Estimating gas masses from optical spectroscopy

Jarle Brinchmann (Leiden)
Stephane Charlot, Guinevere Kauffmann, Tim Heckman, Christy Tremonti, Simon White, Sascha Zeegers, Babs Beemster

A need for gas estimates for large galaxy samples

- We routinely obtain stellar mass estimates for galaxies. Thus we have a fairly good idea of the stellar content for large samples of galaxies.

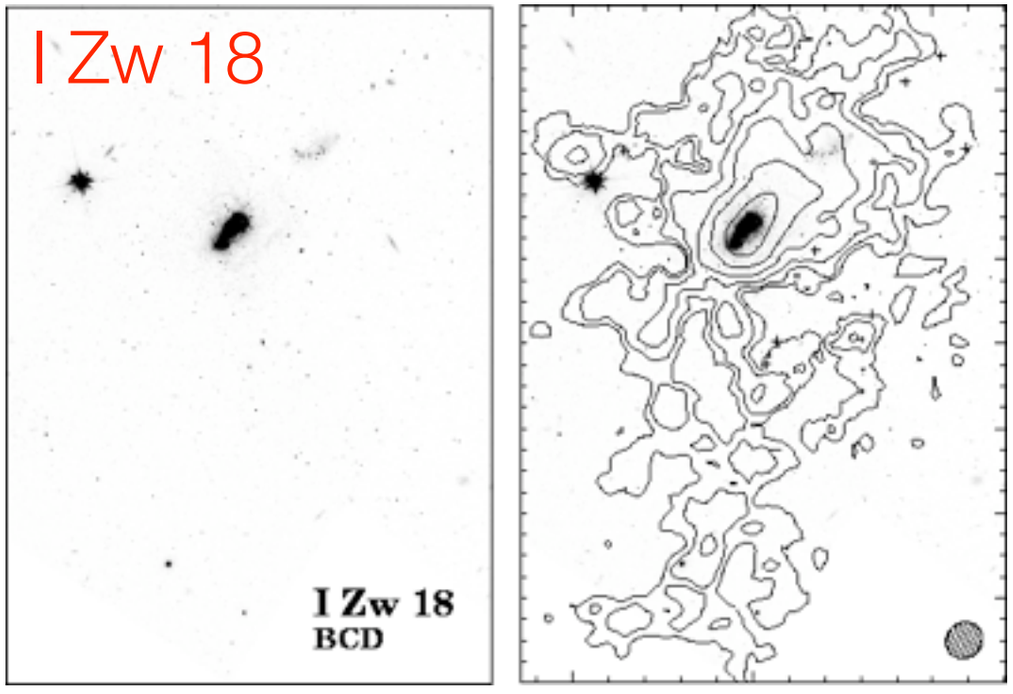
- However, the gas content of galaxies is much harder to measure for large (or distant) samples. So we haven't got gas mass estimates for samples of comparable size to those we have SFRs & stellar masses for.

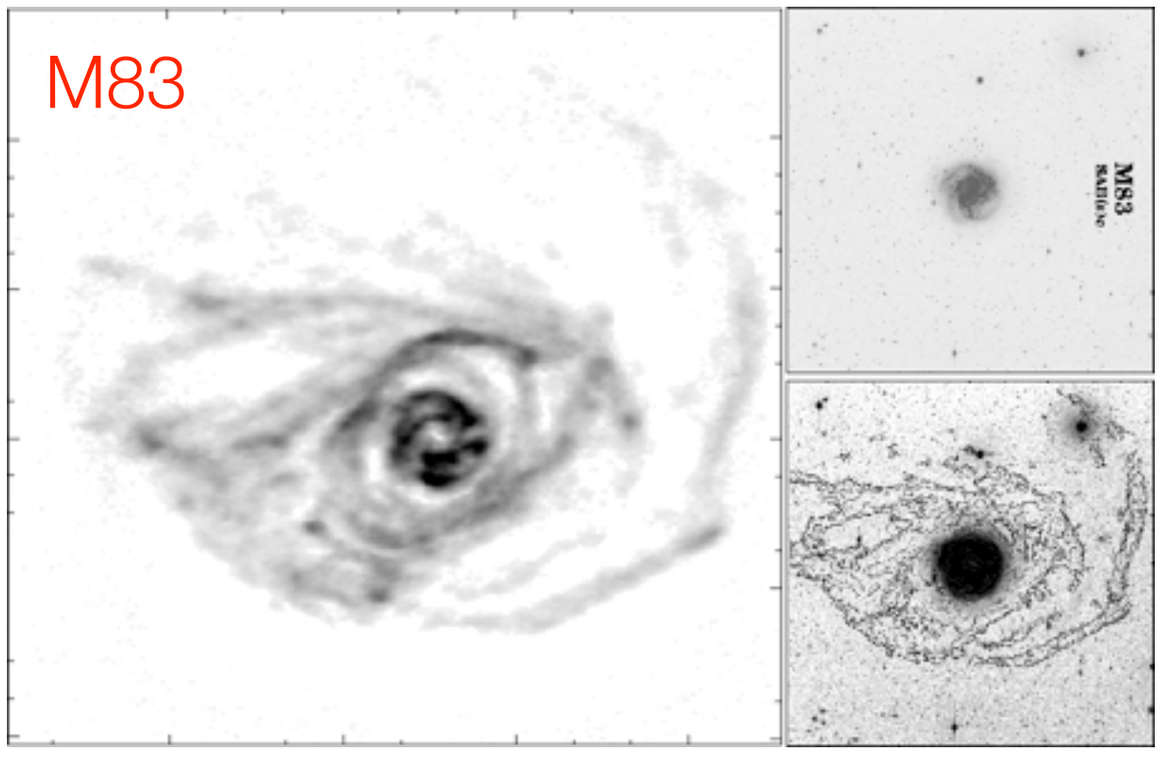
- This lack of gas measurements means that we often have to make recourse to scaling relations that have been tested mostly in the nearby Universe and are not well understood (for instance the Kennicutt-Schmidt relation).

How do we estimate the gas content of a galaxy?

21 cm

The classical measurement - this is sensitive to atomic H. ALFALFA, HIPASS, GASS. Mapping is also possible although quite time-consuming.





http://www.nrao.edu/astrores/HIrogues/

But:

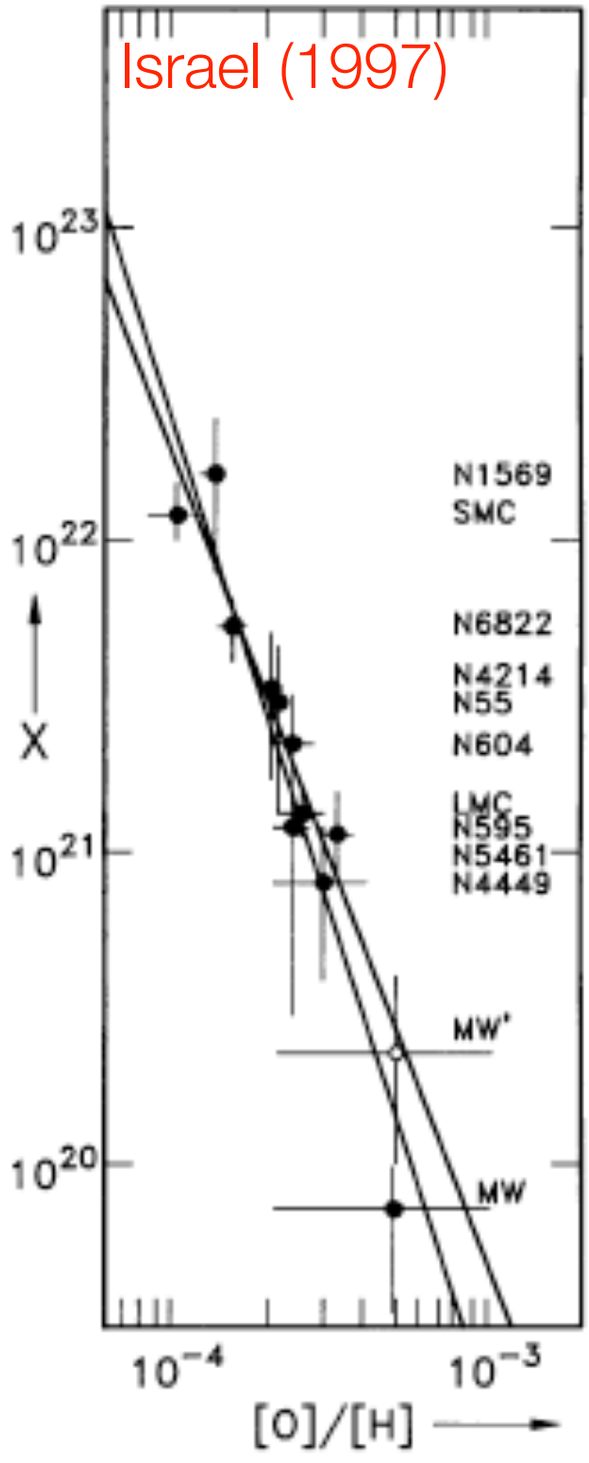
Stars don’t form from atomic gas

Difficult to extend to high redshift.

How do we estimate the gas content of a galaxy?

mm-observations

Cold H_2 can *not* be observed directly so we need proxies. The most common approach is to use CO and extrapolate from there.



But:

The conversion factor from CO to H_2 is uncertain (by orders of magnitude)

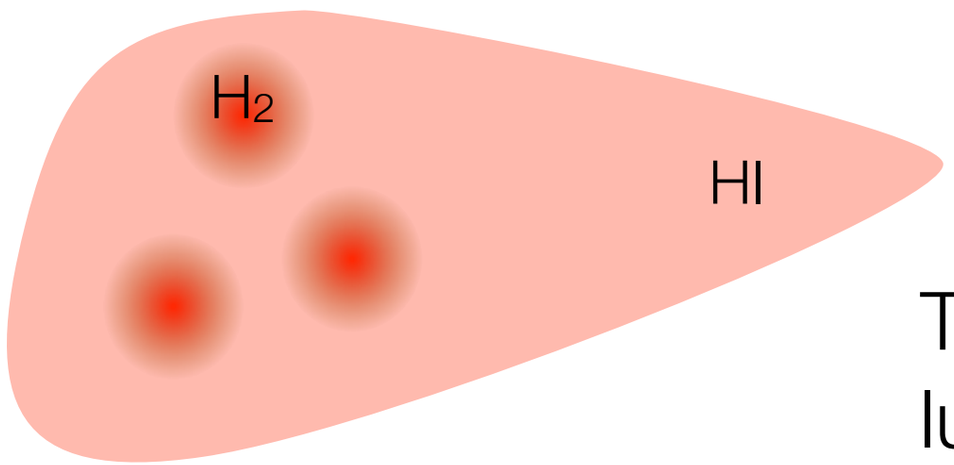
Useful also at high redshift - but then different transitions. The low redshift calibrations are (typically) for CO(0-1).

How do we estimate the gas content of a galaxy?

Total gas column from dust

It is well-known that dust & gas are closely related and the dust can be traced in emission using far-IR imaging (and also PAH emission - Gratier et al 2010)

By combining this with H I maps you can derive the total gas column density. Alternatively you can assume a dust-to-gas ratio.

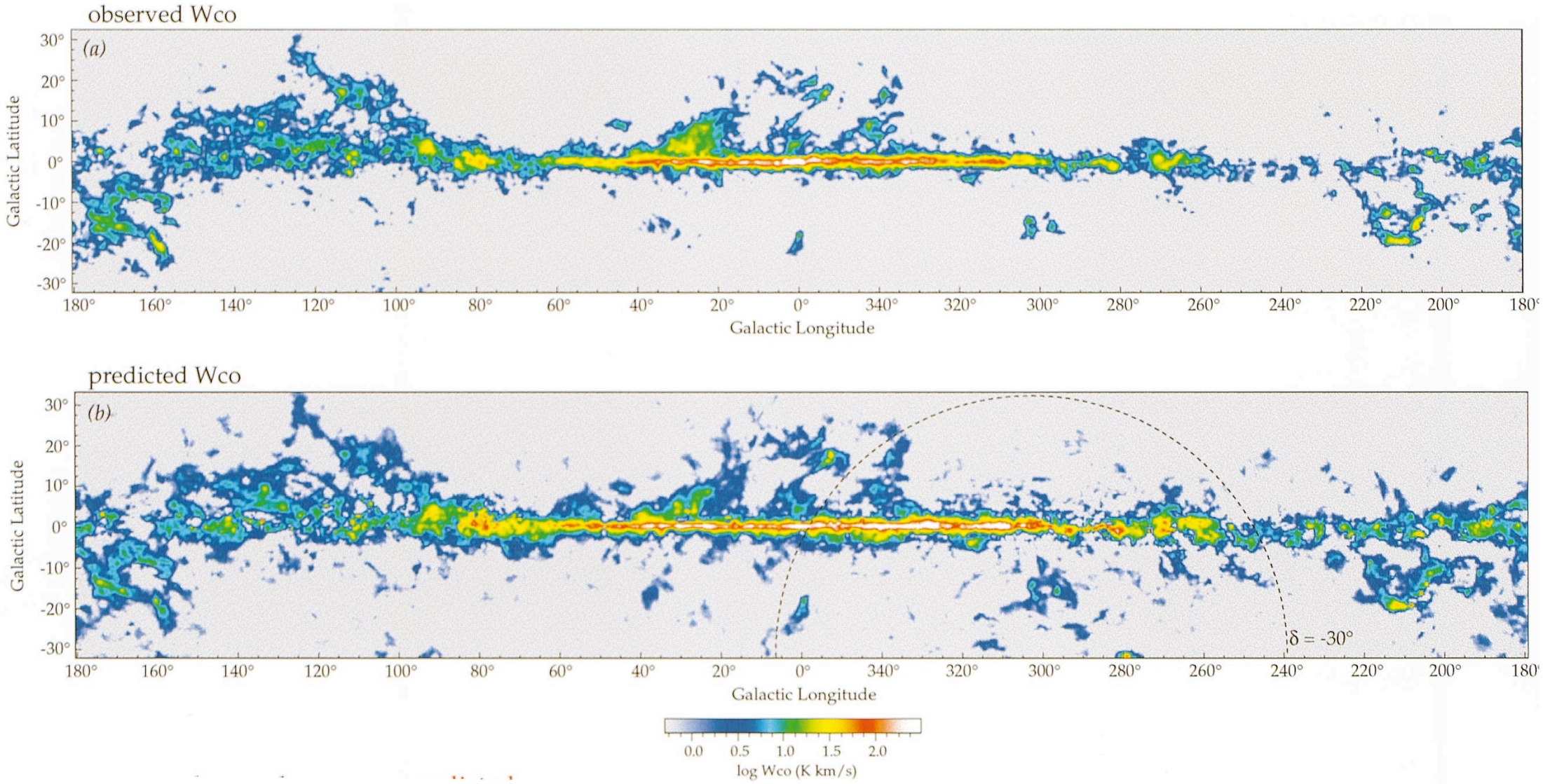


$$\frac{\Sigma_{\rm FIR}}{\Sigma_{\rm HI}} \approx {\rm const}$$
$$T_{\rm dust} \approx {\rm const}$$

This gives a way to relate total FIR luminosity to total gas mass.

Dust is a good tracer of gas - in the MW at least!

From Dame et al (2001): Based on IRAS 100μm maps it is possible to reproduce the observed CO distribution in the MW way:



See also: Boulanger, Baud & Van Albada 1985; Désert, Bazell & Boulanger 1988, Israel (1997ab, 2005); Reach, Wall & Odegard (1998) +++

How do we measure gas content?

Direct

Indirect

Mostly large spatial scales at z>0

Atomic gas

H I - 21 cm

Robust and reliable

Molecular H_2

CO (+ other) ⇒ H_2

Systematic uncertainties

Total gas content

Dust emission ⇒ Gas

Dust absorption ⇒ Gas

Fitting formulae

Kennicutt-Schmidt relation

Colour - gas relations

(When) Do they work?

The SDSS DR7

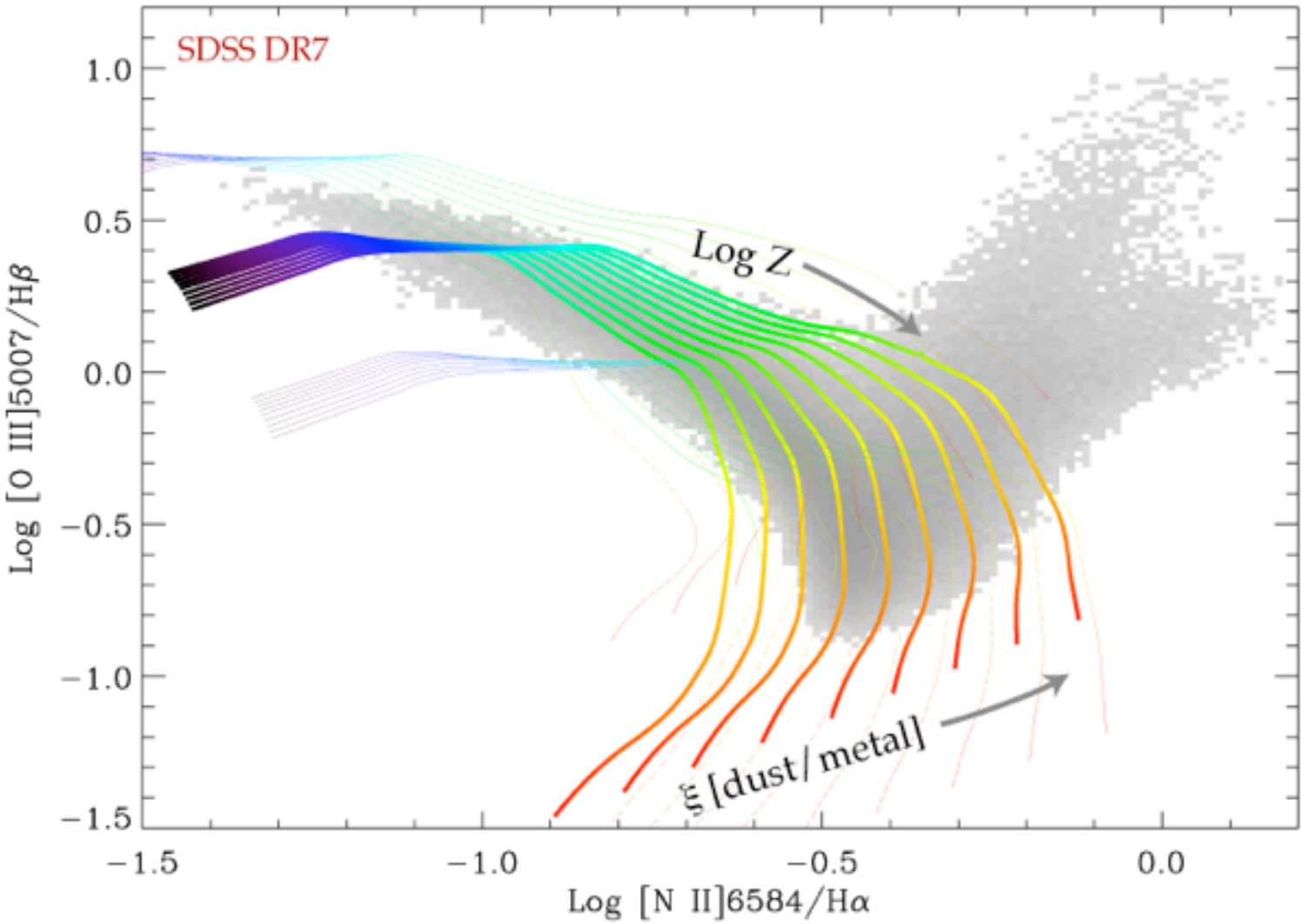
- Spectral measurements, star formation rates, stellar masses for ~10^6 galaxies. Spectra cover 3800Å-9000Å in observed frame, redshift spans from z=0 to z~0.2-0.3 for the main galaxy sample.

- Around 200,000 of these have emission line spectra whose dominant ionising source is stellar. For these we also can get metallicities, and, hopefully, estimate gas content.

- These datasets will allow us to sample wide ranges in parameter space and methodology: Good for population studies!

- But how do we get gas estimates for the SDSS?

Predicting emission lines



$$\xi = \mu_{dust}/\mu_{metals}$$
$$Z = \mu_{metals}/\mu_{gas}$$

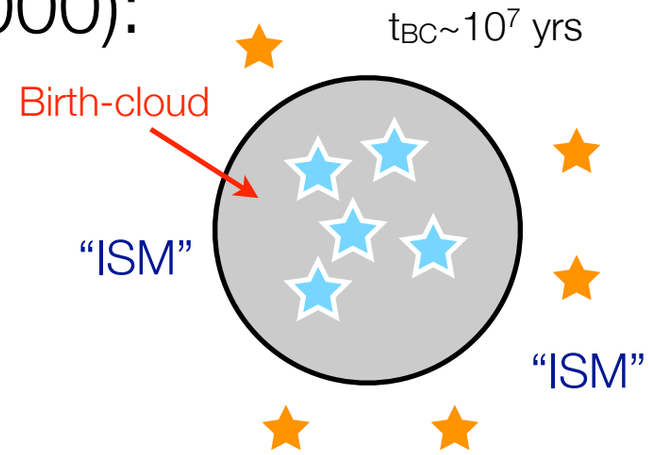
Increasing the metallicity increases the cooling.

At high temperature this is insensitive to abundance variations, but at low T (high Z), small variations in abundance (for instance due to depletion) has strong effects on the emission lines.

So we have dust, dust-to-gas & metallicty

$$\xi = \mu_{dust}/\mu_{metals}$$
$$Z = \mu_{metals}/\mu_{gas}$$

Charlot & Fall (2000):



Put together:

$$\mu_{gas} = 0.2 \frac{\tau_V}{\xi Z} \; M_\odot/pc^2$$

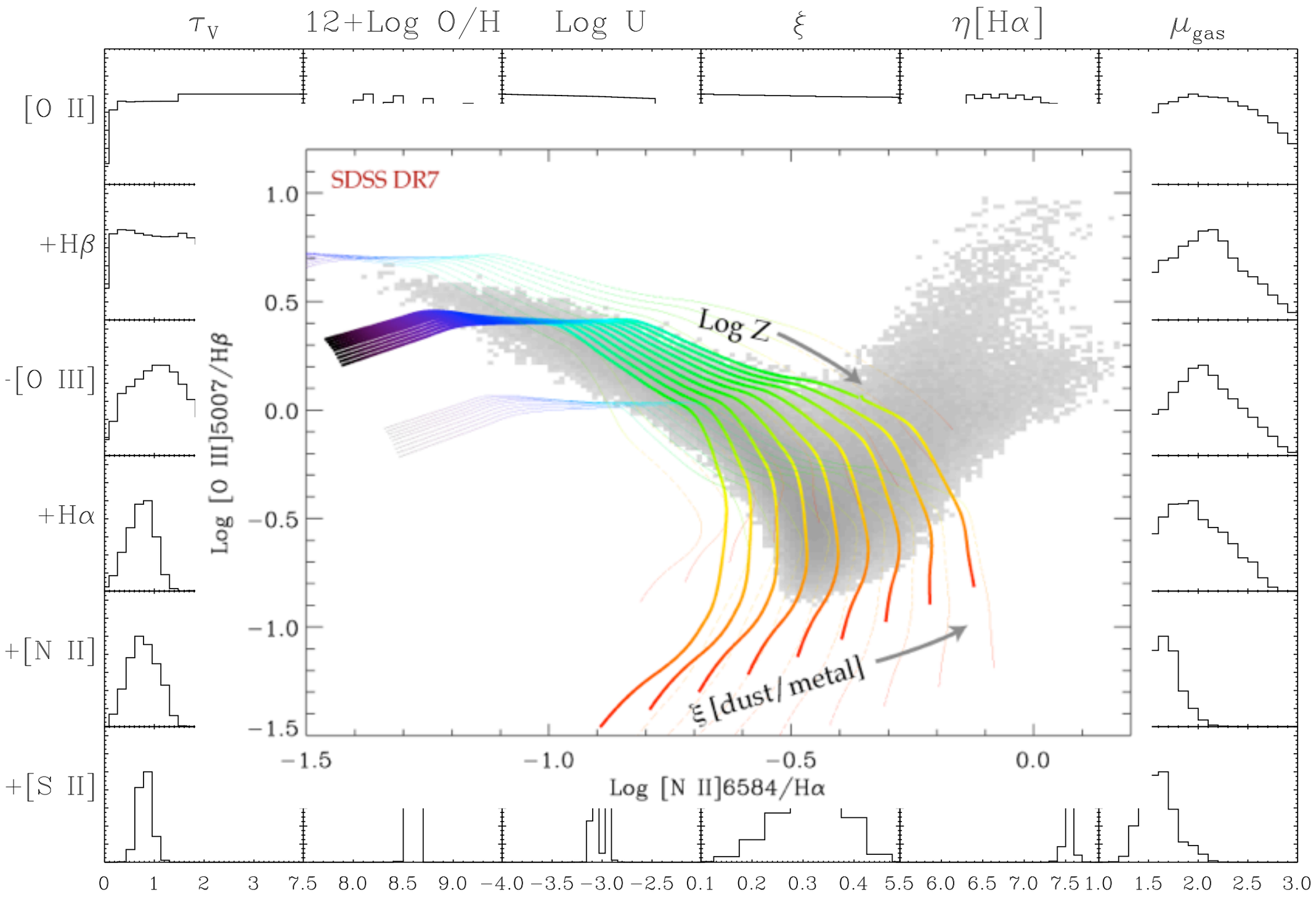
$$\mu_{gas}^{ISM} \approx \frac{\tau_{ISM}\, m_{dust}}{\sigma_{dust}\, \xi\, Z}$$

$$\mu_{gas}^{BC} = \frac{\tau_{BC}\, m_{dust}}{\sigma_{dust}\, \xi\, Z}$$

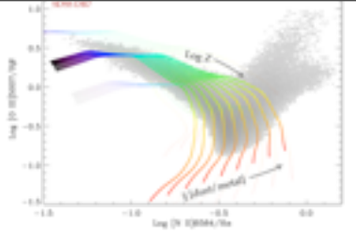
This is sensitive to the **total** gas column.

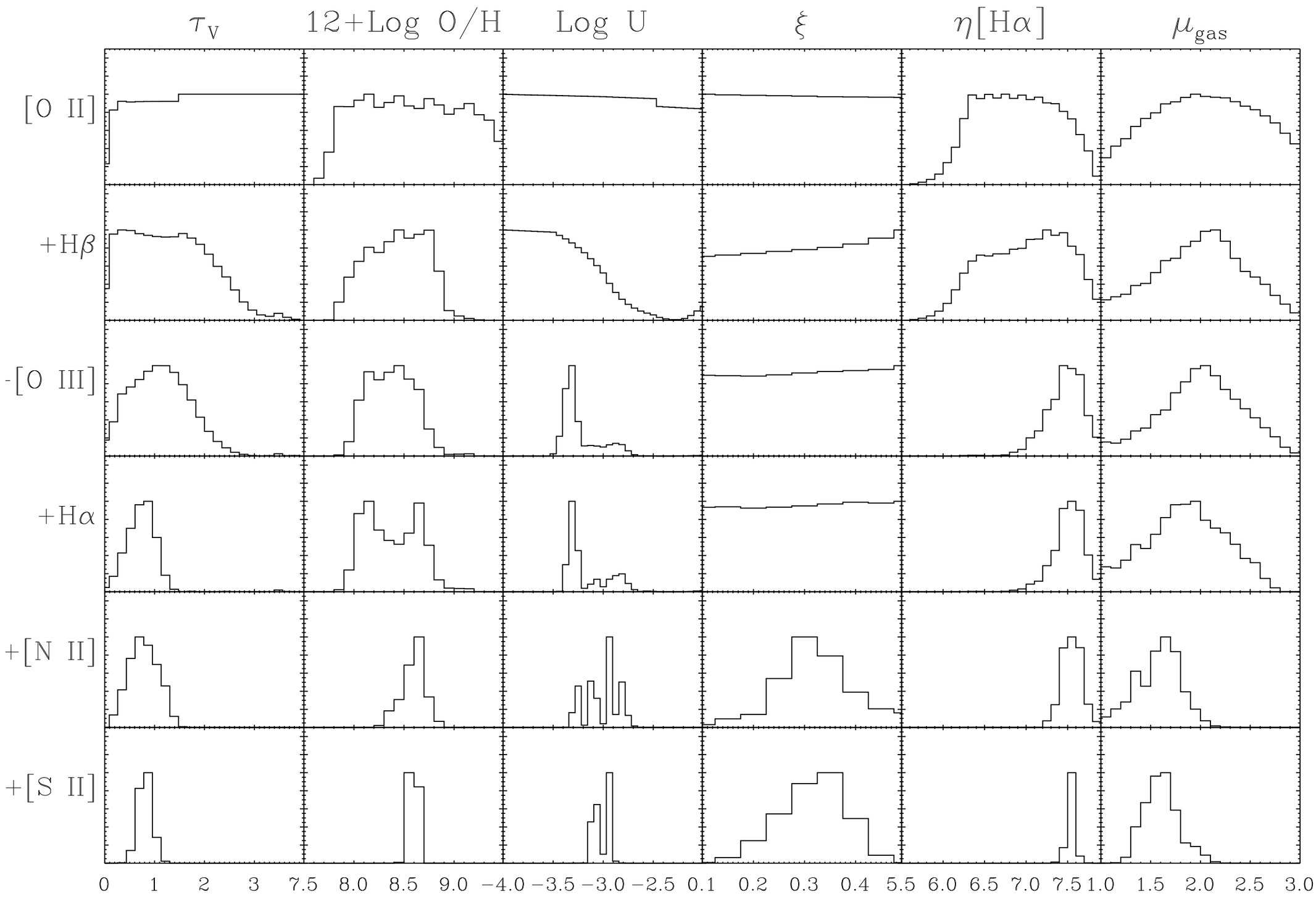
We estimate this by fitting to a grid of photoionization models and calculate $P(\mu_{gas}|data)$.

Fitting emission lines

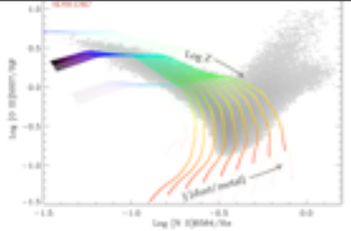


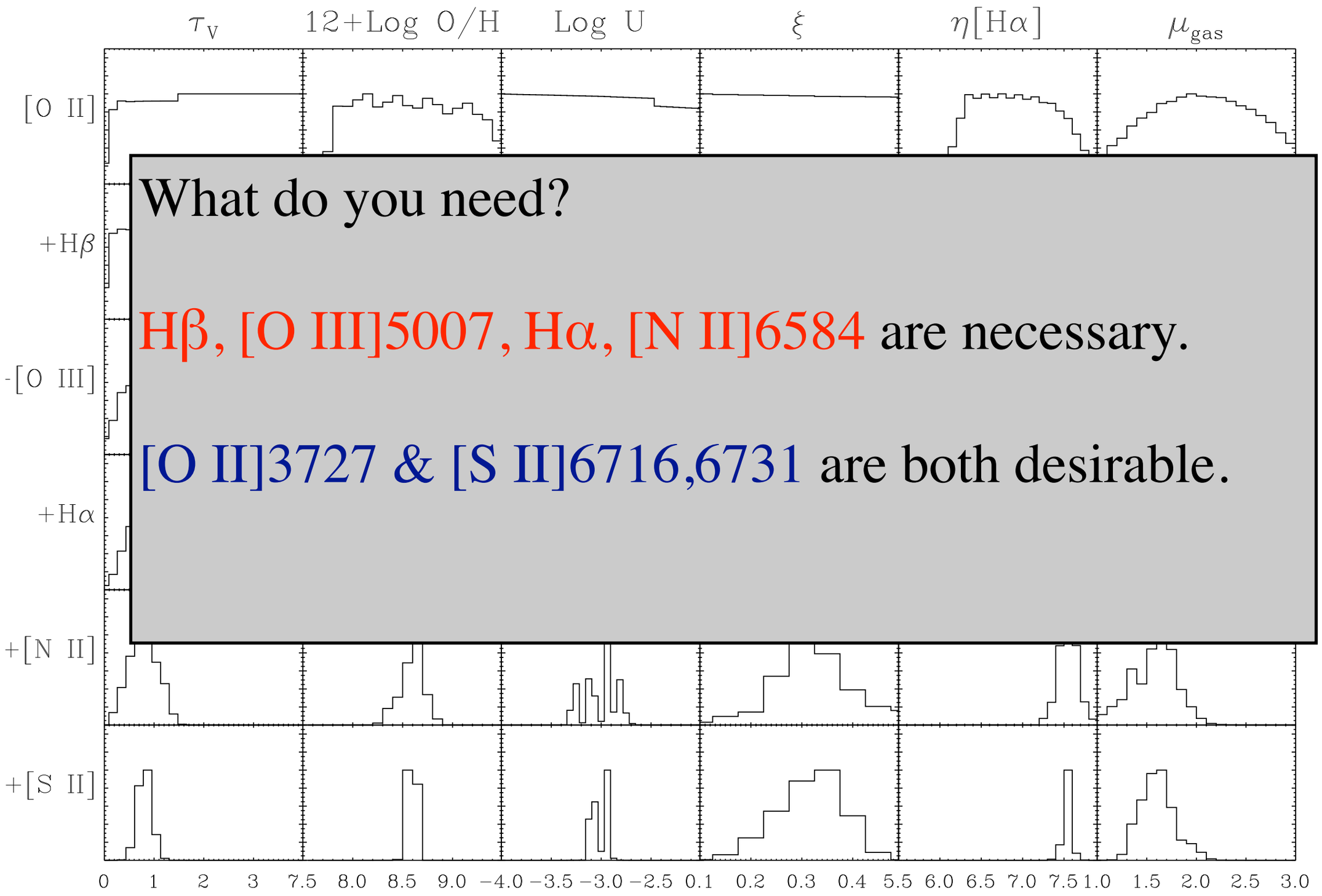
Fitting emission lines





Fitting emission lines





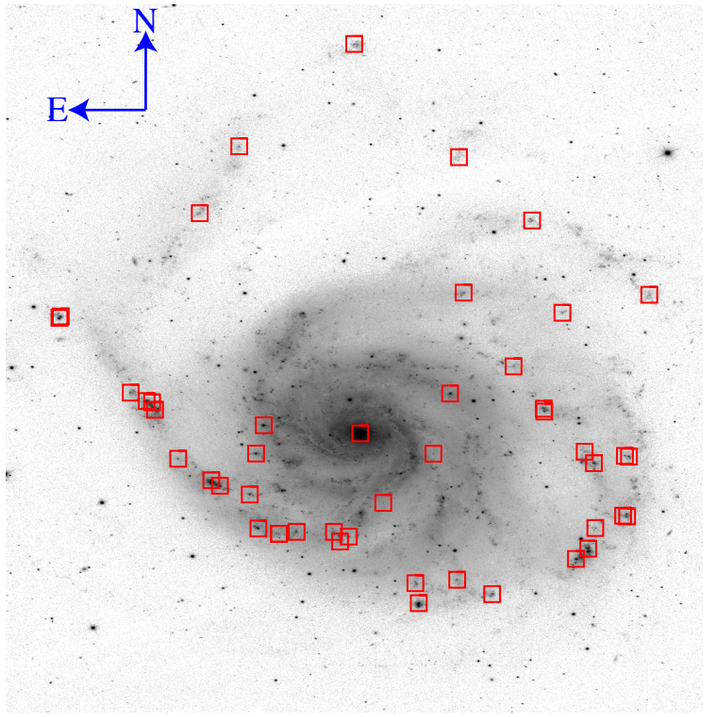
What do you need?

Hβ, [O III]5007, Hα, [N II]6584 are necessary.

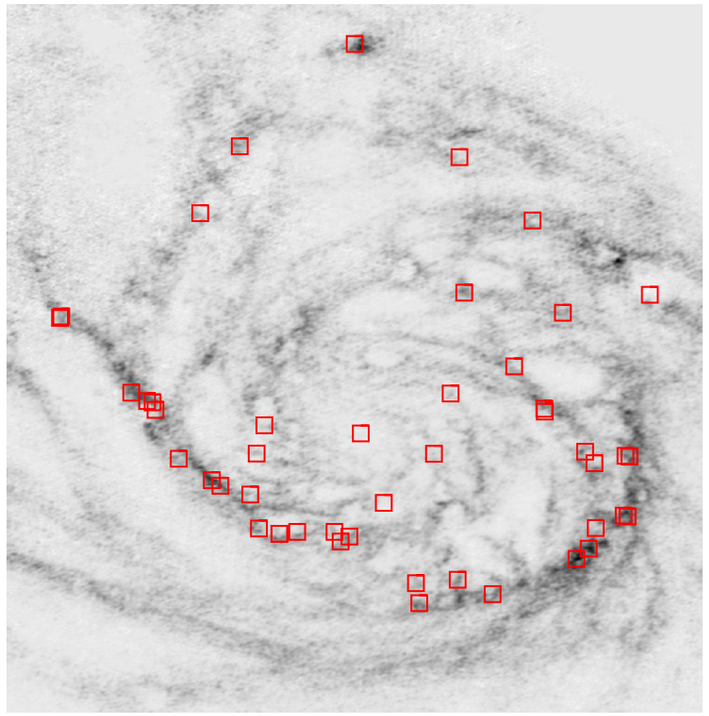
[O II]3727 & [S II]6716,6731 are both desirable.

Testing the gas estimates - M101

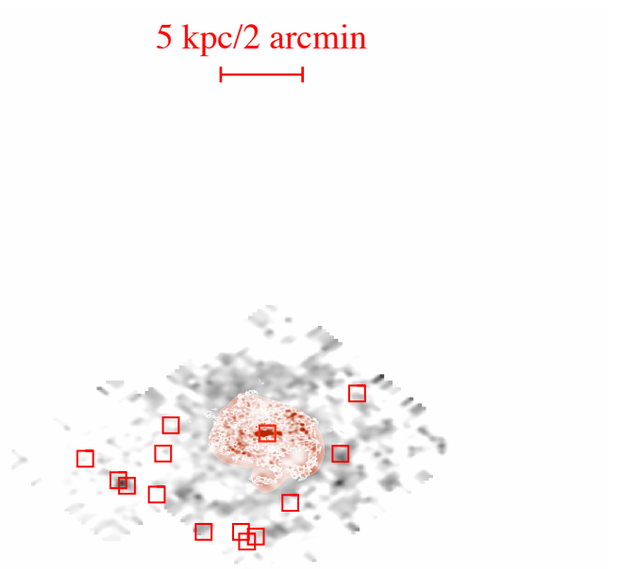
SDSS



HI



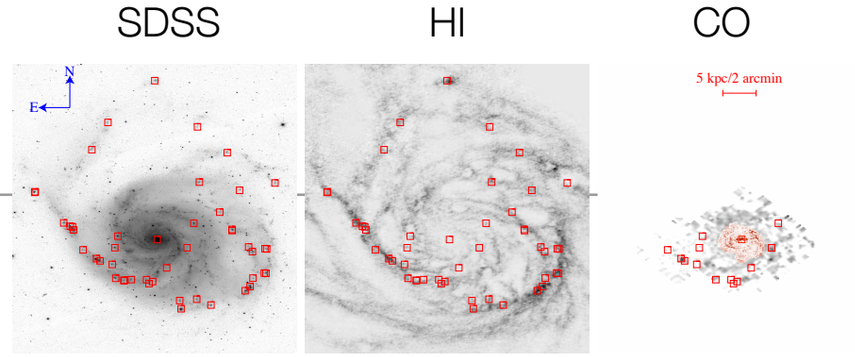
CO

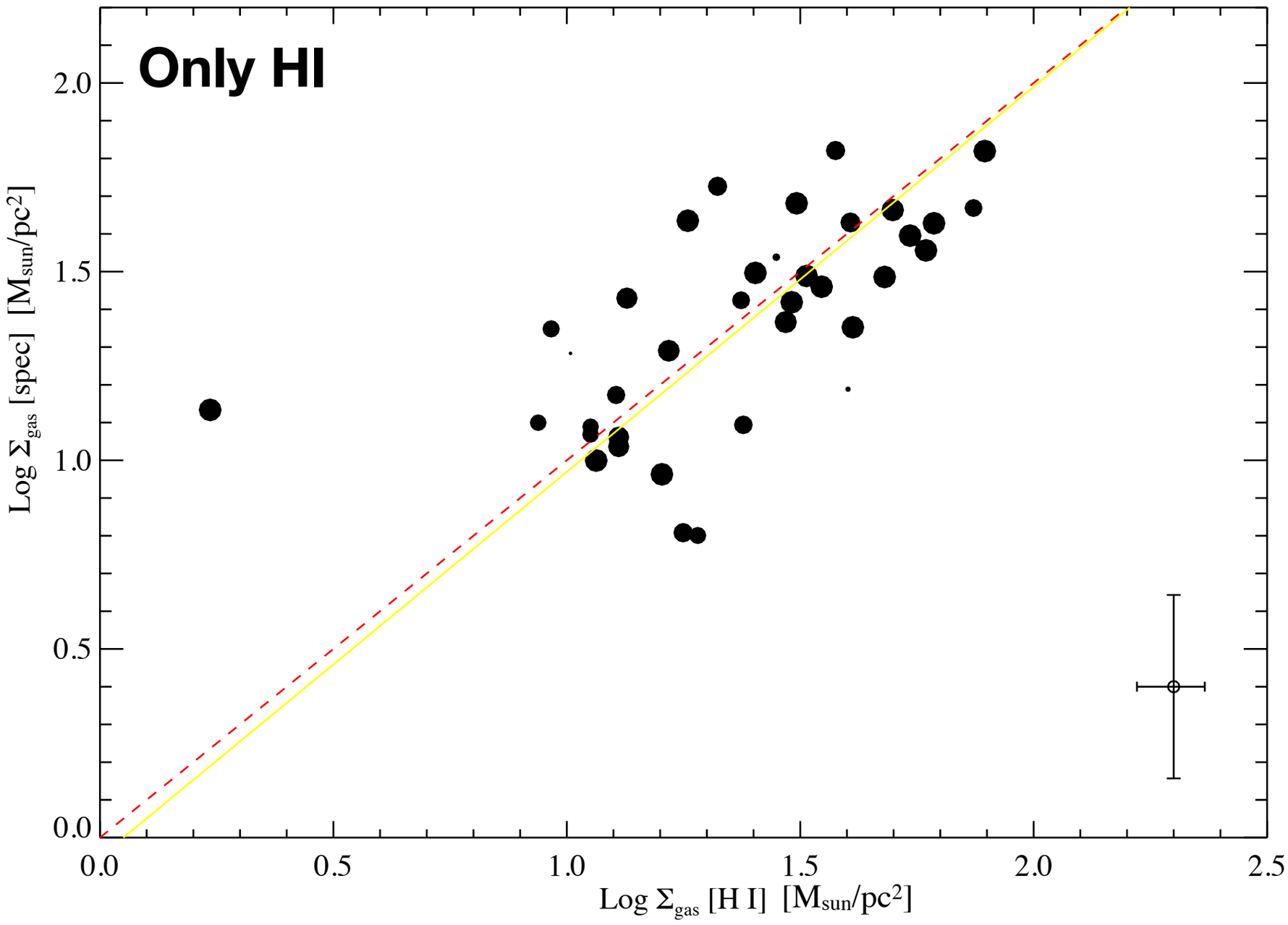


Get gas surface density estimates using the spectra for these.

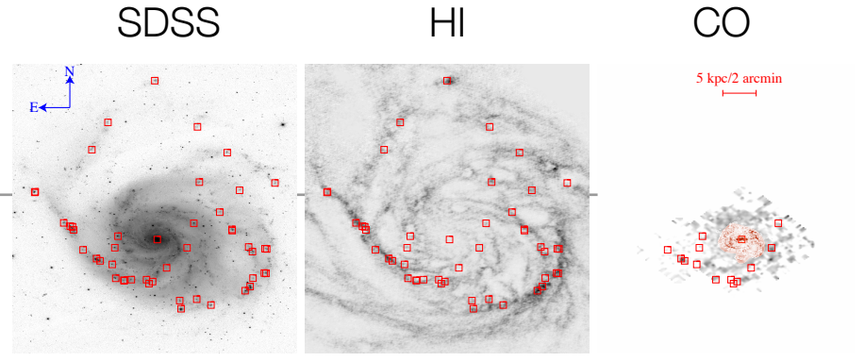
Combine these two to get atomic + molecular gas surface densities.

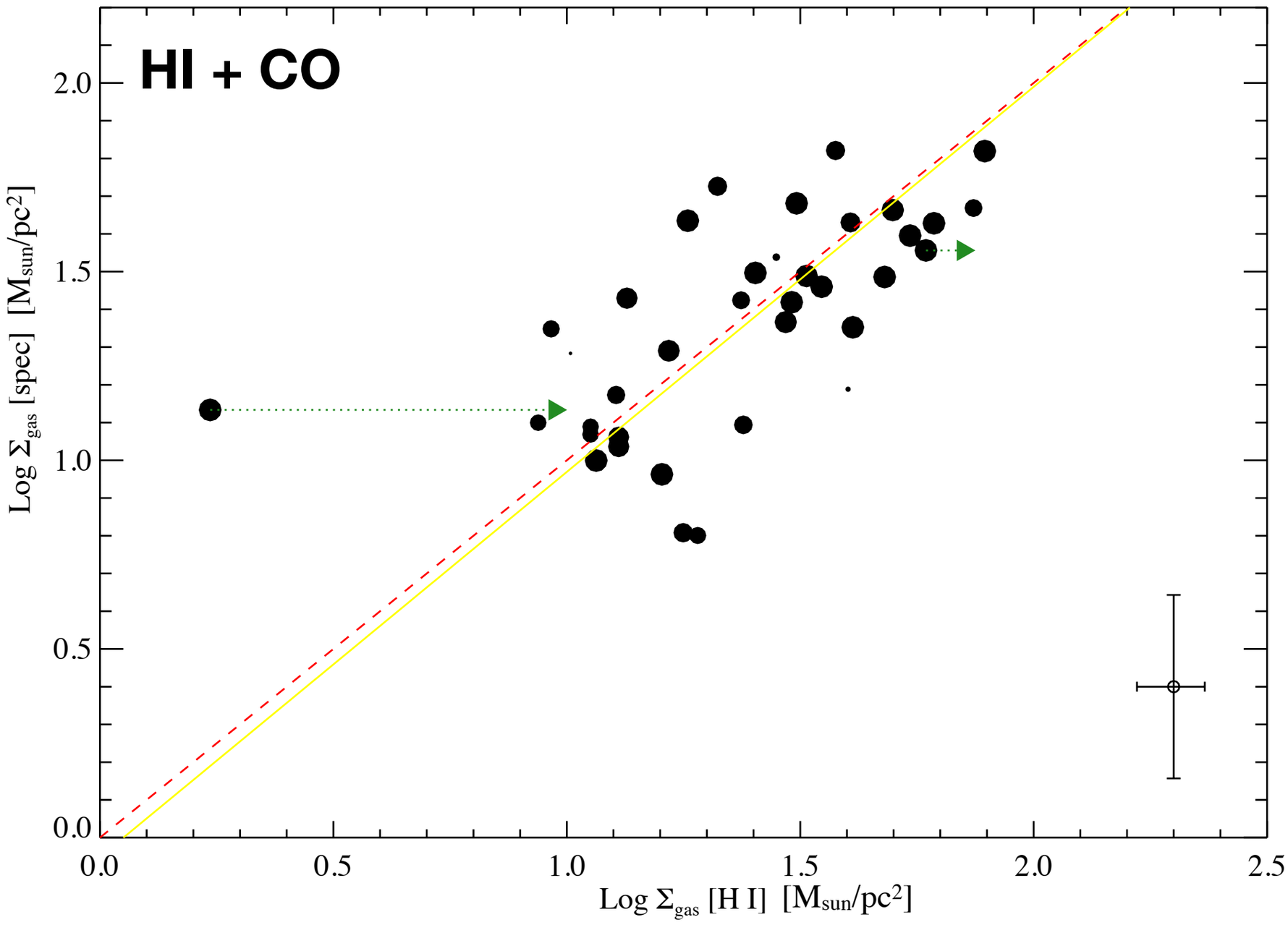
Testing the gas estimates - M101



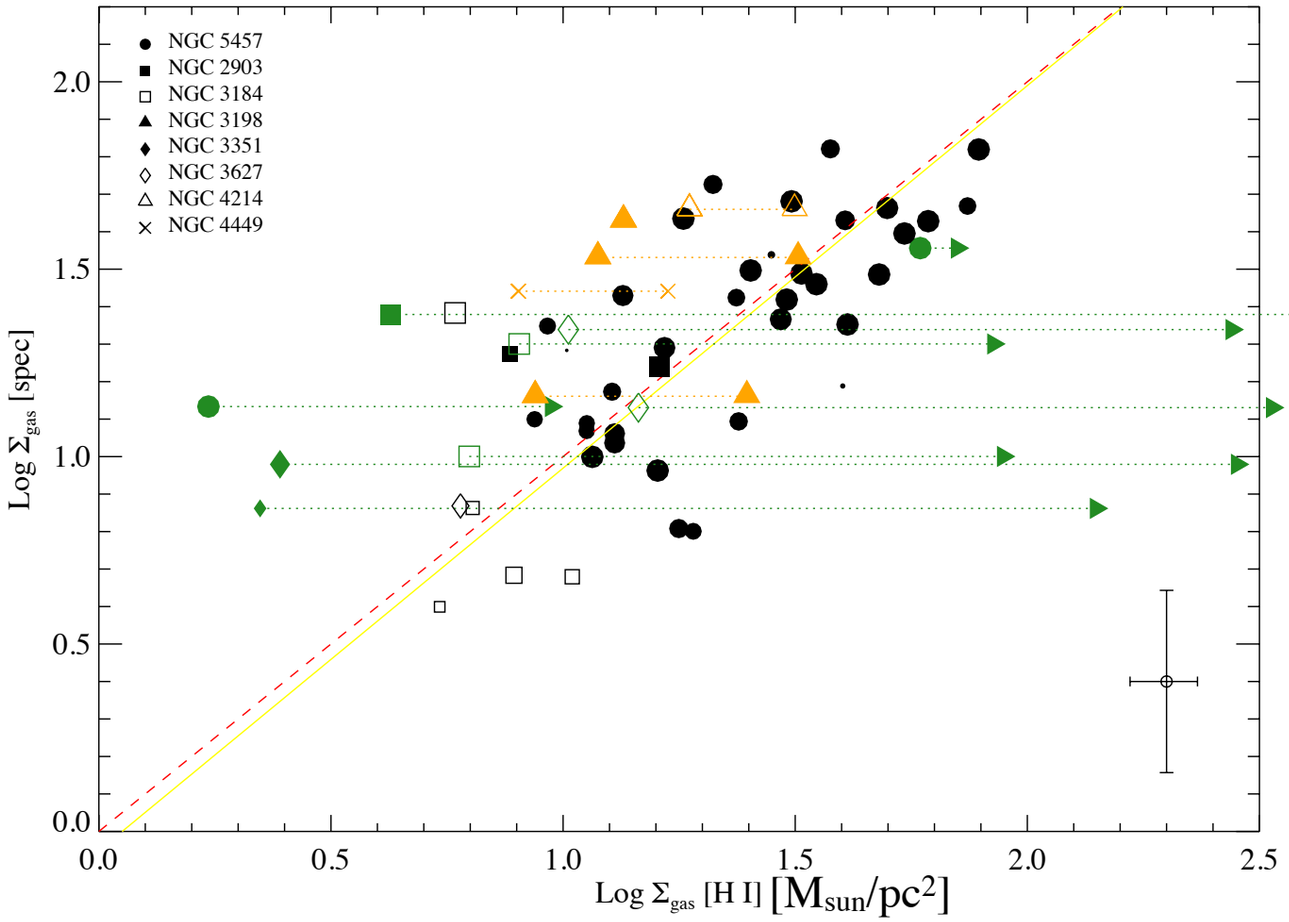


Testing the gas estimates - M101





But it doesn't always work!

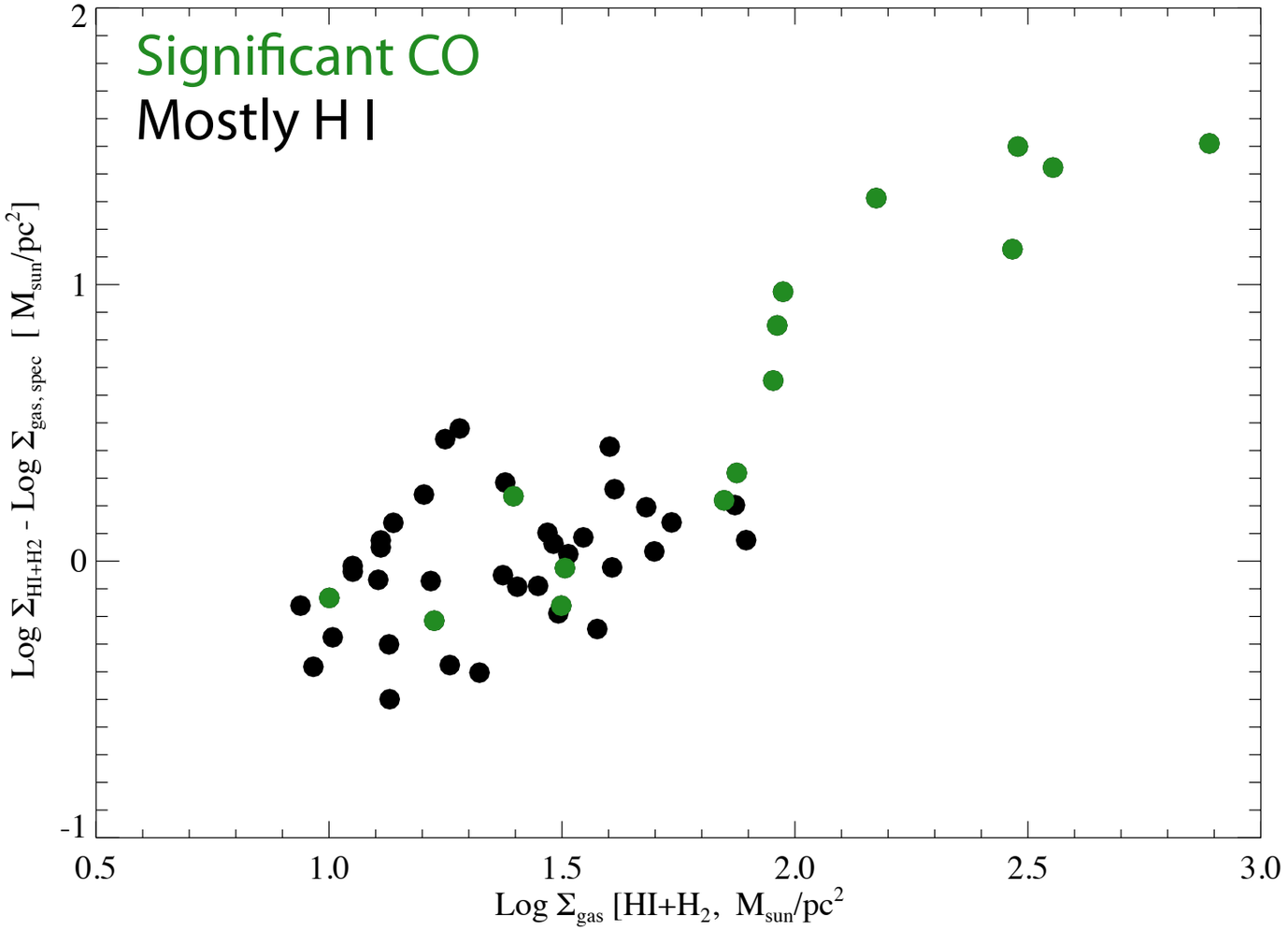


In all the cases where it does **not** work - the spectrum is probing a region with very high molecular surface mass density.

For surface mass densities < 75 M_{sun}/pc^2 - Recovers $\sum_{gas}$ to within a factor of 2.

For surface mass densities > 100 M_{sun}/pc^2 - Method tends to break down.

But it doesn't always work!



In all the cases where it does **not** work - the spectrum is probing a region with very high molecular surface mass density.

For surface mass densities < 75 M_{sun}/pc^2 - Recovers $\sum_{gas}$ to within a factor of 2.

For surface mass densities > 100 M_{sun}/pc^2 - Method tends to break down.

Other techniques

Use colour: Bothun 1984; Kannappan 2004; Zhang et al 2009

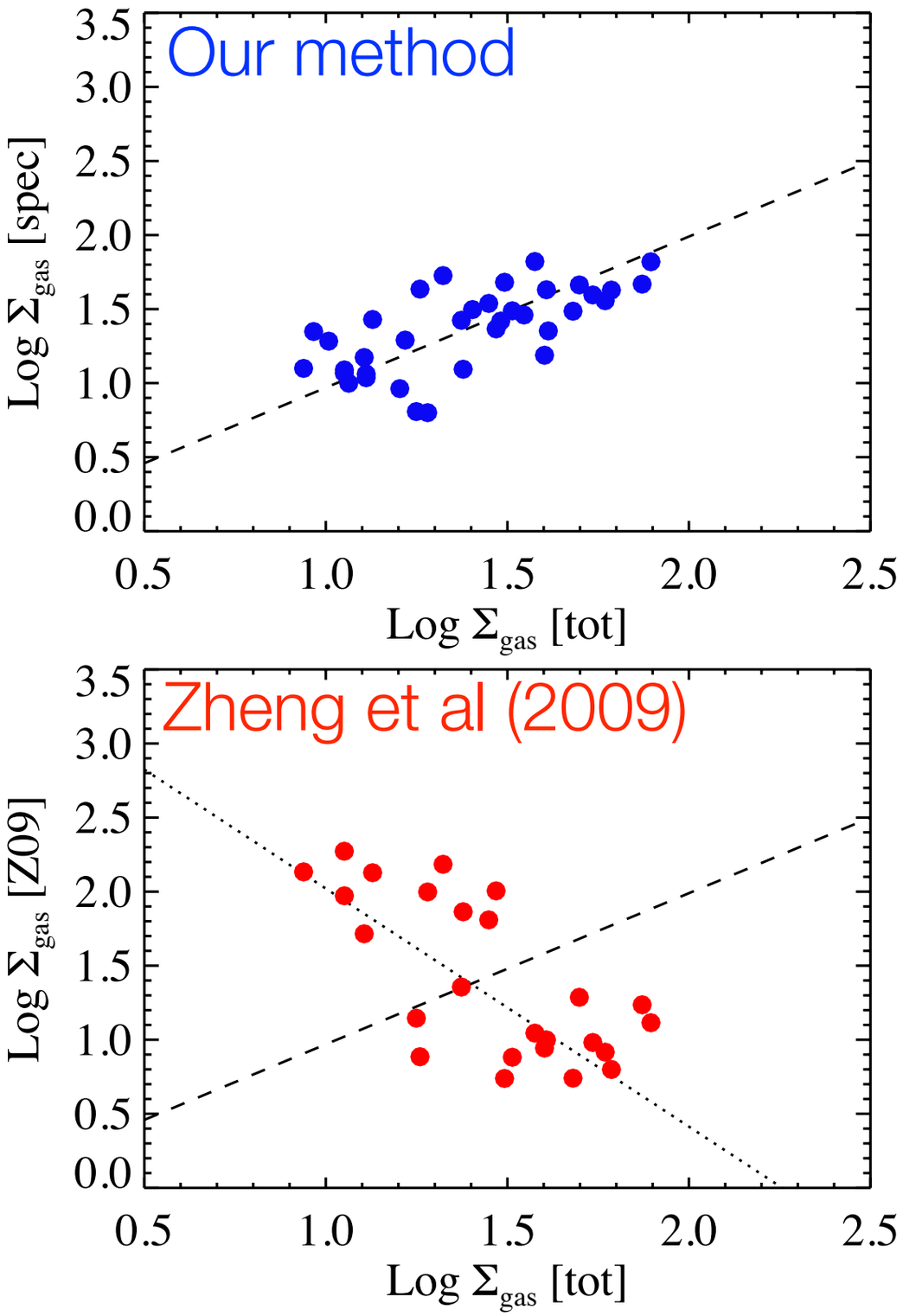
e.g.: log r_{HI} = 1.46 - 0.106 (u-r) [K04]

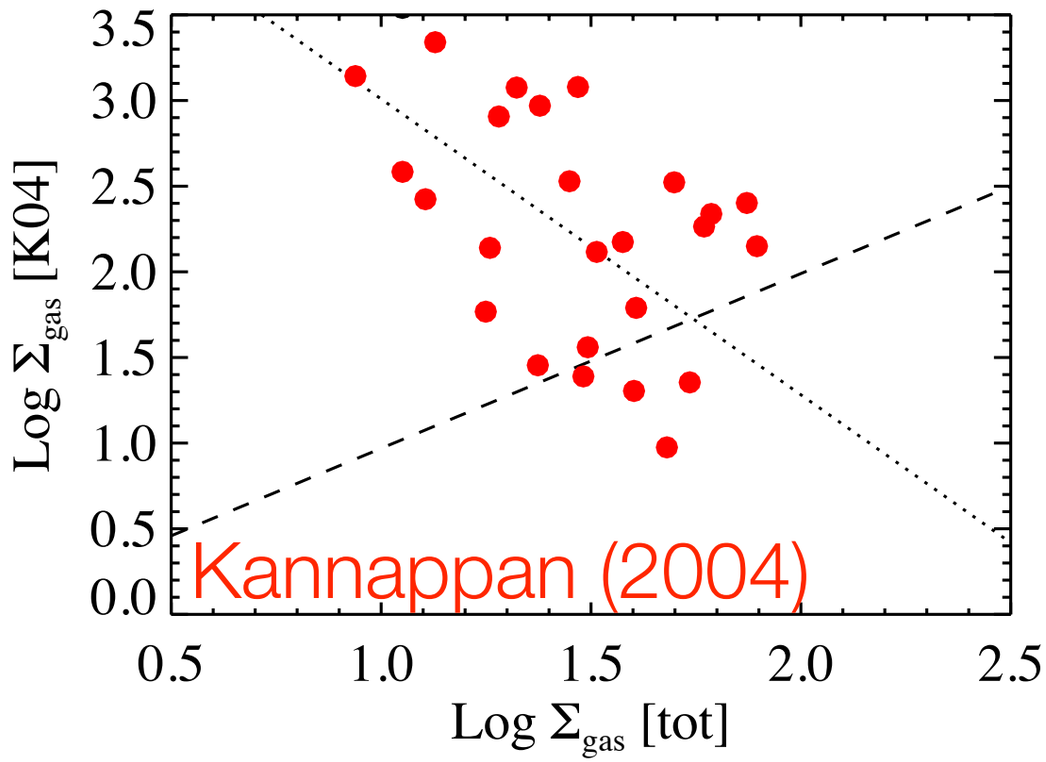
Invert the Kennicutt-Schmidt law:

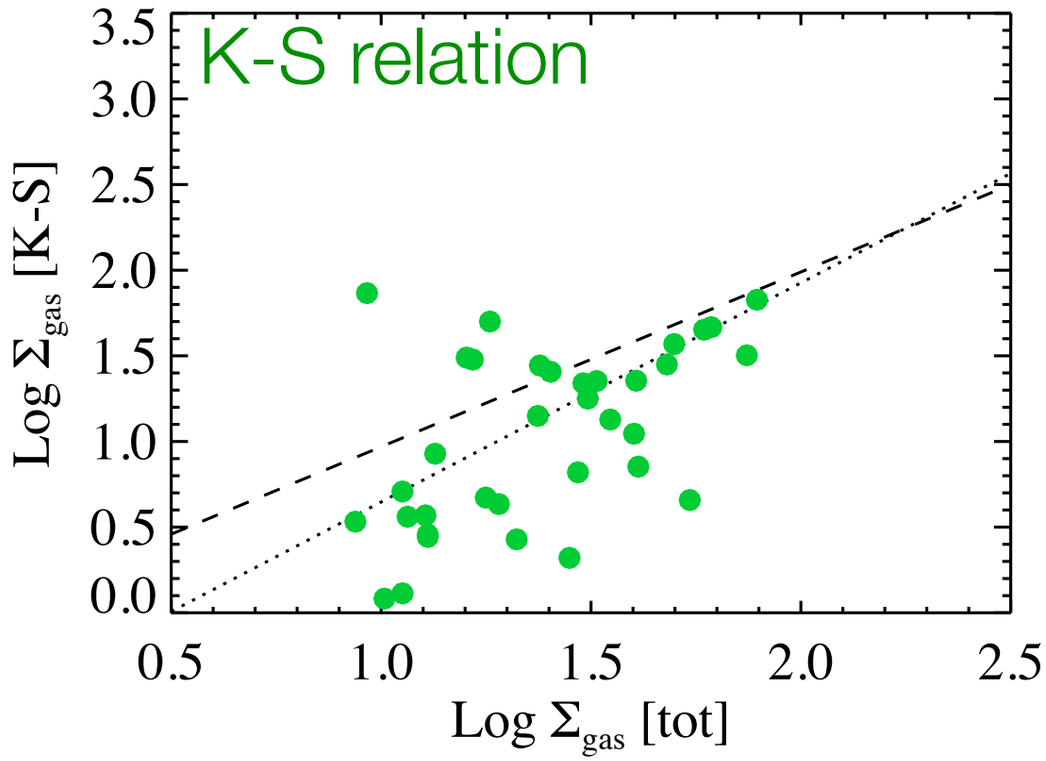
$$\Sigma_{\rm SFR} = 2.5 \times 10^{-4} \Sigma_{\rm gas}^{1.4}$$

Both methods are calibrated on local data and implicitly assume that these calibrations can be applied at different redshifts/different environments.

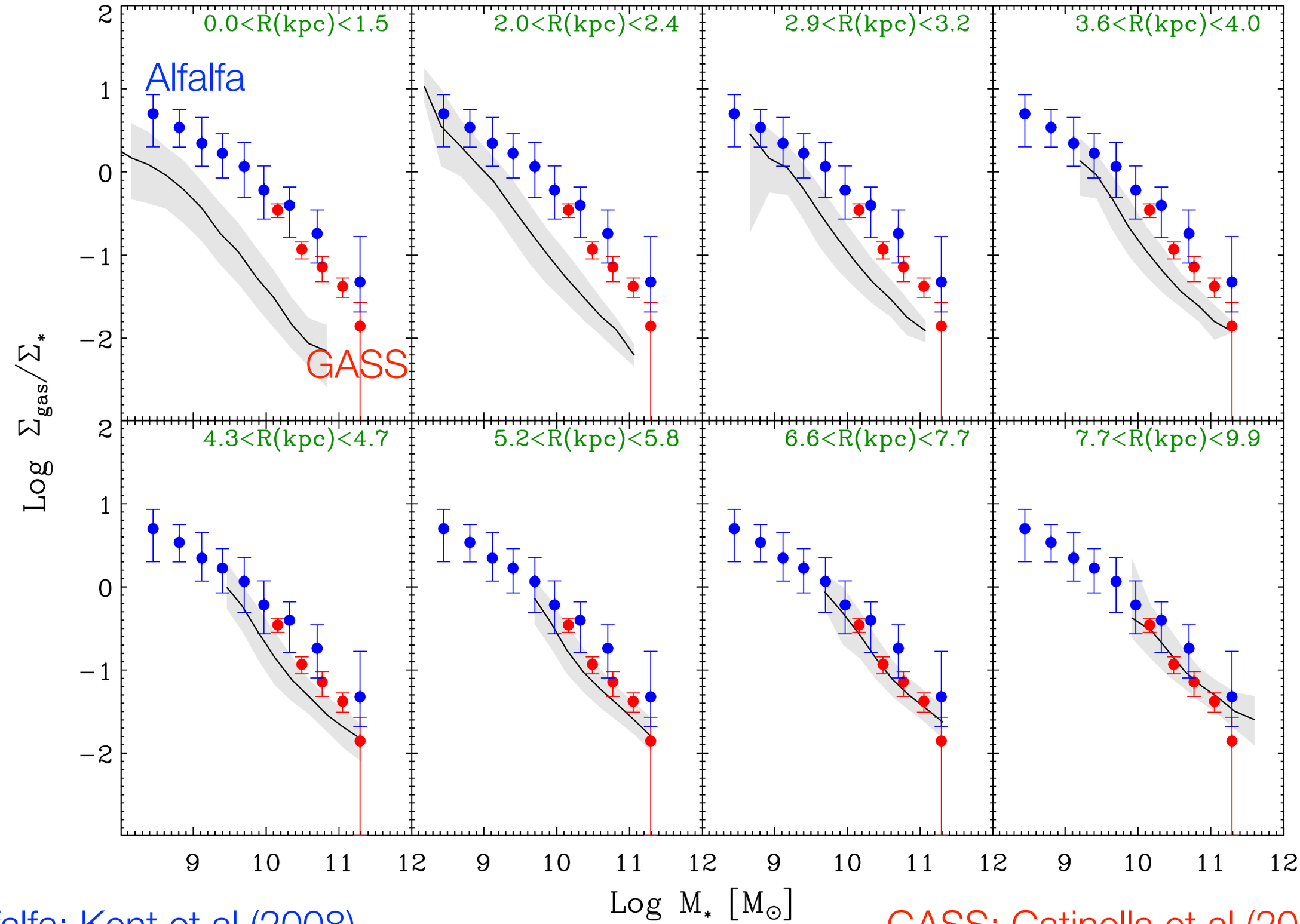
Other techniques - applied to M101 data







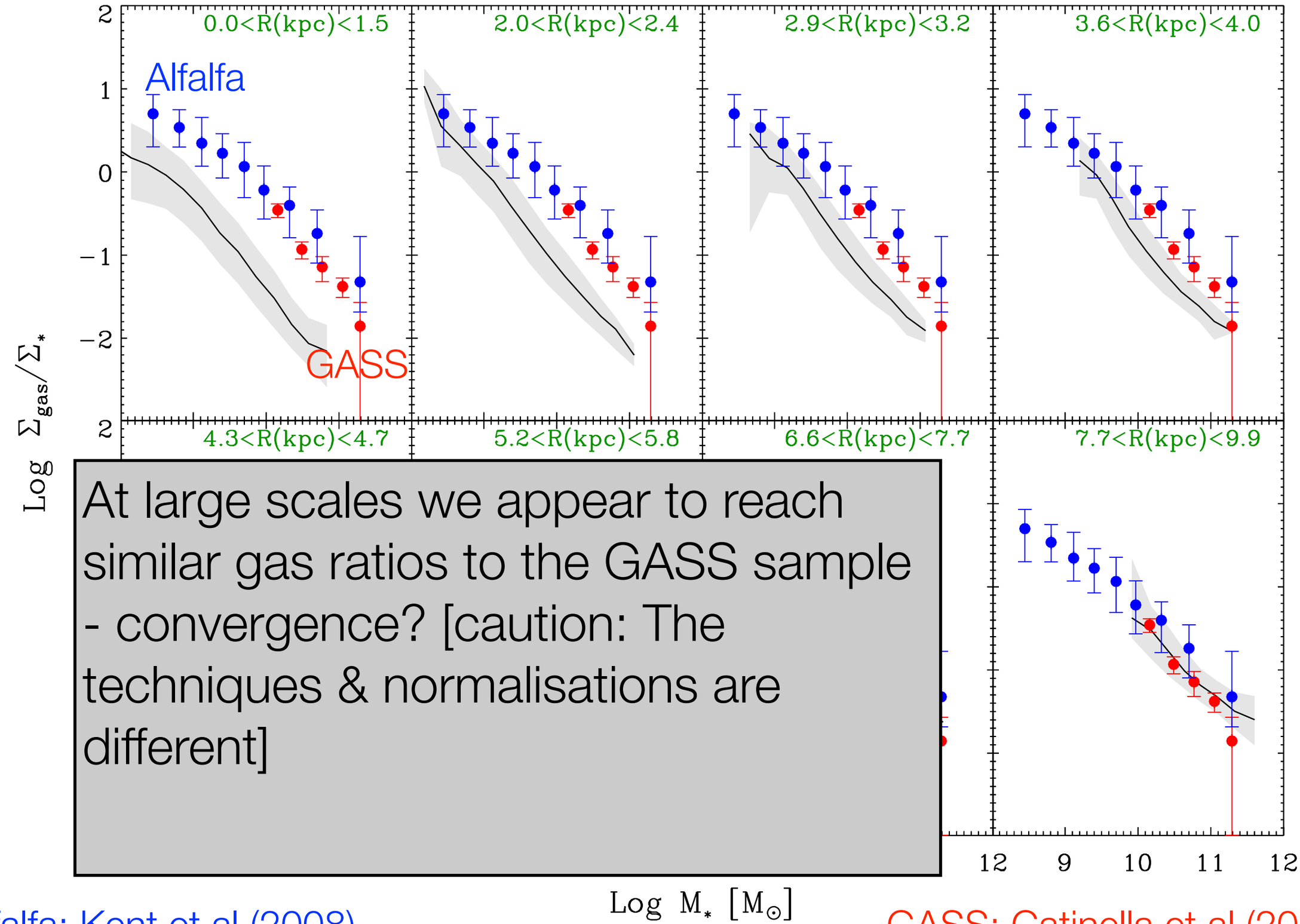
Aperture effects - a curse & a blessing



Alfalfa: Kent et al (2008)

GASS: Catinella et al (2010)

Aperture effects - a curse & a blessing

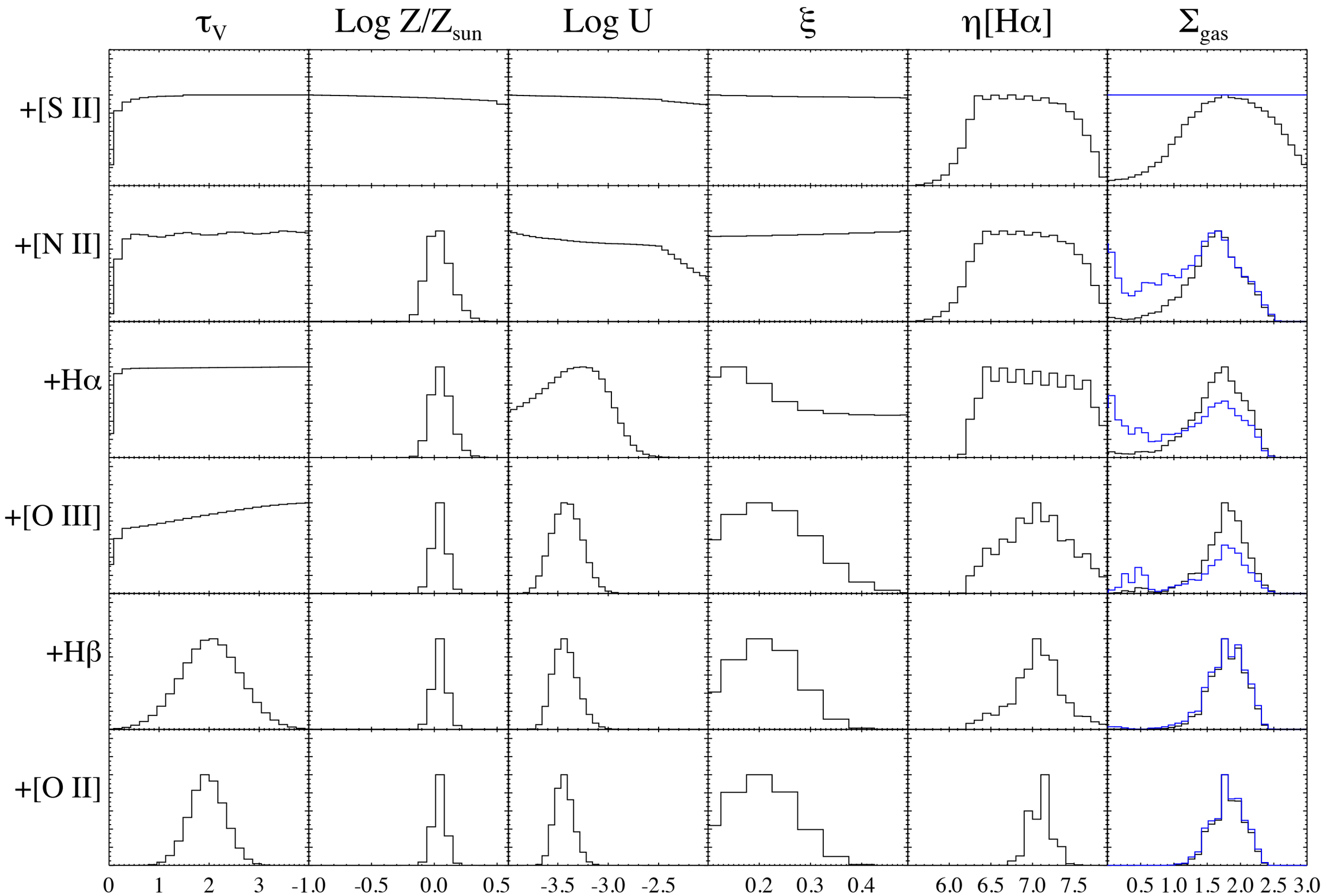


At large scales we appear to reach similar gas ratios to the GASS sample - convergence? [caution: The techniques & normalisations are different]

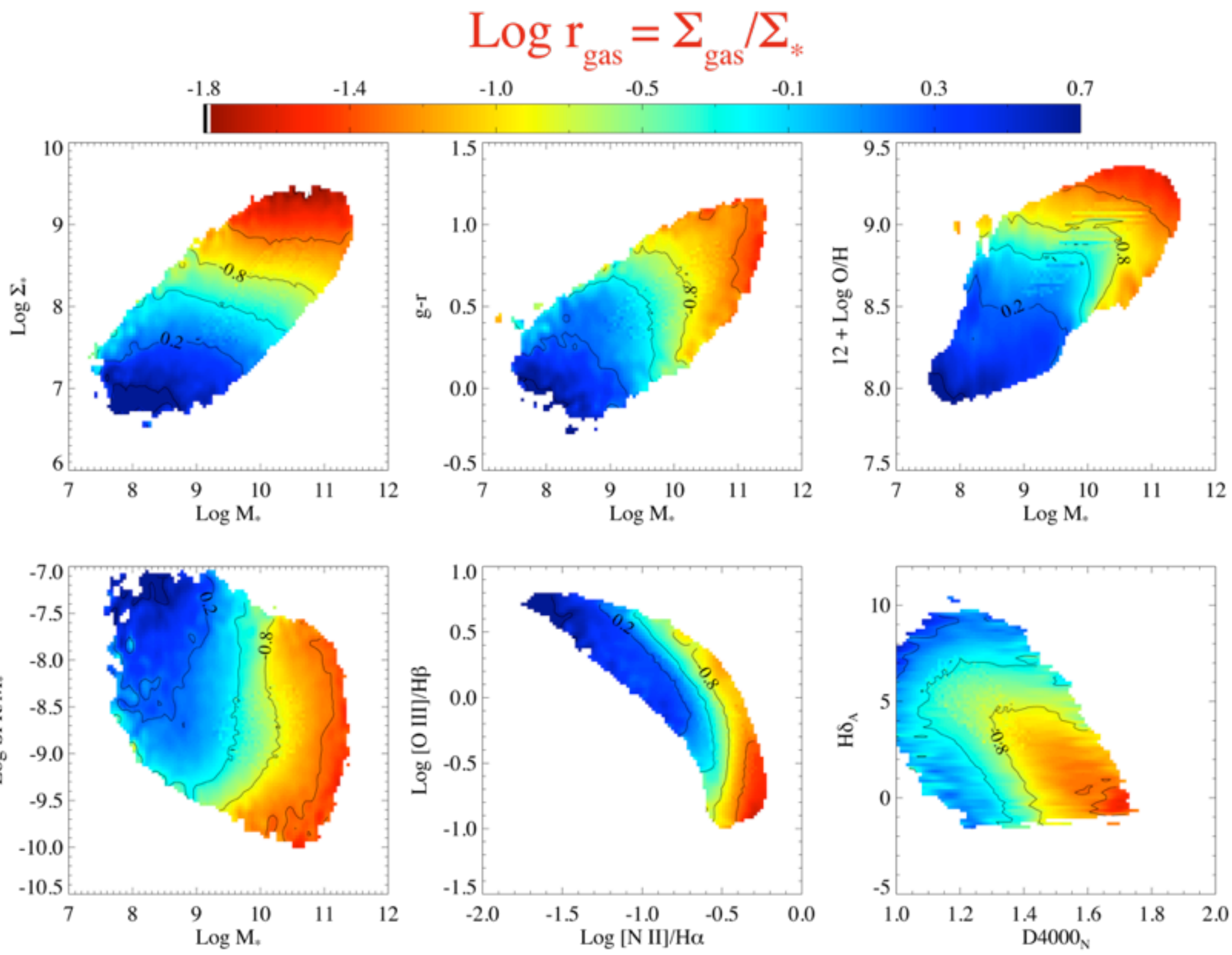
Alfalfa: Kent et al (2008)

GASS: Catinella et al (2010)

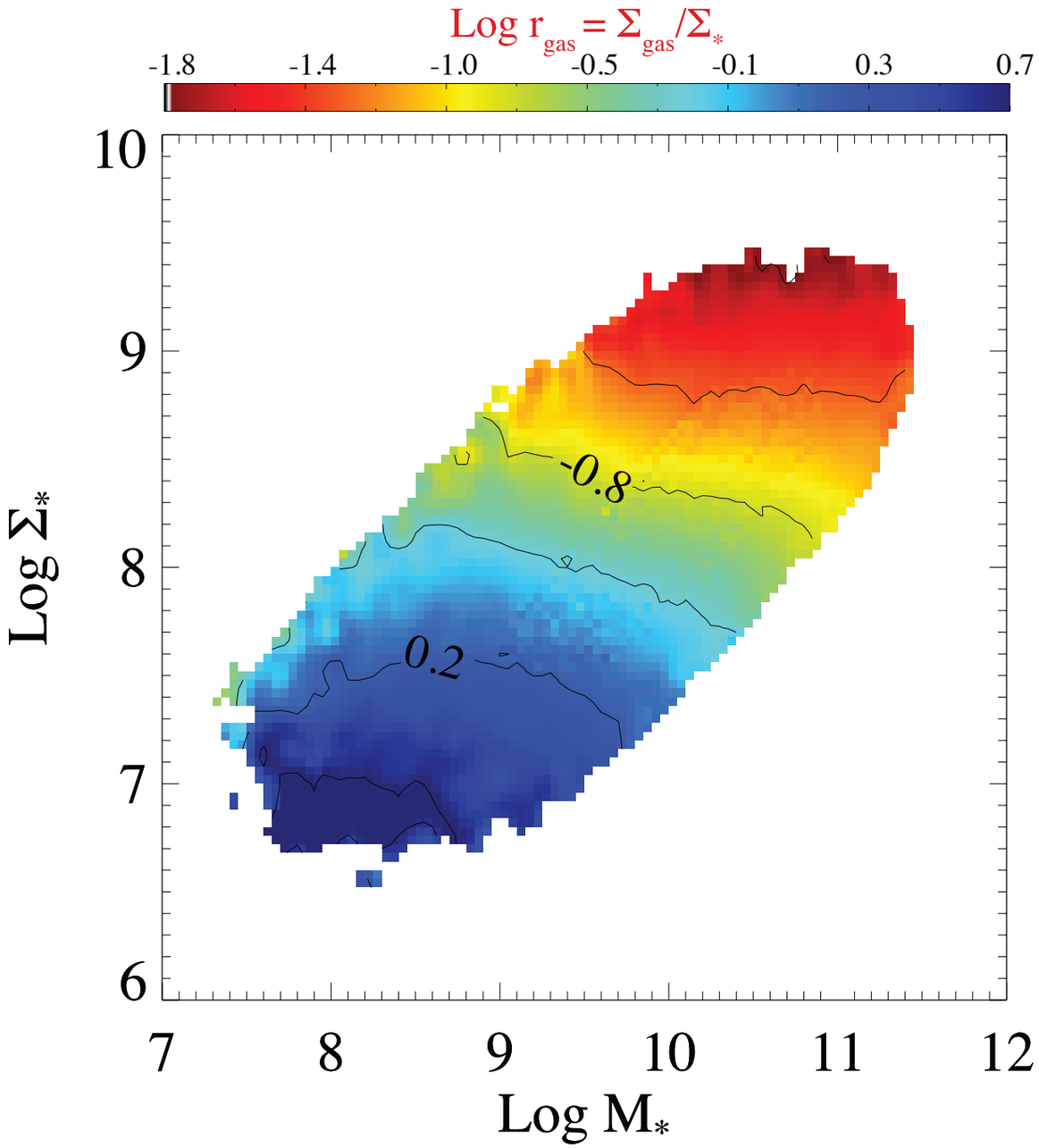
Fitting in reverse order & μ_{gas} prior



The 2D view of the *central gas content* of galaxies.



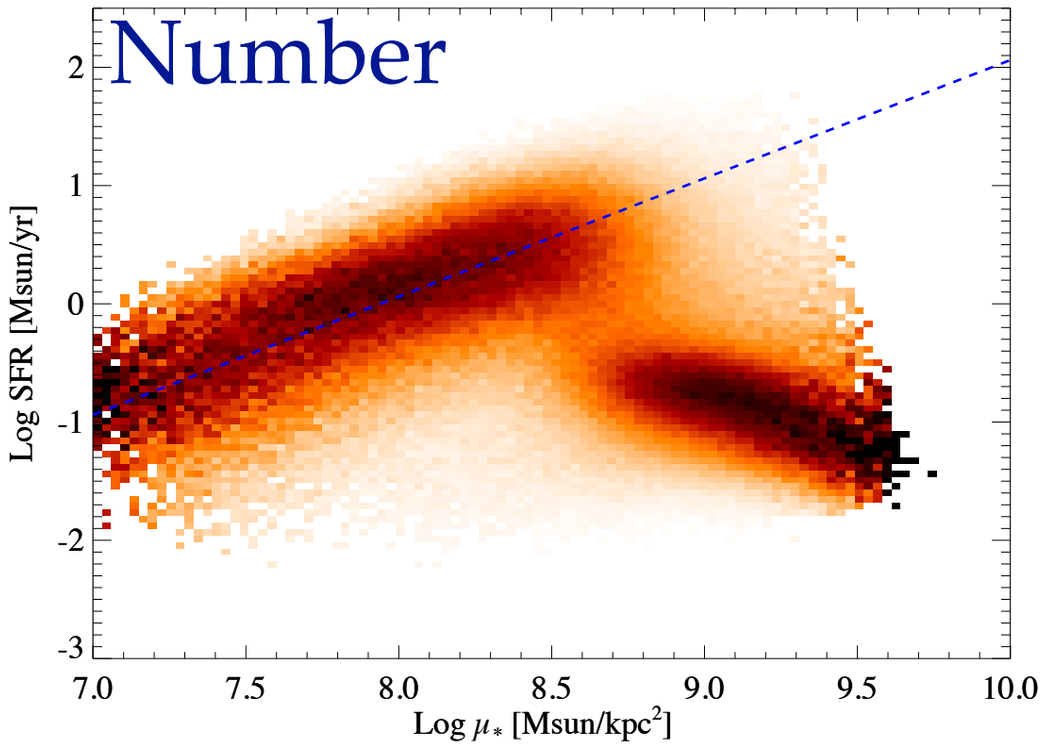
Mass-surface mass density

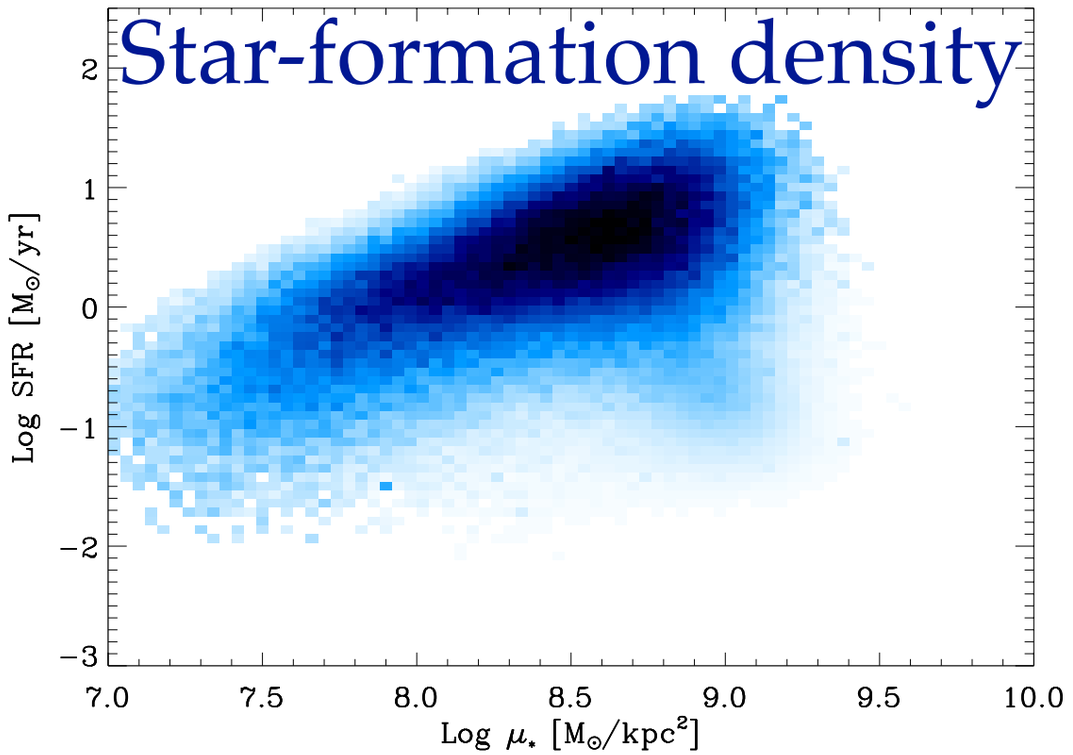


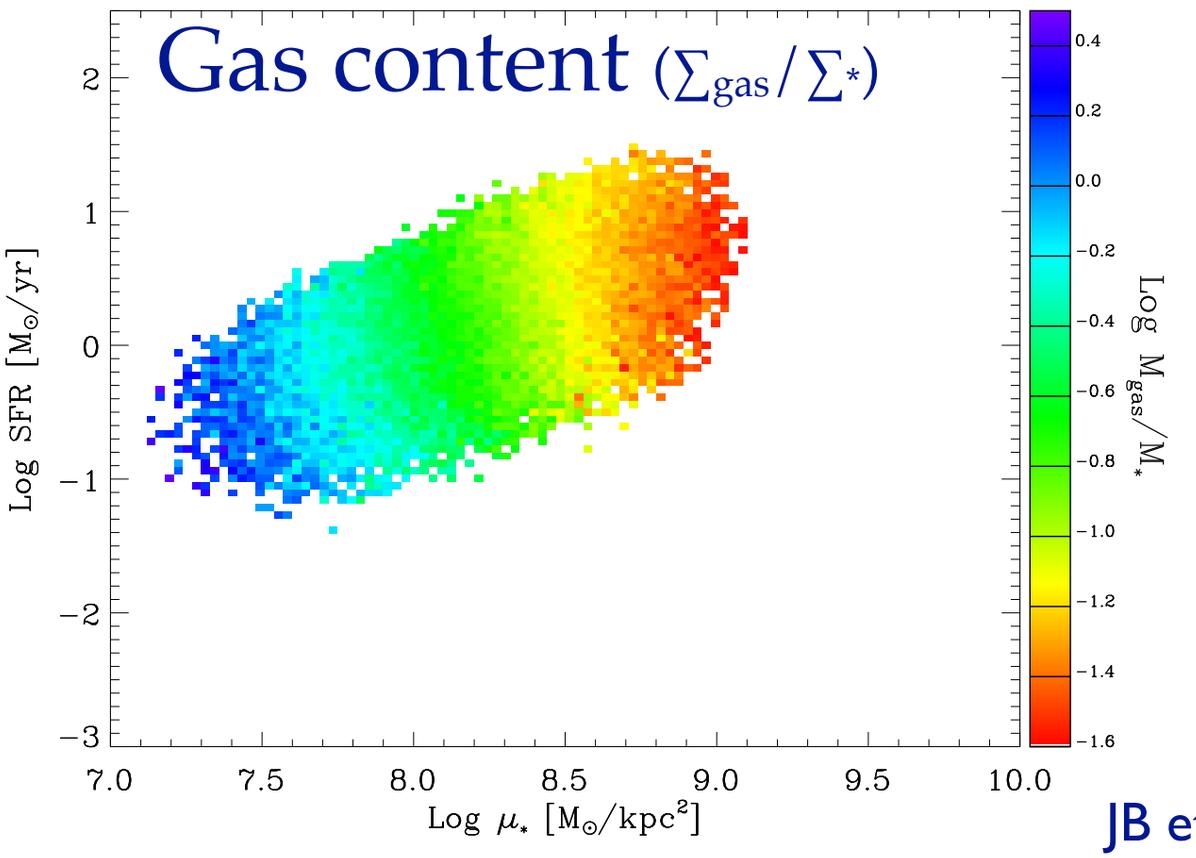
The gas fraction is a weaker function of mass than of surface mass density.

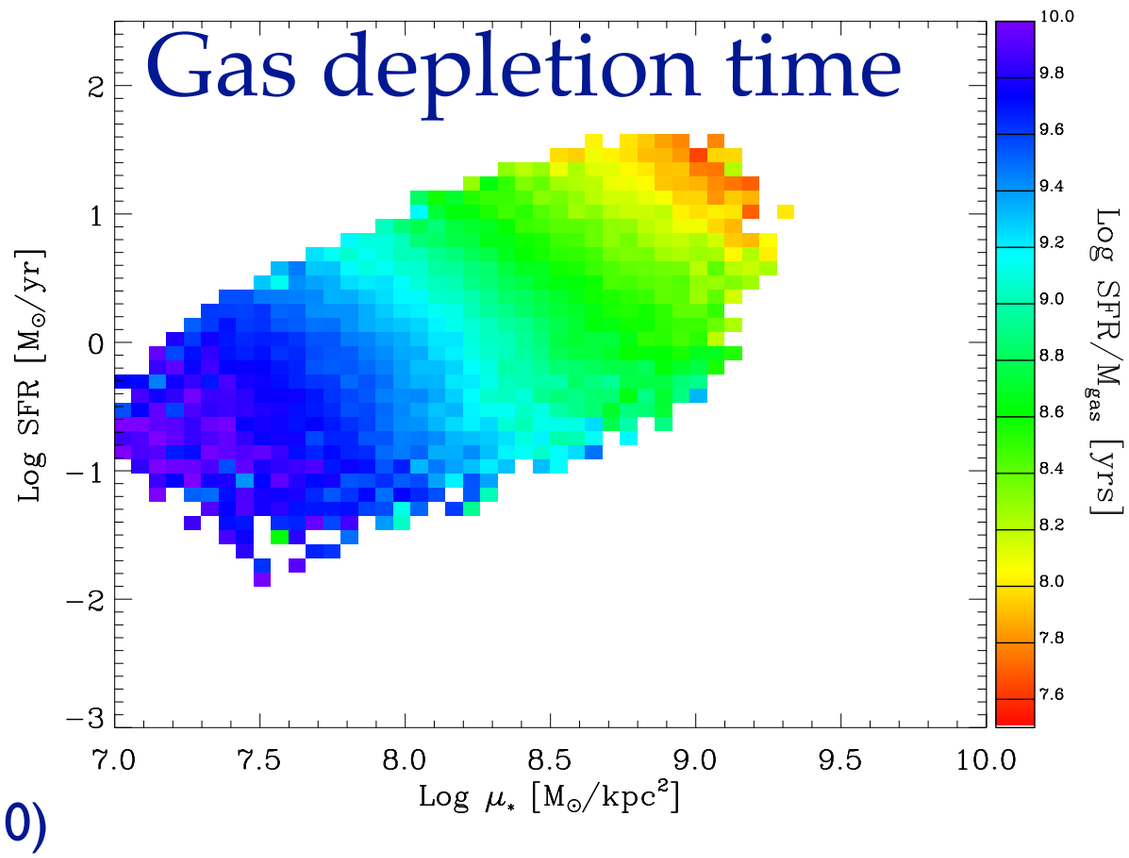
Thus $\sum_*$ appears to be a better indicator of whether a galaxy has low or high gas fraction than M_*.

Mass(density)/SFR scaling



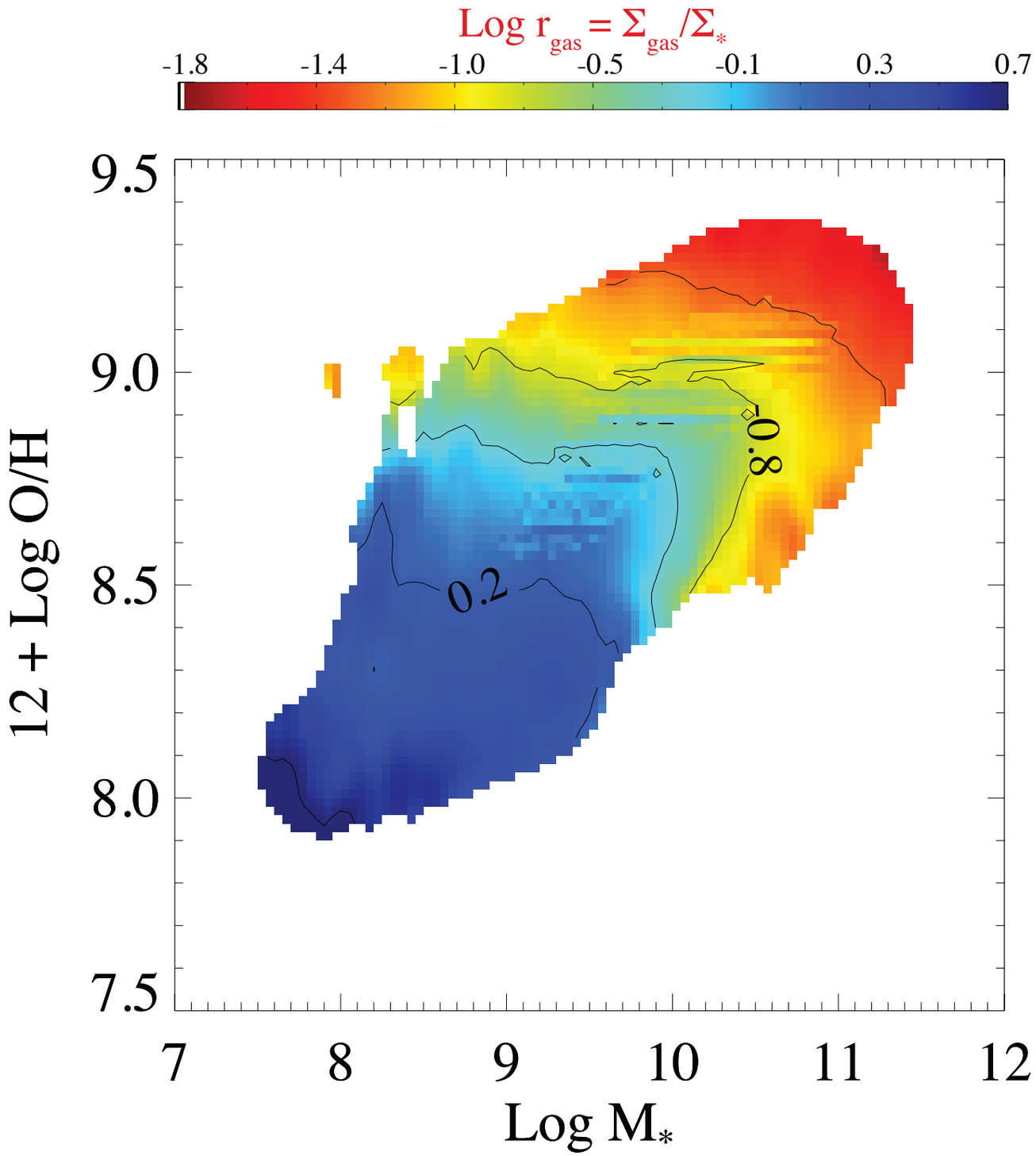






JB et al (2010)

Mass-metallicity



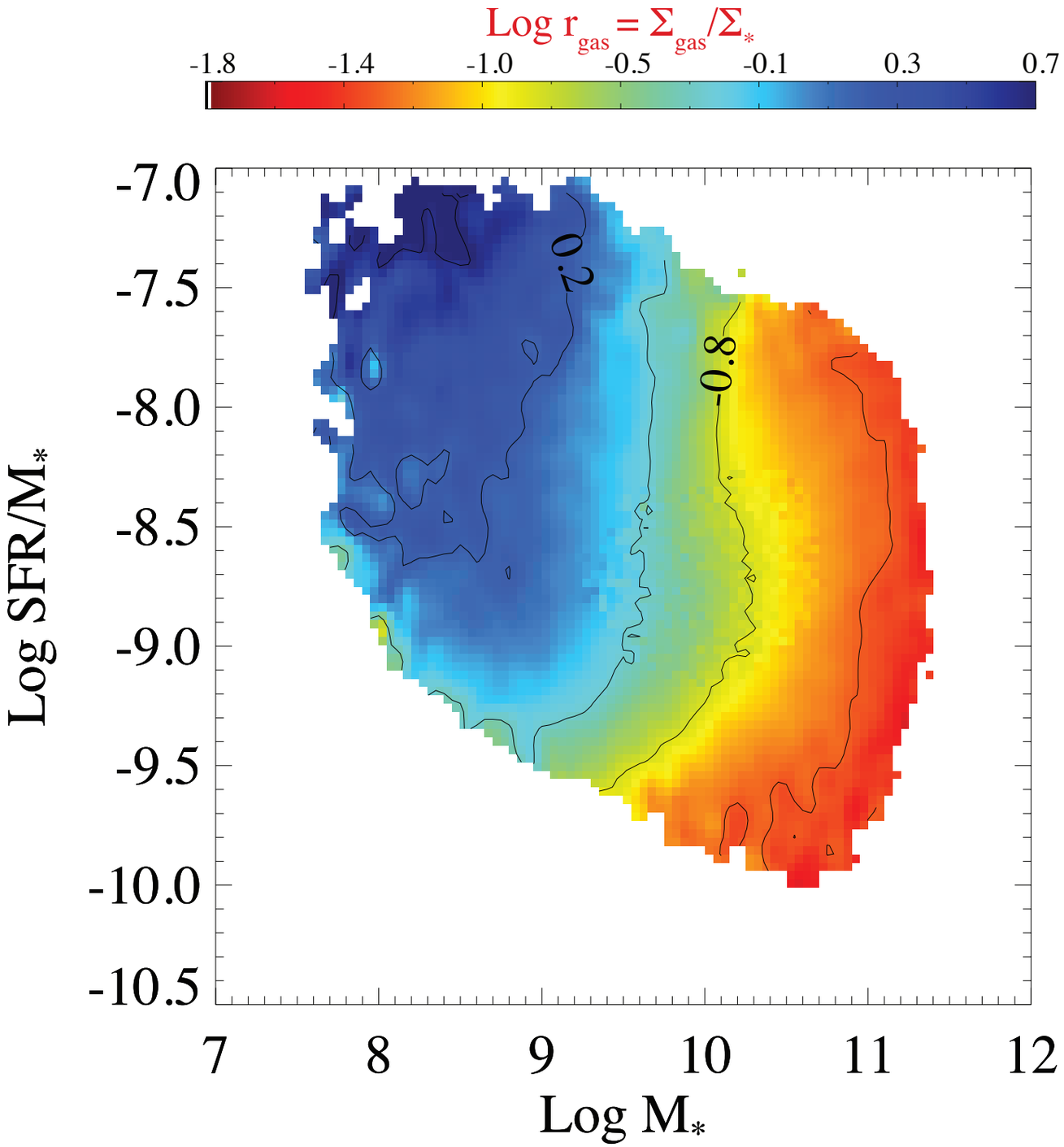
Closed box:

$$Z = y \ln f_{\rm gas}$$

Thus in large regions of the M-Z relation we see evidence of galaxies behaving consistent with a closed box model.

Below M-Z relation ⇒ low O/H - infall? (c.f. Ellison et al 2008, Zheng et al 2009)

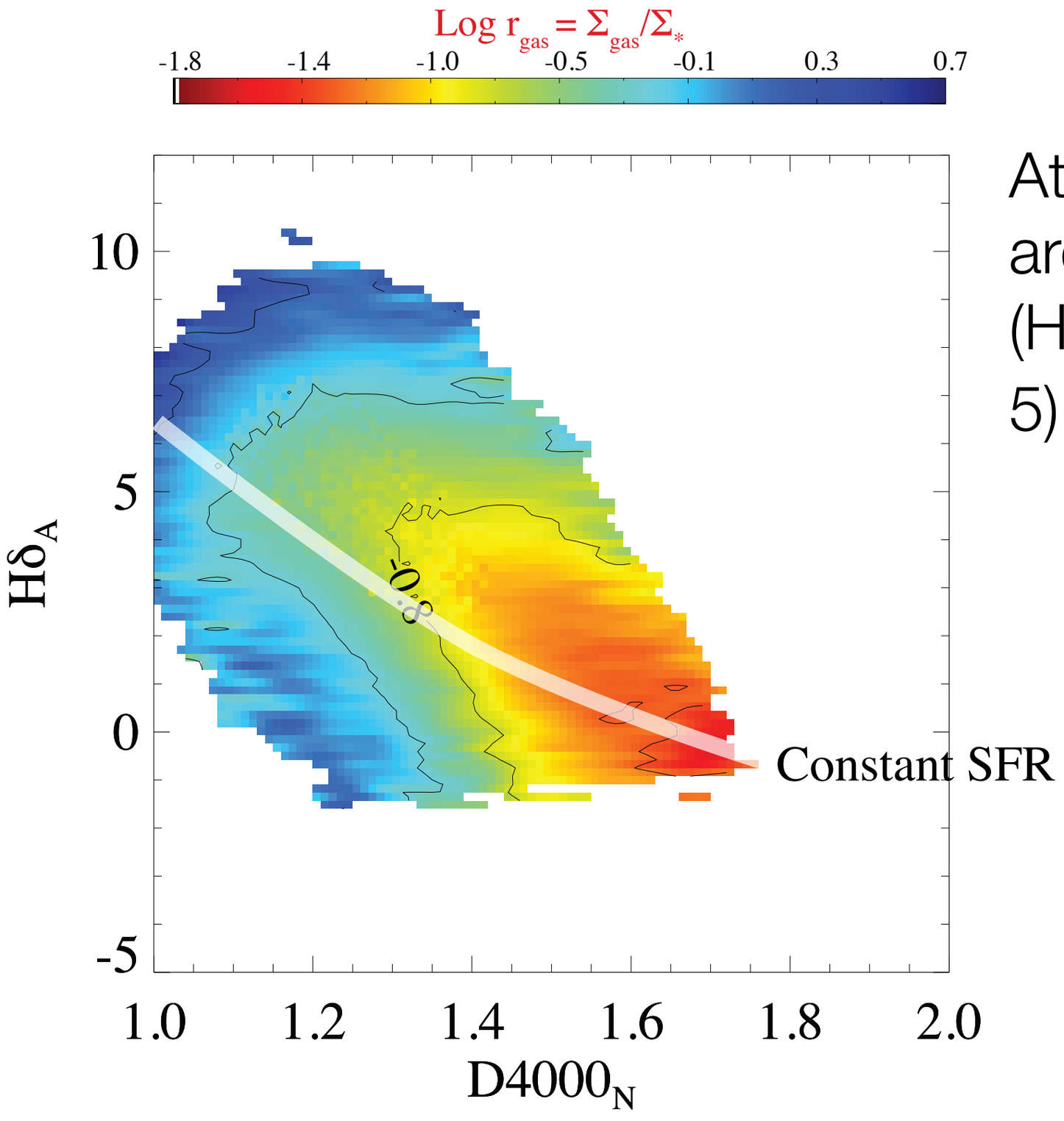
Mass-sSFR



Surprisingly weak relationship between sSFR and gas fraction?

Slight trend that low SFR/M* goes with low gas fraction.

D4000 - $H\delta_A$



At low $D4000_N$ gas fractions are high at both ongoing ($H\delta_A < 0$) and recent ($H\delta_A > 5$) bursts.

Gas depletion time

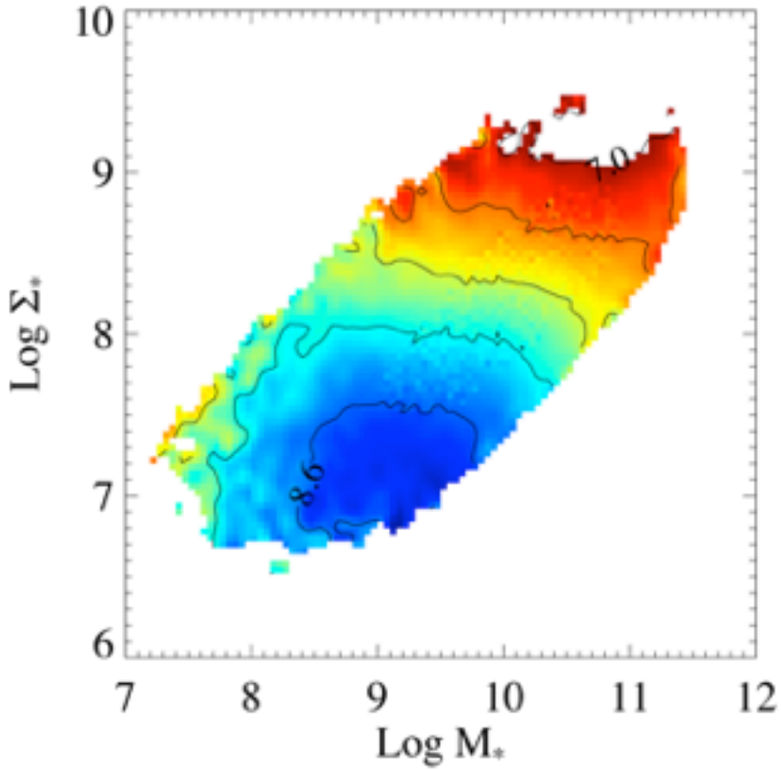
Since the estimates are not from the K-S relation we can also look at the gas depletion time:

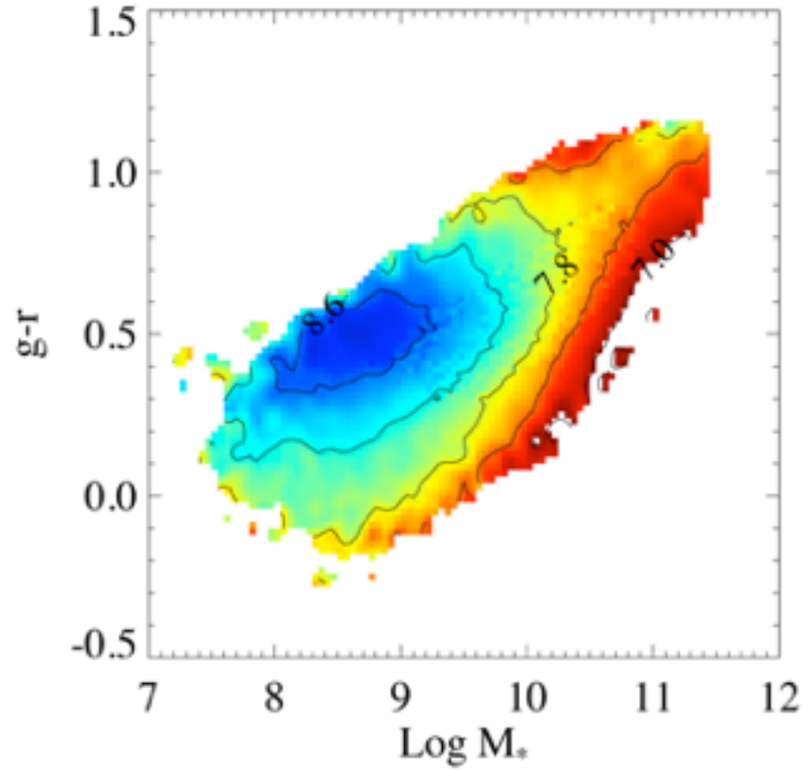
$$T_R = \frac{\Sigma_{\rm gas}}{\Sigma_{\rm SFR}}$$

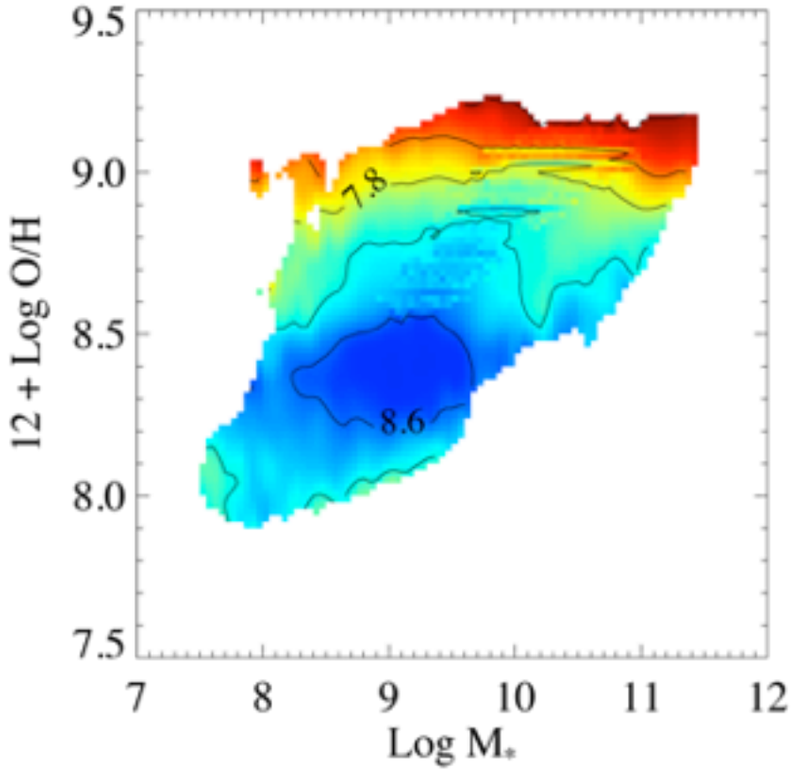
It is generally found to be short relative to the Hubble time within galaxies. Note that we only probe in small spatial regions.

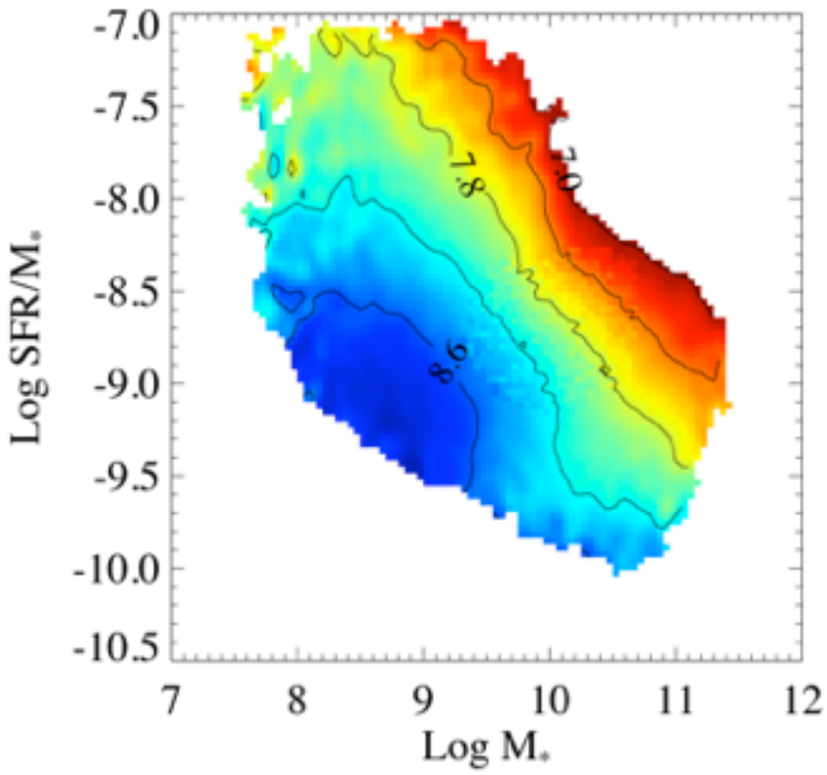
$\mathrm{Log}\ T_R = \mathrm{Log}\ \Sigma_{gas}/\Sigma_{SFR}$

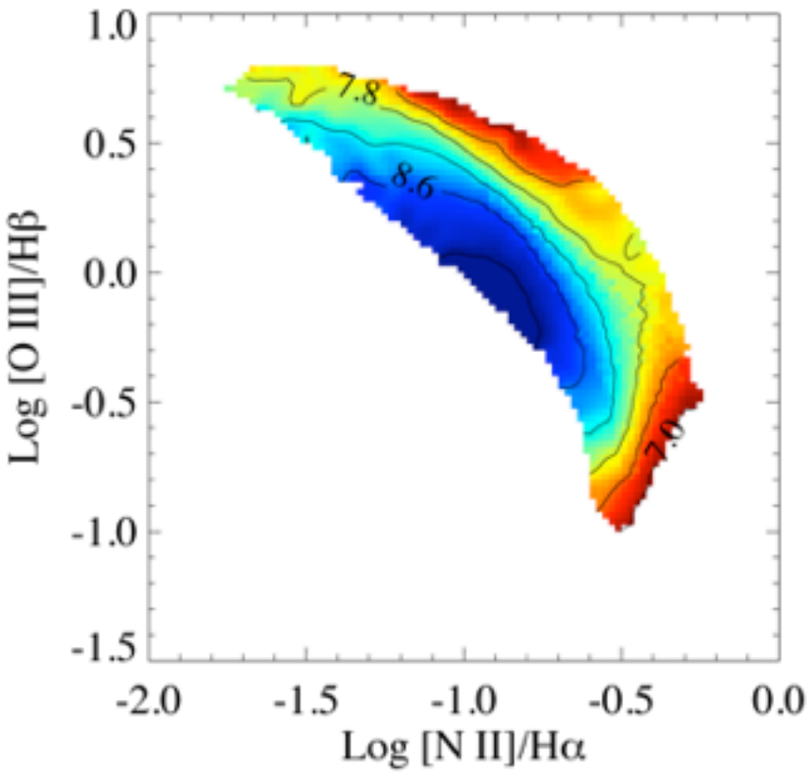


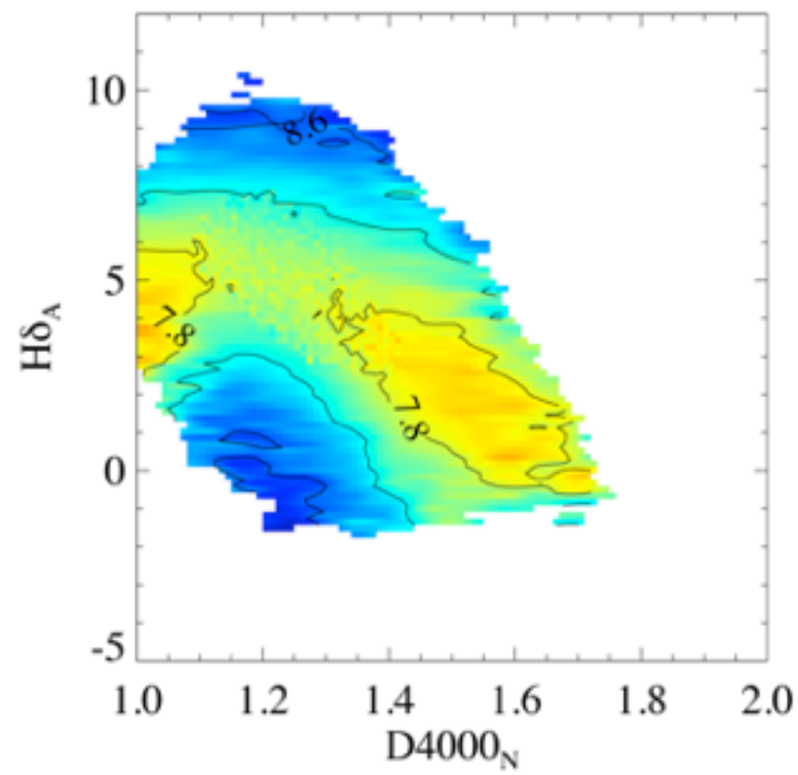




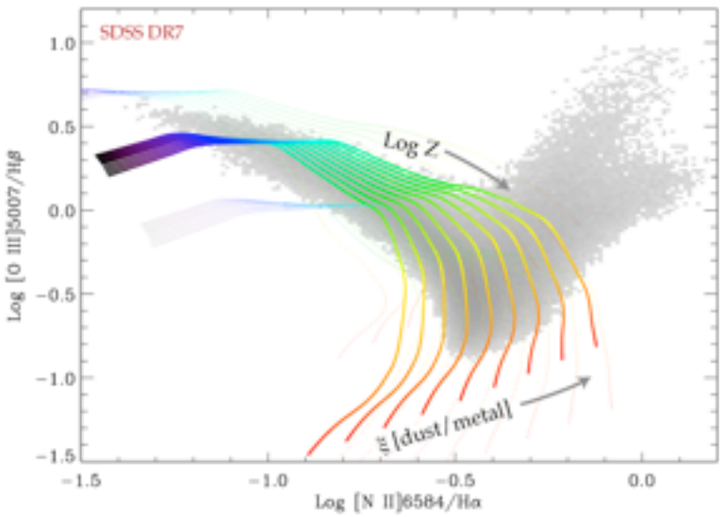




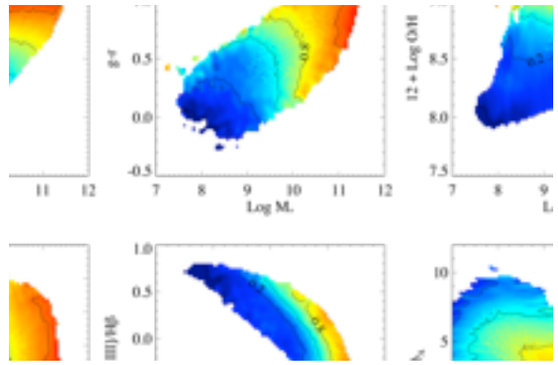




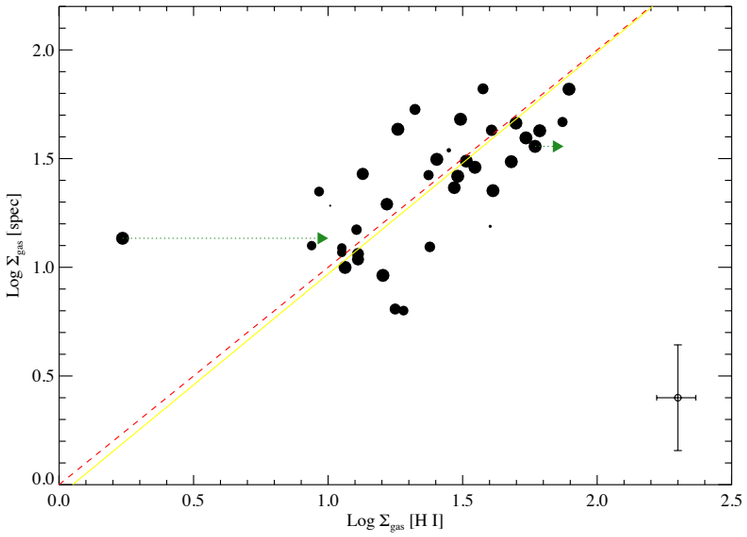
Conclusions



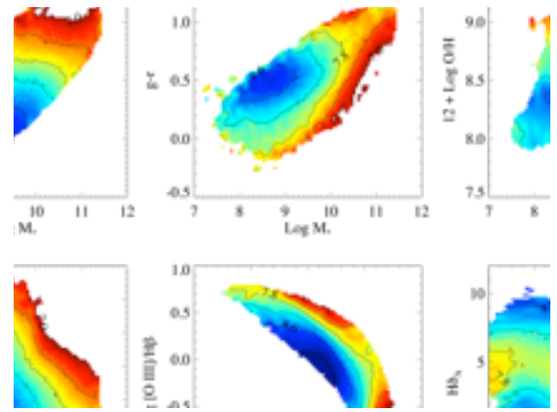
Using optical emission lines we can constrain total gas surface densities within the region probed by the spectrum.



Application to the SDSS allows us to provide a comprehensive overview of gas in ~200,000 galaxies.



Tests show that these estimates agree with those from HI + CO to within a factor of ~2.



[O II]3727, Hβ, [O III]5007, Hα, [N II], [S II]

Are necessary (useful but not a show-stopper)