Durham University

ICC Institute for Computational Cosmology

"Cosmic evolution of the gas content of galaxies"

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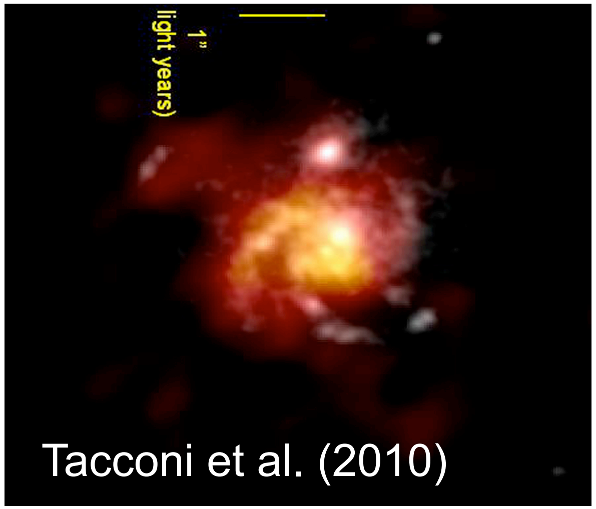
Useful theoretical tool to predict galaxy evolution in CDM structures:

Semi-analytic models

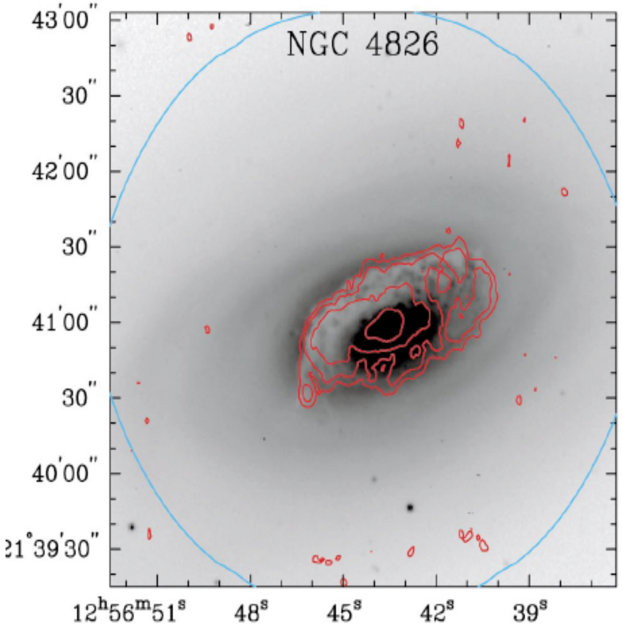
(i) All **relevant physics** included shaping galaxy evolution.

(ii) ***Model gas content/star formation in a self-consistent scenario.***

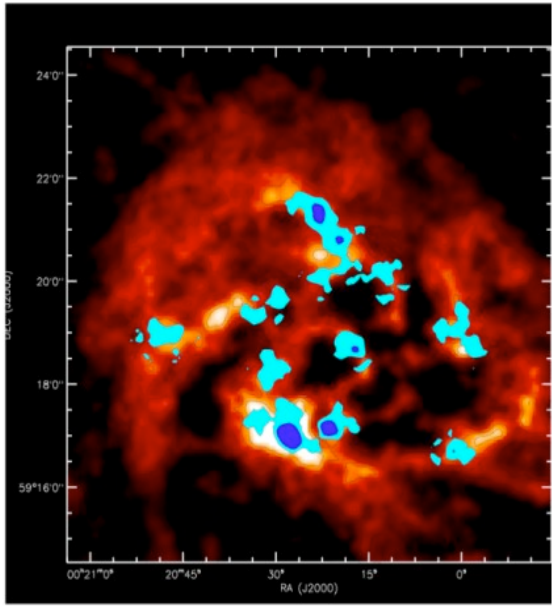
CO(3-2) and I-band



CO(1-0) and optical



BIMA-SONGS



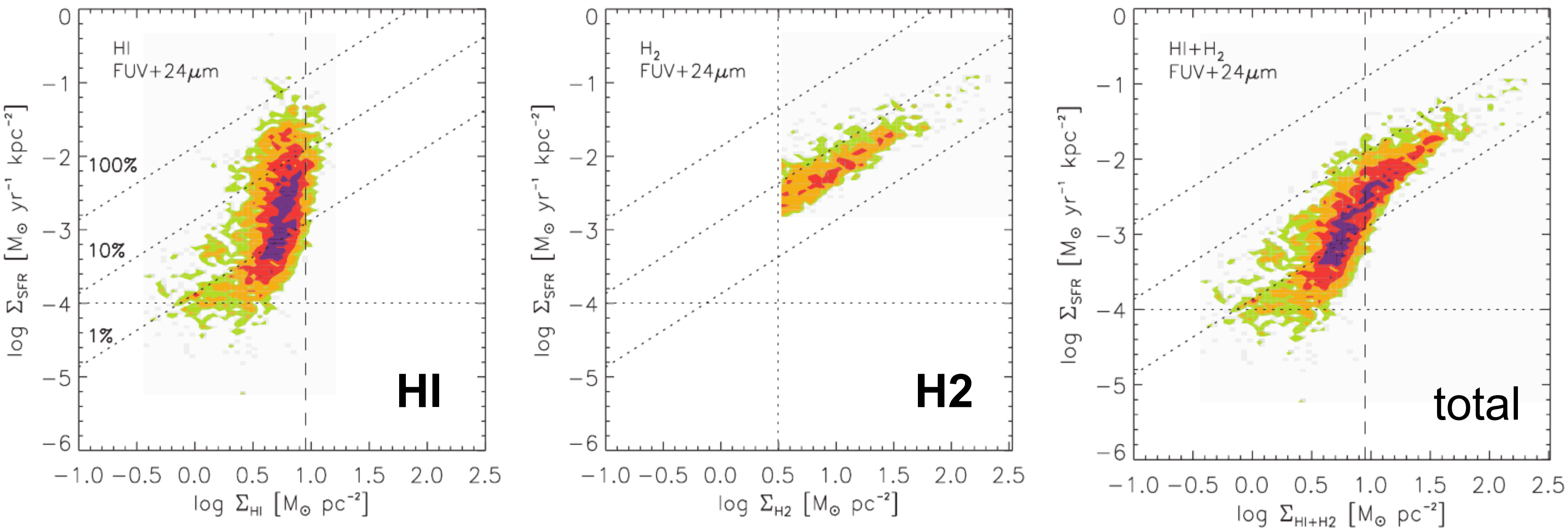
THINGS+CO

GALFORM: Cole et al. (2000), Baugh et al. (2005), Bower et al. (2006), Lagos et al. (2011)

Characterisation of the SF law in local galaxies

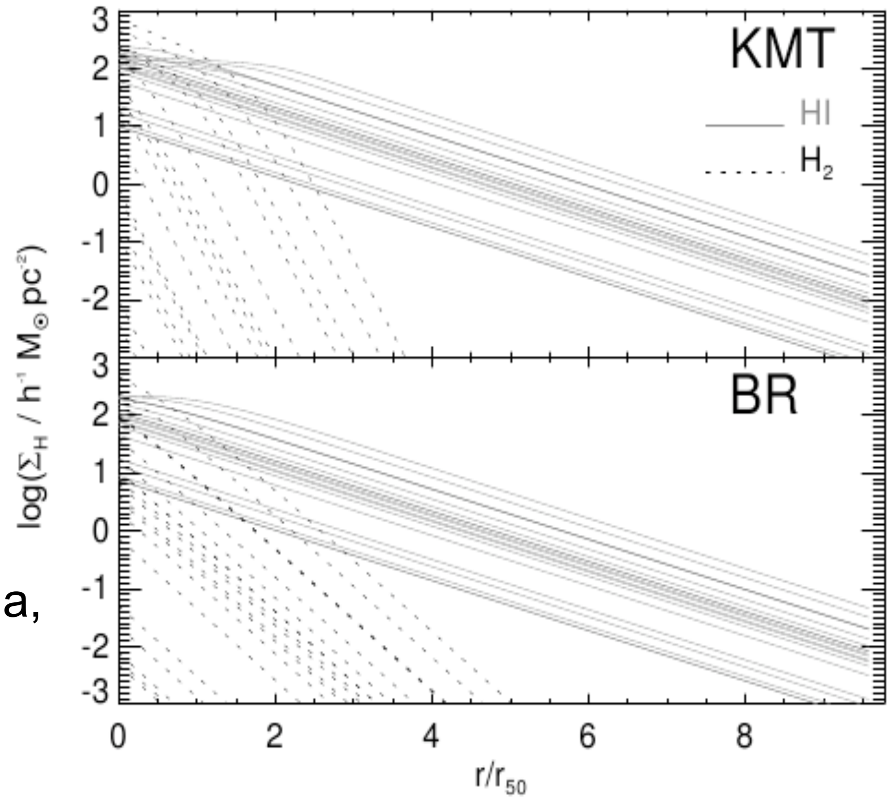
Bigiel et al. (2008): 18 late-type (THINGS, HERACLES, BIMA-SONGS, Spitzer, GALEX)

Kennicutt et al. (2007), Wyder et al. (2009), Roychowdhury et al. (2009), Onodera et al. (2010), Schruba et al. (2010, 2011), Bigiel et al. (2011), etc.



- No correlation with HI
- Linear correlation with H_2
- Multiples regimes with total gas density

New SF laws: Splitting the interstellar medium- He, atomic and molecular Hydrogen



Lagos et al. (2011a, in press)

$$f_{\rm mol}(\Sigma_{\rm comp}, Z)$$

Krumholz et al (2008, 2009)

FUV photo-dissociation
+formation on dust grains

$$\frac{\Sigma(\mathrm{H_2})}{\Sigma(\mathrm{HI})} = \left(\frac{P_{\rm ext}}{P_0}\right)^{\alpha}$$

Wong & Blitz (2002), Blitz & Rosolowski (2006), Kennicutt et al. (2007), Leroy et al. (2008)

Model that reproduces properties related to the stellar content and gaseous content at the same time.

How do the molecular and atomic hydrogen relate with other galaxy properties?

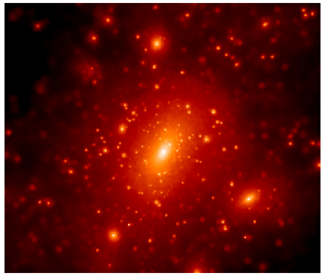
How do these relations extent to high-redshift?

We use GALFORM. Without changing any other model parameter.

The GALFORM semi-analytic model
Cole et al. (2000)

Cosmological model →

$\Omega_0, \Lambda_0, \sigma_8, h, P(k)$



DARK MATTER HALOS

Large scale structure

AGN feedback
Bower et al. (2006)

Gas cooling

Disk formation

Star formation feedback

Galaxy mergers
Disk instabilites

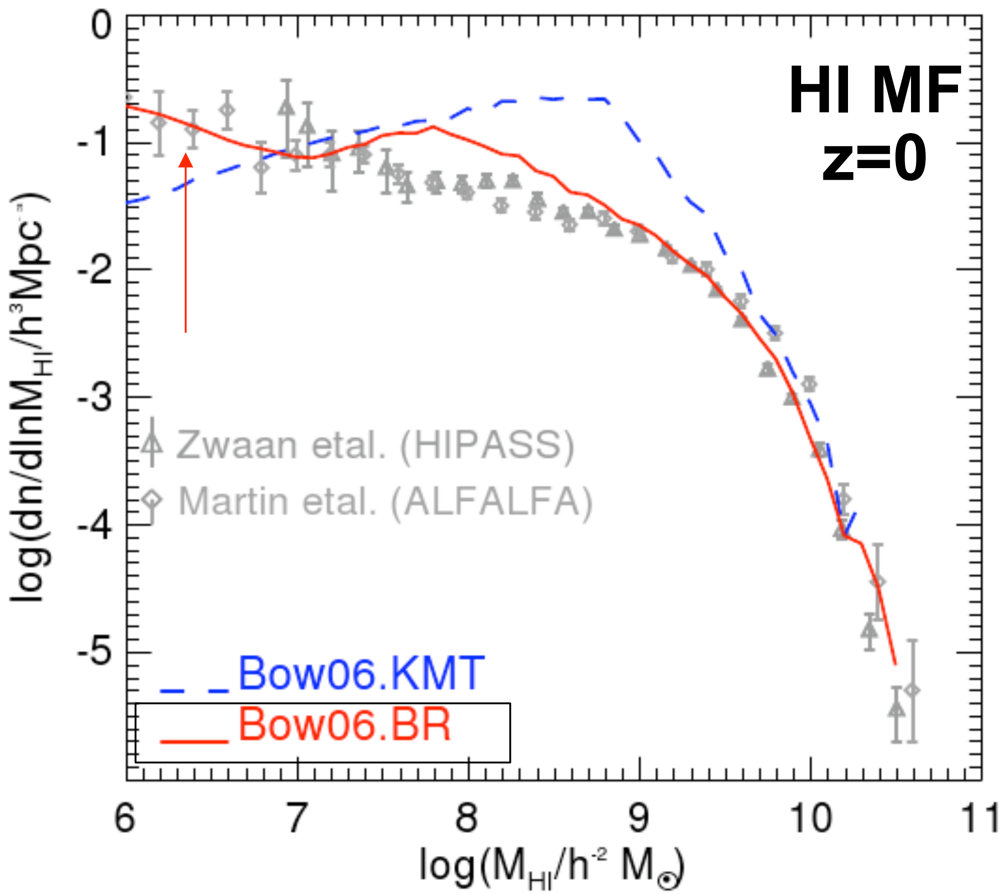
Bulge formation

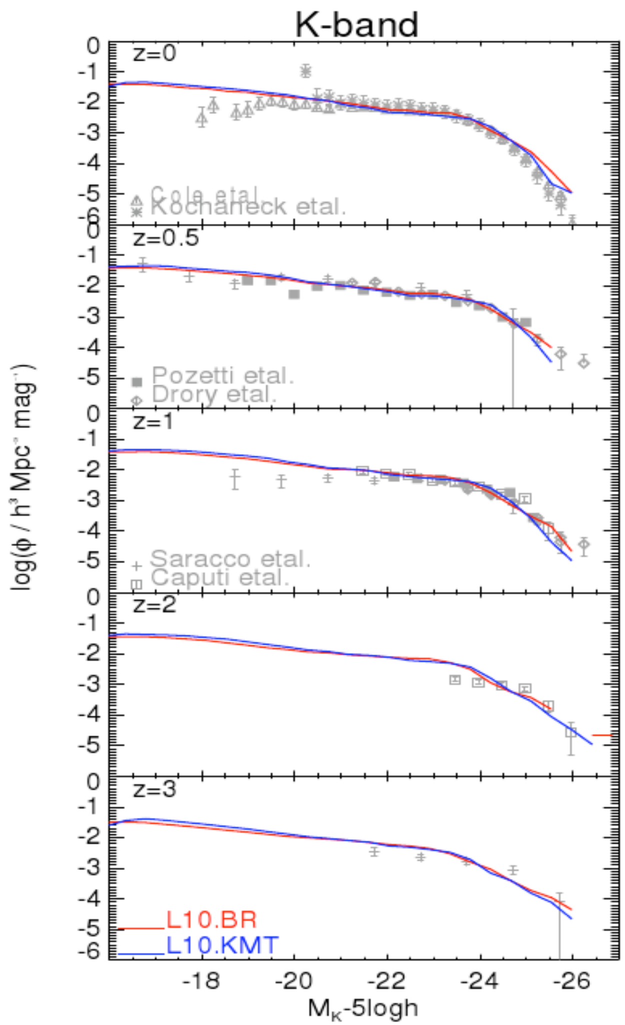
starbursts

(i) BR SF law (pressure, Bow06.BR)
(ii) KMT SF law (metallicity, Bow06.KMT)

Formalism developed in
Lagos et al. (2011a, in press)
Do not change model parameters

The stellar and HI mass functions (Lagos et al. 2011a, 2011b)

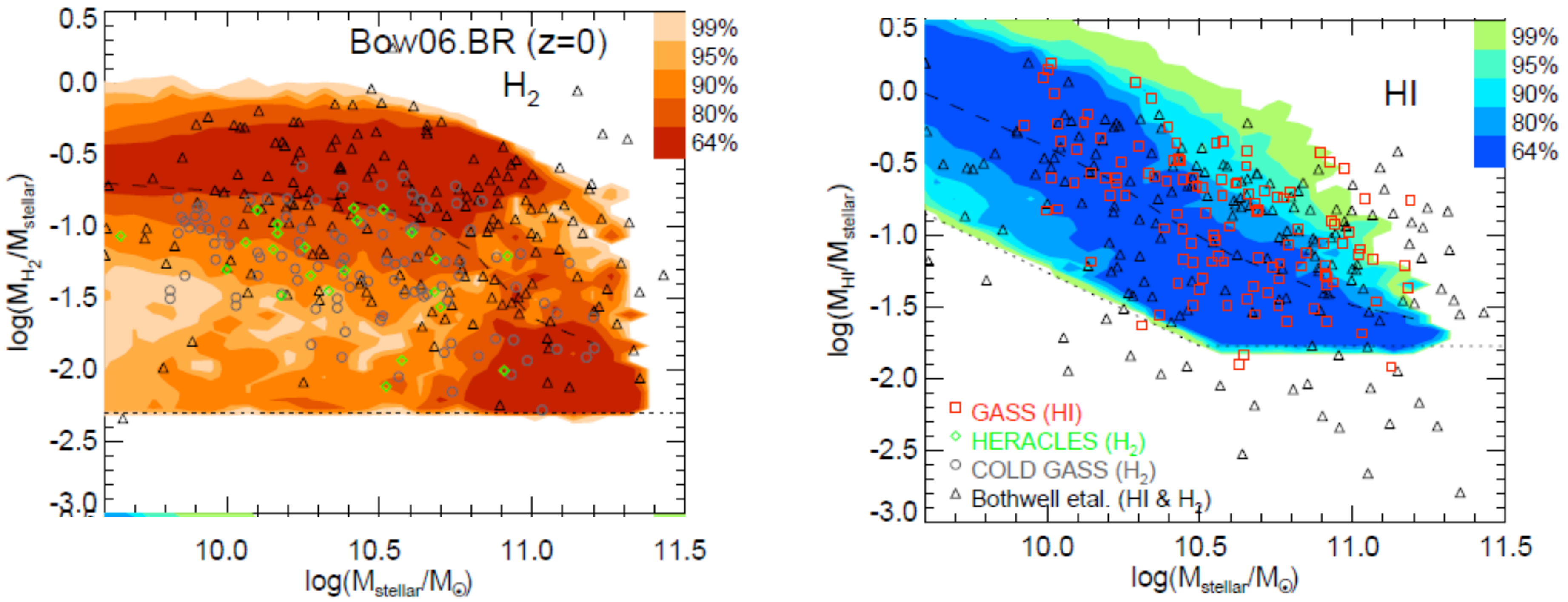




Predicted HI MF in good agreement!

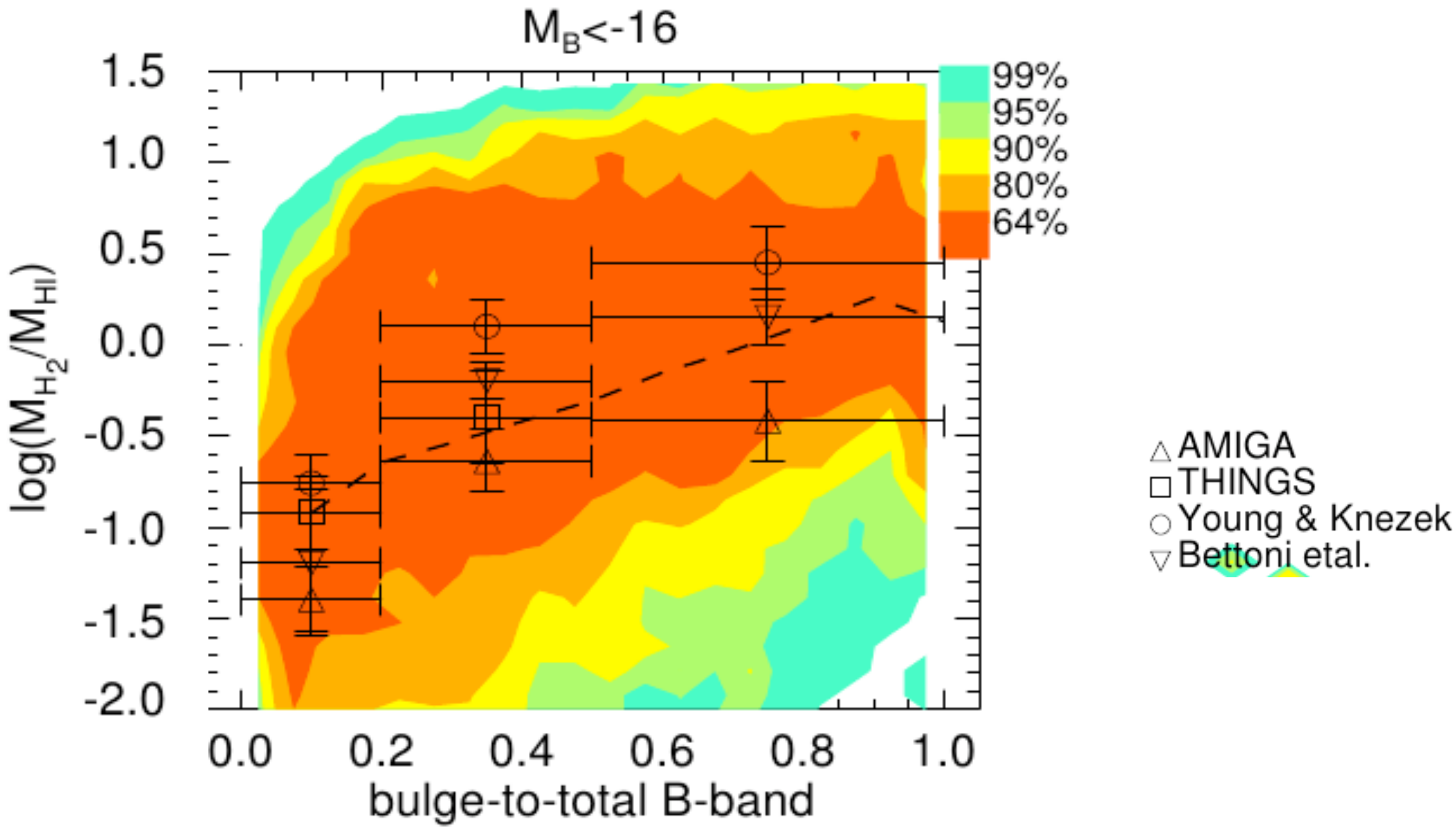
Faint end is a fundamental success of the new SF law

Scaling relations: stars/cold gas (Lagos et al. 2011b)



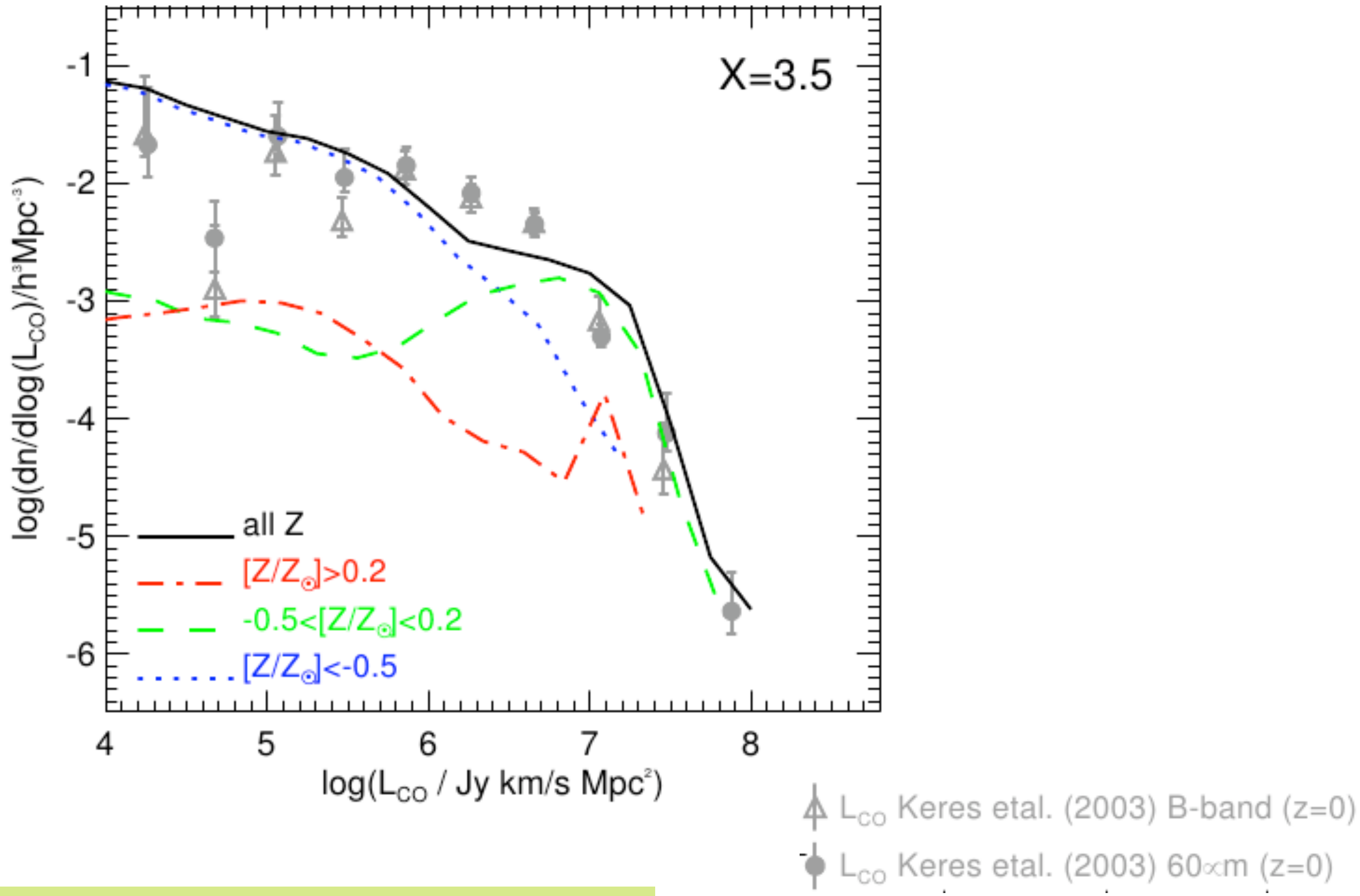
Scaling relations: a direct consequence of the pressure-based law and fundamental predictions of the model (Lagos et al. 2011a)

Scaling relations: morphology (Lagos et al. 2011b)



Statistically stellar content contributes more to gas pressure in early-type galaxies.

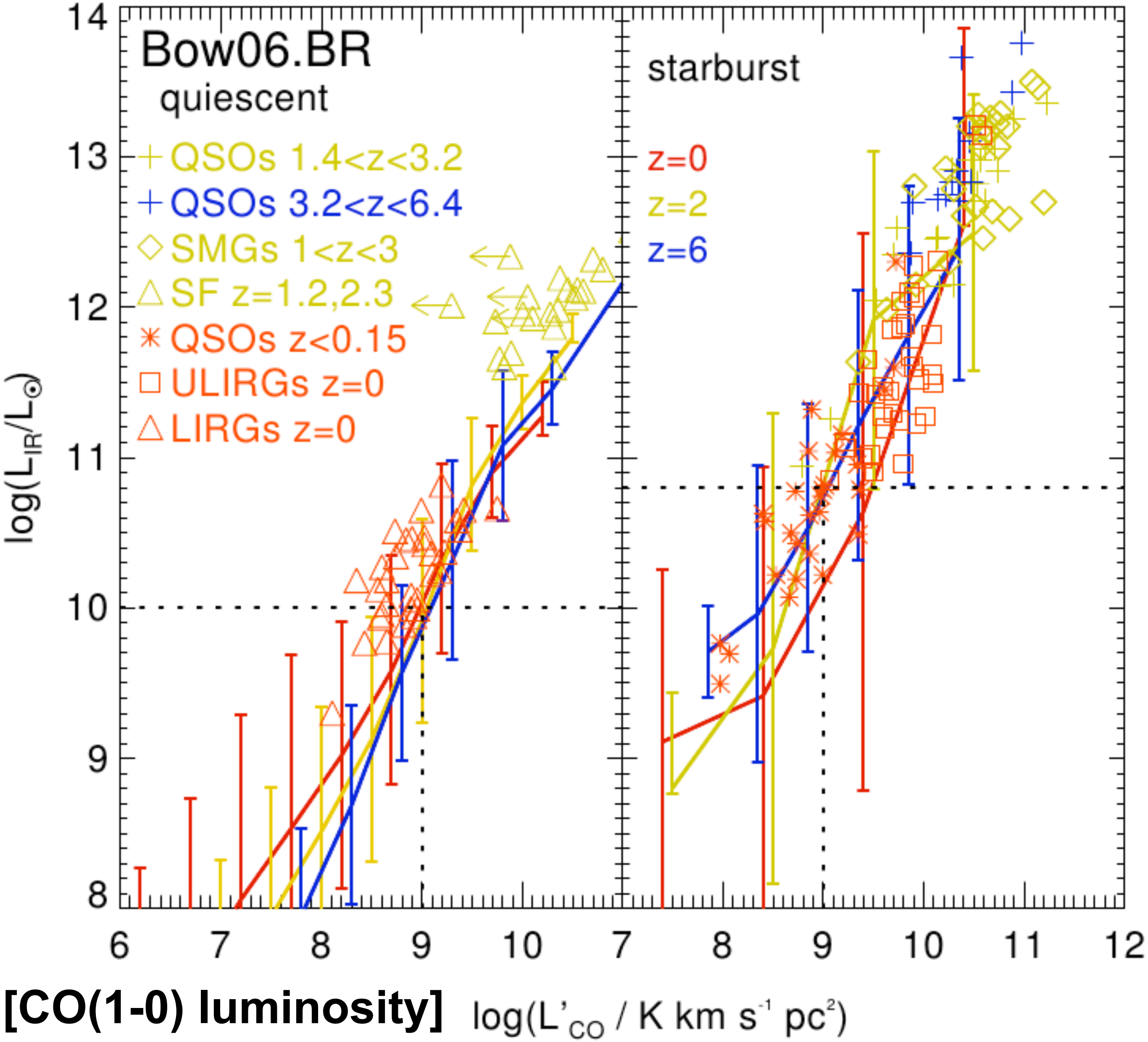
The H2 mass function (Lagos et al. 2011b)



WARNING: constant H2-CO conversion factor
(fundamental uncertainty)

CO - IR luminosity relation (Lagos et al. 2011b)

[IR luminosity]

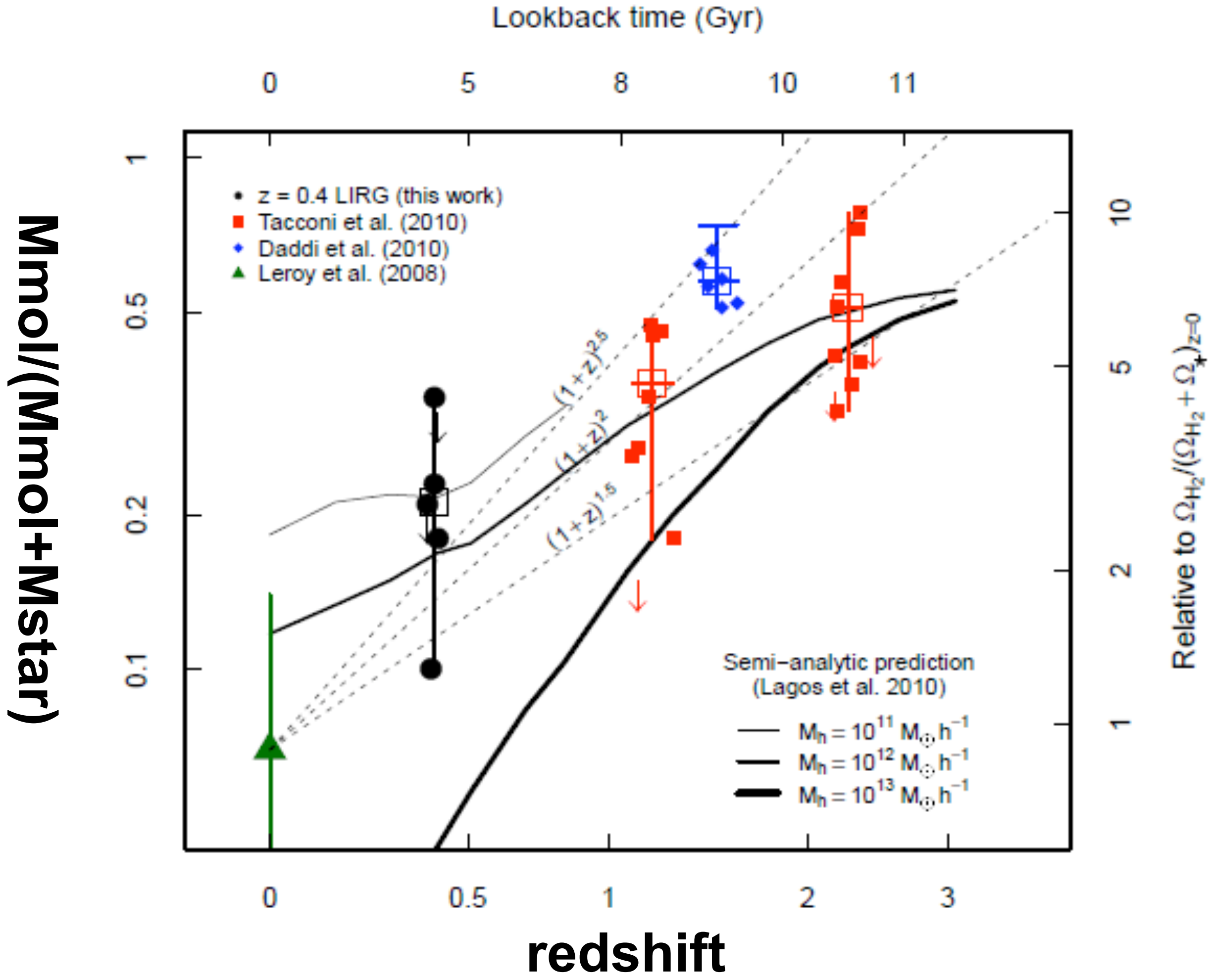


[CO(1-0) luminosity]

Evolution in molecular gas fractions (Geach et al. 2011)

- Molecular hydrogen content evolution: CO(1-0), CO(2-1), CO(3-2) transitions

- Strong molecular fraction evolution: can be explained by higher ISM pressure (Lagos et al. 2011b, Swinbank et al. 2011 in prep.)



Conclusions

Lagos et al. (2011a), Lagos et al. (2011b), Geach et al. (2011), Kim et al. (2011, in prep.)

- **SAM: Powerful tool to study the connection SF/H2/HI (assumptions and relations on the ISM).**

- The **SF law has a small impact on the total SFR density** and b_J/K LF, but large on the gas content.

- HI, CO LF at z=0 well matched by the predictions of the BR SF law.

- Scaling relations at z=0: Fundamental prediction of pressure-based law and GALFORM.

- IR-CO luminosity relation: 2 regime of star formation

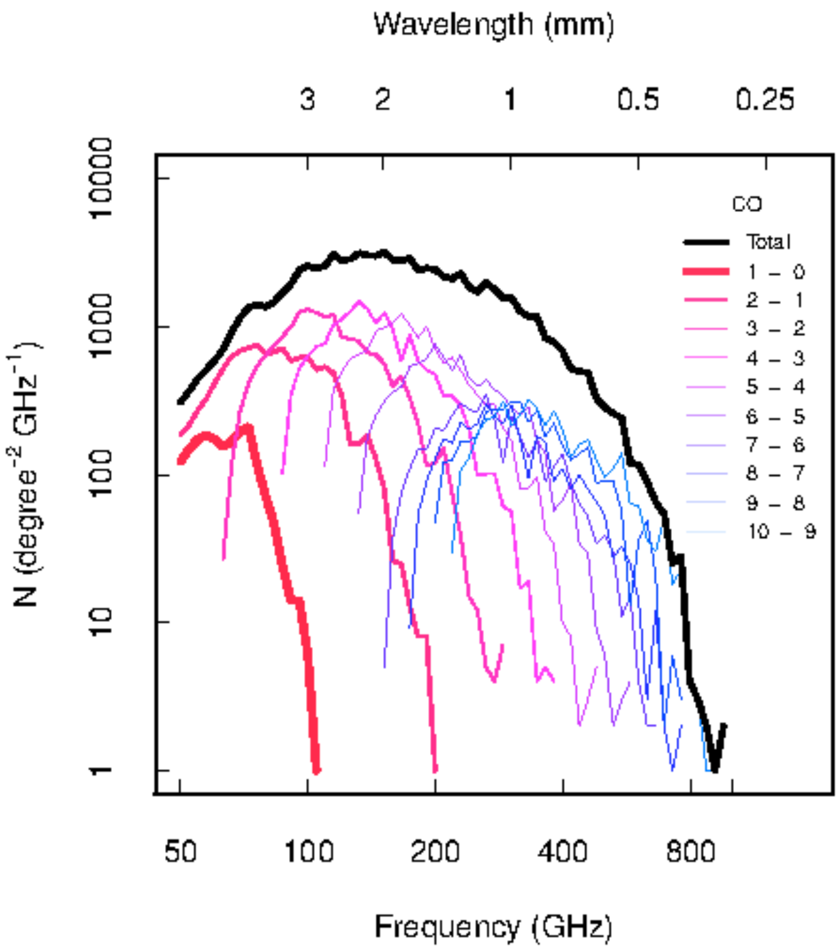
- Molecular gas fraction evolution: ***Strong evolution with z due to higher pressure driven by size evolution.***

ALMA / GMT / SKA / WALLABI / ASKAP:
Applying the Lagos10 model to study the capacity of new instruments/surveys

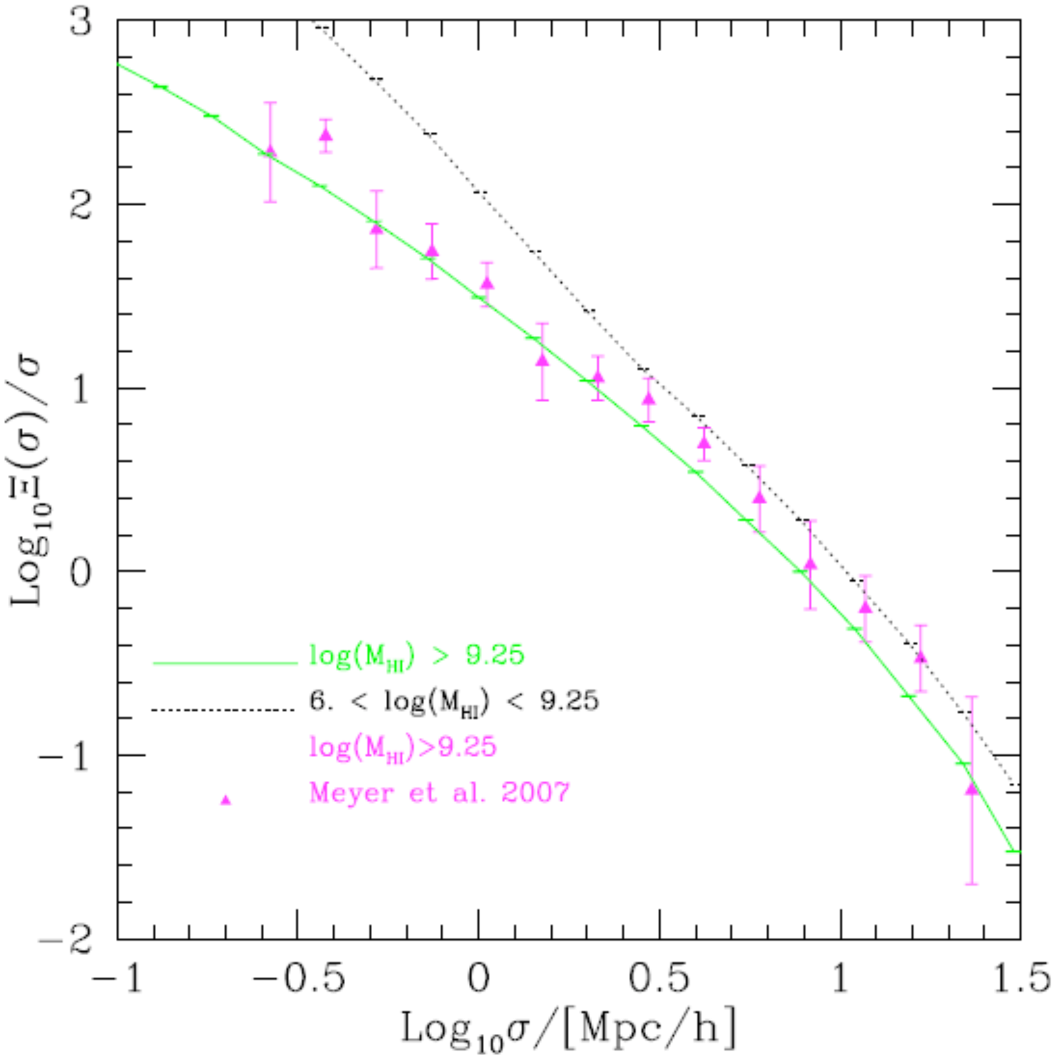
ALMA/GMT: Jim Geach (Mc Gill), Juan Gonzalez (ESO), Carlton Baugh (Durham), Cedric Lacey (Durham), Richard Bower (Durham), myself
PDR modelling: Estelle Bayet (Oxford) + UCL team

SKA/WALLABI/ASKAP (HI in general): Chris Power (Western U), Hank Kim (Melbourne) + Durham team

Lightcones for all projects: Alex Merson (Durham), John Helly (Durham), Carlton Baugh (Durham)



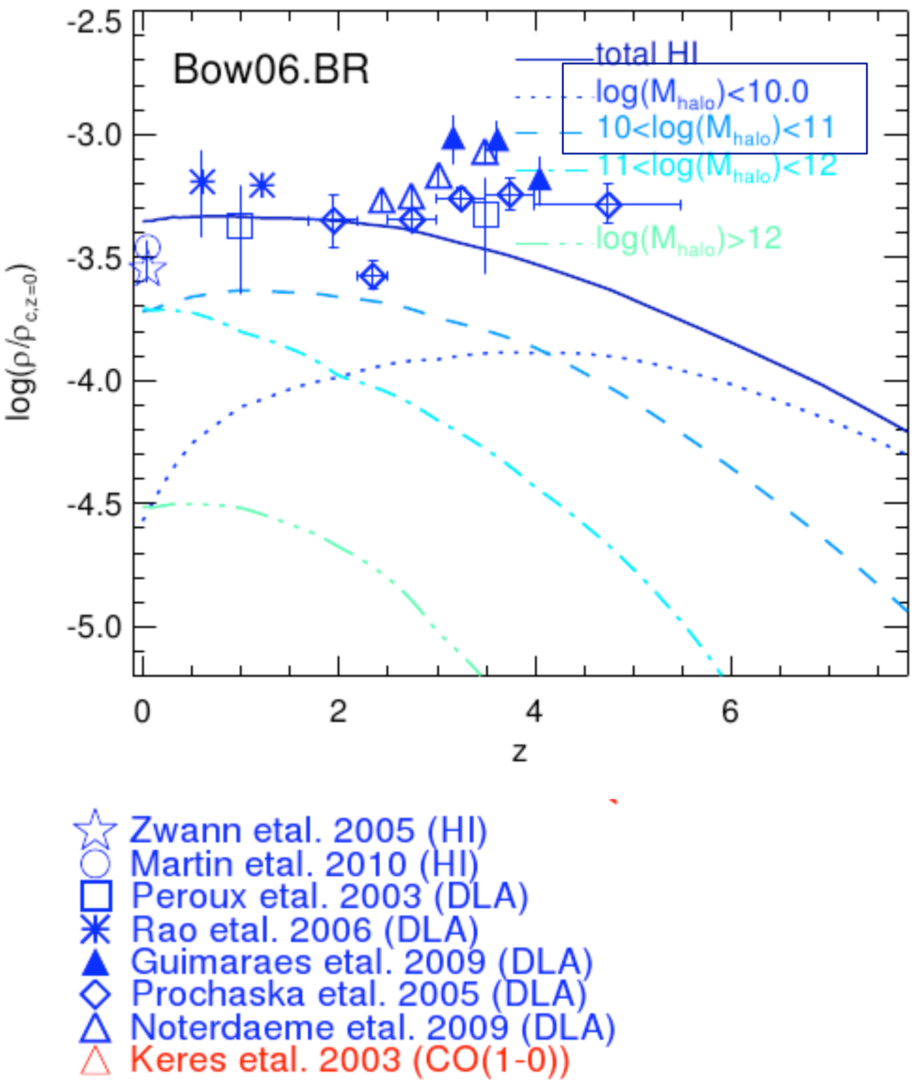
Clustering of HI sources (Kim et al., in prep.)



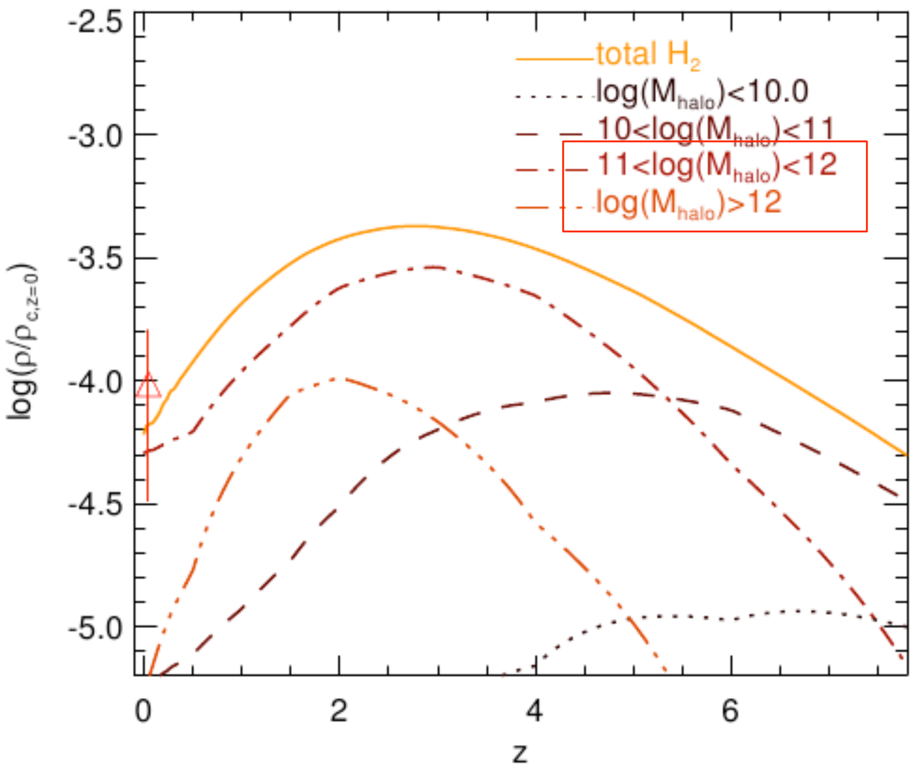
Model predictions: parameters have not been modified

Split ISM – Atomic and molecular H cosmic evolution (Lagos et al., 2011)

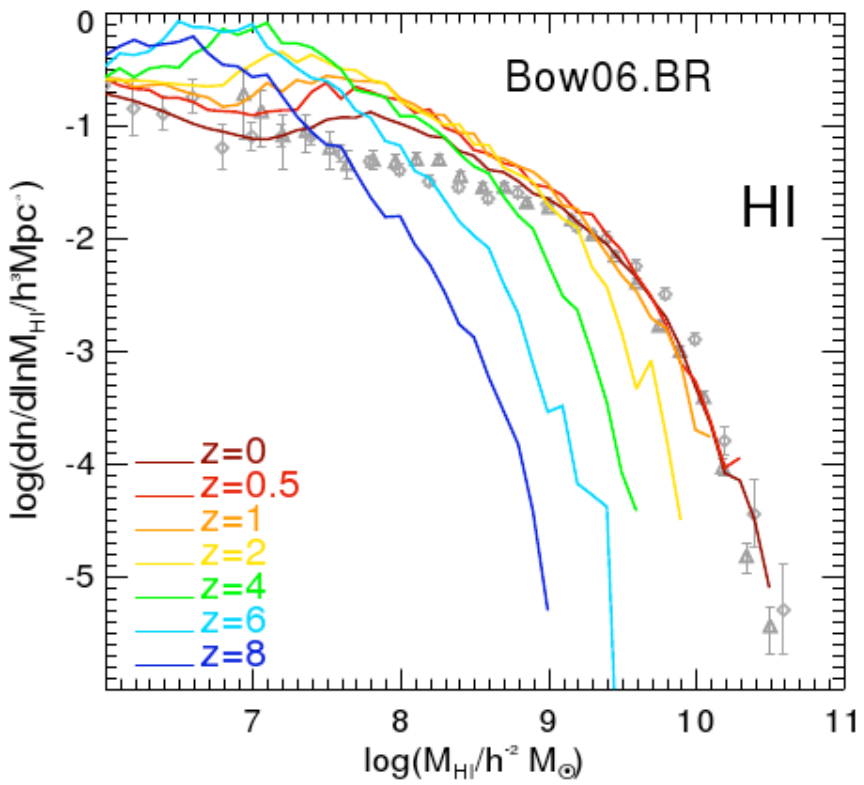
HI – found in low mass halos

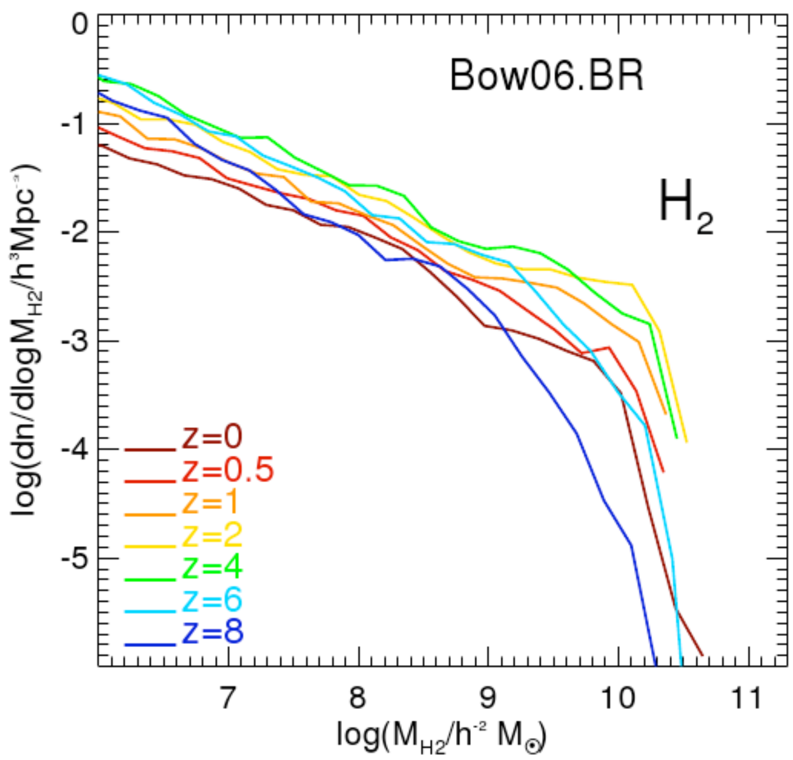


H_2 – found in inter/high mass halos



Split ISM – Atomic and m olecular hydrogen MFs evolution (Lagos et al. 2011)





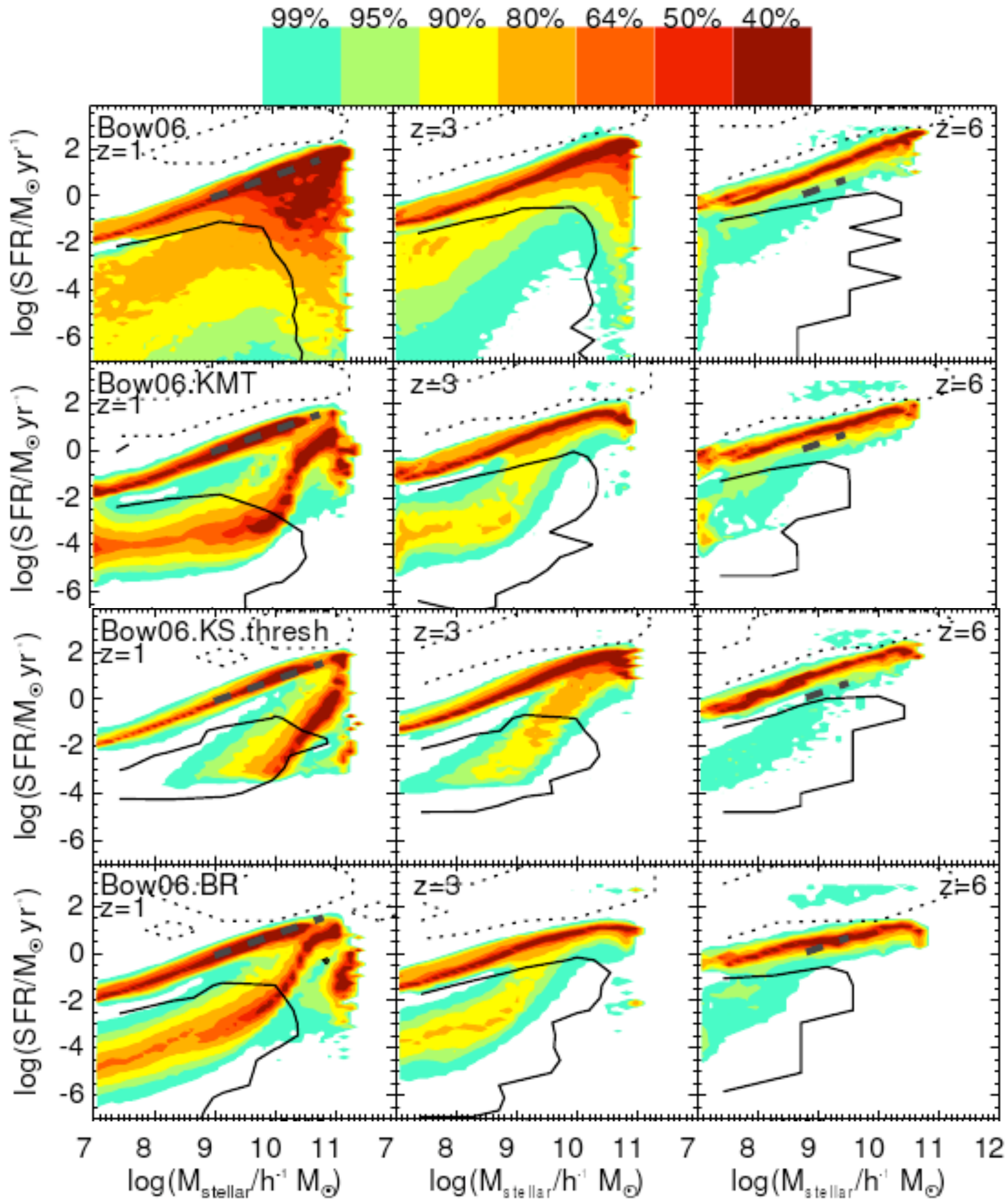
Different evolution → evolution in the H2/HI ratios

An attractive tool!
SF activity in galaxies: SFR-M_{star} plane

→ Passive sequence: still
strongly
pres
e
nt up to z=1, but weakens at z>2.

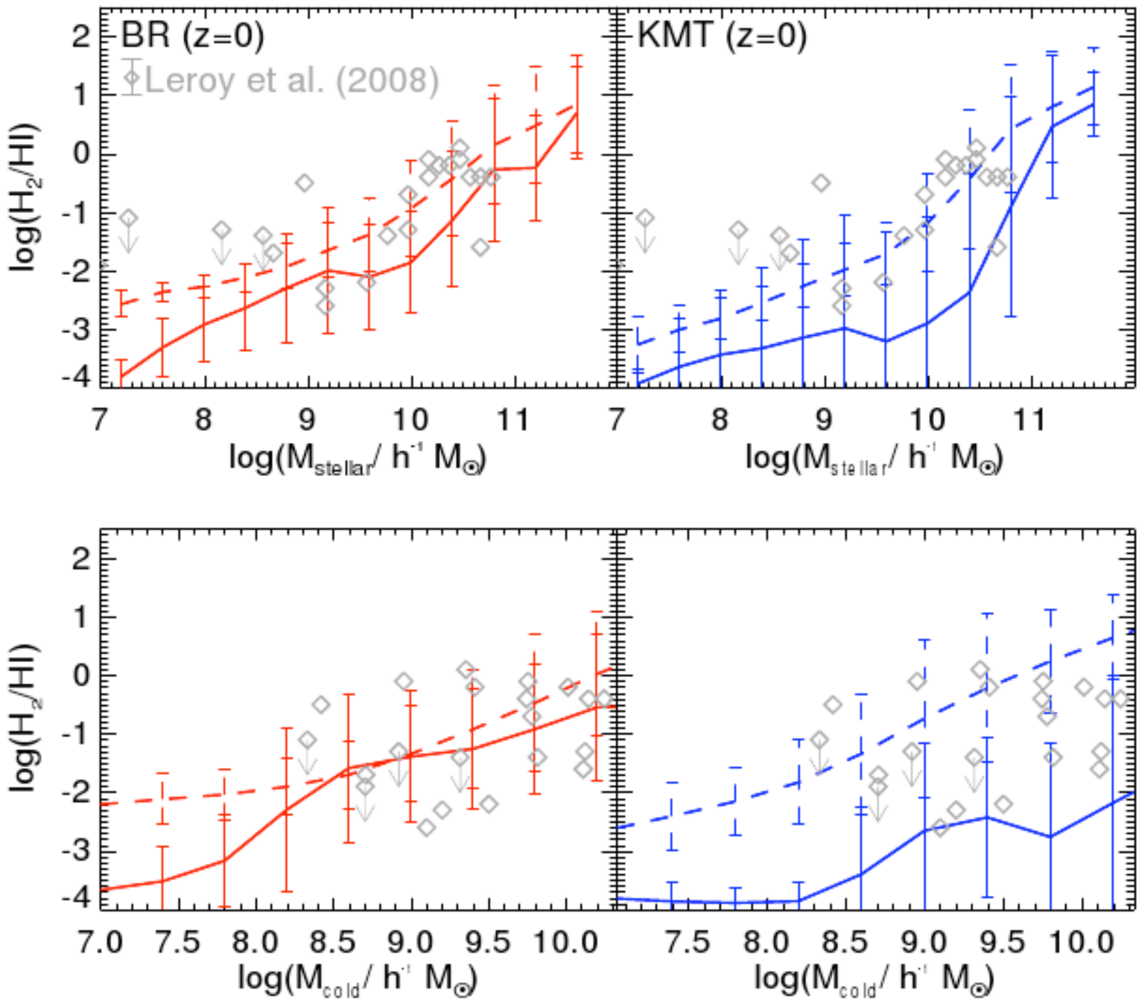
→ satellites
al
w
ays dominate passive sequence.

→At z=6 most of galaxies
per
f
orm strong SF (active sequence).



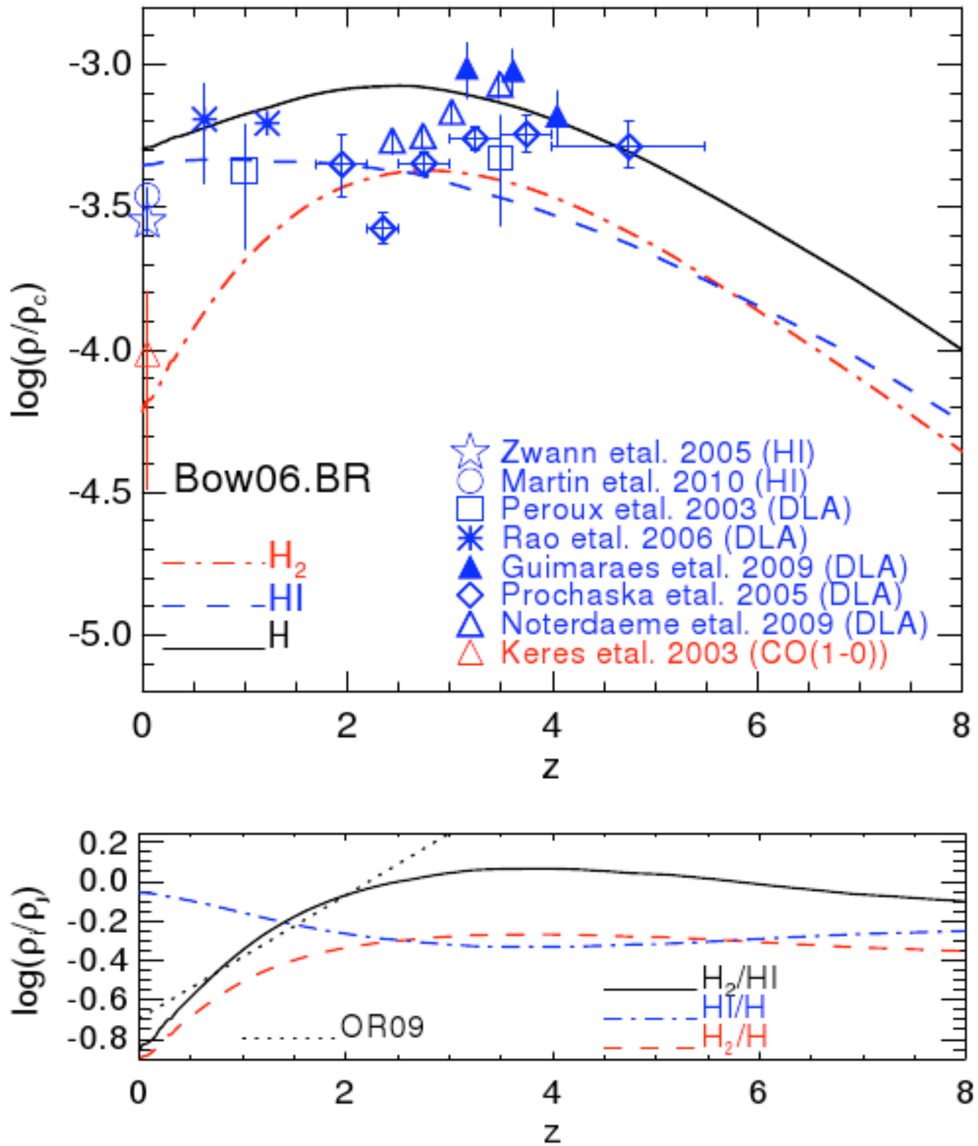
(Obs: Santini
e
t al. 2009, Rodighiero et al. 2010)

Scaling relations (Lagos et al. 2011)



Split ISM – Atomic and molecular H cosmic evolution

Lagos et al. (2011b)



Empirical and theoretical SF laws to test

parameter-free (to some degree)

(ii) The Kennicutt-Schmidt law (KS) →

$$\Sigma_{\rm SFR} = A\,\Sigma_{\rm gas}^{1.4}$$

$$\Sigma_{\rm crit}$$

(i) The Blitz & Rosolowski law (BR) →

Leroy et al. (2008), Bigiel et al. (2008)

$$\frac{\Sigma({\rm H}_2)}{\Sigma({\rm HI})} = \left(\frac{P_{\rm ext}}{P_0}\right)^{\alpha}$$

$$\Sigma_{\rm SFR} = \nu_{\rm SF}\,\Sigma_{\rm mol}$$

Empirical laws

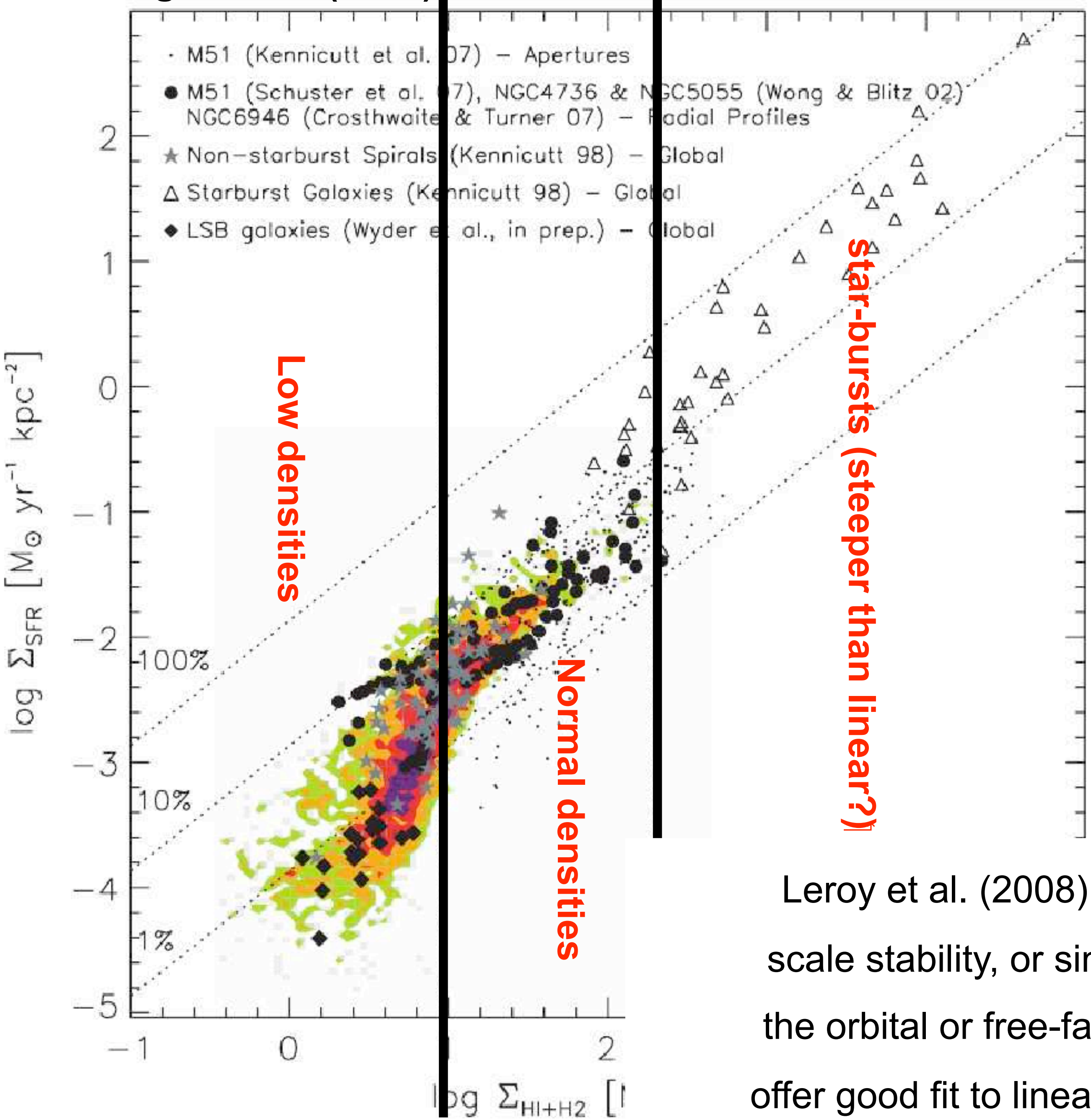
Theoretical laws

(iii) The Krumholz, McKee & Tumlinson theoretical law (KMT)

$$\Sigma_{\rm SFR} = \nu_{\rm SF}(\Sigma_{\rm gas})\,f_{\rm mol}\,\Sigma_{\rm gas}$$

$$\nu_{\rm SF}(\Sigma_{\rm gas}) = \nu_{\rm SF}^{0} \times \begin{cases} \left(\frac{\Sigma_{\rm gas}}{\Sigma_0}\right)^{-0.33}, & \frac{\Sigma_{\rm gas}}{\Sigma_0} < 1 \\ \left(\frac{\Sigma_{\rm gas}}{\Sigma_0}\right)^{0.33}, & \frac{\Sigma_{\rm gas}}{\Sigma_0} > 1 \end{cases}$$

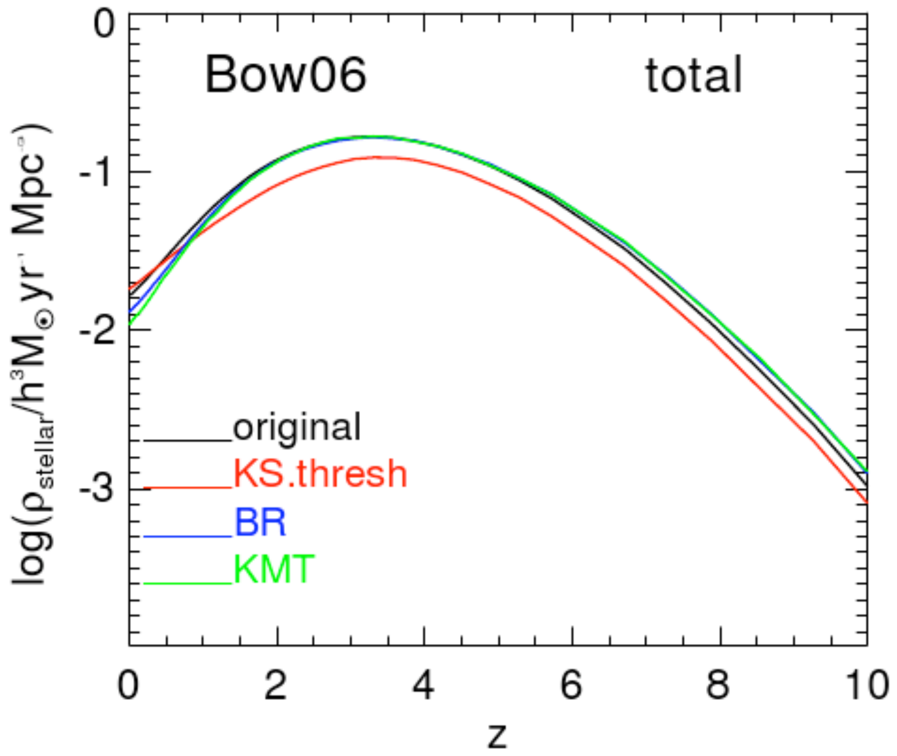
Bigiel et al. (2008)



Leroy et al. (2008): thresholds of large scale stability, or single dependence on the orbital or free-fall timescale do not offer good fit to linear SFR-mol relation.

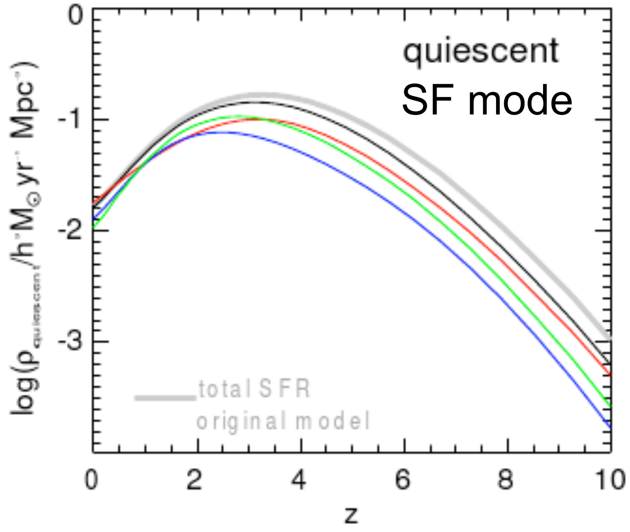
RESULTS: insensitive properties – SFR density evolution (Lagos et al. 2011a, arXiv:1011.5506)

Total SFR density insensitivity

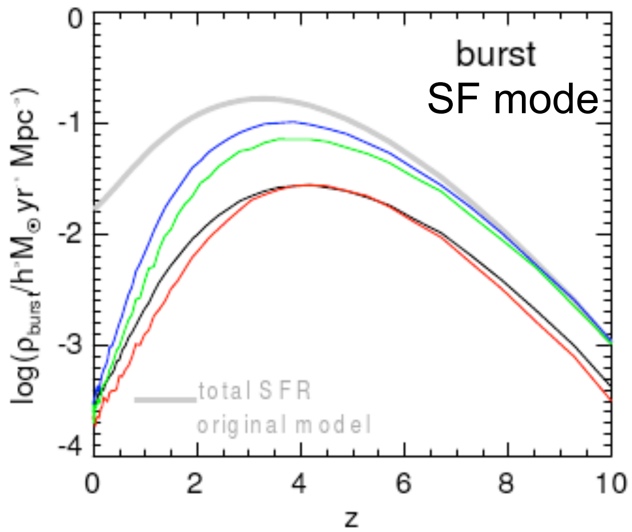


Quiescent

starbursts



An order of magnitude lower!



More gas in disks
→ more fueling to starbursts (mergers and disk instabilities)

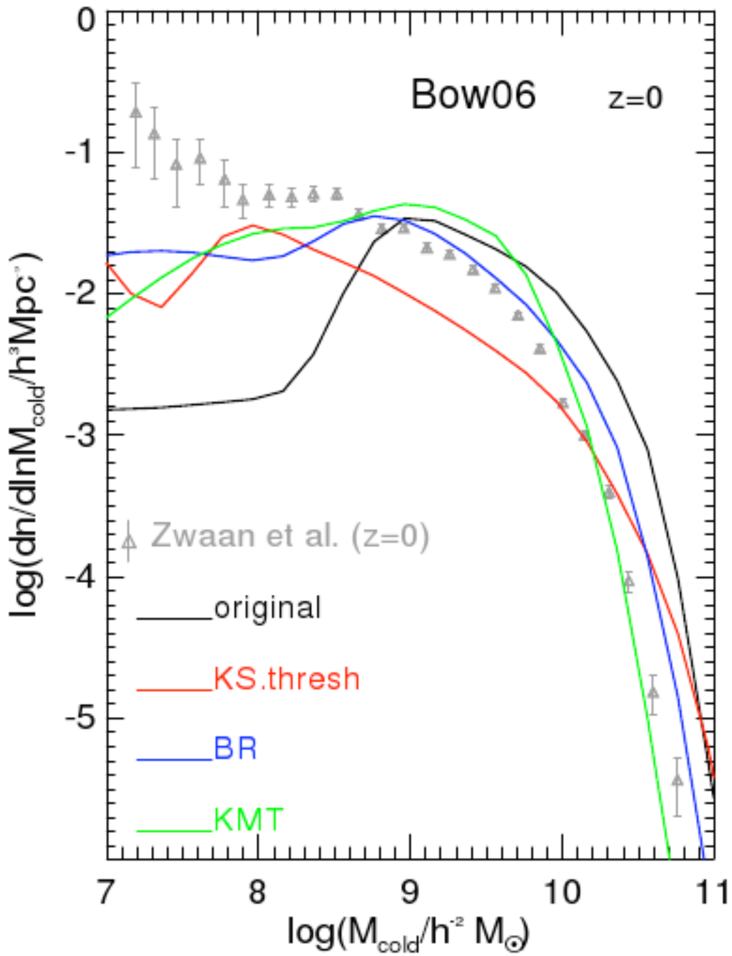
Efficient balance of mechanisms regulating SF.

Strongly sensitive properties- the cold gas mass content

Change in the burst/quiescent → change in the way the cold gas is consumed

→ Change in the evolution of the cold gas content

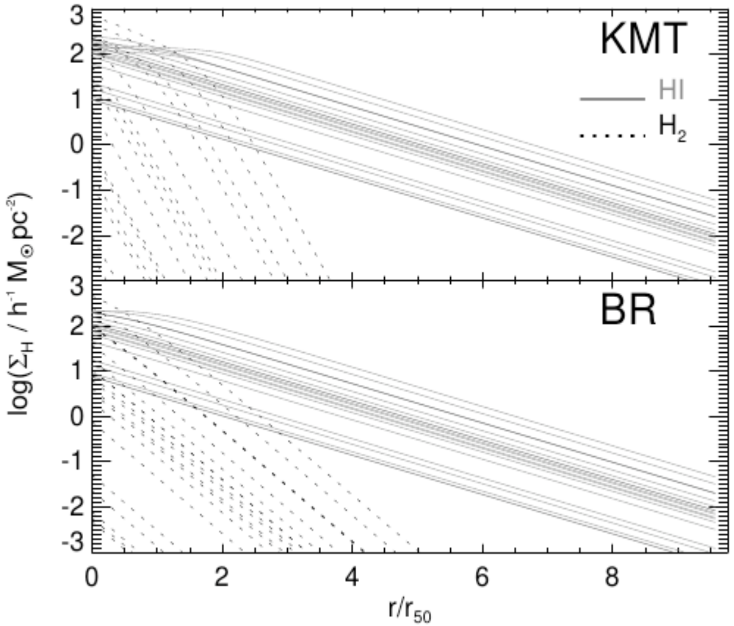
→ More low-mass cold gas objects τ_{SF} → now depends on M_{cold}



Lagos et al. (2011a, arXiv:1011.5506)

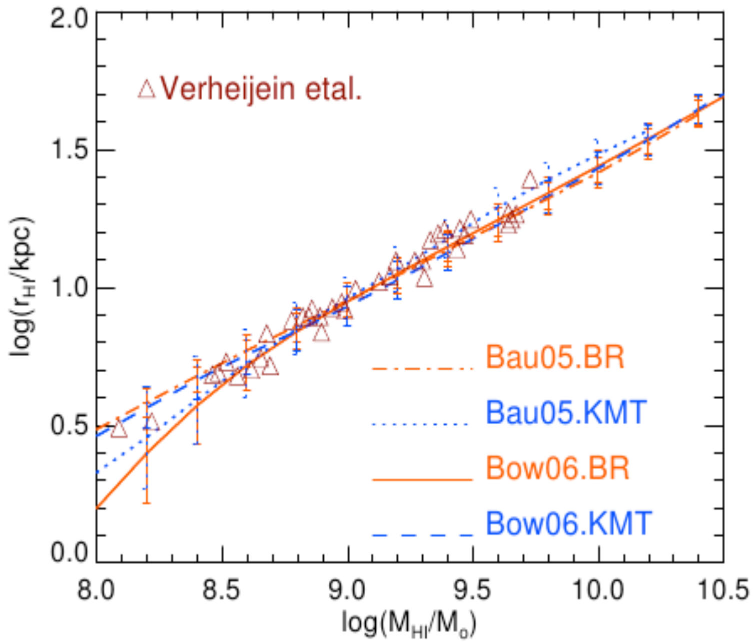
(Power et al. 2010; Obreschkow et al. 2009; Cook et al. 2010)

Splitting the interstellar medium- He, atomic and molecular Hydrogen (Lagos et al. 2011b, arXiv1105.2294)

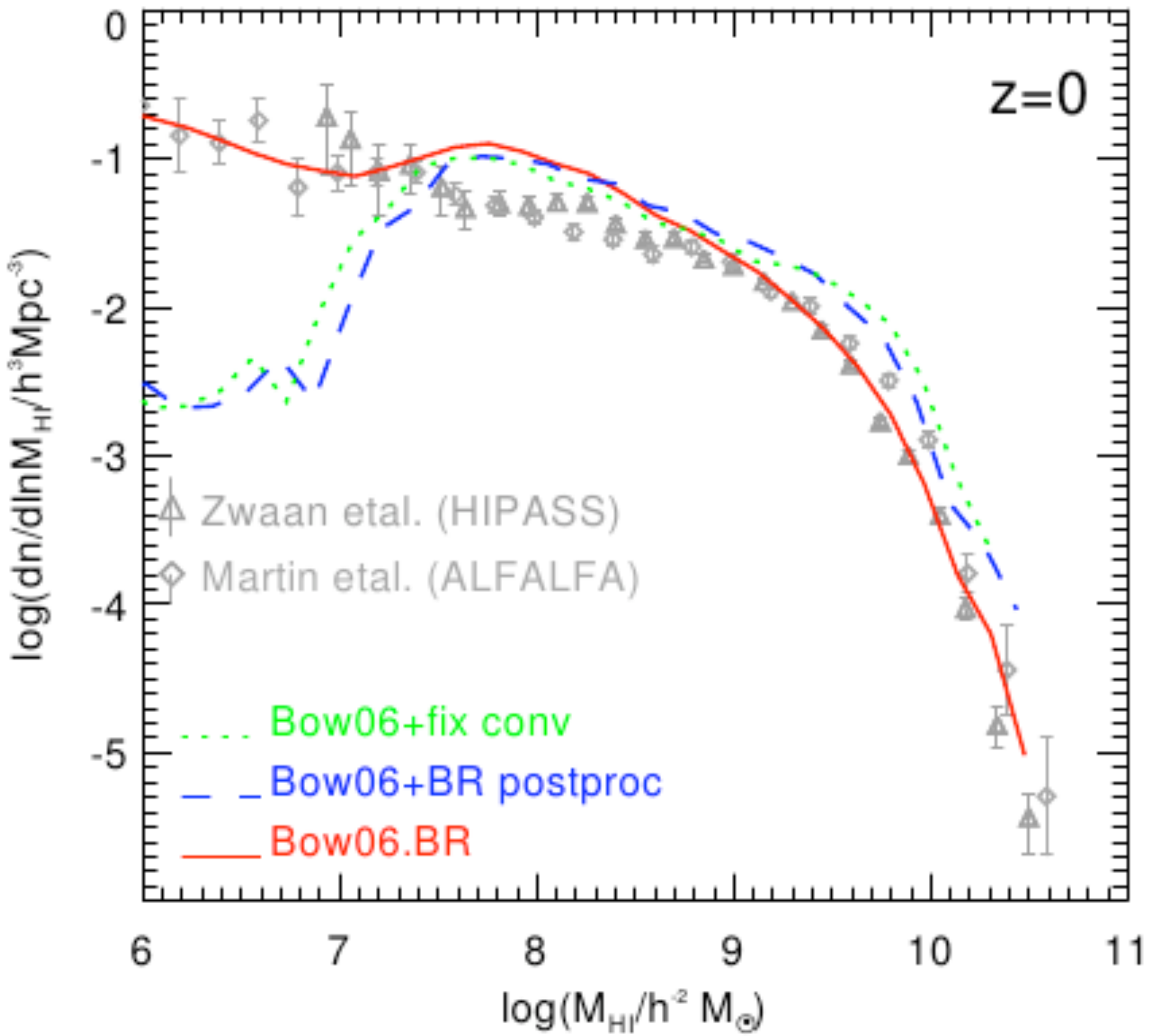


Blitz & Rosolowski (2006), Krumholz et al. (2009)

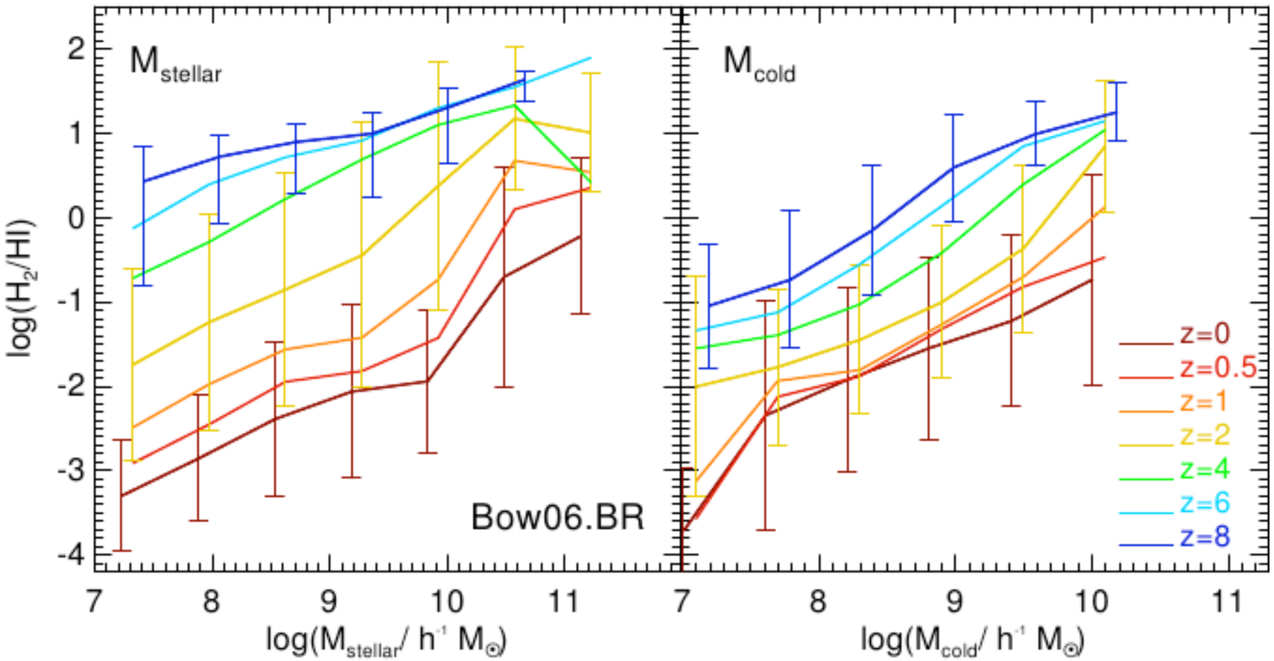
Split ISM: study HI, H2 content of galaxies compare with available observations. Lagos et al. (2011b)



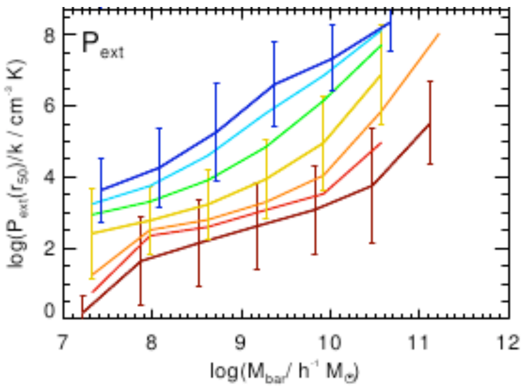
The HI mass function: the importance of the new modelling (Lagos et al. 2011b)



Scaling relations: redshift evolution (Lagos et al. 2011b)

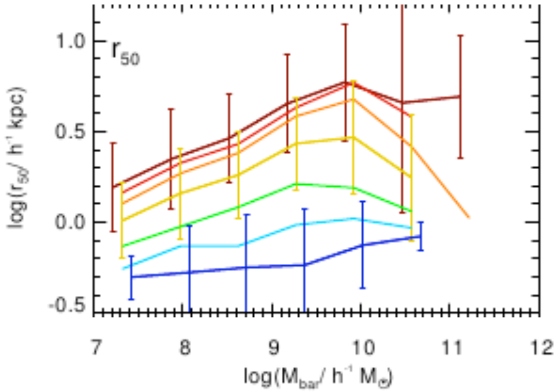


log(gas Pressure)



log(baryonic mass)

log(disk size)



log(baryonic mass)