The role of molecular gas in feeding star formation and AGN activity

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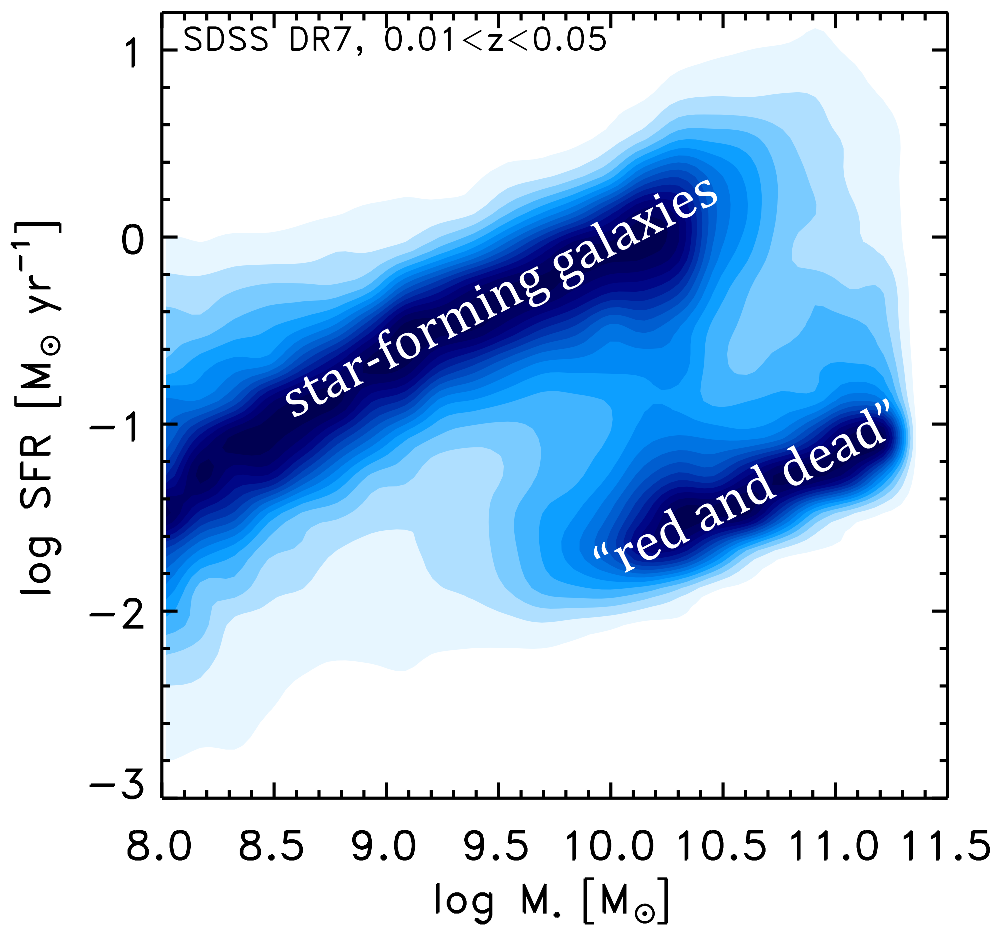
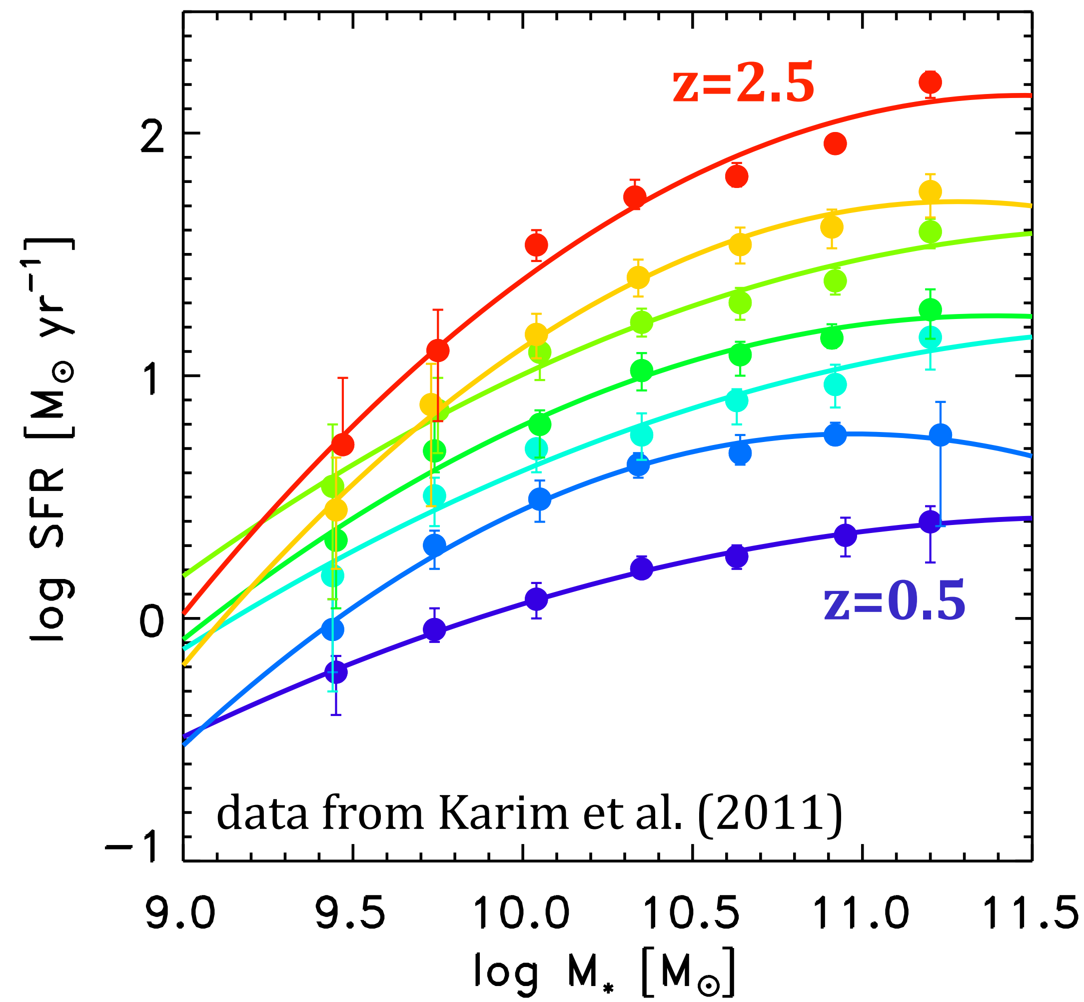
accretion-driven galaxy evolution

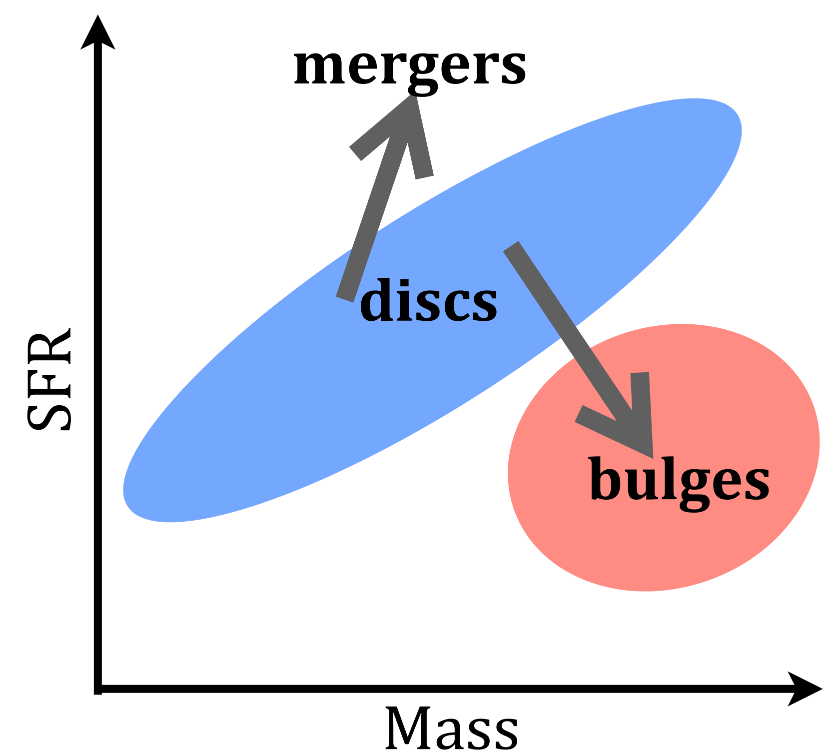
the star formation "main sequence"
see e.g.: Schiminovich et al. (2007), Elbaz et al. (2007), Noeske et al. (2007), Daddi et al. (2007), Perez-Gonzalez et al. (2008), Peng et al. (2010)





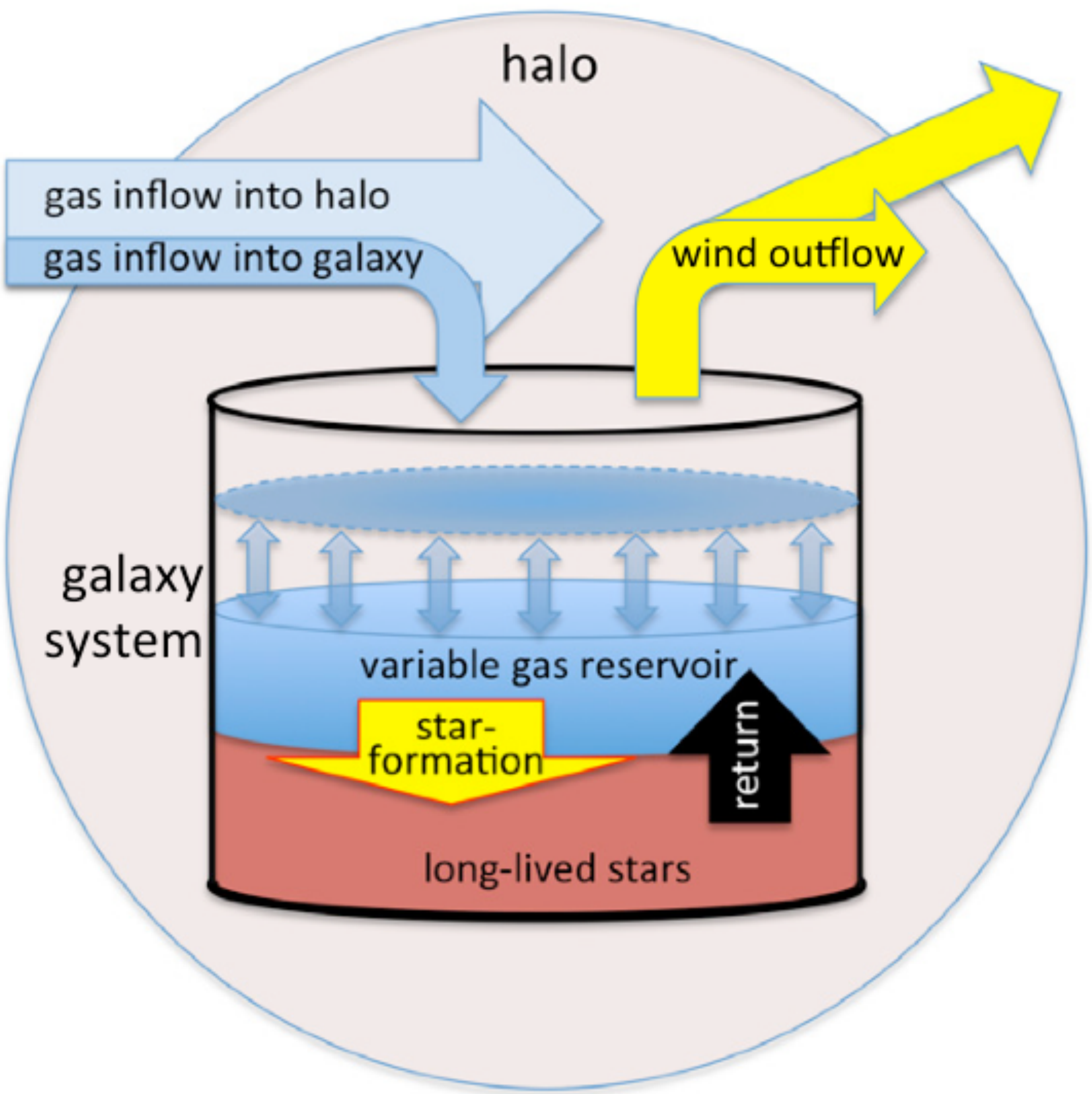
SFR ~ $M_*^a(1+z)^b$, where a~0.8, b~2.5

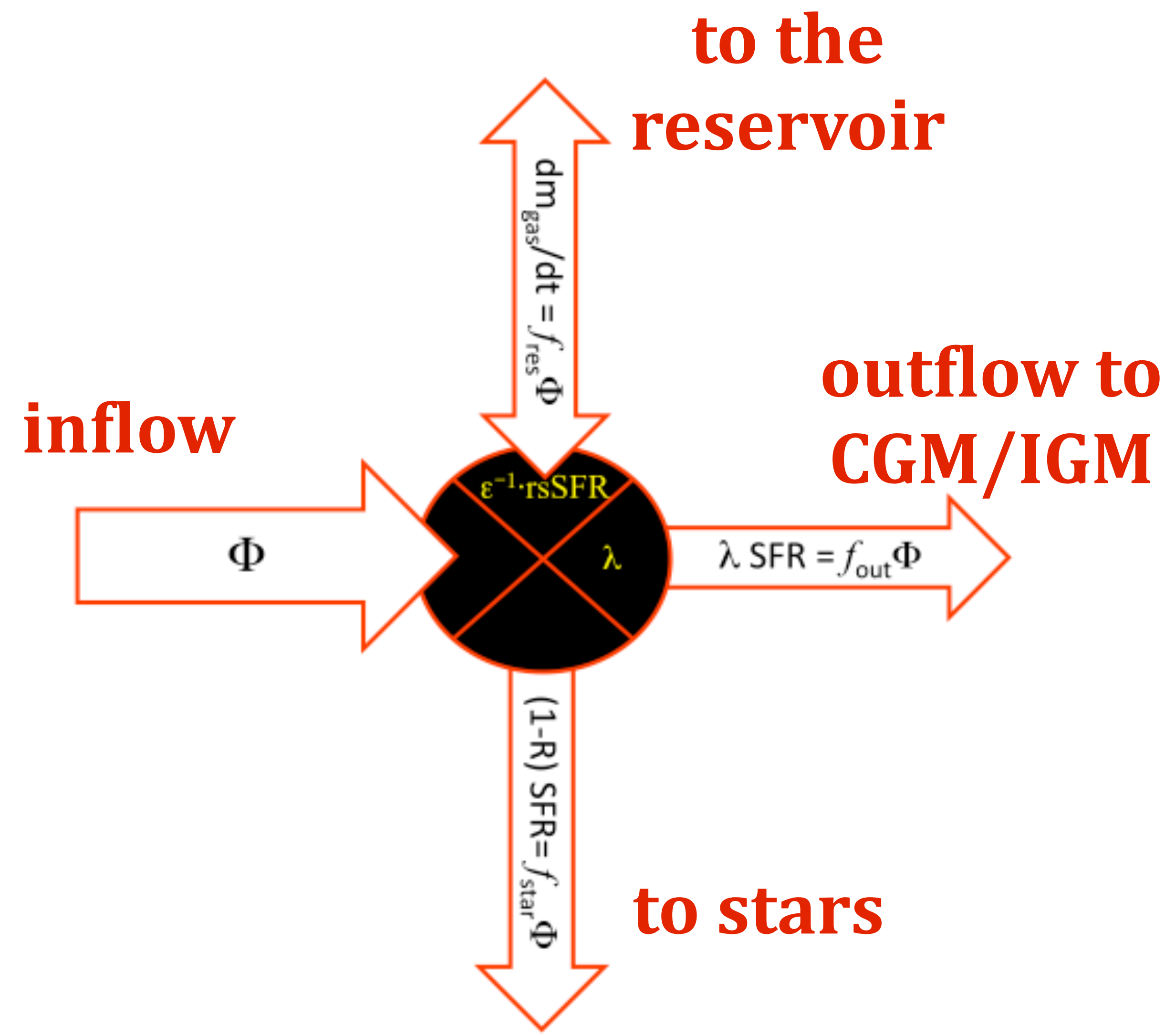
- Galaxies on the main sequence (MS) contribute ~90% of the star formation.
- Duty cycles on the MS are high at 40-70% (e.g. Noeske et al. 2007)



the “equilibrium” (or regulator) model

Star formation is regulated by the mass of gas in a reservoir, which itself is affected by the inflow rate, the star formation efficiency, and the mass loading factor of outflows.





$$\Phi = (1 - R + \lambda) \cdot \mathrm{SFR} + \frac{dm_{\mathrm{gas}}}{dt}$$

Lilly et al. (2013), see also, e.g. Genel et al. (2008), Bouché et al. (2010), Davé et al. (2011,2012), Krumholz & Dekel (2012)

IRAM surveys for molecular gas in normal galaxies

direct molecular gas measurements for large, representative samples of ***normal star forming galaxies*** from both IRAM facilities

COLD GASS

PIs G. Kauffmann (MPA), C. Kramer (IRAM)
600h IRAM 30-m Large Programme
+1000h Arecibo Programme for HI

365 SDSS-selected galaxies with $0.025<z<0.050$, $M^*>10^{10}$
see Saintonge et al. 2011a,b, Kauffmann et al. 2012, Saintonge et al. 2012.

PHIBSS

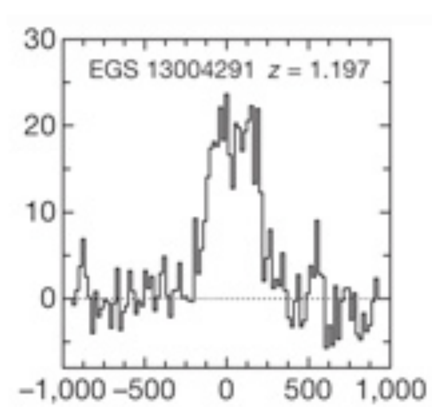
PIs L. Tacconi, R. Genzel (MPE), F. Combes (Paris)
500h IRAM PdBI Large Programmes

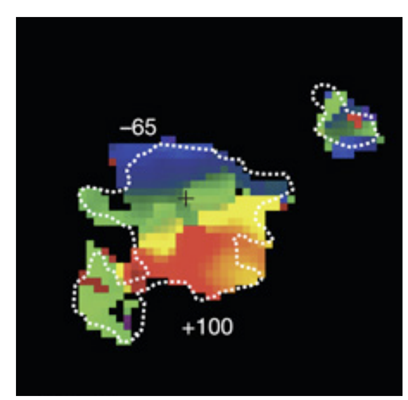
64 star forming galaxies with $1.0<z<2.5$, $3\times10^{10}<M^*<3\times10^{11}$
+ high-resolution follow-up
see Tacconi et al. 2010,2013, Genzel et al. 2010,2012,2013, Freundlich et al. 2013.

Lensed galaxies

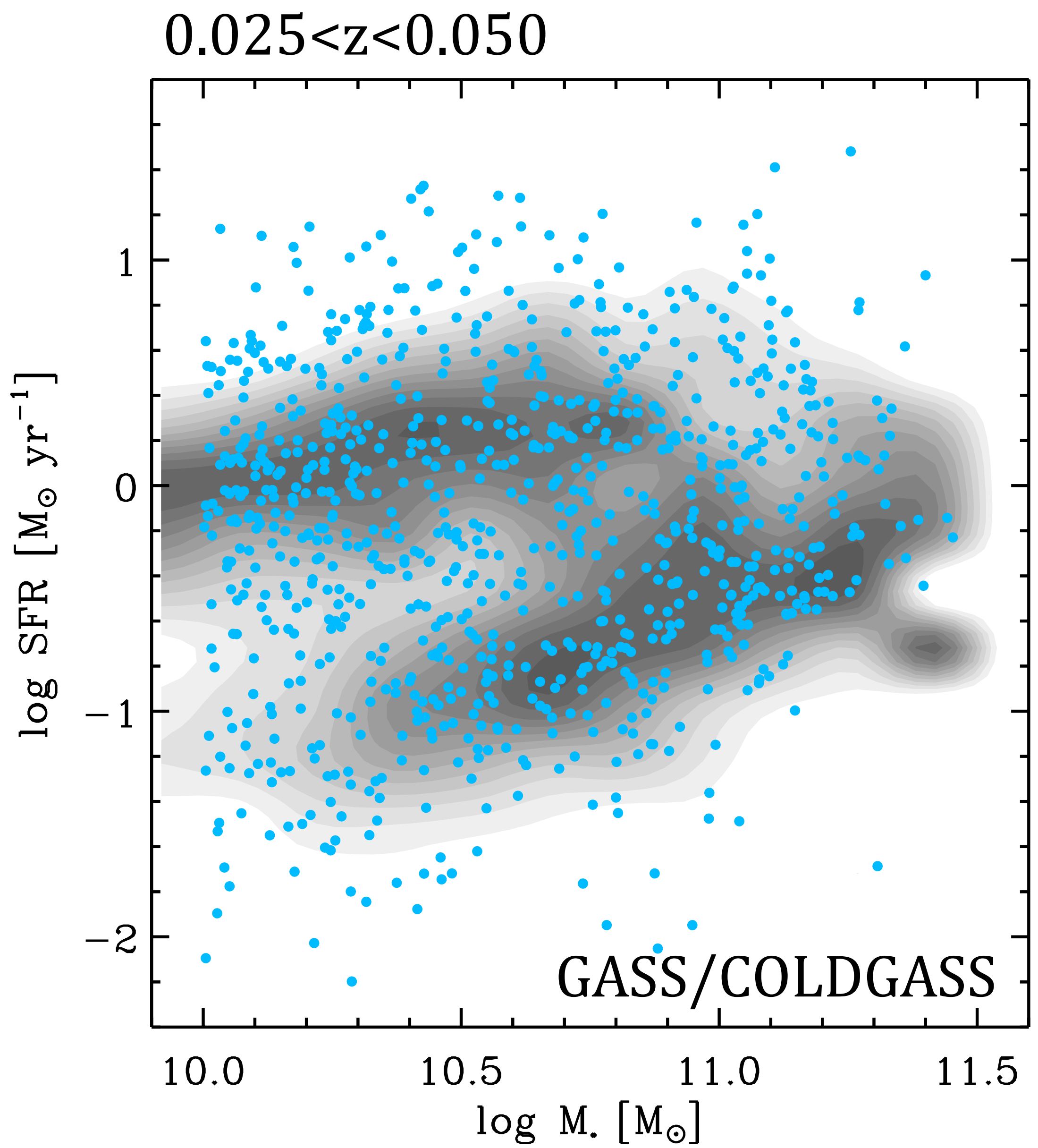
PI D. Lutz (MPE), A. Baker (Rutgers)
IRAM PdBI

17 lensed star forming galaxies with $1.5<z<3.1$, $M^*>10^9$
includes full Herschel PACS+SPIRE photometry
see Saintonge et al. 2013





Cold gas in the SFR-M* plane



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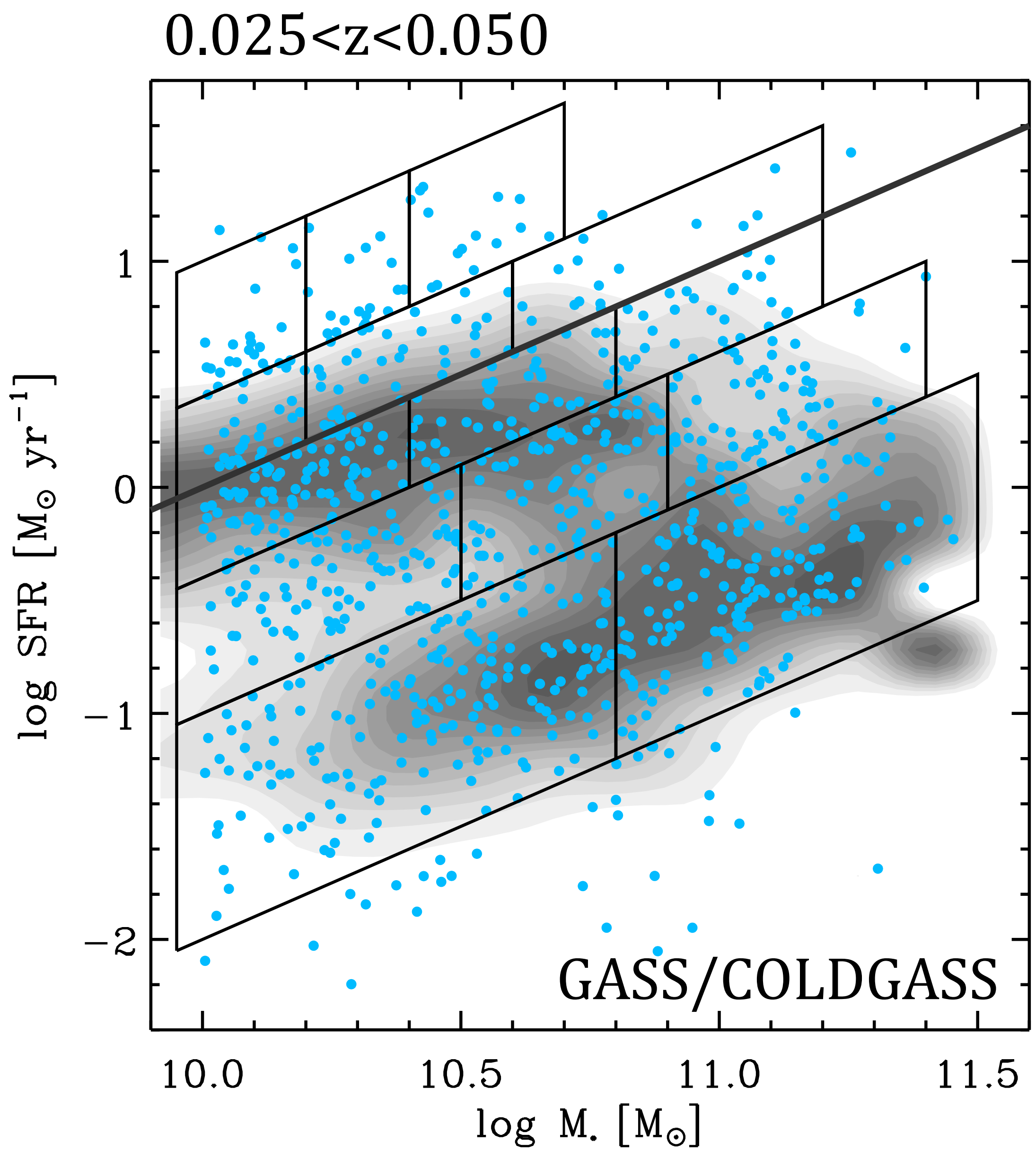

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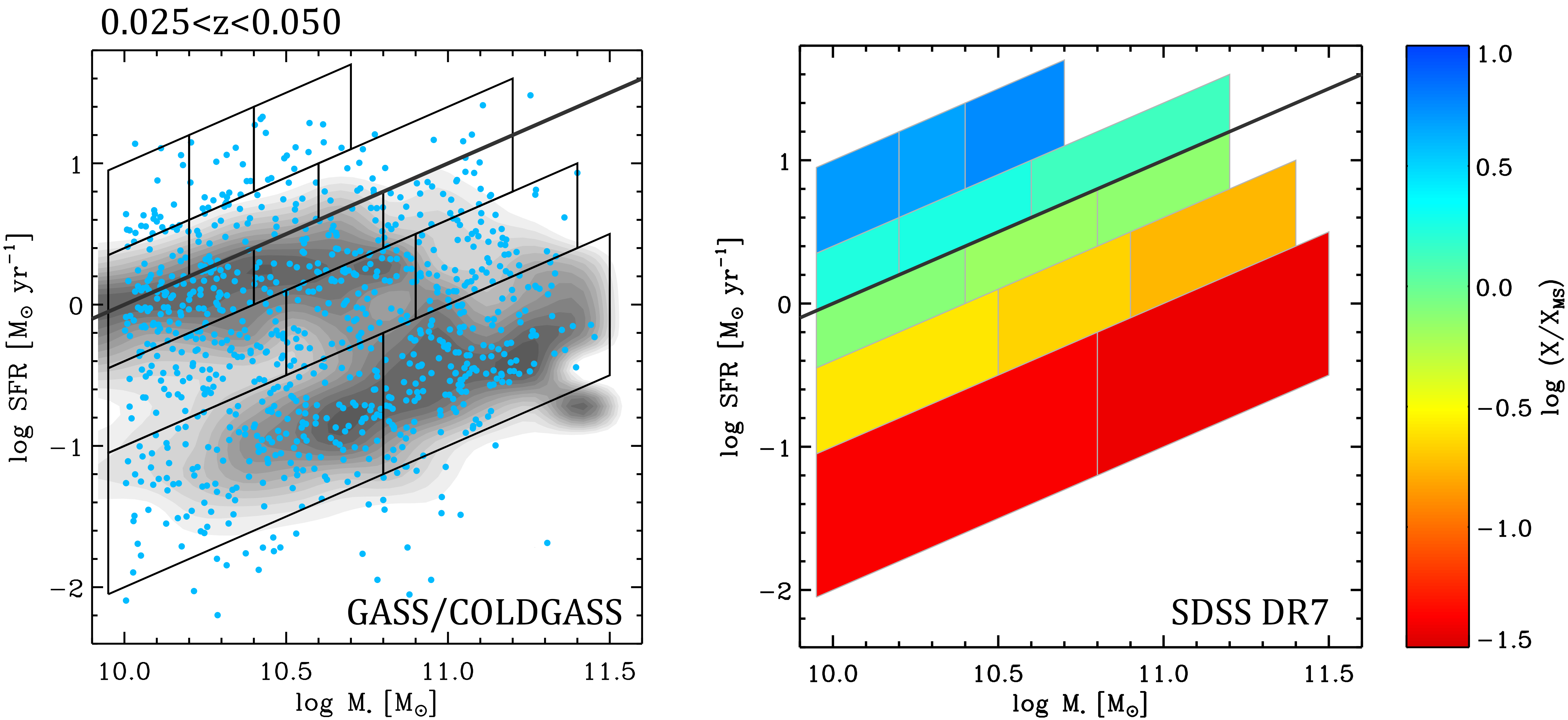

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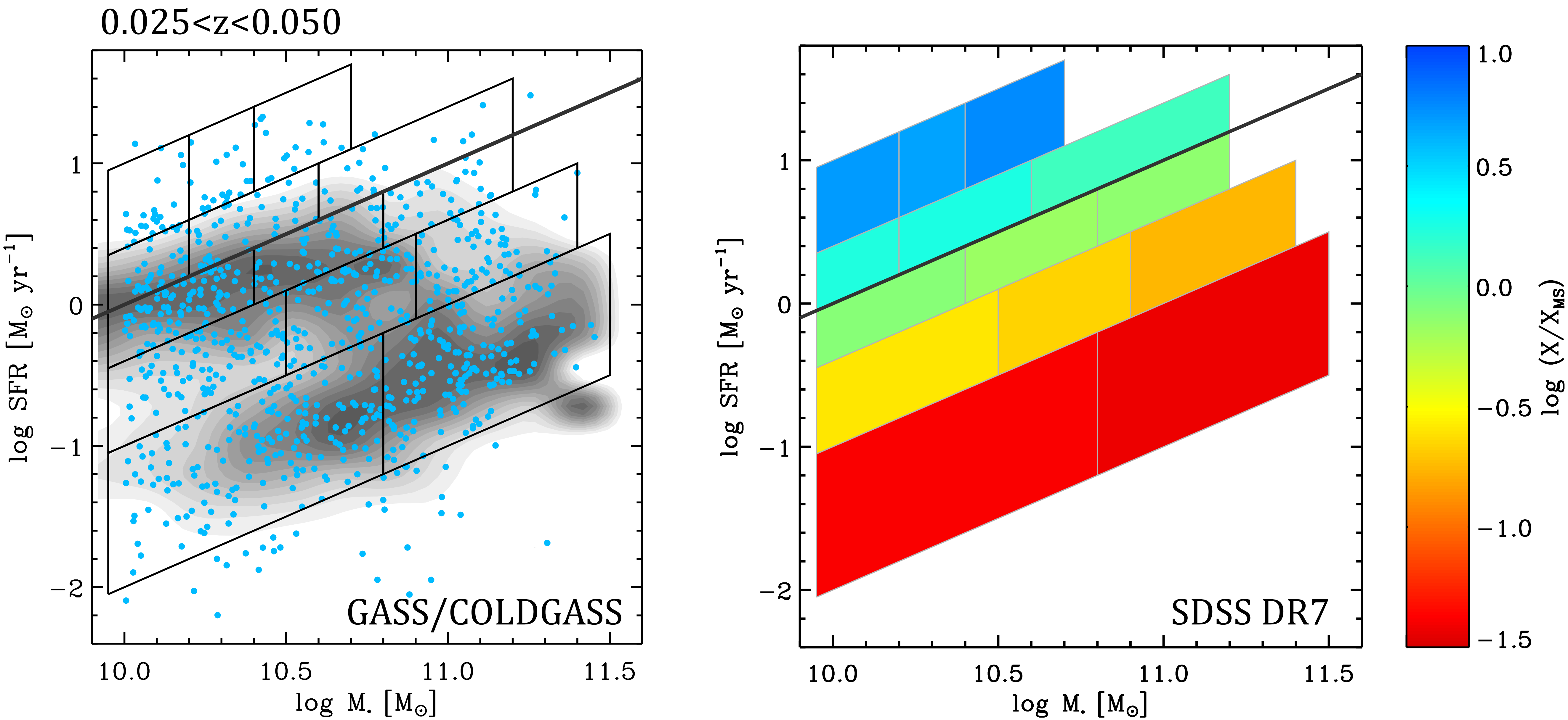
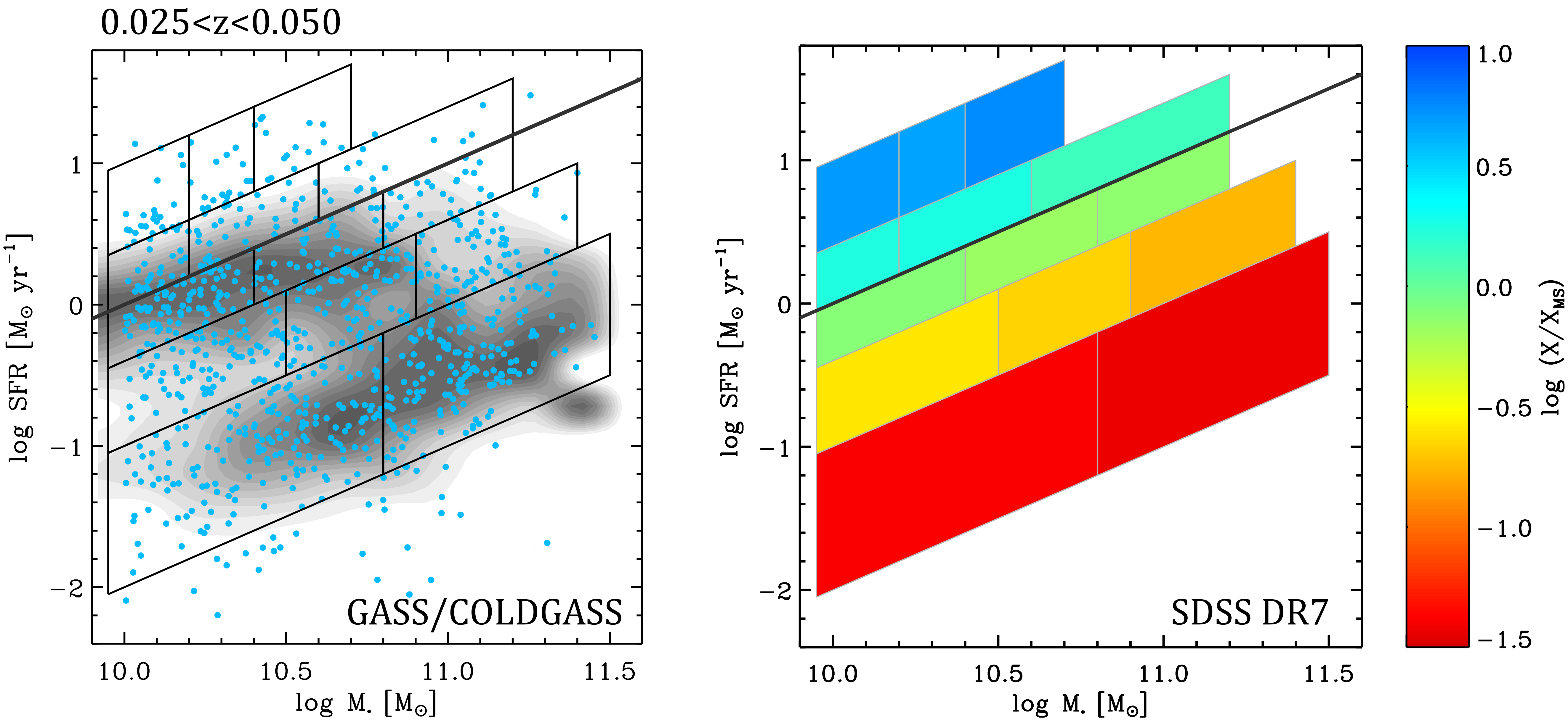


$$\mathrm{sSFR} = \frac{\mathrm{SFR}}{M_*} = \frac{M_{\mathrm{HI}}}{M_*}\,\frac{M_{\mathrm{H2}}}{M_{\mathrm{HI}}}\,\frac{\mathrm{SFR}}{M_{\mathrm{H2}}}$$

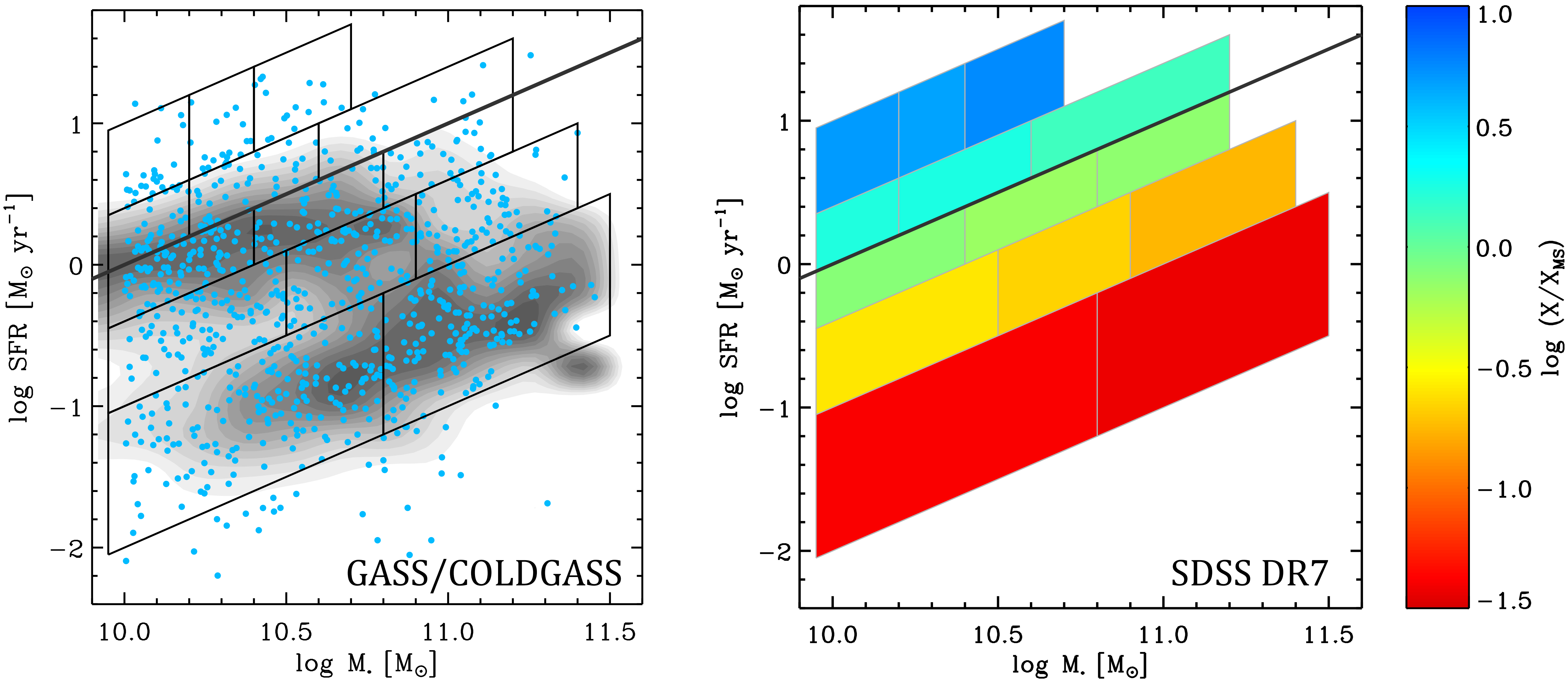
Cold gas in the SFR-M* plane



$$sSFR = \frac{SFR}{M_*} = \frac{M_{HI}}{M_*}\frac{M_{H2}}{M_{HI}}\frac{SFR}{M_{H2}}$$

$$= f_{HI}\ R_{mol}\ SFE$$

Cold gas in the SFR-M* plane



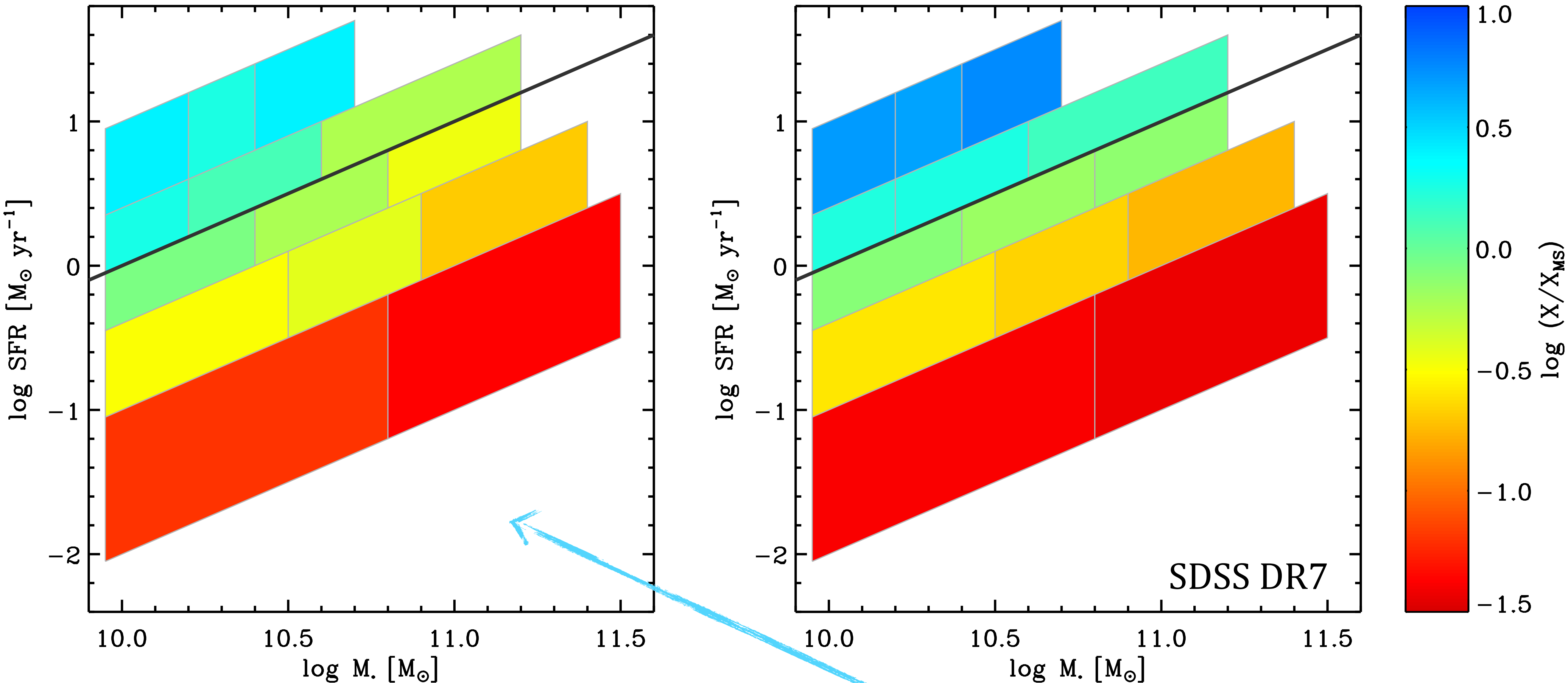
$$\mathrm{sSFR} = f_{HI}\ R_{mol}\ \mathrm{SFE}$$

"feeding"

"fueling"

"consuming"

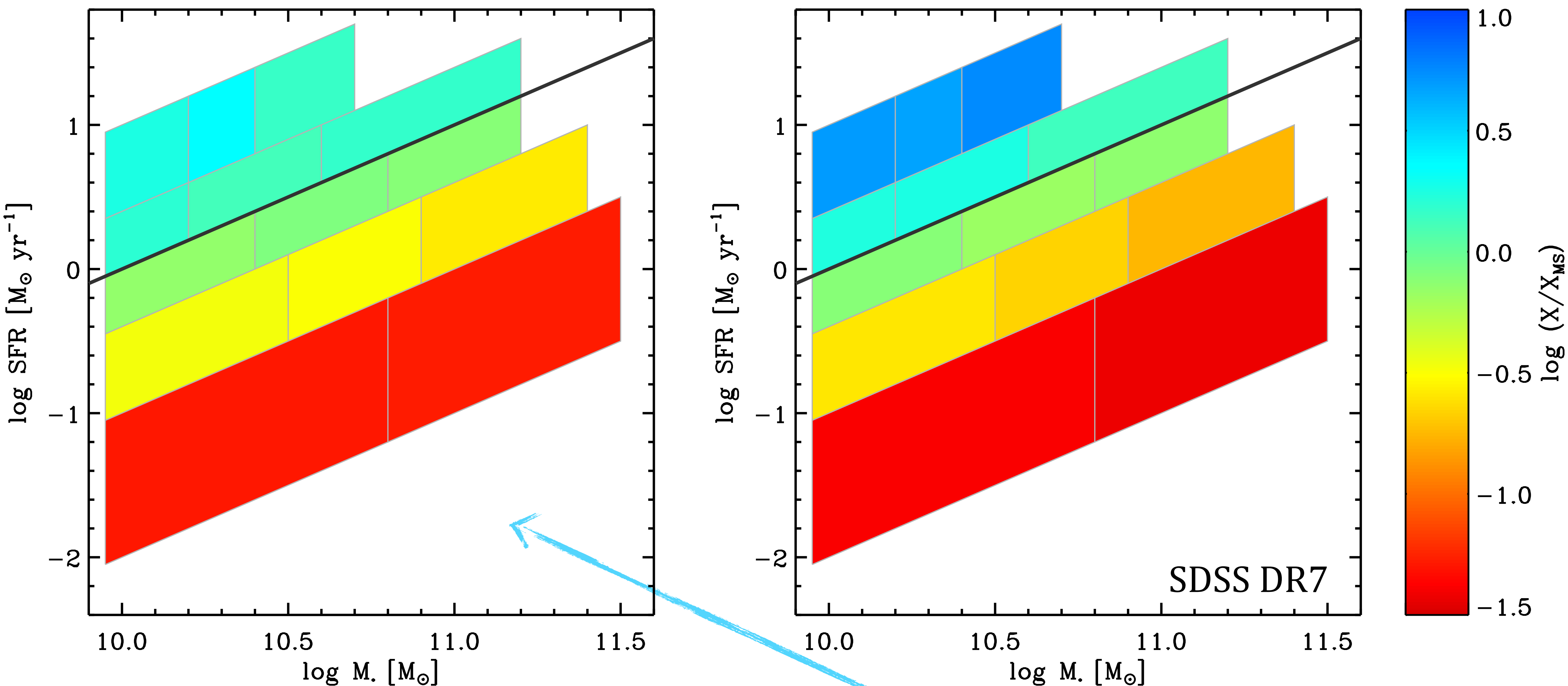
Cold gas in the SFR-M* plane



$$sSFR = f_{HI} \, R_{mol} \, SFE$$

HI contents varies mostly ***across*** the MS, but also ***along*** (high SFR+low M* = more HI)

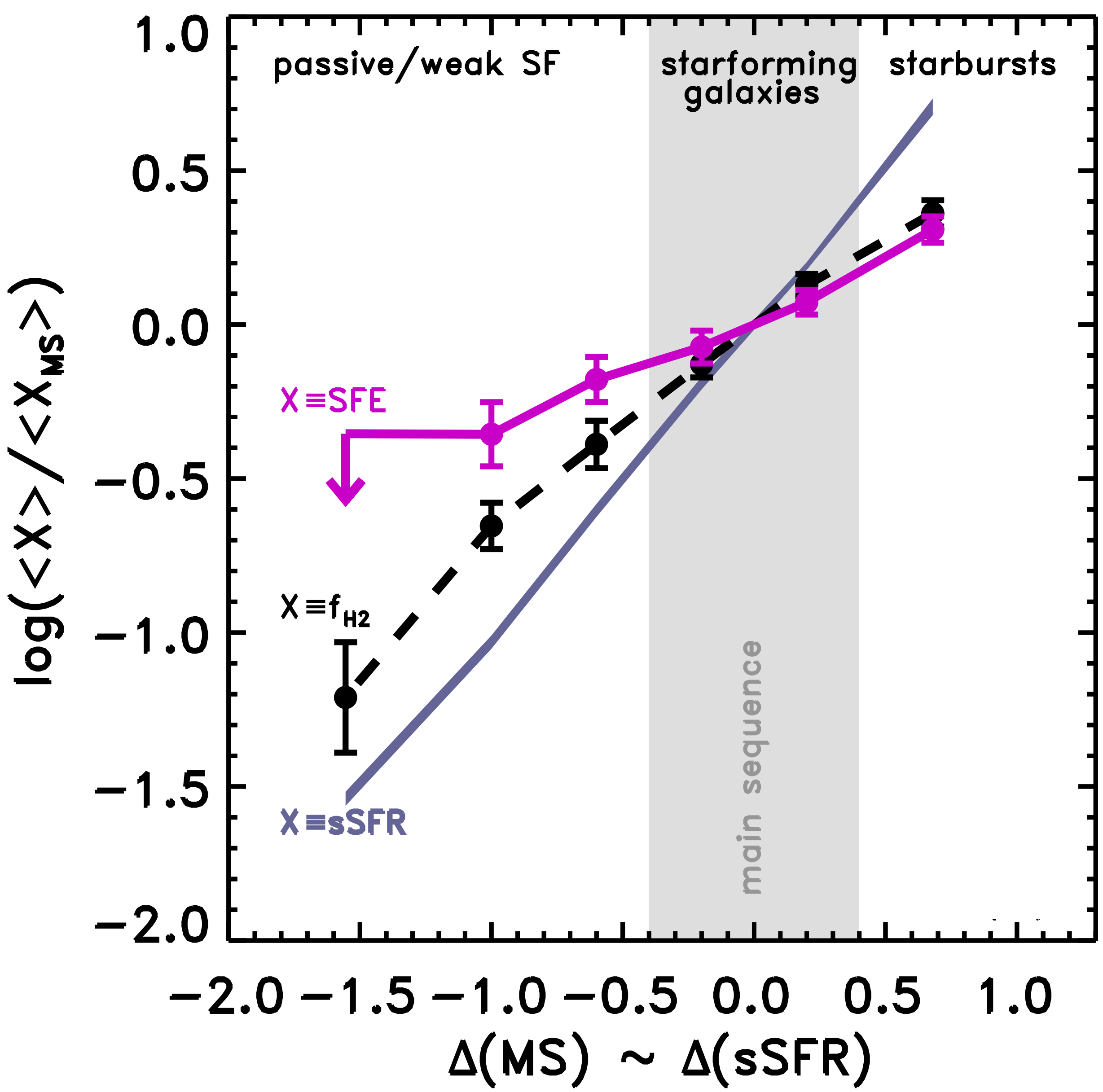
Cold gas in the SFR-M* plane



$$sSFR = f_{HI}\ R_{mol}\ SFE \qquad (f_{HI}\ R_{mol} = f_{H2})$$

H2 contents varies almost exclusively ***across*** the MS (high SFR = more H_2)

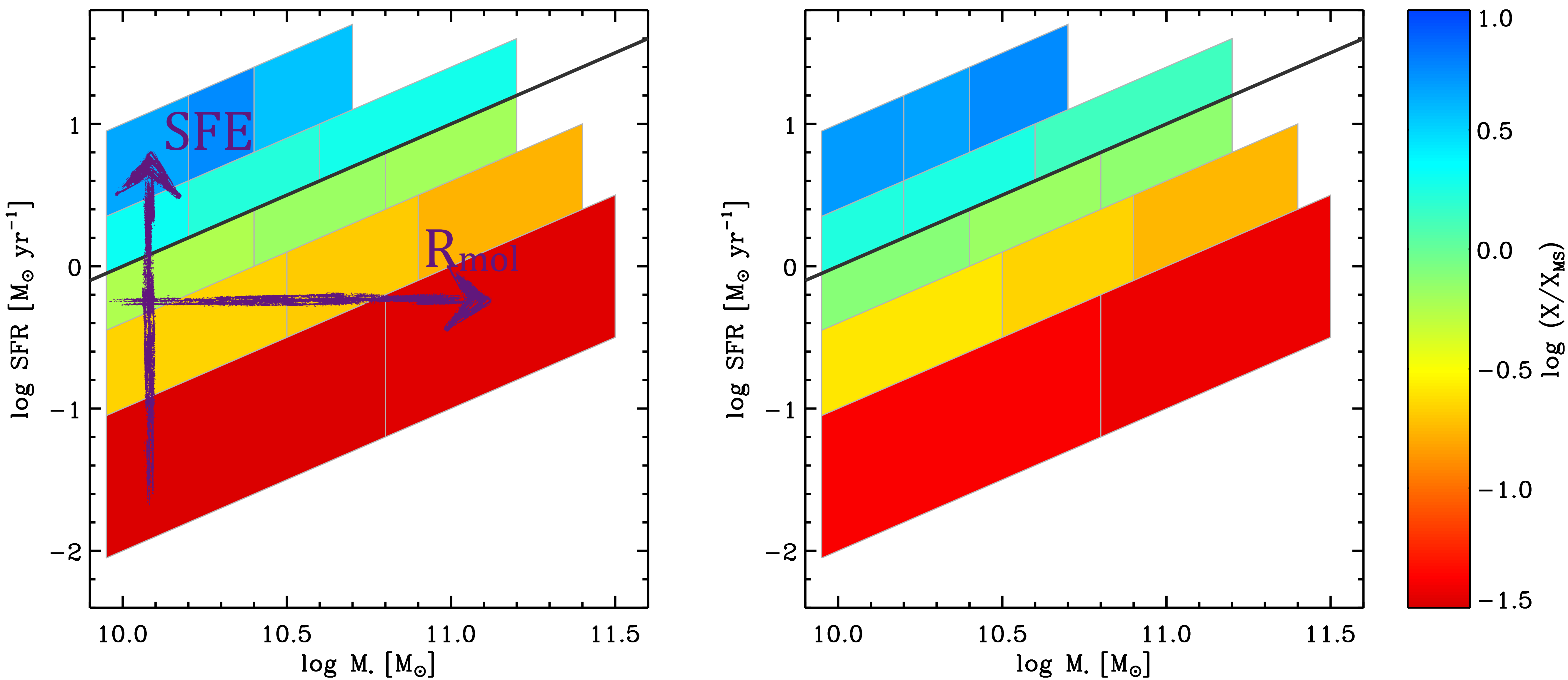
Star formation efficiency variations in the SFR-M* plane



Saintonge et al. (2012)

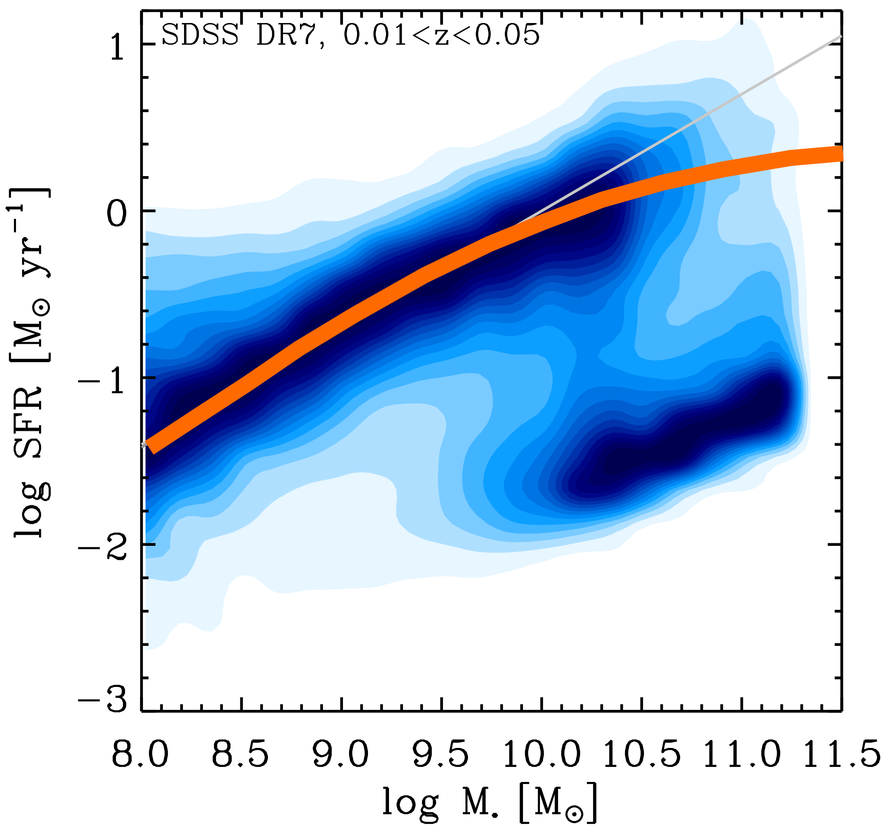
BOTH H_2 contents and star formation efficiency vary ***across*** the MS

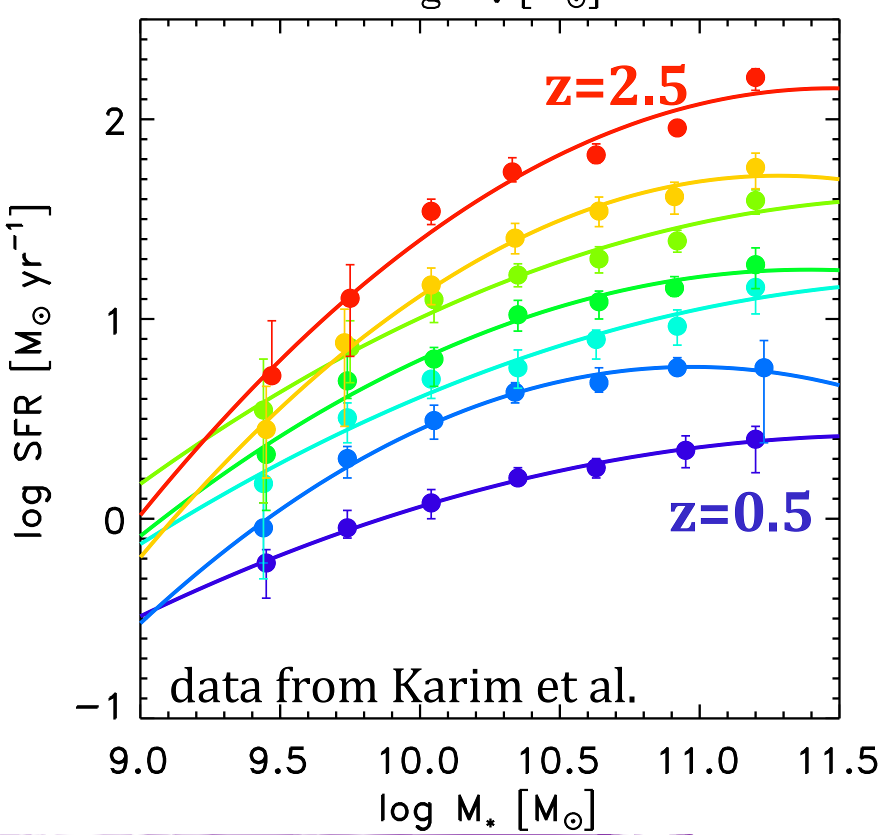
Gas and star formation efficiency explain the SFR-M* plane

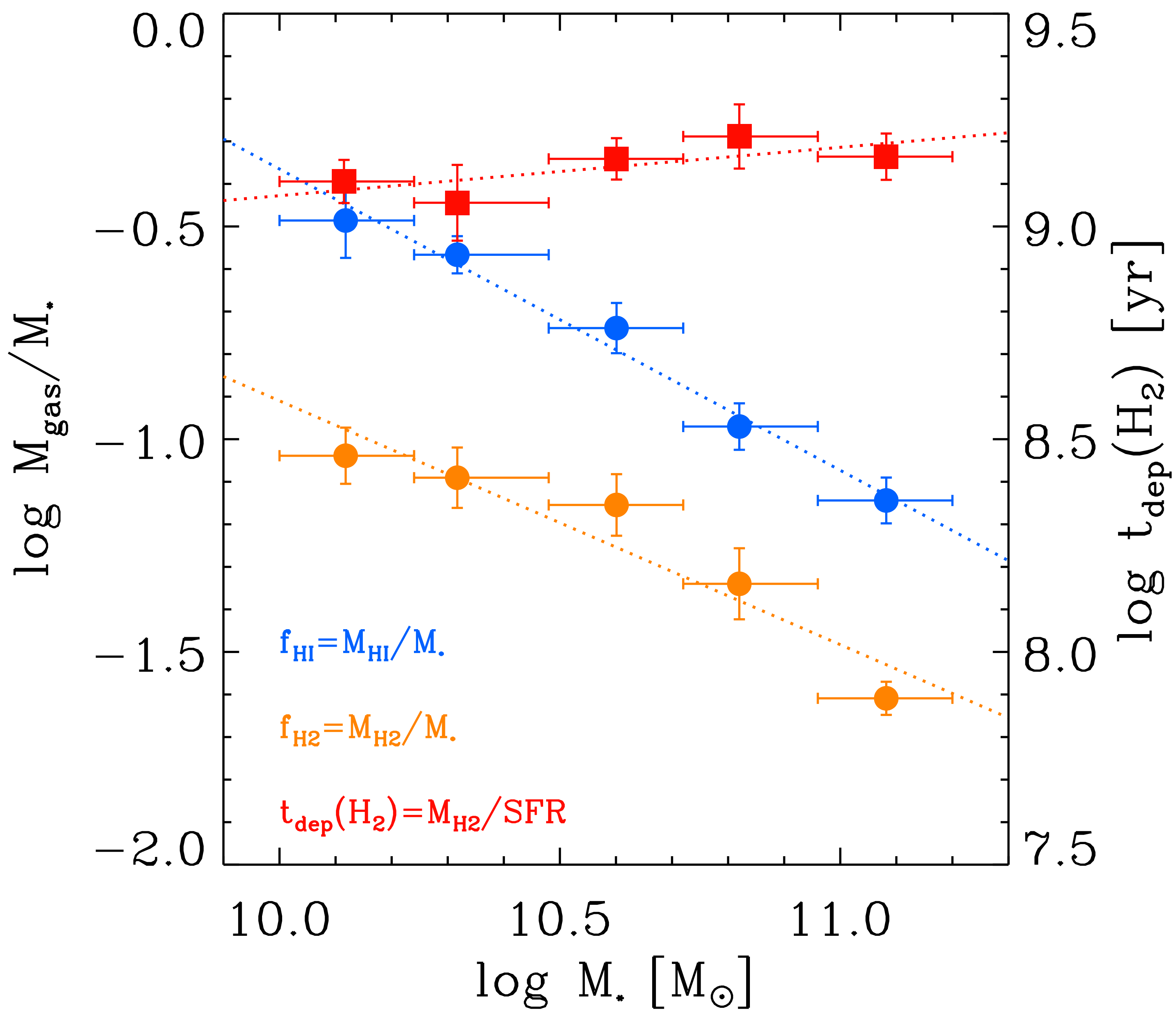


The position of a galaxy in the SFR-M* plane depends on:
(1) how much fuel it has
(2) how much of it is available for star formation
(3) the efficiency of the conversion of this gas into stars

Gas on the main sequence and star formation quenching

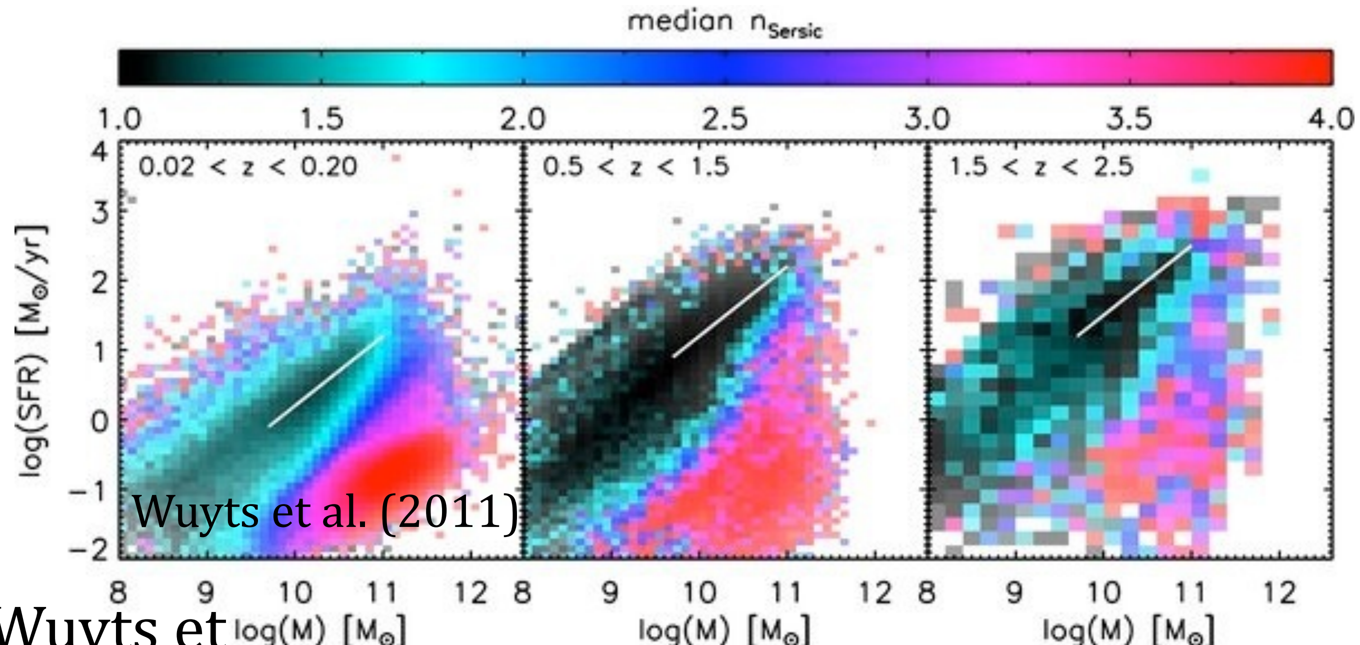




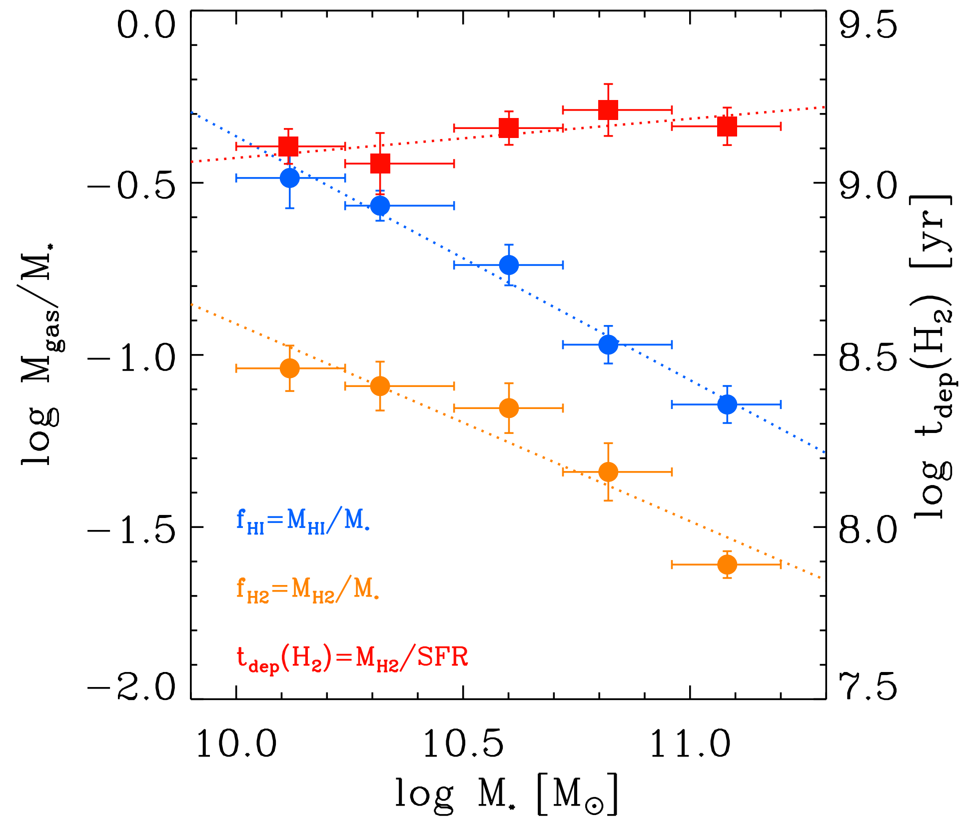


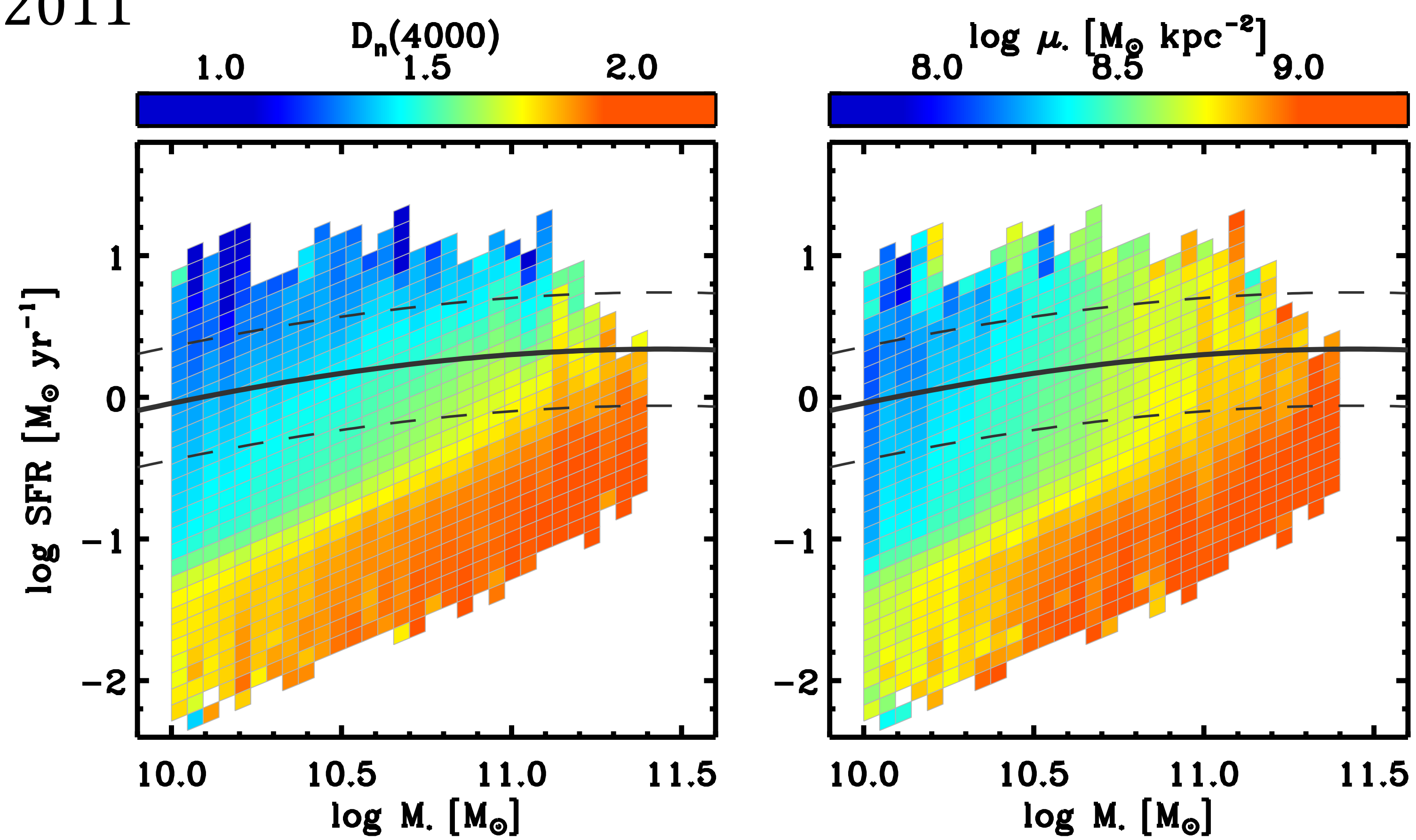
as galaxies evolve along the main sequence, they steadily consume their gas supplies

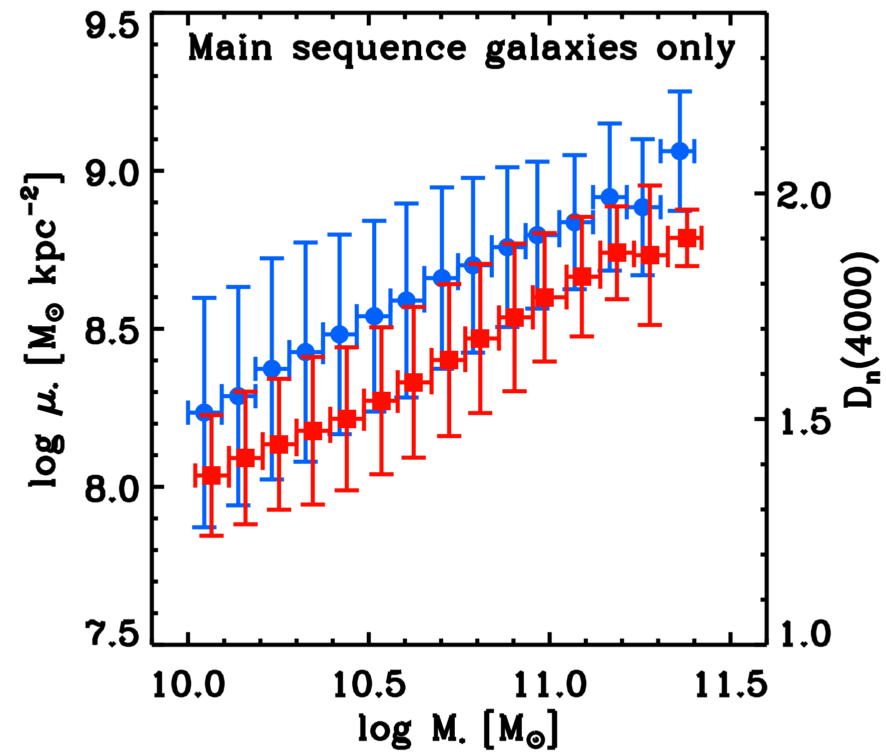
Morphology in the SFR-M* plane



Wuyts et al. 2011

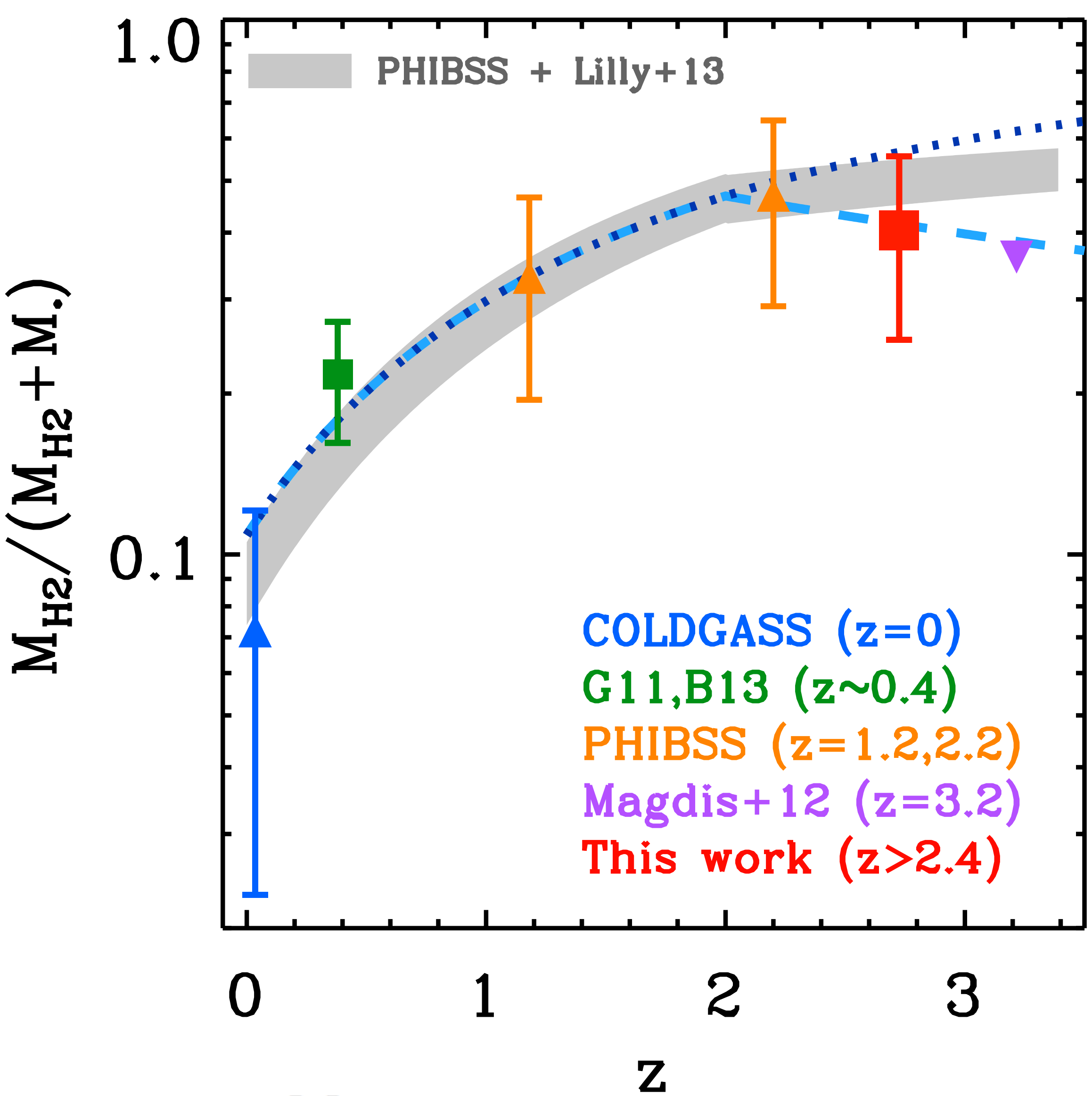


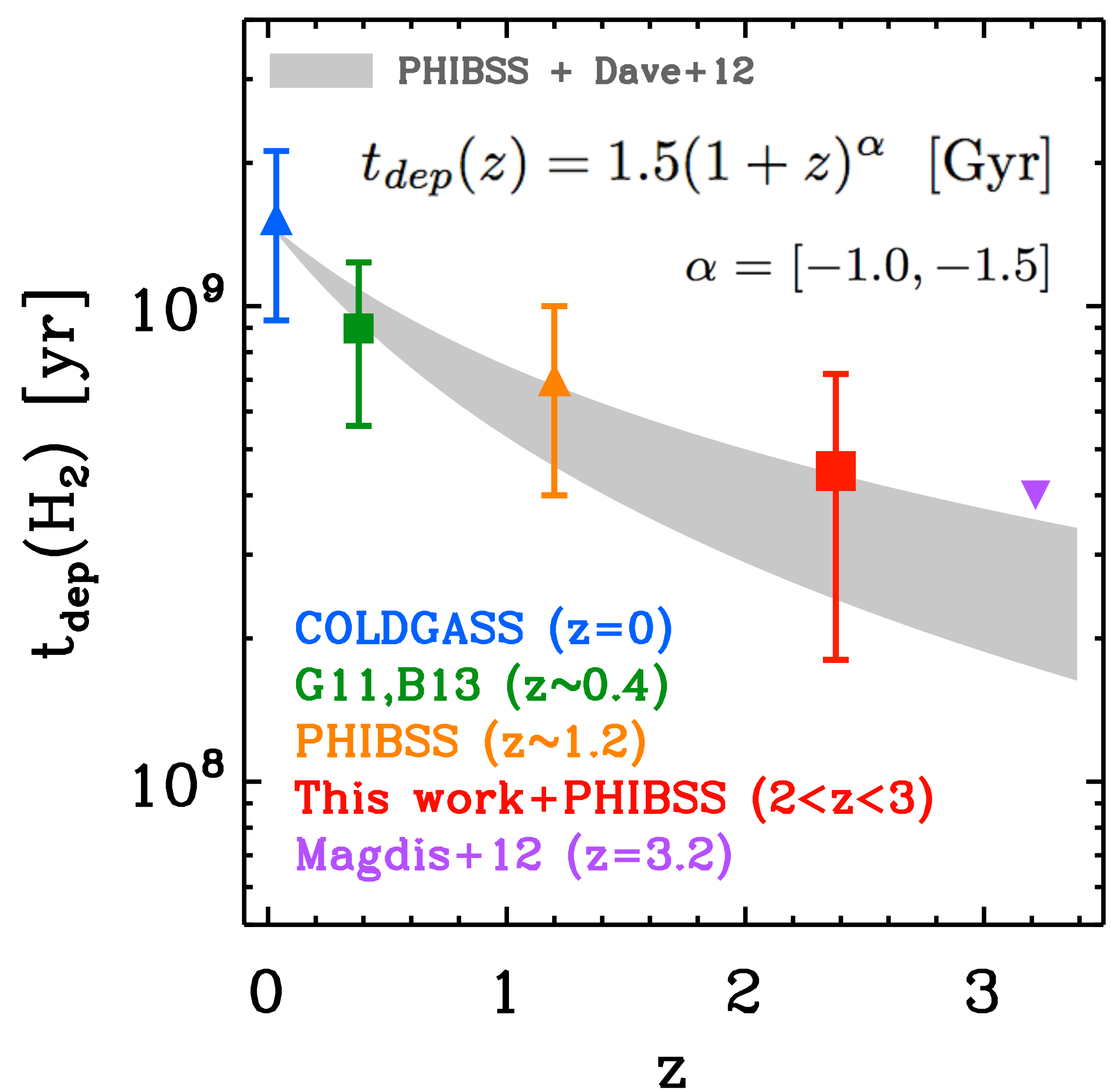




as galaxies evolve along the main sequence, they steadily consume their gas supplies *and grow more prominent bulges*

Gas fractions increase up to z=2





$$f_{gas} = \frac{M_{H2}}{M_{H2} + M_*}$$

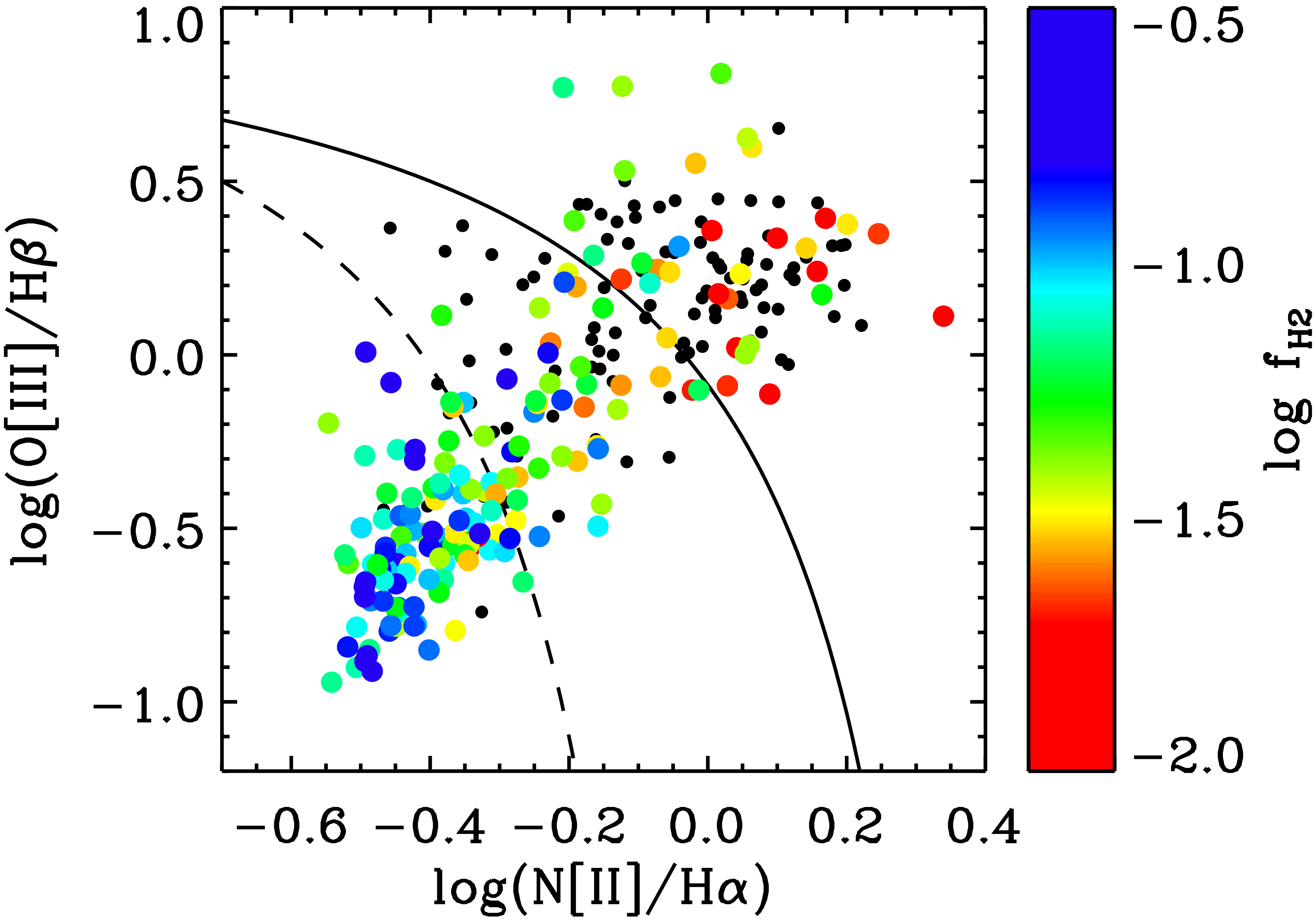
$$= \frac{1}{1 + (t_{dep}\ \mathrm{sSFR})^{-1}}$$

$$t_{dep}(H_2) = \frac{M_{H_2}}{\mathrm{SFR}} = \frac{1}{\mathrm{SFE}}$$

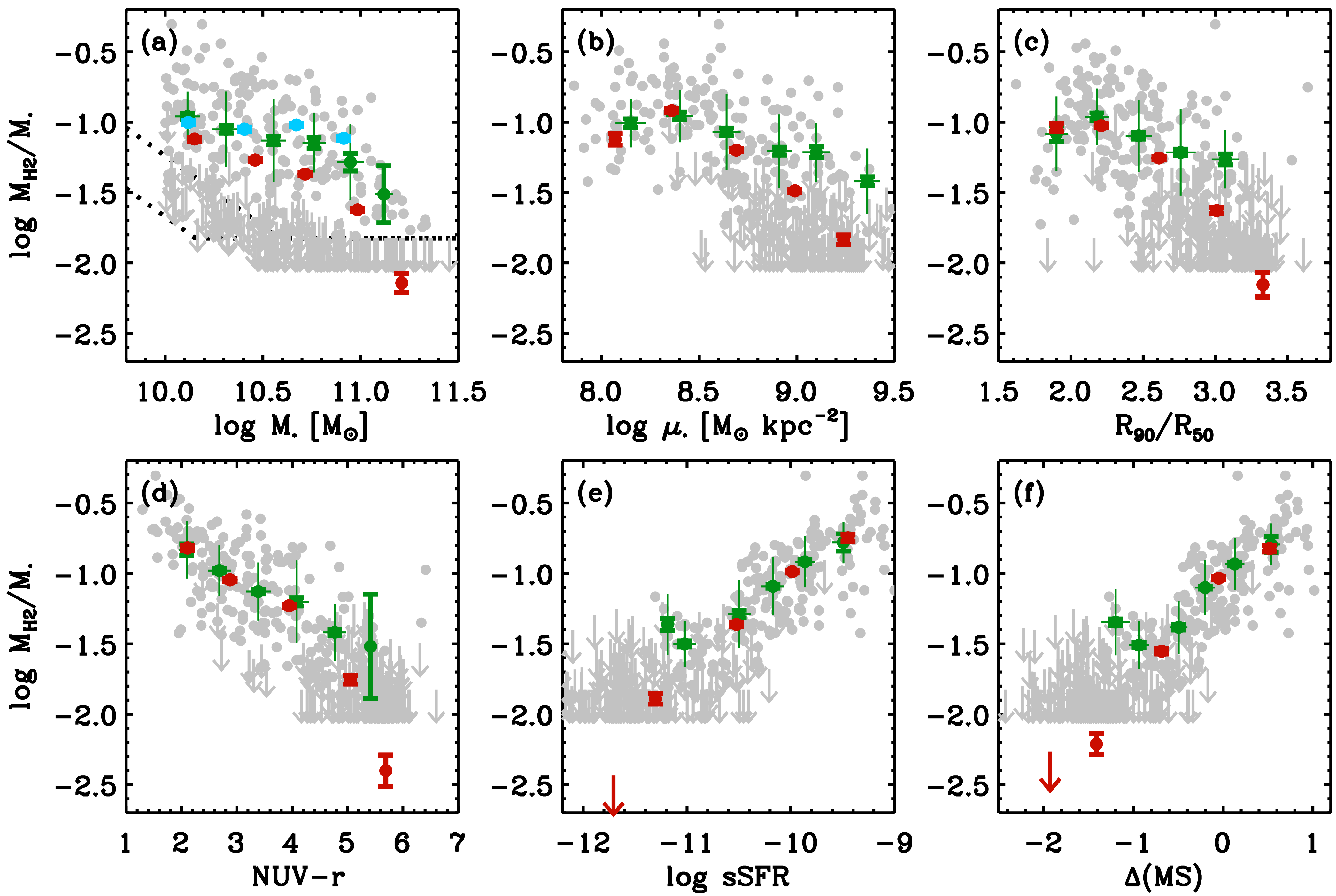
the redshift evolution of the mean SSFR is mainly driven by gas fractions and a slowly evolving depletion timescale

Saintonge et al. (2013), Tacconi et al. (2013)

AGN in the COLD GASS sample



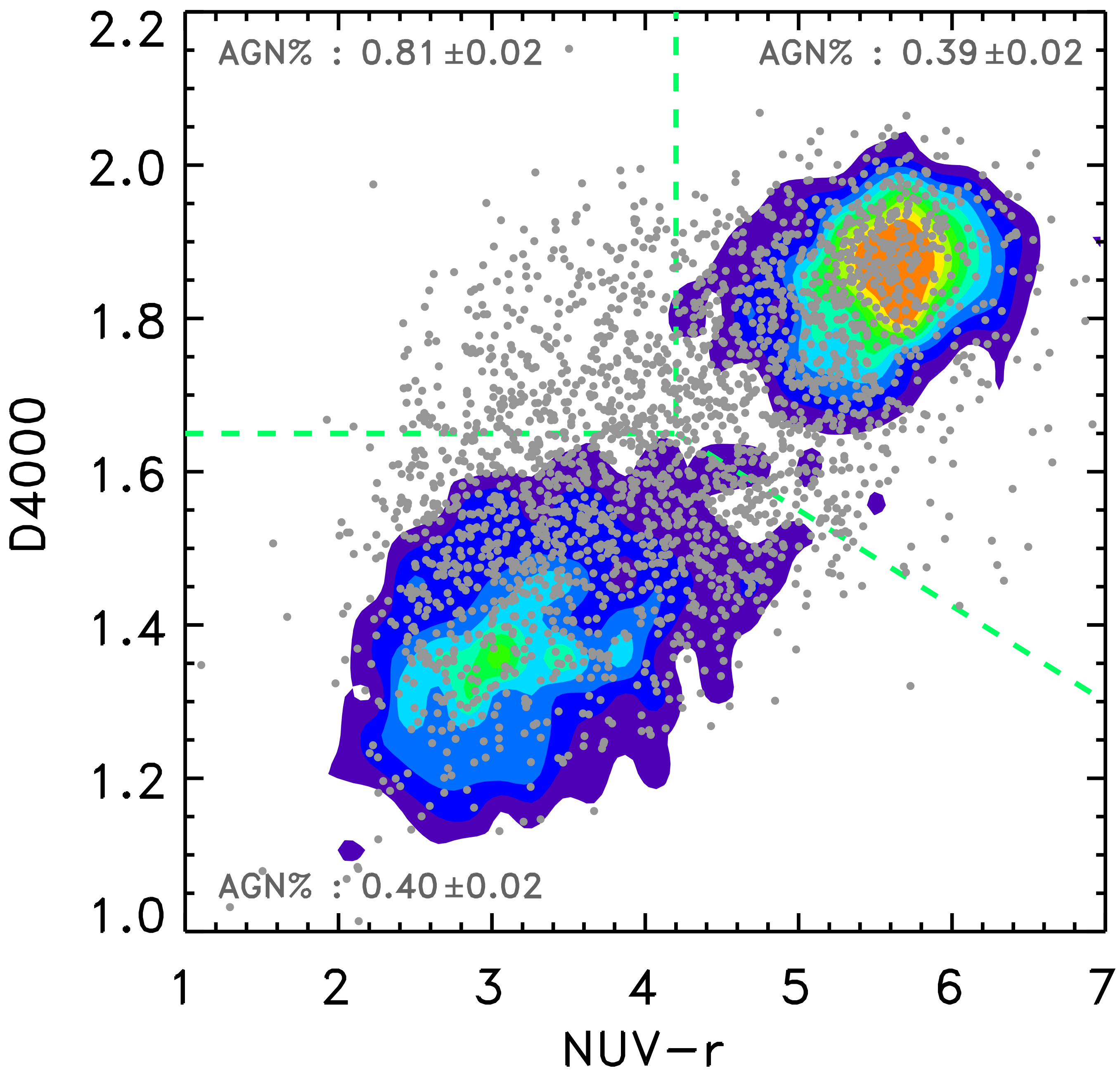
Molecular gas scaling relations



care must be taken when choosing a control sample for any galaxy sub-population!

AGN in the COLD GASS sample

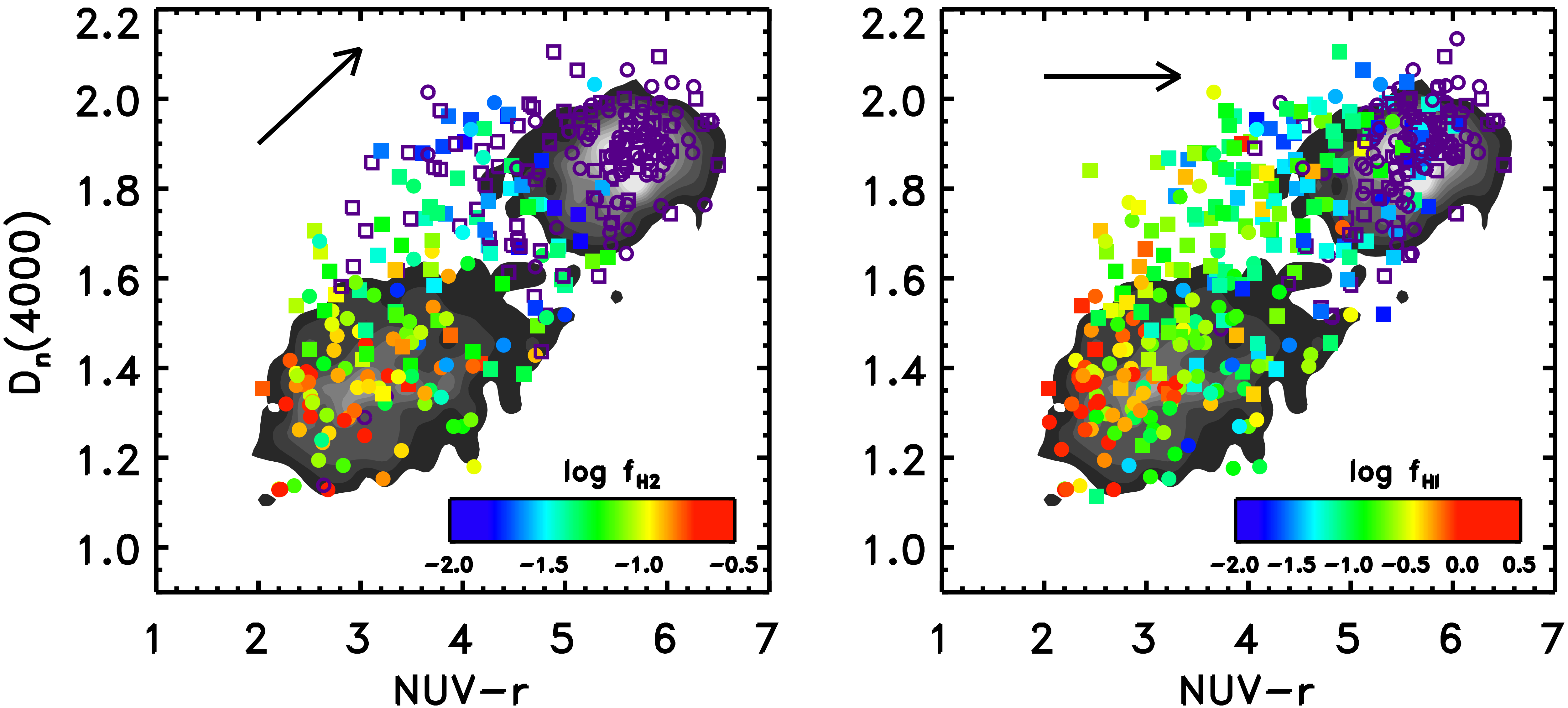
~ SSFR in the central region



~ SSFR in the outer disk

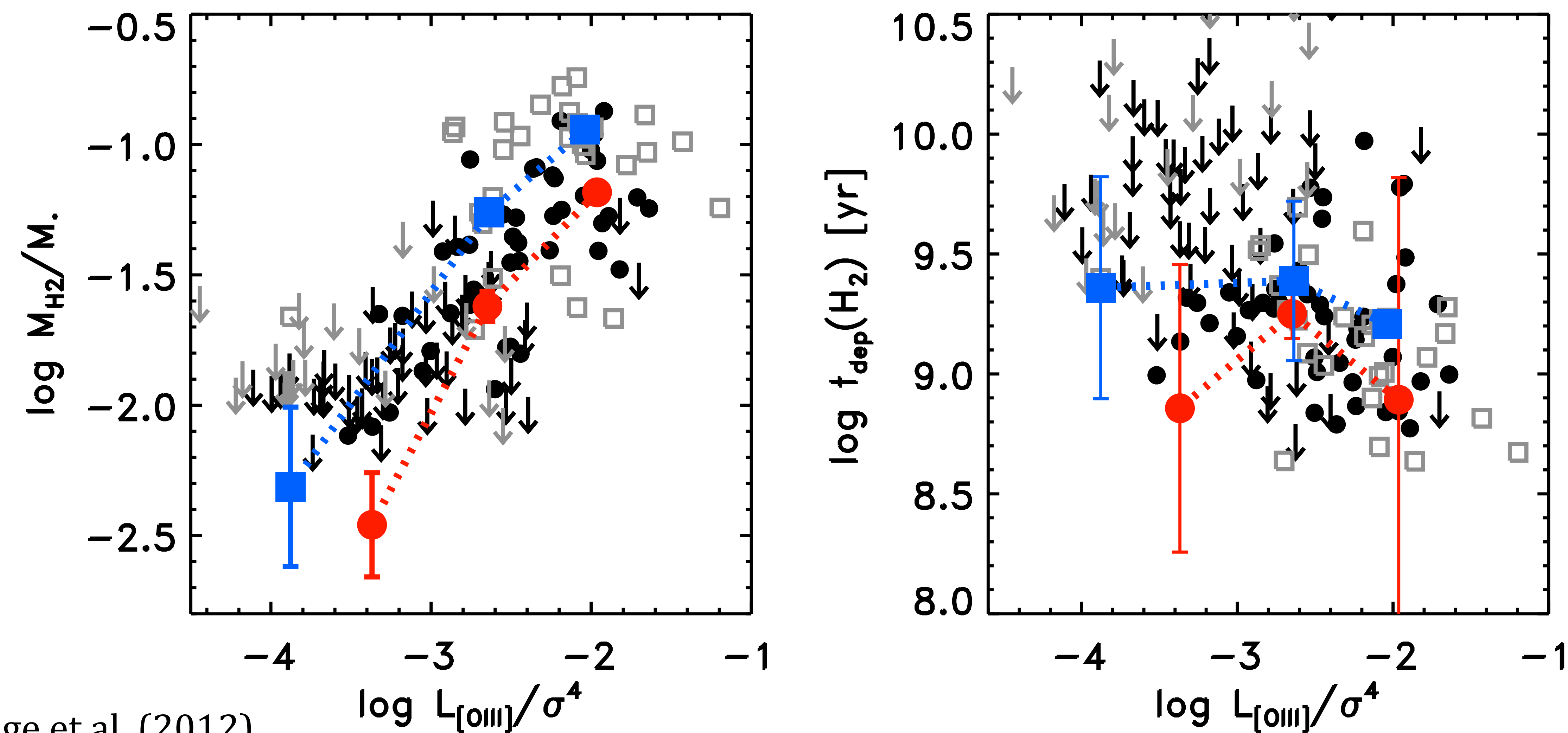
care must be taken when choosing a control sample for any galaxy sub-population… **in particular AGN**!

AGN in the COLD GASS sample



no link between atomic HI gas contents and AGN activity
see also Ho et al. (2008), Fabello et al. (2011)

AGN in the COLD GASS sample

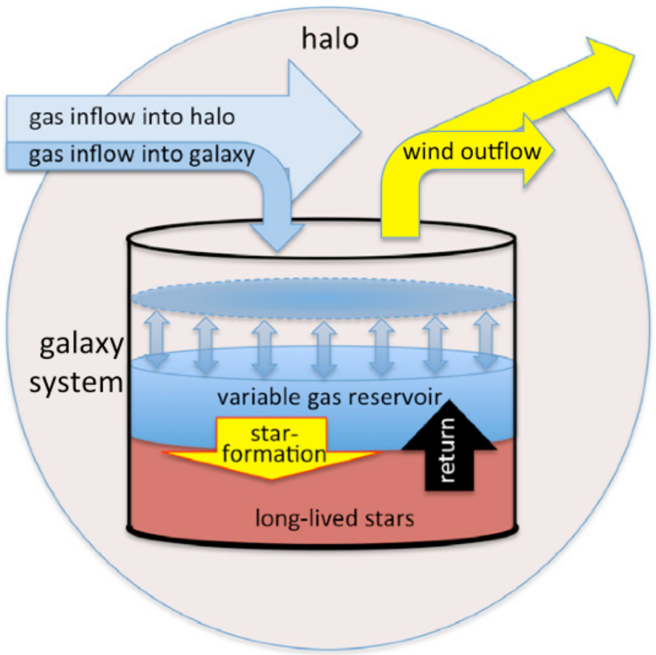


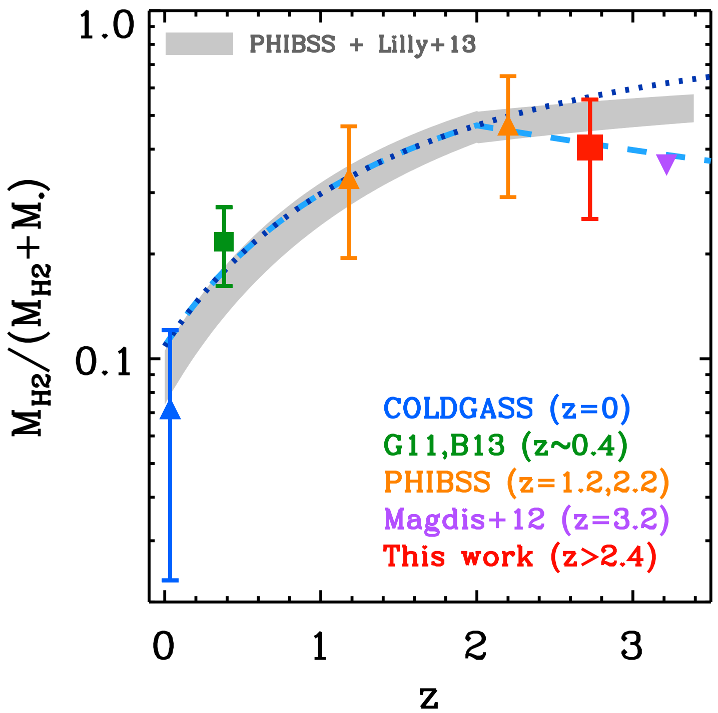
Saintonge et al. (2012)

in these weak AGN, molecular gas fractions are **lower** than in their matched control sample

Conclusions

Significant evidence for star formation and stellar mass growth of galaxies to be driven by the properties of the gas reservoir.





Cosmic evolution of SSFR (**and BH accretion?**) driven by evolving gas fractions

Conclusions

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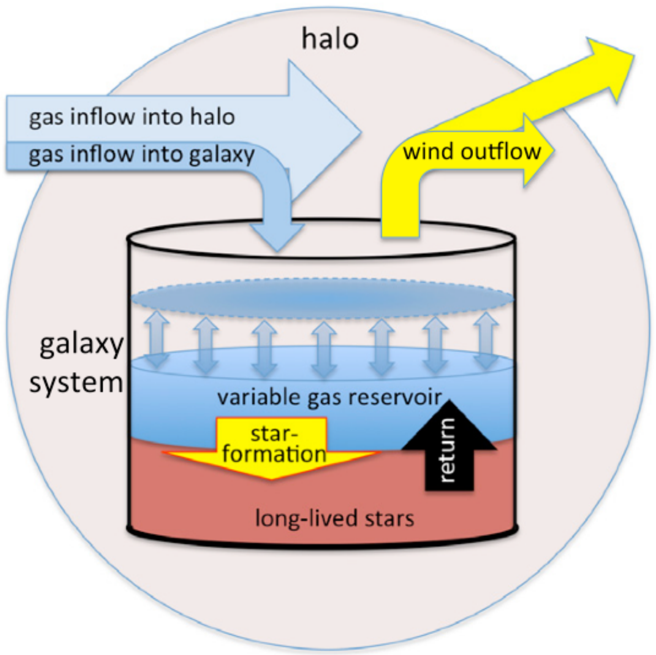

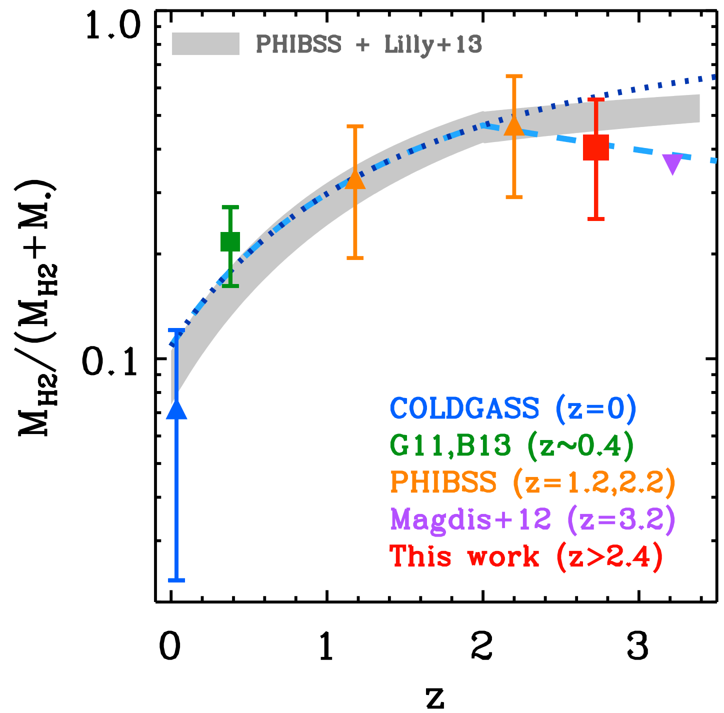

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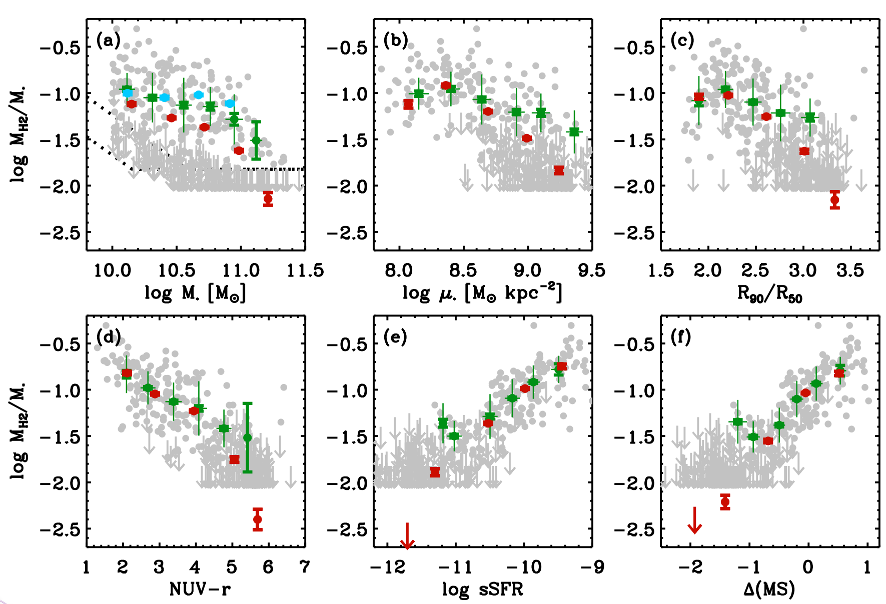
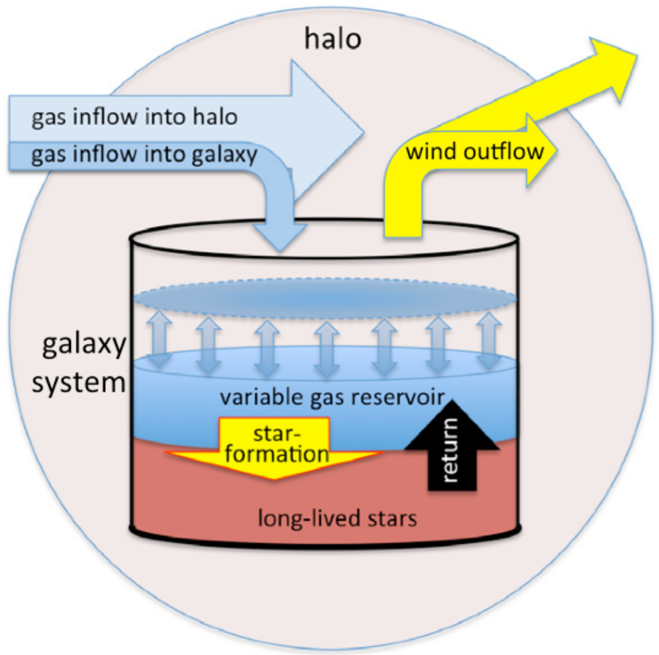
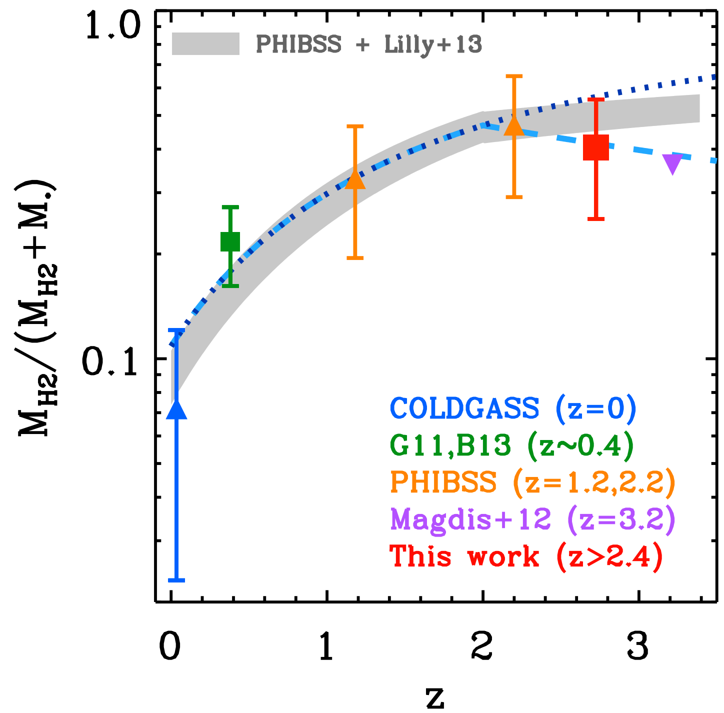


Scaling relations between gas contents and a large number of physical properties need to be kept in mind when choosing control samples!

Conclusions

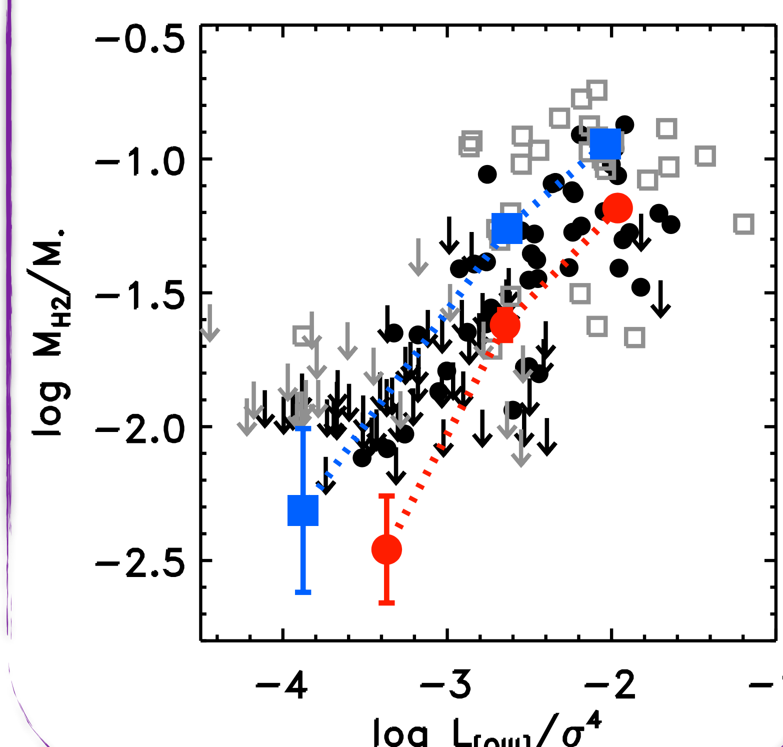
Significant evidence for star formation and stellar mass growth of galaxies to be driven by the properties of the gas reservoir.

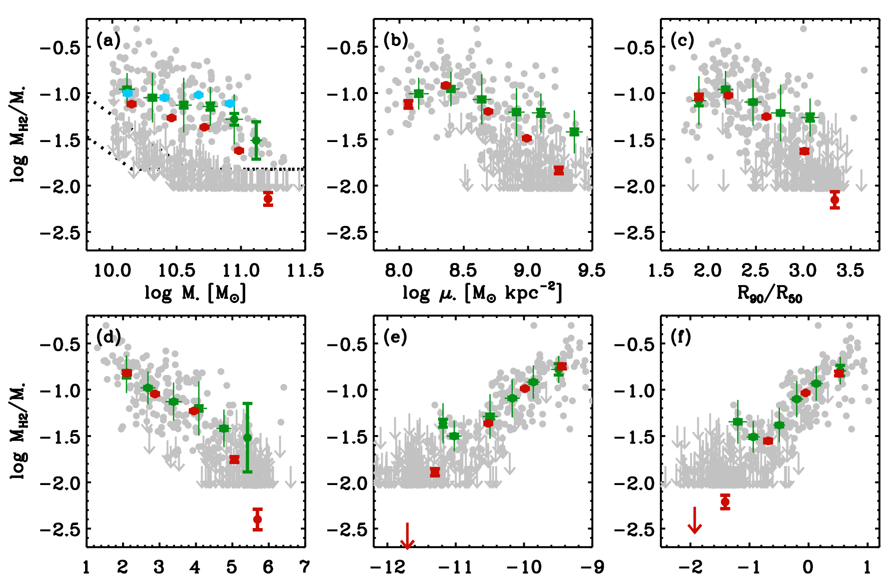




Cosmic evolution of SSFR (**and BH accretion?**) driven by evolving gas fractions

Suggestion that galaxies hosting weak AGN have lower molecular gas fractions than a matched control sample of non-active galaxies.





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