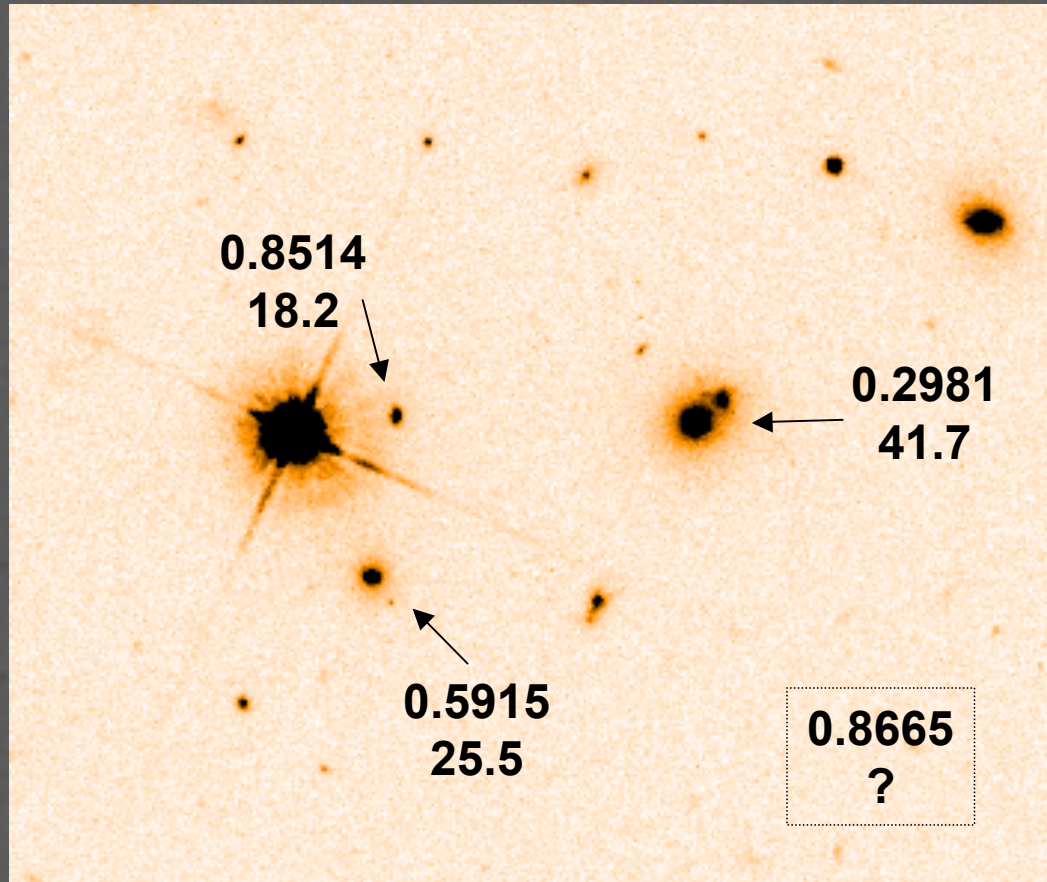


$z=0.2981$

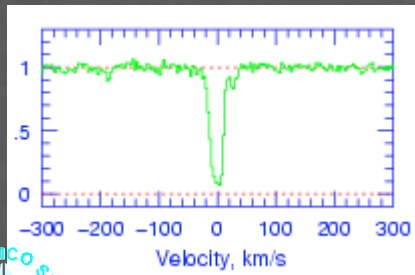
$z=0.5915$



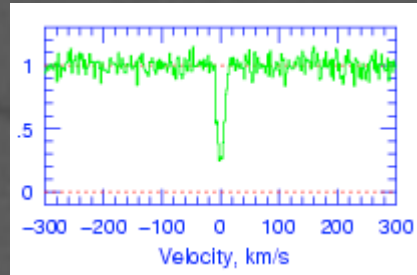
The Q0002+051 Field



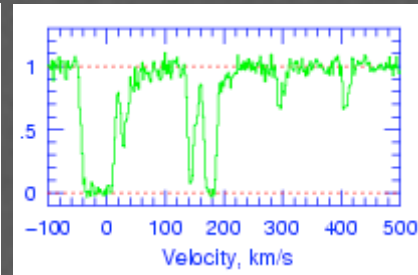
$z=0.2981$



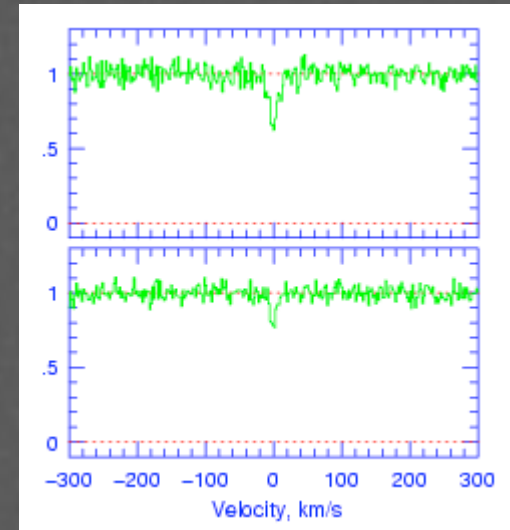
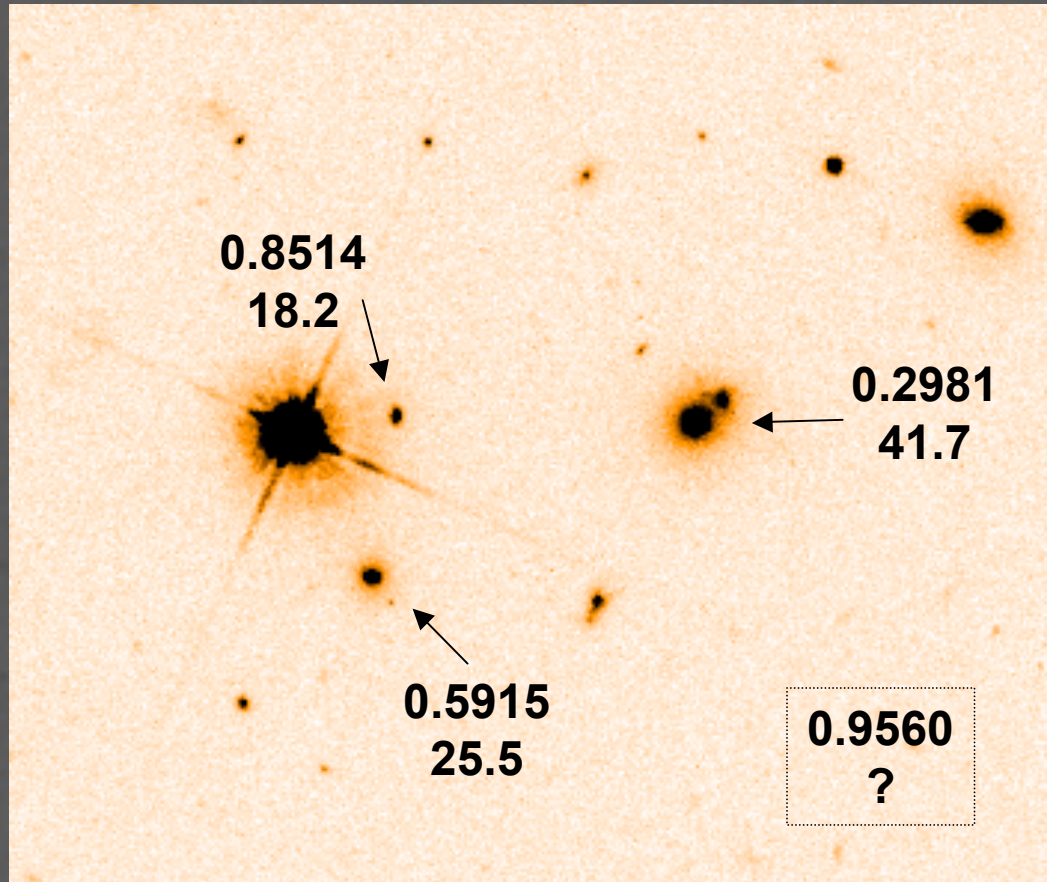
$z=0.5915$



$z=0.8514$



The Q0002+051 Field

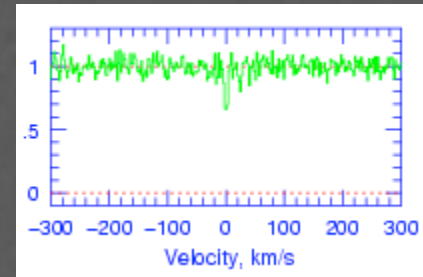
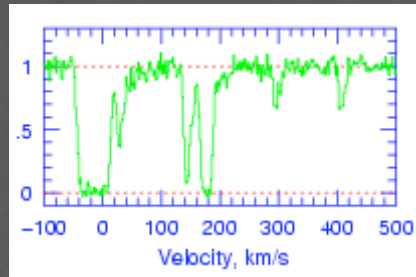
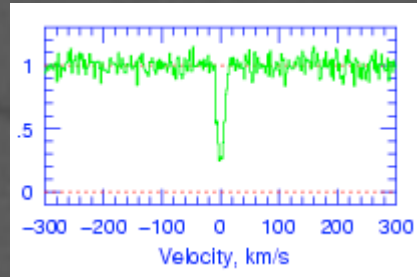
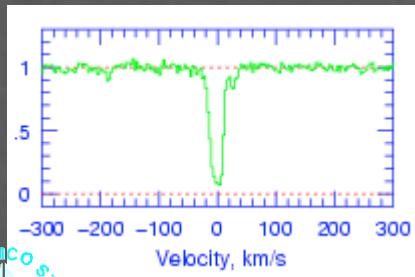


$z=0.2981$

$z=0.5915$

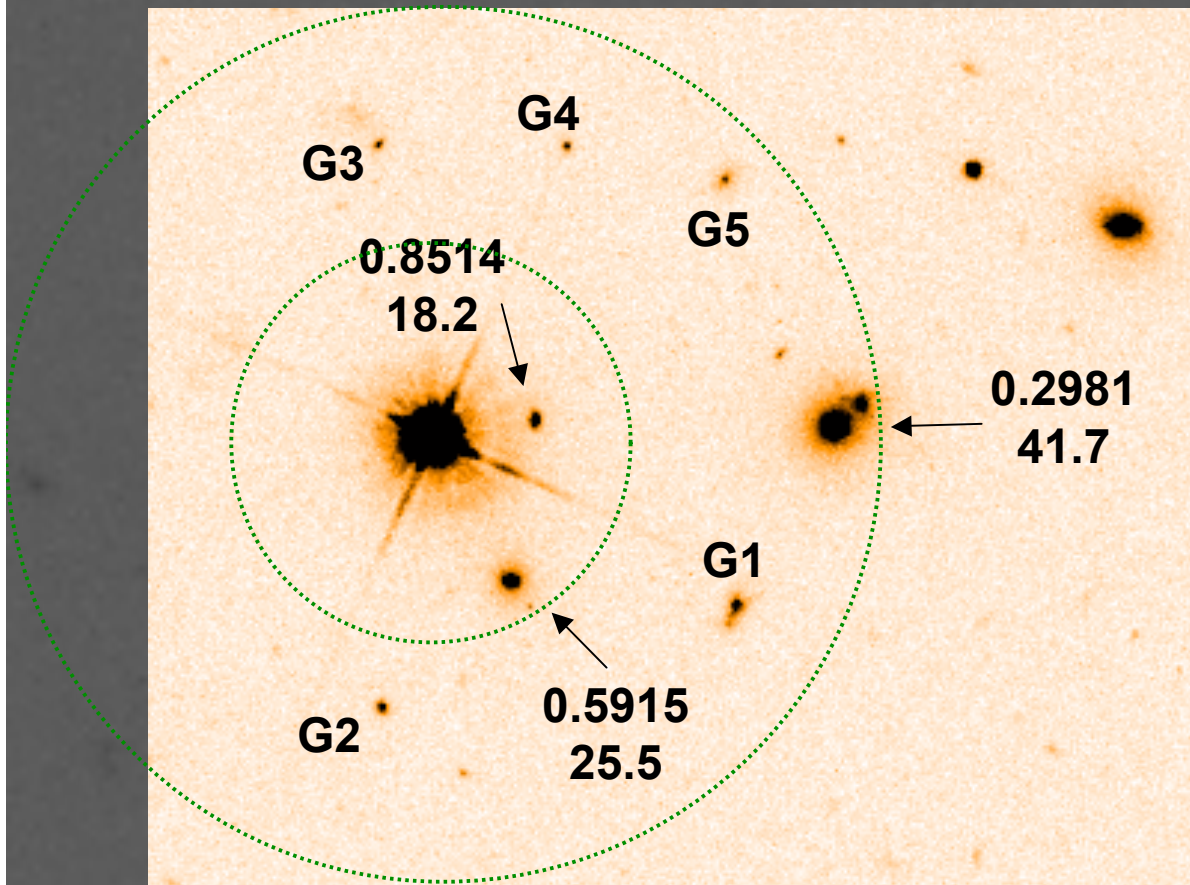
$z=0.8514$

$z=0.8665$



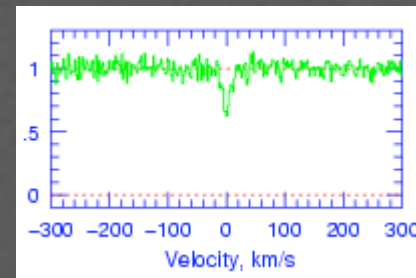
The Q0002+051 Field

Galaxies at
 $z=0.8665$ & 0.9560 ?

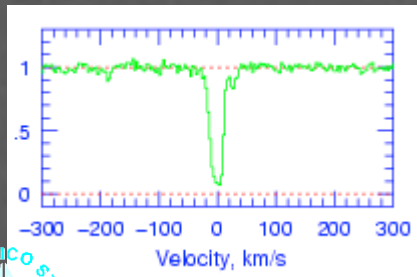


Candidate	$D h^{-1}$
G1	63
G2	50
G3	54
G4	58
G5	70

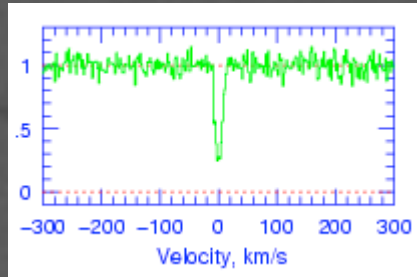
$z=0.9560$



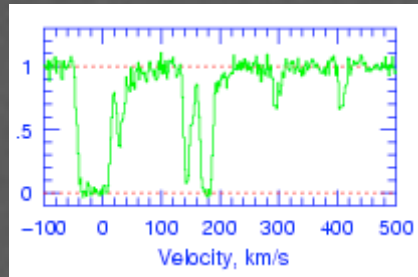
$z=0.2981$



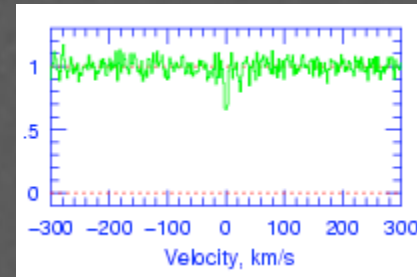
$z=0.5915$



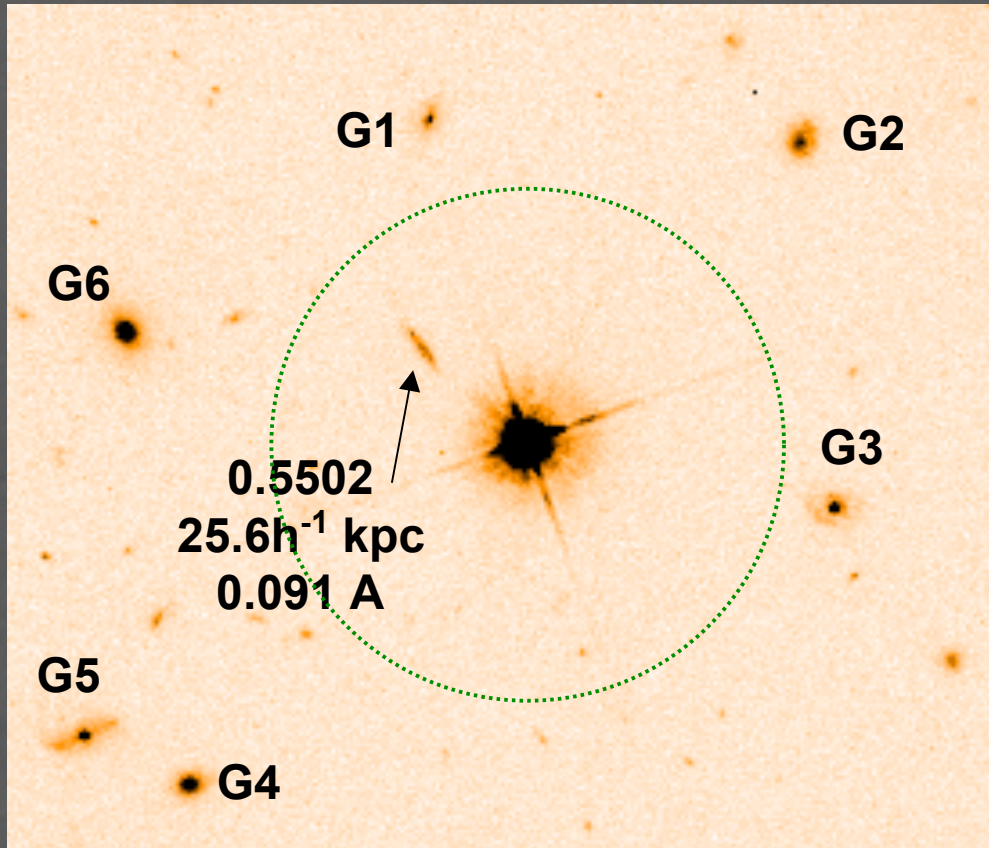
$z=0.8514$



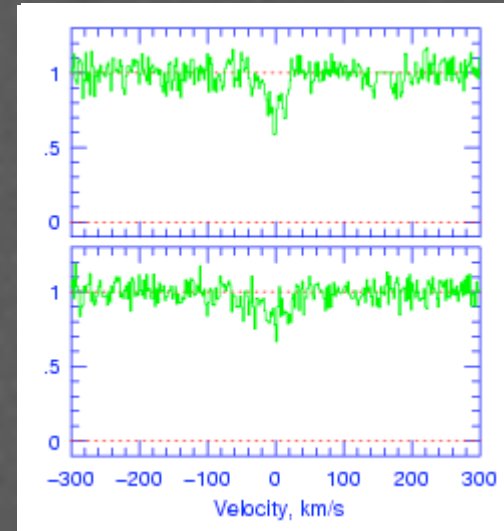
$z=0.8665$



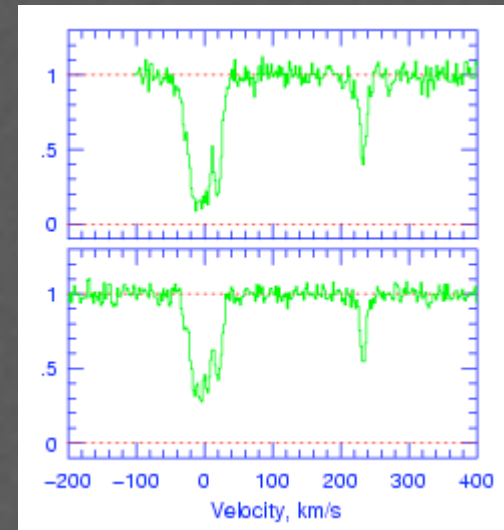
The Q1222+228 Field



$z=0.5502$



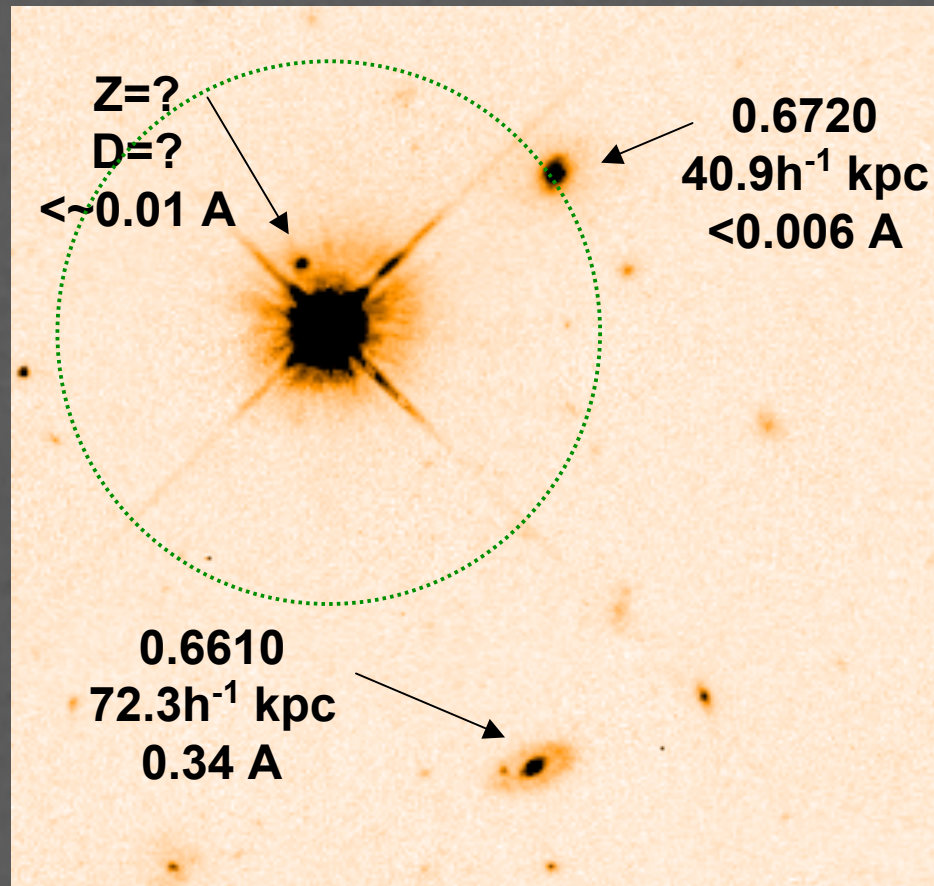
$z=0.6681$



Galaxy at $z=0.6681$?

Candidate	$D h^{-1}$	Candidate	$D h^{-1}$
G1	69	G4	97
G2	83	G5	108
G3	63	G6	86

The Q1317+174 Field

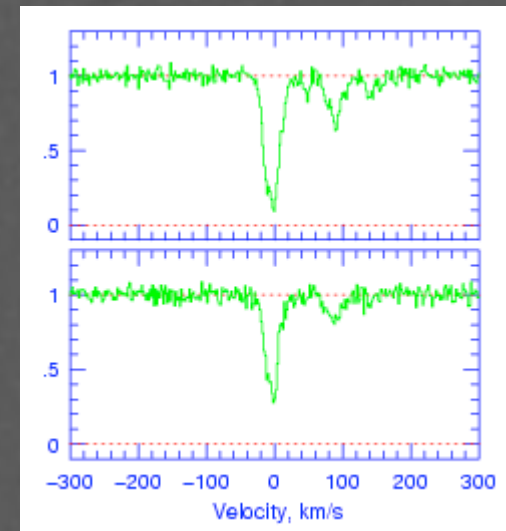


$z=0.6610$ absorption significantly beyond
“expected” $40h^{-1} \text{ kpc}$ impact parameter

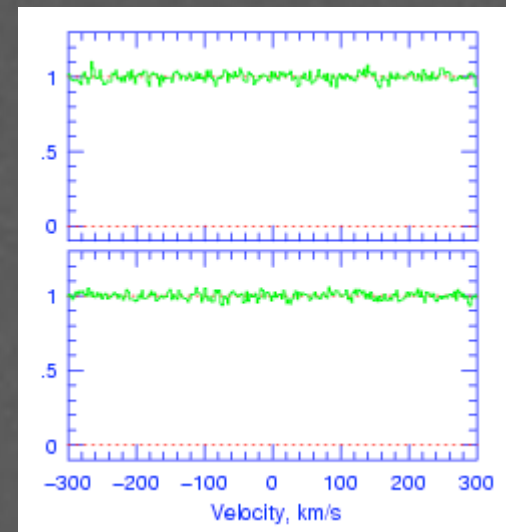
$z=0.6720$ a true non-absorbing galaxy

Small D galaxy with no abs (in covered I)

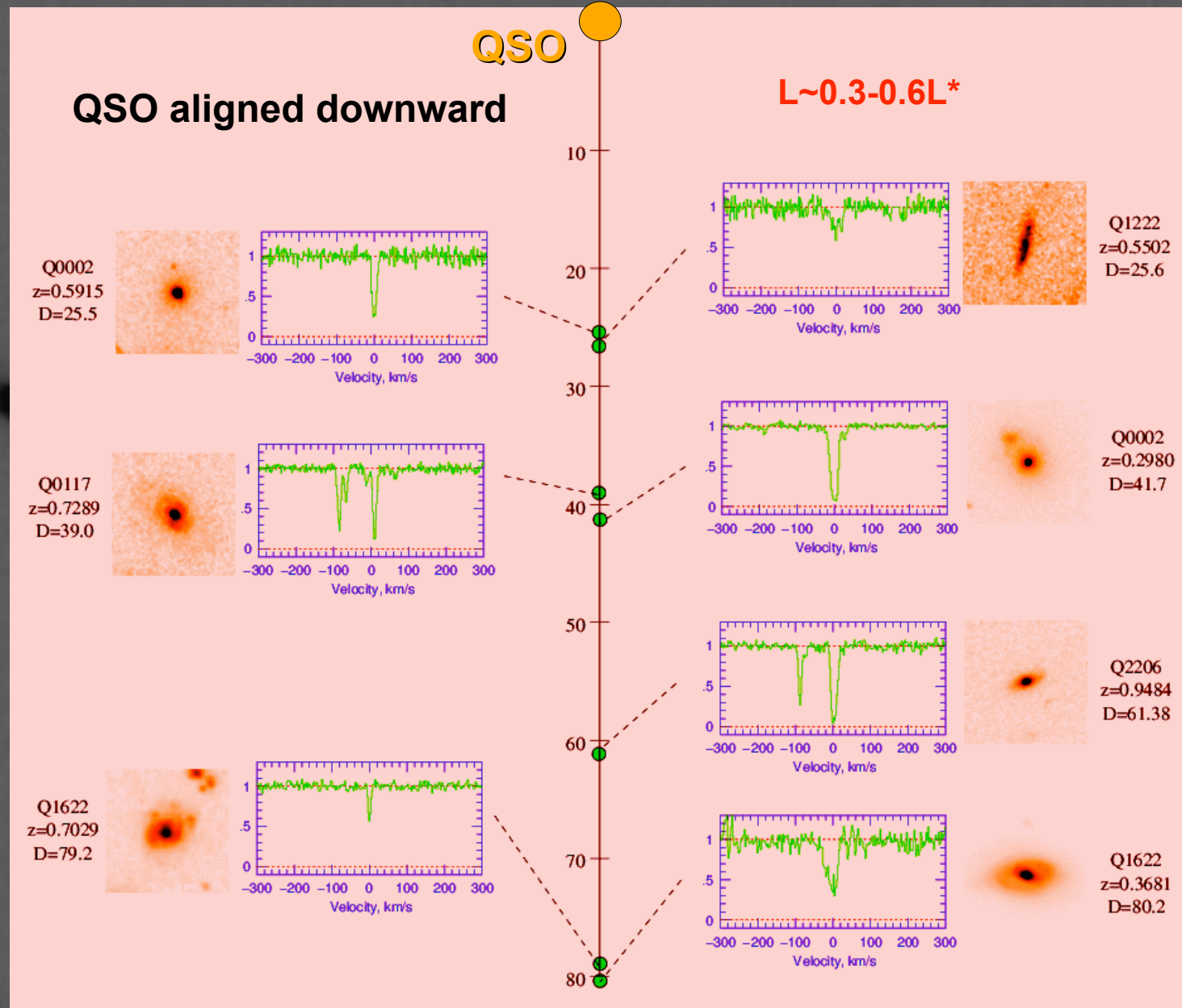
$z=0.6610$



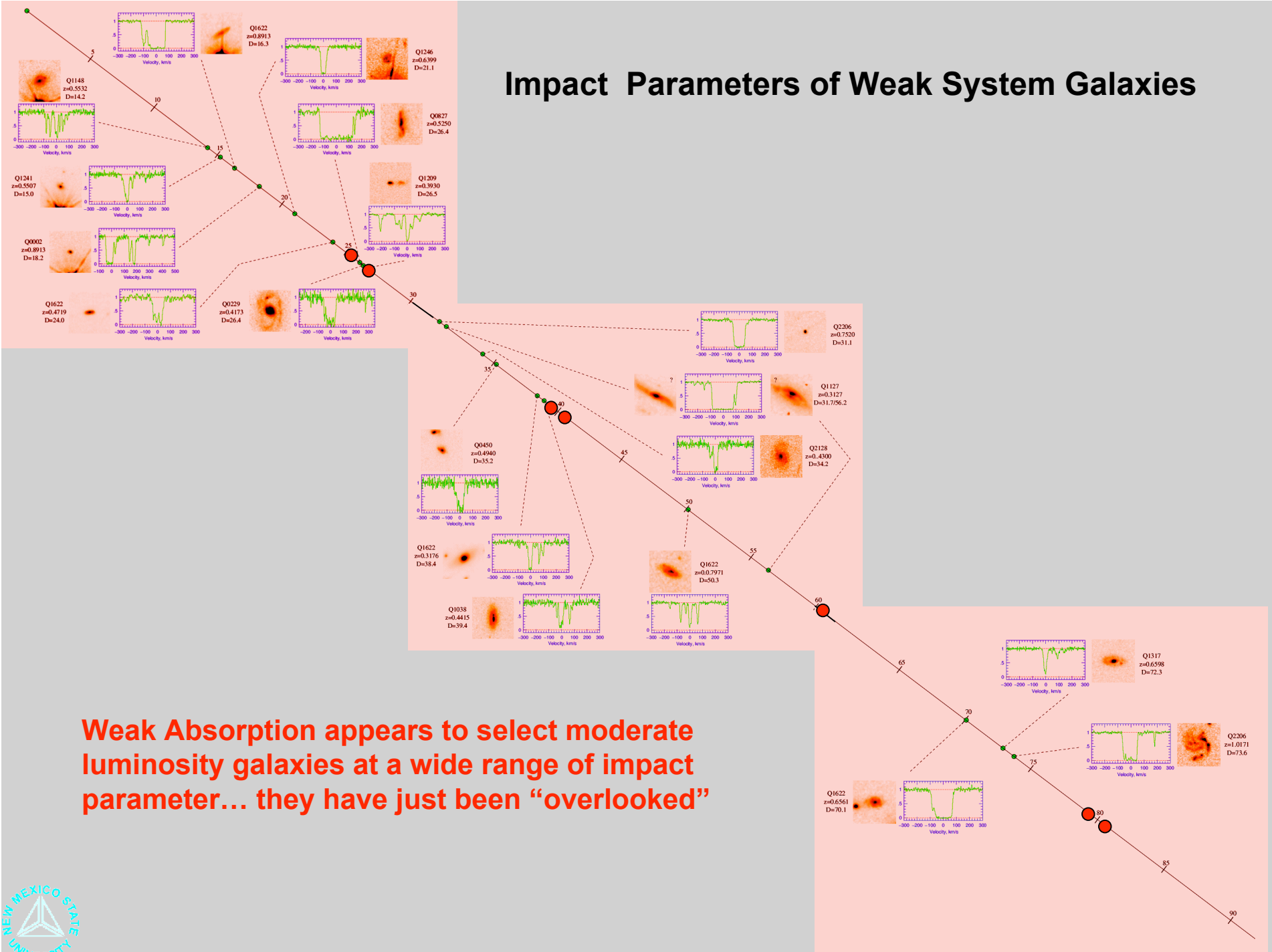
$z=0.6720$



Galaxies Selected by Weak Mg II Absorption



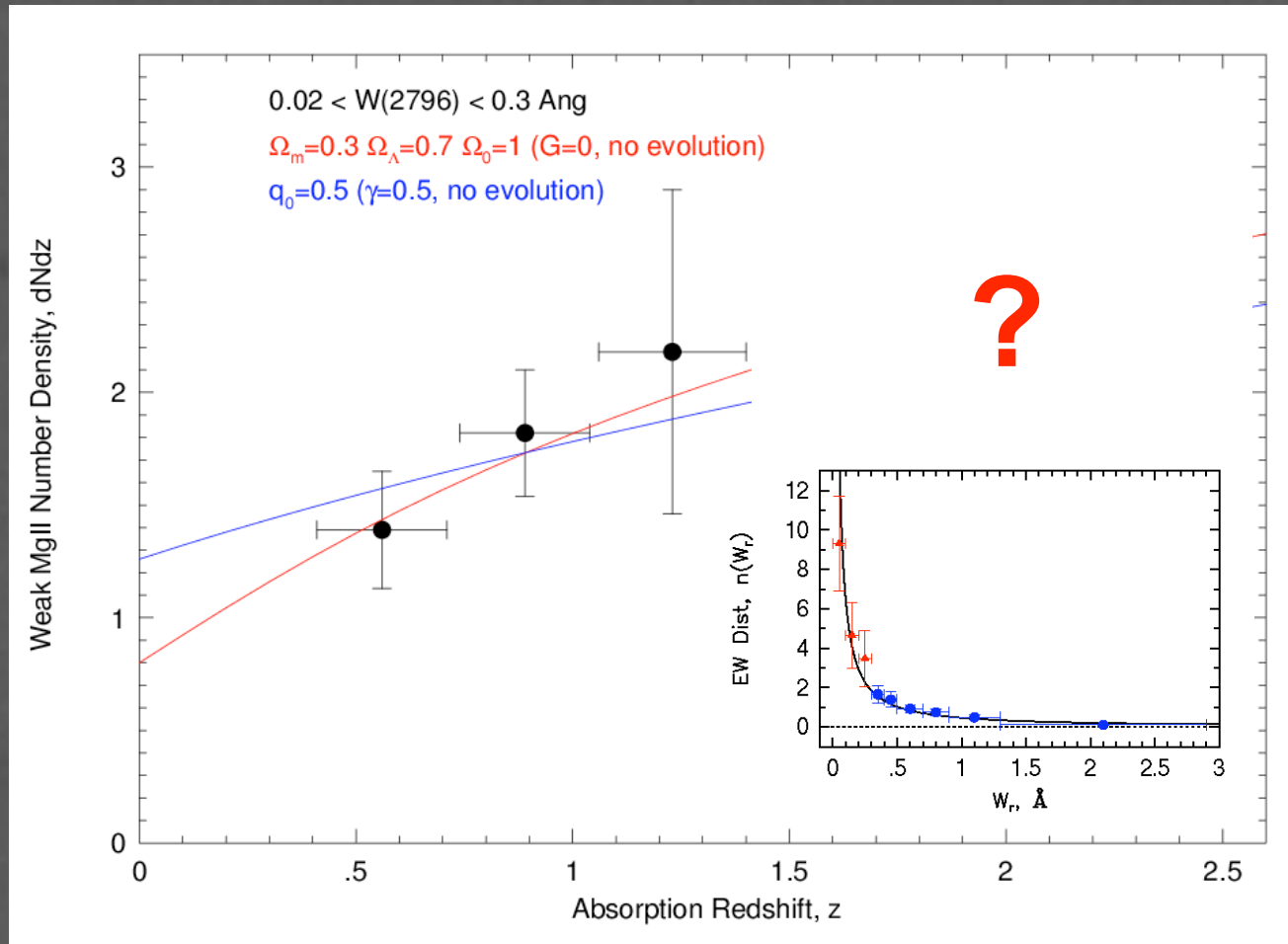
Impact Parameters of Weak System Galaxies



Weak Absorption appears to select moderate luminosity galaxies at a wide range of impact parameter... they have just been “overlooked”

Mg II Weak Absorption Studies...

Statistical population study presently extends from $0.4 < z < 1.4$



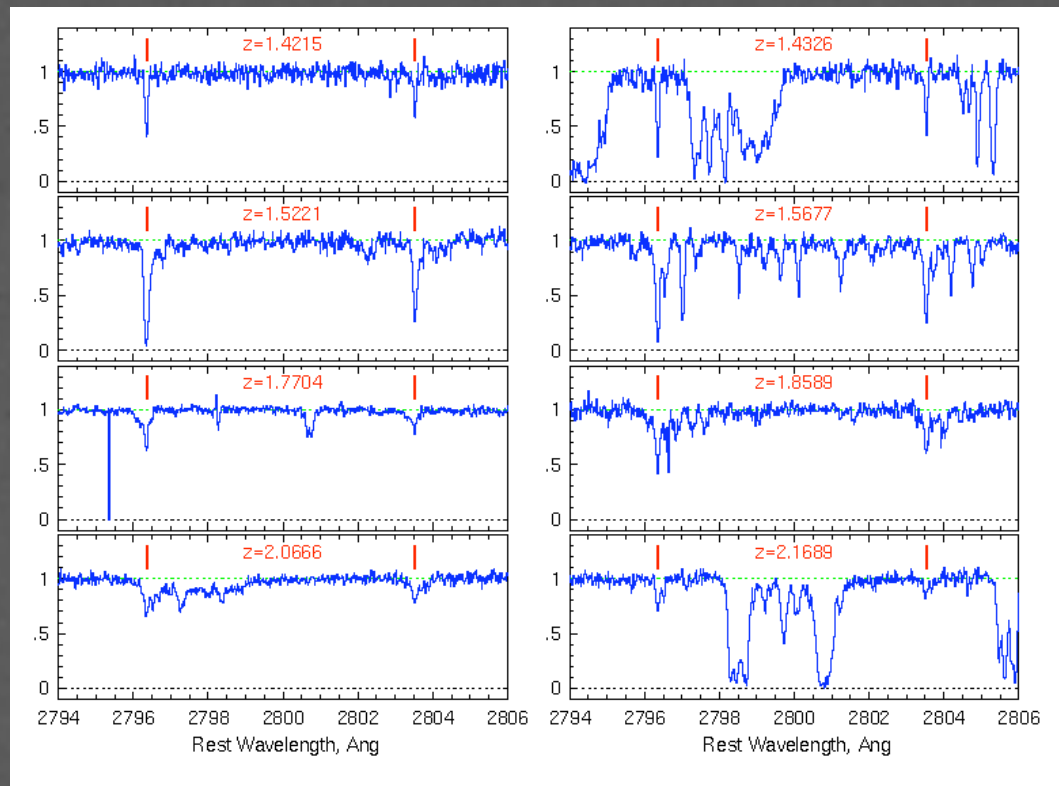
Mg II Weak Absorption Survey at $z > 1.4$

w/ Wal Sargent, Michael Rauch, & Michael Murphy

108 HIRES/Keck spectra

81 UVES/VLT spectra

Have analyzed only 78 HIRES Spectra so far....

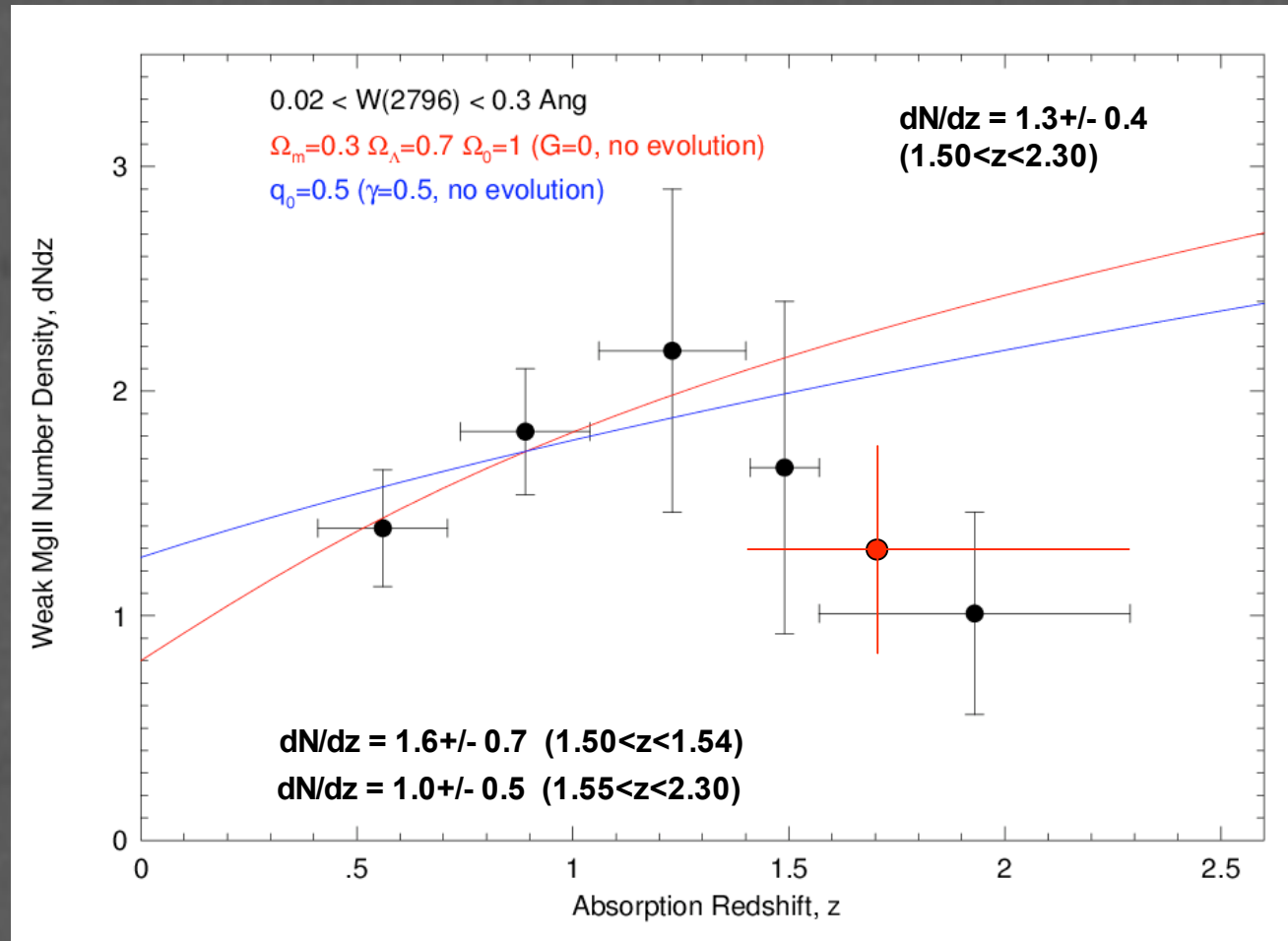


At higher redshift, the critical calculation is the redshift path of the survey... sky lines, blends, and heavy atmospheric absorption requires careful accounting

So far, we find...

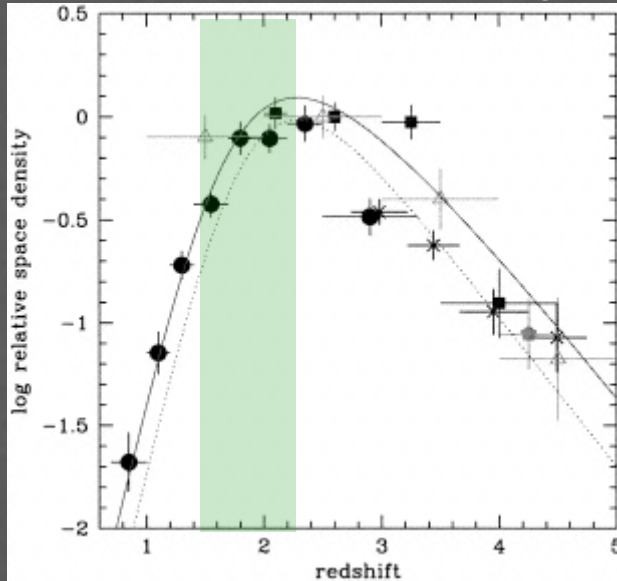
Mg II Weak Absorption Survey at $z > 1.4$

With additional 100 spectra, most with redder wavelength coverage, we anticipate a factor of two decrease in the error bars...



See Poster: Misawa et al

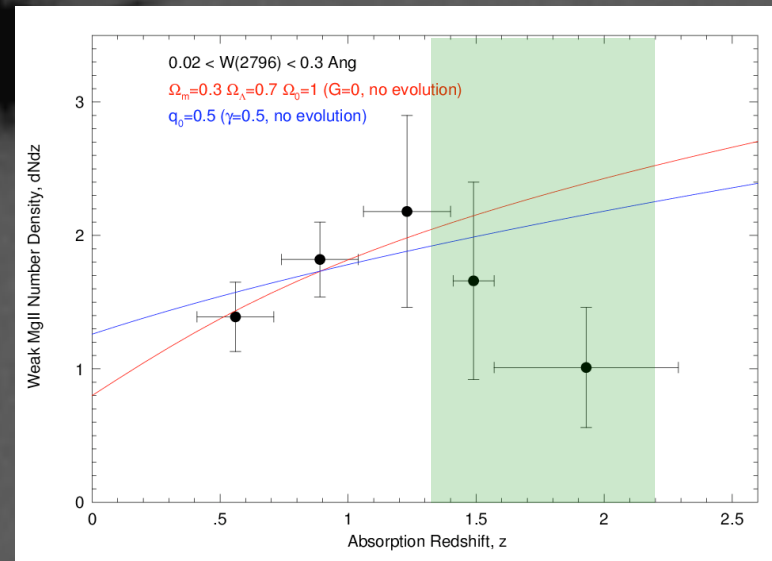
QSO z-Space Density



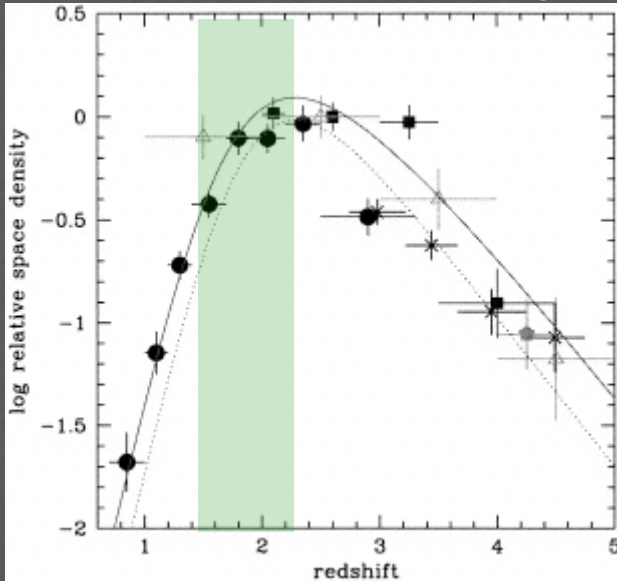
Space density of quasars drops
0.7 dex from $z=2.2$ to $z=1.4$

It drops a further 2 dex by $z=1.0$!

Weak Mg II z-path Density

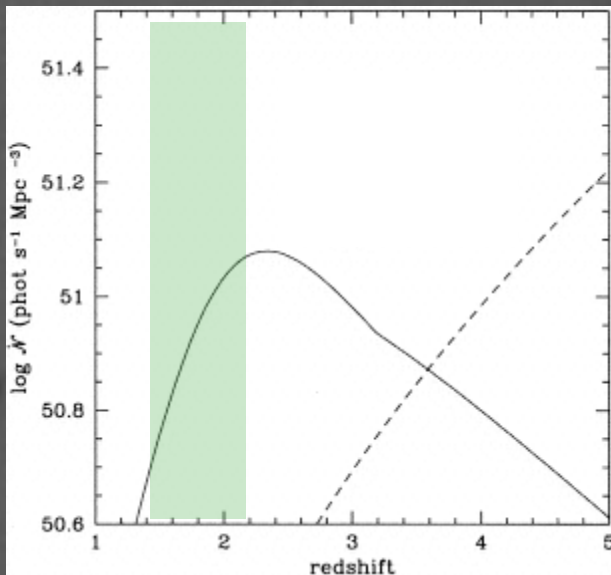


QSO z-Space Density

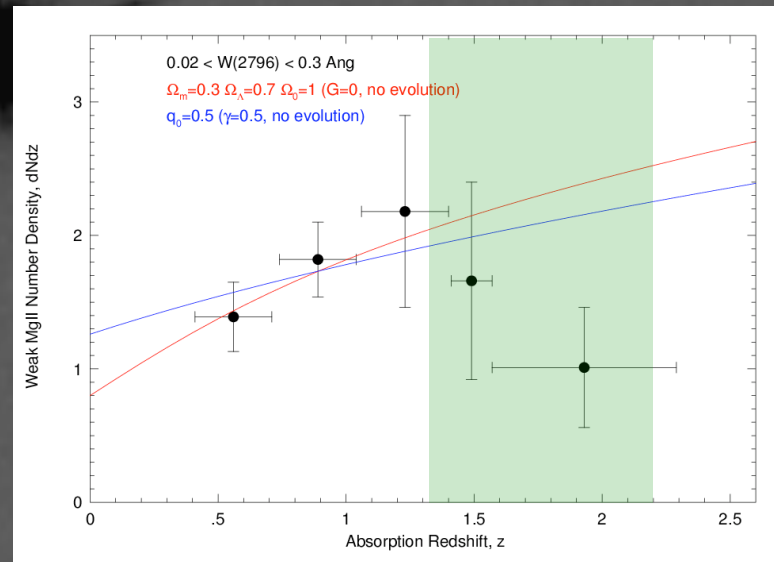


Space density of ionizing photons drops 0.5 dex from $z=2.2$ to $z=1.4$, and continues to drop rapidly with decreasing redshift.

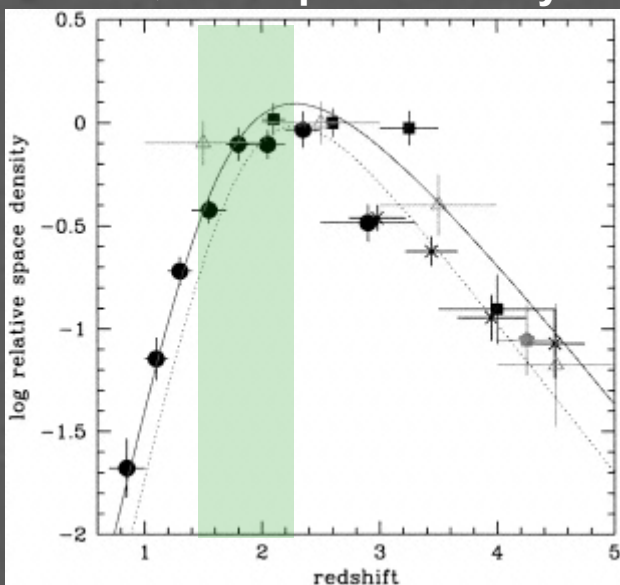
I_{912} z-Space Density



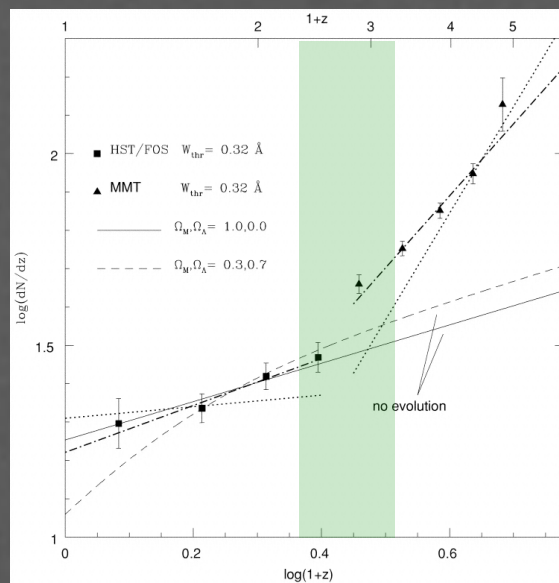
Weak Mg II z-path Density



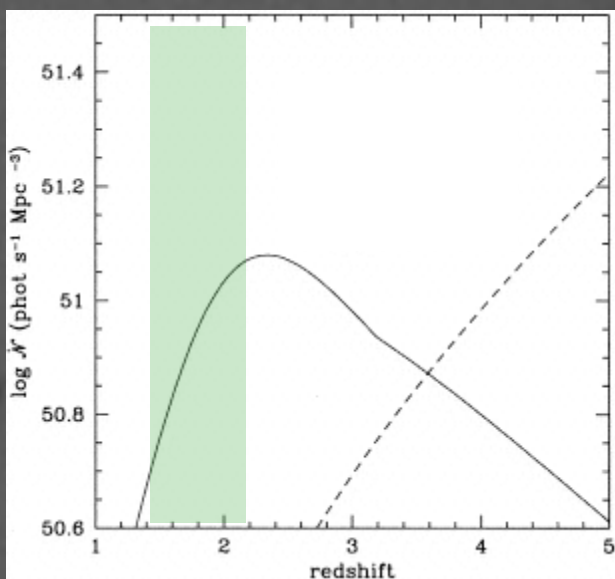
QSO z-Space Density



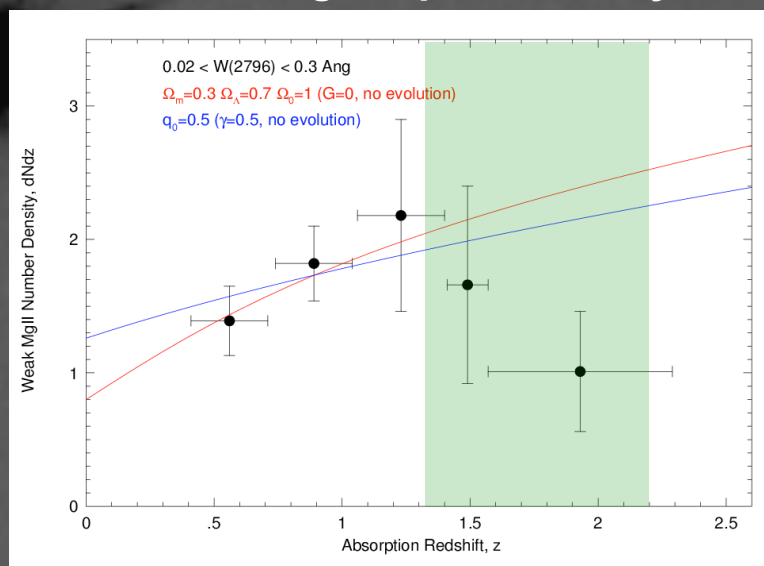
Lya z-path Density



I₉₁₂ z-Space Density



Weak Mg II z-path Density



Concluding Remarks...

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Stay tuned...