Loïc Le Tiran
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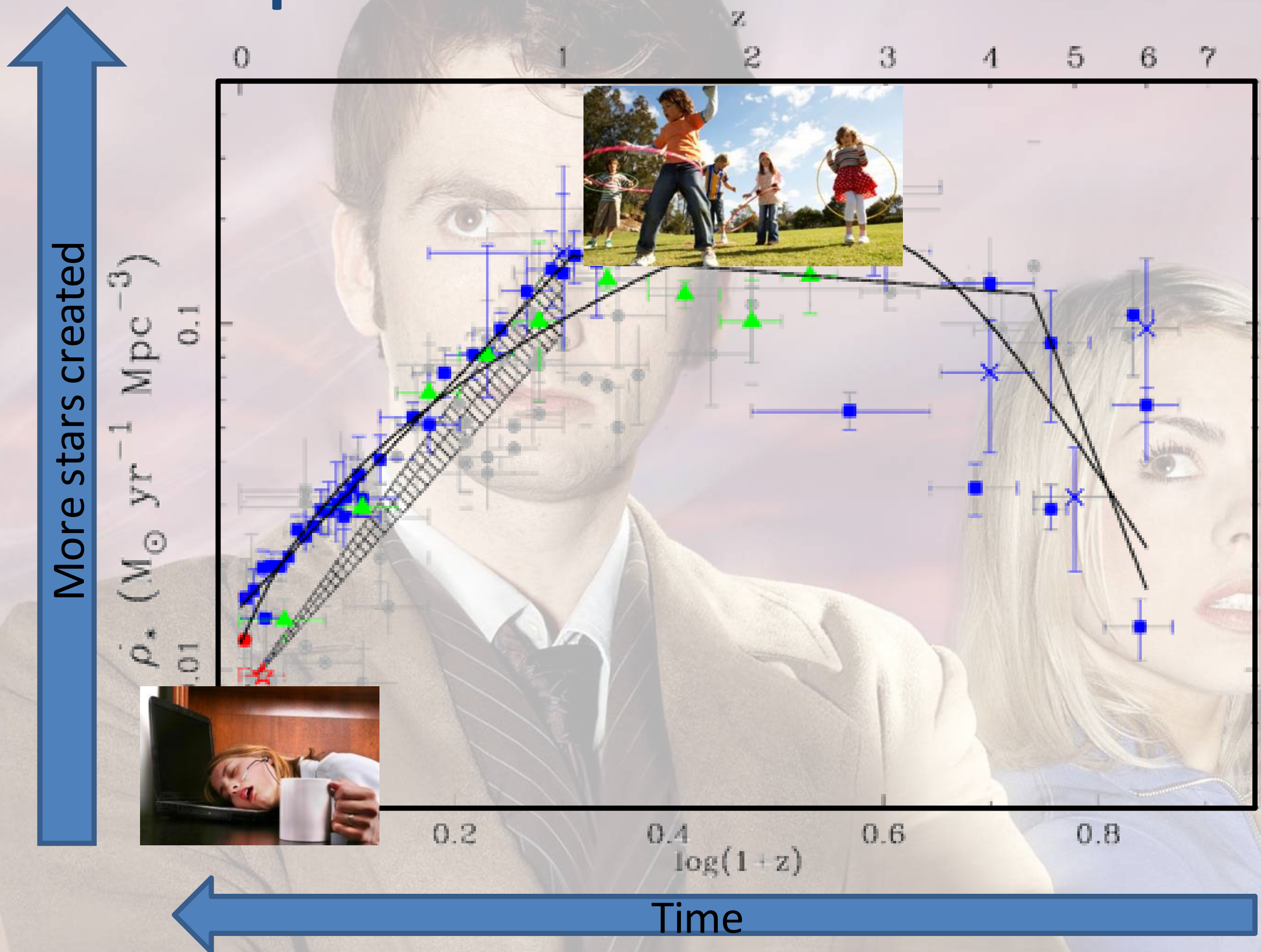
ESO Santiago
March 23rd, 2015

Stirring Up the Gas: Star Formation and Powering High Pressures in galaxies 10 Billion Years Ago

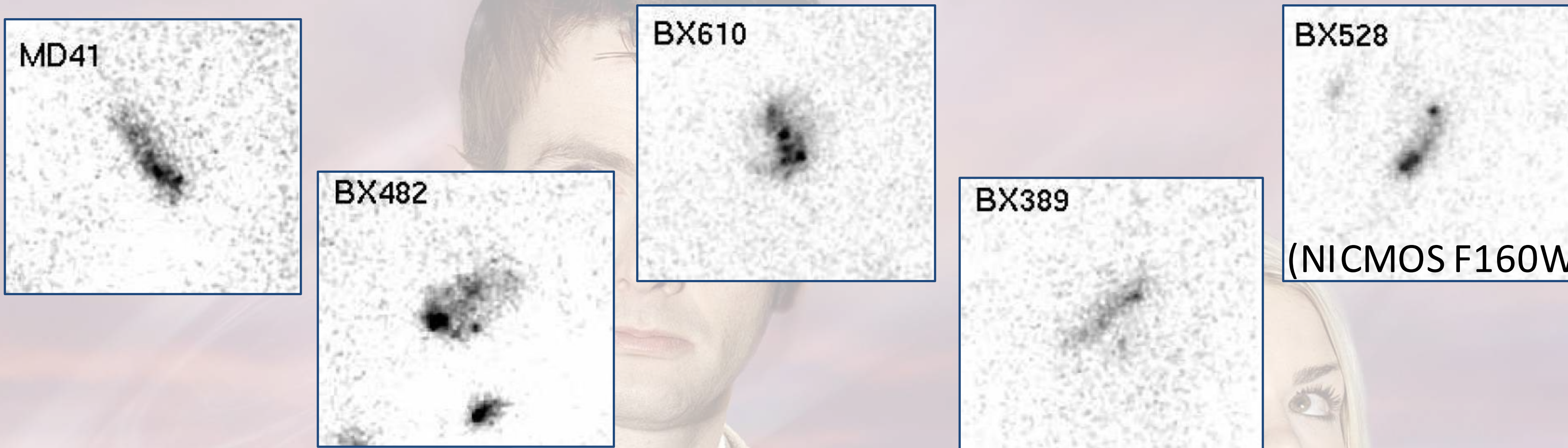
USP 80 1934 2014
FAPESP
l'Observatoire de Paris GEPI

An epoch of intense activity



Hopkins & Beacom, 2006

Irregular morphologies

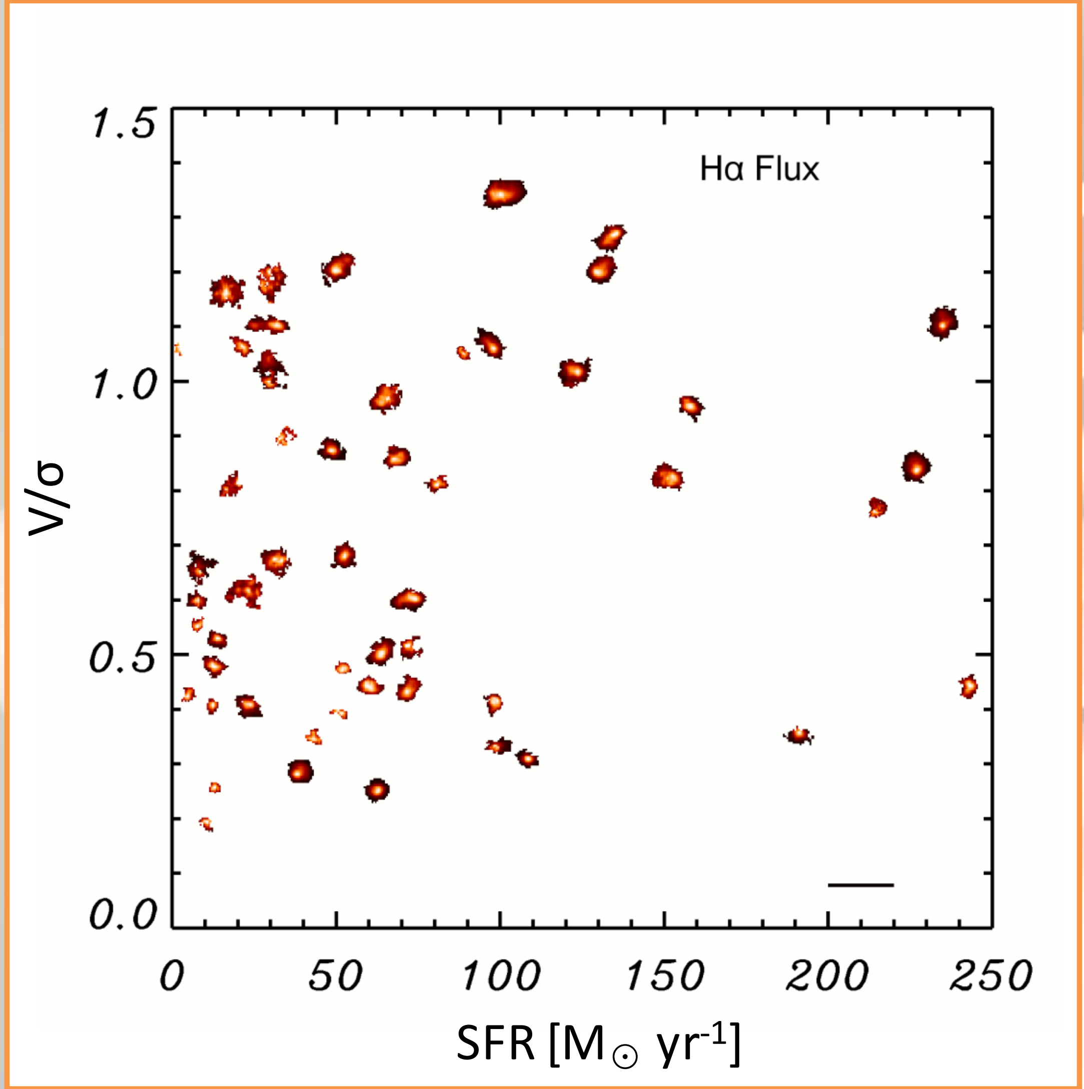


- Morphologies are increasingly irregular towards higher redshifts.

- The covering fraction of star forming regions appears to be high in intensely star forming galaxies.


Put your glasses on Rose,
we’re doing
3D spectroscopy!

The sample used for this work



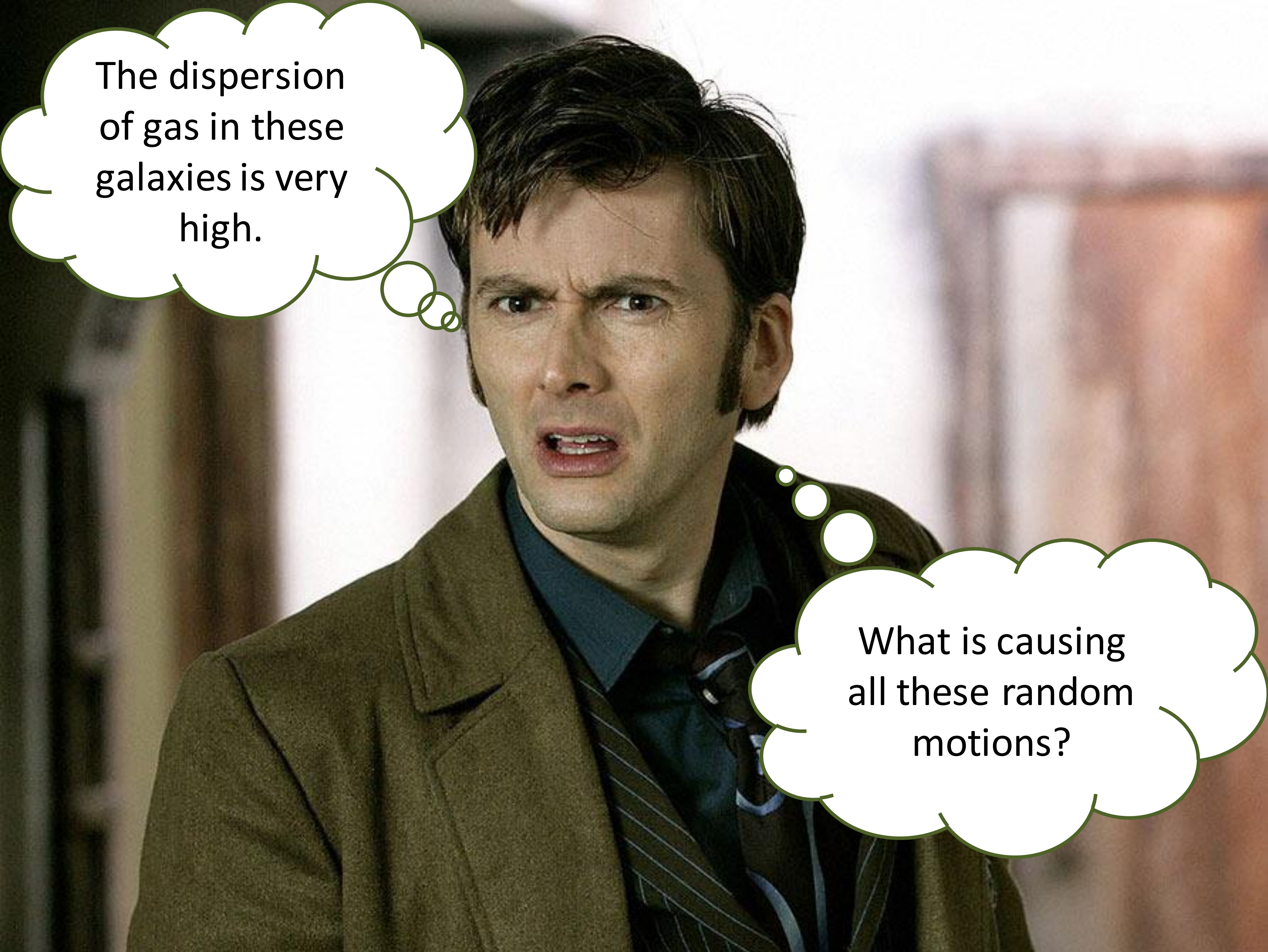
53 galaxies

$1.3 < z < 2.7$

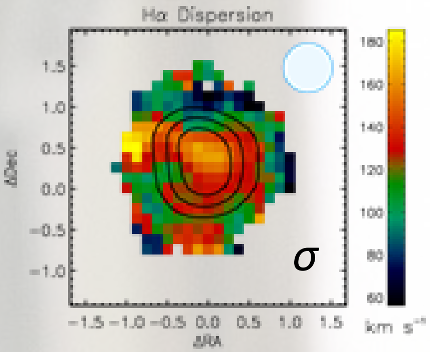
<Area> ≈ 200 kpc^2

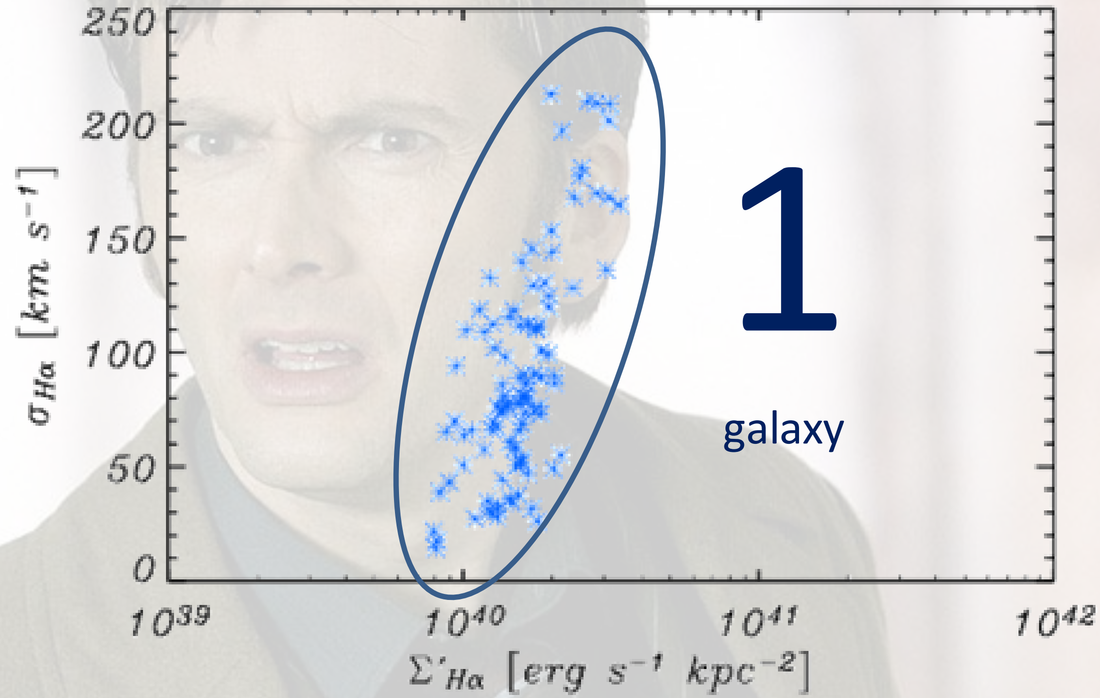
<SFR> ≈ 70 $M_\odot$ yr^{-1}

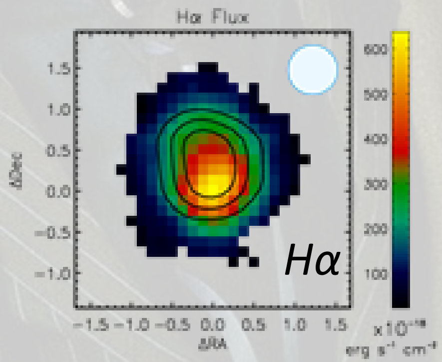
<v/σ> ≈ 1


The dispersion of gas in these galaxies is very high.
What is causing all these random motions?

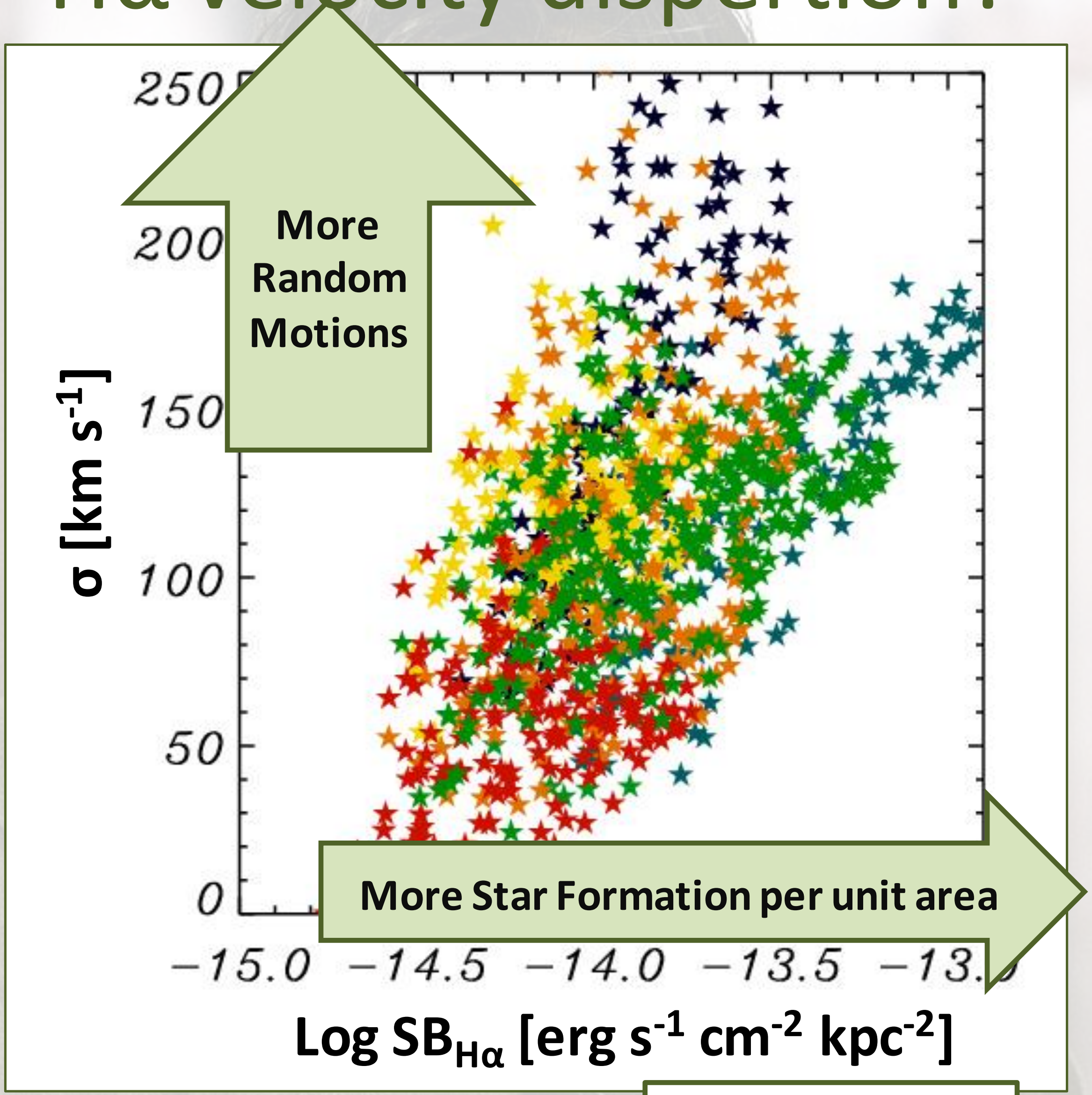
Random motions VS Hα luminosity





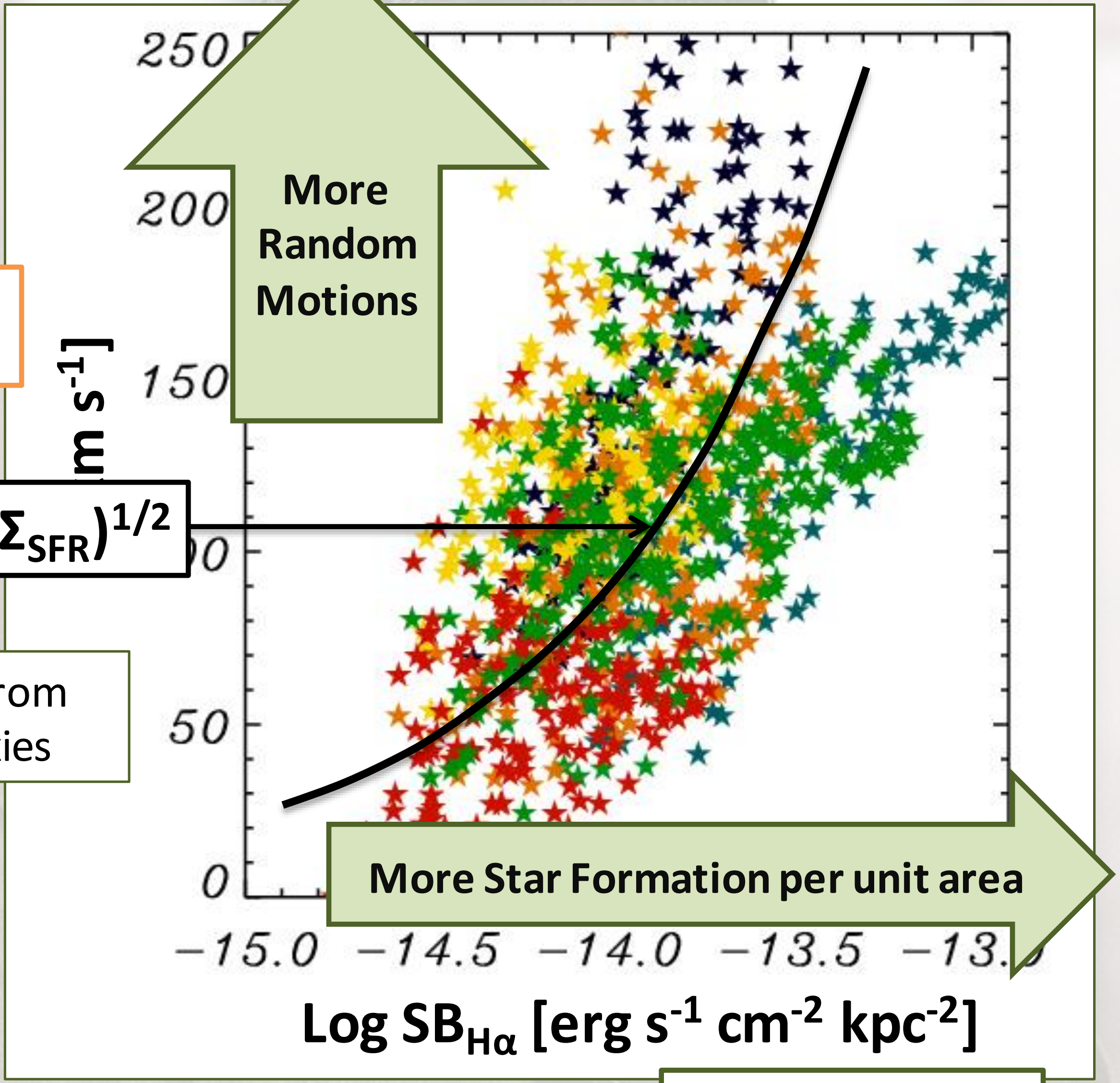


Is there a trend between SFR and Hα velocity dispertion?



Lehnert et al. (2009)

Is there a trend between SFR and Hα velocity dispertion?



That's just $E \propto v^2$

$\sigma = (\varepsilon \Sigma_{SFR})^{1/2}$

ε: scaling from local galaxies

Lehnert et al. (2009)


So do you think these random motions are produced by the intense star formation?
All your praying moments amount to just one


What else?
Lehnert+2009,2013, Le Tiran+2011ab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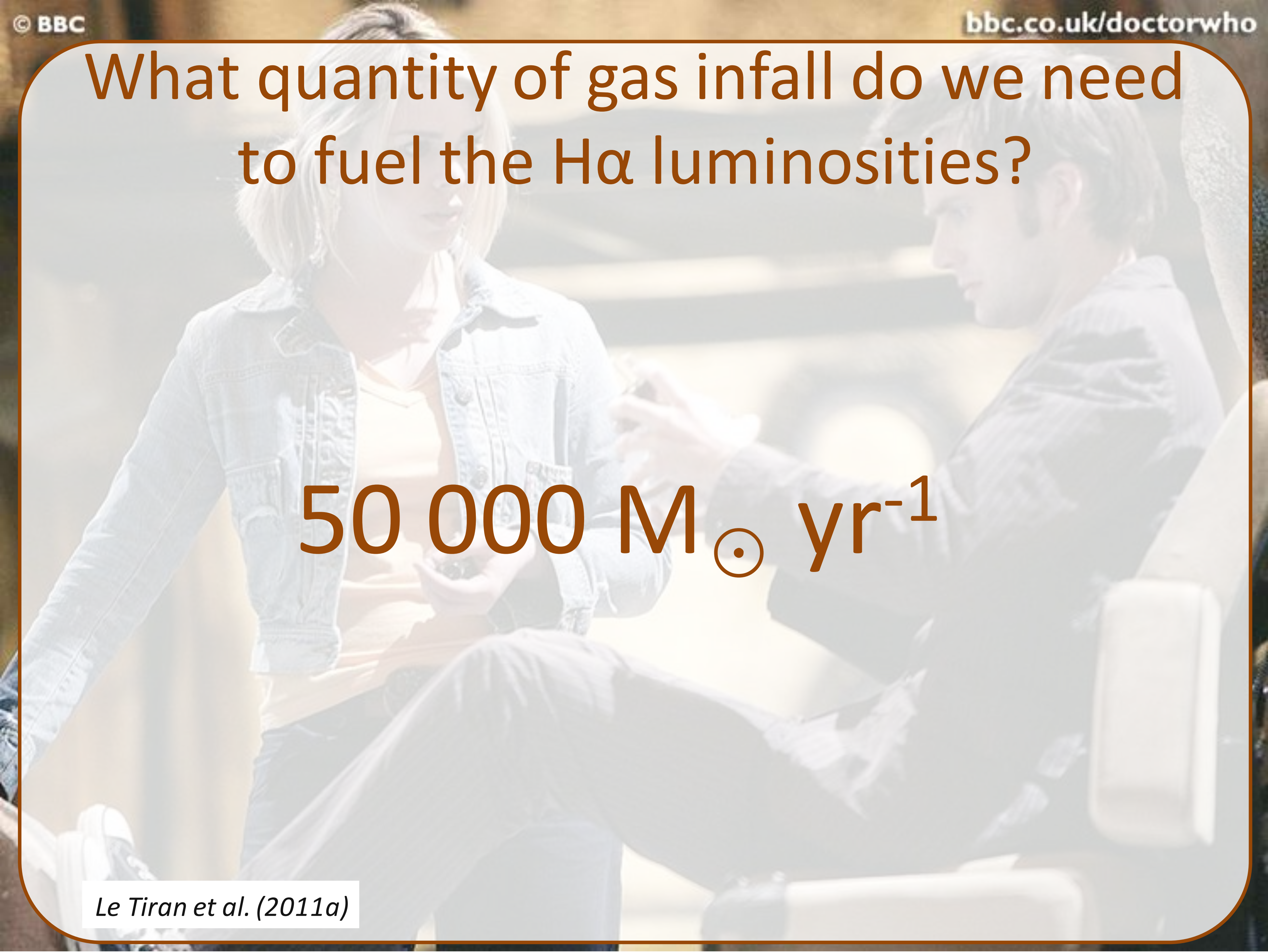
bbc.co.uk/doctorwho
Maybe gas accretion produces these random motions?
Let’s check!



What quantity of gas infall do we need to fuel the Hα luminosities?

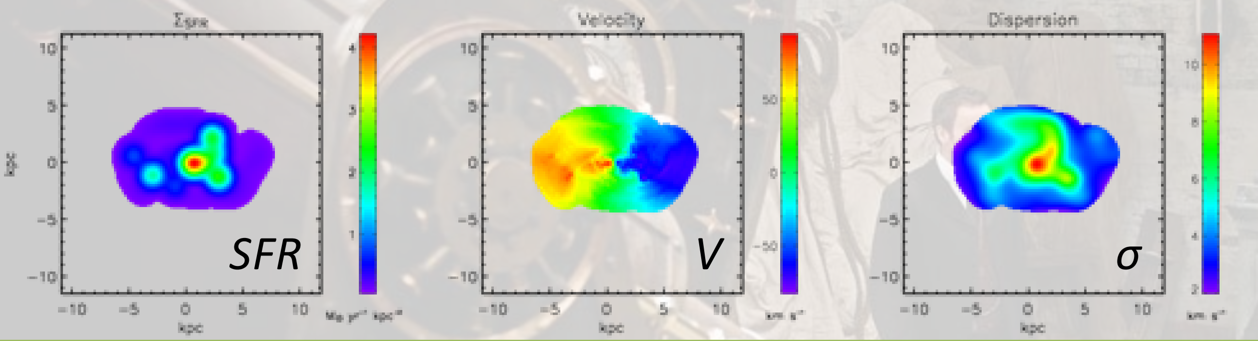
$50\,000\ M_{\odot}\ yr^{-1}$

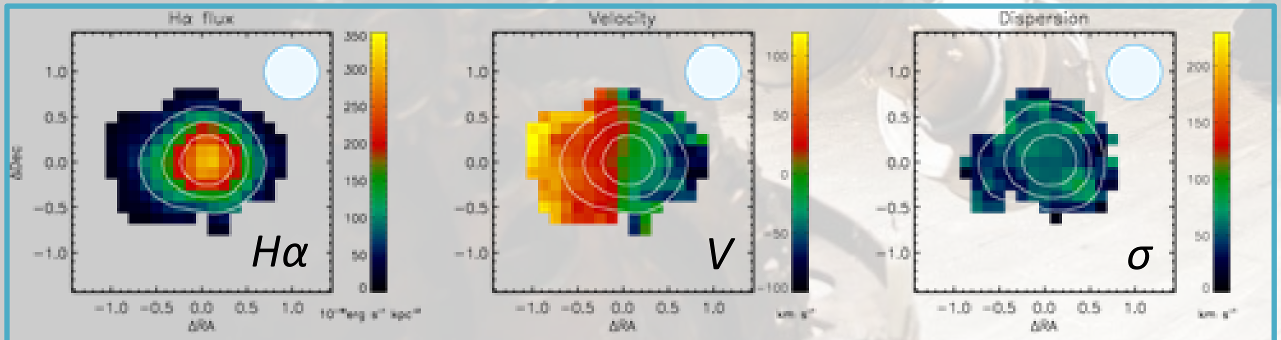
Le Tiran et al. (2011a)


Maybe the large Hα linewidths are just an instrumental effect?
Beam smearing? I don’t think so. Here’s why…

Quantifying the Effects of Beam Smearing

N-body/SPH Simulation (Di Matteo, Bournaud et al. 2008)



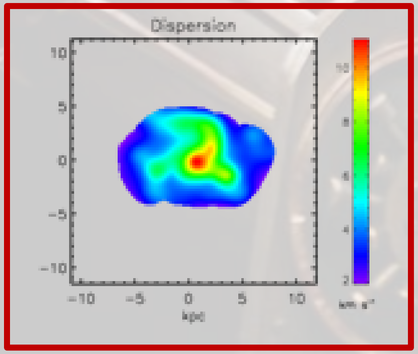


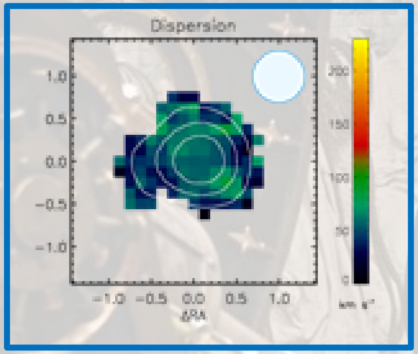
Virtual observation

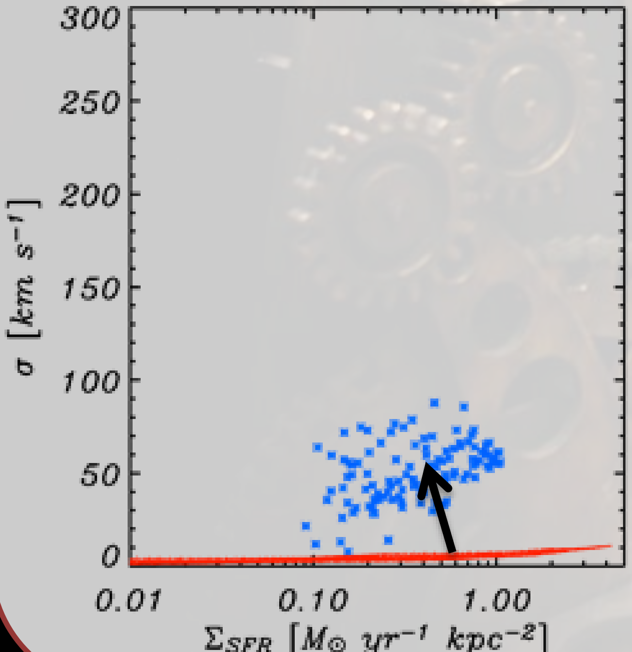
We can use simulated "clumpy disks" and analog them to a virtual SINFONI observation, in order to study the importance of beam smearing

Quantifying the Effects of Beam Smearing

gravitational dispersion







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Quantifying the Effects of Beam Smearing

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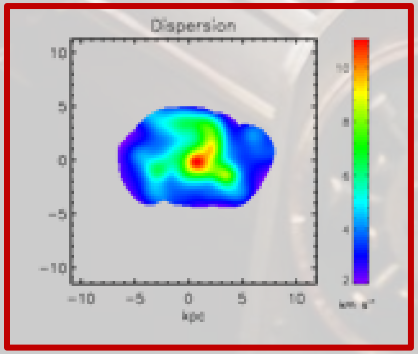
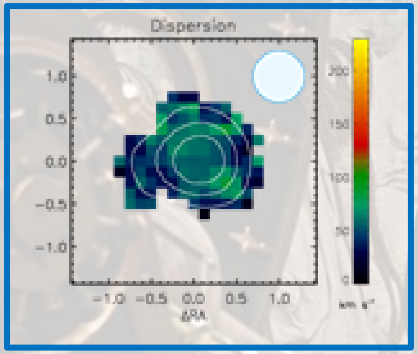
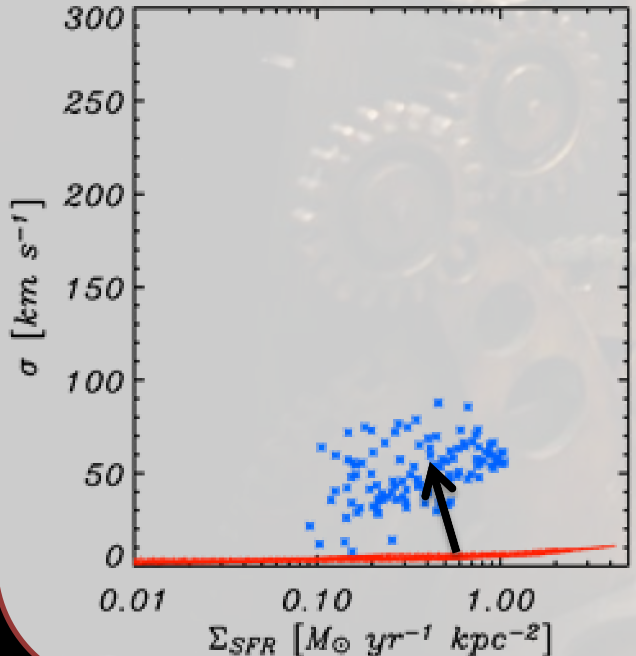
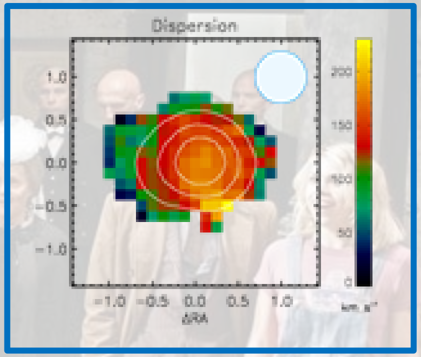




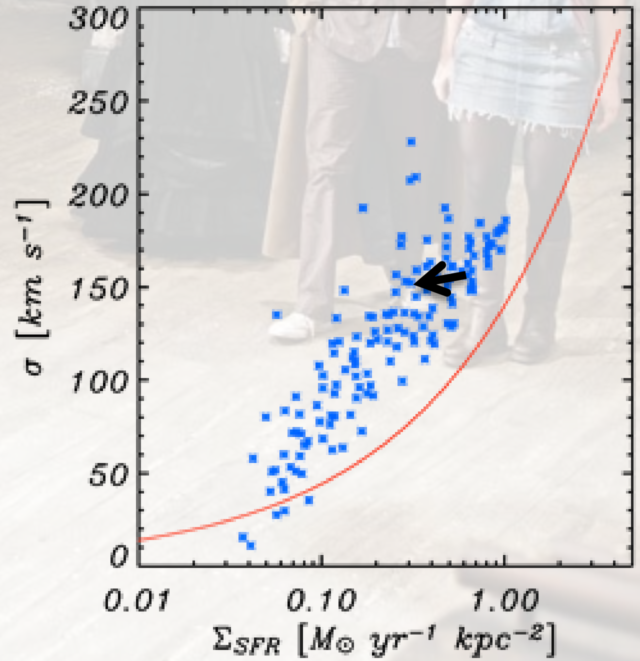


analytic dispersion

$\sigma=(\varepsilon\Sigma_{SFR})^{1/2}$



We can use simulated "clumpy disks" and analog them to a virtual SINFONI observation, in order to study the importance of beam smearing




WHO WANTS TO BE A
MILLIONAIRE
WHO WANTS TO BE A
x2
$1 Million
16
What is stirring up the gas?
A: Gas accretion
B: An instrumental effect
C: Star formation
D: The moon


You know M82, the starburst, right? Well, it's a bit the same thing that in M82…
…but different.


Thanks!

Mensageiro Sideral
De onde viemos, onde estamos e para onde vamos

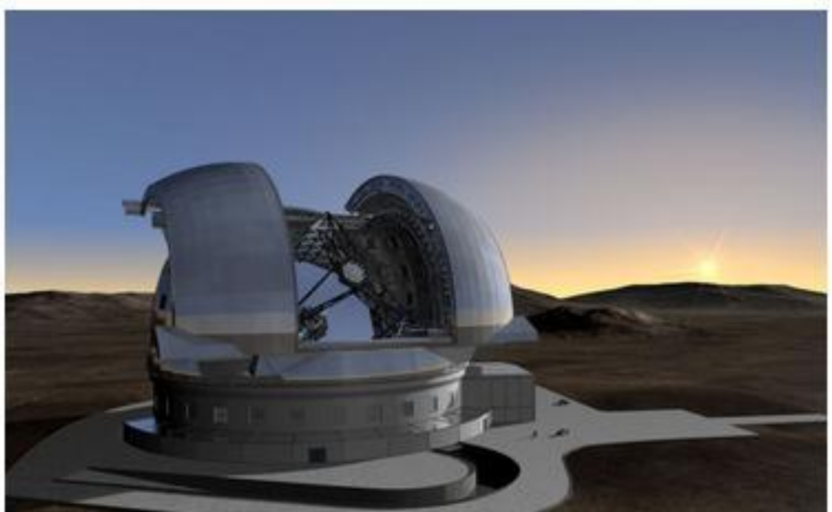
Perfil
Salvador Nogueira é jornalista de ciência e autor de oito livros
PERFIL COMPLETO

Câmara aprova Brasil no ESO

POR SALVADOR NOGUEIRA

19/03/15 18:49

Depois de algumas idas e vindas que causaram comoção na comunidade astronômica, o acordo de adesão do Brasil ao ESO (Observatório Europeu do Sul) foi aprovado nesta quinta-feira (19) pelo Plenário da Câmara dos Deputados.



ÚLTIMAS DE MENSAGEIRO SIDERAL

1 Câmara aprova Brasil no ESO

2 Treinamento em jornalismo científico

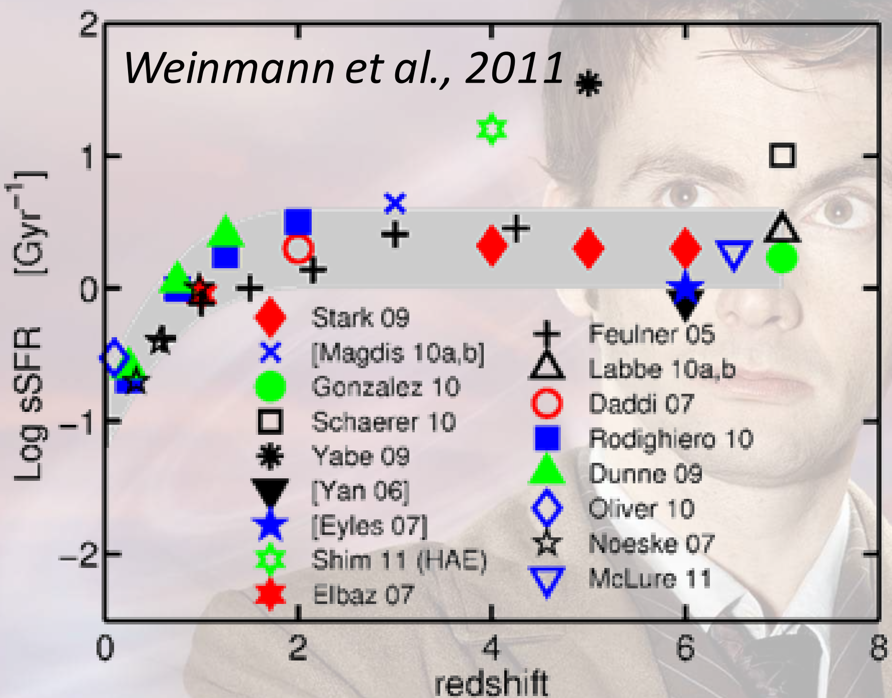
What's stirring-up the gas?

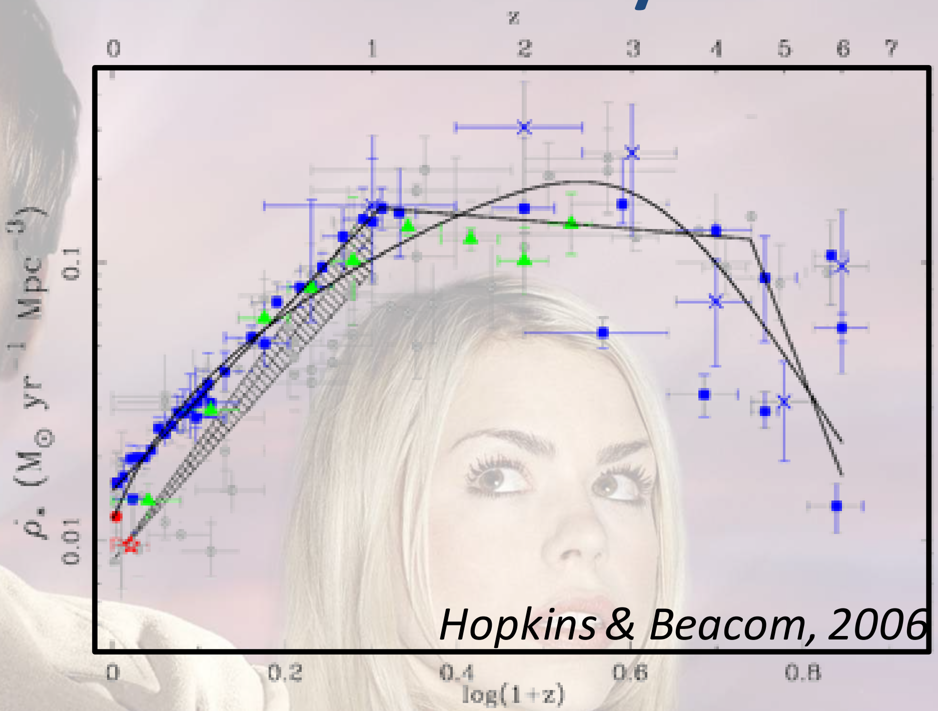
- Not an instrumental effect
- Not due to gas accretion
- Star formation!


POLICE PUBLIC CALL BOX


Where are we travelling today Doctor?
3 billion years after the Big Bang Rose…

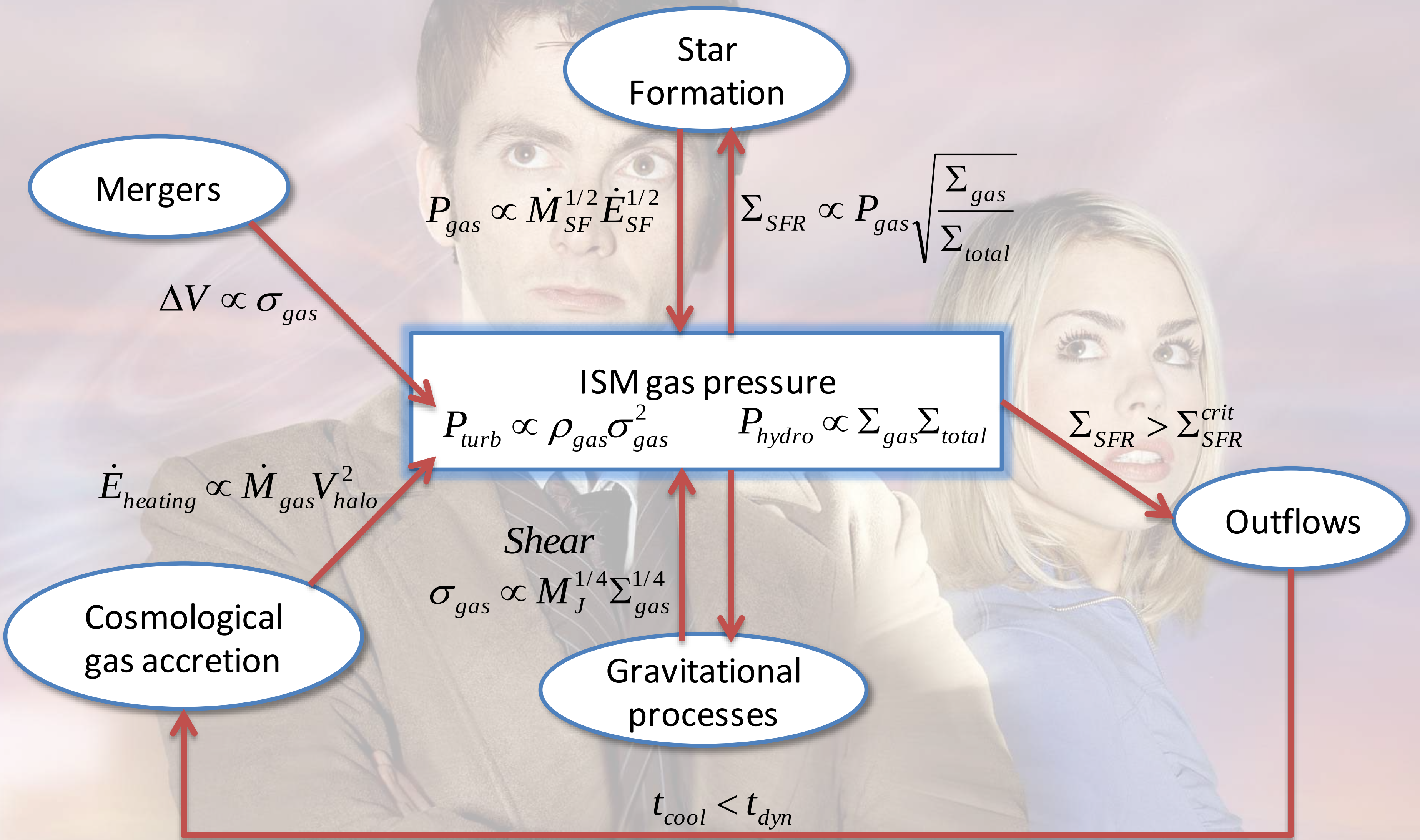
An epoch of intense activity



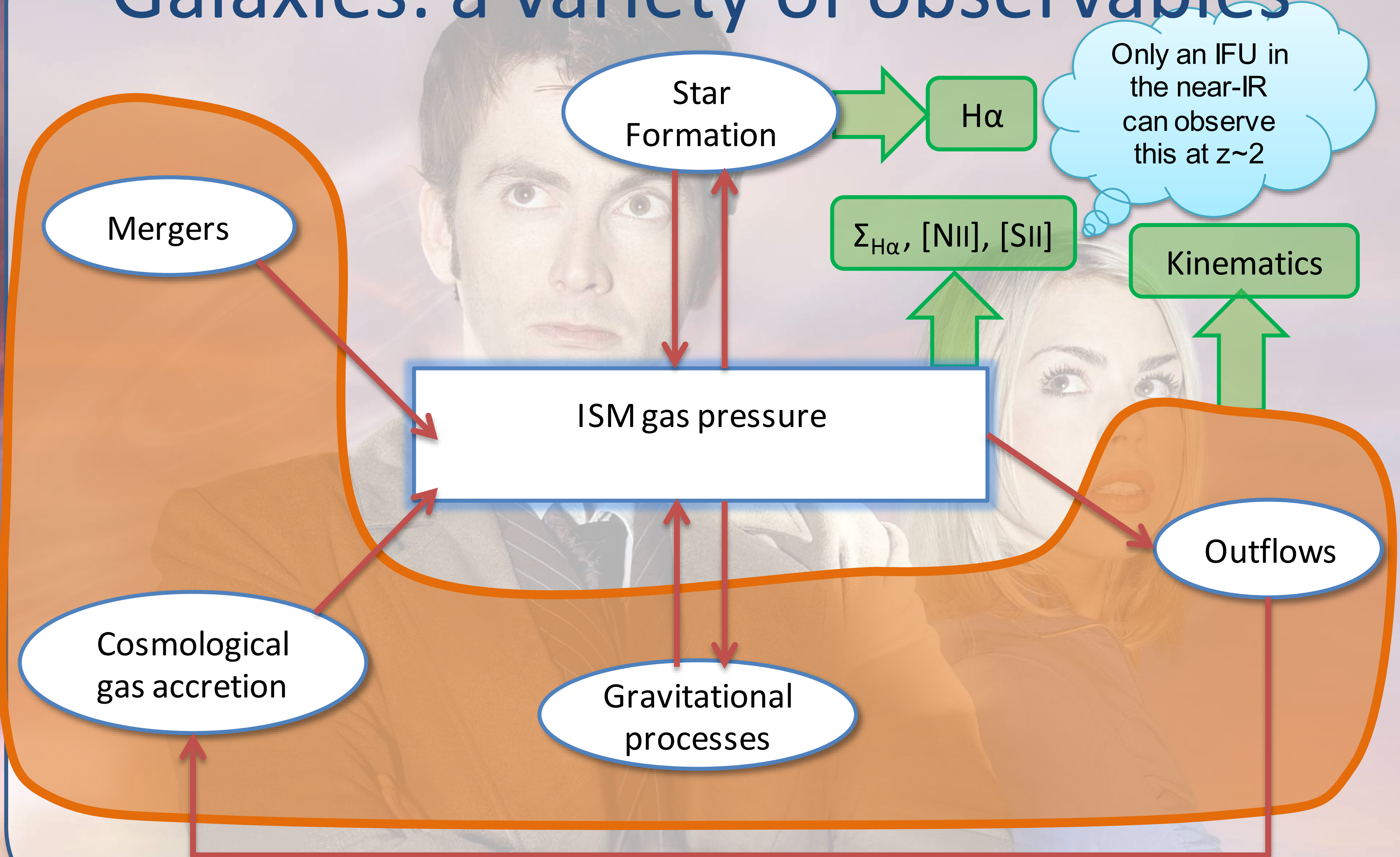


The relative growth rate of individual galaxies, and of the ensemble of galaxies, reaches a maximum at z=1-3

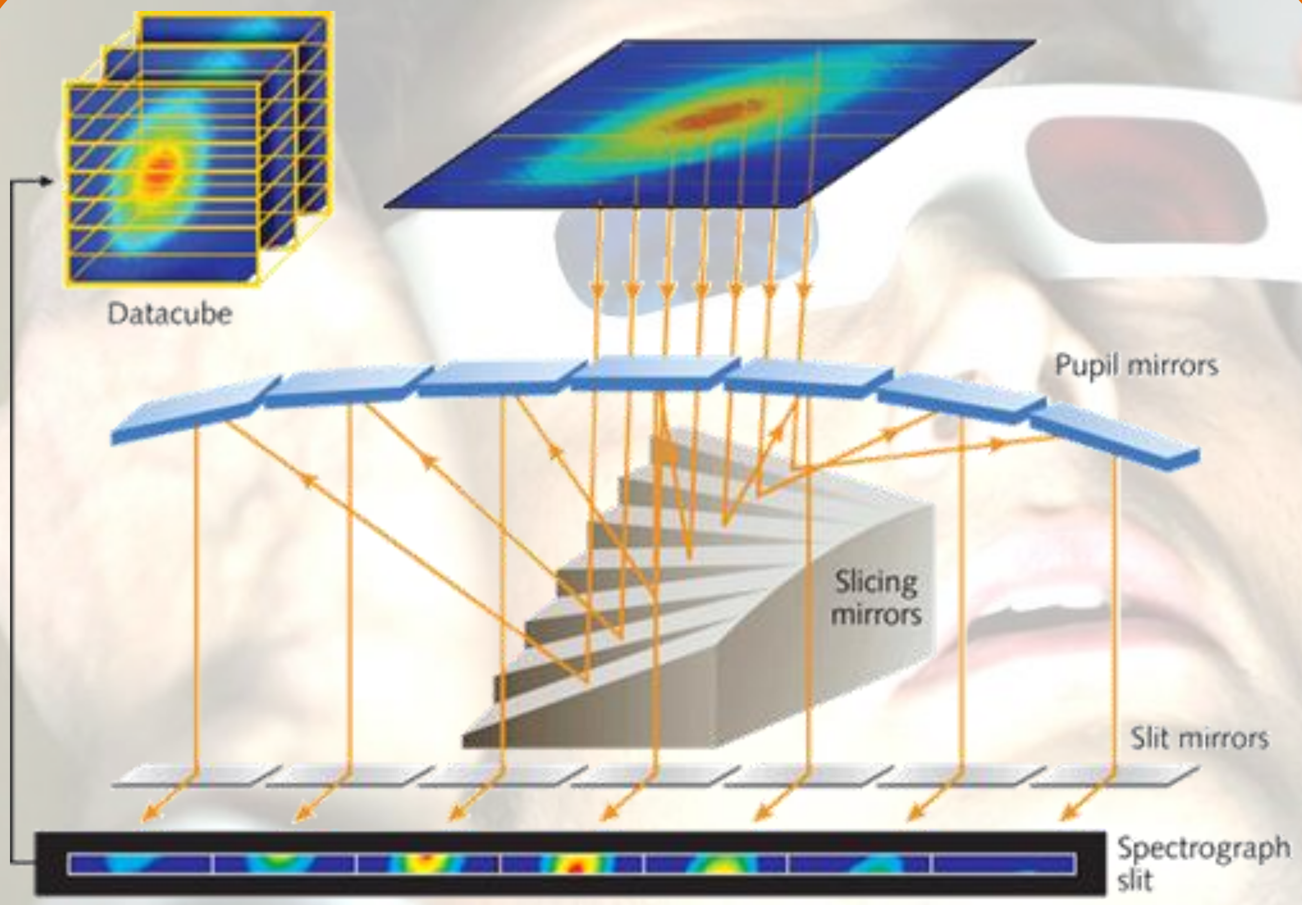
Galaxies: a variety of processes

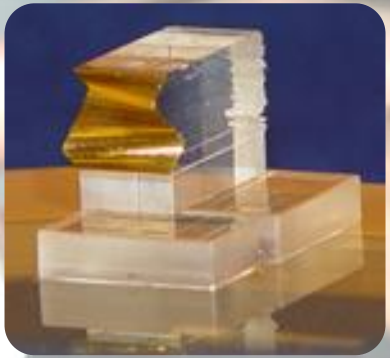


Galaxies: a variety of observables



Integral Field Spectroscopy with SINFONI

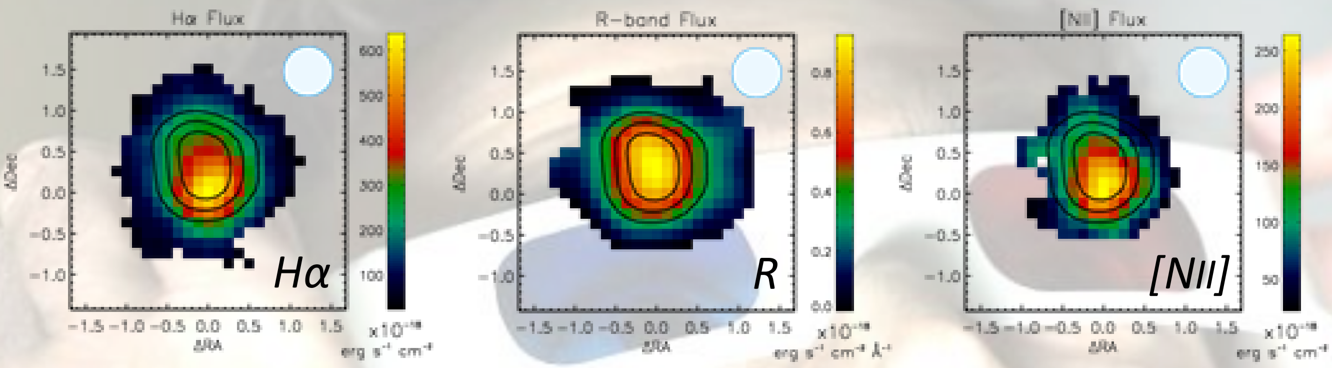




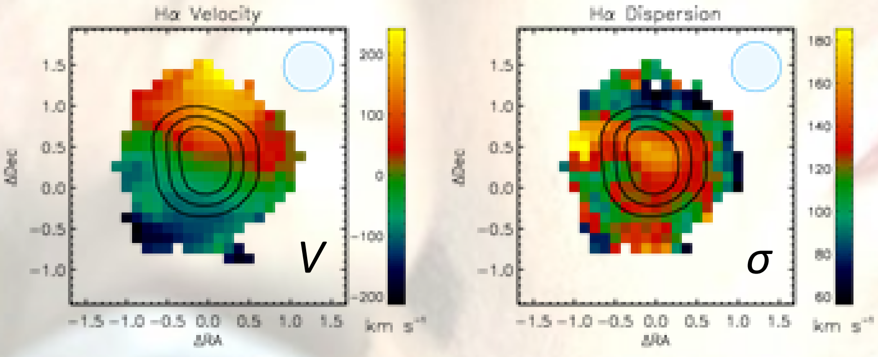
SINFONI uses an image slicer to produce spatially resolved spectroscopic data.

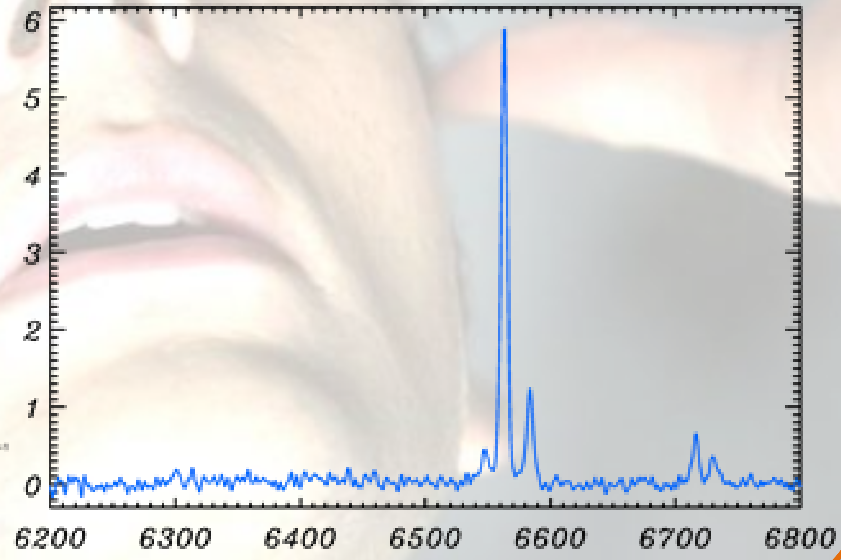
The observables

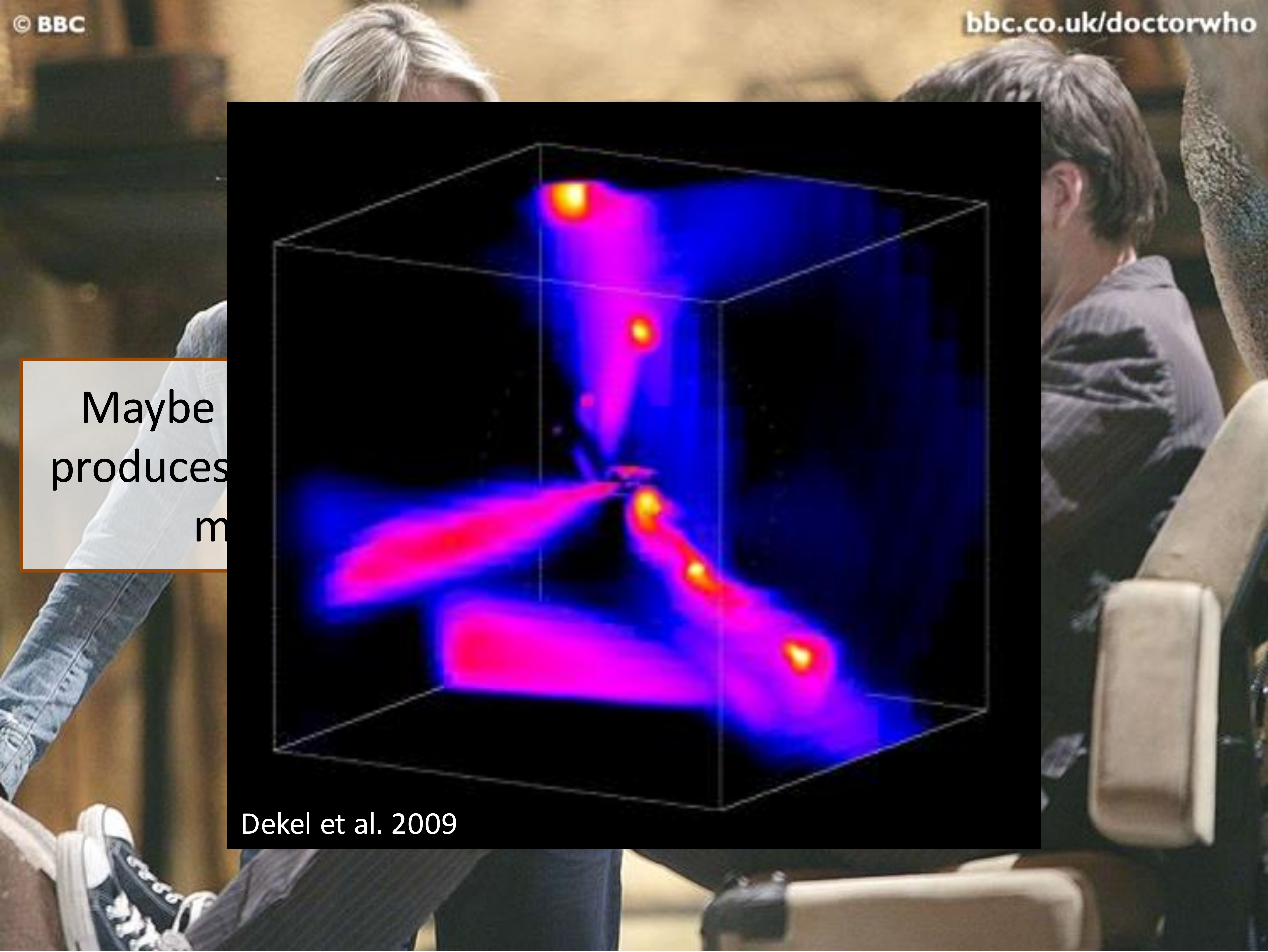
Morphology



Dynamics



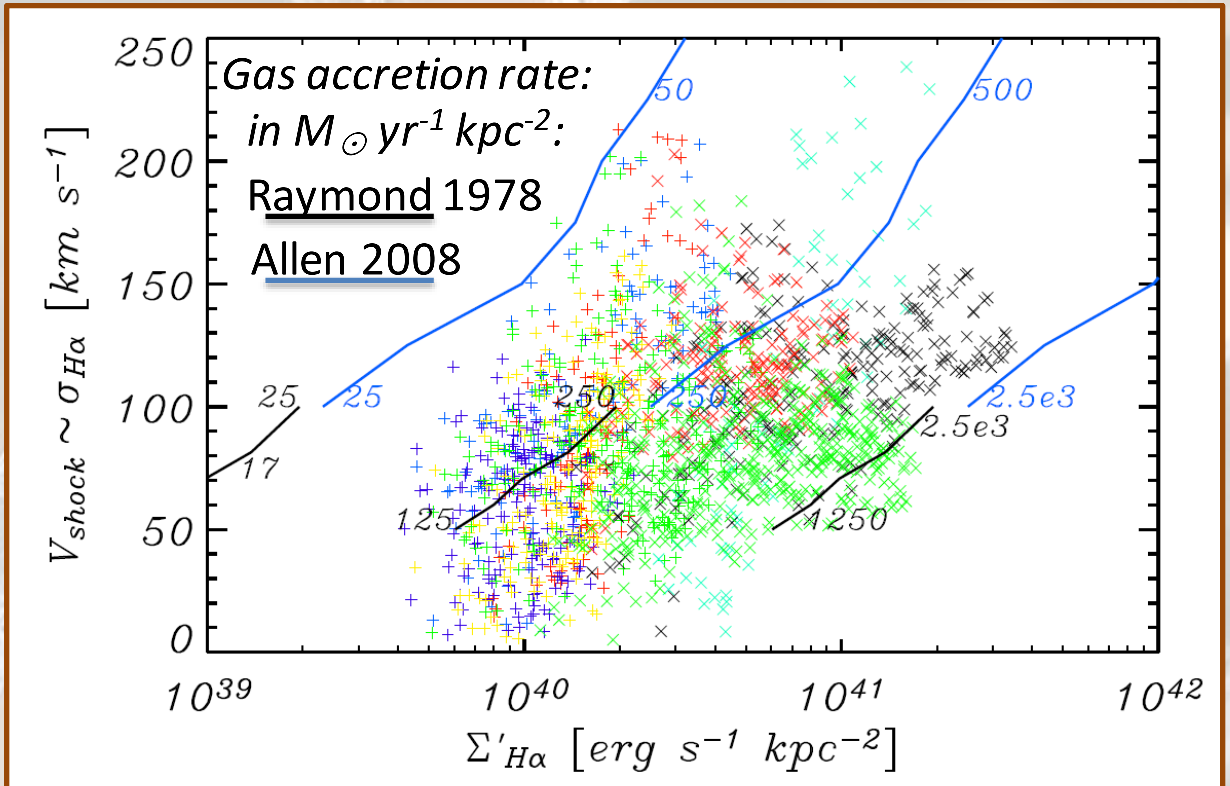




Maybe
produces
m

Dekel et al. 2009

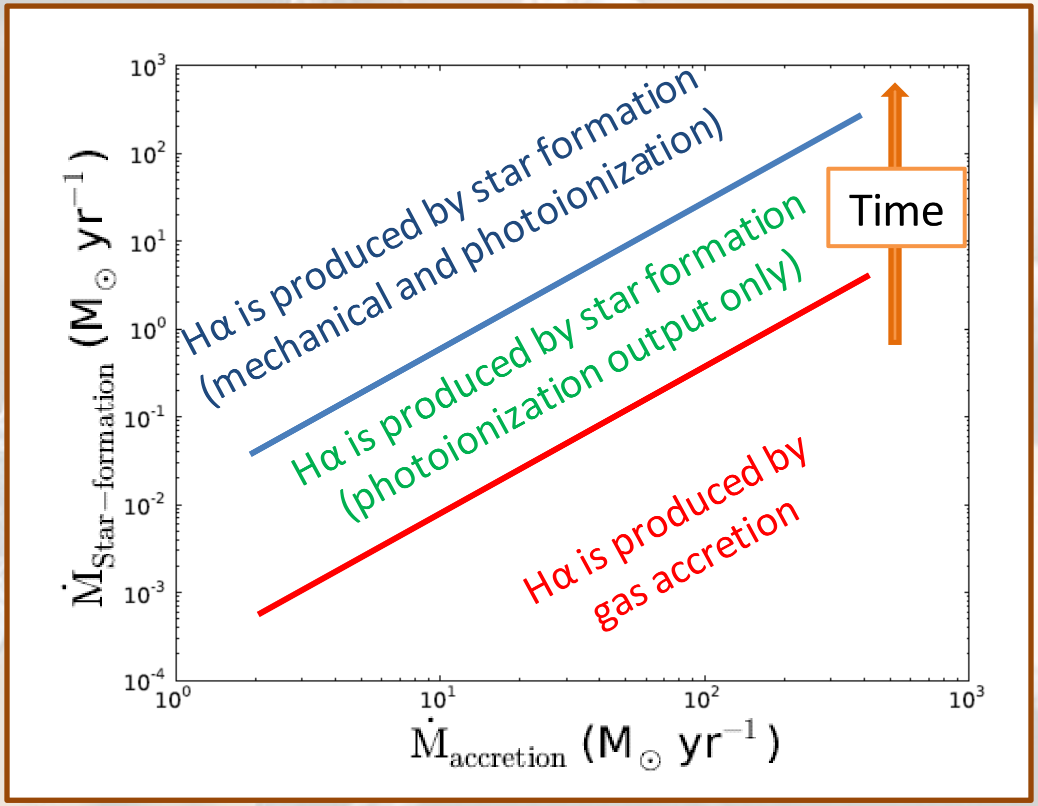
What quantity of gas do we need to fuel the Hα luminosities?



From shock models, we can show that an unrealistic gas accretion rate is needed to power the Hα velocity dispersions and luminosities.

Le Tiran et al. (2011a)

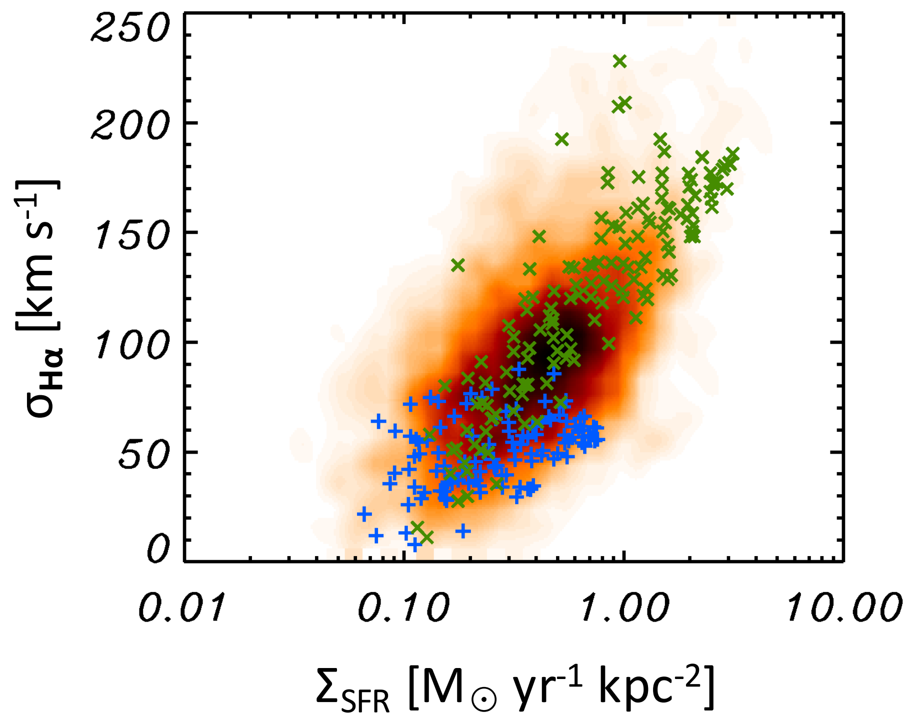
Distinguishing between the different contributions of Hα luminosity



We can model the different contributions from accretion and star formation. Observing the effect of gas accretion in Hα will be difficult.

Le Tiran et al. (2011a)

Quantifying the Effects of Beam Smearing



Normalized distribution for the whole sample of galaxies

analytic dispersion $\sigma=(\epsilon\Sigma_{SFR})^{1/2}$

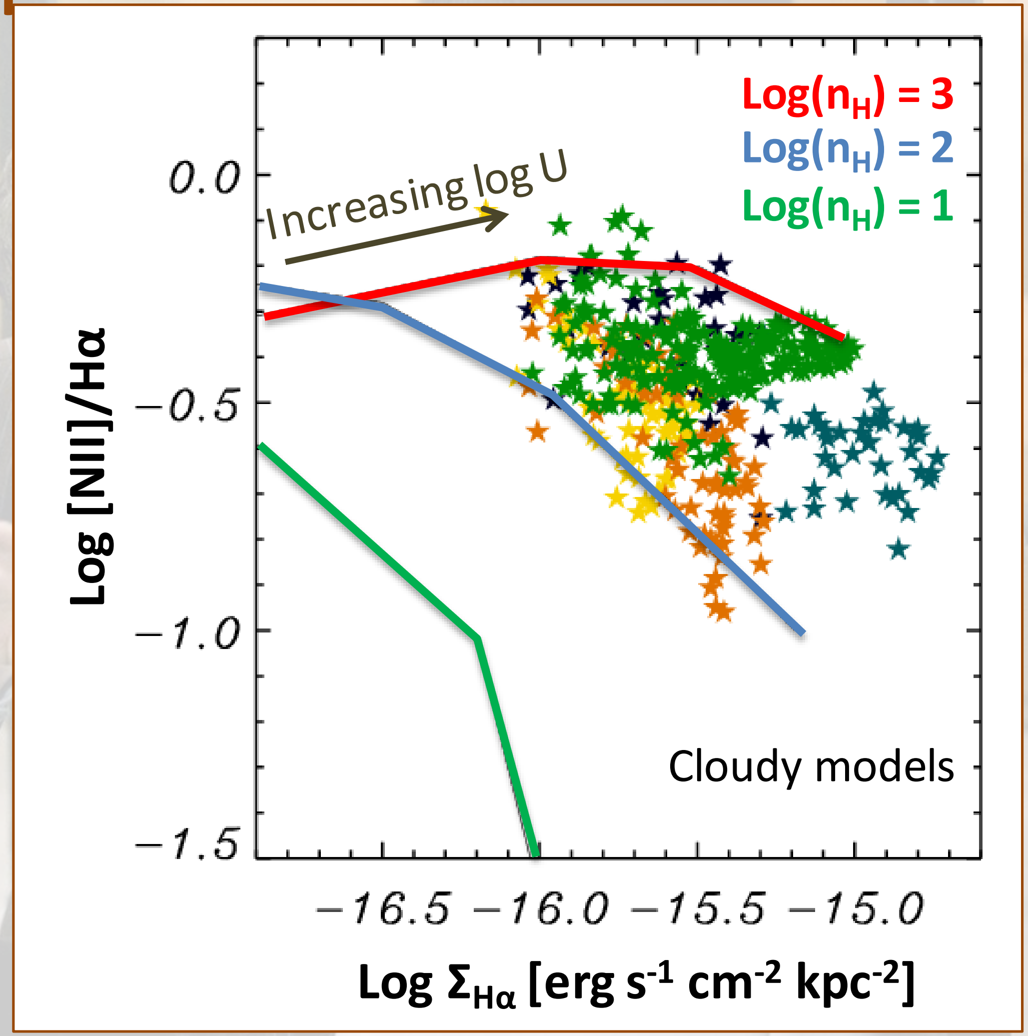
gravitational dispersion

Even when taking account of the effects of beam smearing and spectral resolution, the range of dispersions in our sample of galaxies are best explained with energy output from star formation $\sigma=(\epsilon\Sigma_{SFR})^{1/2}$


You know M82, the starburst, right? Well, it's a bit the same thing that in M82…
…but different.

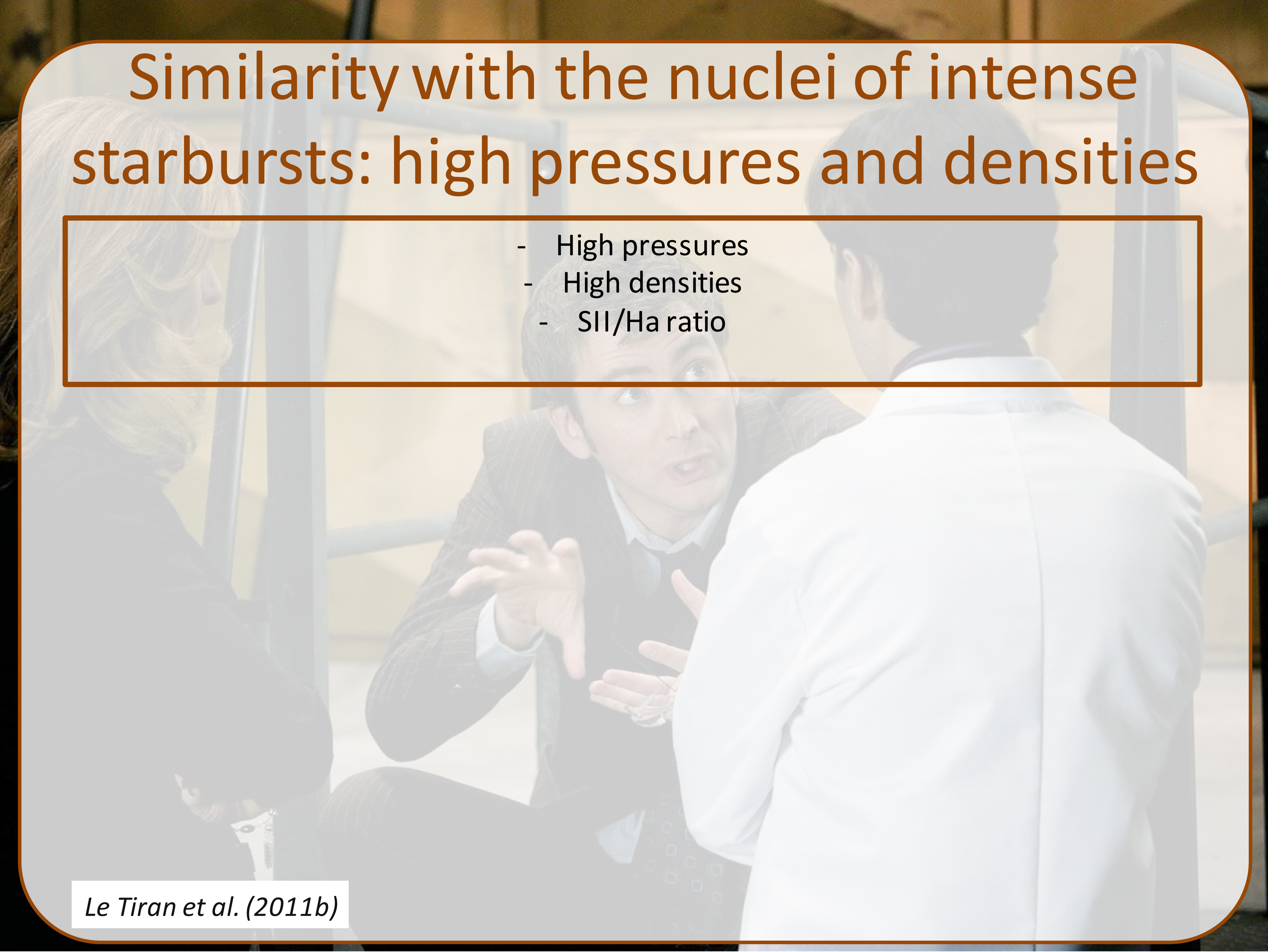
Similarity with the nuclei of intense starbursts: high pressures and densities

Modeling the line ratio of [NII]/Hα and $\Sigma_{H\alpha}$ suggests the need to have high pressures and ionization parameter.



Lehnert et al. (2009)

Similarity with the nuclei of intense starbursts: high pressures and densities



- High pressures
- High densities
- SII/Ha ratio

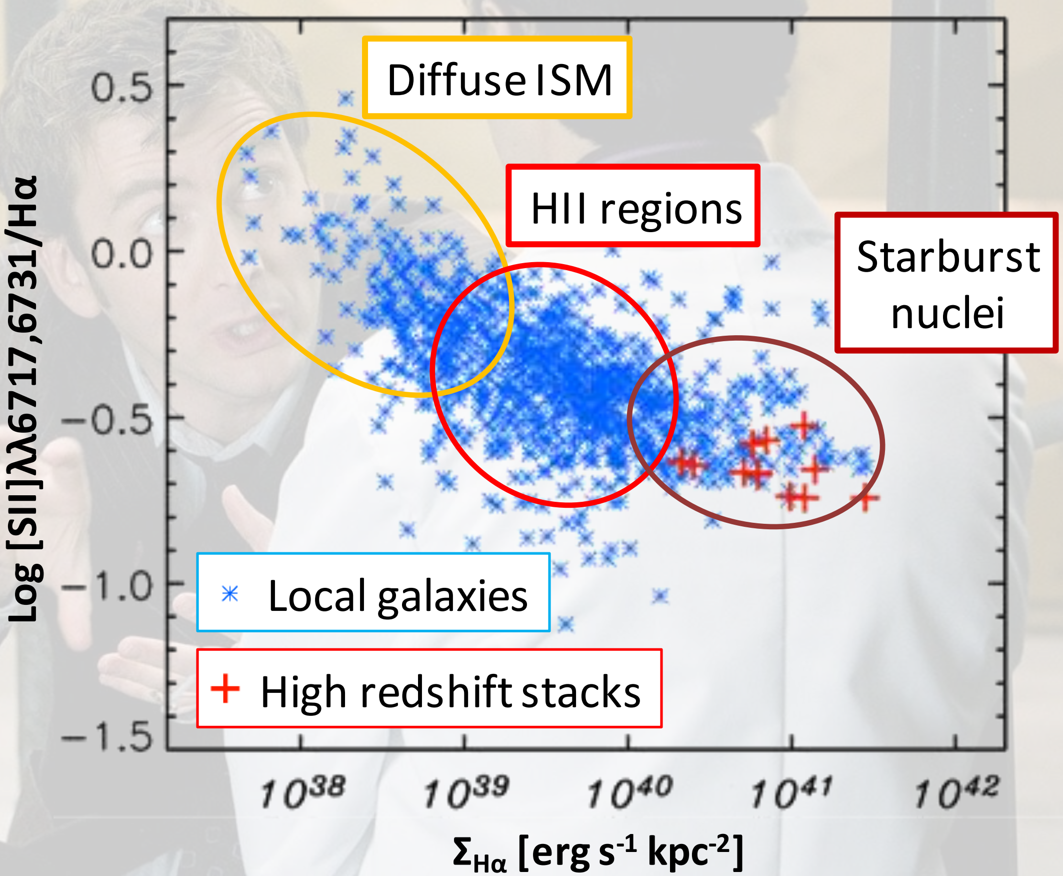
Le Tiran et al. (2011b)

Similarity with the nuclei of intense starbursts: high pressures and densities

The diffuse ISM, HII regions, and starburst nuclei in nearby galaxies form a single parameter family (*Wang et al. 1998*).

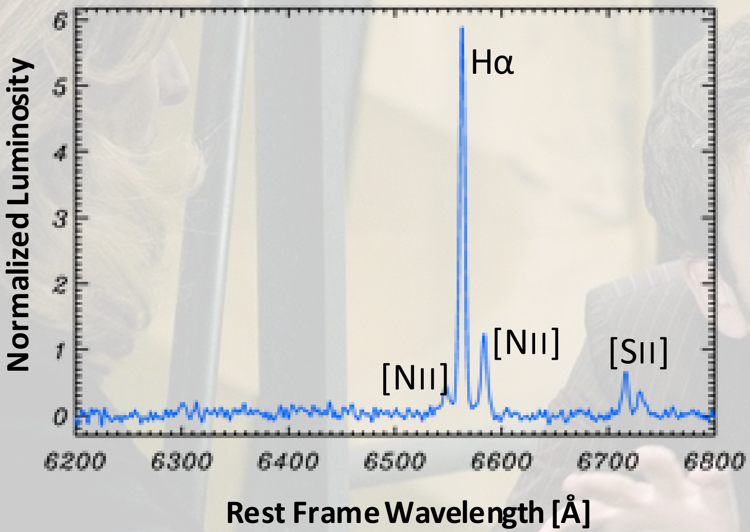
Our data from high redshift stacks are coherent with the physical conditions in nearby starburst nuclei (high densities and high ionization parameter).

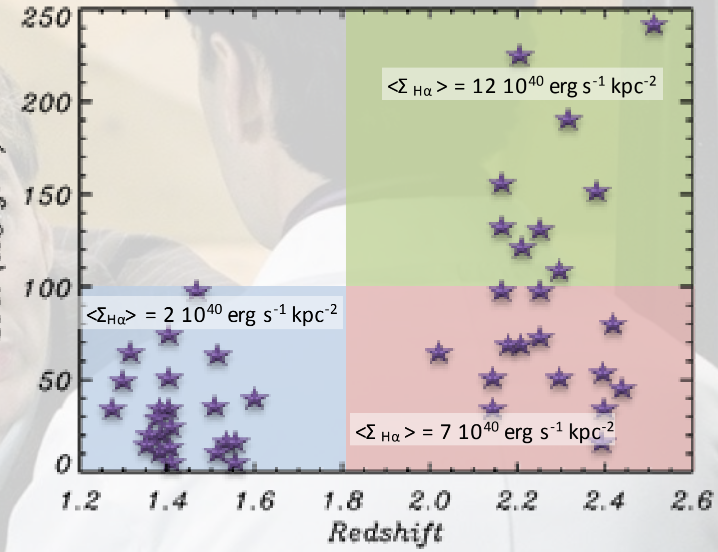
This is showing the same overall trend as the spatially resolved [NII]/Hα versus $\Sigma_{H\alpha}$ plot confirming the high ionization parameters and pressures in these galaxies.



Le Tiran et al. (2011b)

Extracting the precious signal: stacking analysis

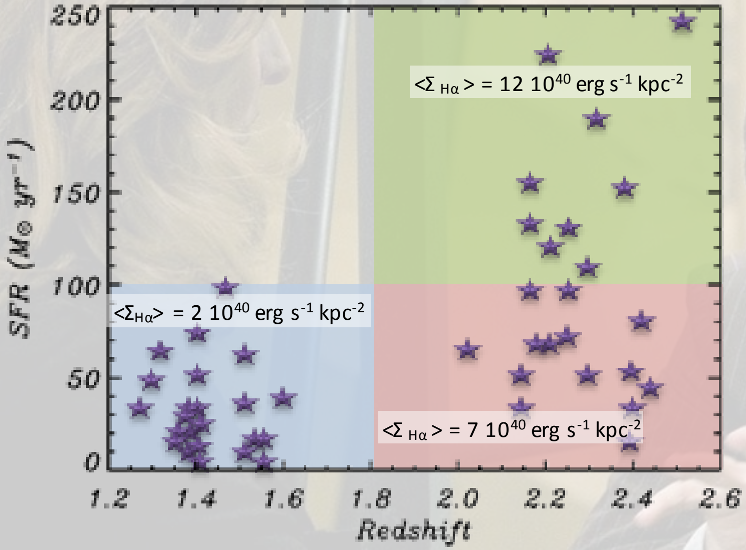


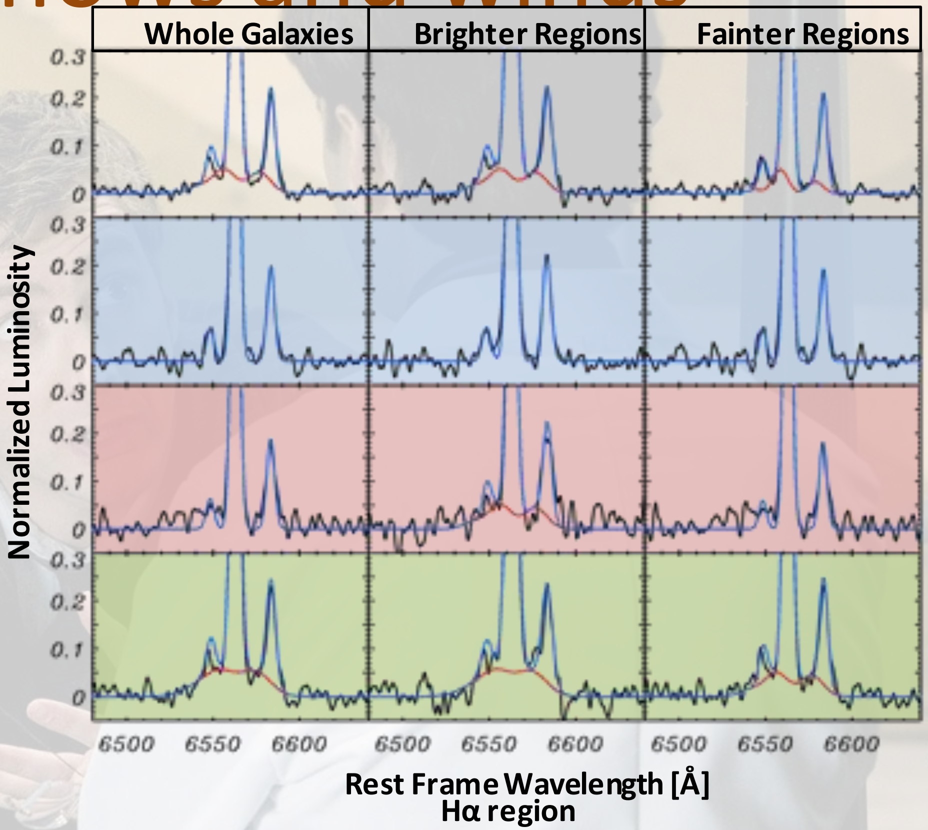


We use a stacking analysis to detect the average contributions of weak components in the observed spectra.

Spectra from each galaxy are summed according to:
- The position in the z – SFR diagram of the galaxy
- The Hα brightness in the spectrum compared to the rest of the galaxy

Similarity with the nuclei of intense starbursts: Outflows and winds

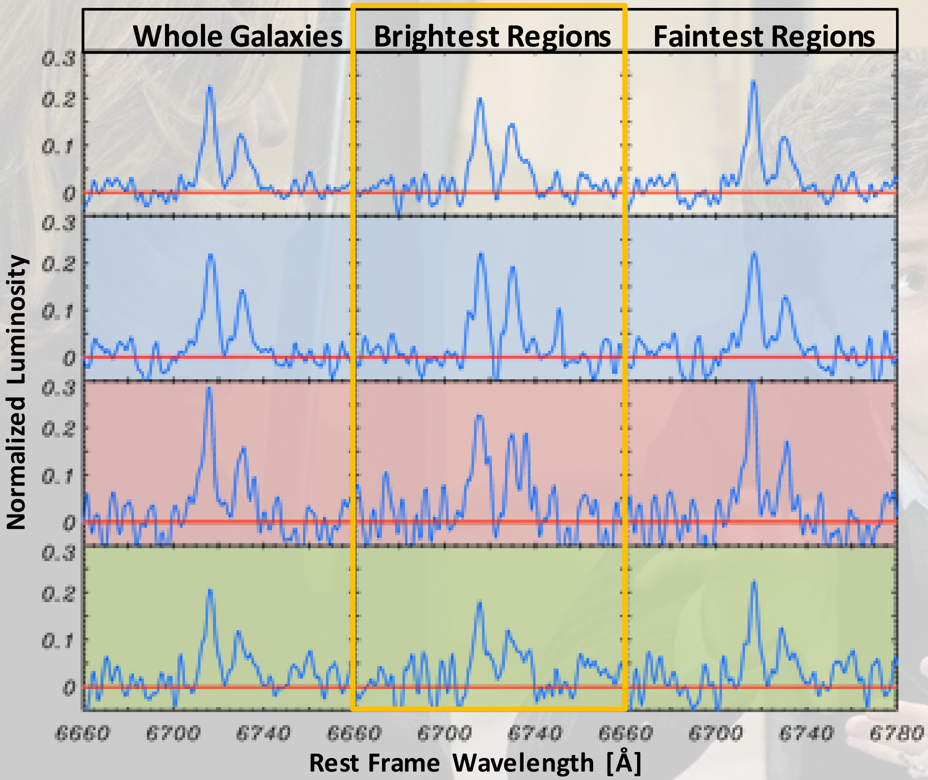




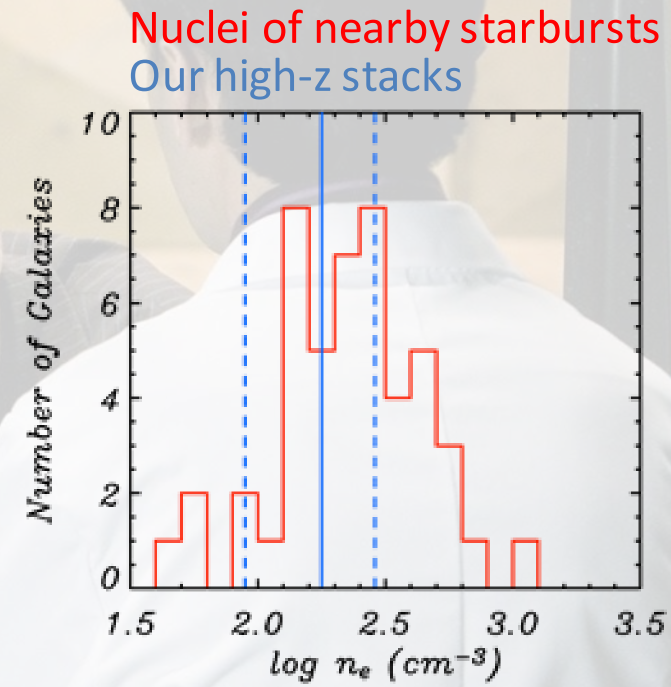
The stacks composed of the galaxies or areas with the highest <$\Sigma_{H\alpha}$> show the best evidence for a broad component. This is consistent with intense star formation driving outflows in these galaxies.

Le Tiran et al. (2011b)

Similarity with the nuclei of intense starbursts: Electron densities



[SII] region



The electron densities in the brightest regions of the galaxies are comparable to those observed in the nuclei of intense starbursts.

Le Tiran et al. (2011b)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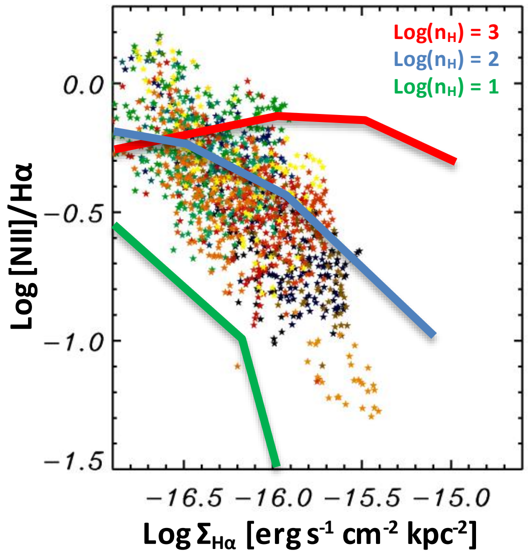
Is it always the same for all your sample?
Let’s have a look!

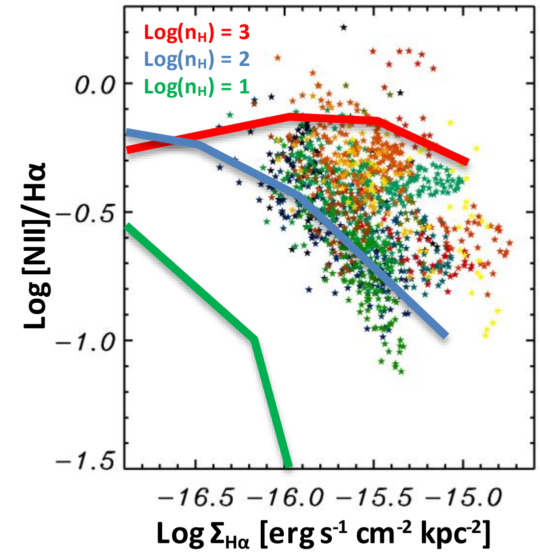
A different regime probed at lower redshift?

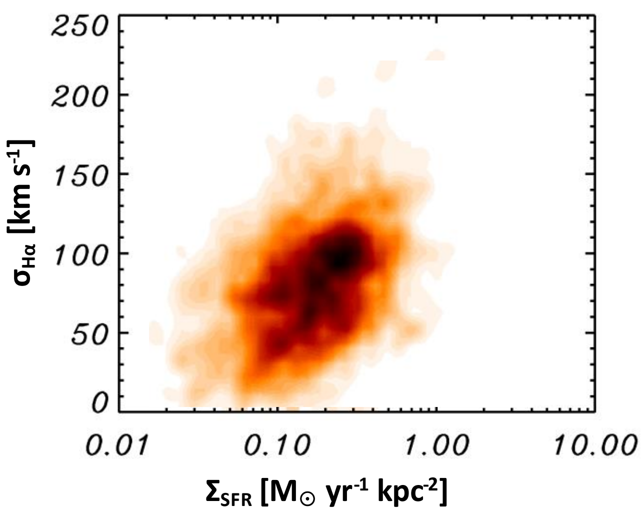


1.3<z<1.8

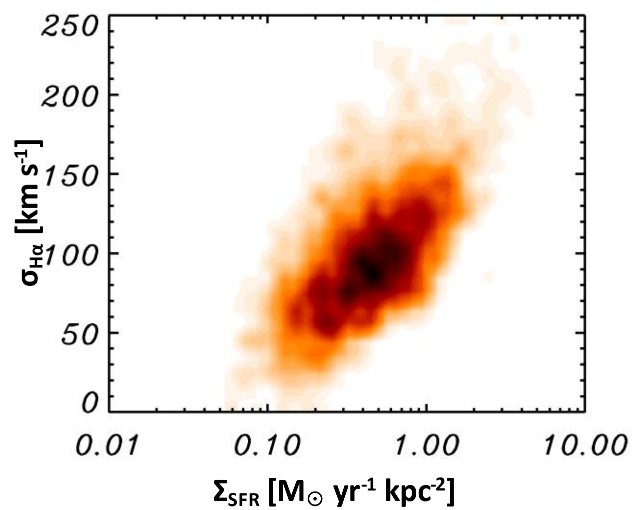
1.8<z<2.7

Increasing surface brightness dimming





At lower redshifts, we can spatially resolve galaxies with lower $<\Sigma_{H\alpha}>$, perhaps starting to probe a regime that is not completely dominated by the star formation.



Conclusions

- Star formation dominates the ISM pressure in the most star-forming galaxies at high redshift.

- Gas accretion cannot explain these Hα luminosities and velocity dispersions.

- The self regulation of star formation through the pressure occurs at high redshift just as it does in intense starbursts at low redshift.


Thanks!

+++

Todo:

- Find image with SF in bow shock
- Red Há SF image
- Morphologies

The future…

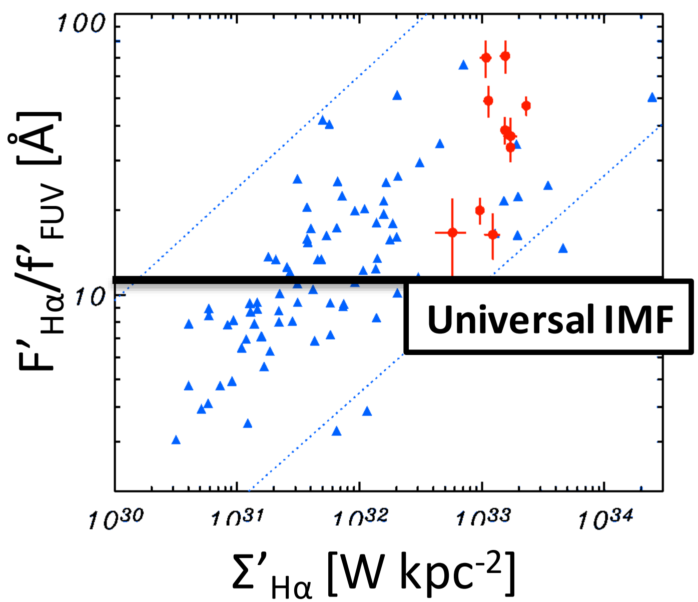
Projeto de pesquisa de pós-doutorado

UM PASSEIO NO VALE VERDE:
RUMO A UMA MELHOR COMPREENSÃO DA
EVOLUÇÃO DAS GALÁXIAS COM J-PAS

Candidato à bolsa: Loïc Le Tiran
Supervisor: Laerte Sodré Jr

Instituição:
Instituto de Astronomia, Geofísica e Ciências Atmosféricas,
Universidade de São Paulo

The ISM at z≈1.4: IMF variations, bursts of star formation, high pressures?

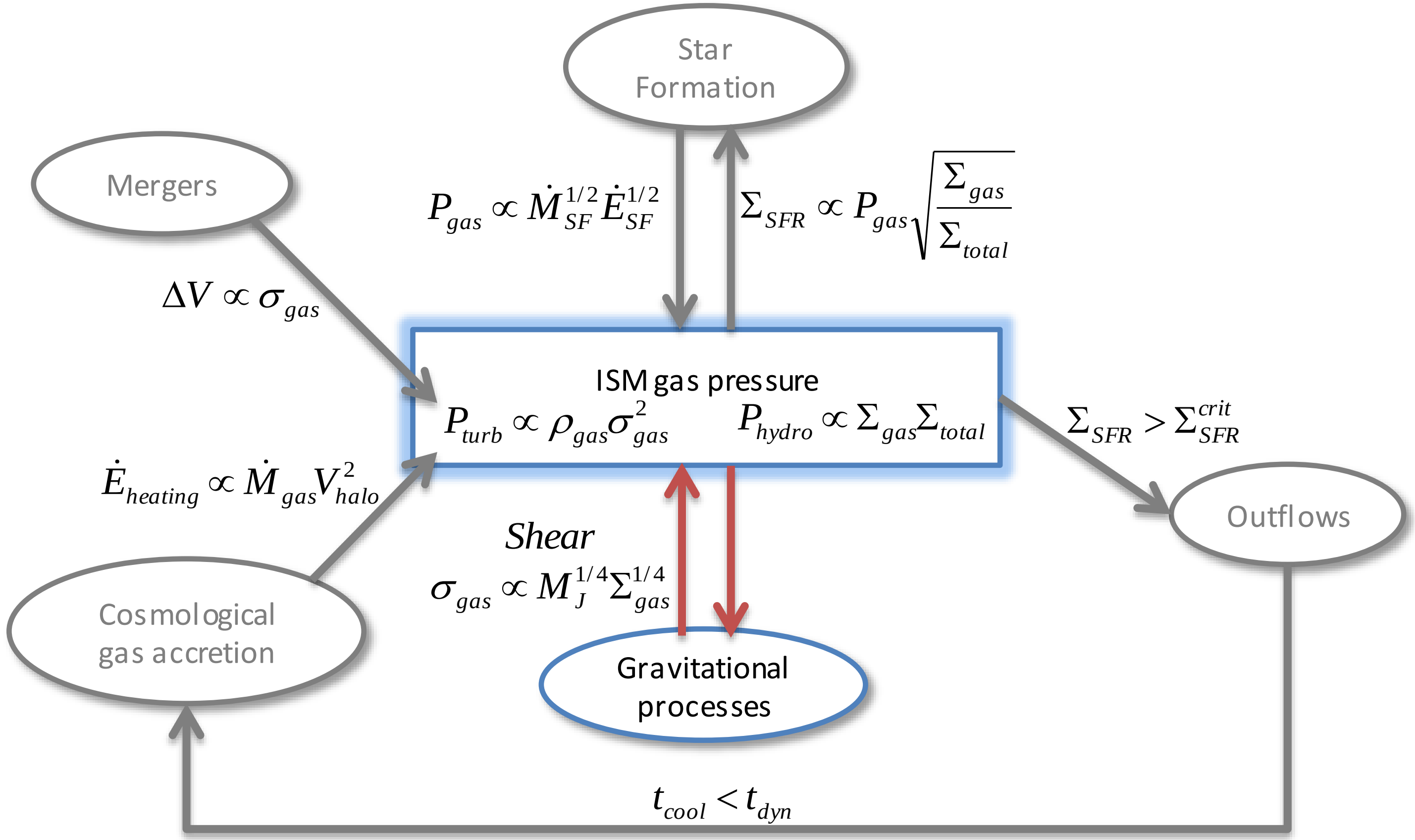


▲ Local galaxies, *Meurer et al. 2009*
● z ≈1.4

- ➢ Examine the relationship between $F_{H\alpha}/f_{FUV}$ and $\Sigma_{H\alpha}$ or Σ_R: does it extend to higher redshift and higher surface brightnesses? Linearly? Is there a relationship between the position of the galaxies on these plots and their dynamics?

- ➢ Explore galaxies at z ≈ 1 – 1.5 and lower mass galaxies at z > 2, in order to study an ISM less dominated by intense star formation and more by gravitational processes.

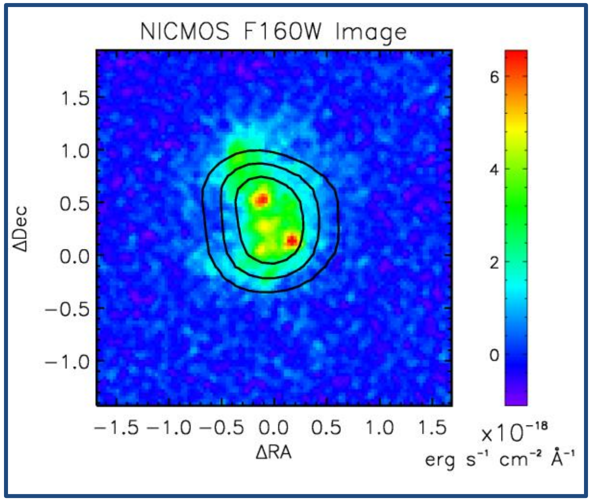
- ➢ Probe higher density medium using molecular lines observations and compare its distribution to ionized gas.



GRAVITATIONAL PROCESSES

CONCLUSIONS AND PERSPECTIVES

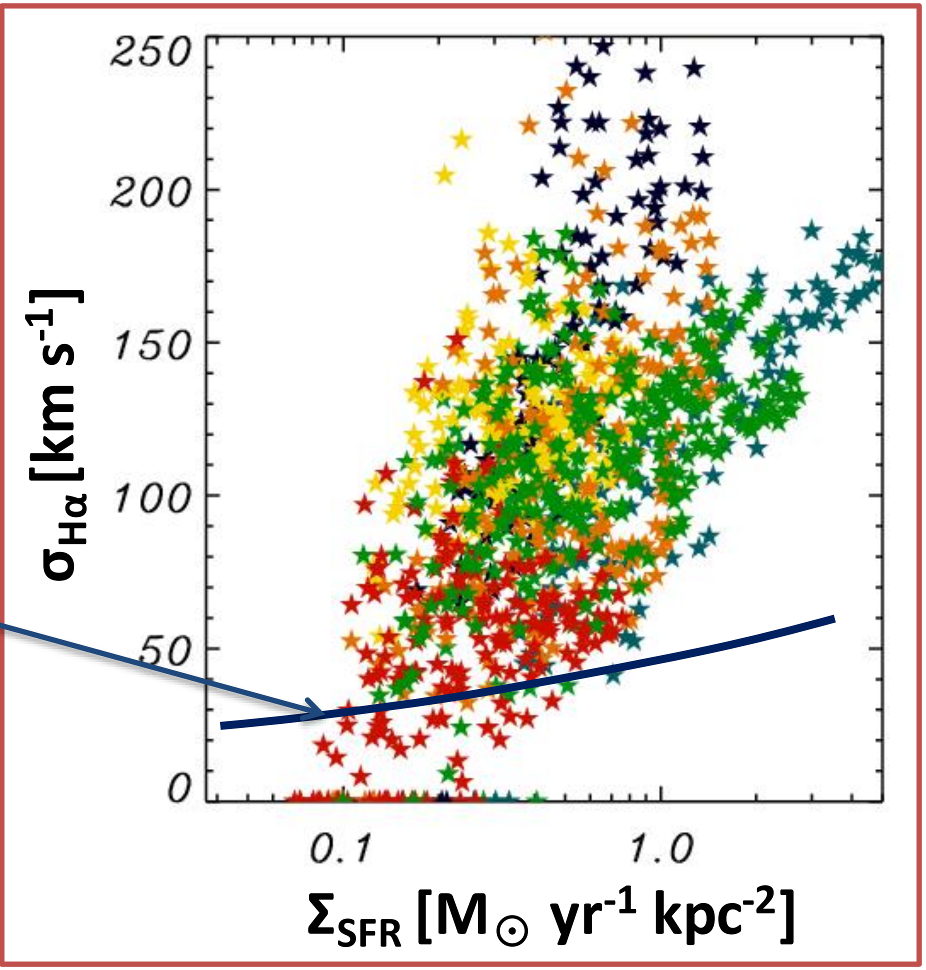
Dispersion due to clumps



Jeans instability:

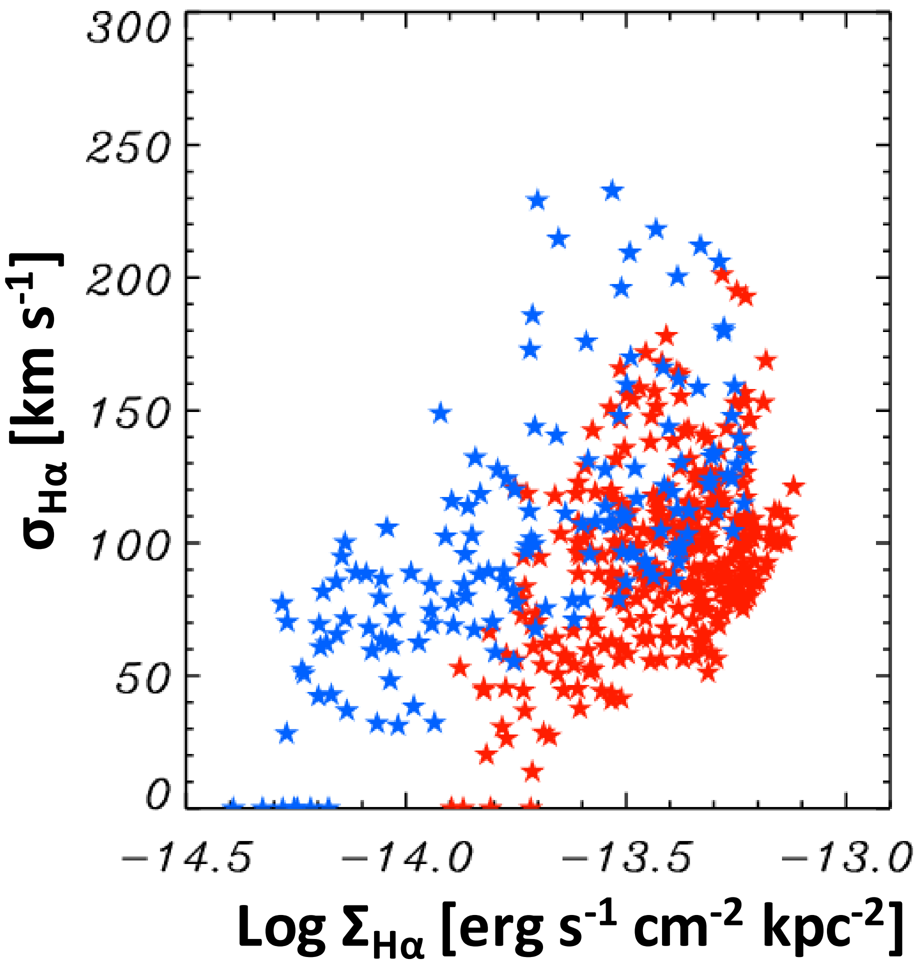
$$\sigma_{gas} \sim M_J^{1/4} G^{1/2} \Sigma_{gas}^{1/4} = 54 M_{J,9}^{1/4} \Sigma_{SFR}^{0.18}\ \mathrm{km\ s^{-1}}$$

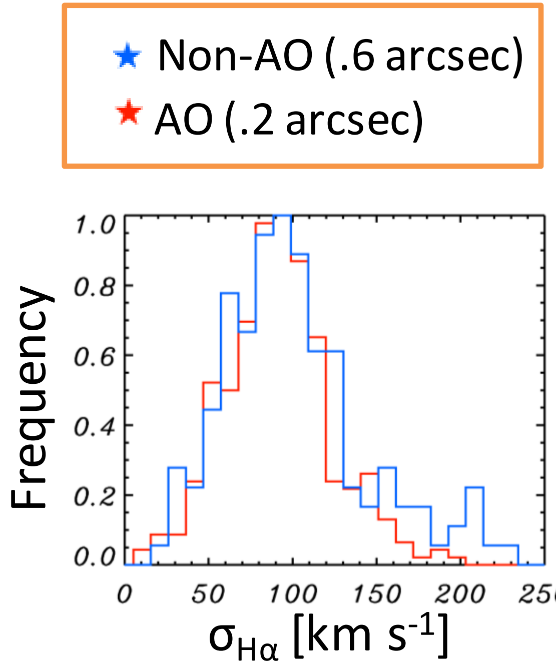
The velocity dispersions estimated from the effect of Jeans unstable clumps are not consistent with the data.



Lehnert et al. (2009)

The beam smearing effect

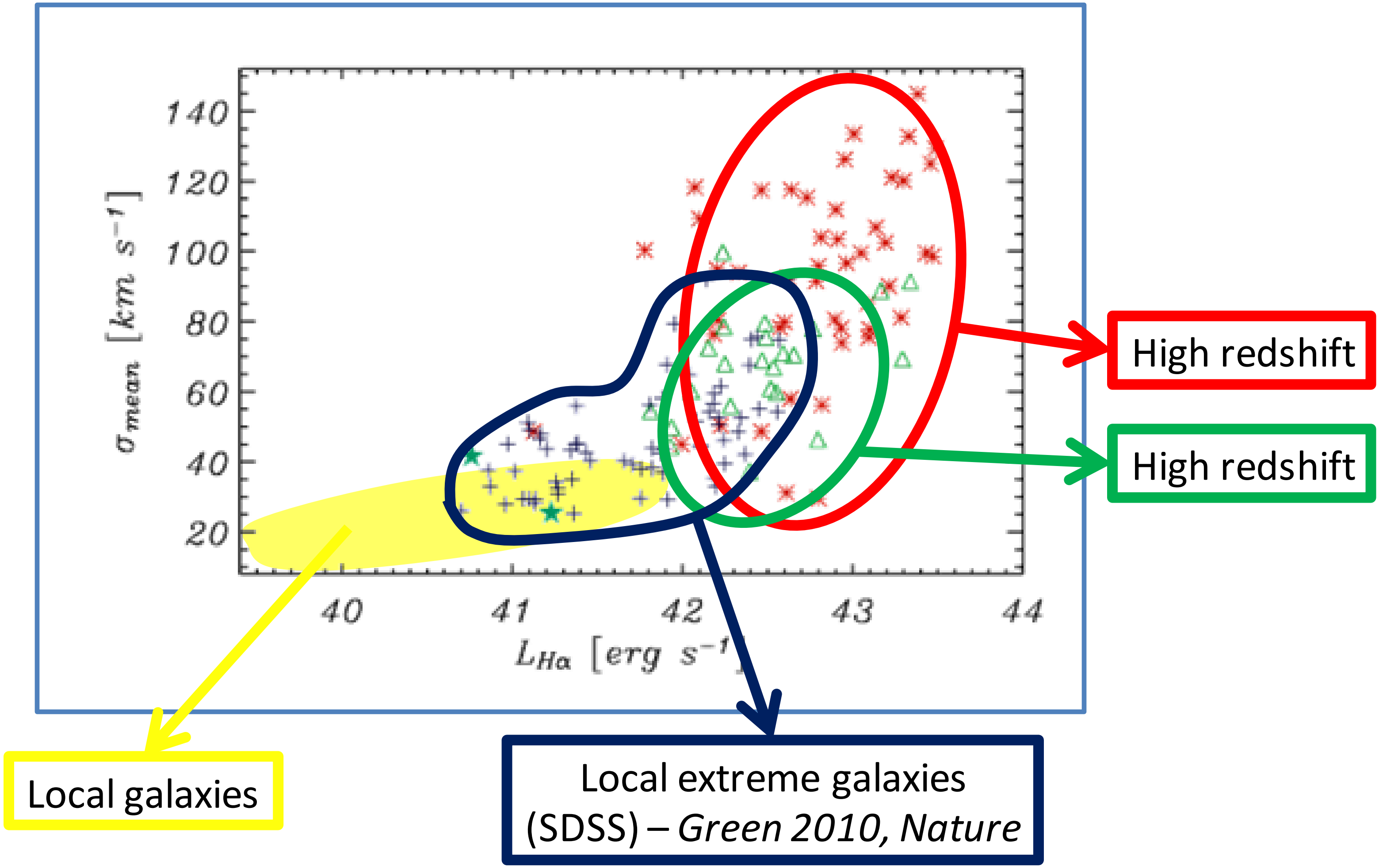




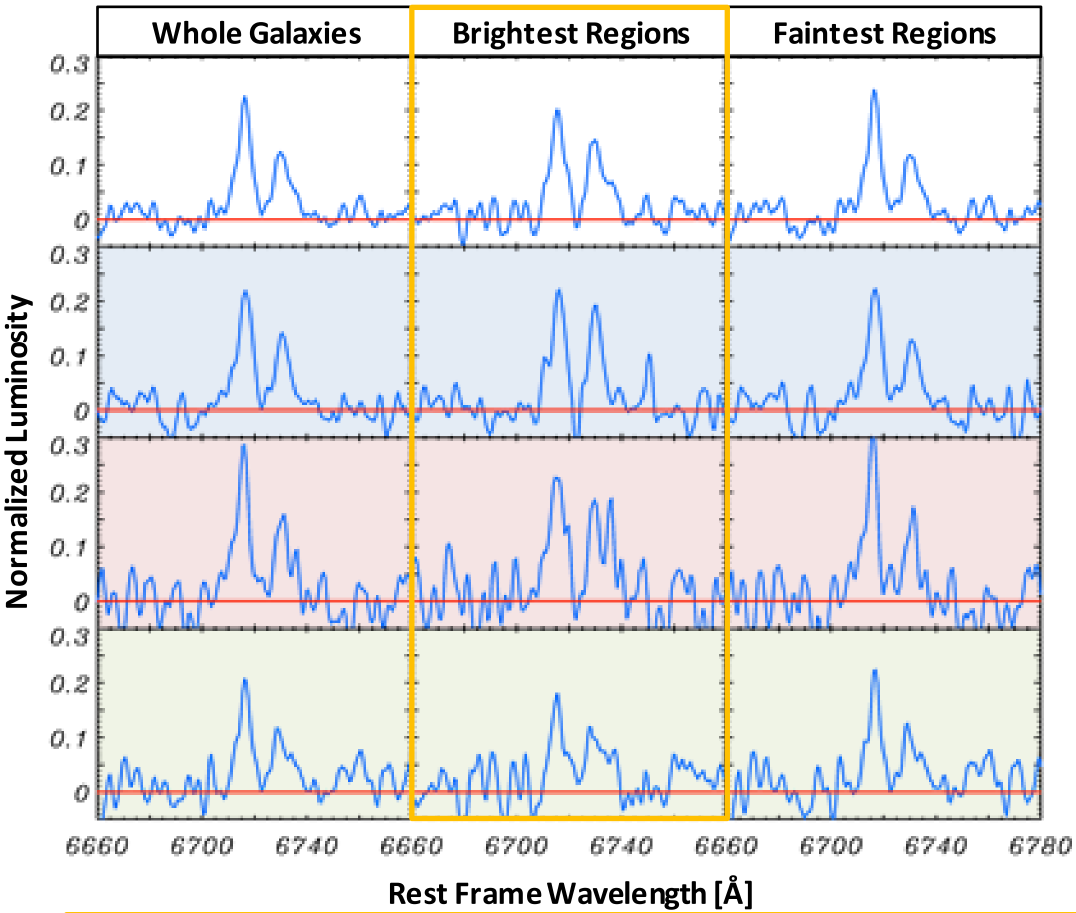
AO and non-AO observations of the same galaxy have the same range of velocity dispersions, which suggests that the effect of beam smearing is small.

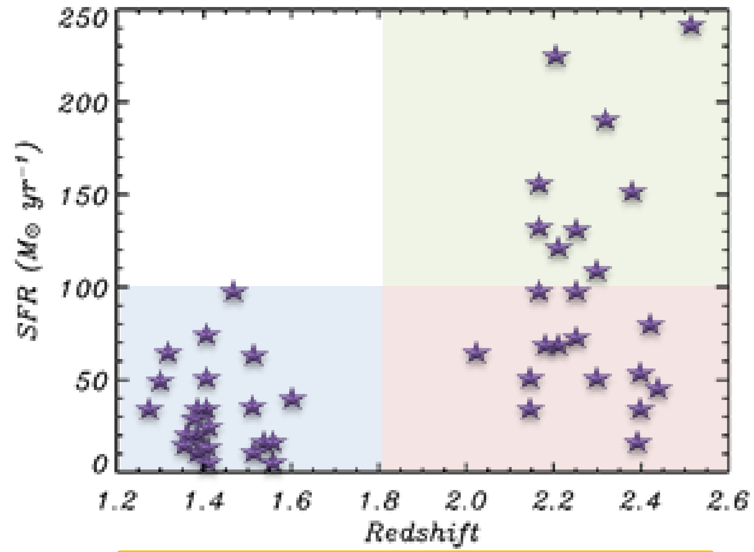
Lehnert et al. (2009)

Integrated measurements

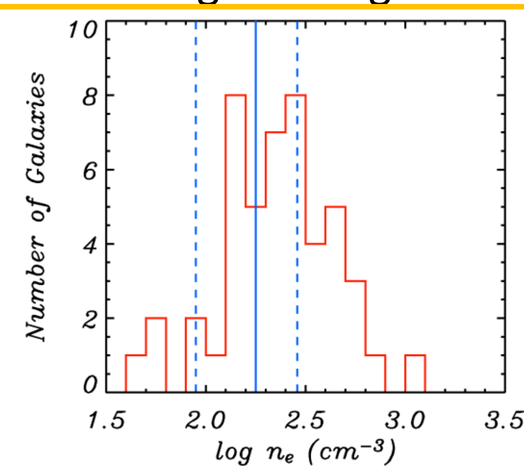


Electron densities in the brightest regions





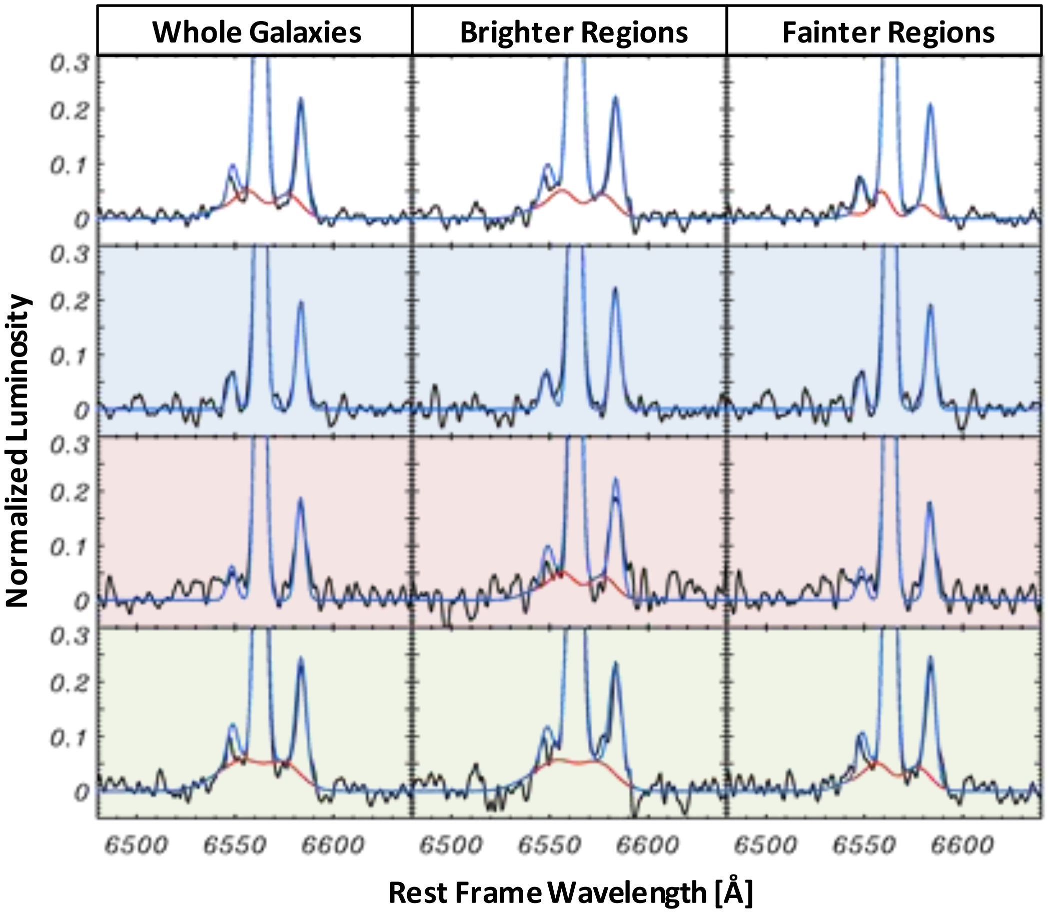
High electronic densities in the brightest regions



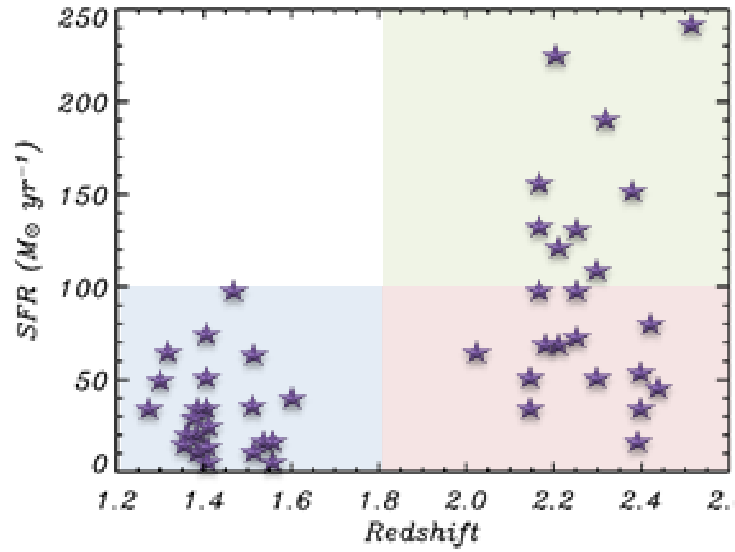
From the line ratio of the [SII] doublet, we find high [de]nsities in the brightest regions.

Le Tiran et al. (2011b)

Outflows and winds



Le Tiran et al. (2011b)



In red: Simple Broad Lines Model for Ha & NII]:

$V_{offset} = \sigma_{H\alpha} = \sigma_{[NII]}$

= [NII]/Hα constraint

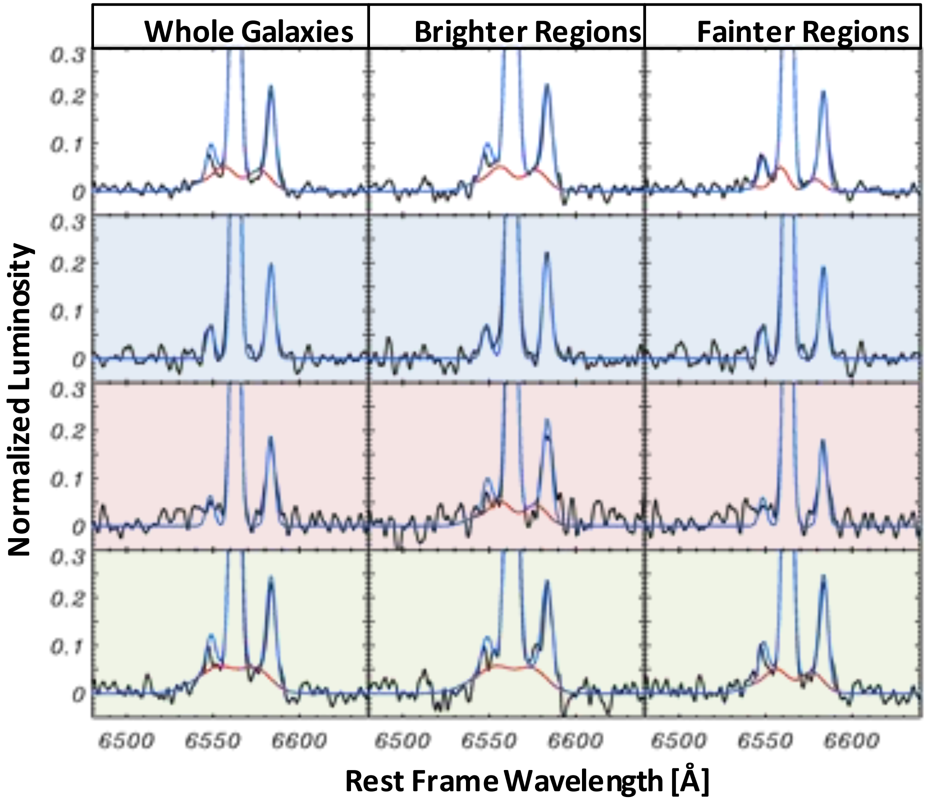
Similar conditions that extended emission in nearby starbursts

Outflows and winds

We can mimic the broad component (in red) with a very simple model:

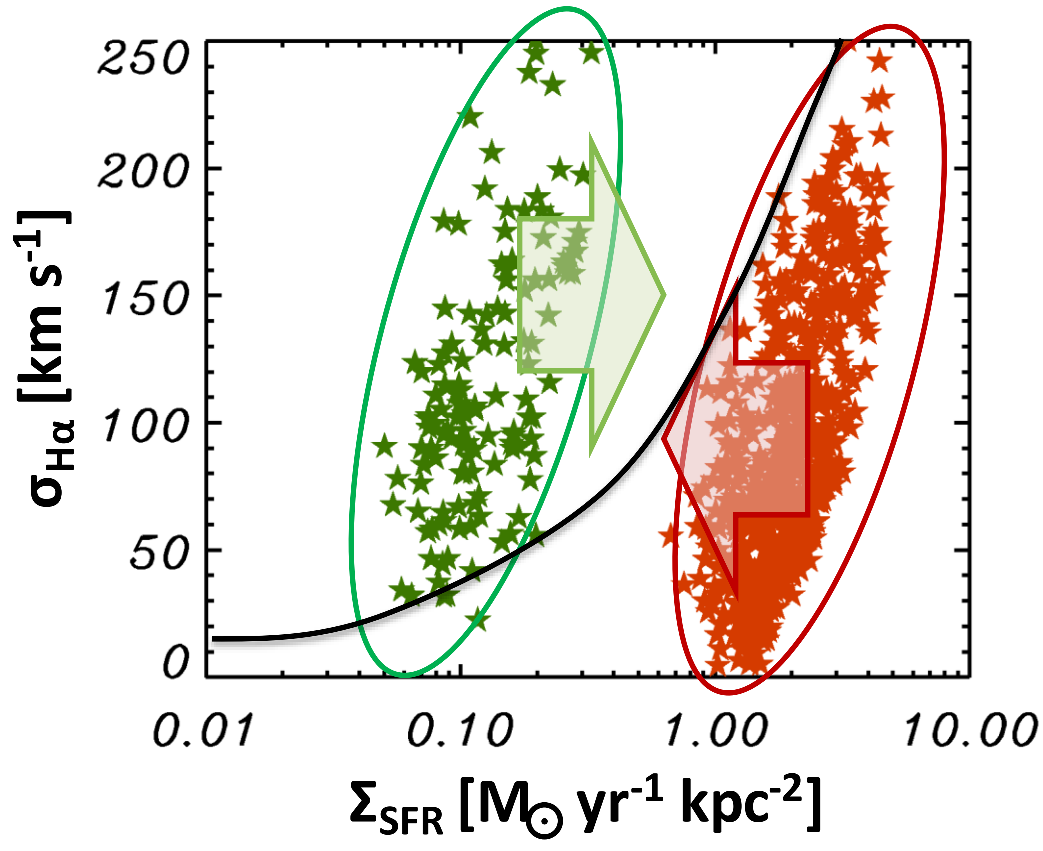
- 3 broad lines for Hα & [NII]
- $V_{offset} = \sigma_{H\alpha} = \sigma_{[NII]}$ and the line ratio [NII]/Hα is constrained from shock models.
- $F_{H\alpha, broad} = 0.05 \times F_{H\alpha, narrow}$

Those conditions are similar to the extended emission in nearby starbursts .

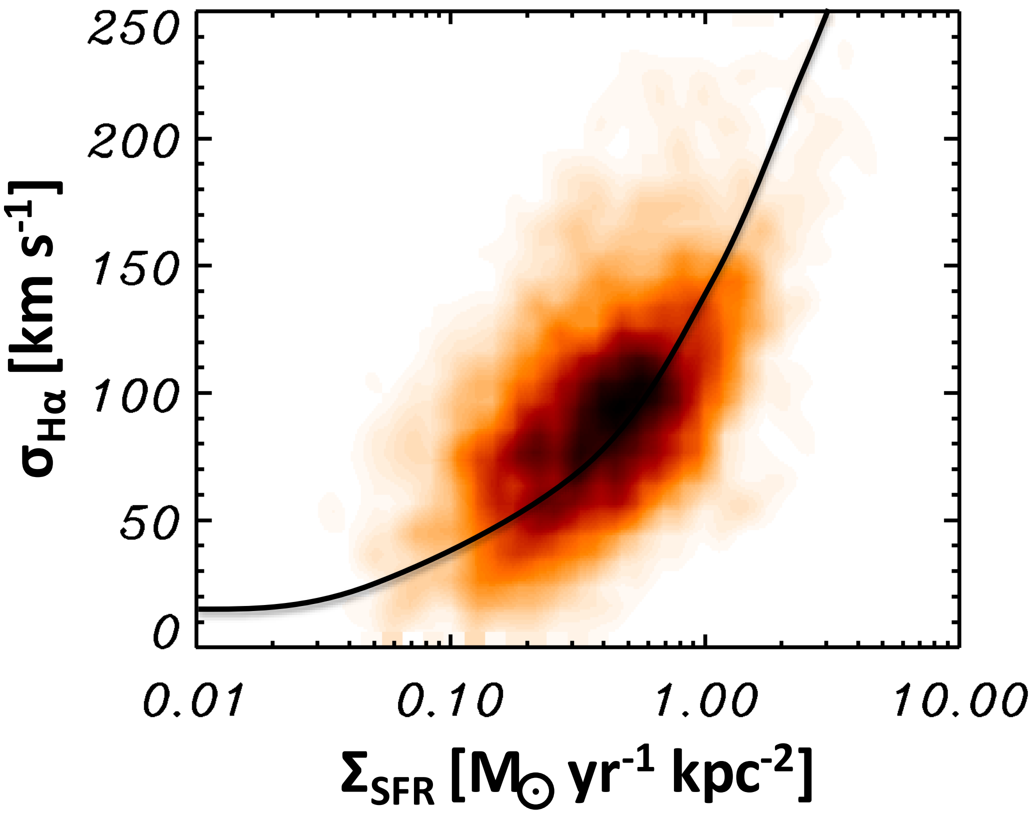


Le Tiran et al. (2011b)

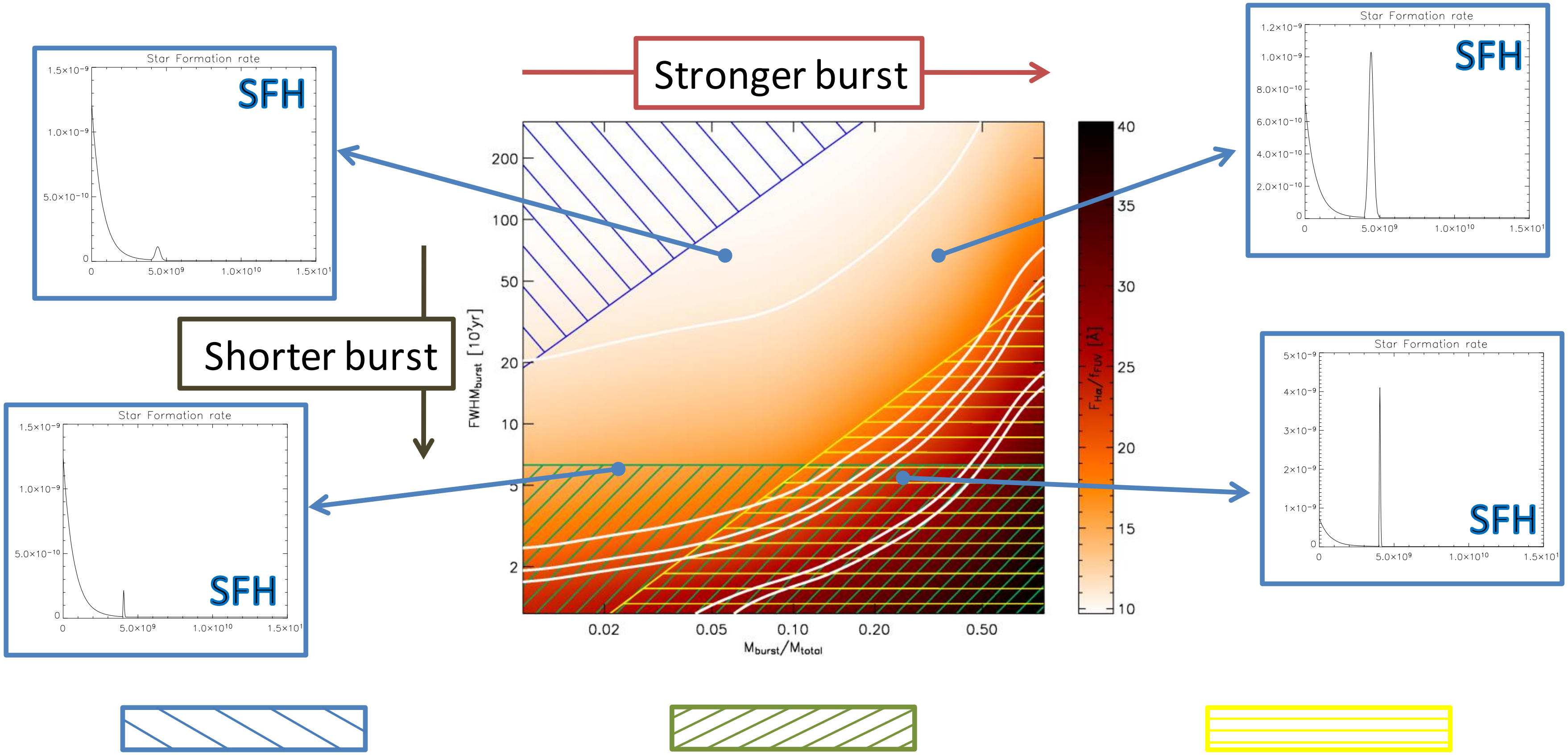
Making a normalized relation



Making a normalized relation



Bursts of Star Formation



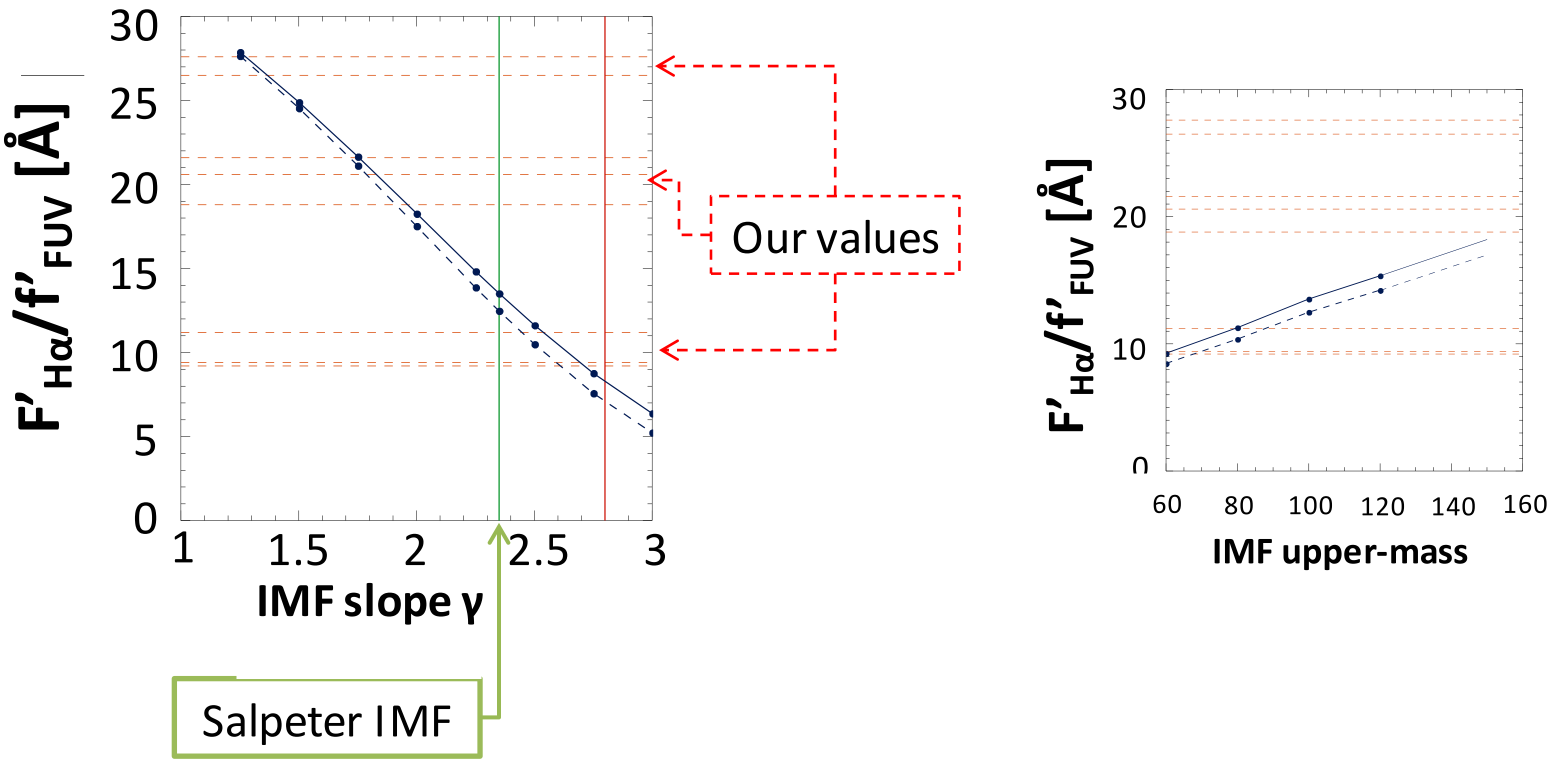
Low Hα equivalent width

Causality argument

High Hα equivalent width

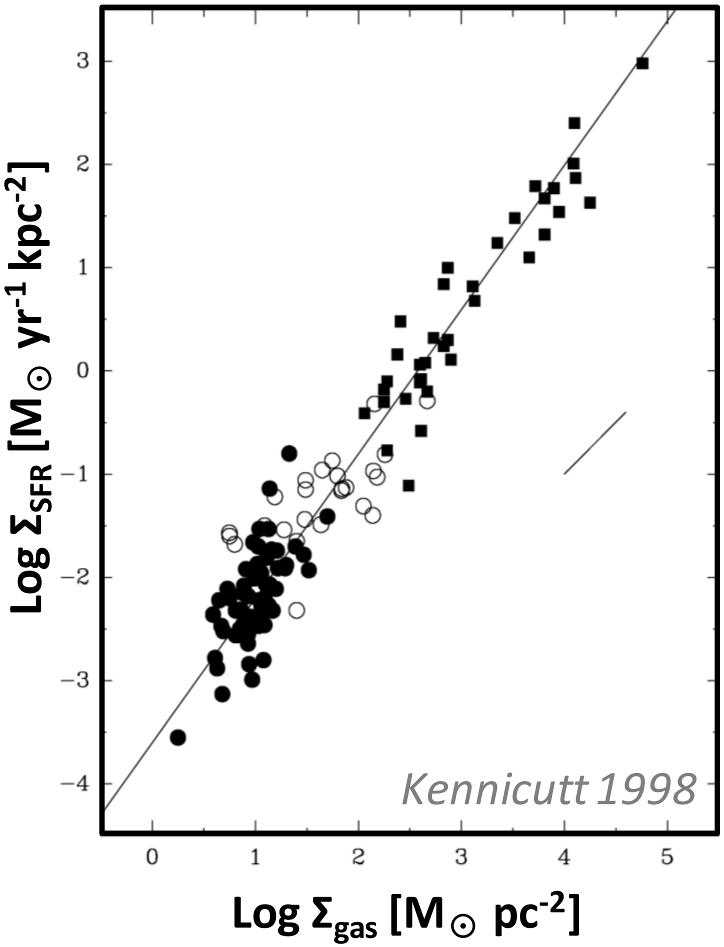
A burst of star formation that could explain such high values of $F_{H\alpha}/f_{FUV}$ would be unrealistic.

Variation of the IMF?



Variations of the slope (or upper-mass) of the IMF could explain our observations

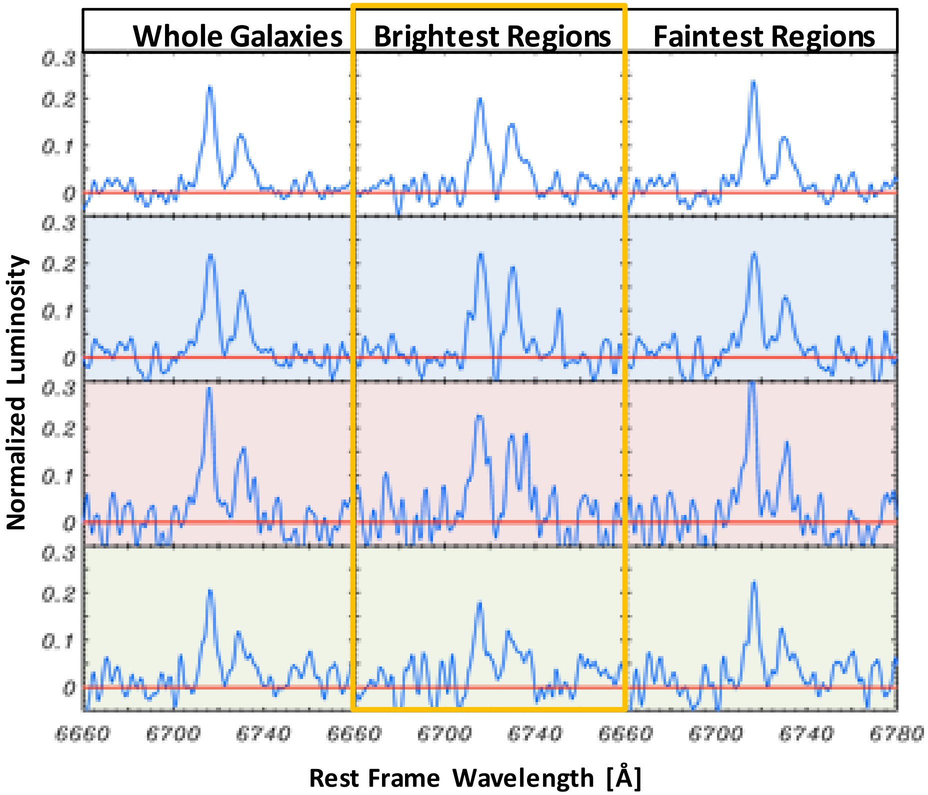
Self regulation of star formation

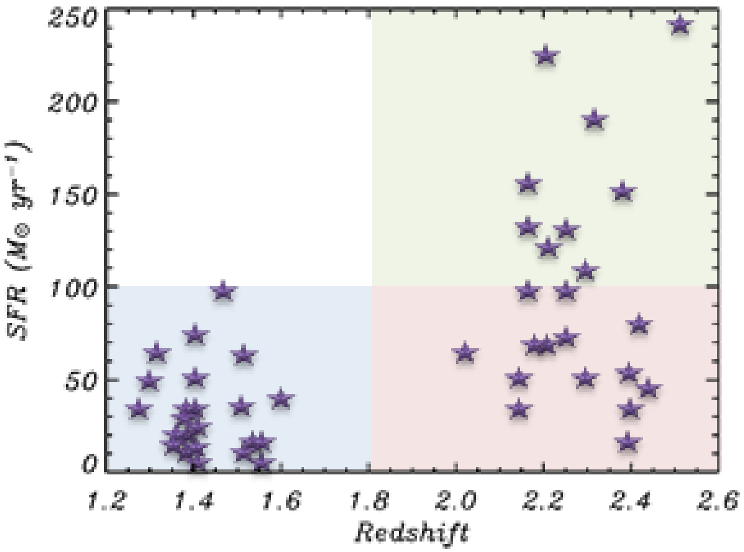


The Schmidt-Kennicutt law tells us that there is a simple relationship between pressure and star-formation rate over many orders of magnitudes.

Self regulation of star formation:
Star formation increases the pressure in the ISM and higher pressures increase the star formation rate.
It has been proposed for the regulation of star formation in nearby galaxies (*Silk 1997, 2001; Wang+1998*).

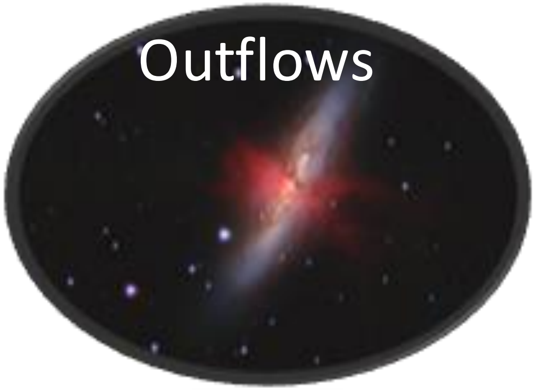
Electron densities in the brightest region





Le Tiran et al. (2011b)

Diversity of phenomena



However, galaxy evolution might not be dominated by these large scale mechanisms!

PURPOSE OF THIS THESIS

Main questions to answer

?

What is the primary driver of the large spatially resolved line widths observed in the optical emission line gas in galaxies at z≈2?

- Turbulence generated by gravity in a collapsing disk?
- Cosmological accretion of gas?
- Intense star formation?

?

How do gas densities, pressures, intensity of the radiation fields, and/or shocks compare to local galaxies?

How? Investigate the physical processes that shape the warm ionized media in galaxies from z=1-3 by carefully analyzing the properties of their optical emission lines. Get insight into the physics underlying the dynamics and excitation of the warm ionized gas and to compare this with the properties of nearby galaxies.