Gas content of galaxies in the Millennium database (coming soon!)

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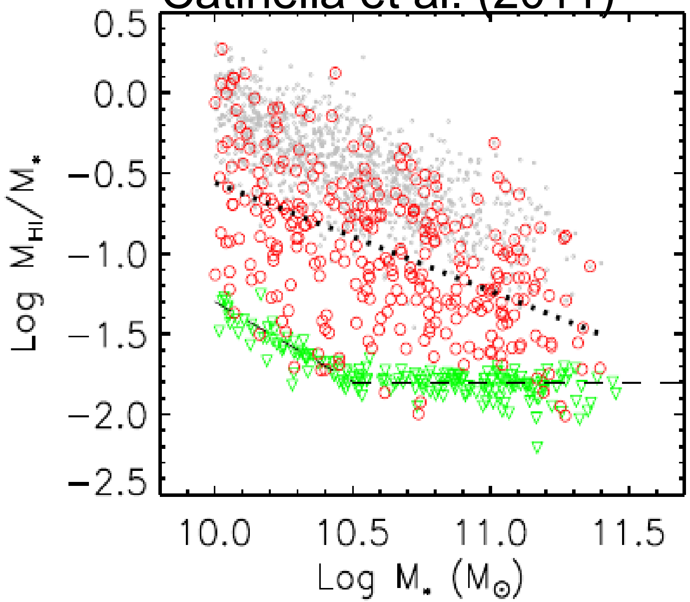
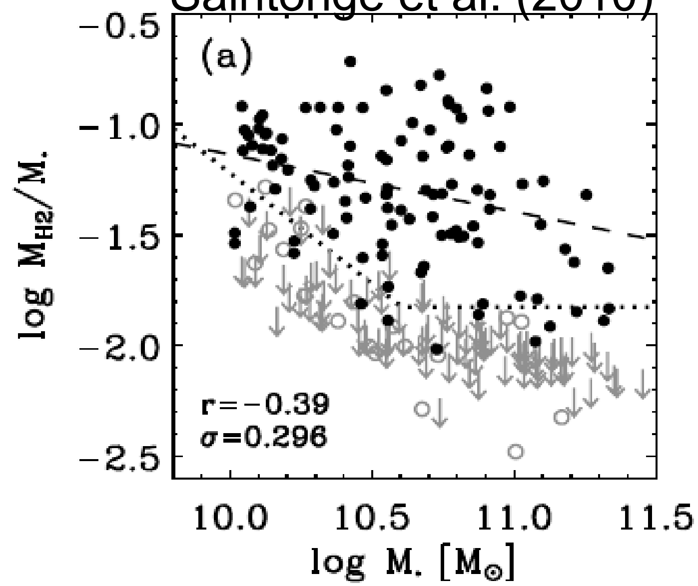
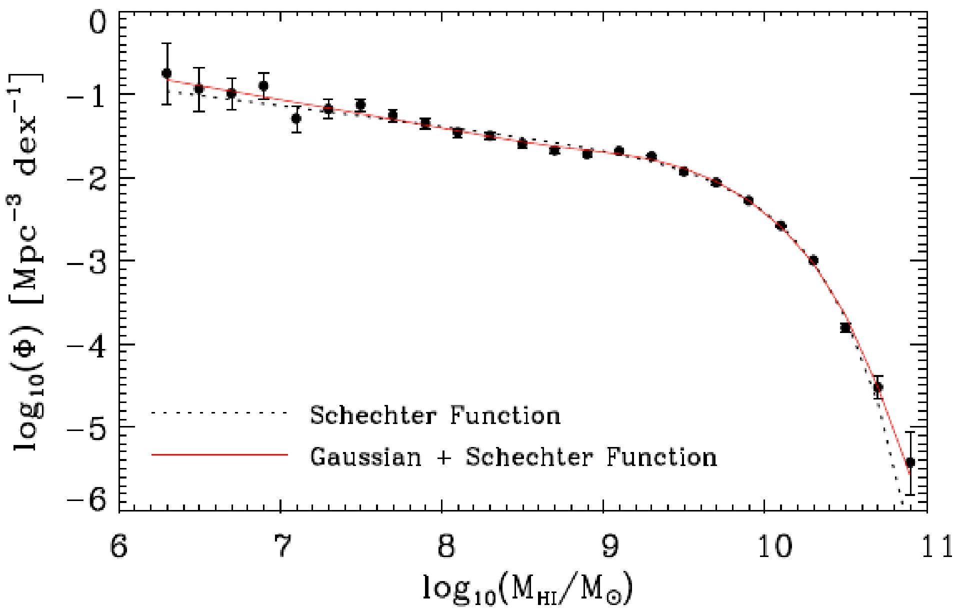
The neutral gas content of the Universe

Catinella et al. (2011)



Saintonge et al. (2010)





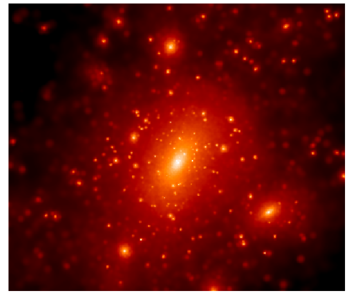
Very exciting times to be working in gas! (in and outside galaxies)
- WALLABY, ASKAP, SKA, ALMA, LMT, EVLA, JVLA, … (lots more)

Martin et al. (2010)

The galaxy formation paradigm
Cole et al. (2000), Lagos et al. (2011a)

Cosmological model →

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

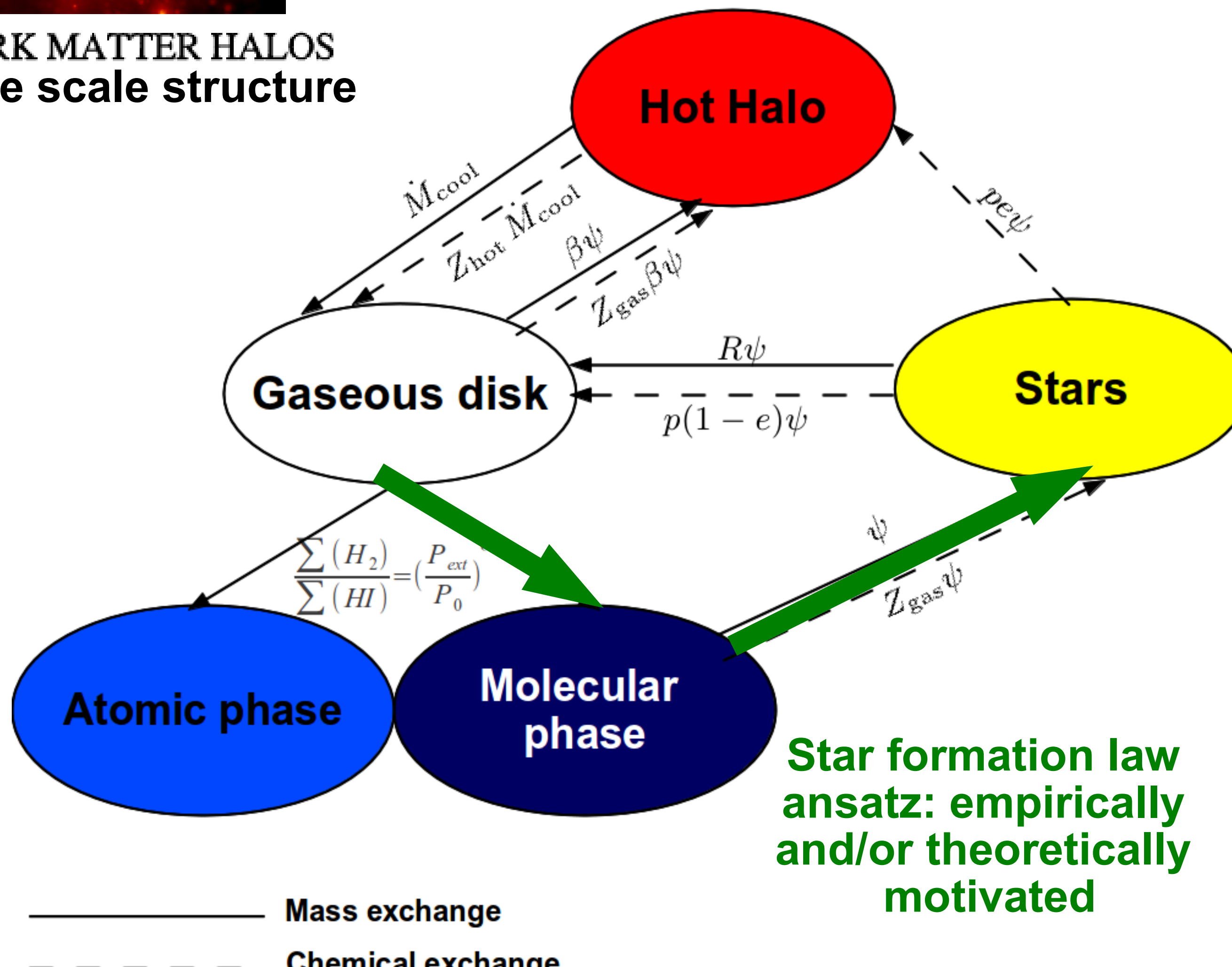


DARK MATTER HALOS

Large scale structure

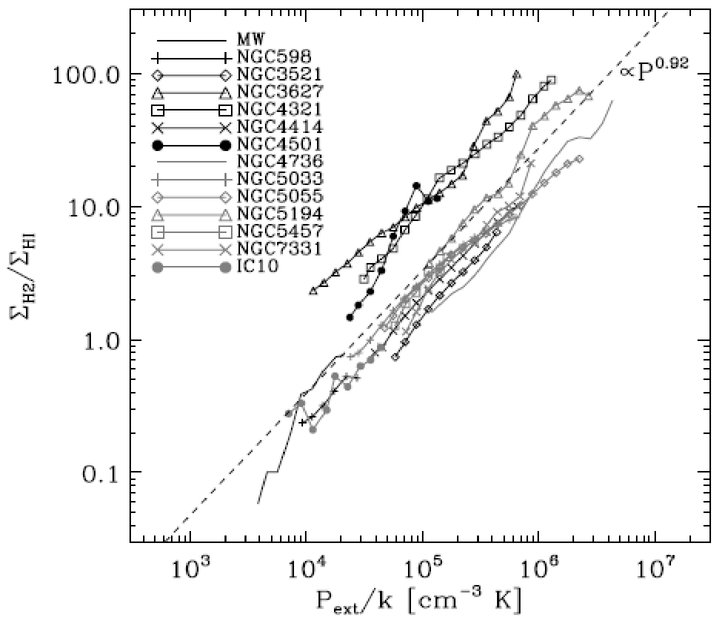
$\psi =$ Star formation law

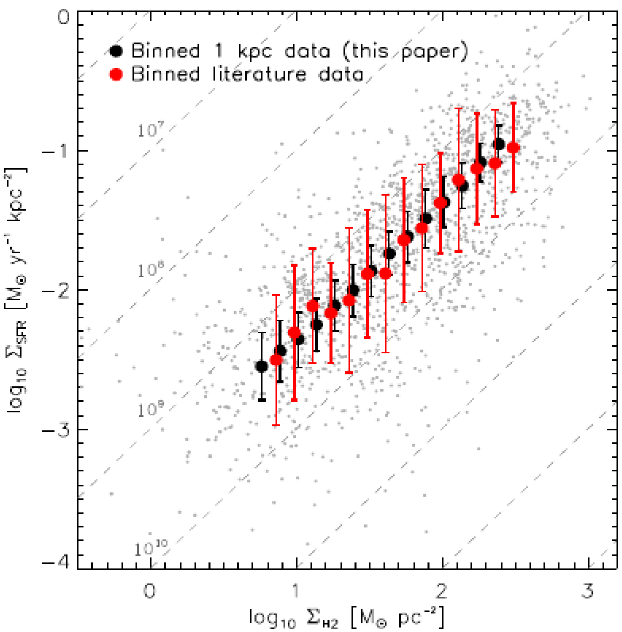
$$\begin{aligned}
\dot{M}_\star &= (1-R)\psi \\
\dot{M}_{\rm cold} &= \dot{M}_{\rm cool} - (1-R+\beta)\psi \\
\dot{M}_{\rm hot} &= -\dot{M}_{\rm cool} + \beta\psi \\
\dot{M}_\star^Z &= (1-R)Z_{\rm cold}\psi \\
\dot{M}_{\rm cold}^Z &= \dot{M}_{\rm cool}Z_{\rm hot} \\
&+ (p-(1+\beta-R)Z_{\rm cold})\psi \\
\dot{M}_{\rm hot}^Z &= -\dot{M}_{\rm cool}Z_{\rm hot} + (p\,e+\beta Z_{\rm cold})\psi.
\end{aligned}$$



Pressure star formation law

Blitz & Rosolowsky (2006); Wong et al. (2002); Leroy et al. (2008); Bigiel et al. (2008,2010)





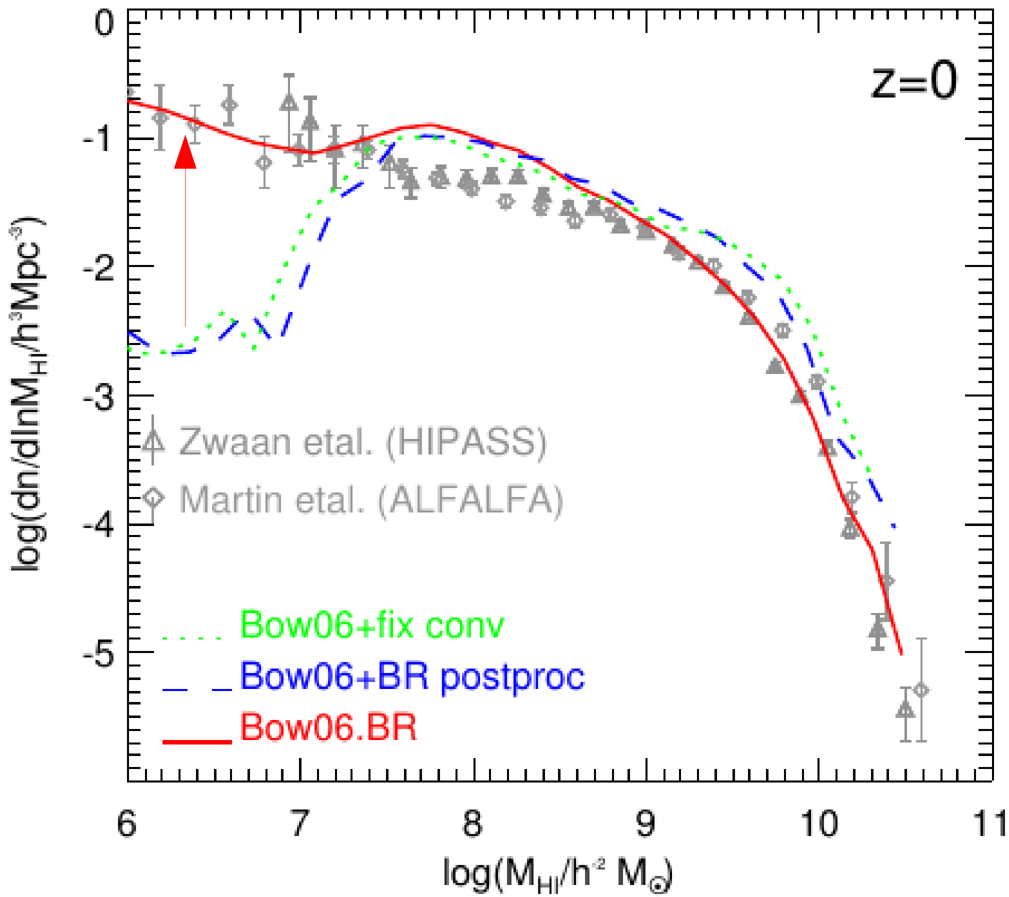
$$\frac{\Sigma(\mathrm{H_2})}{\Sigma(\mathrm{HI})} = \left(\frac{P_{\mathrm{ext}}}{P_0}\right)^{\alpha}$$

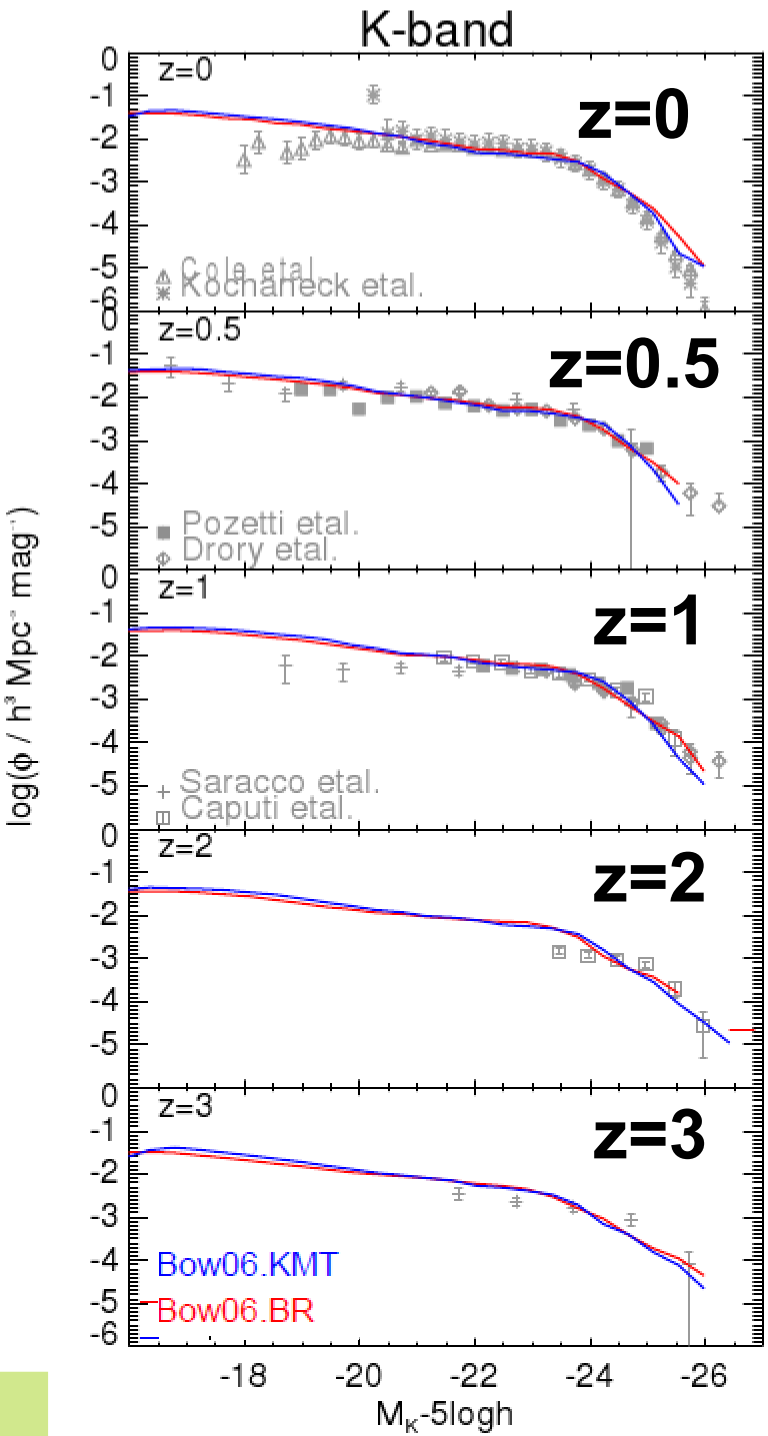
$$P_{\mathrm{ext}} \approx \frac{\pi}{2} G \Sigma_{\mathrm{gas}} \left[\Sigma_{\mathrm{gas}} + \left(\frac{\sigma_{\mathrm{g}}}{\sigma_\star}\right) \Sigma_\star\right]$$

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

GALFORM is a modular code, so any version of GALFORM can be run with any of the star formation laws discussed in Lagos et al. (2011a).

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

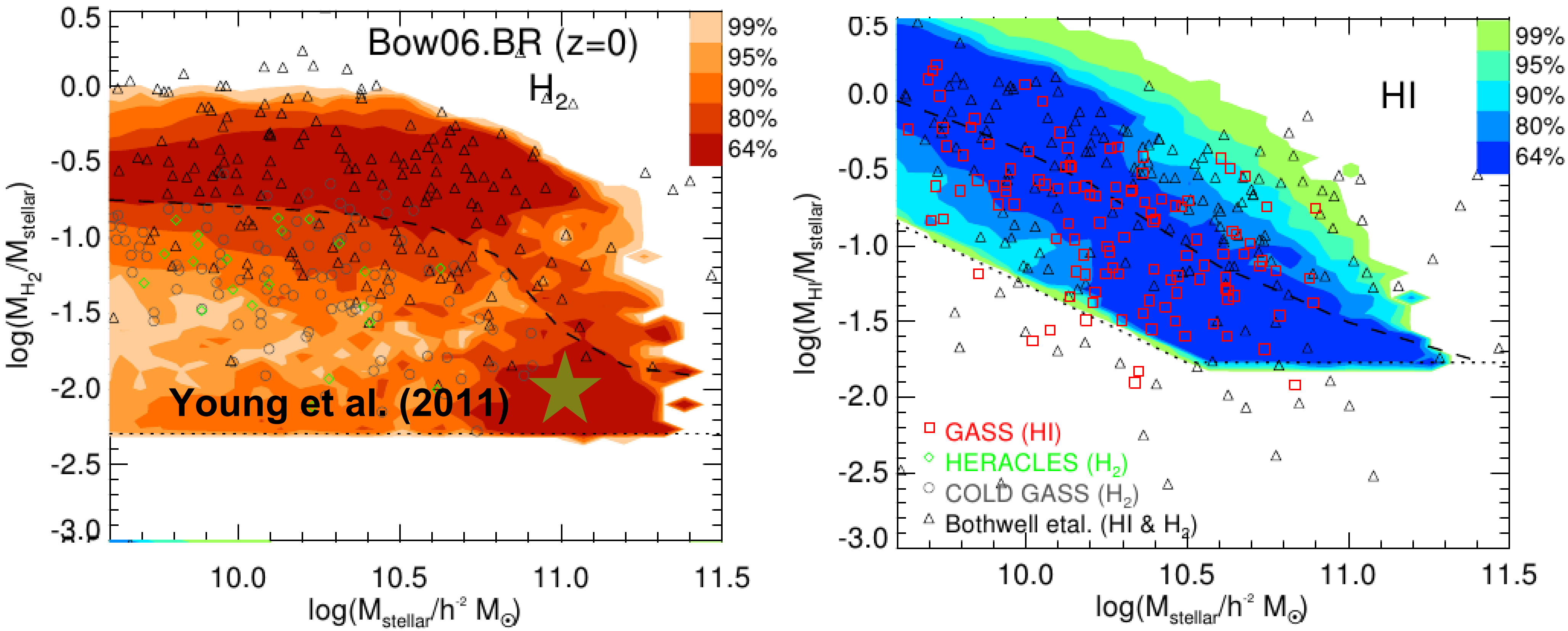




Results from non-linear relation between depletion timescale and gas content

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

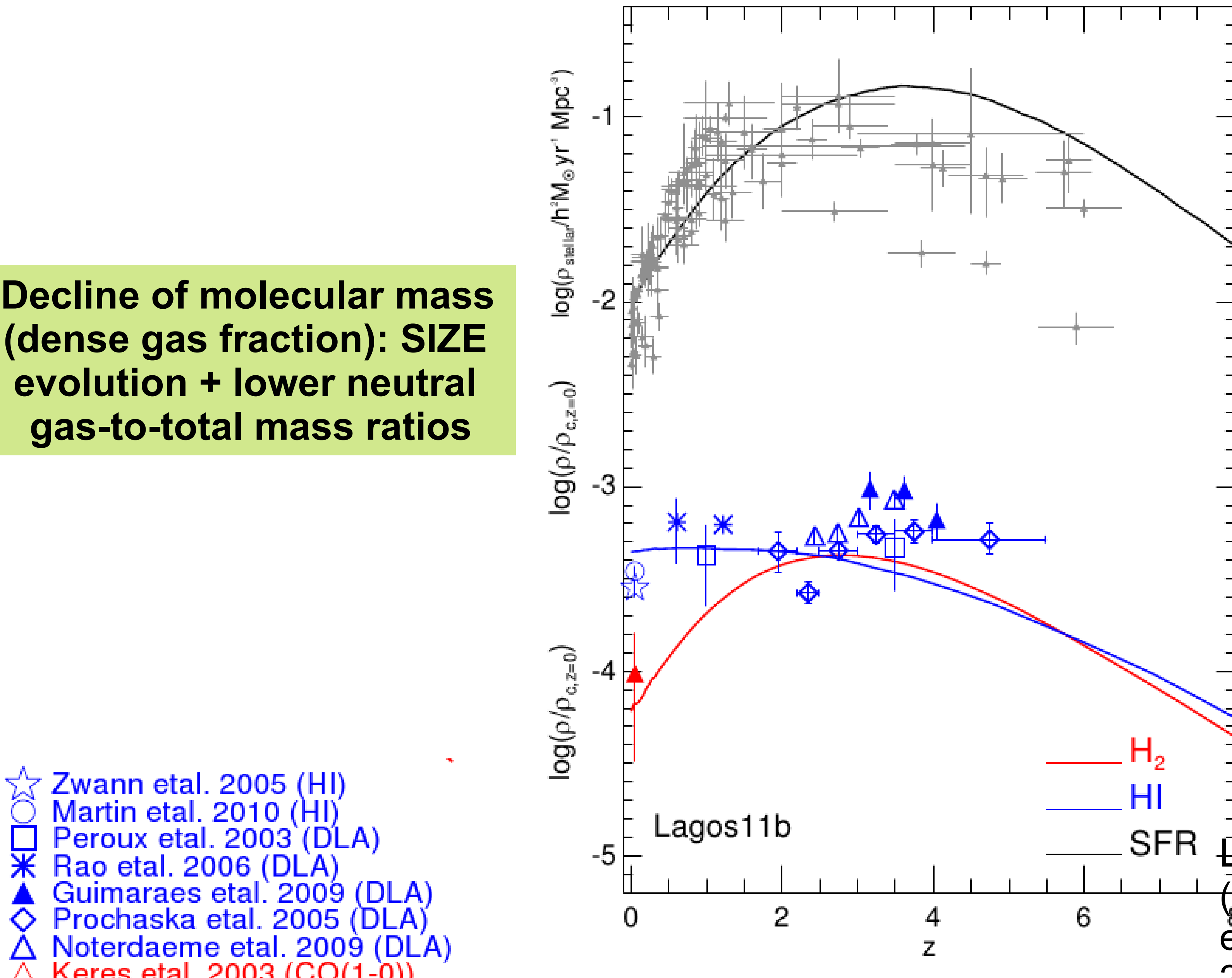
→ Compared against volume limited samples of Catinella et al., Saintonge et al.



Scaling relations: a direct consequence of the pressure-based SF law and fundamental predictions of the model (Lagos et al. 2011a, MNRAS, 416, 1566L)

The SFR decline: a consequence of dense gas fraction decline

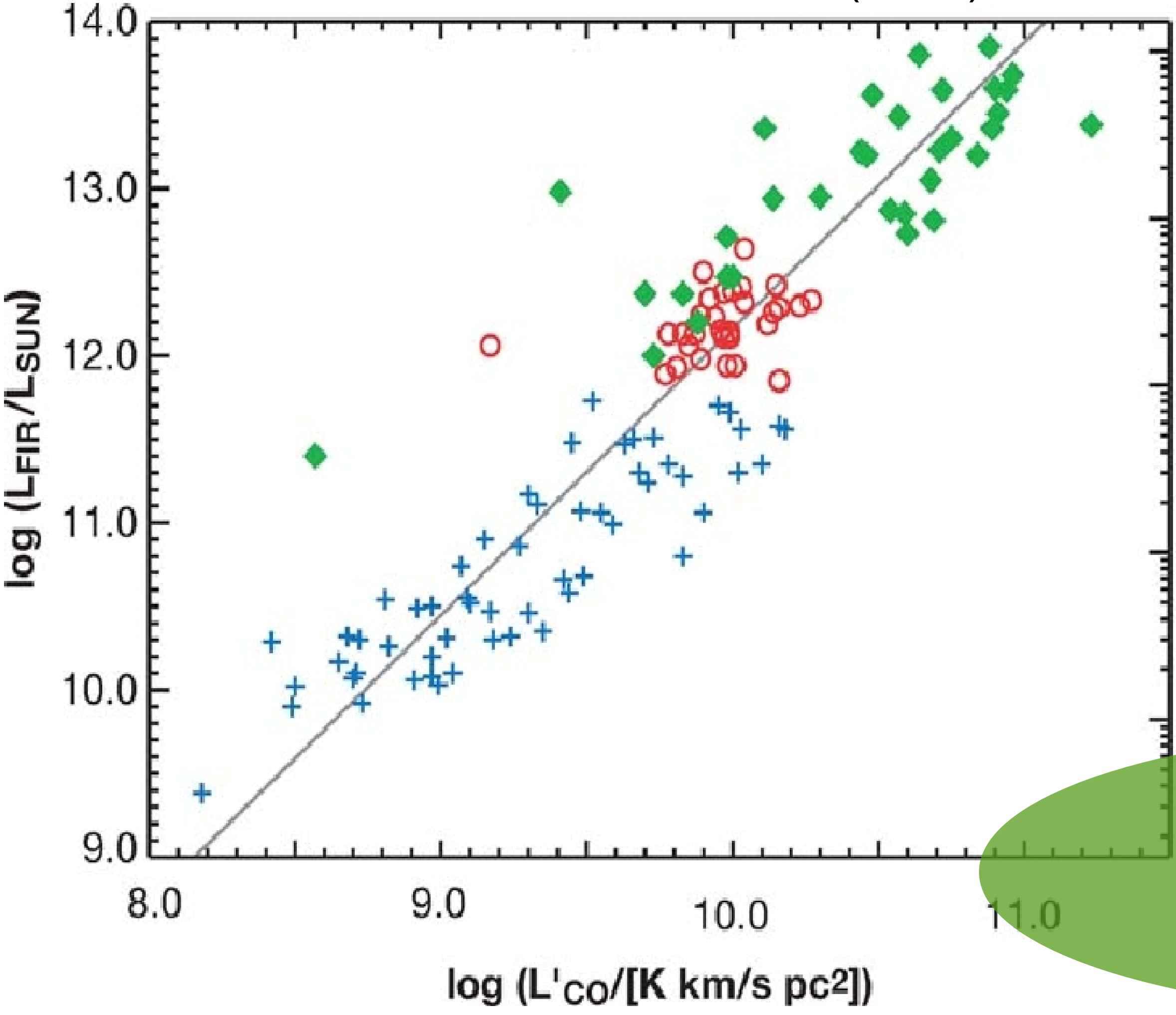
Decline of molecular mass (dense gas fraction): SIZE evolution + lower neutral gas-to-total mass ratios

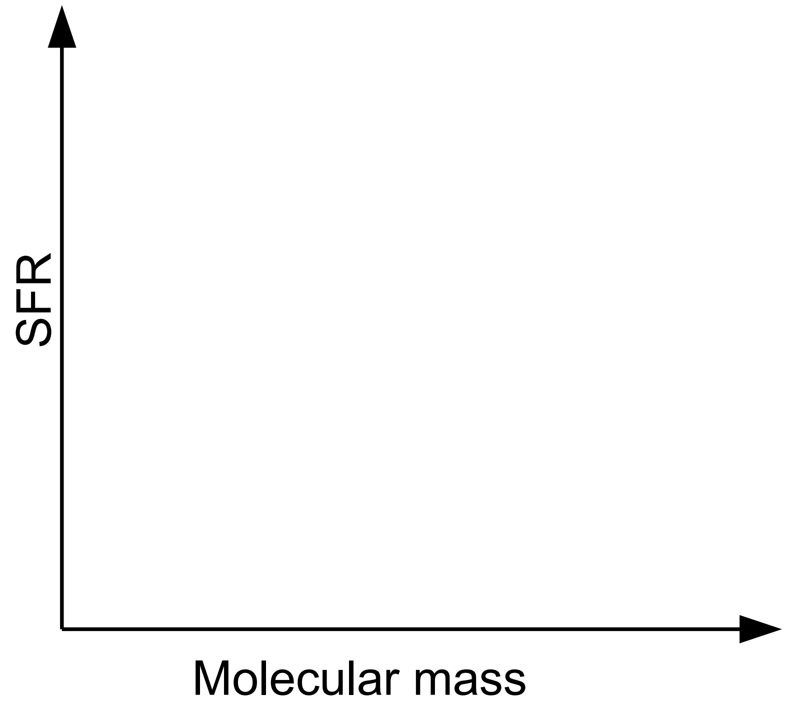


Lagos et al. (2011b) (see also Obreschkow et al. 2009; Fu et al. 2012)

Connection between molecular hydrogen and CO

Solomon & Vanden Bout (2005)

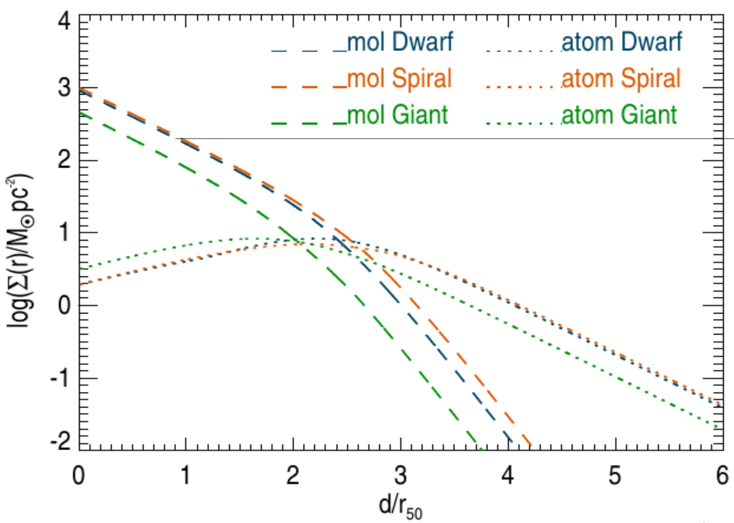


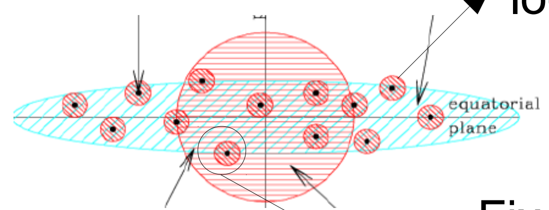


Need to assume a CO(1-0) to H_2 and a CO(J→J-1) to CO(1-0)

Combining GALFORM with the UCL_PDR RT
(Lagos et al, 2012 & Bayet et al., 2011)

Any GALFORM version can be run with any of the star formation laws discussed in Lagos et al. (2011a).





Molecular mass locked up in GMCs

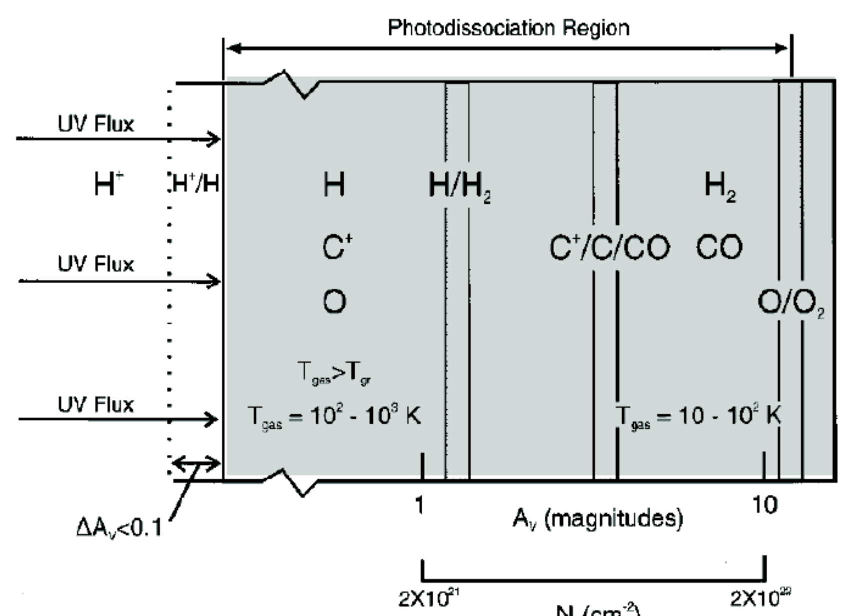
Fix density or fix G_{UV}/n_H

Characterise the ISM

G_{UV}

F_X

Z_{gas}

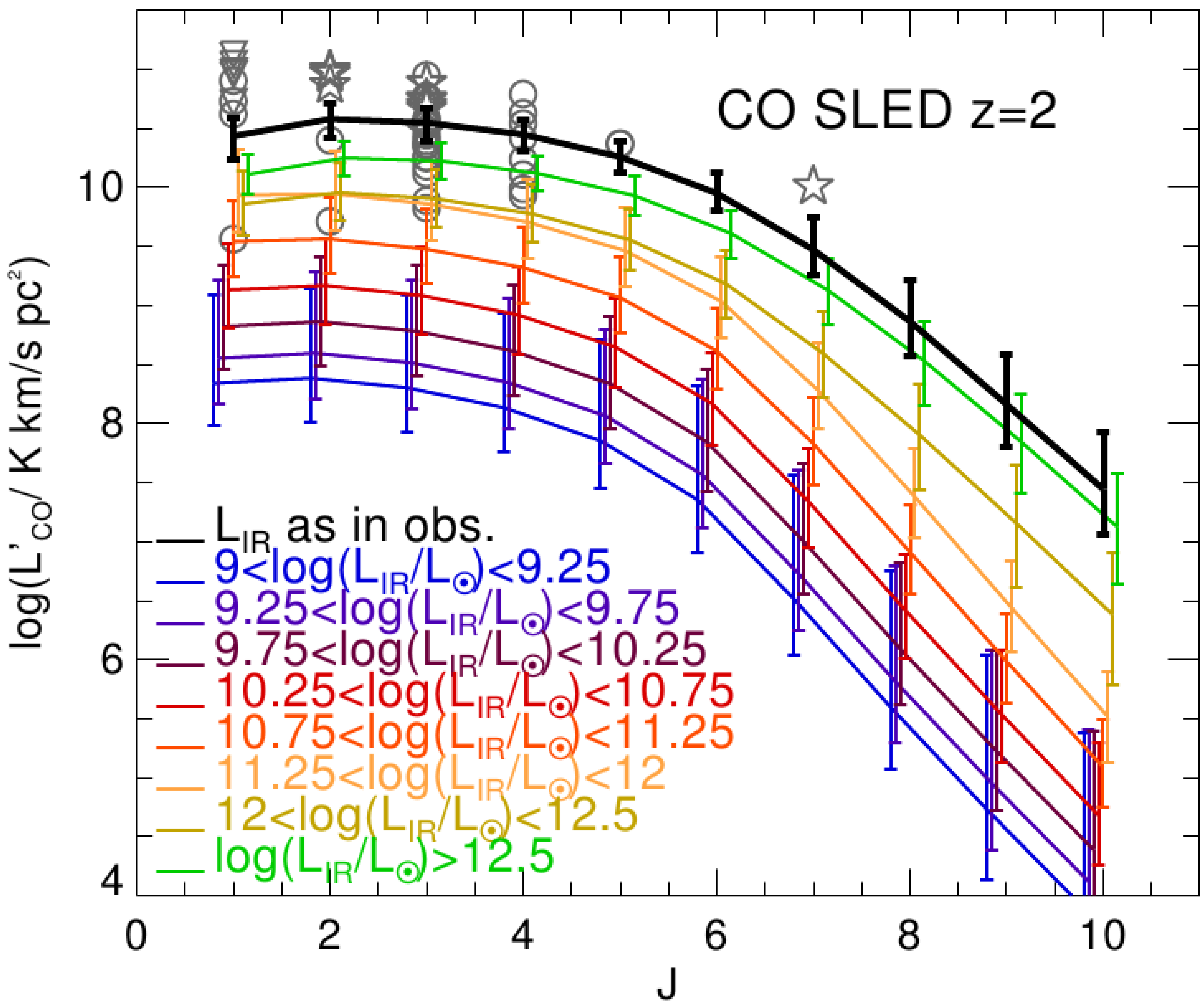


Output:

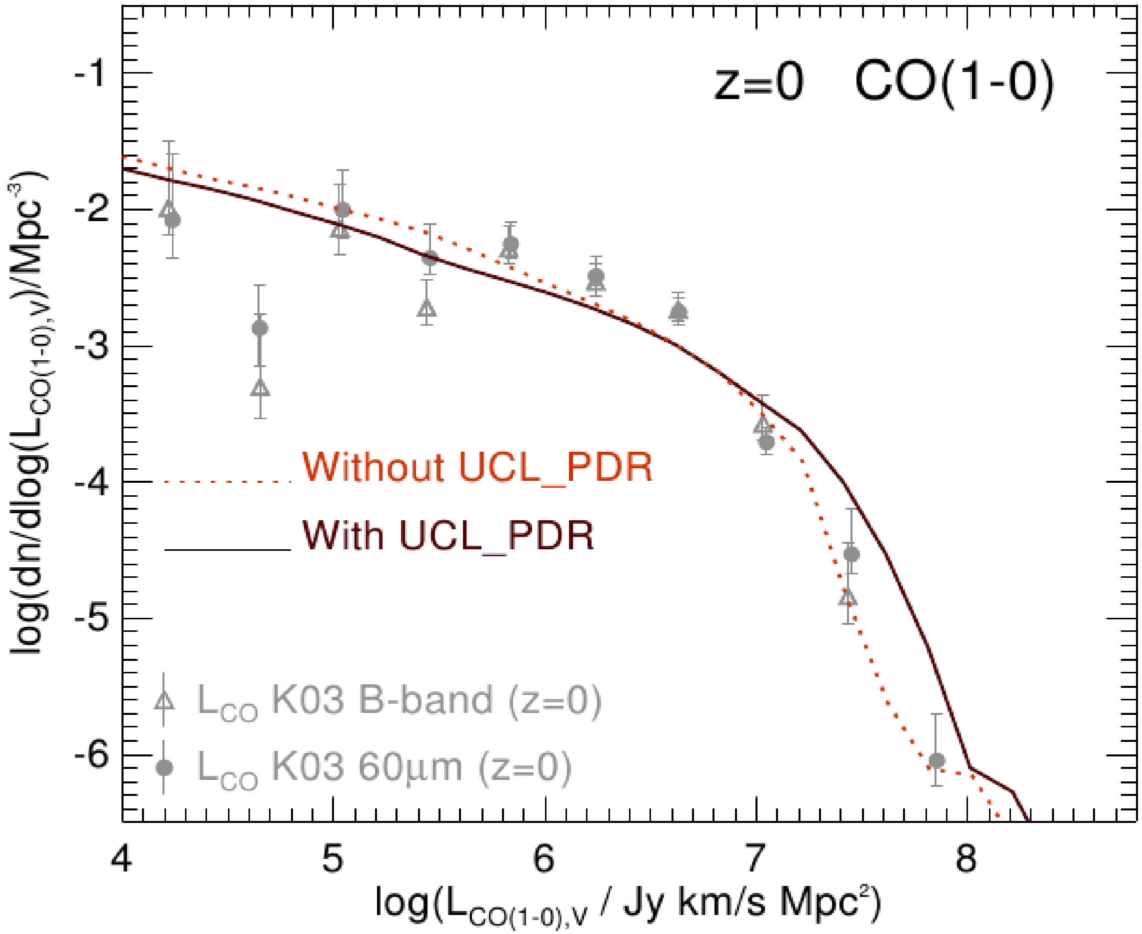
X_{CO} T_{gas}

We run this for each galaxy in the model and build their CO SLED

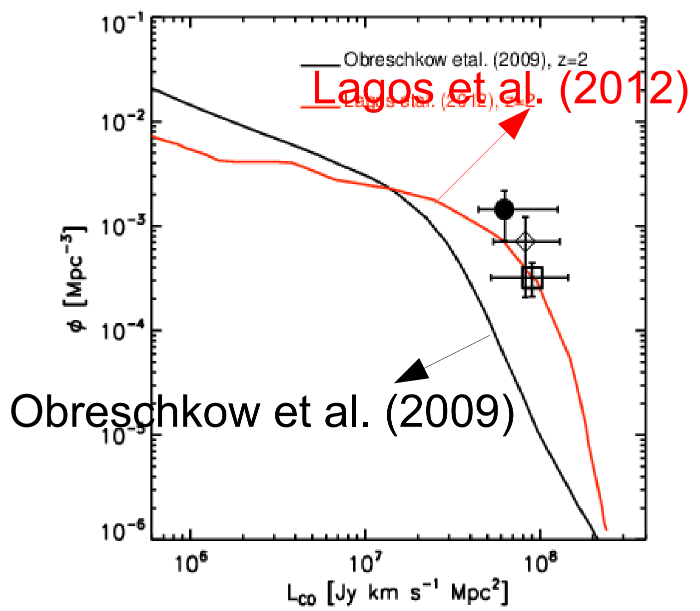
The CO SLED of high-z SMGs
(Lagos et al, 2012)



The predicted local CO(1-0) luminosity function

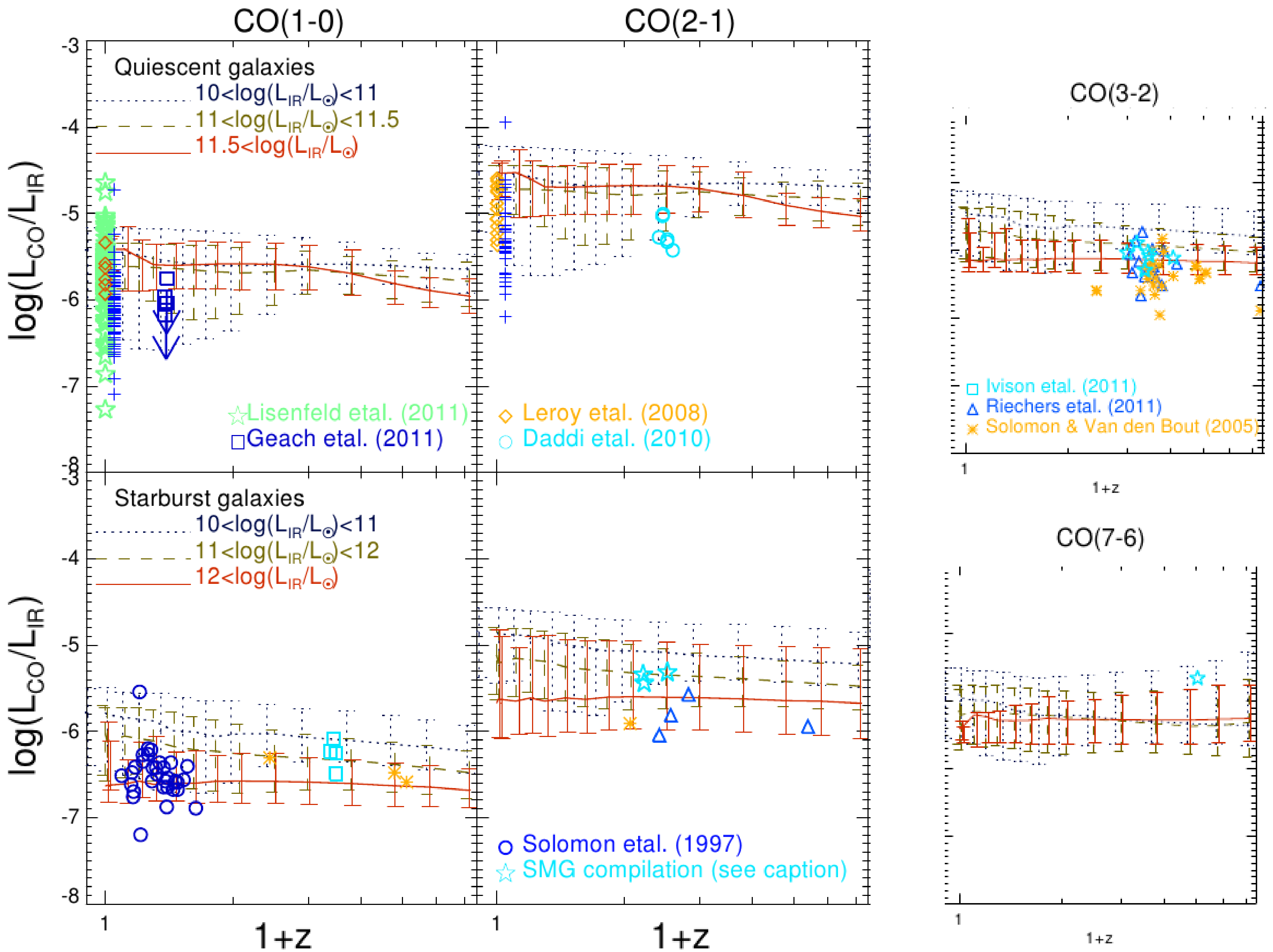


z=2; Aravena et al. (2012)

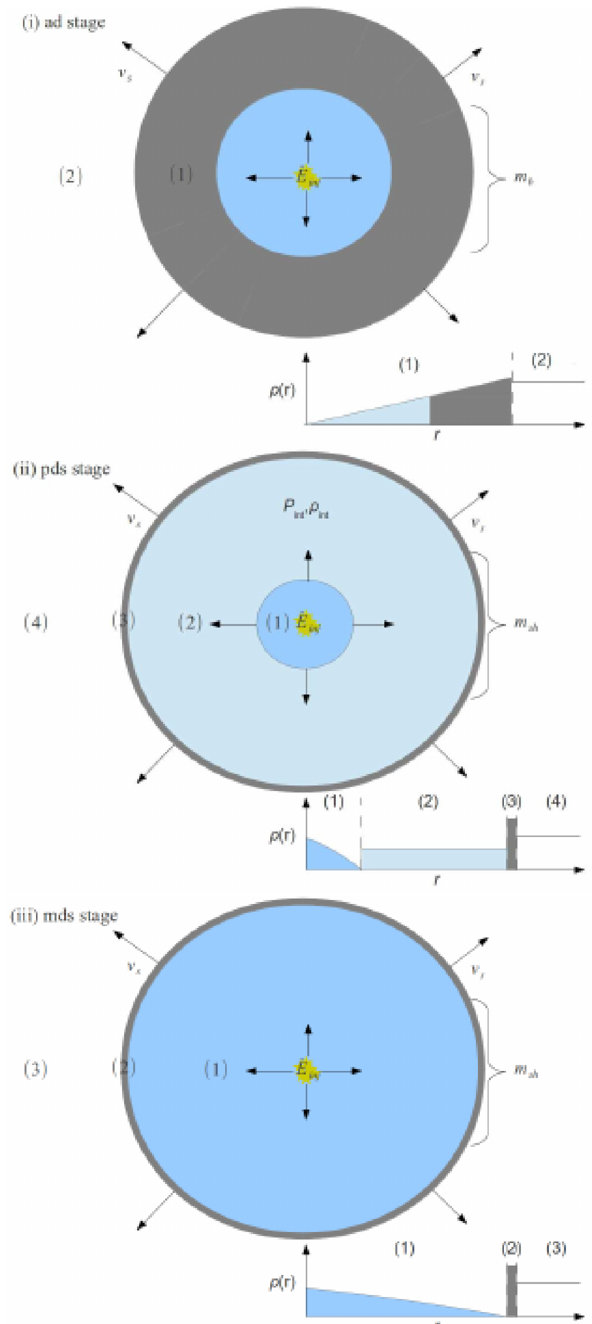


CO(1-0) → H2 conversion does make a difference, although not huge given that most of galaxies with the luminosities in the range observed have "normal" properties (see also Fu et al. 2012).

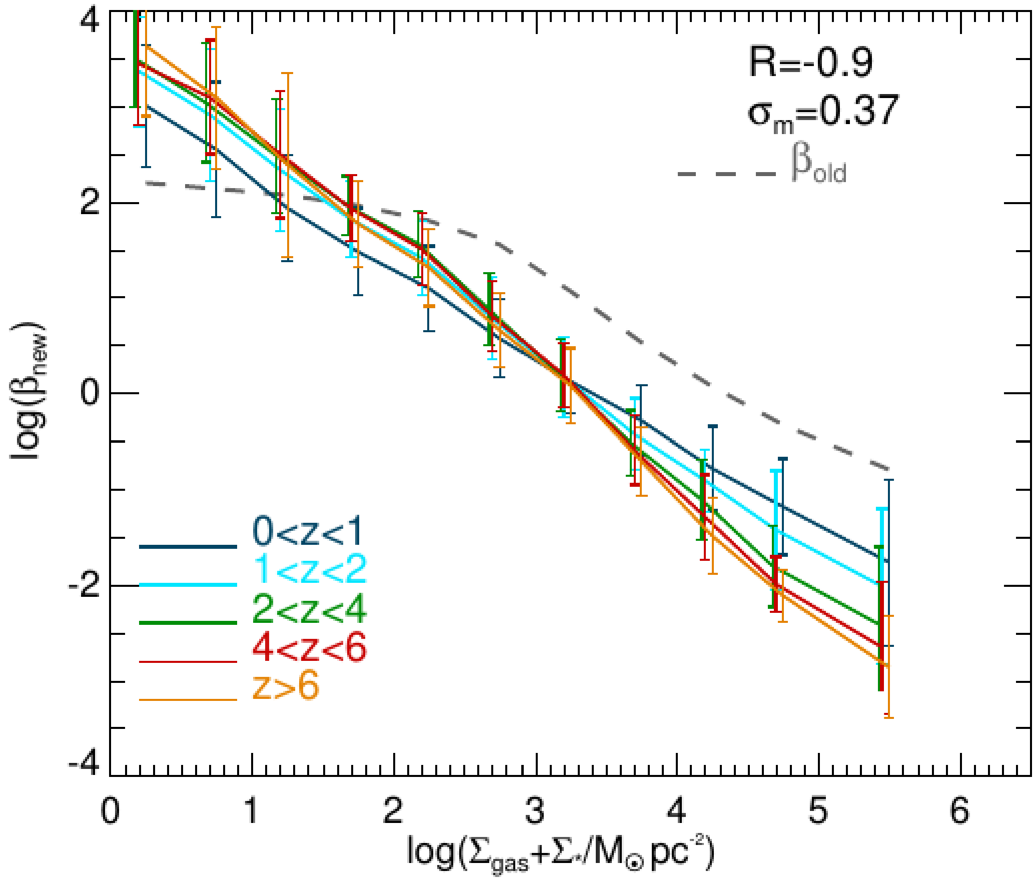
The CO-to-IR luminosity ratio evolution
(Lagos et al, 2012)



Comments on supernovae feedback
(Lagos, Lacey & Baugh, soon!)



→ Multi-phase ISM + detailed evolution of SNe inflated bubbles in the ISM



$$\beta = \left[\frac{\Sigma_{\rm gas}(r_{50}) + \Sigma_\star(r_{50})}{1300\, M_\odot\, {\rm pc}^{-2}}\right]^{-0.4\, f_{\rm gas} - 0.83}$$

Conclusions

Lagos et al. (2011a,b), Geach et al. (2011), Lagos et al. (2012a,b), Kim et al. (2012), Lacey et al. (2013, in prep.)

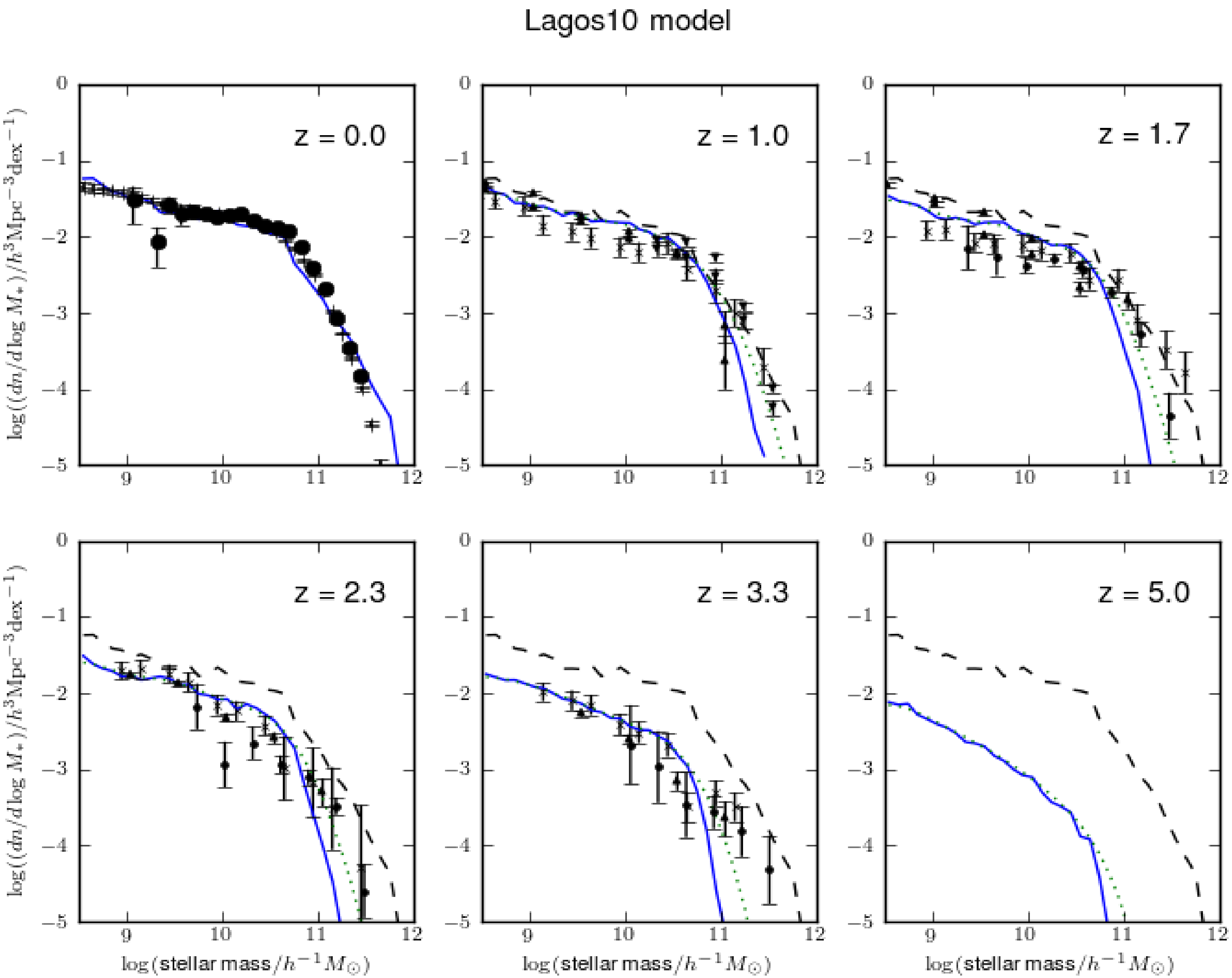
- Future exciting opportunities to explore galaxy formation in cold gas. SAMs do currently have the power to explore scaling relations and absolute abundance properties (see Lagos et al., Fu et al., Kauffmann et al.)

- **GALFORM: good agreement with** scaling relations H2/HI, HI mass function and clustering and global abundances, gas fractions, LFs, reasonable stellar mass functions and SSFRs.

- **GALFORM+UCL_PDR**: CO emission lines in 1-0 to 10-9 rotational transitions (Lagos et al. 2012).

- Future GALFORM models will include the information of HI, H2 and CO in the database (Lagos 2012 and Lacey 2013 models).
  - Lagos12 model should be in the database with all this info by January.

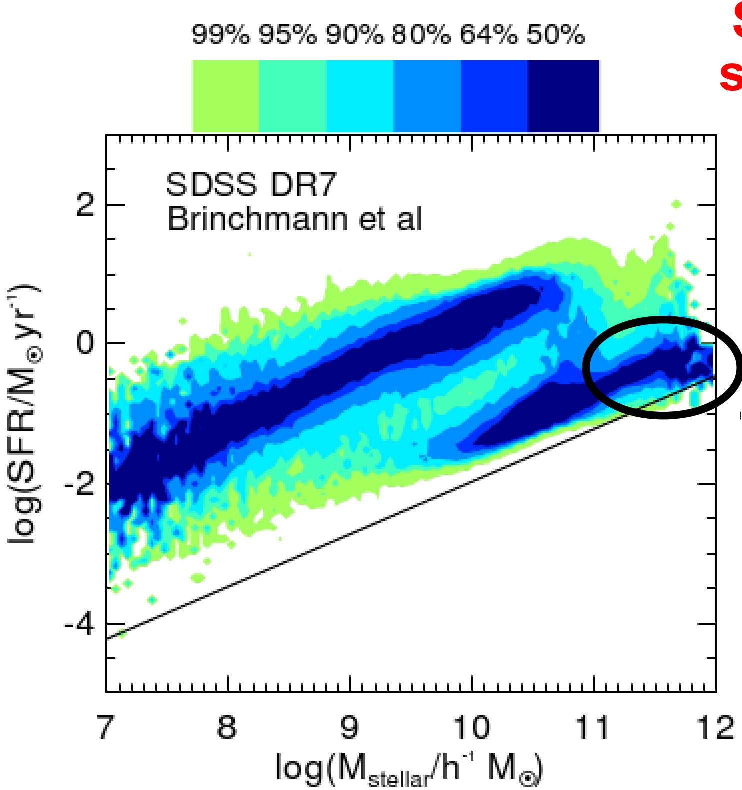
The effect on dwarf galaxies: less SF



Courtesy Richard Bower

The impact of the SF law in the SFR-$M_{stellar}$ plane

Lagos et al. (2011a)

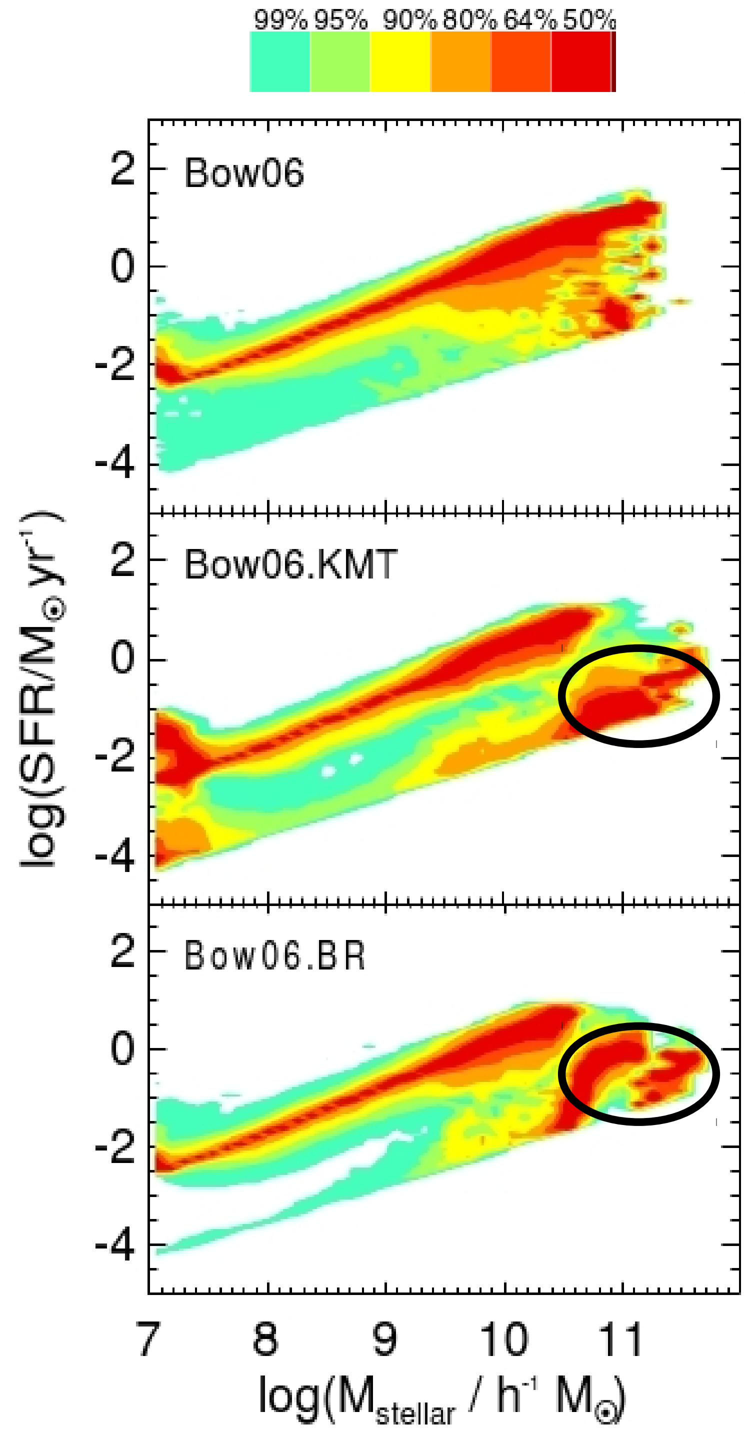


- SFR sensitivity limit
- r-band magnitude cut

Passive galaxies
(satellites) greatly aff

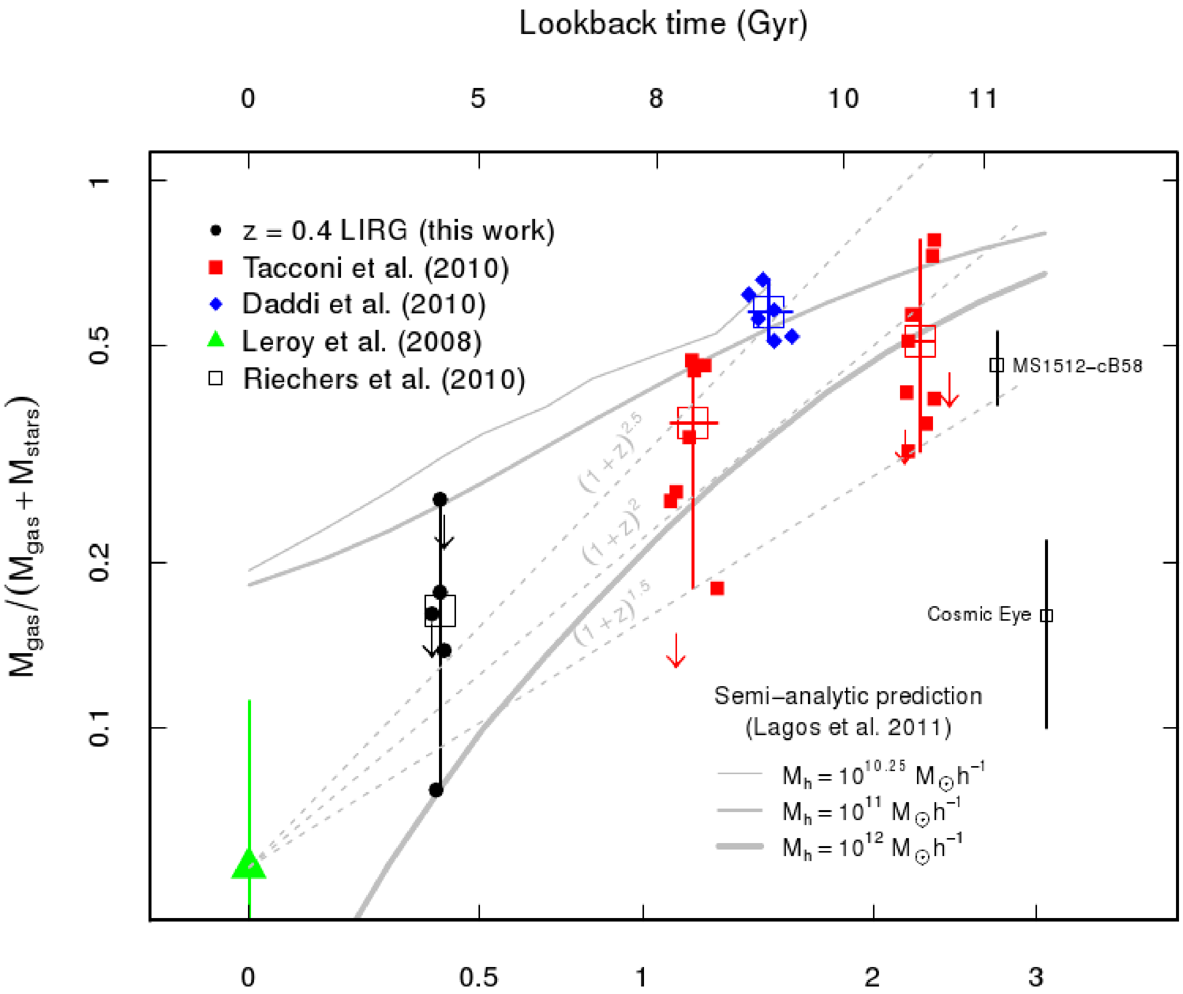
Shape of the pass sequence: form of SF law

Slope shaped
accretion/outf
balance

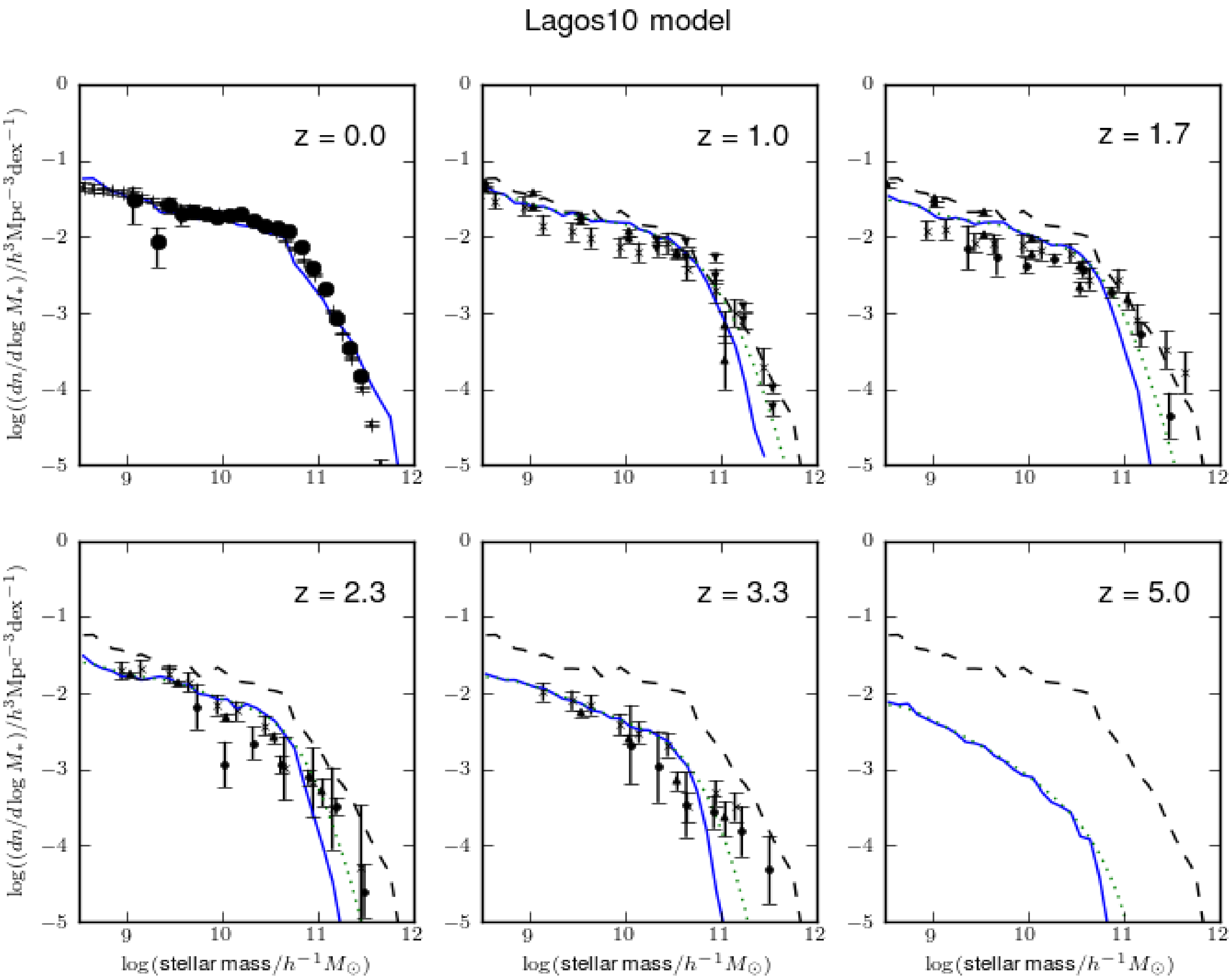


Evolution of molecular gas fractions
(Geach et al. 2011)

- Strong molecular fraction evolution explained by higher ISM pressure (Lagos et al. 2011b)



The effect on dwarf galaxies: less SF



Simulating observations for ALMA: BzK galaxies
(Lagos et al, 2012)