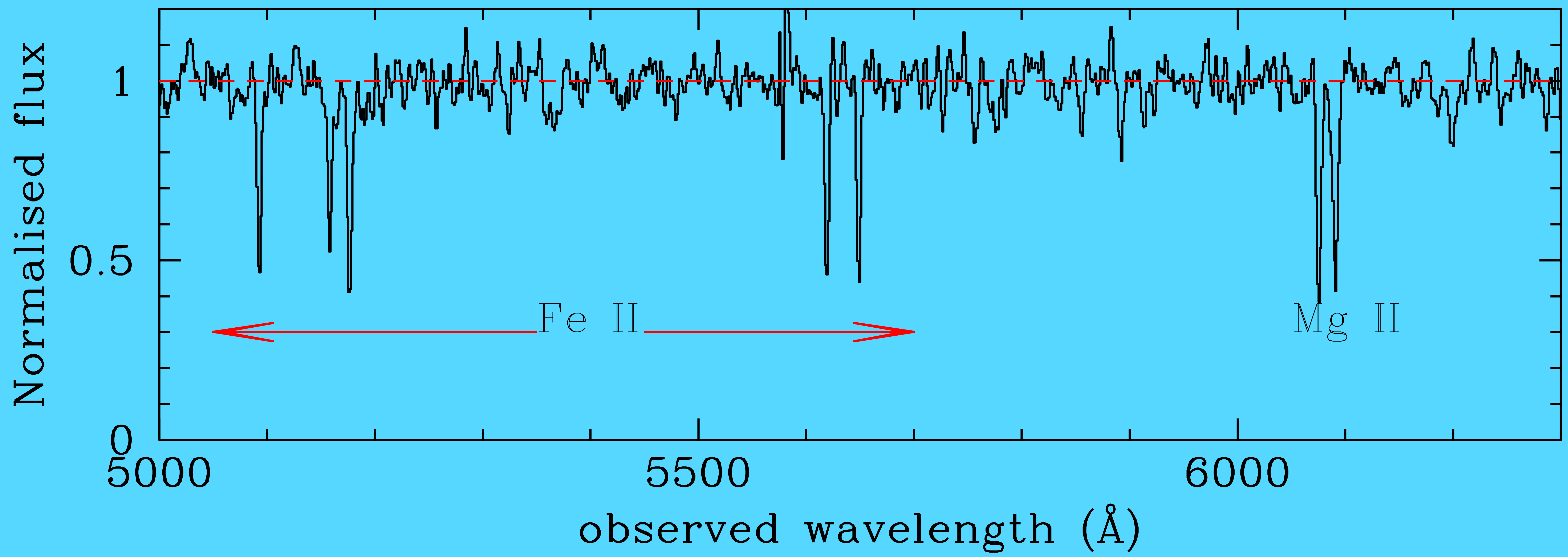
R. SRIANAND (IUCAA)

REVIEW OF SCIENCE QUESTIONS IN CGM AND IGM STUDIES

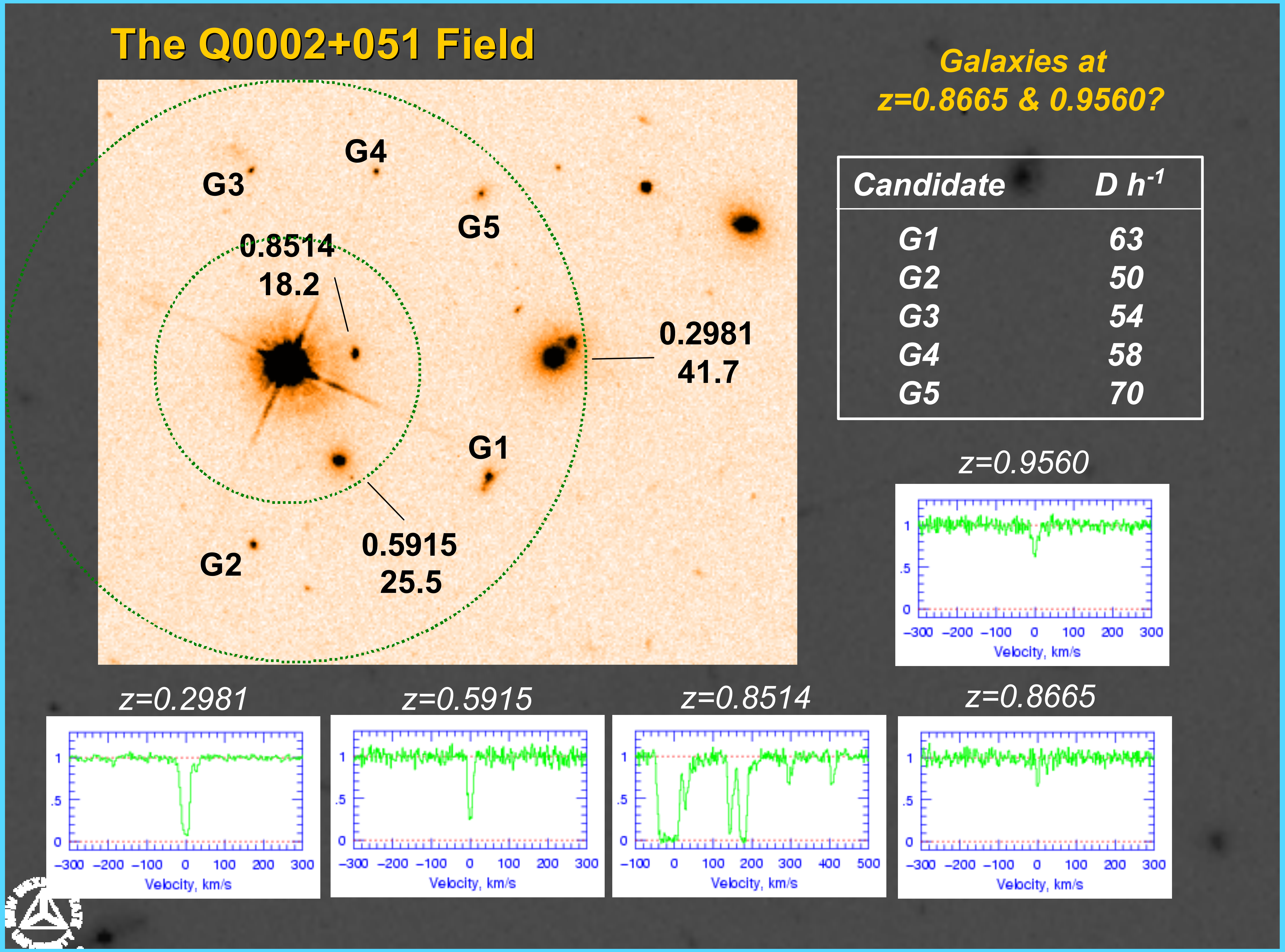


SOME NUMBERS RELATED TO THE MGII ABSORBERS

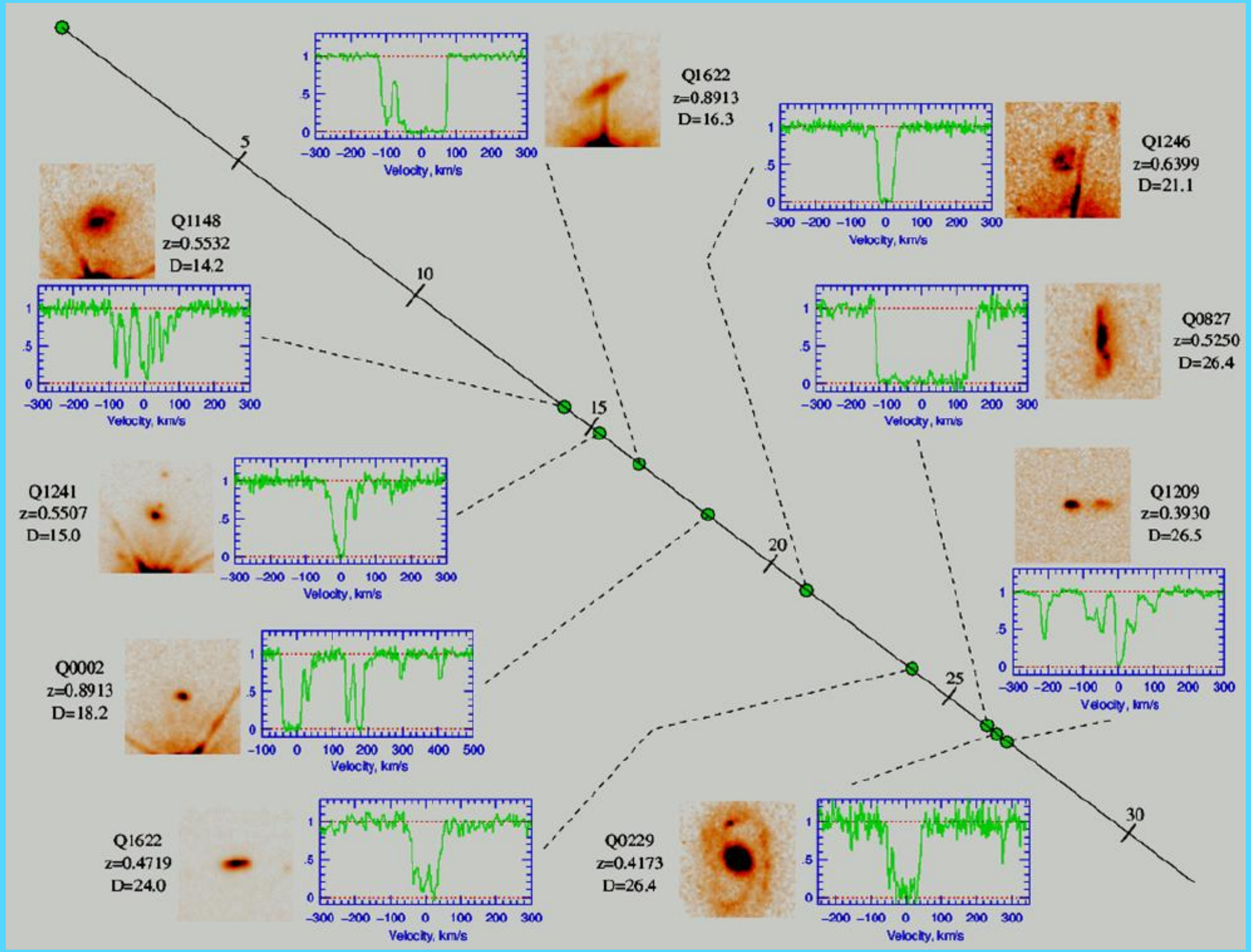
- λ_r = 2796 and 2804 Å. In the case of SDSS/BOSS one can detect it beyond $z \sim 0.28$ upto $z \sim 2.3$. In principle good UV spectrographs allow one to go upto $z \sim 0.1$ in the blue.
- Mg I, Mg II and Mg III $->$ 7.646, 15.036, 80.143 eV – In LLS Mg will be mostly in Mg II. The corresponding energy for Fe are 7.86, 16.6, 30.651 eV.
- Mg and Fe have identical abundance in Sun. When shielded Mg II and Fe II will have identical column densities. W(Fe IIλ2600)/W(Mg IIλ2796)$>$0.5.
- For SDSS spectrum with a s/n of 5 per pixel a typical 5σ detection limit is 0.6Å. You will be comfortably detecting Mg II doublets with rest equivalent width in excess of 1Å. This is the detection threshold for most statistical samples.

	b= 10 km/s	20 km/s	$>$ 50 km/s
log N(Mg II)	17.00	16.00	13.5
log N(H I), Z = $Z_\odot$	21.42	20.42	17.9
log N(H I), Z = 0.1 $Z_\odot$	22.42	21.42	18.9
DR	1.00	1.00	2.00

MG II ABSORPTION GALAXY CONNECTION

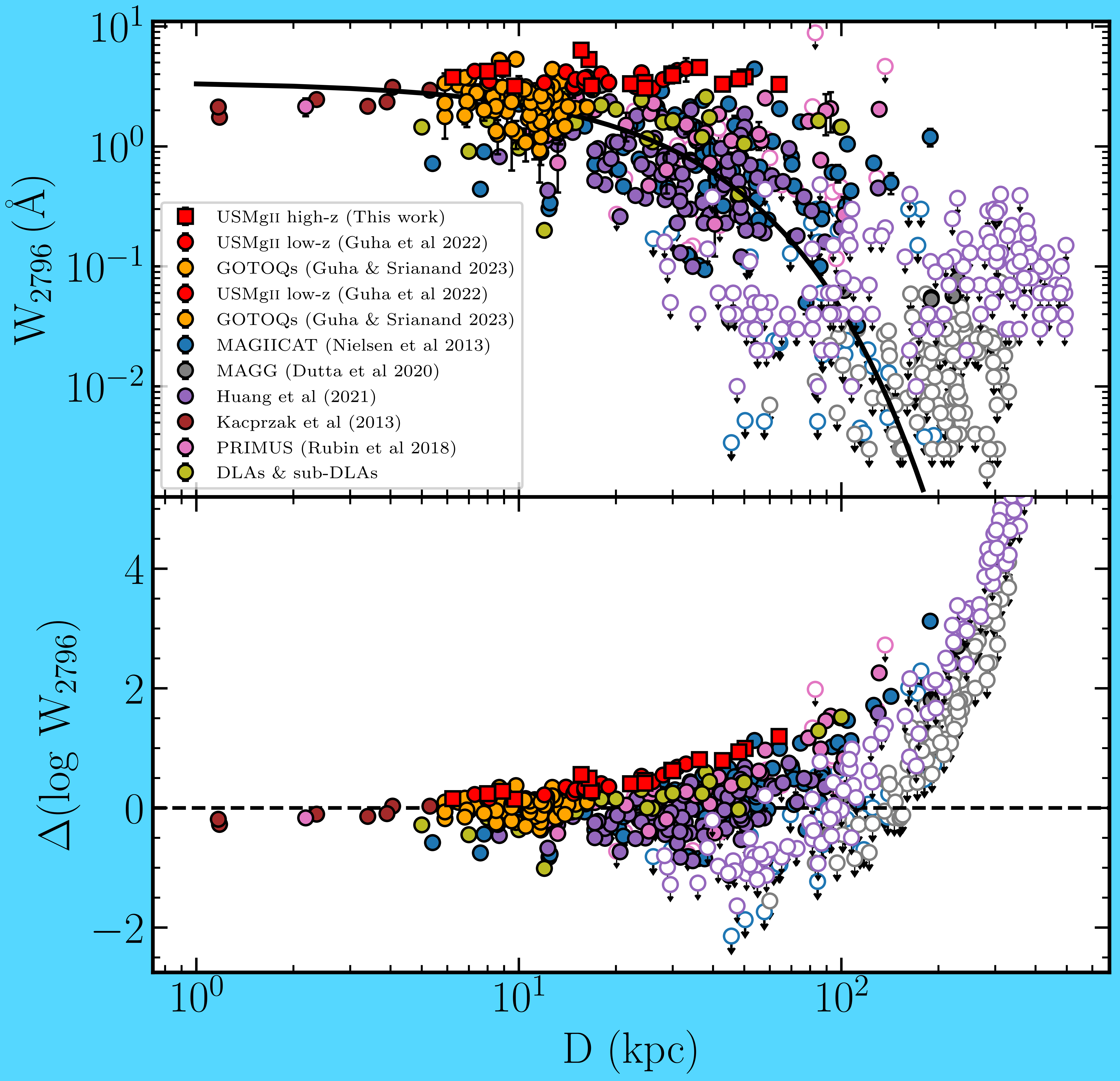


Candidate	D h^{-1}
G1	63
G2	50
G3	54
G4	58
G5	70

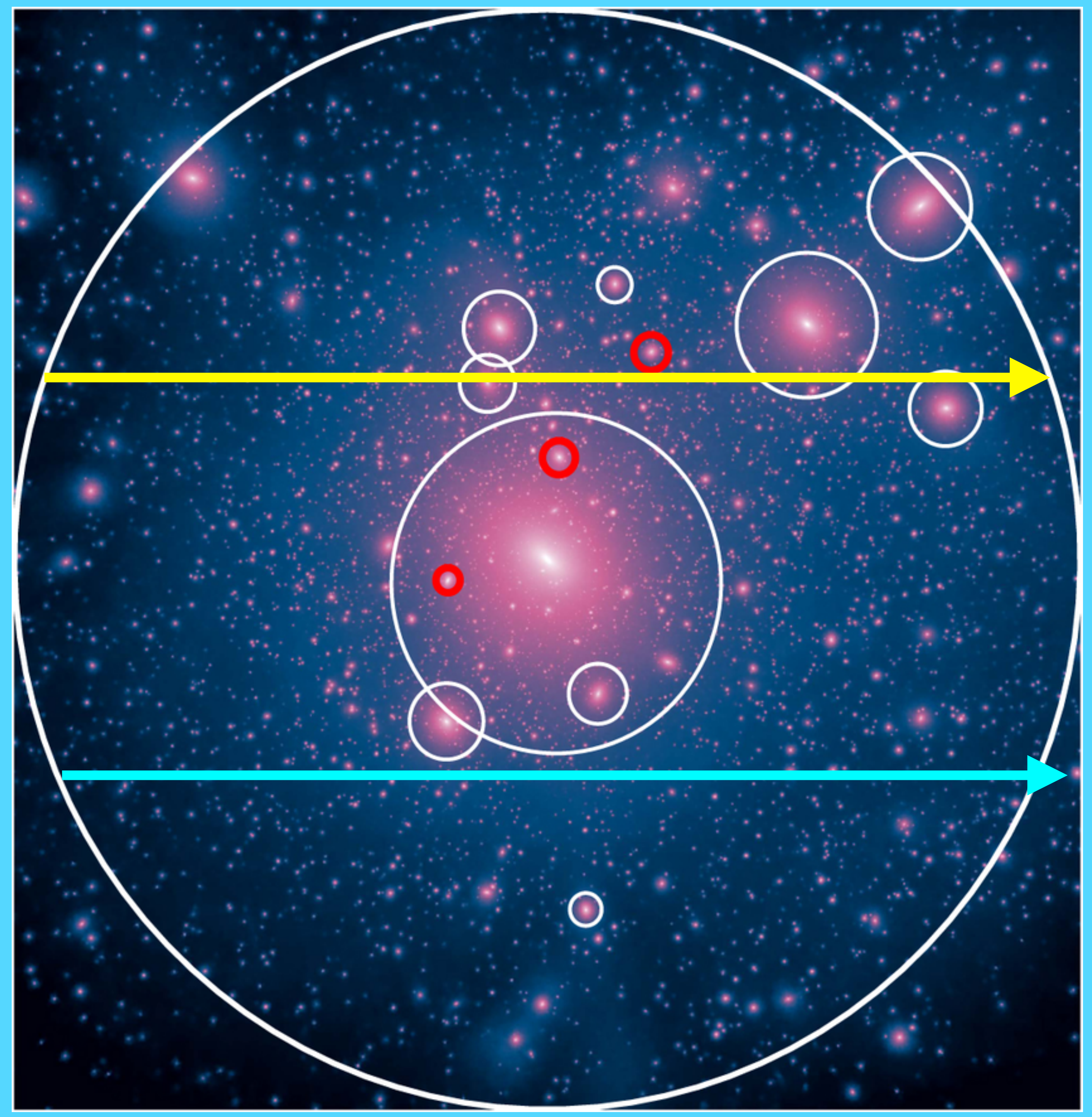


- Main argument is, absorber based galaxy selection is a luminosity unbiased way of detecting galaxies!. Does it probe a new population of galaxies.

REST EQUIVALENT WIDTH AND IMPACT PARAMETER

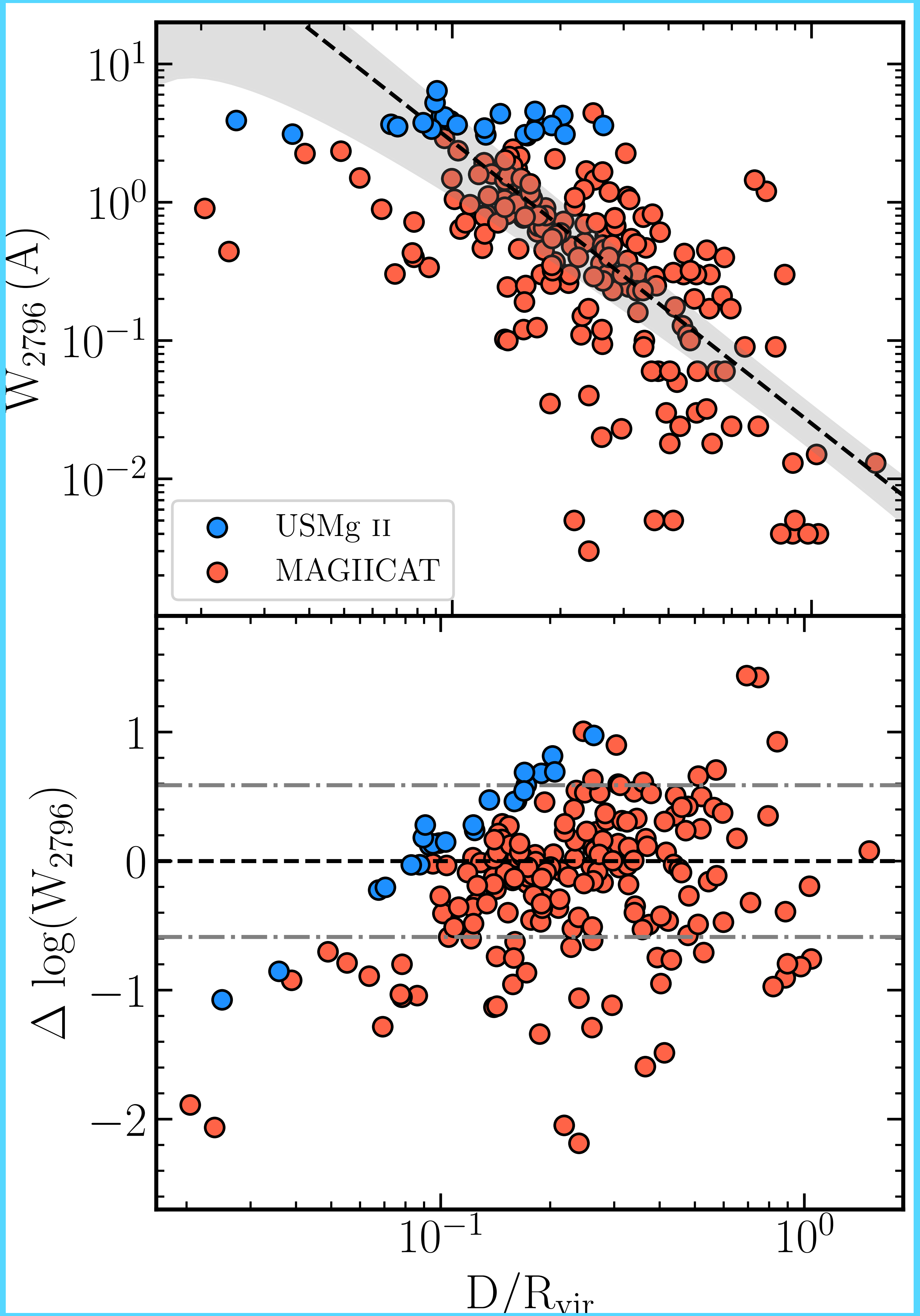


- The Mg II absorbing gas is associated with foreground galaxies.
- At any given impact parameter (D) one has a large scatter in W. There are other parameters (stellar mass, star-formation rate, environment etc.,) at play.



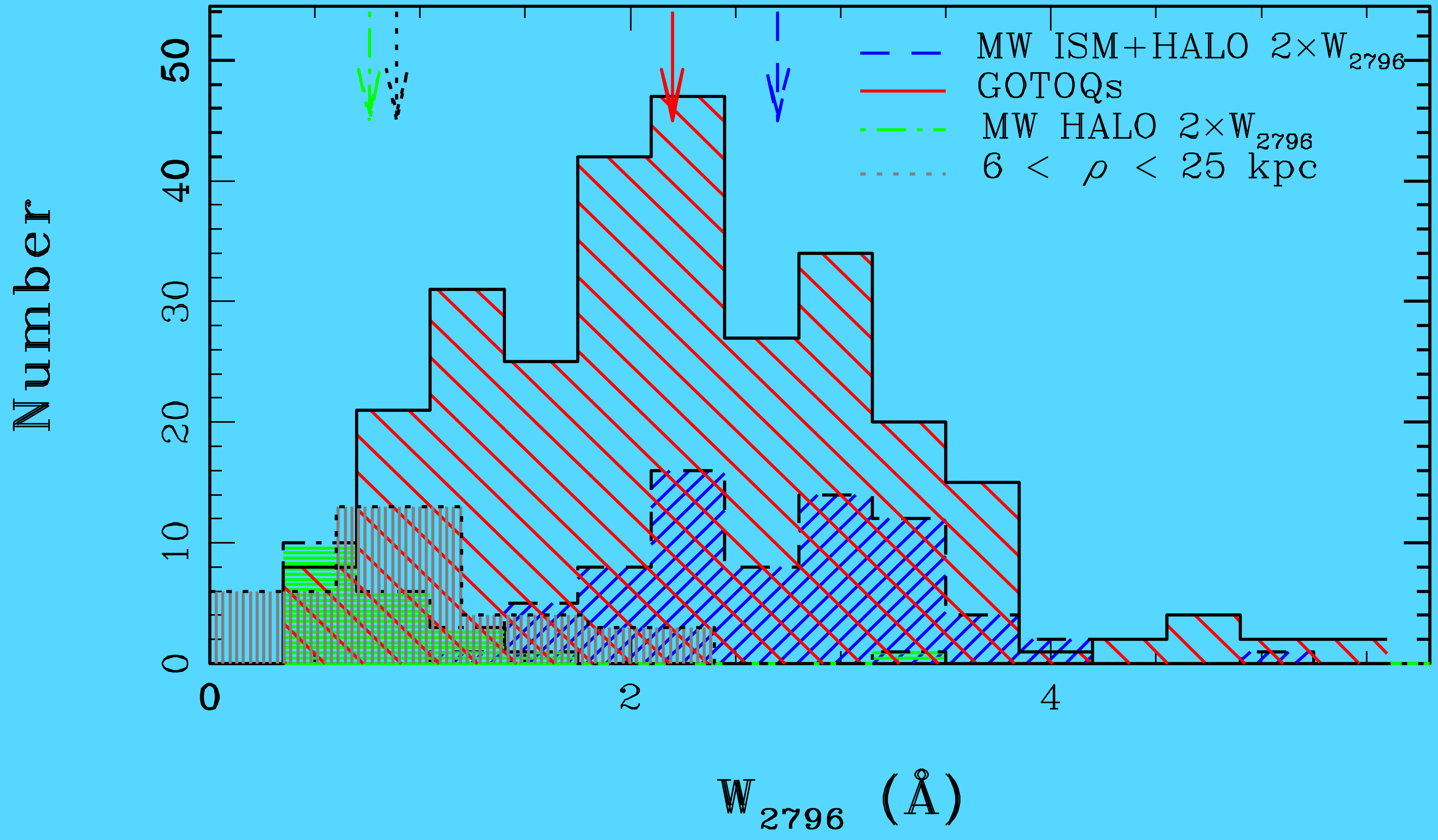
For a given impact parameter absorption will depend on the velocity and density field of gas associated with the satellite galaxies and gas from Interactions.

REST EQUIVALENT WIDTH AND SCALED IMPACT PARAMETER

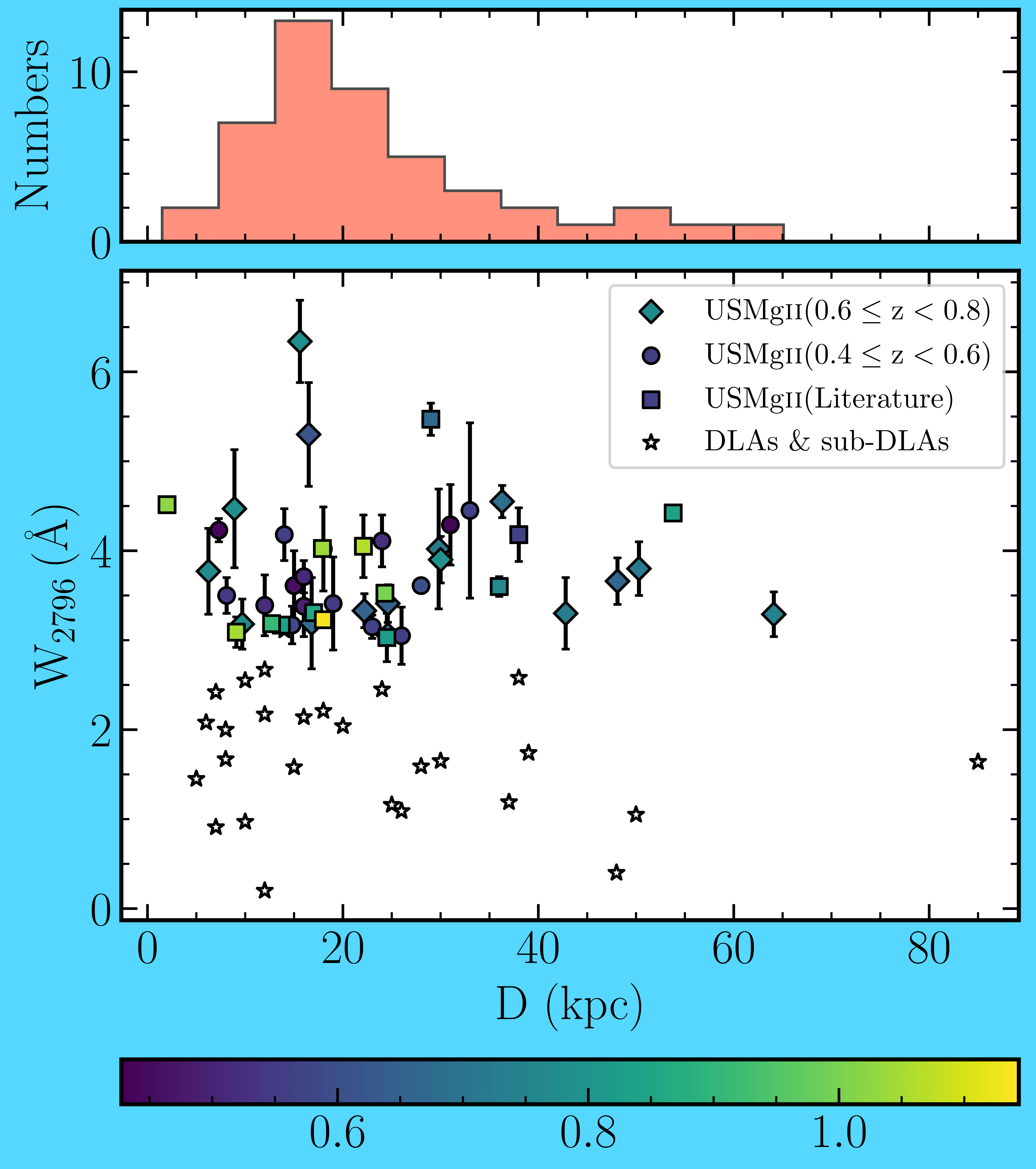


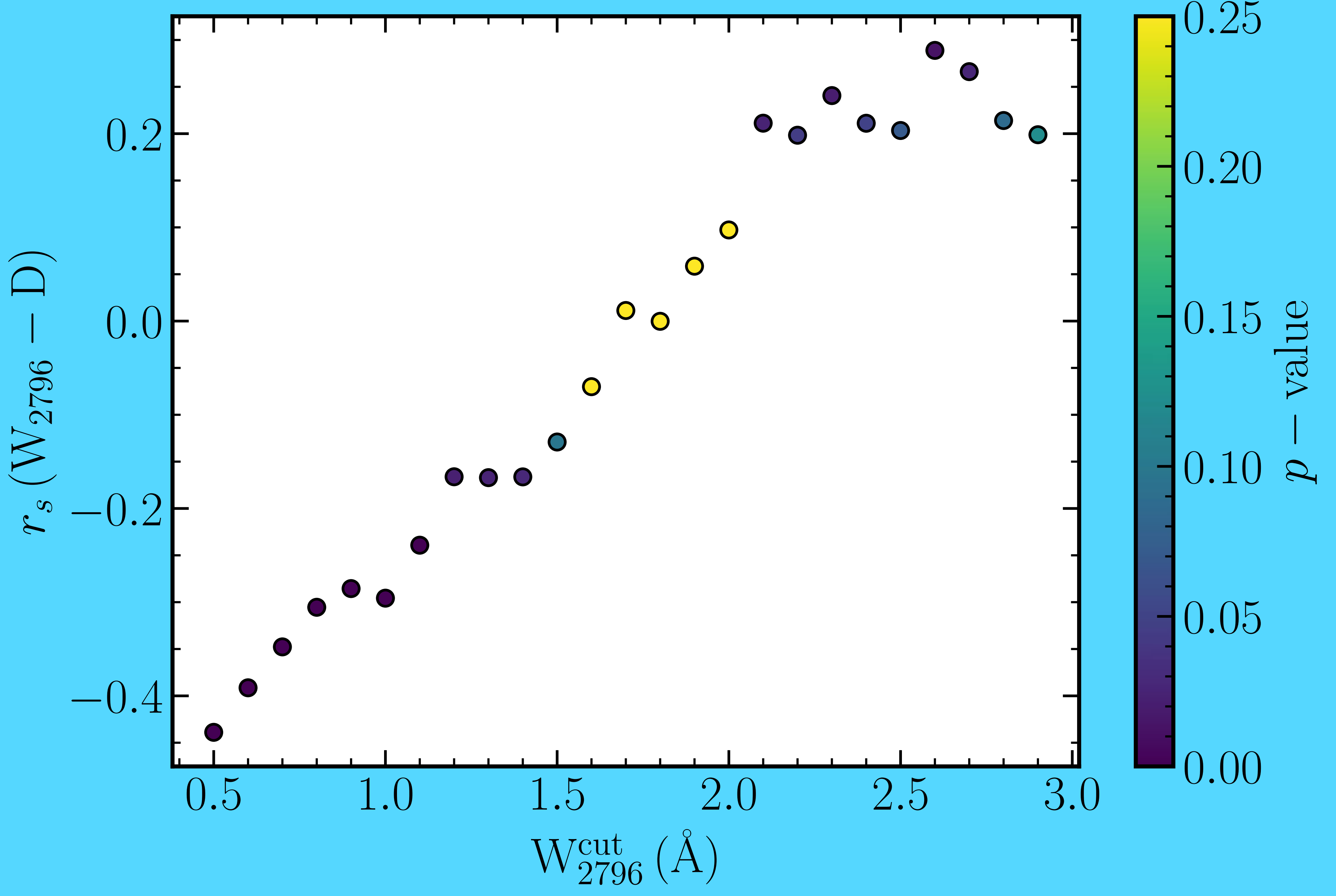
- Instead of impact parameter, one tries to use the impact parameters scaled by the viral radius.
- There is a feeling that the scatter is reduced when we use the scaled impact parameter.
- Still for a given scaled impact parameter there is large scatter in the equivalent width.
- Also are we sure we estimate the correct Virial radius (Stellar mass—>halo mass—>Viral radius).

EQUIVALENT WIDTH DISTRIBUTION AT DIFFERENT SCALES?



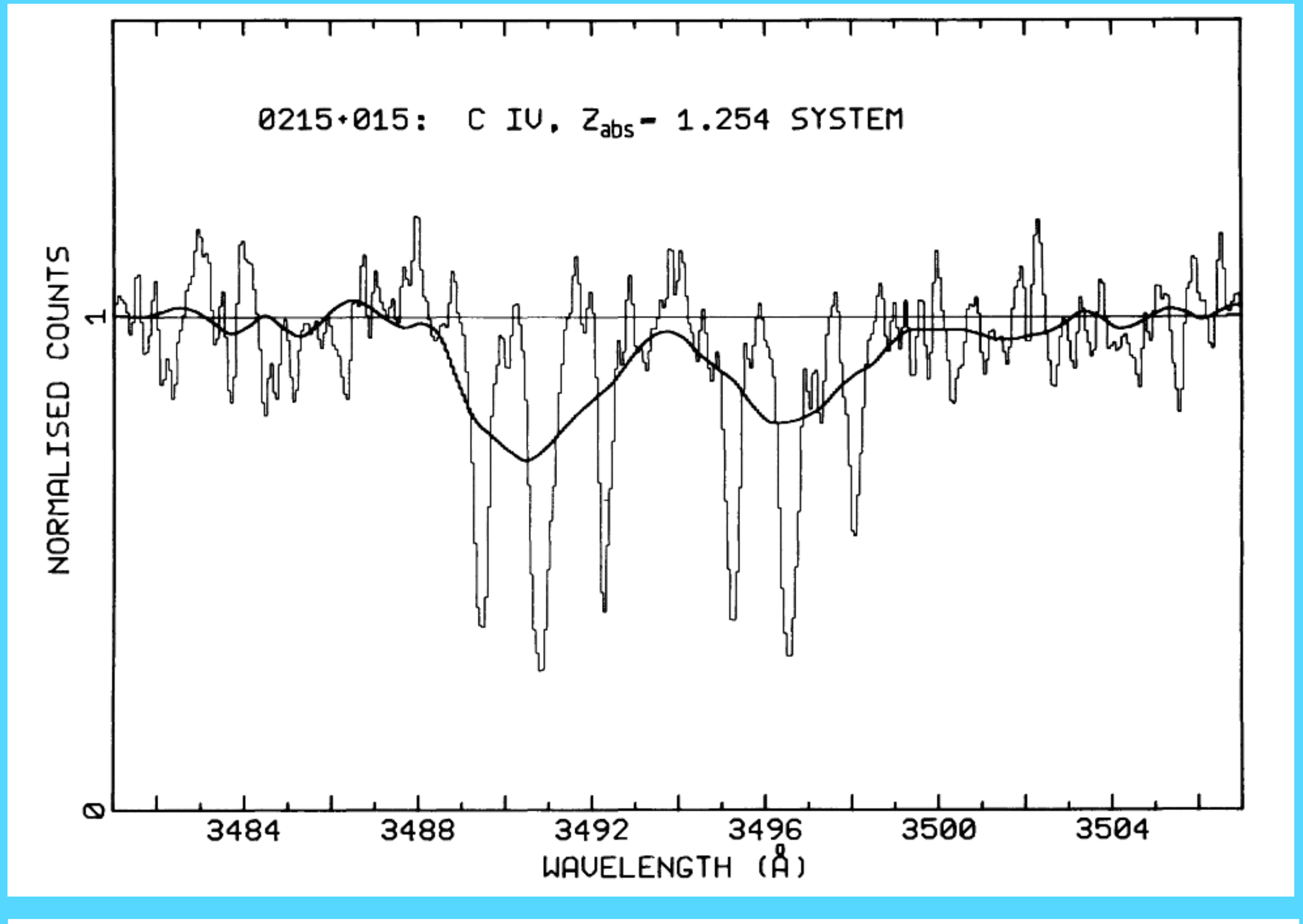
REST EQUIVALENT WIDTH AND IMPACT PARAMETER

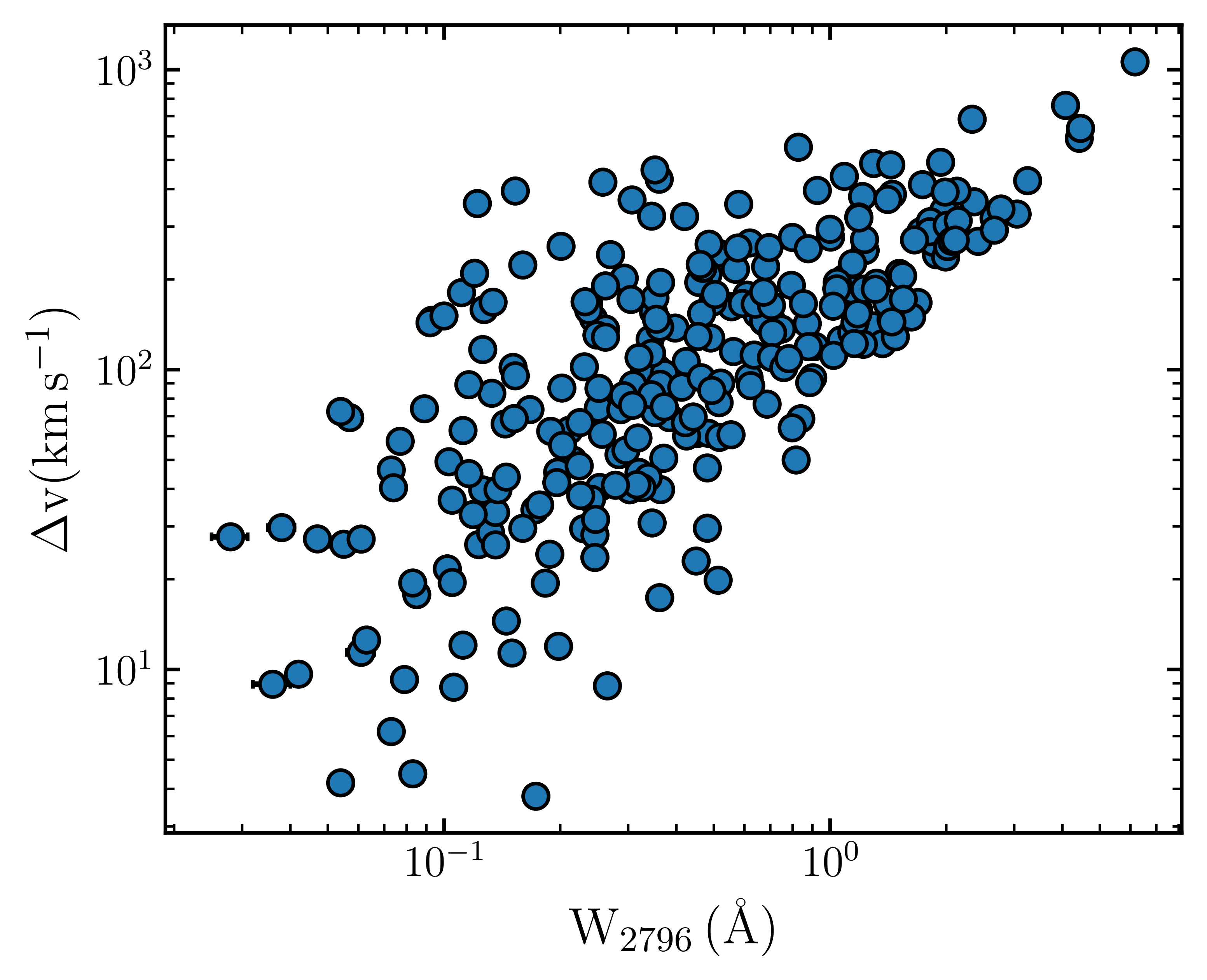


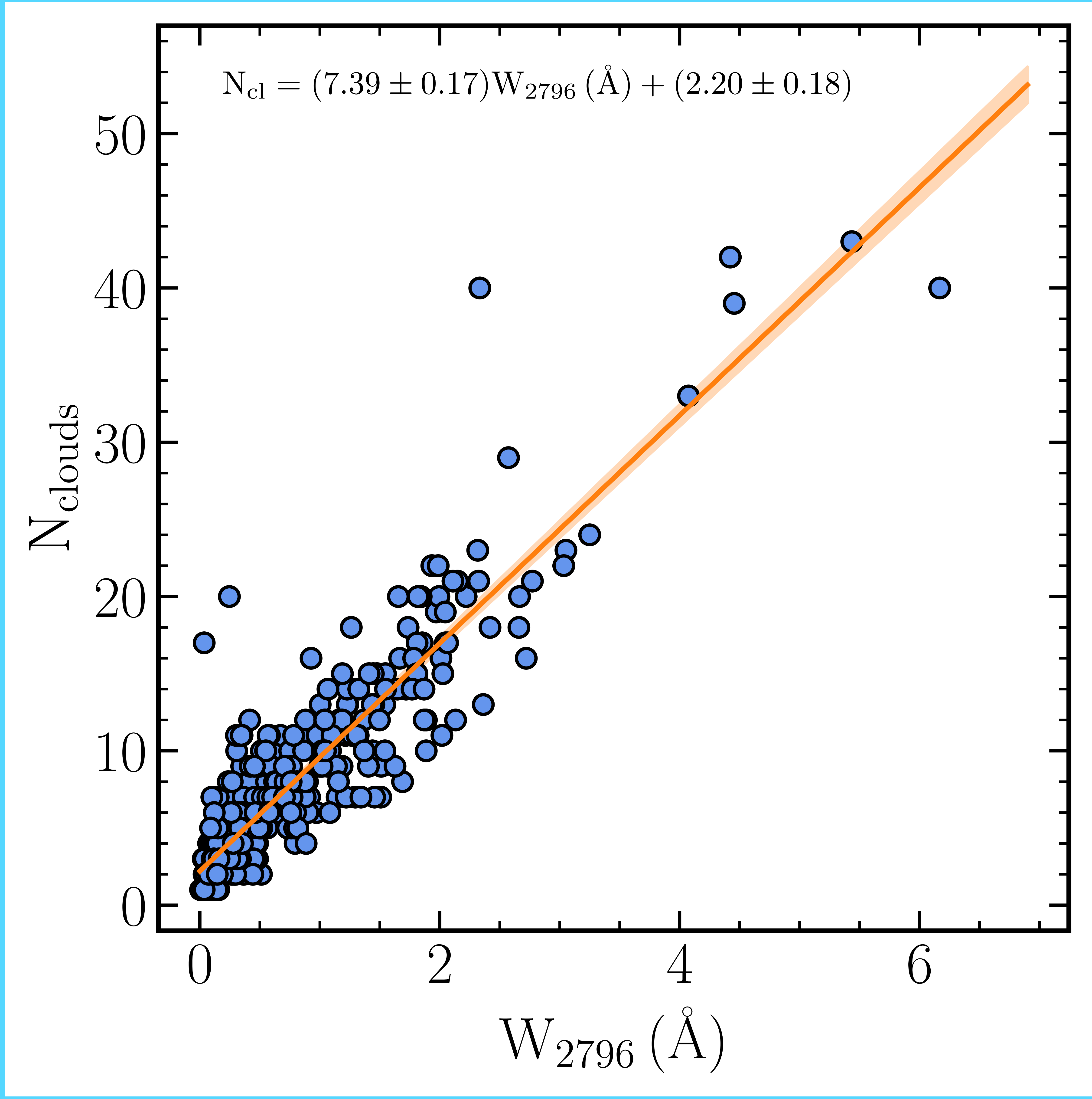


- Correlation emerges only when a wide range of equivalent widths are considered.
- Absorbers selected based on DLAs does not show any clear W vs. D correlation.

REST EQUIVALENT WIDTH AND NO. OF CLOUDS







WHAT ARE THESE CLOUDS?

5410 *M. McCourt et al.*

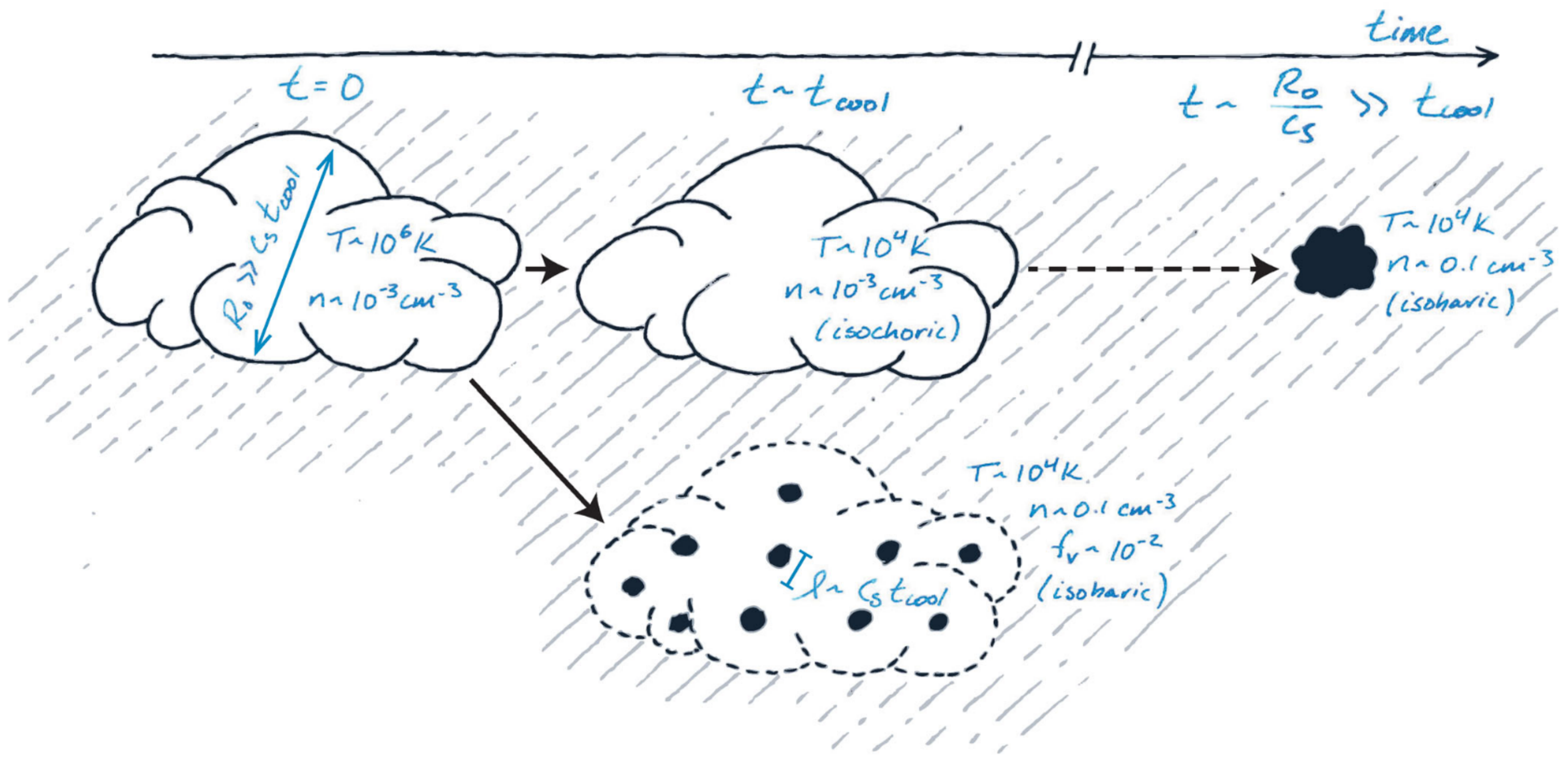
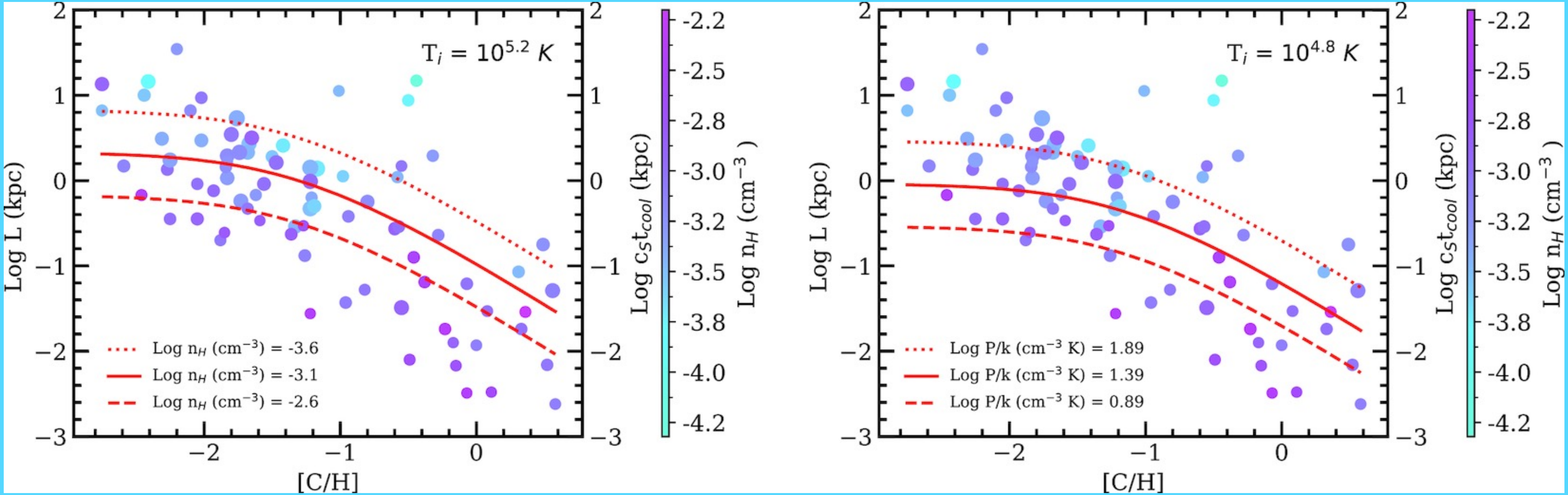
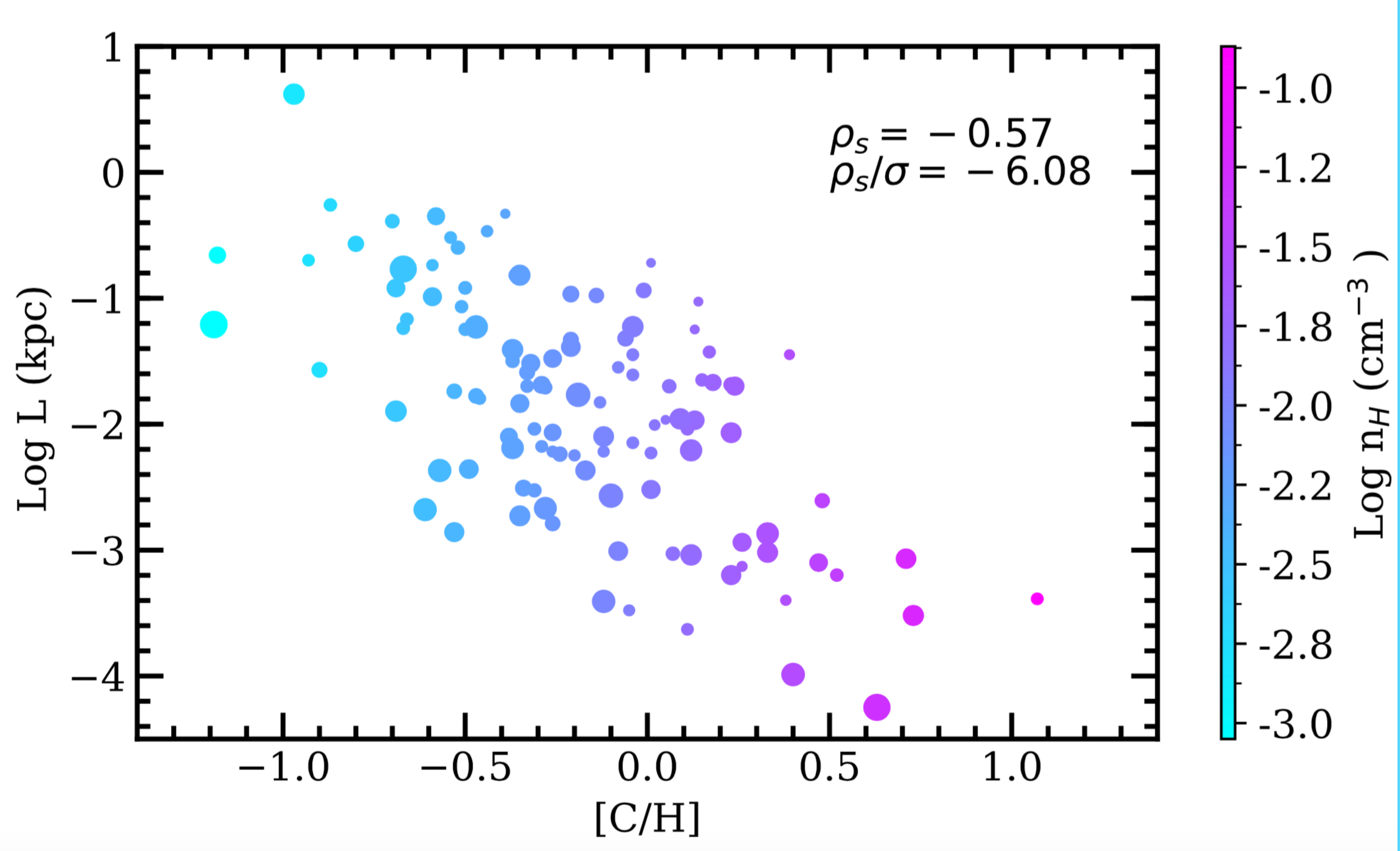


Figure 3. The fastest path to equilibrium is to shatter. We imagine a cooling perturbation with an initial size $R_0 \gg c_s t_{\rm cool}$ embedded within an ambient medium, represented by grey hatching. (*top route*): It is commonly assumed (e.g. Field 1965; Burkert & Lin 2000) that such a perturbation will cool isochorically, reaching 10^4 K after one cooling time, with little change in the cloud size or density. The resulting cloud is severely underpressured and out of equilibrium; it contracts on the (much larger) sound-crossing time-scale, only afterwards reaching pressure equilibrium. (*bottom route*): A much more direct path to pressure equilibrium is for the cloud to fragment into smaller pieces, each with a scale $\sim c_s t_{\rm cool}$; such fragments can cool isobarically, never leaving equilibrium. (Not shown.) As these fragments cool, the lengthscale $c_s t_{\rm cool}$ shrinks; when this happens, the clumps fragment to yet smaller scales, never deviating dramatically from pressure equilibrium.

- Multiphase medium in pressure equilibrium? - what keeps the phase structure?- is there hydrostatic equilibrium?
- Instabilities: cooling instability, Rayleigh–Taylor instability etc..
- Survival issues: Evaporation, destruction due to high speed, collisions with other gas clouds, falling to the galaxy due to gravitational forces.
- Time scales: free fall time, collision time, cooling time, typical reheating frequency/ time, interaction and stripping time-scales.

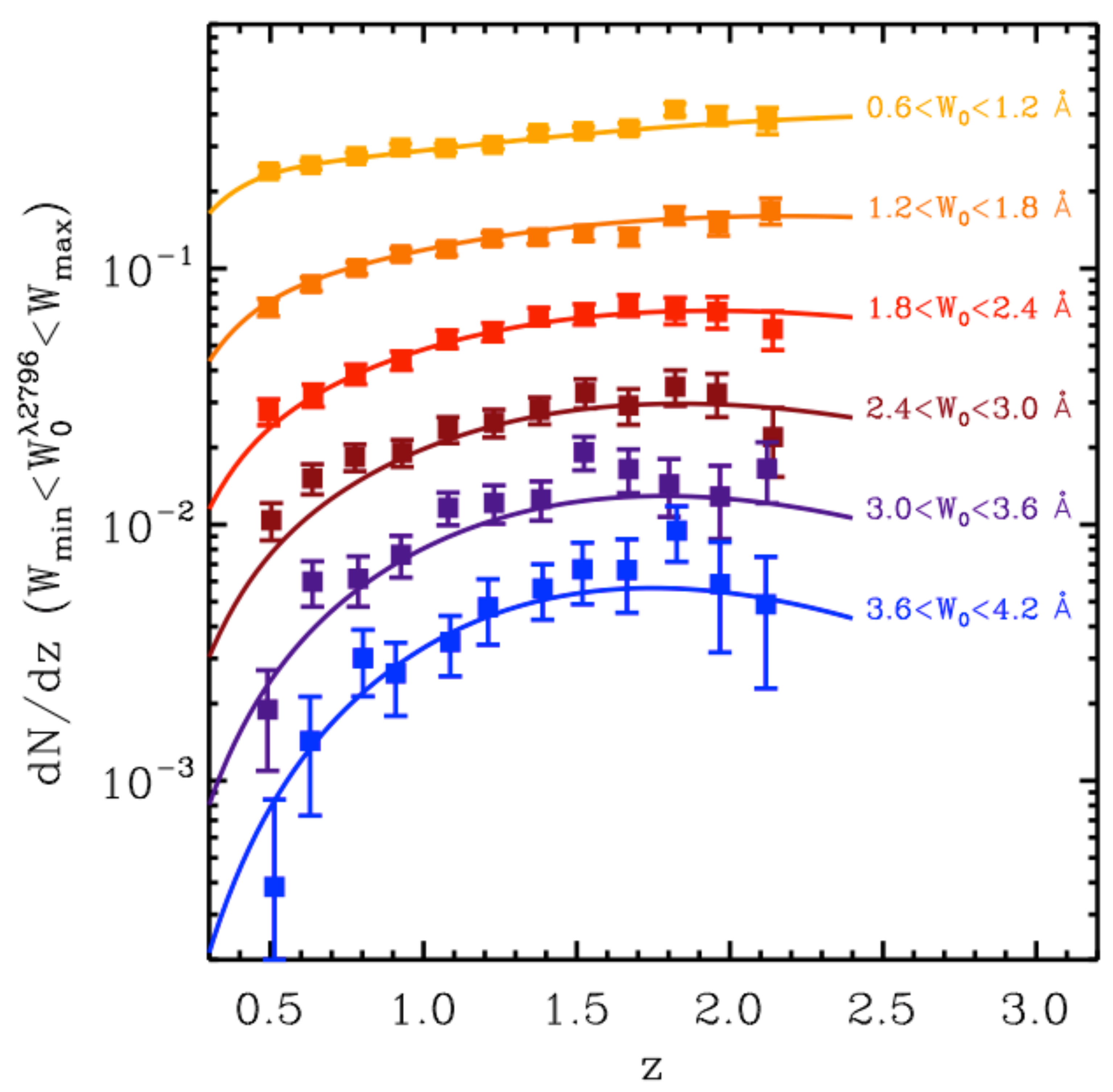
ANY HINTS ON THE PHYSICS OF CLOUDS?

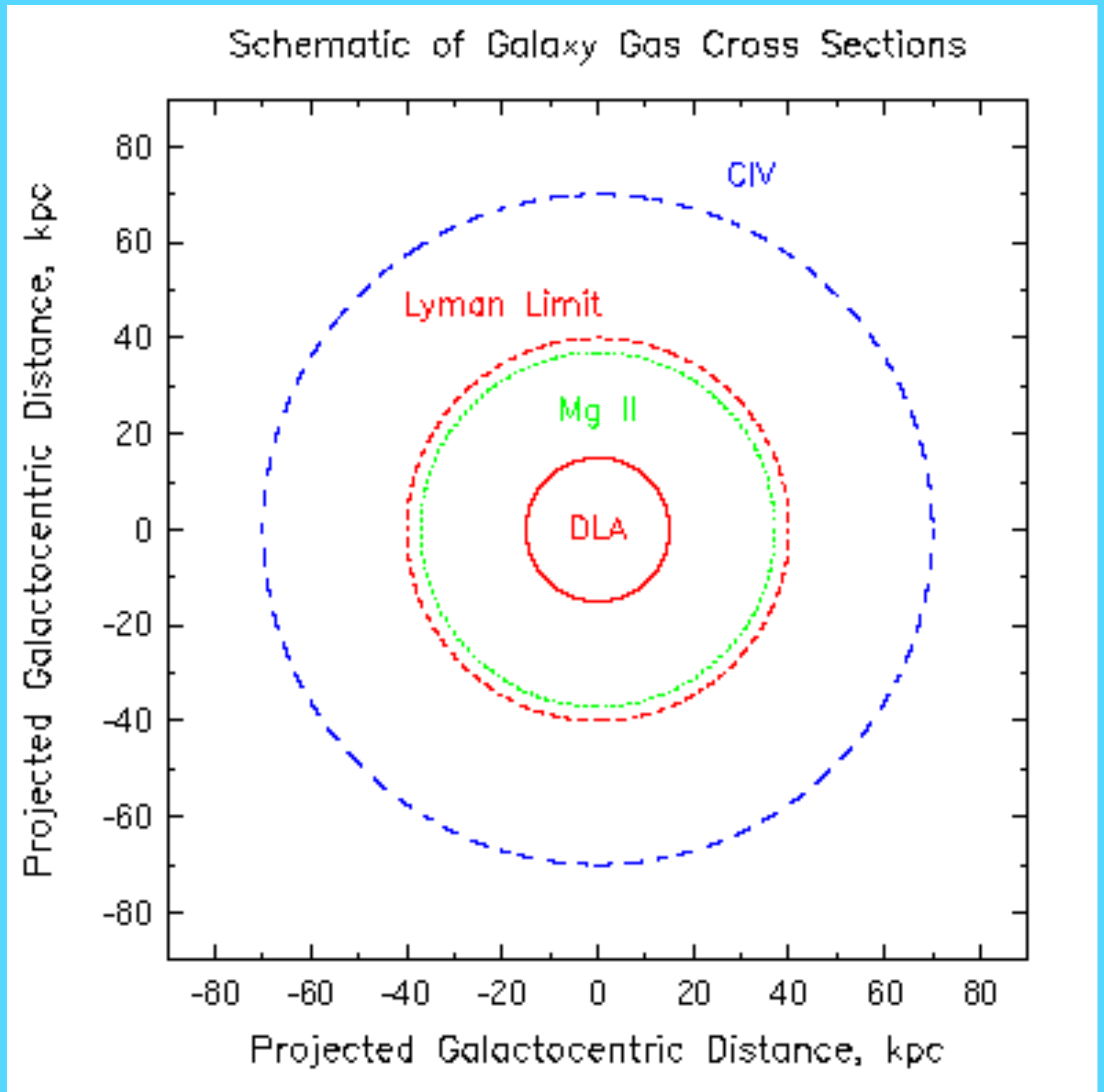


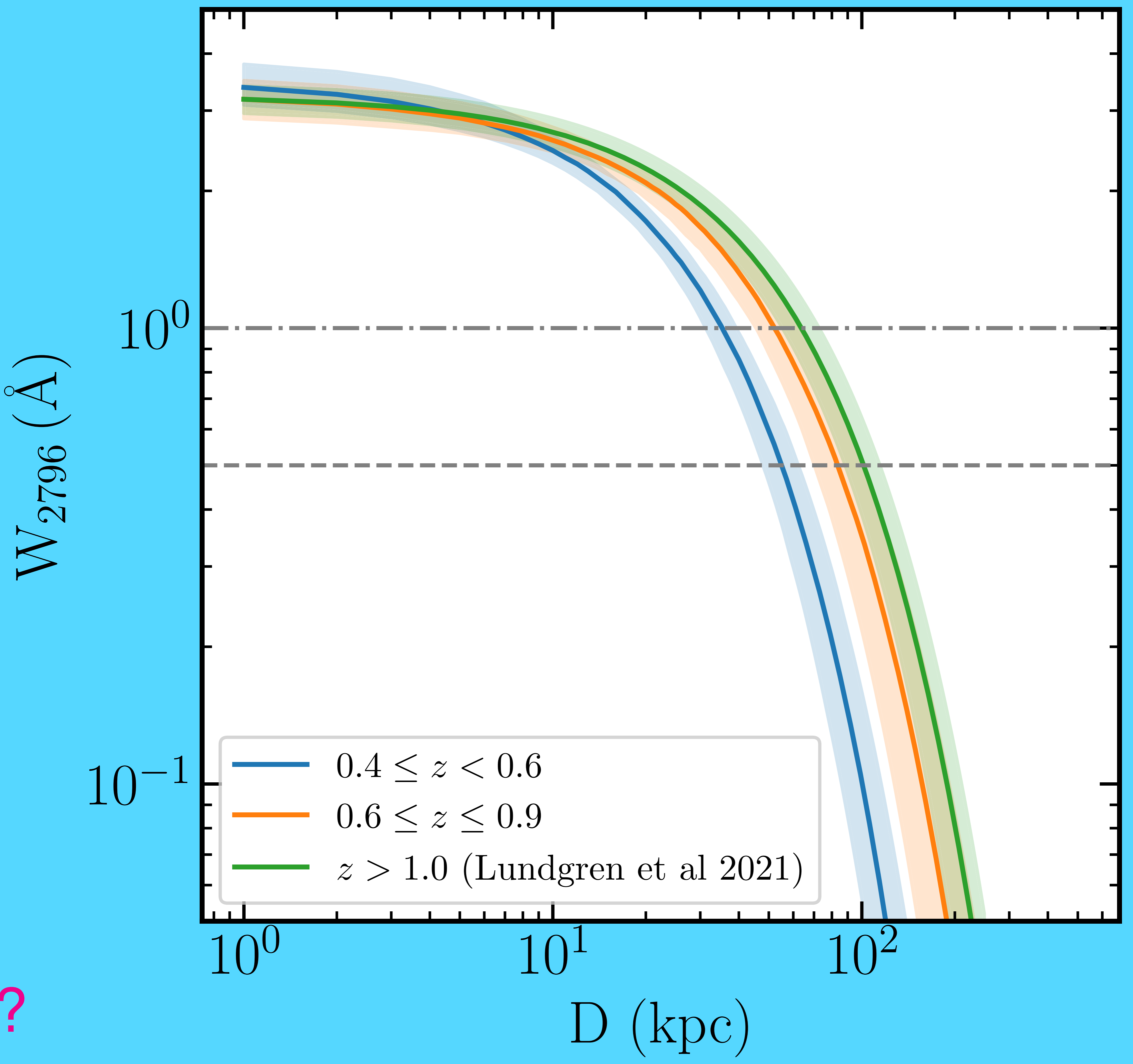


- A strong anti-correlation is seen between L and metallicity (and density) at low as well as high-z.
- It seems one can easily explain this if we related L to the cooling length as for a given density the cooling rates are higher for higher metallicities.
- As all time scales are small we need a steady state formation of such clouds to explain the observations.

GAS AROUND GALAXIES:







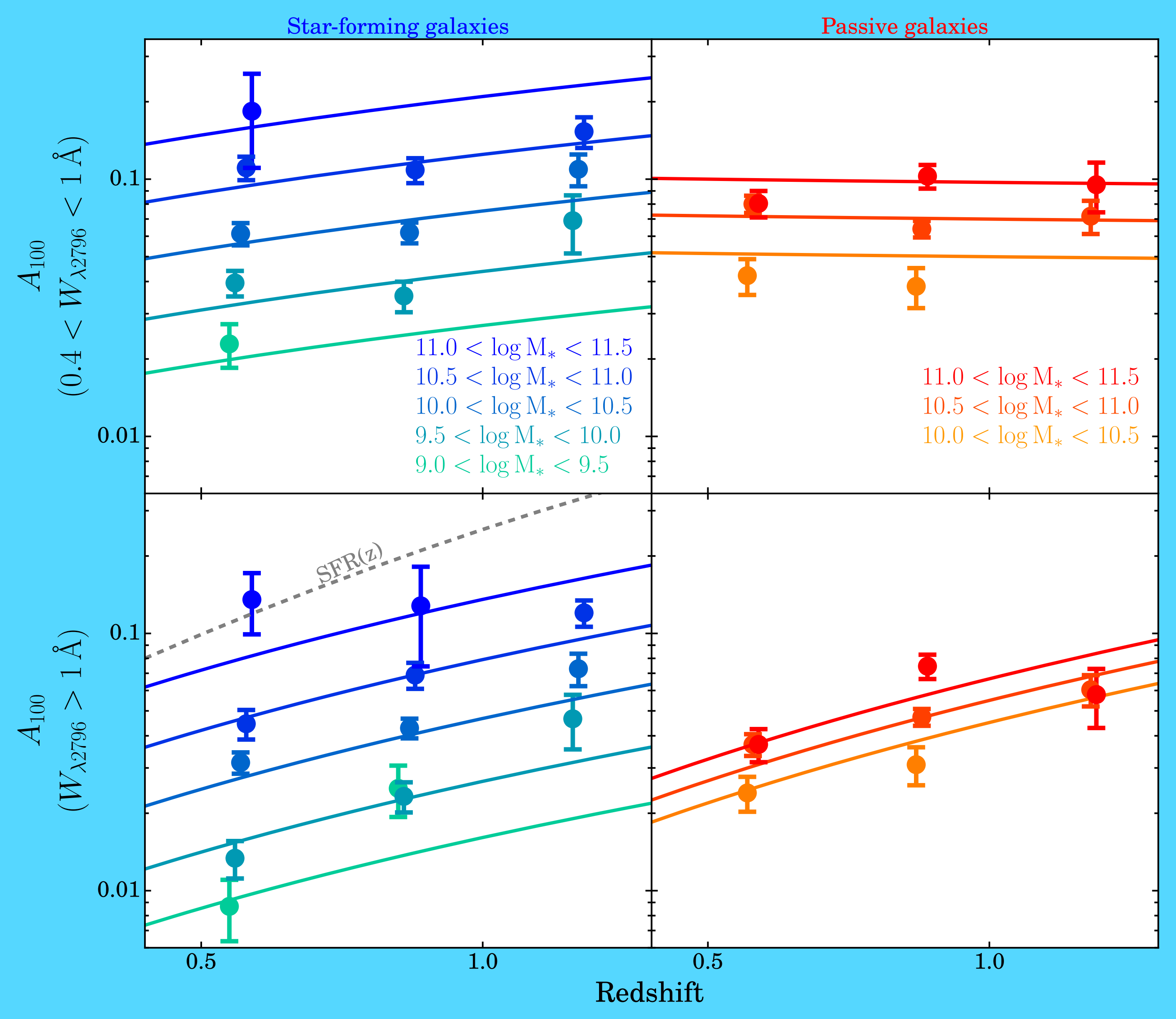
what about including gas covering factor?

Gas covering factor
Should evolve with z

equivalent width. In a simple model where all-known galaxies have a spherical gaseous halo of the same radius and gas covering factor f_c, the average number of Mg II absorbers per unit redshift interval is given by $\langle dN/dz \rangle = f_c \pi D^2_{\rm max} \int_{L_{\rm min}}^{\infty} \phi(L,z) dL \times dl/dz$. Here, $D_{\rm max}$ is the maximum impact parameter for a given value of W^{cut}_{2796} for which dN/dz is computed. $\phi(L,z)$ is the galaxy luminosity function at redshift z, and dl/dz is the differential comoving path length per unit redshift interval.

From Faber et al. (2007) we find the average number density of galaxies (with $-30 \le M_B \le -10$ and $M^*_B \sim -21.3$) per unit physical volume is ~0.90 and ~1.74 Mpc^{-3} at z = 0.5 and 1.1, respectively. Thus a factor of 2 change in dN/dz over the redshift range $0.5 \le z \le 1.1$ can purely originate from the redshift evolution of the galaxy luminosity function. From Fig. 8, if the covering fraction

GAS AROUND GALAXIES: COVERING FACTOR



$$f_c = A_{100} \times \left(\frac{r_p}{100\ \mathrm{kpc}}\right)^{\gamma},$$

$$A_{100} = A \times (1+z)^{\alpha} \left(\frac{M_*}{10^{10} M_\odot}\right)^{\beta}.$$

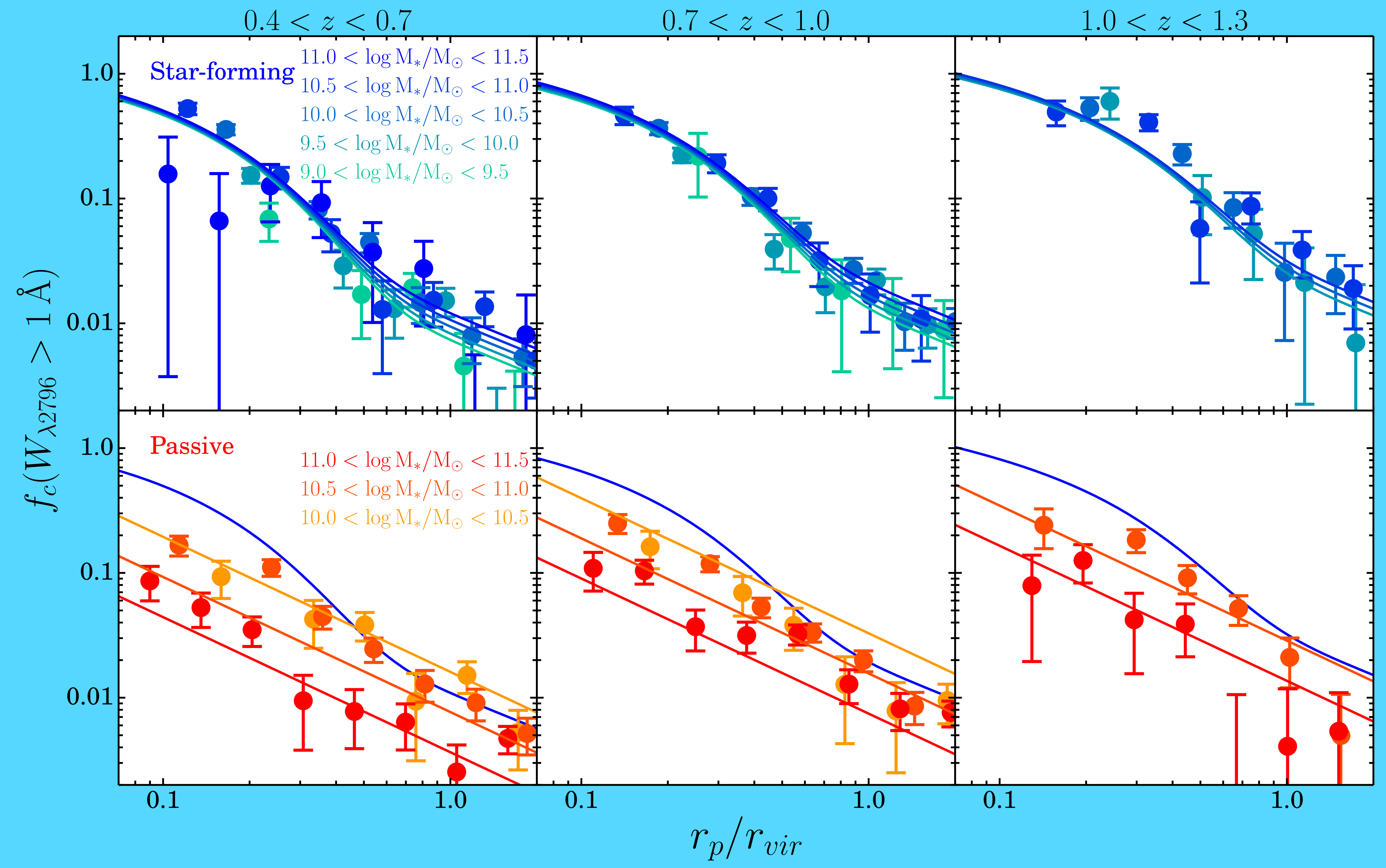
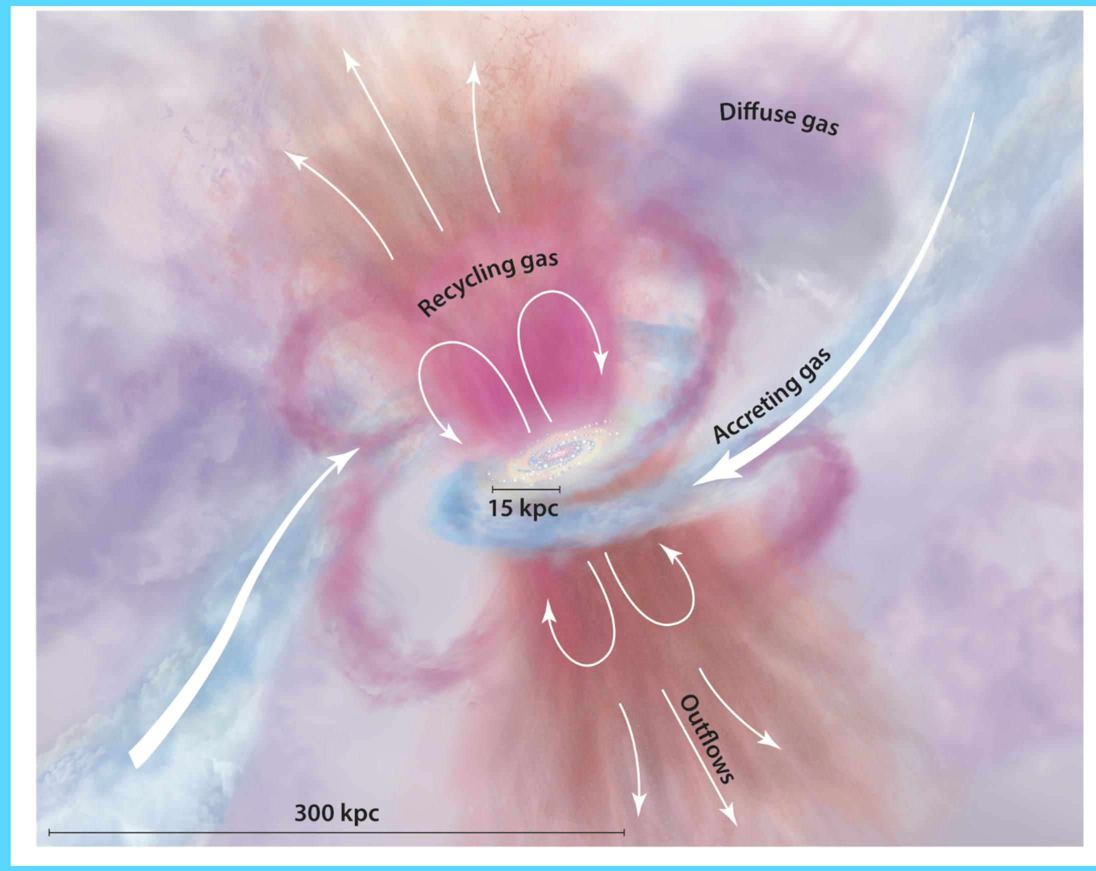


Table 2

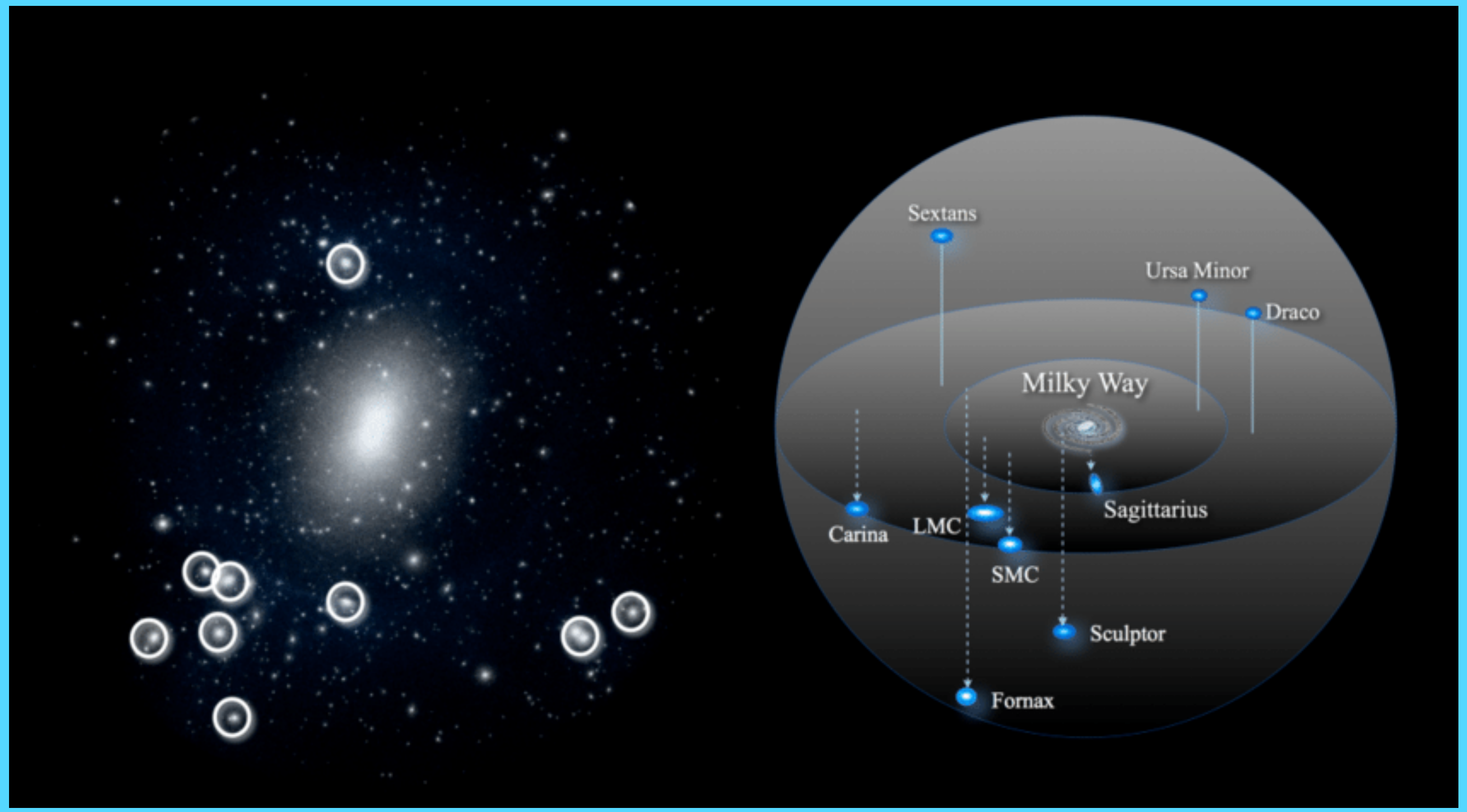
Best-fitting Parameters for Mg II Covering Fraction from $50 < r_p < 600$ kpc (Top) and for Neutral Hydrogen Mass within $r_{\rm vir}$ (Bottom)

	Star-forming			Passive galaxies		
	A	α	β	A	α	β
$0.4 < W_{\lambda2796} < 1$ Å	0.026 ± 0.006	1.2 ± 0.4	0.50 ± 0.05	0.040 ± 0.010	-0.1 ± 0.4	0.34 ± 0.07
$W_{\lambda2796} > 1$ Å	0.008 ± 0.002	2.2 ± 0.4	0.53 ± 0.05	0.007 ± 0.002	2.5 ± 0.4	0.20 ± 0.07
$M_{\rm H\,I}(0.4 < W_{\lambda2796} < 1$ Å$)(10^9 M_\odot)$	0.18 ± 0.05	1.6 ± 0.5	0.75 ± 0.07	0.12 ± 0.04	0.3 ± 0.5	1.17 ± 0.12
$M_{\rm H\,I}(W_{\lambda2796} > 1$ Å$)(10^9 M_\odot)$	0.23 ± 0.06	3.1 ± 0.4	0.64 ± 0.06	0.10 ± 0.03	2.9 ± 0.5	0.95 ± 0.12

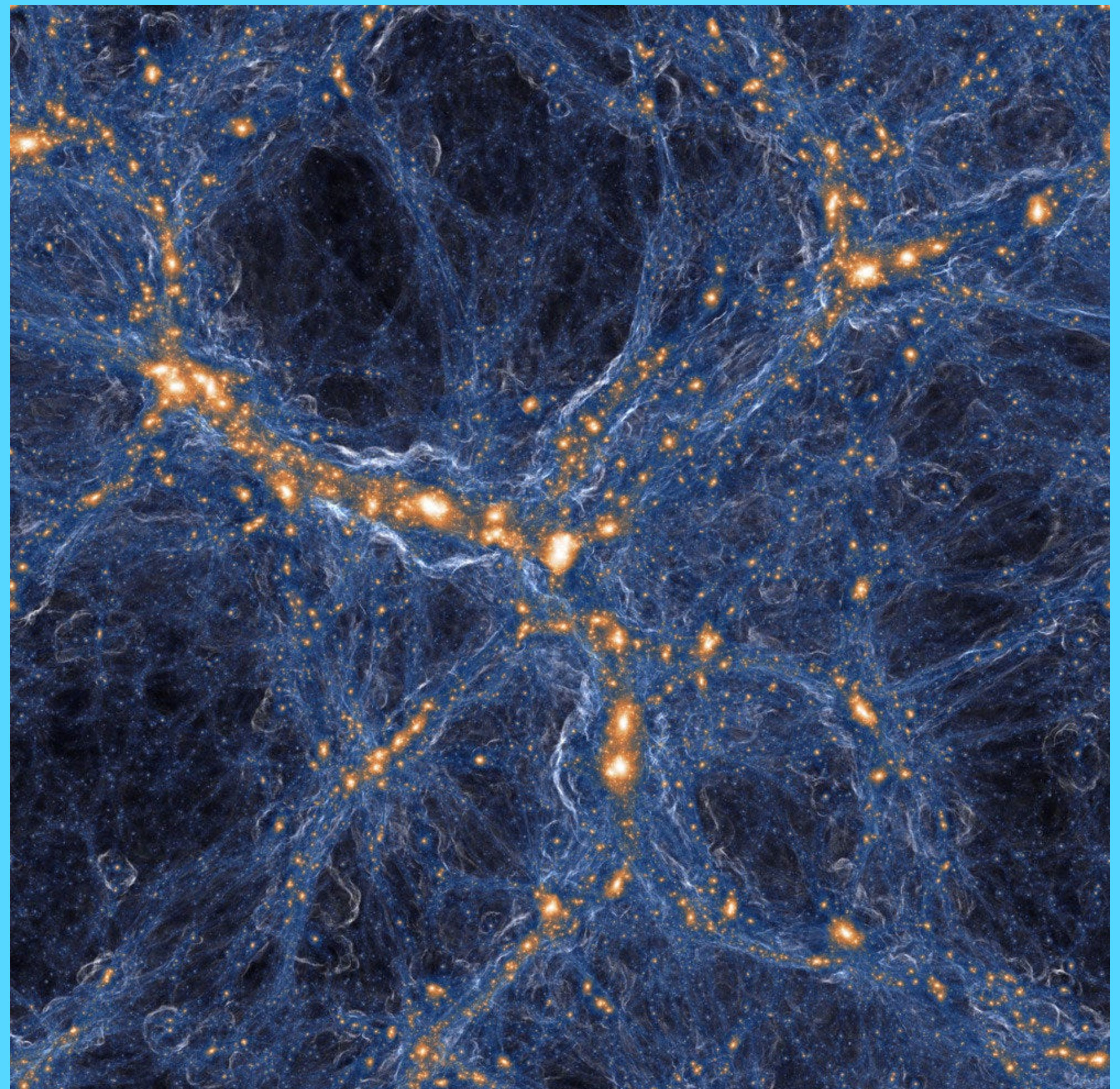
GAS DISTRIBUTION IN REALITY



Disk, Disk halo interface, halo, infall, outflow



Gas gravitationally bound to each galaxy and bound to the group.



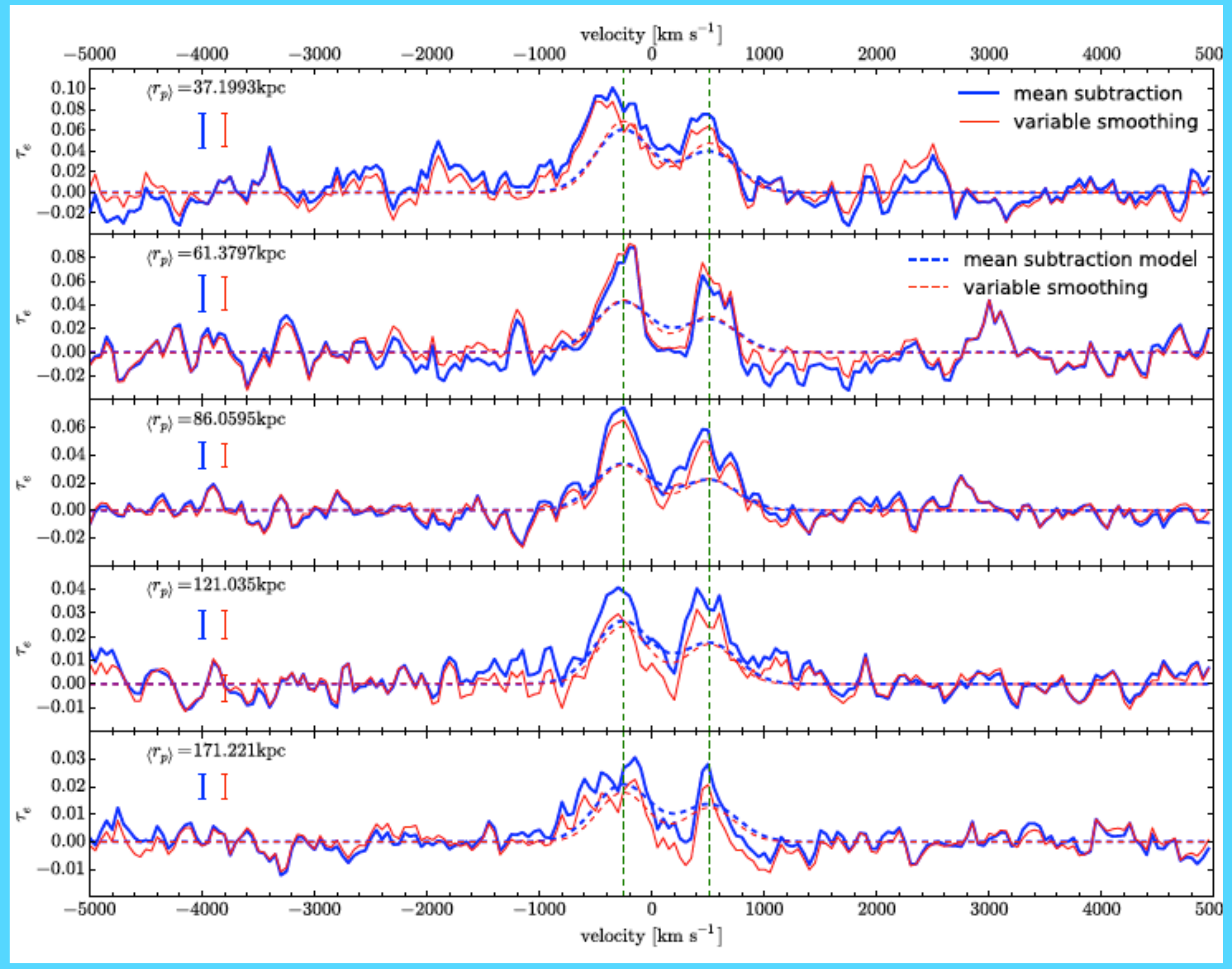
Gas associated with large scale distribution .

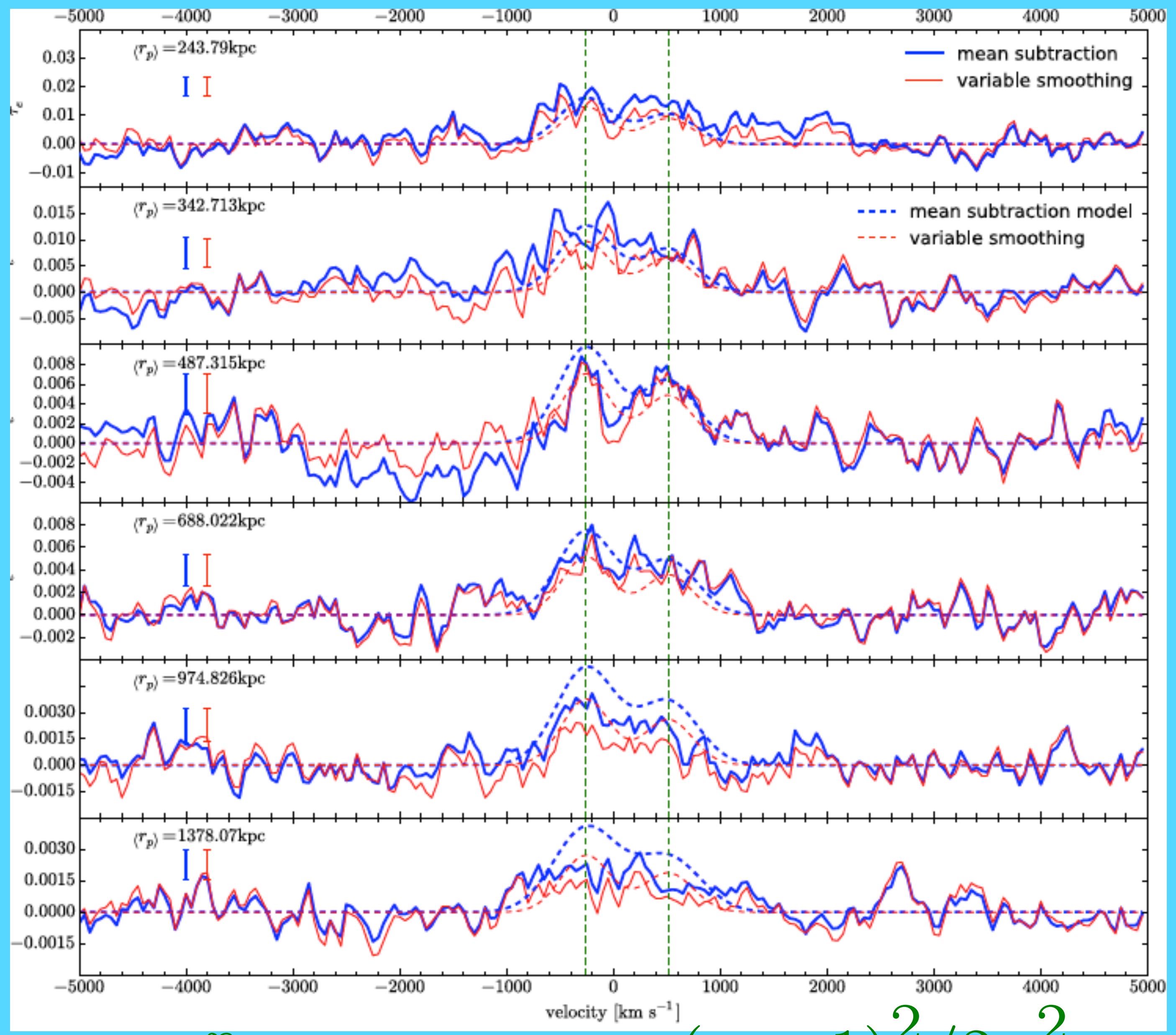
- When you measure absorption as a function of D you are actually measuring the clustering of gas around that point.
- Clustering at different scale is dominated by different physical process.
- How good a given species behaves as a tracer depends on what drives the physics of the tracer.
- Metal lines: metal pollution, correct ionization state which makes interpretation very difficult.

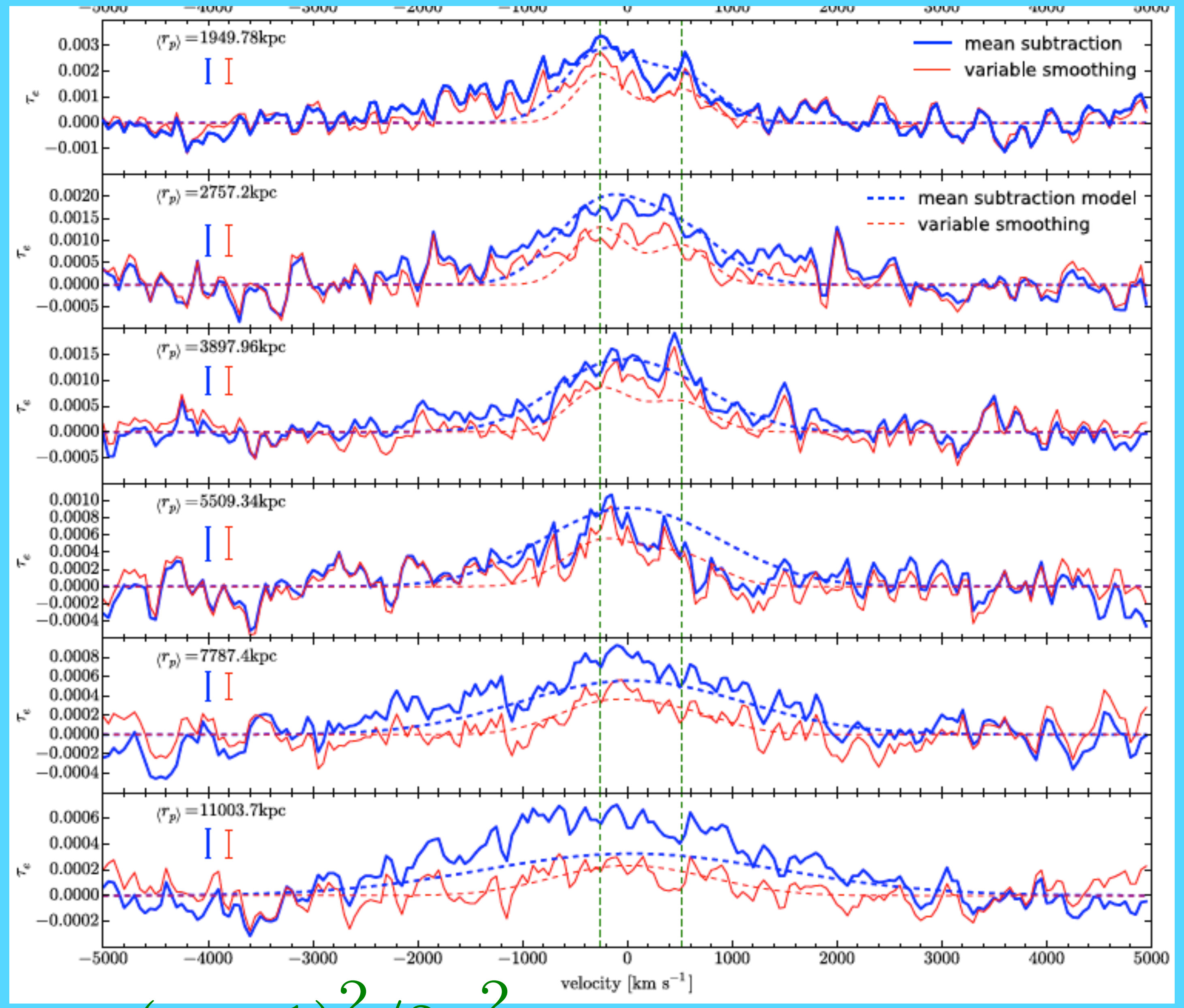
CROSS CORRELATION OF MGII ABSORBERS AND GALAXIES

Ref: Perez-Rafols, 2015, MNRAS, 447, 2784

8,95,472 galaxies @$z > 0.35$; $\geq$3 QSO sight lines per galaxy @ <30 h^{-1} Mpc





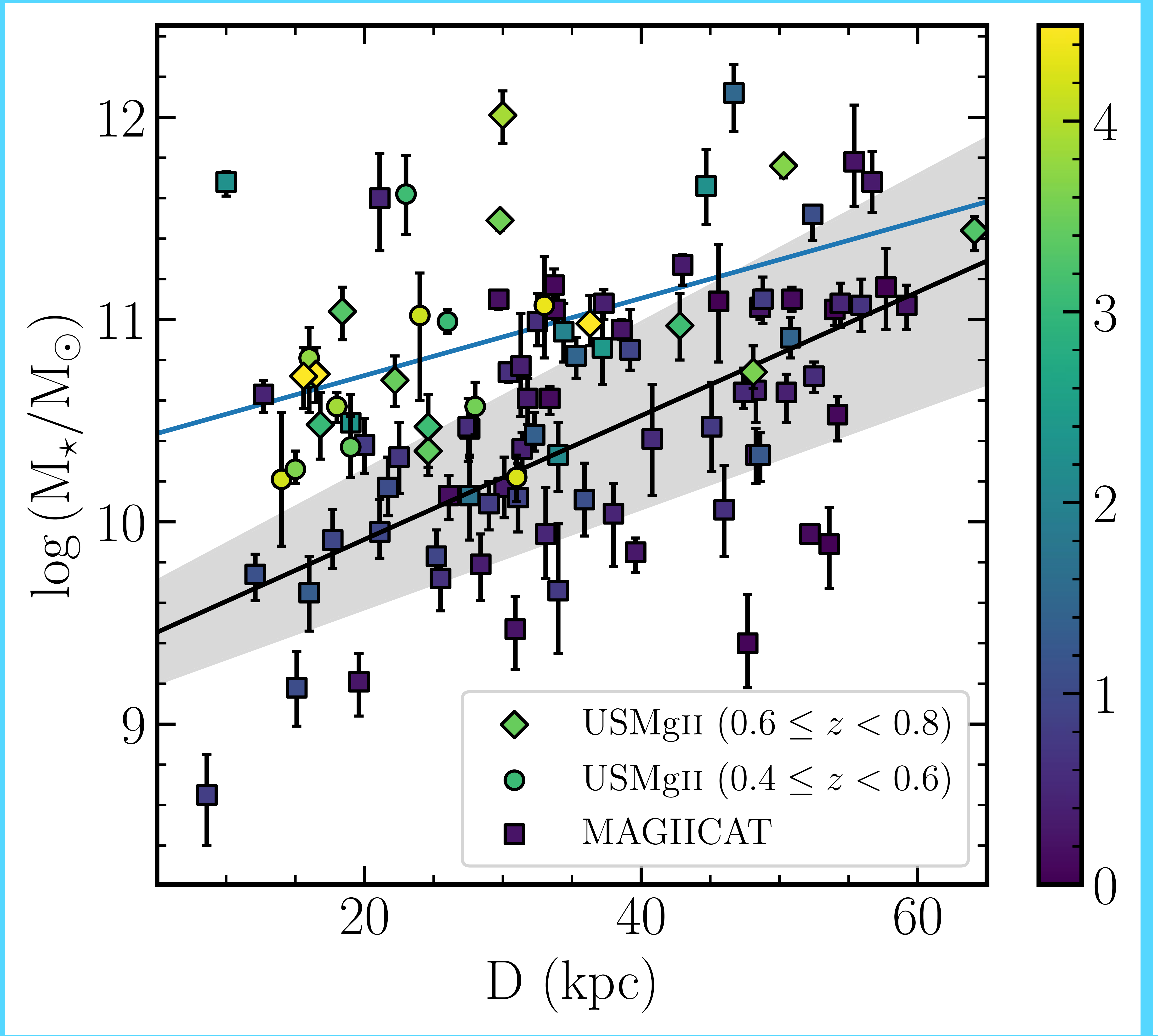


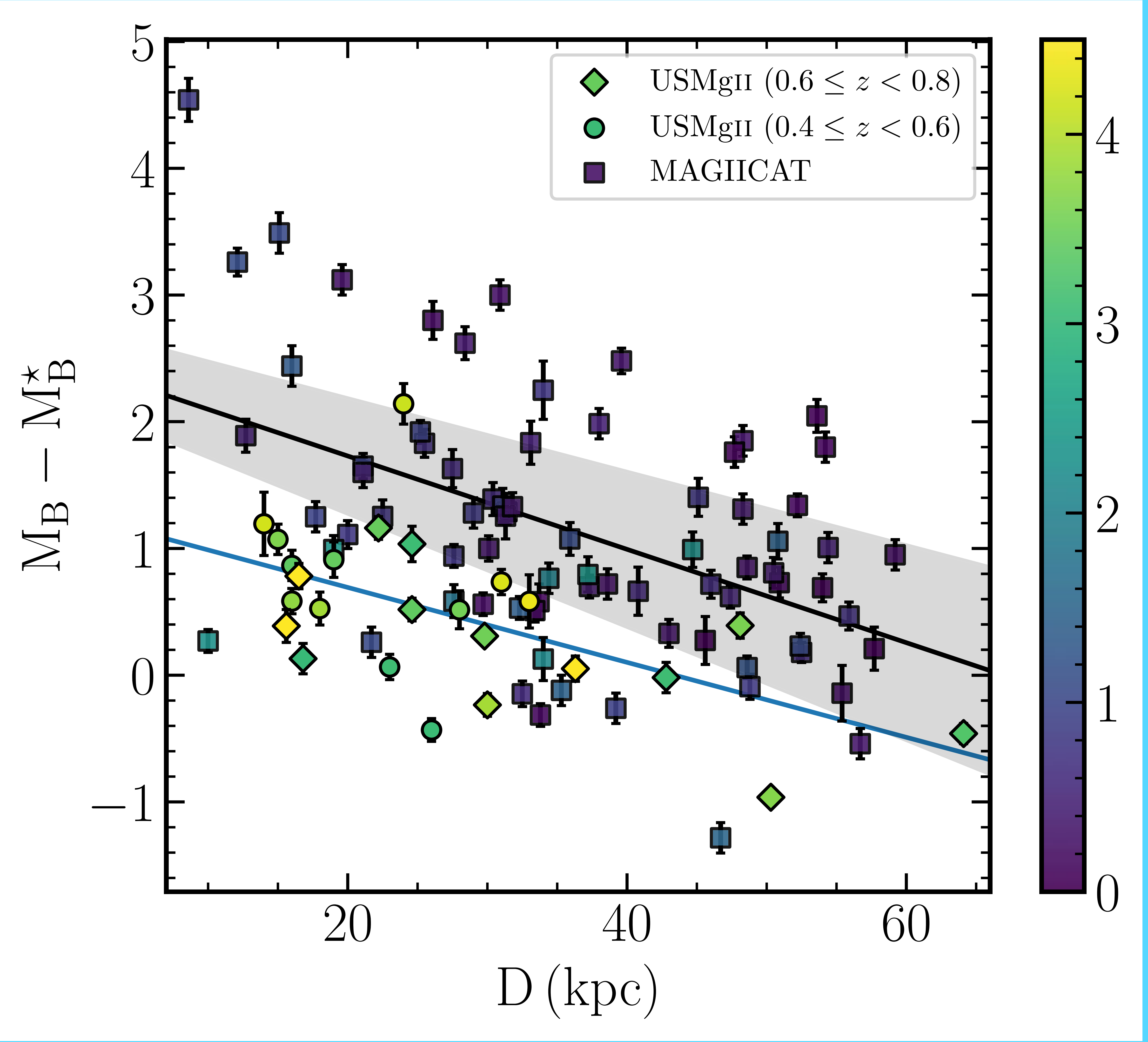
$$\delta\tau_e(r_p, v) = \frac{\tau_0}{\sqrt{(1+(xHrp\sigma_0)^2)}}\left(\frac{rp}{rp0}\right)^{-\alpha} \times \left[e^{-(v-v1)^2/2\sigma^2} + qe^{-(v-v1)^2/2\sigma^2}\right]$$

$v_1 = -265.05$ km s^{-1}, $v_2 = +513.28$ km s^{-1}, r_{p0} = 1 Mpc; $\sigma_0 = 250$ km s^{-1}

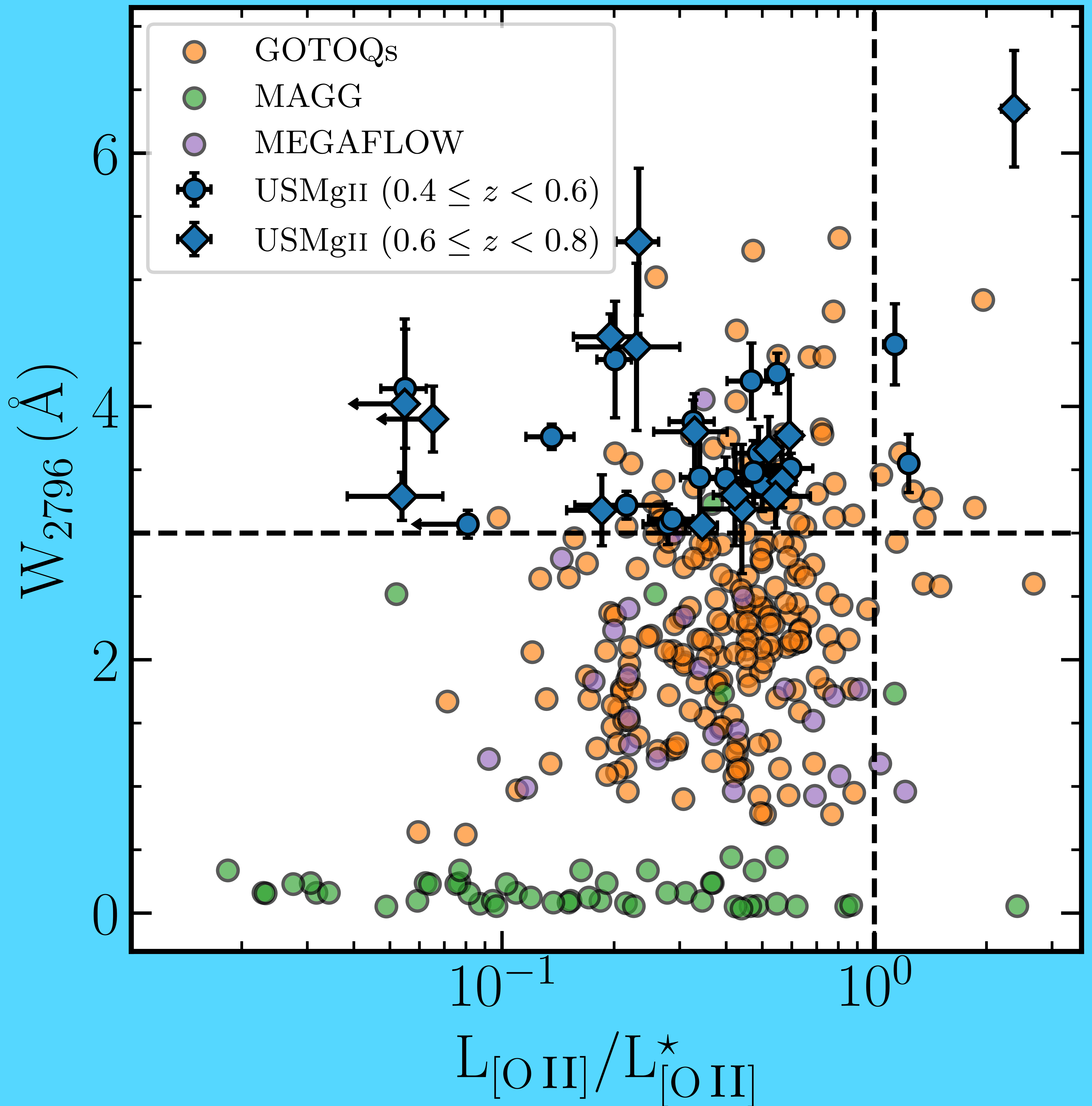
$\tau_0 = 0.0060 \pm 0.0001; \alpha = 0.70 \pm 0.01; x = 1.35 \pm 0.06; W_{0e} = 6.27 \pm 0.10$ km s^{-1}.

IMPACT PARAMETER AND GALAXY PROPERTIES:



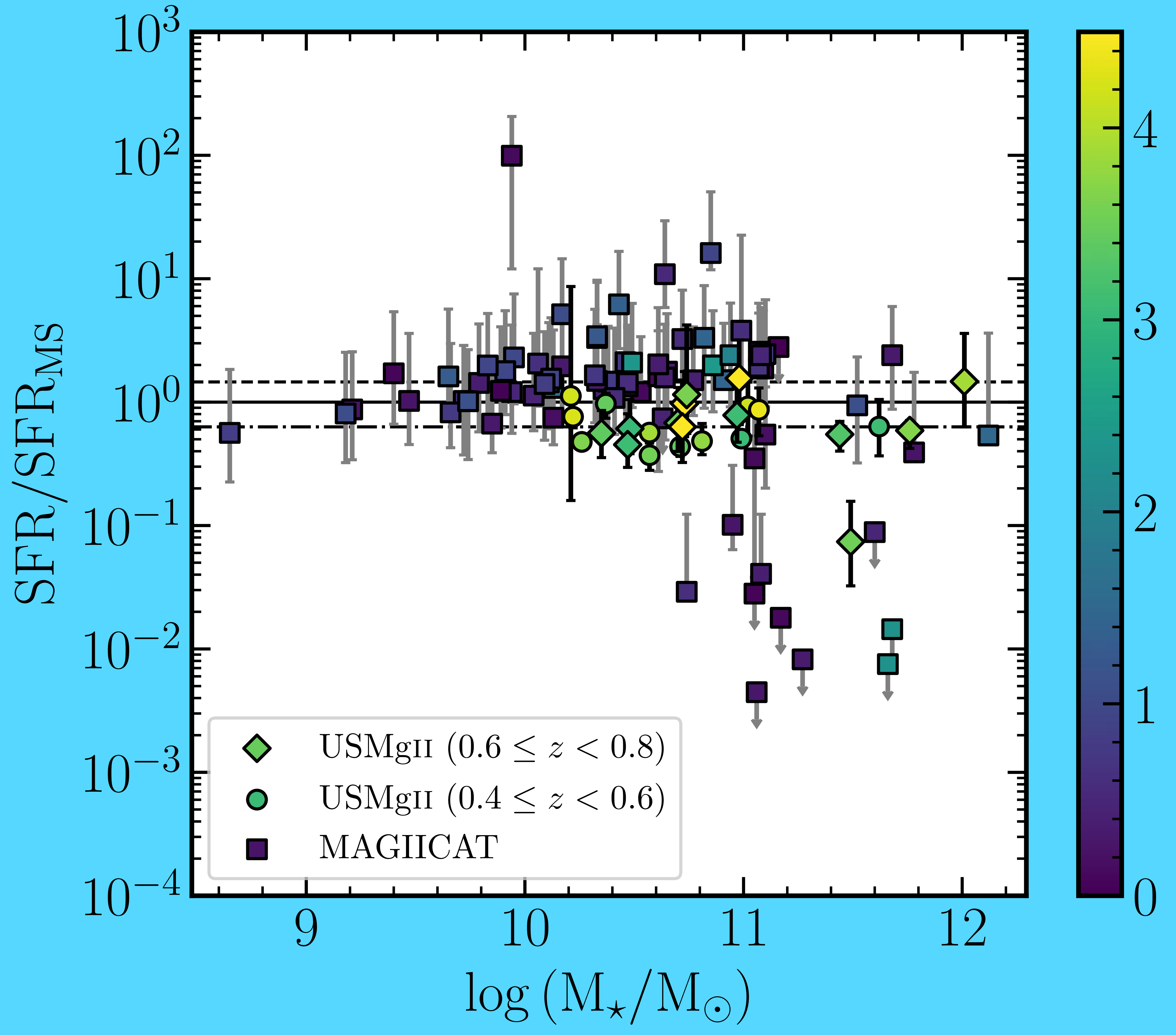


EQUIVALENT WIDTH AND [OII] LUMINOSITY



- There is a tendency of largest equivalent width systems to be associated with L[OII]>L*[OII] galaxies.
- However, Mg II equivalent width does not correlate with OII luminosity. Such a correlation was proposed to argue that highly star forming galaxies with have strong OII emission and large reservoir of gas.
- However, unlike HI Balmer lines [OII] may not be a good indicator of SFR!

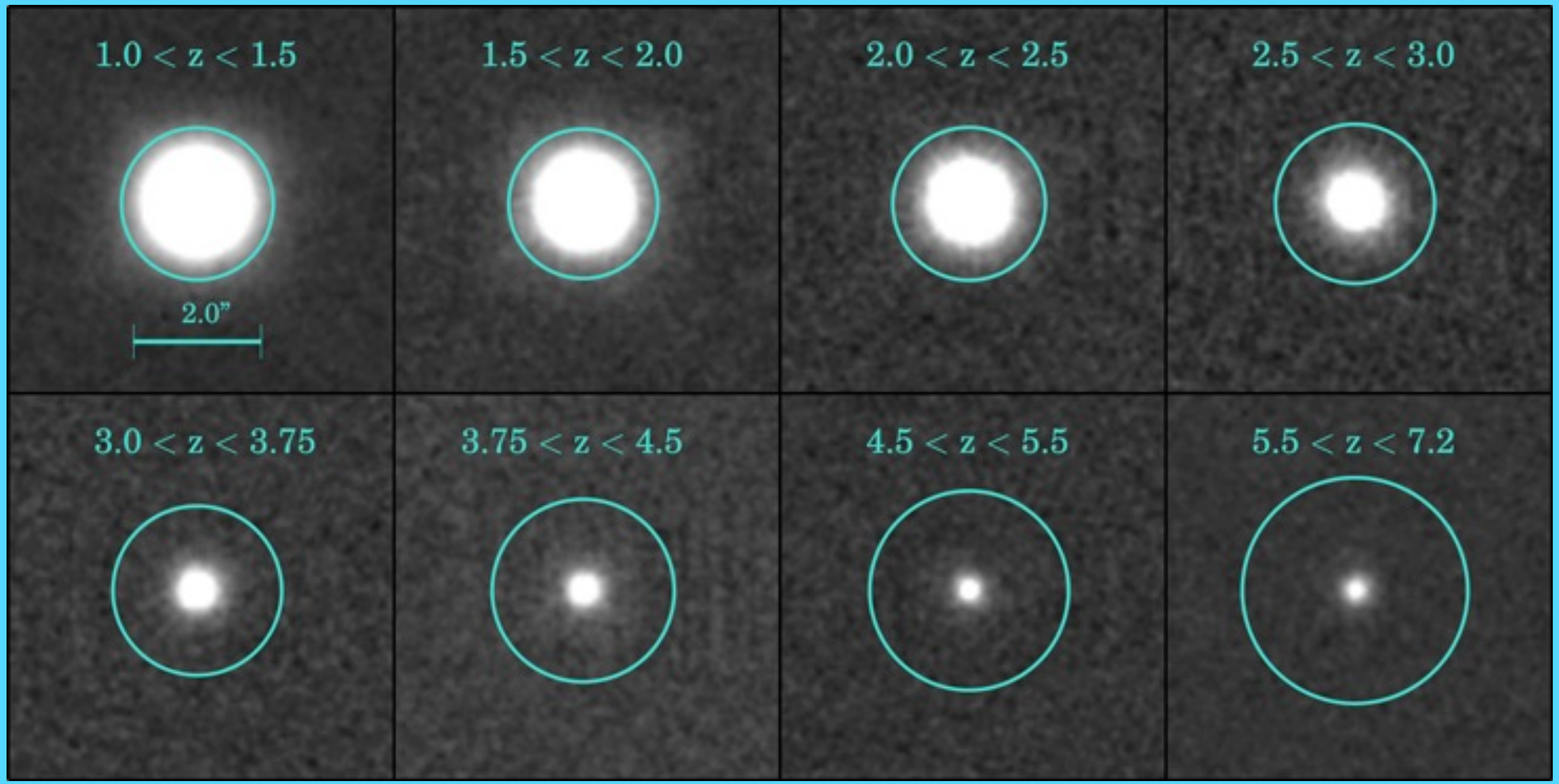
MG II HOST GALAXIES AND STAR FORMING MAIN-SEQUENCE

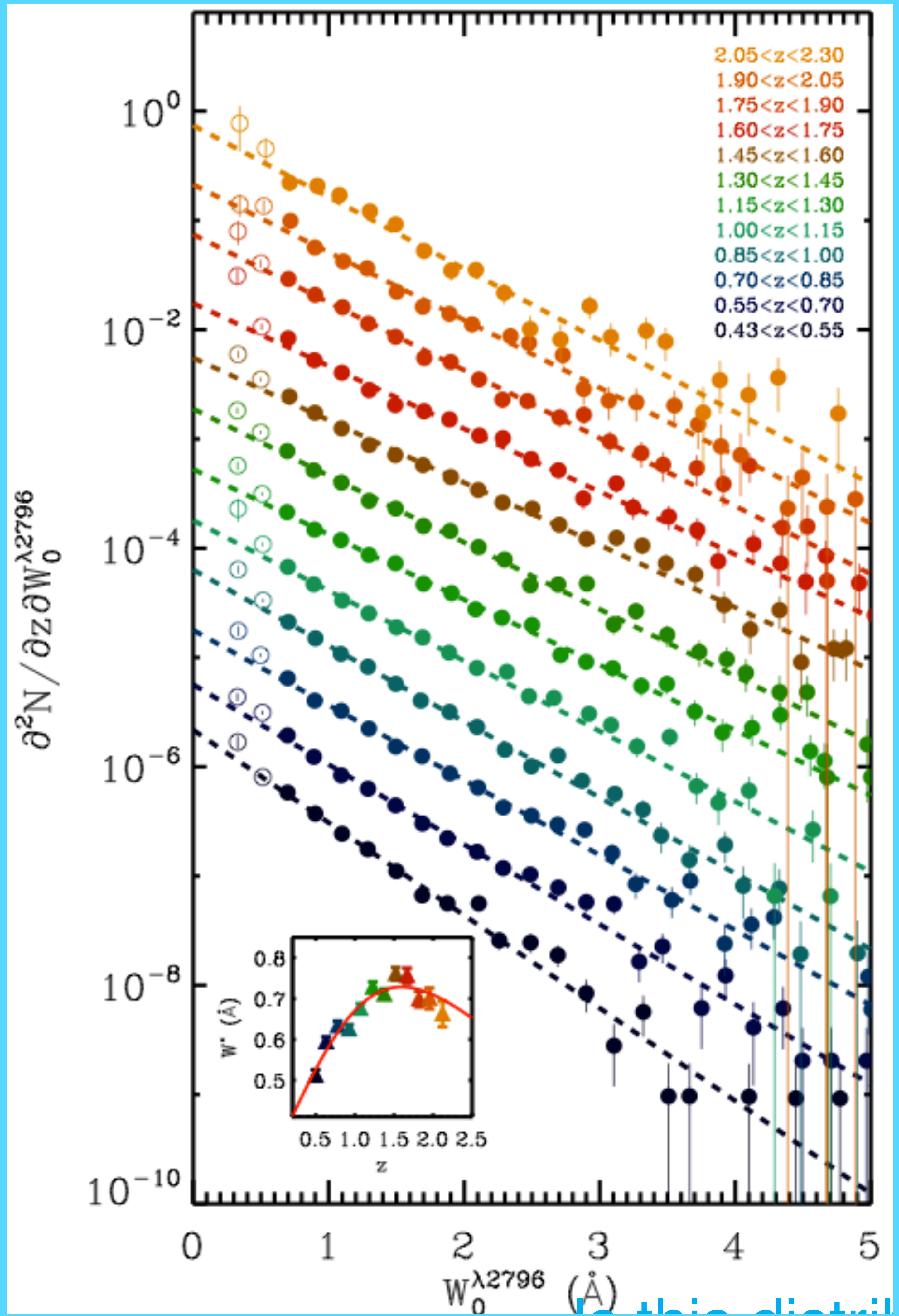


- Is the absorption based selection (that is unbiased) pick different population of galaxies that are missed by optical surveys?
- Host galaxies of Mg II absorbers by and largely follow what has been in the case of field galaxies.
- Mg II absorbers with large equivalent widths do not originate from star bursting galaxies. Rather some of them originate from quenched or galaxies with slightly lower SFR then expected from the main sequence.

SOME QUESTIONS I HAVE?

- Do you understand the standard statistics of Mg II systems?

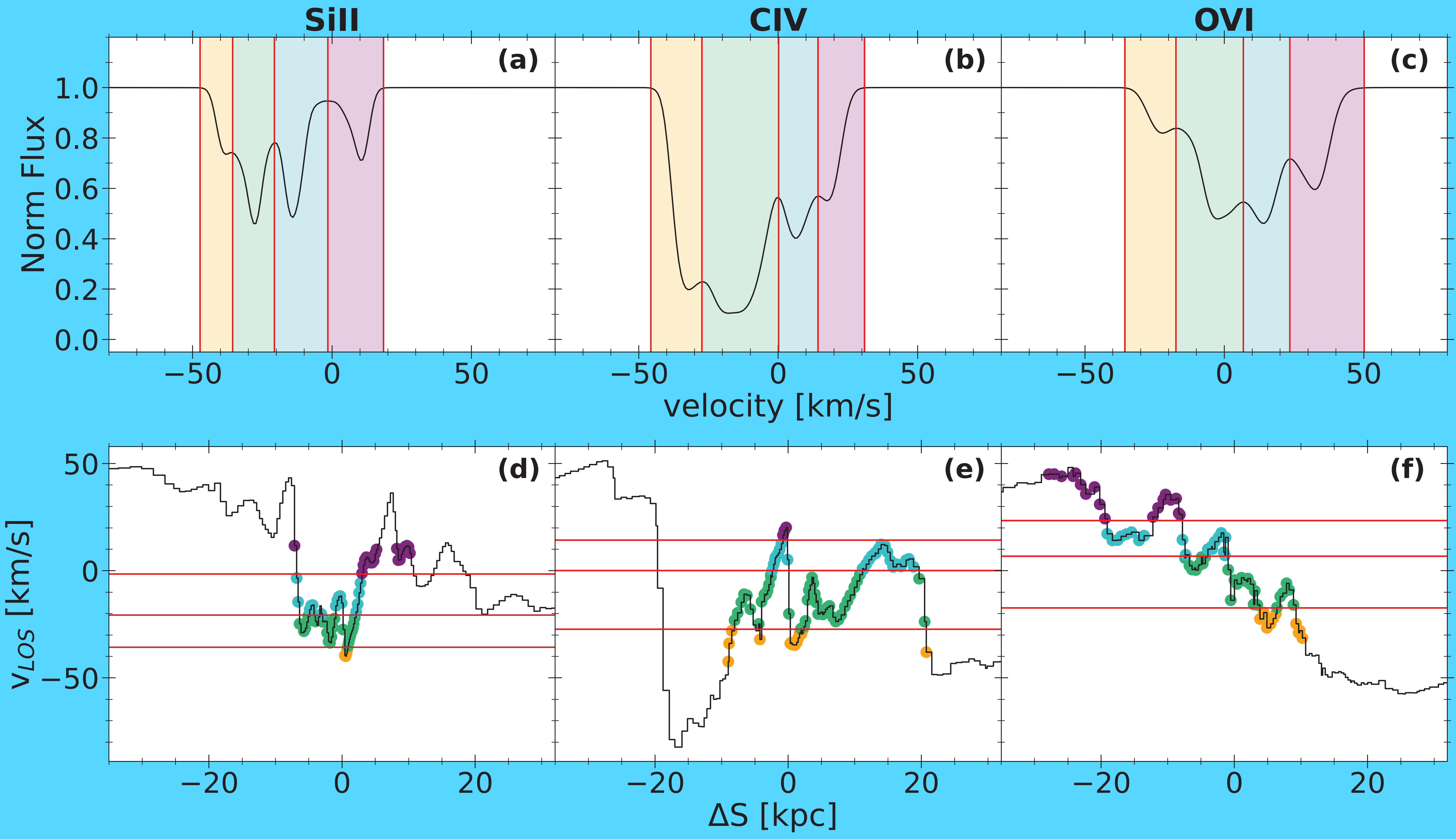




- High-z galaxies are smaller in size.
- Absorption line studies suggest there were more/strong metal absorption in the past (say upto z~2.0).
- Therefore, relative size of metal enriched gaseous halos in comparison to the optical galaxy size should increase with z.

SOME QUESTIONS I HAVE?

- Does Voigt profile fitting method get the physics right?



- There is no relationship between velocity and spatial location. Gas producing absorption at a given Voigt profile can originate from different regions with different physical conditions - what one measures is probably the property of the most contributing region.
- What is the correct spectral resolution to get better physical parameters - This will depend on the structure in the absorbing region.

SOME QUESTIONS I HAVE?

- Do we really make any progress by fitting absorption profile with physical model?

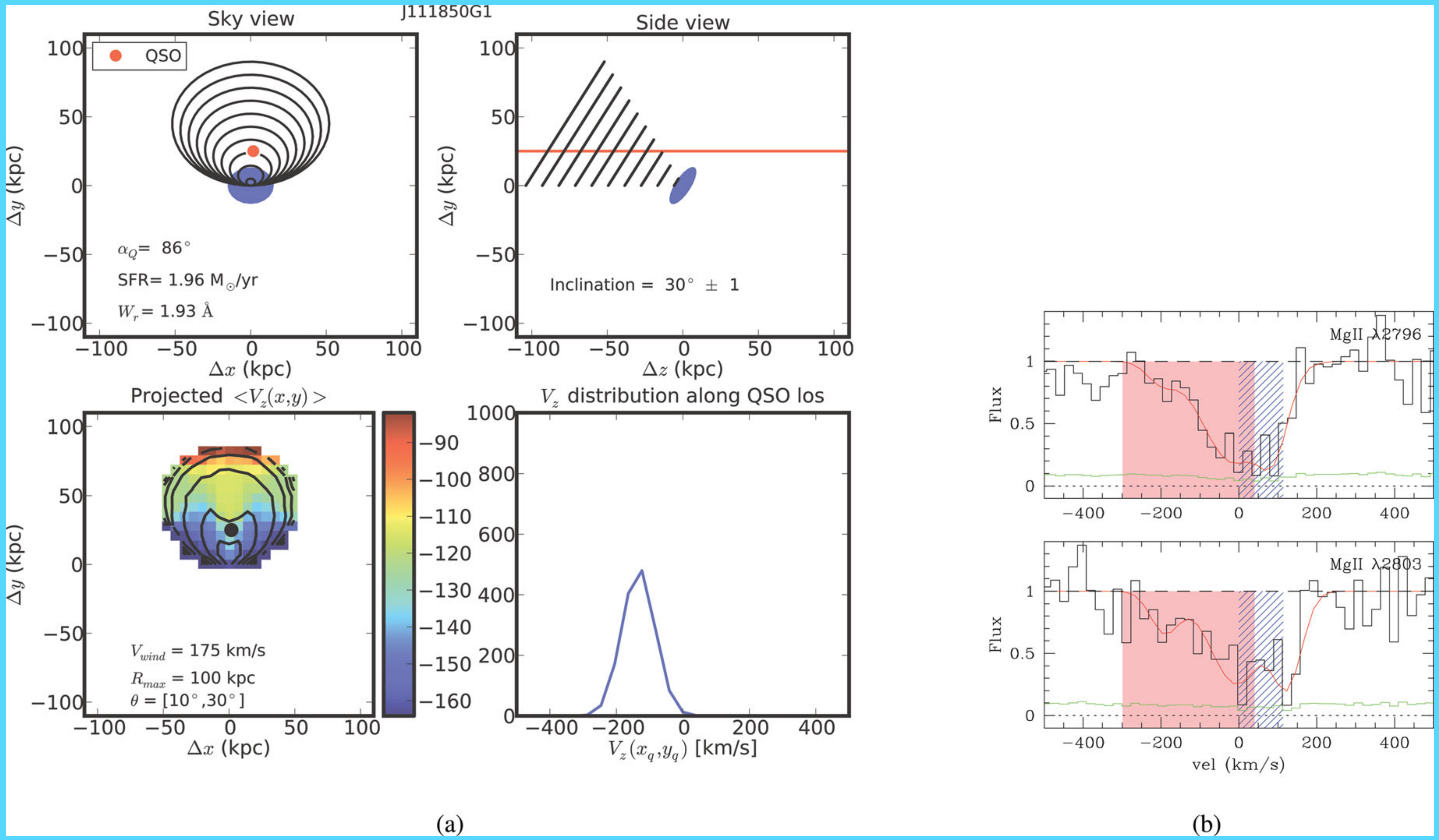
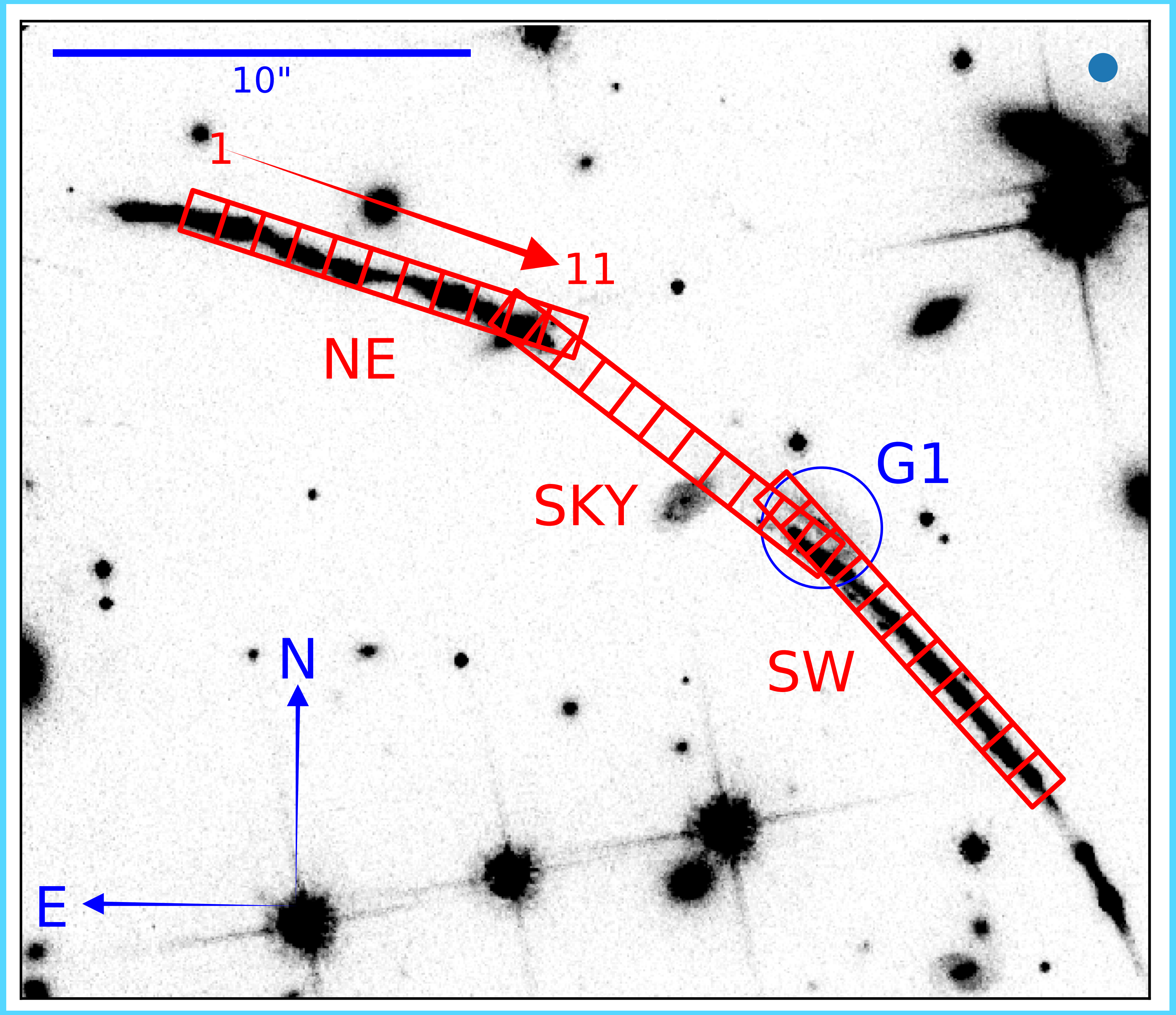


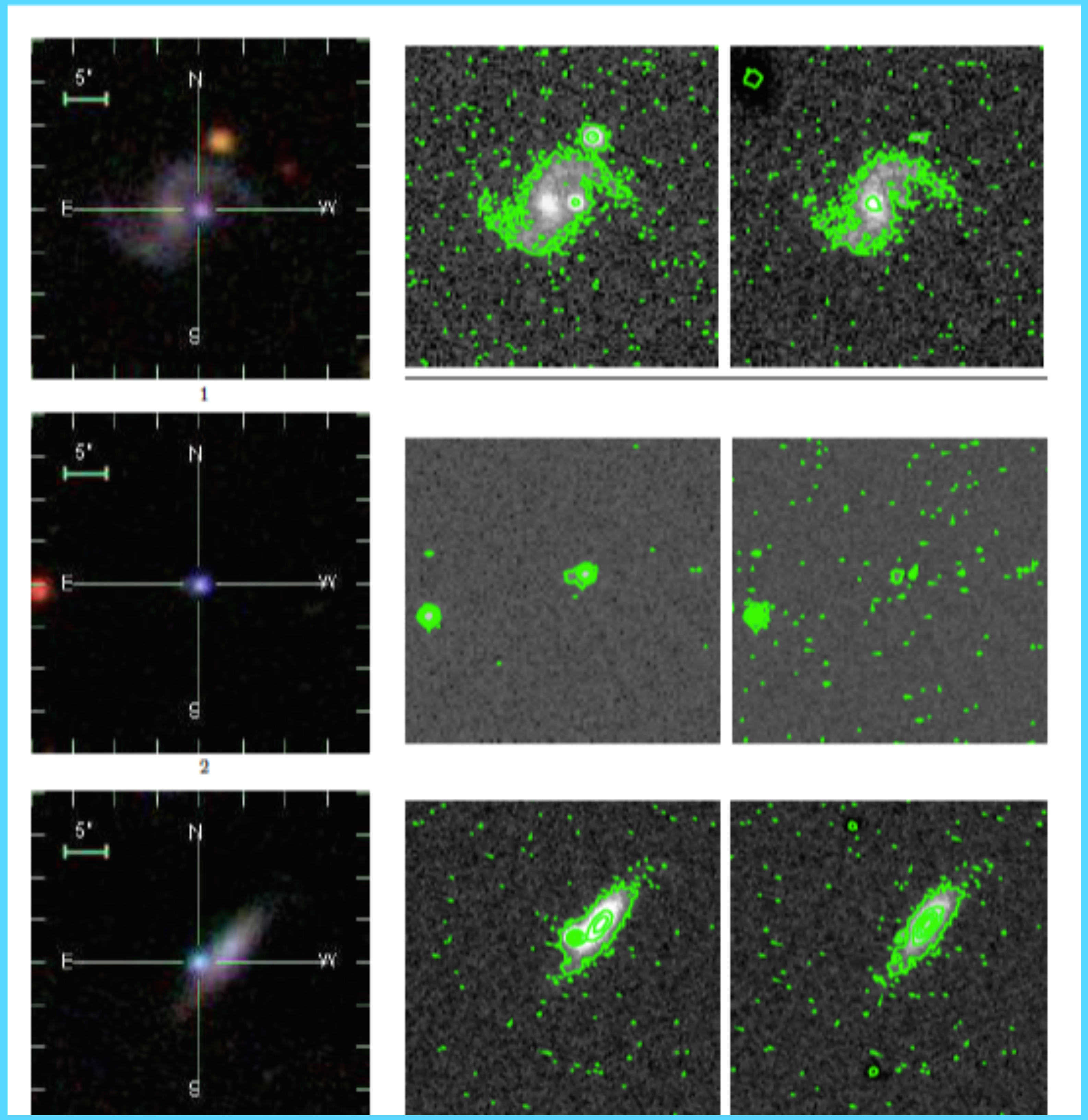
Figure 8. (a) Kinematic model of conical wind for J111850G1 as in Fig. 5. (b) The observed Mg II kinematics with respect to the systemic velocity as in Fig. 5. Given the low inclination, this sightline is likely contaminated by absorption from the disc. Indeed, the blue hatched area shows the disc–halo model of Kacprzak et al. (2011a).

- Such modelling is driven by the orientation dependence of equivalent withs and covering factor -This should be the case when the sight line is going close to the galaxies and not necessarily the case when the impact parameter is >100 kpc
- Consistency of the profiles is not the truth - It will be important to include physics of gas flow in addition to the kinematics.

SOME QUESTIONS I HAVE?

- Do we really make any progress by using multiple sightlines?





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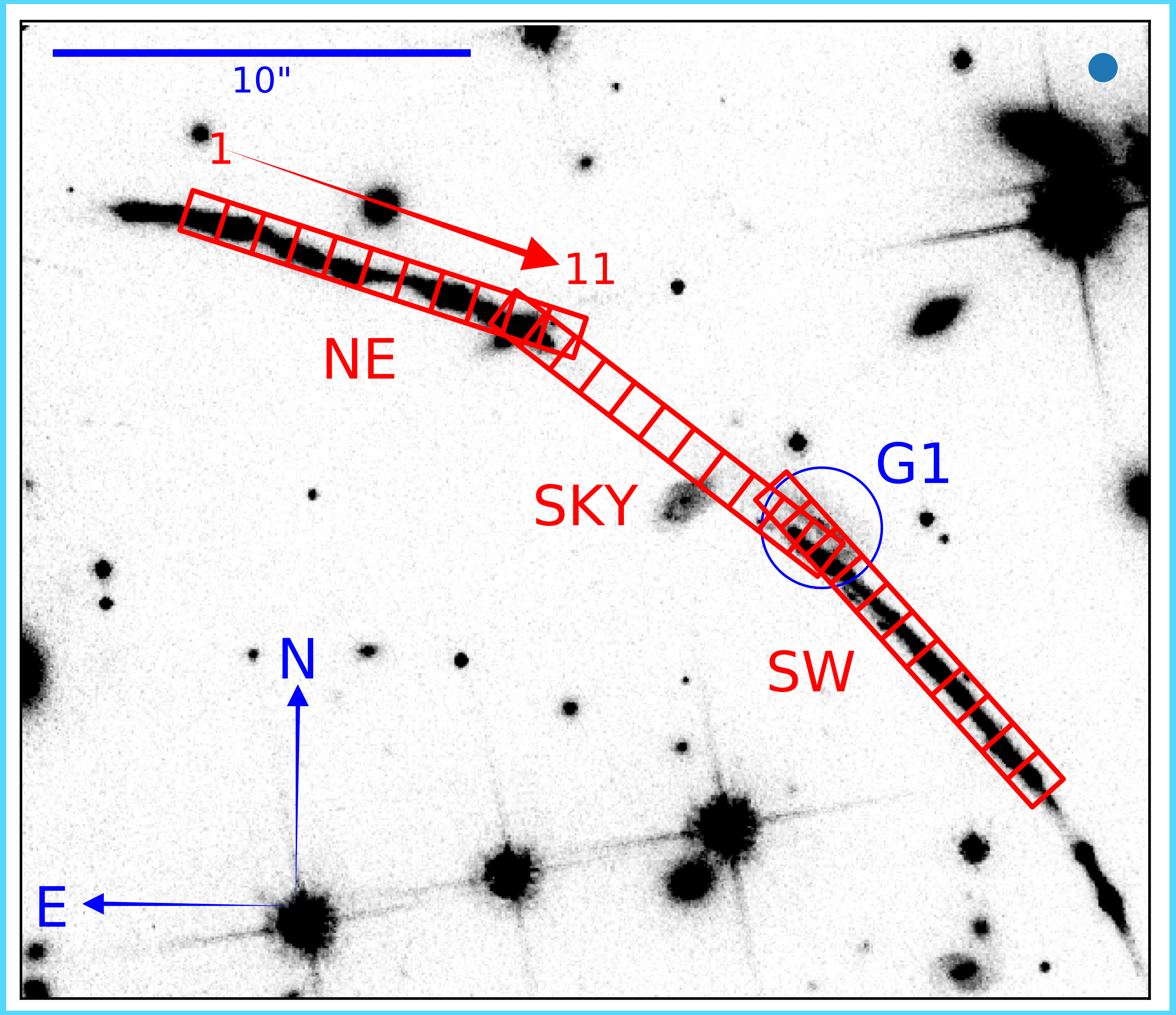

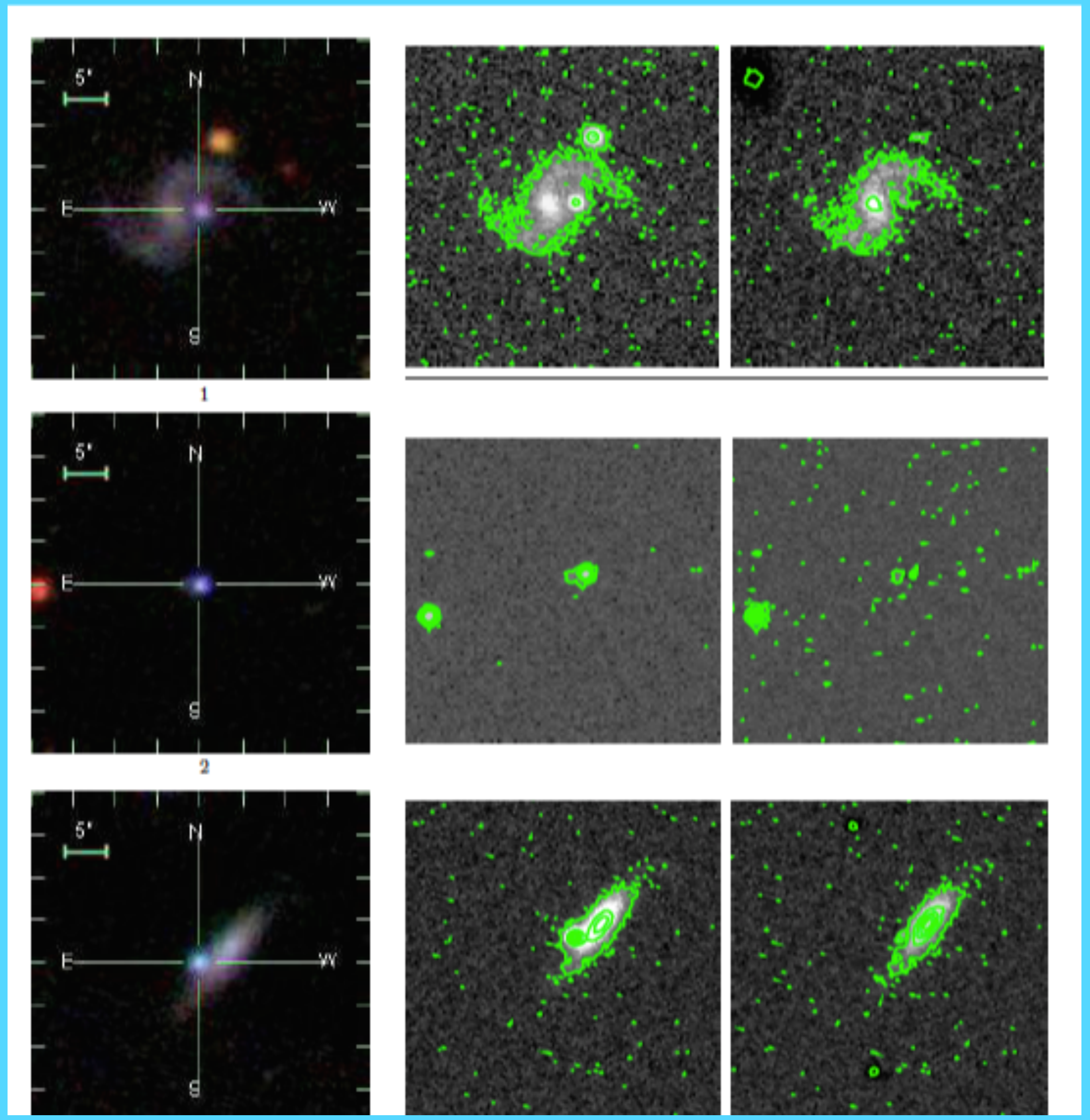

SOME QUESTIONS I HAVE?

- How the emission line mapping of the CGM is going to improve our understanding?
- Are we doing the ionization modelling correctly?
- What is the understanding of aligned absorbers?
- How to improve the situation of covering limited number of transitions along a given LOS?

SOME SCOPE WITH NUMERICAL SIMULATIONS?

- I have not seen numerical simulations correctly producing observed correlations with equivalent widths and properties of galaxies.
- Upto what scale (time as well as space) the galaxy orientation dictates the ion distribution.
- Probing the gas, metal and ion distribution as a function of time before, during after a strong episode of star-formation.
- Trying to do large scale clustering using simulated box.
- Understanding the importance of local ionising sources and non-equilibrium ionization. Should one worry about the orientation?