Exploiting HI surveys with stacking.

The HI content of massive galaxies from ALFALFA and GASS

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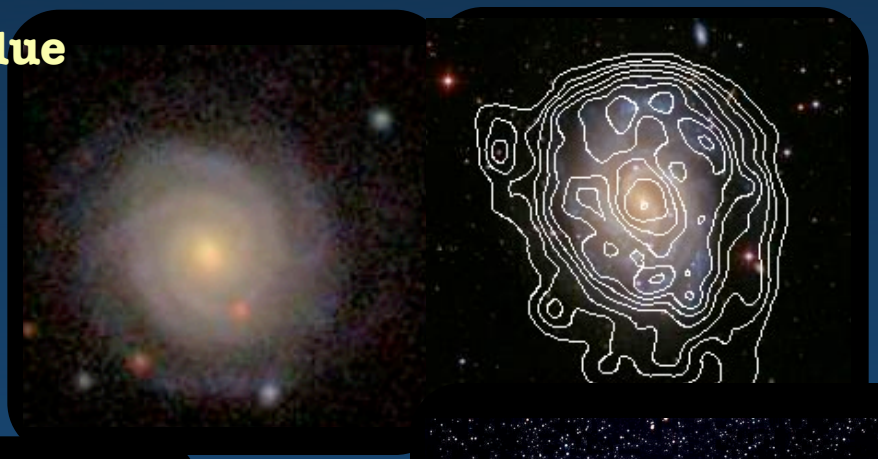
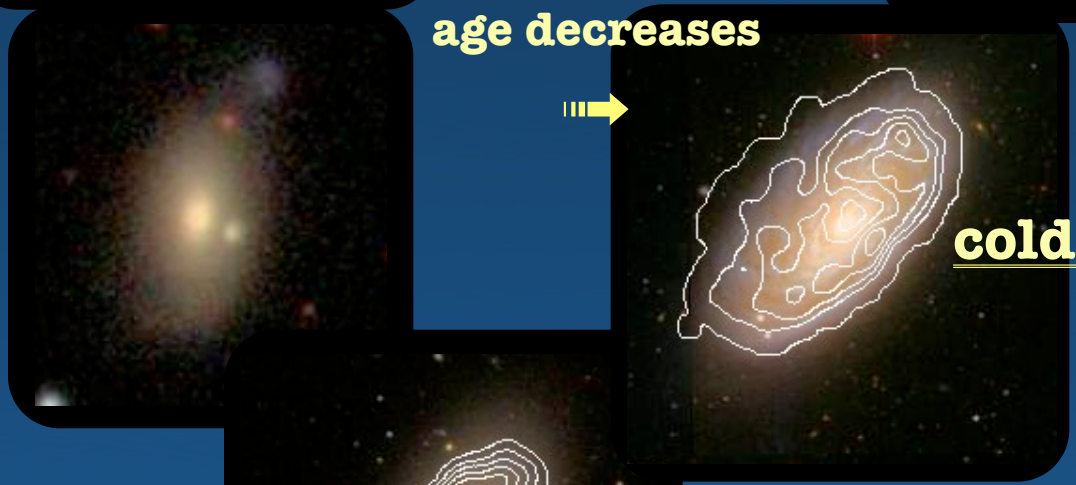
colors from red to blue



stellar population age decreases



cold gas increases

bulge-to-disk ratio decreases

Roberts & Haynes 1994

Early-types: quiescent/red sequence/ bulge dominated
(Bernardi+ 2003, Graves+ 2009a)

- Detection rates varies with samples and depth (from 2 up to 44 %), as well as properties observed
- Missing a statistically representative sample

Previous works by: Knapp+ 1985, Wardle & Knapp 1986, Bregman+ 1992, Serra+ 2006, Morganti+ 2006, Helmboldt+ 2007, Grossi+ 2009, ...

⇓

Large HI surveys will allow systematic studies

ALFALFA – Arecibo Legacy Fast ALFA survey

Giovanelli+ 2005

- blind HI survey of the sky, complete census of local HI
- Will survey 7000 deg^2 of the sky out to z ~ 0.06
- Low sensitivity → biased toward gas-rich galaxies (mostly late-types)

GASS – The GALEX Arecibo SDSS Survey

Catinella, Schiminovich, Kauffmann, SF et al. 2010

- targeted HI survey of ~1000 massive galaxies, selected by:
  SDSS spectroscopic survey + GALEX MIS + ALFALFA
  $0.025 < z < 0.050$; $10 < \log M_*/M_\odot < 11.5$.

⇓

Stack ALFALFA spectra of GASS-selected sample

This work

- Stacking of ALFALFA data to constrain HI in the gas poor regime
- HI stacking: eg. Zwaan 2000, Chengalur+ 2001, Lah+ 2007, 2009 Verheijen+ 2007
- Understanding quenching mechanisms:
  why early-types are passive and remain so?

  AGN feedback? Environmental processes?

  Morphological quenching? Does the bulge affect the gas content?

Cold Gas (?)

Fuel for future SF

Stars, mass...

Star Formation

The Samples

Starting from GASS parent sample (~12000 objects):

- $10 < \log M_*/M_\odot < 11.5$;
- $0.025 < z < 0.050$;
- maximum overlap SDSS and ALFALFA data available.

⇒

Sample A:

4726 targets.

(23 % already detected)

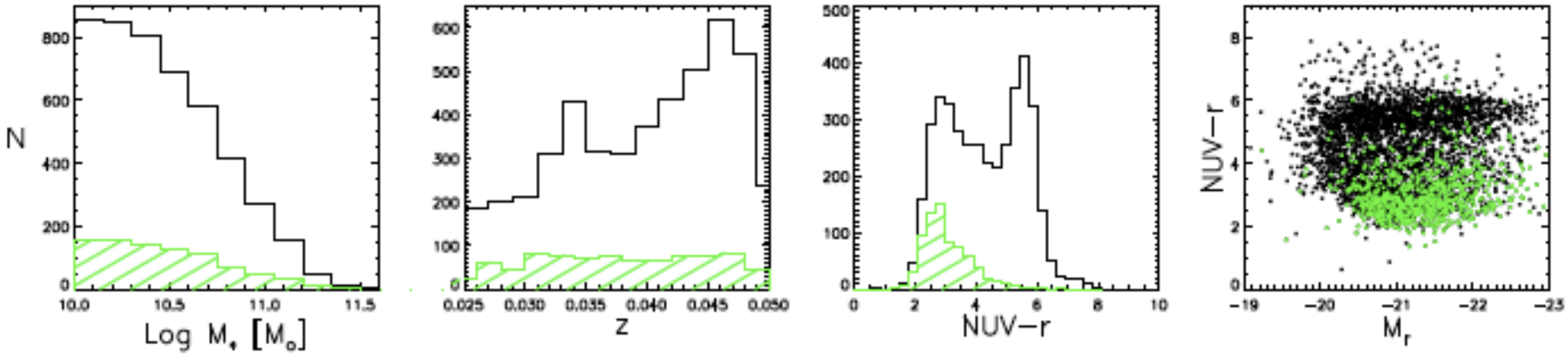
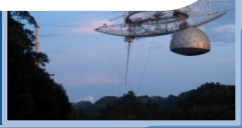


Figure 1. *Sample A* characterization: (a) stellar mass, (b) redshift and (c) NUV-*r* colour (corrected for Galactic extinction only) distributions, (d) colour-magnitude diagram. The black solid lines/black dots represent the whole sample, while the dashed green histograms/green dots show where the ALFALFA detections lie.

Sample A

ALFALFA detections



Starting from Sample A, extracted bulge-dominated galaxies:

- $C \equiv R_{90}/R_{50} \geq 2.6$;
  best tracer of bulge-to-total ratio
  (Gadotti 2009; Weinmann+ 2009)
- Best fit De Vaucouleurs;
- Inclination < 70°

$\Rightarrow$

B-D sample:
1833 targets.

(10 % already detected)

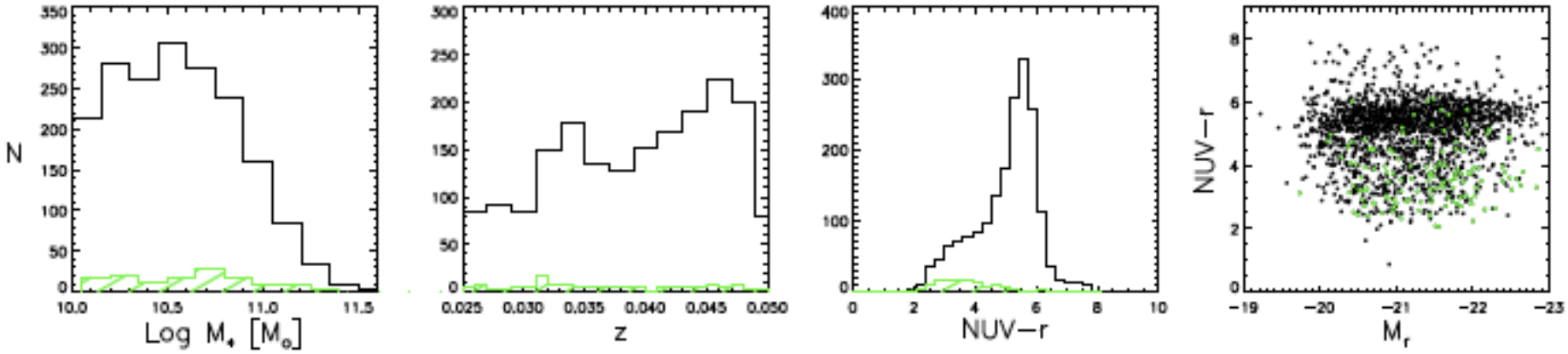
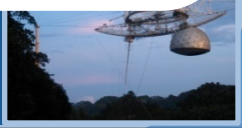


Figure 2. *Early-type sample* characterization: (a) stellar mass, (b) redshift and (c) NUV-*r* colour distributions, (d) colour-magnitude diagram. The solid lines/black dots represent the whole sample, while the dashed green histograms/green dots show the ALFALFA detections.

B-Ds

ALFALFA detections



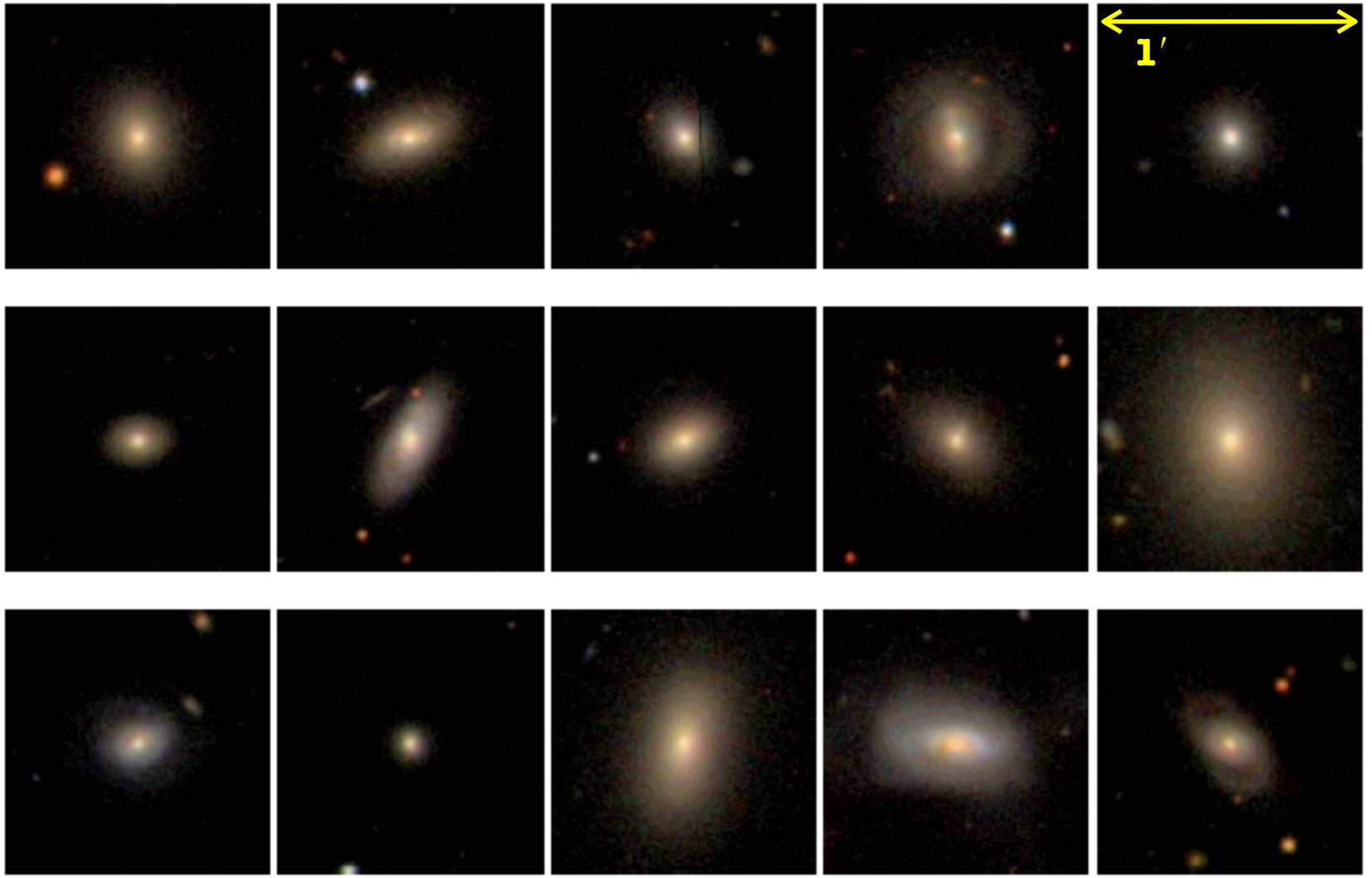


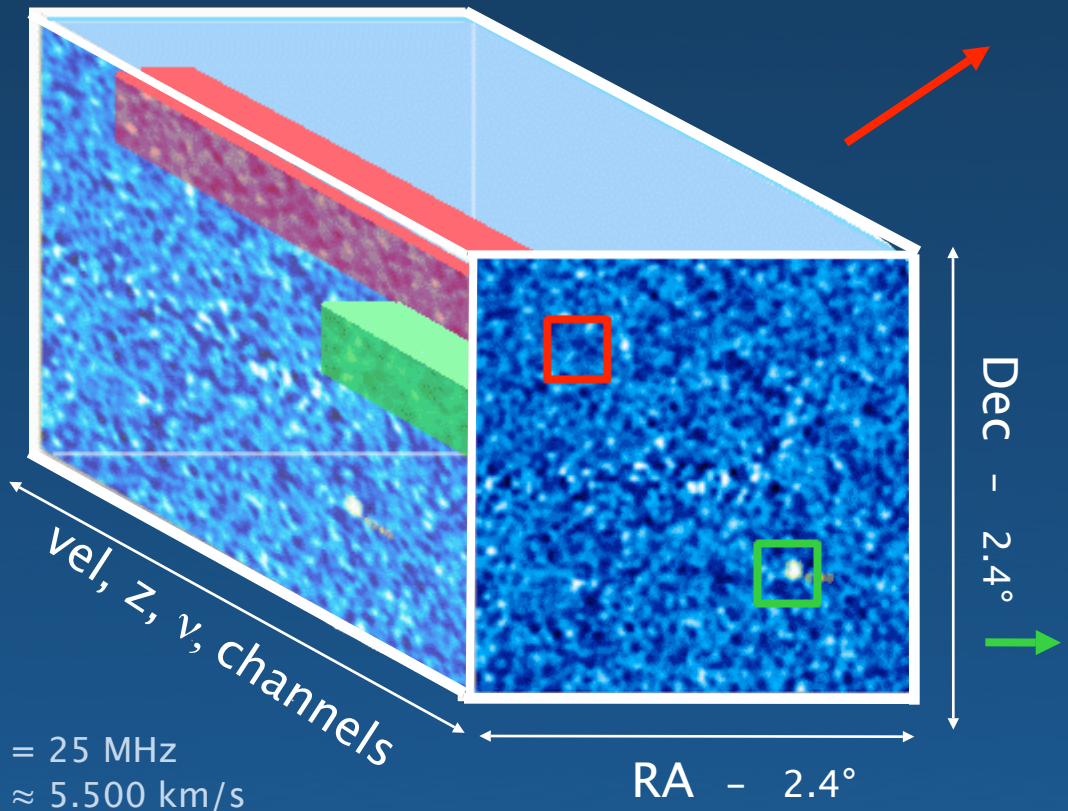
Figure 3. Example of bulge-dominated galaxies, randomly selected from *sample B-D*. The SDSS images are 1 arcminute square in size.

The Stacking Tool

ALFALFA data-cube: RA, Dec, velocity

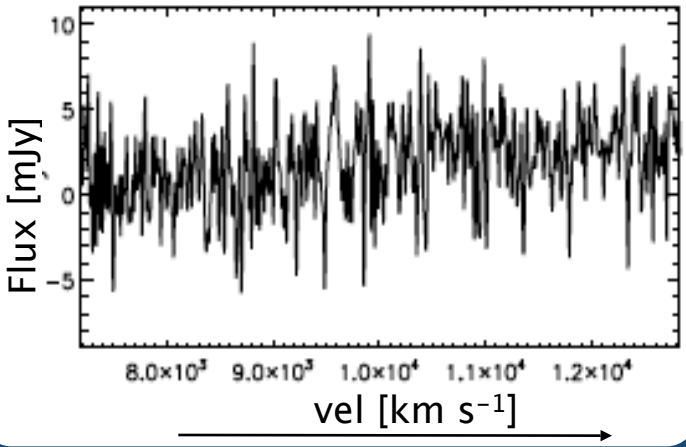
extracting spectra at given position and redshift

$$S_\nu\,[\mathrm{mJy\,km\,s^{-1}}] = \frac{\Sigma_x \Sigma_y s_\nu(x,y)}{\Sigma_x \Sigma_y B(x,y)}$$

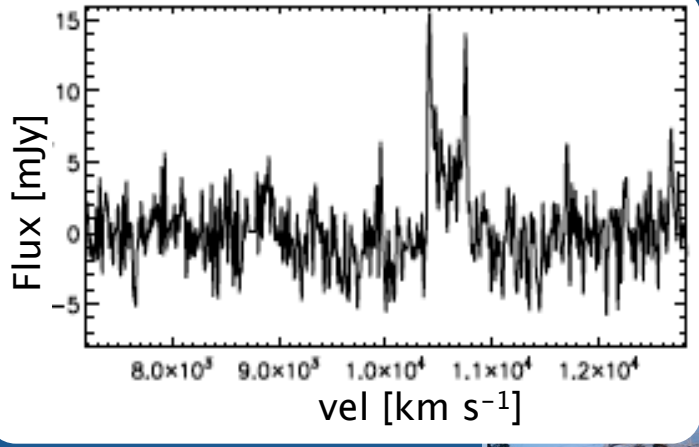


Δν = 25 MHz
Δν ≈ 5.500 km/s
Nchn = 1024

Non-detection



Detection



STACK = co-add signal of non-detections

higher S/N → $Flux_{HI}$ → M_{HI}

Extract a spectrum where a source is known to be (α,δ,z)

↓

Align the spectra

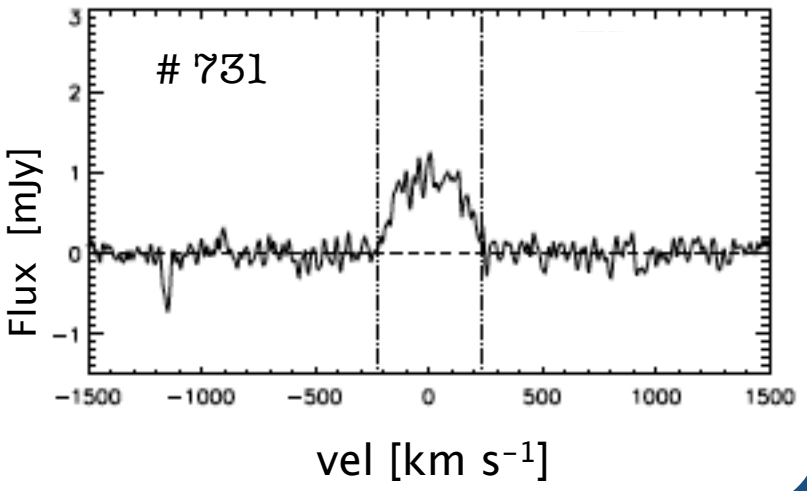
↓

Co-add their signal

↓

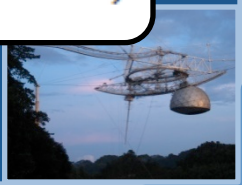
Recover a signal! (Δnoise ∝ √N ⇒ higher S/N)

$$S'_{\nu}[\mathrm{mJy\,km\,s^{-1}}] = \frac{\sum_{i=0}^{N} \frac{S_{i;\nu}}{rms_i^2}}{\sum_{i=0}^{N} \frac{1}{rms_i^2}}$$



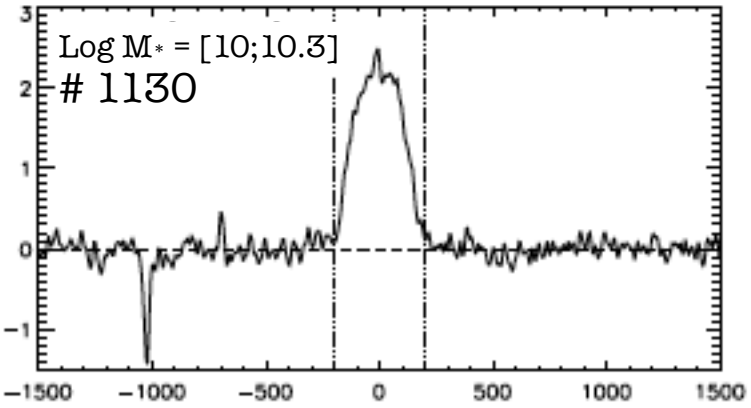
$$\frac{M_{HI}}{M_{\odot}} = \frac{2.356 \times 10^5}{1+z} \left(\frac{D_L(z)}{\mathrm{Mpc}}\right)^2 \left(\frac{\int S\,dv}{\mathrm{Jy\ km\ s^{-1}}}\right)$$

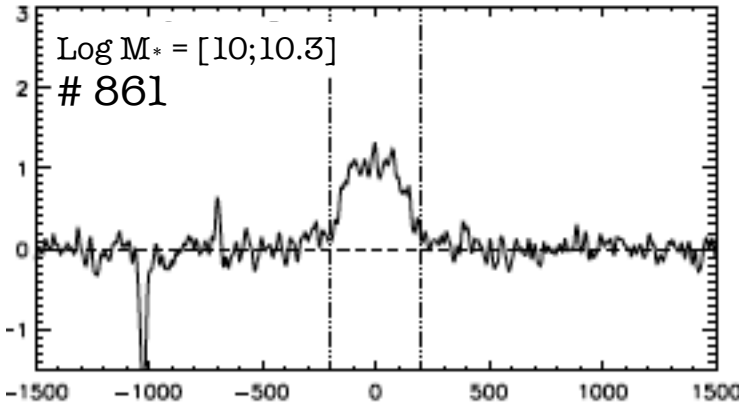
Roberts 1963

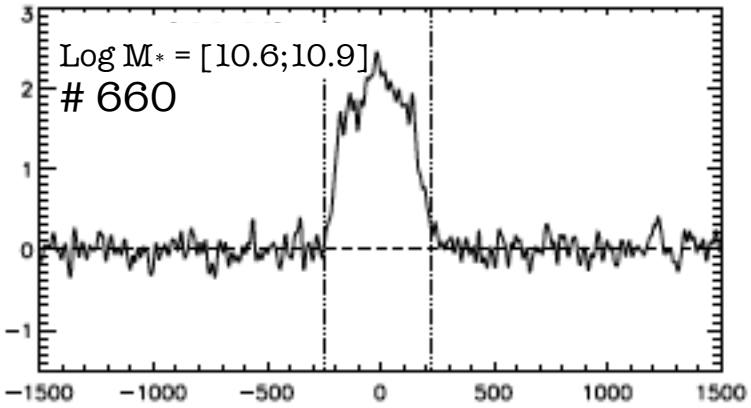


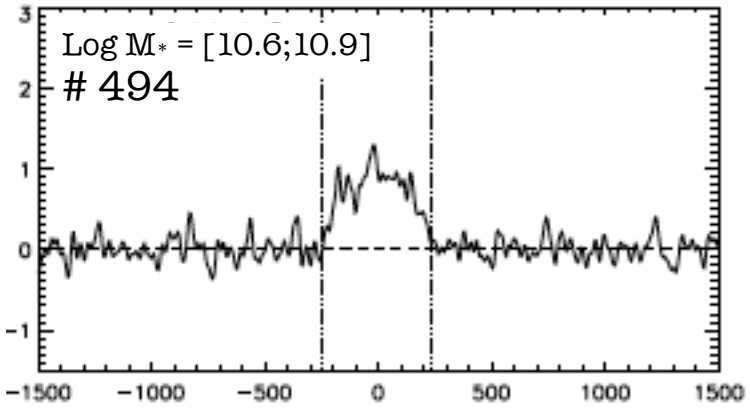
All spectra

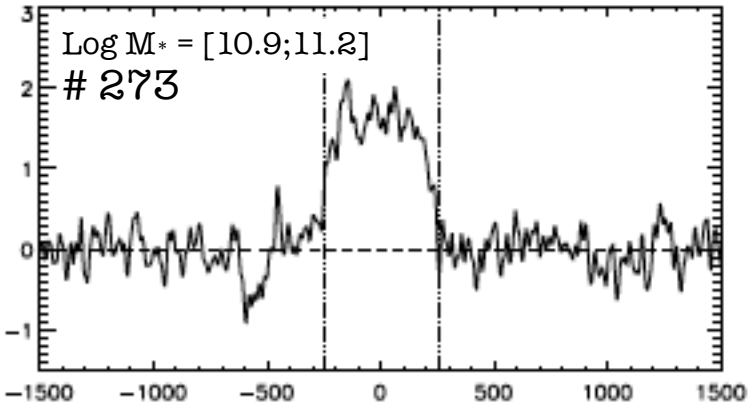
Non-detection only

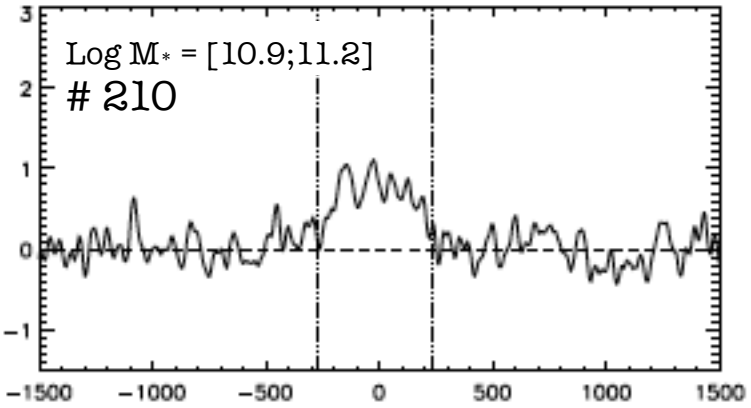










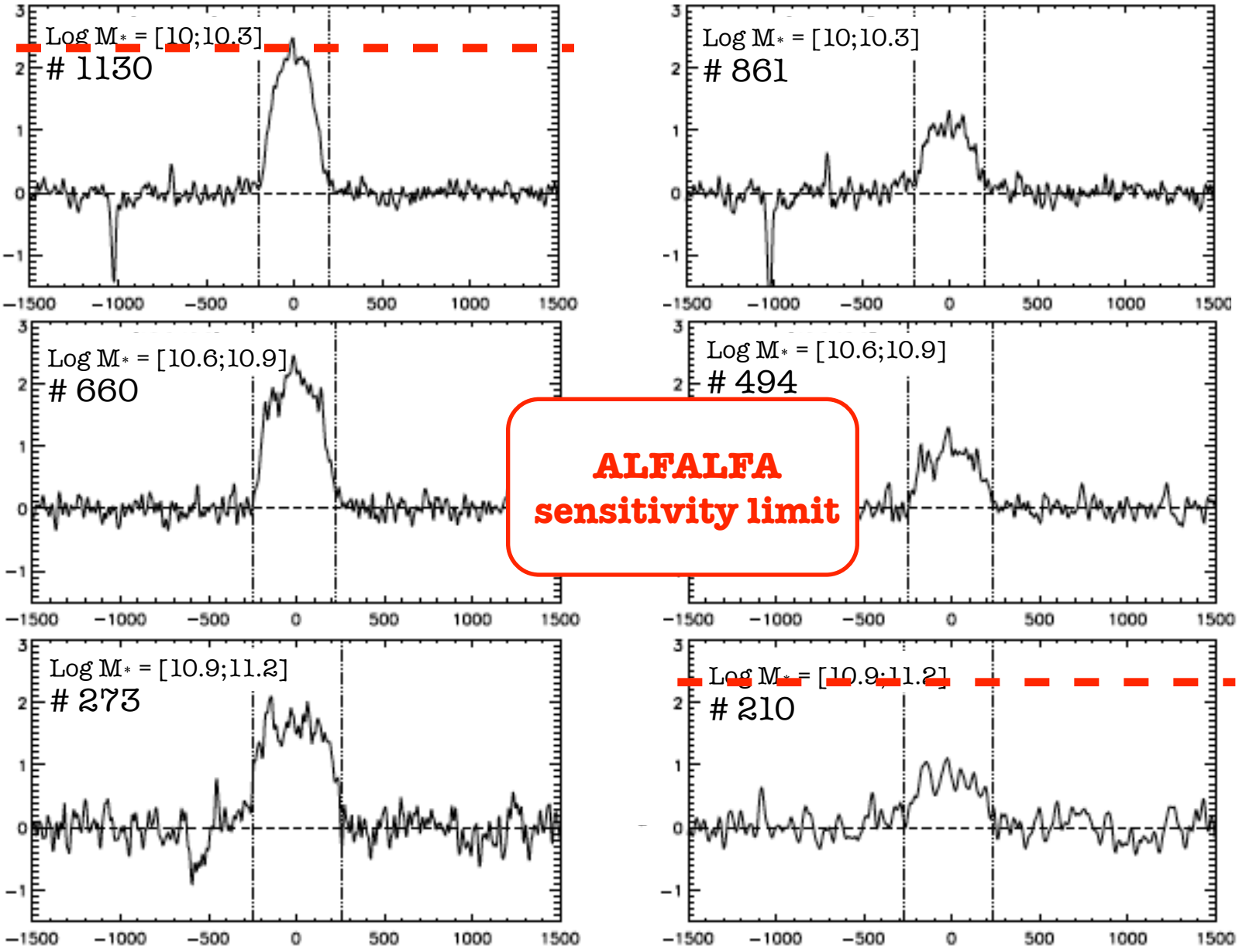


Flux [mJy]

vel [km s^{-1}]

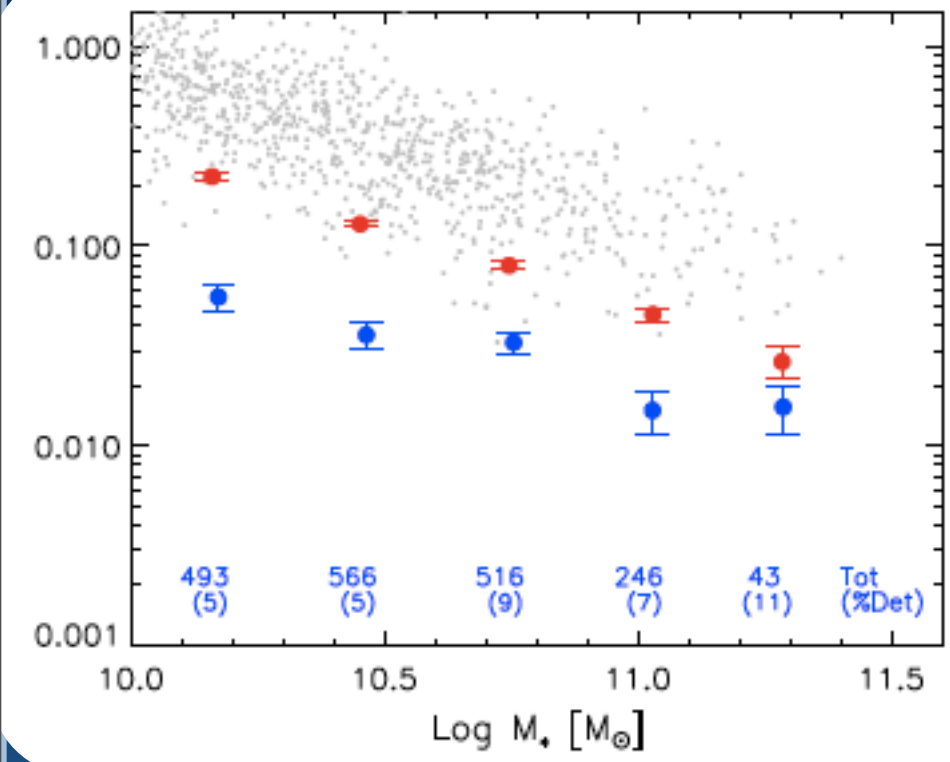
All spectra

Non-detection only



Study of Bulge-Dominated Galaxies

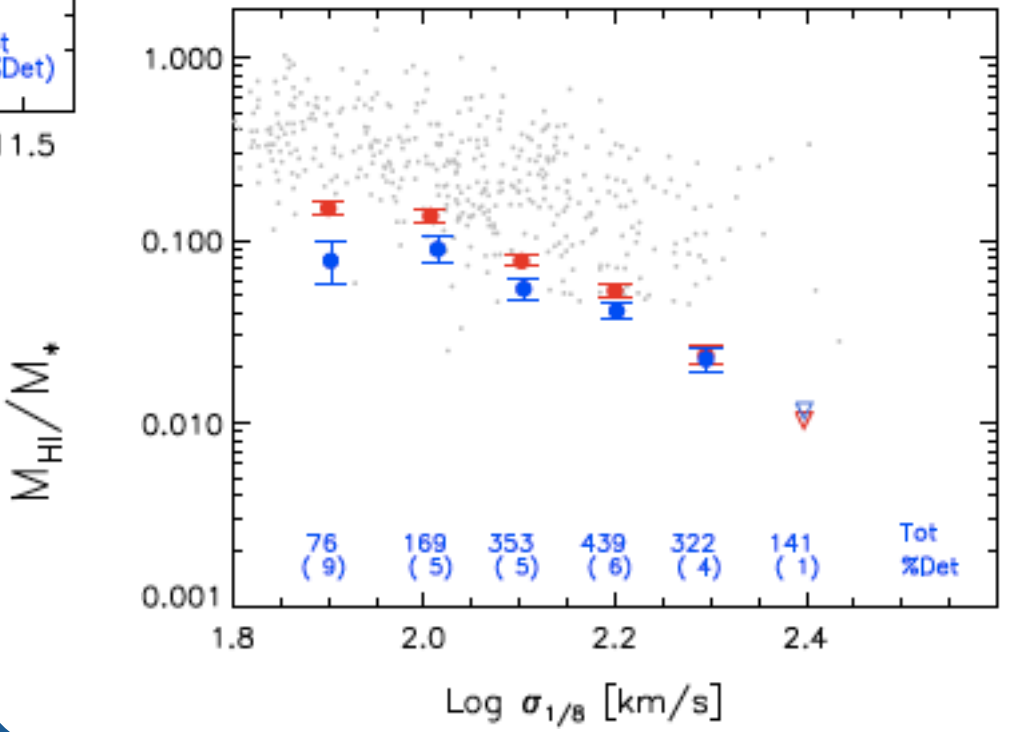
HI scaling relations



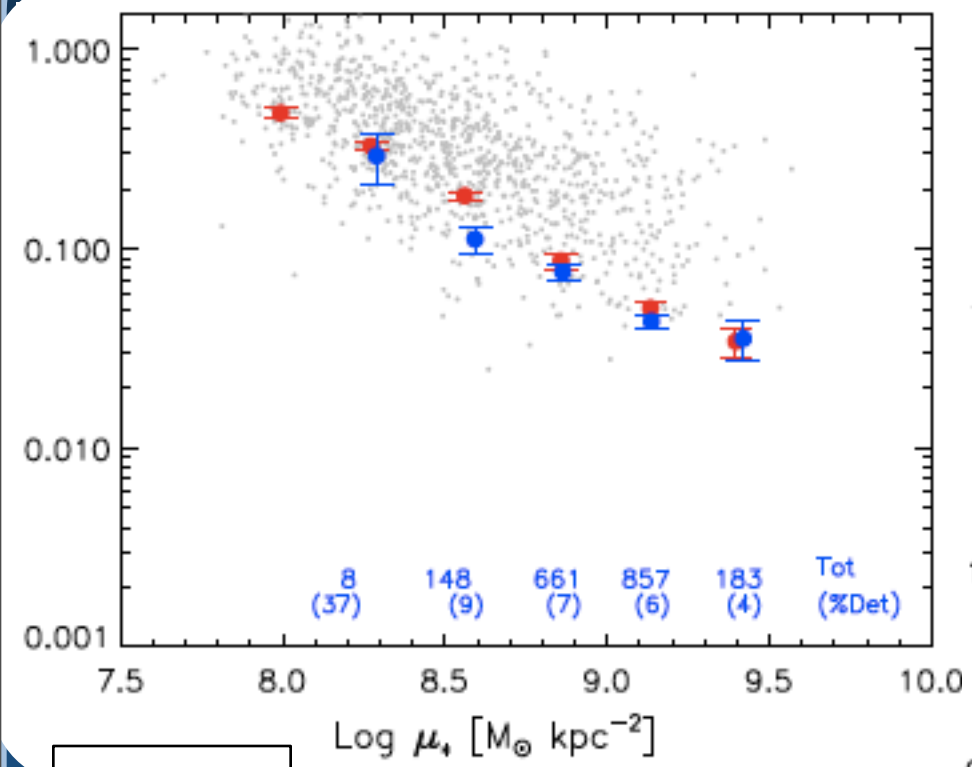
At fixed M_* Bulge-Dominated are gas-poorer, but...

Sample A

B-D sample



HI scaling relations

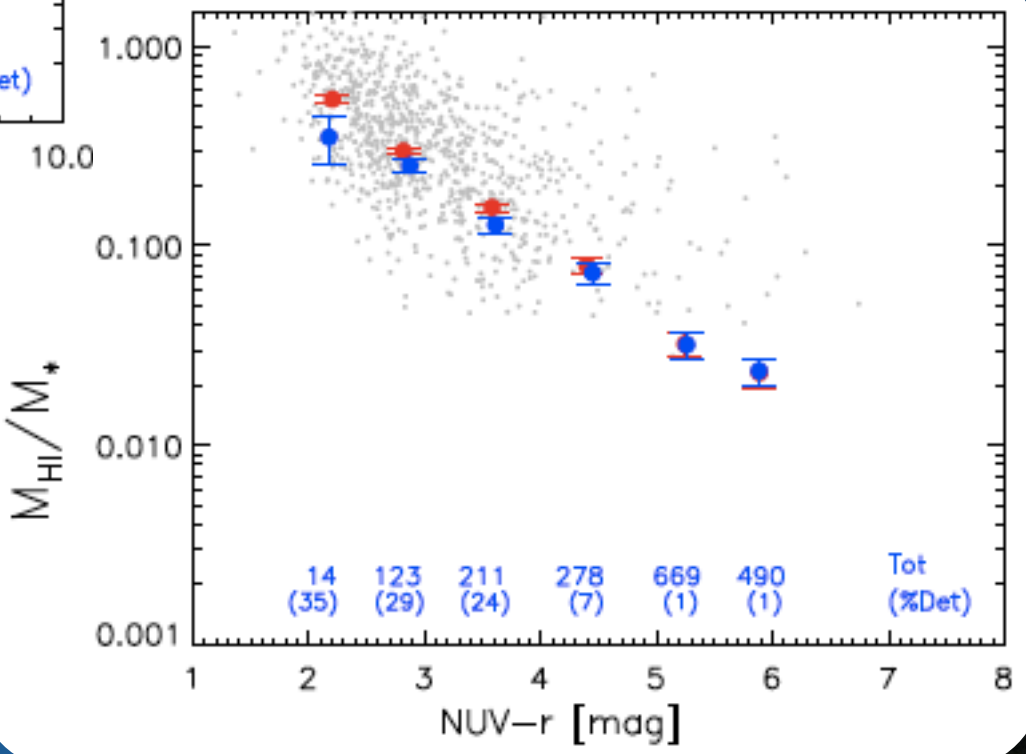


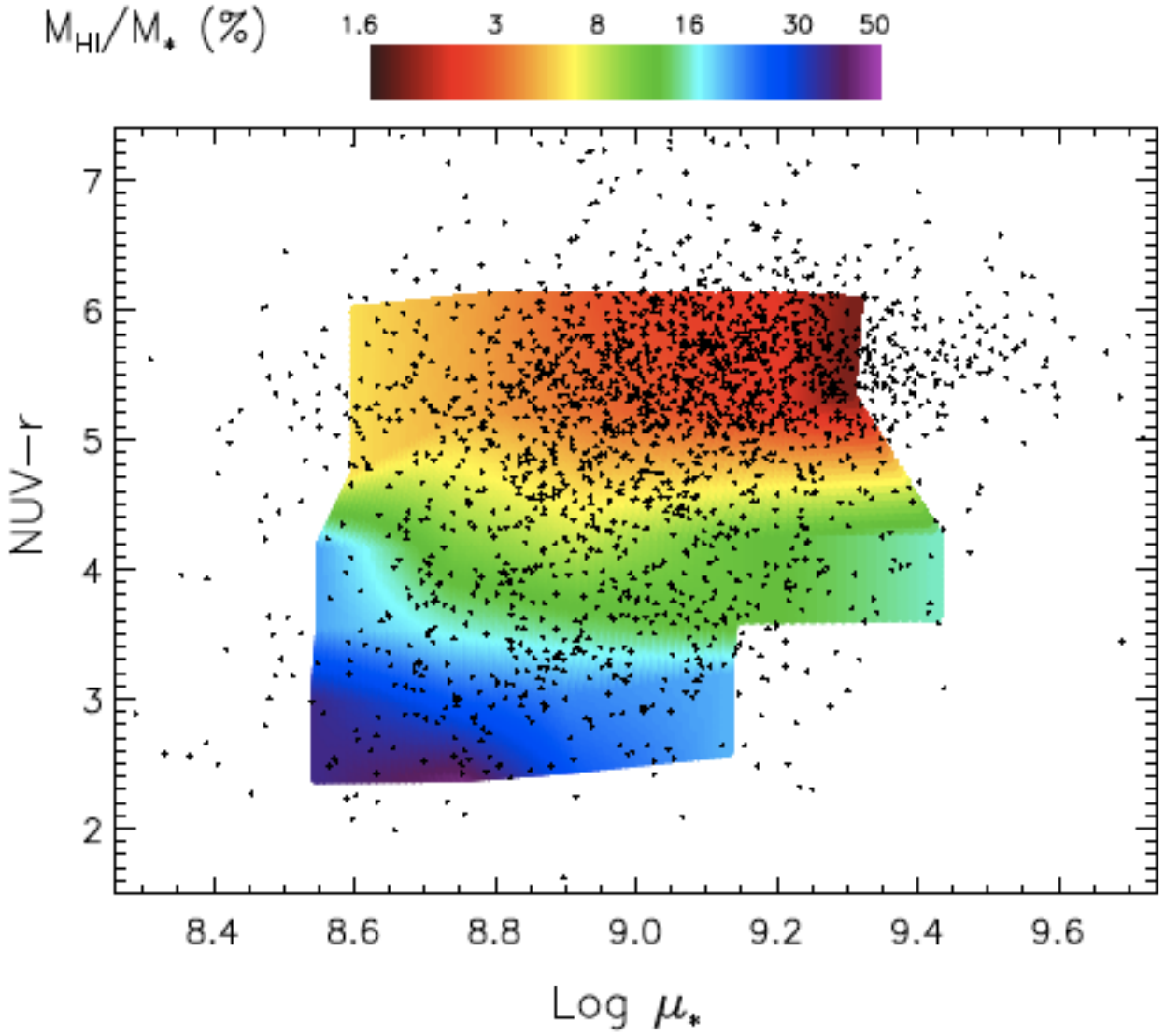
$M_*/2\pi R_e^2$

At fixed colour and μ_*
B-D have same HI content!

Sample A

B-D sample





Colour is the main parameter which drives the gas content

Summary:

- The bulge does not affect the gas content.
- Colour (and μ) can be used to predict the average HI content of massive galaxies.
- Our results for sample A in excellent agreement with GASS.
  Catinella, Schiminovich, Kauffmann, SF et al. 2010

Morphological Quenching

- A gas disk embedded in the steep potential of a hot spheroid is stable against perturbation.

  Ostriker & Peebles 1976

- "Transition from stellar disk to spheroid sufficient to quench star formation, turn the galaxy red and dead while gas accretion continues"

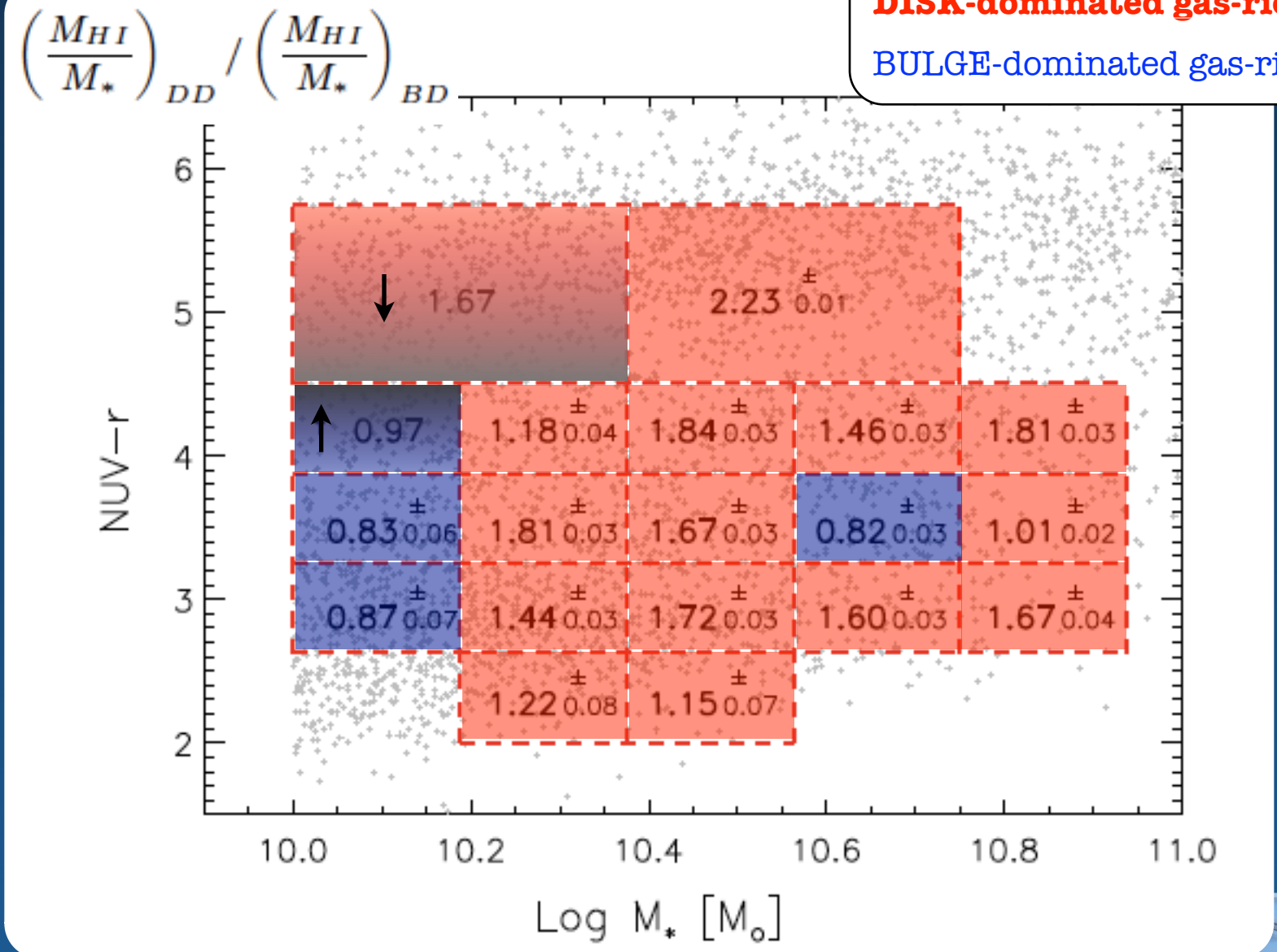
  Martig+ 2009

- At fixed stellar mass and colour, bulge-dominated objects are expected to be gas richer than disk dominated ones.

Morphological Quenching

DISK-dominated gas-richer

BULGE-dominated gas-richer



Summary:

- The bulge does not affect the gas content.
- Colour (and μ) can be used to predict the average HI content of massive galaxies.
- Our results for sample A in excellent agreement with GASS.
  Catinella, Schiminovich, Kauffmann, SF et al. 2010
- Our data seem to contradict the Morphological Quenching hypothesis.

Future work:

- explore other quenching mechanisms in the gas poor regime (AGN feedback, environment)
- Apply stacking to SKA precursor facilities
  eg. ASKAP, MeerKAT
- Extend analysis to higher z

Thank you!