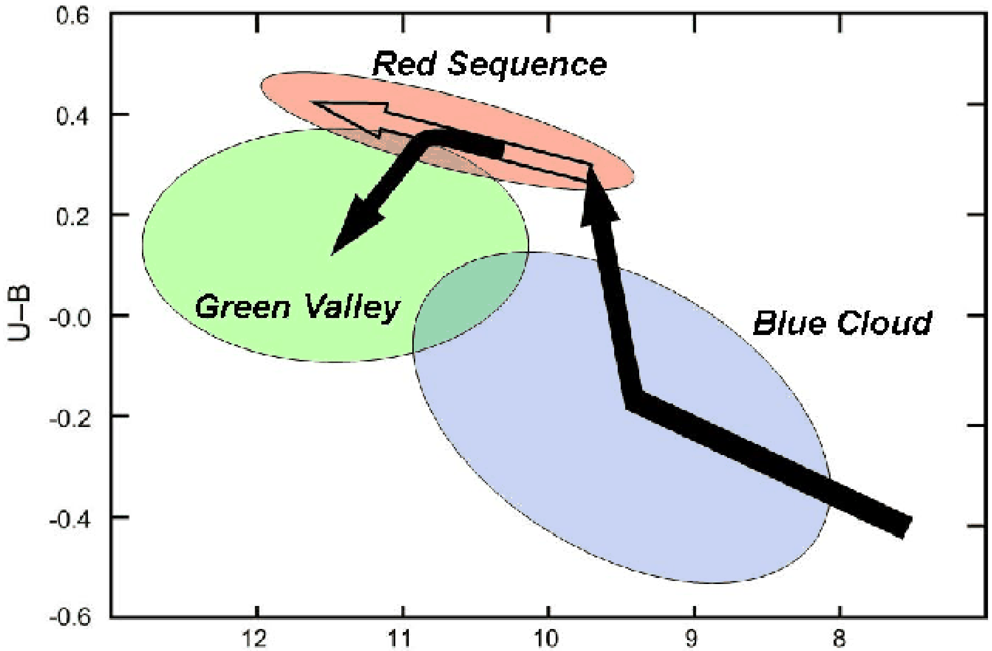
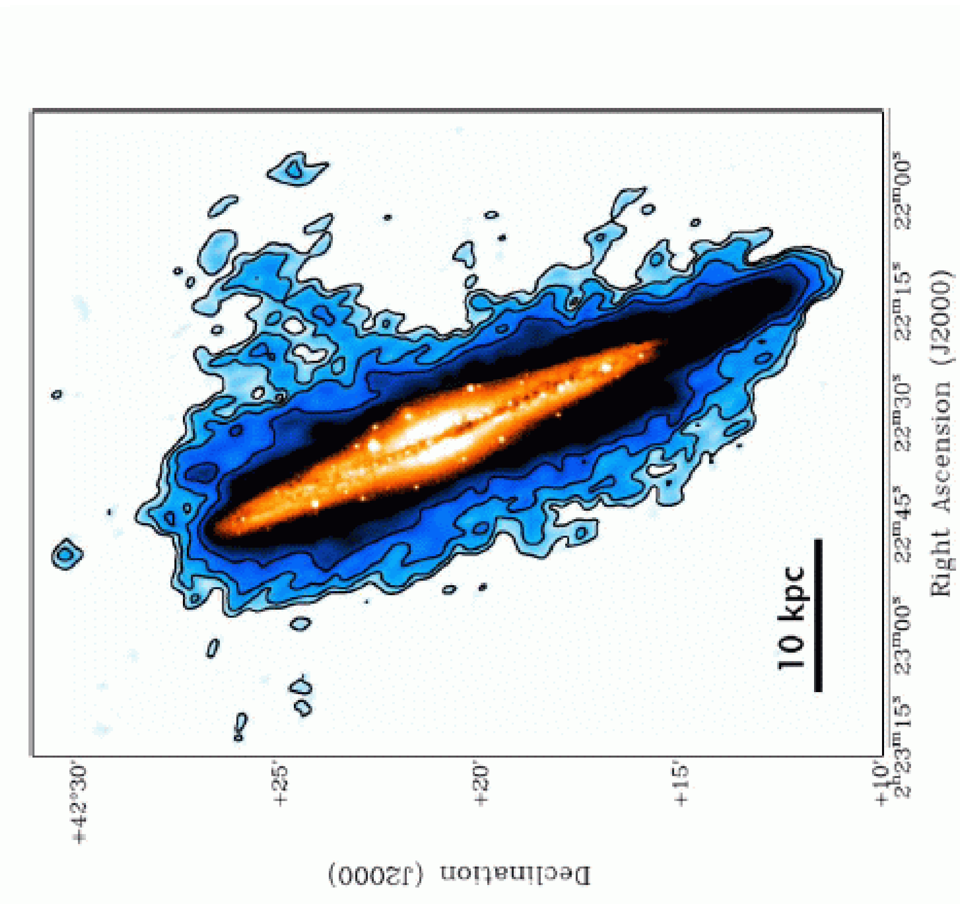
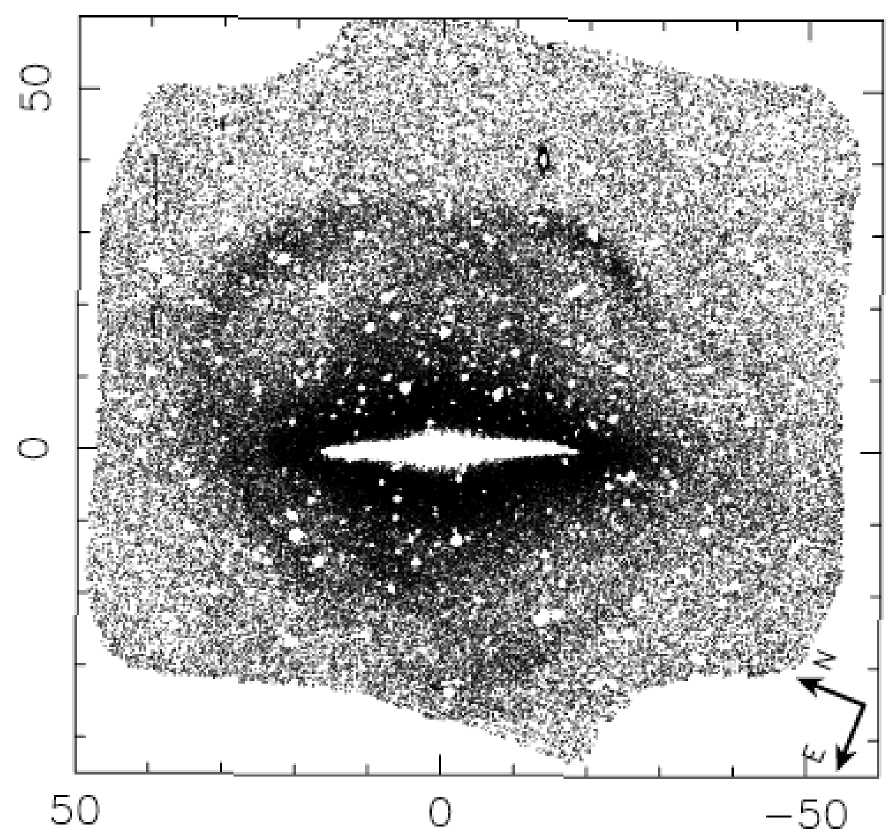


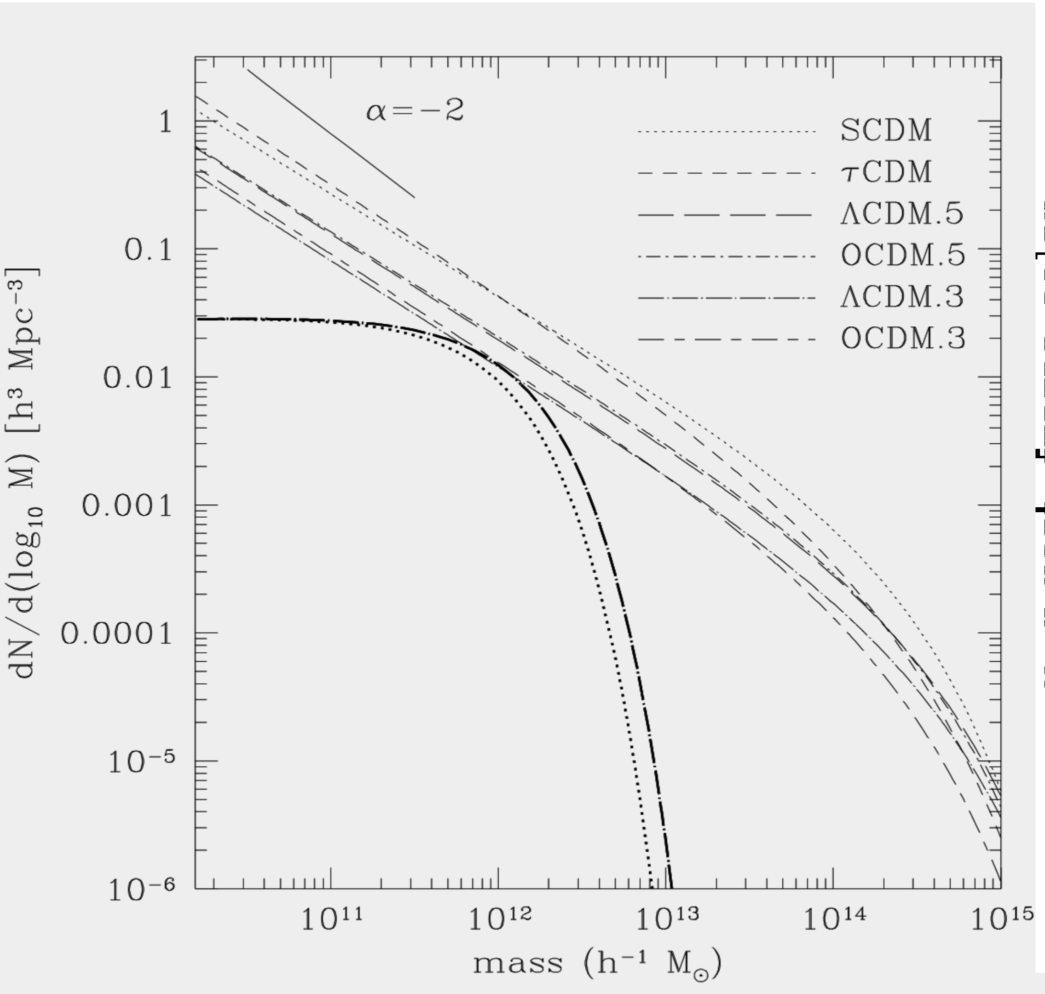
What Can We Learn From Surveys of Atomic and Molecular Gas in Nearby Galaxies?



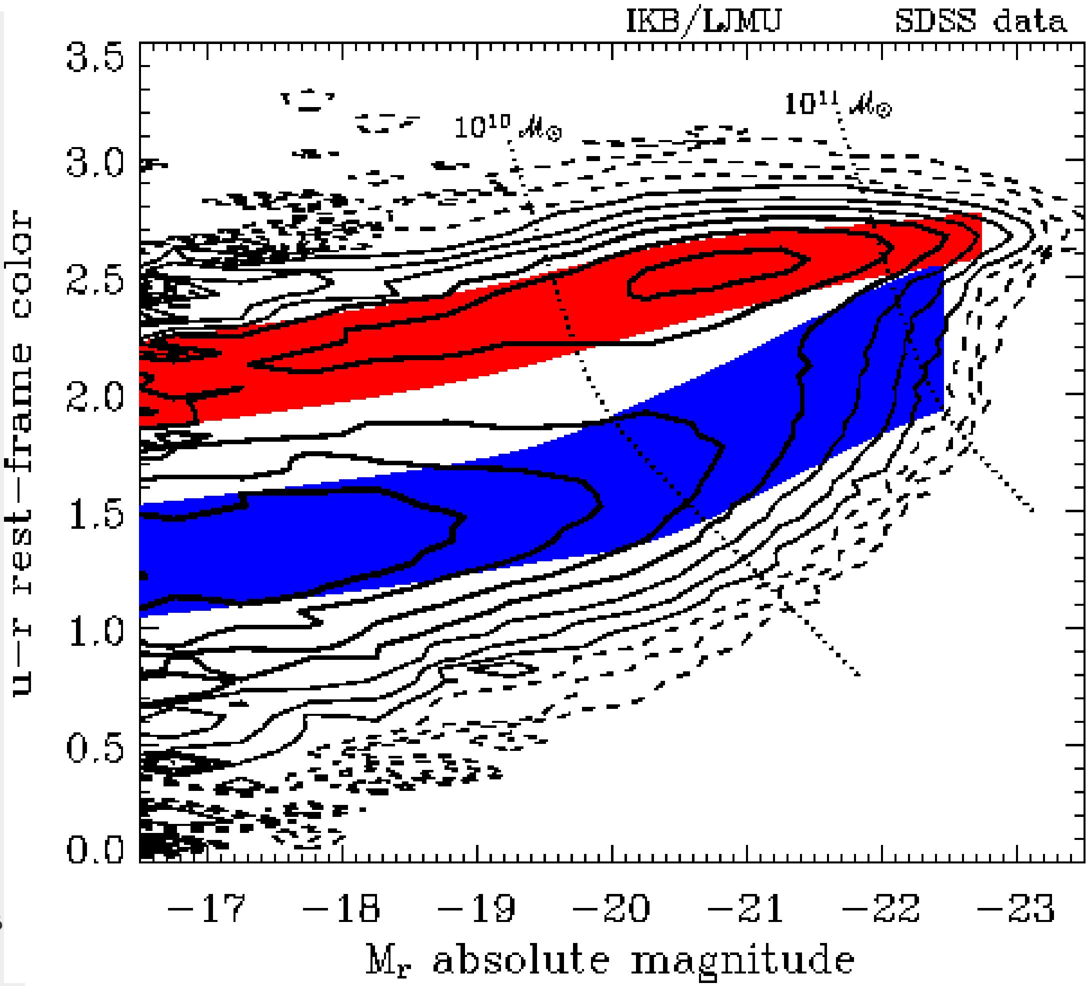


VERY BASIC QUESTIONS WE DO NOT YET UNDERSTAND

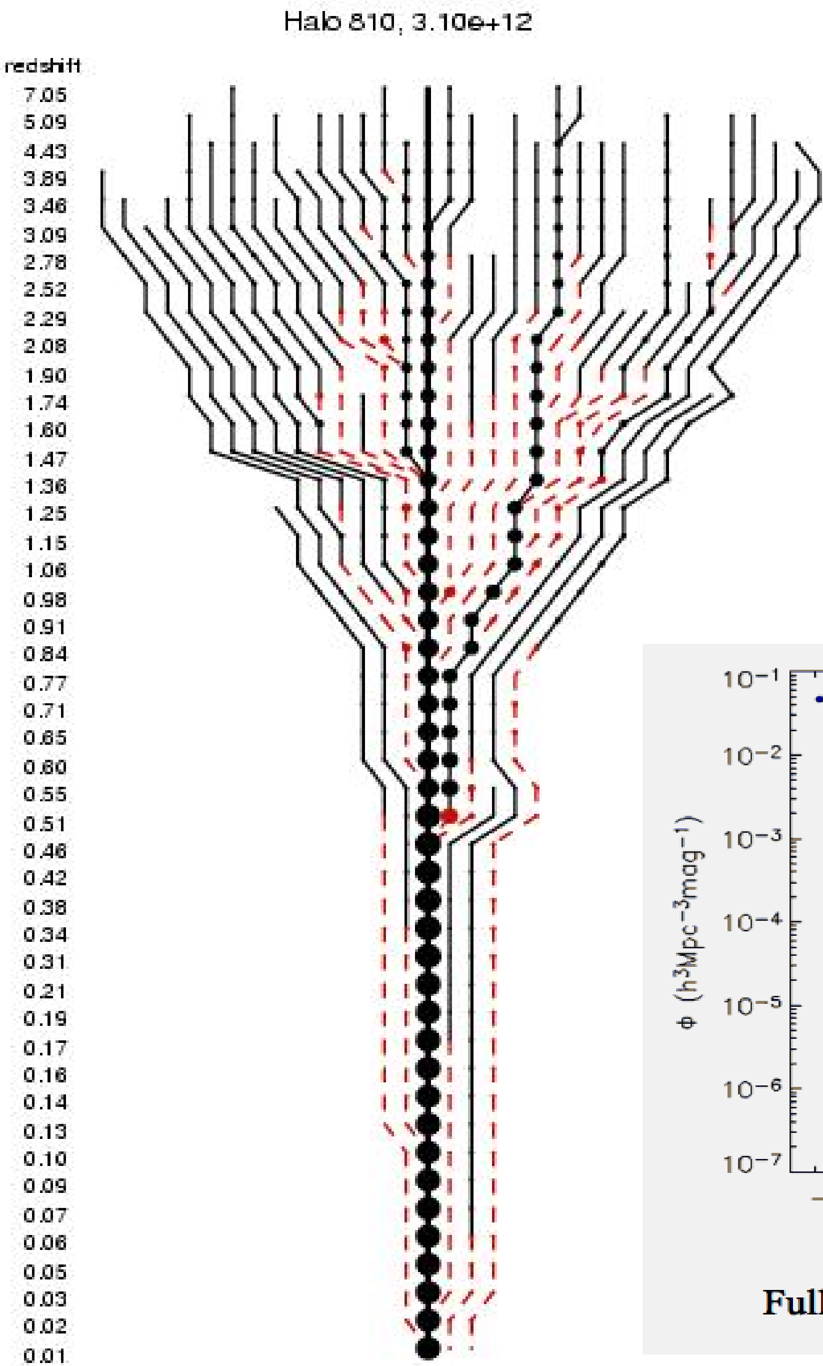
Which physical processes set the characteristic mass scales of galaxies today?

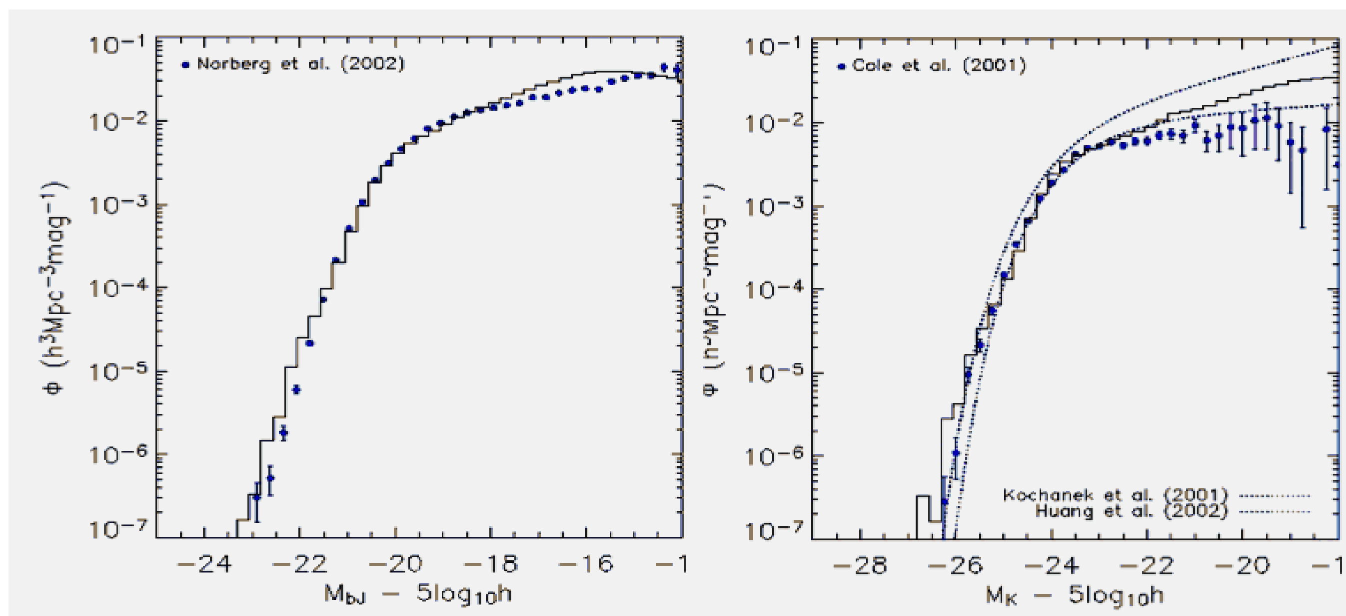


Why are there two clearly distinct galaxy populations?



One can build galaxy formation models that follow gas cooling, star formation, feedback processes from supernova and AGN, merging as a function of cosmic time. These models are “successful” in that they reproduce global statistical properties like the luminosity function. But are they correct?

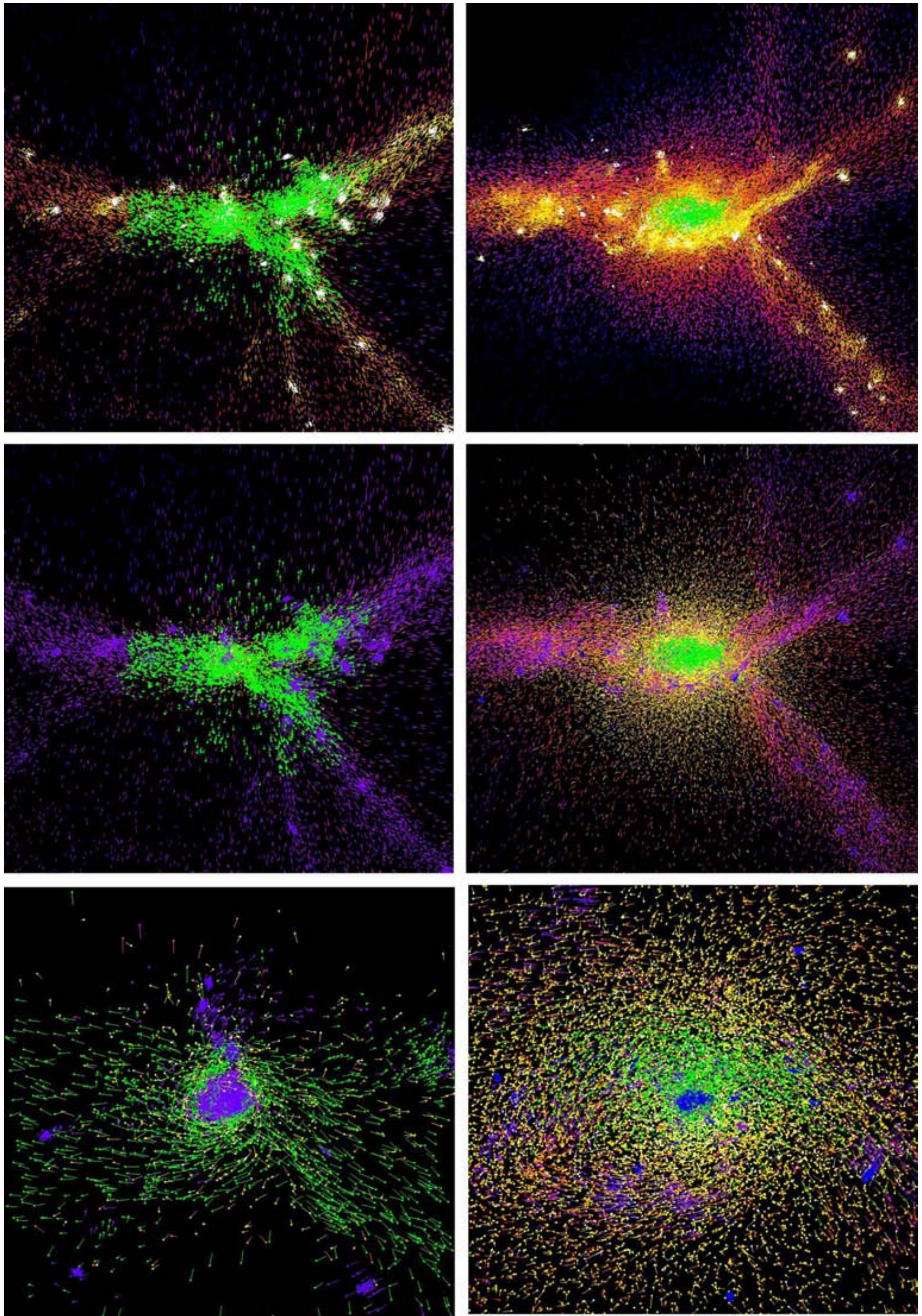




Full model with reionisation, AGN and SN feedback Croton et al 2006

FORMATION: GAS ACCRETES IN TWO "MODES"

COLD MODE

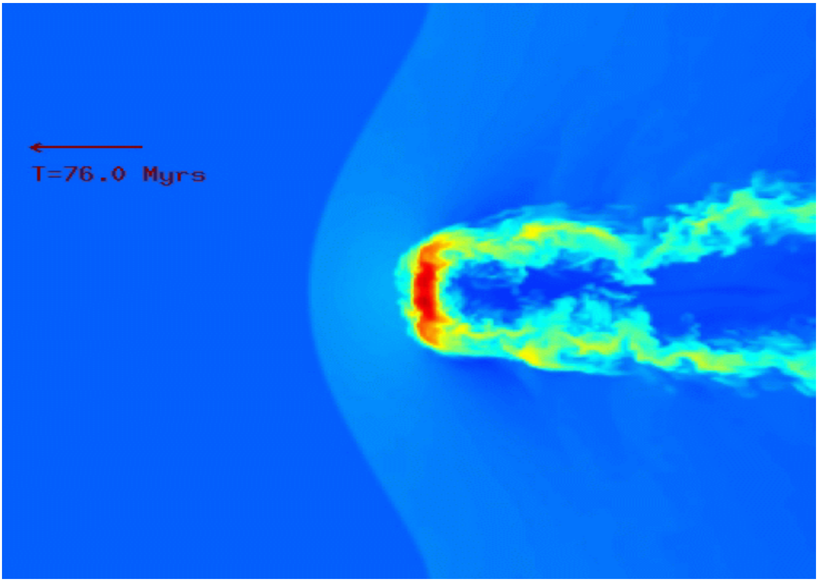


HOT MODE

Keres et al 2005

And "Quenching".....

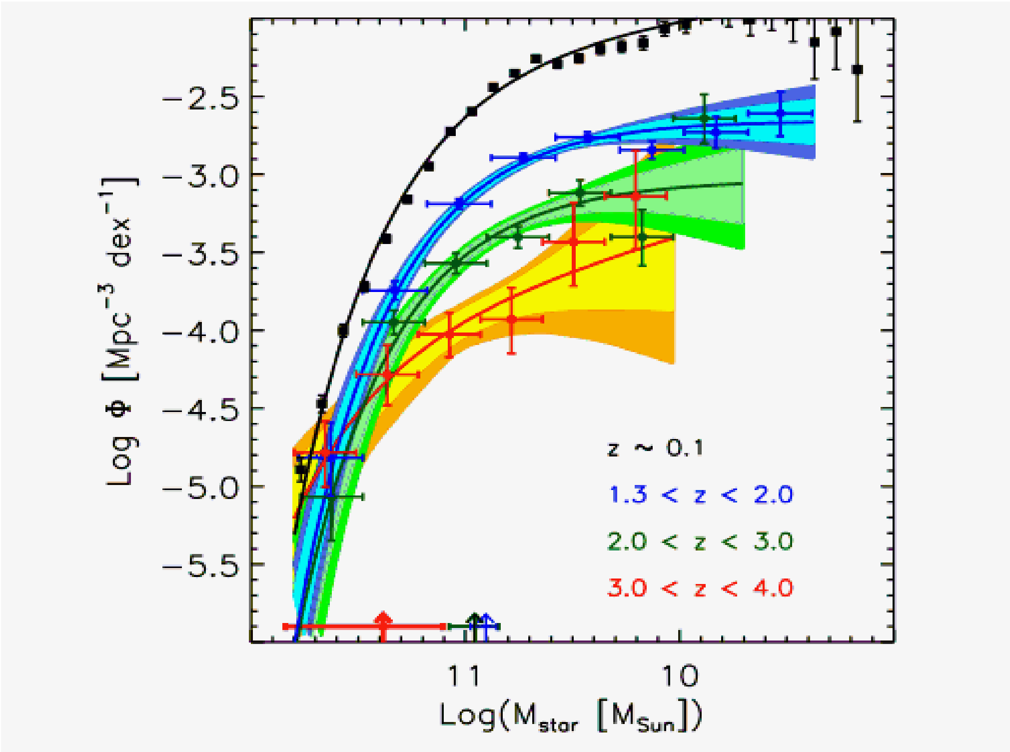
Supernova eject metals and decrease the efficiency of star formation in low mass galaxies



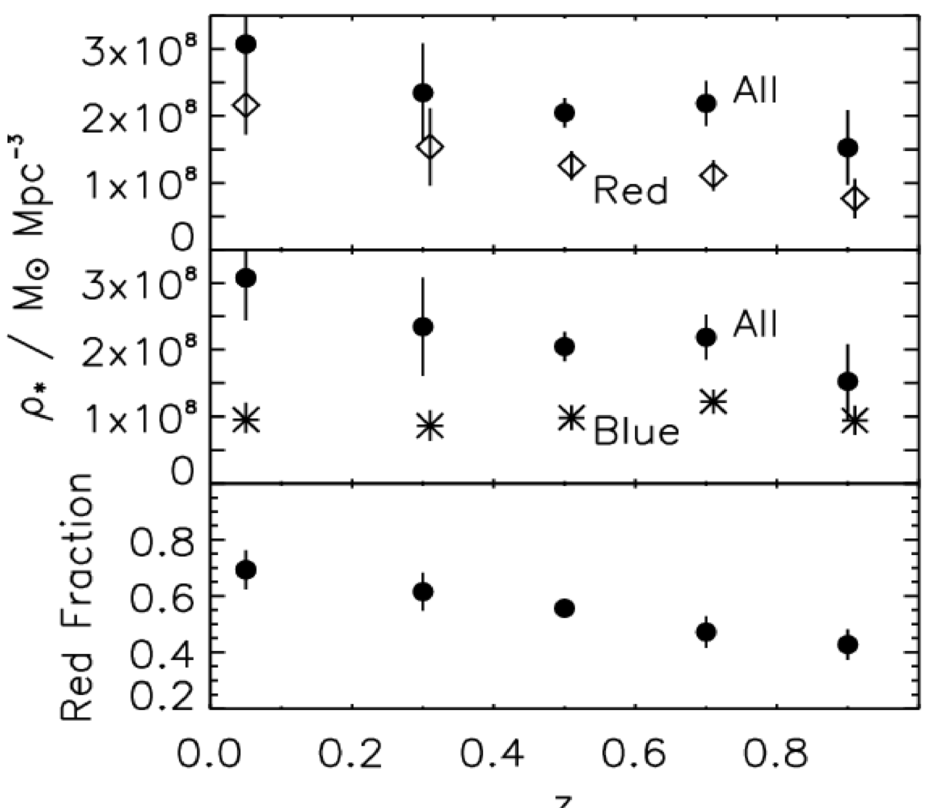
Gas may be stripped in clusters...needed to explain relation between star formation and environment

AGN feedback may quench star formation in massive galaxies when supermassive black holes are formed

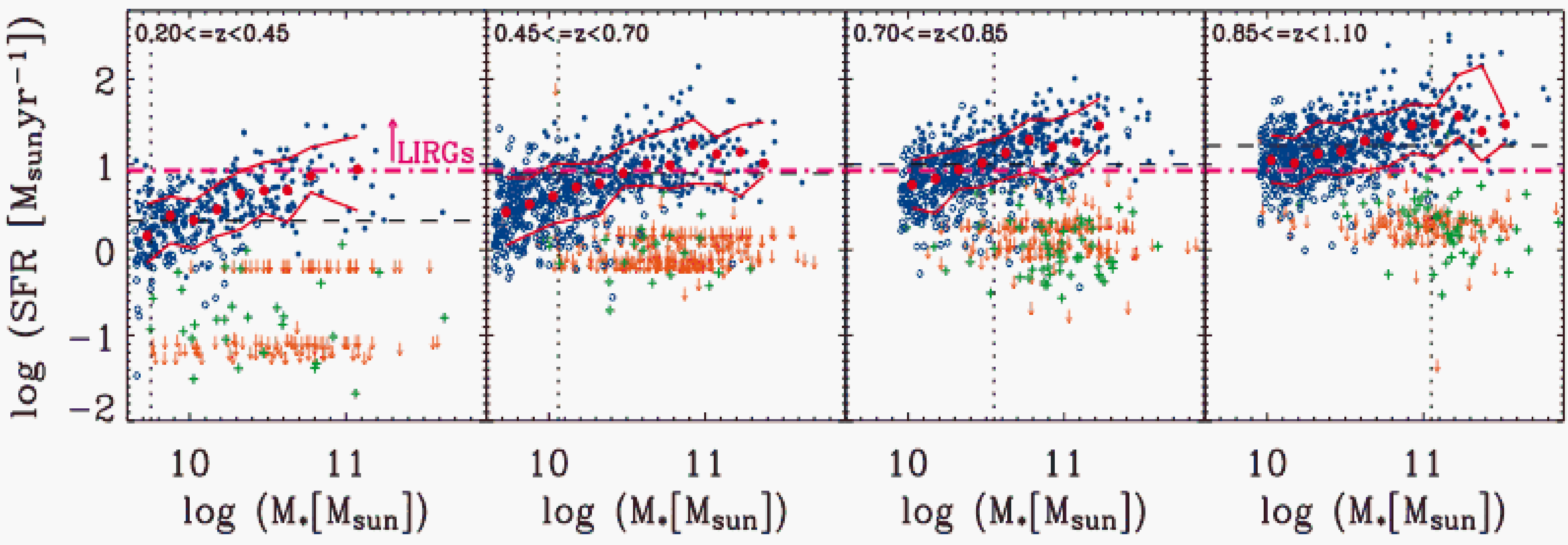
Note that “Formation” and “Quenching” both apply to the **GAS,** but observational astronomers who study galaxy evolution to high redshifts have focused almost exclusively on the cosmic evolution of **stars** (either the stellar mass or the star formation rate density)



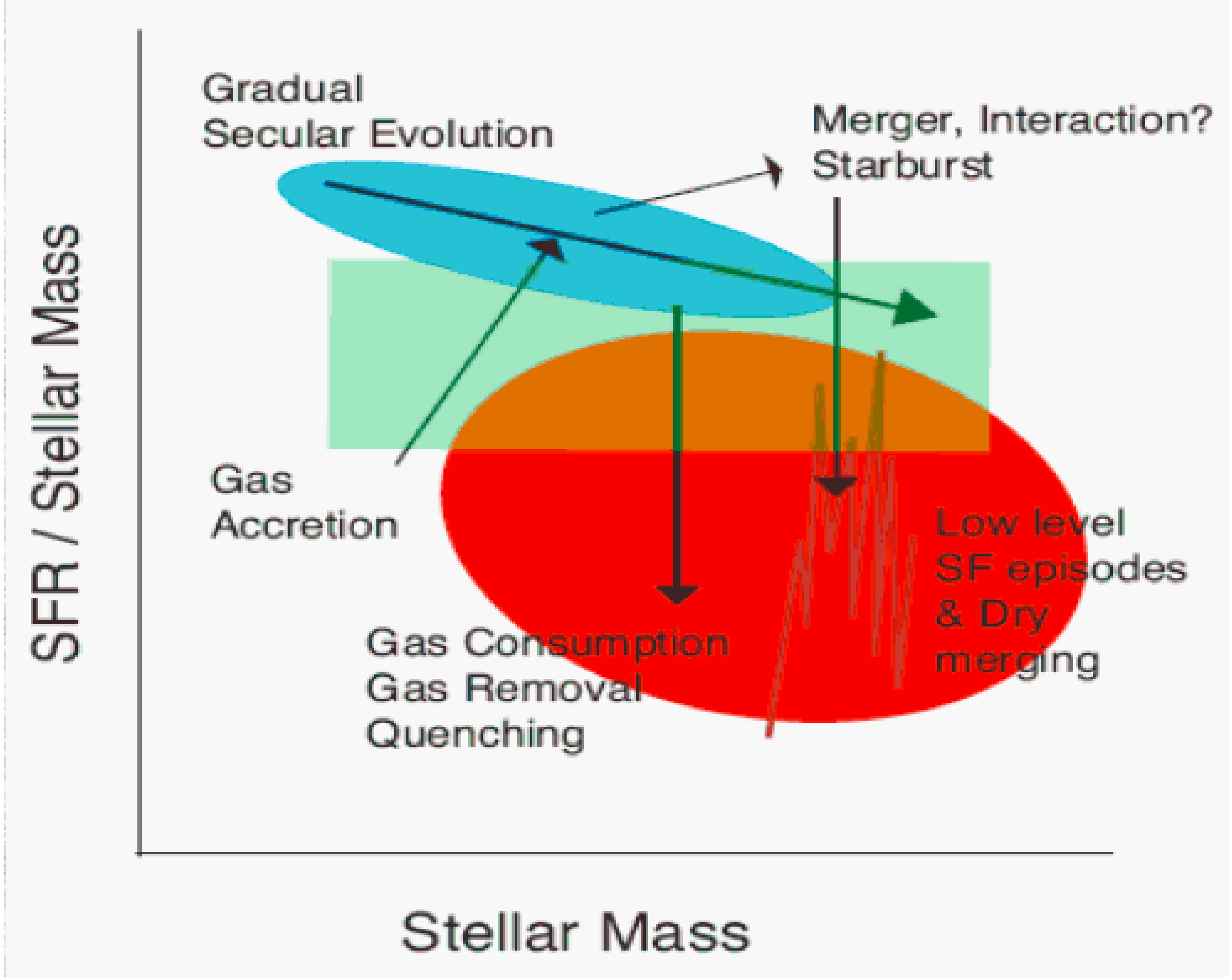
Evolution of the **stellar mass function** with cosmic lookback time. (e.g. Marchesini et al 2008)



Evolution of the **stellar mass** contained in the “red” and the “blue” galaxy populations (e.g. Bell et al 2003, Faber et al 2007)

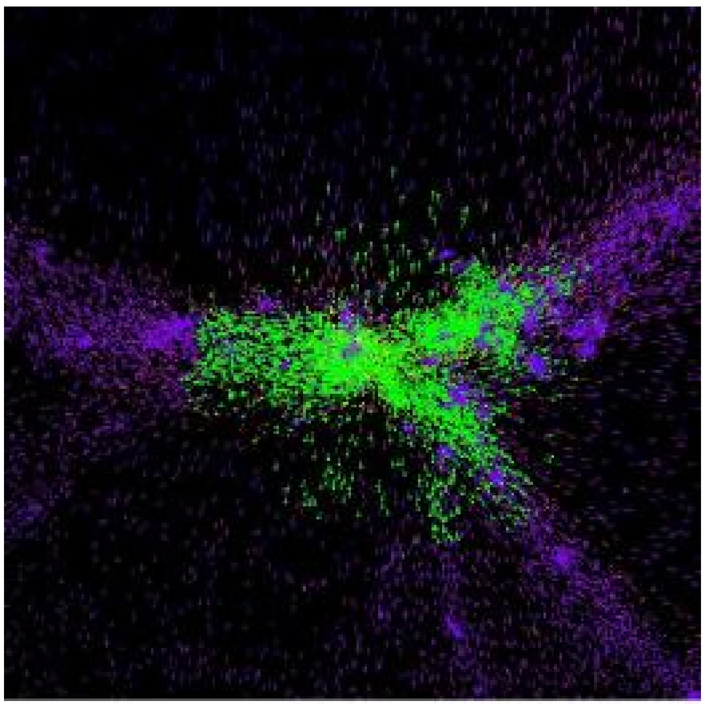


Evolution of **star formation** in blue sequence galaxies (Noeske et al 2007)



The high-redshift observers frequently attempt to interpret their results in terms of "accretion" and "quenching" processes. However, because these processes relate most directly to the **GAS** and not to the stars, the arguments are by necessity very indirect.

WHAT IS NEEDED TO MAKE PROGRESS!



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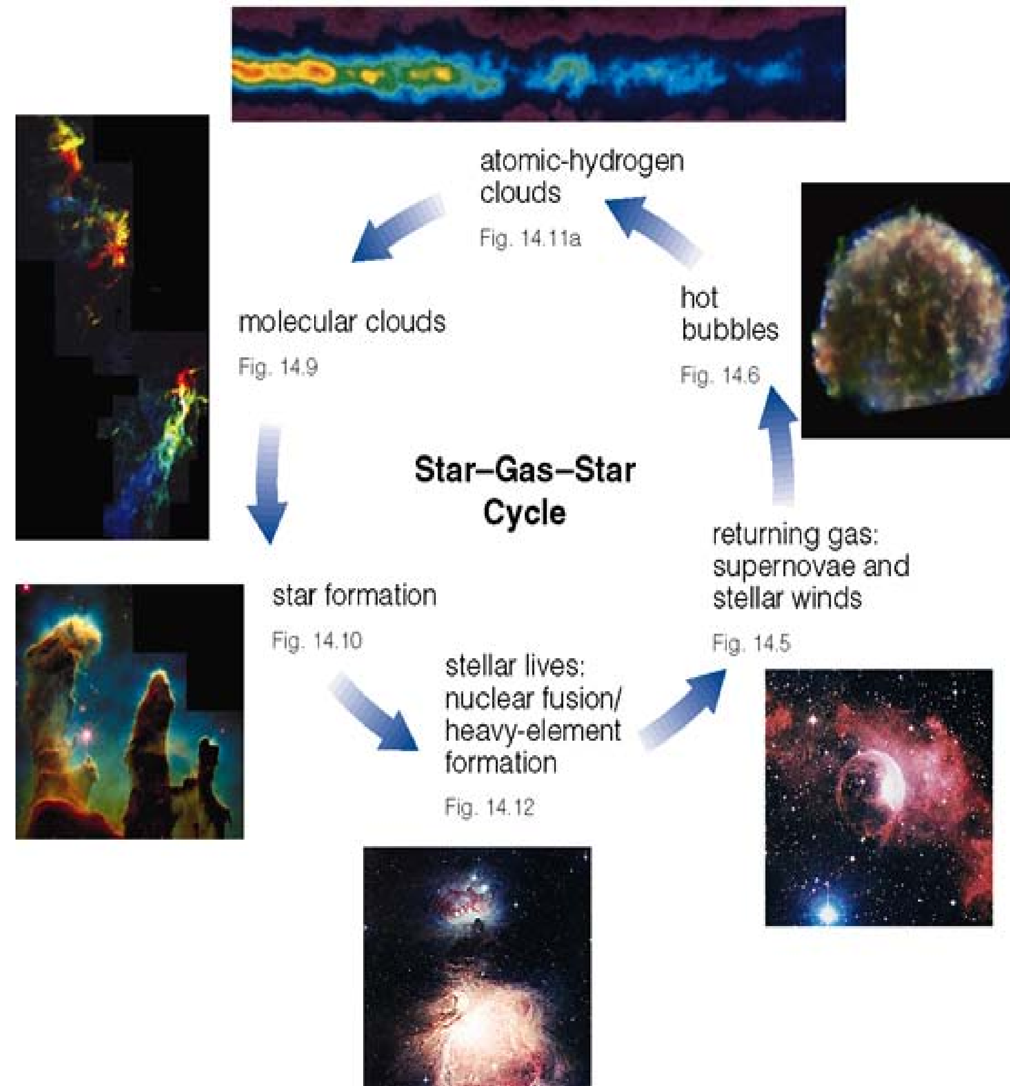
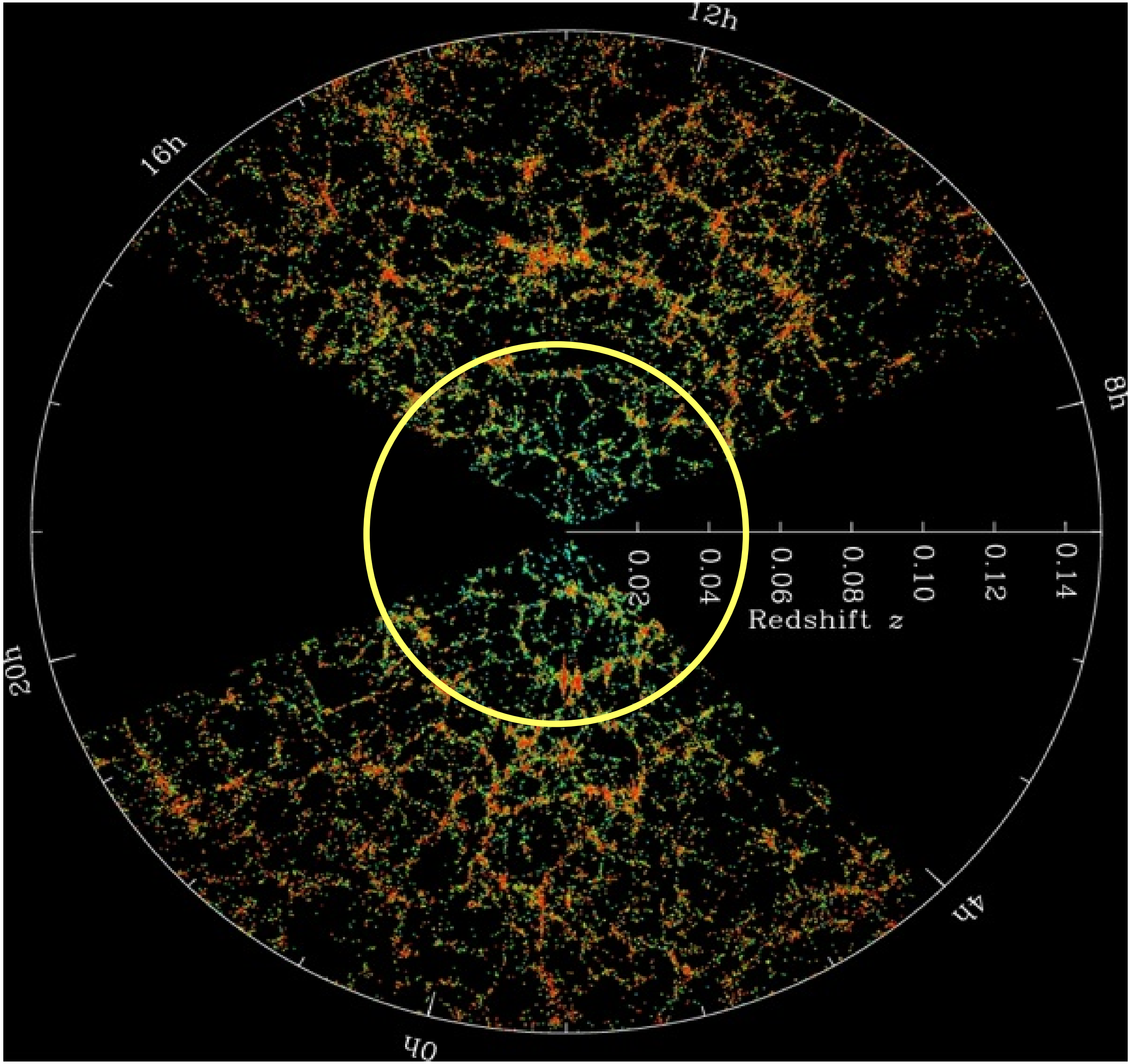


Sloan Digital Sky Survey

Mapping the Universe



THE GALEX ARECIBO SDSS SURVEY (GASS)

David Schiminovich (PI)

Barbara Catinella

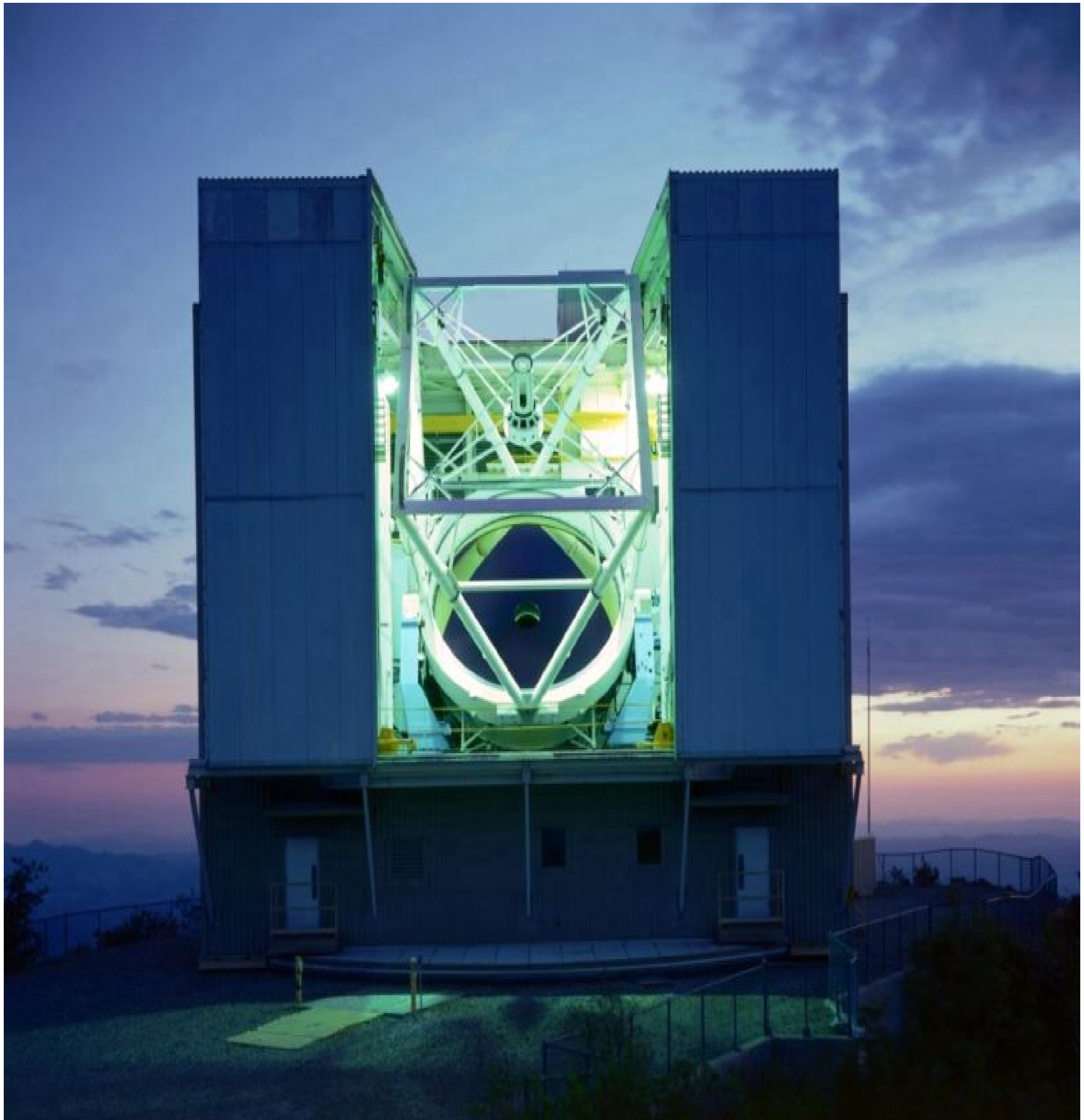
COLD GASS

CO Legacy Database for GASS

An IRAM Large Program

Amelie Saintonge

Program of long-slit spectroscopy on the MMT



Sean Moran (JHU)

GALAXY SELECTION

a) Redshift range : $0.025 < z < 0.05$

Motivation:

1) We want to detect HI and H2 down to levels of a few percent in M(gas)/M* in about an hour of integration time.

2) We want to get an accurate estimate of the **total** cold gas mass with a single pointing of both the Arecibo and IRAM telescopes.

b) Stellar mass range: log M* > 10

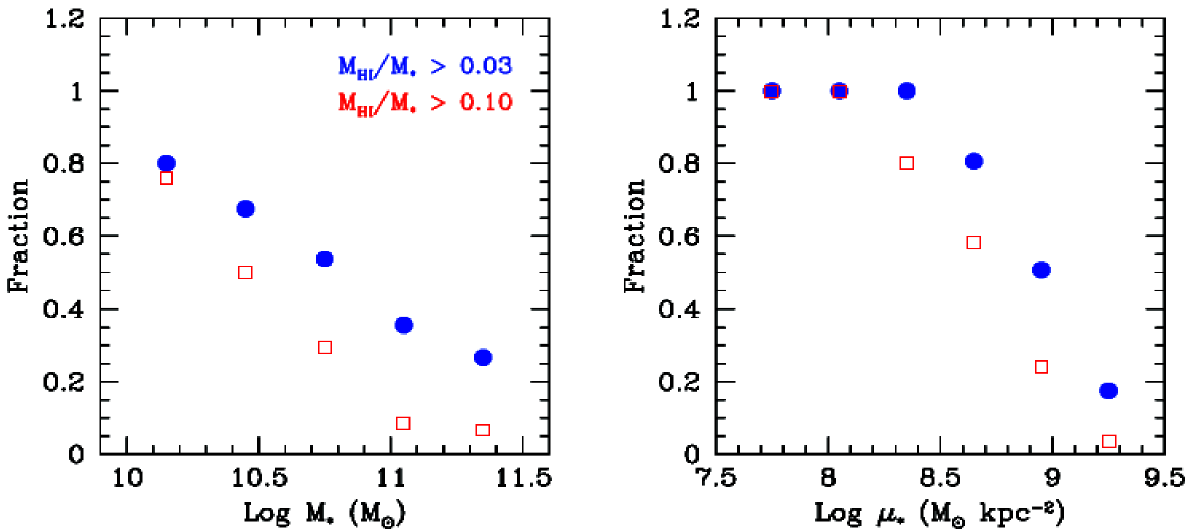
Motivation:

1) Span a range of stellar masses encompassing both “active” star-forming galaxies and “passive” systems => quantify how the transition between these two populations is reflected in their cold gas content. Avoid any selection on morphology, environment etc.

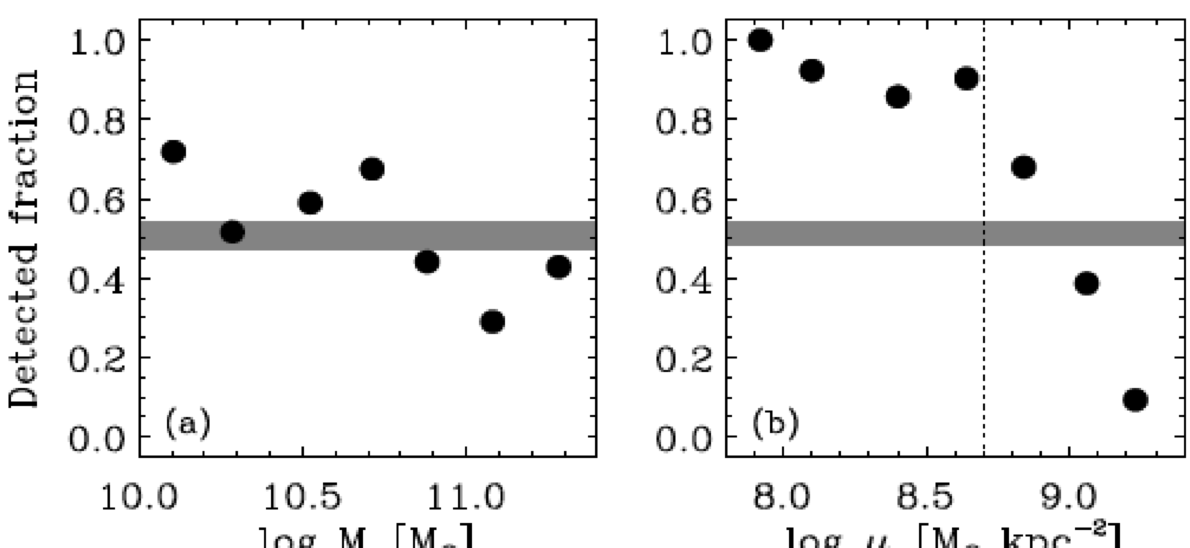
2) In the mass range, all galaxies have roughly solar metallicity: conversion factor forom CO luminosity to H2 mass is simplified.

OBSERVING STRATEGY: Integrate until the galaxy is detected or a limiting HI/H2 mass fraction ~1.5-3% is reached, i.e. **Our survey will quantify the full condensed baryon budget in these galaxies.**

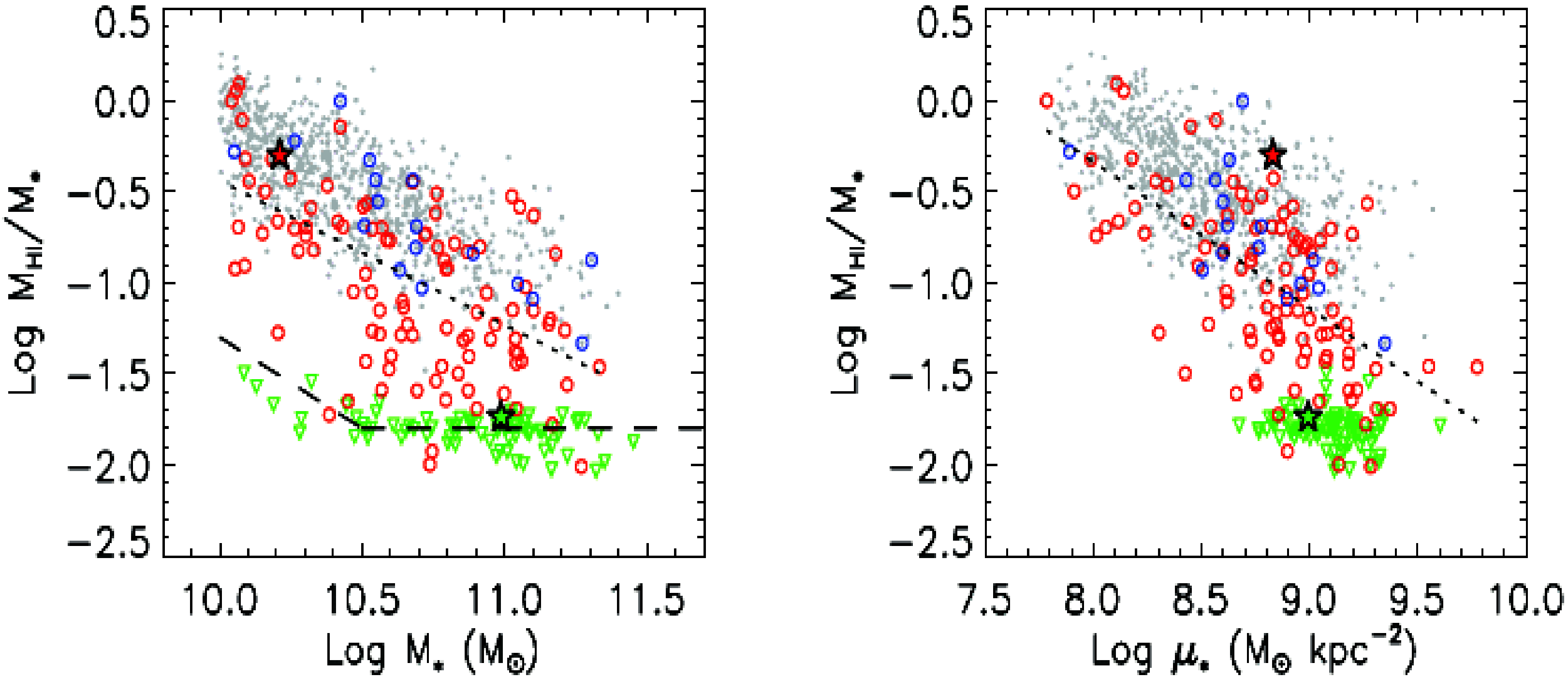
EMPIRICAL RESULT : There exist sharp thresholds in galaxy properties where a transition is seen from a population of galaxies with significant gas content to a population with little or no gas. This thresholding is clearly seen in structural properties (stellar surface mass density), but **NOT in stellar mass.**



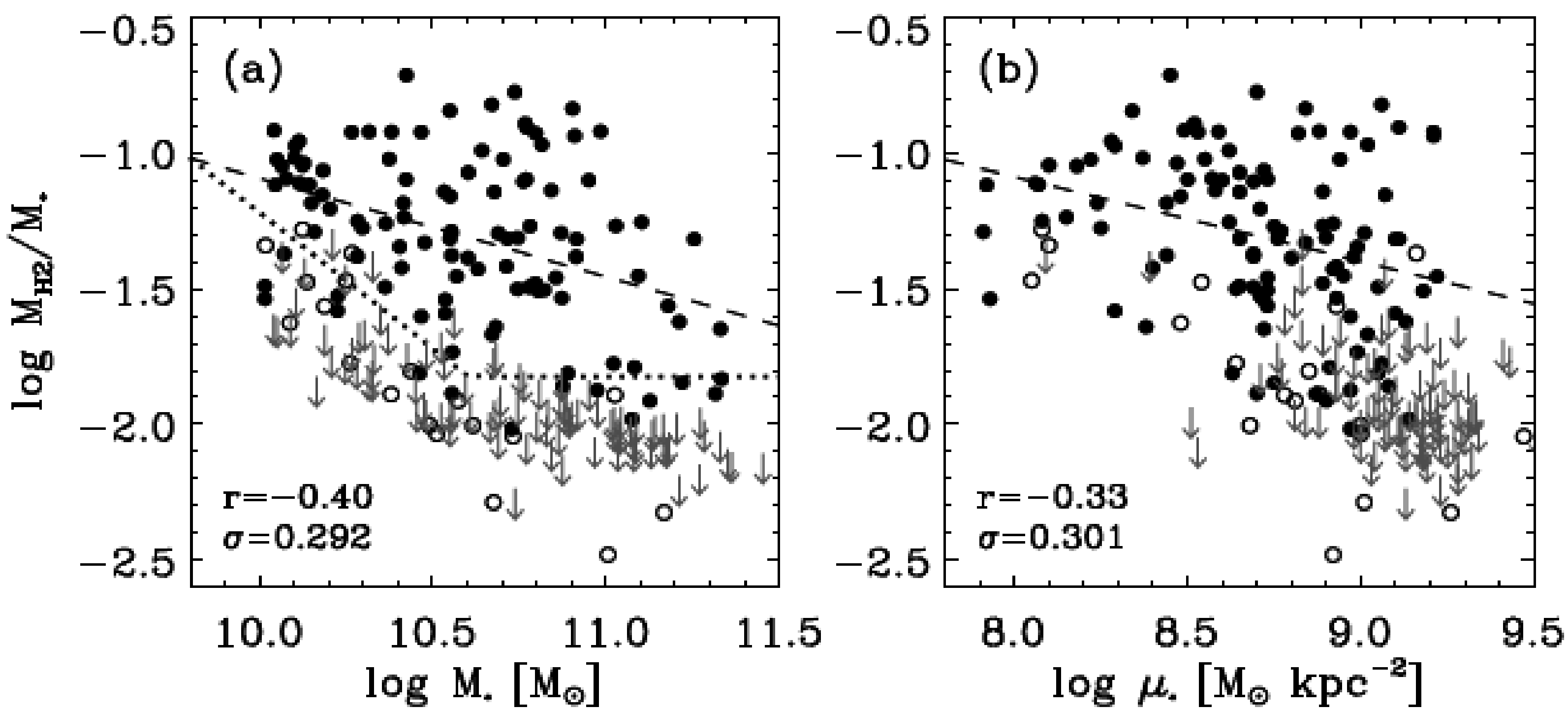
HI detected fraction:
Catinella et al 2010



CO (1-0) detected fracton:
Saintonge et al 2010
(submitted)

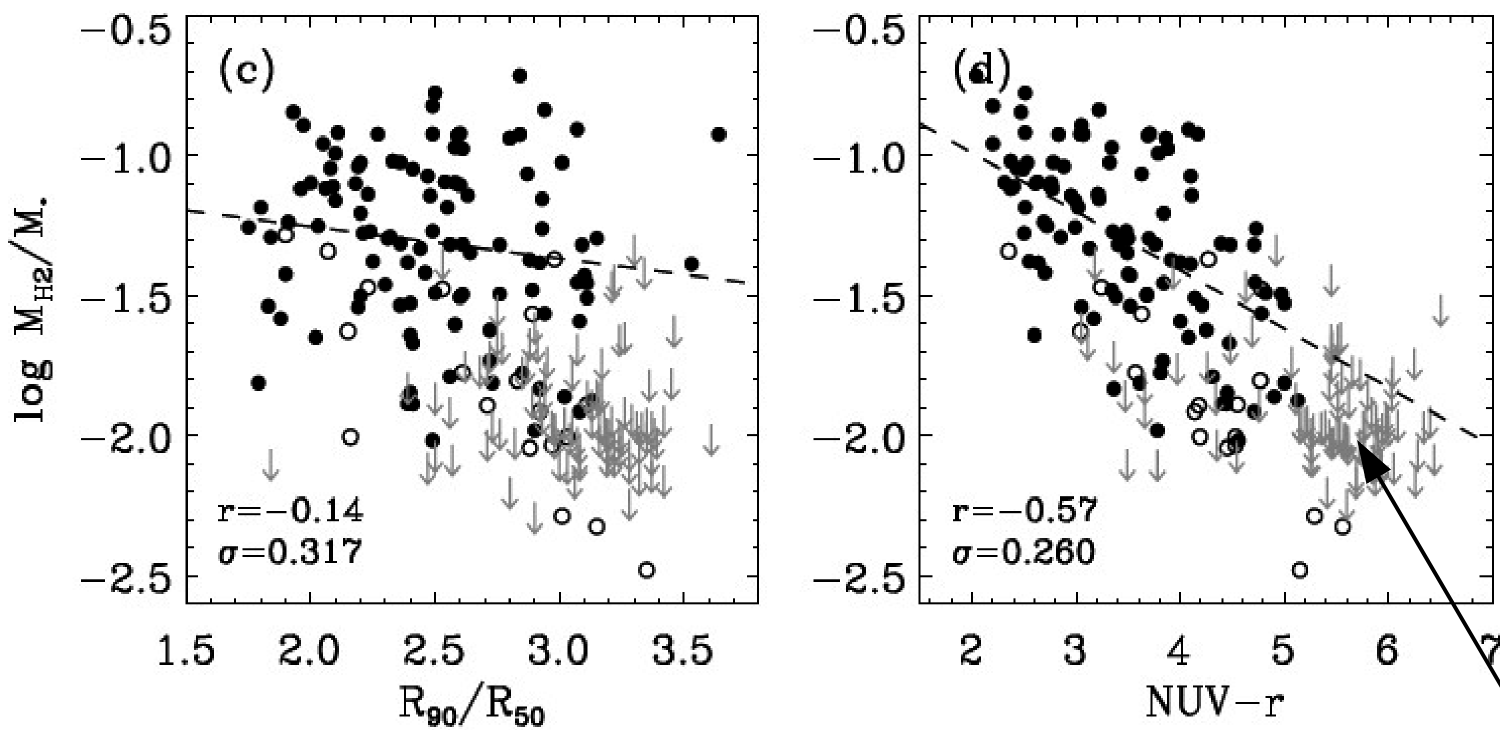


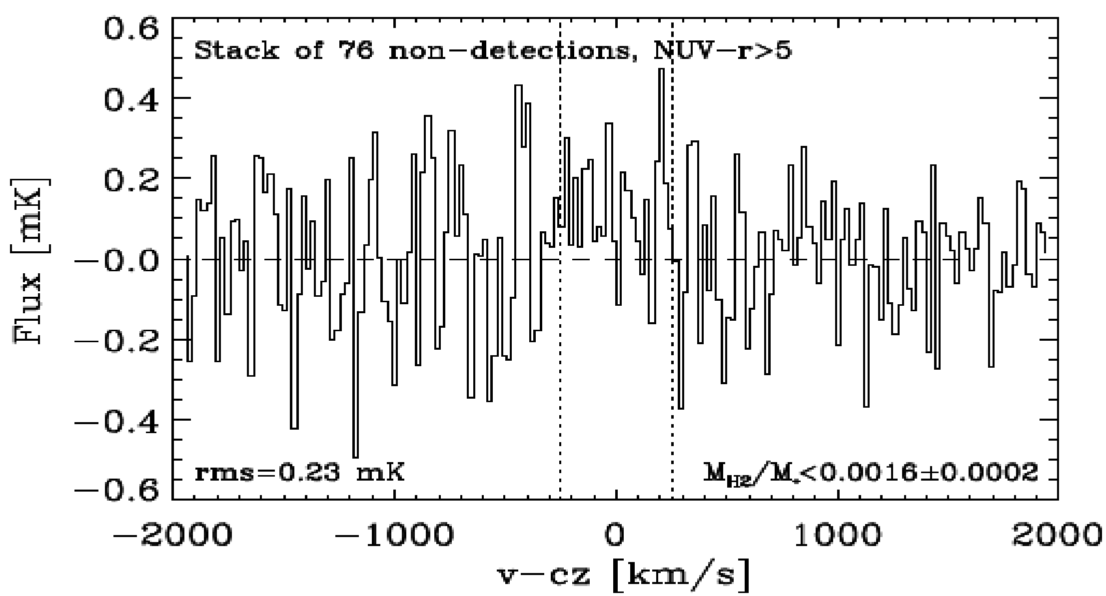
Catinella et al (HI)



Saintonge et al (H2)

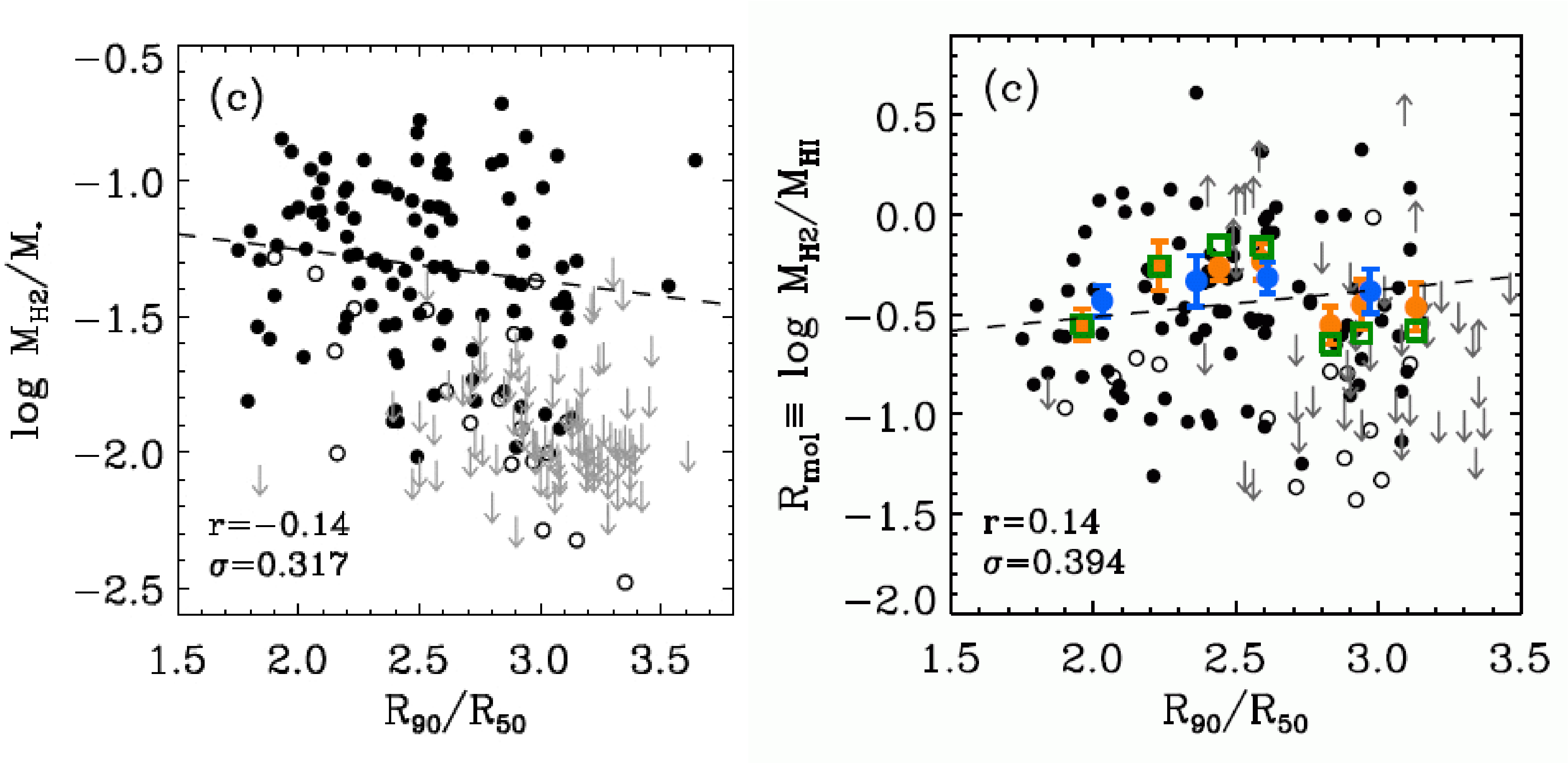
THE MOLECULAR GAS-POOR POPULATION: As well as high surface mass densities, they have high concentrations (i.e. bulge-to-disk ratios) and are red.





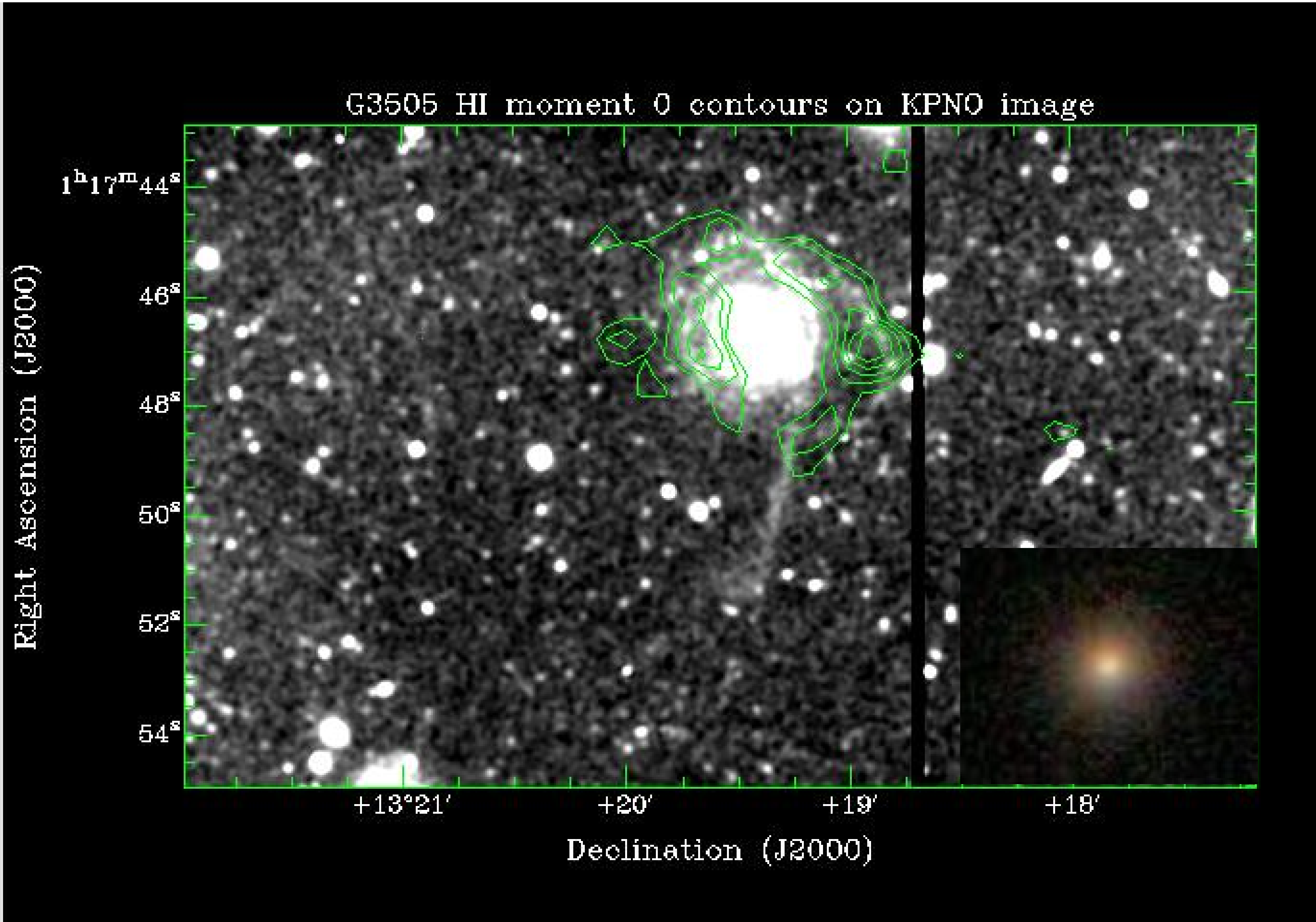
Stacking the **red NUV-r>5** population yields an upper limit on the average H2 mass fraction of 0.16% !!

Empirical Result: There exists a sub-population of “early-type” H2-poor galaxies with significant cold gas in the form of atomic hydrogen.



WHY? Possible explanations: “morphological quenching” ; re-accretion of gas

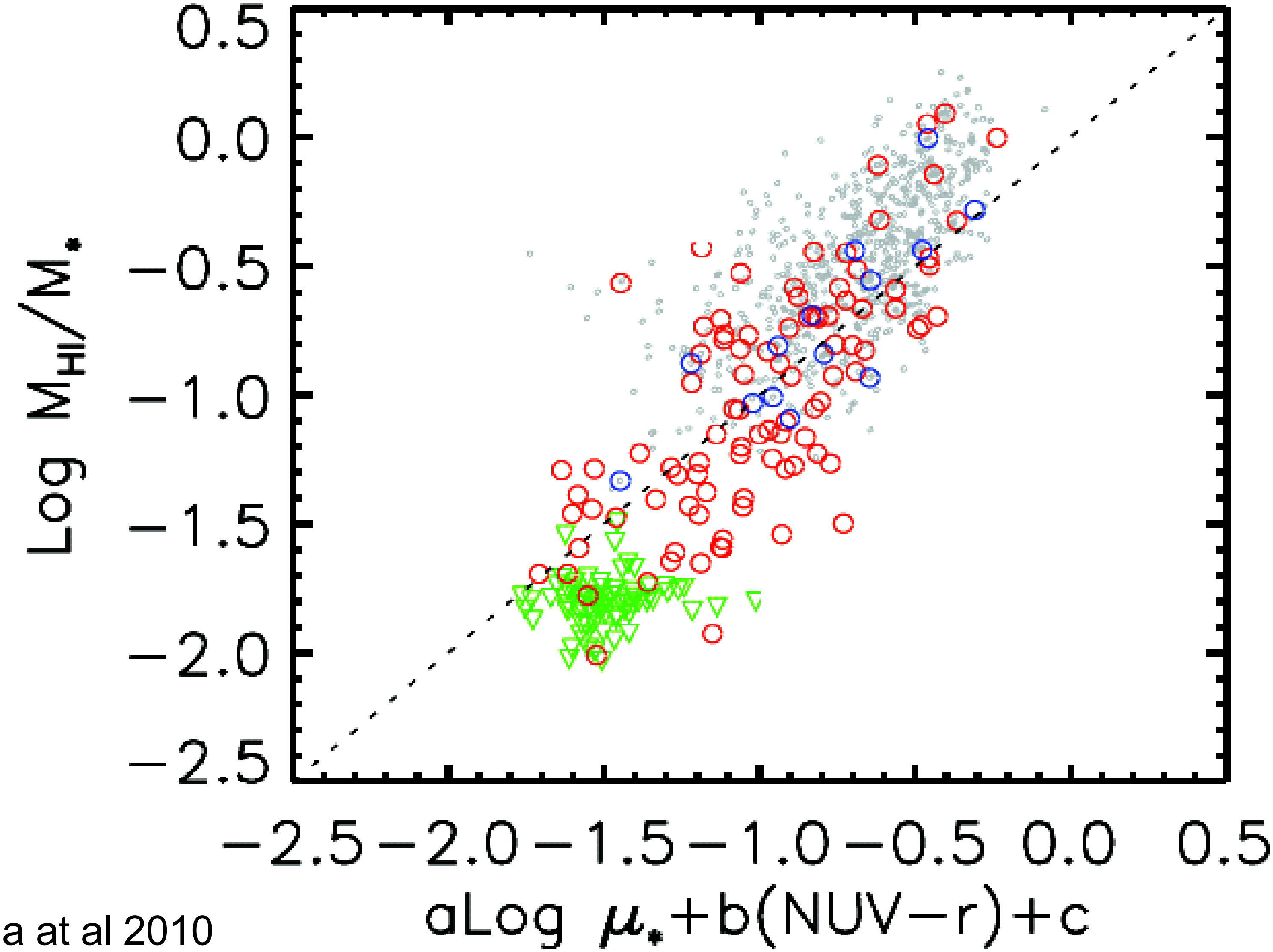
One extreme example: GASS 3505 an elliptical galaxy with M(HI)/M*=1



Catinella et al, in prep

THE STAR-FORMING POPULATION

An empirical best-fit "plane" for predicting HI mass fraction



Catinella at al 2010

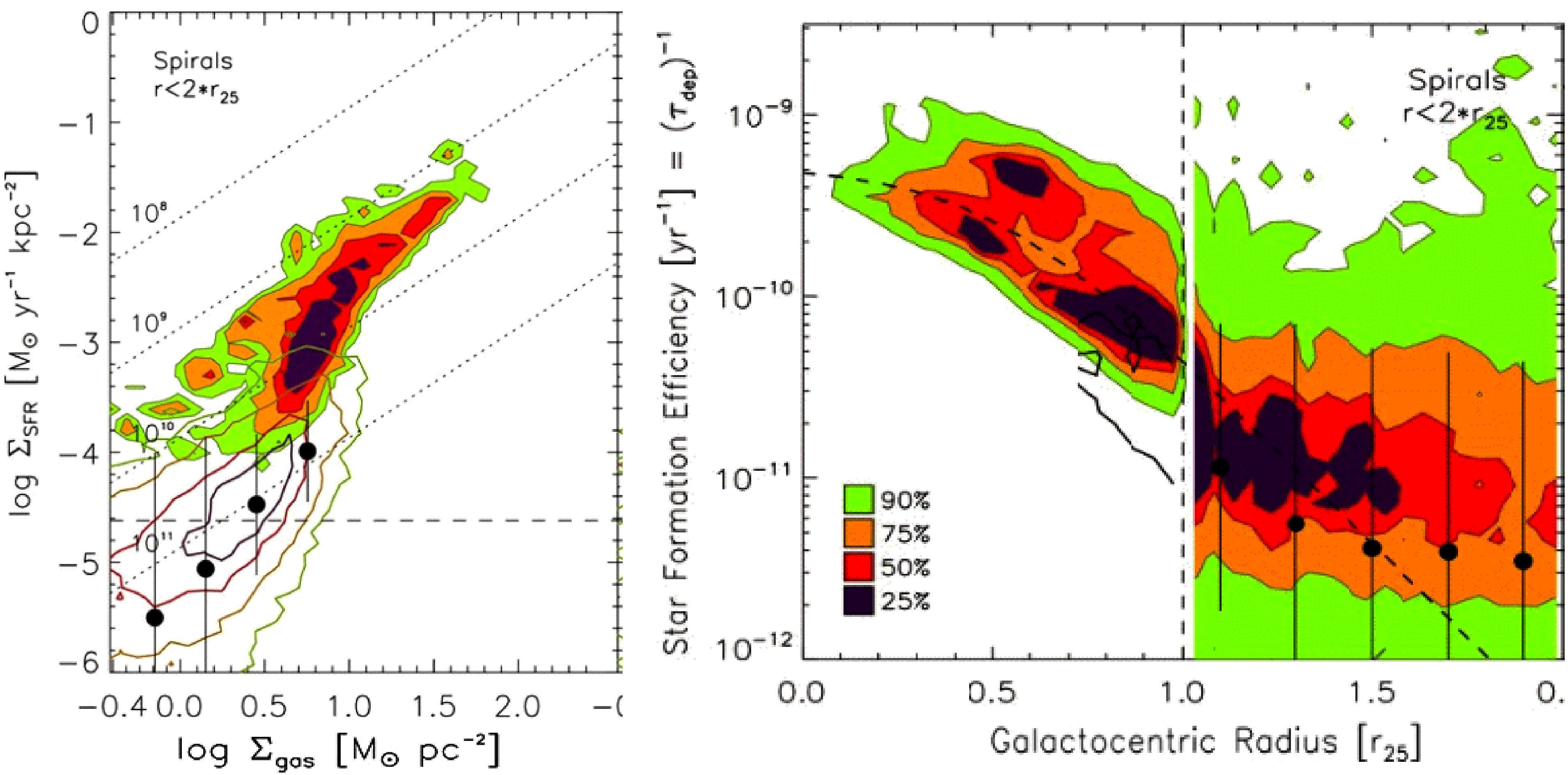
What is the physical explanation for this plane?

$$\Sigma_{\mathrm{SFR}} \propto \Sigma_{\mathrm{gas}}^{n} \quad ==> \quad \mathrm{SFR}/M_* \propto (G/S)^n \mu_*^{n-1} \quad ==>$$

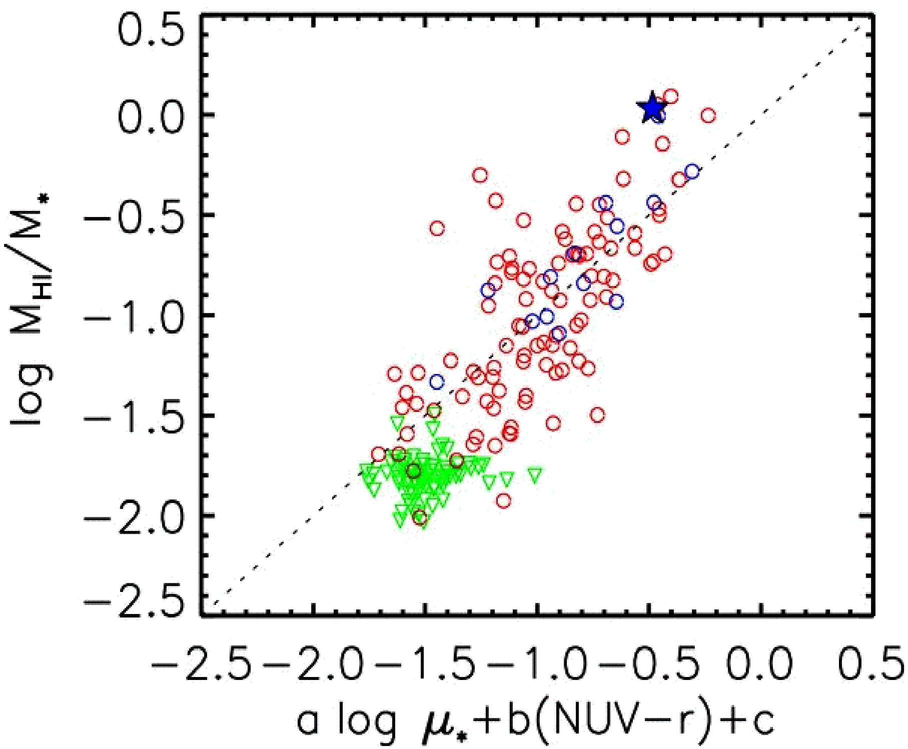
$$\log G/S = \log M_{\mathrm{gas}}/M_* = a \log \mu_* + b \log \mathrm{SFR}/M_* + c$$

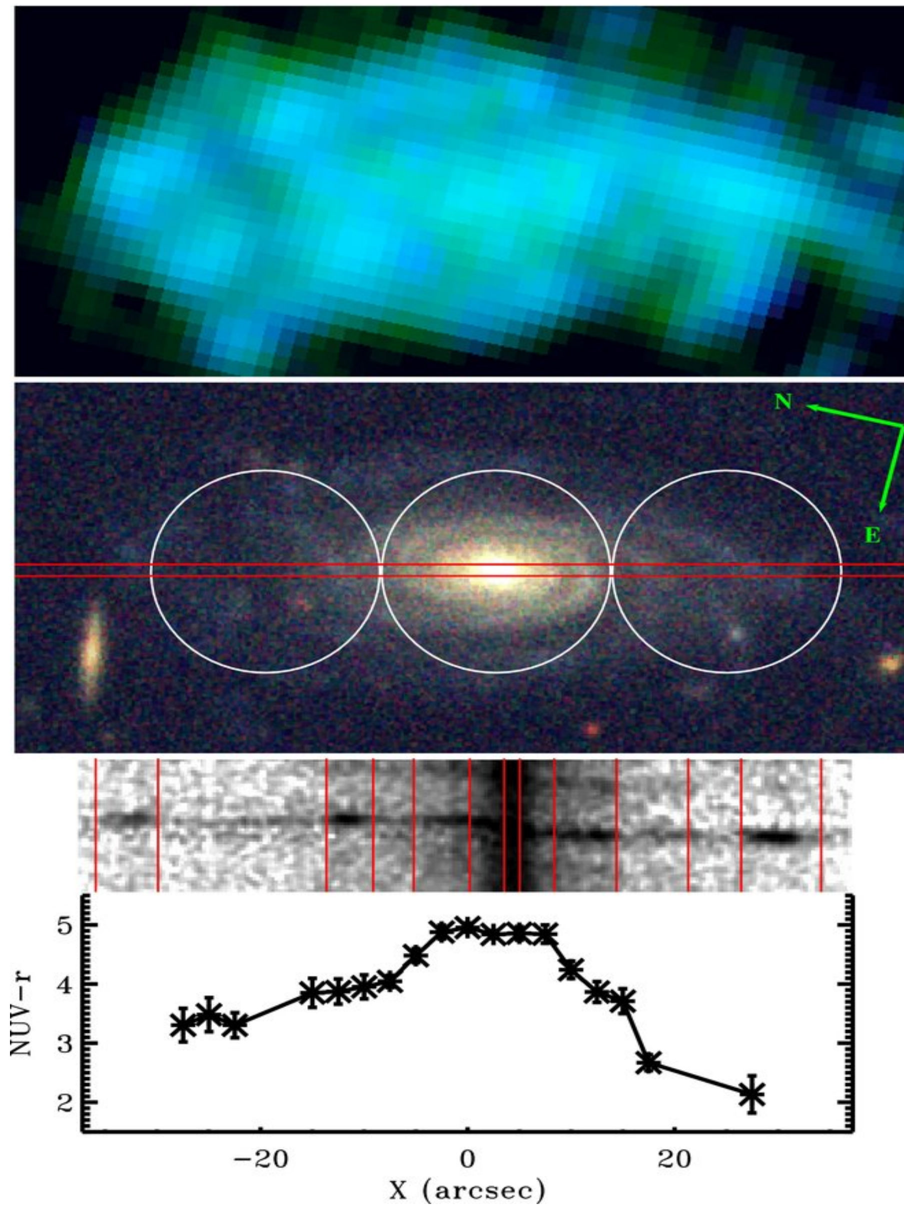
BUT we find that the plane has smaller scatter using NUV-r rather than SFR/M* ! Why?

Bigiel et al 2010



UGC 8802: A Case Study of a Star-Forming Outlier from the HI “plane”

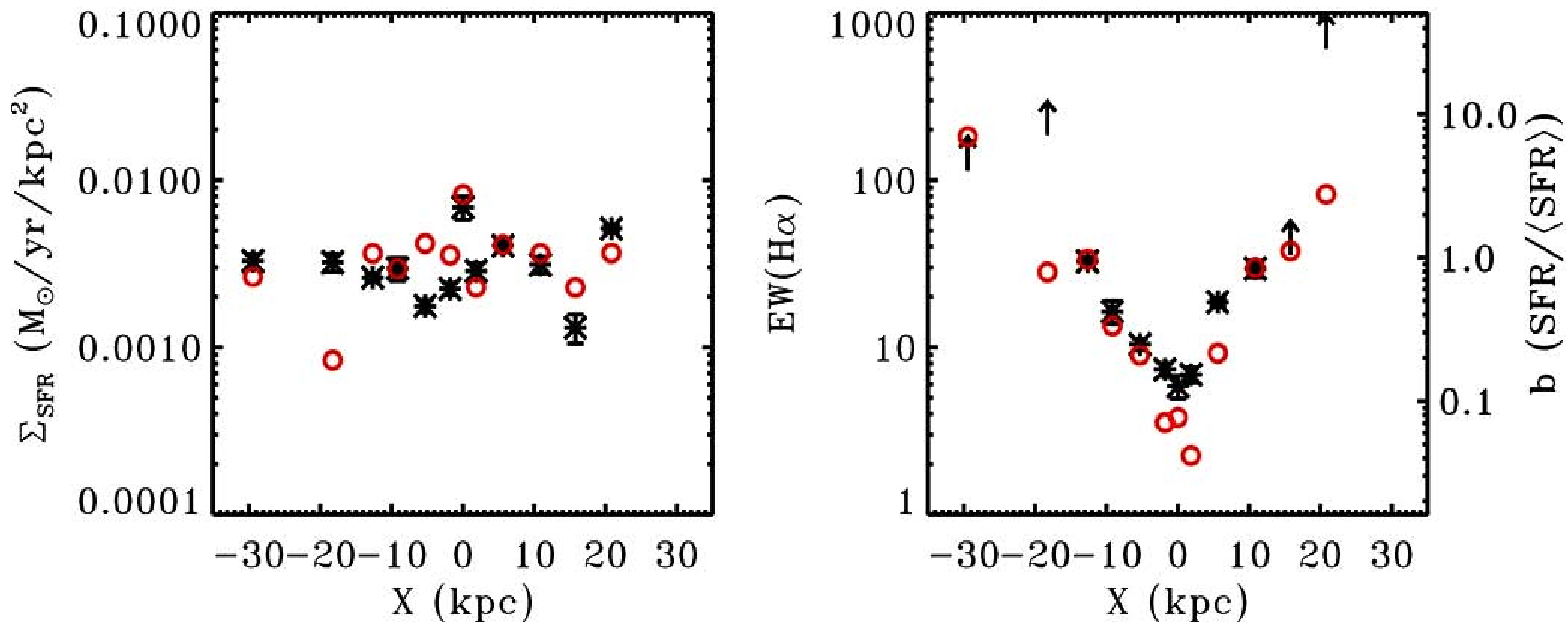


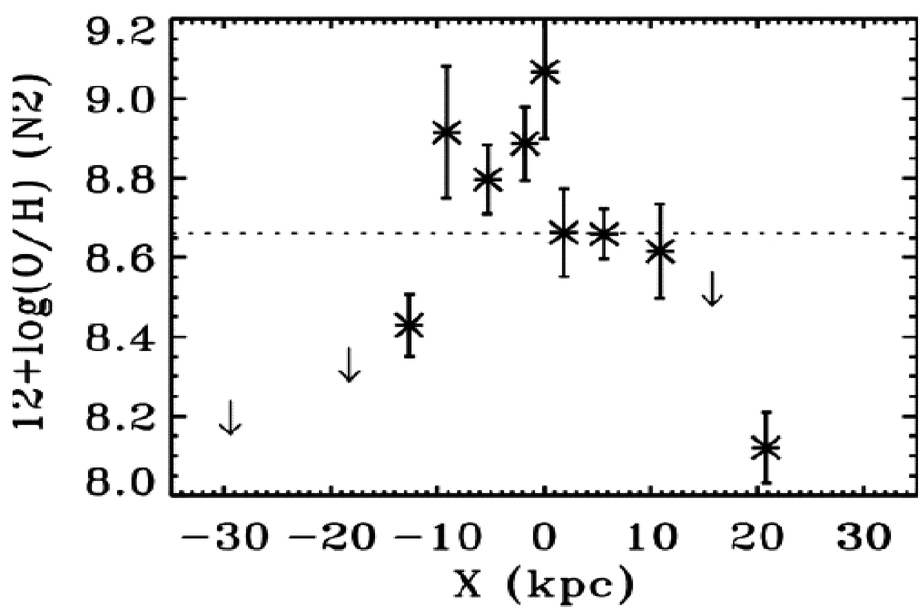


M(HI) = 2 x 10 [10] M_sol

Moran et al 2010

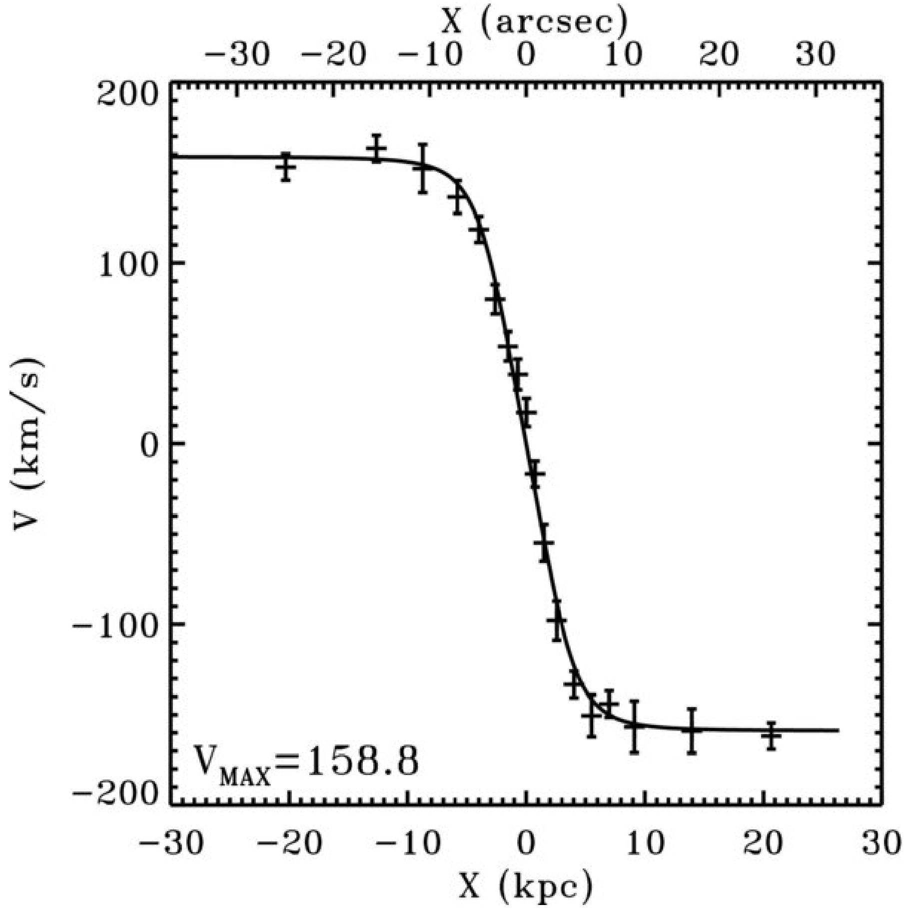
Star-formation surface density and b-parameter profiles



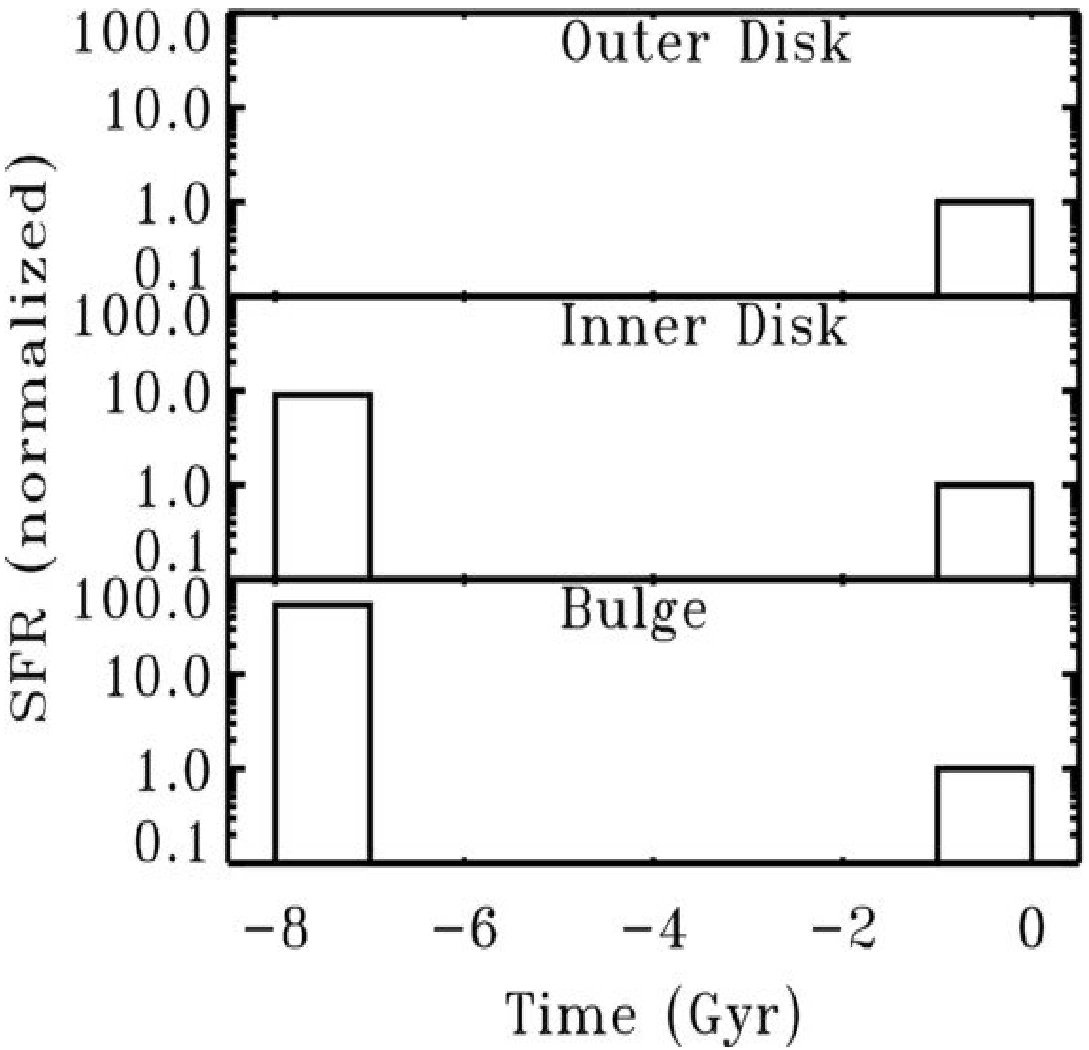


Gas-phase metallicity profile

Very regular rotation curve!

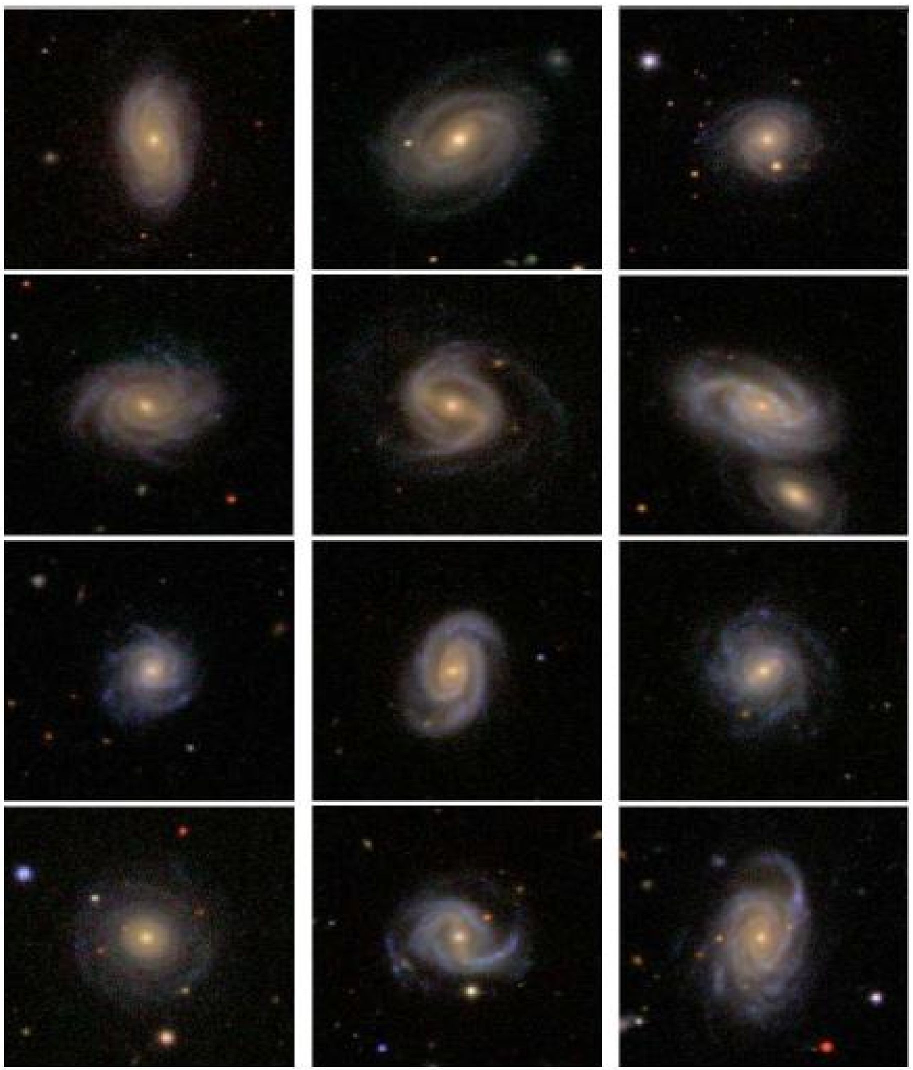


Summary of our Understanding of the Star Formation History of this System

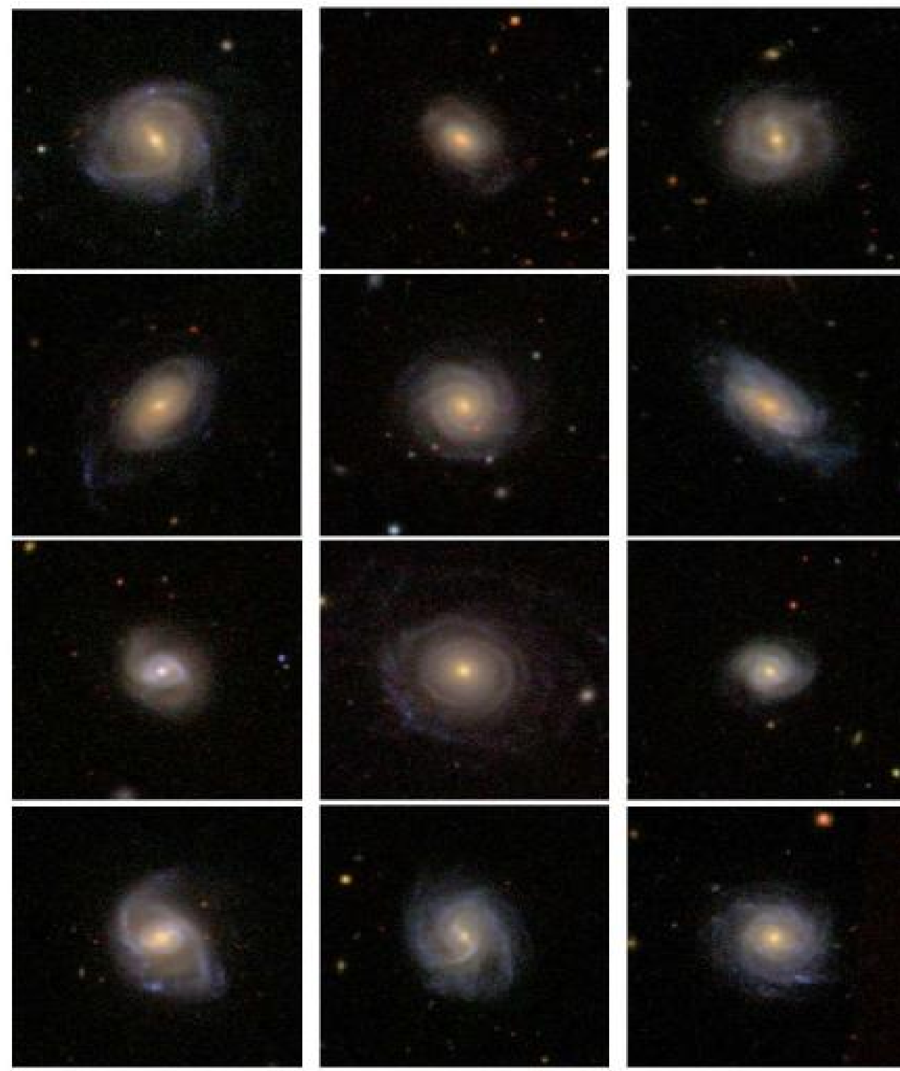


But is this generic to ALL Very HI-rich Galaxies?

Wang et al 2010

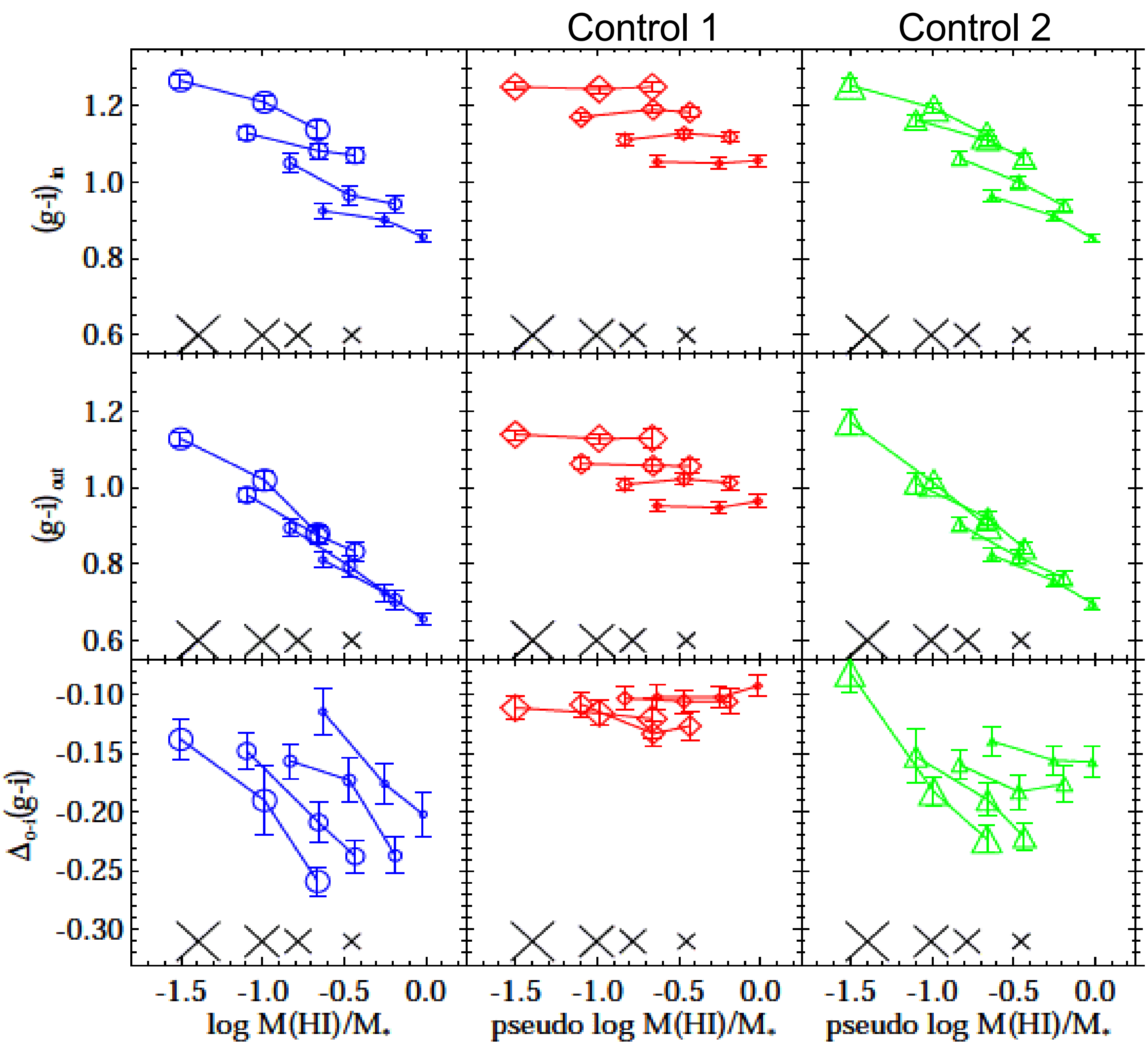


Sample with HI mass measurements



CONTROL sample matched in stellar mass,redshift and NUV-r colour

As the HI gas fraction increases, galaxies become bluer on the outside relative to the inside. This effect is absent or much weaker in control samples.

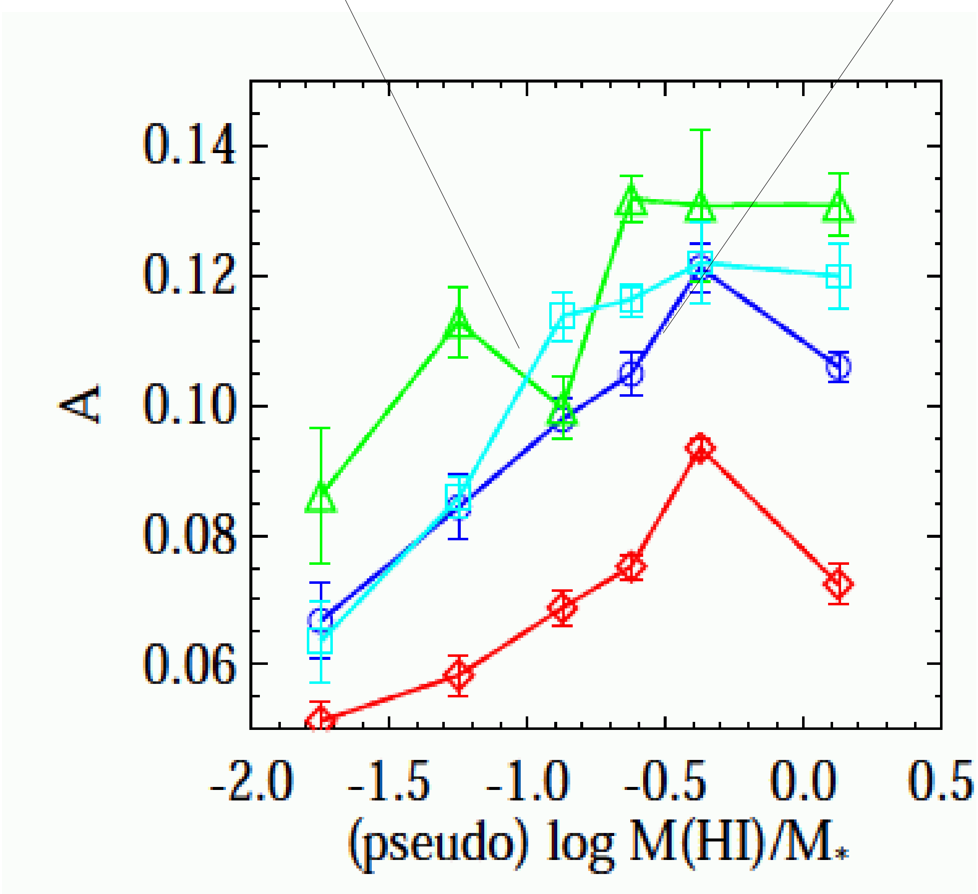


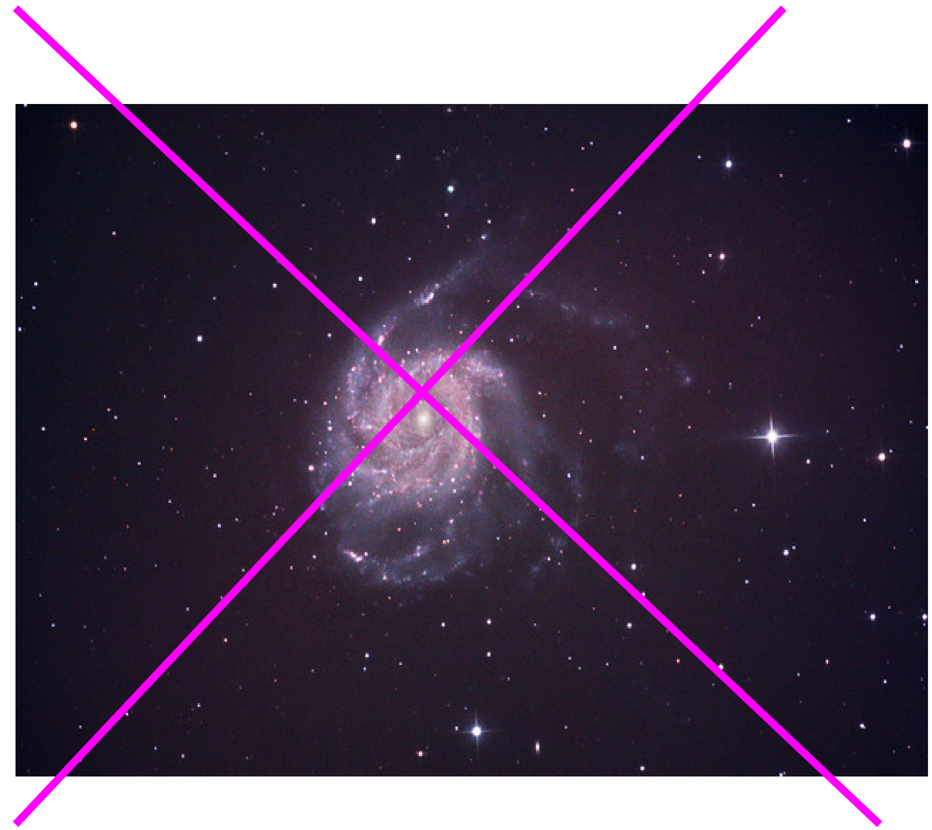
Conclusion: HI rich disk galaxies appear to be growing from the "inside out".

Although more HI-rich galaxies are more asymmetric, the same effect is seen in control samples, i.e. There is **no evidence that HI excess and asymmetry are causally linked.**

Control sample matched in mass and colour

The HI sample

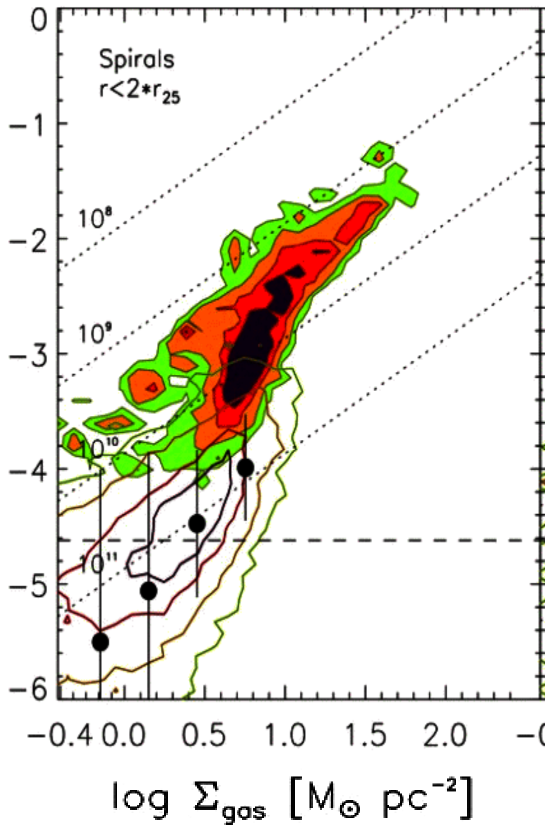


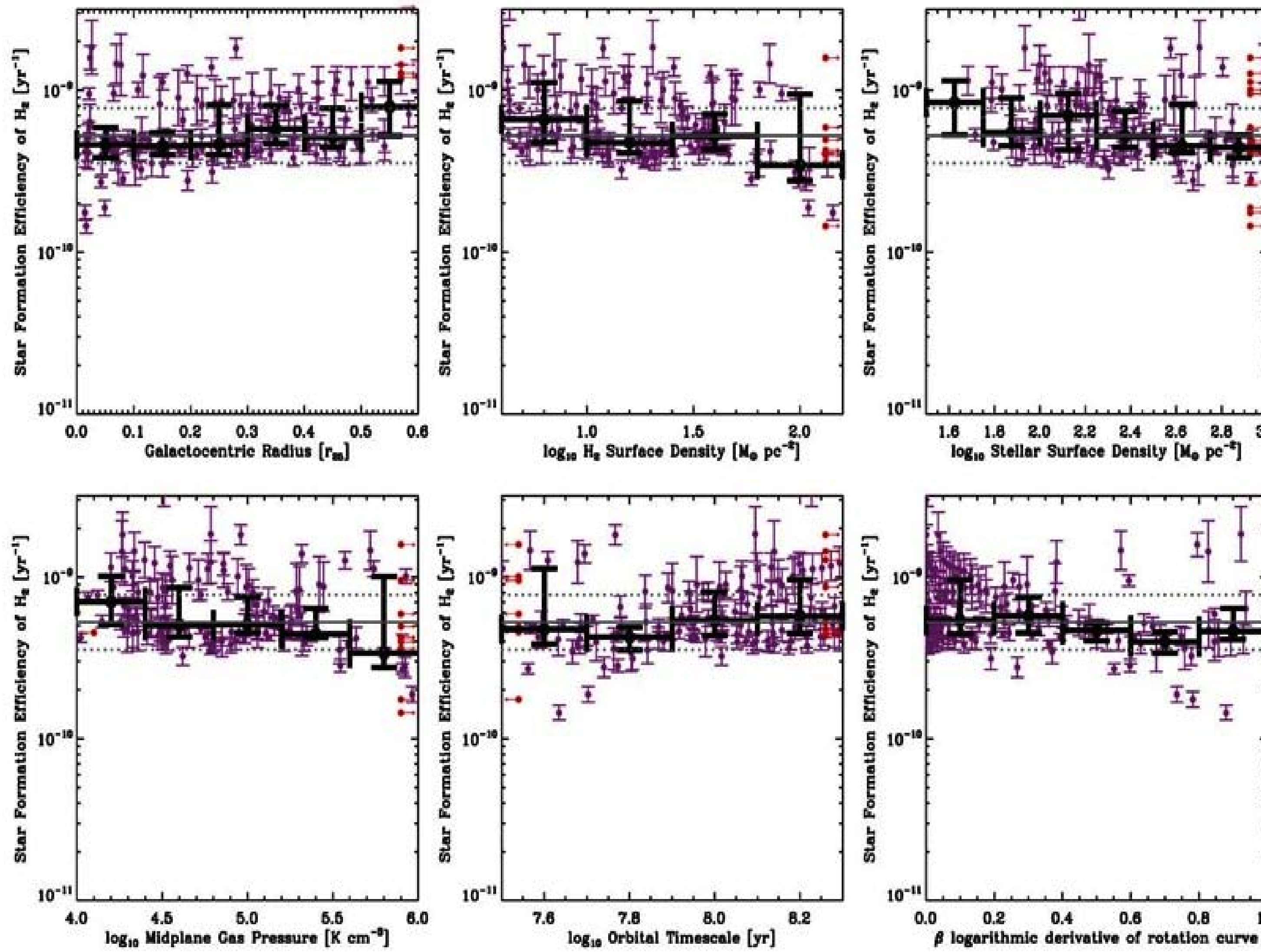


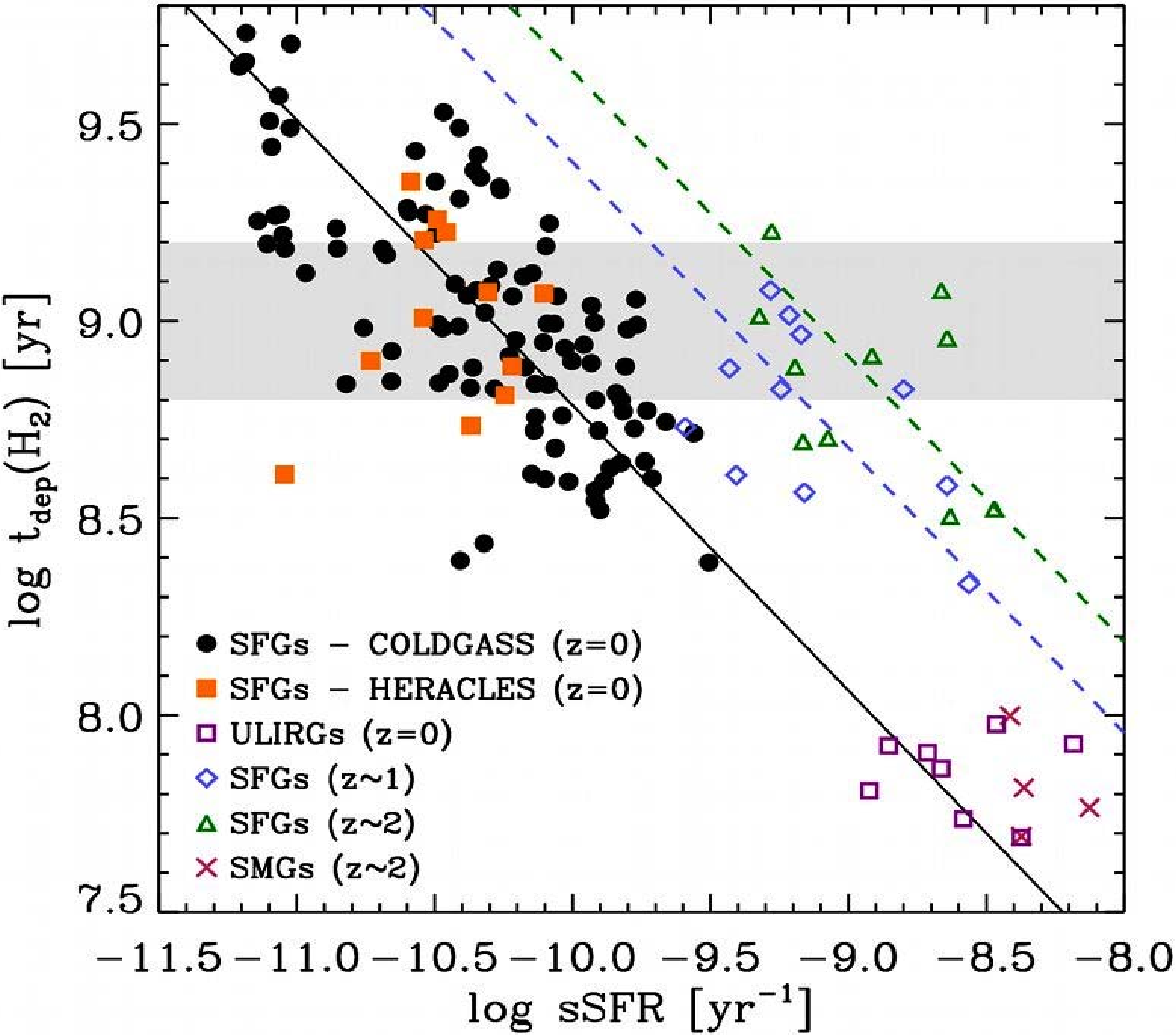
An asymmteric galaxy

FROM GAS TO STARS

Leroy et al 2008: the conversion time from molecular gas into stars appears to be constant. No residual dependence on any local galaxy property is found.

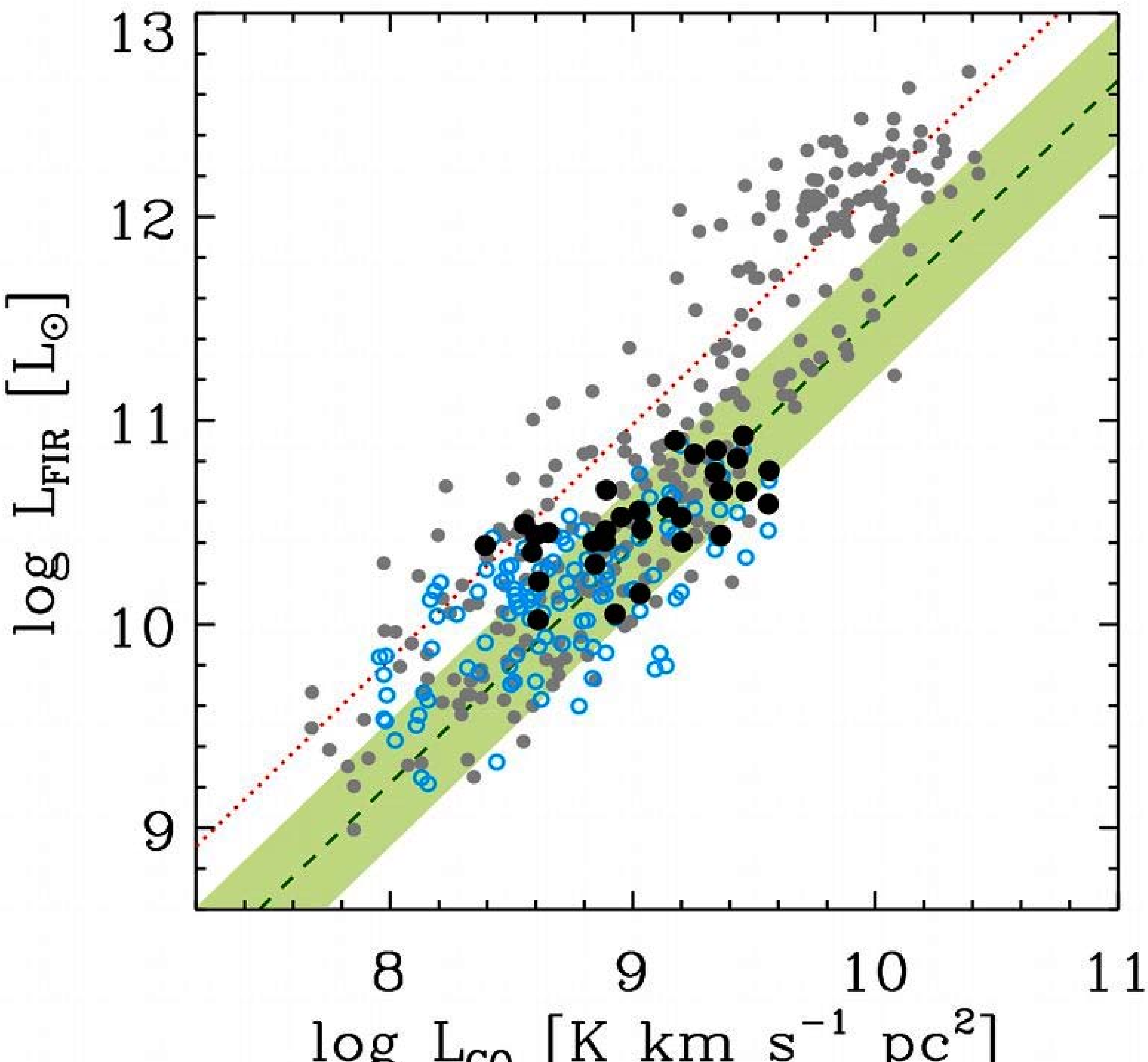






log t_dep(H_2) [yr]
log sSFR [yr^-1]
9.5
9.0
8.5
8.0
7.5
−11.5
−11.0
−10.5
−10.0
−9.5
−9.0
−8.5
−8.0
SFGs – COLDGASS (z=0)
SFGs – HERACLES (z=0)
ULIRGs (z=0)
SFGs (z~1)
SFGs (z~2)
SMGs (z~2)

As a check on the integrity of our SFR estimates:



CONCLUSIONS

1) There are clear thresholds in galaxy **structural parameters** where a sharp transition occurs between a population galaxies that contain significant cold gas, and a population galaxies that is very gas poor. This transition is **not seen for stellar mass.**

2) We place a strong upper limit on the average molecular gas fraction of red (NUV-r>5) galaxies of 0.16%

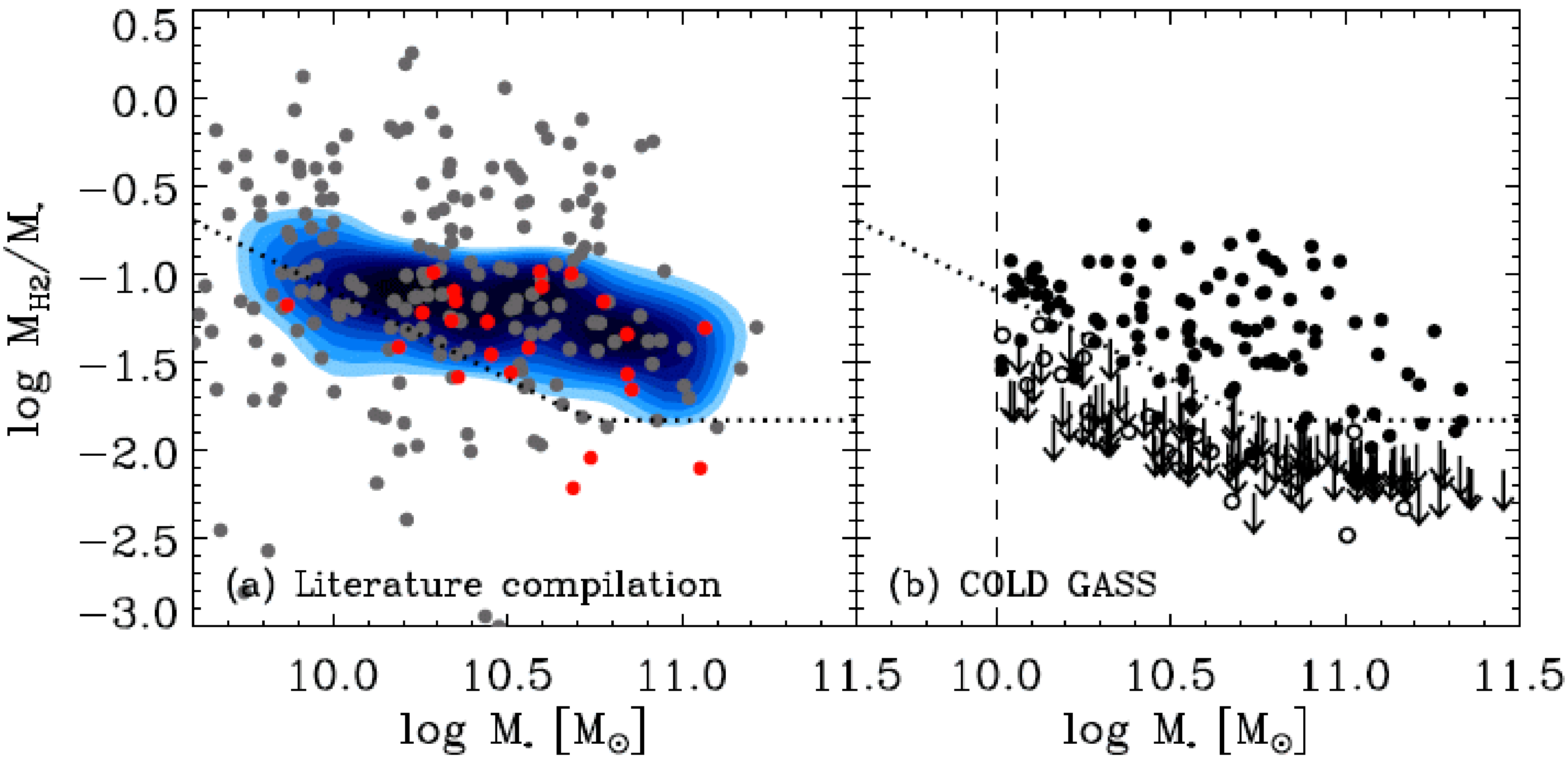
3) There is a sub-population of red, early-type galaxies with significant atomic gas. Question: Are these remnants or do galaxies can undergo rejuvenation?

4) The majority of the star-forming galaxy population lies on a well-defined “plane”, linking HI gas fraction, NUV-r colour and stellar surface mass density

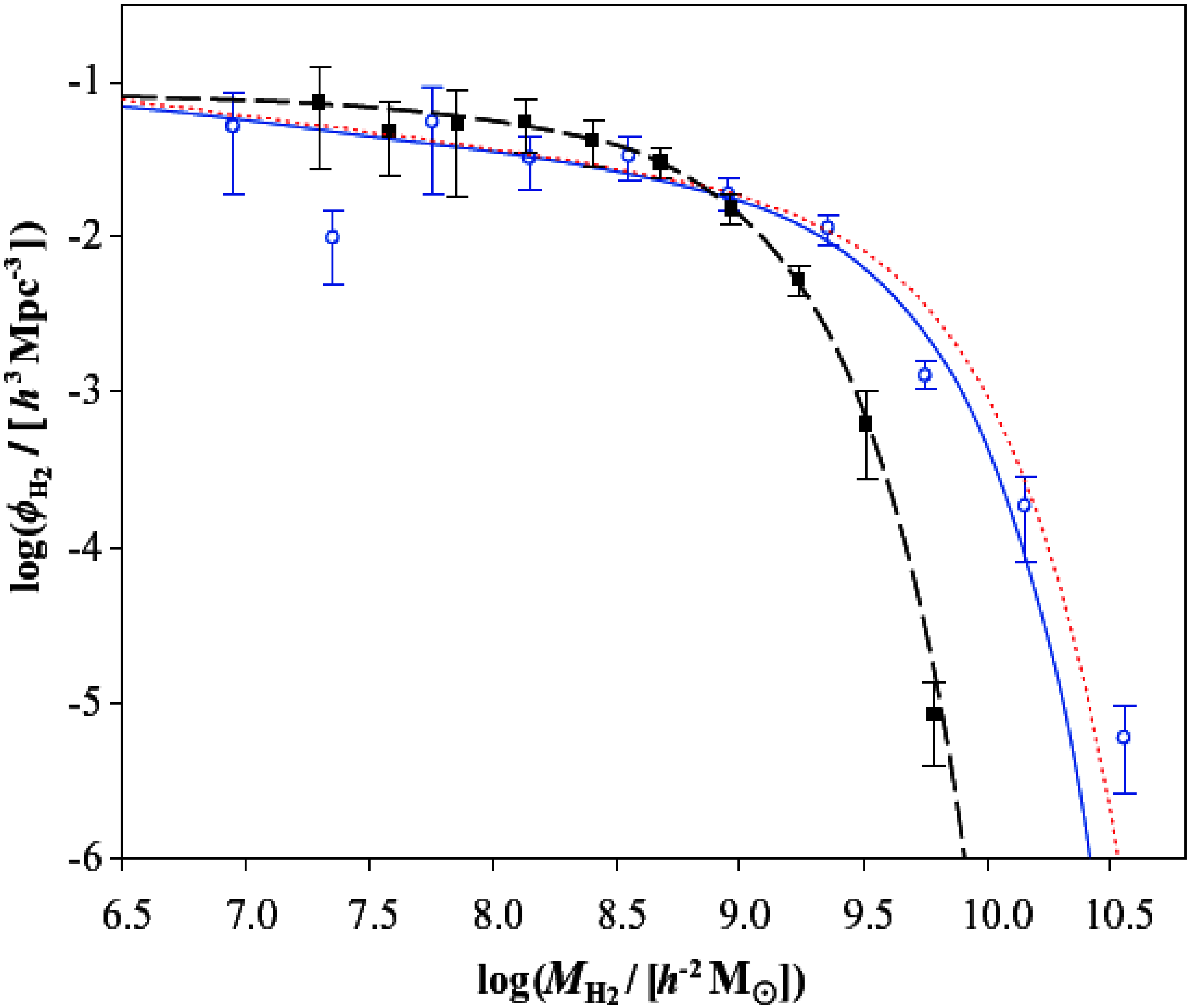
5) Galaxies that have excess HI gas have unusual properties: they have bluer, more actively star-forming outer disks, indicating that they are growing from the “inside out”. Our ongoing program of MMT spectroscopy will allow us to understand the link between this growth and the chemical evolution of the disk.

The global conversion efficiency of molecular gas into stars is NOT constant across the nearby “normal” galaxy population. It is a strong function of the star formation activity level in the galaxy. It will be important to understand the ISM physics that drives this result in more detail.....

We have come a long way!



REMINDER to those working at higher redshifts: We cannot understand galaxy **evolution** if we have not properly quantified the nature of galaxies in the local Universe



Keres et al and Obreschkow & Rawlings H2 mass functions are based on these ancient samples!