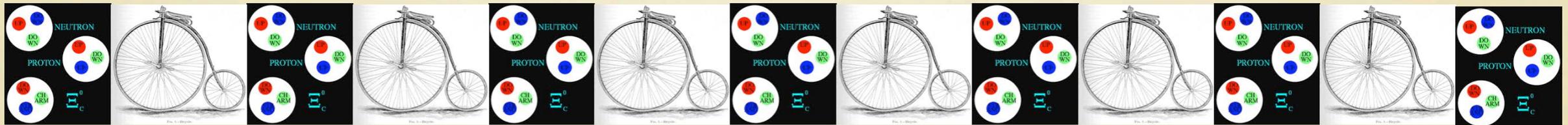


# The MgII View of the Baryon Cycle

Daniel Nestor (UCLA)



# Outline

## *INFLOW*

- Most baryons in stars today were accreted into halos over  $z \sim 0-5$ , (and were once in the ionized IGM, even those acquired through cold streams). [1 slide]

## *OUTFLOW*

- Mini-review: the evidence connecting strong MgII absorbers to galactic outflows. [11 slides]

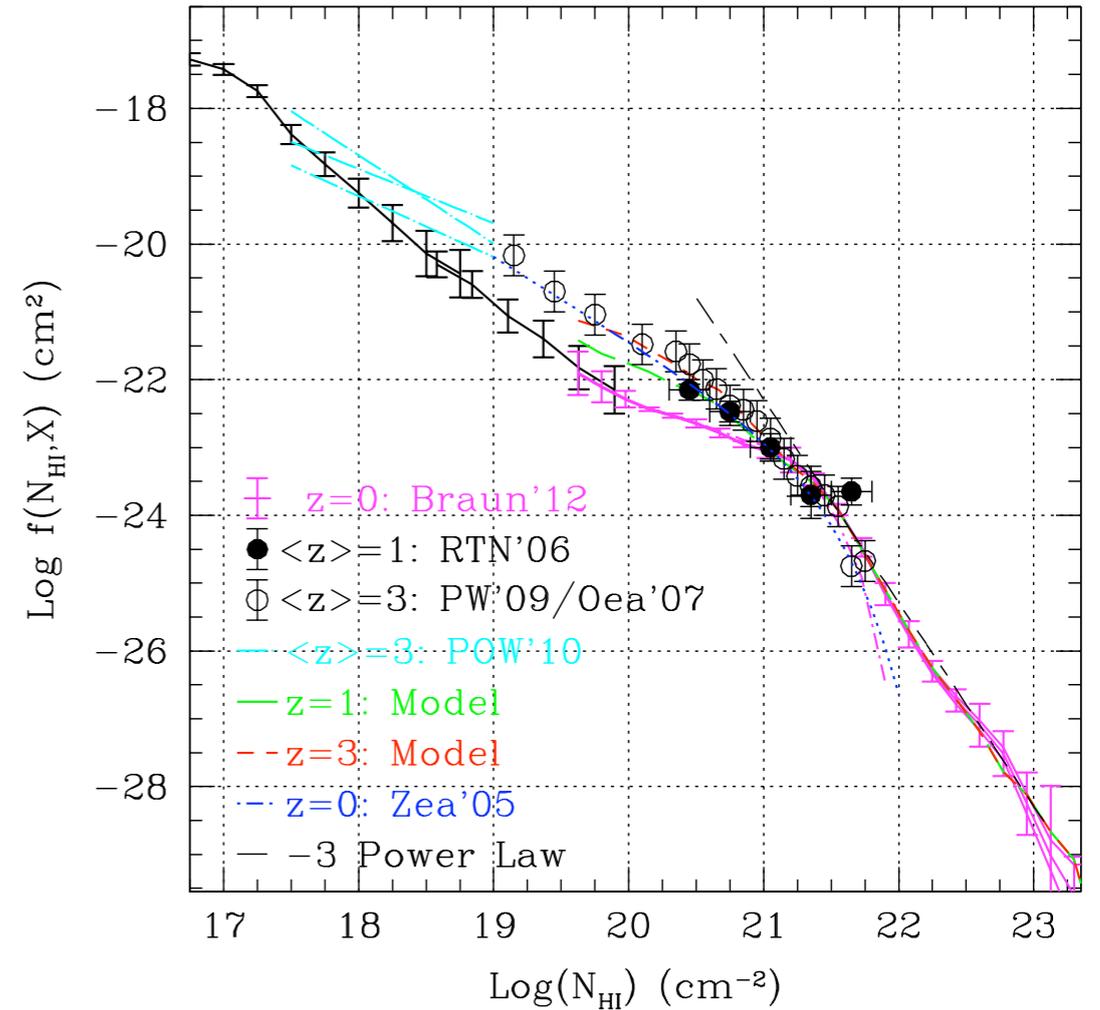
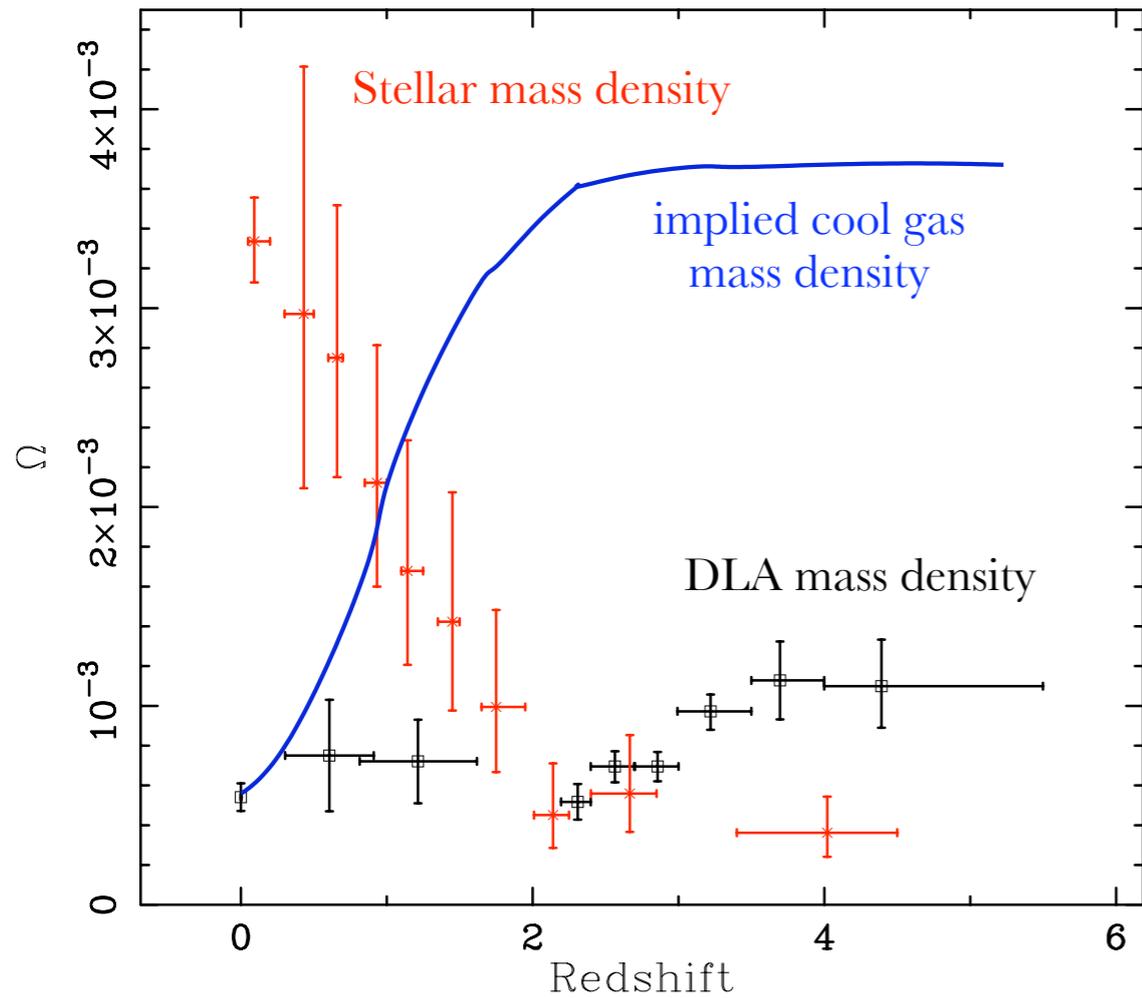
## *STAR FORMATION*

- MgII absorption traces star formation. [5 slides]

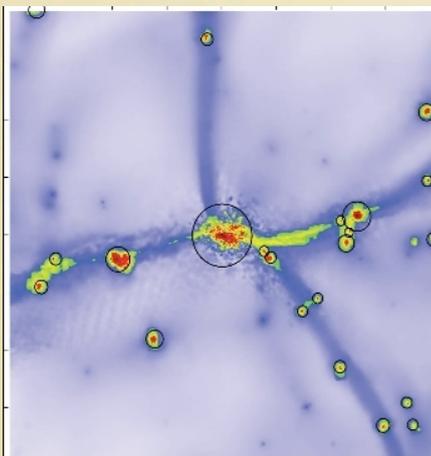
Time permitting....

- Preview of ongoing MgII and DLA projects.
- Shameless ad for my poster.

# Halos must accrete cool gas over cosmic time.



Braun 2012



- Swept-up Ly $\alpha$  forest, LLSs, subDLAs? X
- Dense, low-cross section filaments? X
- Condensation from ionized IGM? ✓

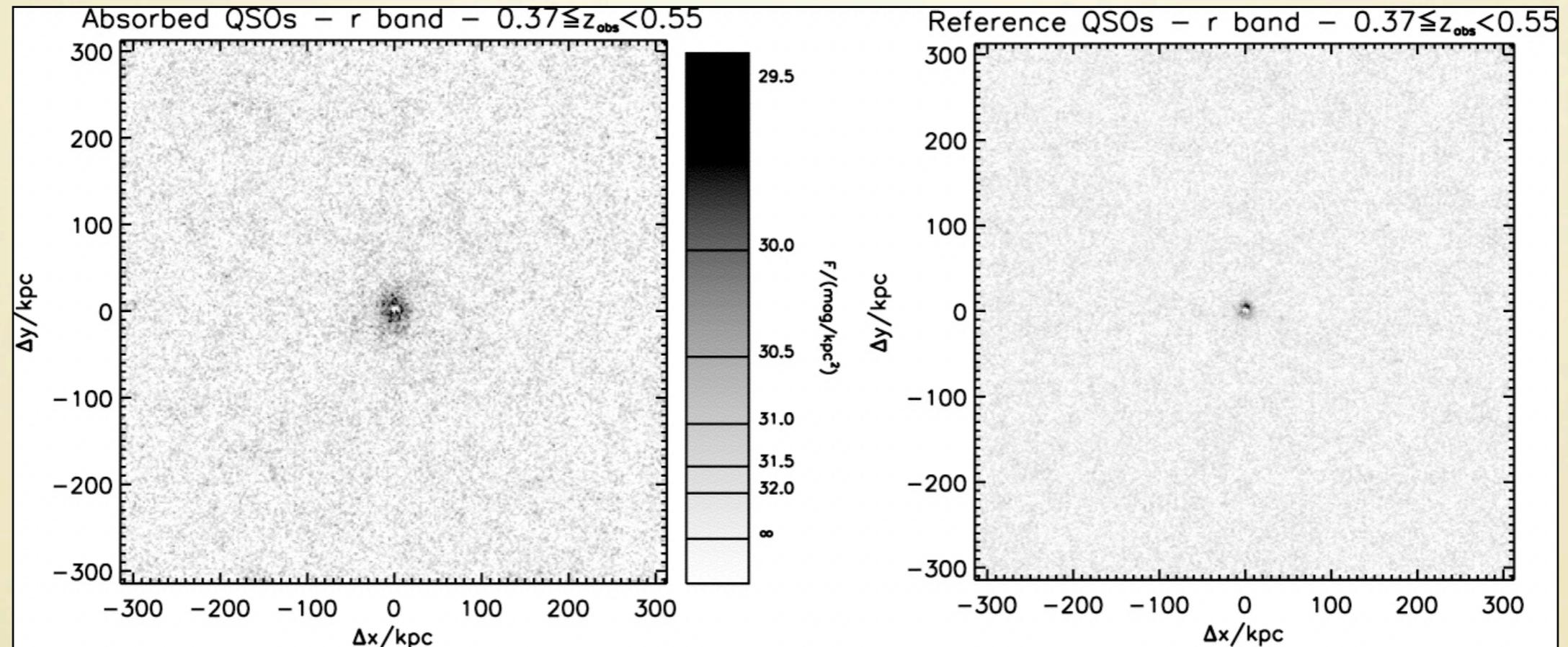
# The connection between strong MgII absorbers & galactic outflows.

Over the past  $\sim 1/2$  decade, much evidence connecting strong MgII absorbers to galactic outflows has been uncovered.

Much of this work has been accomplished by **people who are at one of the CGEs, and/or are in this room.**

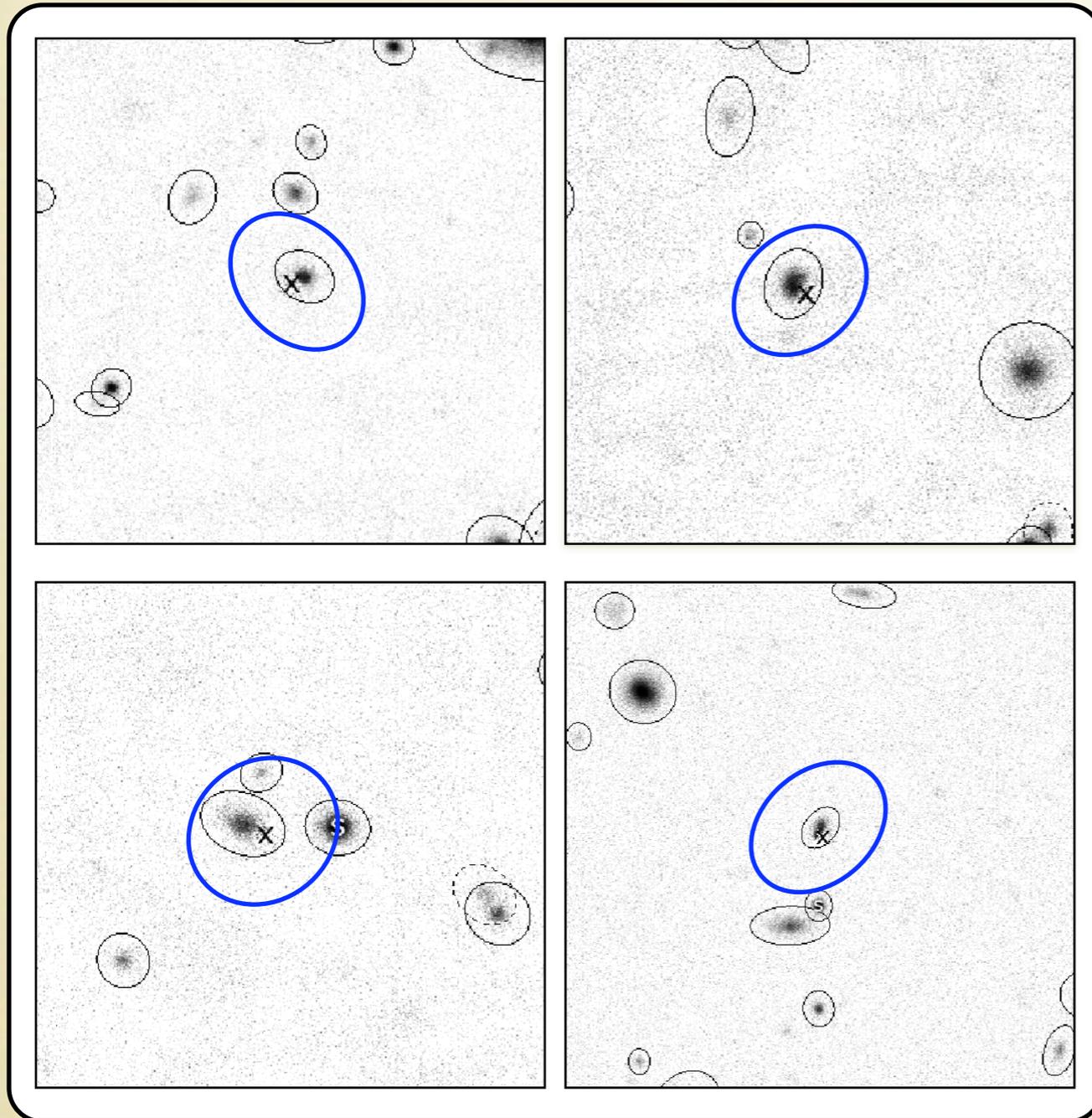
...let's review.

# The connection between strong MgII absorbers & galactic outflows.



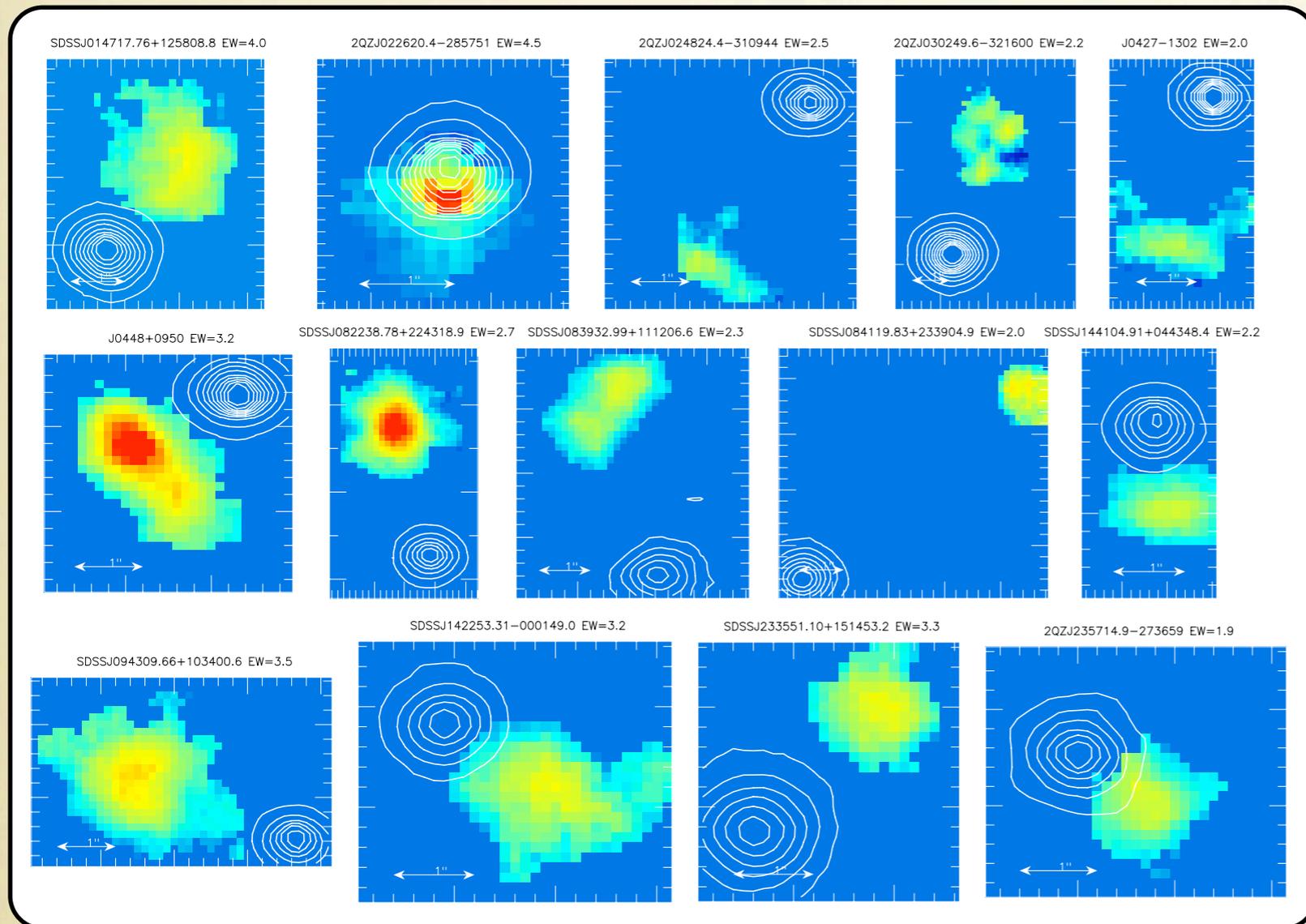
By stacking  $\sim 3000$  SDSS g, r, i, and z images of MgII fields, Zibetti, **Ménard**, **Nestor+** (2007) demonstrated that galaxies associated with stronger absorbers are bluer and at smaller impact parameters to the QSO sightlines.

# The connection between strong MgII absorbers & galactic outflows.



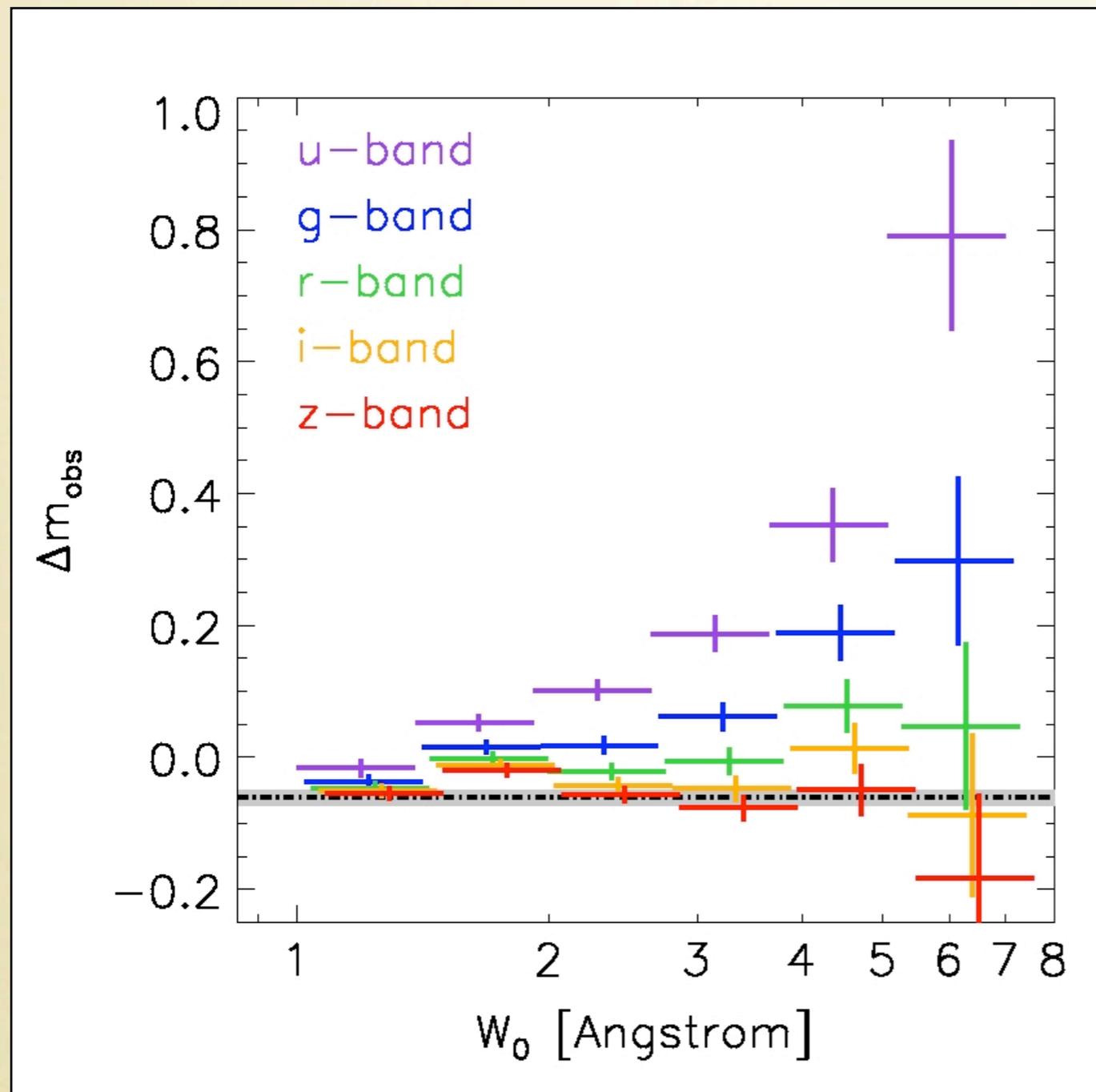
In a sample of 15 “ultra strong” MgII absorbers **Nestor** et al. (2007) found that *individual* systems are associated with relatively bright galaxies at relatively small impact parameters.

# The connection between strong MgII absorbers & galactic outflows.



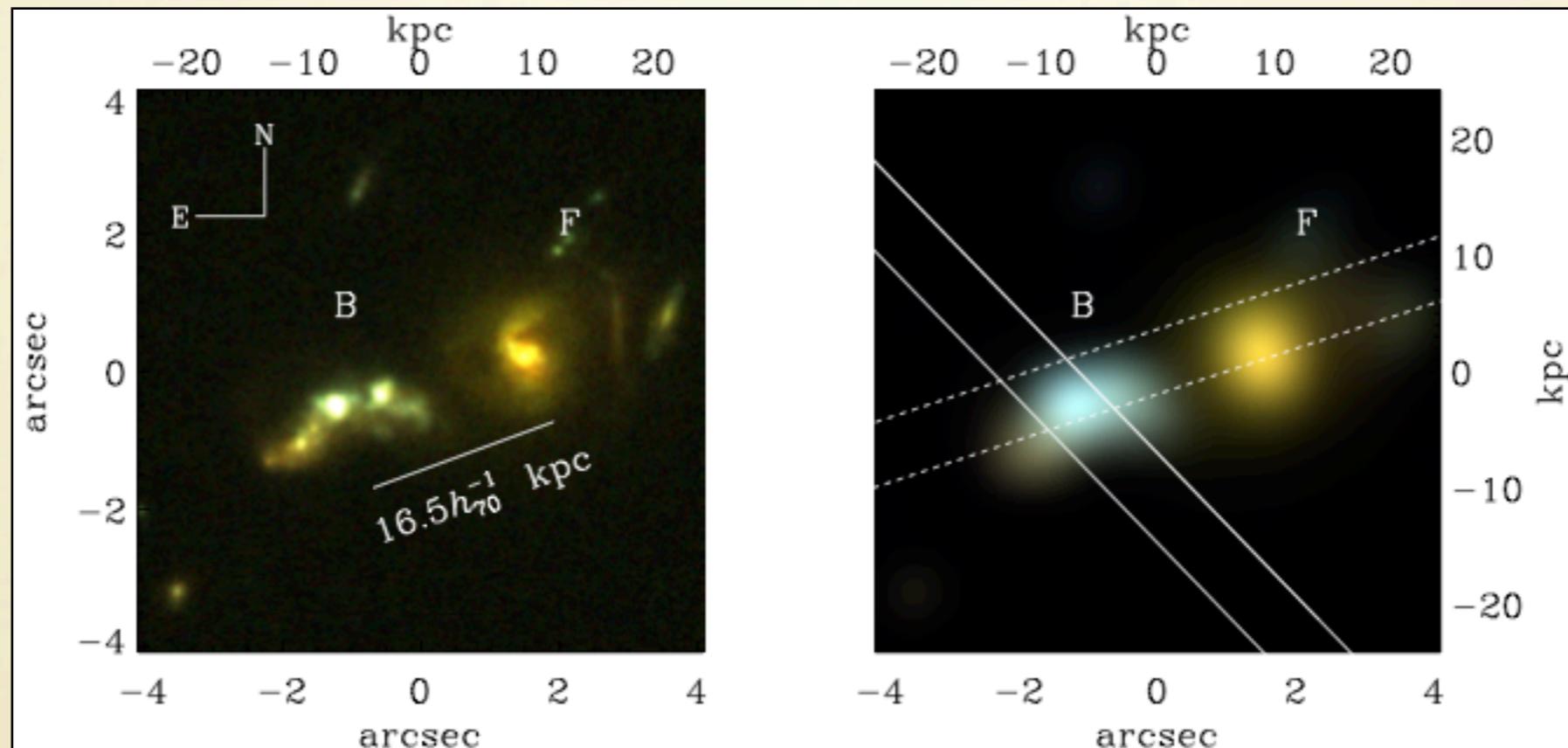
Using VLT/SINFONI IFU data, **Bouché** et al. (2007) found H $\alpha$  emission at the redshift of strong MgII absorbers.

# The connection between strong MgII absorbers & galactic outflows.



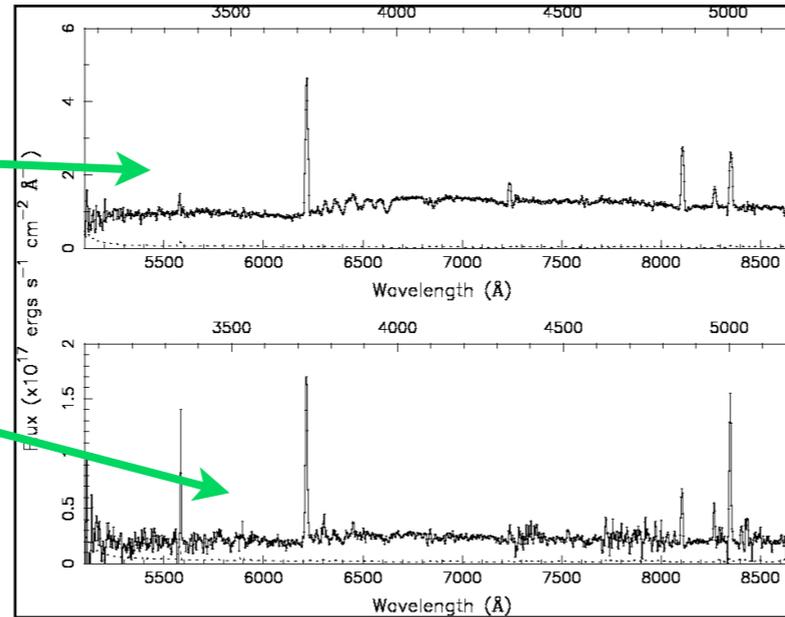
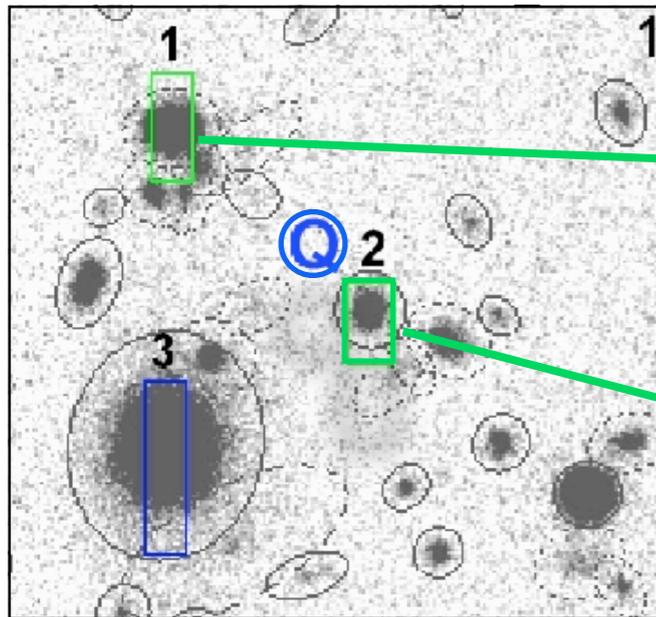
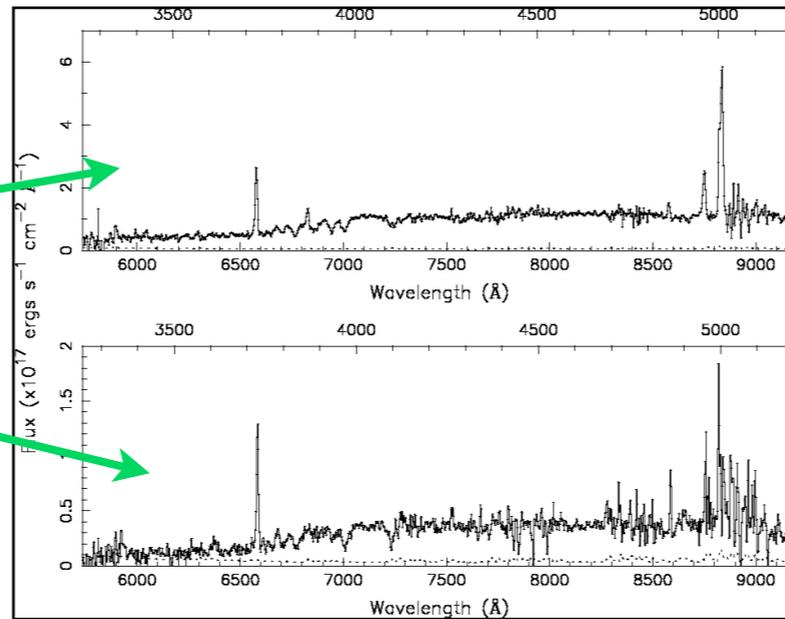
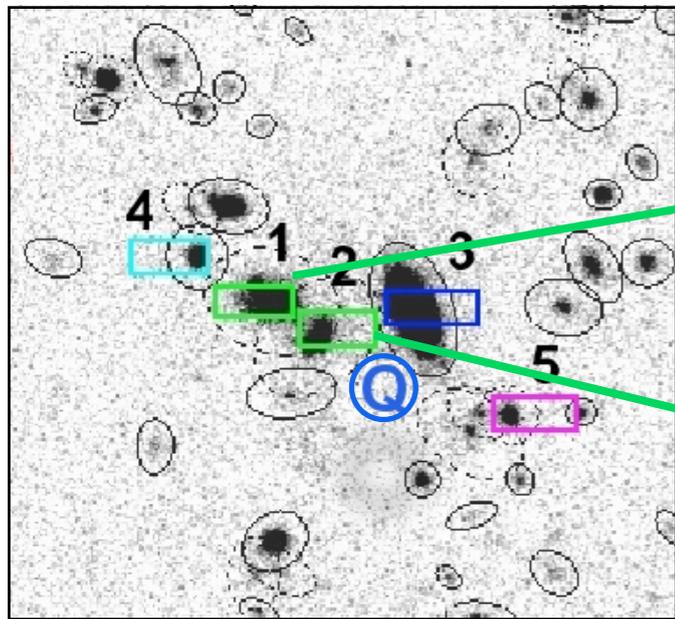
Using  $\sim 7000$  MgII absorbers, **Ménard, Nestor et al. (2008)** demonstrated that stronger MgII absorption systems are dustier.

# The connection between strong MgII absorbers & galactic outflows.



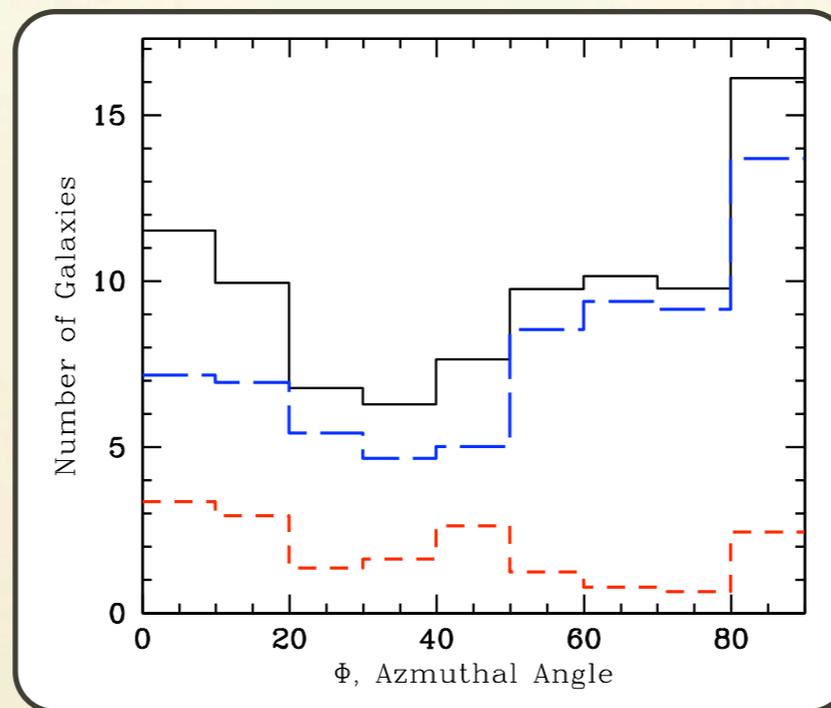
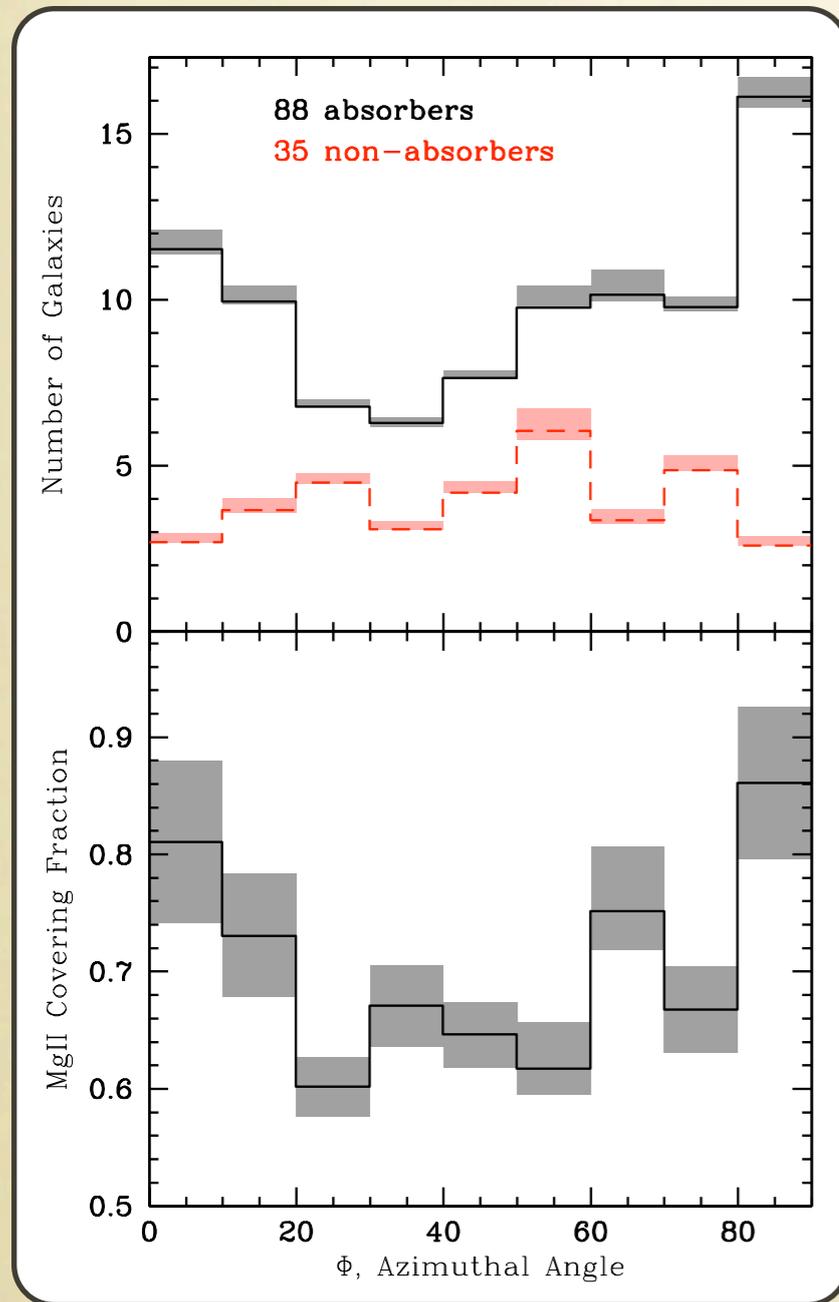
**Rubin et al. (2010)** found ultra-strong MgII absorption at the redshift of a post-starburst galaxy in the spectrum of a background galaxy.

# The connection between strong MgII absorbers & galactic outflows.



**Nestor, ... Ménard+ (2011) found starburst and post-starburst galaxies at the same redshifts as two USMgII absorbers.**

# The connection between strong MgII absorbers & galactic outflows.



**Kacprzak, Churchill+ (2012) and Bouché,...**  
**Kacprzak, Martin,...**  
**Churchill+ (2012) found bimodal orientations of MgII absorber galaxies wrt the QSO sightline, indicating absorption arises in either disks or outflows.**

## The connection between strong MgII absorbers & galactic outflows.

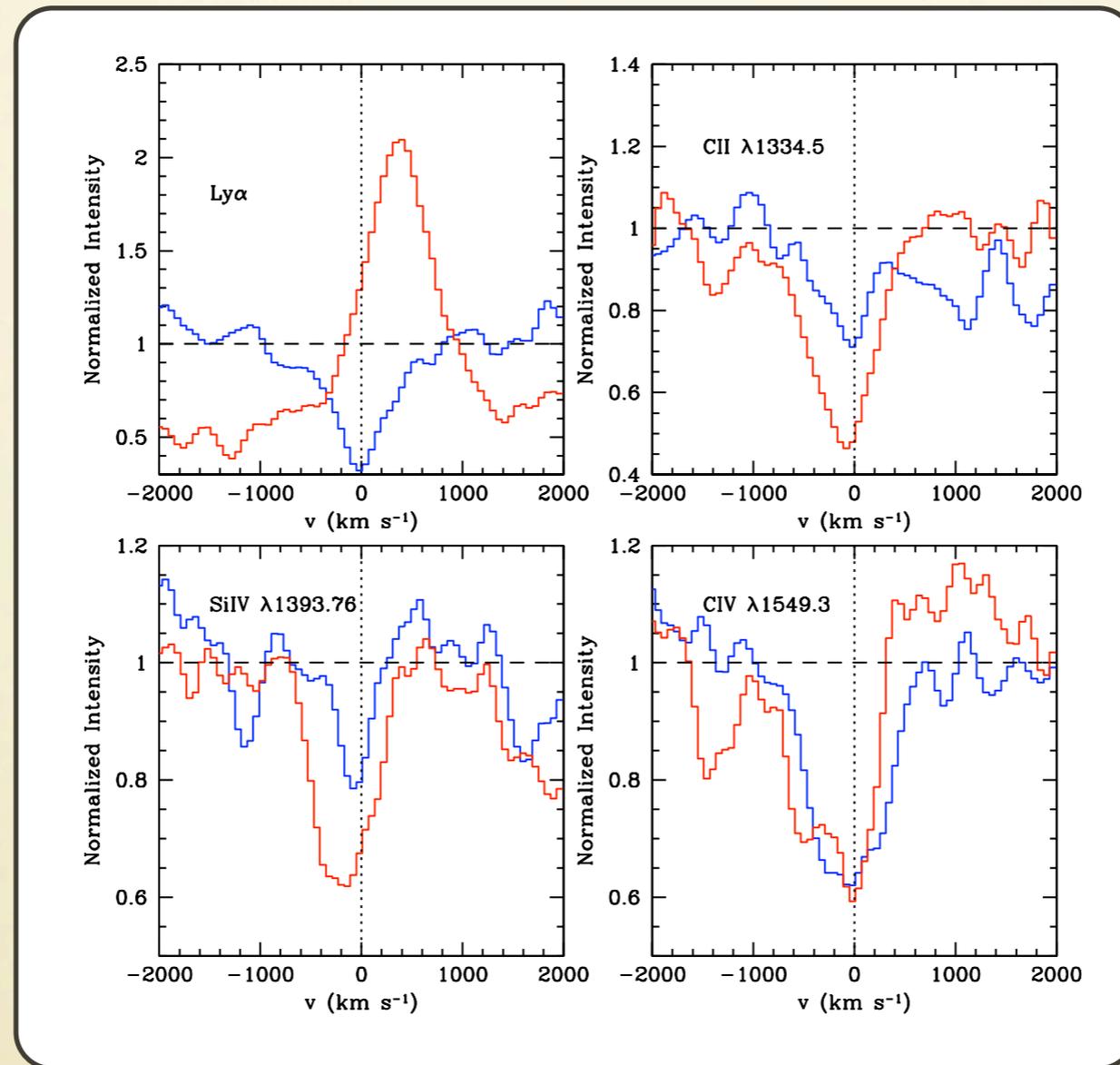
For some time now, “down the barrel” spectra of star-forming galaxies have shown the presence of outflowing gas. See works by: **Alison Coil, Tucker Jones, Kathy Kornei, Crystal Martin, Gwen Rudie, Alice Shapley, Charles Steidel, Christy Tremonti, Benjamin Weiner**, etc.

Are the blueshifted low-ion ISM absorption lines seen in the spectra of star forming galaxies — which are at unknown galactocentric distances — the same things as the intervening low-ion absorption systems seen in QSO spectra — which are often at large galactocentric distances?

# The connection between strong MgII absorbers & galactic outflows.

foreground  
galaxy

background  
galaxy



**Steidel, Erb, Shapley, Pettini, Reddy,  
Bogosavljevic, Rudie, & Rakic (2010)**

# The connection between strong MgII absorbers & galactic outflows.

A couple of caveats:

Winds don't account for *all* strong low-ion absorption.

Disks have clearly been shown to contribute as well. Also, some absorption likely comes from re-accreting gas.

I'm only talking about strong lines.

Weaker lines likely probe wind relics, low-level star formation in galactic outskirts, or edges of disks.

# MgII absorbers trace star formation.

(Ménard, Wild, Nestor, Quider, Zibetti, Rao & Turnshek 2011 explained)

One method of measuring the cosmic SFR density:

- Identify emission lines arising in HII regions from galaxies in a given volume (either through spectroscopy or narrow-band imaging).
- Compute line flux density  $\rho_{\text{flux}} = \Sigma_{\text{flux}} / V$
- Convert line flux density to SFR density:  $\rho_{\text{SFR}} = \rho_{\text{flux}} \times C_{\text{line flux to SFR}}$

Cosmic variance!

Alternate method:

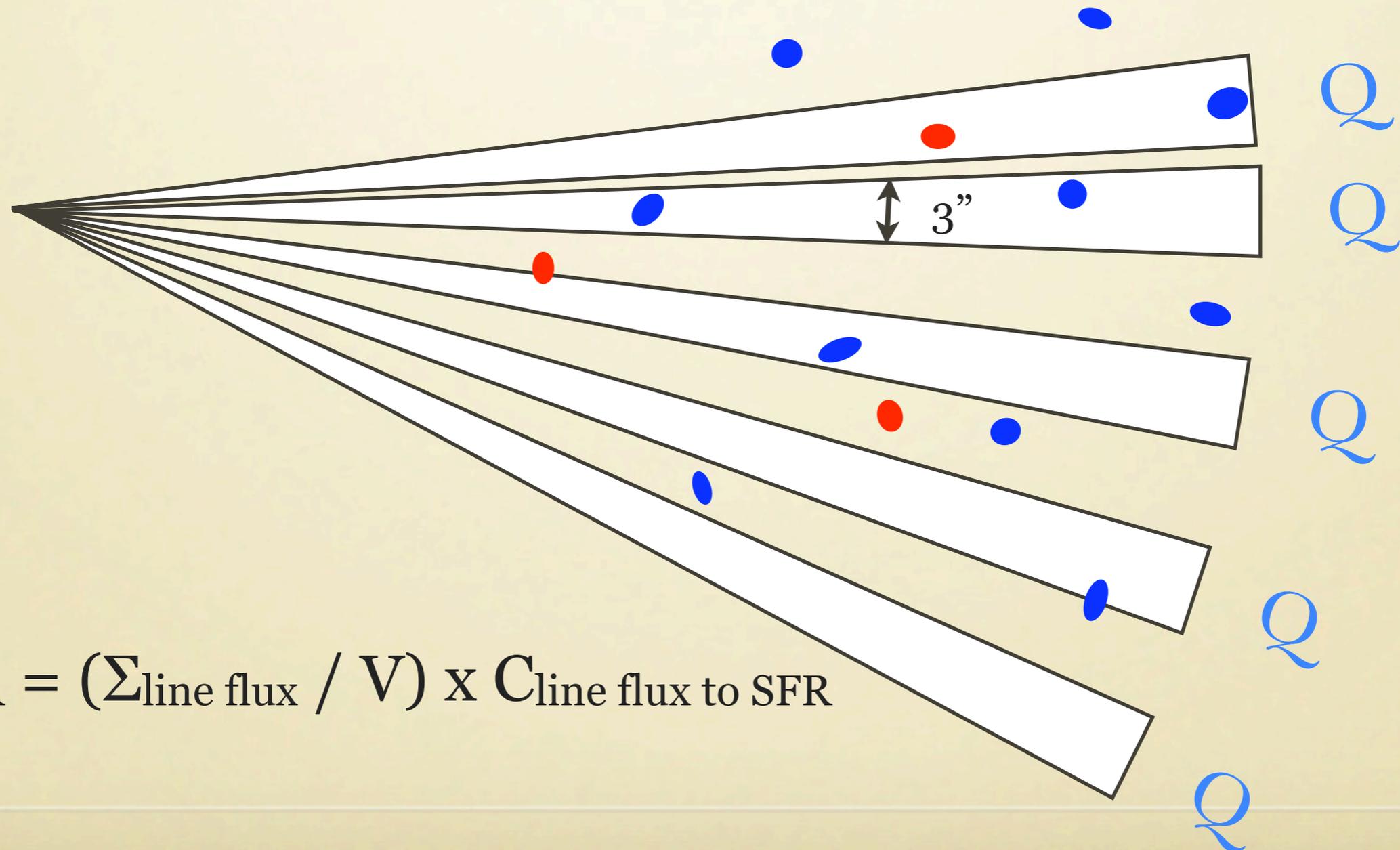
- Identify emission lines arising in HII regions from galaxies in volumes probed by the tens of thousands of SDSS QSO spectra sightlines.
- Compute line flux density  $\rho_{\text{flux}} = \Sigma_{\text{flux}} / V$
- Convert line flux density to SFR density:  $\rho_{\text{SFR}} = \rho_{\text{flux}} \times C_{\text{line flux to SFR}}$

No cosmic variance!

# MgII absorbers trace star formation.

(Ménard, Wild, Nestor, Quider, Zibetti, Rao & Turnshek 2011 explained)

Concept illustrated:

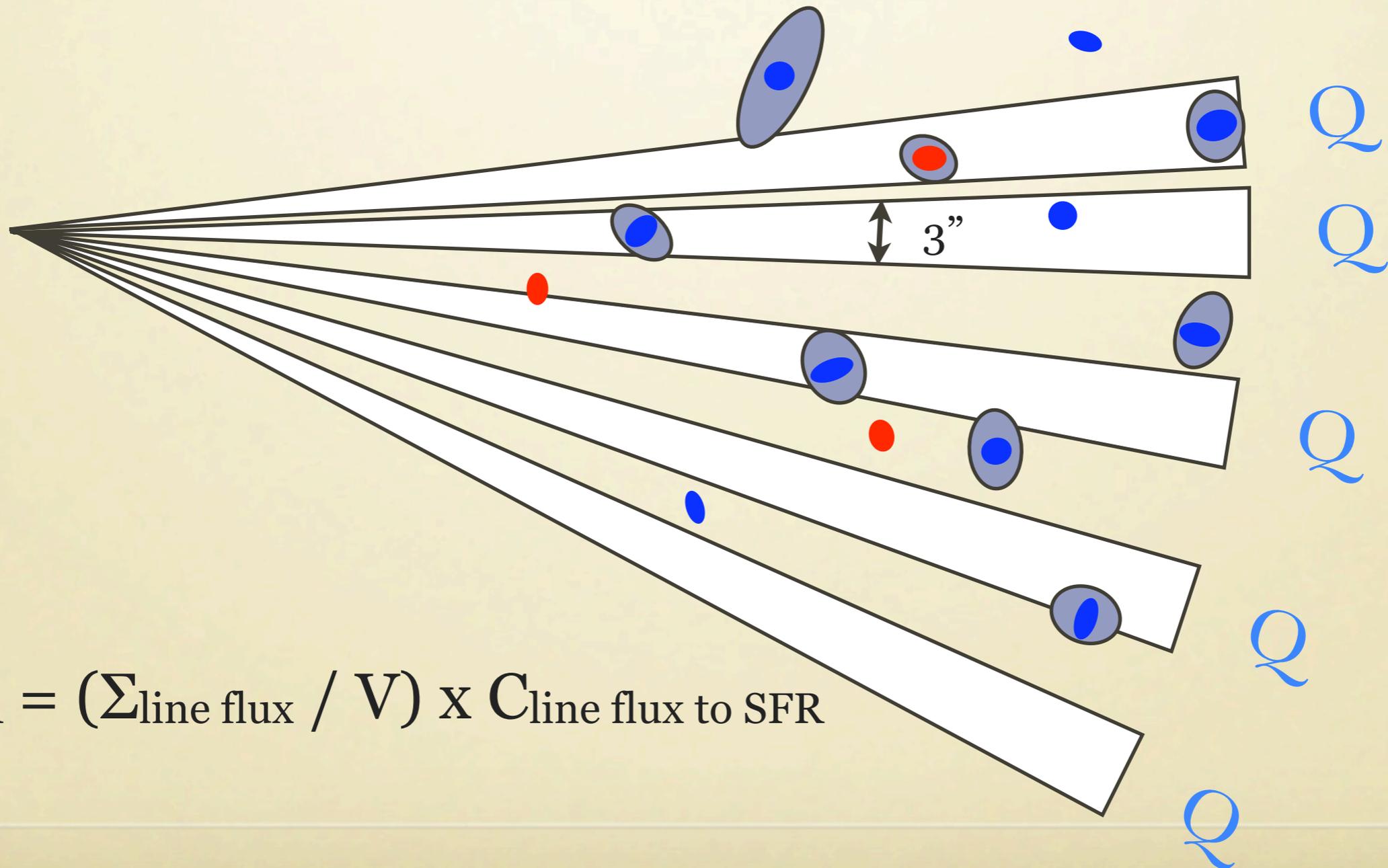


$$\rho_{\text{SFR}} = (\Sigma_{\text{line flux}} / V) \times C_{\text{line flux to SFR}}$$

# MgII absorbers trace star formation.

(Ménard, Wild, Nestor, Quider, Zibetti, Rao & Turnshek 2011 explained)

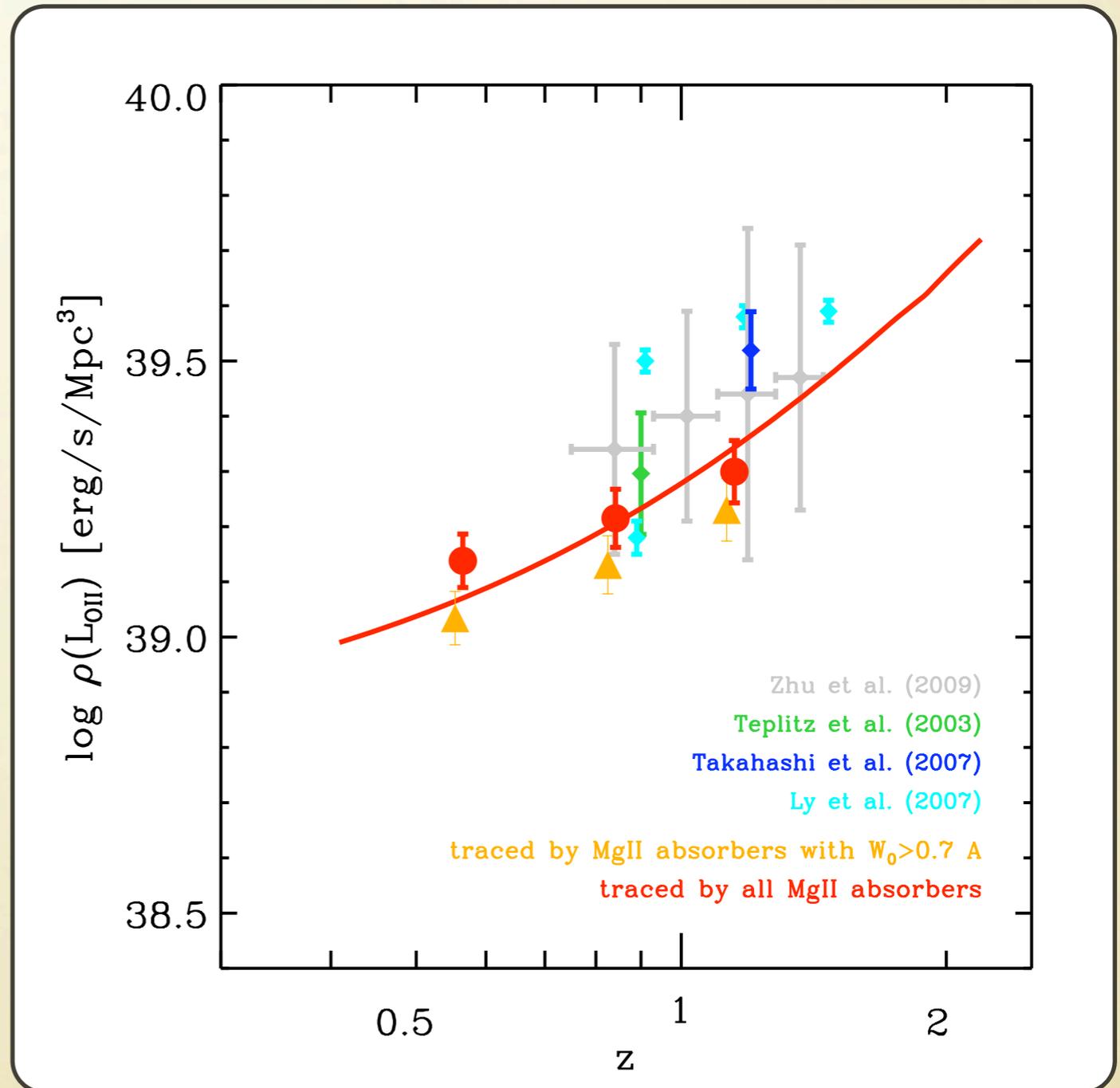
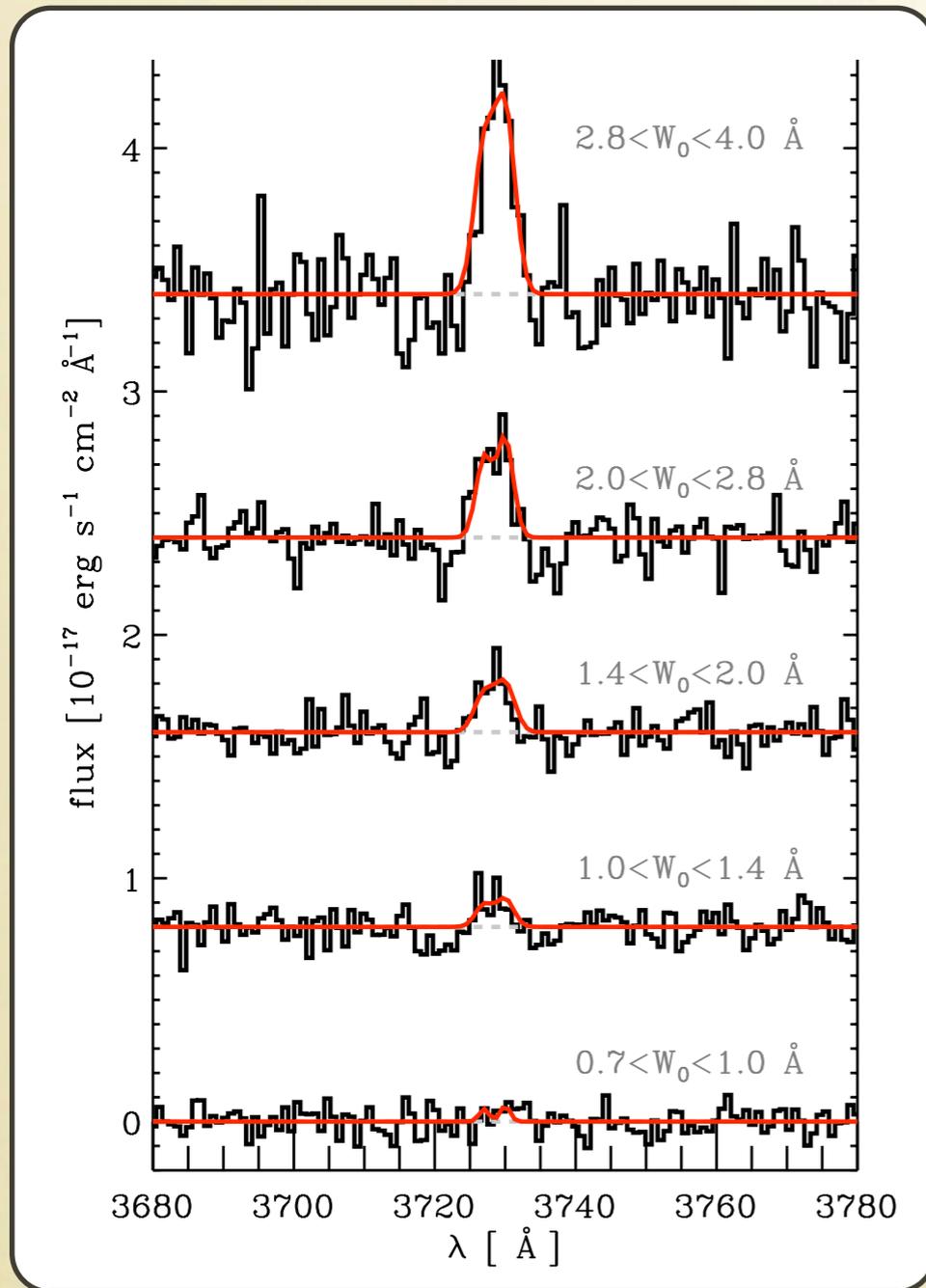
Concept illustrated:



$$\rho_{\text{SFR}} = (\Sigma_{\text{line flux}} / V) \times C_{\text{line flux to SFR}}$$

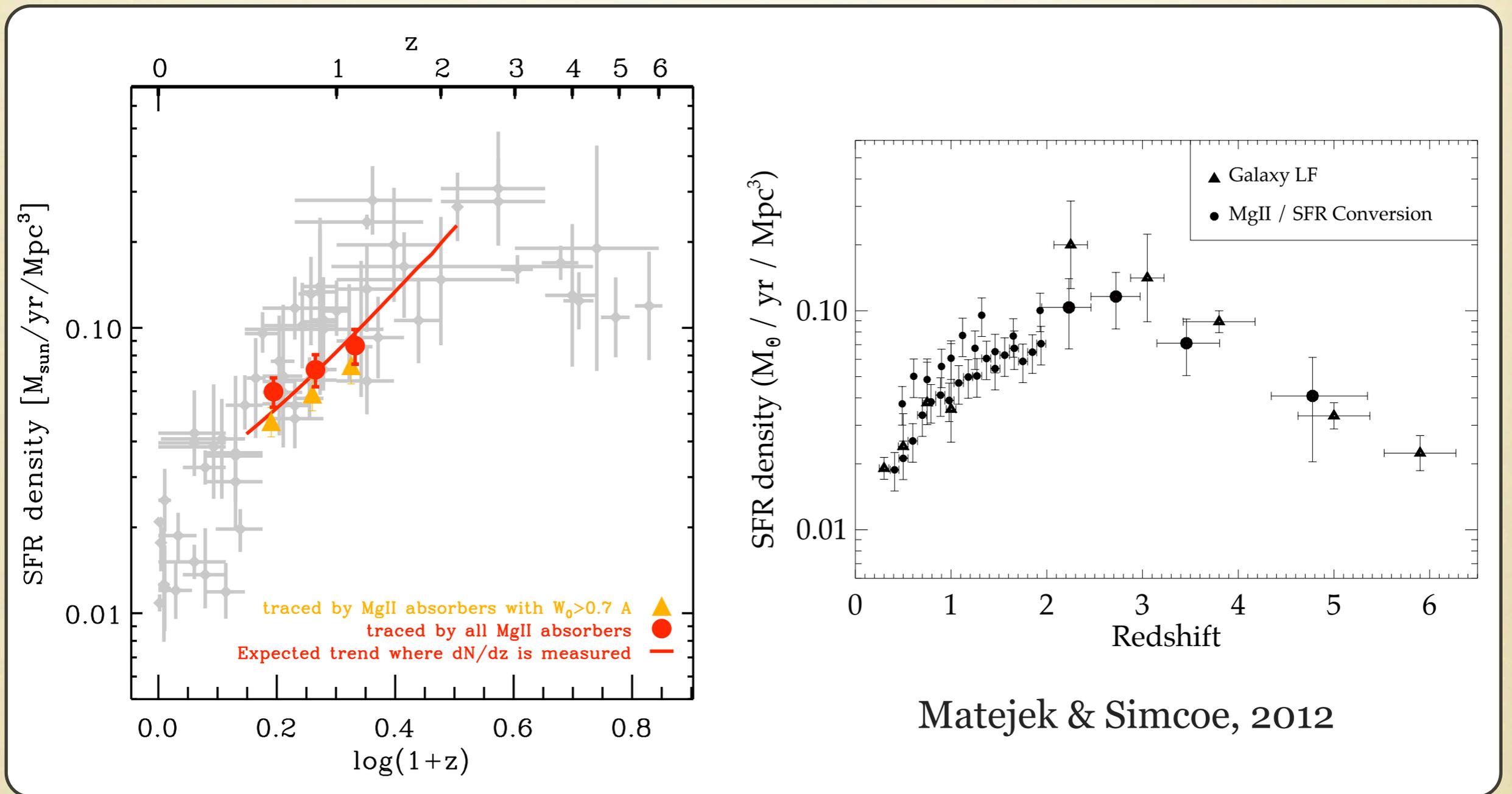
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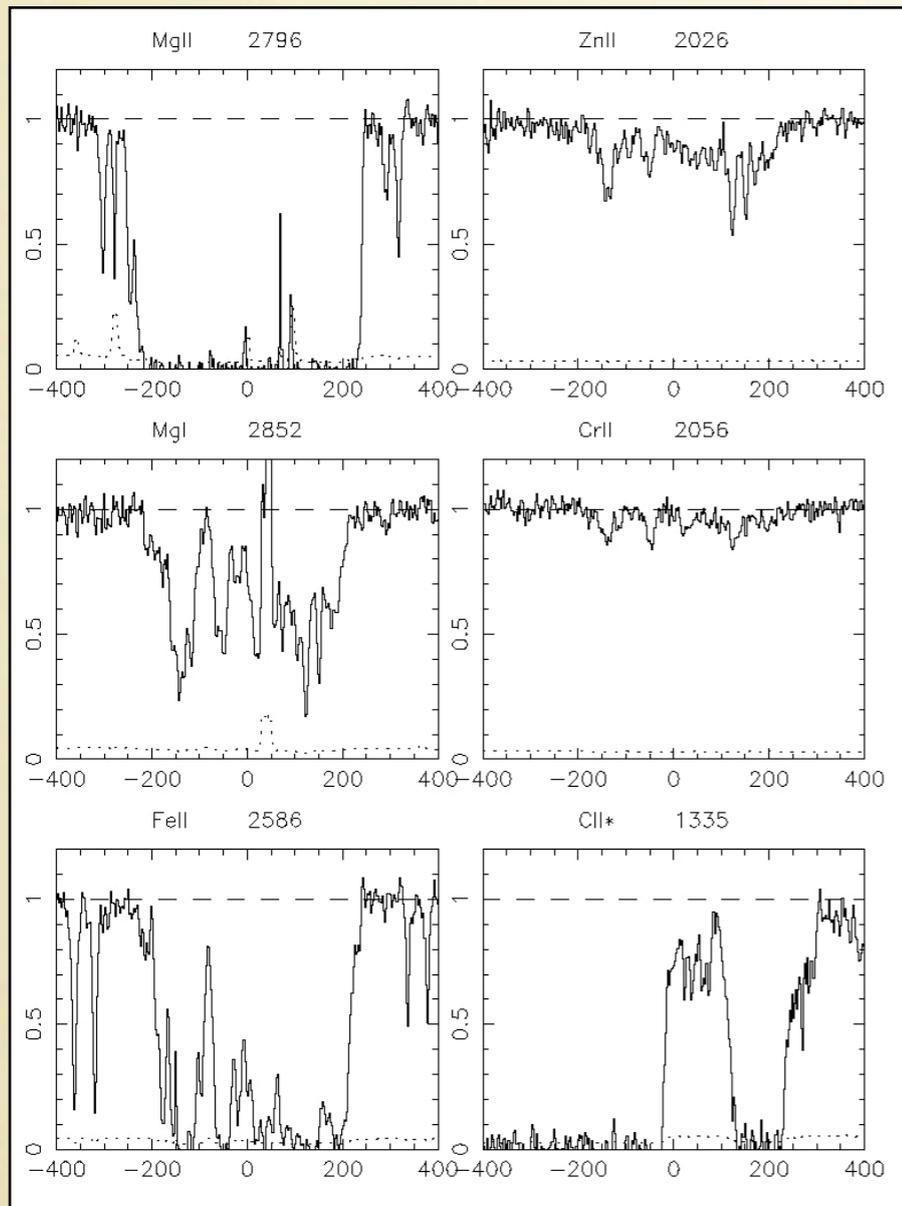
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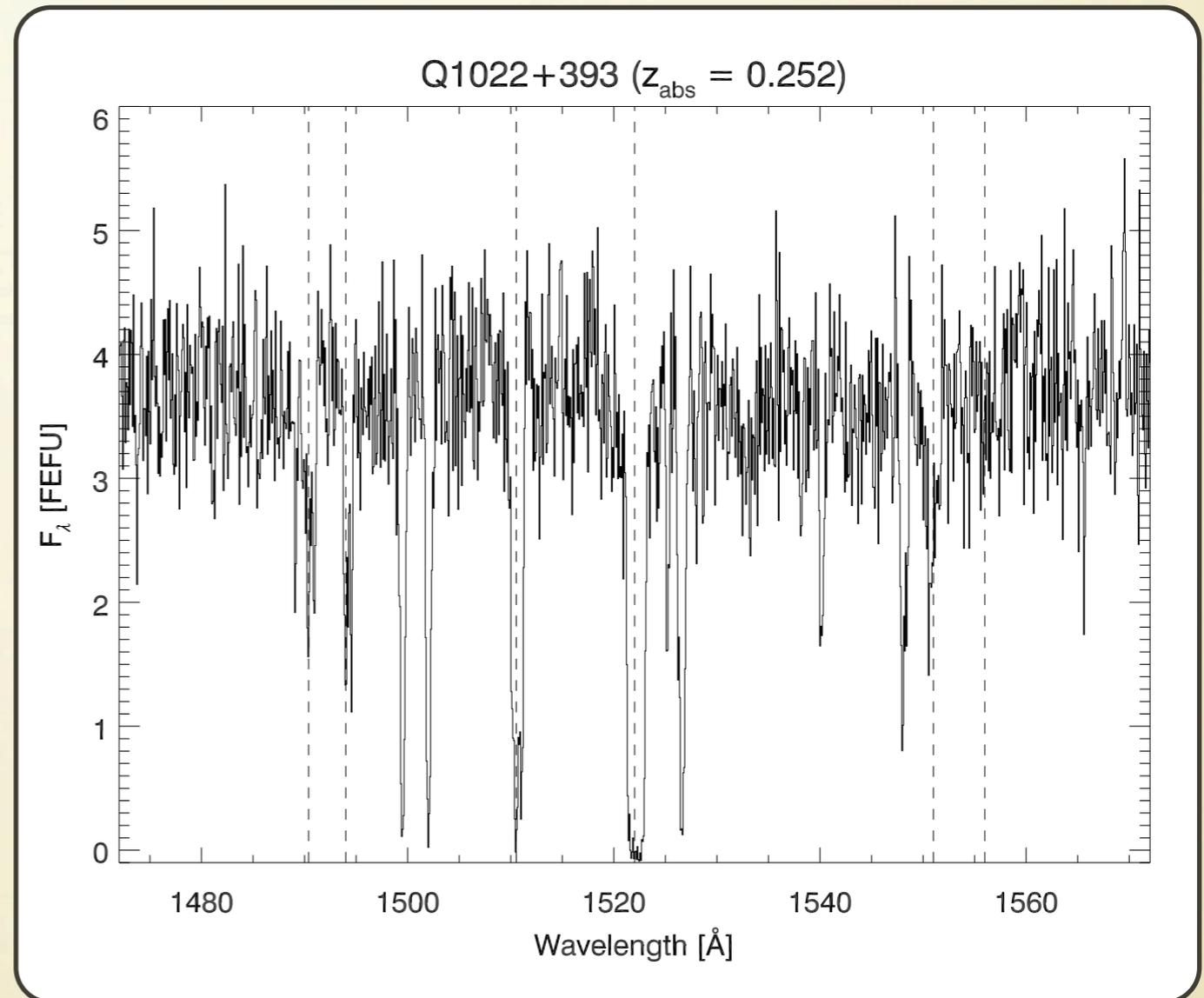


Most SF in Universe is in regions that will cause MgII absorption if sightline passes through that region.

# Preview of ongoing abs line work:



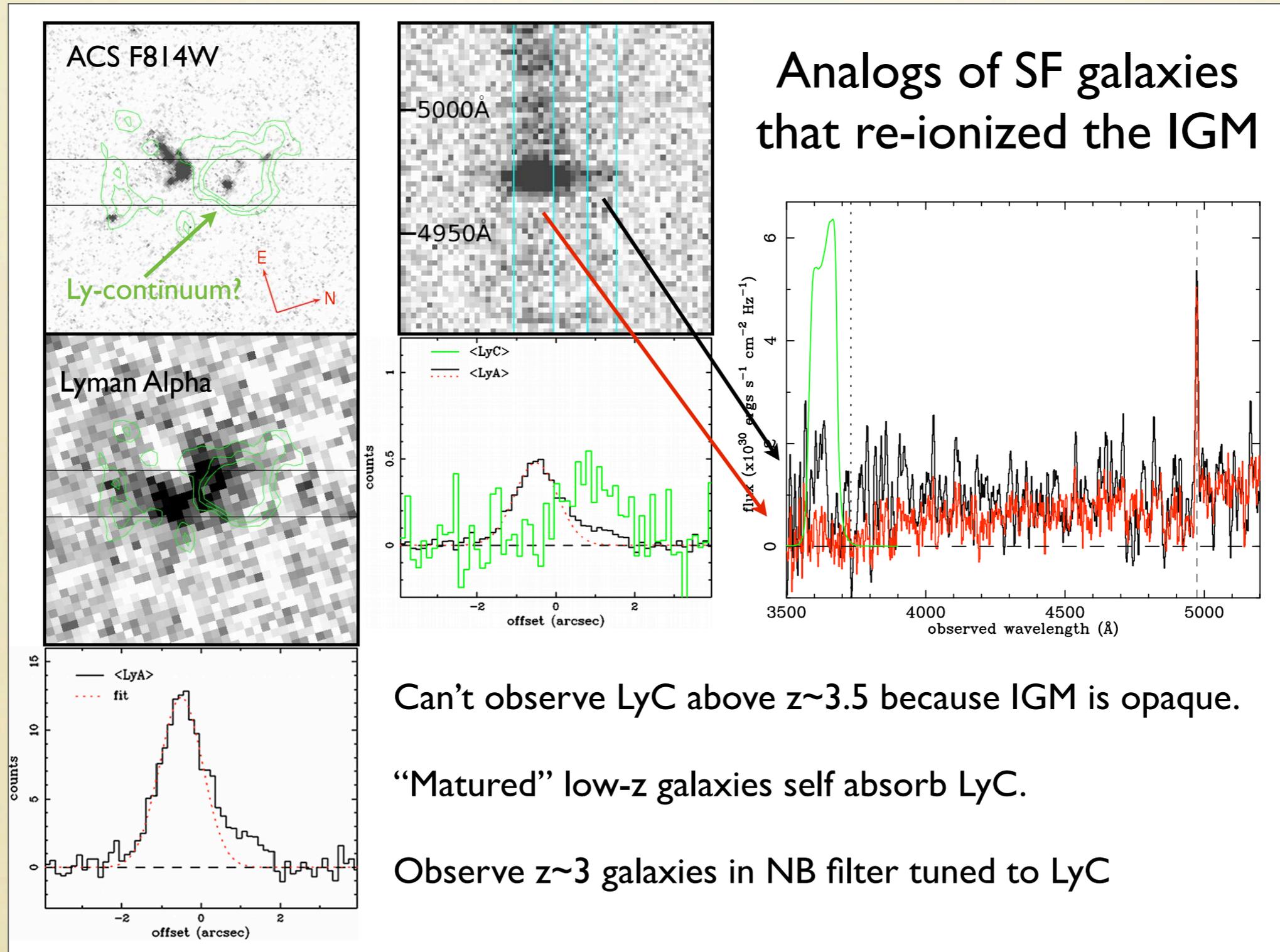
UVES spectra of strongest MgII abs in the Universe, covering HI Ly $\alpha$  to MgII  $\lambda$ 2800.



HST/COS spectra of lowest- $z$  known MgII abs in the Universe, covering HI Ly $\alpha$  to determine  $N(\text{HI})$  at  $z < 0.4$ .

# Because Molly wouldn't give me a 1 minute slot...

At Bat: Daniel Nestor



# Summary

## *INFLOW*

Galaxies accrete cool gas at rates on the order of SFR through hot- and cold-modes, but the vast majority of baryons in stars today were once in the ionized IGM.

## *OUTFLOW*

Many independent studies indicate that strong intervening low-ion absorption features in the spectra of background QSOs and galaxies arise in galactic winds.

## *STAR FORMATION*

Most of the SF in the Universe can be associated with MgII absorbers. Thus the statistics of MgII systems can tell us about the cosmic history of star formation.