AMAZE with LSD:
Metallicity evolution in the early Universe

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Galaxy Formation

Durham, 21/07/2011

Metallicity: a fundamental parameter

⋆ Indirectly traces the integrated galaxy SFH, not only the current SFR

⋆ Relative element abundances reflect the cycling of gas through stars, and any exchange of gas between galaxy and its environment (infall/outflows)

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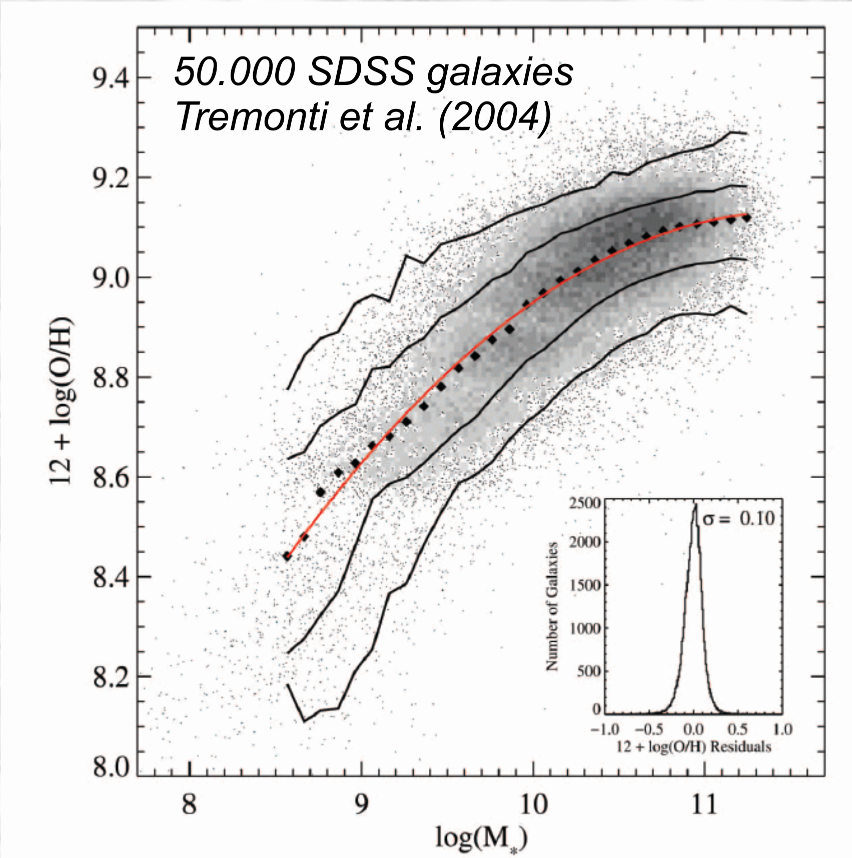
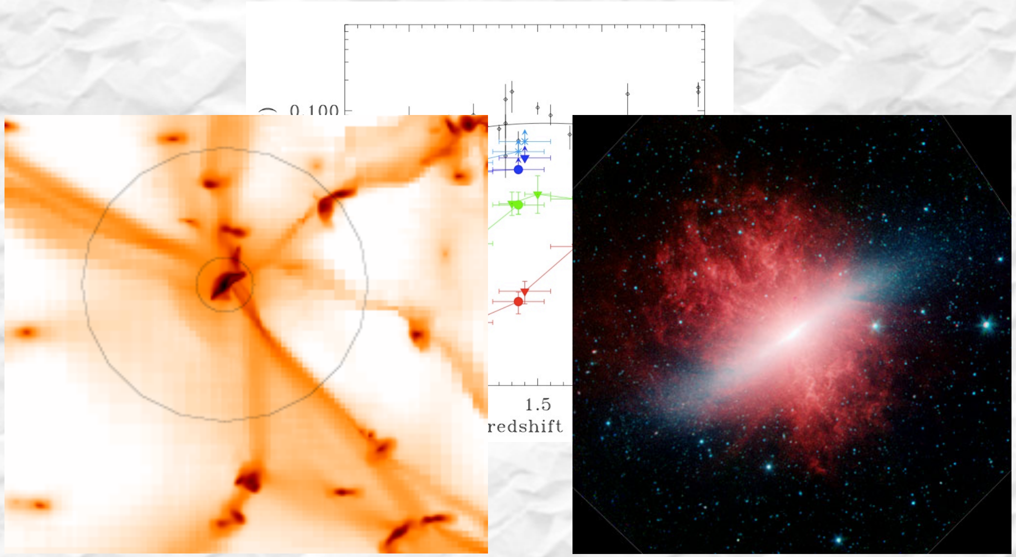
Understanding its evolution is essential to isolate the physical mechanisms that drive Star Formation

The mass-metallicity relation



Possible Drivers:

- ✓ star formation history and mass lost
- ✓ downsizing
- ✓ inflows and merging
- ✓ outflows and feedback (AGN, SNe)
- ✓ evolution in IMF
- ✓…

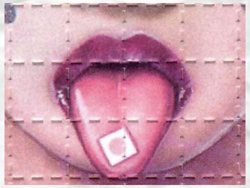


Crucial test for models!

Expecially at high-z, where the predictions of different models diverge more

See Kobayashi+ 2007; Brooks+ 2007; de Rossi+ 2007;Dave' & Oppenheimer 2007; Dalcanton, 2007; De Lucia+ 2004; Tissera+ 2005; Koppen+ 2007; Cid Fernandes+ 2007; Finlator & Dave', 2008, Panter+ 2008, Governato+ 2008, Sakstein+ 2009; Calura+ 2009, Dave', Finlator & Oppenheimer 2011…

AMAZE… …with LSD



1. Near-IR Integral Field Spectroscopy with SINFONI@VLT

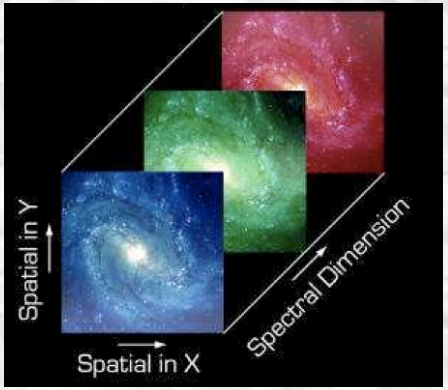
AMAZE (Assessing the Mass-Abundance redshift(Z) Evolution):

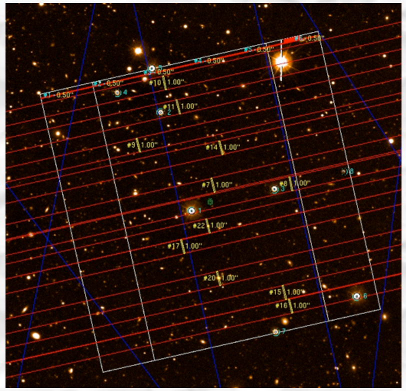
- seeing limited, a sample of 30 LBGs at 3<z<5
- 180h (PI: Maiolino) Maiolino et al. 2008, Cresci et al. 2010, Troncoso et al. 2011

LSD (Lyman-break galaxies Stellar populations and Dynamics):

- diffraction limited with AO, an unbiased sample of 10 LBGs at 3<z<4
- 70h (PI: Mannucci) Mannucci et al. 2009, Gnerucci et al. 2010, Sommariva et al. 11

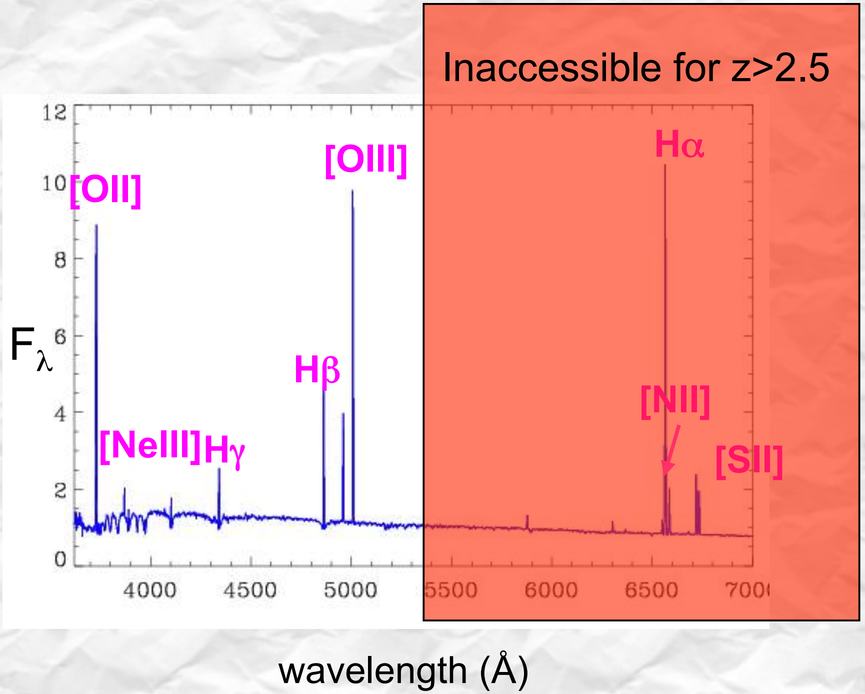
2. Near-IR Multi Object Spectroscopy with LUCIFER@LBT
   - 4 Steidel fields, ~10 z=3 LBGs/field
   - 40h (PI: Cresci) observations ongoing…

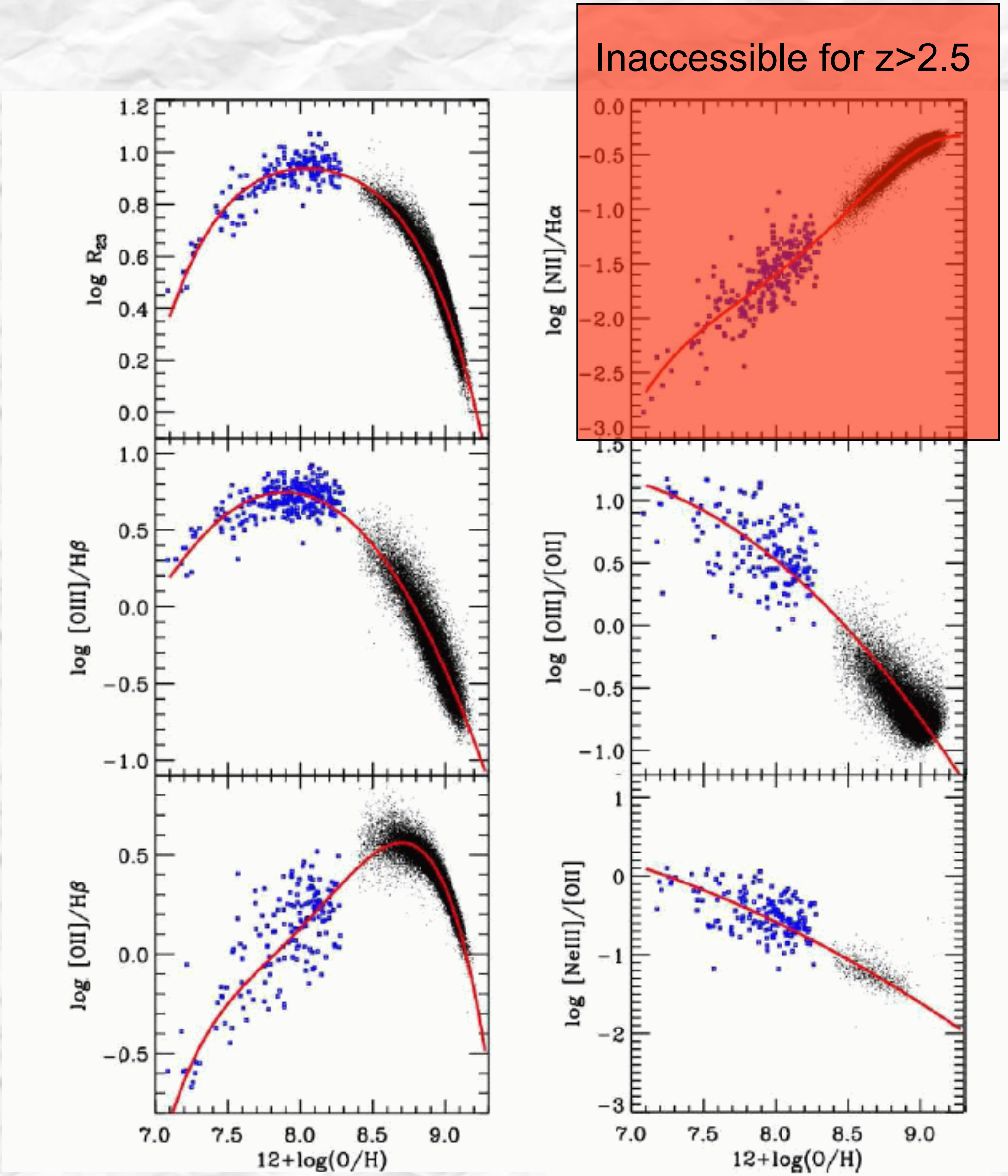




Measuring metallicities

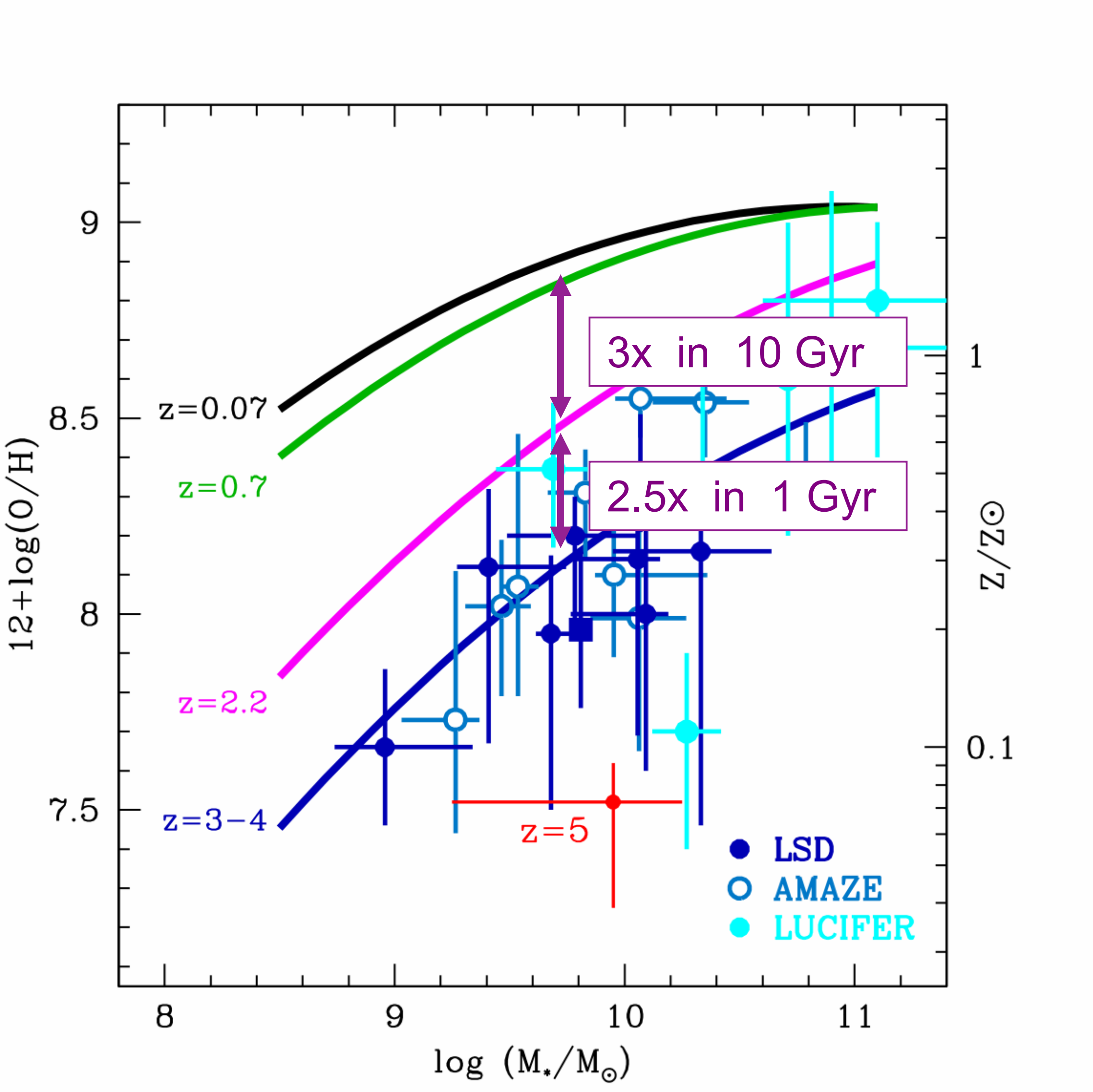
Gas phase metallicity from strong lines





Nagao et al. 06: improved calibrations with low metallicity samples

Evolution of the mass-metallicity relation



z~0.07 SDSS (Kewley&Ellison08)

z~0.7 GDSS+CFRS (Savaglio+05)

z~2.2 LBG (Erb+06)

z~3.3 ○ AMAZE (Maiolino+08)
● LSD (Mannucci +09)
● LUCI (Cresci+11)

z~5 ● AMAZE

M-Z relation already in place at z~3.5

Strong and fast evolution of the M-Z relation beyond z~2?

(BUT: it is not tracing the evolution of individual galaxies)

Inflows and Outflows

In a "*closed box model*" with instantaneous recycling, instantaneous mixing, and low metallicities:

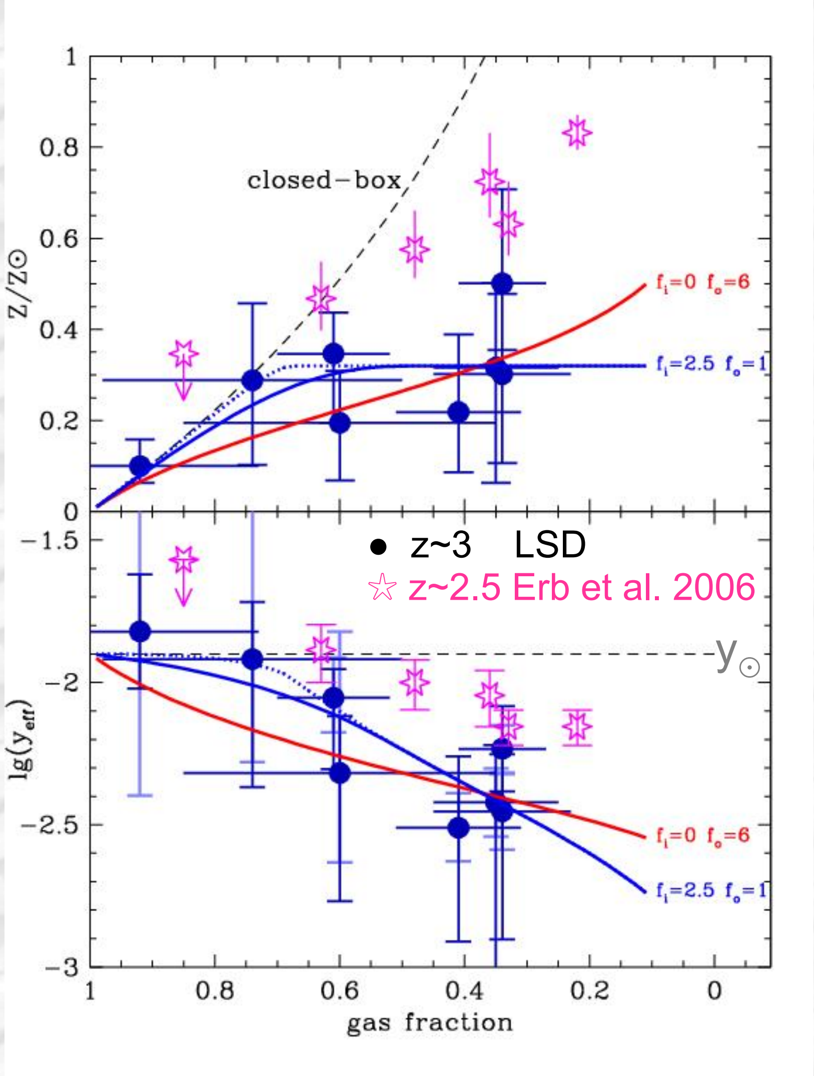
$$Z = y_{true} \cdot \ln(1/f_{gas})$$

y_{true} = stellar yield, i.e., the ratio between the amount of metals produced and returned to the ISM and the mass of stars.

The measured values of $y_{eff} = Z/\ln(1/f_{gas})$ could differ from the true stellar yields y if some of the assumptions do not hold, in particular if the system *is not a closed box*

↓

Inflows and outlows



Metallicity Gradients

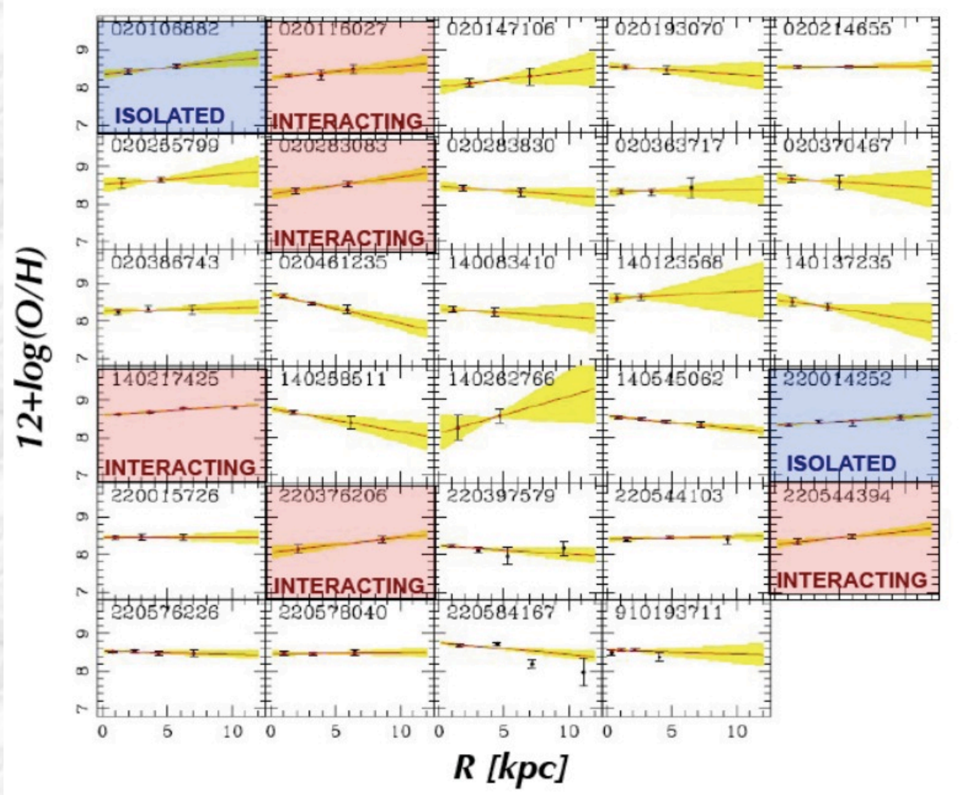
Interplay between in- and out-flows, redistribution of mass within galaxies, radially dependent SFH, mixing due to a stellar bar, clump migration, etc

→ ***Fingerprints of galaxy evolution!***

Negative radial metallicity gradient in local spiral galaxies: the central disk region is more metal-enriched than the outer regions.
(but see also Werk et al. 2010)

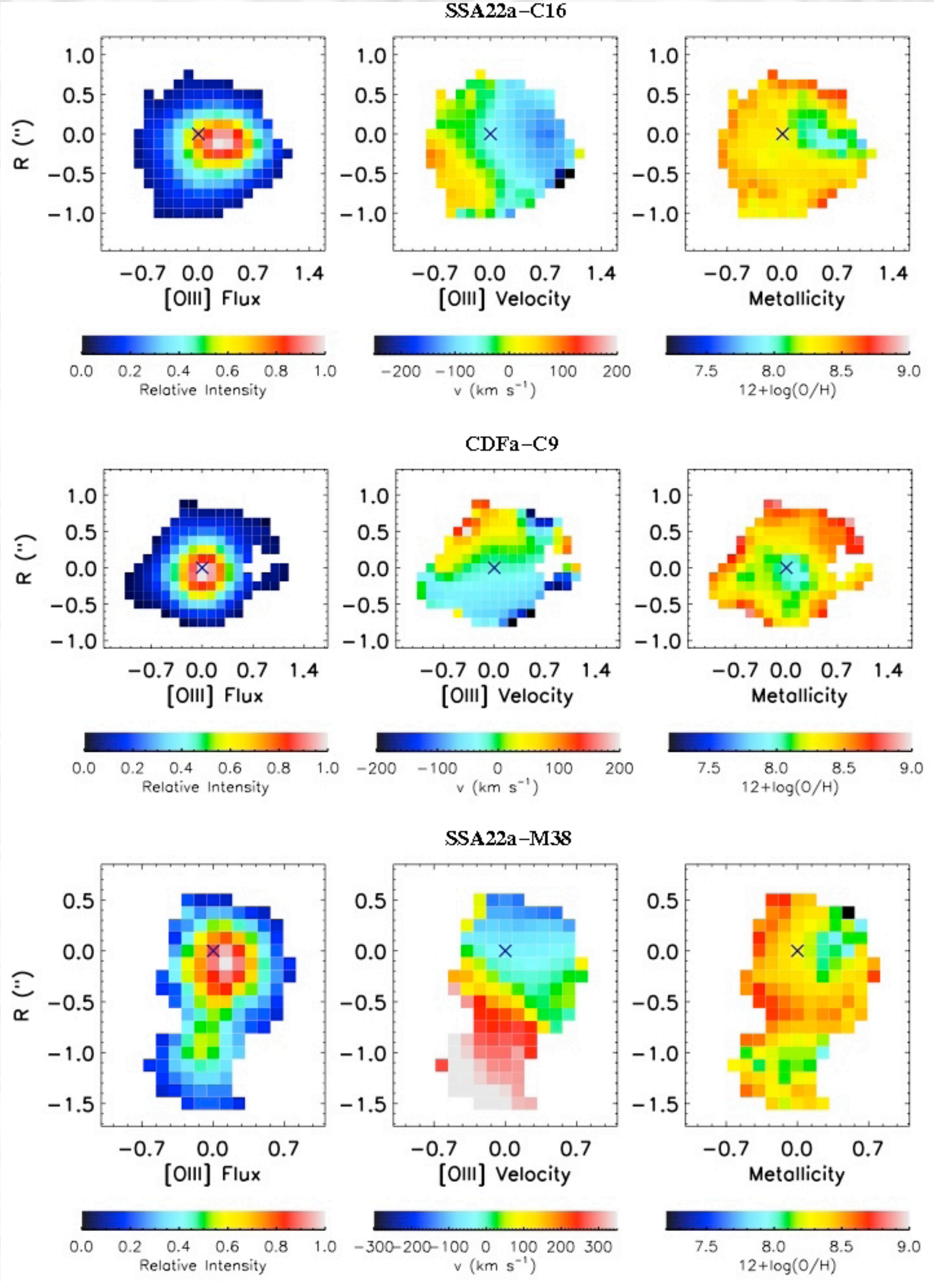
At higher redshift, steeper gradients measured in two gravitationally lensed galaxies at z~1.5 and z~2 with near-IR IFU spectra, supporting "inside-out formation" (see T. Jones poster)

But more complex situation in larger samples: even positive "inverted" gradients at z~1.5 in MASSIV galaxies



Contini et al. 2011

Metallicity Gradients



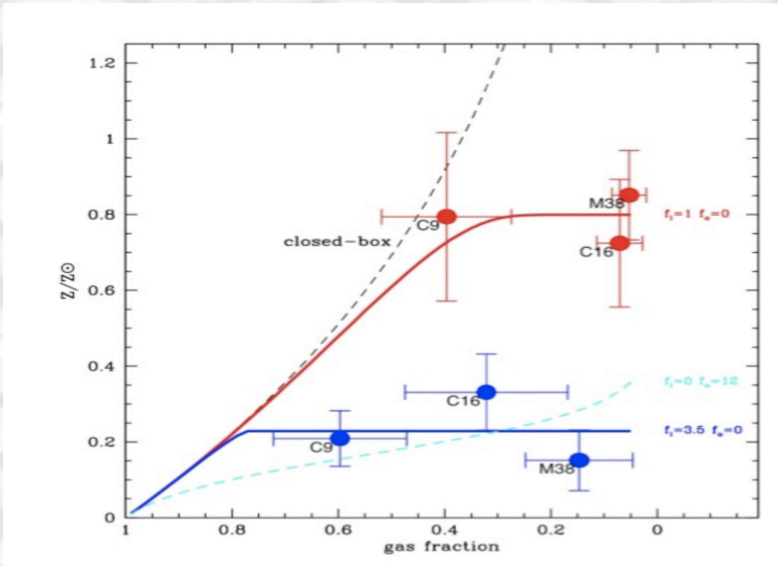
Cresci et al. 2010, Nature

Thanks to the AMAZE/LSD data

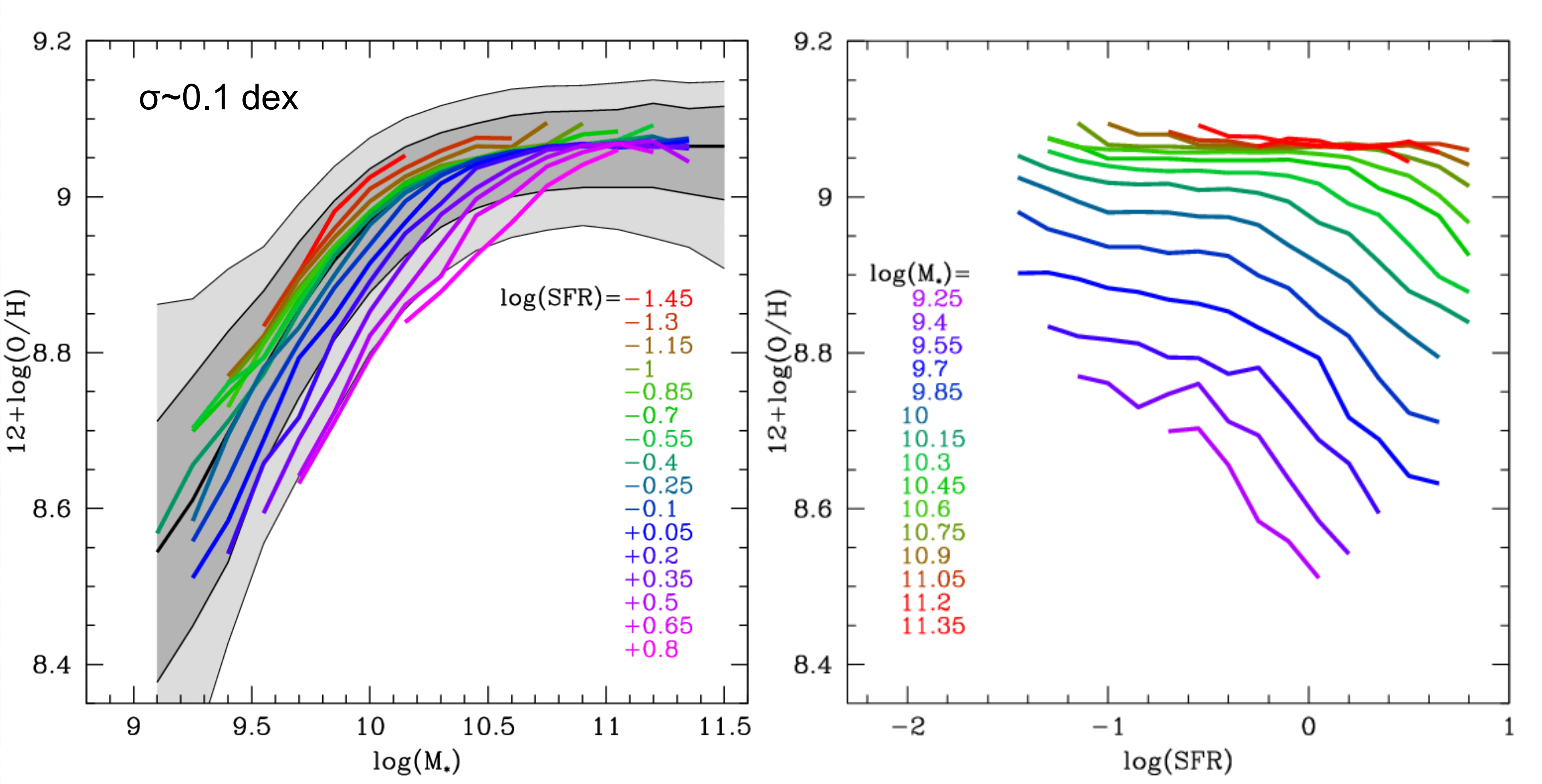
First metallicity maps at z~3:

- Three undisturbed disks
- Well defined regions close to the SF peak are less metal enriched than the disk

Direct evidence for massive infall of metal poor gas feeding the star formation



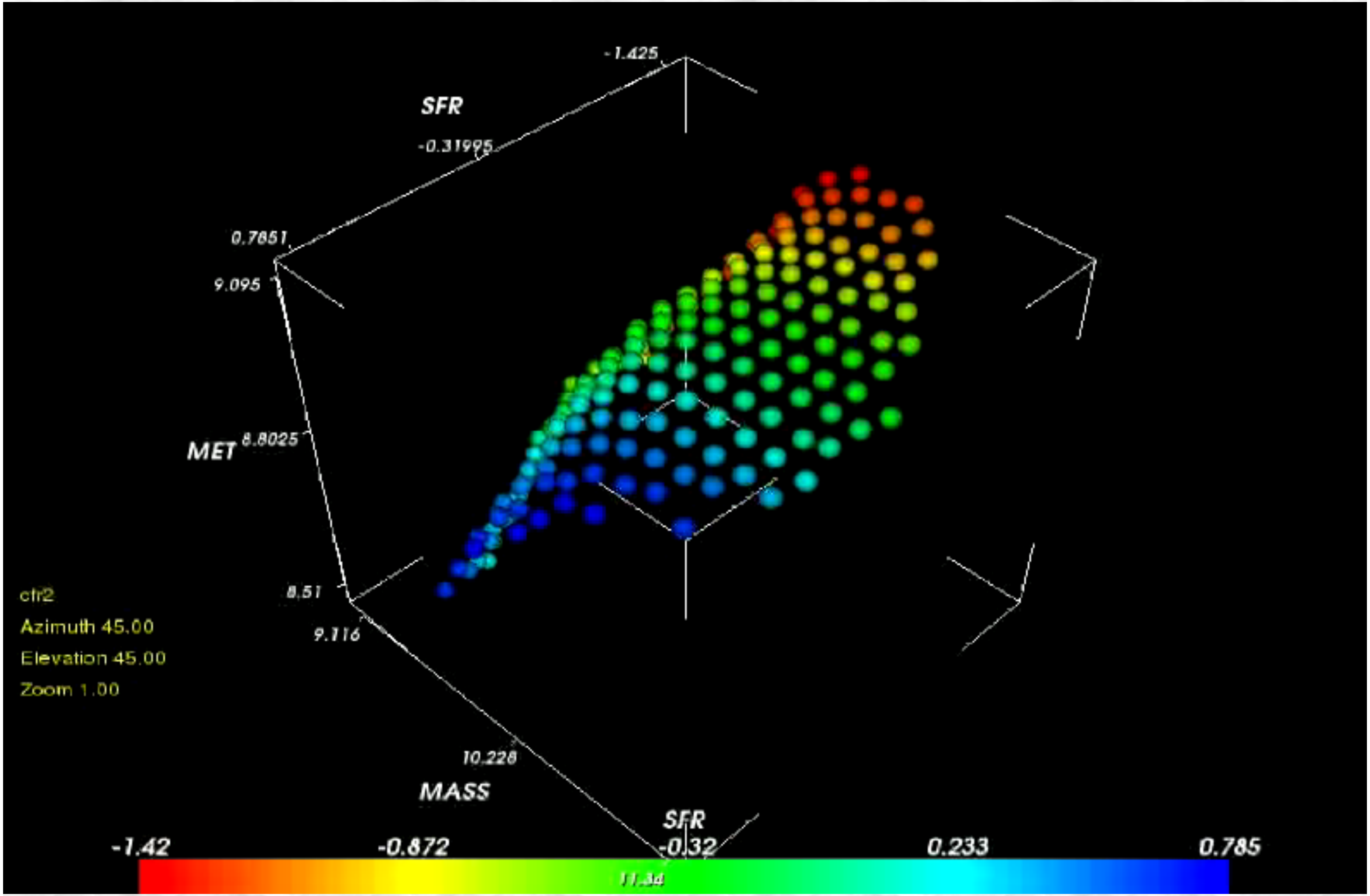
Is there a relation between metallicity, mass and SFR?



141.000 local SDSS galaxies, selected to have SNR(Hα)>25, z>0.07

- Stellar Mass: SED fitting + spectra
- SFR: Hα (Kennicutt) + Balmer dec.
- Gas metallicity: strong lines: [NII]/Hα and R23

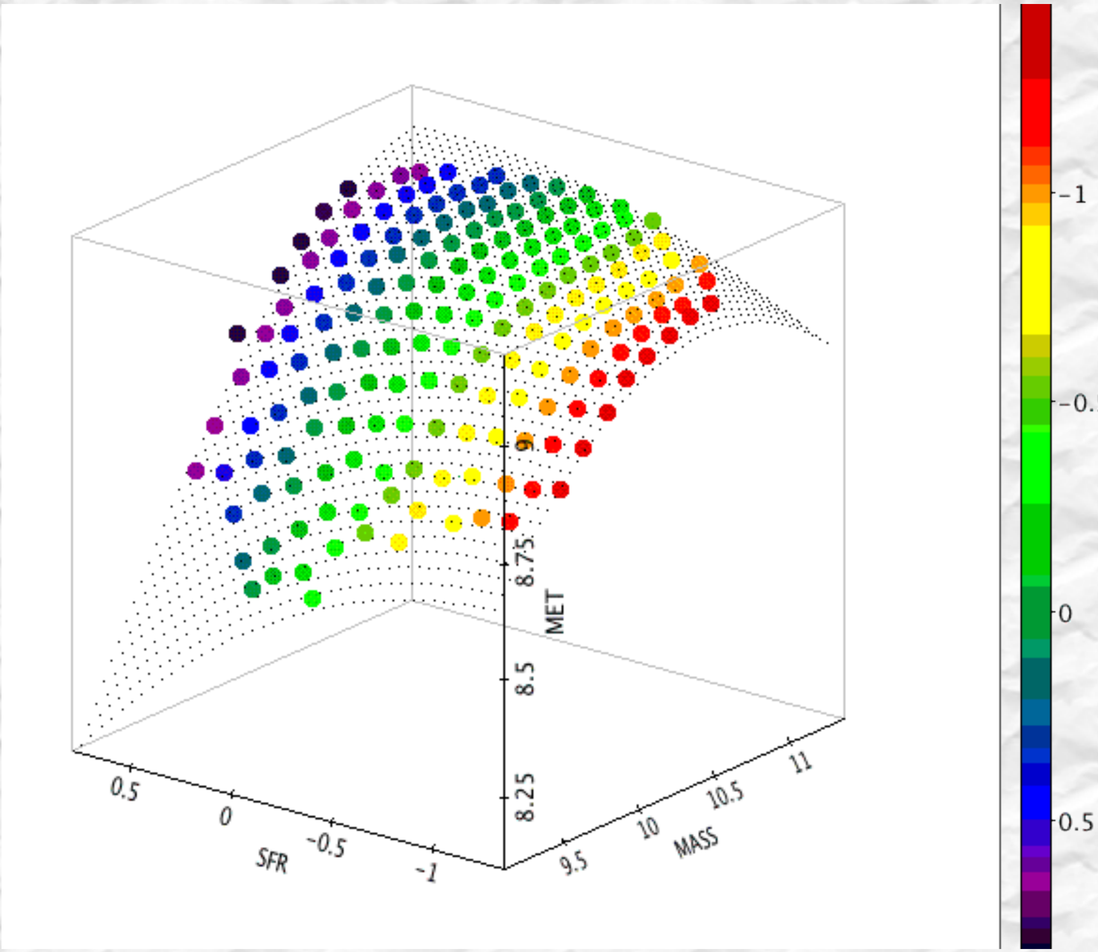
The Fundamental Metallicity Relation



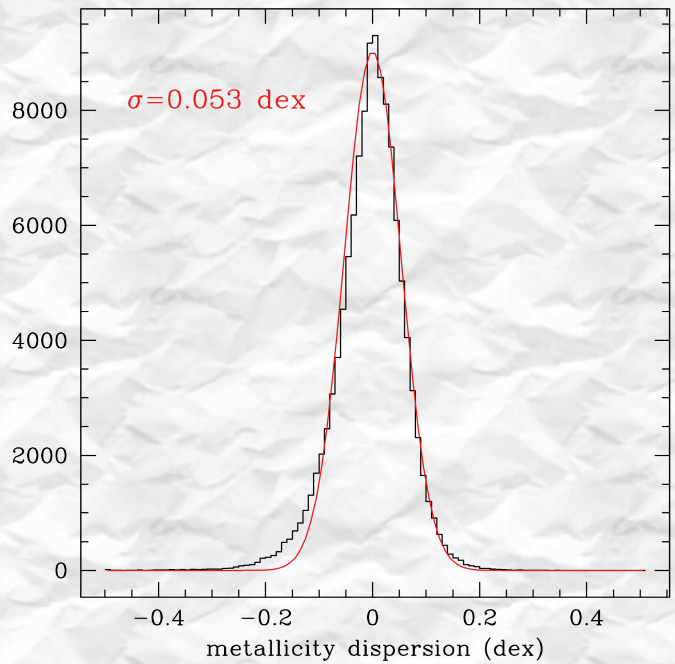
Mannucci, Cresci et al. 2010

The Fundamental Metallicity Relation

Small scatter => Long lasting equilibrium between gas accretion, star formation and metal ejection *(e.g. Dave', Finlator & Oppenheimer 2011)*



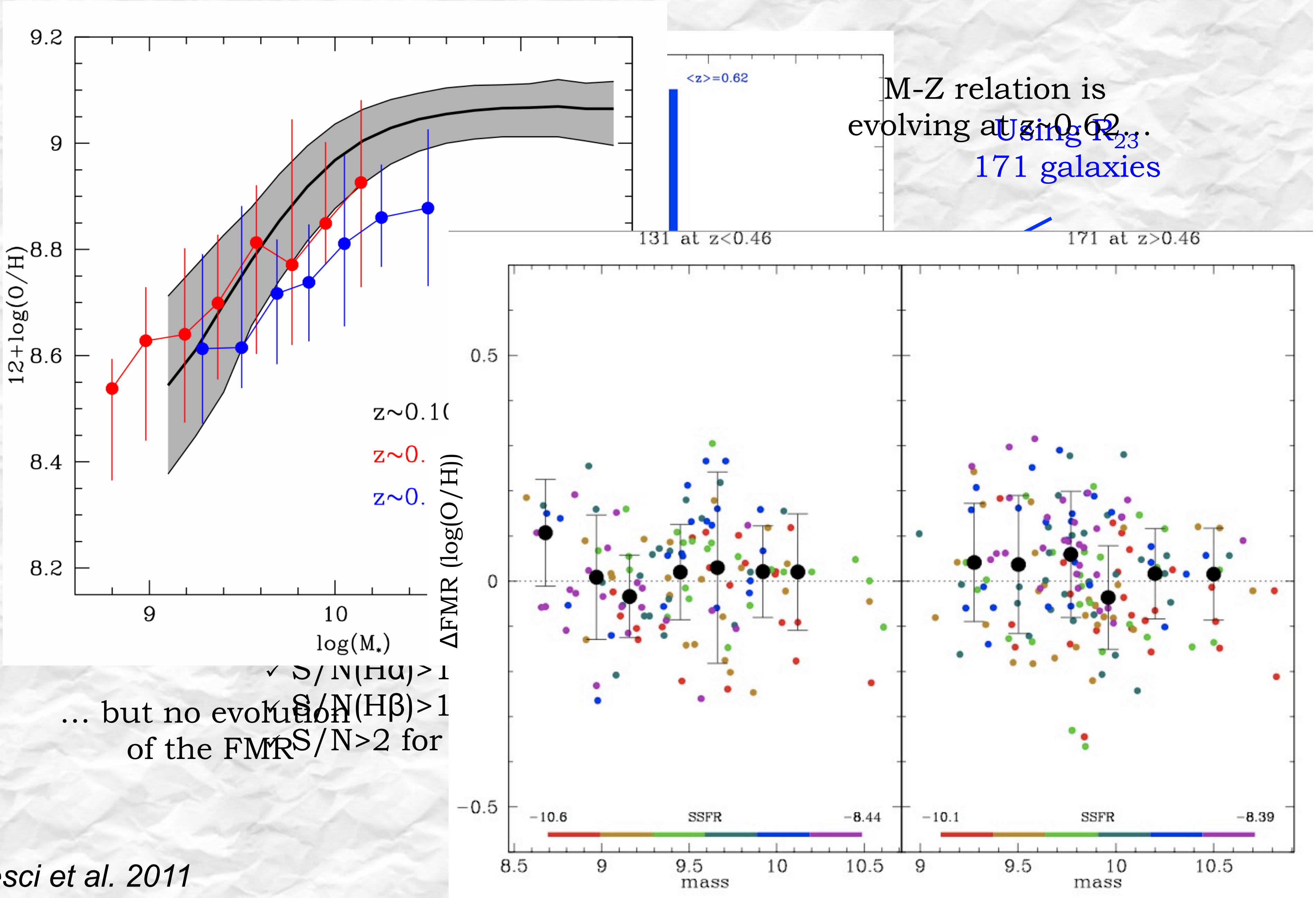
Dispersion of the original Mass-Met:
- half systematic (SFR)
- half intrinsic: ~12%



Mannucci, Cresci et al. 2010

Going to higher z with zCOSMOS

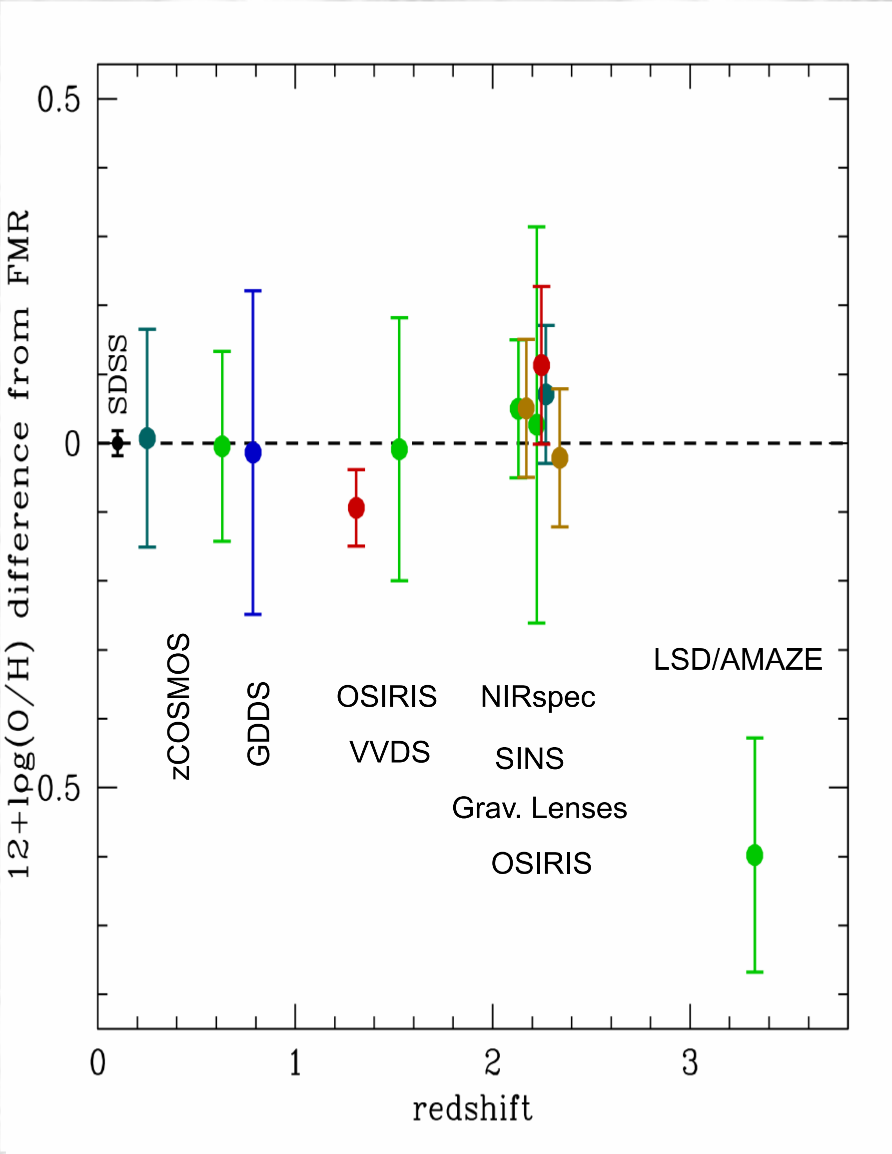
M-Z relation is evolving at z~0.62...



... but no evolution of the FMR

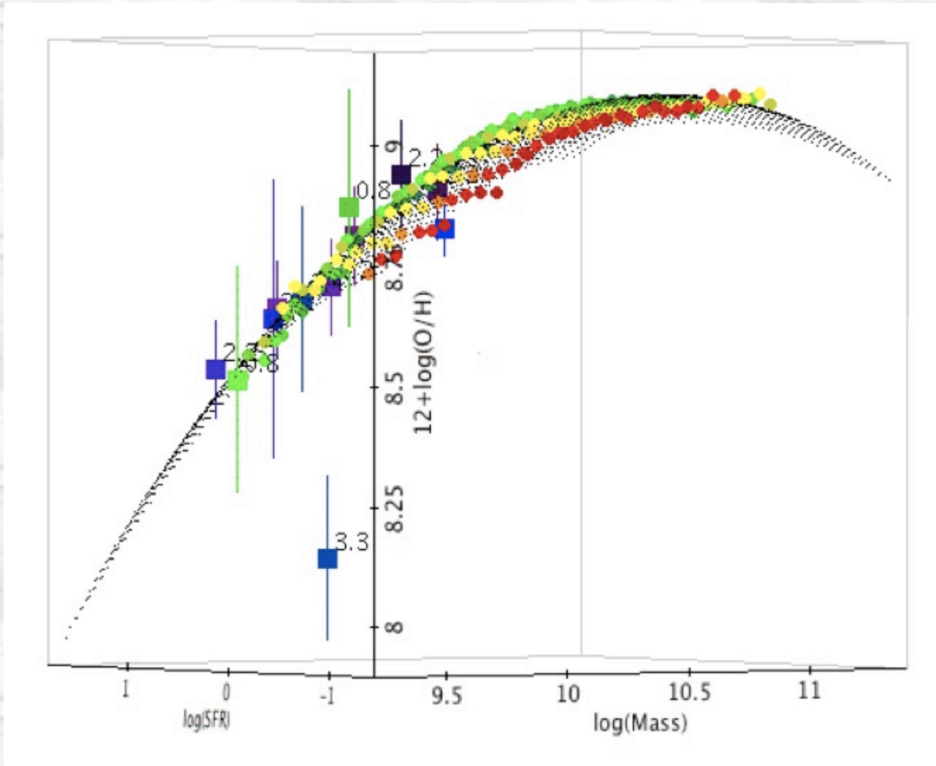
Cresci et al. 2011

Is the mass-metallicity really evolving?



Adding distant Galaxies at: z=0.8 (*Savaglio et al. 2006*) z=1.4 (*Shapley et al. 2005, Liu et al. 2008, Wright et al. 2009, Epinat et al. 2009*) z=2.2 (*Erb et al. 2006, Law et al. 2008, Lehnert et al. 2009, Forster Schreiber et al. 2009*) z=3.3 (*Maiolino et al. 2008, Mannucci et al. 2009*)

The Mass-Met evolution seems to be *only related to the increase of the SFR with z*, at least up to z~2

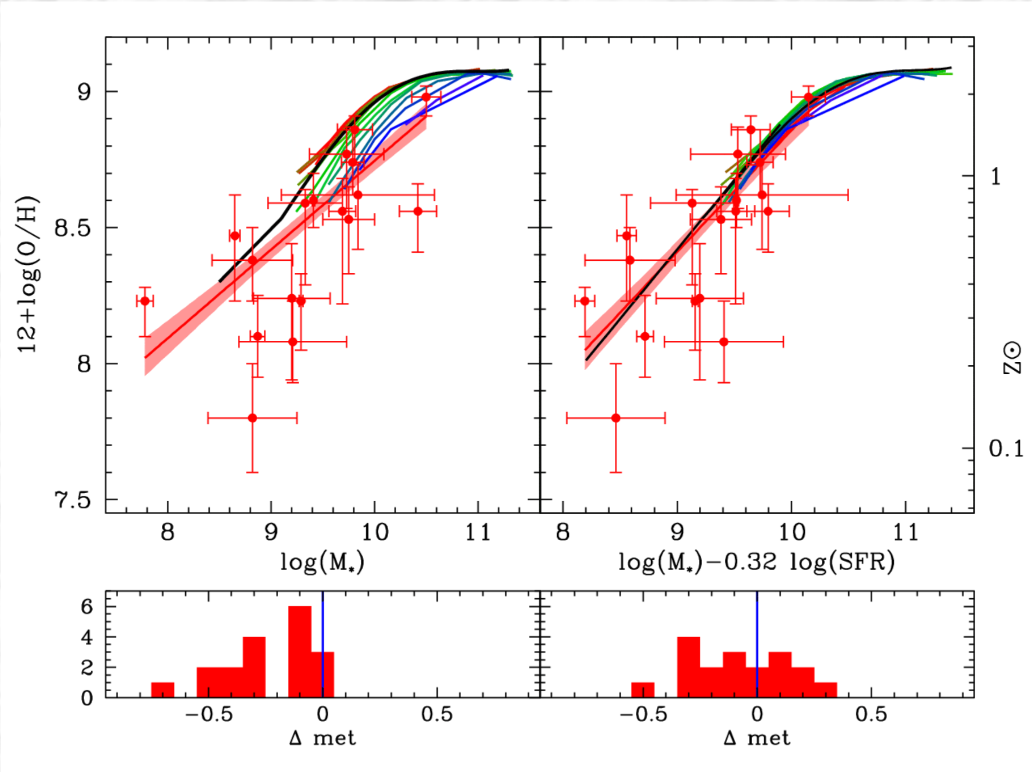


Mannucci, et al. 2010, Cresci et al. 2011

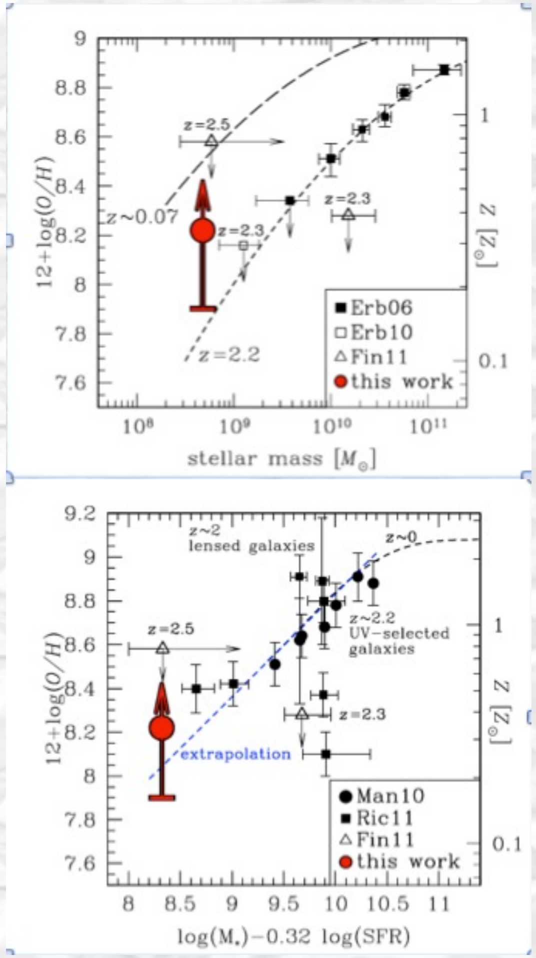
See also C. Maier's poster

Still not convinced?

The presence of a FMR up to z~2.5 confirmed by several other *independent* observations of *differently selected* galaxy samples at low and high z



Long GRB host galaxies (Mannucci et al. 2011, Vergani et al. 2011)



Stacked Ly α emitters at z=2.2 (Nakajina et al. 2011)

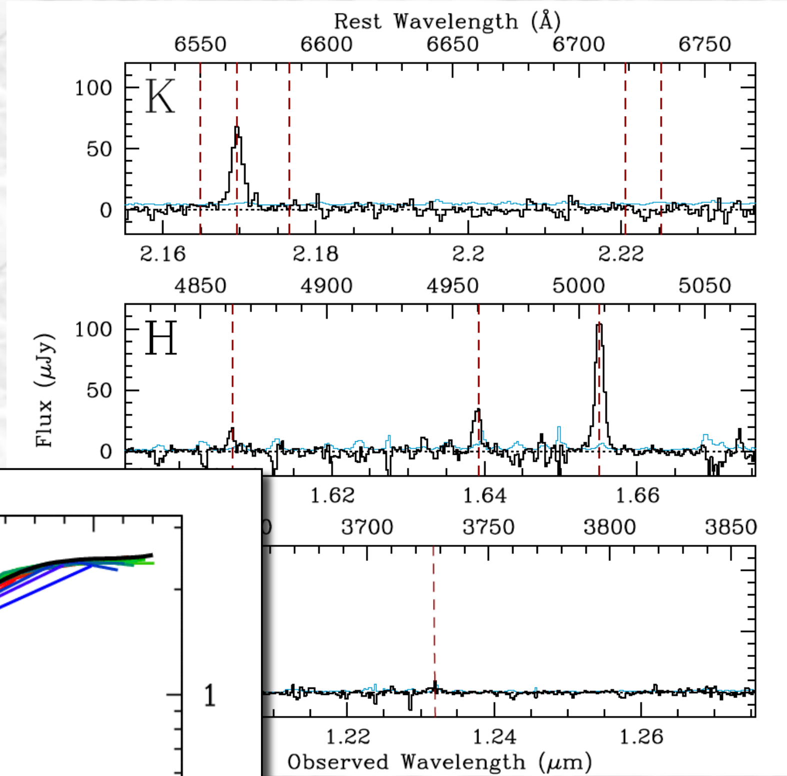
Not yet ???

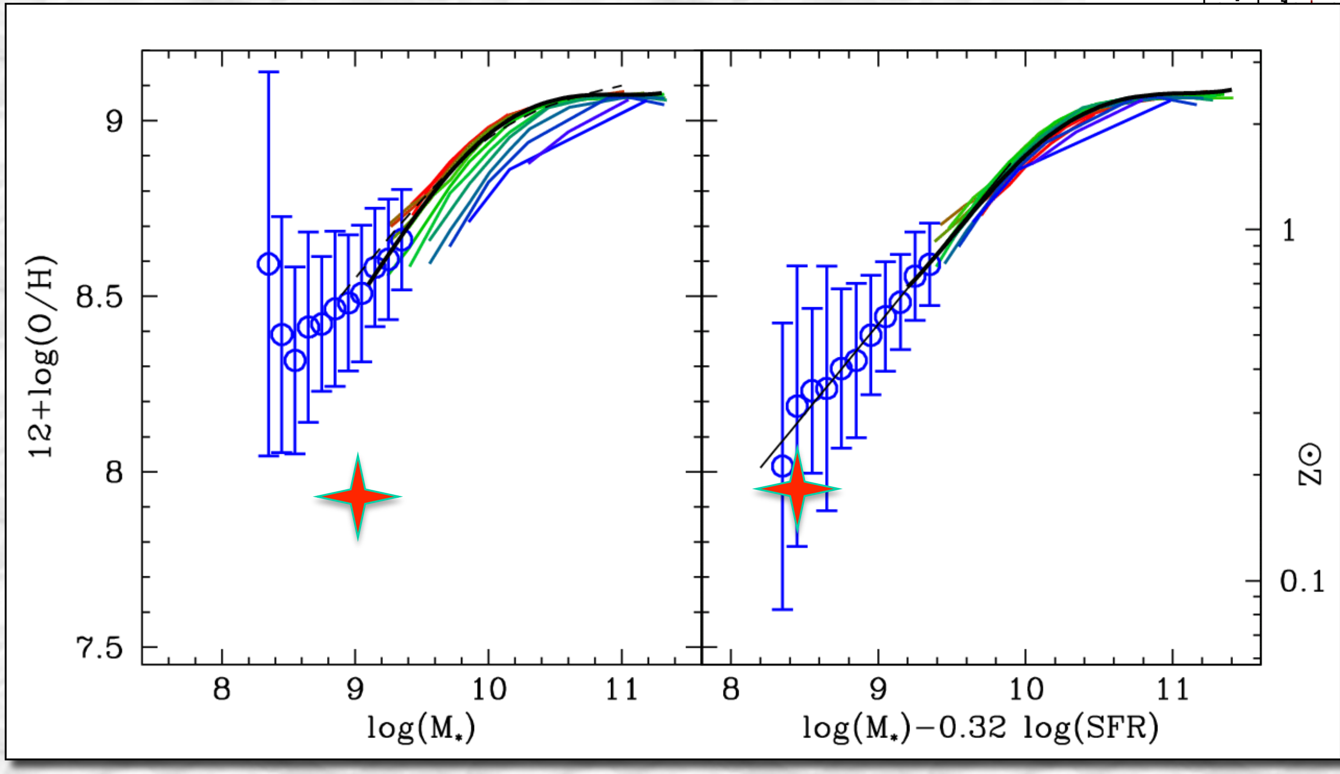
Erb et al. (2010) Q2343-BX418 z=2.3

Deep spectrum: 12h Keck time

Observed 12+log(O/H)=7.90+/-0.2

SFR = 15 +/- 2 $M_{\odot}$/yr

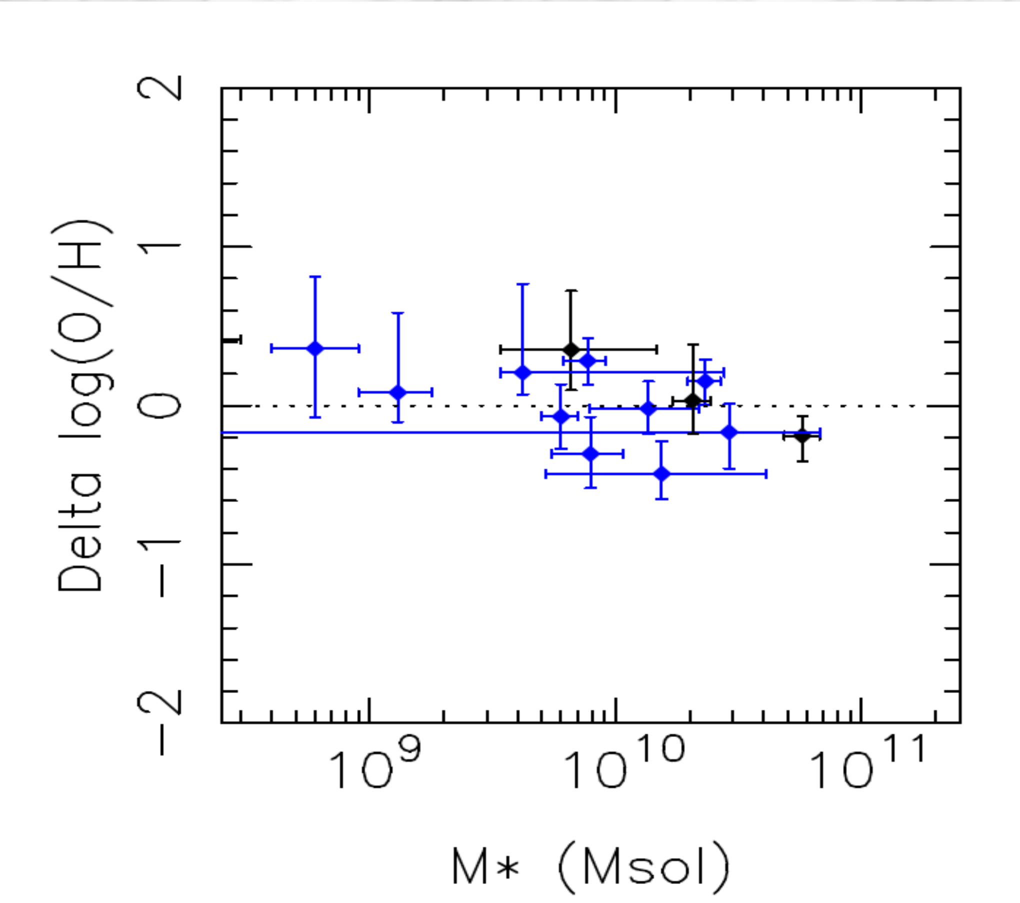


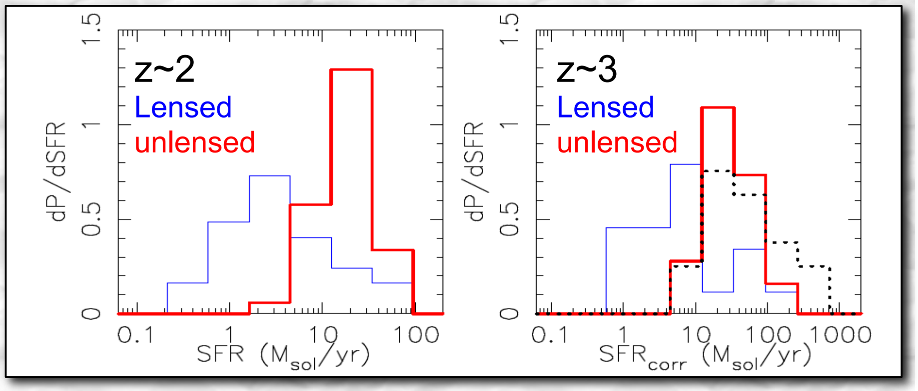


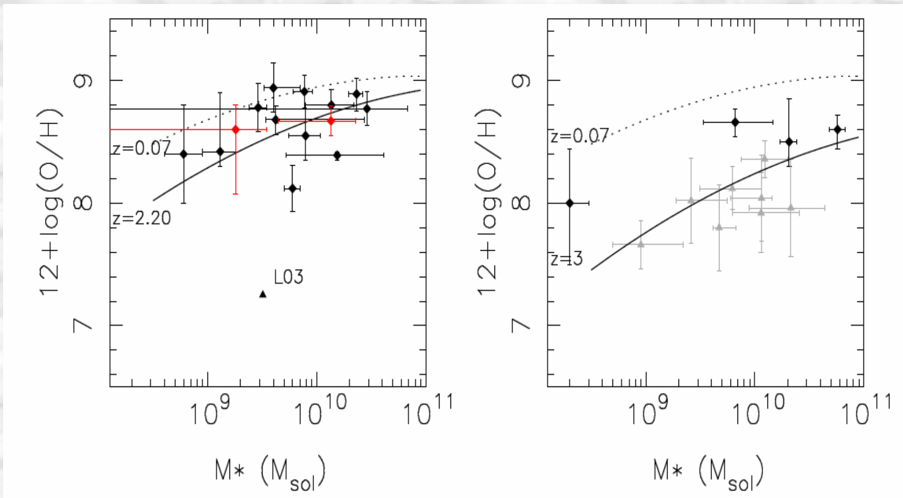
Some more ?

Richard et al. 2010: Gravitationally Lensed galaxies at z~2.5

Sampling lower SFRs







See also Contini et al. 2011 at z~1.5, Kassin et al. 2011 at z~0.8, Yates et al. and J. Scudder's poster at z

Summary

Metal Content in Galaxies

Fundamental to understand the main drivers of galaxy evolution, especially meaningful when considered in concert with stellar and gas content

Chemical evolution in high-z star-forming galaxy:

Evidence for rapid metal enrichment and significant inflows/outflows at high-z;

Resolved metallicity gradients provide evidence of pristine gas accretion in star forming disks at high redshift;

First measure of stellar metallicity in high-z star forming galaxies

Fundamental Metallicity Relation:

Local galaxies define a tight surface in this 3D space SFR-Met-M$_*$, which appear not to evolve up to z~2.5;

It has to be explained by the interplay of infall of pristine gas, outflow of enriched material and star formation history (see e.g. Dave', Finlator & Oppenheimer 2011)