ISM and dynamical scaling relations in the local Universe

Luca Cortese

International Centre for Radio Astronomy Research
The University of Western Australia

Outline

ISM scaling relations - ALFALFA/GASS/COLDGASS/HRS

Define `normalcy' in galaxy population: constraints to theory

Insights into physical link between ISM and integrated galaxy properties

→ when it comes to cold gas, M_* is not the king

Unique tools to discriminate between nature and nurture

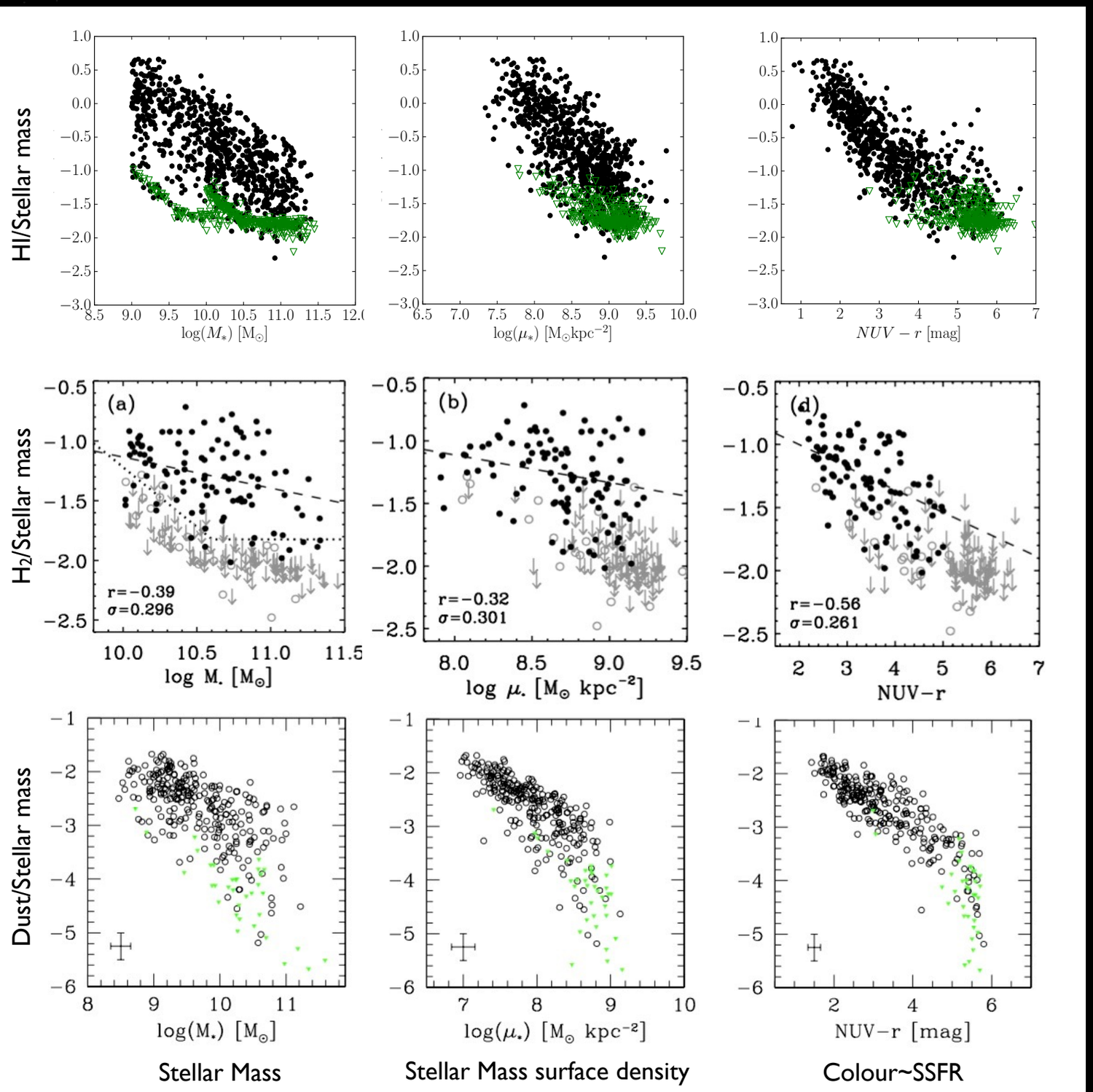
→ statistical evidence for fast and direct gas stripping from pairs to clusters

Dynamical scaling relations - SAMI

IFS surveys: investigate scaling relations for all galaxy types at once

→ M*-angular momentum - spin/morphology plane: a possible way to unify galaxies

Global HI-H_2-dust scaling relations



Atomic Hydrogen

Catinella+ 2010
Cortese+2011
Huang+2012
Kannappan+2004,2014

Molecular Hydrogen

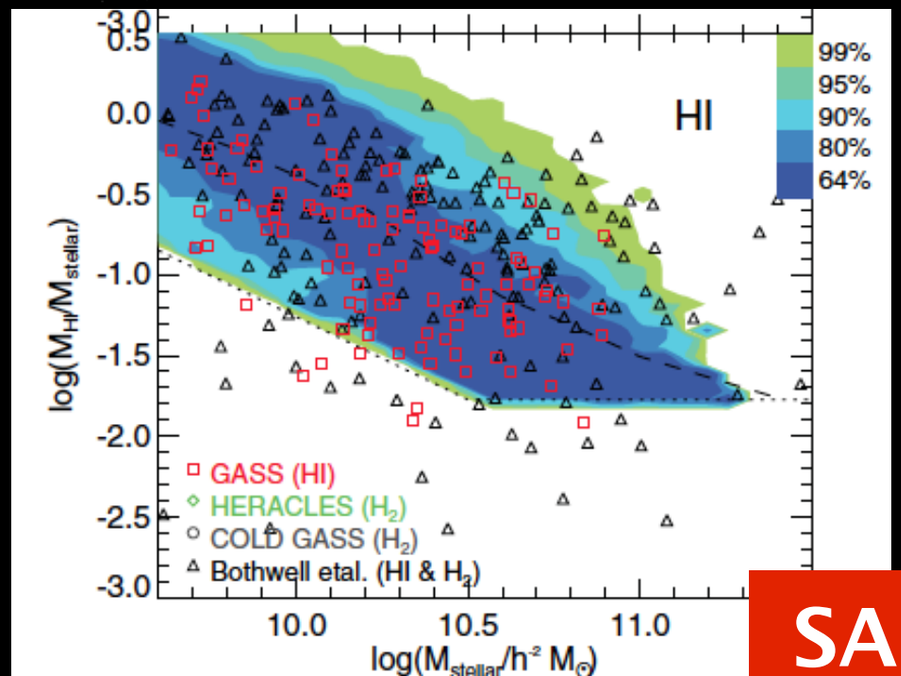
Saintonge+ 2011
Boselli+2014
Bothwell+2014

Dust

Cortese+ 2012
Viaene+2014
Clark+2015

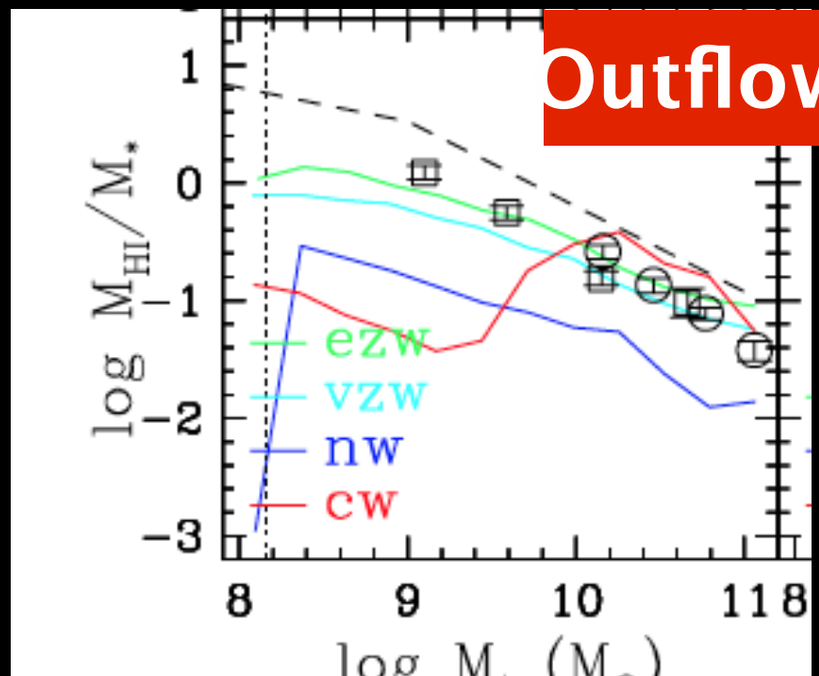
ISM scaling relations and galaxy models

Lagos et al. 2011



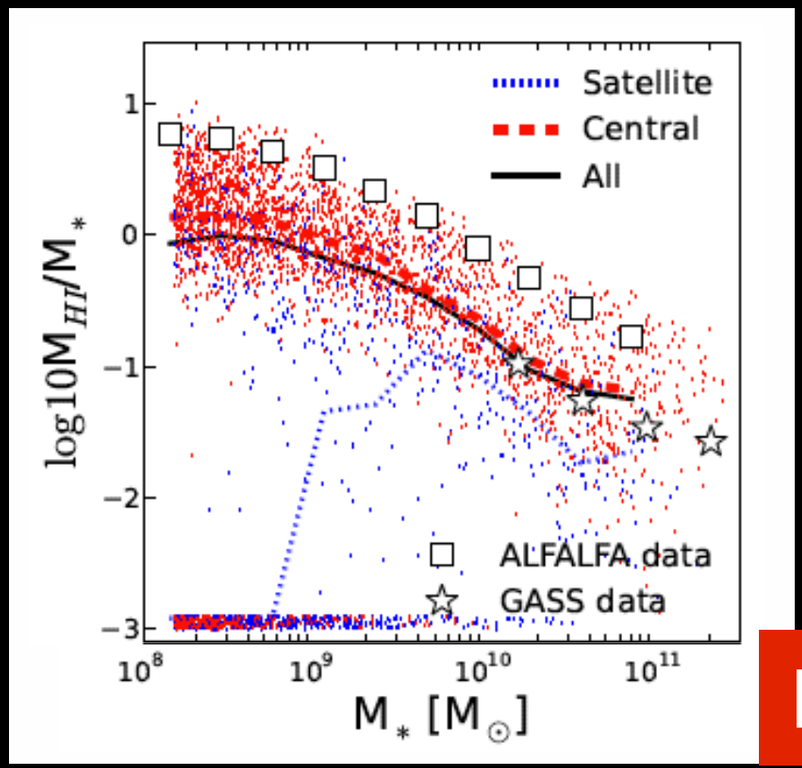
SAMs

Dave' et al. 2013



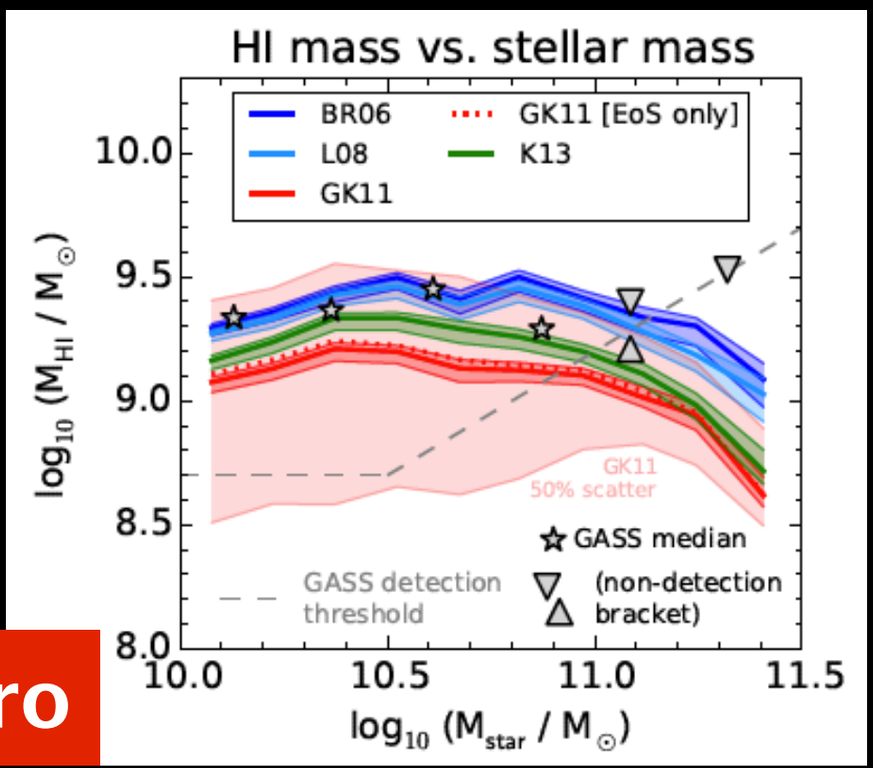
Outflow models

Rafieferantsoa et al. 2015



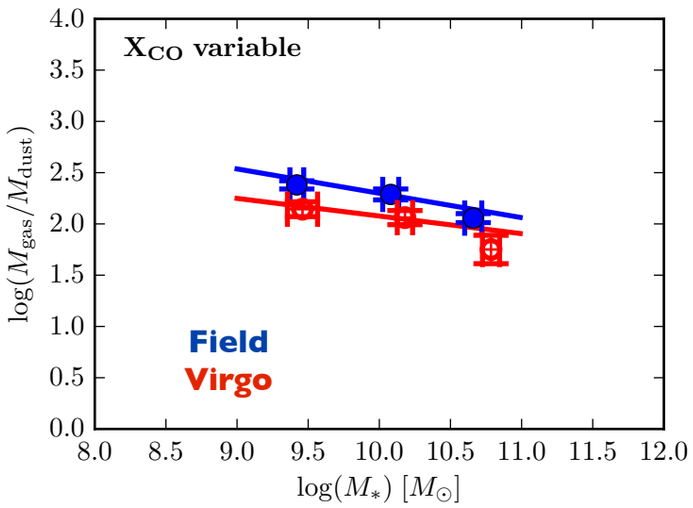
Hydro

EAGLE, Bahe et al. 2015

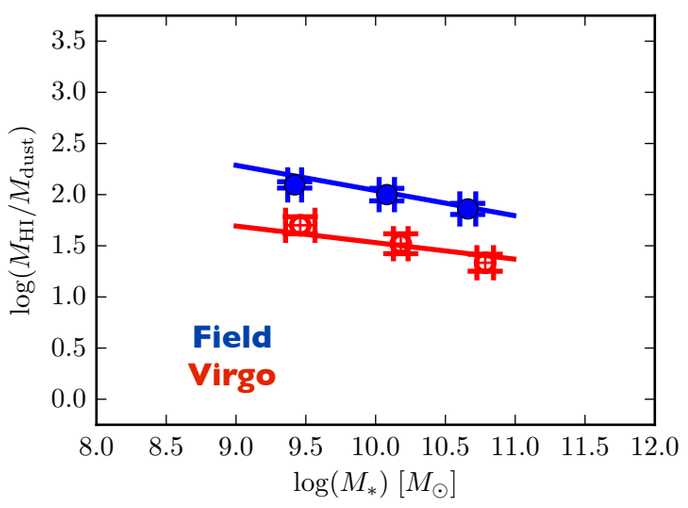


ISM scaling relations and environment

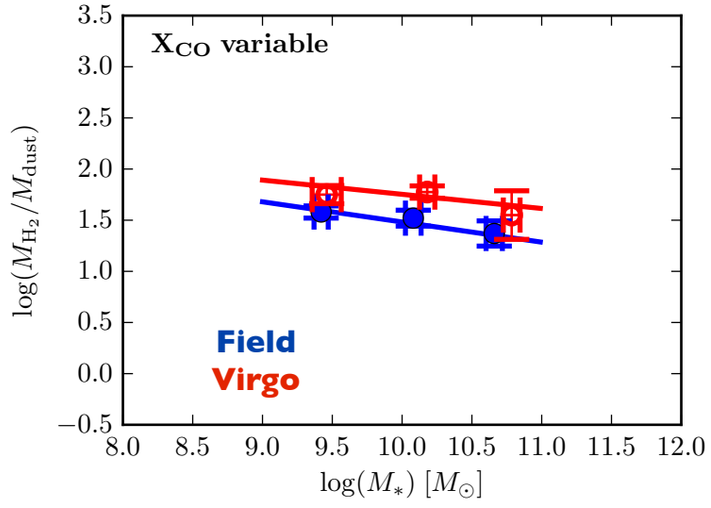
Total Gas/Dust



HI/Dust



H_2/Dust

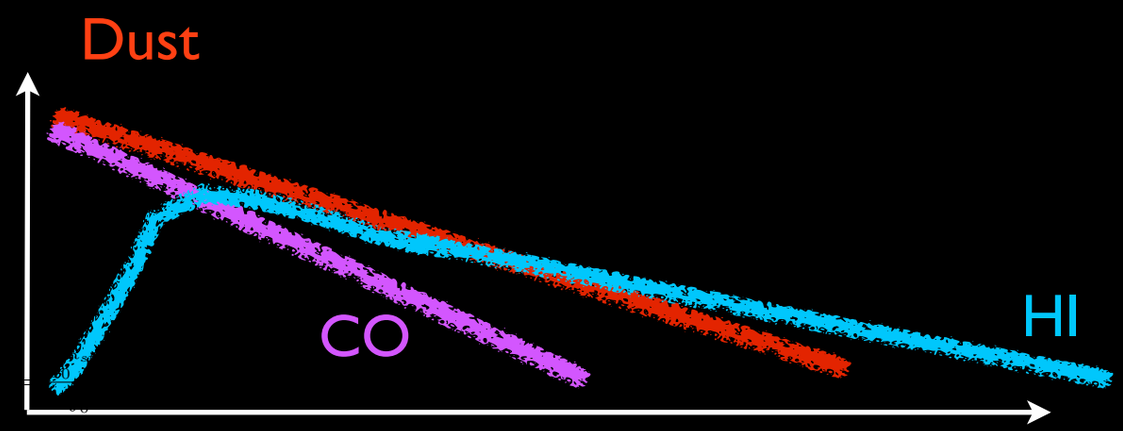


LC+ 2016a

Total G/D ratio varies very little between field and cluster

HI and H_2 behave differently: HI/Dust decreases - H_2/Dust increases

Stripping: CO<Dust<HI



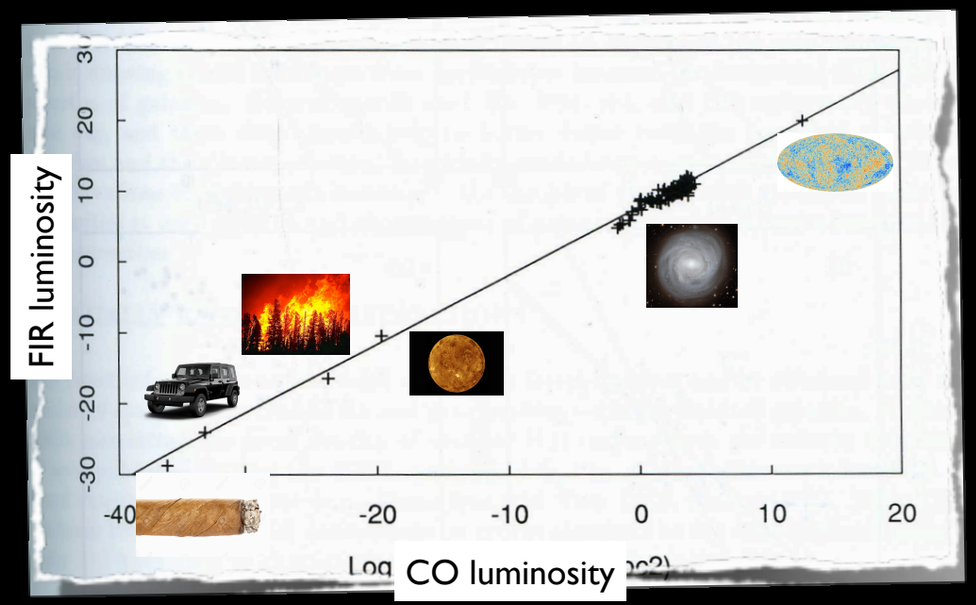
All consistent with differential stripping acting outside-in

Current Challenges

Identify `physically-driven' relations

Most of the comparison with theory
(as well as environmental studies)
based on relation with stellar mass

Isn't this just "bigger galaxies have more gas/dust"?
Remember nice plot by Kennicutt 1990



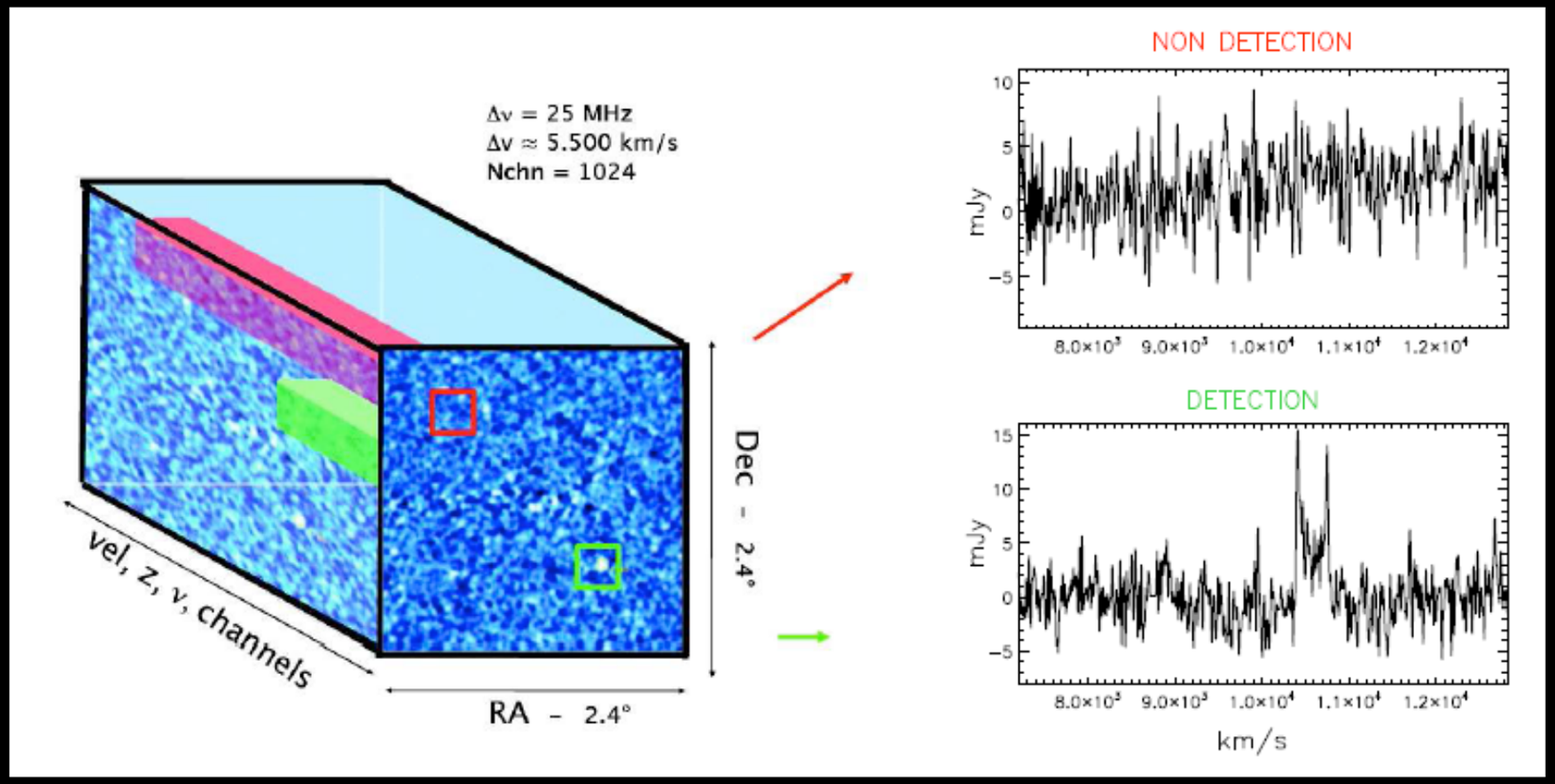
Extend ISM environmental studies outside clusters

Virgo/Coma-like systems extremely rare.
Impossible to extrapolate these studies to groups/pairs.

Number statistics our main limitation!
Representative samples limited to ~300 (H_2/dust) - ~1000 (HI) galaxies

For HI we can make progress now

The power of stacking and ALFALFA HI observations



Fabello+ 2011

- extract HI spectra at known coords, z
- align in velocity, co-add & measure

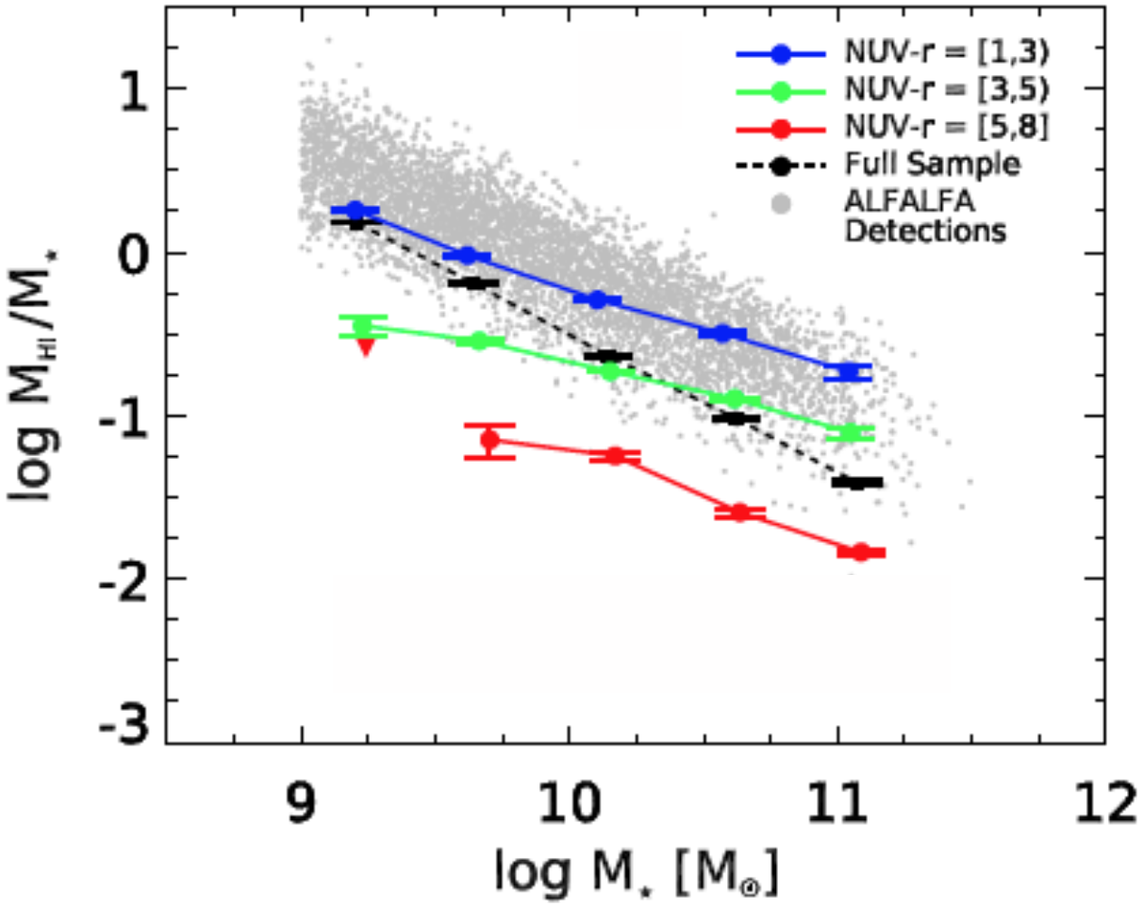
Commonly used for cosmic HI density (Lah+ 2007, 2009; Rhee+ 2013)

Even more powerful in the context of gas scaling relations (Fabello+ 2011, 2012; Brown+ 2015)

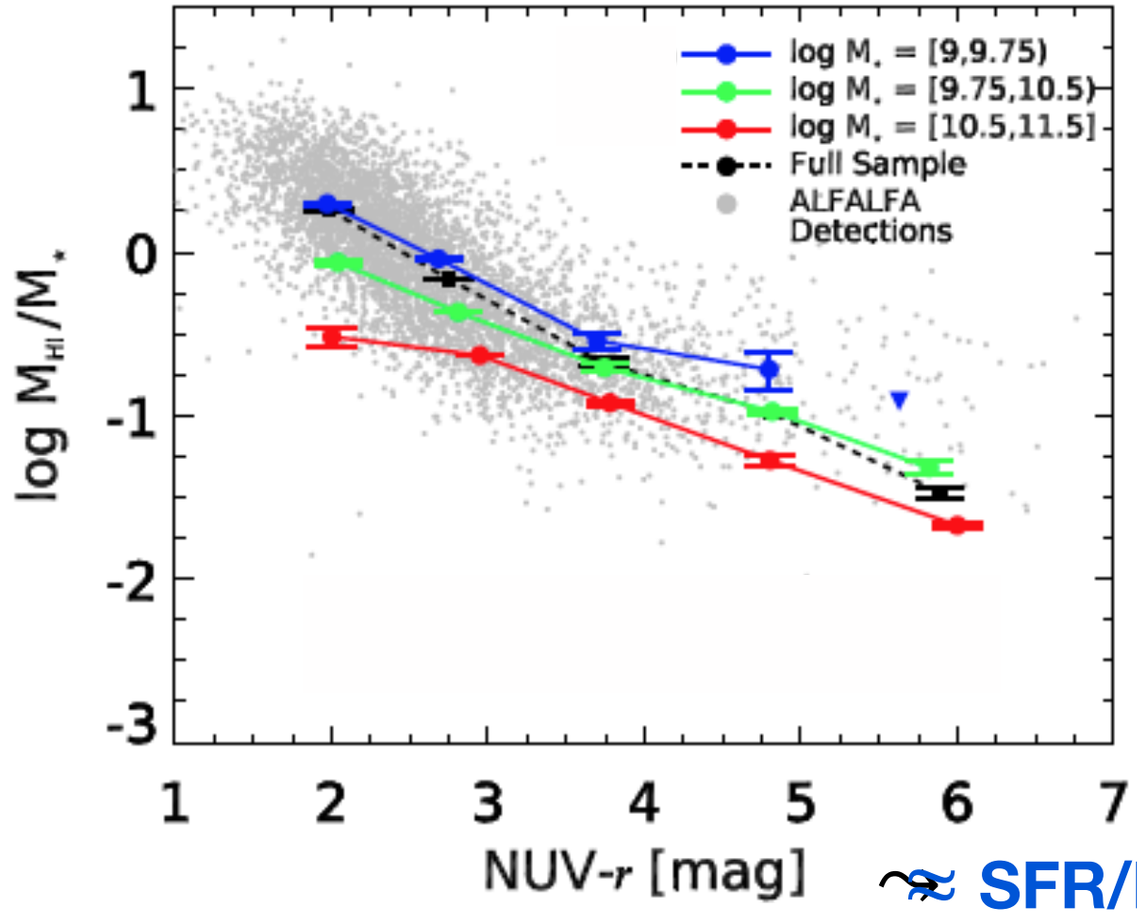
Primary vs secondary dependencies

Dissecting gas scaling relations with ~25000 galaxies

NUV-r bins



Stellar mass bins



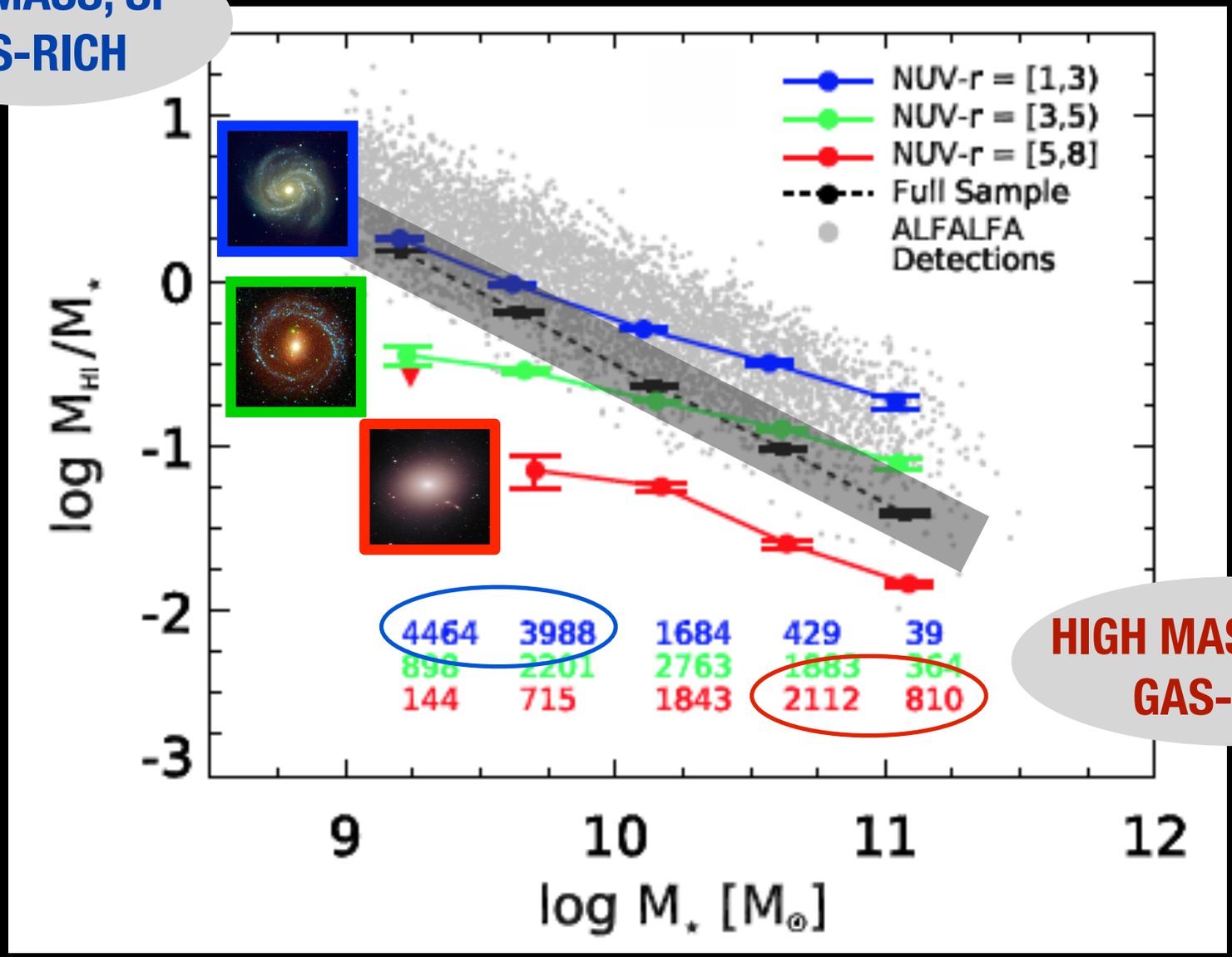
≈ SFR/M$_*$

Brown, Catinella, LC+ 2015

Gas content primarily related with color/SSFR, not stellar mass

Stellar mass is not the king

LOW MASS, SF
GAS-RICH



HIGH MASS, not SF
GAS-POOR

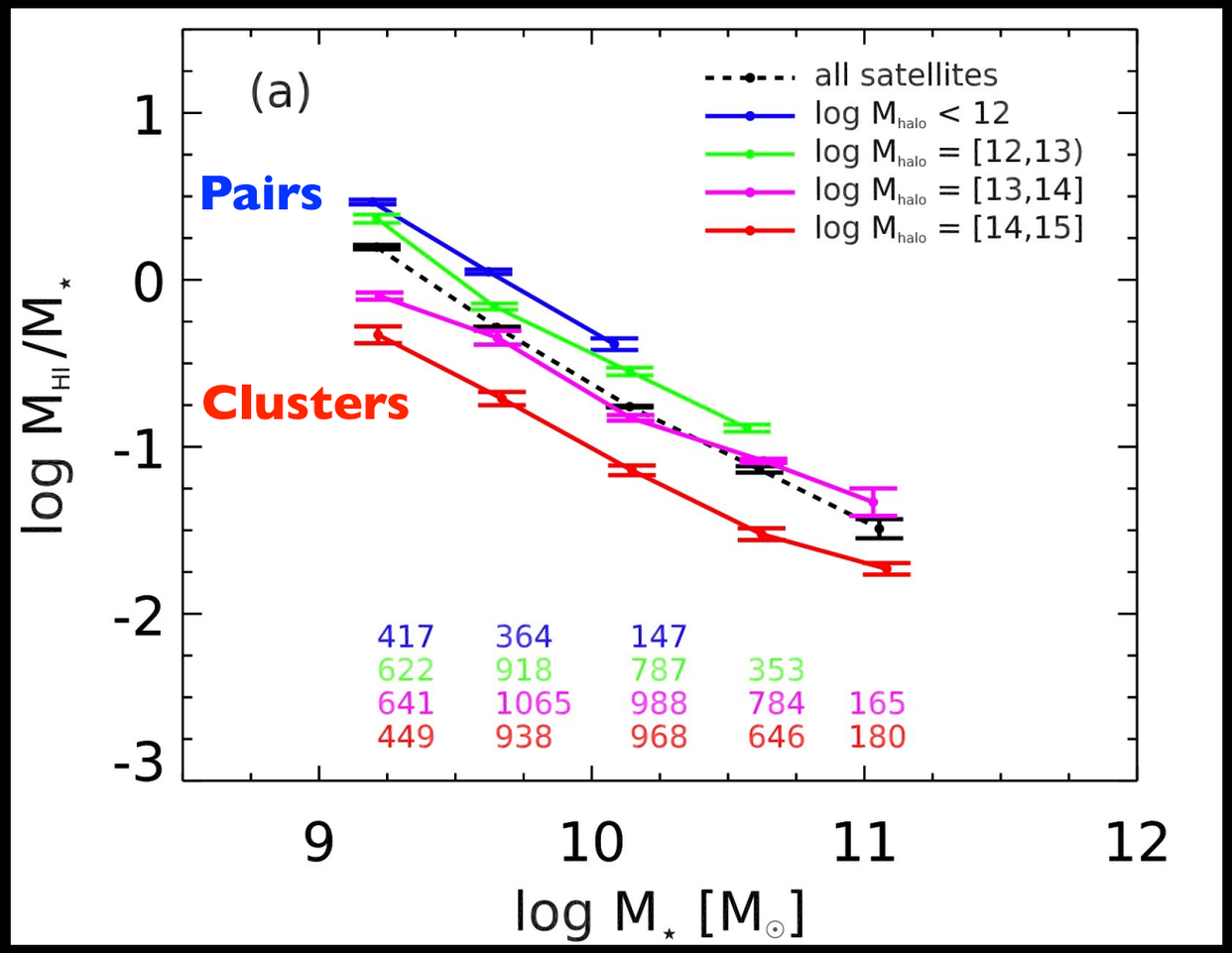
Brown, Catinella, LC+ 2015

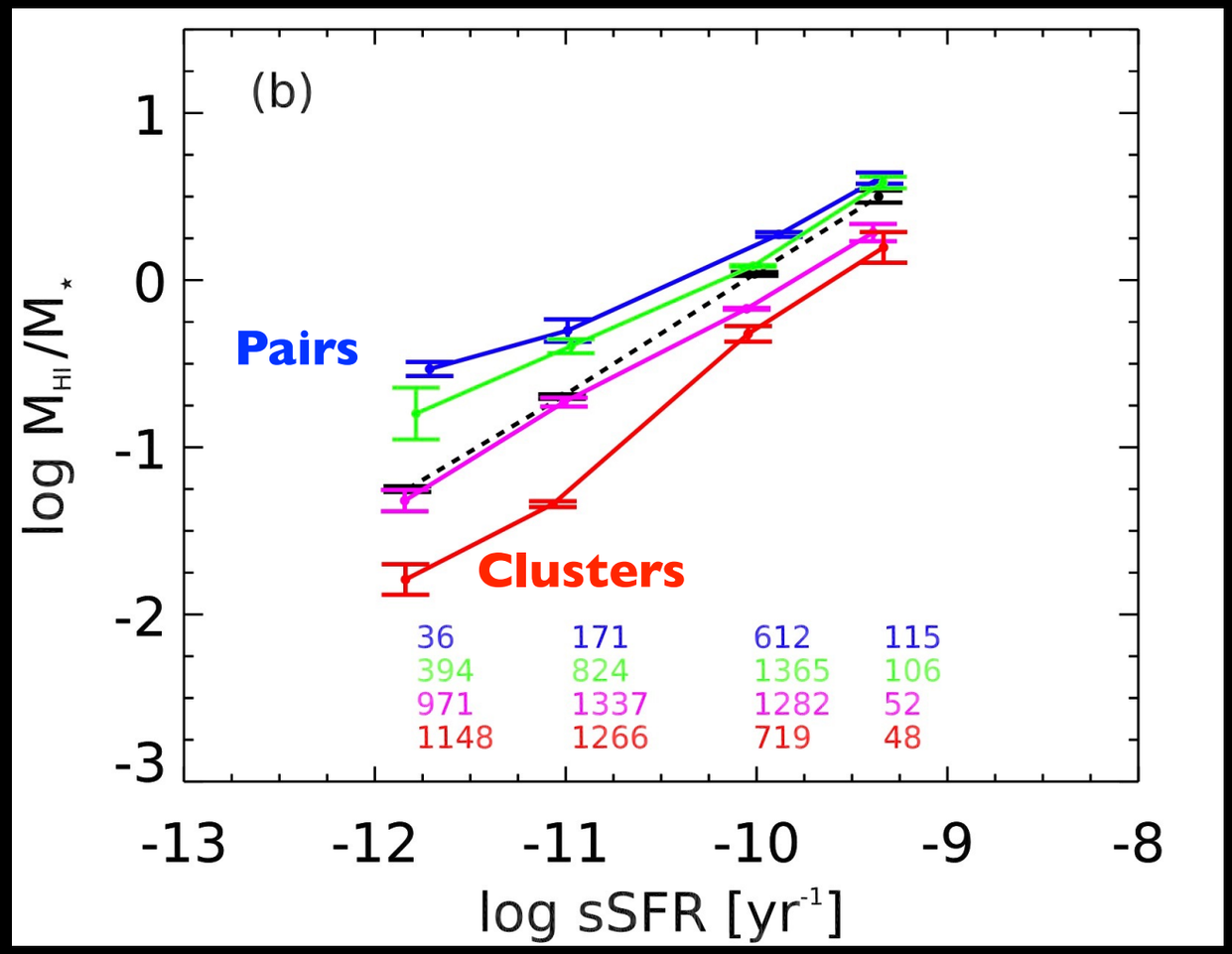
The gas fraction-M* slope mainly a consequence of galaxy bimodality

Not the best observational constraint to theoretical models

Tracing HI stripping across environments

Satellite galaxies binned by halo mass





Brown, Catinella, LC+ in prep.

Gradual decrease of gas content with group size: i.e., no threshold

Reduction of gas fraction also at fixed SSFR
HI removed faster than SF quenched! => stripping!

Summary (I)

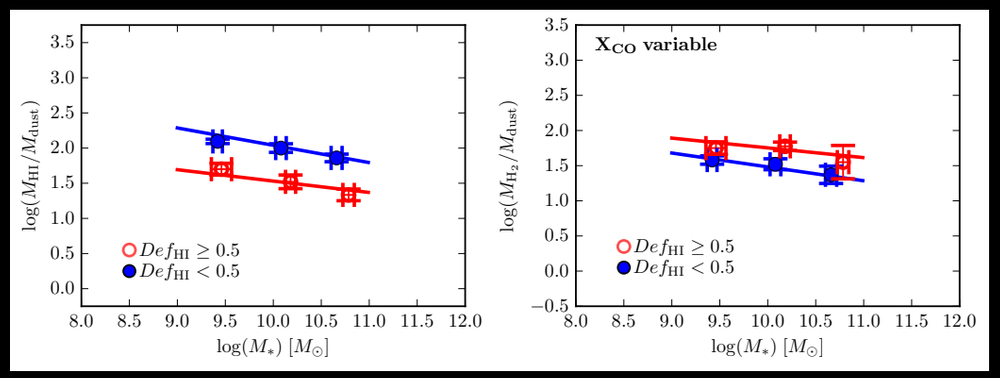
ISM scaling relations

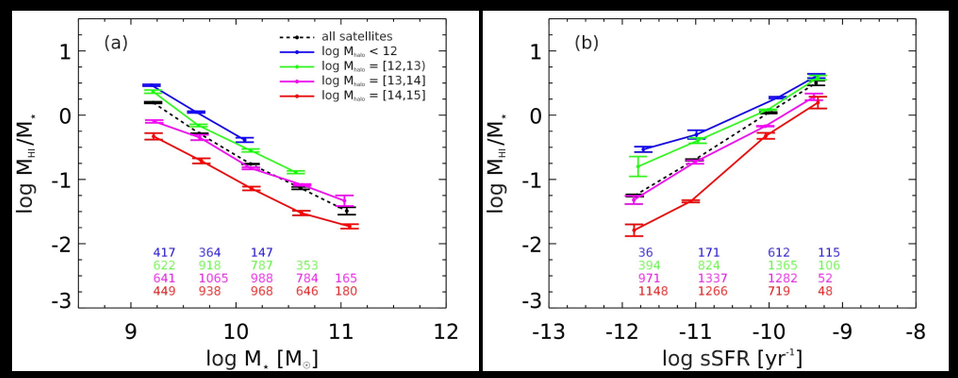
When it comes to cold gas, M_* is not the king

Statistical evidence for fast and direct gas stripping from pairs to clusters

Challenges

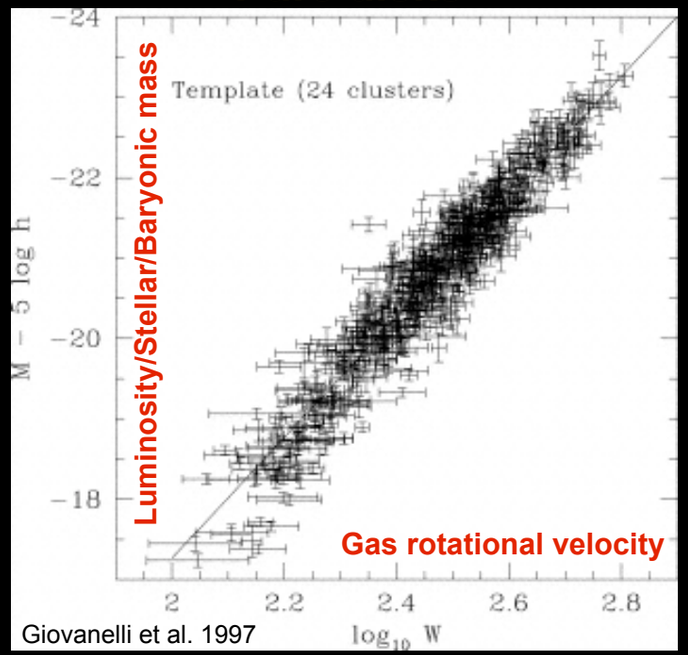
Need large number statistics to do this with detections.
H_2 and dust studies (in the local Universe) suffering the most





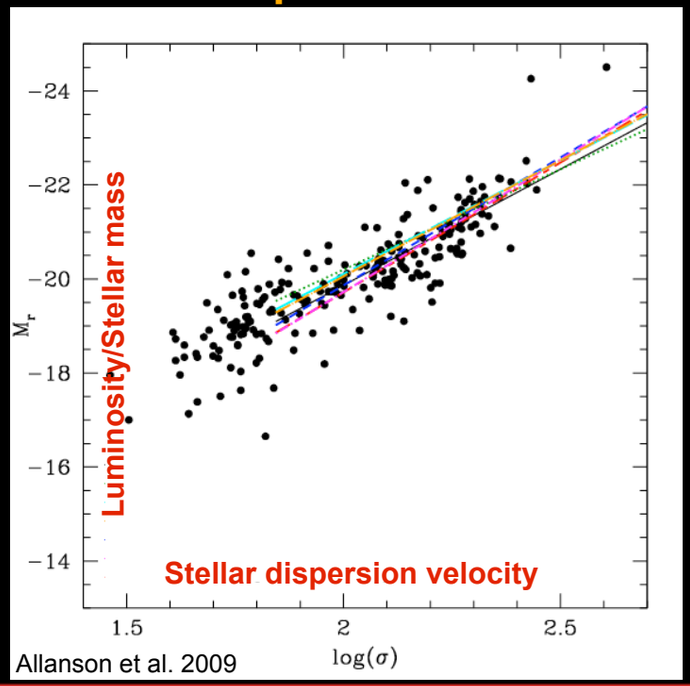
Dynamical scaling relations for galaxies of all types

Tully-Fisher (1977) relation
Pure disks



Giovanelli et al. 1997

Faber-Jackson (1976) relation
Spheroids



Allanson et al. 2009

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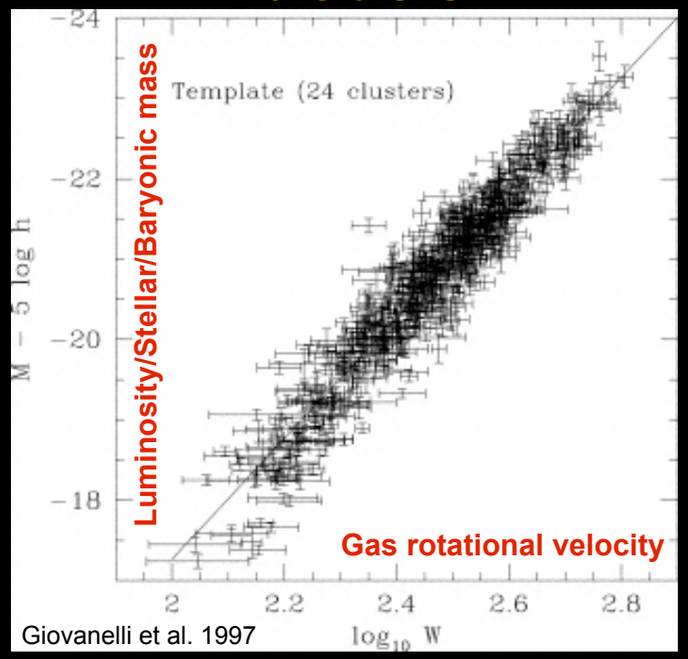

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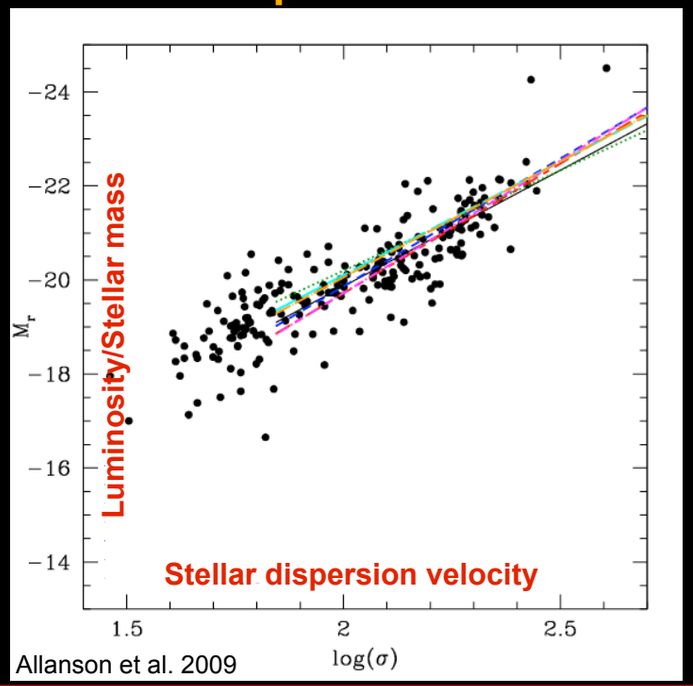
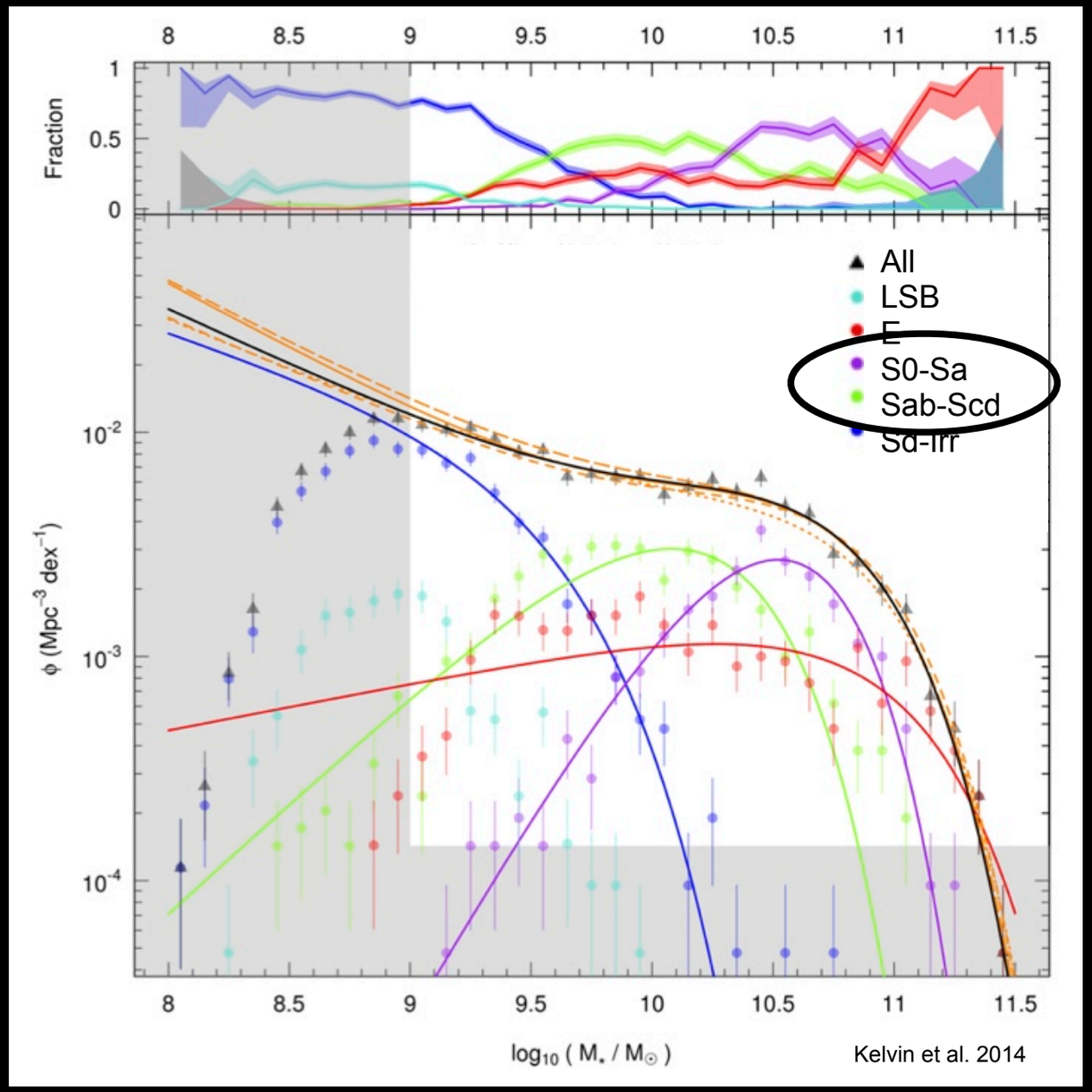


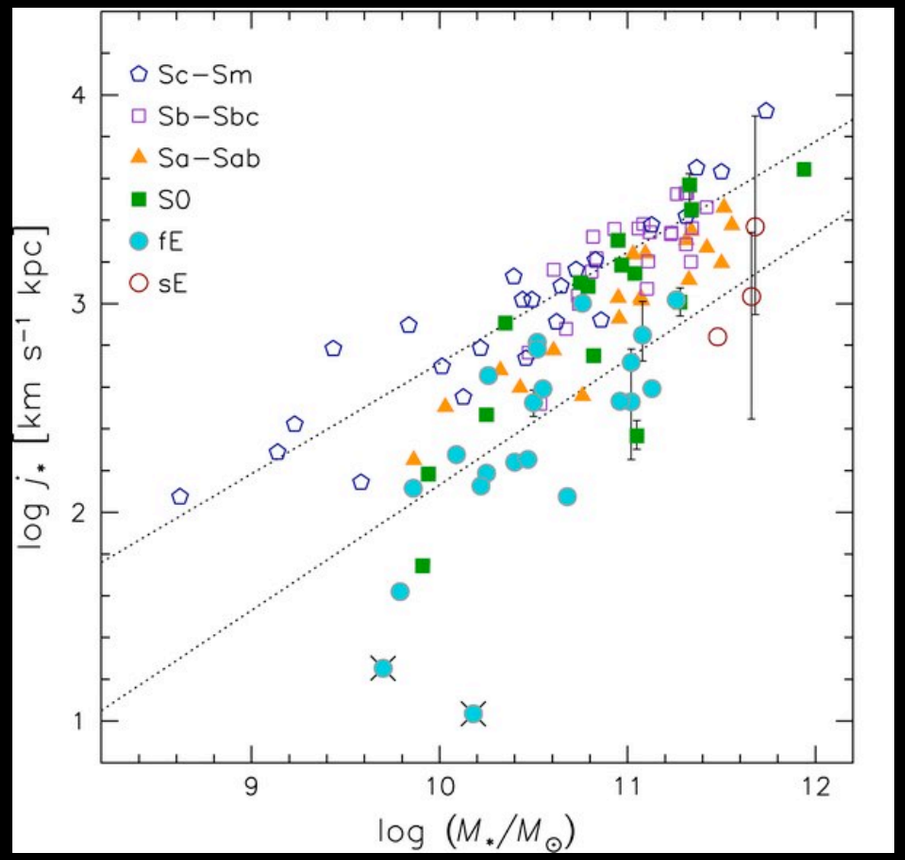
Allanson et al. 2009



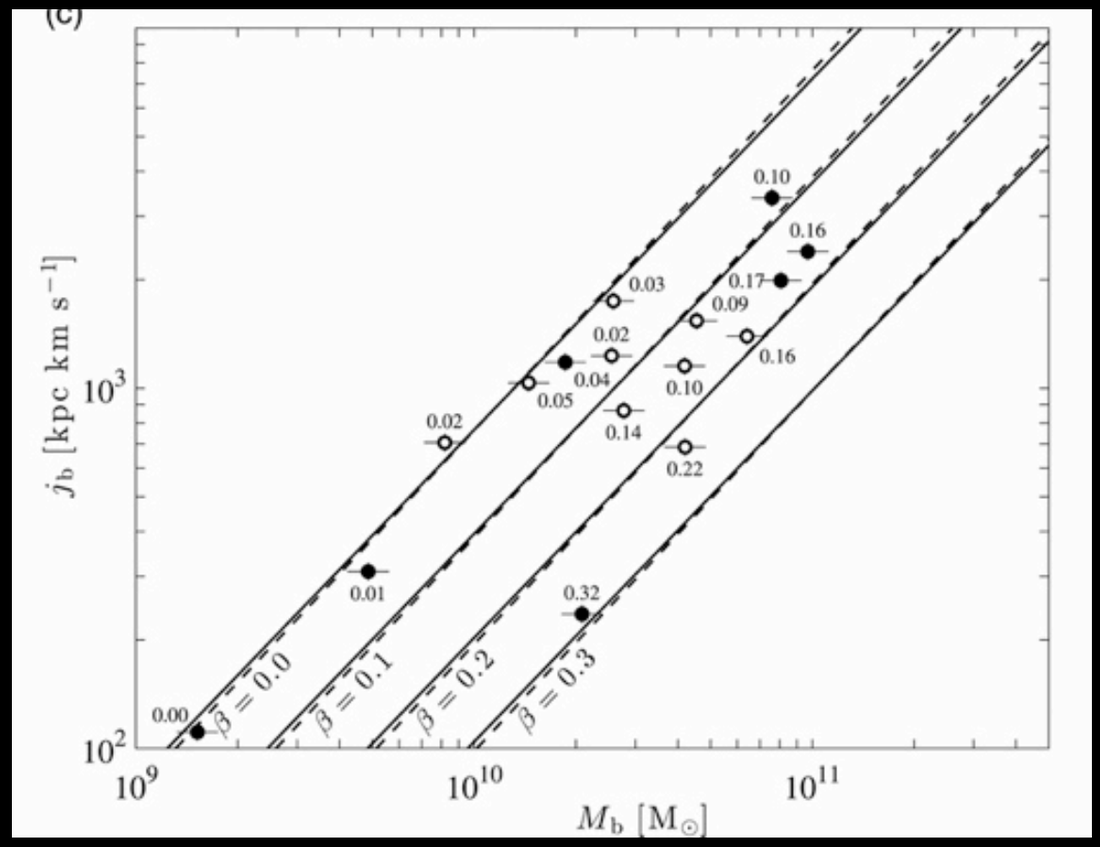
Kelvin et al. 2014

Average galaxy is neither a pure disk or spheroid

Mass-Specific Angular momentum-Morphology plane



Romanowsky & Fall 2012

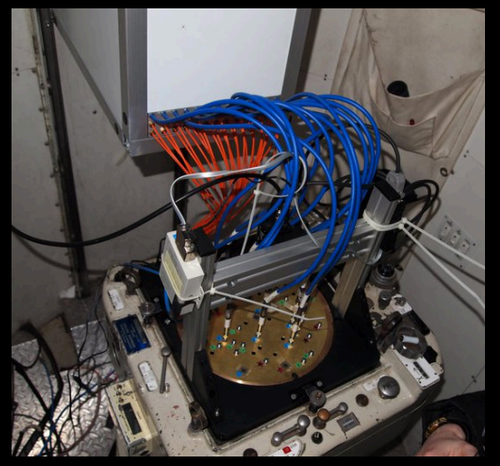


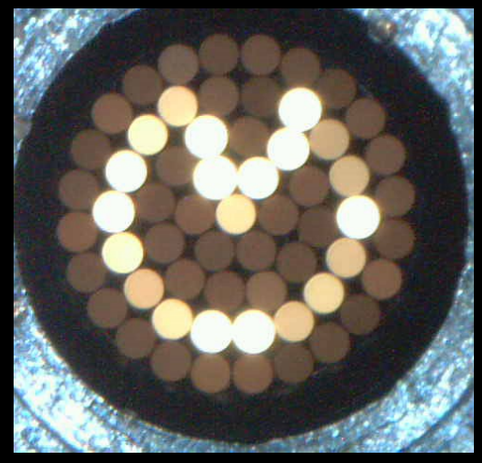
Obreschkow & Glazebrook 2014

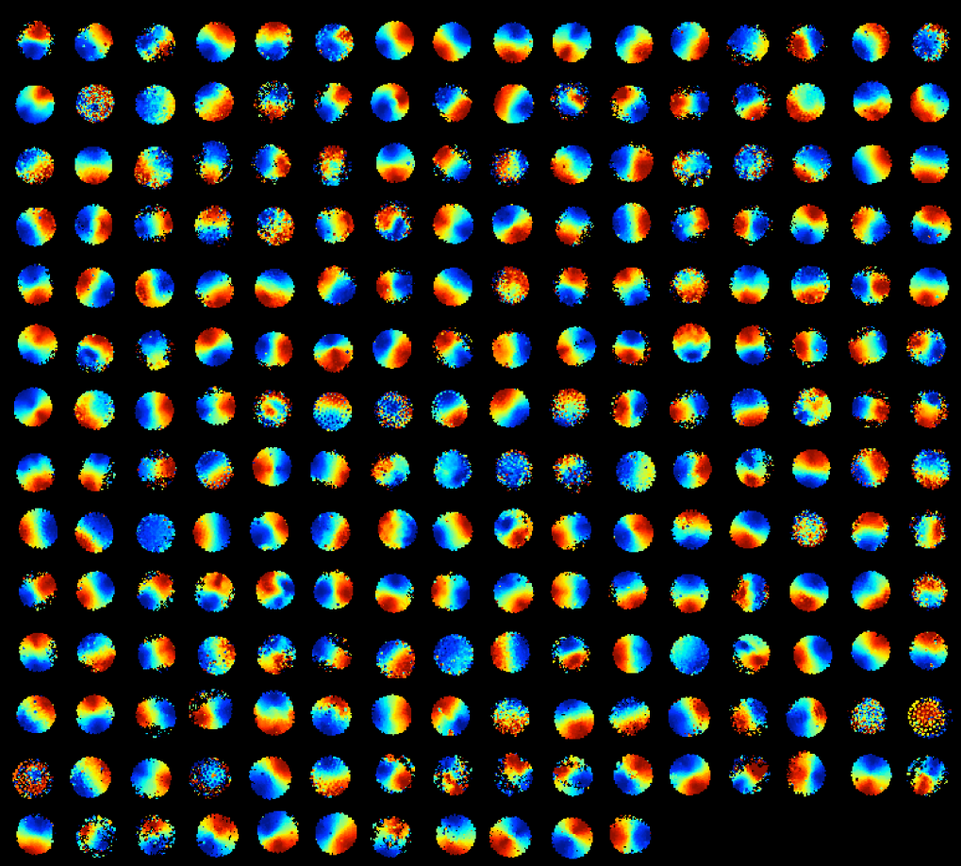
Galaxies distributed along a M*-j relation
Scatter related to morphology - i.e., balance between random and ordered motions

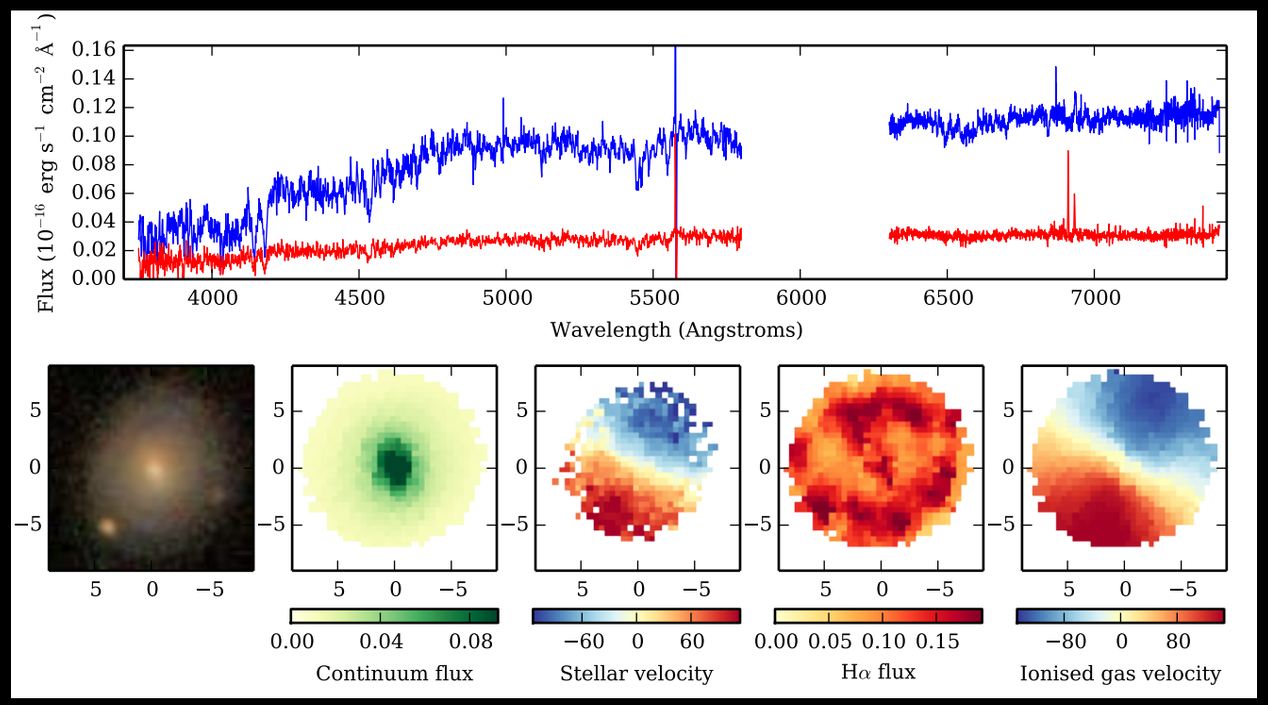
The SAMI Galaxy Survey

- IFU survey of ~3400 nearby galaxies
  (2800 field/groups - 600 clusters)
- SAMI instrument at AAT (12 gal/obs.)
- Selection by $M_*(10^{7.5}\text{-}10^{11.5}\ M_\odot)$ and z ($\lesssim$0.1)
- Kinematics for both gas and stars!
- >1750 galaxies already observed



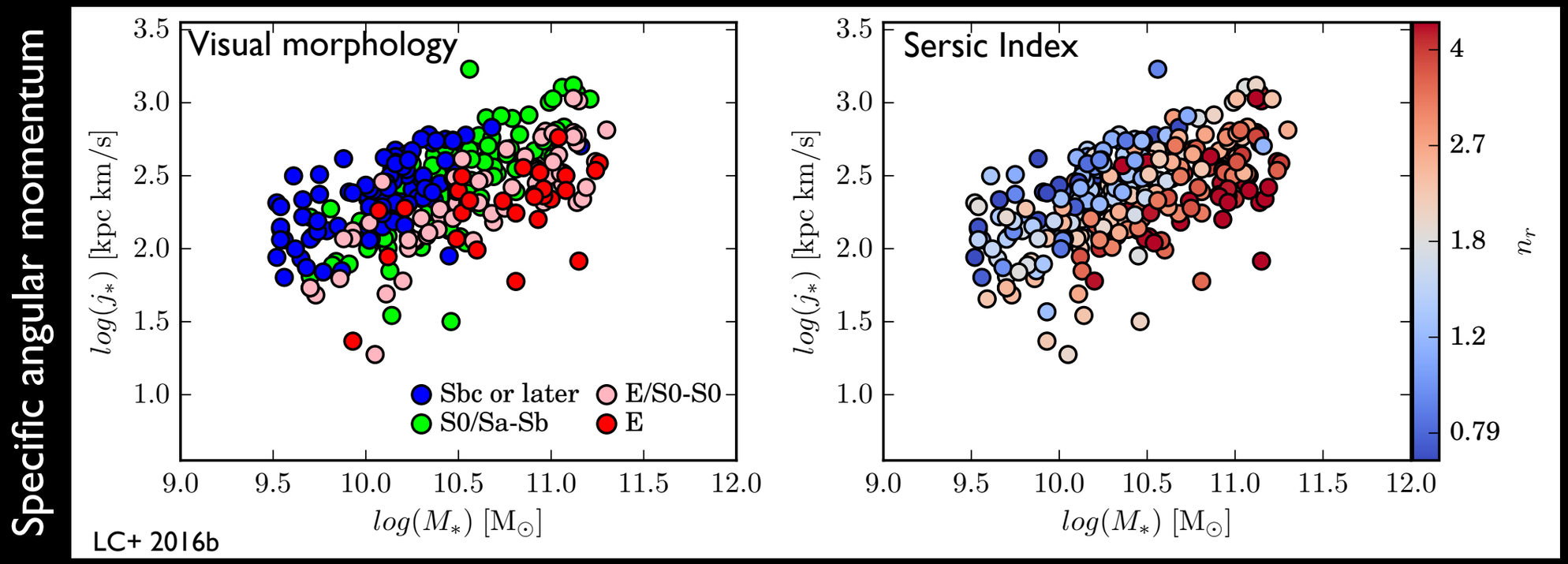






See http://sami-survey.org for details and first DR!

Stellar spin to trace morphology

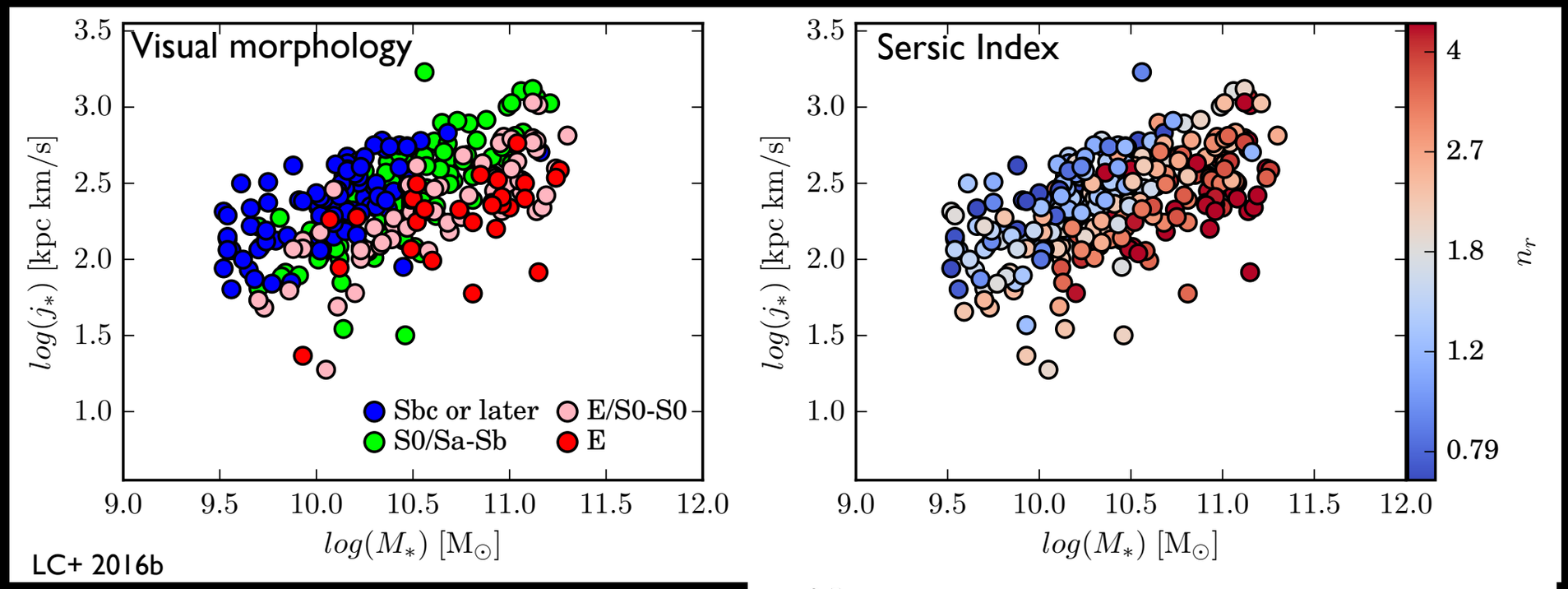


The scatter of M_*-j_* relation correlates with morphology

Gives us info on the balance between ordered and random motions

Note: this is just within 1 r_e!

Stellar spin to trace morphology



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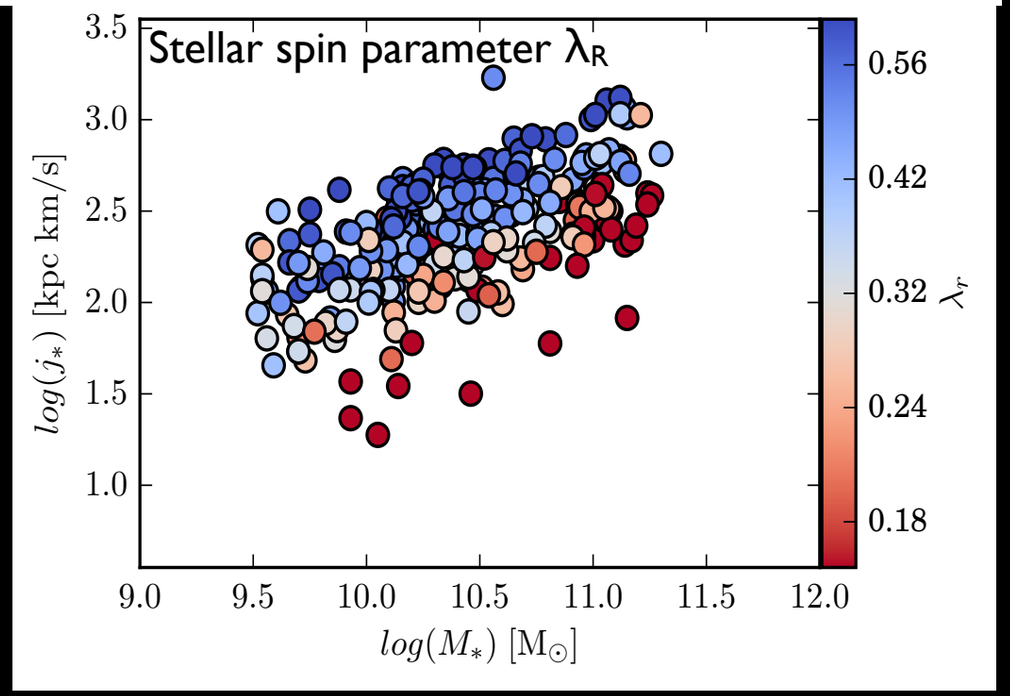
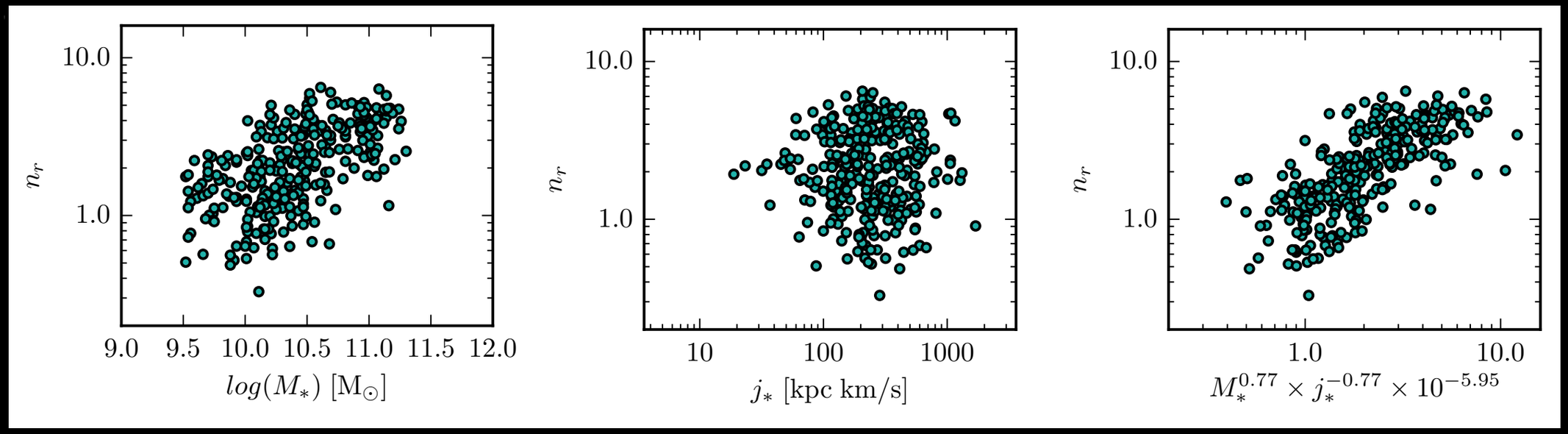
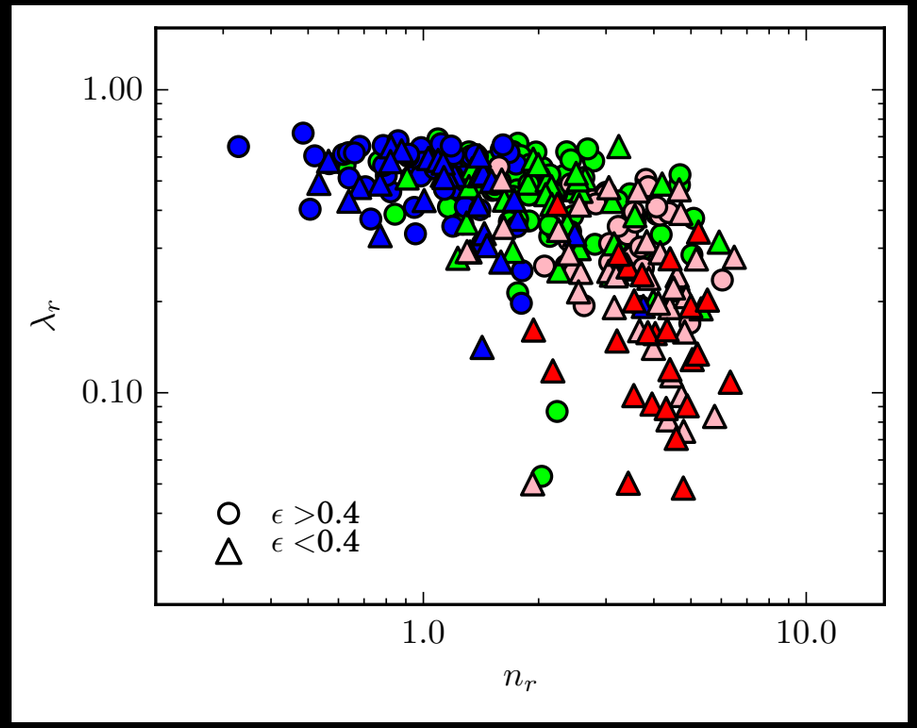


The SAMI view of the M*-j*-n plane





LC+ 2016b

We can look at all this as a plane
linking Mass - morphology - angular momentum
(scatter <0.1dex)

Spin correlated with morphology
but relation not linear!

Kinematical classification
better separates rotation-vs-dispersion
in bulge-dominated systems

Projection of the plane that minimises scatter

$$j \propto \lambda_R M_*^{a} \longrightarrow M_* \propto [R\,(V^2+\sigma^2)^{0.5}]^{1/a}$$

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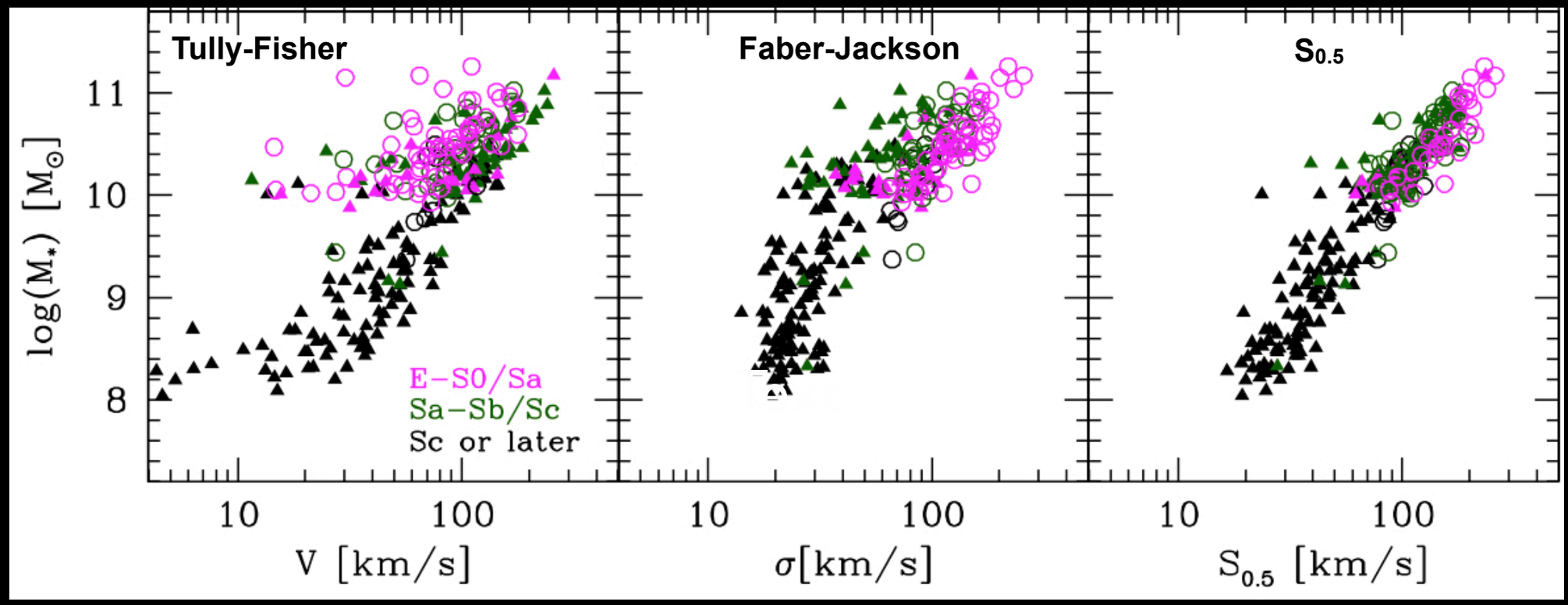


LC et al. 2014

$S_{0.5}=(0.5V^2+\sigma^2)^{1/2}$

Different dynamical scaling relations as projections of M-j-spin plane

Combining contributions of random and ordered motions key for unified scaling relation including all galaxy types

Scatter (0.1dex) similar to pruned TF and FJ relations

Summary (II)

Dynamical scaling relations - SAMI

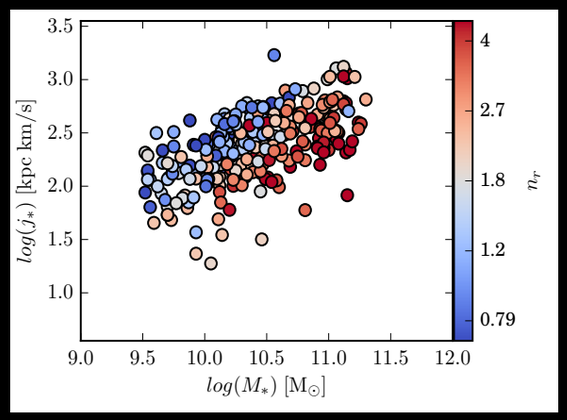
Critical to move beyond pre-pruning by morphology, SF, etc.

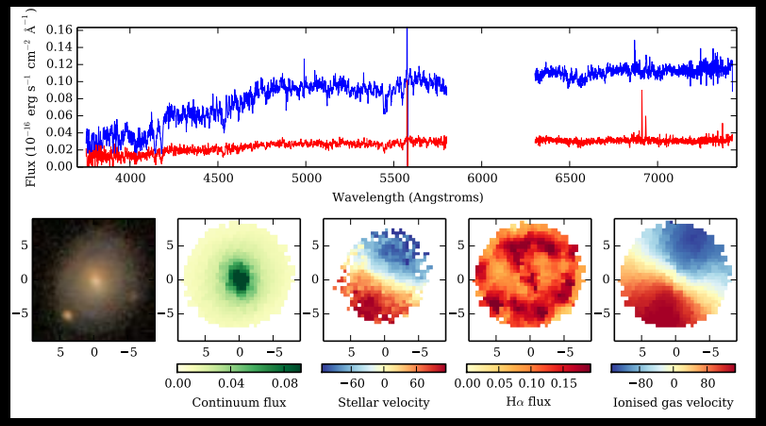
IFS surveys: investigate scaling relations for all galaxy types at once

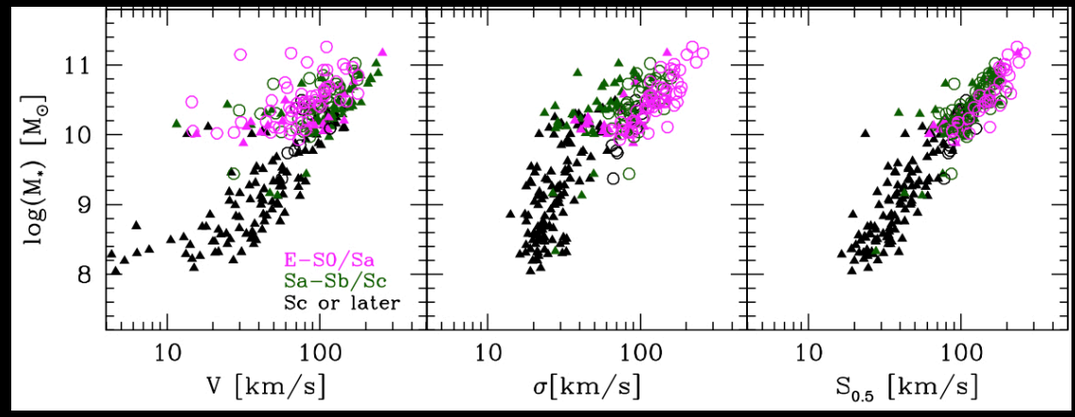
→ the M*-angular momentum - spin/morphology plane possible way to unify galaxies
→ TF/FJ/S0.5 relations can be seen as different projection of the same plane
→ Chance to move towards a more physically motivated morphological classification

Challenges

Current IFS studies mainly limited to 1re... need to go to larger radii
We should also look at baryonic dynamical scaling relations: need HI!







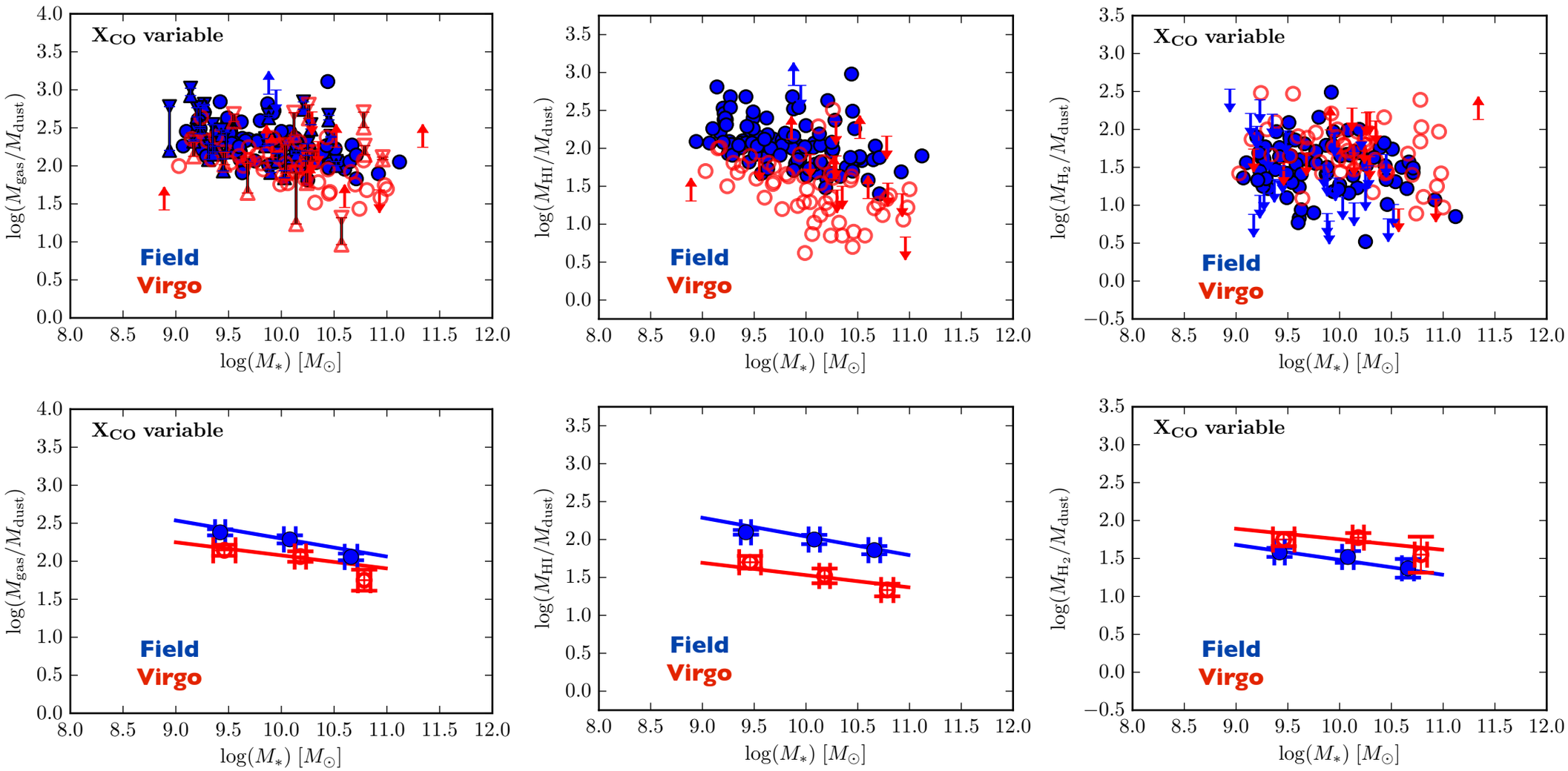
Thank you

ISM scaling relations and environment

Total Gas/Dust

HI/Dust

H_2/Dust



LC+ 2016a

Total G/D ratio varies very little between field and cluster

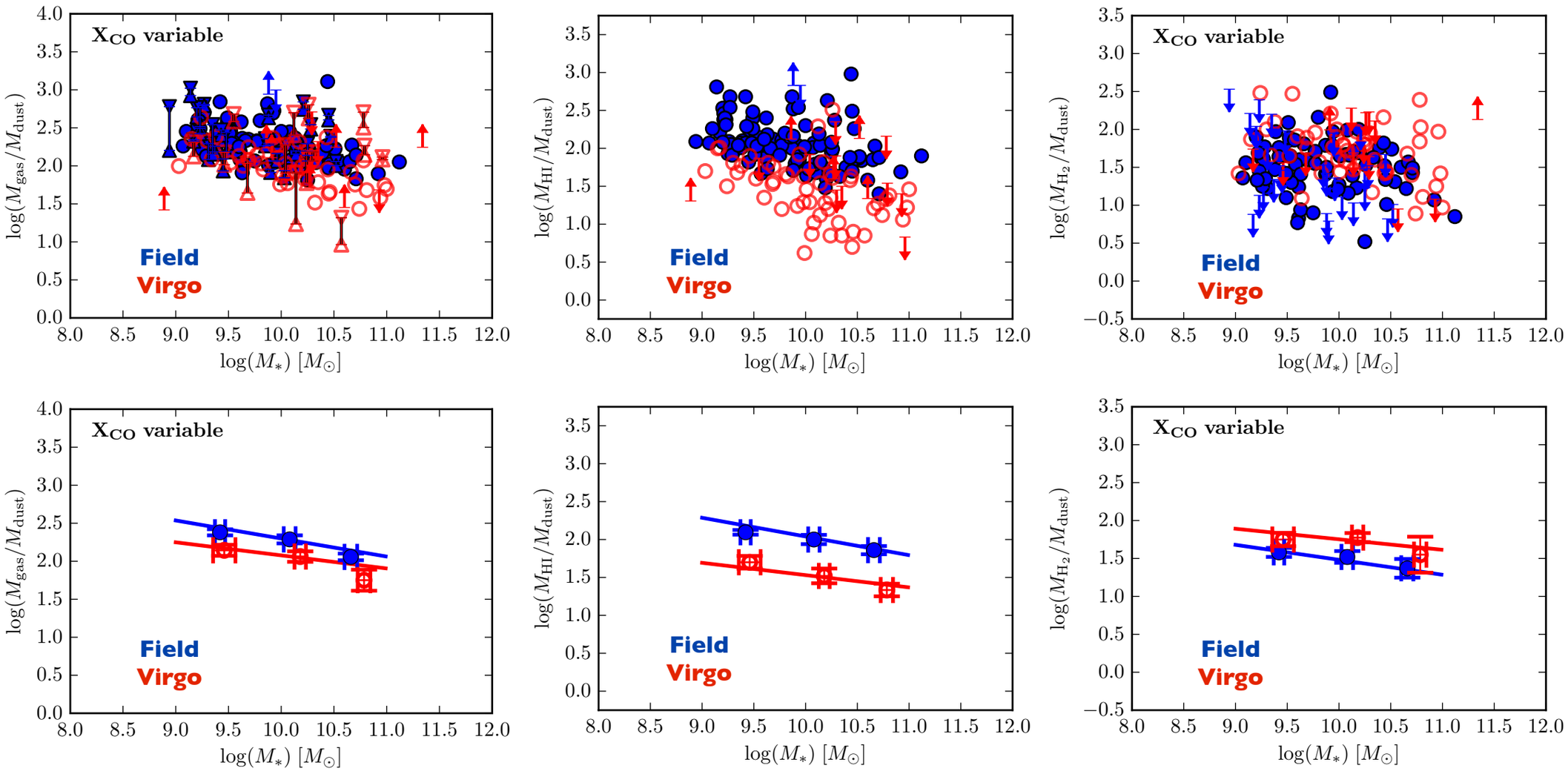
HI and H2 behave differently: HI/D decreases - H2/Dust increases

ISM scaling relations and environment

Total Gas/Dust

HI/Dust

H_2/Dust



LC+ 2016a

Total G/D ratio varies very little between field and cluster

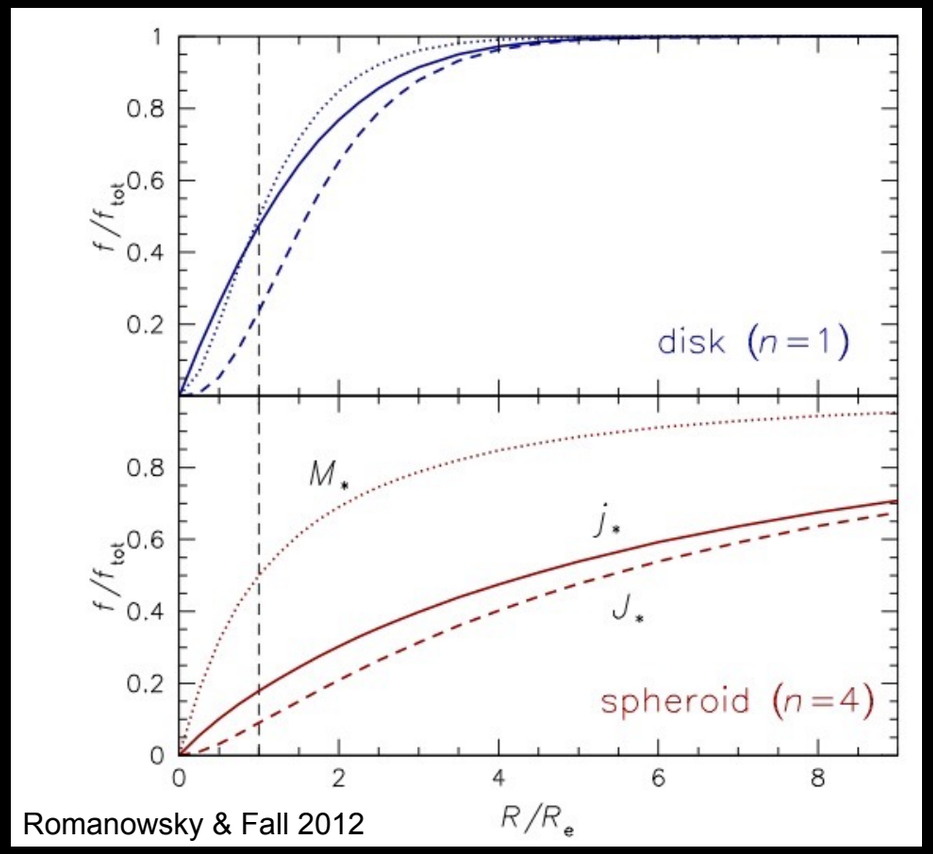
HI and H2 behave differently: HI/D decreases - H2/Dust increases

All consistent with differential stripping in clusters

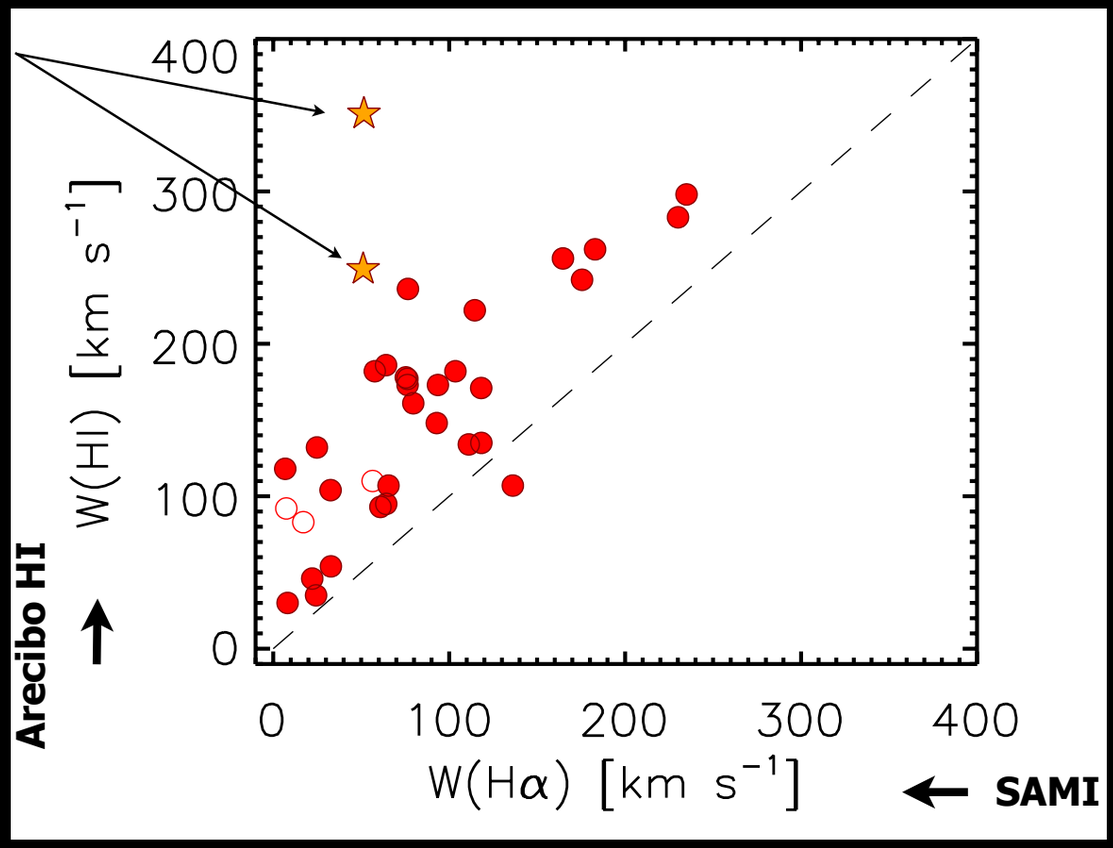
Current limitations… and possible solutions

Most of what we know from current IFS surveys is limited to 1 re

We might be missing the bulk of angular momentum budget



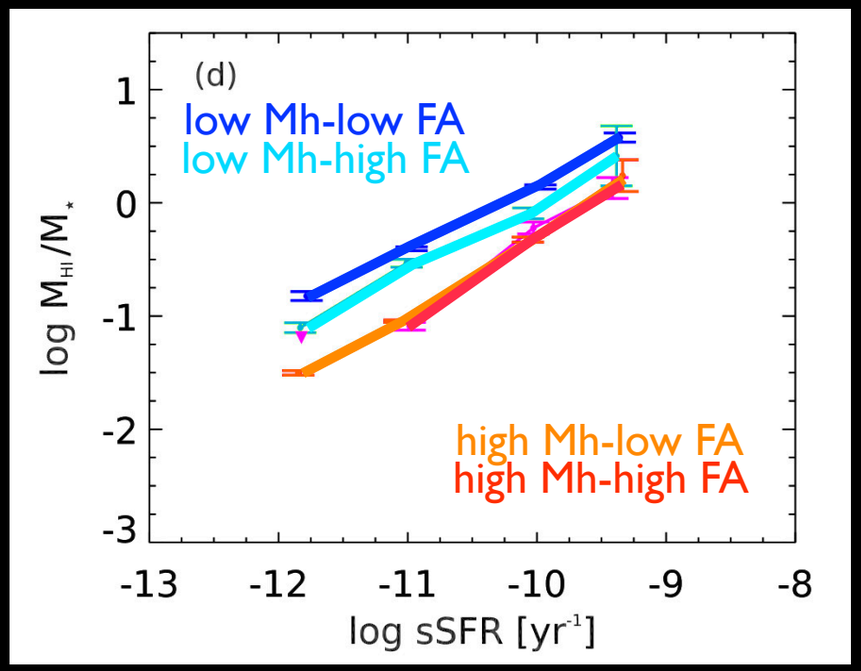
Romanowsky & Fall 2012



Tracing HI stripping across environments

Which `environment' better traces stripping?

Mh fixed - FA varies



Brown, Catinella, LC+ in prep.

Global environment (i.e., halo mass) more directly related to stripping than the local one?

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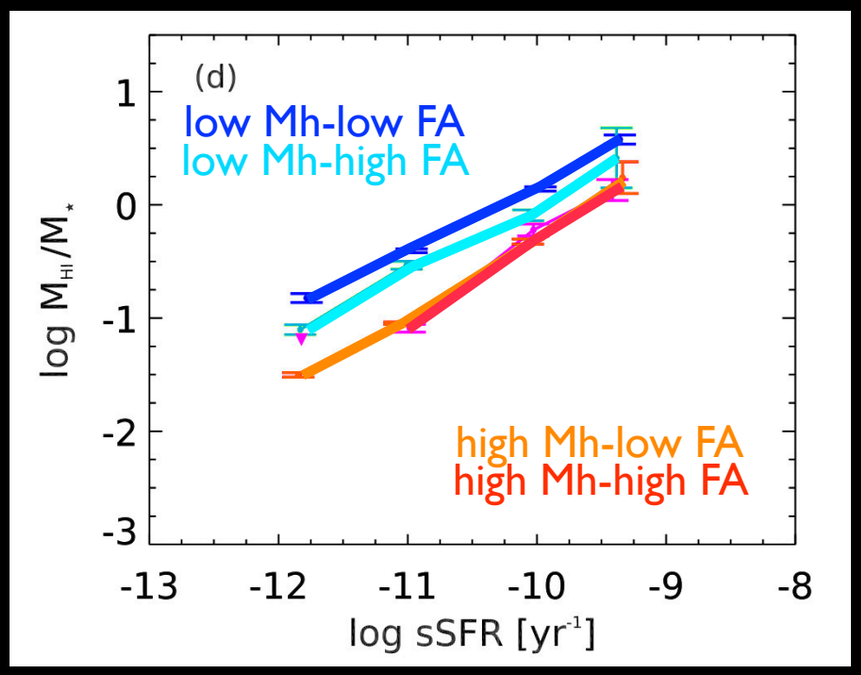

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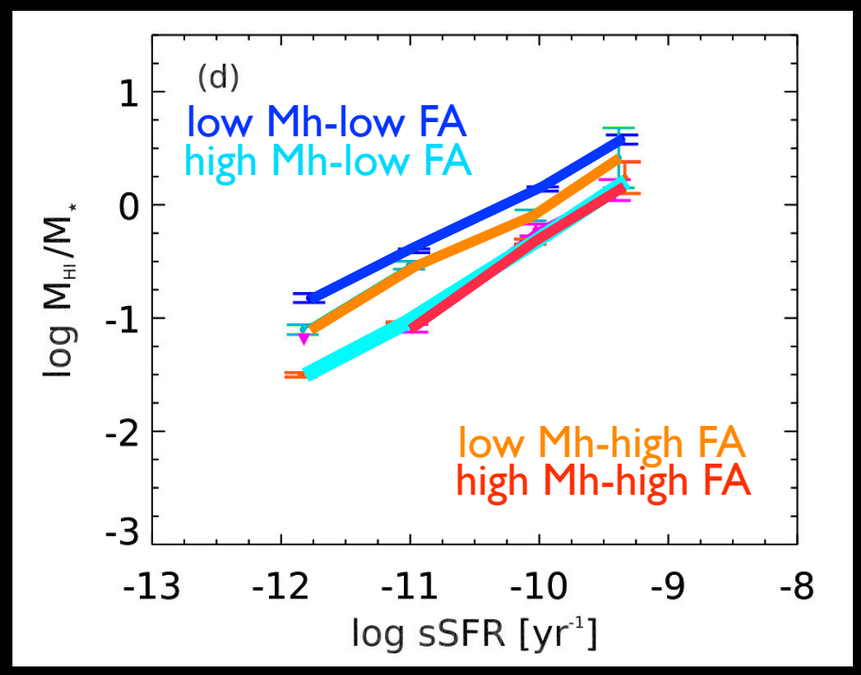

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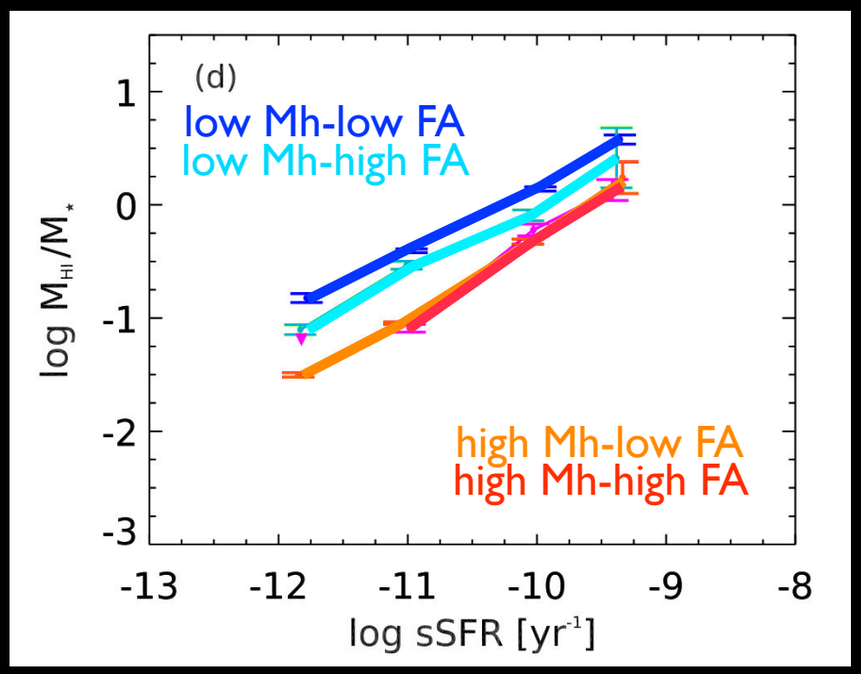
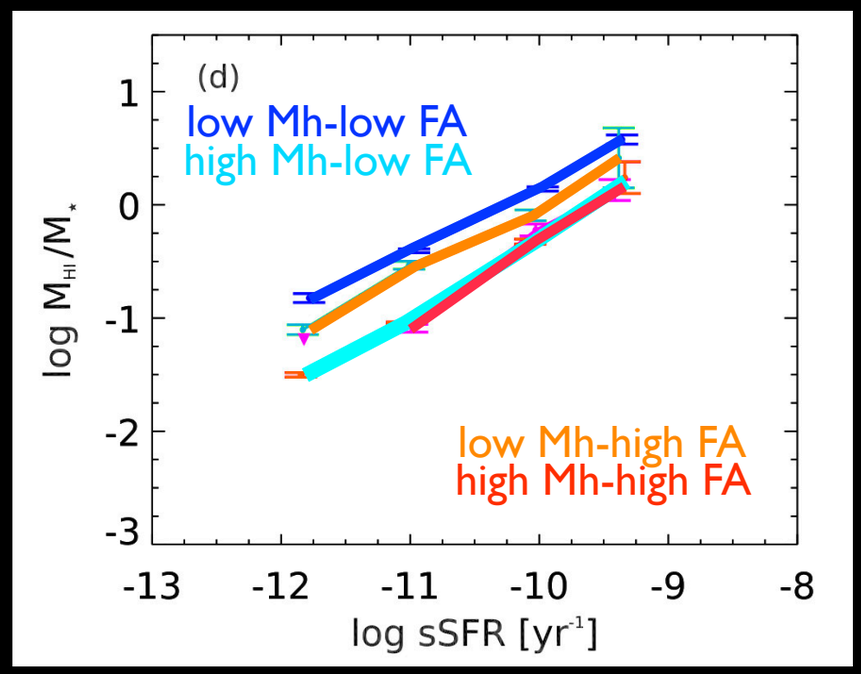
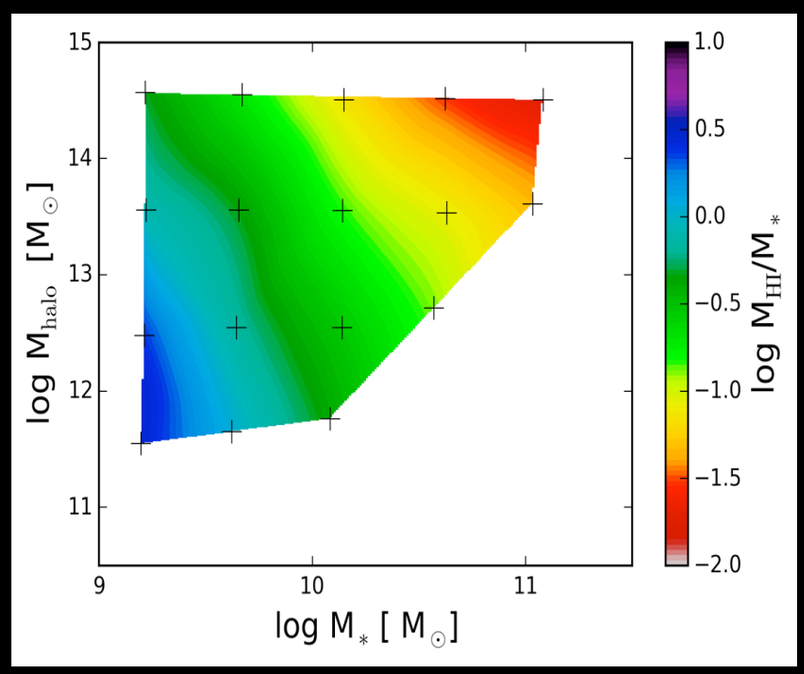


Mh varies - FA fixed



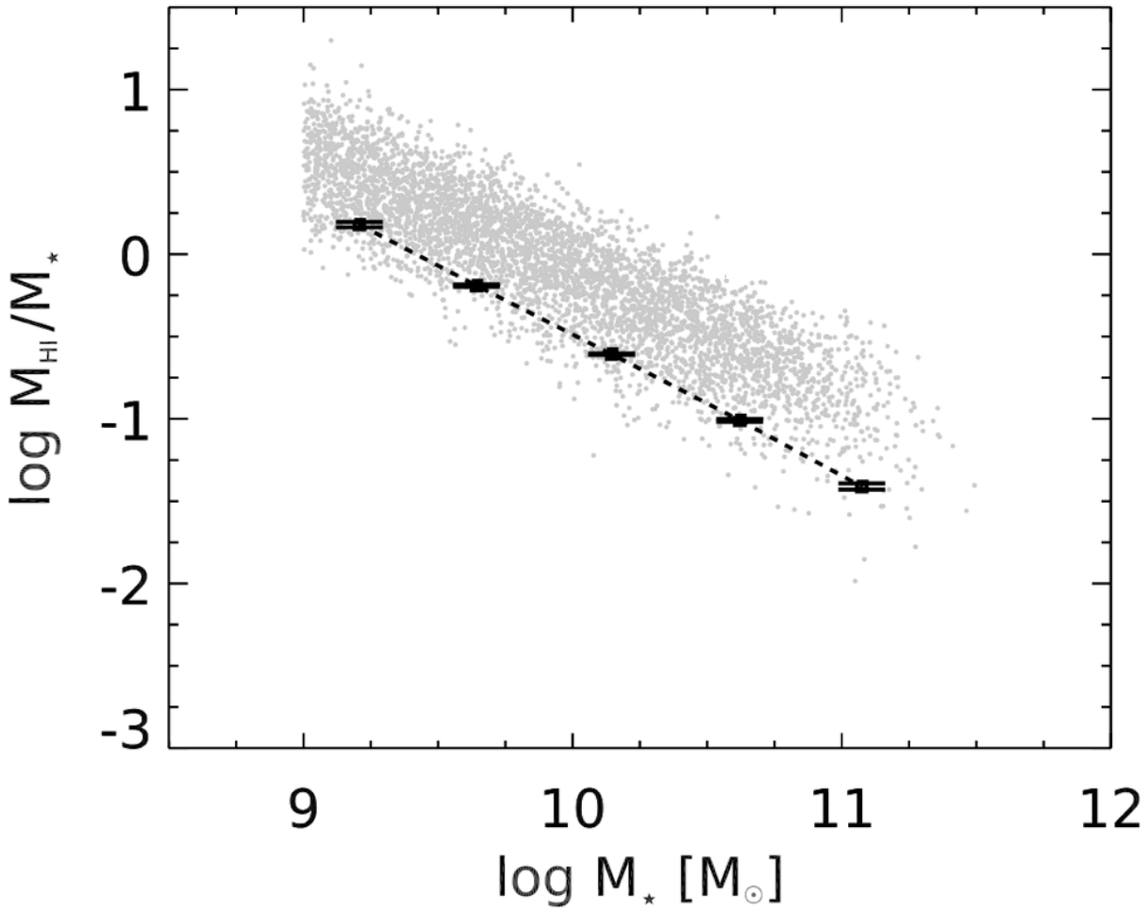


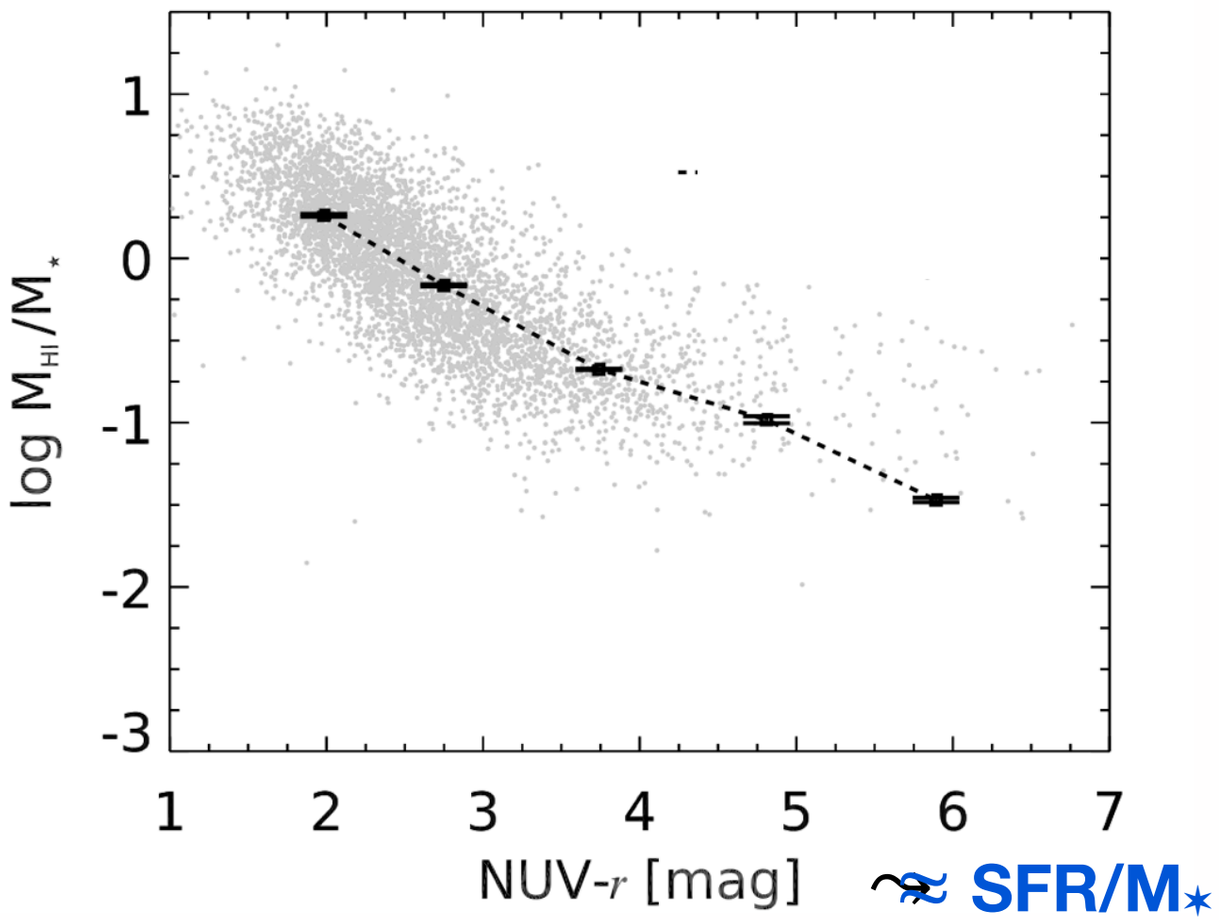
Brown, Catinella, LC+ in prep.

Global environment (i.e., halo mass) more directly related to stripping than the local one?

Primary vs secondary dependencies

Dissecting gas scaling relations with ~25000 galaxies



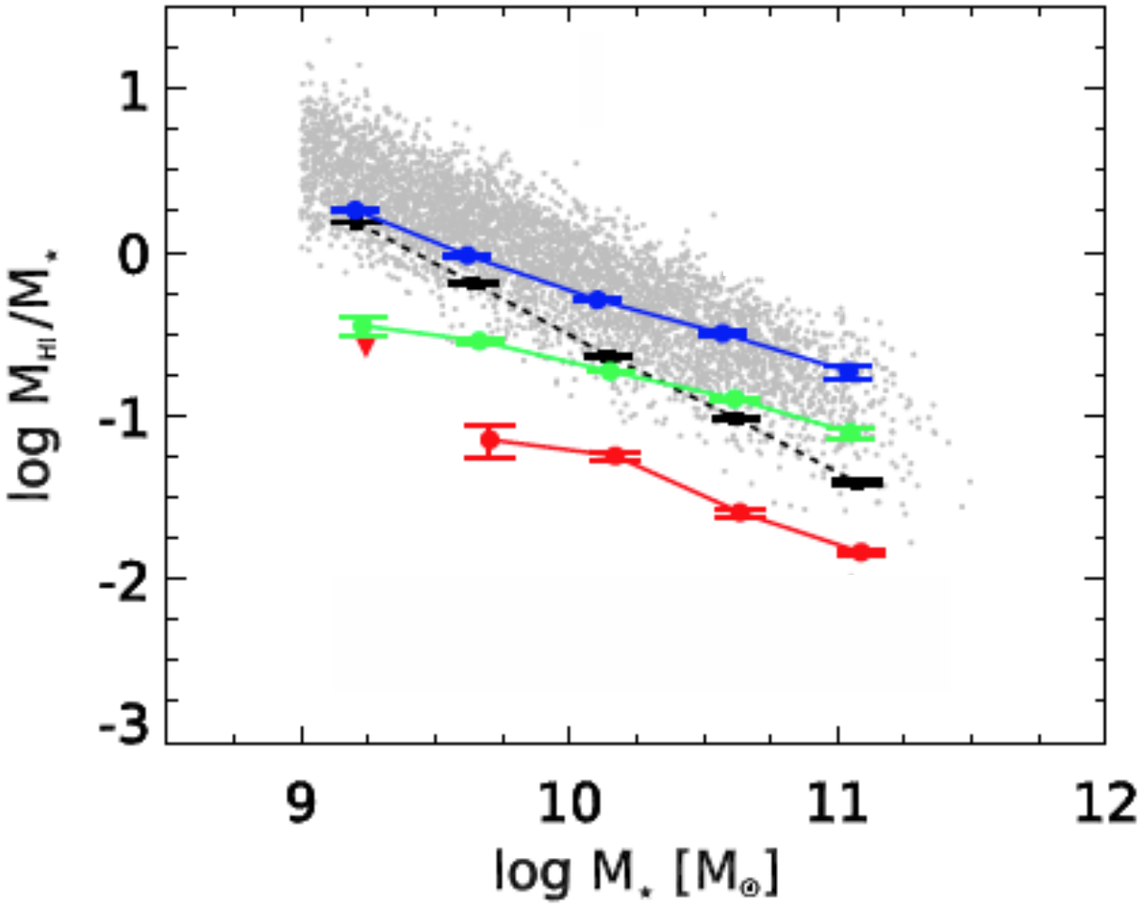


Brown, Catinella, LC et al. 2015

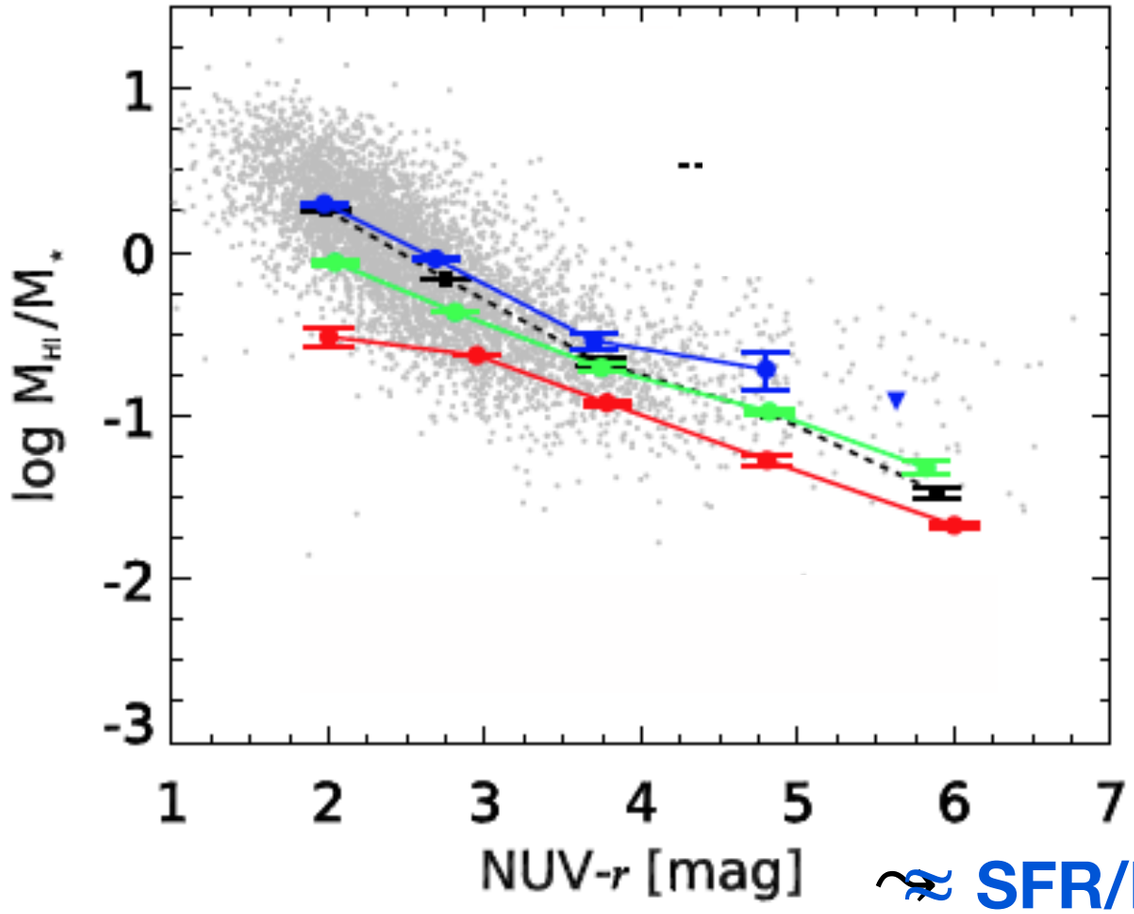
Primary vs secondary dependencies

Dissecting gas scaling relations with ~25000 galaxies

NUV-r bins



Stellar mass bins



Brown, Catinella, LC et al. 2015

Gas content primarily related with color/SSFR, not stellar mass