PHISCC, Dwingeloo
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Neutral Gas in galaxies: the perspective of semi-analytic models

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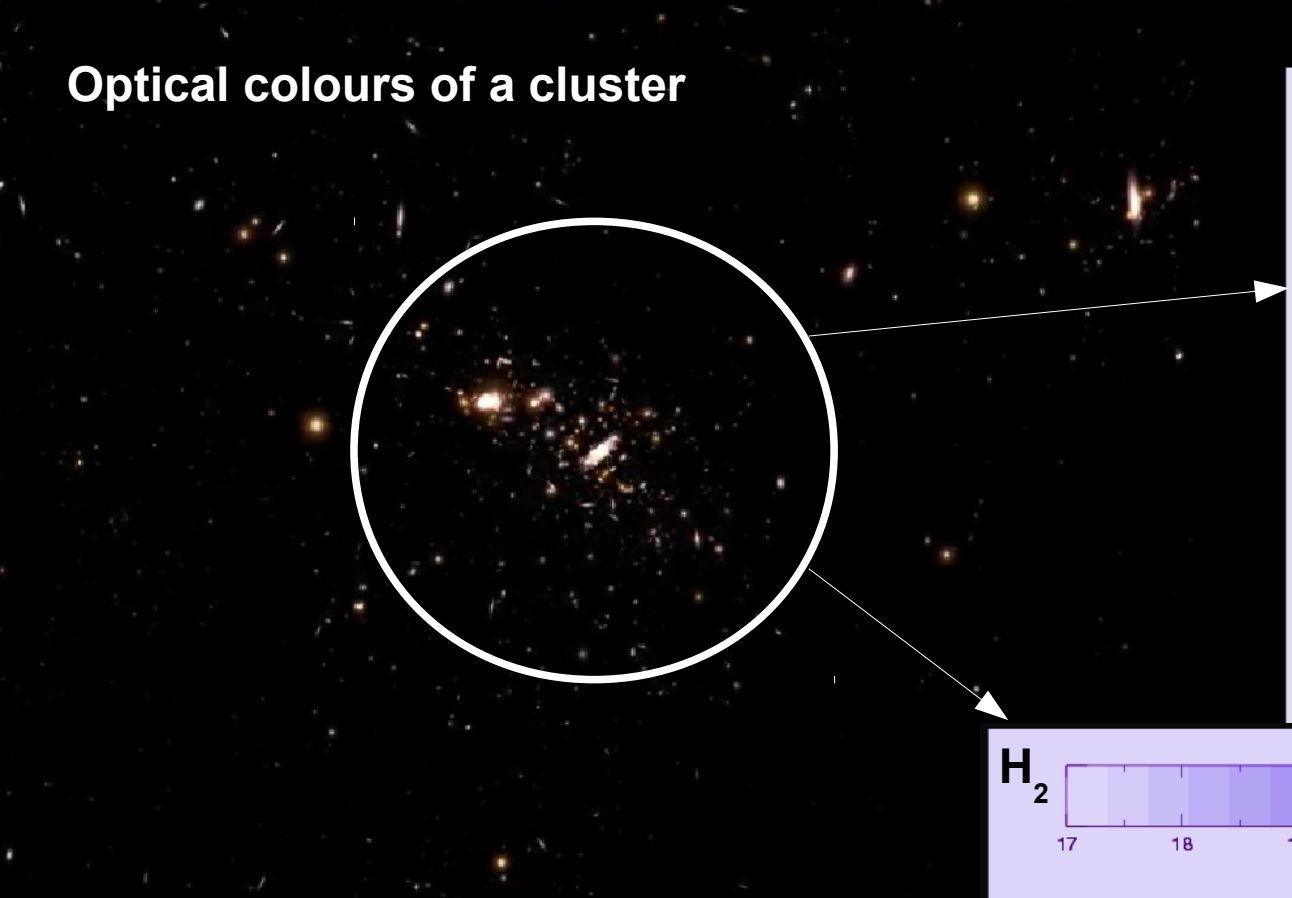
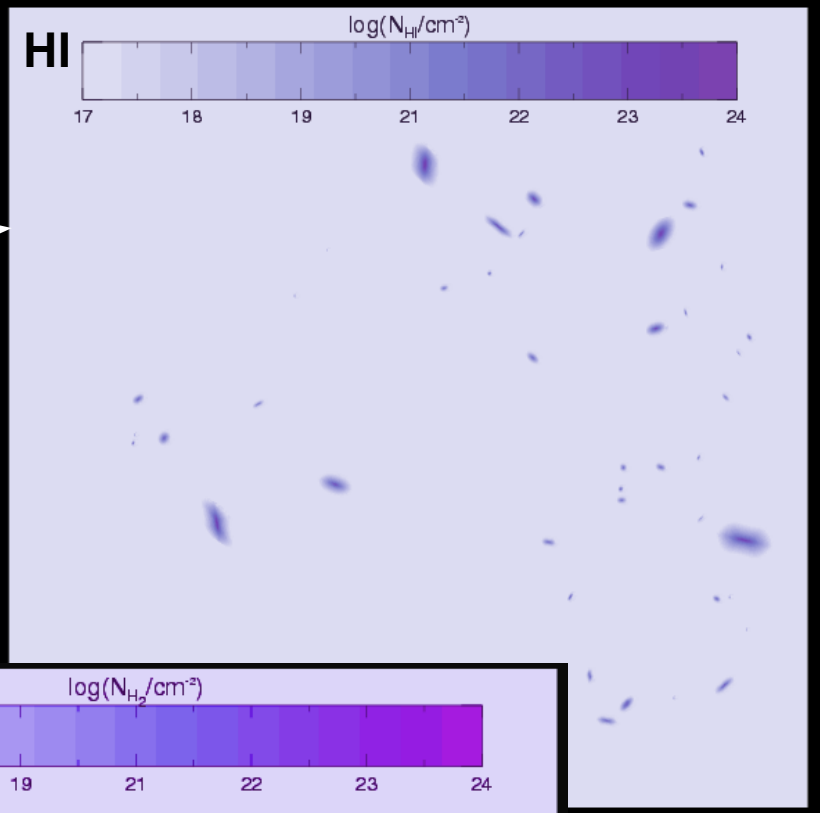
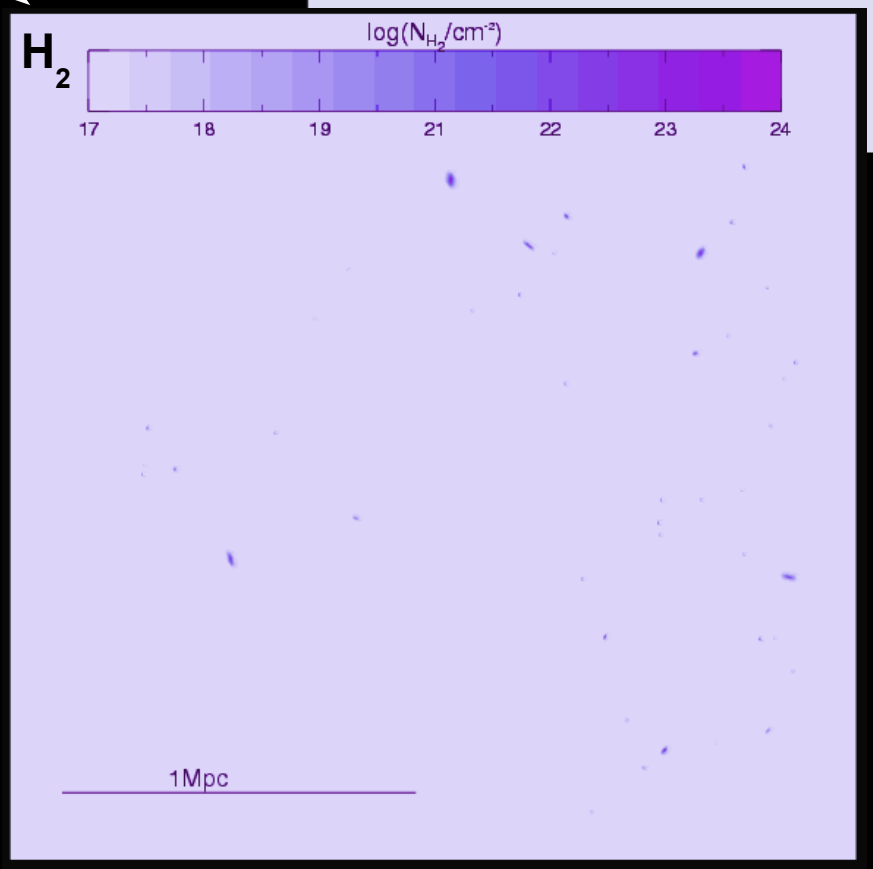
Optical colours of a cluster



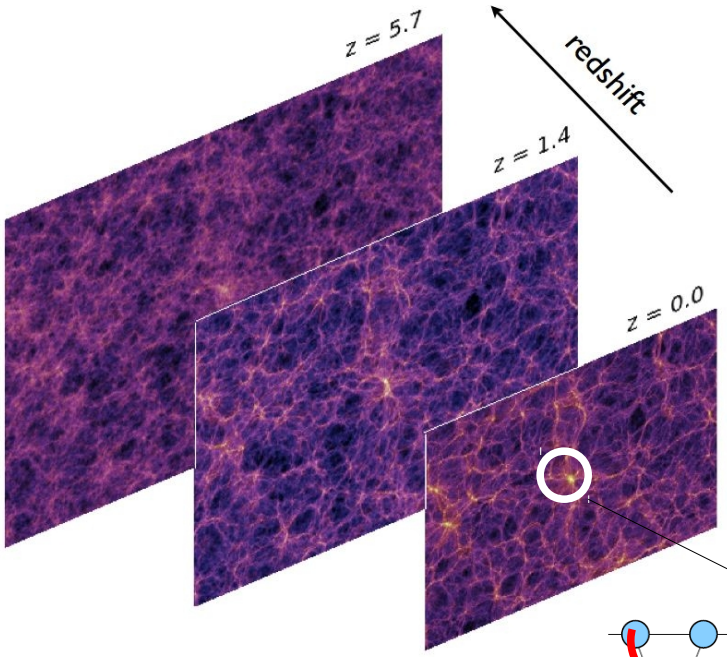




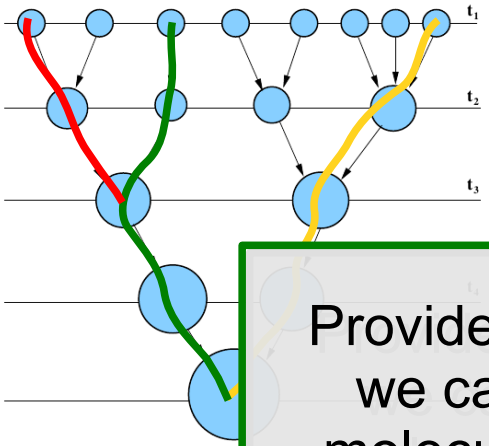
→ State-of-the-art 2009: Obreschkow+09a,b and Power+10.
→ Currently (progress in 3-4 years): Connection gas ↔ stars in galaxy formation semi-analytic models in a self-consistent way.

The galaxy formation semi-analytic technique

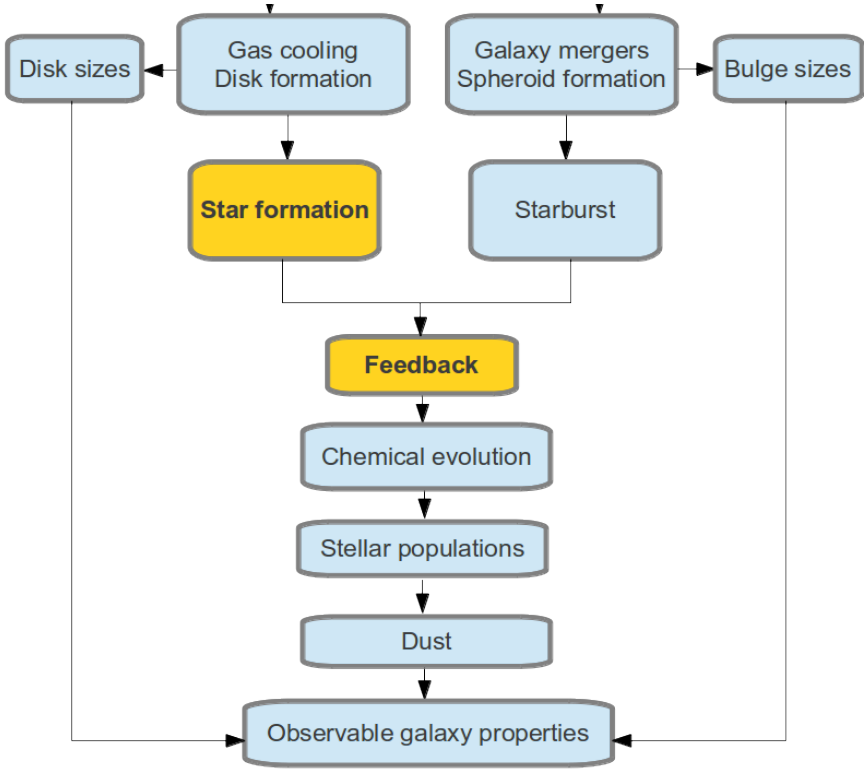
(1) Dark matter N-body simulation



(2) Halo, sub-halo finder a
merger trees construction



(3) Semi-analytic technique



Intrinsic properties, plus full SED and emission lines.

Provide a *theoretical framework* in which we can study SF, its relation with the molecular/atomic gas, and other galaxy properties (stellar mass, colours, B/T, etc).

Semi-analytic models: Connecting galaxy formation and evolution with the growth of structures in the Universe...

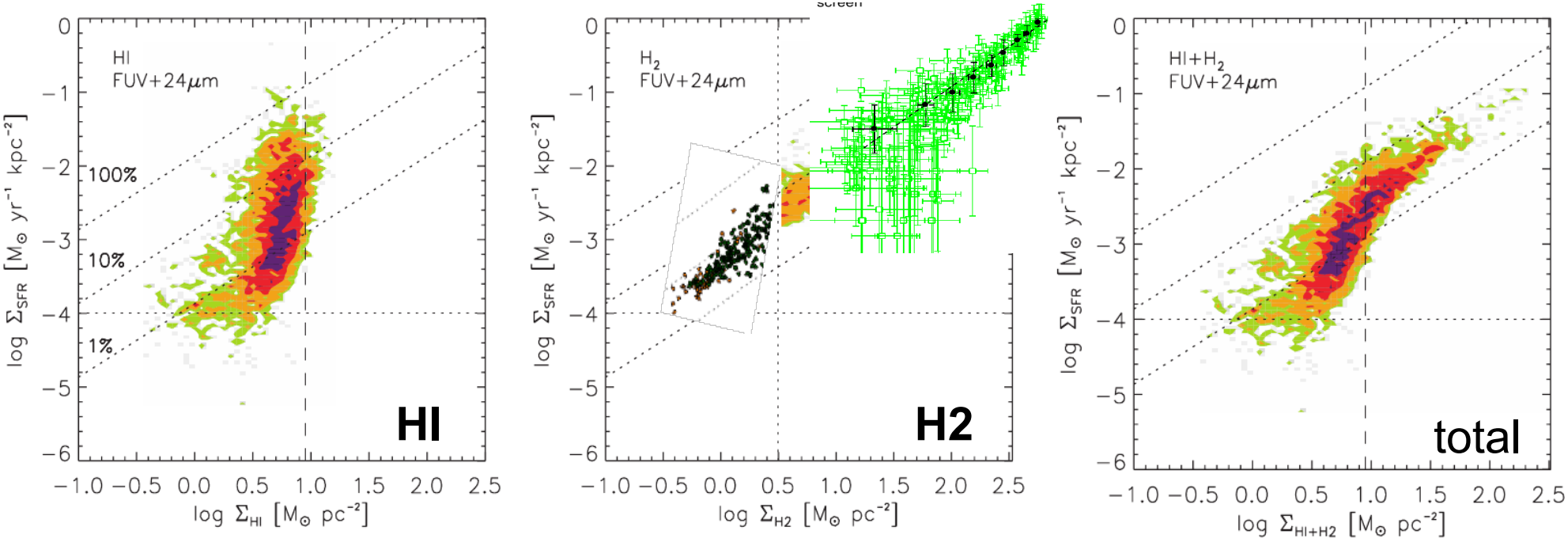
Galaxies and their optical colours

Dark matter

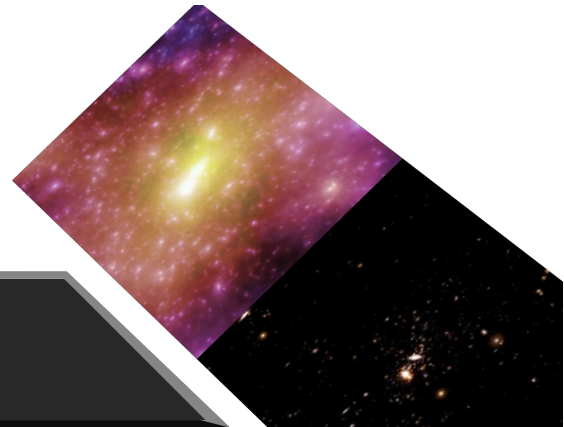
Characterisation of the SF law in local galaxies

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, 2013), Genzel et al. (2013), etc.

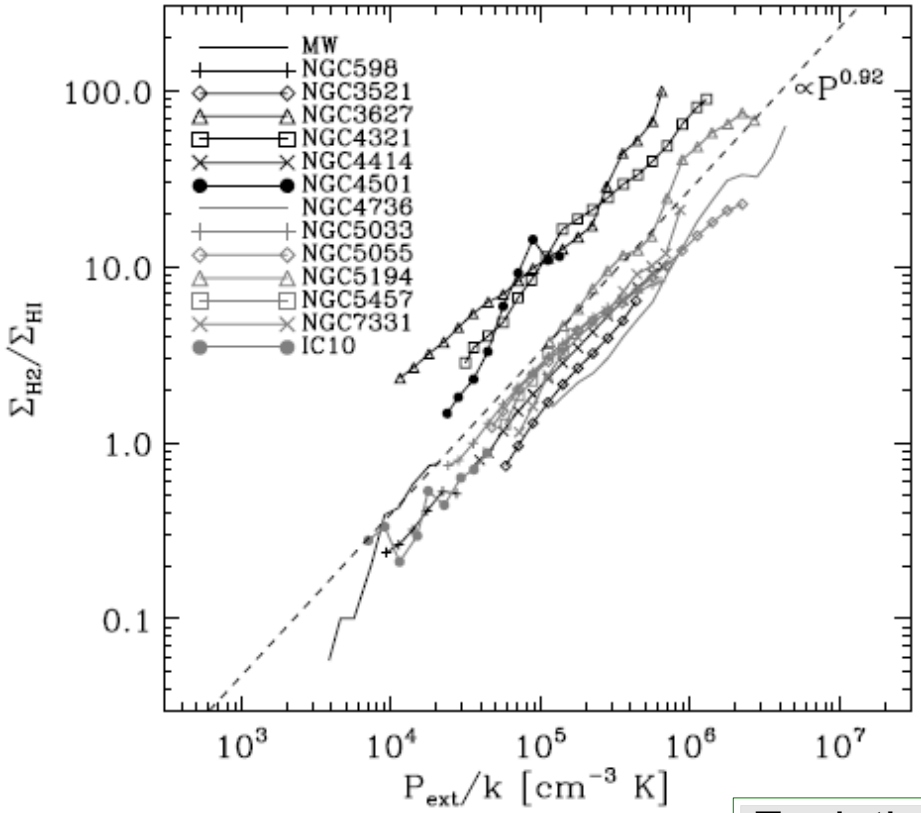


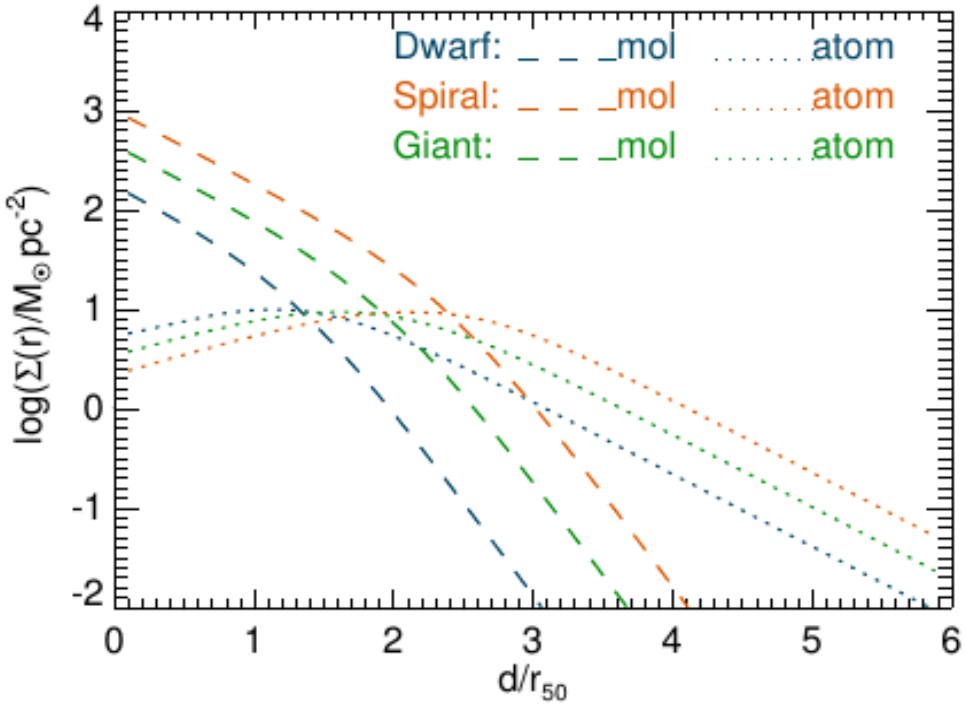
(i) No correlation with HI
(ii) Linear correlation with H_2
(iii) Multiple regimes with total gas density



Development: The Pressure Star Formation Law

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





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

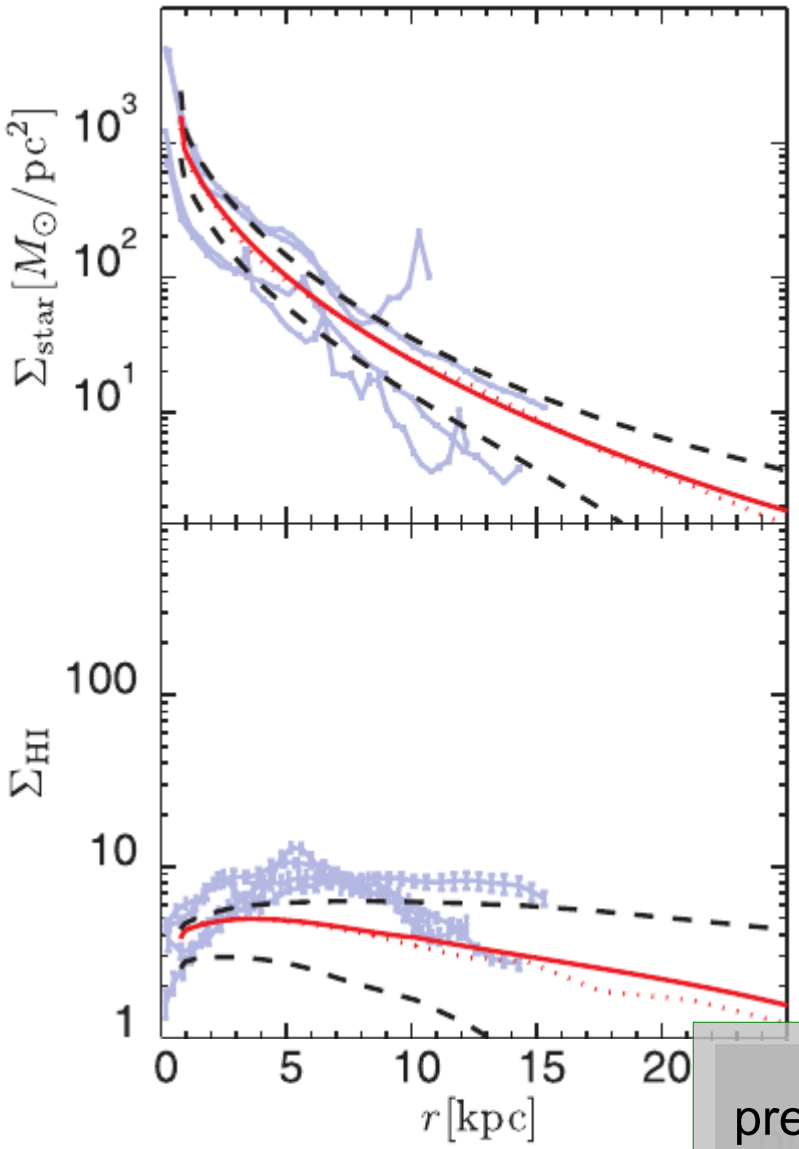
$$P_{\rm ext} \approx \frac{\pi}{2} G \Sigma_{\rm gas} \left[\Sigma_{\rm gas} + \left(\frac{\sigma_g}{\quad}\right)\Sigma_*\right]$$

Evolution of HI, H2 and other galaxy properties followed self-consistently (Lagos et al. 2011a,b, 2012; Fu et al. 2010, 2012; Cook et al. 2010; Popping et al. 2013).

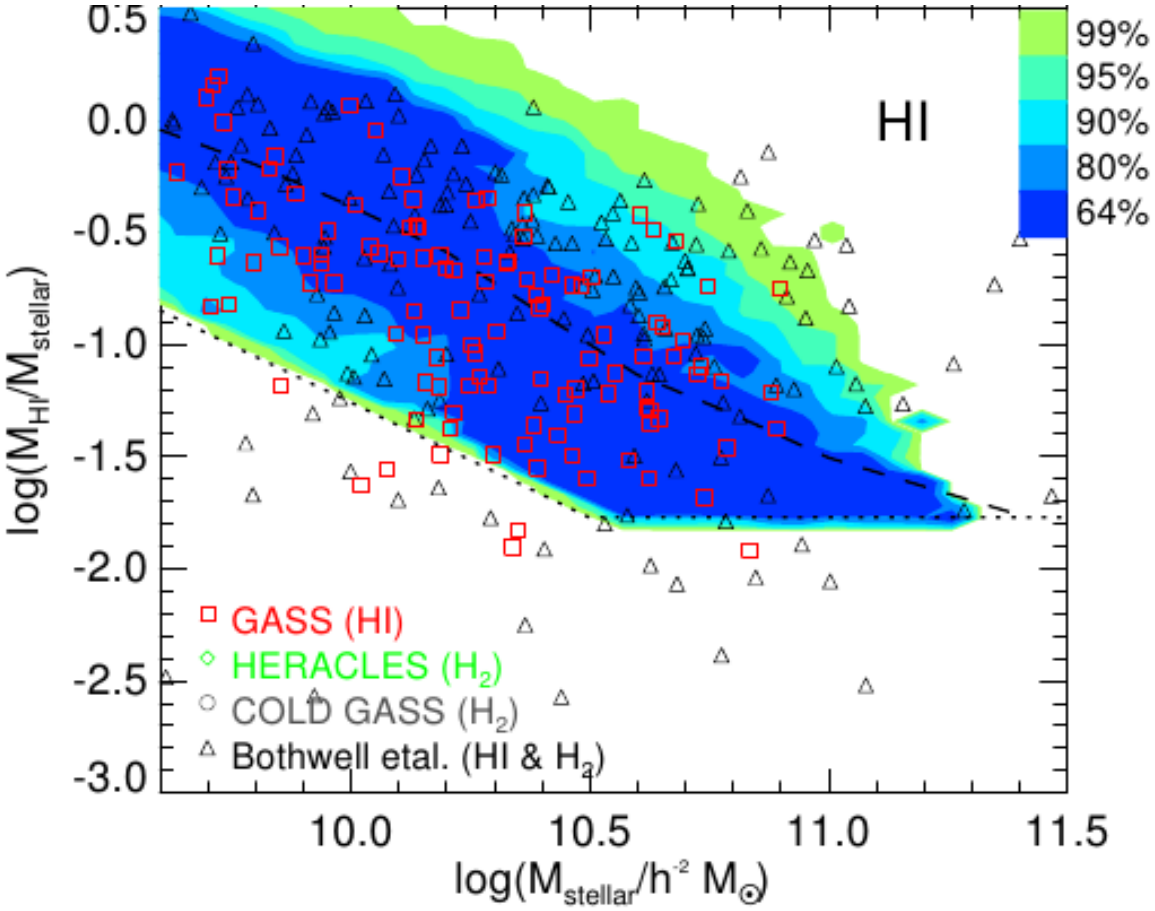
Prior treatment ignored the different gas phases and used free parameters to describe SF efficiency.

Radial profiles of neutral gas and scaling relations

Fu et al. (2010)



Lagos et al. (2011a,b)

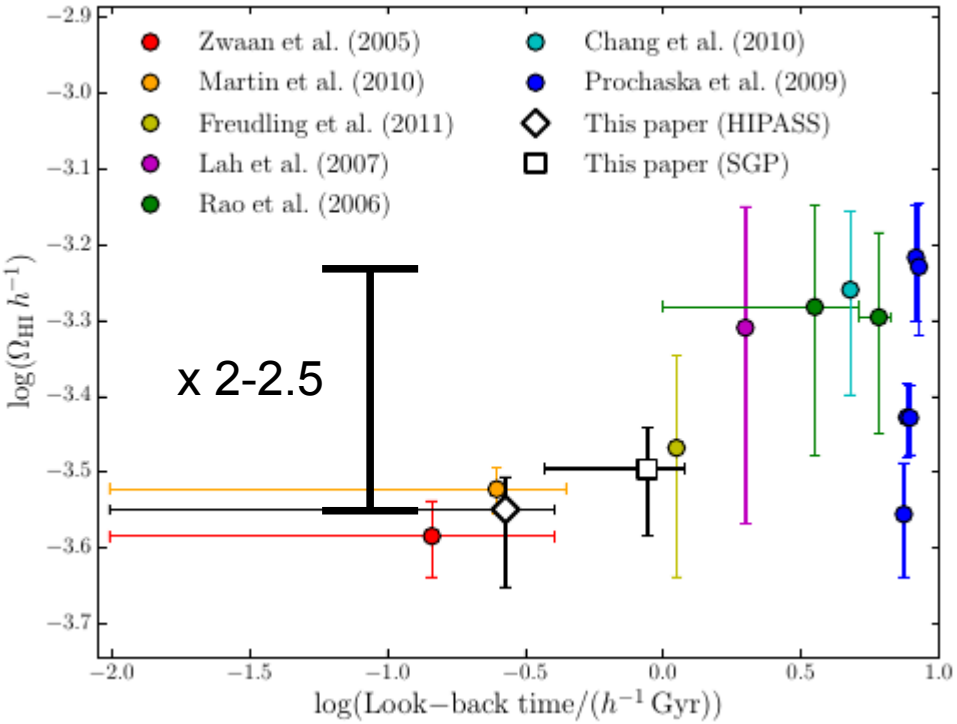


Scaling relations: a direct consequence of the pressure-based SF law and fundamental predictions of the model (Fu et al. 2010, Lagos et al. 2011a)

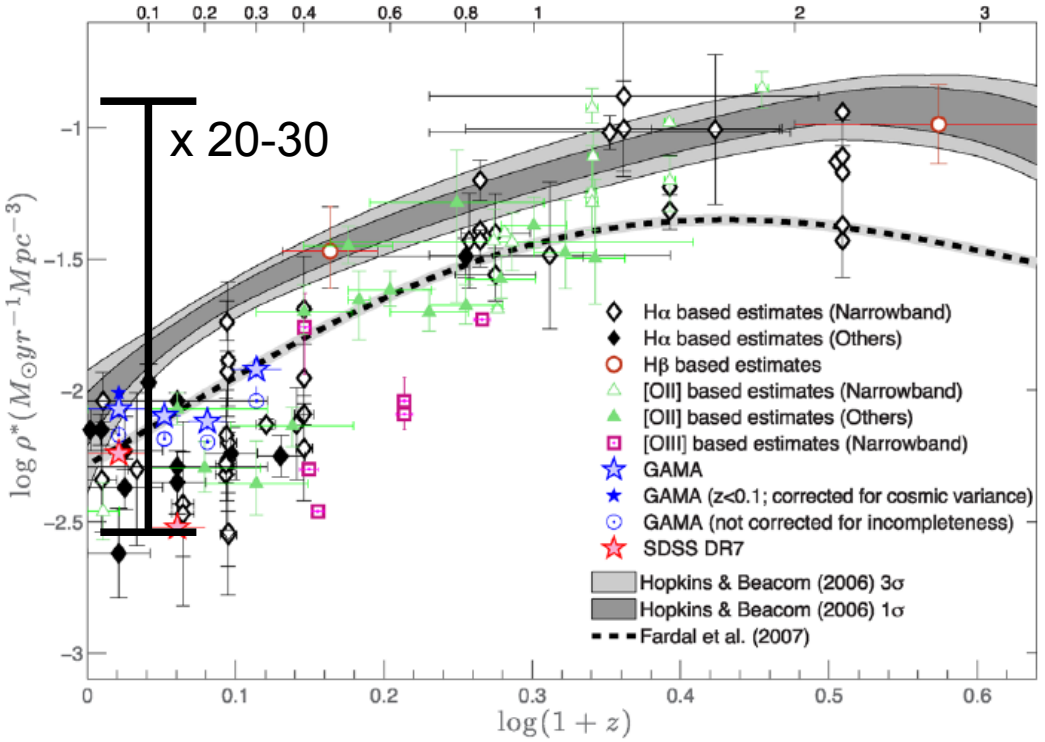
The neutral gas content of the Universe

An outstanding problem in extragalactic astrophysics:

Delhaize et al. (2013)

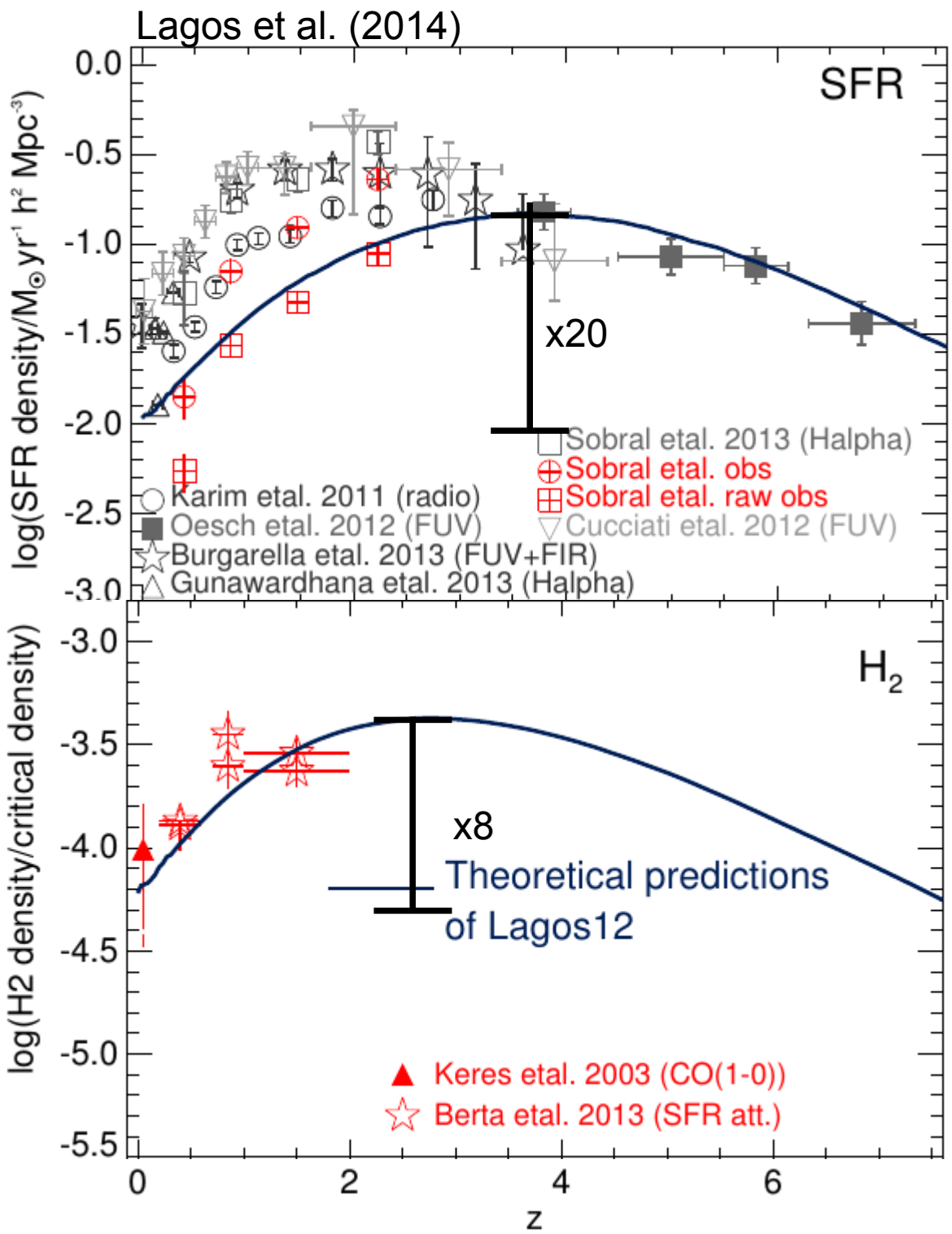


Gunawardhana et al. (2013)



If neutral gas is the fuel for star formation, ***why the star formation history of the Universe looks so much different than the HI history of it?***

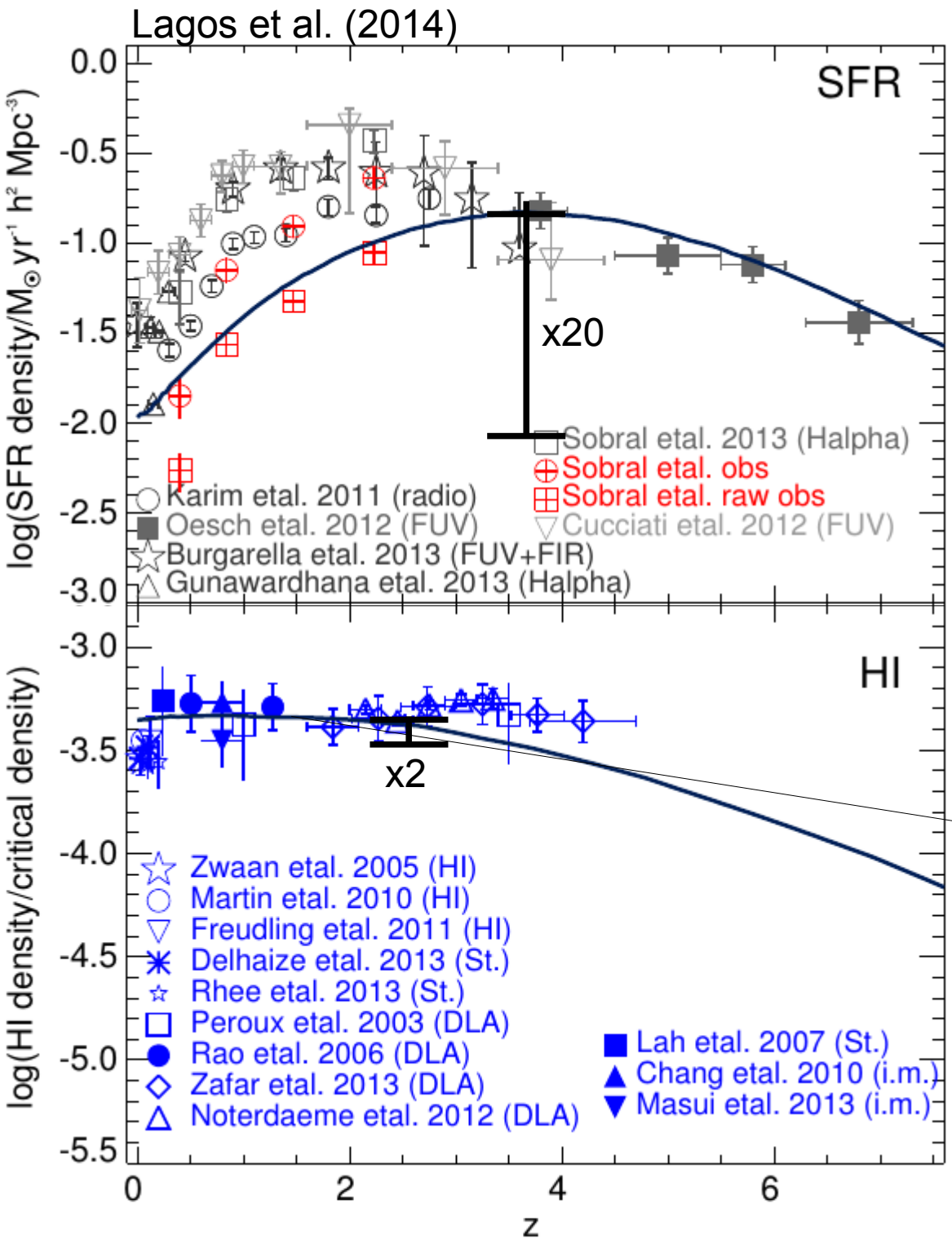
The densities of SFR and H2



Difference comes from the contribution from starbursts: it's larger in SFR than in H_2

See also Obreschkow+09a,b, Fu et al. 2012; Popping et al. 2013a

The densities of SFR and HI



(1) The evolution of total neutral gas: outflow vs. inflow
(2) The size evolution of galaxies: gas density

CHALLENGE: It's necessary to resolve all galaxies that make an important contribution to the HI in the Universe:
→ ***Very high resolution*** (so far achieved with MC trees or Millennium-II)

The densities of SFR, HI and H2

Lagos et al. (2011a,b) Lagos et al. (2014)

(1) The evolution of total neutral gas: outflow vs. inflow
(2) The size evolution of galaxies: gas density

More compact galaxies

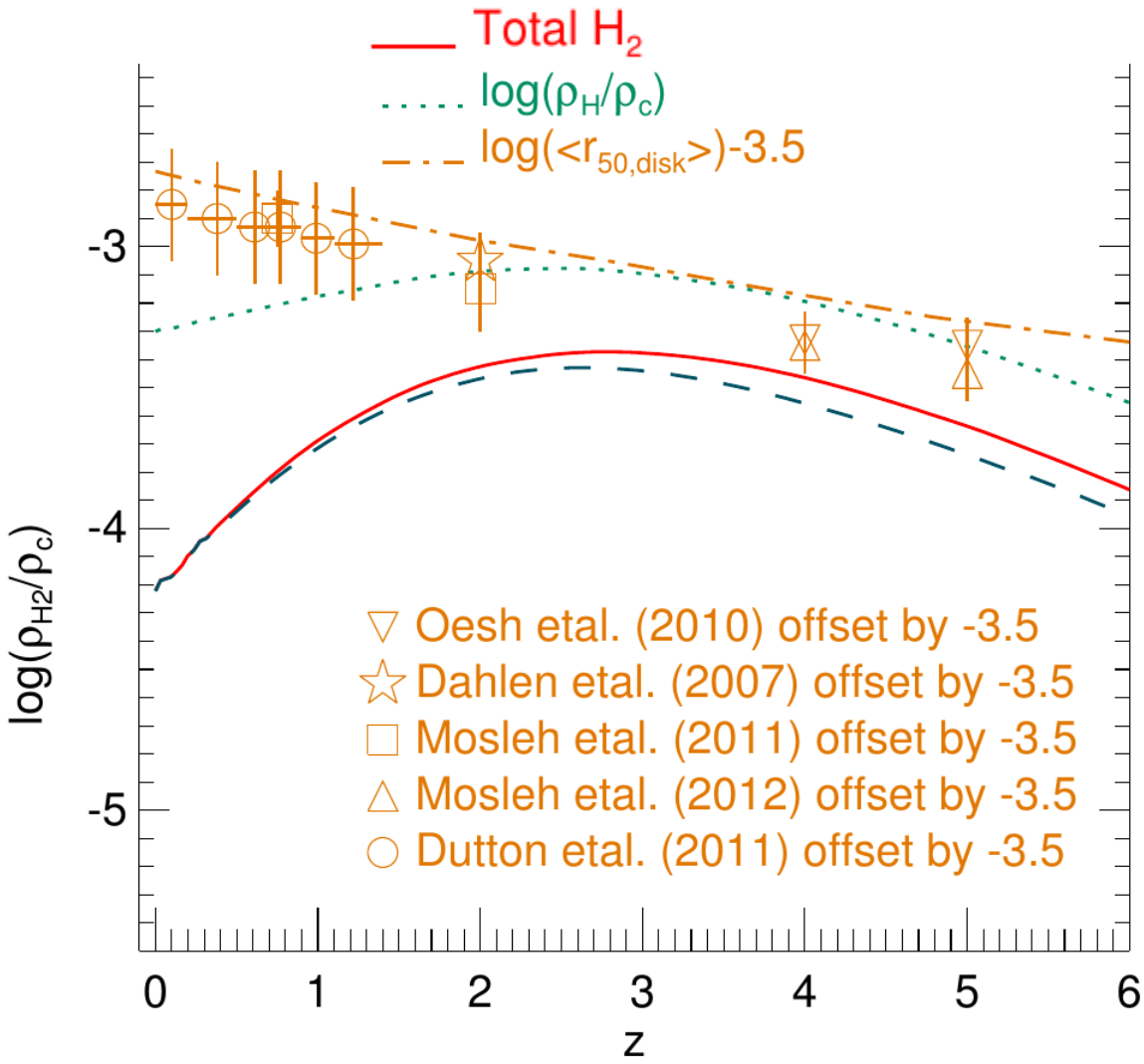
↓

Higher internal pressure

↓

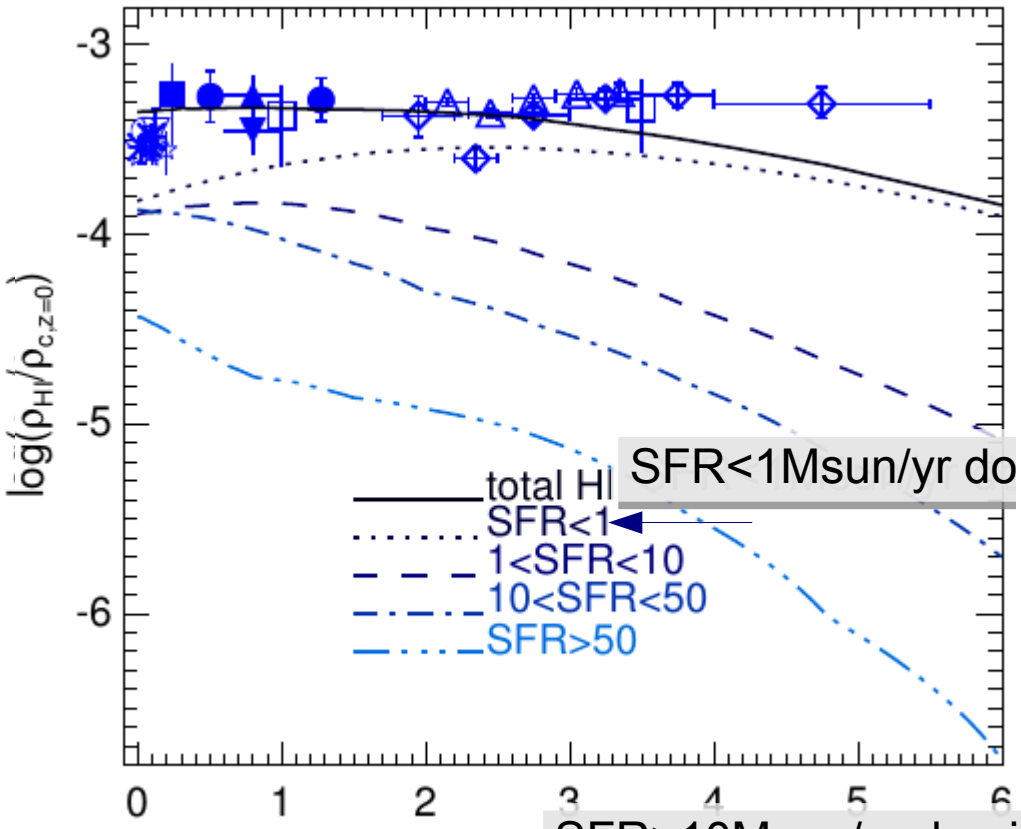
Higher H2/HI

For the same amount of gas in a galaxy, the higher-z one will have more H_2, and therefore more SF

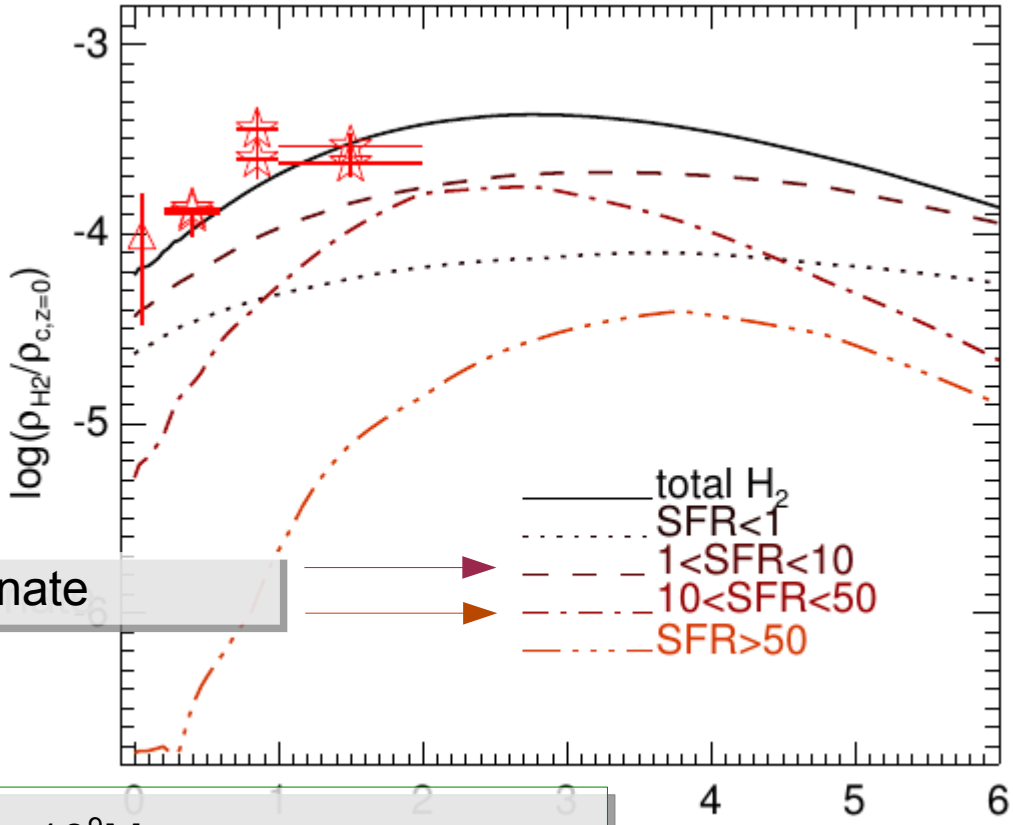


Which galaxies dominate the HI and H2 content of the universe?

Lagos et al. (2014)



SFR<1Msun/yr do

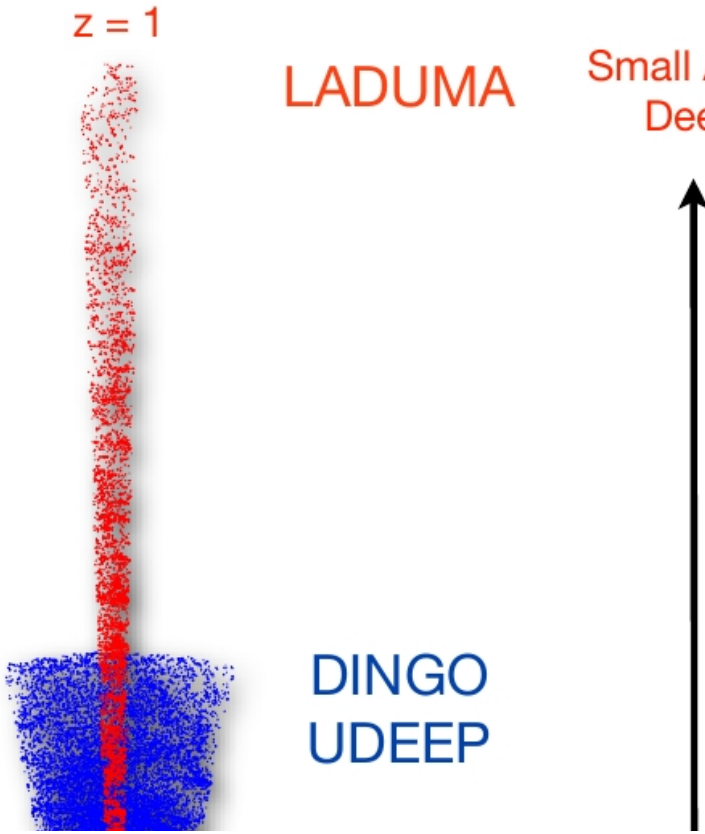


SFR>10Msun/yr dominate

For HI: those with SFR<1M_o/yr, Mstellar<few $10^9 M_o$

For H_2: those with SFR>few M_o/yr, Mstellar>$10^{10} M_o$

Challenges for upcoming HI surveys



Headline science: **how does the HI content relate to multi-wavelength galaxy properties and environment?**

Given the faint nature of HI counterparts, what are our chances to find optical/near-IR counterparts?

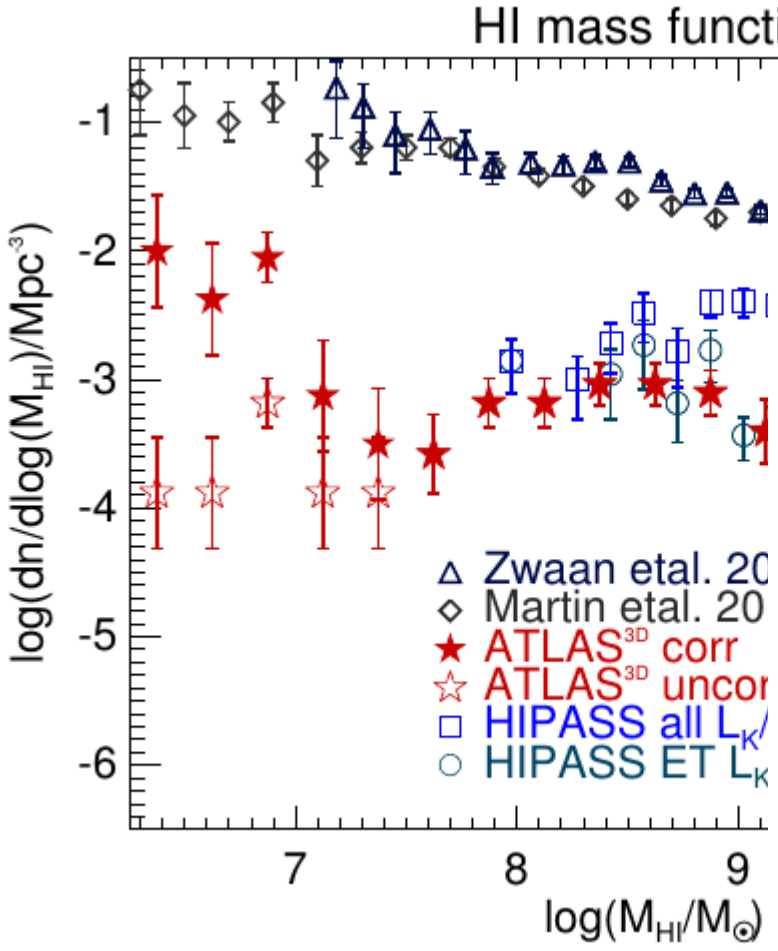
Lagos et al. (2014)

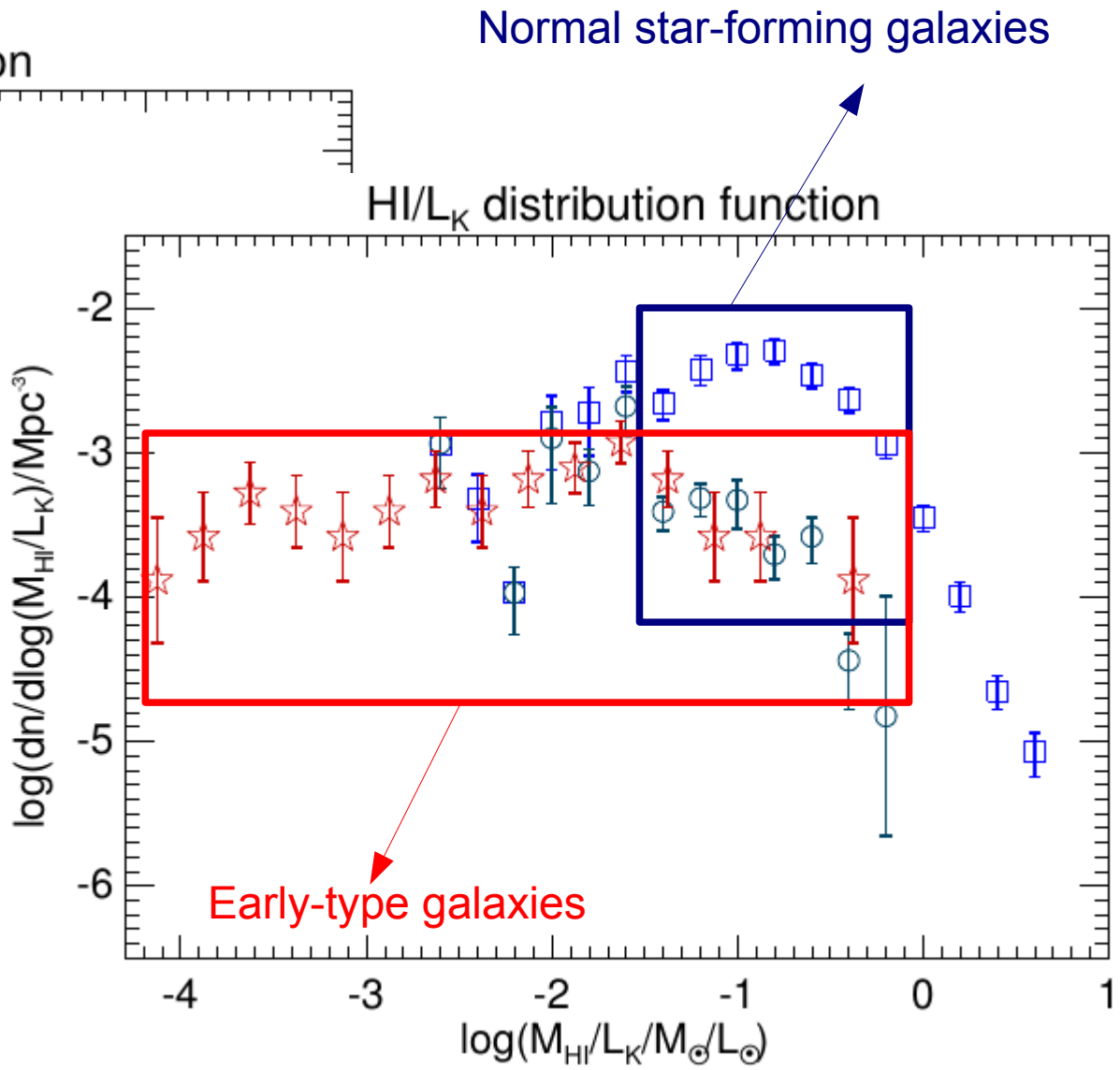
HI detected galaxies with $M_{stellar}$ <10^8 M_o

(1)	(2)	(3)	(4)	(5)	(6)
1σ sensitivity in mJy km s^{-1}	$z = 0.08$	$z = 0.17$	$z = 0.5$	$z = 0.8$	$z = 1.1$
0.09 (DINGO DEEP)	86%	83%	35%	-	-
0.2 (DINGO)	85%	75%	10%	-	-
1.592 (WALLABY)	64%	18%	-	-	-
0.106 (LADUMA BAND-L)	86%	83%	28%	12%	2%

The HI gas fraction distribution function as higher order constraint

What is the neutral gas content of the early-type galaxy population?
Higher order constraints on the physics (see also Lemonias et al. 2013).
Lagos, Davis, Baugh, Lacey & Zwaan (soon)

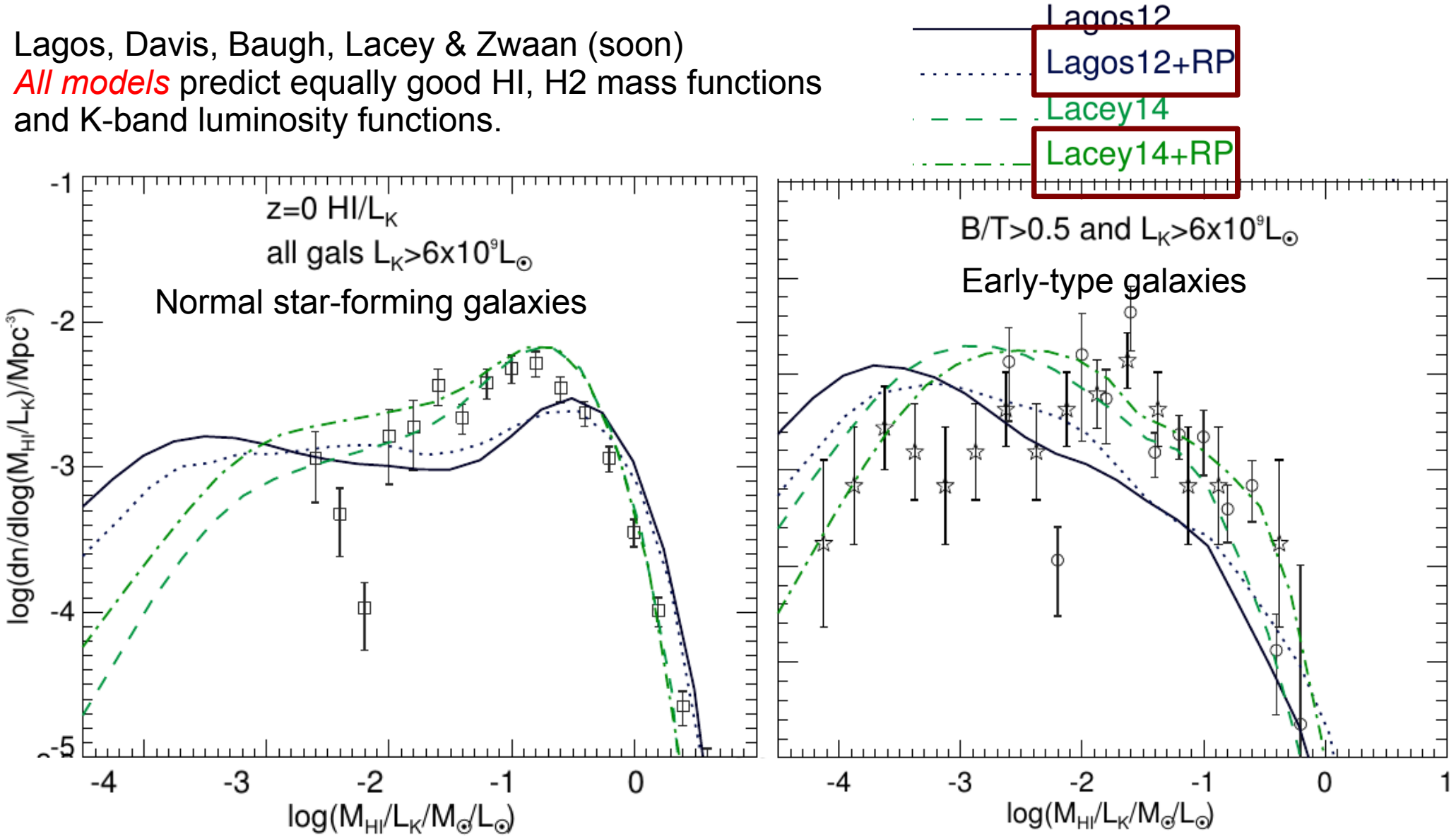




Meyer et al. (2004); Zwaan et al. (2005);
Martin et al. (2010); Serra et all. (2012);
Young et al. (2011)

The HI gas fraction distribution function as higher order constraint

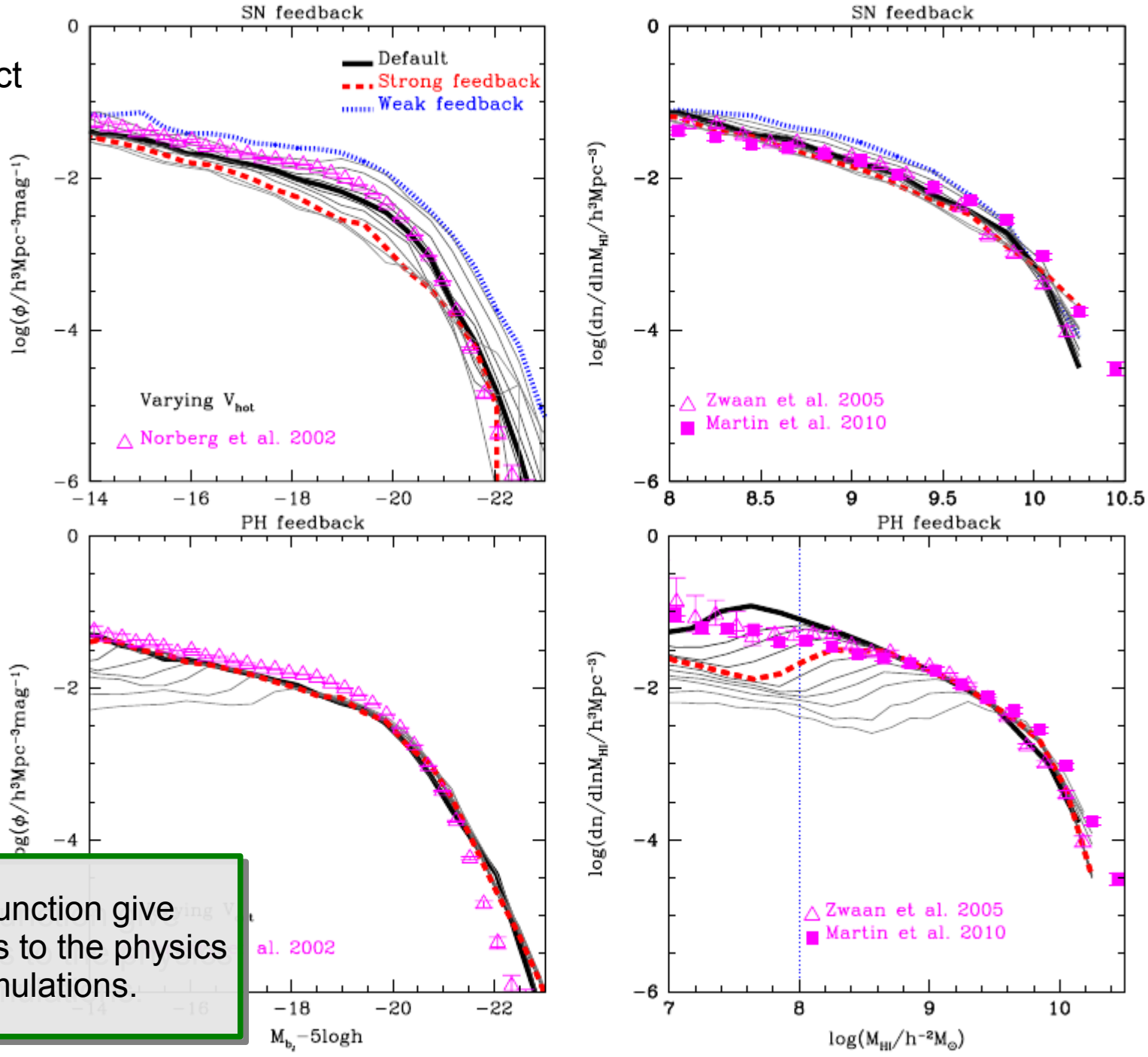
Lagos, Davis, Baugh, Lacey & Zwaan (soon)
All models predict equally good HI, H2 mass functions and K-band luminosity functions.



With future HI surveys we will be able to put very stringent constraints on the physics of the gas in simulations.

The beauty of HI...

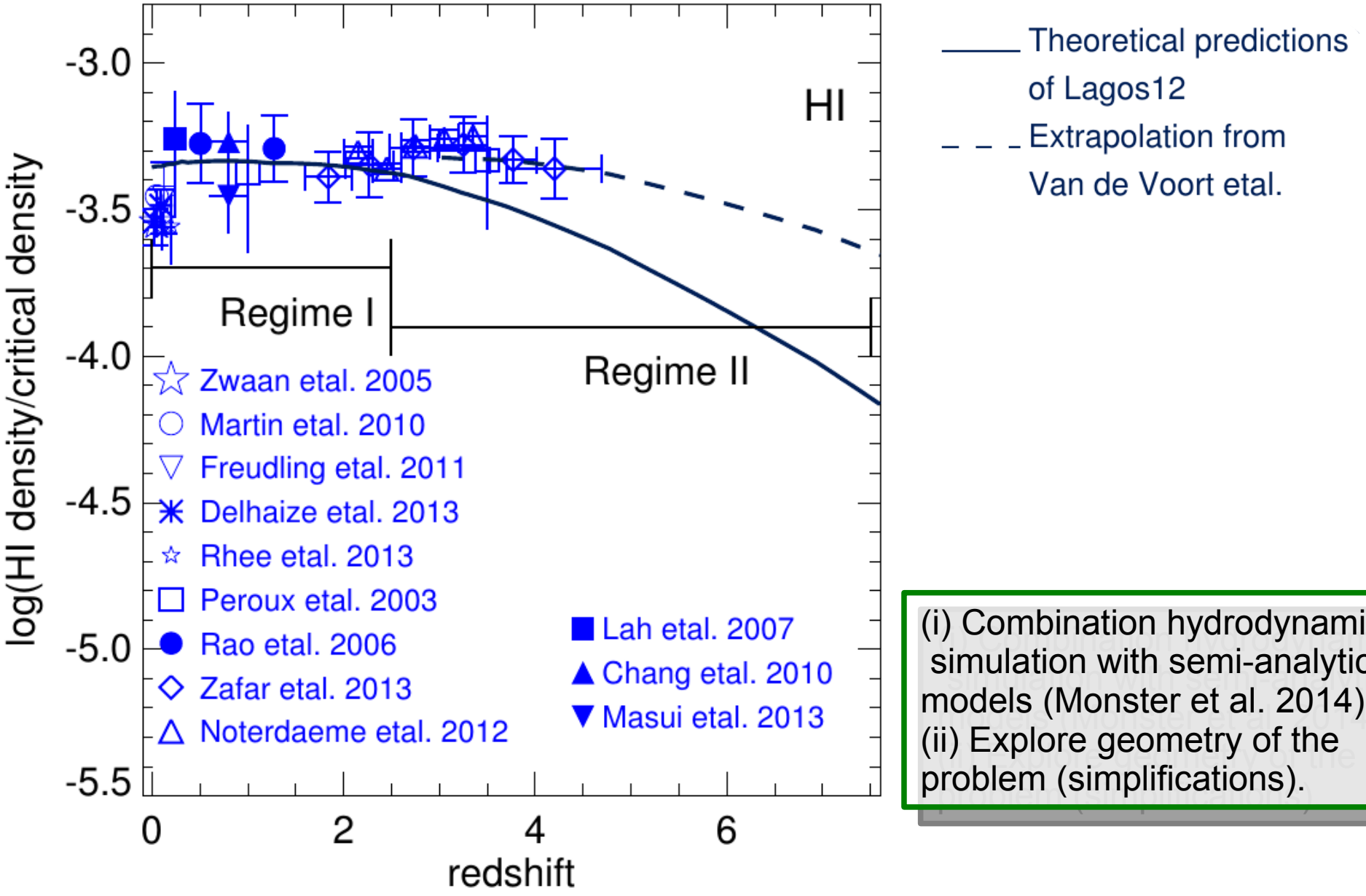
Kim et al. (2013): Effect of different physical processes included in the model



HI and stellar mass function give very different constraints to the physics included in the simulations.

Challenges for HI and H_2 science for semi-analytic models

(1) Description of neutral gas outside galaxies:



Theoretical predictions of Lagos12

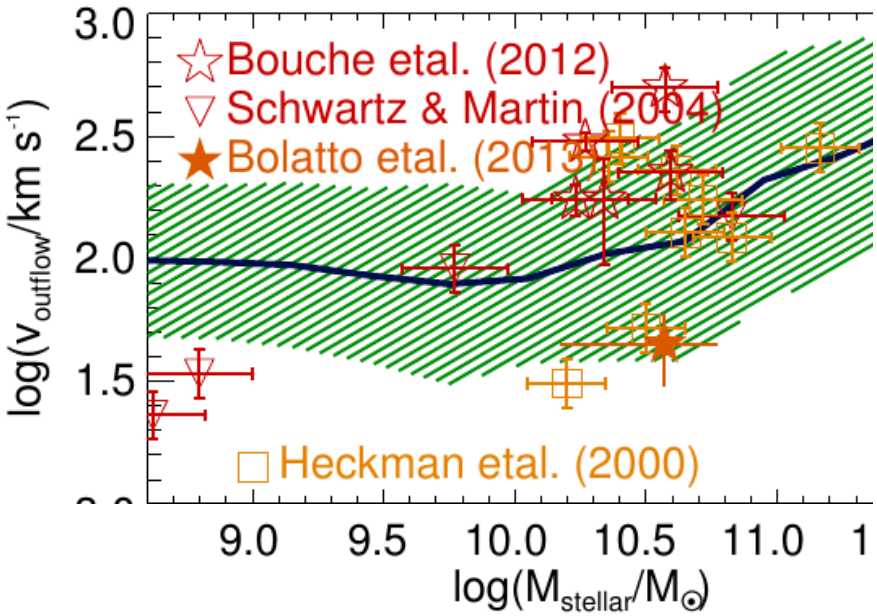
Extrapolation from Van de Voort etal.

(i) Combination hydrodynamic simulation with semi-analytic models (Monster et al. 2014)
(ii) Explore geometry of the problem (simplifications).

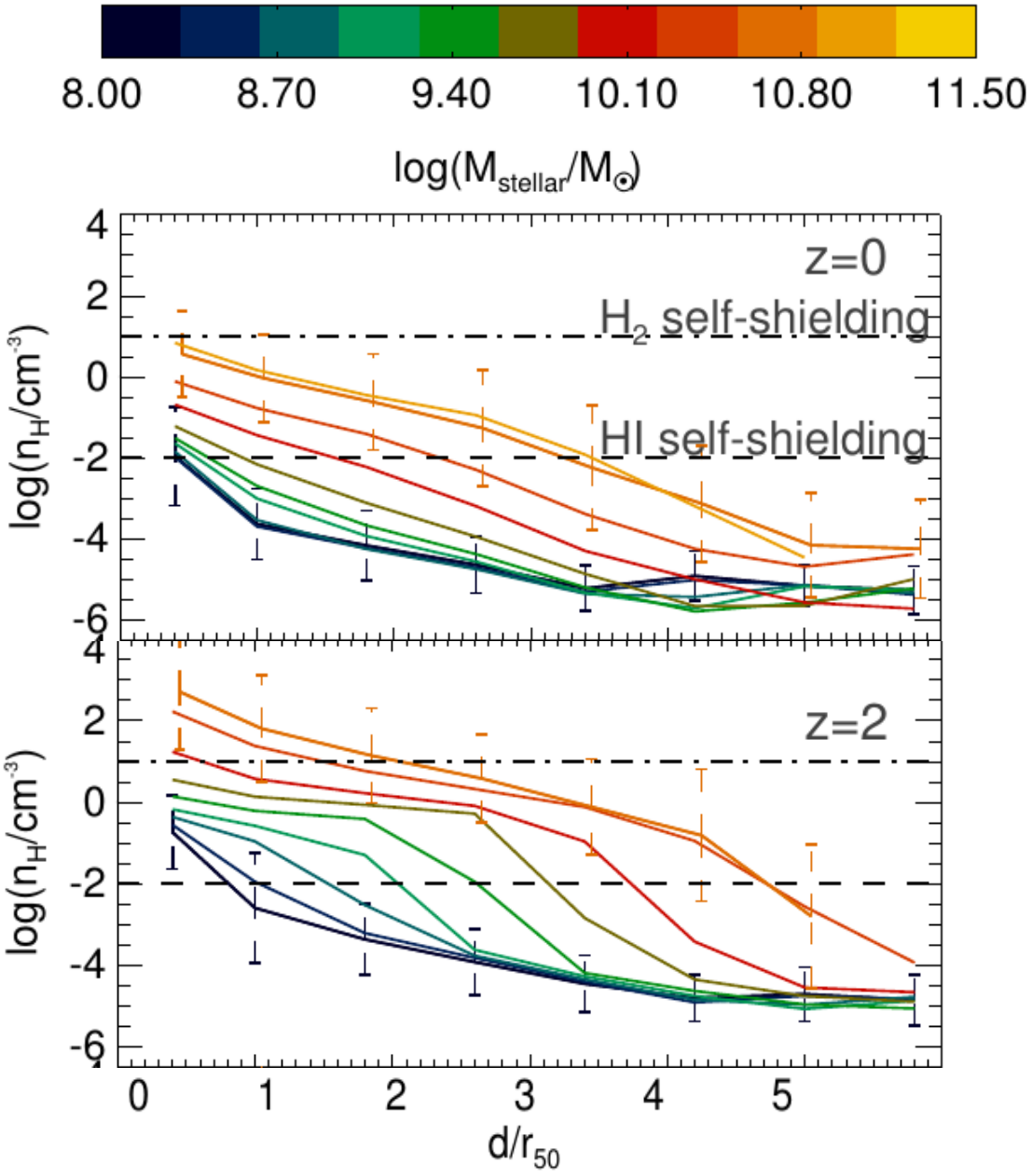
Challenges for HI and H_2 science for semi-analytic models

(1.2) The effect of outflows: neutral gas outflowing galaxies

Lagos, Lacey & Baugh (2013a)



Lagos et al. (in prep.)

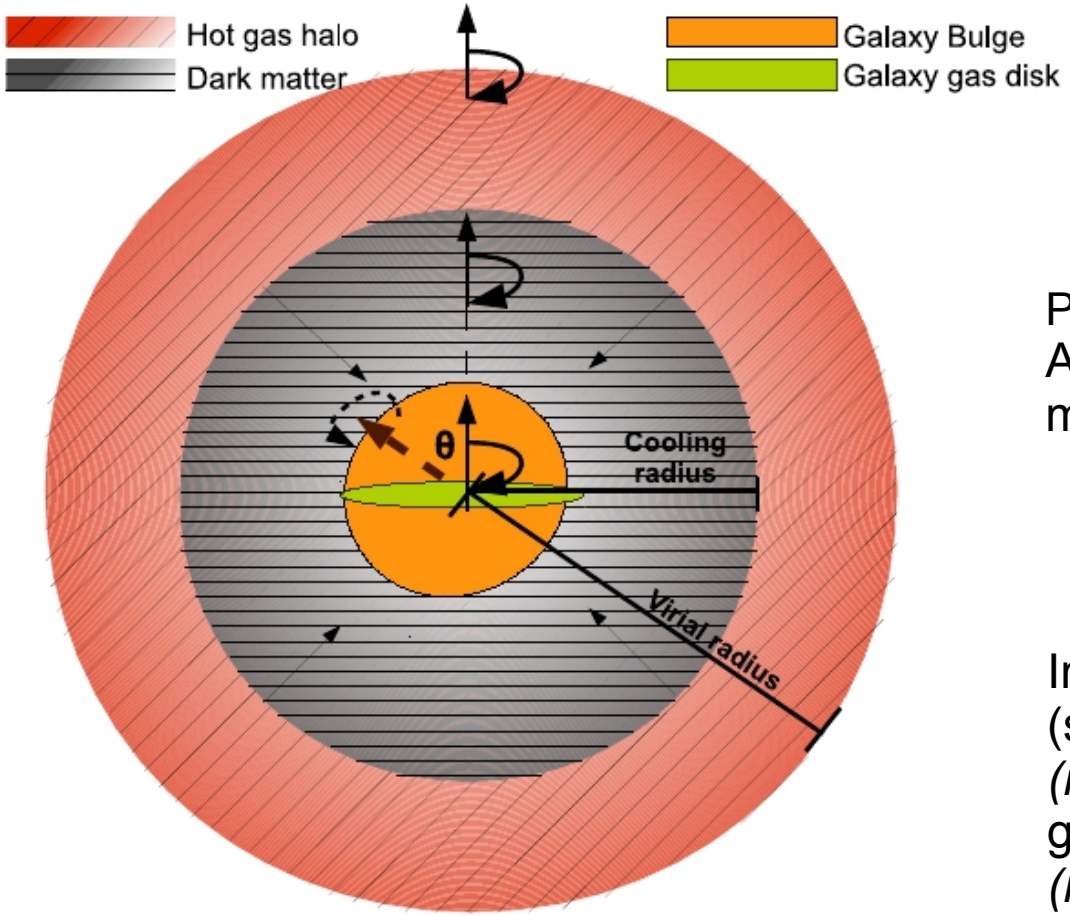


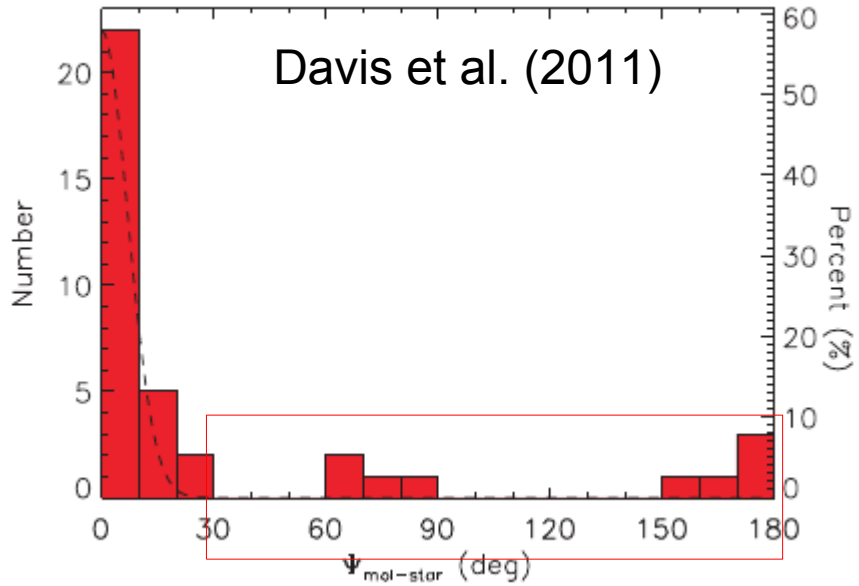
Expectation for the equivalent width of emission lines (better descriptions of radial profiles)

Challenges for HI and H_2 science for semi-analytic models

(2) Angular momentum treatment in SAMs

30% of ETGs have gas discs misaligned with stellar angular momentum (Davis et al. 2011; Serra et al. 2012)



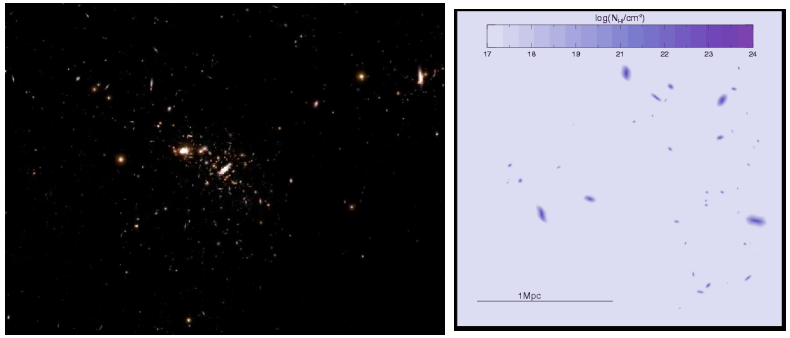


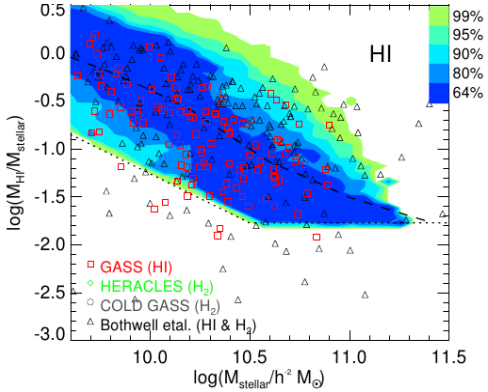
Padilla et al. (2014), Lagos, Davis et al. (soon)
Account for by minor mergers AND misaligned smooth accretions.

Improve treatment of angular momentum (see Obreschkow's talk)
(i) Higher-resolution simulations (to follow DM gals momentum accurately)
(ii) better modelling/synergy with hydrodynamical sims.

Conclusions and Future

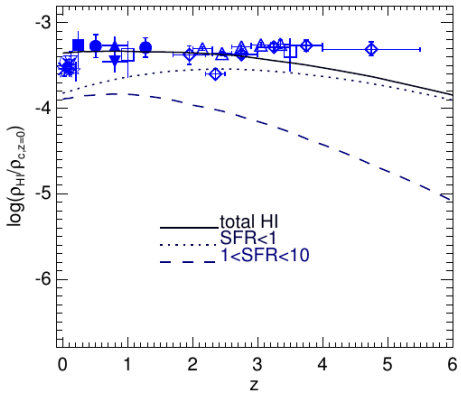
(1) Lots of progress: *SAM has shown to be a powerful tool* to study the connection SF/HI/H2

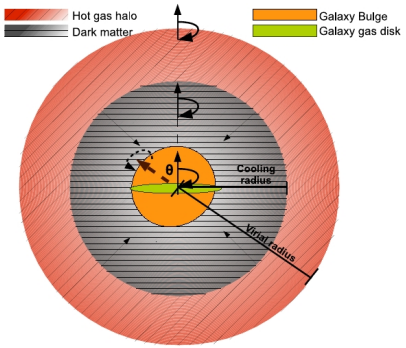




(2) GALFORM *has been tested extensively:* H2, HI MFs, HI clustering, scaling relations, etc.

(3) Models predict the *predominance of low mass galaxies* in the HI Universe (may hamper future surveys).





(4) Challenges for SAMs: accounting for HI gas outside galaxies, and improve angular momentum treatment. ***Clear synergy*** between SAMs (faster and more flexible tools) and hydro sims (accurate treatment of hydrodynamics outside galaxies).

Lagos et al. (2011a,b); Geach et al. (2011); Lagos et al. (2012a,b); Kim et al. (2013b, 2014); Swinbank et al. (2013); Lagos et al. (2013a); Lagos et al. (2014a,b)