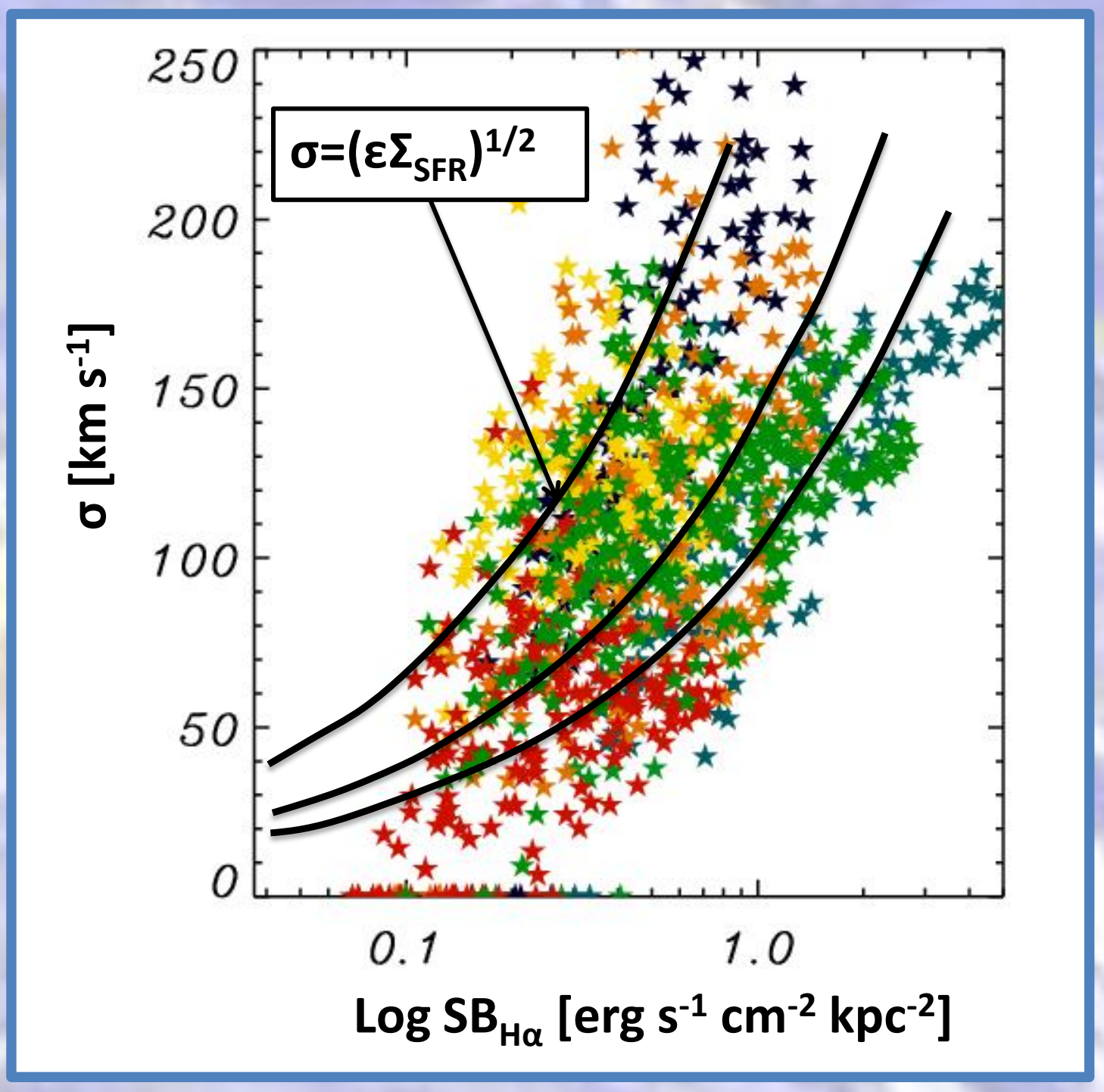
Star Formation and Powering High Pressures in Galaxies 10 Gyrs ago

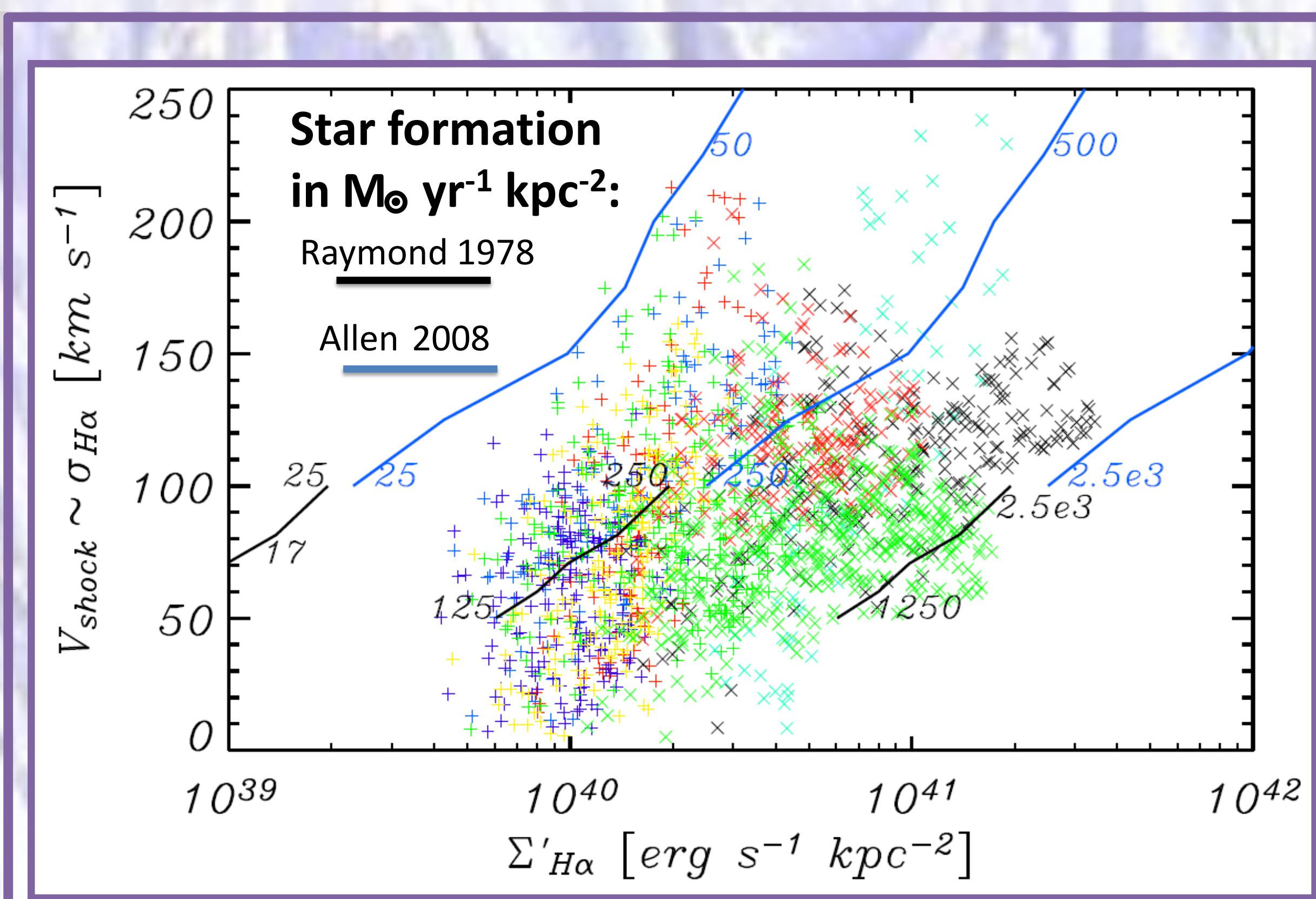
Loïc Le Tiran[1], Matt Lehnert[1], Nicole Nesvadba[2], Paola Di Matteo[1], Wim van Driel[1]
1: GEPI – Observatoire de Paris 2: IAS – Université Paris-Sud



We have analyzed the properties of the Hα and [NII] rest-frame optical emission lines of a sample of 53 galaxies observed with SINFONI on the ESO-VLT. Our sample spans the redshift range z=1.3 to 2.7. All are intensely star-forming galaxies. We find that the large line velocity dispersions observed compared to nearby disk galaxies (few 10-250 km s^{-1} compared to 10 km s^{-1}) are most likely driven by the intense star-formation taking place within these galaxies: a relationship between the star formation intensity and the velocity dispersion of the emission line gas is found and it can be explained by a simple energy injection relation (Lehnert et al. 2009).

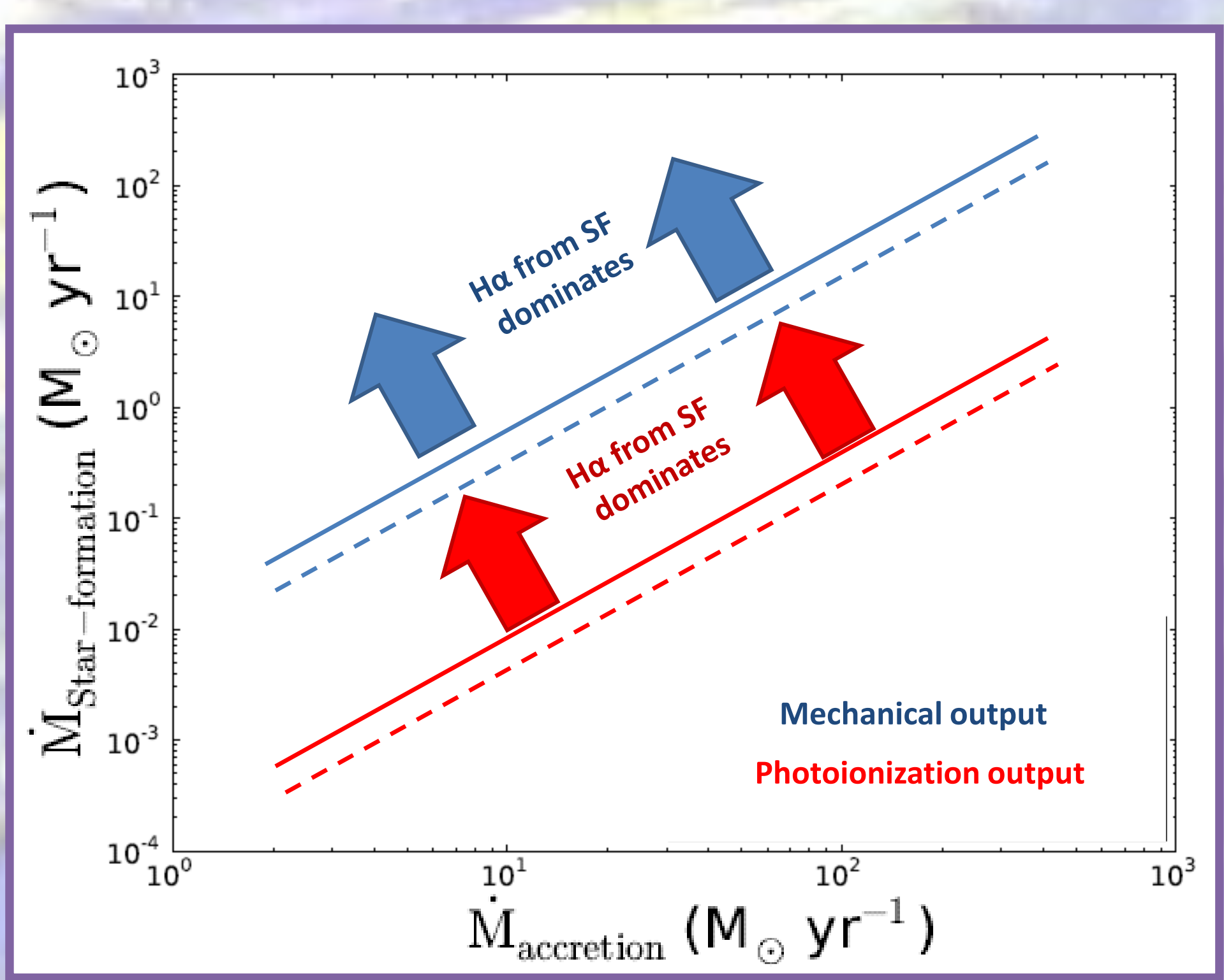
Can cosmological accretion be observed in Hα?

Le Tiran et al., 2011a



Observed pixel-by-pixel Hα line widths (assumed equal to the shock velocities) as function of Hα surface brightnesses for 10 galaxies. Lines correspond to Hα surface brightnesses derived using shock models from Raymond (1979) (black) and Allen et al. (2008) (blue). The numbers along each line indicate the surface accretion rates which produce the Hα surface brightness. The 3 sets of lines are for pre-shock densities of 10, 100 and 1000 cm−3, respectively, from left to right.

We find that the surface brightnesses can be explained by shock models, but only if the mass flow rates through the shocks are very high, with accretion rate densities of a few hundred M$_{sun}$ yr^{-1} kpc^{-2} !

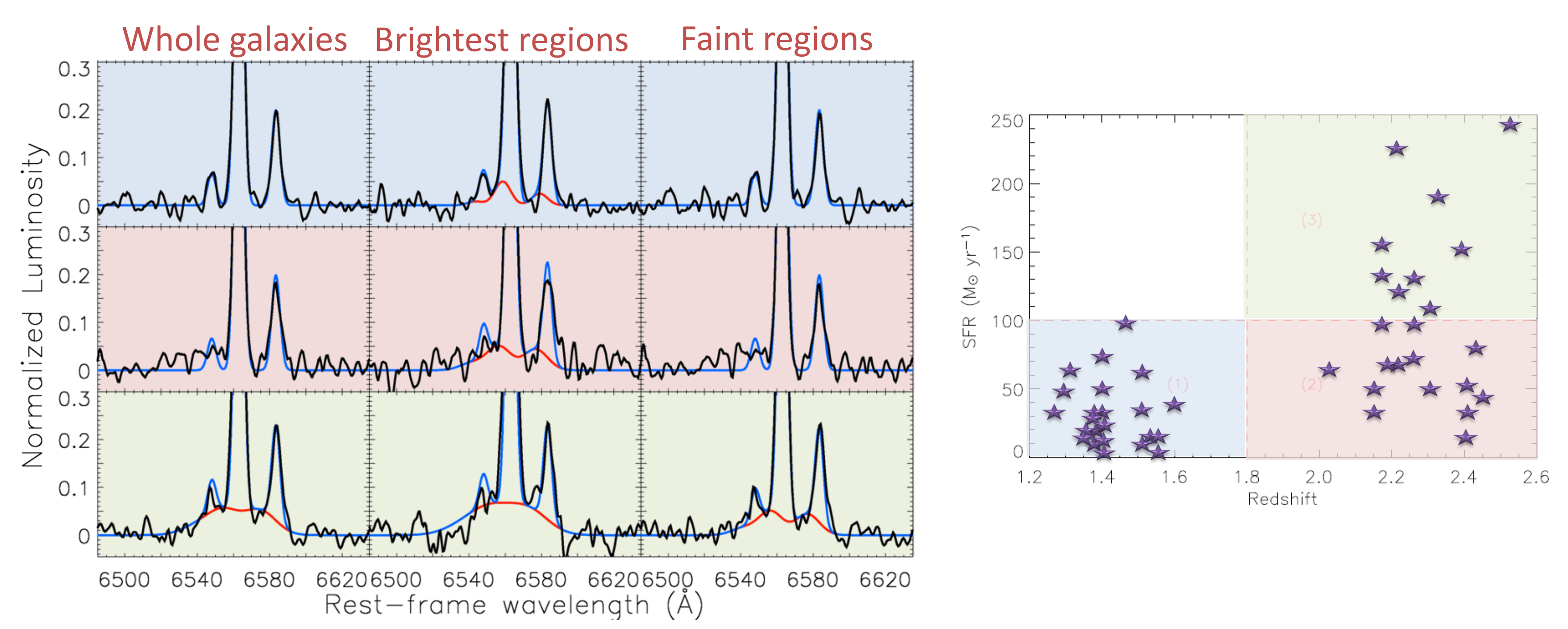


Comparison of the star formation rates and cosmological gas mass accretion rates at which accretion energy generates the same Hα luminosity as young stars through their ionizing photons (red solid and dashed lines) and as mechanical energy released by supernovae and stellar winds (blue lines); the difference between the two sets of lines is the efficiency at which the ionization or mechanical energy output couples to the ISM. Both comparisons assume the same accretion model. Regions above the blue and red lines are dominated by the influence of the intense star formation.

What is the nature of their ISM?

Le Tiran et al., 2011b, submitted

Evidence for winds in stacked spectra

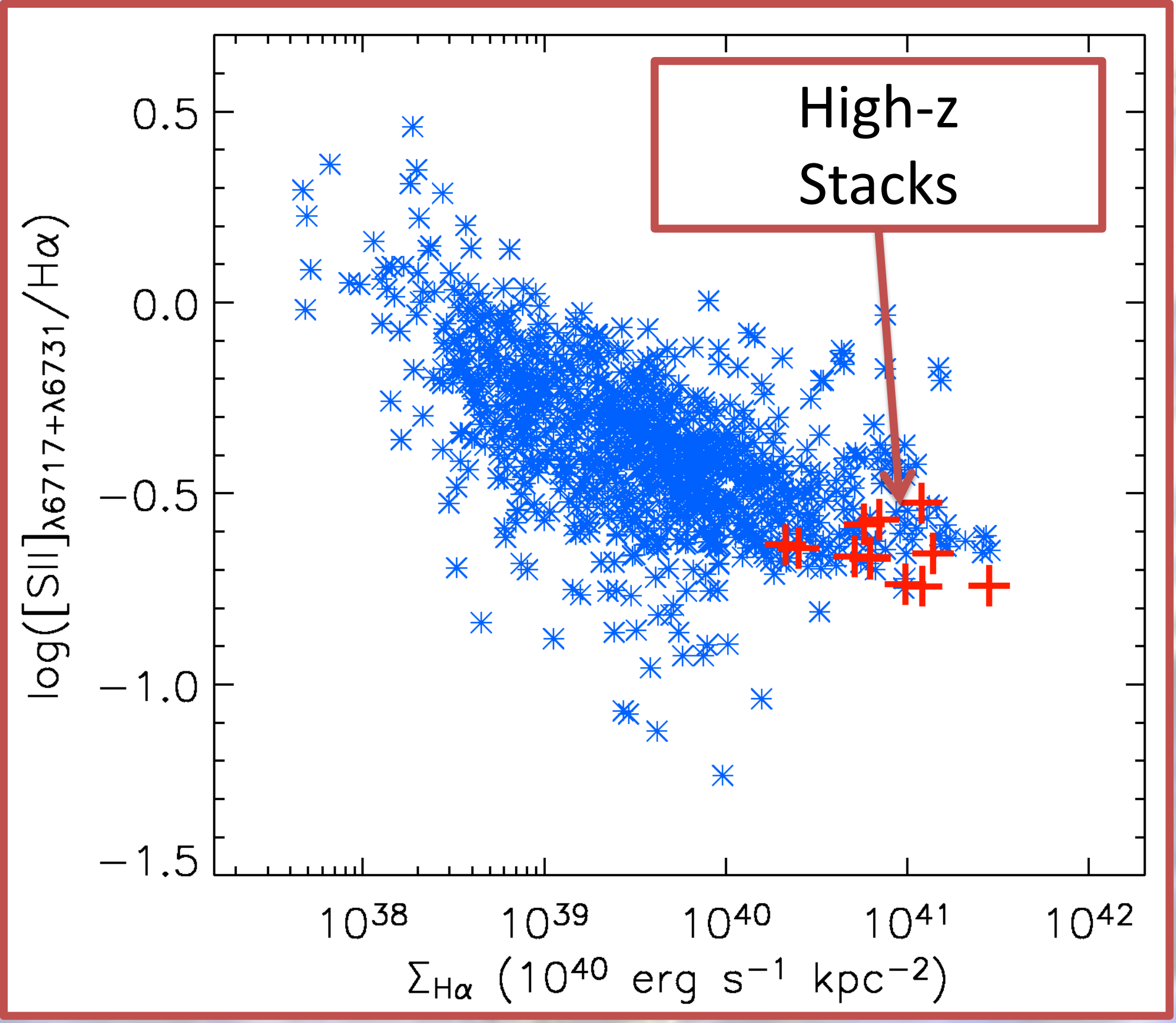


In red: Simple Broad Lines Model for Hα & [NII]:

1. (1) All three additional lines have the same offset velocity
2. (2) Velocity dispersions are the same for each Hα and [NII] line component and are equal to the offset velocity
3. (3) The flux ratio of [NII]/Hα is that given by fast shock models (Allen et al. 2008)
4. (4) The velocity offset and the shock speed are the same
5. (5) The amplitude of the offset Hα component is 5% of that of the main Hα line.

We find that these fits are as significant as assuming a single broad component for velocity offsets of a few 100 km s^{-1} and narrow-to-broad Hα flux ratios of about 10% (although this is partially constrained by our assumption of a fixed 1:20 Hα peak ratio). **These values are similar to those in the extended (i.e., wind) emission in nearby starbursts (Lehnert & Heckman 1996). The derived pressures are also similar to those in nearby starbursts, which is a necessary condition for driving winds.**

A continuity with nearby galaxies…



We have already argued that the galaxies have high pressure (Lehnert et al. 2009). This figure illustrates that the warm ionized medium in nearby star-forming and starburst galaxies and in our galaxies forms a continuity – a one parameter family. Going from low to high Hα surface brightness we progress from diffuse ISM in nearby galaxies, through HII regions (and their surroundings) to nuclei of nearby starburst galaxies (e.g. Wang et al. 1998). **On average our high-redshift galaxies lie at the high surface brightness, low [SII]/Hα end of the relationship, similar to the positions of local powerful nuclear starbursts.**

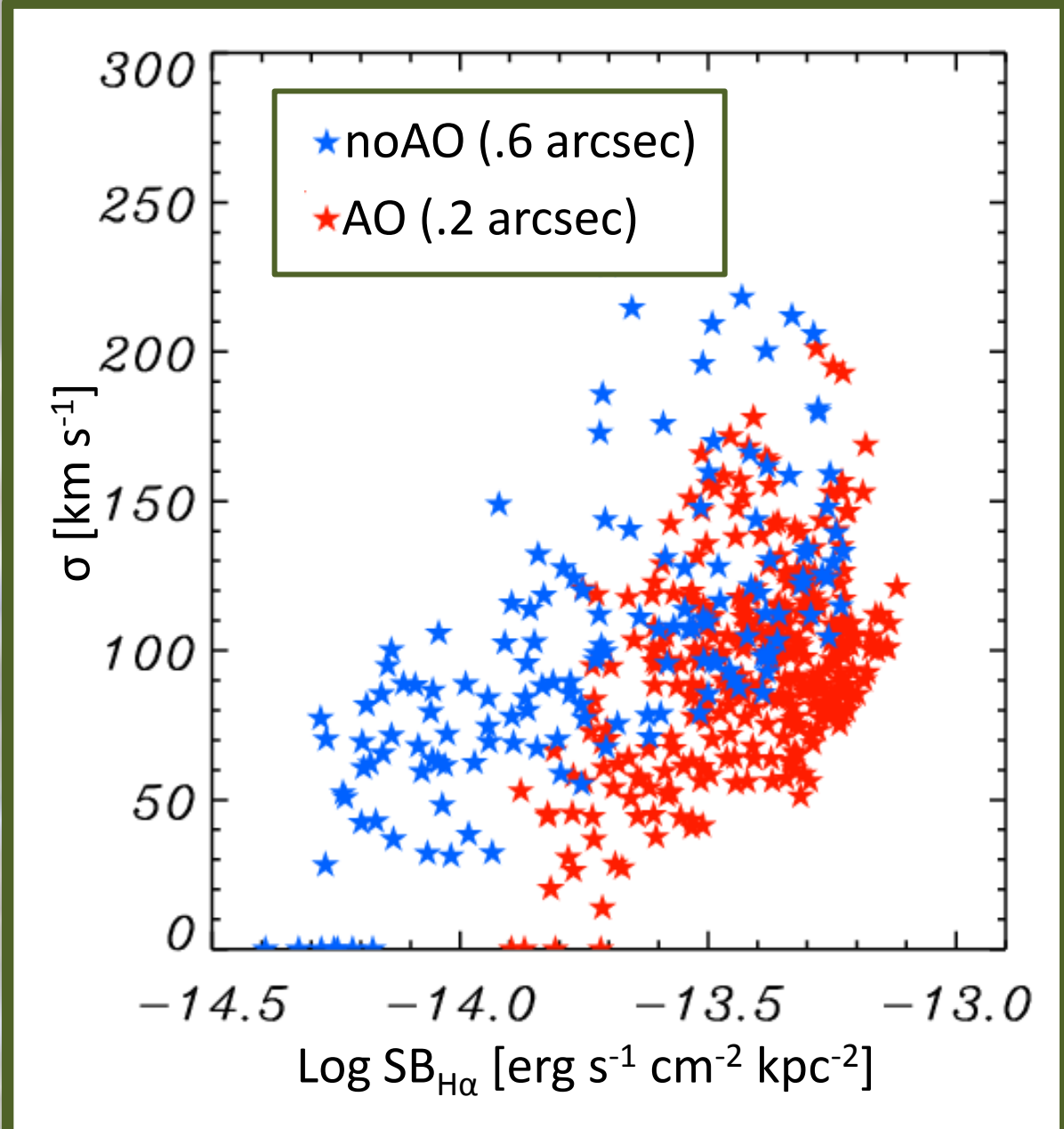
We favor a picture where the pressure in the ISM is determined by the intensity of the star-formation and where feedback sets the scaling between pressure and star-formation intensity. Since the pressure is being regulated by the star-formation and pressure likely determines the nature of star-formation, this suggests that the star-formation in these high redshift galaxies is self-regulating (Silk 1997).

Why it is not an effect of beam smearing:

Le Tiran et al., 2011c, in prep.

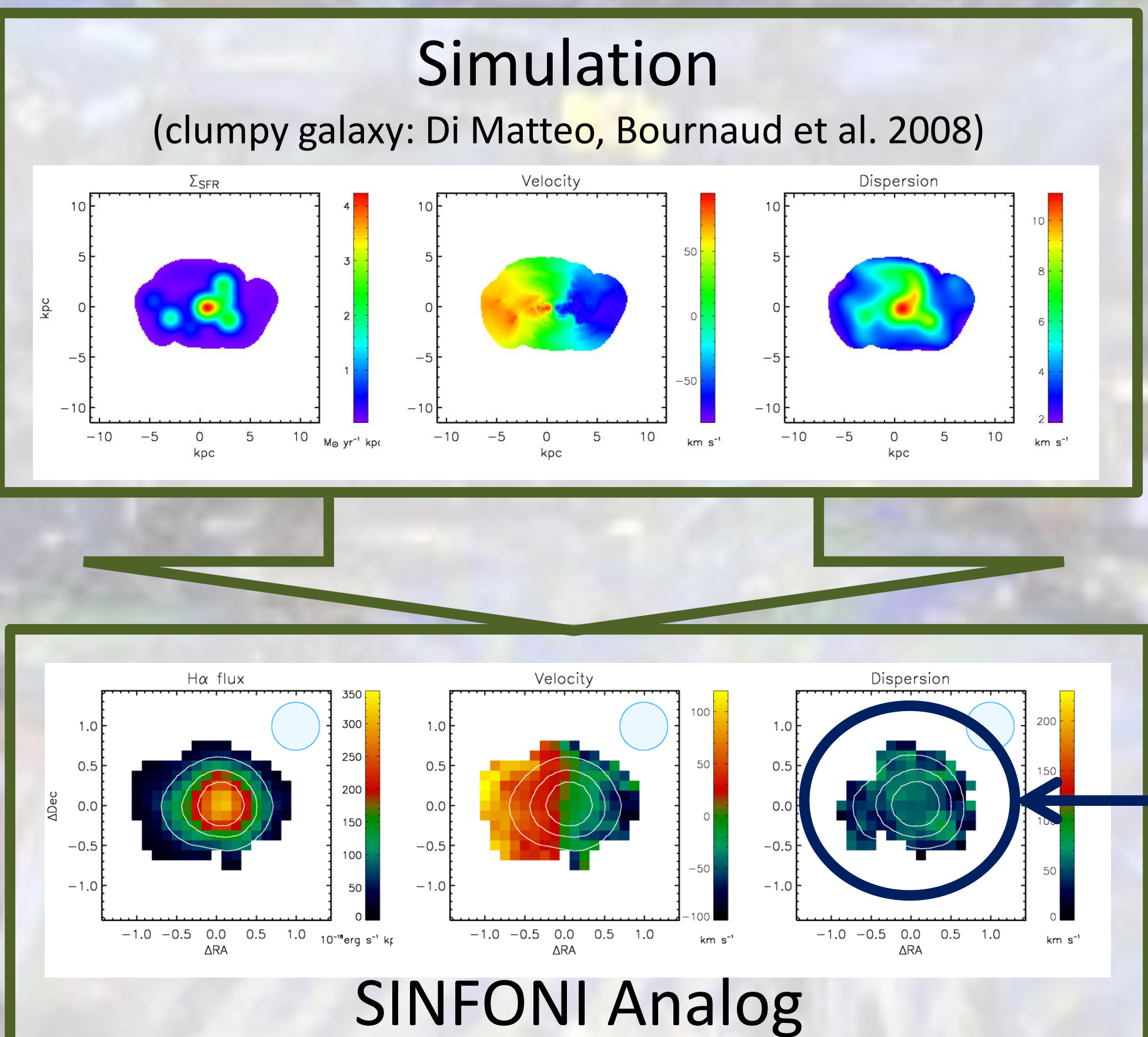
From observations:

Rest-frame H*α* surface brightness *vs.* the observed velocity dispersion for object ZC782941 for which we have both seeing limited (blue) and adaptive optics assisted (red) data sets. **We generally do not find a substantial increase in line widths when comparing the seeing-limited data with data taken with the adaptive optics system,** although as expected, we observe higher H*α* surface brightness in some regions.



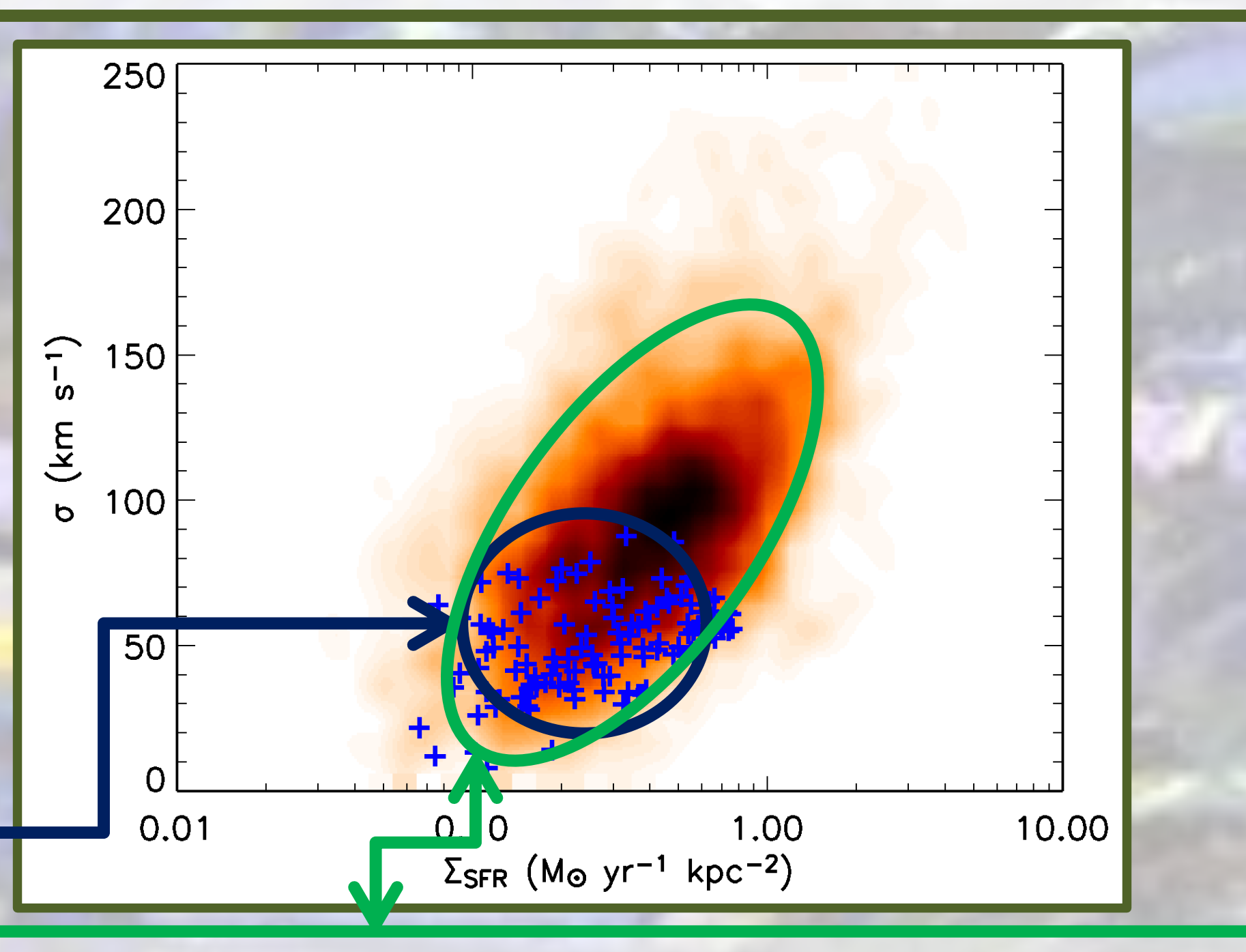
From simulations:

The values of the simulated and "SINFONIZED" Hα line dispersion are too low to explain the high values of the linewidths we generally observe in our sample of galaxies.


Simulation

(clumpy galaxy: Di Matteo, Bournaud et al. 2008)

SINFONI Analog



Normalized 2-dimensional histogram of the frequency of occurrence in the observed data of Hα line widths as function of star formation rate surface density.