KITP, April 2014

The Distribution of Atomic and Molecular Gas in Galaxies

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OUTLINE

- Statistics of gas content in galaxies
- Face-on distribution of HI and H_2
- Vertical distribution of HI and H_2
- Comments on star formation relations

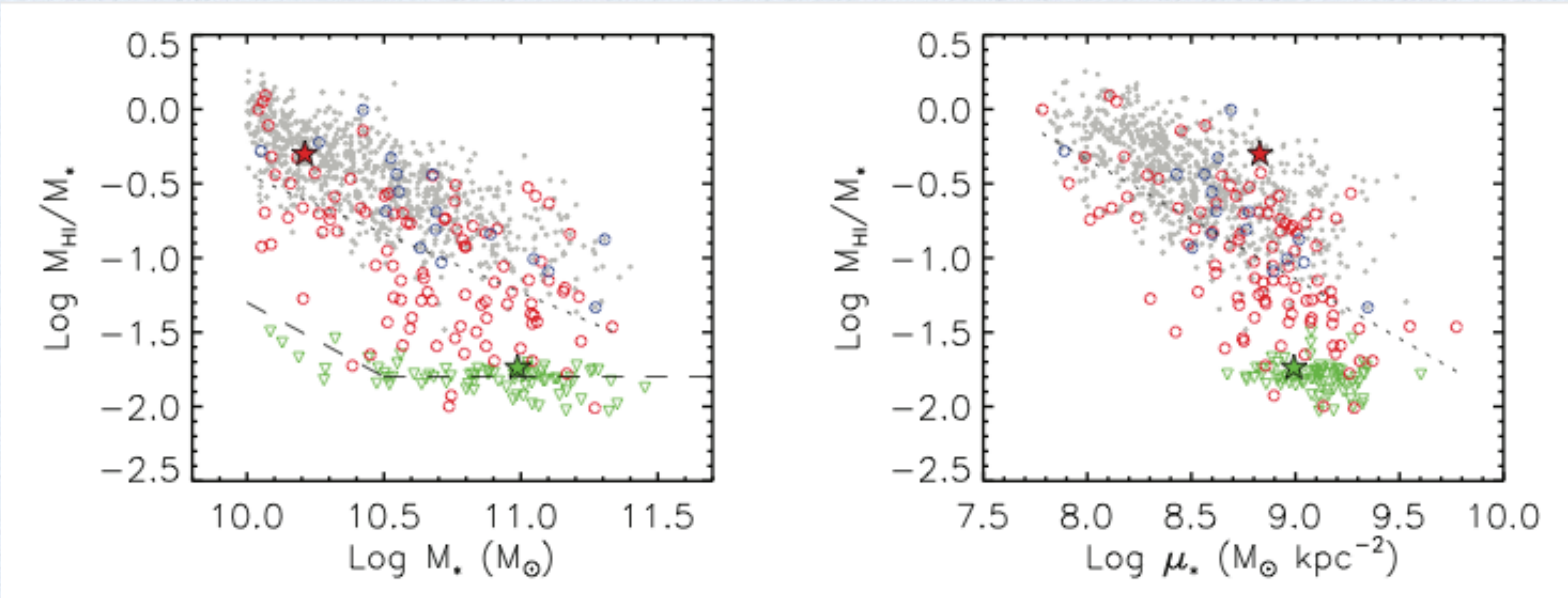
Motivation

- Molecular gas (at least in our vicinity) is dense, cold, and closely related to star formation.
- This is ***unlike*** atomic gas, which is multiphase (CNM/WNM) under a wide range of conditions.
- Thus non-star-forming HI will tend to be heavily overrepresented when weighting by area or volume.
- Spatially resolved studies critical, but sampling and detection biases can become quite important.
- A star formation "law" can only be formulated once the dense, cold gas component has been isolated.

Statistics of gas content in galaxies

Global Gas Content: HI

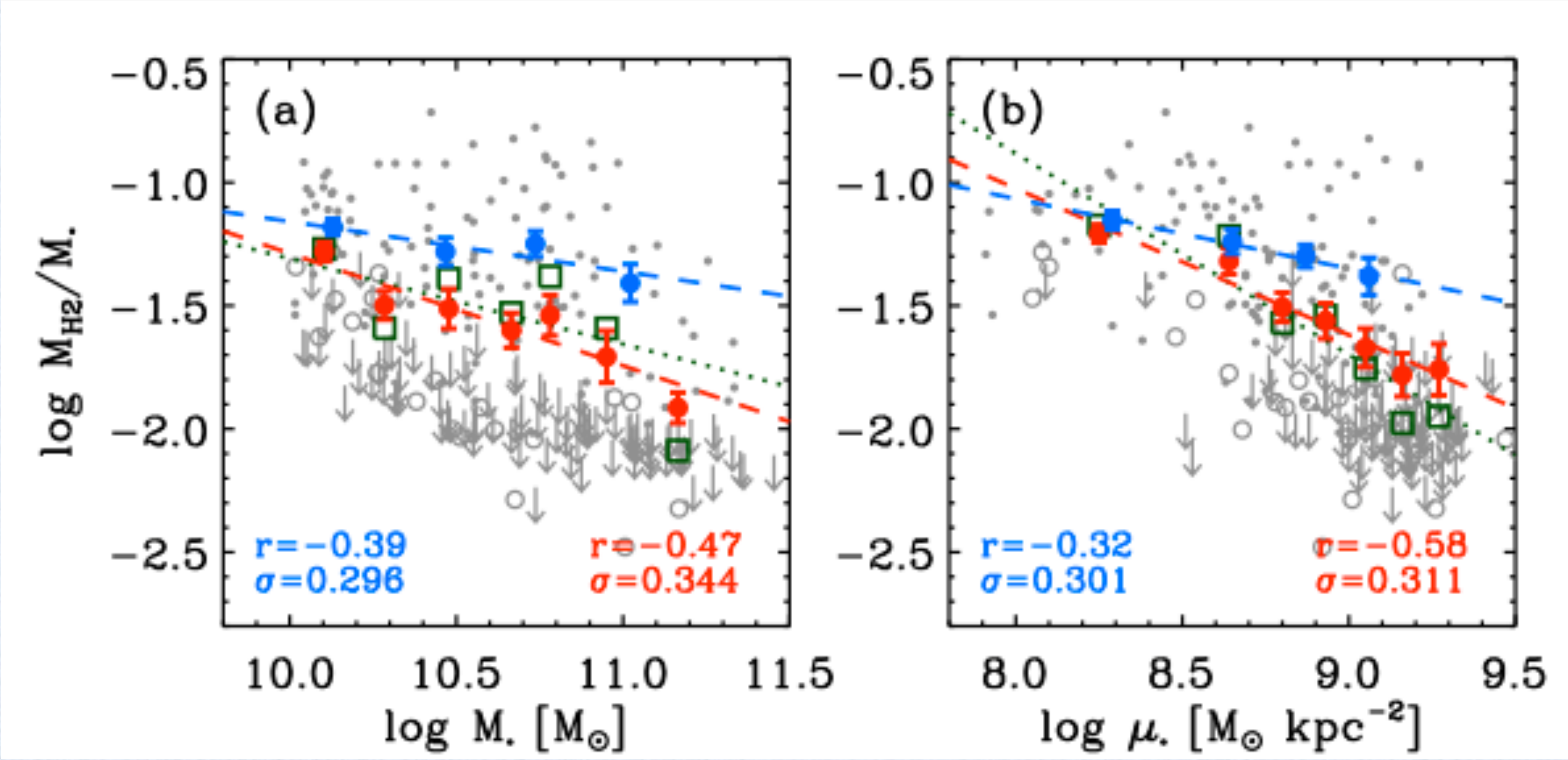
- Data from GALEX Arecibo SDSS Survey (GASS); red circles and green triangles are HI detections and non-detections respectively
- HI mass fraction decreases with stellar mass and surface density (surface density seems more important—bulge dominated?)



Catinella+ 2010

GLOBAL GAS CONTENT: H_2

- H_2 mass fraction fairly constant once CO is detected.
- However, detection rate of H_2 is a strong function of stellar surface density.



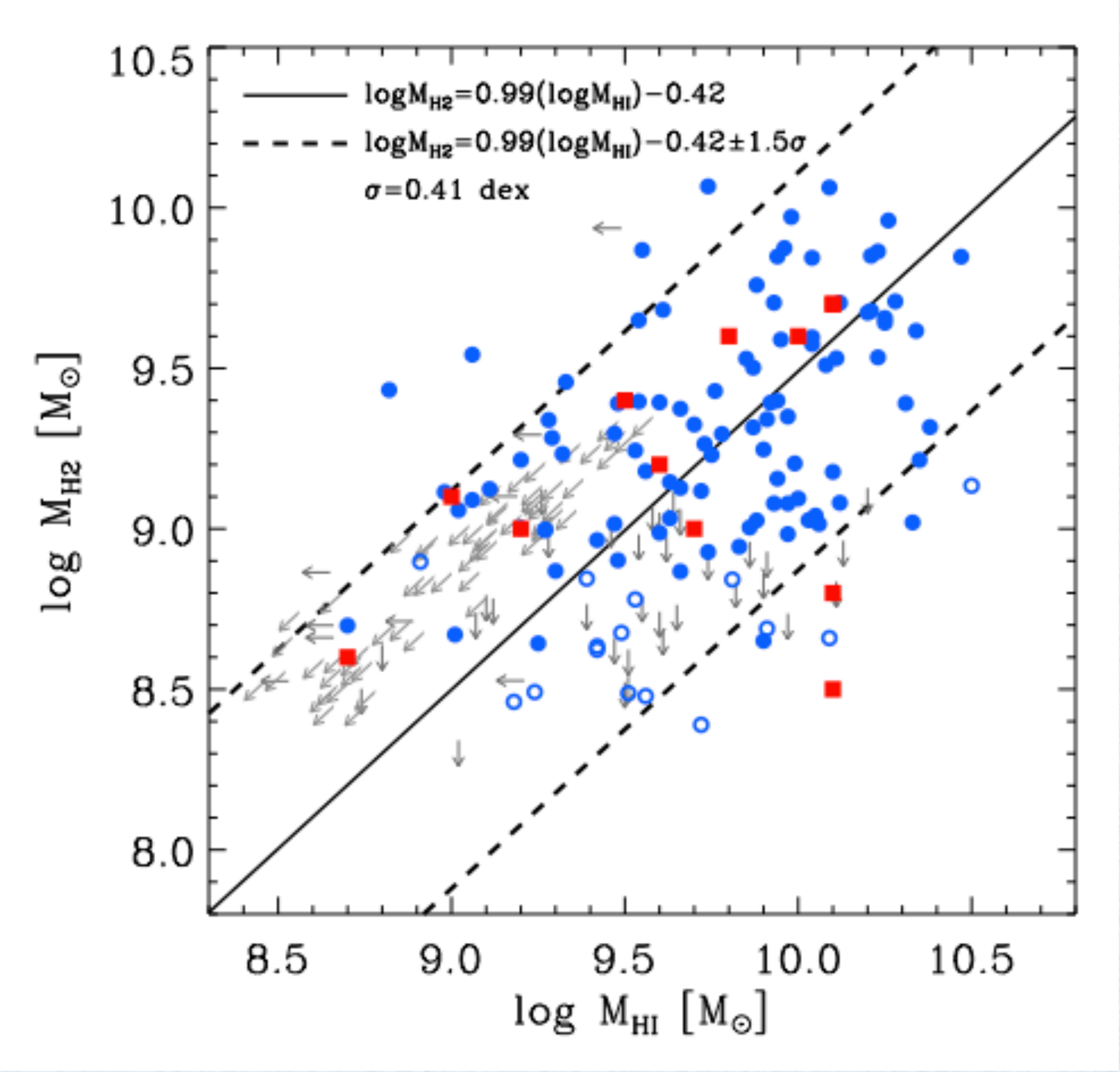
Blue circles: CO detections only

Red circles: CO non-detections given upper limit values

Saintonge+ 2011: COLD GASS

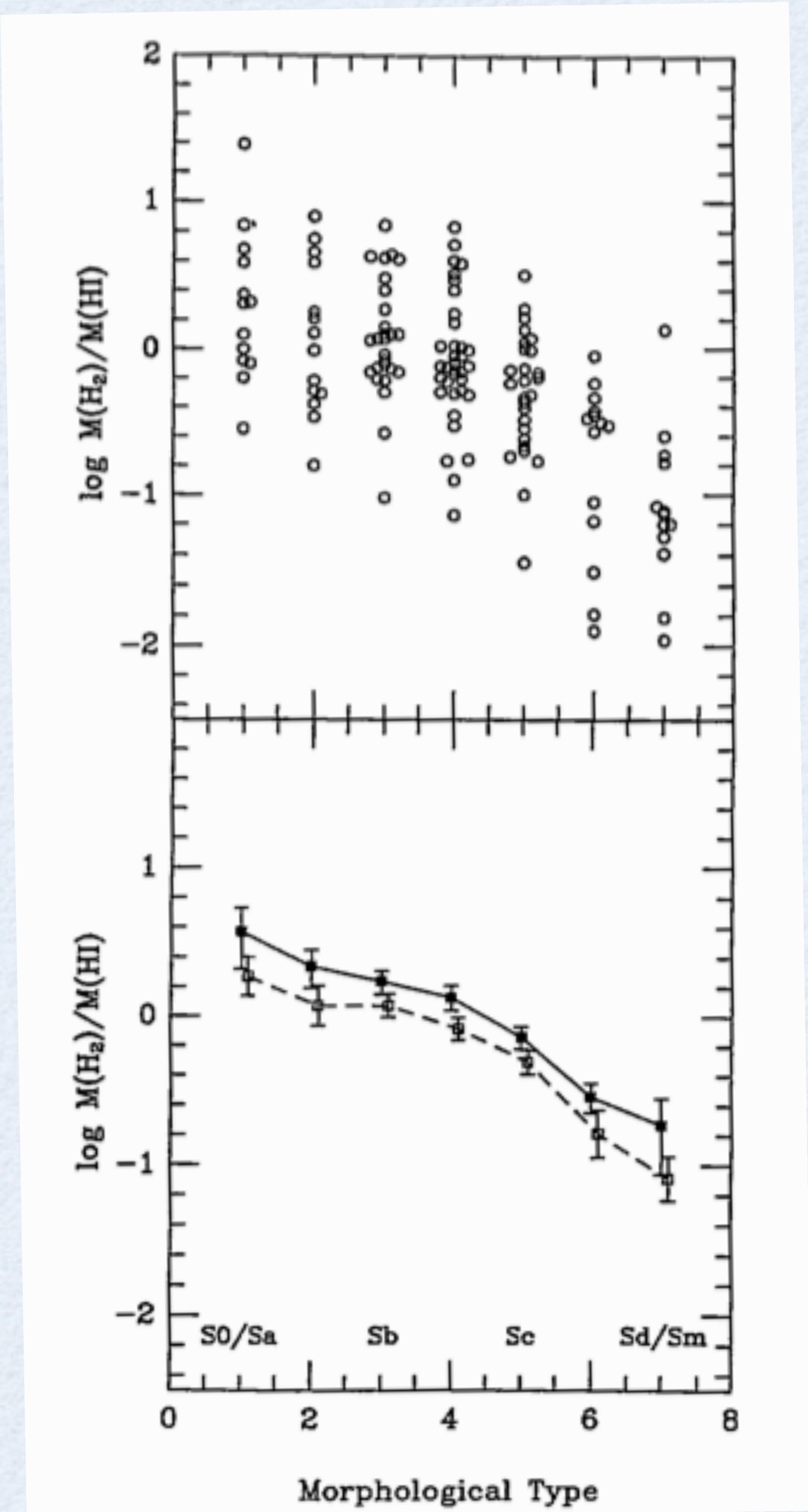
Galaxies are HI-dominated...

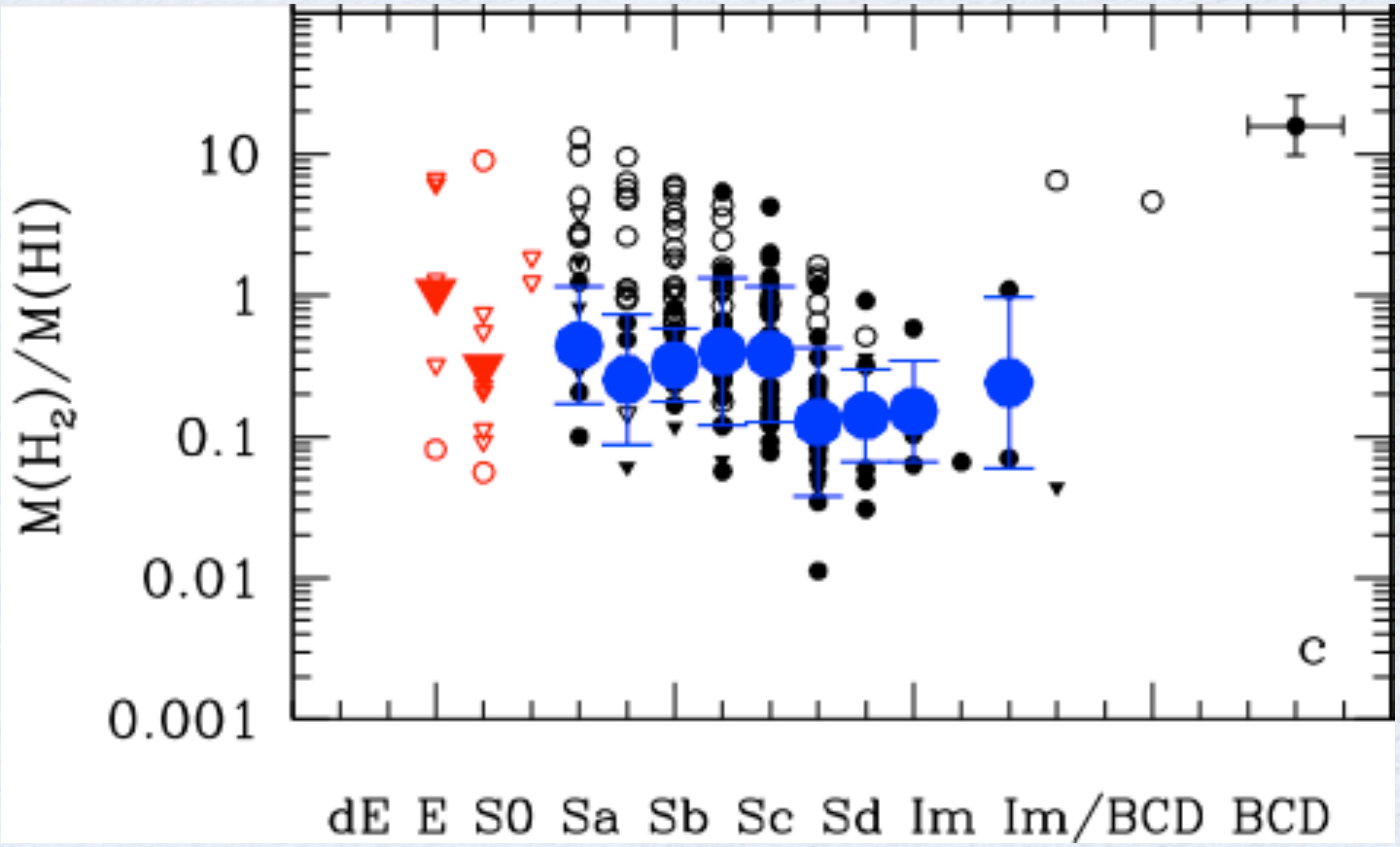
- Based on HI and CO flux measurements with single-dish telescopes
- $M(H_2) \sim 0.3 \times M(HI)$, with large scatter.
- Blue circles: COLD GASS (Saintonge+ 2011).
- Red squares: HERACLES (Leroy+ 2008).



Saintonge+ 2011

...But early types H_2 dominated



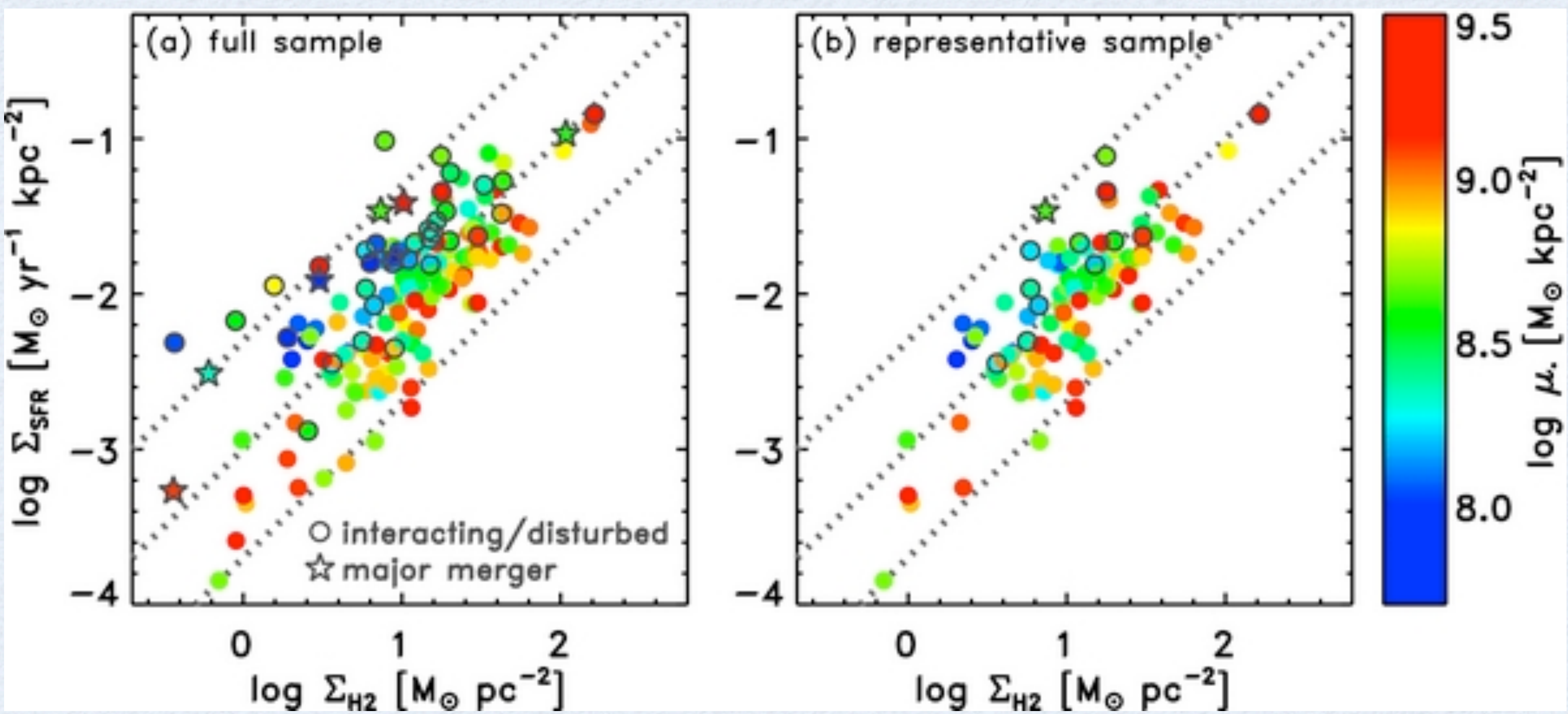


Boselli+ 2014; binned values exclude HI-deficient objects (open circles)

Young & Knezek 1989

H_2 and Star Formation

- The tendency for high μ_* galaxies to prefer molecular over atomic gas *does **not** imply that they experience more star formation*.
- These galaxies are displaced below the usual Kennicutt-Schmidt relation between H_2 and star formation.
- Bulge stabilization of disk, or H_2 in more diffuse phase?

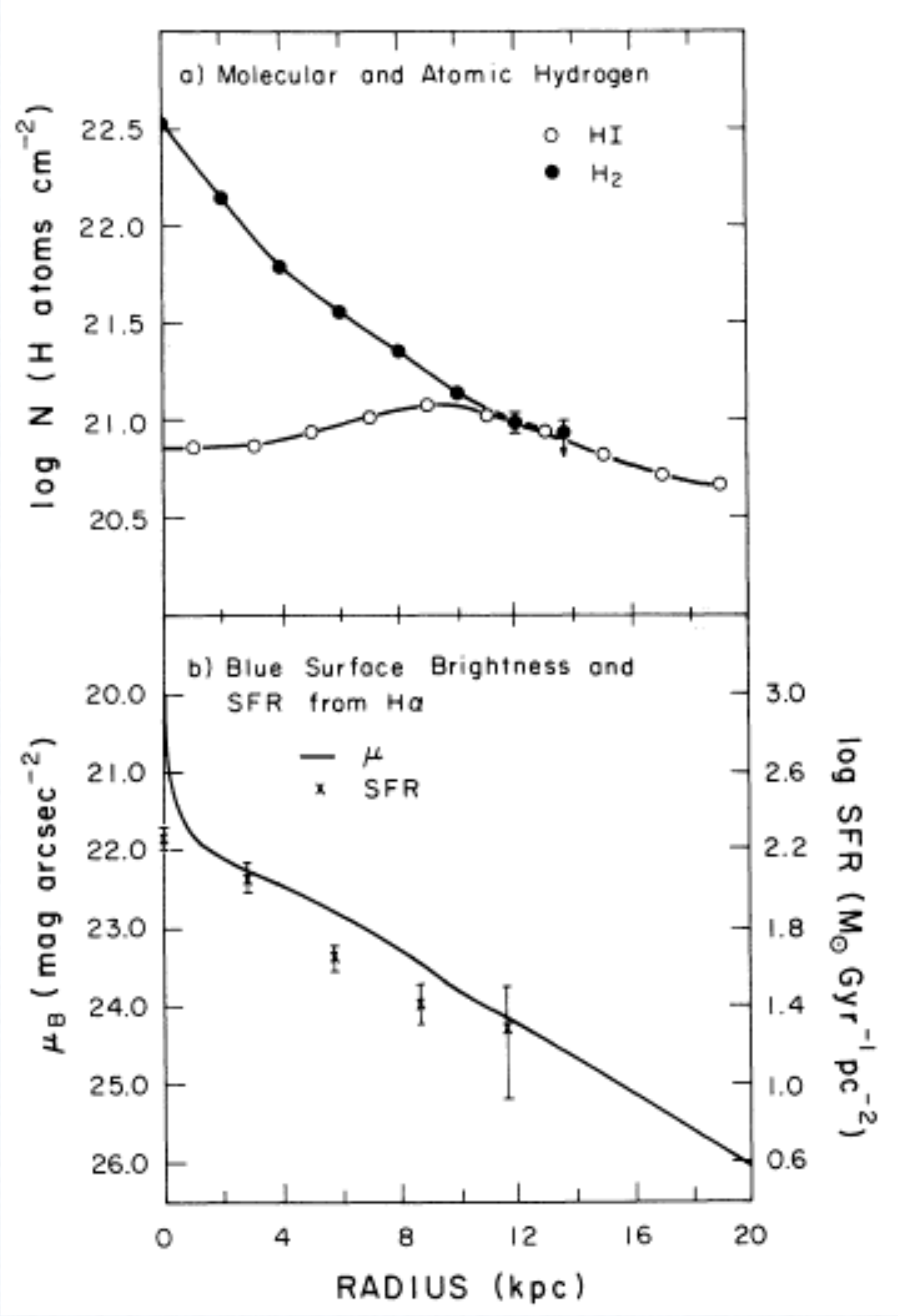


Saintonge+ 2012

The ISM Surface Density Distribution

Radial Distributions

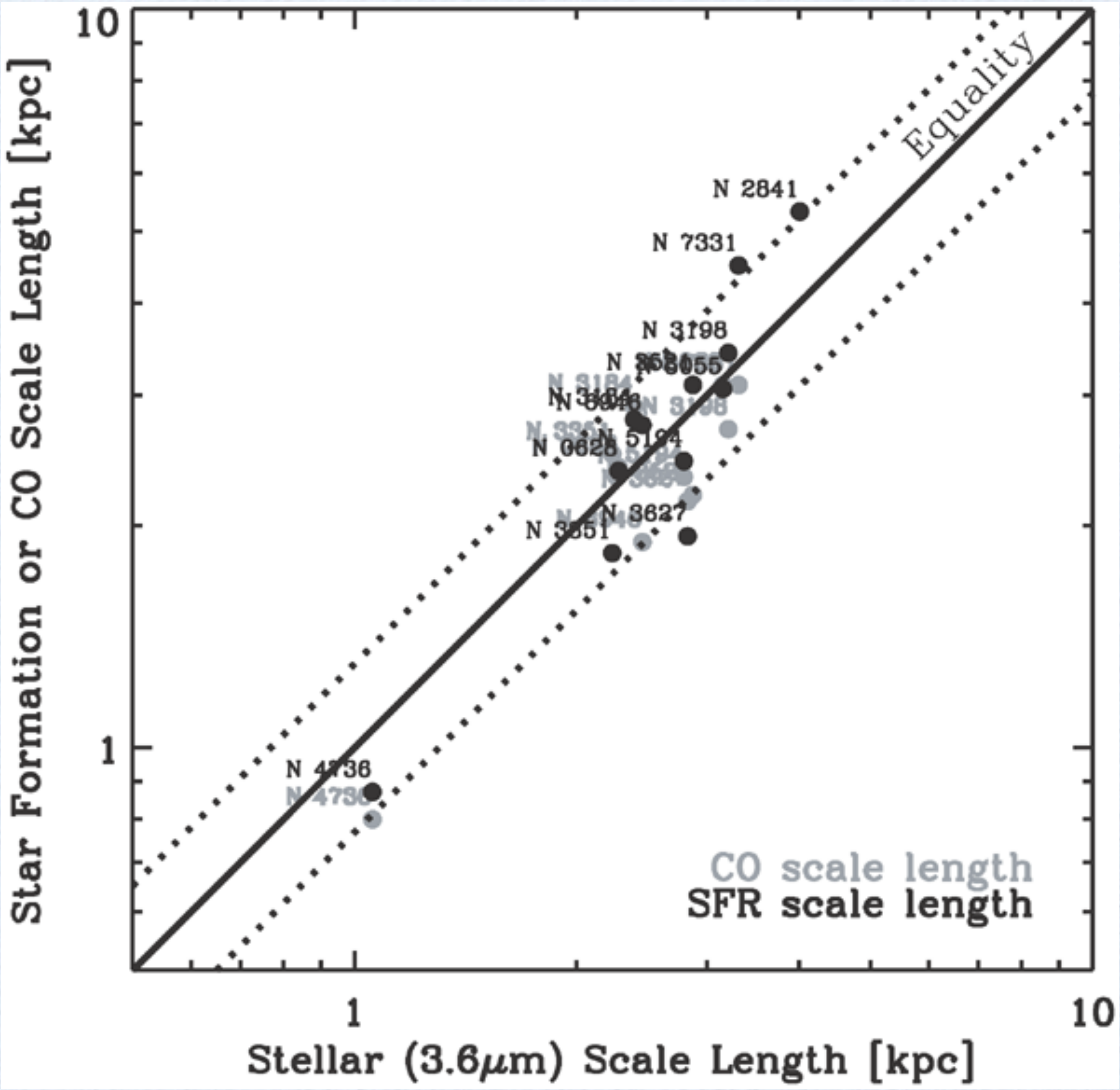
- Early work in the 1980's (typically major axis profiles) showed that the radial CO distribution traces the stellar disk well in the nearest face-on galaxies.



NGC 6946 by Tacconi & Young 1986

Radial Distributions

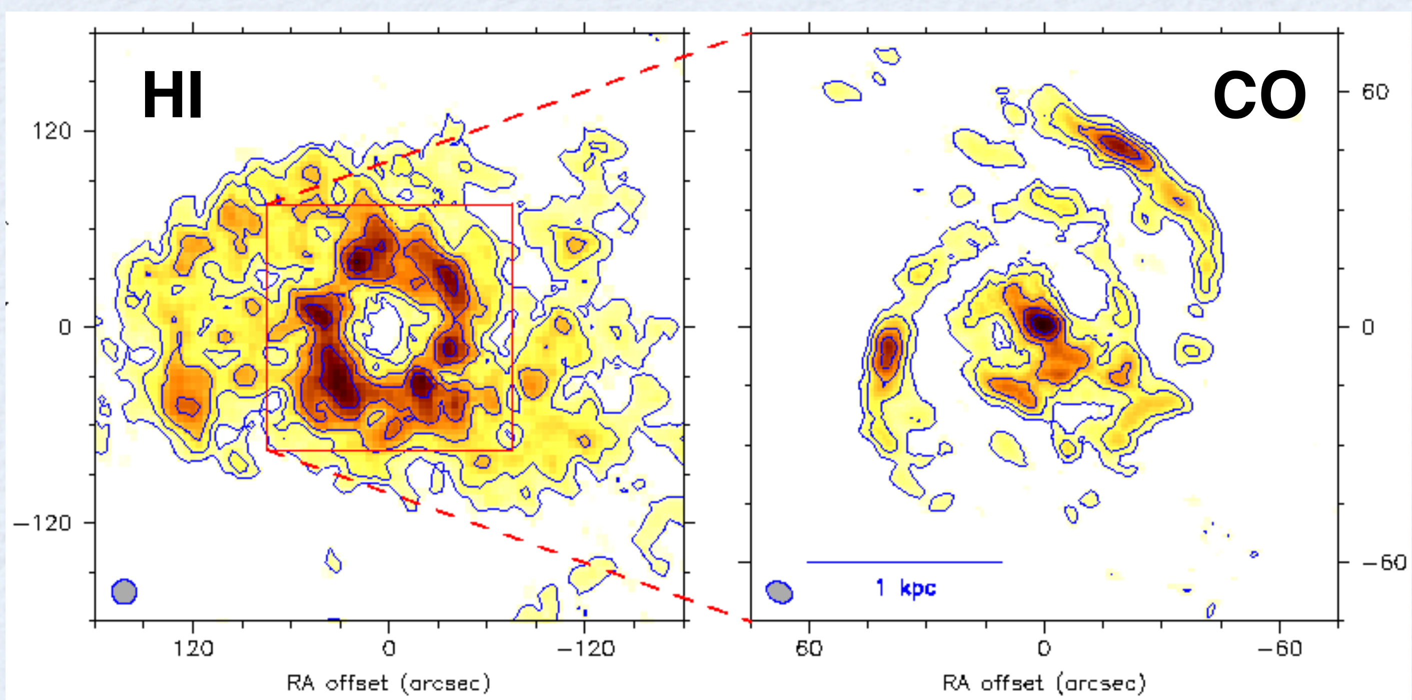
- Early work in the 1980's (typically major axis profiles) showed that the radial CO distribution traces the stellar disk well in the nearest face-on galaxies.
- Confirmed by many later studies, most recently by full-disk CO(2-1) mapping with the IRAM 30m HERA receiver (Leroy+ 2008).



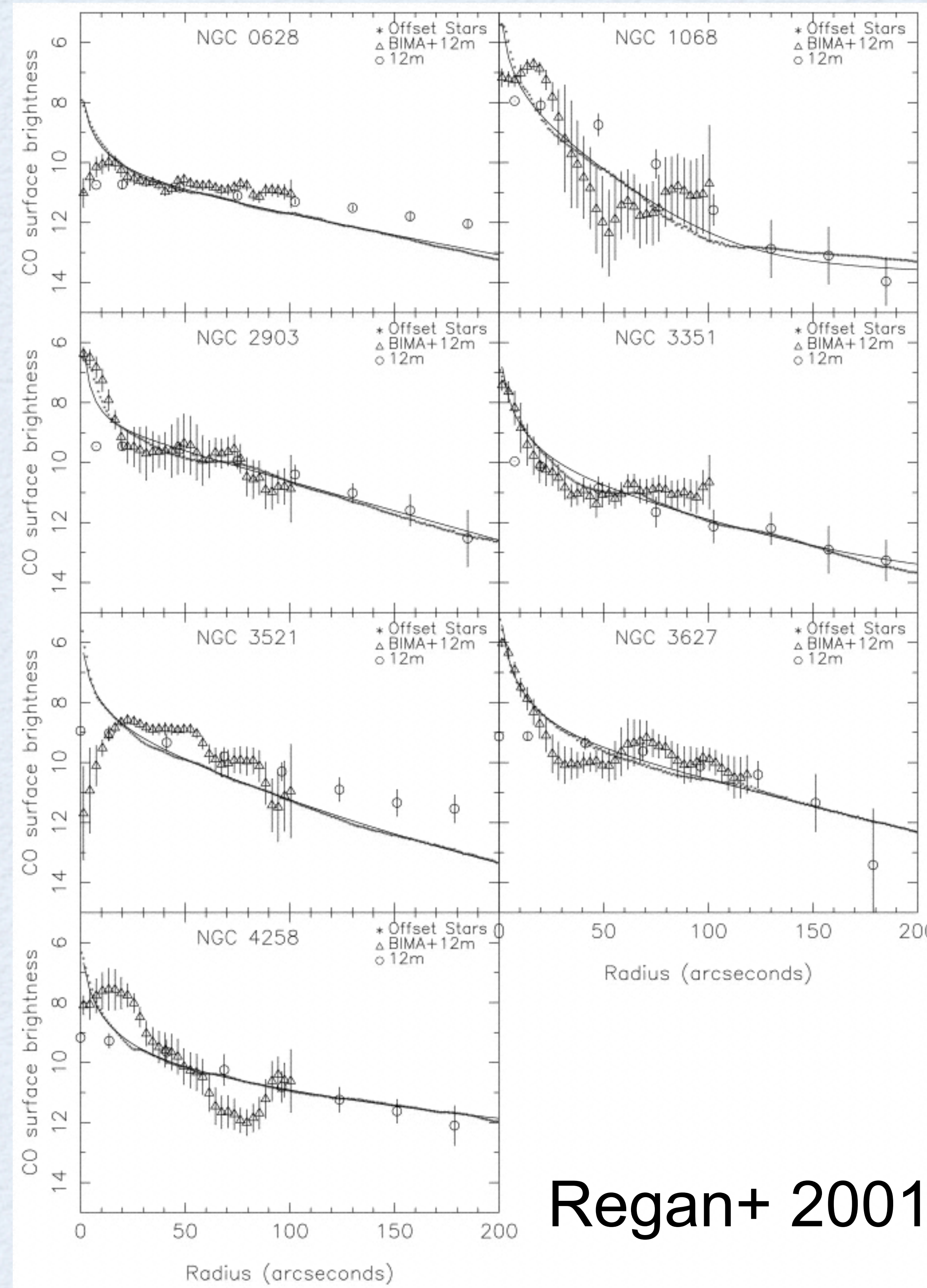
Leroy+ 2008

Radial Distributions

- Radio interferometric studies like BIMA SONG have been key to resolving central CO concentrations ("bulges") as well as depressions ("central holes").



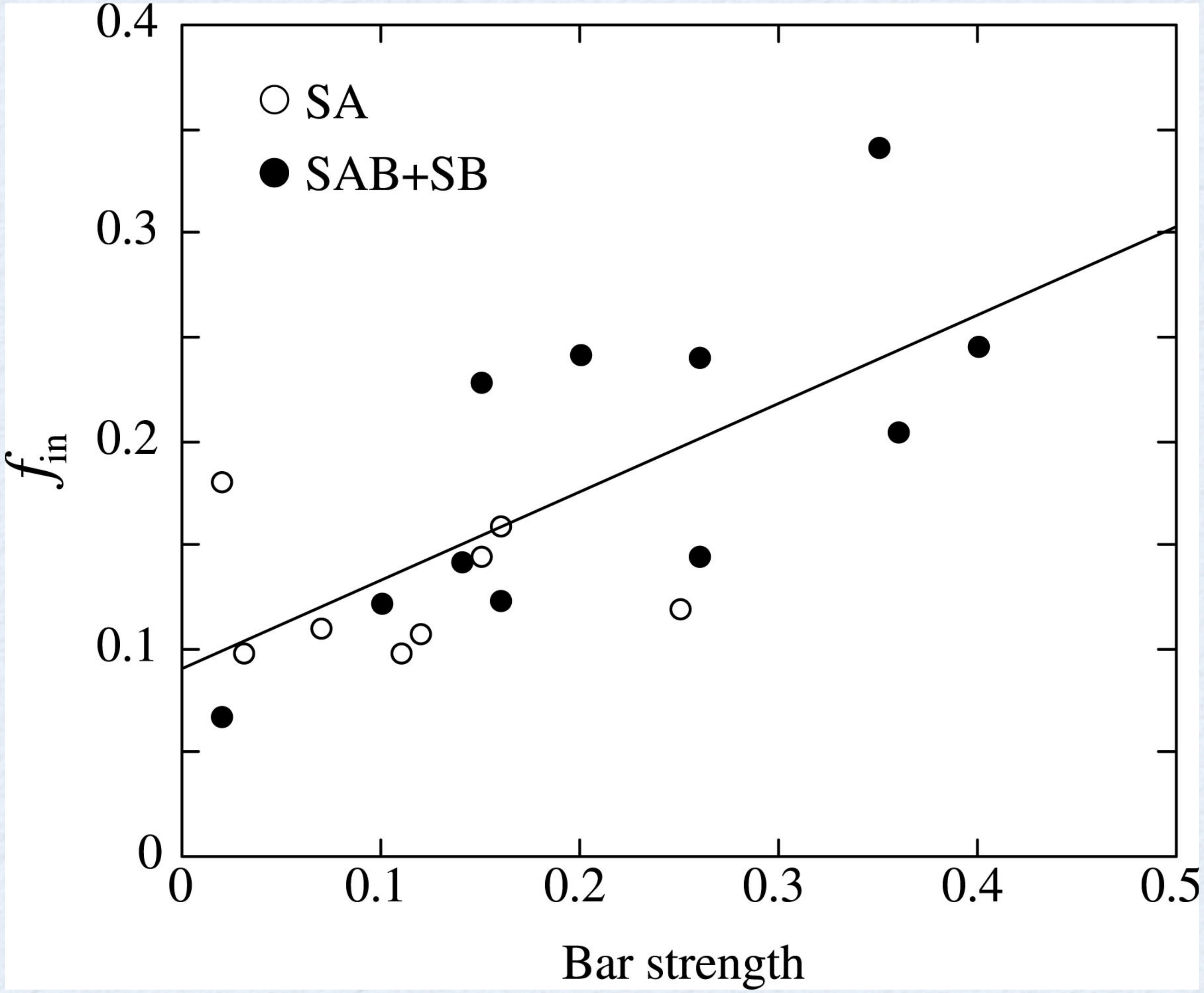
NGC 4736 by Wong & Blitz 2000



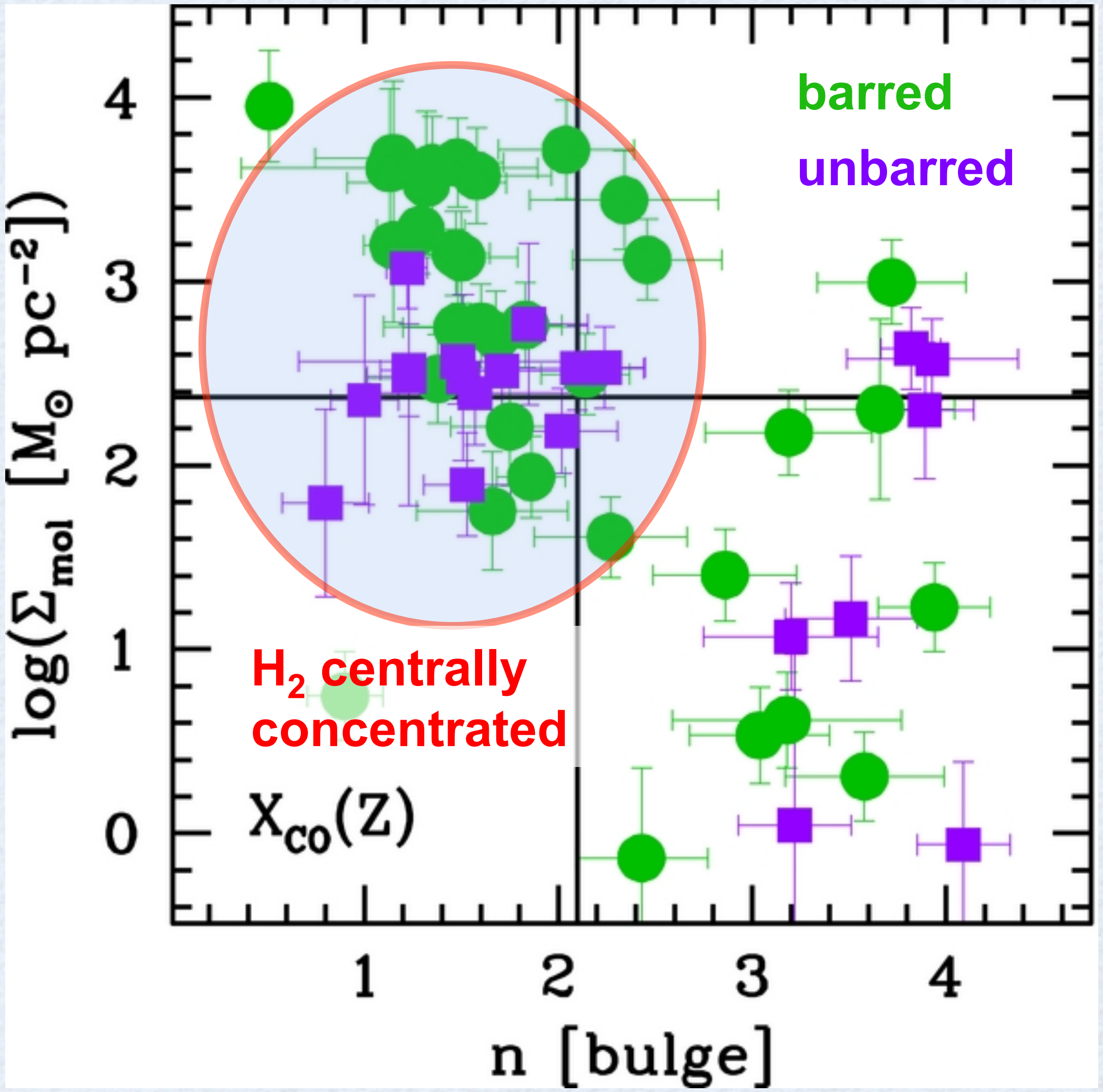
Regan+ 2001

Radial Distributions

- Bars appear to concentrate CO towards the centers of galaxies, leading(?) to formation of low Sersic index "pseudobulges".



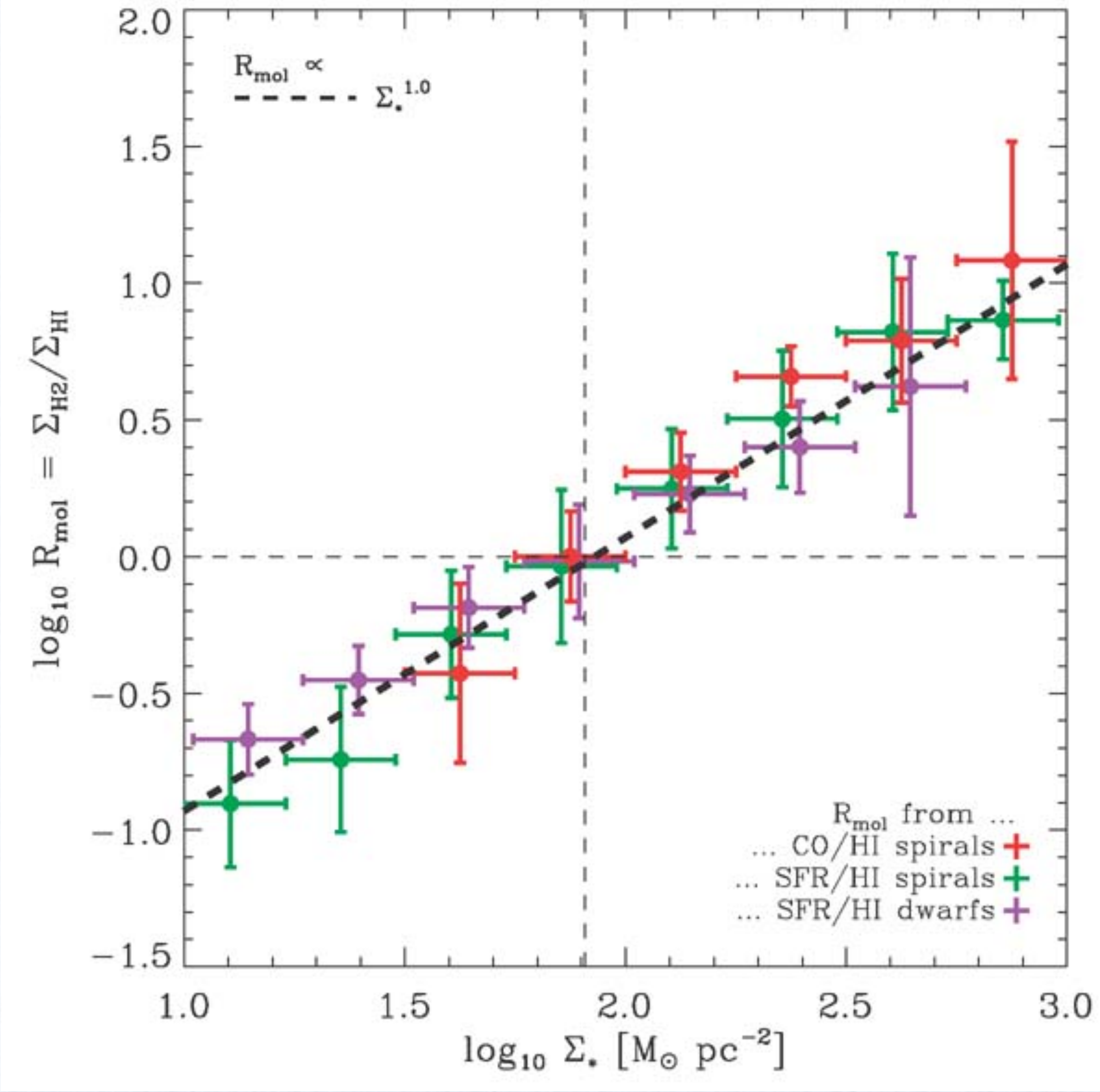
Kuno+ 2007



Fisher+ 2013

Radial Distributions

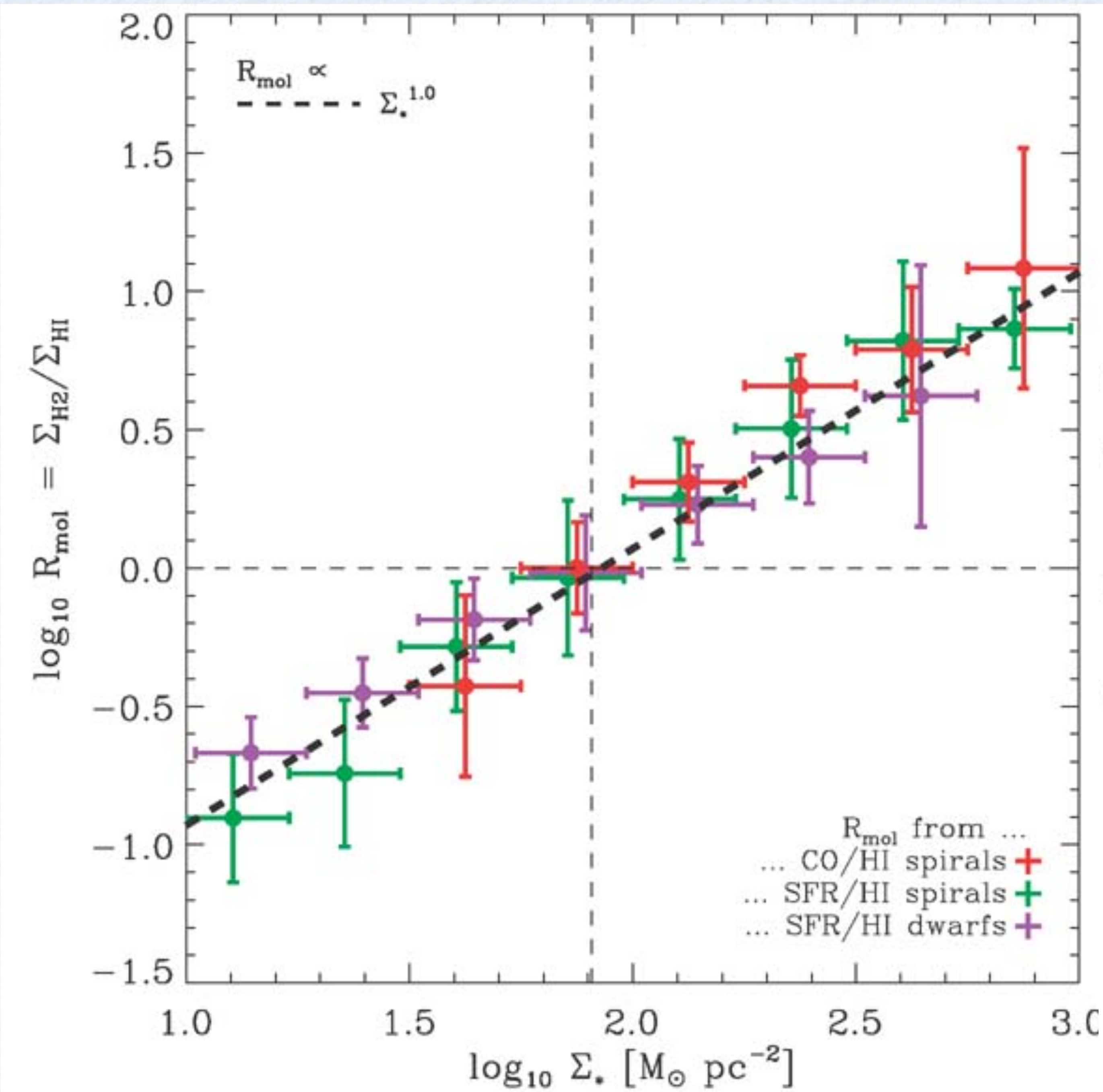
- Strong correlation of $R_{mol} = \Sigma_{H_2} / \Sigma_{HI}$ with Σ_*

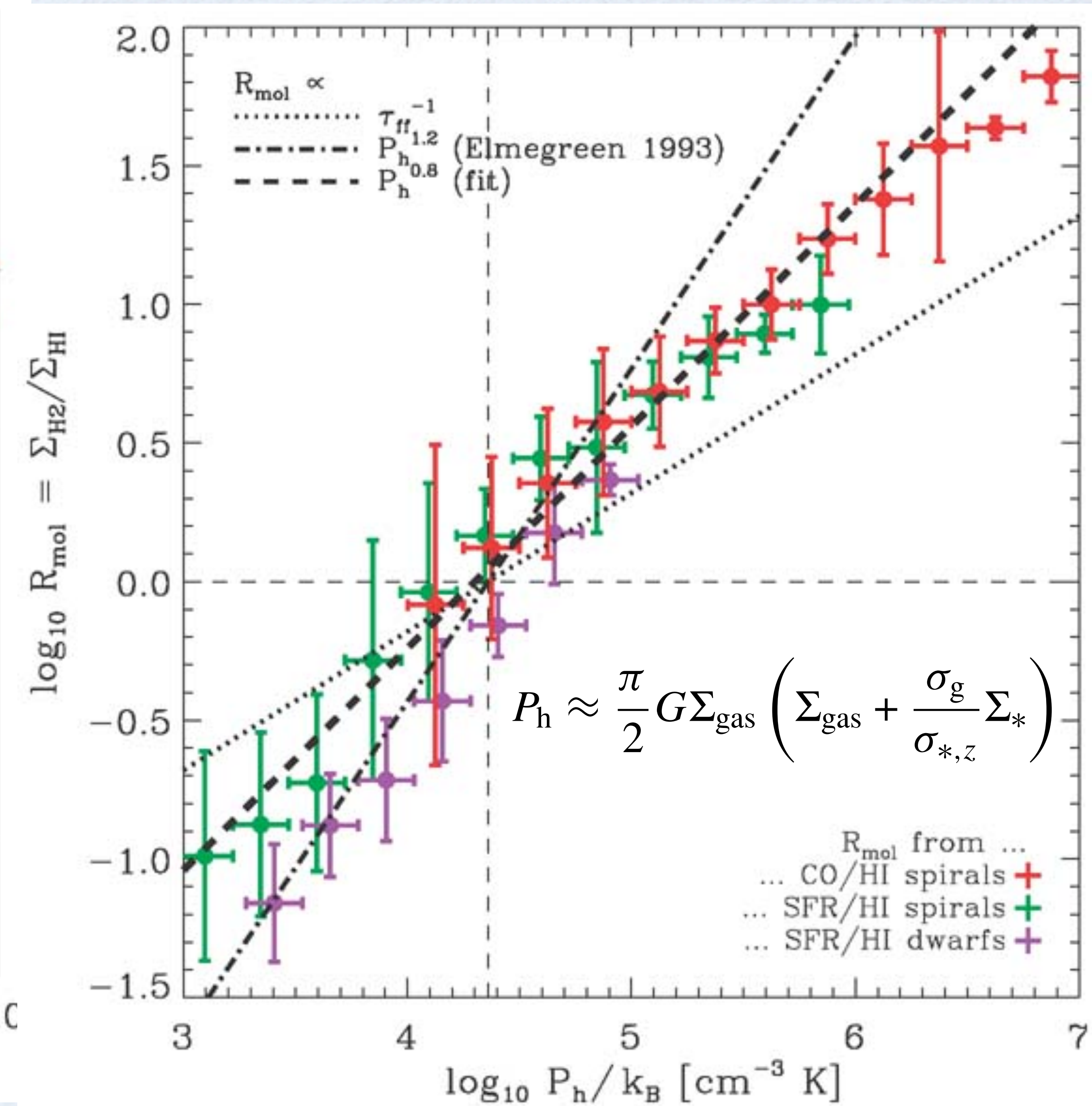


Leroy+ 2008, HERACLES

Radial distributions

- Strong correlation of $R_{mol} = \Sigma_{H_2} / \Sigma_{HI}$ with Σ_*: hydrostatic pressure?



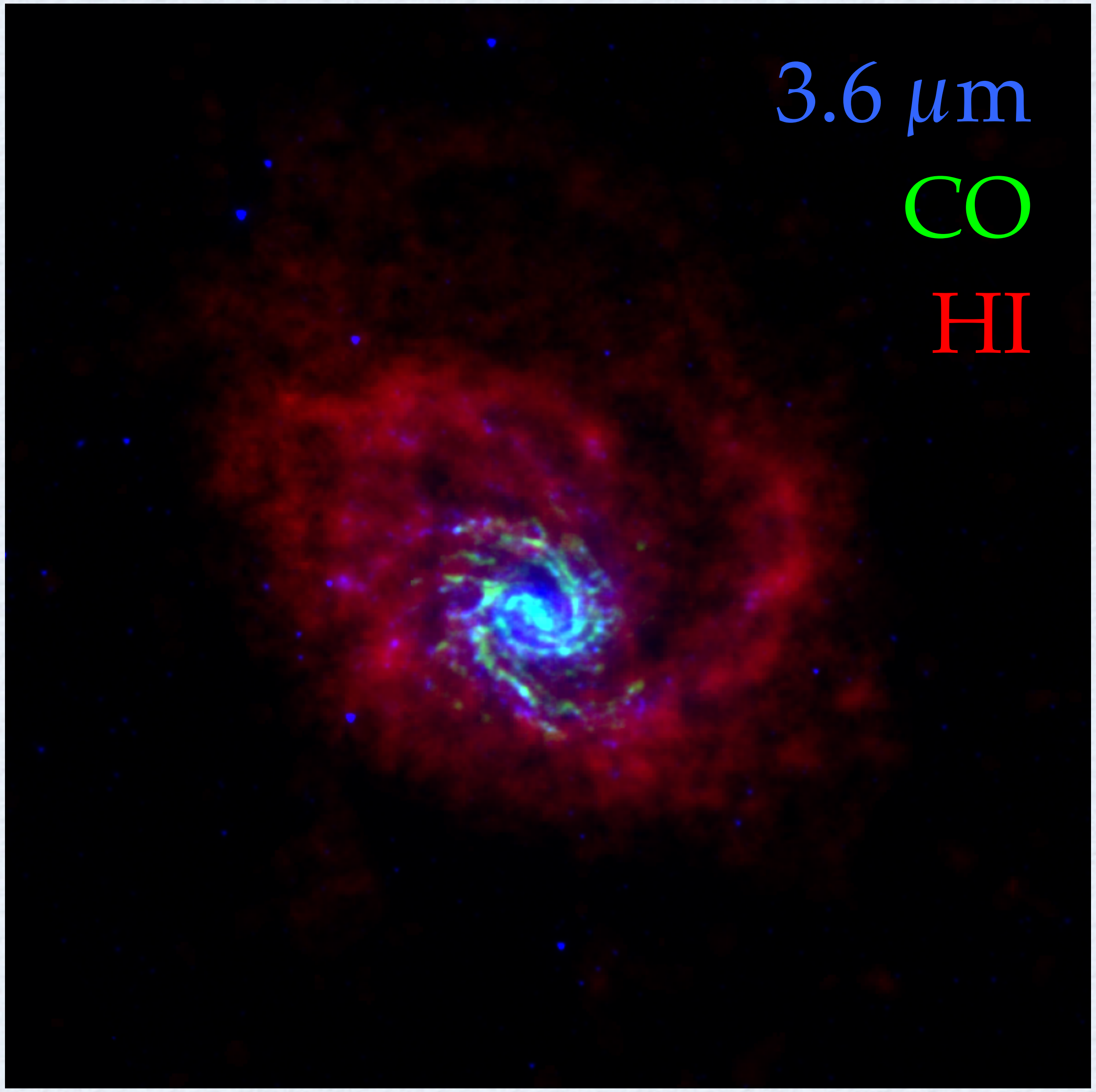


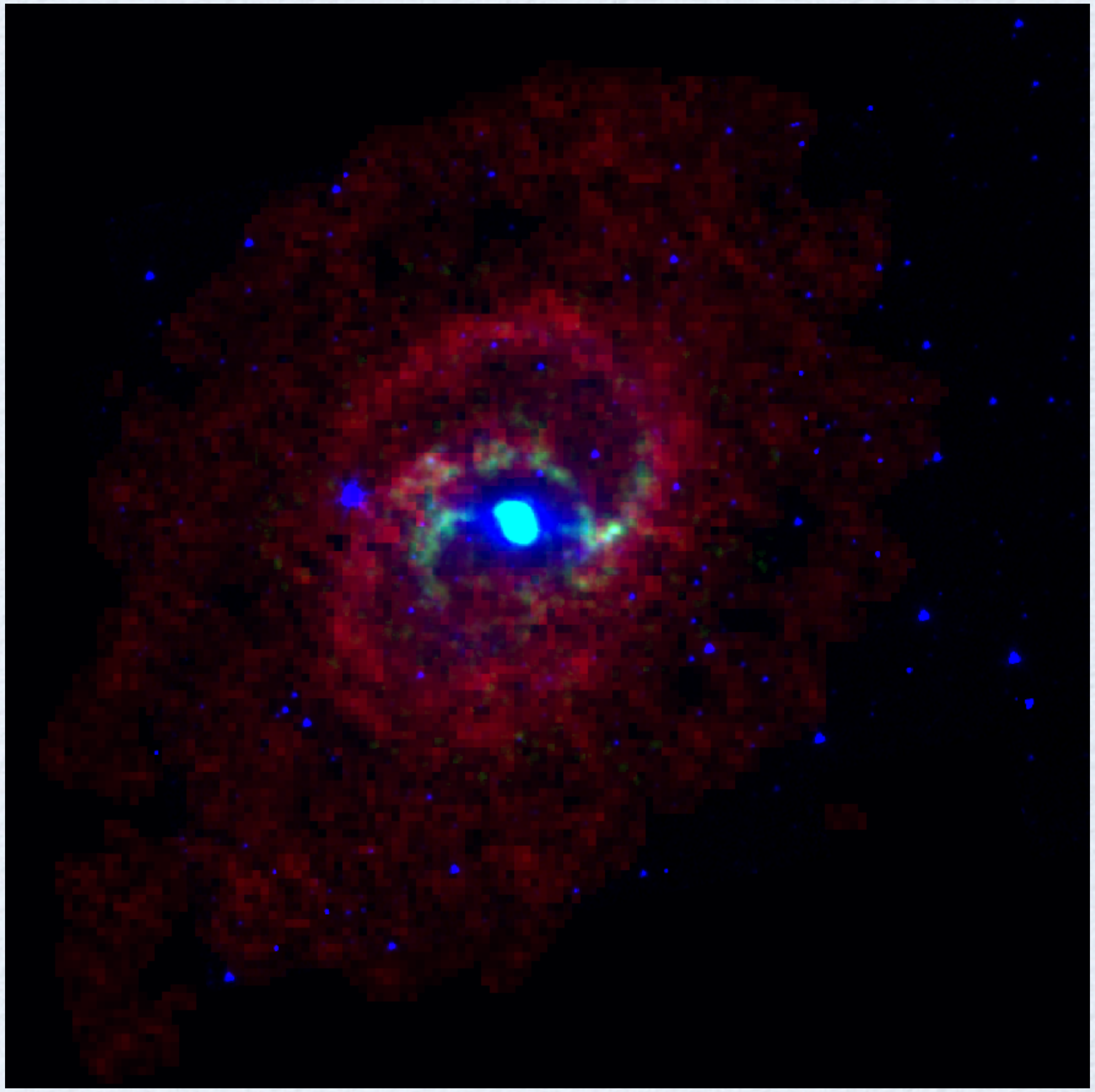
Leroy+ 2008, HERACLES

Correlation with pressure not as good!

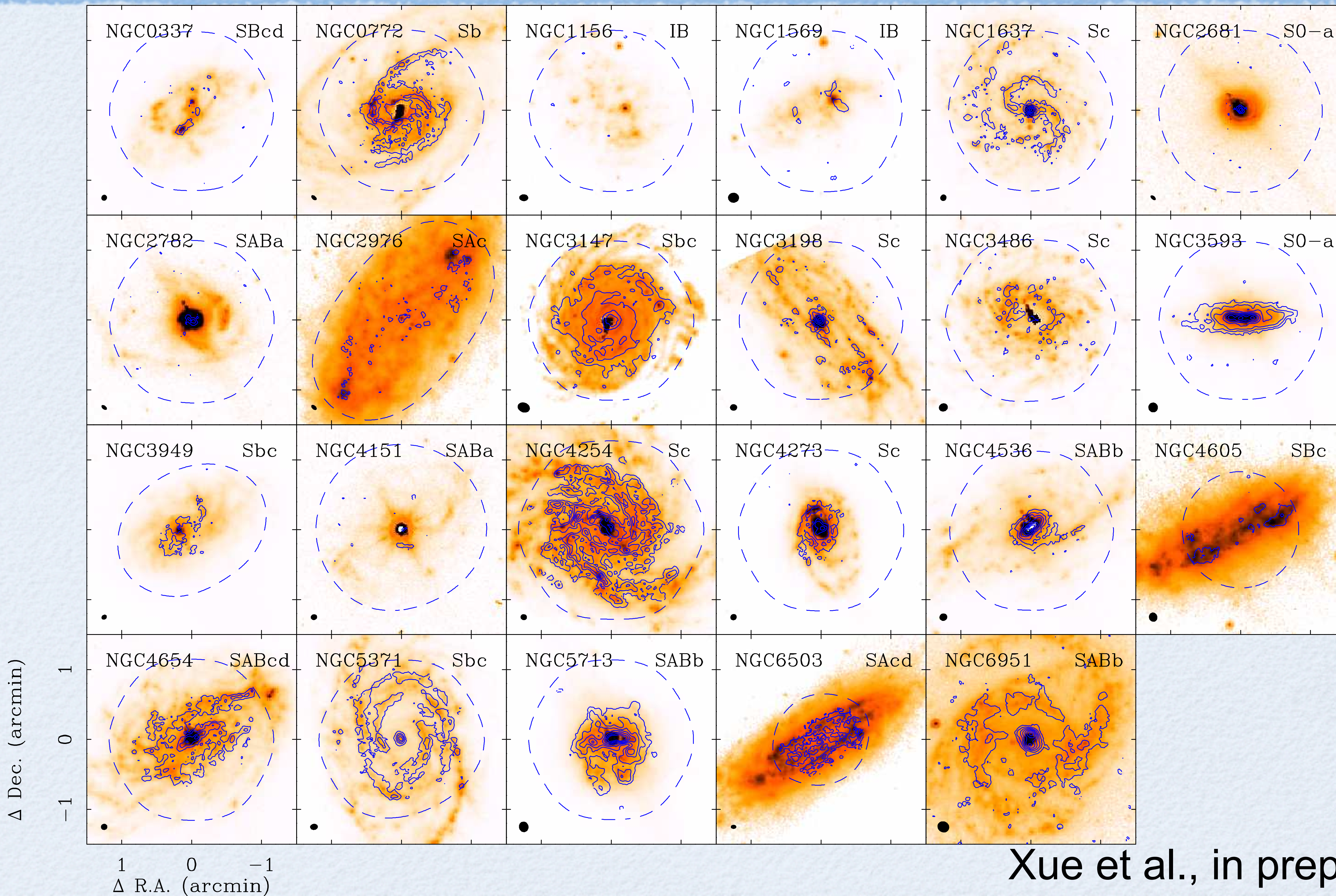
HI to H_2 Transition

- A clue to the origin of the $R_{mol} - \Sigma_*$ correlation comes from pixel by pixel comparison of CO, HI, and 3.6 μm maps for 18 galaxies in the CARMA STING project (R. Xue, PhD thesis).



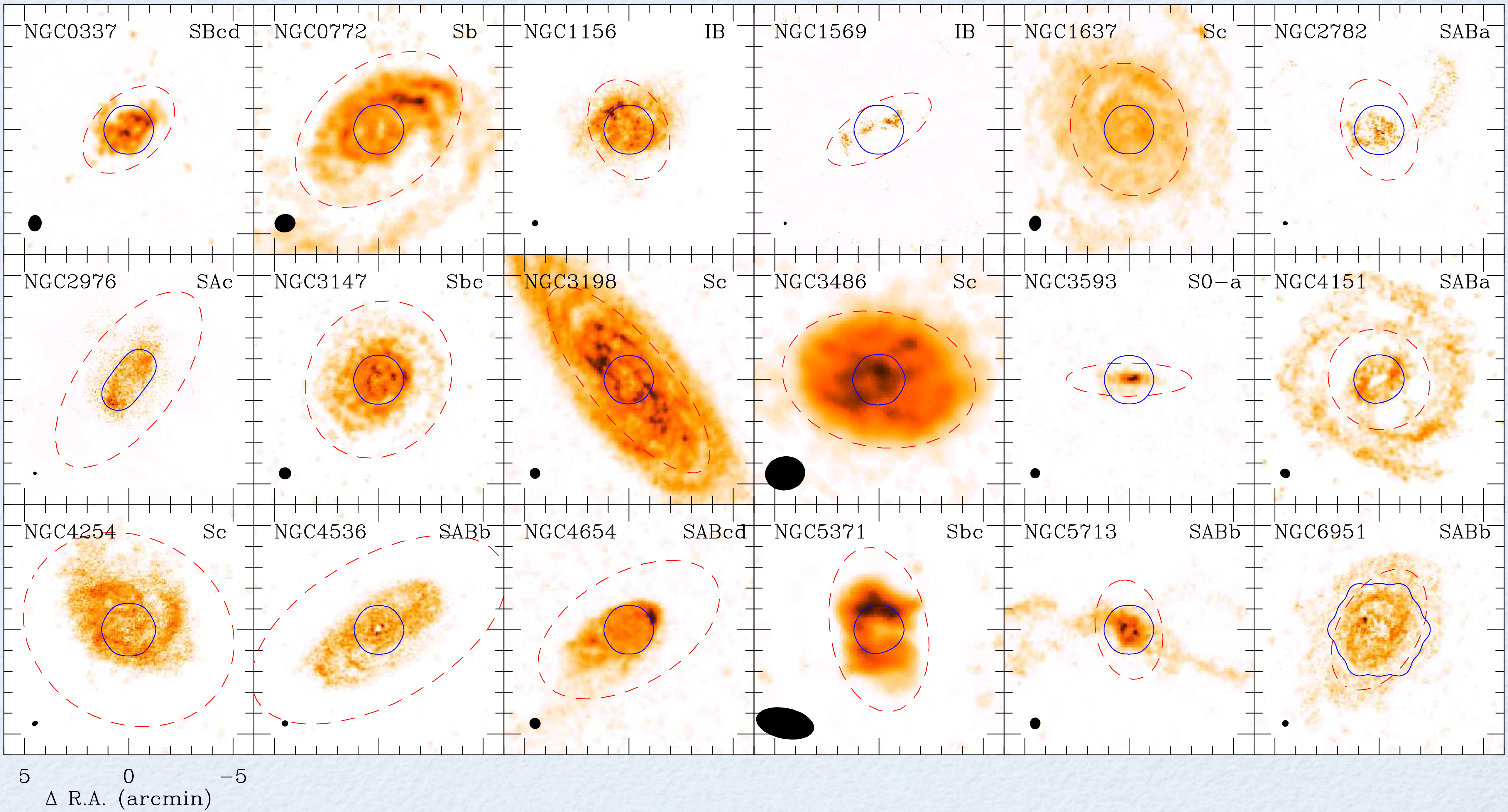


CARMA STING [CO]



Xue et al., in prep.

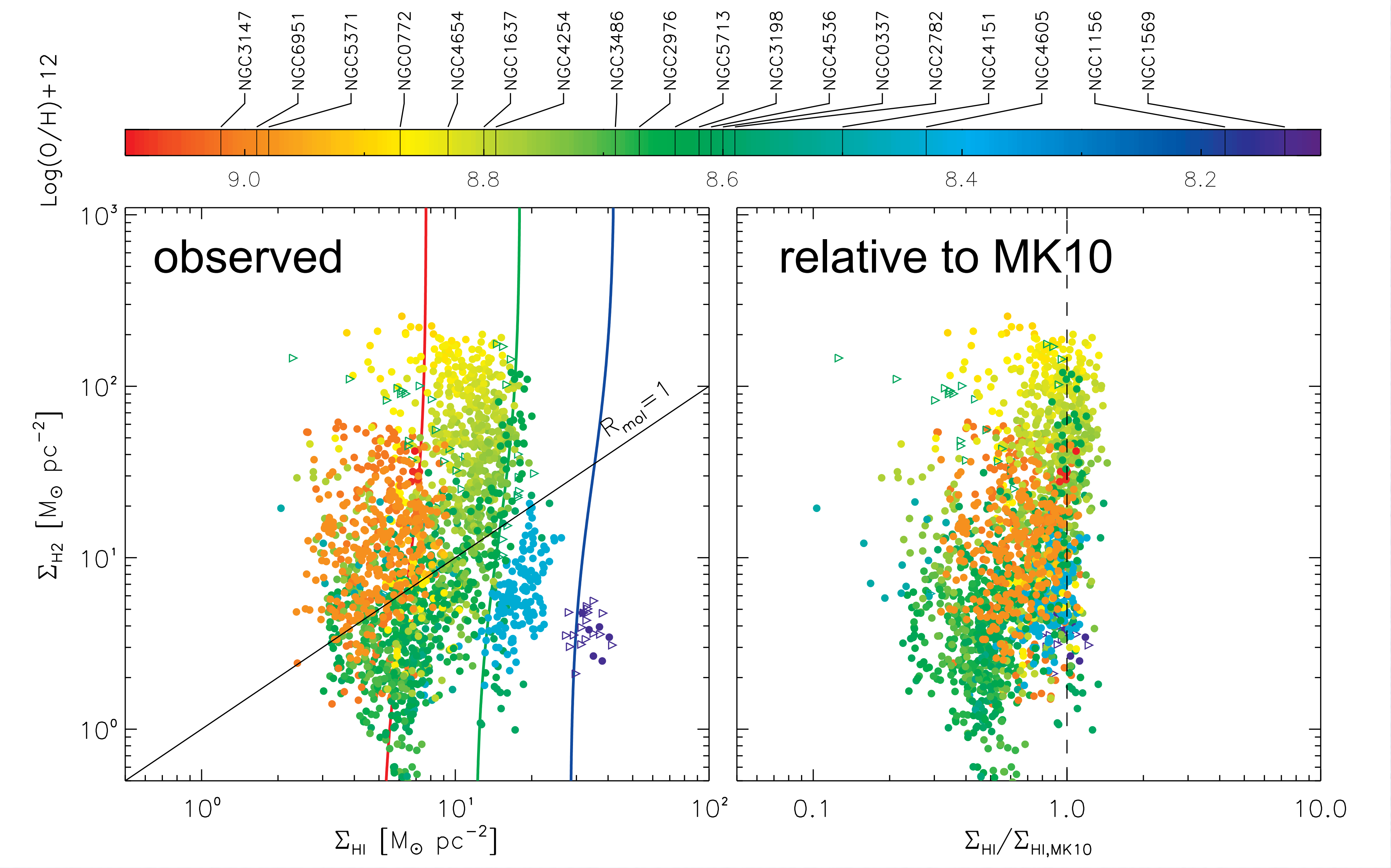
CARMA STING [HI]



Xue et al., in prep.

HI to H_2 Transition

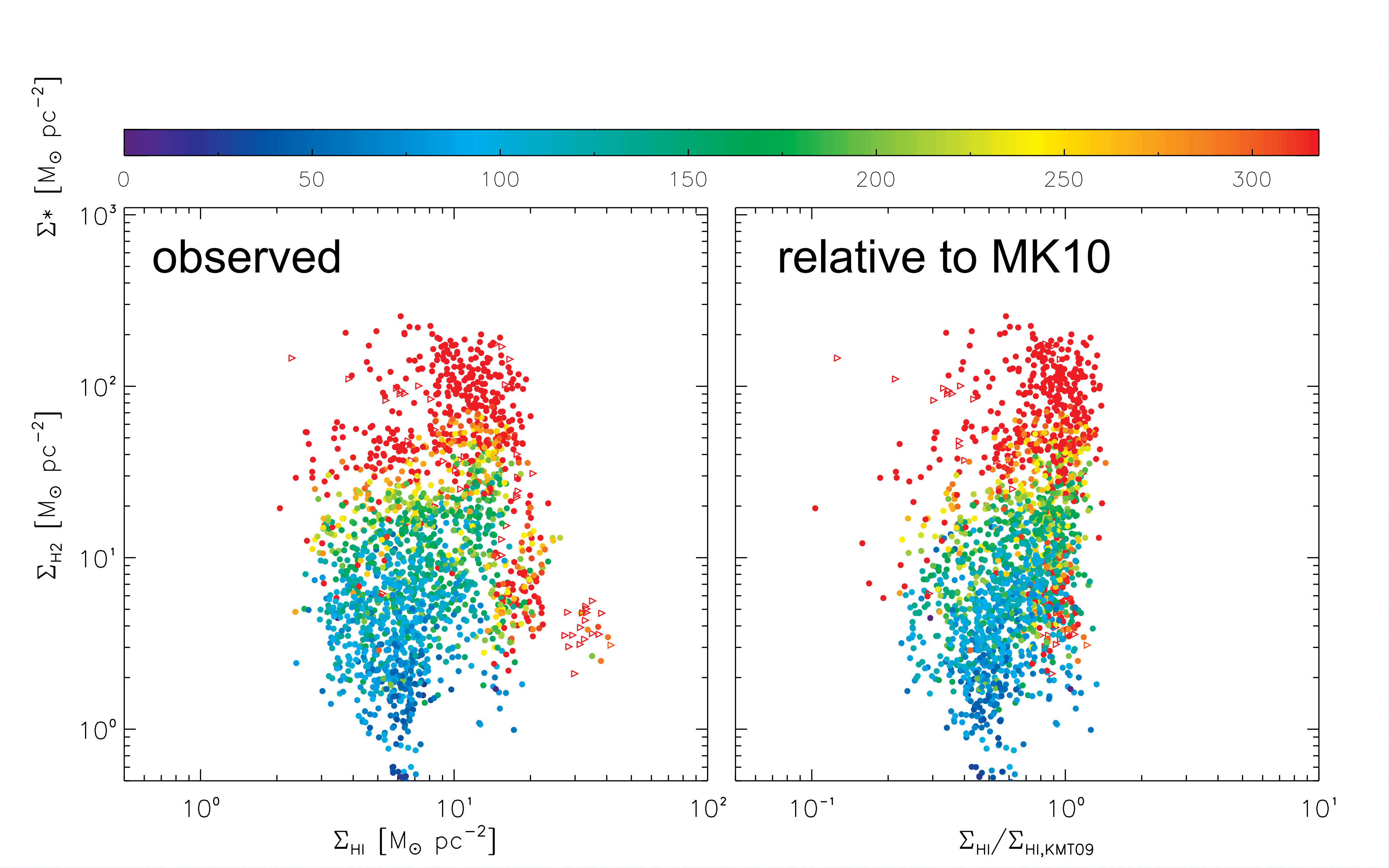
- In the regime where CO is detected, Σ_{HI} is confined to a narrow range of values that is metallicity dependent, as predicted by self-shielding models (Krumholz+ 2009).



Wong+ 2013

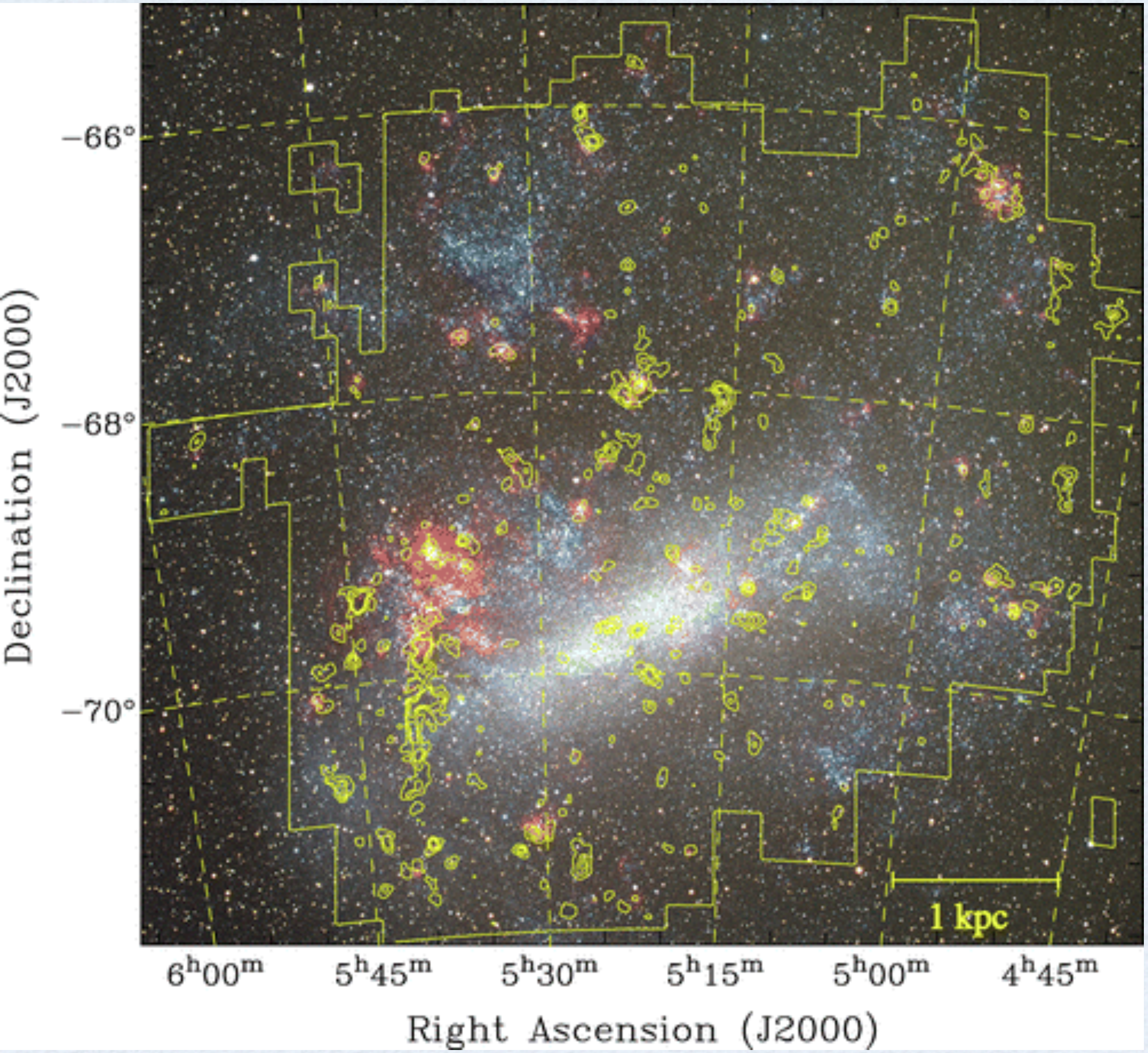
HI to H_2 Transition

- Σ_{H_2} on the other hand correlates strongly with Σ_*.
- Suggests that H_2 supply is "regulated" by the stellar disk.
- Remember that only CO-detected galaxies are considered here.

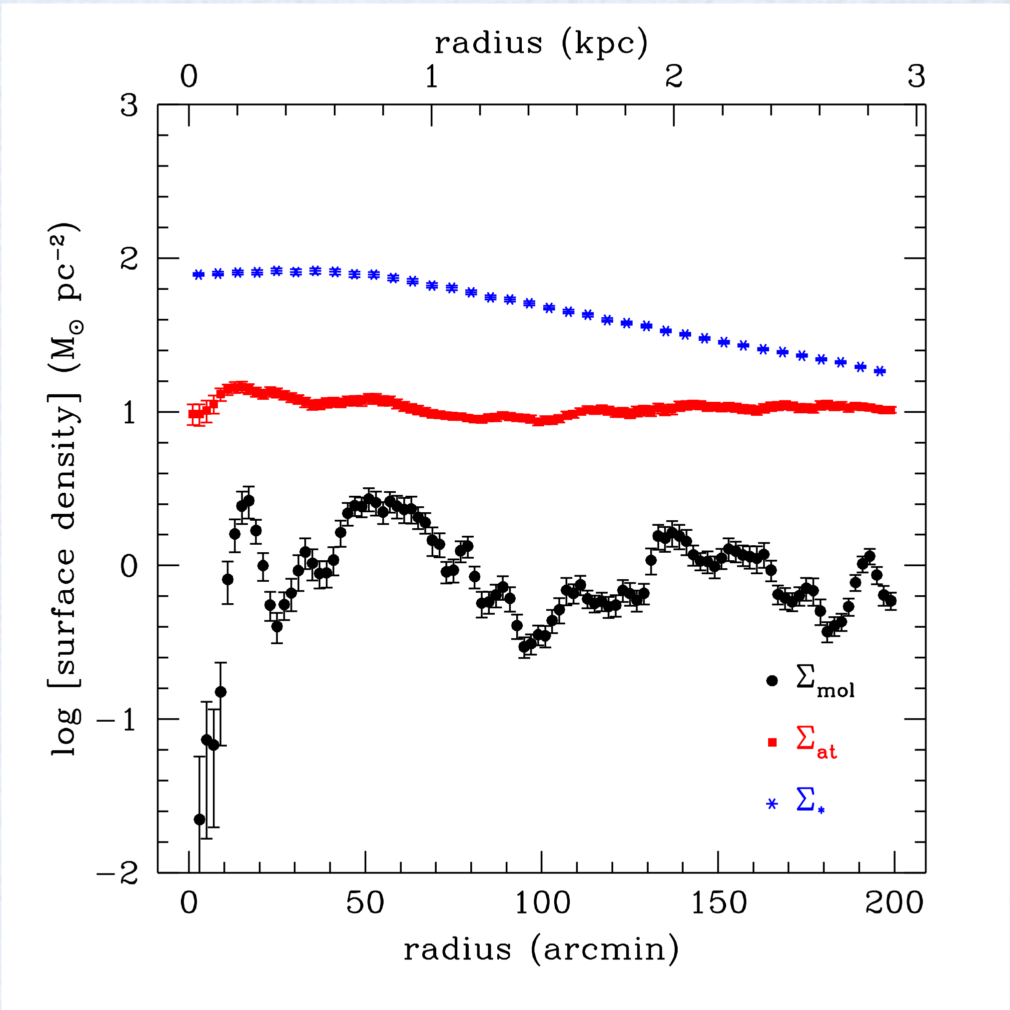


Wong+ 2013

Spirals only?



Fukui+ 2008



Wong+ 2009

But in the Large Magellanic Cloud, stellar and CO distributions are decoupled.

The Vertical ISM Distribution

Why Study Gas Thickness?

- Possibility that gas volume density is more important than surface density for star formation

$$\dot{\rho}_* = f_{\mathrm{H_2}} \epsilon_{\mathrm{ff}} \frac{\rho}{t_{\mathrm{ff}}} = f_{\mathrm{H_2}} \epsilon_{\mathrm{ff}} \sqrt{\frac{32 G \rho^3}{3\pi}},$$

Krumholz, Dekel & McKee 2012

- Midplane hydrostatic pressure depends on vertical distributions of the gas and stars

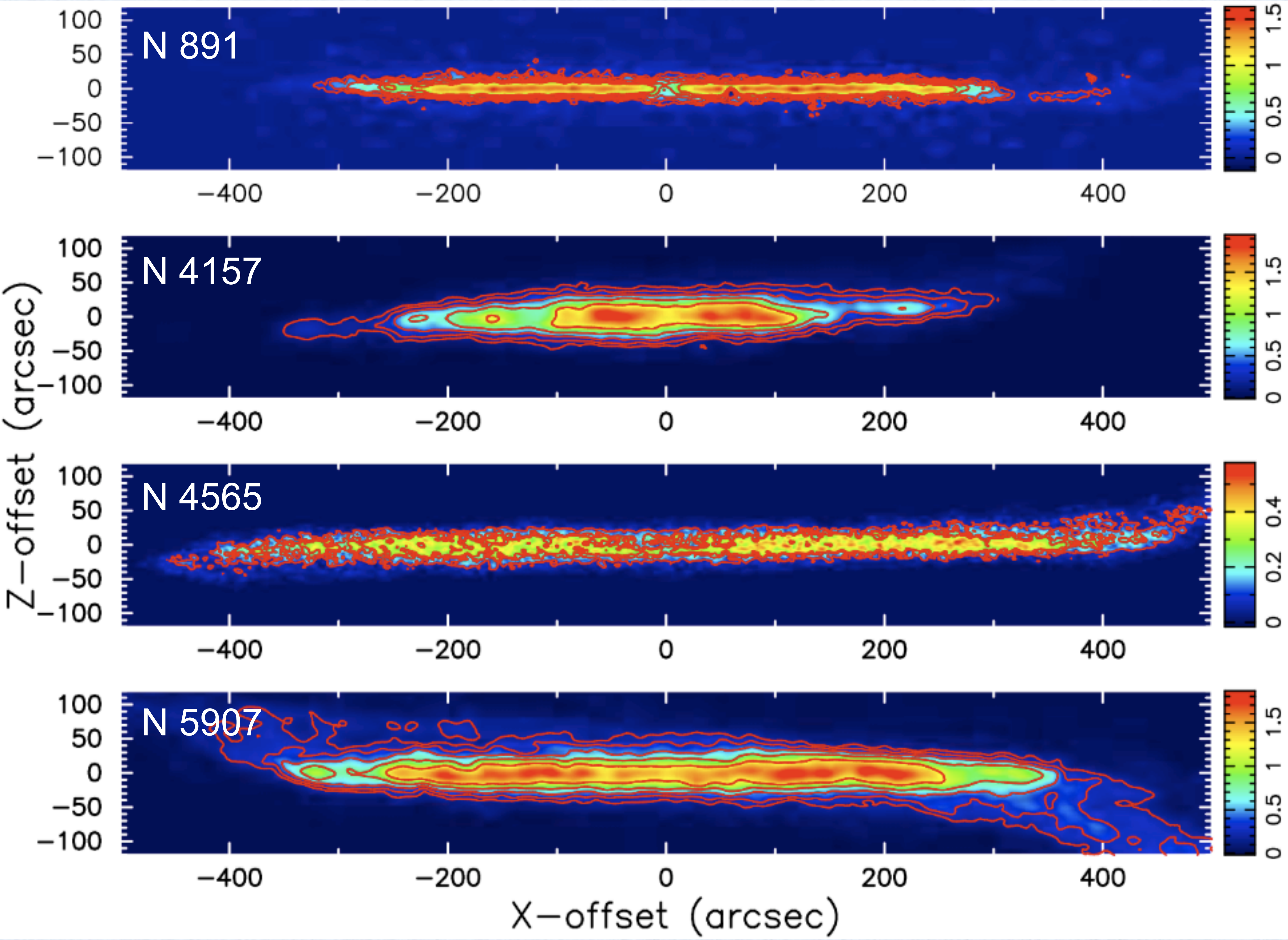
$$P_{\mathrm{ext}} = 0.84 (G\Sigma_\star)^{0.5} \Sigma_g \frac{v_g}{(h_\star)^{0.5}}$$

Blitz & Rosolowsky 2006

$$P_{\mathrm{mp}} \approx \frac{\pi}{2} G \Sigma_{\mathrm{HI}}^2 + \pi G \Sigma_{\mathrm{HI}} \Sigma_{\mathrm{H_2}} + 2\pi \zeta_d G \frac{\rho_{\mathrm{sd}}}{\rho_{\mathrm{mp}}} \Sigma_{\mathrm{HI}}^2$$

Ostriker+ 2010 via Krumholz 2013

EDGE-ONS: HI DATA

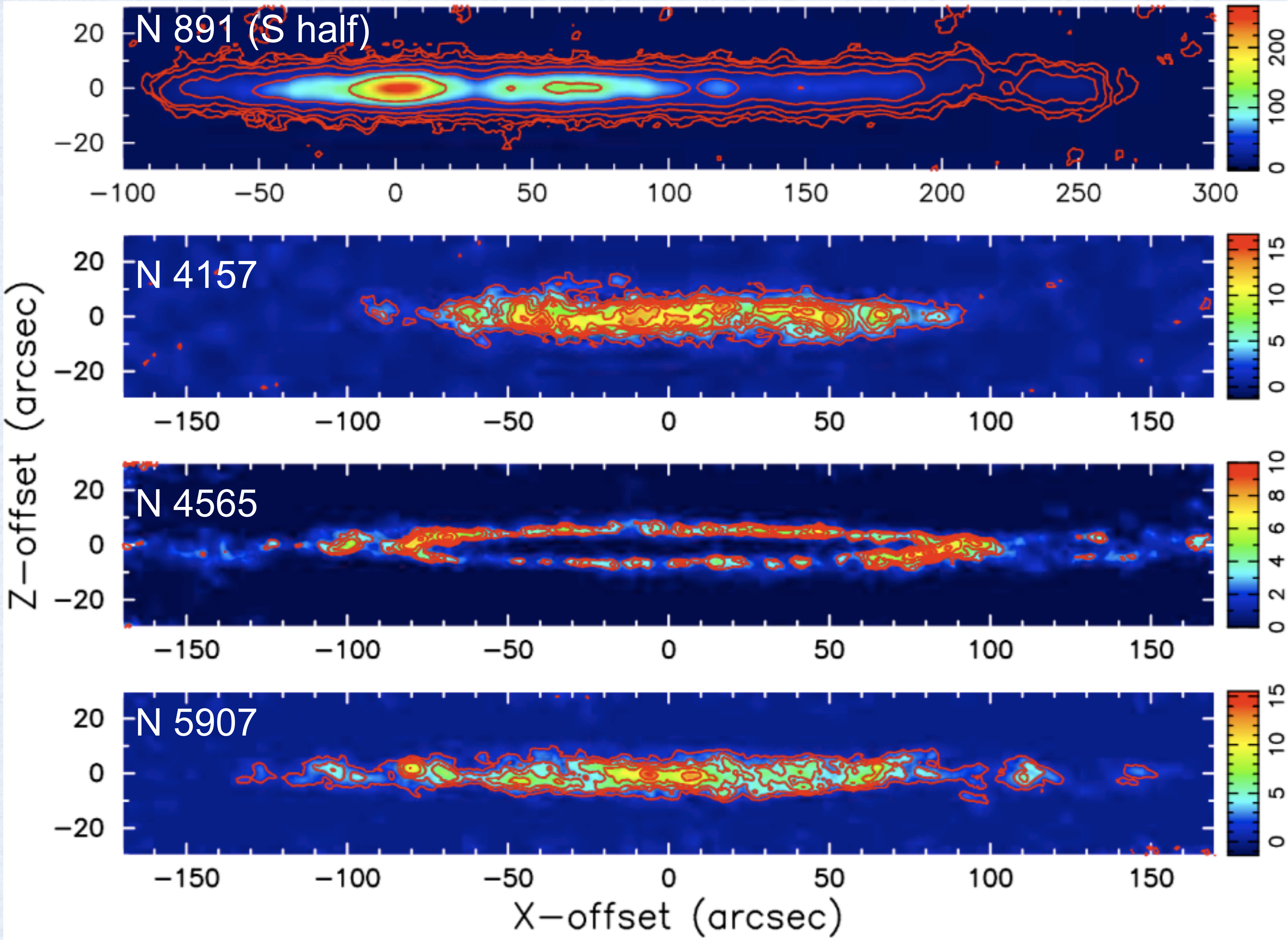


VLA

Typical resolution: 15” (750 pc)

Kijeong Yim PhD 2012

Edge-ons: CO data



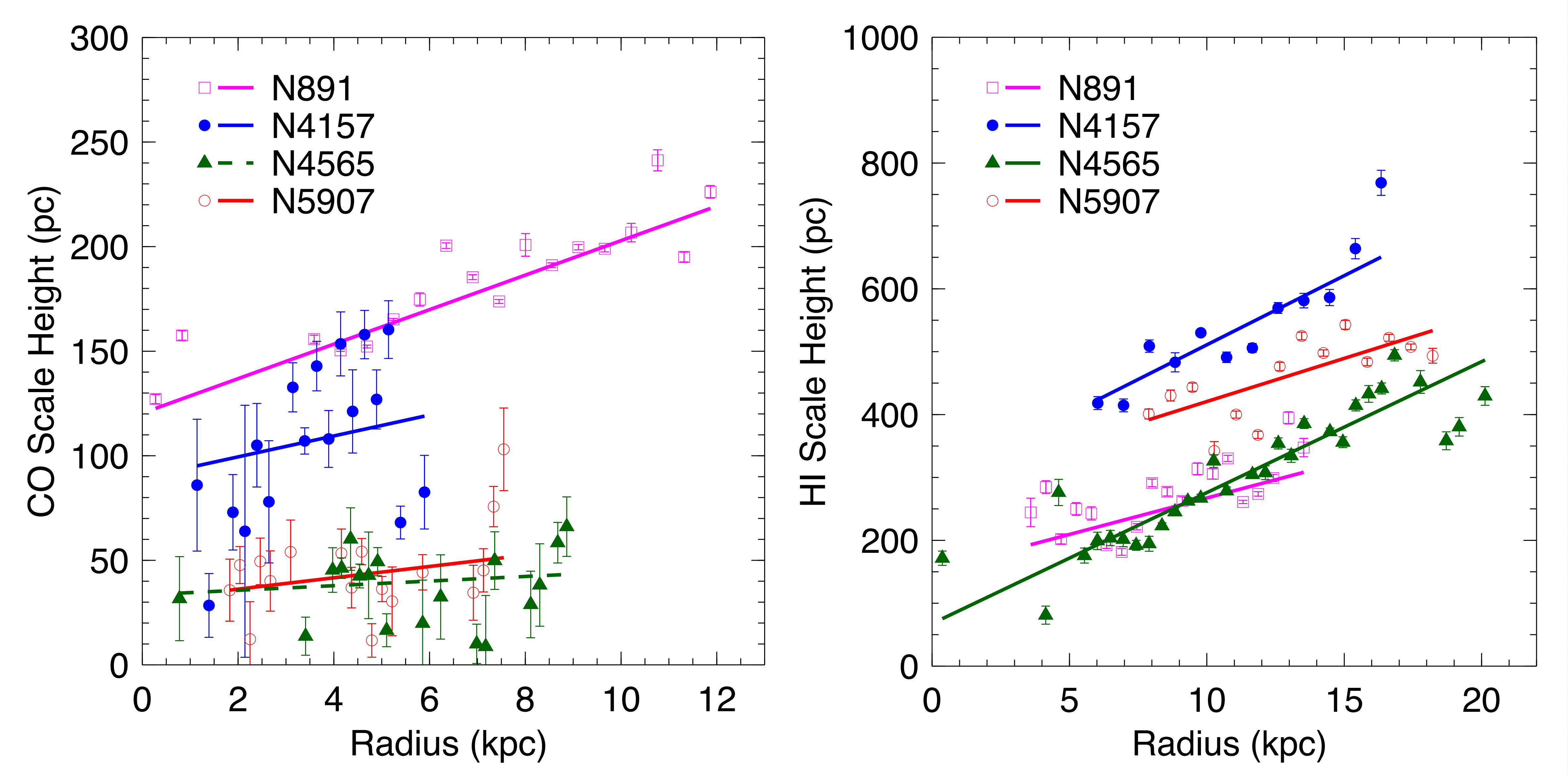
BIMA, CARMA

Typical resolution: 3” (150 pc)

Kijeong Yim PhD 2012

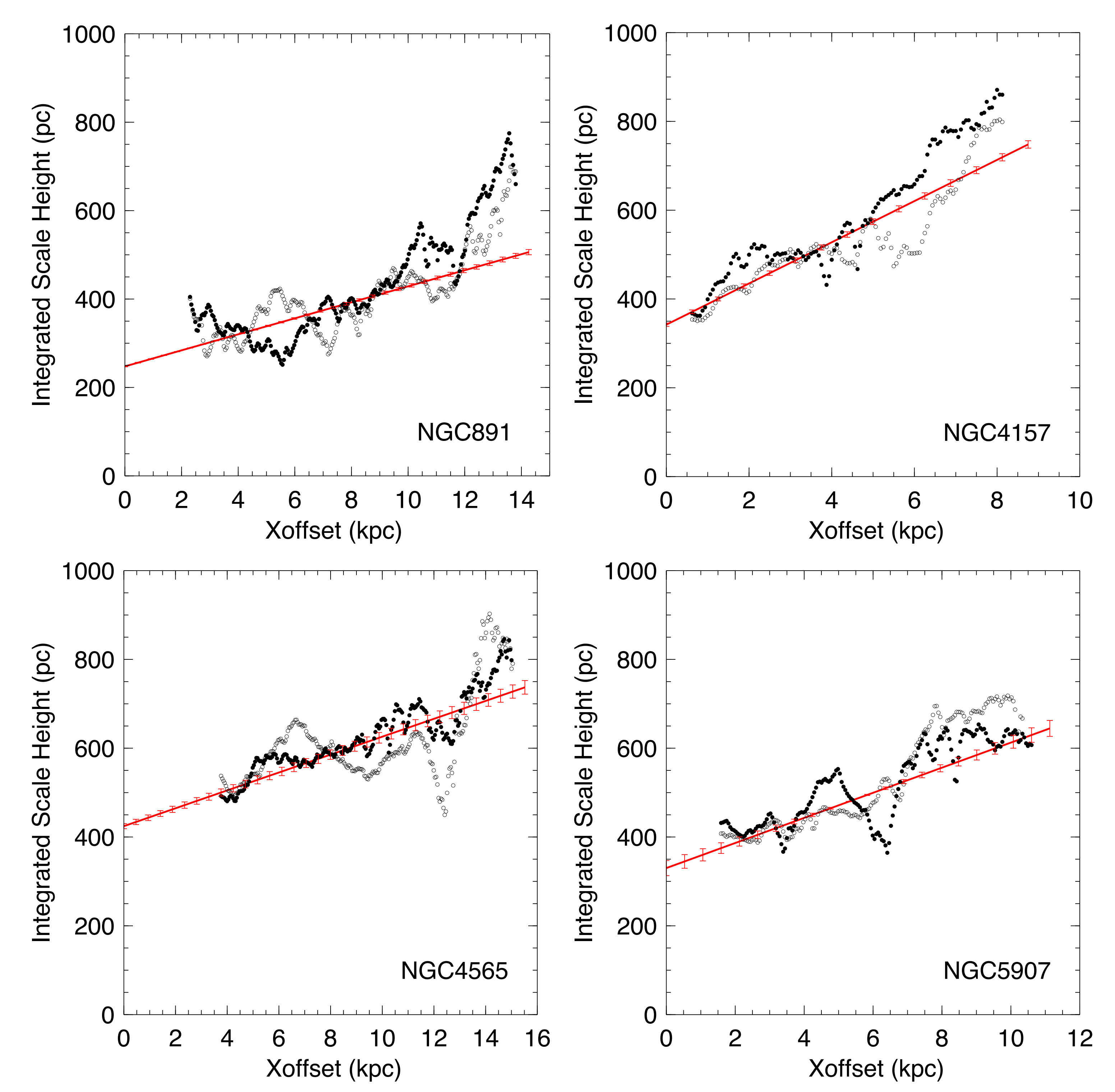
DISK FLARING

- CO disk flaring modest, needs confirmation in most cases
- HI disk flaring more prominent (change in CNM/WNM mix?)



Yim+ 2014 submitted

Disk Flaring

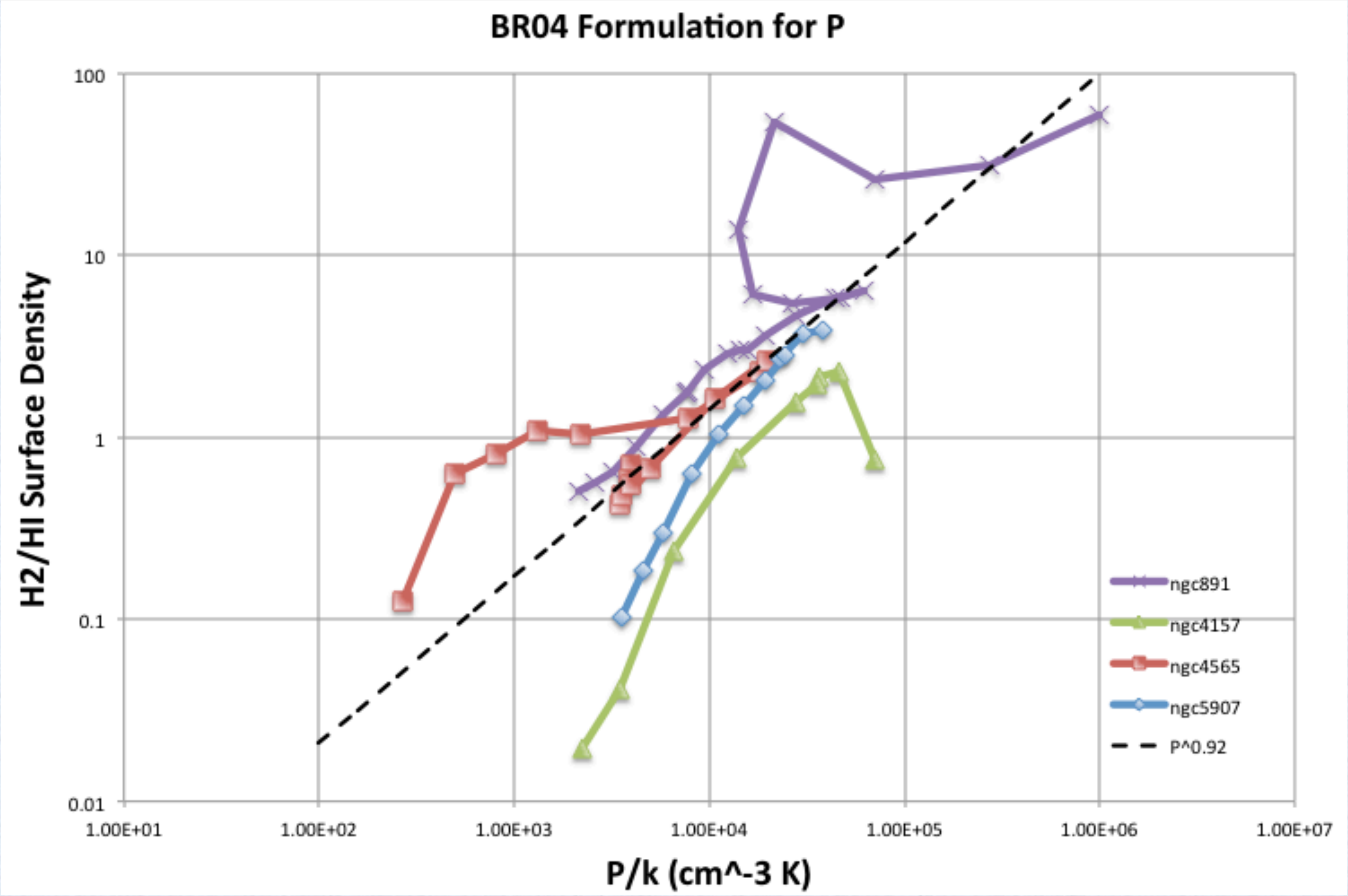


Yim+ 2014 submitted

Stellar disk flaring also seen in Spitzer 3.6 μm imaging, contrary to usual expectation of a constant scale height.

H_2/HI and Pressure

- How do different pressure estimates relate to the atomic-molecular balance?



H_2/HI and Pressure

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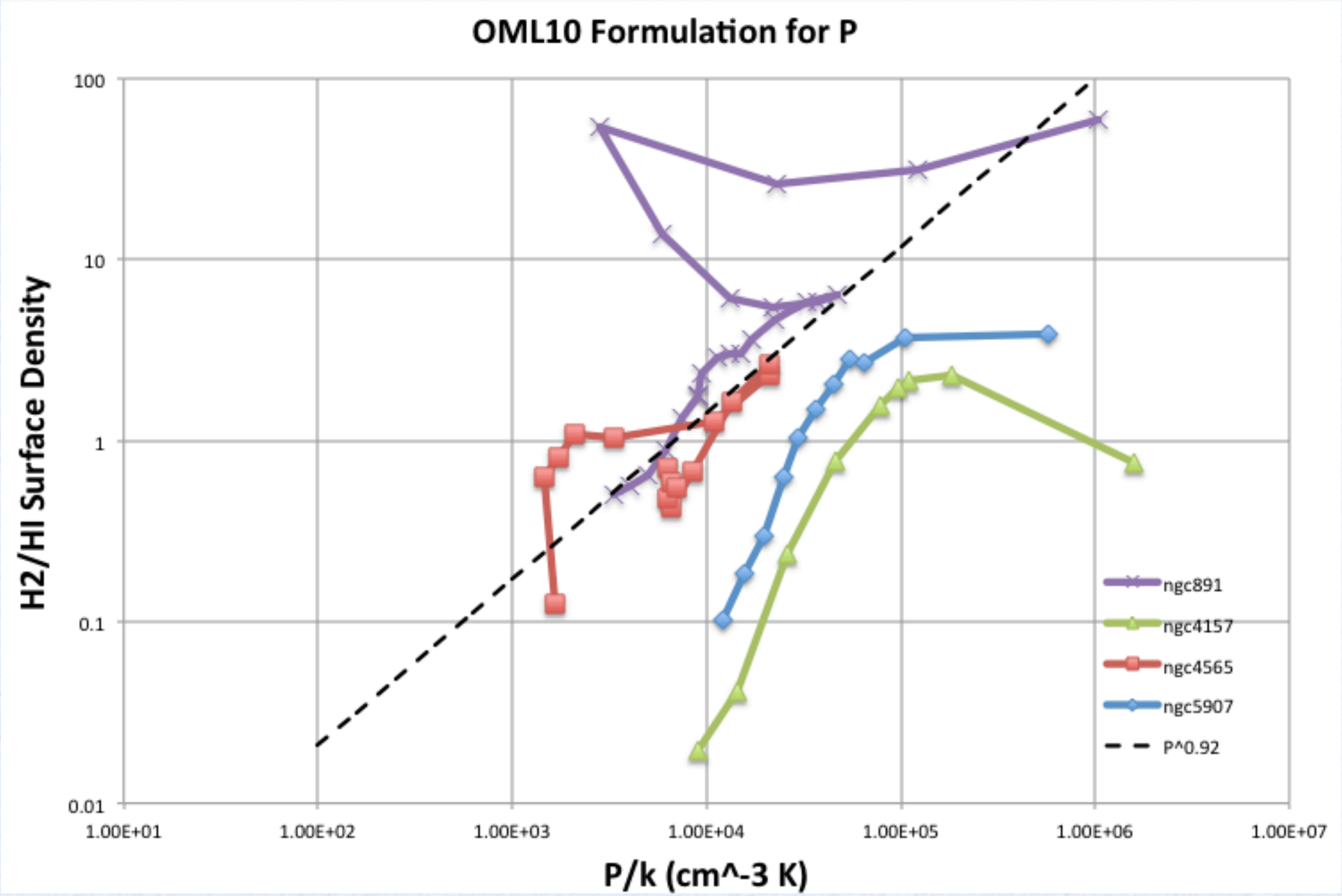
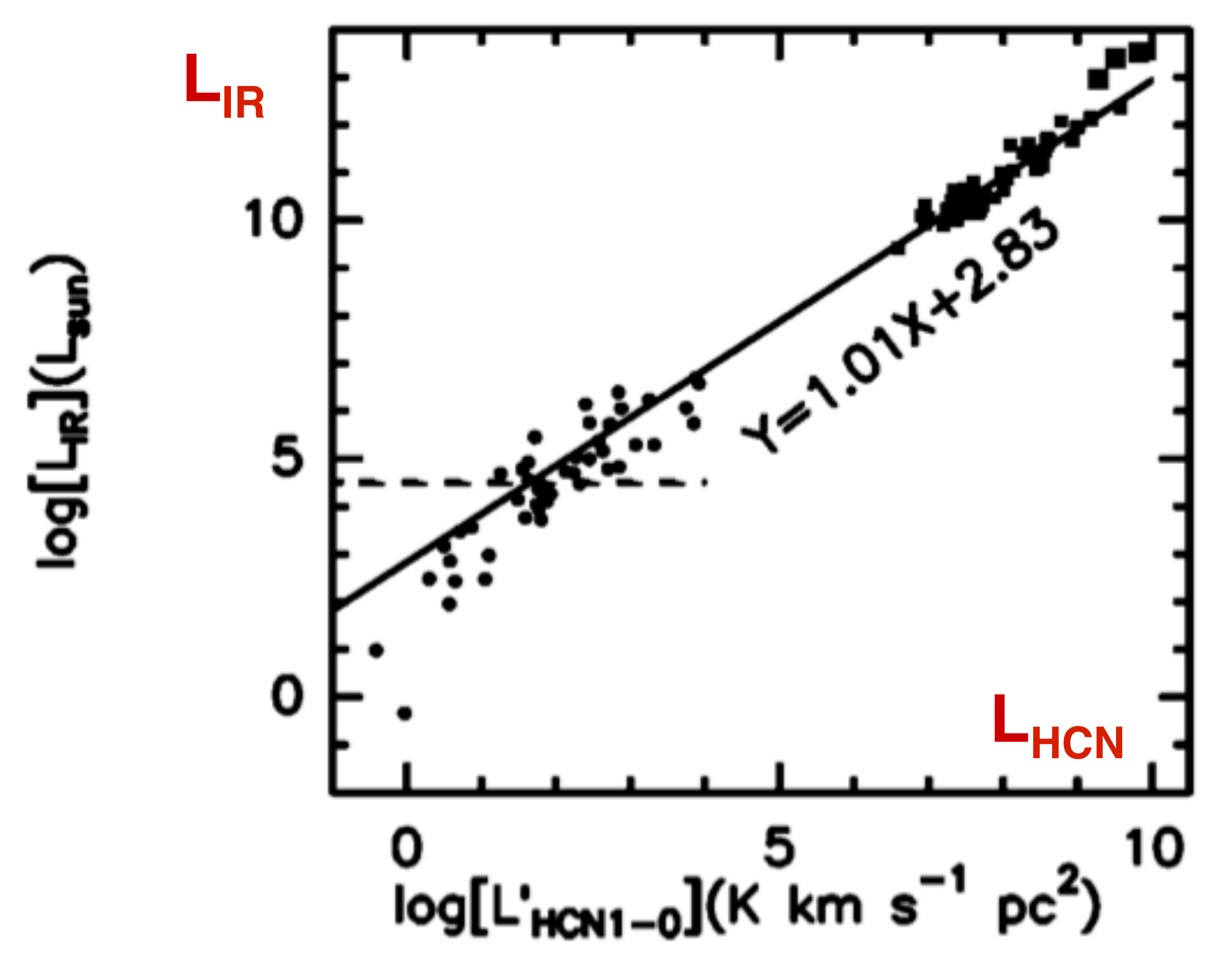


Thinking about Star Formation Relations

Beware richness effects

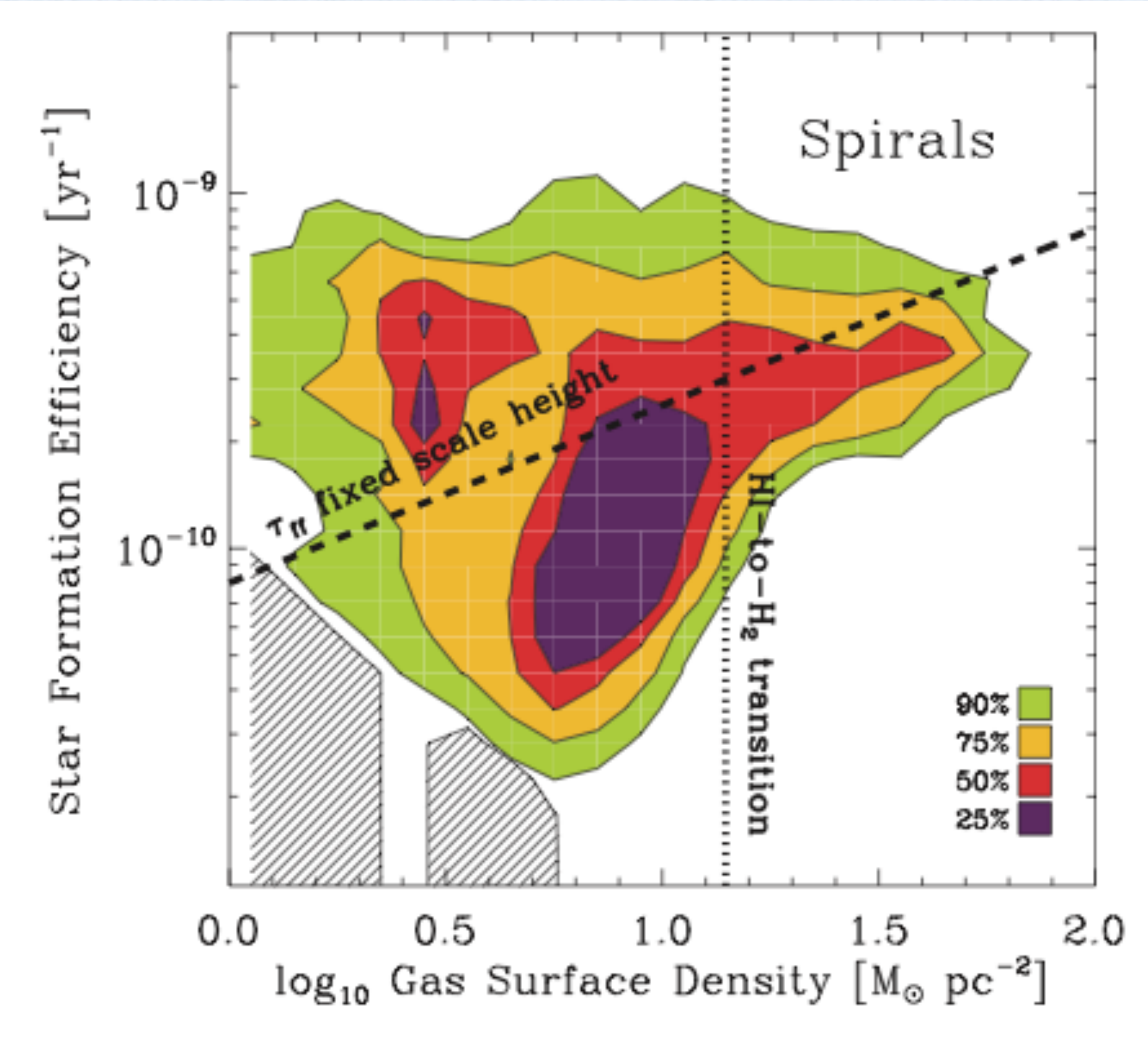
- Although normalized by area, Σ is still essentially a mass measurement.
- Inner parts of galaxies will have more of everything!



Wu+ 2005

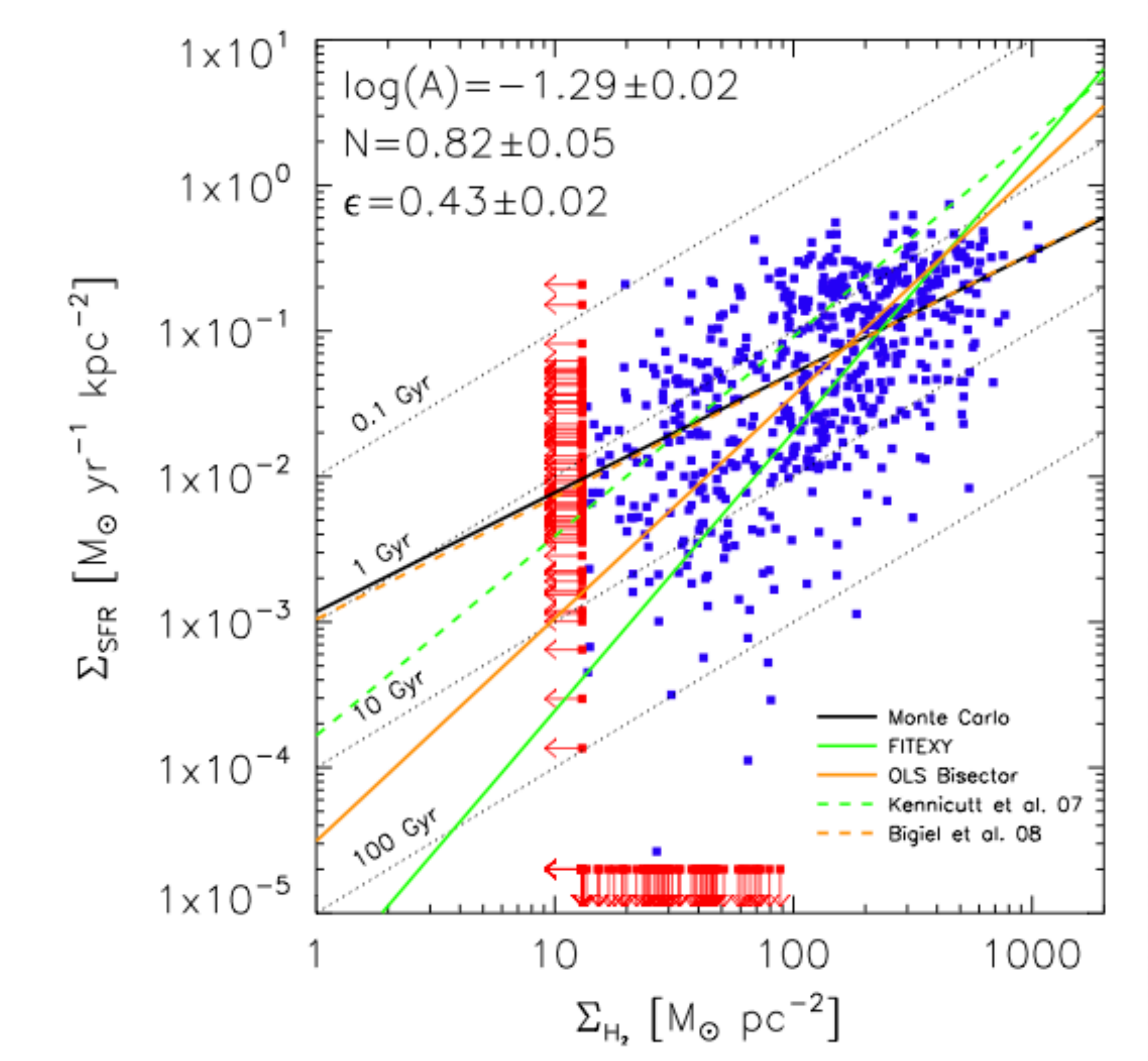
DON'T INCLUDE THE HI

- When Leroy et al. removed the richness effect by normalizing the SFR by the gas mass, the residual correlation with gas was virtually non-existent.



Leroy+ 2008

Beware Non-Detections



Blanc+ 2009

- Even "molecular" SF law shows large scatter
- Groups get discrepant results working on the same data!
- Green line: discard upper limits, slope=1.9

Summary

- Observationally, H_2 in CO-bright spirals is strongly coupled to stellar surface density, leading to in-plane CO distributions very distinct from HI.
- On the other hand, the H_2 disk is much thinner than the stellar disk, suggesting any coupling may be indirect (e.g. related to disk dynamics).
- Midplane gas pressure is a strong contender for underlying this coupling, but R_{mol} correlates more poorly with it than with Σ_* alone.

$$P_0 = \frac{1}{2}\Sigma_g \sigma_g \left[\pi G \left(\frac{\Sigma_g}{\sigma_g} + \frac{\Sigma_*}{\sigma_*}\right)\right]$$

vertical oscillation freq ~ Ω/Q_{eff}