Chemical evolution of star forming galaxies up to z~3 "AMAZE+LSD"

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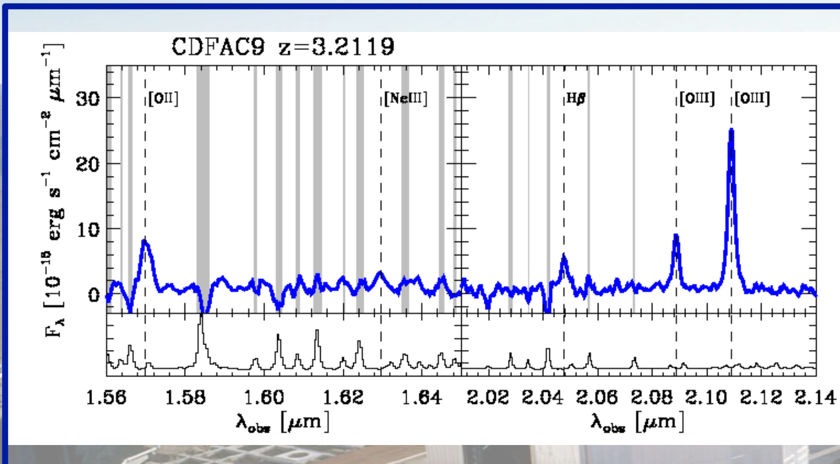
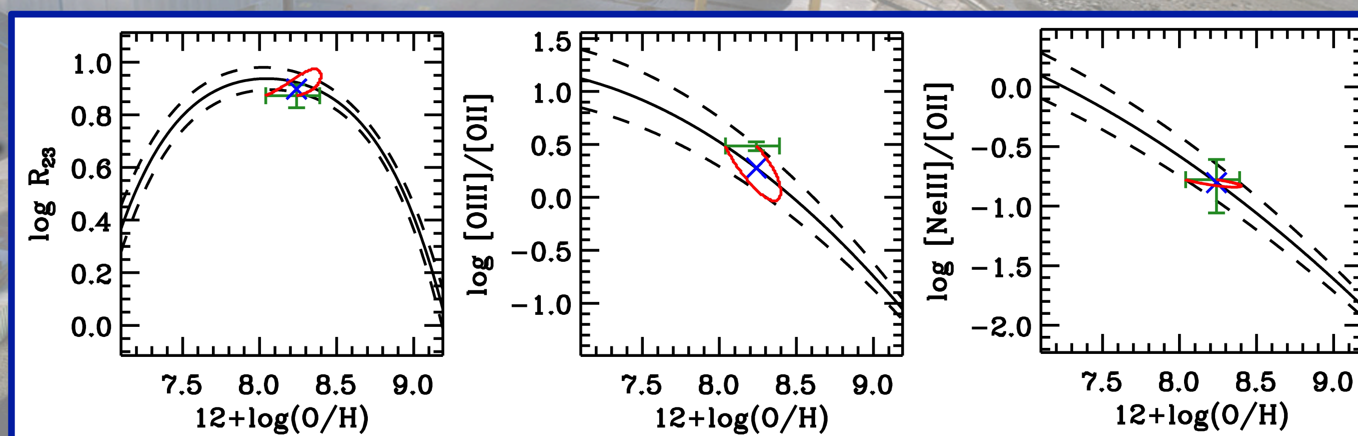
AMAZE Assessing the Mass-Abundance redshift[Z] Evolution

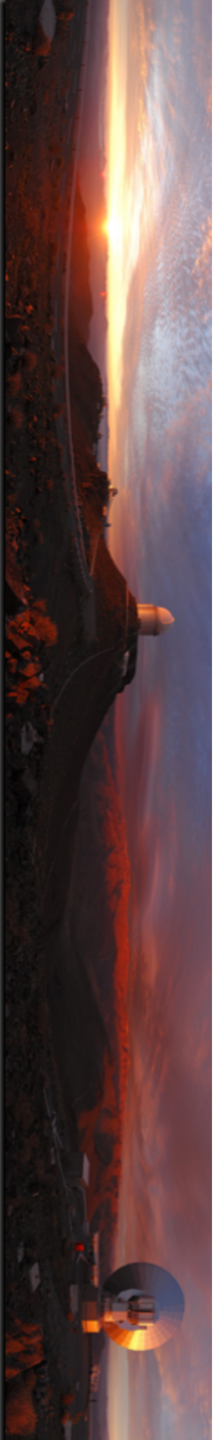
LSD Lyman-break galaxies Stellar populations and Dynamics



- **Sample of 34 LBG's at z~3.3**
- **Metallicity measured with [OIII], [OII], Hβ and [NeIII] ratios.**
- **26 seeing limited.**
- **8 AO, diffraction limited.**

SINFONI - VLT
NIR - IFU





Outline

I Integrated properties.

- Galaxy scaling relations such as Mz, FMR, FP, etc.
- Metallicity evolution at z~3.4?.

II Resolved properties

- Dynamics.
- Metallicity gradients.
- Resolved ΣSFR → Gas content morphology & sizes.

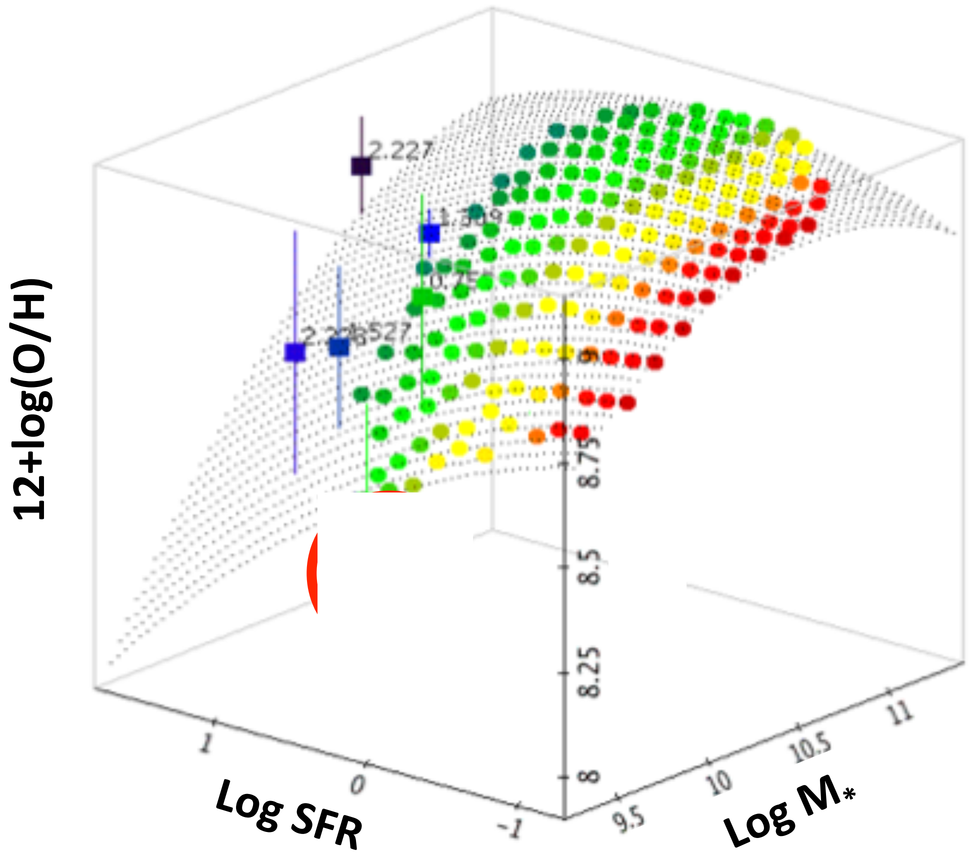
III Comparison with models

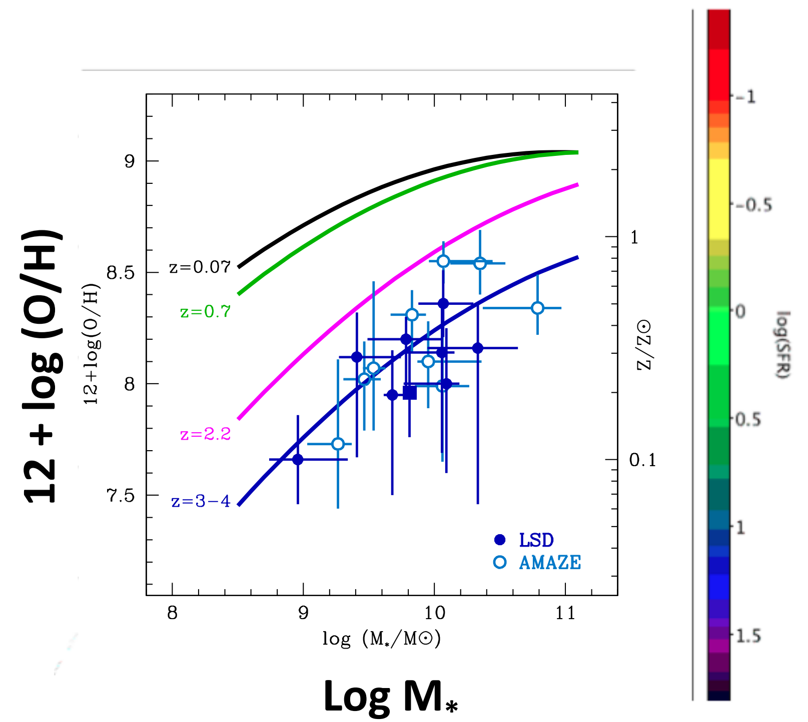
- Analytical models with flows proportional to SFR (Erb08).
- Cosmological simulation **RAMSES & RAMSES-CH.**

IV Summary

I) Integrated properties at z~3

Fundamental Metallicity Relation (FMR)



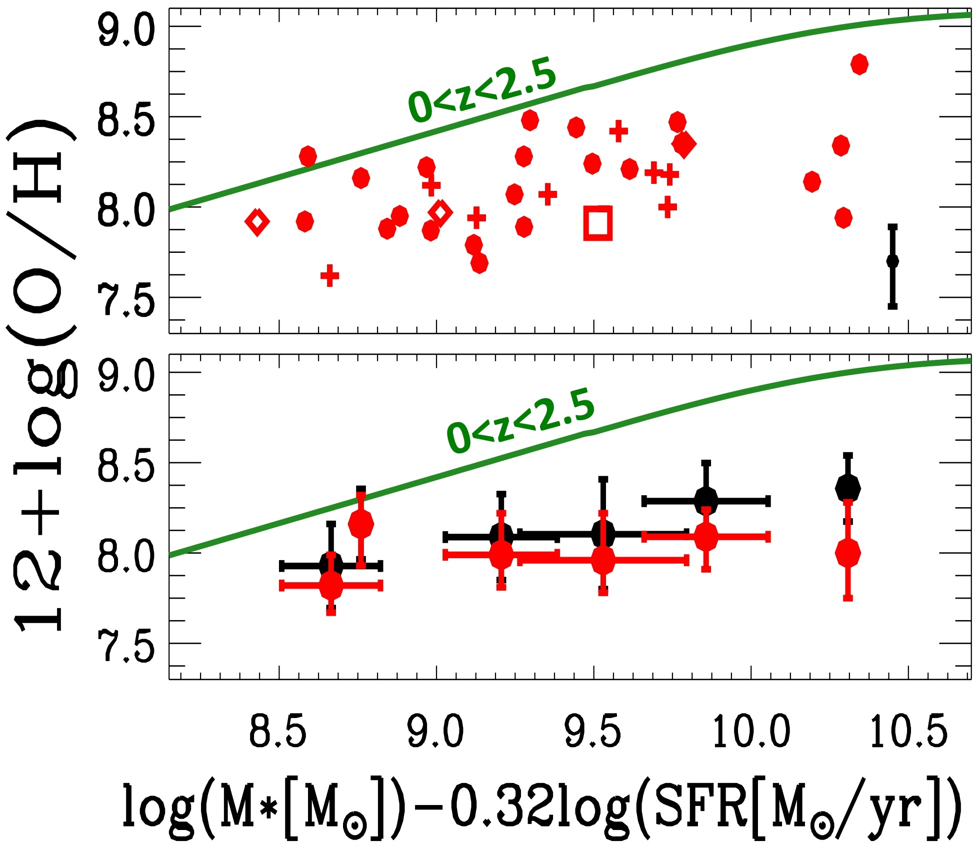


Mannucci et al. 2010

- Scatter 0.05 dex.
- FMR holds homogeneity 0 < z < 2.5.

"Star forming galaxies live in a slowly equilibrium between star formation, inflows and ubiquitous outflows "(**Filantor +11**)

Metallicity evolution at z~3.5



-Strong feedback by UV field & SNe change SF efficiency at z~3?

- Mergers?

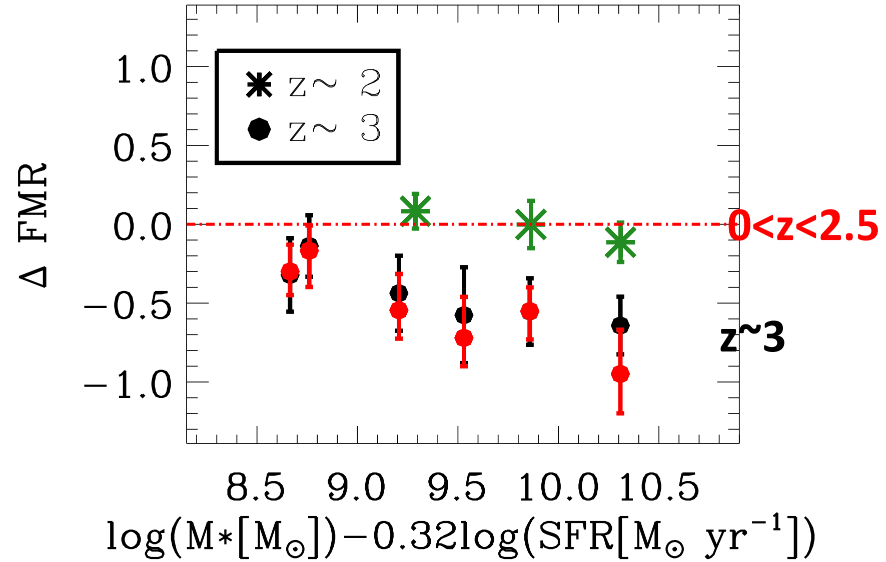
-Pristine gas excess?

Troncoso in prep. 2012

Asterisk: Law et al. 2009

Lehnert et al. 2009

Circles: AMAZE+LSD at z~3.3



Massive, low-SFR galaxies present higher deviation respect to FMR.

II) Resolved properties.

AMAZE Assessing the Mass-Abundance redshift[Z] Evolution

LSD Lyman-break galaxies Stellar populations and Dynamics

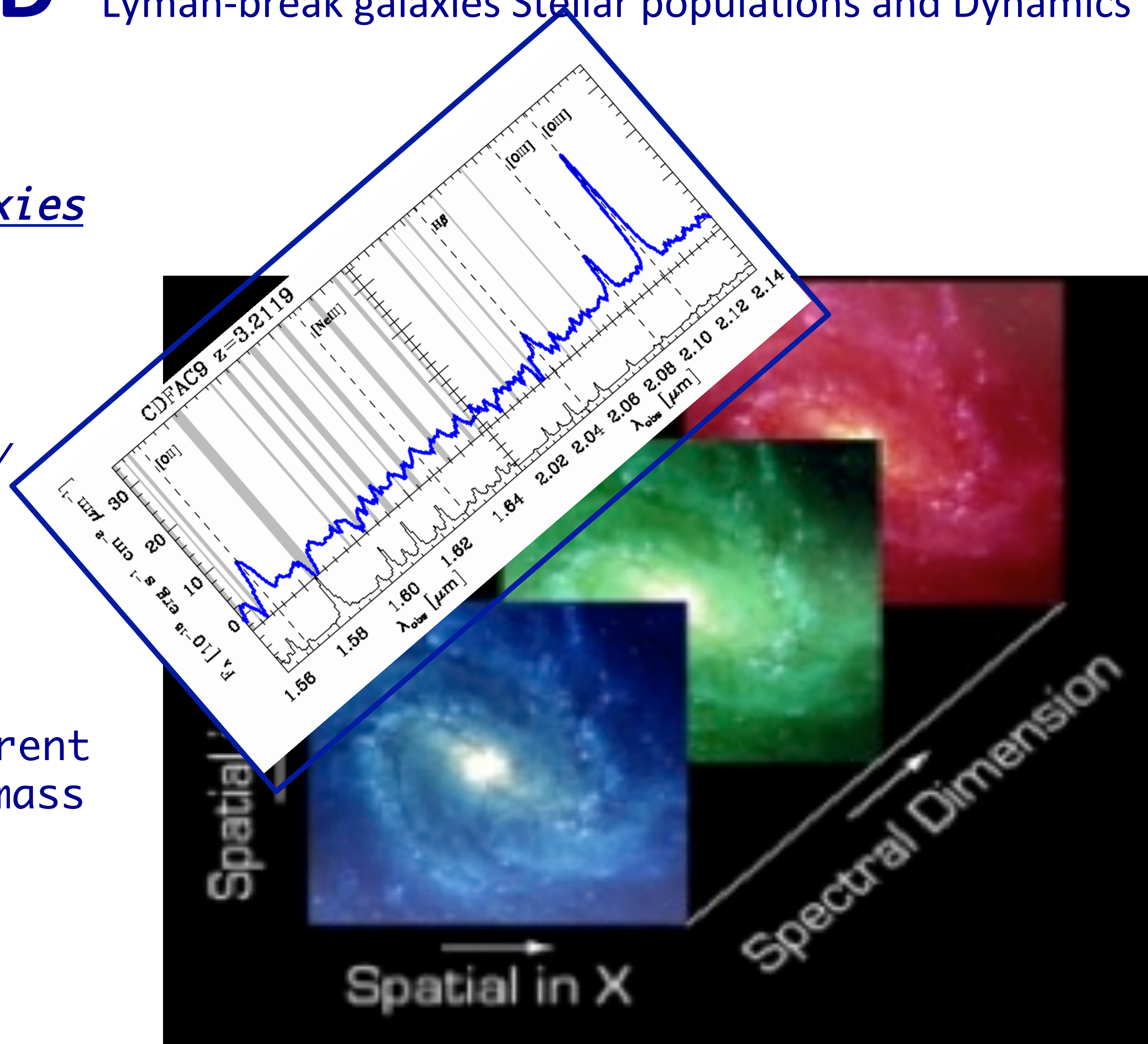
Spatially resolved galaxies

1) Dynamics from the brightest lines.

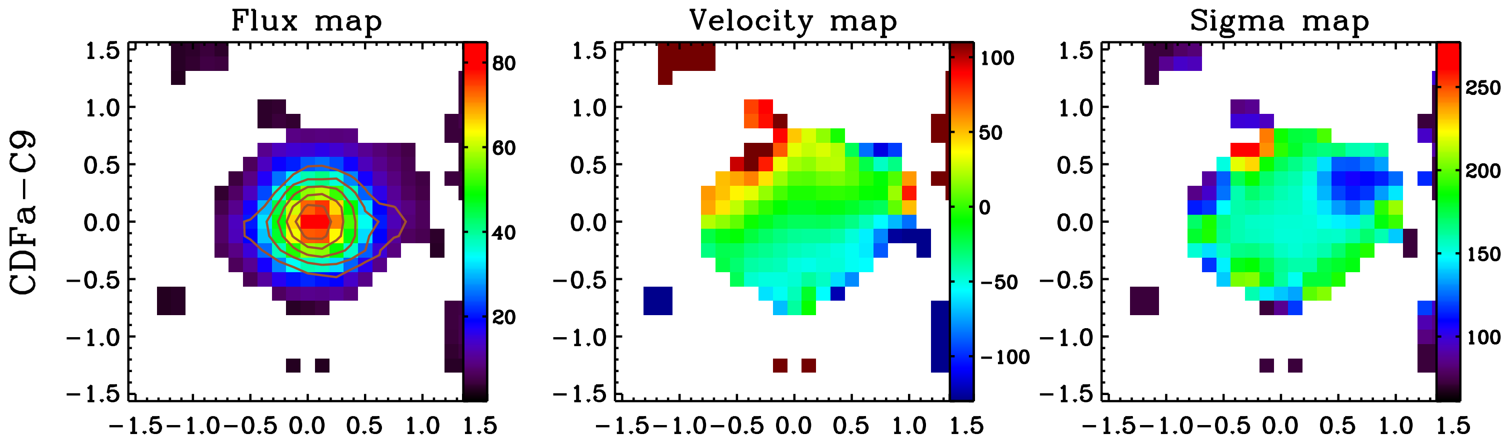
2) Lines ratios at every pixel → Metallicity gradients.

3) Resolved SFRs.

“Disentangle the different process of galaxy mass assembly”



Dynamics: AMAZE+LSD at z~3.4

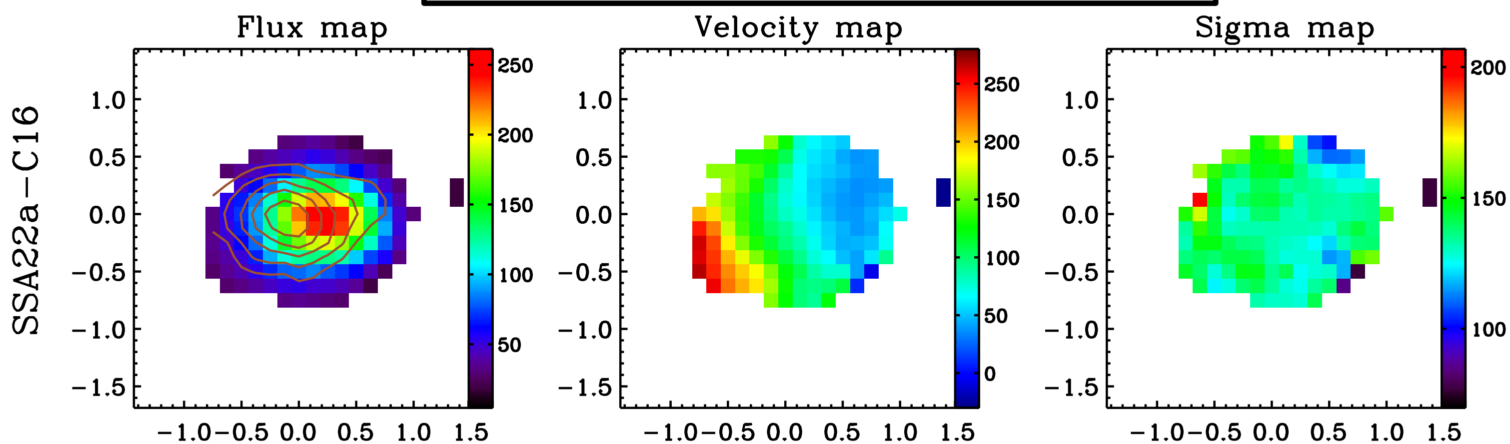


Gnerucci et al. 2011

35% extended, clumpy, rotating disks, although highly turbulent

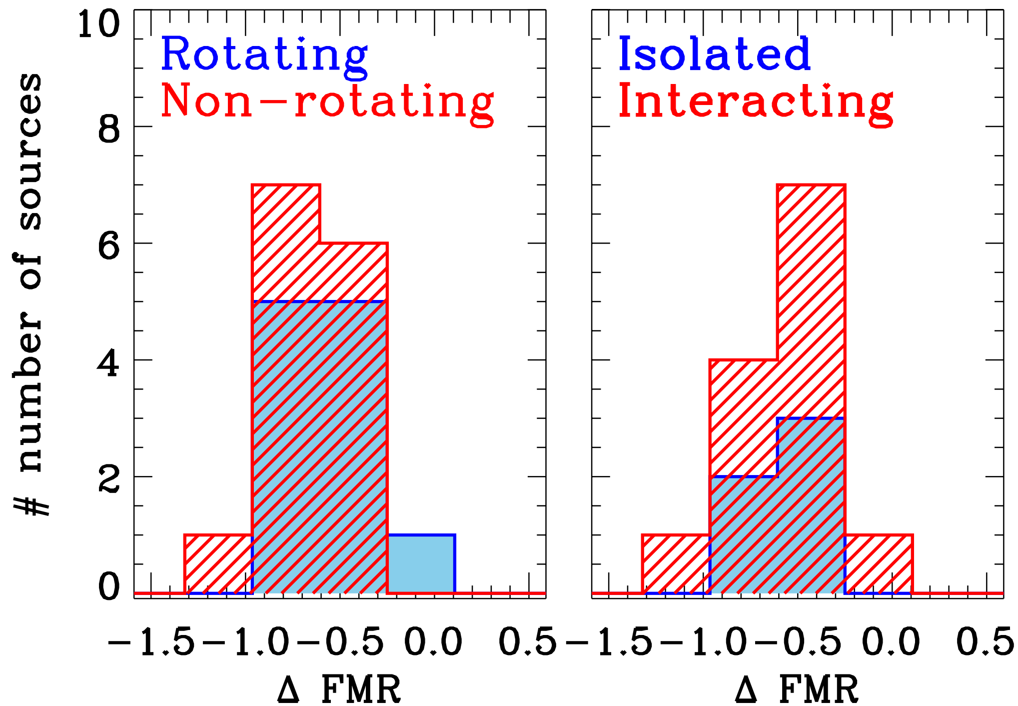
45% not rotating (mergers?)

20 % not classified



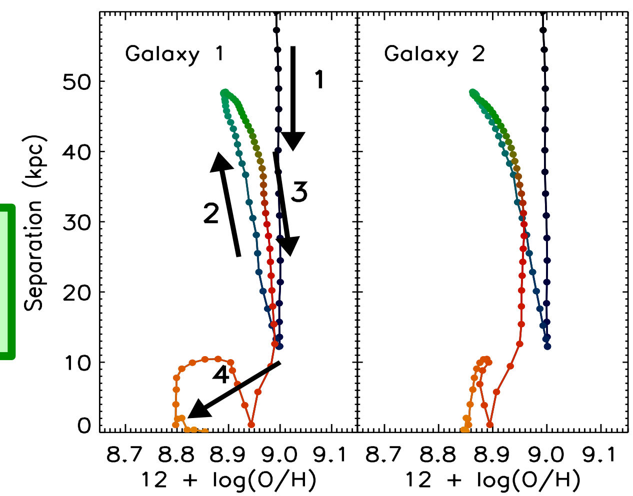
Why do we find differences respect to the FMR?

AMAZE+LSD at z~3.3



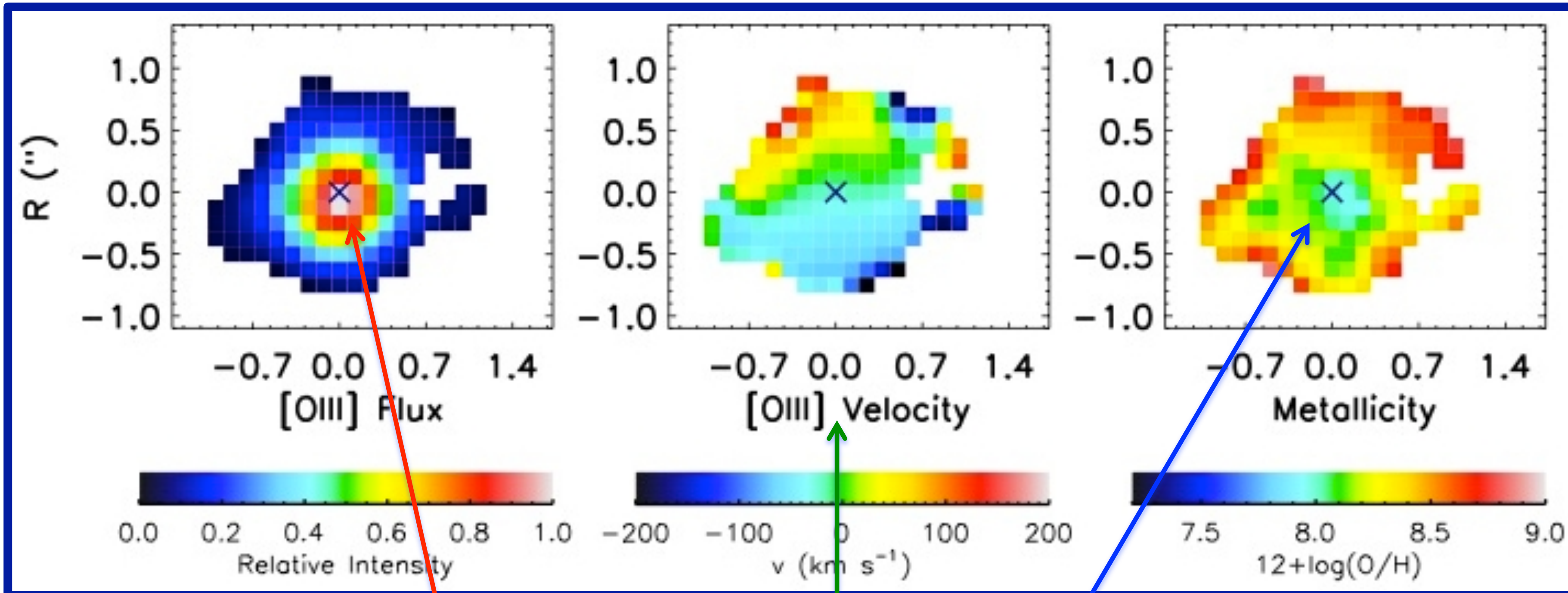
Enhanced mergers at z>3.3 can NOT be the only reason for the deviations from the FMR at z>3. Which other mechanisms play a rol?

Rupke+11, Perez+11, Torrey +12



No correlation between dynamical state/environment and differences with respect to FMR.

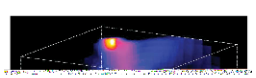
Correlation between the peak of the star formation and the part of the galaxy with lowest metallicity



Likely due to prominent *inflows of pristine* gas which boost the star formation but also dilute the metals.

Cresci+10

Troncoso in prep.



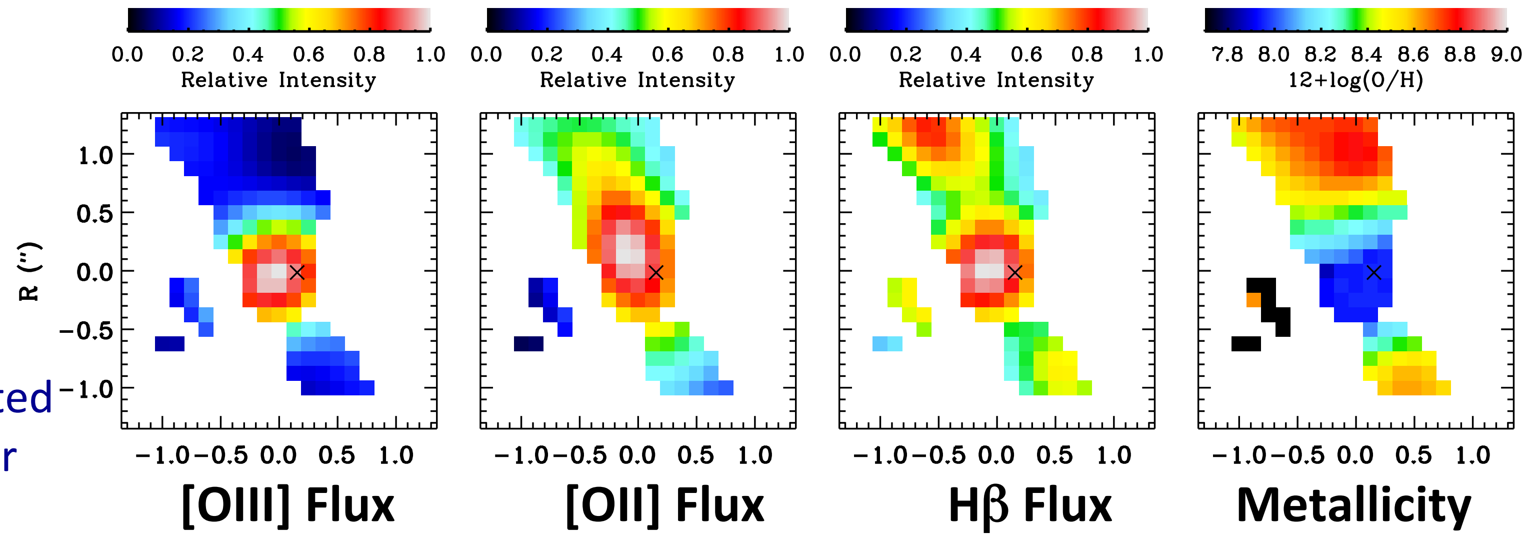
Massive rotating disk

Dekel+09,+10

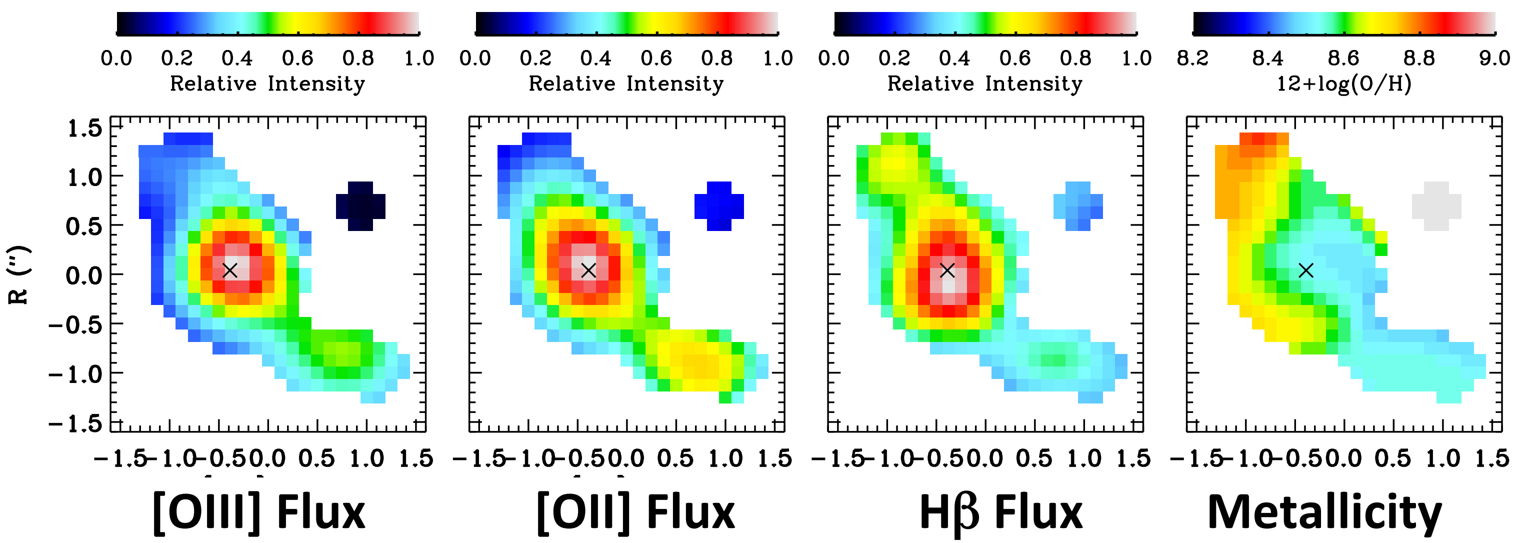
Dave+11

Metallicity gradients resolved in 10 sources

CDFS16767
z=3.6241



- Minimums of metallicity associated with peaks of star formation.

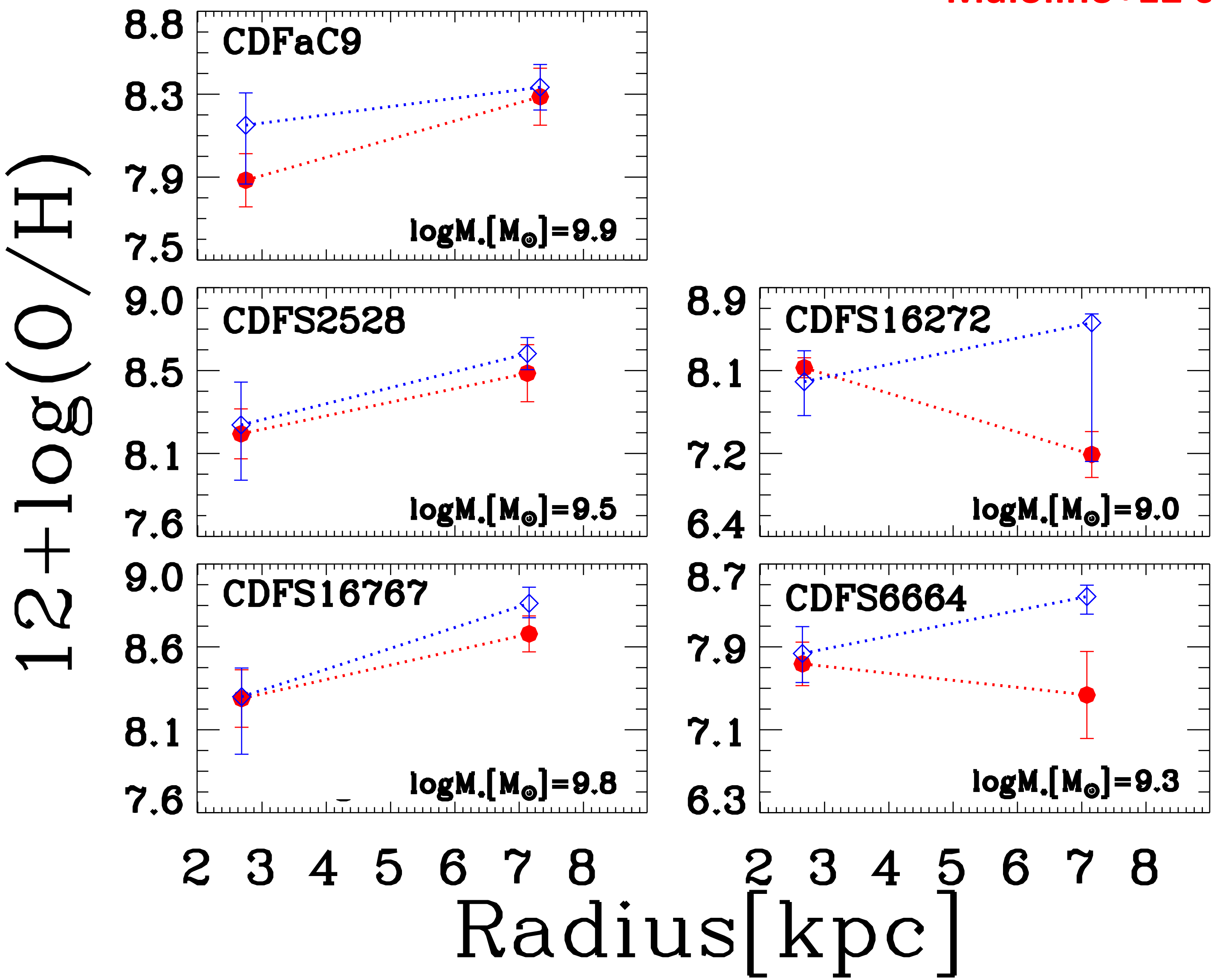


CDFS4417-CDFS4414
z=3.4733-3.4714

Troncoso in prep. 2012

Metallicity gradients I

Maiolino+08 calibration
Maiolino+12 calibration



Metallicity gradients I

Maiolino+08 calibration
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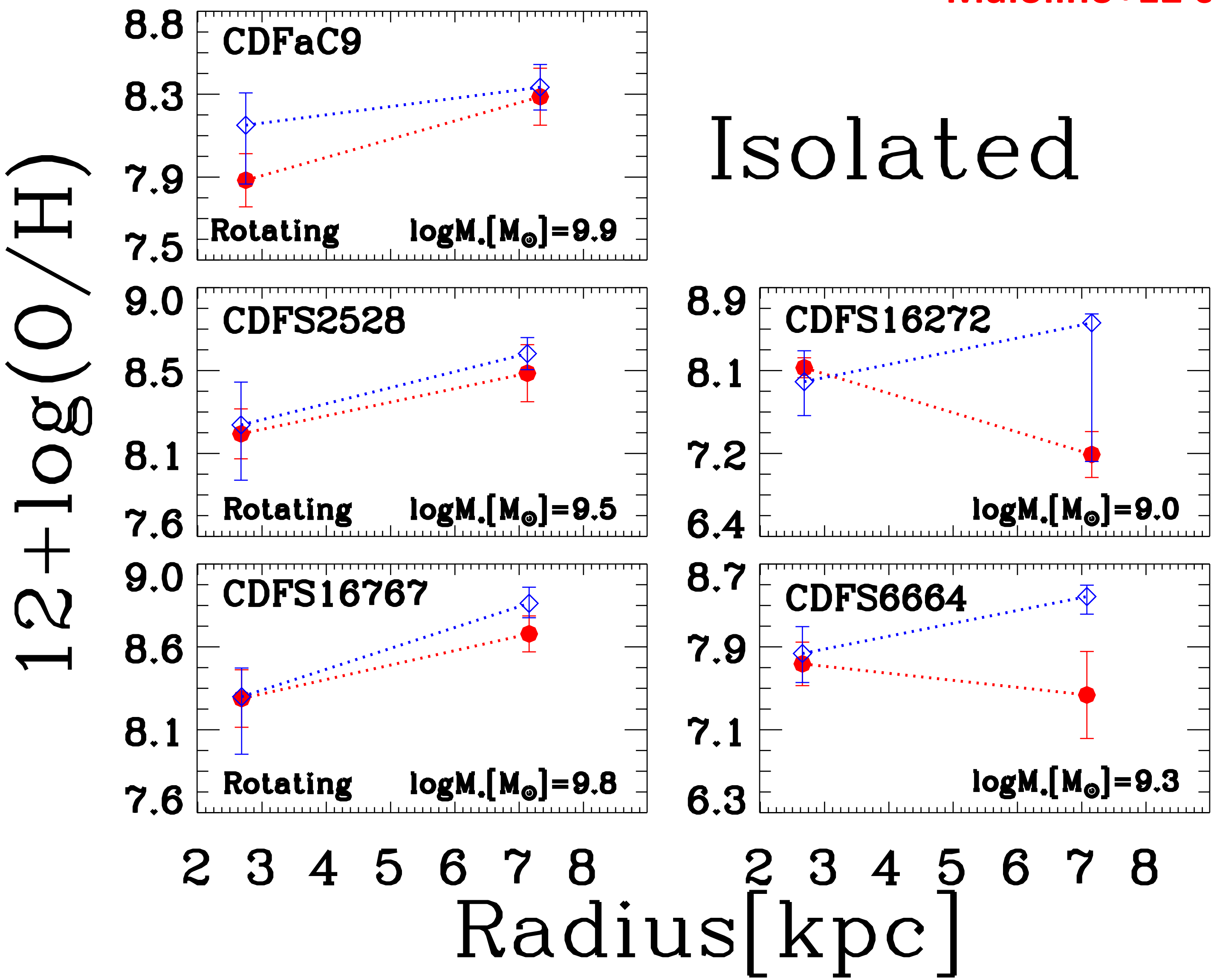
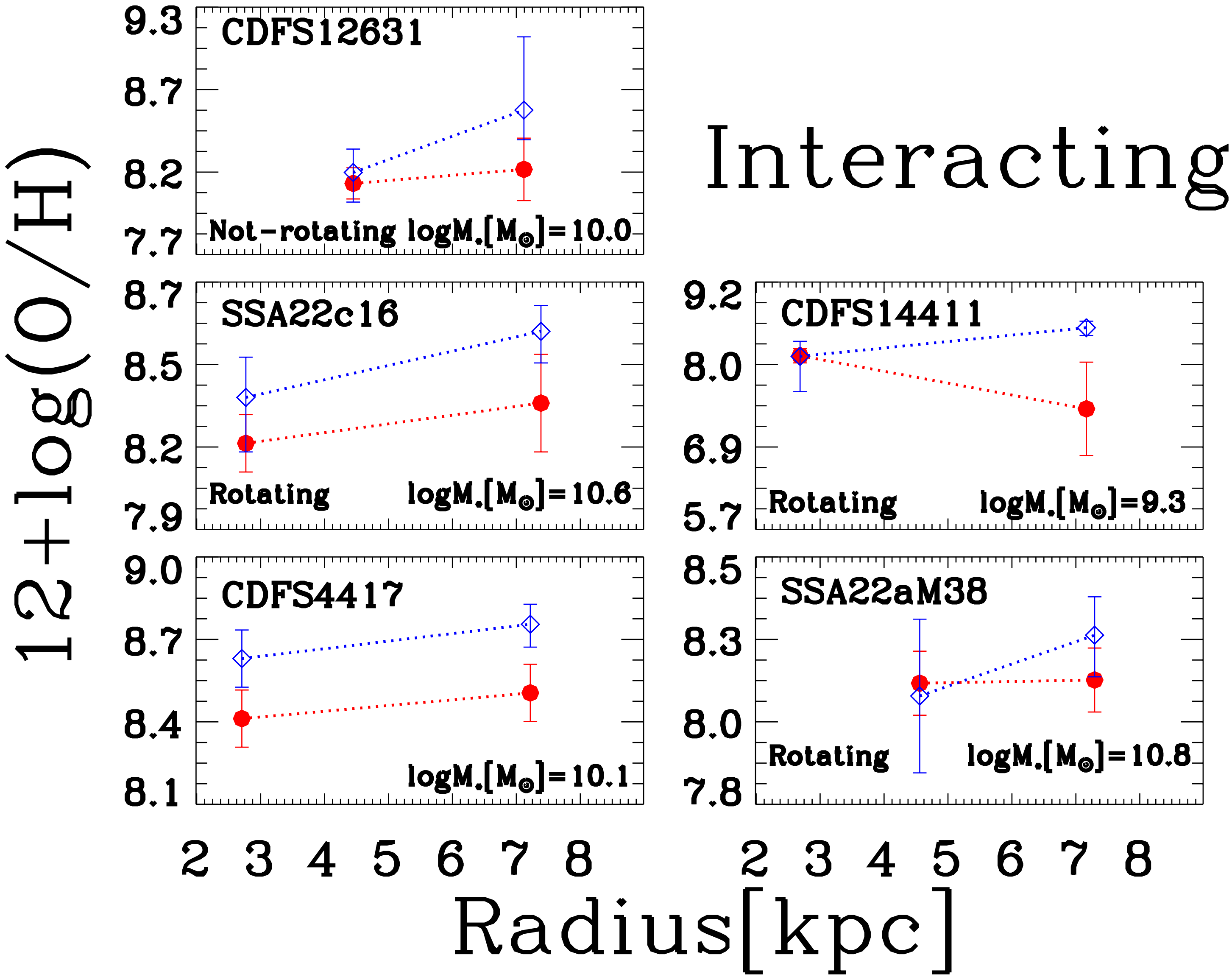
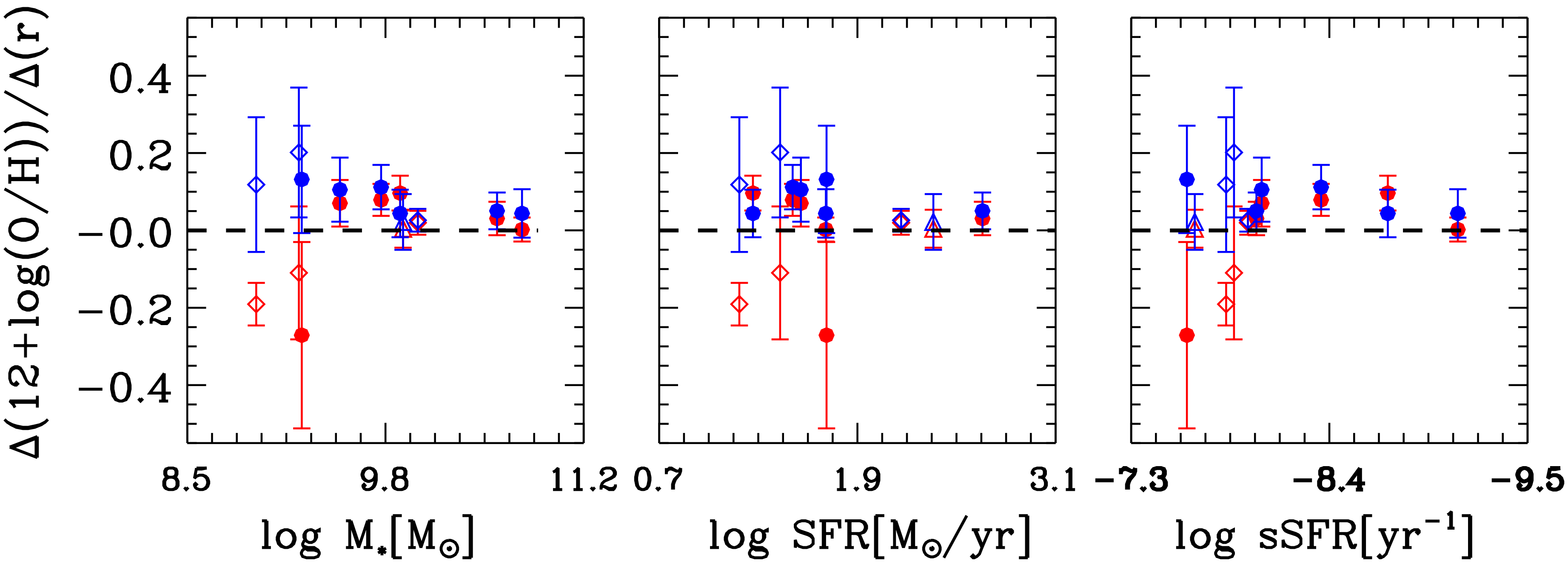


Metallicity gradients II

Maiolino+08 calibration
Maiolino+12 calibration

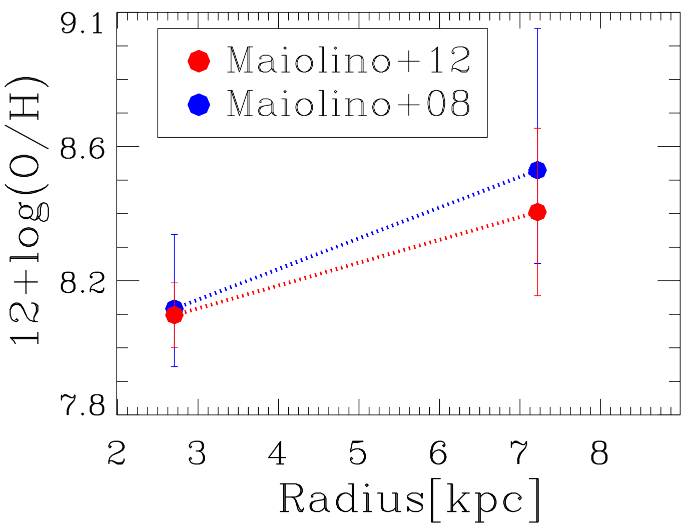


Metallicity gradients



Maiolino+08 calibration

Maiolino+12 calibration



Metallicity gradients as fingerprints of galaxy evolution!

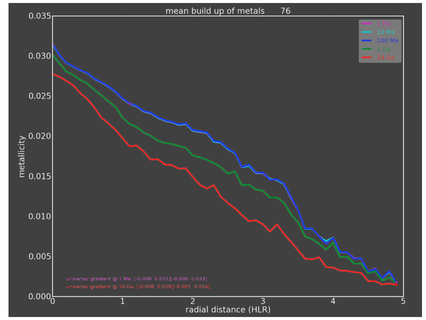
Gas role?

TIME

Gas fraction

z ~ 0

Negative gradients, some exceptions, Werk+11, Florido+12.



Inside-out formation

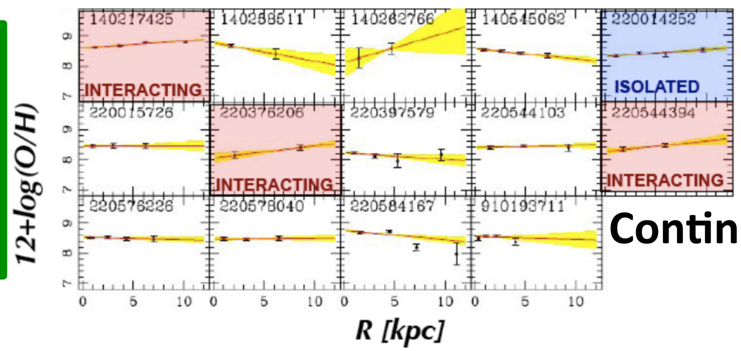
μ~ 0.06

E. Pérez-CALIFA team

z ~ 1

z ~ 2

Negative, positive and flat gradients.
Positive gradients pref. in interacting systems.



Gas inflows driven by tidal forces? (Rupke+11)

μ~ 0.3

Contini+11

μ~ 0.4

Massive accretion cosmic cold gas?

z ~ 3

Positive, flat gradients, no preference about interacting/ isolated(Cresci+10, Troncoso+12).

μ~ ?

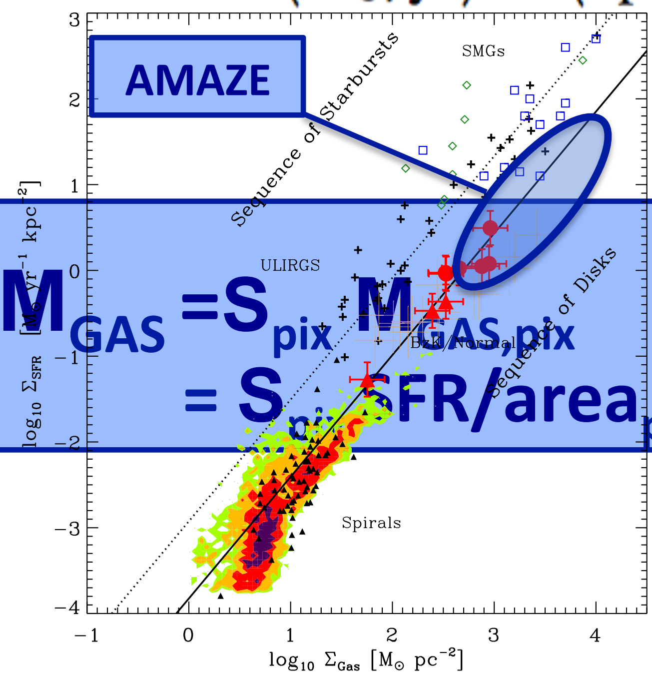
Troncoso in prep.

Gas content through SK law

at high –z ?

S SFR ~ $(S_{GAS})^n$

$$M_{gas}(M_\odot) = 757\times 10^6 \left(\frac{\mathrm{SFR}}{M_\odot/\mathrm{yr}}\right)^{0.71}\left(\frac{r}{\mathrm{kpc}}\right)^{0.58}$$

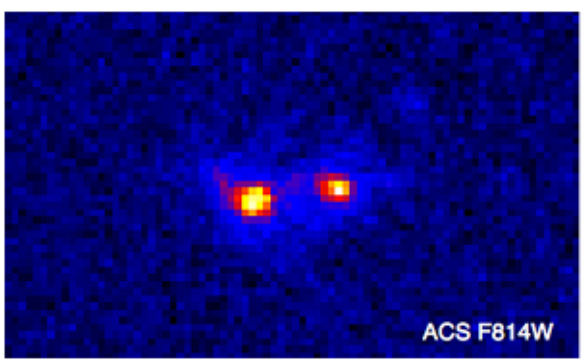


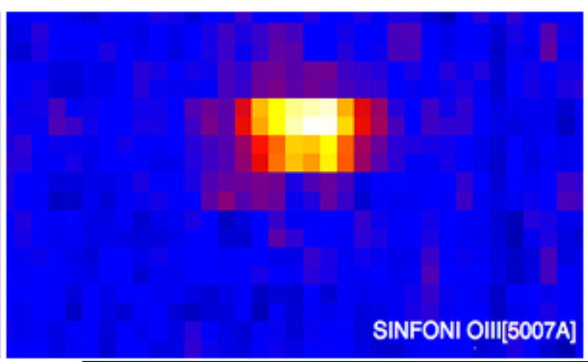
$M_{GAS} = S_{pix} M_{GAS,pix}$

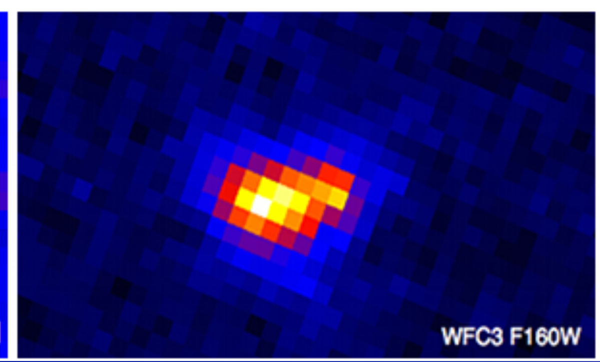
$= S_{pix}$ SFR/area$_{pix}$

Galaxy size

- 3 methods: SB, Galfit & Moffat.
- Images: OIII seeing limited, OIII AO & continuum HST.



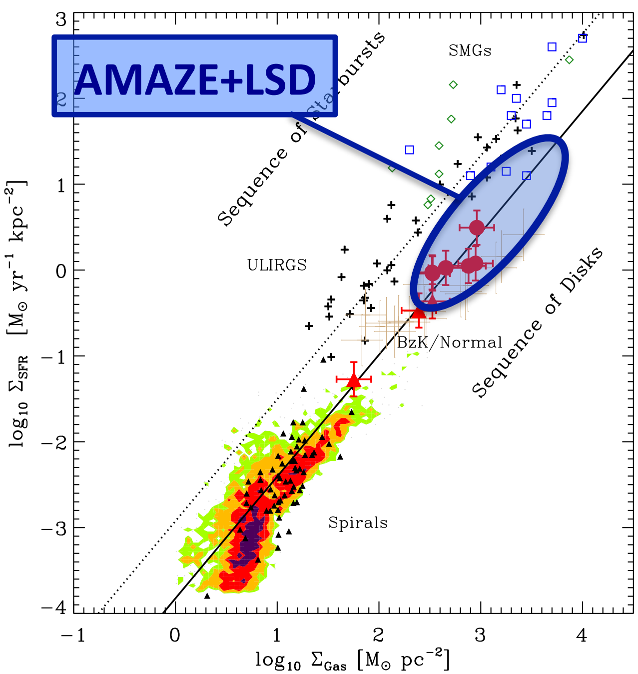


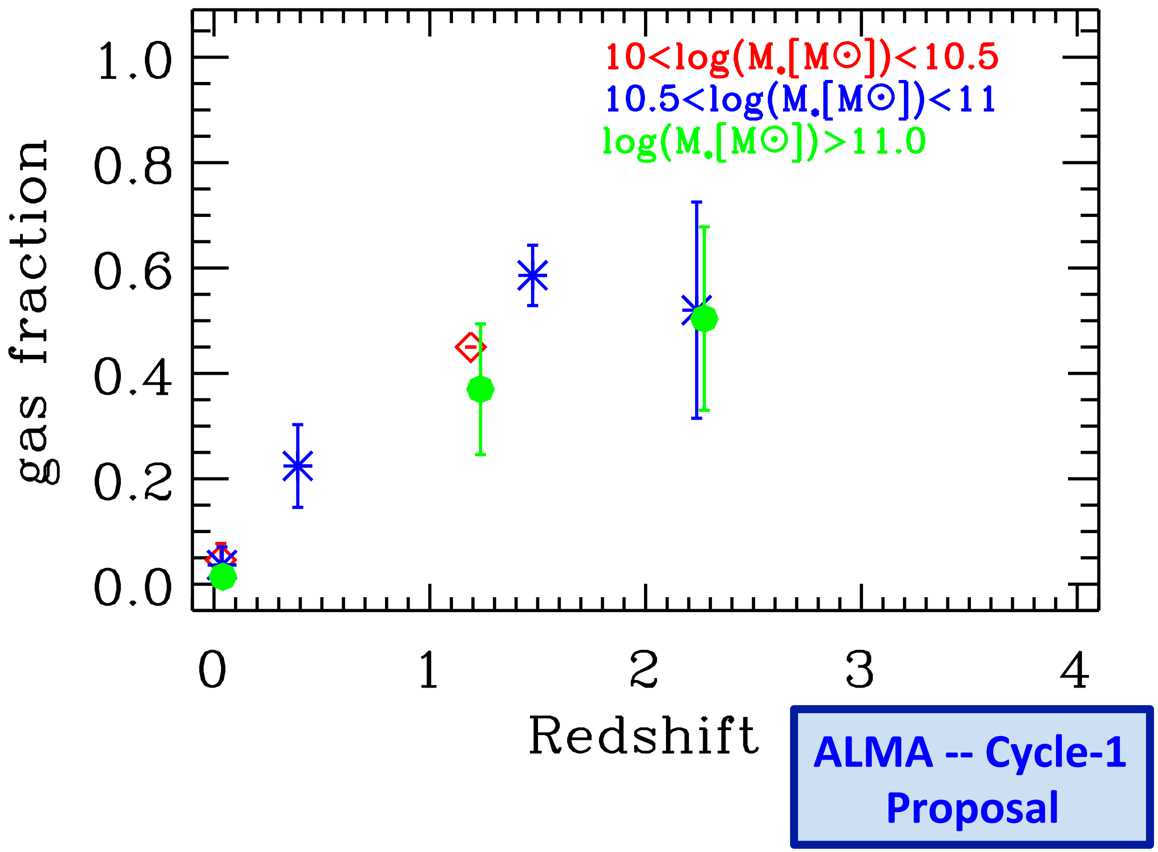


Gas content estimation: AMAZE+LSD at z~3.3

Cosmic evolution gas fraction

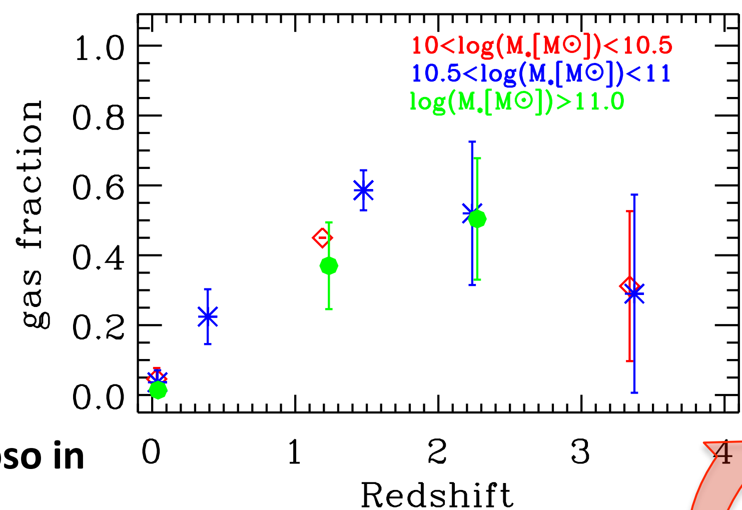
By inverting the SK law, and using Σ_{SFR} information from IFU data we can determine the mass of gas.



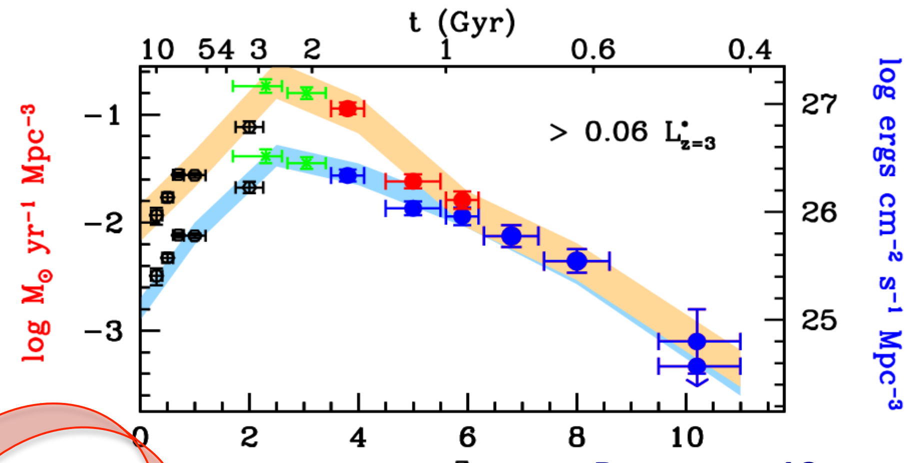


Cosmic evolution gas fraction : AMAZE+LSD at z~3.3

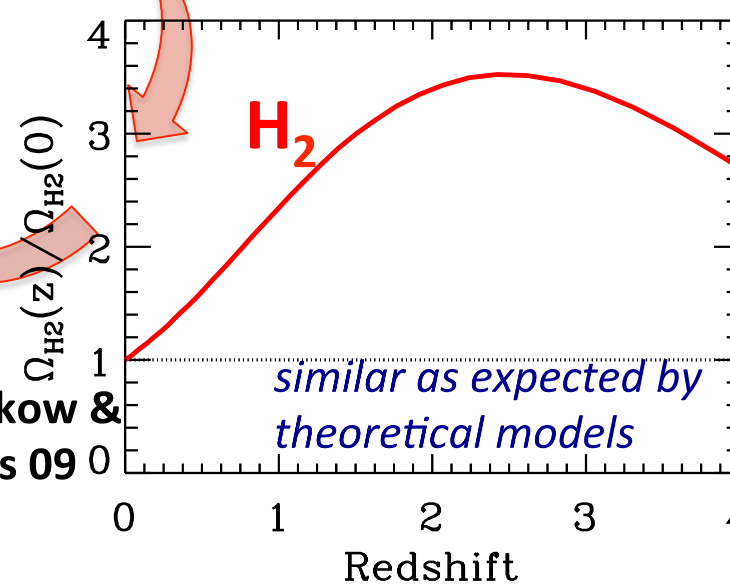
The evolution of the gas fraction in massive galaxies strongly resembles the evolution of the cosmic star formation rate density.



Troncoso in prep.



Bouwens+12



Obreschkow & Rawlings 09

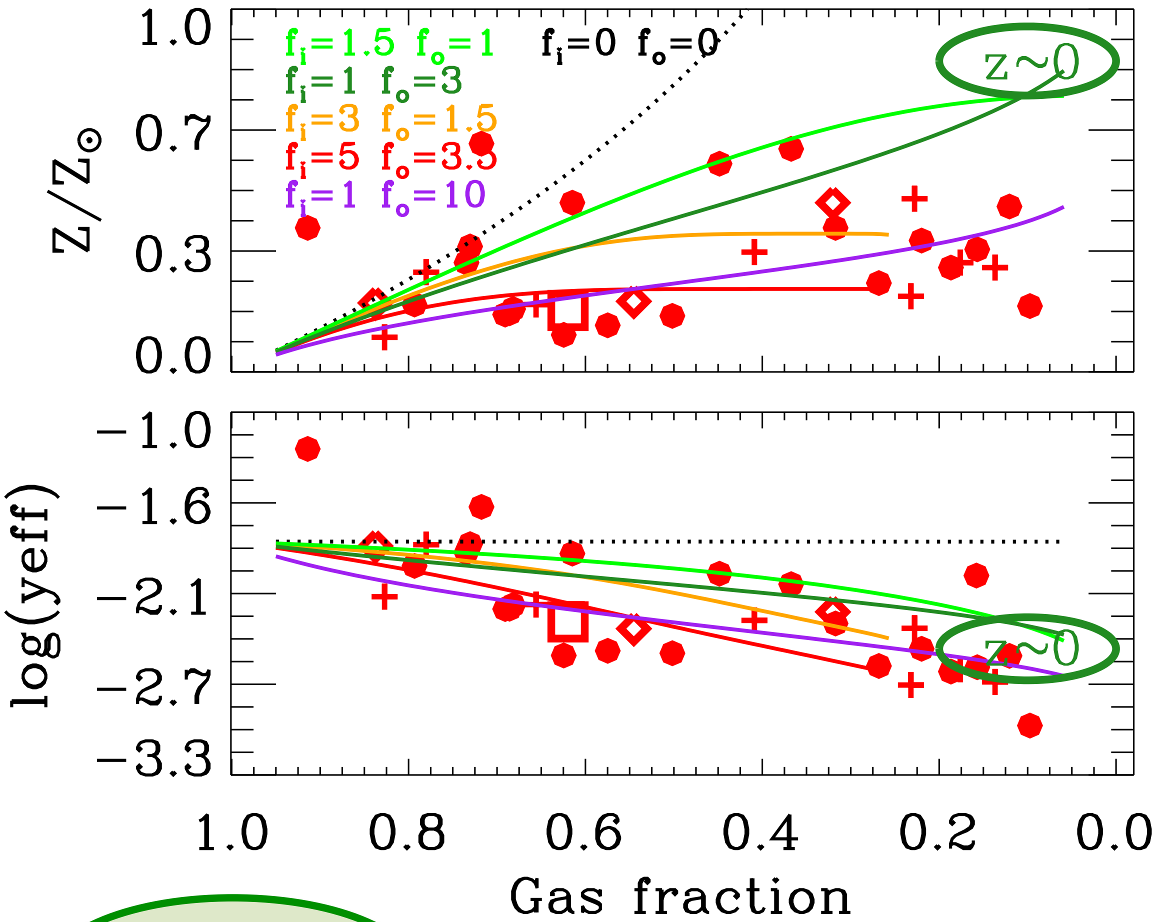
SFRD evolution is actually driven by gas content evolution through the SK law and not SFE evolution!, i.e. amount of gas & how it was acquired, loss at different cosmic epochs.

III) Chemical evolutionary models

Analytical model(Erb 2008)

How different are these galaxies respect to a closed box model?

Include → inflows and outflows proportional to SFR.

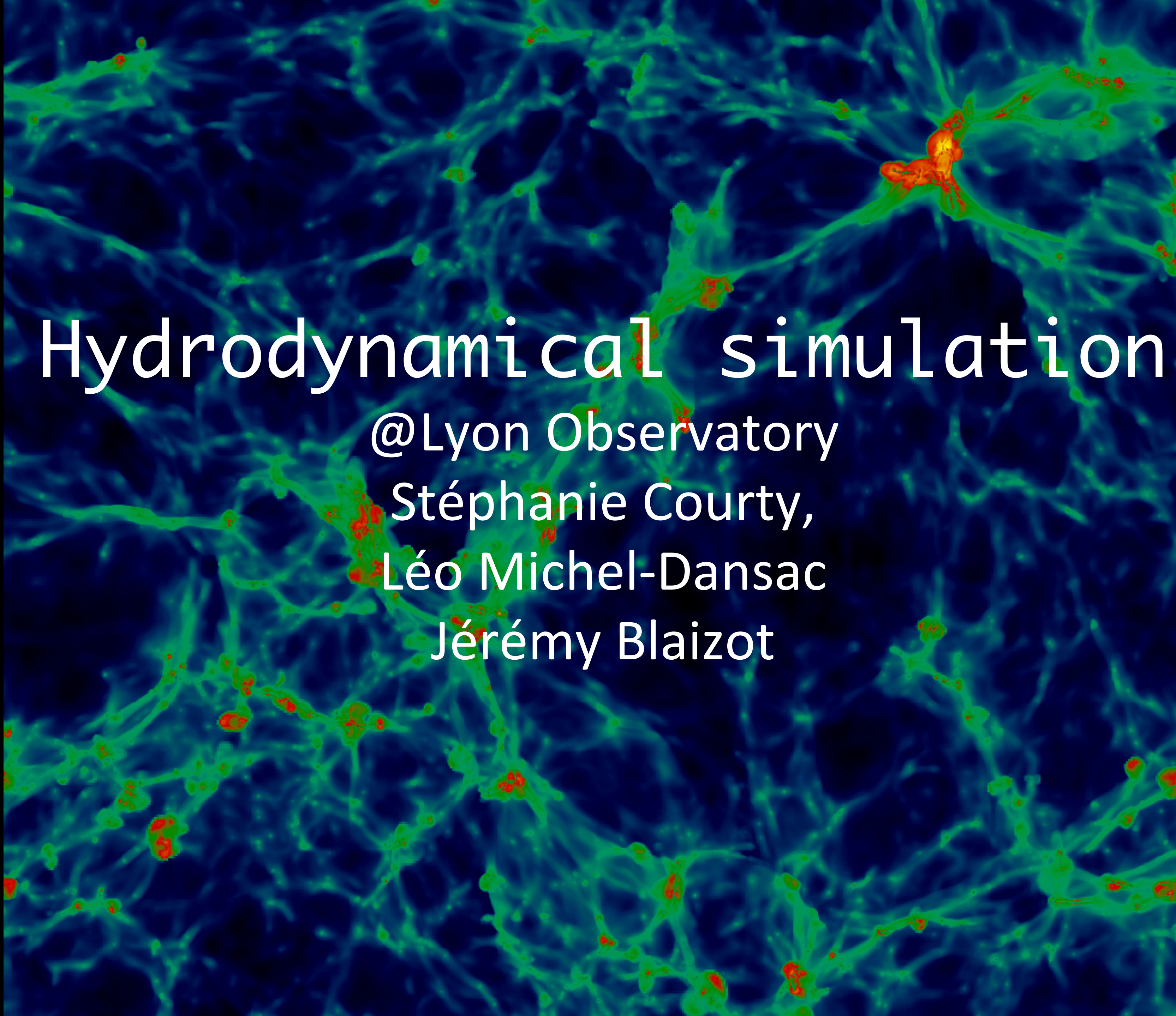


Preferent models:
f_i=(3-5)SFR
f_o=(1.5-3.5)SFR

- **High gas fractions at z~2-1** due to replenishment of fresh gas to young galaxies (Tacconi+10).

- **Also at z~3.5? Gas metallicity dilute by** infalls?

f_i=1.5, f_o=1
Local galaxies



Hydrodynamical simulation

@Lyon Observatory

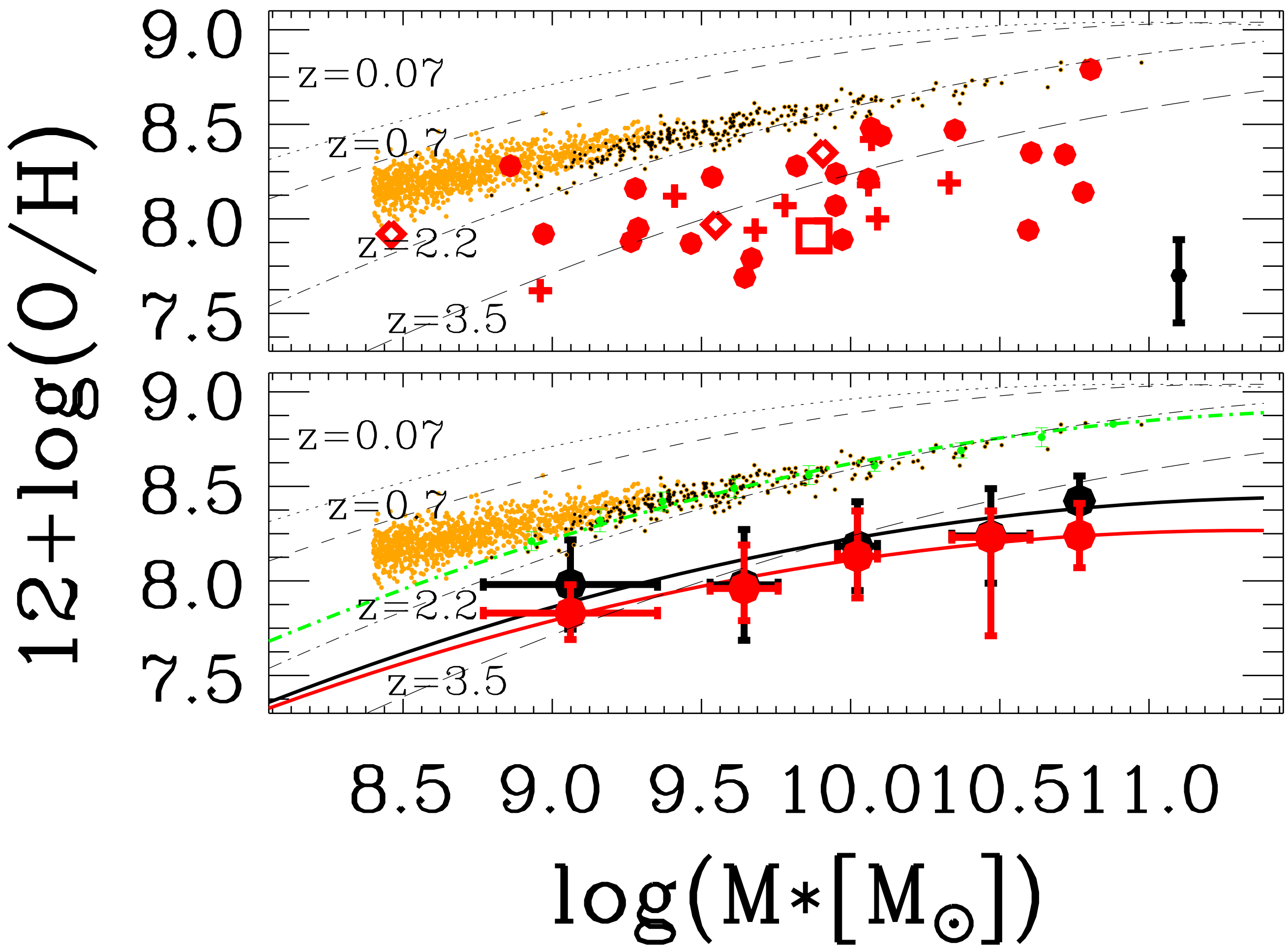
Stéphanie Courty,

Léo Michel-Dansac

Jérémy Blaizot

Mass-metallicity relation: AMAZE+LSD at z~3.3

Comparison with cosmological hydro-dynamical simulation



-RAMSES-CH
Teyssier 2002,
Few+12.

-Cooling, SN,
Feedback.

-20 h^{-1} Mpc
Res. .4-7kpc
N=512^3

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Mass-metallicity relation: AMAZE+LSD at z~3.3

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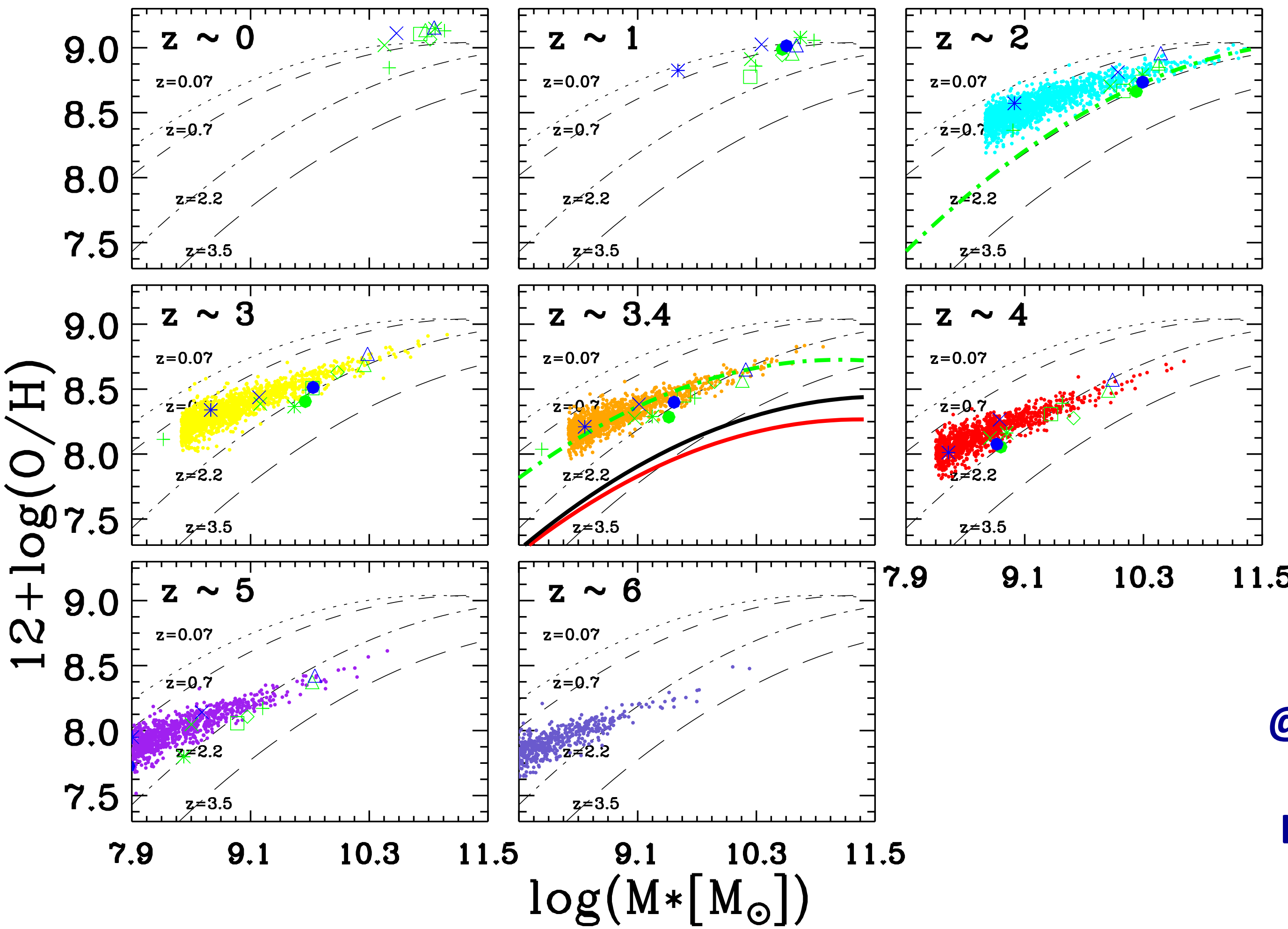


-RAMSES-CH Teyssier 2002, Few+12.

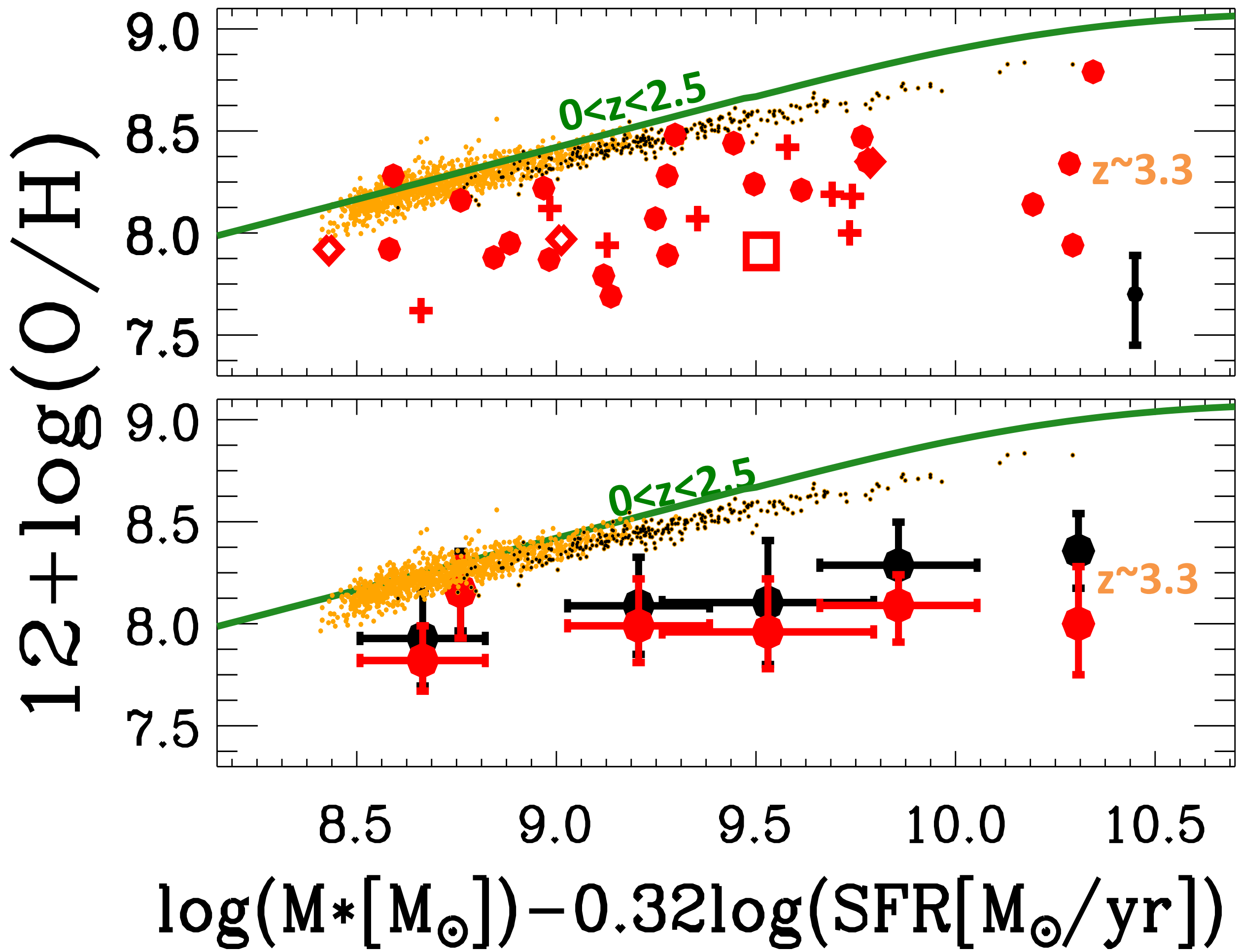
-Cooling, SN, Feedback.

-20 h^{-1} Mpc Res. .4-7kpc N=512^3

@Lyon Observatory Stéphanie Courty, Léo Michel-Dansac Jérémy Blaizot

Fundamental metallicity relation: AMAZE+LSD at z~3.3

Comparison with cosmological hydro-dynamical simulation



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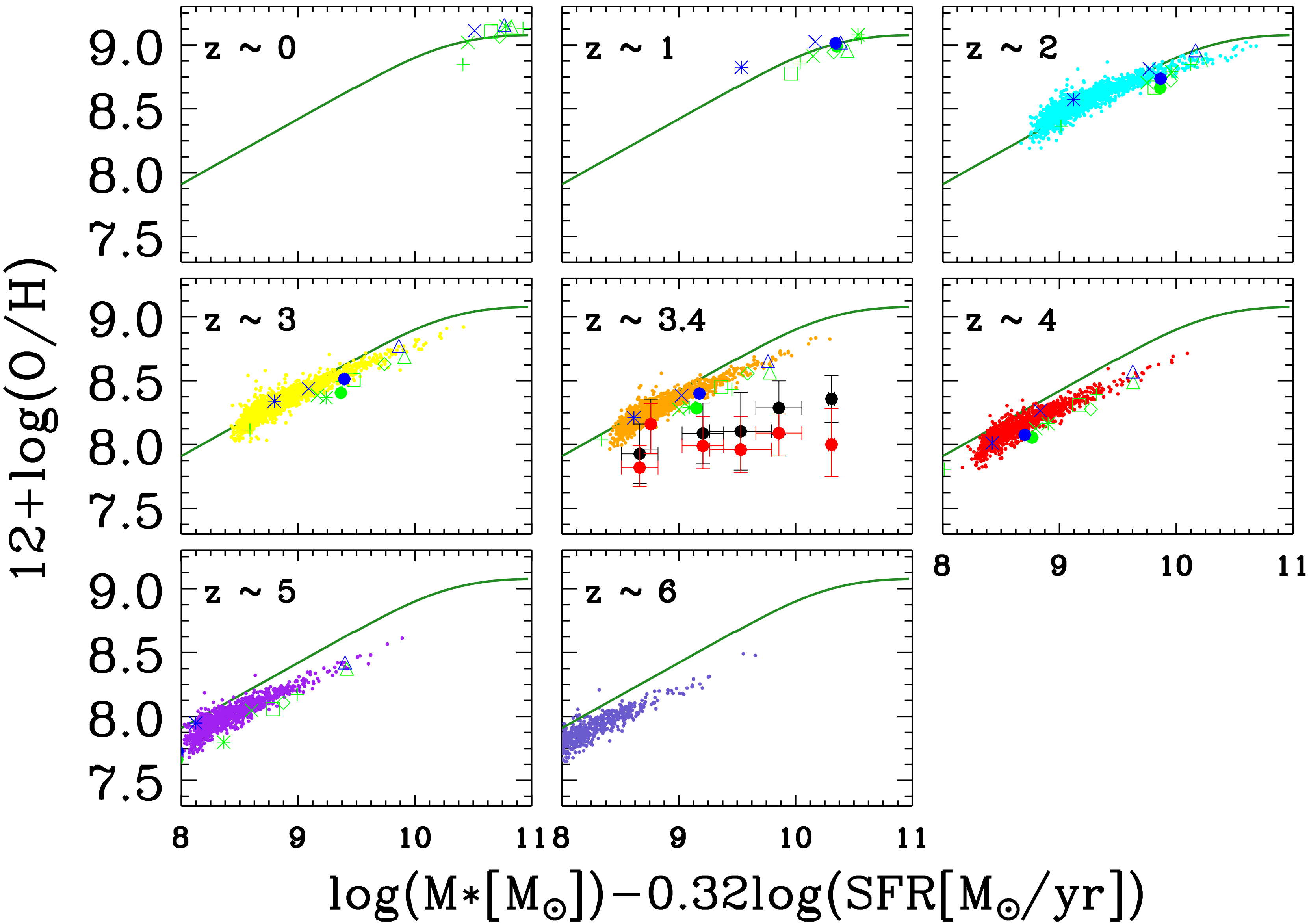
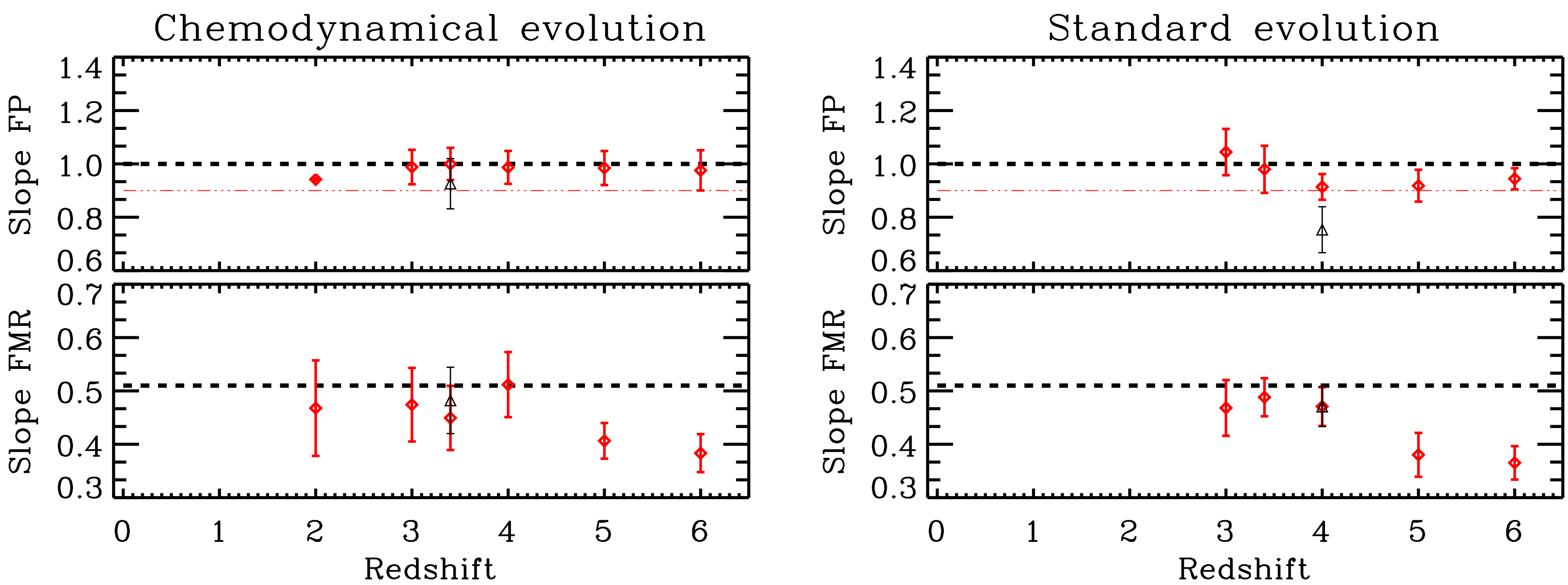
Galaxy evolution on the FMR: AMAZE+LSD at z~3.3



Slope evolution of FMR and FP

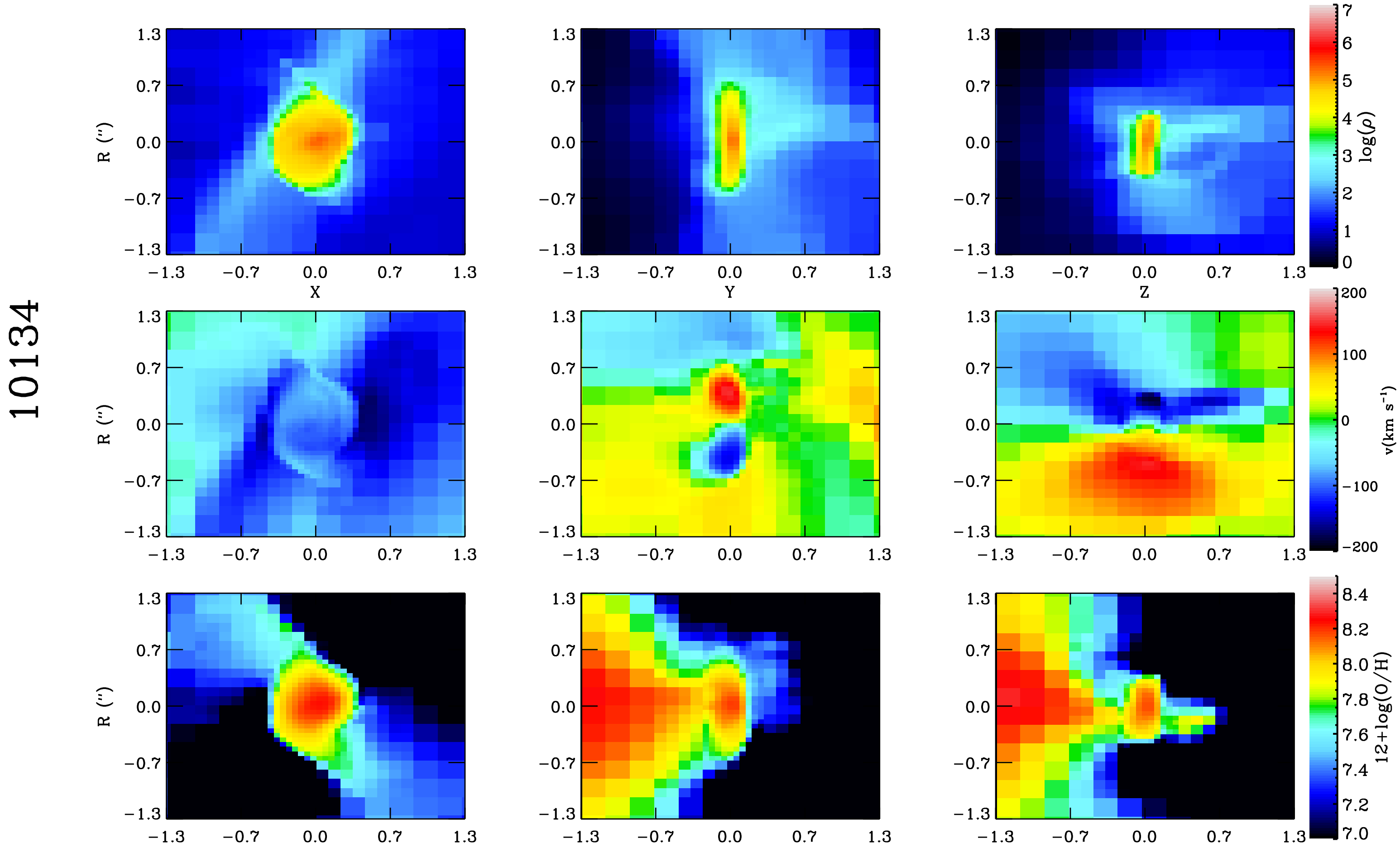


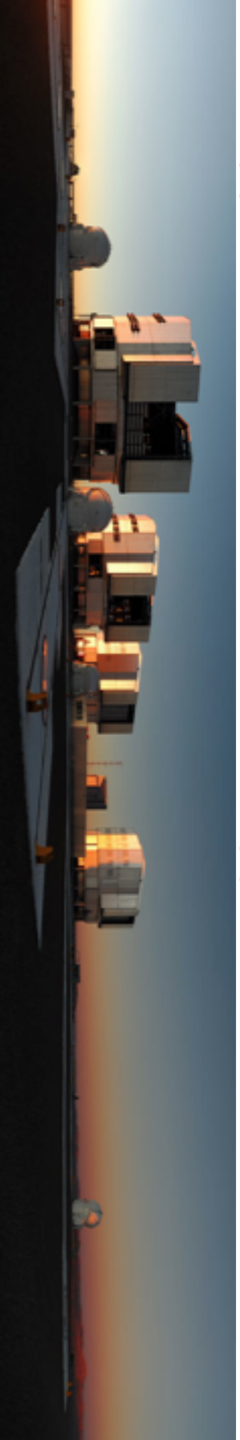
Chemo and standard hydro-dynamical simulations follows the FMR from the local Universe up to z~4.
Decline of the slope at z~4.

Chemo and standard hydro-dynamical simulations follows the FP from the local Universe up to z~6.

Resolved properties: AMAZE+LSD at z~3.3

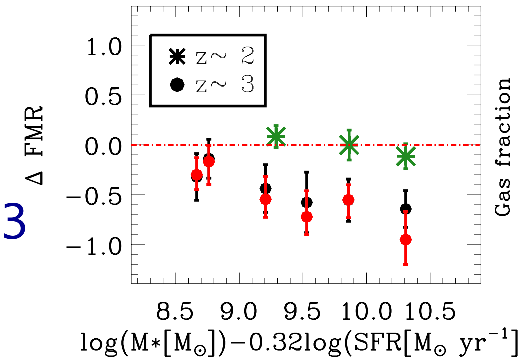
<u>By "Observing a simulated galaxy"</u> we measure the metallicity gradients and look for physical mechanisms which flattens the gradients.

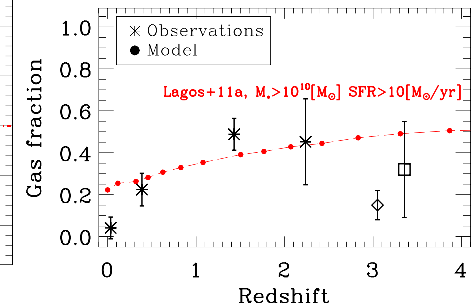


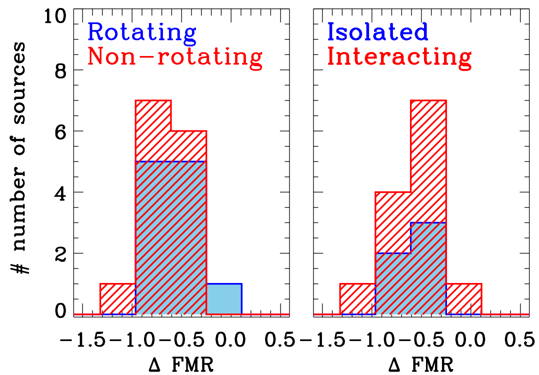


Summary

I) Change on the mode of galaxy evolution from local Universe (up to z<2.5) and z~3.3

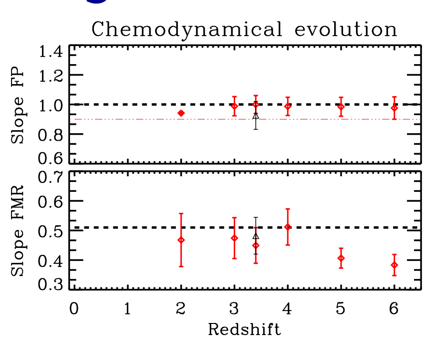






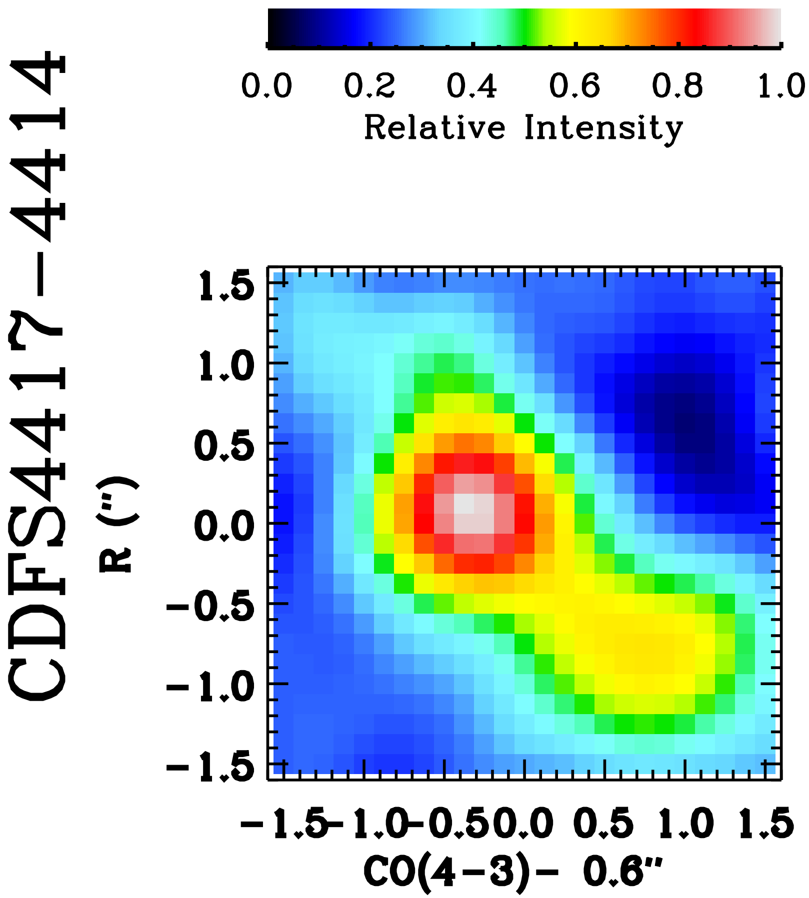
II) Enhanced merging at z>3.4 can't be the only reason for the deviations from the FMR at z>3.

III) Four rotationally disks show positive metallicity gradient. Mergers are not the only reason.



IV) Hydro dynamical simulations follows the FMR up to z~4 and FP up to z~6. By "observing" simulated galaxies at z~3.5 inverted/flat gradients are found.

CDFS4417-4414 as an ALMA case of study



$z \sim 3.3$, $M_{gas} \sim 10^{11}$, $F_{co}=0.5$[Jy km s^{-1}] & Peak >1[mJy]

✓ Early science

- 1hr, σ_{CO} =1mJy =>2σ detection
- 10 hr, σ_{CO} =0.15mJy => 7σ detection

✓ Cycle 1

- 1.5 hr, σ_{CO} =0.3mJy =>2-3σ detection

✓ Full array

- 1 hr, σ_{CO} =0.14mJy => 7σ detection

ALMA prospects: AMAZE+LSD at z~3.3

- Study the gas content and dynamics of typical star forming galaxies, which physical processes that regulates chemical evolution (SFR, gas inflows and outflows) differs from nearby galaxies (0<z<2.5).
- Prove SK-law at z~3 for typical star forming galaxies.
- Determine the dynamical mass of these galaxies through CO observations. This allows to constrain α_{CO} from independent methods, Mgas=Mdyn-M*-Mdark.
- Non detection of CO rotational numbers higher than CO(J 4-> 3)would confirm the similarity between these galaxies and nearby disks.
- Constrains for galaxy formation models

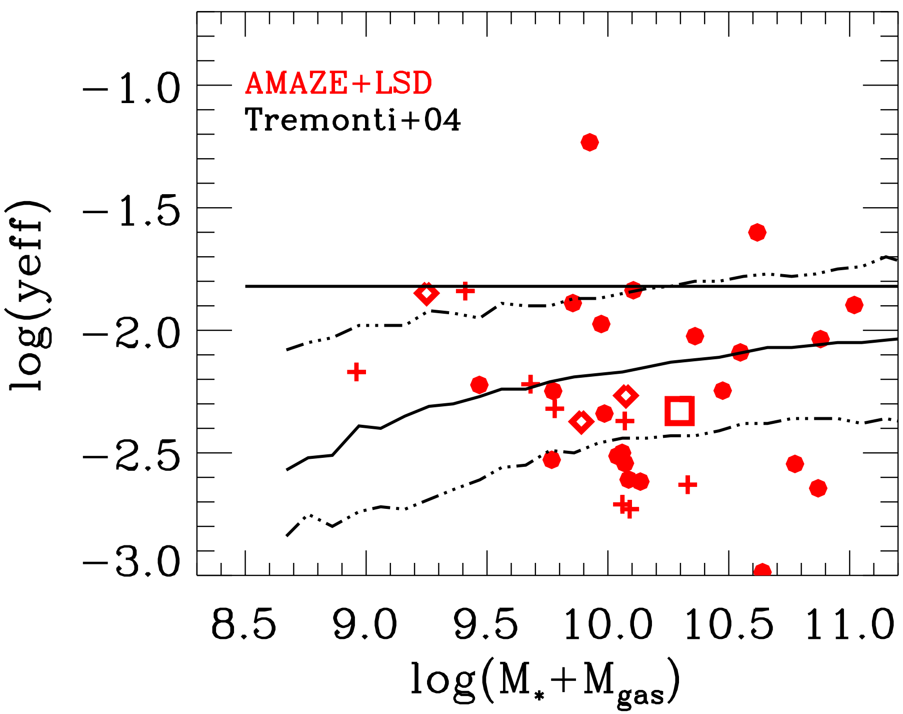
a) evolution of cosmic molecular gas fraction (Lagos et al. 2011a,b, Obreschkow+09).

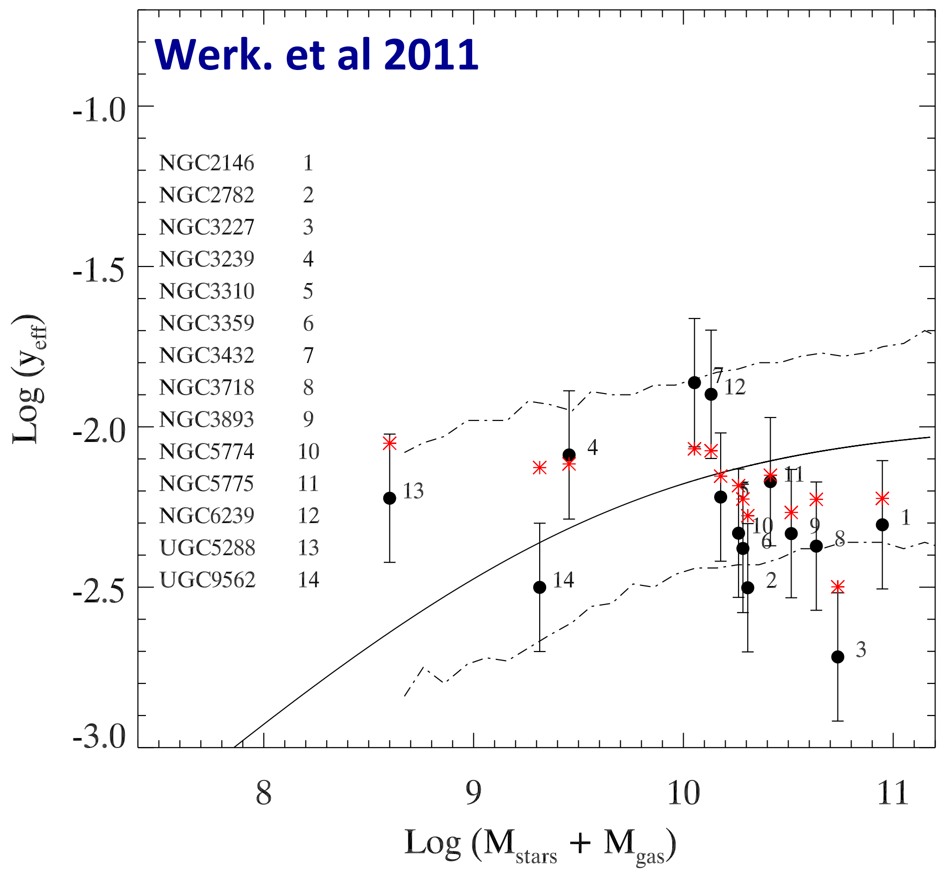
b) α_{CO} has been shown to be dependent on metallicity.

c) gas replenishment mechanism at this early epochs.

d) etc..

Effective yields AMAZE+ LSD: comparison with local galaxies.



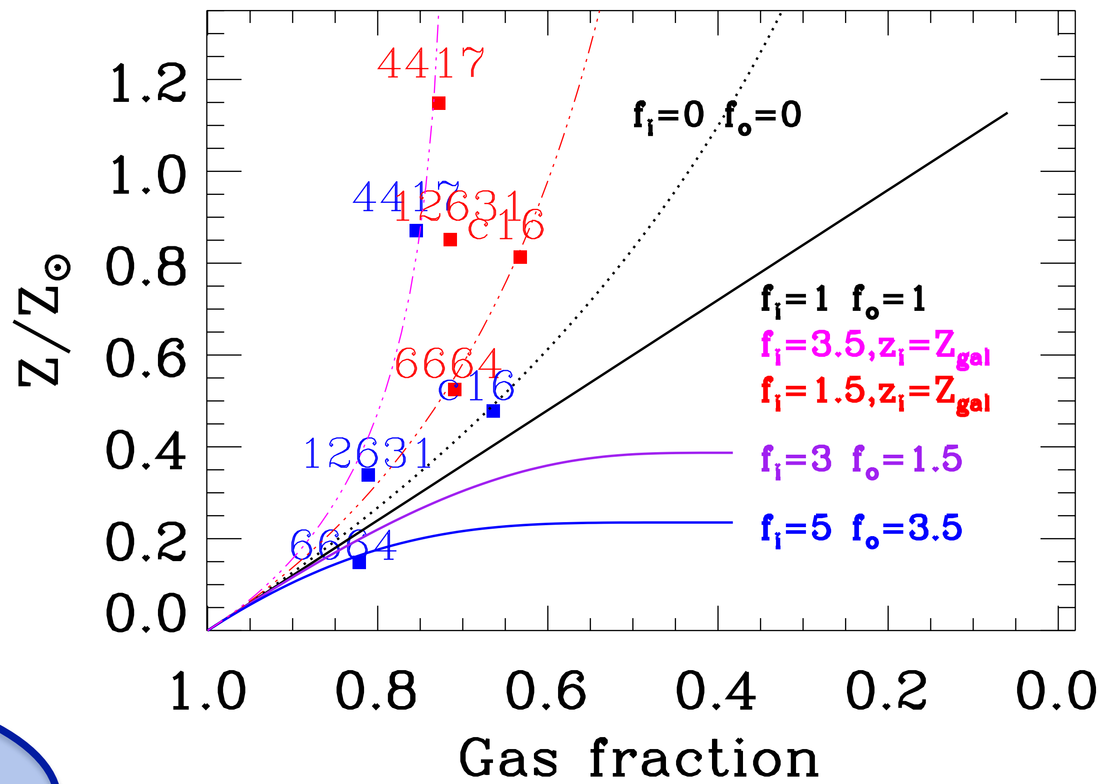


Gas content estimation: AMAZE+LSD at z~3.3

Comparison with chemical evolutionary models

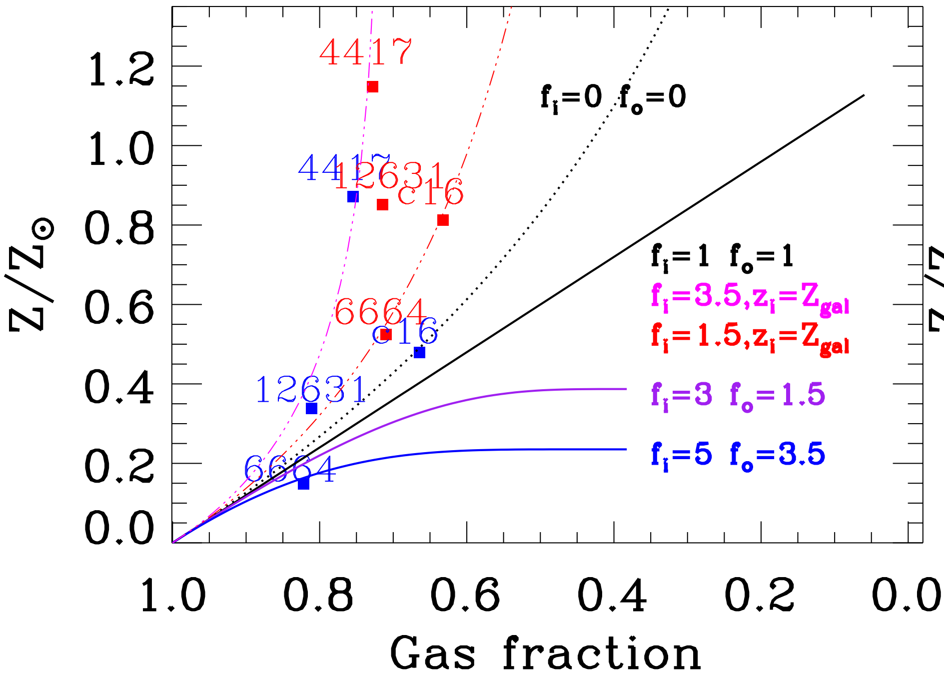
Constrain the amount of inflows, outflows in the inner-outer galaxy regions.

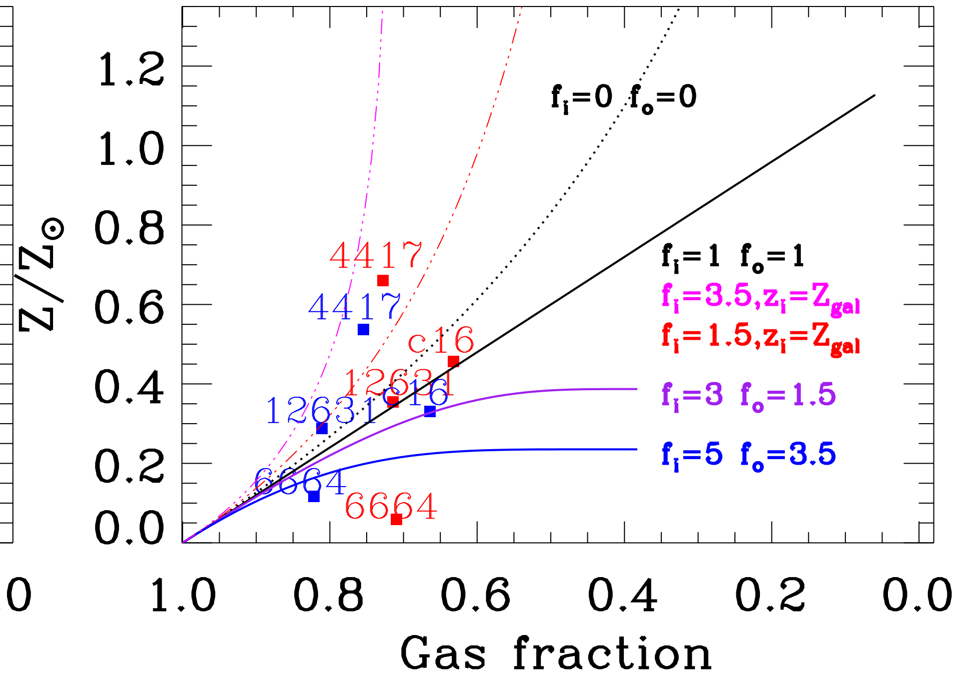
Outer region, lower gas fraction and higher metallicity



Inner region, higher gas fraction and lower metallicity.

Outer region, lower gas fraction and higher metallicity

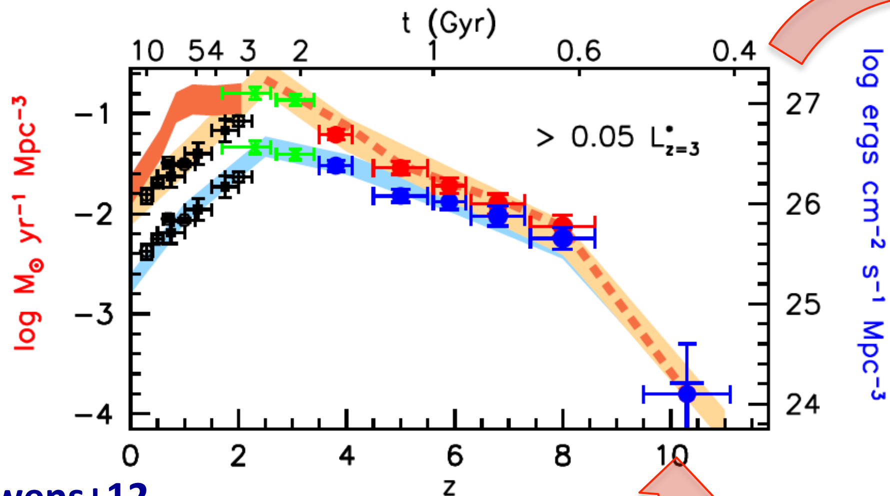




Inner region, higher gas fraction and lower metallicity.

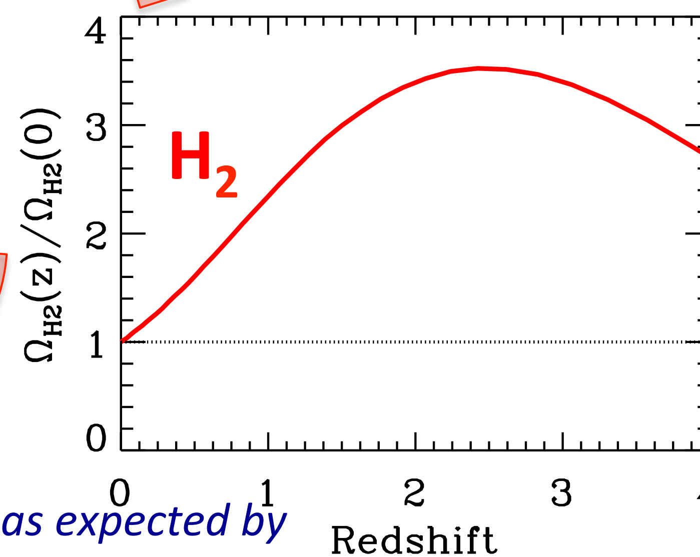
Gas content estimation: AMAZE+LSD at z~3.3

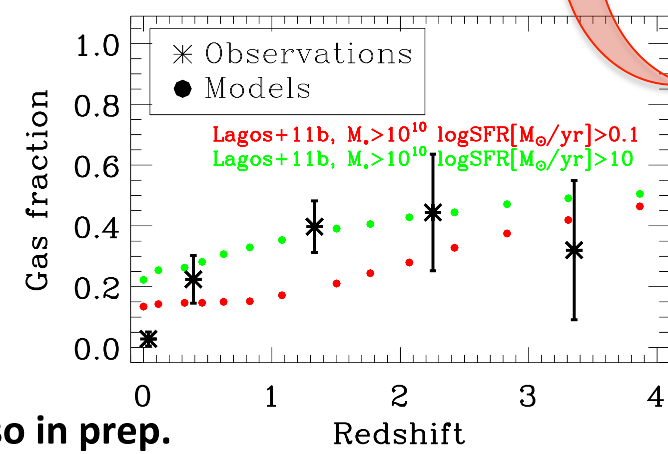
Cosmic evolution gas density-SFR **By inverting the SK law, and using Σ_{SFR} information from IFU data we can determine the mass of gas.**



Bouwens+12

Obreschkow & Rawlings 09





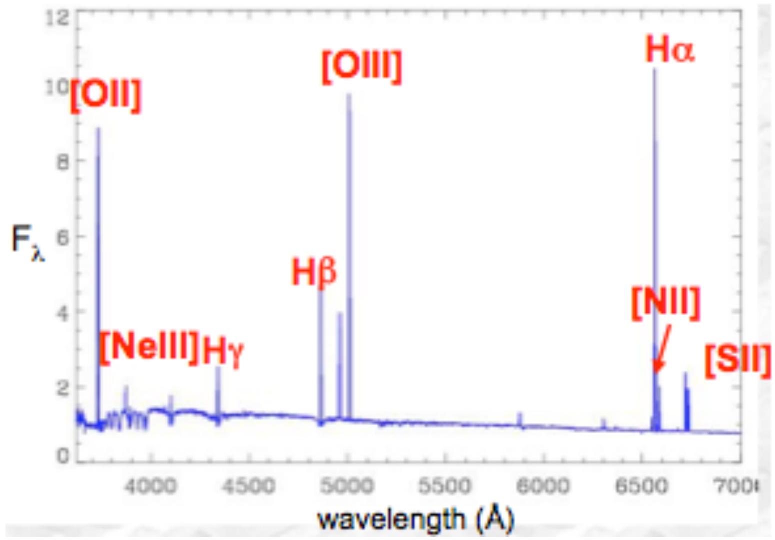
Troncoso in prep.

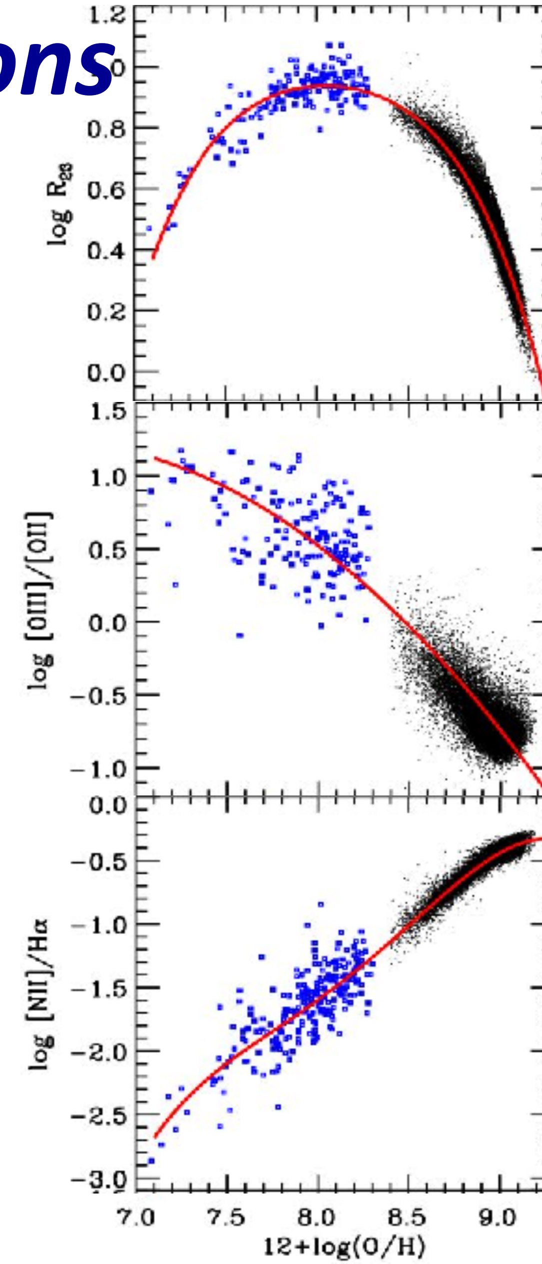
similar as expected by theoretical models

Galaxy evolution drive by the amount of gas & how it was acquired/loss at different cosmic epochs.

How to measure the gas metallicity: Strong line calibrations

- *R_{23}=([OIII]5007+[OIII]4959+[OII]3727)/(Hβ)*
- *[NII]6584/Hα, [NII]6584/[OII]3727, etc.*



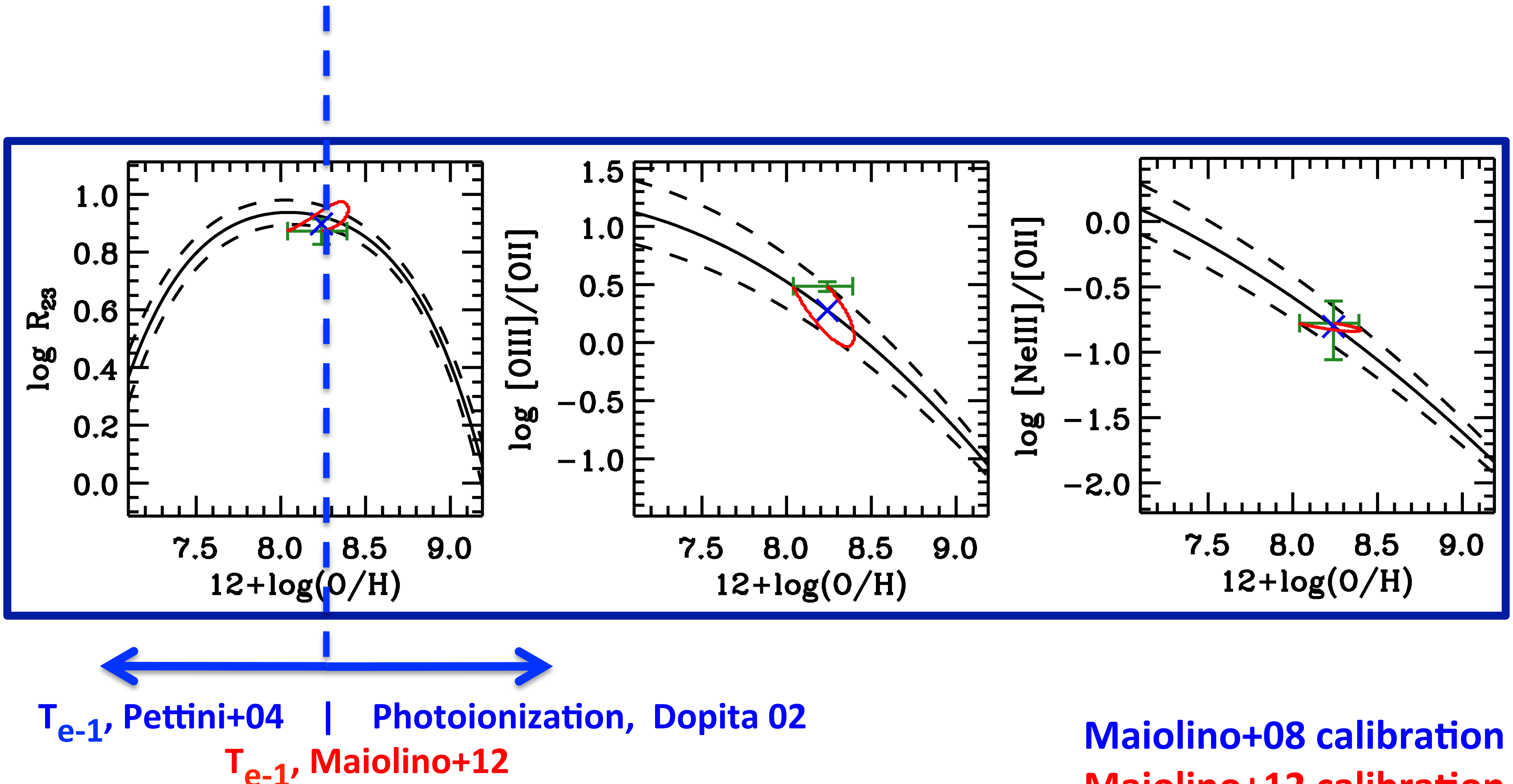


- *Calibrated empirically (Kobulnicky & Zaritsky99, Pilyugin +01,+10; Pettini & Pagel 04, Liang+06).*

T_e, SDSS-DR3 low-Z [OIII]4636 measured (Izotov+06)

- *Through photoionization models (Kewley & Dopita+02,+06; Tremonti+04; Kobulnicky+04, Dors+11).* Photoinization, SDSS-DR4 (Kewley & Dopita +02)

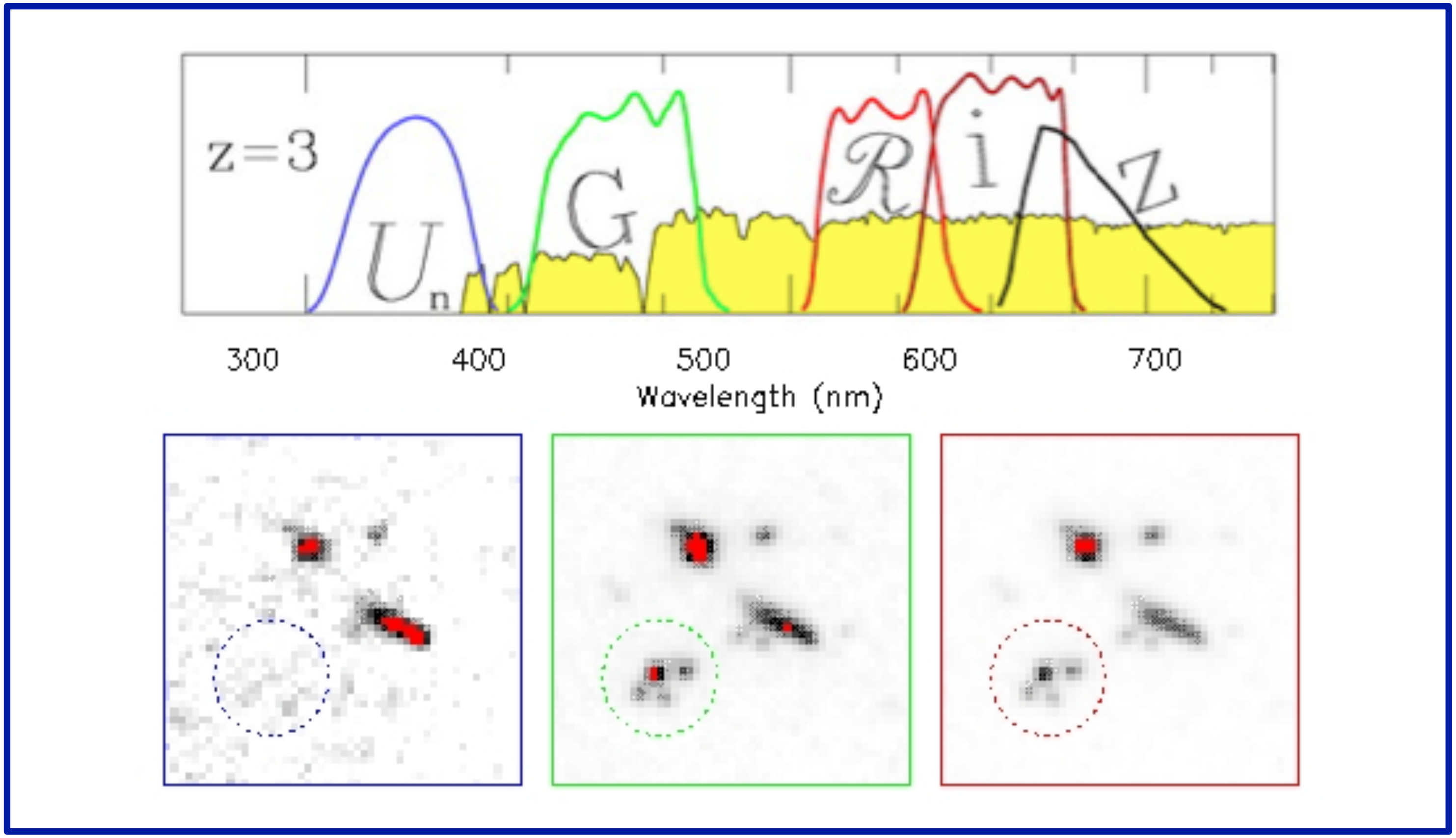
- *Or a combination of the two (Denicolo'+02; Nagao+06; Maiolino+08).*



1.0
0.8
0.6
0.4
0.2
0.0
log R23
7.5
8.0
8.5
9.0
12+log(O/H)
1.5
1.0
0.5
0.0
−0.5
−1.0
log [OIII]/[OII]
12+log(O/H)
0.0
−0.5
−1.0
−1.5
−2.0
log [NeIII]/[OII]
12+log(O/H)
Te-1, Pettini+04 | Photoionization, Dopita 02
Te-1, Maiolino+12
Maiolino+08 calibration
Maiolino+12 calibration

The sample selection: AMAZE+LSD.

The radiation at energies higher than the Lyman limit at 912 Å(3650 Å at z=3, U-band) is almost completely absorbed by the neutral gas around star-forming regions.



UV dropout technique: rest-frame UV star-forming selected galaxies.