Empirical Constraints on the Cool Gas Content of Dark Matter Halos

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Berkeley Cosmology Seminar Series
Oct 19, 2010

.:. Outline .:.

Understanding the origin of cool gas in dark matter halos

Introduction

- **Simulation and model predictions**
  * Cold accretion/cold flows/cold mode
  * Instabilities within a hot medium
- **Observations**
  * Stripped gas from satellites
  * Starburst driven outflows

Our approach

- **Clustering of cool gas at intermediate z (z ~0.5)**
- **Cool gas in massive, group-size dark matter halos**

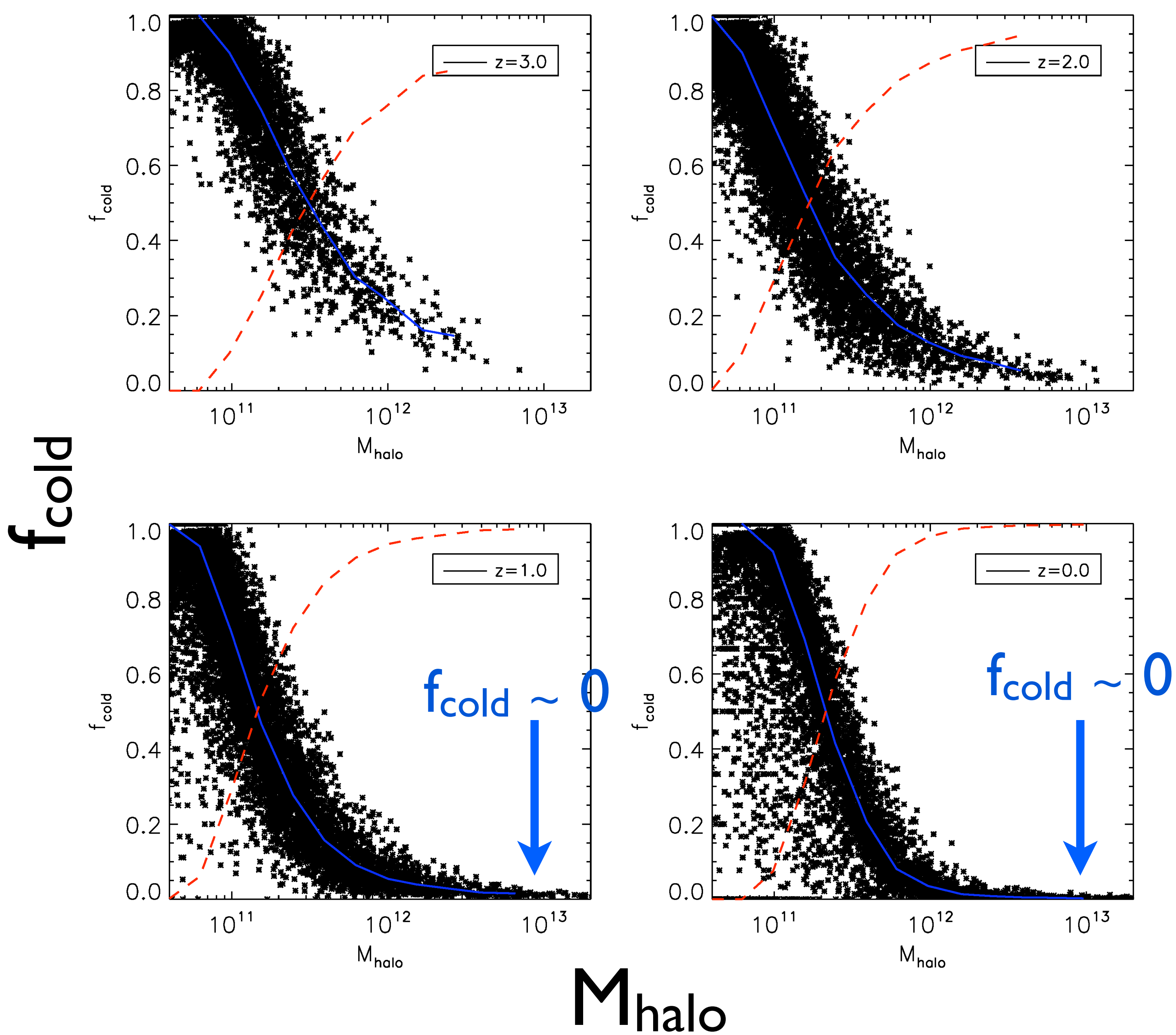
Future Plans

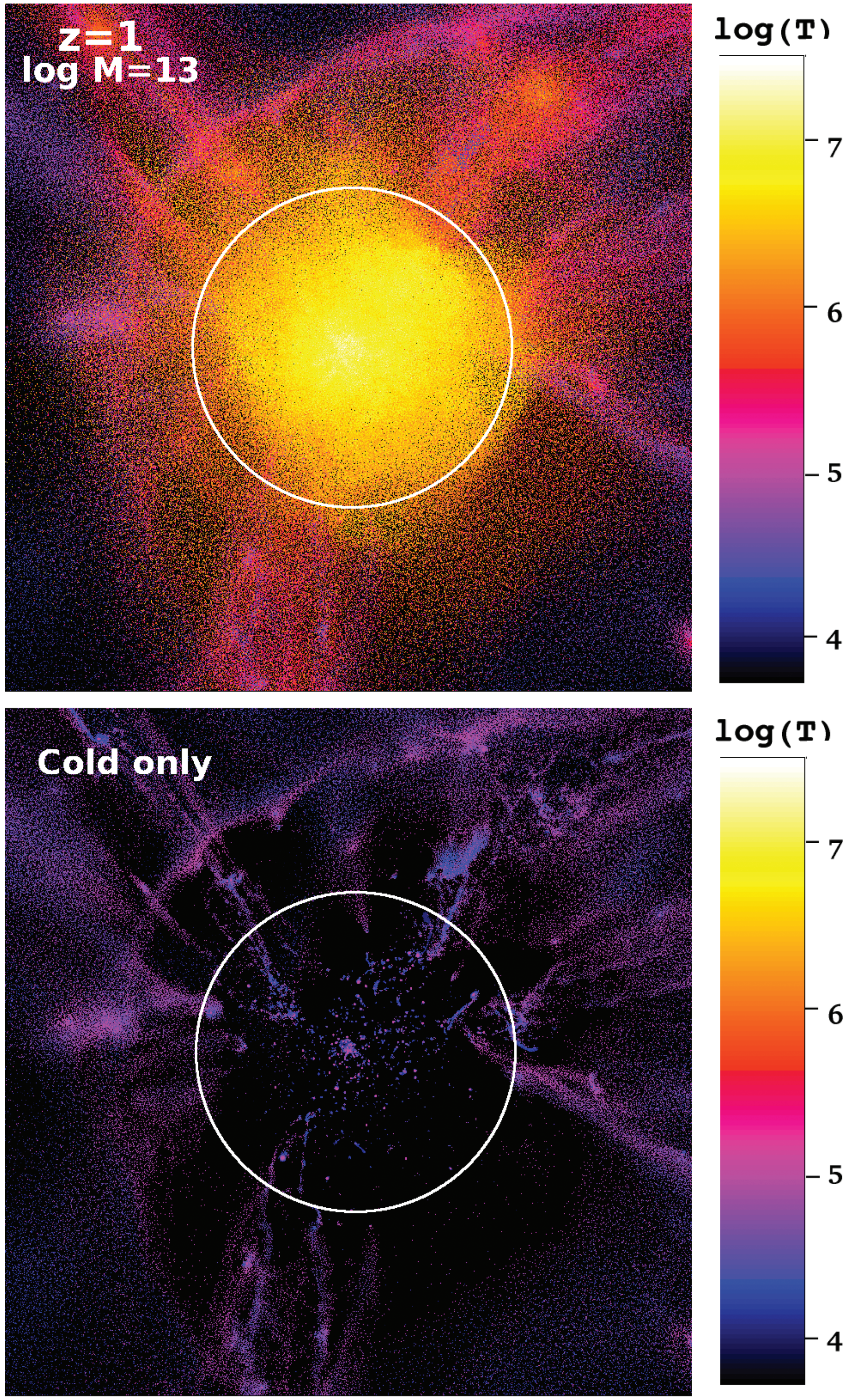
Summary and conclusions

Origin of cool baryons in dark matter halos

Cold Gas Accretion on Dark Matter halos

e.g. Keres et al. 2009





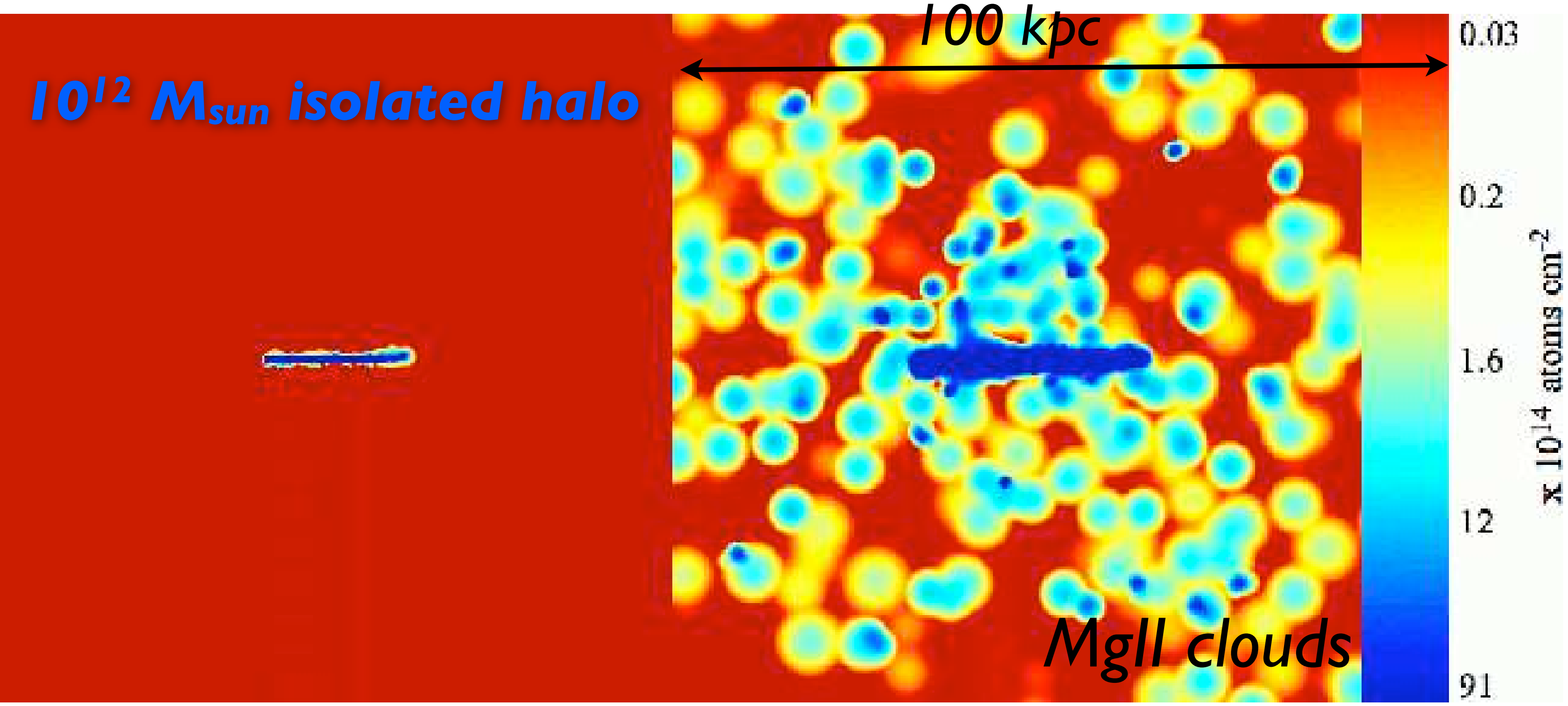
Accretion of cool, T~10^4 K gas, is inefficient in massive halo

Dekel & Birnboim 2006
Dekel et al. 2009

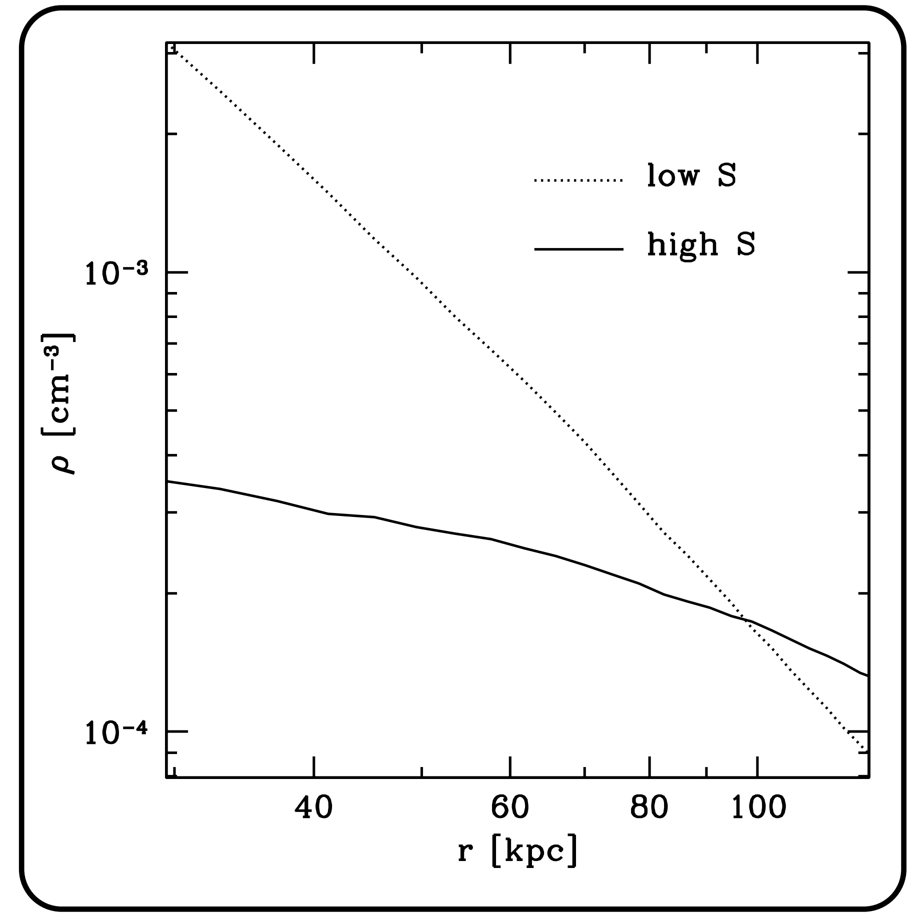
Origin of cool baryons in dark matter halos

Instabilities within the hot halo gas

e.g.: Fields 1965



low-entropy halo ***high-entropy halo***

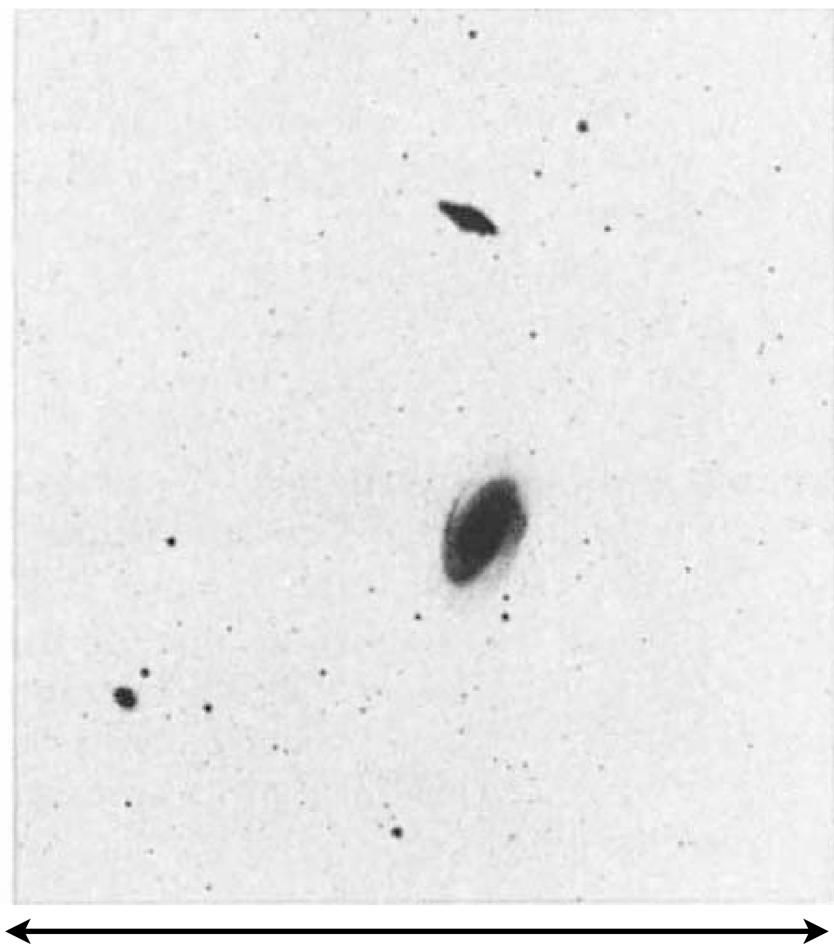


Kaufmann et al. (2009)

see also Mo & Miralda-Escude (1996), Maller & Bullock (2004), Keres and Hernquist (2009)

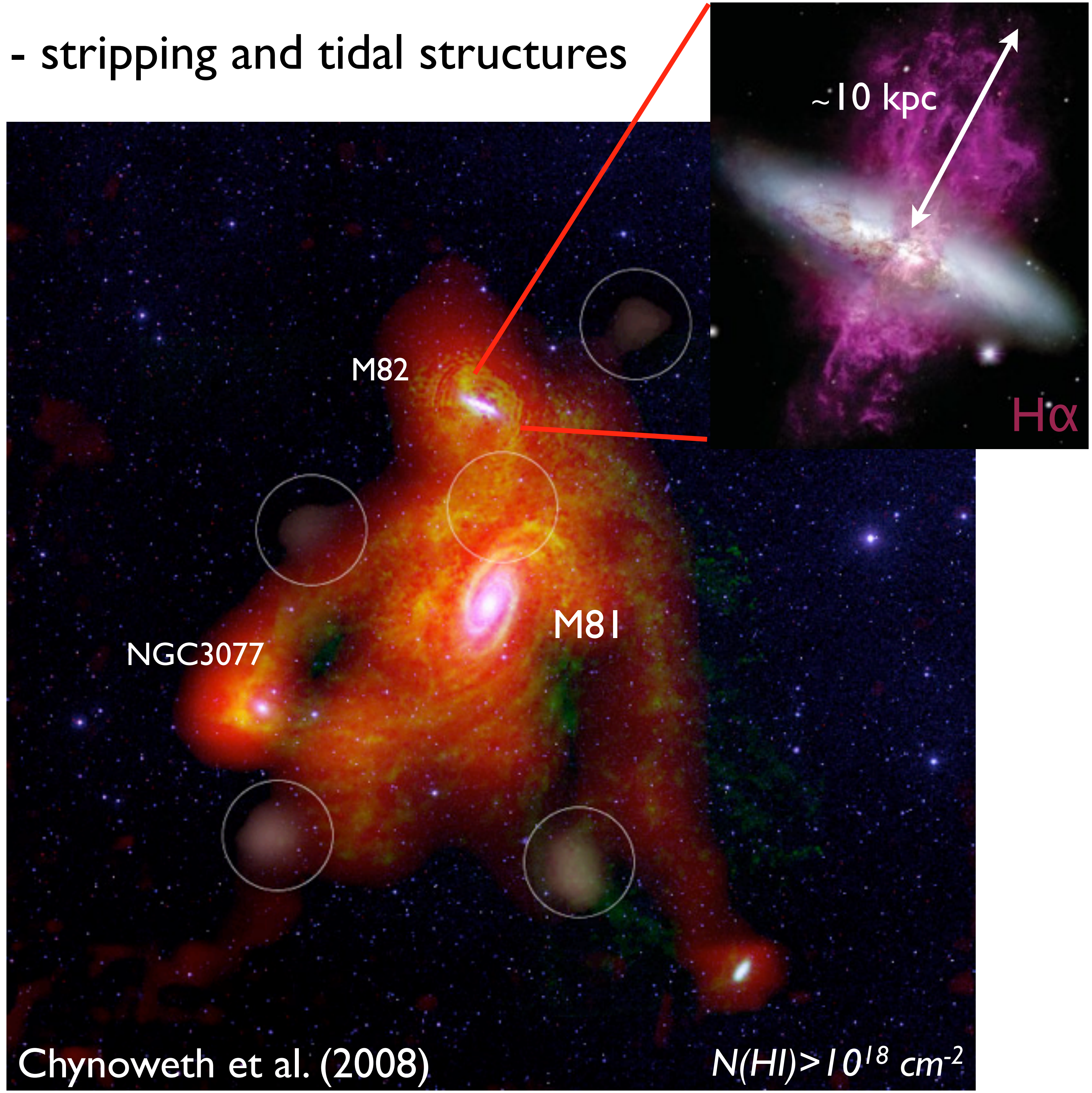
Origin of cool baryons in dark matter halos

Galactic interactions - stripping and tidal structures



150 kpc

Yun et al. (1994)



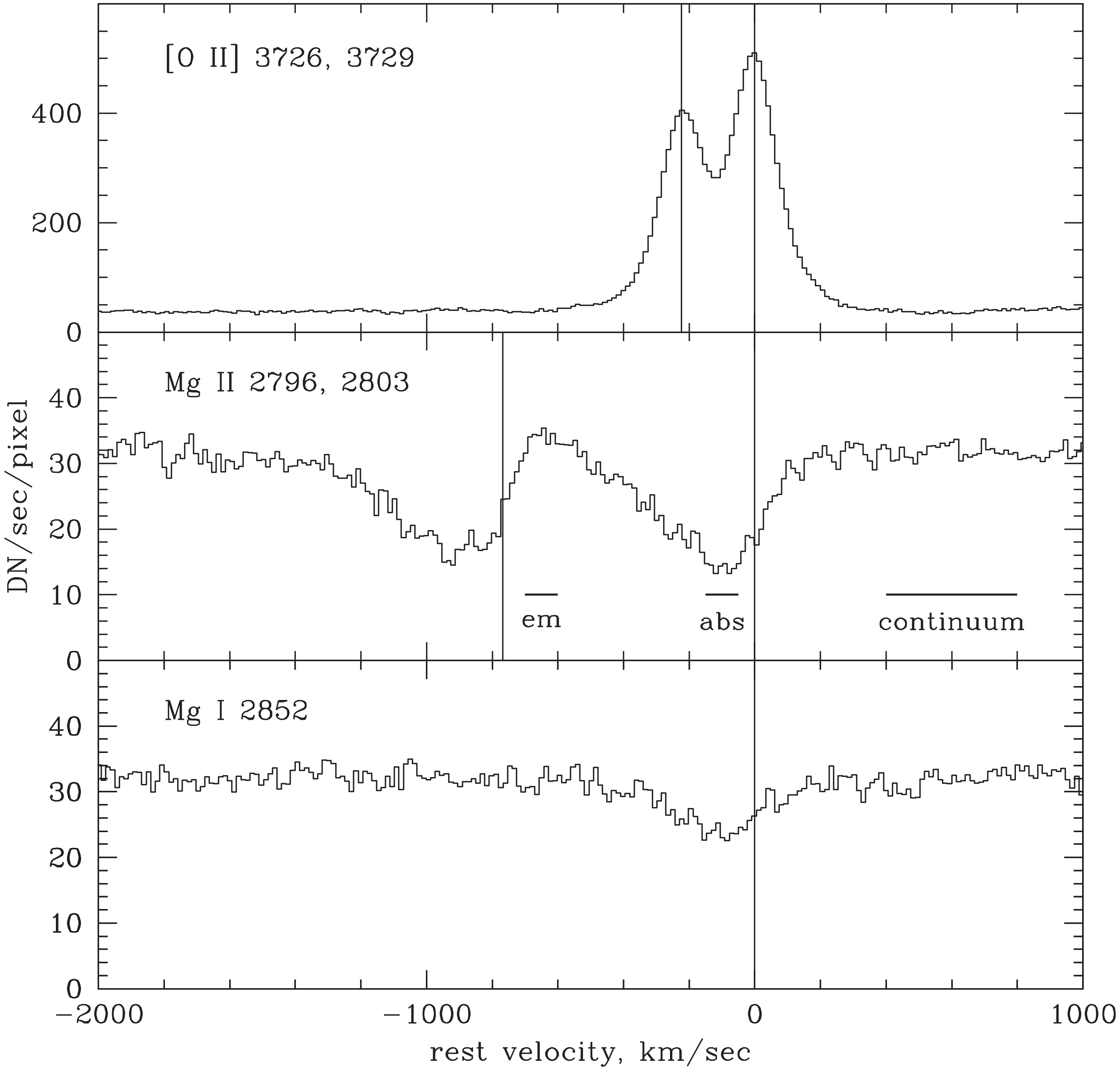
see also Wang (1993)

Credit: Chynoweth et al., NRAO/AUI/NSF, Digital Sky Survey.

Origin of cool baryons in dark matter halos

Starburst driven outflows

Weiner et al. (2009)



MgII λλ2796,2803 absorption doublets are tracers of cool gas in galactic halos

- Co-added spectrum of 1406 DEEP2 galaxies
- MgII absorption doublet is blueshifted with respect to galactic [OII] emission lines

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- How far away is the ouflowing material?
- Does the gas detected at large separations from the galaxy share the same origin?

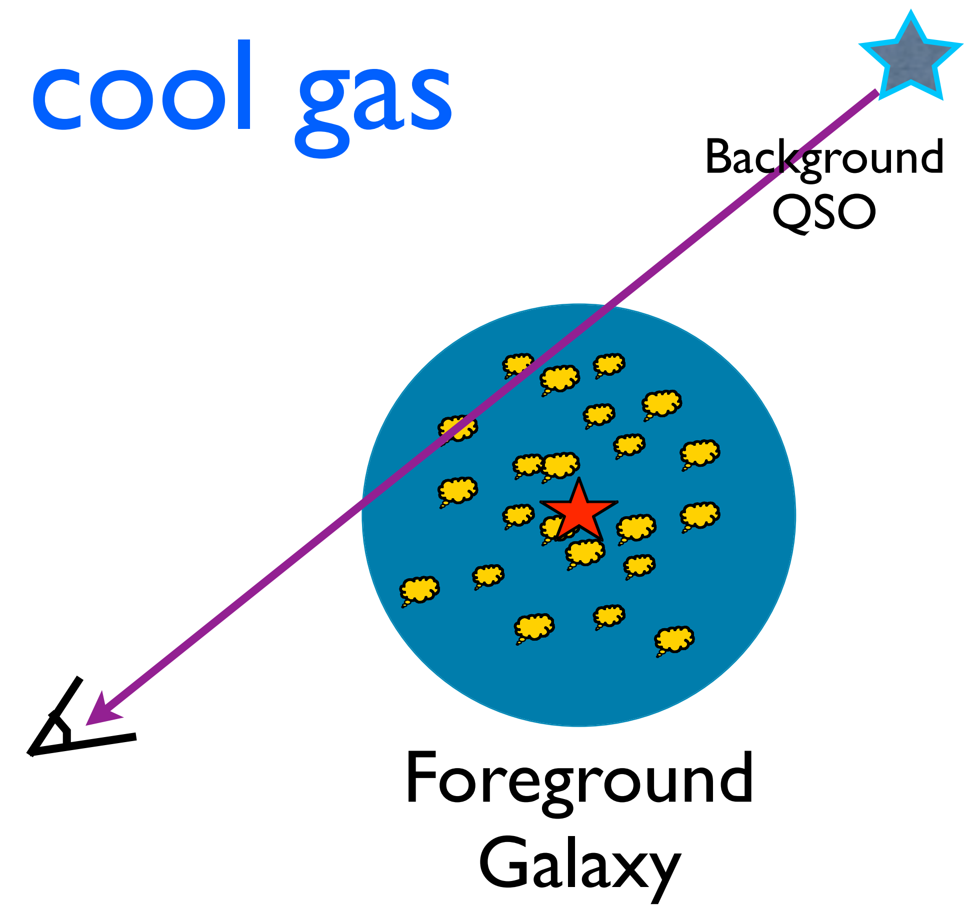
see also Bond et al. (2001), Nestor et al. (2010), Steidel et al. (2010), Menard et al. (2009)

Exploring the cool gas content of dark matter halos

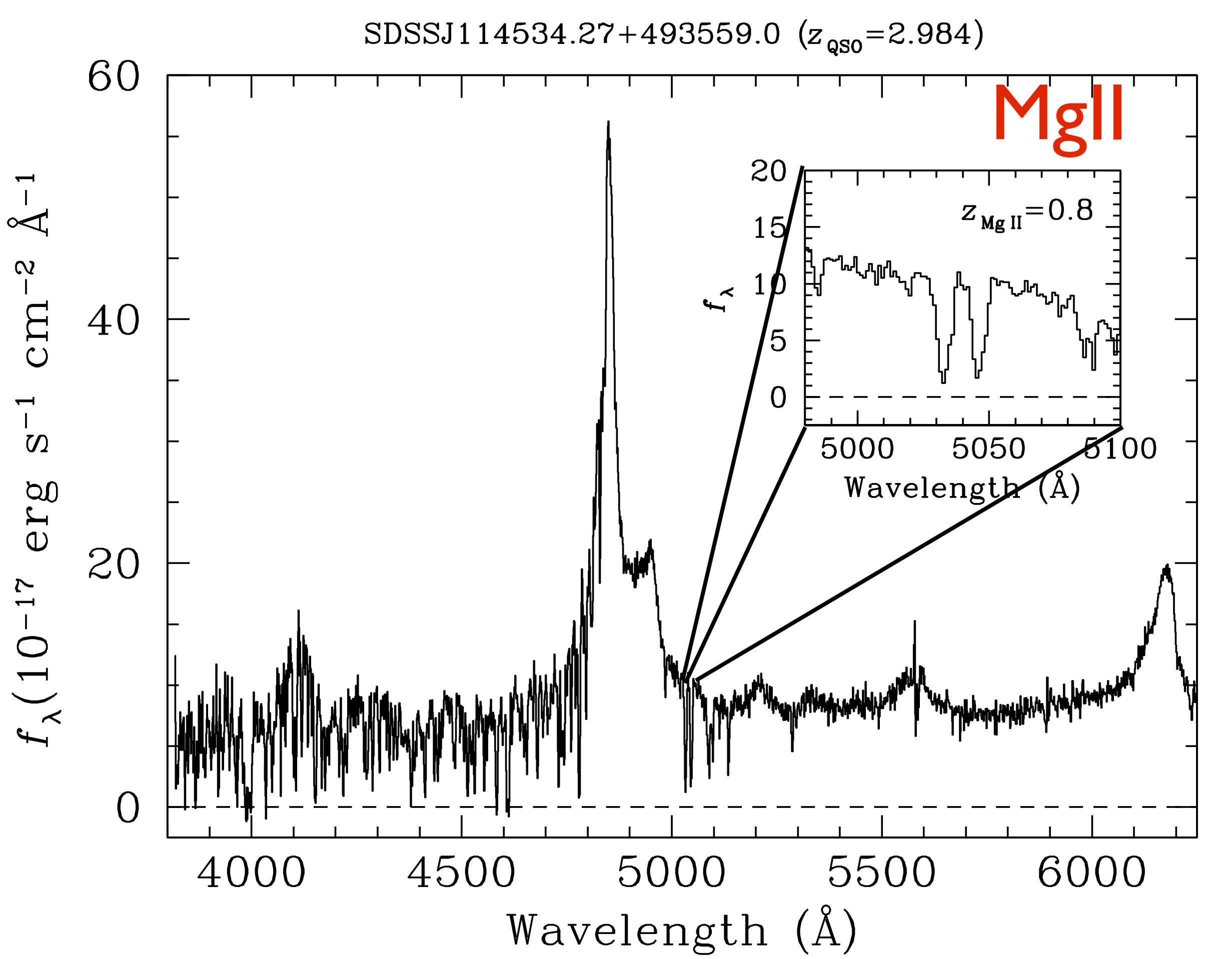
(using QSO absorption line clustering)

- Taking advantage of the large data sample of SDSS (100K QSO spectra and 100M galaxies)
- Need a tracer/indicator of cool gas in halos : MgII absorbers in background QSO spectra
- Need a tracer of dark matter density field : Luminous Red Galaxies

MgII absorbers as a tracer of cool gas



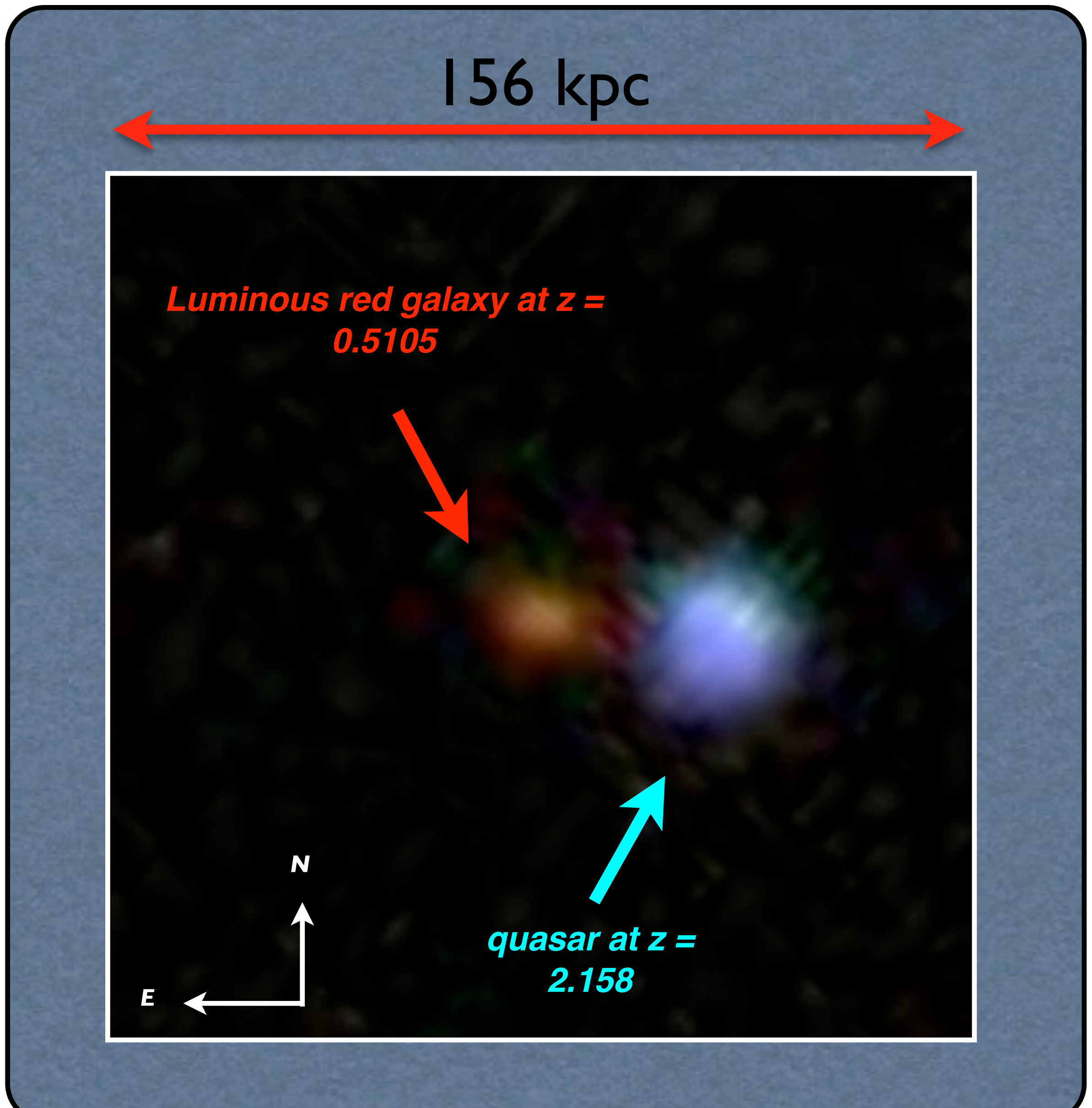
- MgII λλ 2796, 2803 absorption doublet is commonly seen in QSO spectra
- Absorbers arise in photo-ionized gas of $T \sim 10^4$ K and trace high-column density HI clouds with $N(HI) \approx 10^{18} - 10^{22}$ (Bergeron & Stasínska 1986; Rao et al. 2006)
- Large HI column density suggests that MgII absorbers originate in halo gas around individual galaxies (Doyle et al. 2005).
- Many luminous galaxies have been found at projected distances ρ = 50 - 100 h^{-1} kpc from *known* MgII absorbers. (Bergeron 1986; Lanzetta & Bowen 1990, 1992; Steidel et al. 1994; Zibetti et al. 2005,2007; Nestor et al. 2007; Kacprzak et al. 2007).



Cool gas in massive halos

Probing the cool gas of LRGs halos

Gauthier et al. 2009,2010



- LRGs are “red and dead” early-type massive galaxies. They constitute a homogeneous non-evolving population of galaxies. Luminous -> can be detected to high z.
- known to inhabit massive halos and are good tracers of the large-scale cosmic structures.
- Their strong 4000Å break allows for reliable photometric redshift estimates.

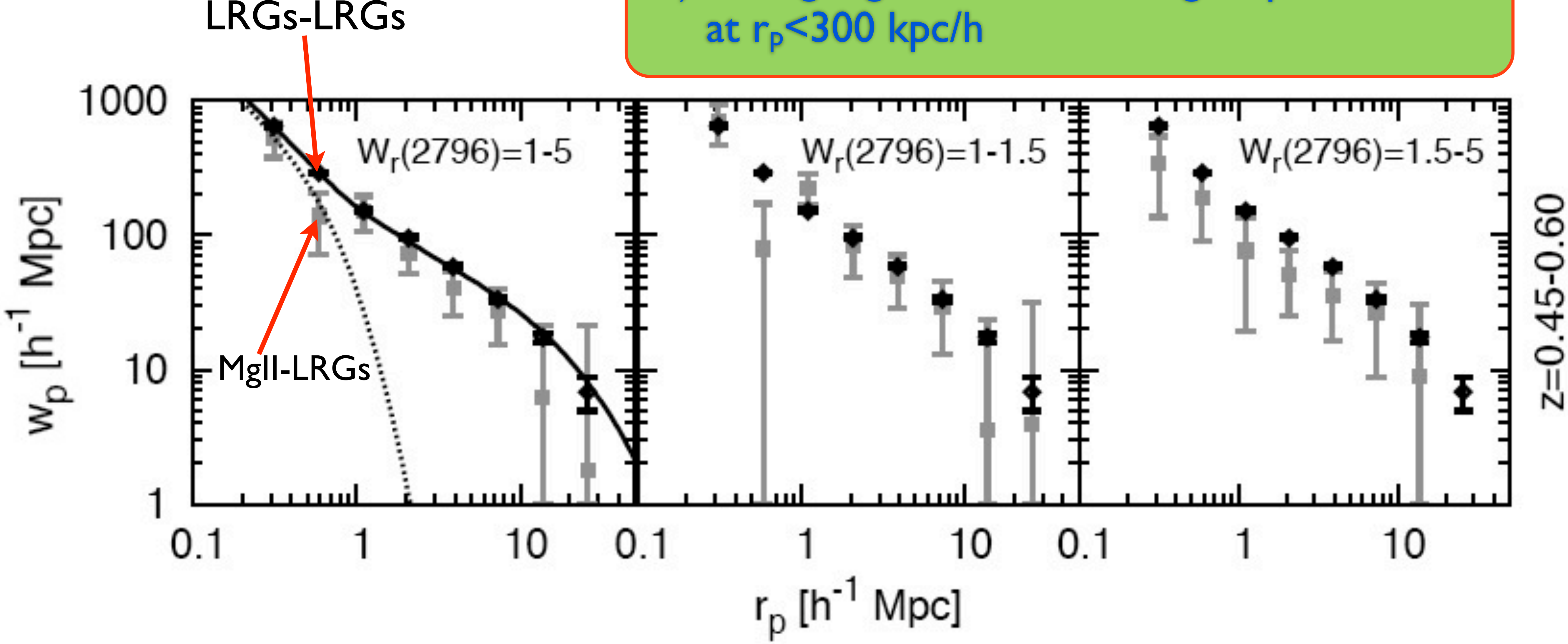
Cool gas in massive halos : the clustering of MgII absorbers

Gauthier et al. (2009)

Cross-correlation MgII - LRGs at z ~ 0.5

1) Large scale clustering amplitude of "weak" absorbers is higher than strong absorbers.

2) strong MgII-LRGs clustering amplitude at r_p<300 kpc/h



projected separation

see also Bouché et al. (2006) and Lundgren et al. (2009)

From the bias of LRGs to the bias of the absorbers hosts

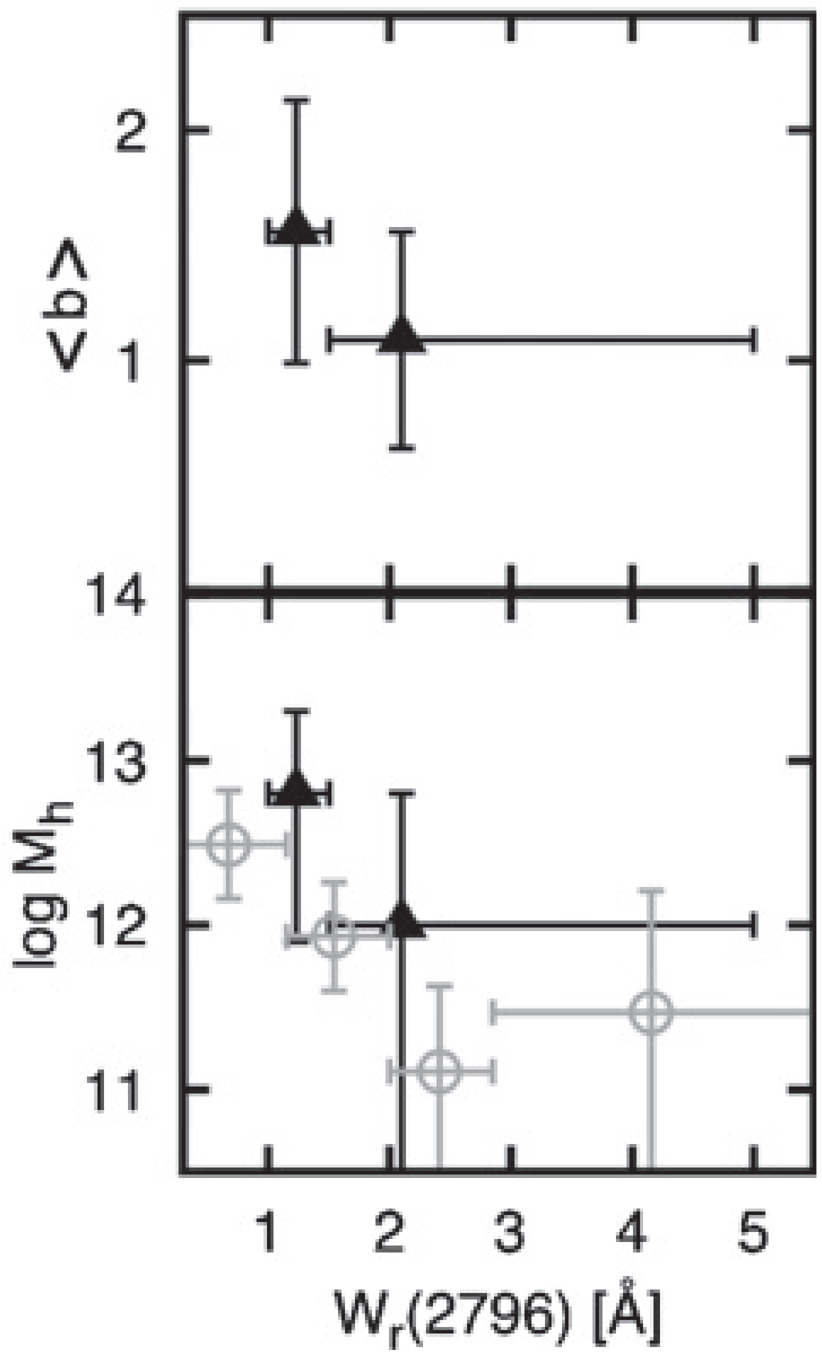
- 1) compute the relative bias of the absorber hosts by computing the ratio between correlation functions on large scales

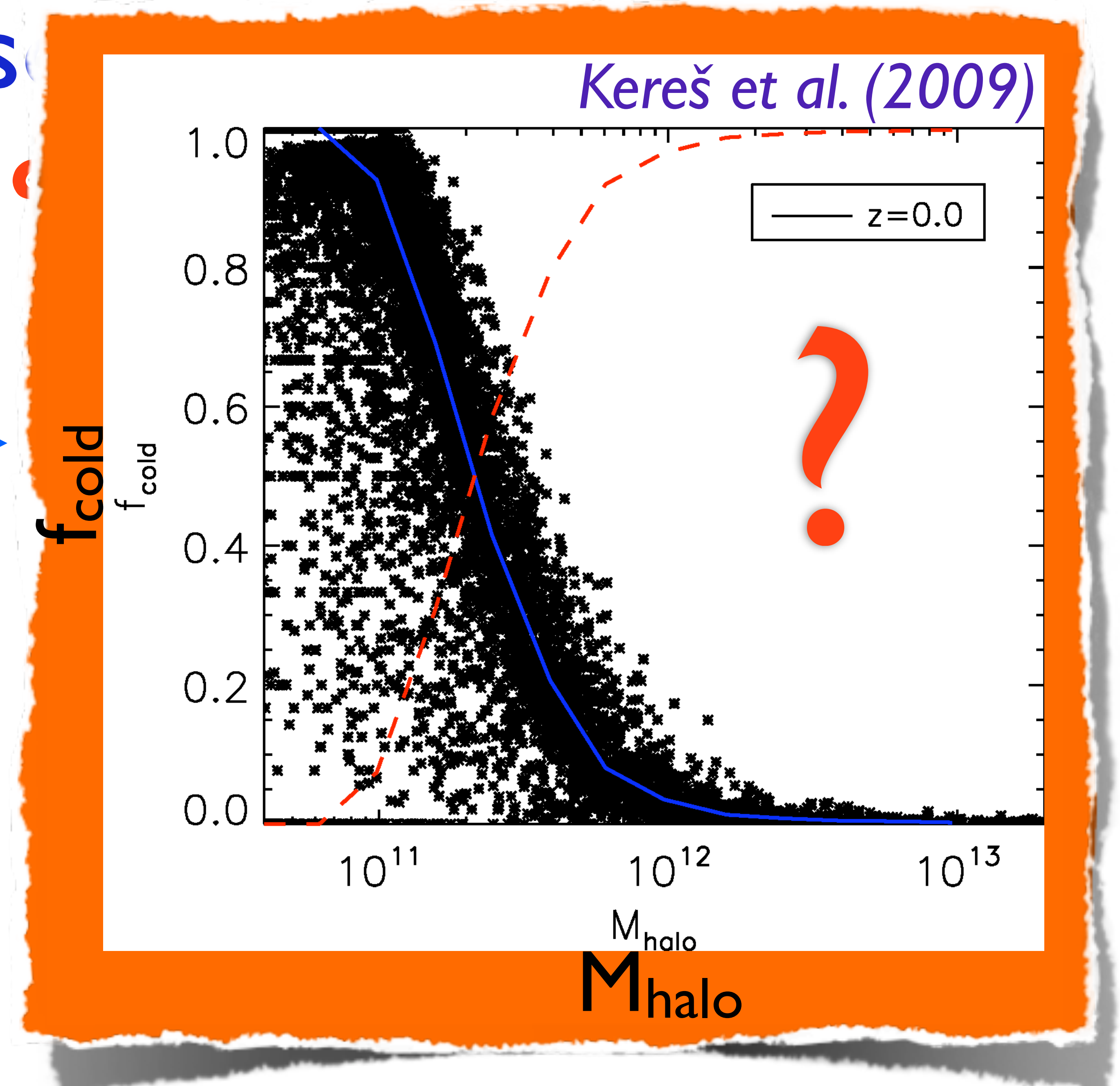
$$\hat{b} \equiv \frac{b_a}{b_g} = \frac{w_{ag}}{w_{gg}},$$

2) We know the bias of LRGs from the HOD fit. We can obtain bias of absorbers hosts.

Clustering of MgII abs

The main results of the c





On average, stronger absorbers are unbiased. Weaker ones are preferentially found in more massive halos

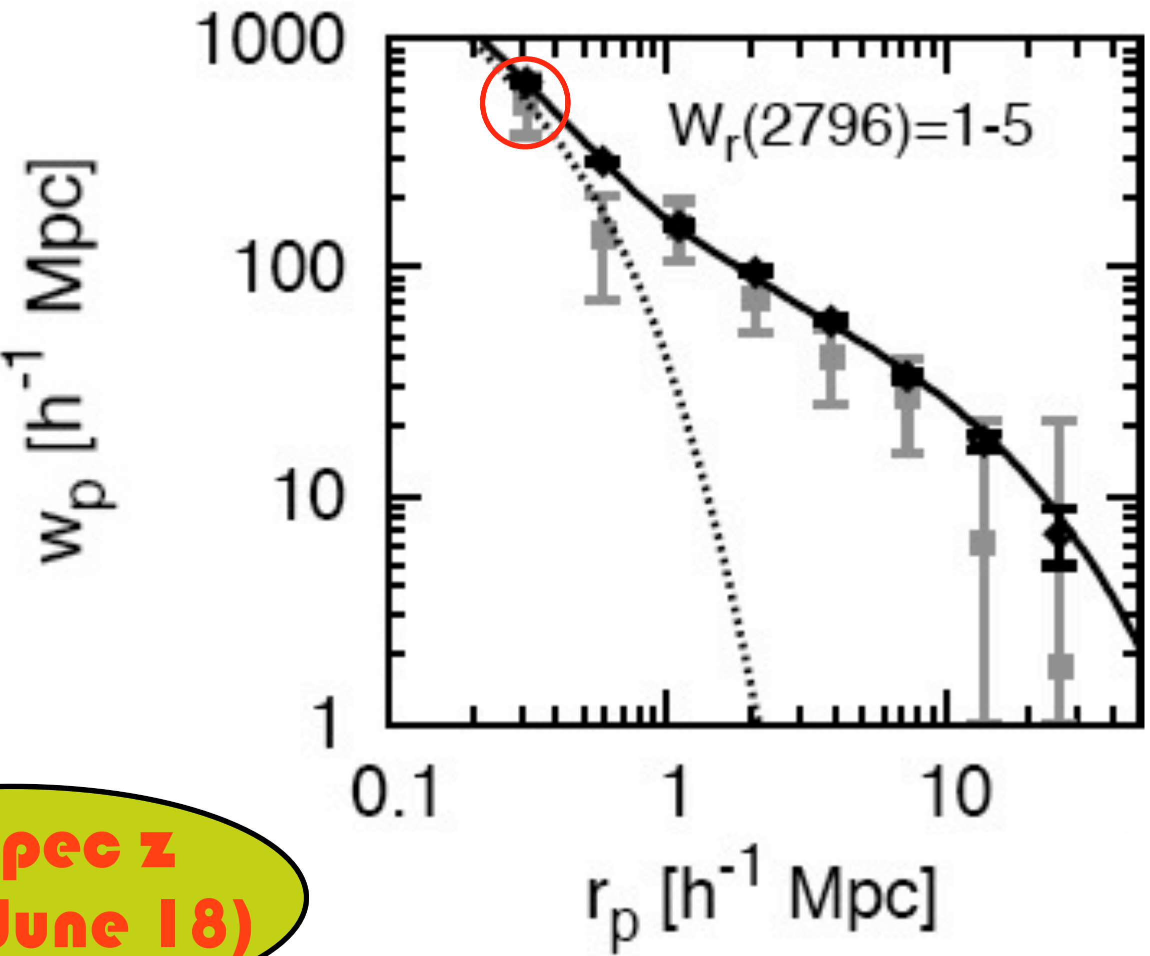
What does this mean physically?

The Astrophysical Journal, 716:1263–1268, 2010 June 20
doi:10.1088/0004-637X/716/2/1263

THE INCIDENCE OF COOL GAS IN $\sim 10^{13}\ M_{\odot}$ HALOS*

Jean-René Gauthier[1,2], Hsiao-Wen Chen[1], and Jeremy L. Tinker[3]

Spectroscopic follow-up of LRGs around QSO sightlines



34 spec z
(as of June 18)

- 11 LRG spectra (pairs with ρ<350 kpc/h)
- 4 have physically associated MgII
  (ρ<300 kpc/h, |Δv| < 350 km/s)

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Spectroscopic follow-up of LRGs around QSO sightlines

In addition of the 11 LRGs from the close LRG-MgII pairs :

- cross-correlation between SDSS QSO database (DR5 : Schneider et al. 2007) and LRG sample (Collister et al. 2007)
- No *a priori* knowledge of the presence/absence of MgII absorber
- Obtain spectra of 4 LRGs
- 1 LRG has physical MgII absorber

35 spec z (as of Oct 2010)

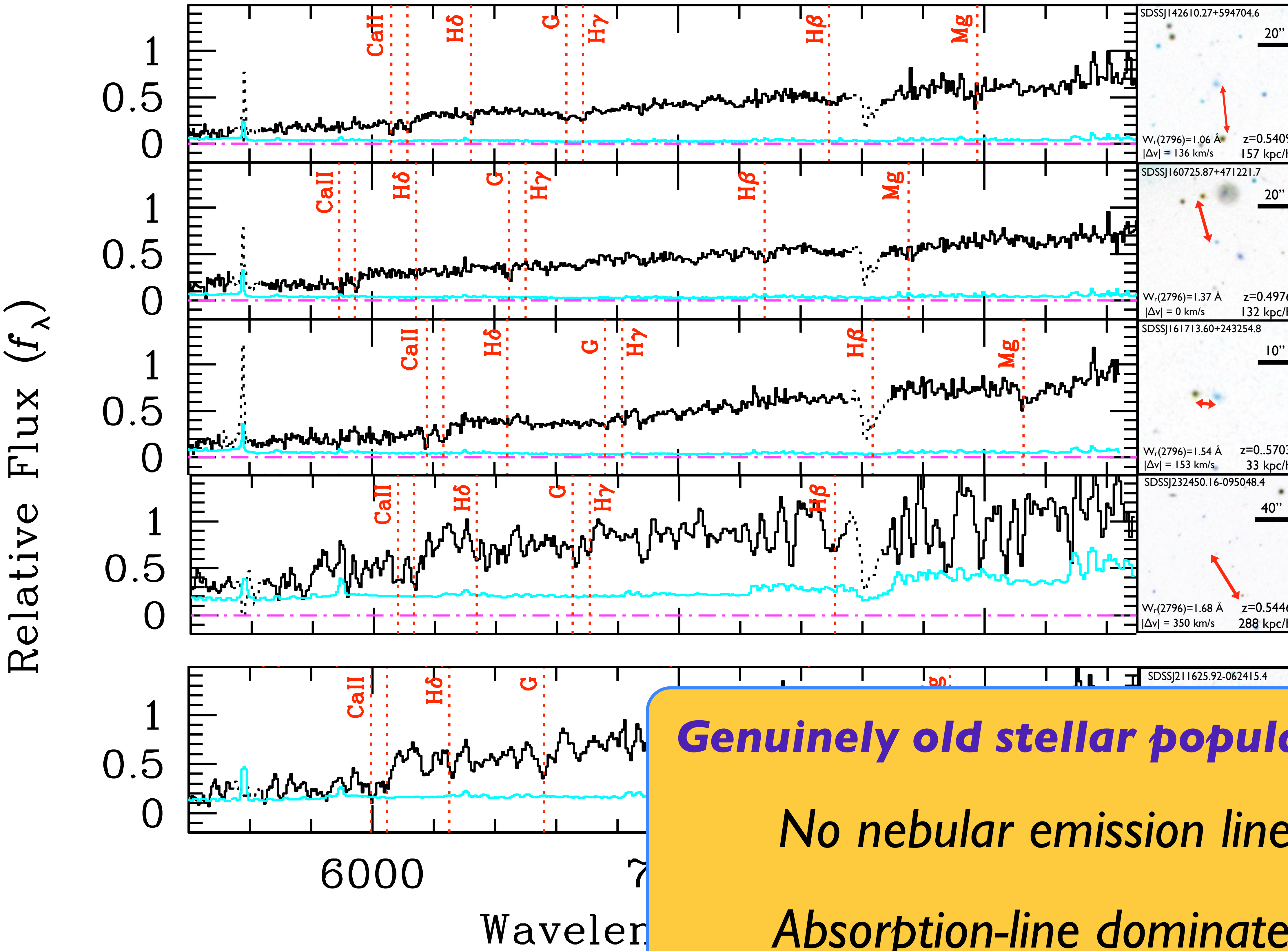
Purpose :

Obtain covering fraction of cool gas in massive halos.

The incidence of cool gas in ~ 10^{13} M_{sun}/h

Gauthier et al. (2010)

The 5 physical pairs



Genuinely old stellar populations

No nebular emission lines

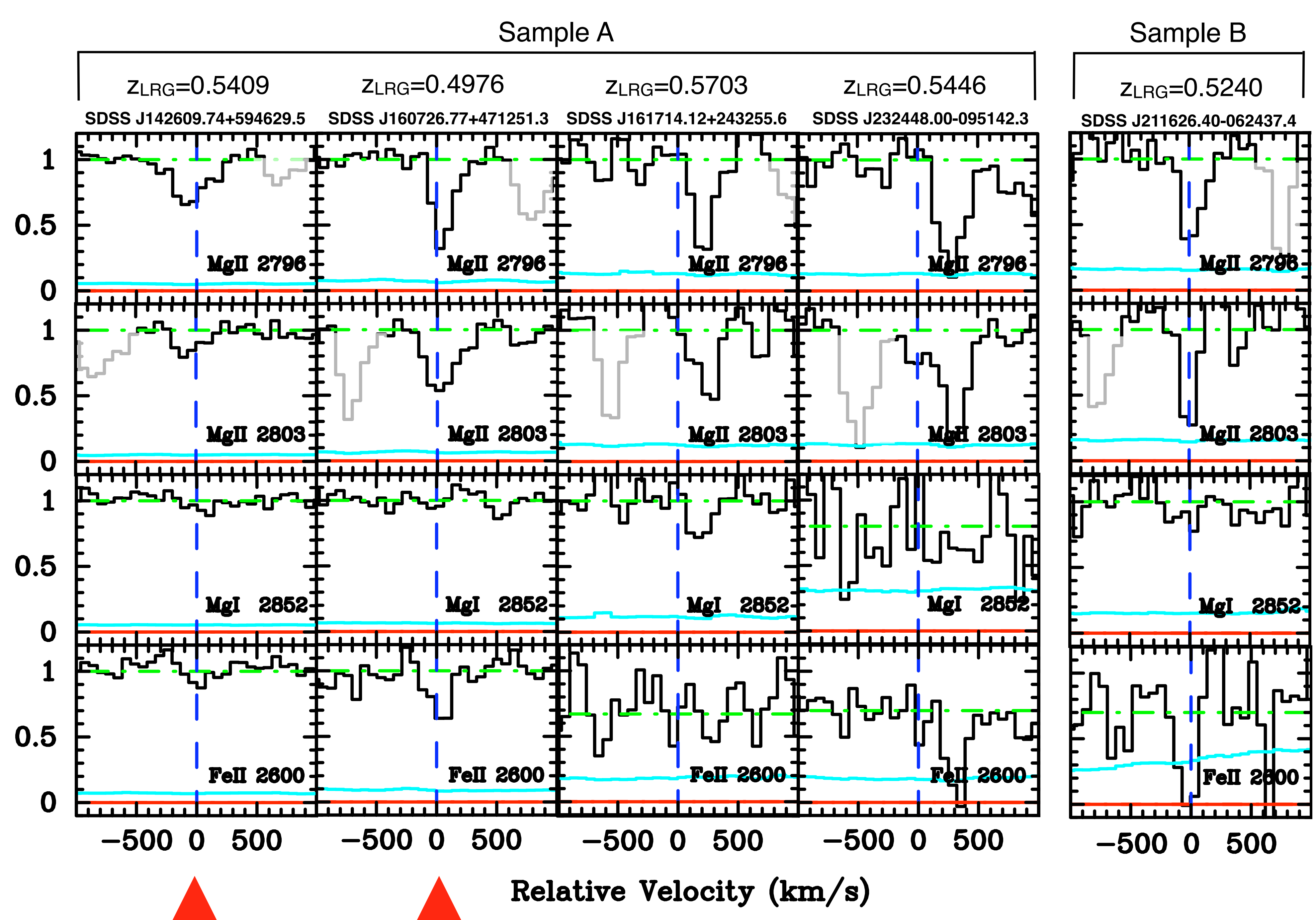
Absorption-line dominated

The incidence of cool gas in ~ 10^{13} M_{sun}/h

Gauthier et al. (2010)

Absorption profiles

SDSS QSO spectra δv=150 km/s



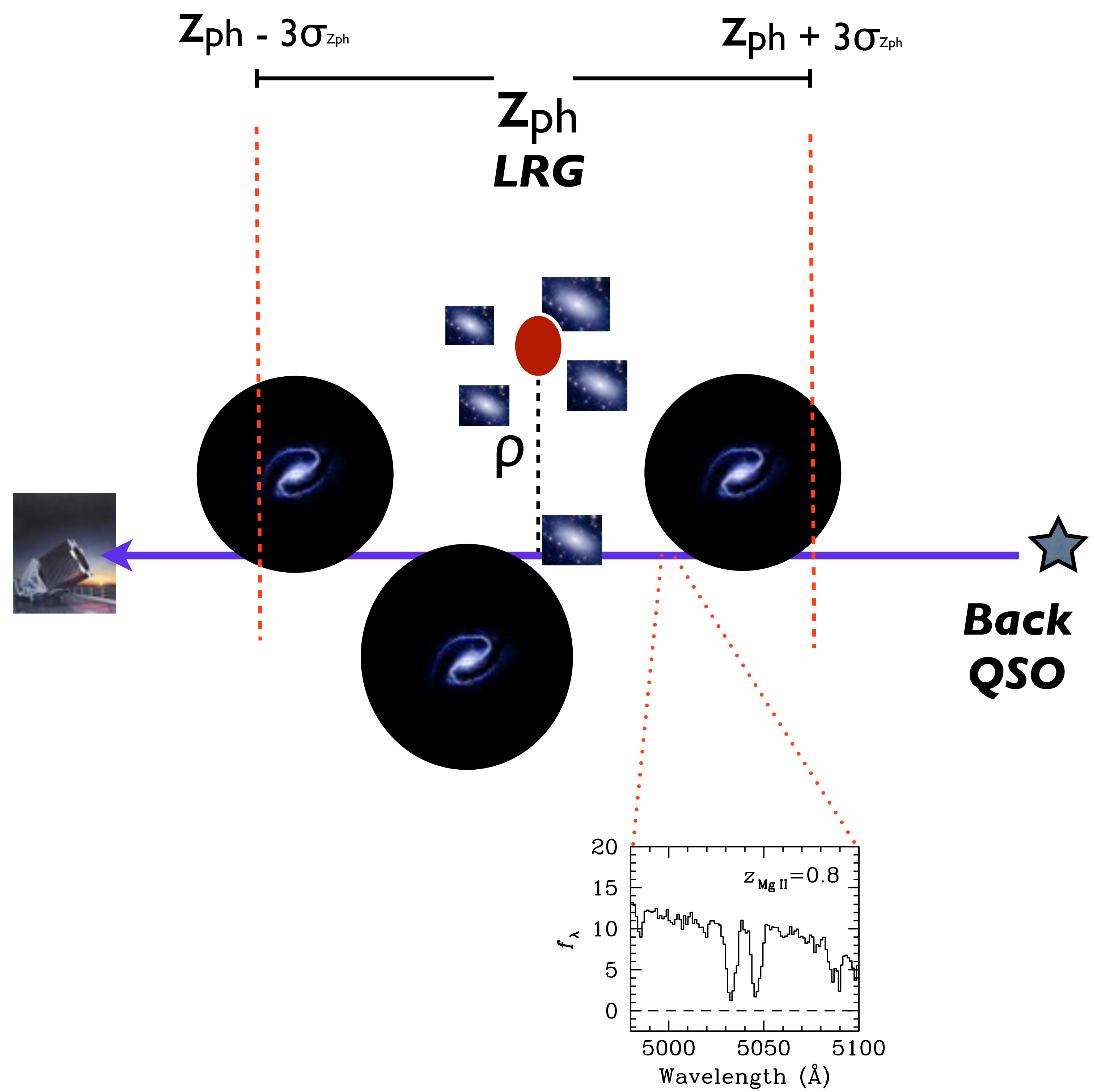
DLAs? *(Rao, Turnshek & Nestor 2006)*

The incidence of cool gas in ~ 10^{13} M_{sun}/h

Gauthier et al. (2010)

An unbiased search for MgII absorbers (within +/- $3\sigma_{Zph}$) in the QSO spectra

- **Using the large SDSS database to put constraints on the incidence of cool gas in massive halos.**
- **Establish a pair catalog of SDSS QSO database vs SDSS LRG sample**
- **Determining an upper-limit on the covering fraction (κ_{max}) of cool gas in massive halos**

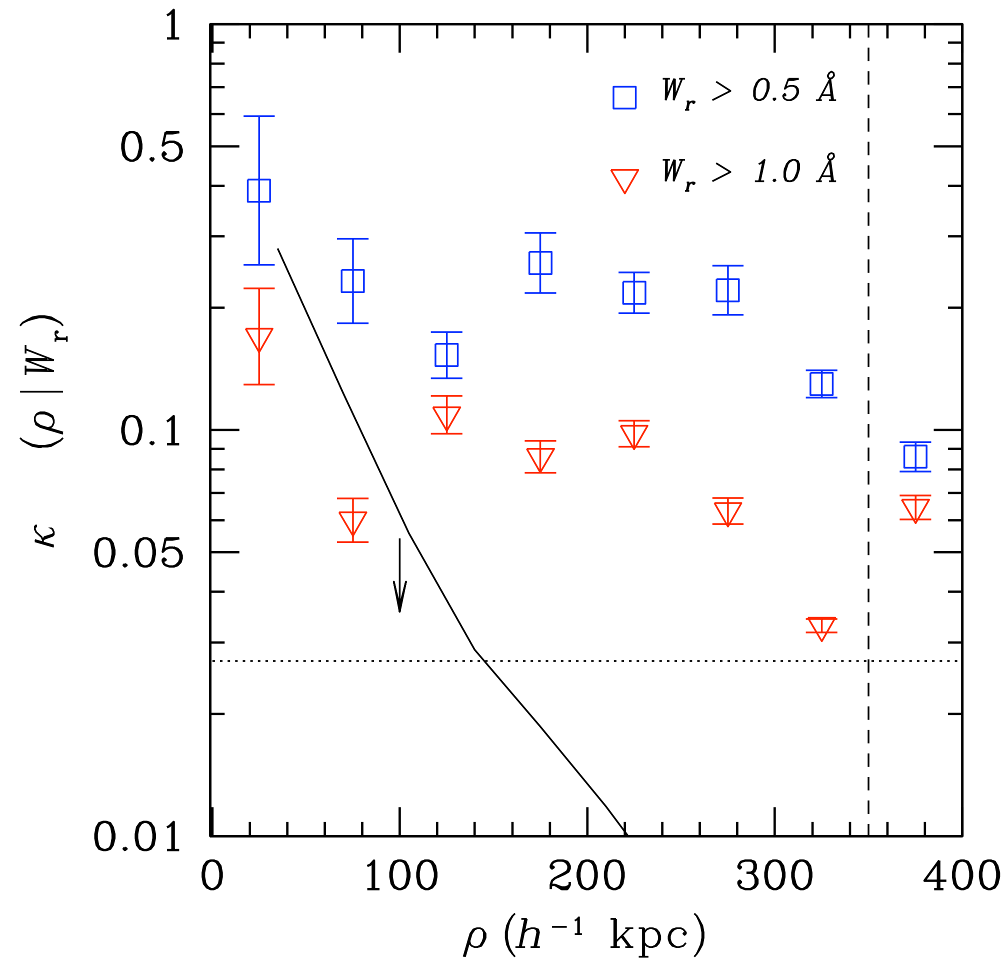


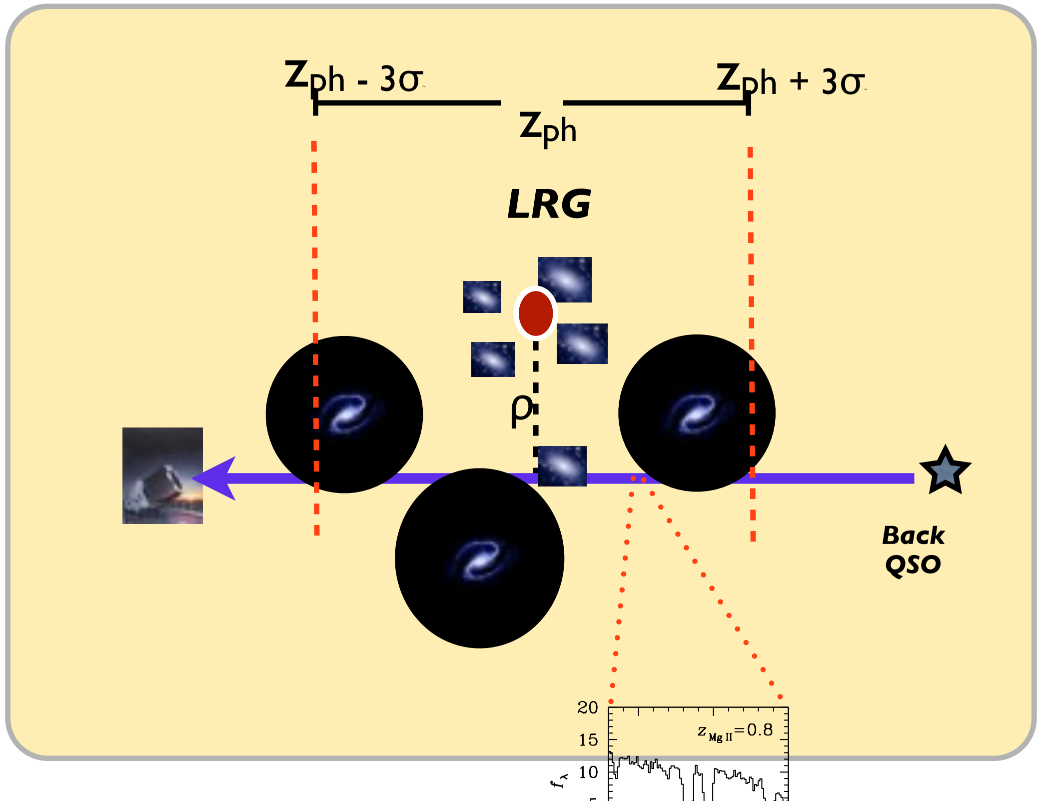
The incidence of cool gas in ~ 10^{13} M_{sun}/h

Gauthier et al. (2010)

An unbiased search for MgII absorbers (within +/- $3\sigma_{Zph}$) in the QSO spectra

- **For LRGs (within 350 kpc/h): κ < 7% for $W_r(2796)$ > 1.0 Å κ < 18% for W_r > 0.5 Å**
- **Cool gas cross-section from satellite galaxies seem to be insufficient (at large seps)**
- **Correlated structures (other galaxies in the surveyed volume) contribute ~ 3%**
- **Where does the cool gas come from?**



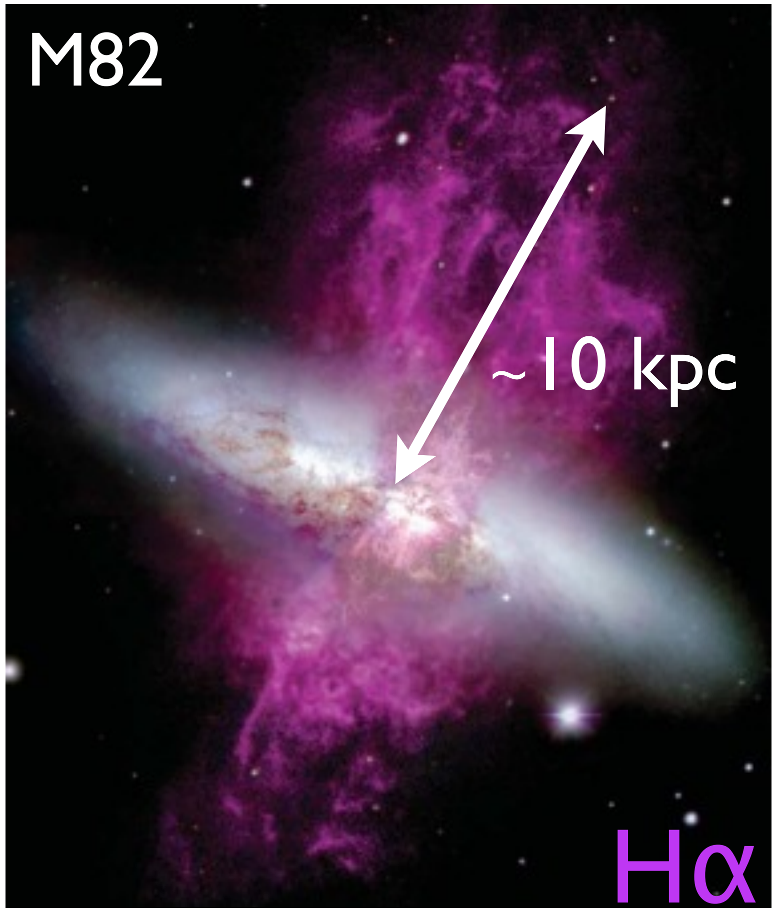


The origin of cool gas in ~ 10^{13} M_{sun}/h

Gauthier, Chen, Rauch & Tinker (2010) In prep.

A stellar population synthesis of the LRGs

- **Is there a connection between the recent SF history of the galaxy and the presence/absence of cool gas in the DM halo?**
- **Are starburst driven outflows a viable hypothesis in this case?**
- **Constrain the recent SF history of the galaxy using stellar pop synthesis.**
- **Generated CB07 templates cover a wide range of SFH, ages, and metallicity.**
- **LRG spectra are corrected for Galactic extinction, atm. extinction & slit losses.**
- **Goal is not to find the precise age of stellar pop, but to look at the distribution of "likely" ages.**

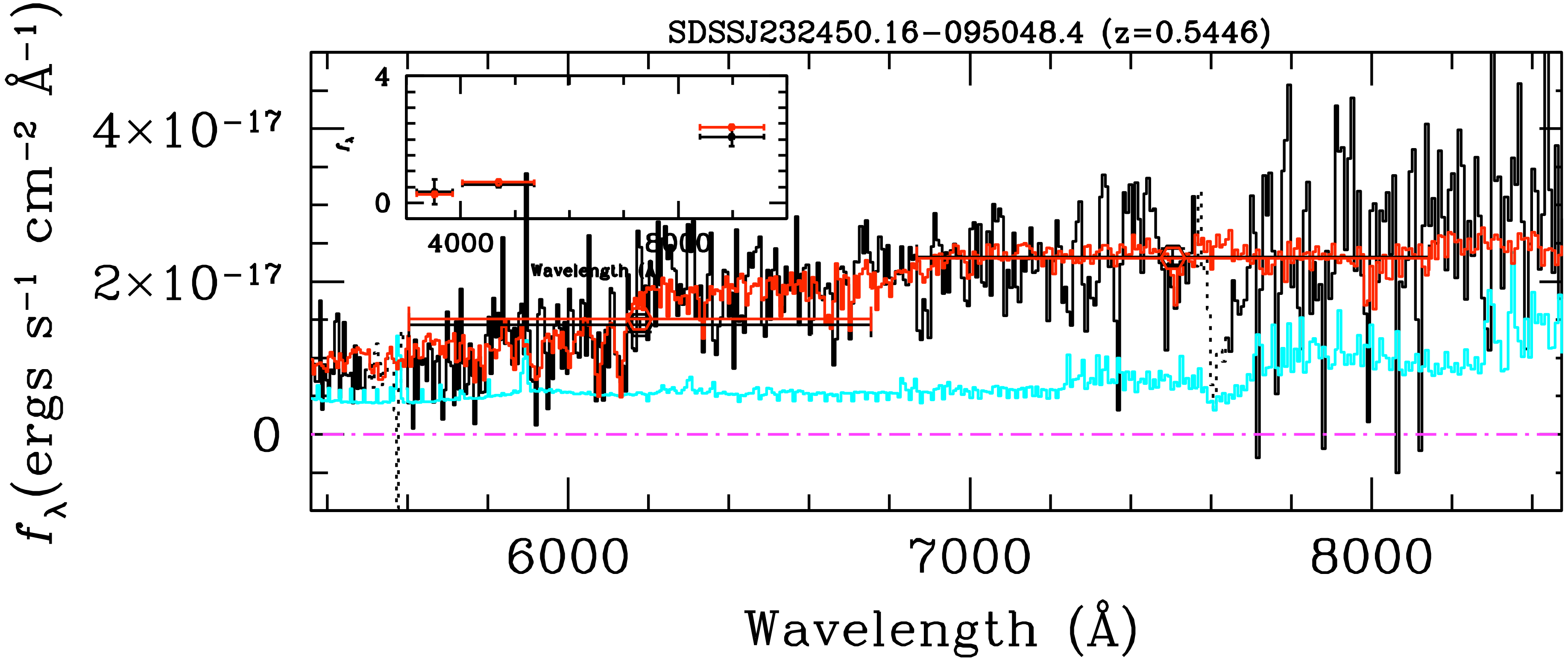


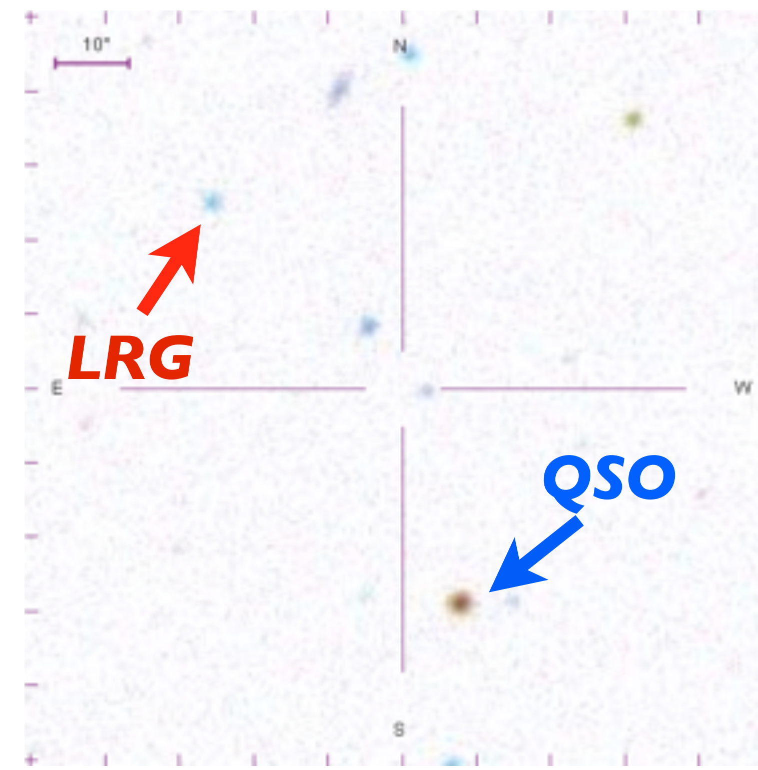
The origin of cool gas in ~ 10^{13} M_{sun}/h

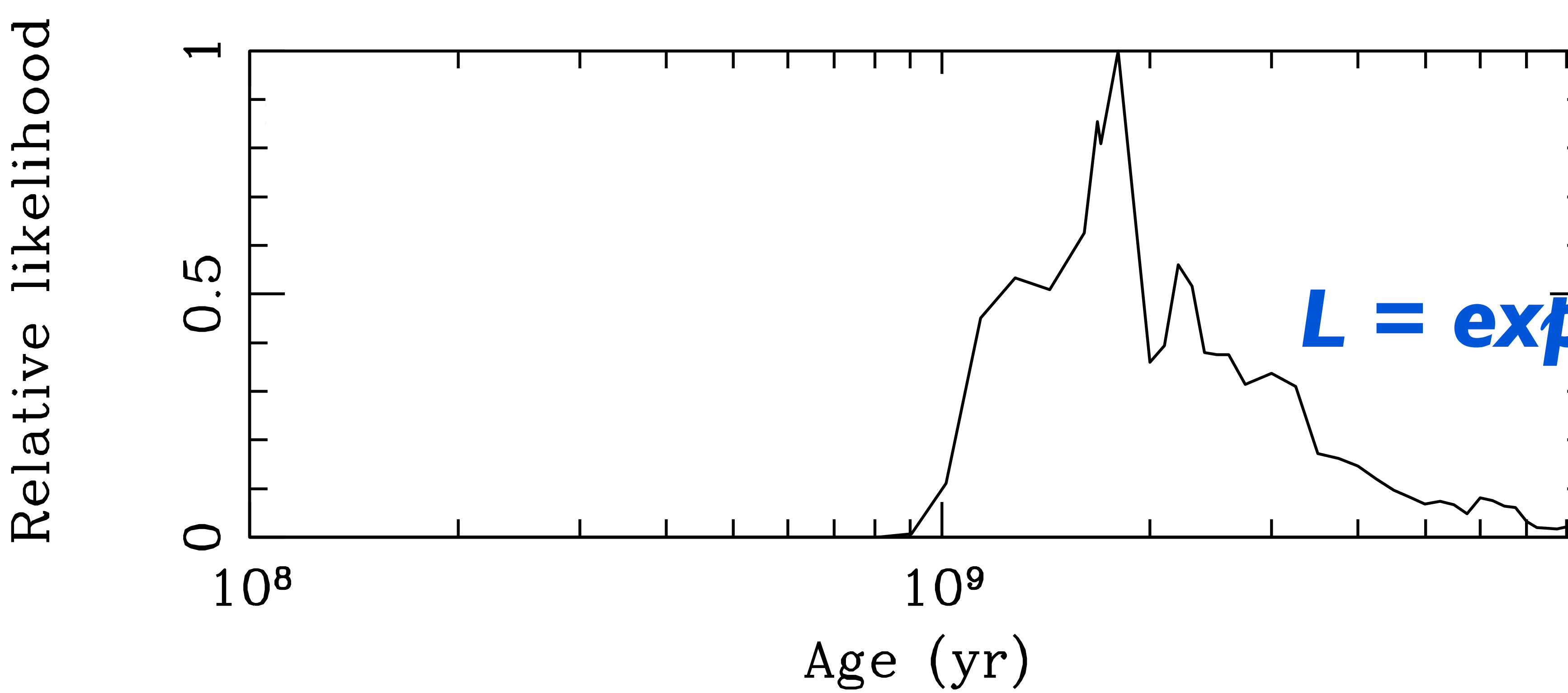
Gauthier et al. (2010) In prep.

A stellar population synthesis of the LRGs

MgII absorber found at ρ=287 kpc/h and |Δv|=350 km/s







$L = exp[-(X^2_i - X^2_{min})/2]$

Future Plans

LRGs :

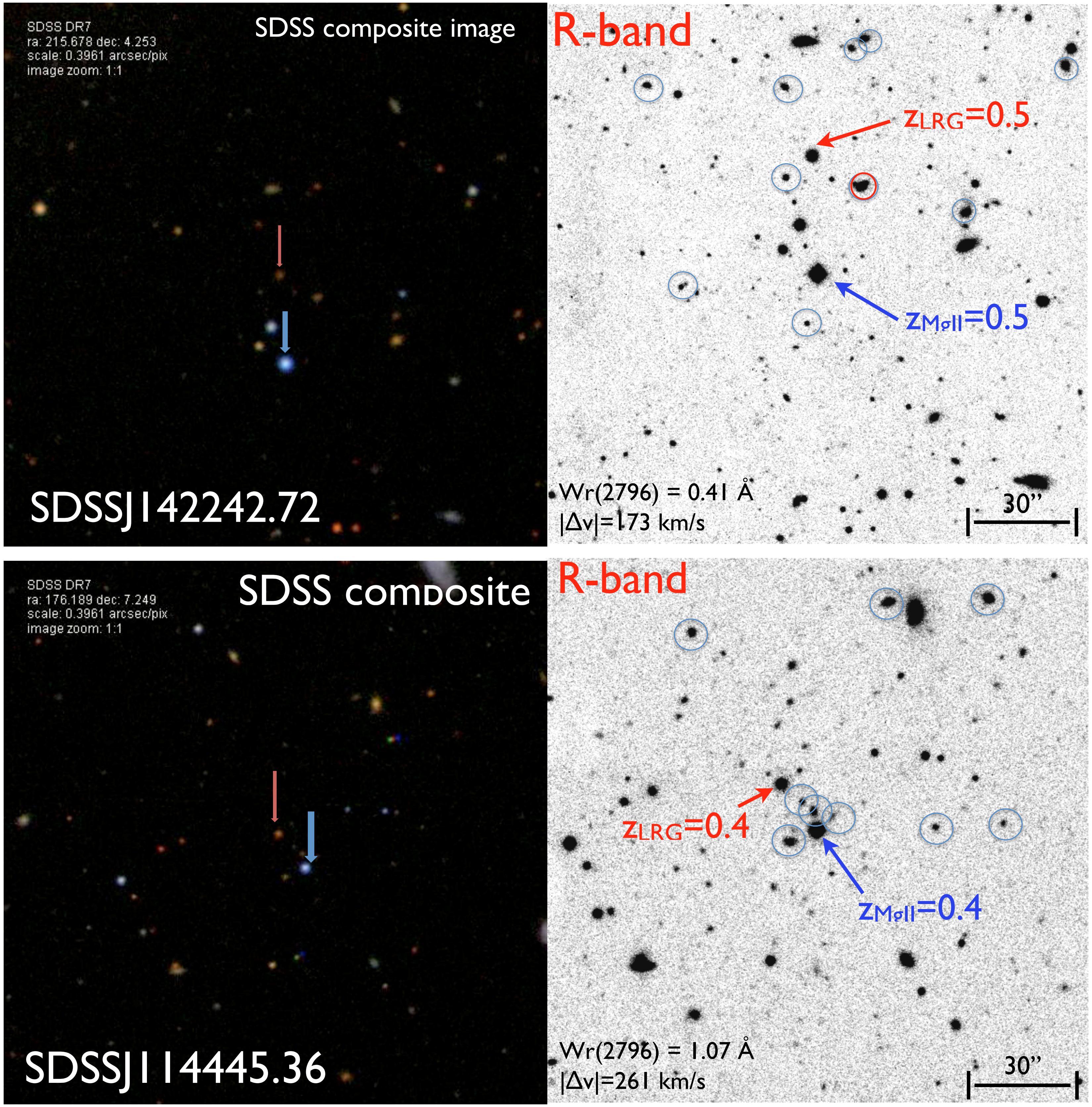
- *Are we tracing the gas in the satellite galaxies?* Deep multi-band L_*) using CCD camera on du Pont Telescope (Las Campanas Observatory) (April-September 2010)

- *Physical characterization of the cool gas traced by MgII absorbers and comparison with simulations.* High-Resolution echelle data (δv = 12 km/s) of 20 MgII absorbers (MgI, FeII) (May-September 2010)

Understanding the cool gas content around low-z SDSS galaxies :

- MagE MgII survey around low-z ($z \sim 0.2$) SDSS galaxies. (see Chen et al. 2010ab)

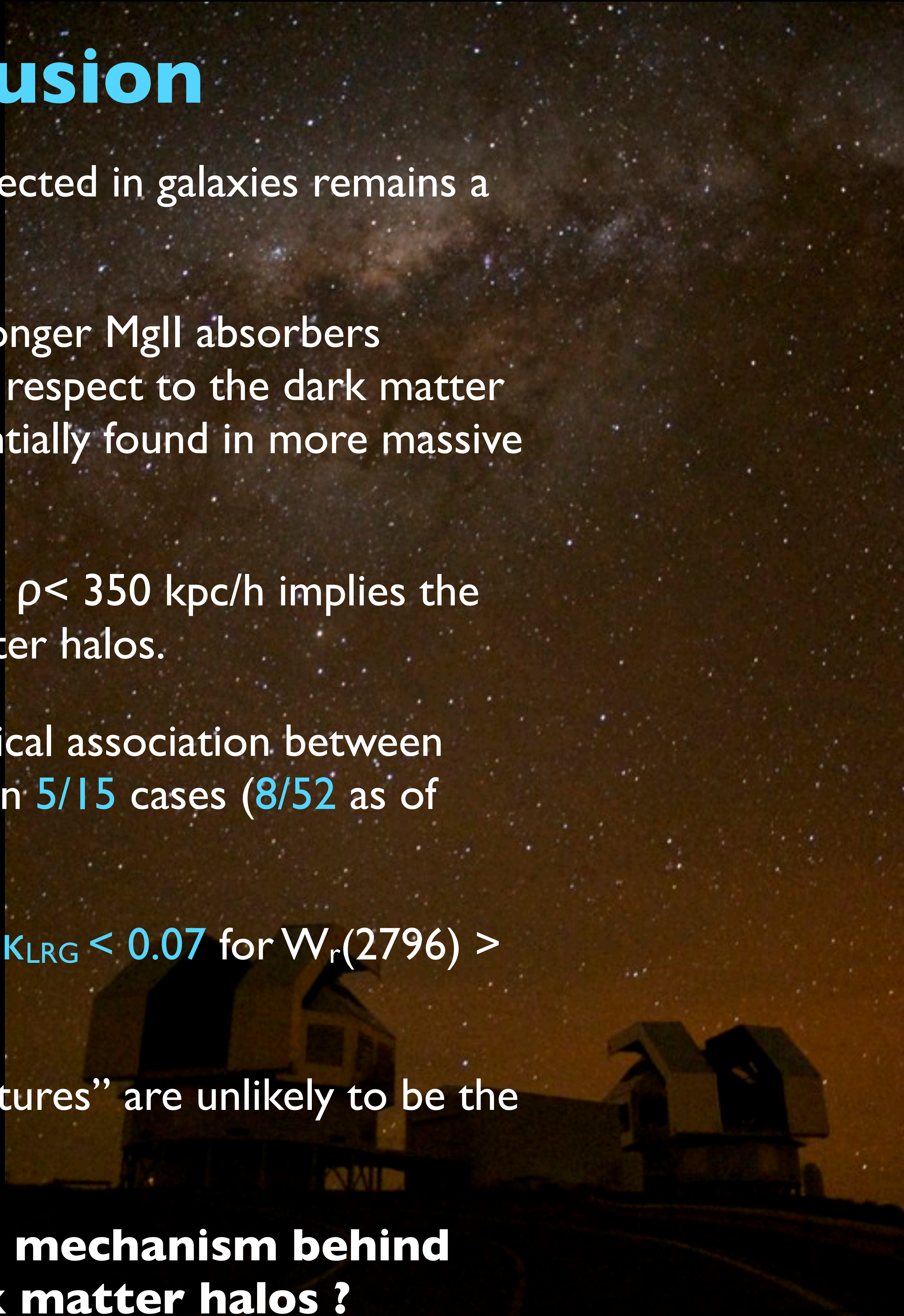
Are we tracing the gas in the satellite galaxies?



Gauthier et al. (2010) in prep

Summary and conclusion

- The physical origin of the cool gas detected in galaxies remains a debated subject
- Our results show that on average, stronger MgII absorbers [$W_r(2796) > 1.5$ Å] are unbiased with respect to the dark matter distribution. Weaker ones are preferentially found in more massive halos.
- Strong clustering signal on small scales $\rho < 350$ kpc/h implies the presence of cool gas in LRG dark matter halos.
- Spectroscopic follow-up shows a physical association between cool gas and LRGs dark matter halos in 5/15 cases (8/52 as of June 18).
- $\kappa_{LRG} < 0.18$ for $W_r(2796) > 0.5$ Å and $\kappa_{LRG} < 0.07$ for $W_r(2796) > 1$ Å
- Satellite galaxies and "correlated structures" are unlikely to be the sole origin of the gas.
- **What is the dominant physical mechanism behind the cool gas found in LRG dark matter halos ?**



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