Evidence for gas accretion sustaining star formation in disk galaxies

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Outline

- Gas accretion in cosmological numerical simulations
- Metallicity drops in Extremely Metal Poor Galaxies
- CGM – IGM around Extremely Metal Poor Galaxies
- Size-Metallicity-Mass relation set by gas accretion
- Summary: take-home message

Gas accretion in cosmological numerical simulations

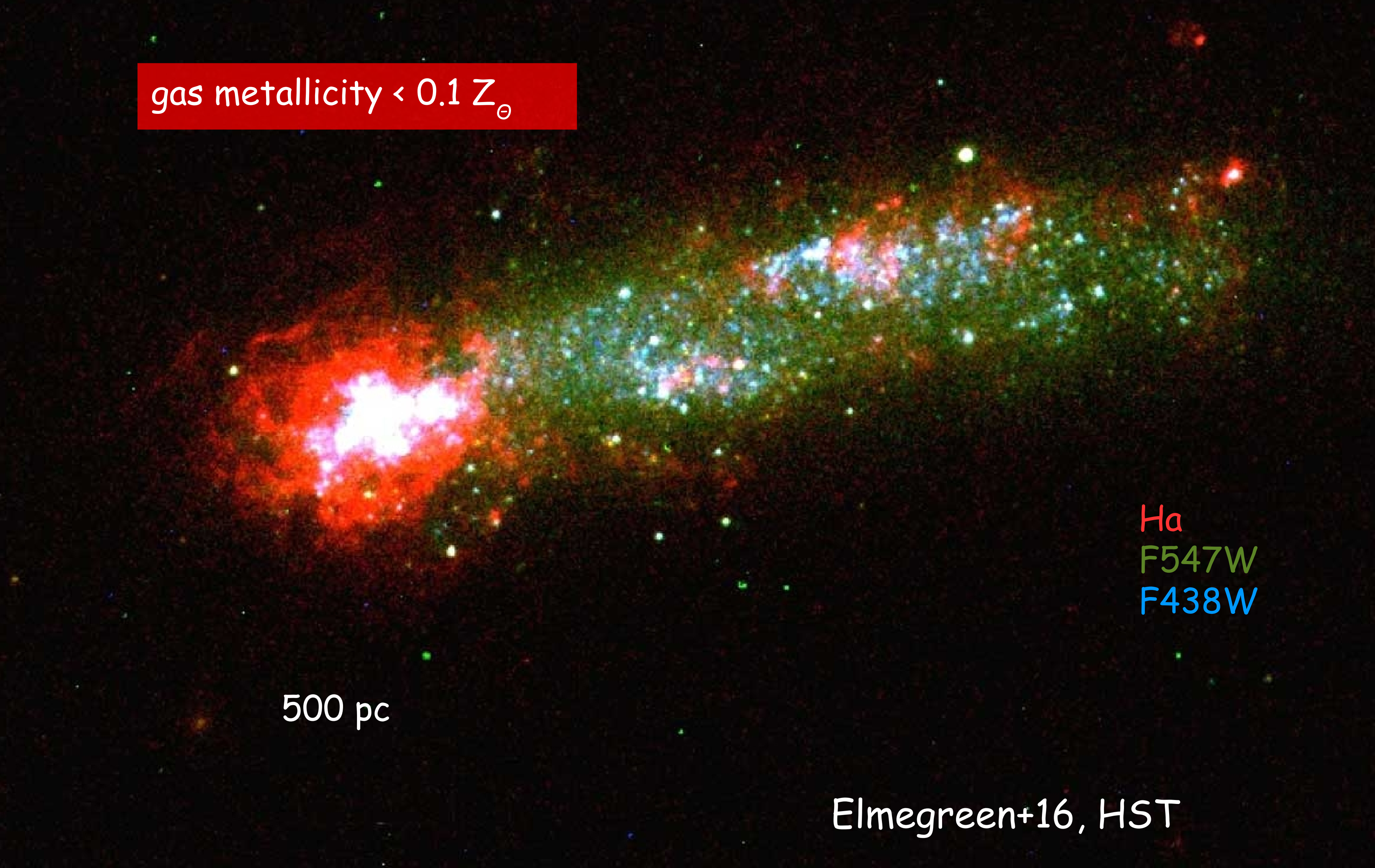
Cosmological numerical simulations produce model galaxies that try to self-regulate so that gas inflows and outflows tend to balance the SFR (*Finlator & Dave 2008; Schaye et al. 2010; Fraternali & Tomassetti 2012; Dave et al. 2012; Dekel et al. 2013; Bothwell et al. 2013; Feldmann 2013; Altay et al. 2013; Forbes et al. 2014*).

This process occurs **at all redshifts**, and is particularly fast via called cold-flow accretion, characteristic of low mass galaxies (halo mass < $10^{12} M_{\odot}$) and provides fresh gas ready to form stars right where it is needed (Birnboim & Dekel 03)

The importance of gas infall is as clear from numerical simulation as it has being difficult to prove observationally.

Many hints pointing in the direction, but no final proof given yet (see, e.g., Sancisi+08,SA+14, SA17)

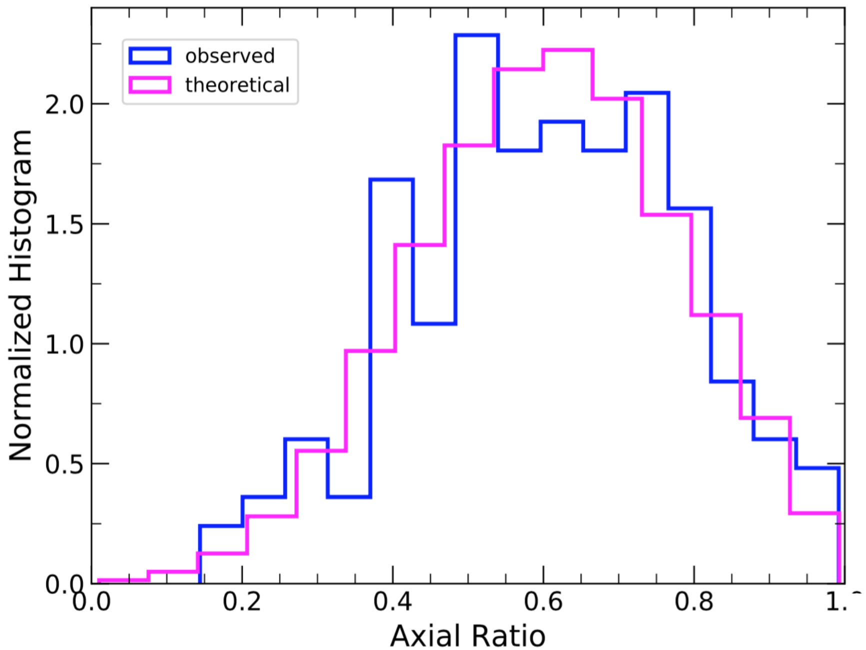
Extremely Metal Poor Galaxies provide a good support for metal-poor gas accretion feeding star formation



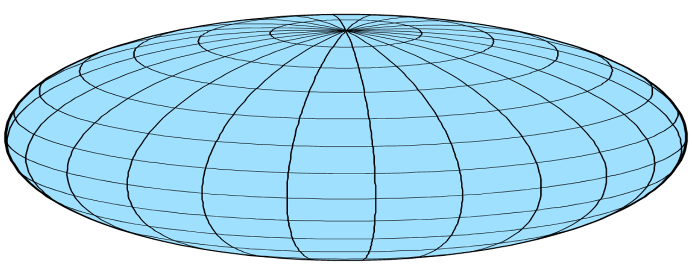
EXtremely Metal Poor galaxies (XMPs)

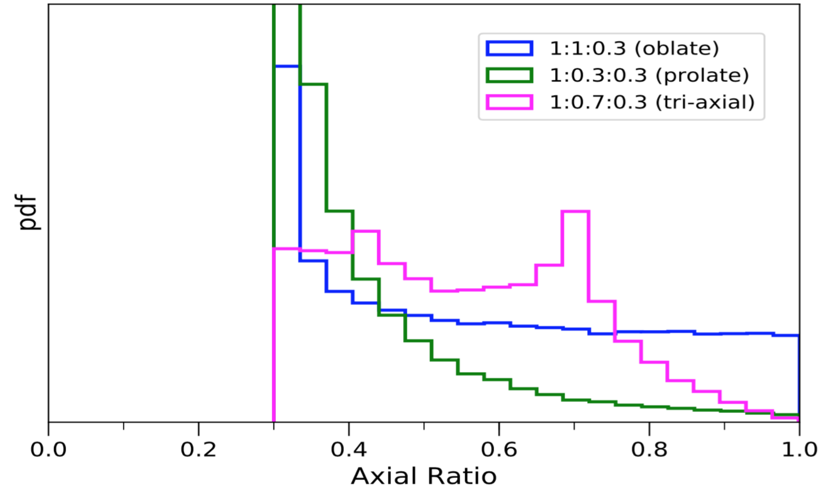
- XMPs are rare in surveys : less than 0.1% of the galaxies in SDSS (e.g., Morales-Luis+11, SA+16)
- XMPs tend to be cometary -- tadpole (70% in systematic searches on SDSS; e.g., Morales-Luis+11; Filho+13; SA+16; Papaderos+2008 already found this association)
- XMPs tend to be Blue-Compact Dwarfs (e.g., Morales-Luis+11), although some are just dIrr (Hirschauer+16).
- XMPs are gas-rich objects $M_{HI}/M_{*} \approx 10$! (Filho+13)
- XMPs often rotate, but with large velocity dispersions as inferred from the emission lines; they seem to be turbulent disks (Sanchez Almeida+13, Olmo-Garcia+17).
- XMPs tend to be isolated, as judged from the number of nearby companions, and they reside in underdense regions as judged from constrained cosmological simulations (Filho+15, SA+16)
- There is lower limit for the metallicity $Z \geq 0.02\ Z_{\odot}$

◇ XMPs are disk-like (prolate) triaxial objects (Putko+18, in prep.)

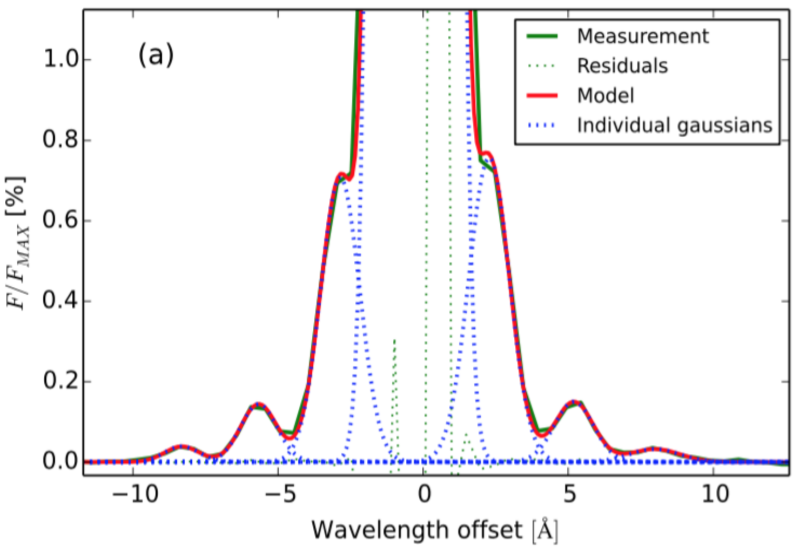


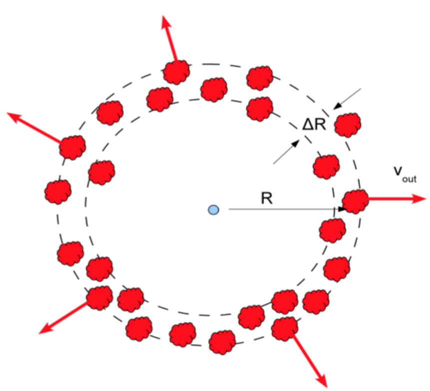
a : b : c => 1 : 0.7: 0.4

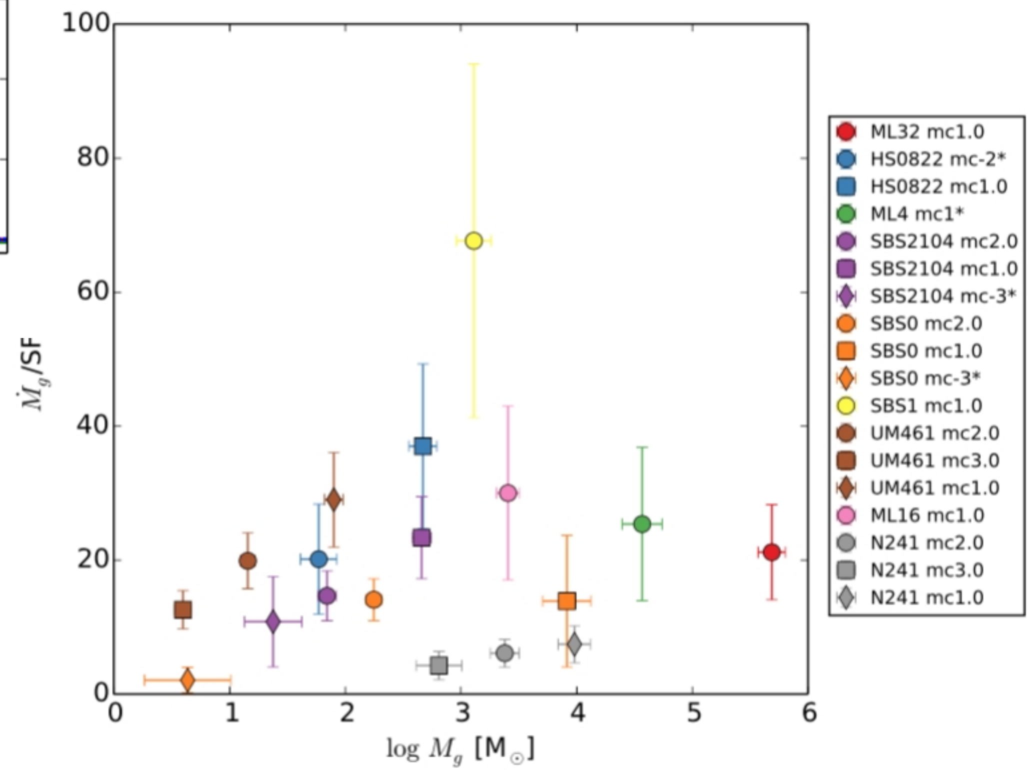




◇ XMPs tend to show large mass loading factors: M_{out}/SFR > 10 !! (Olmo-Garcia+17)

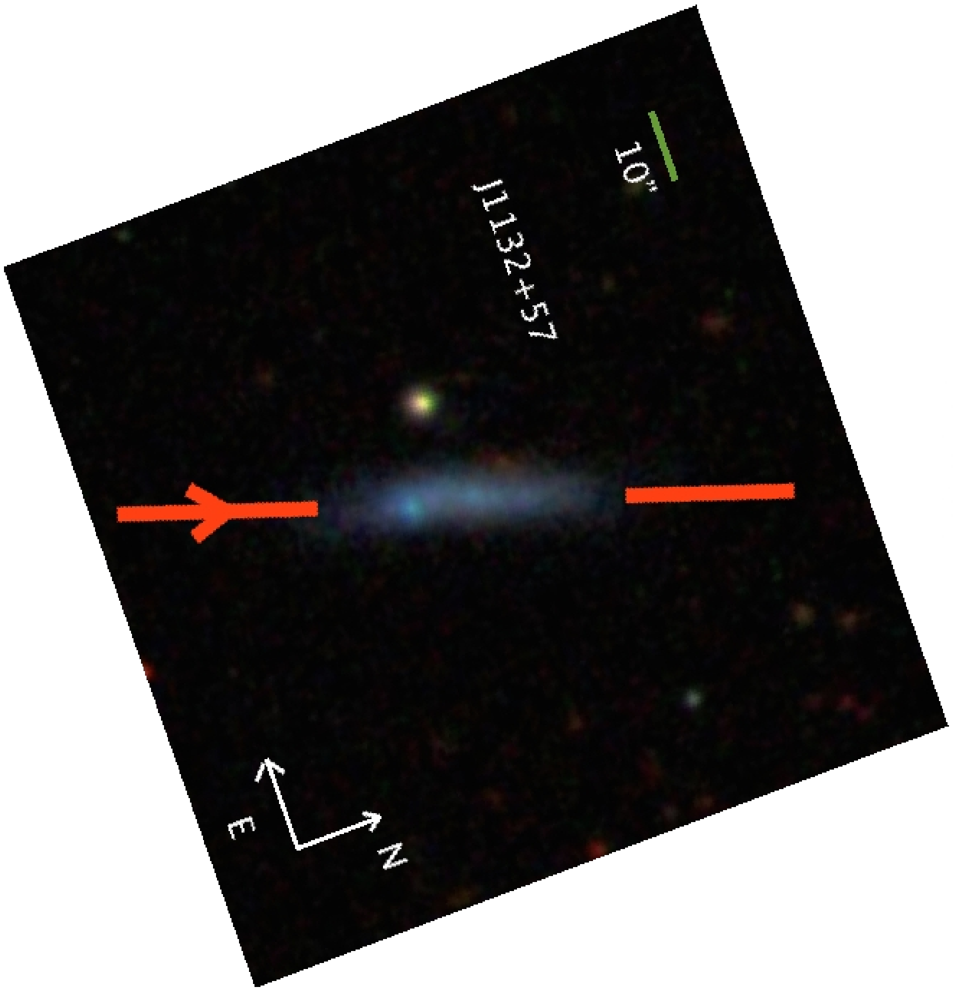


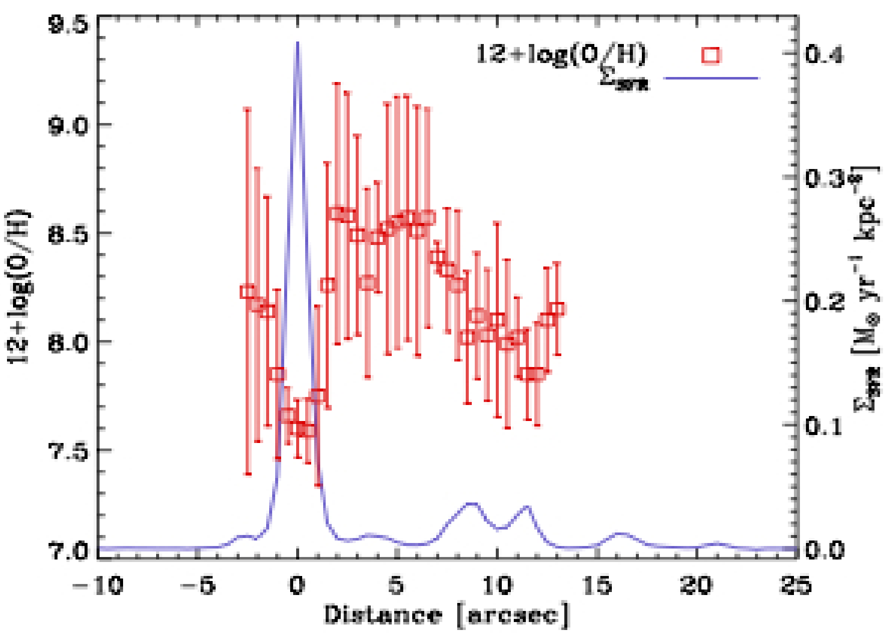




◇ XMPs have chemical inhomogeneities associated with SFR (SA+13,14,15)

SFR ↑ ⇔ Z ↓

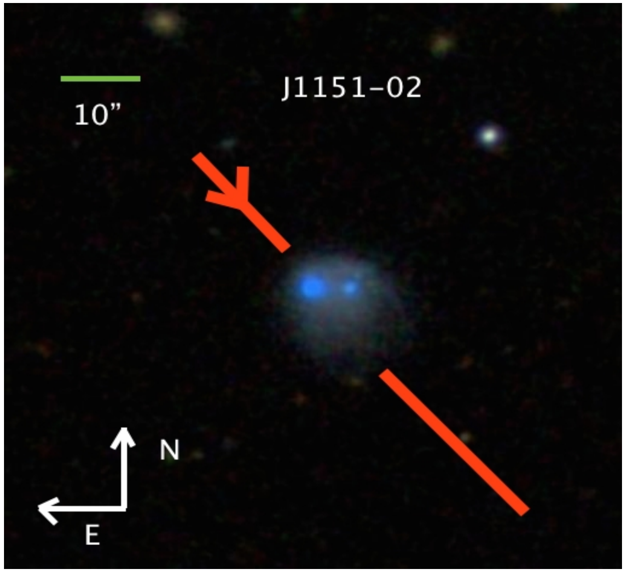




(SA+15, ApJL)

So, XMPs seem to be faint solar-metallicity turbulent disk-like galaxies with one (or more) off-centered starburst of low metallicity

They differ in metallicity by almost one order of magnitude, and it is the starburst that give the XMP character to the XMP galaxies



Keeping in mind the short gas mixing time-scale,the observations are consistent with the heads being a starburst triggered by the recent inflow of metal-poor gas .

XMPs seems to be going through a gas accretion event.

Can we detect the gas that feeds the star-formation process?

Searching for the gas around XMP galaxies

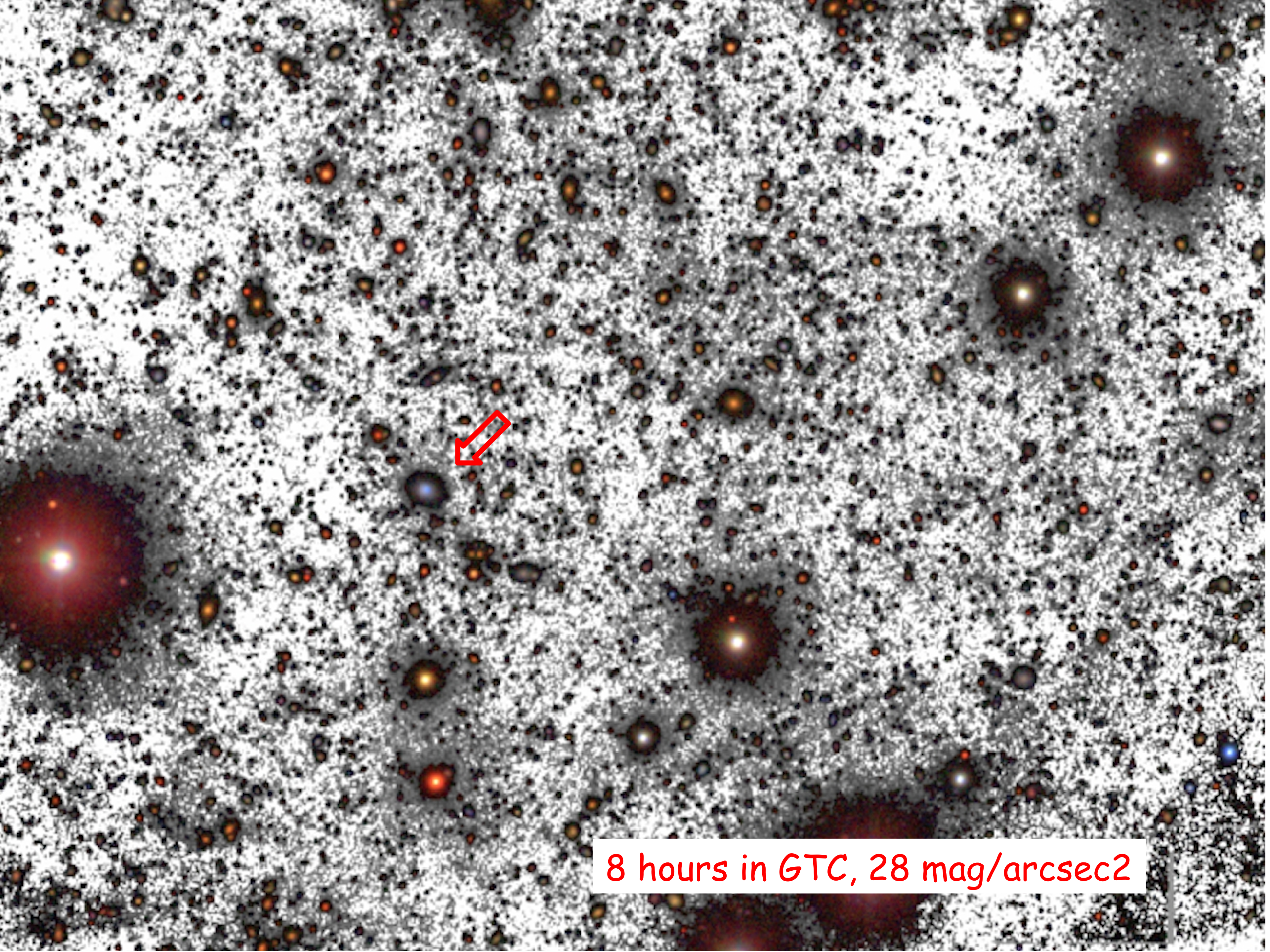
Detected in Lya a redshift 2-3 (Cantalupo+14). The same kind of mechanisms can induce emission in Hα.

Educated guesses of expected flux (e.g., Goerdt+10) point out a range between

10^{-19} -- 10^{-17} erg s^{-1} cm^{-2} $arcsec^{-2}$

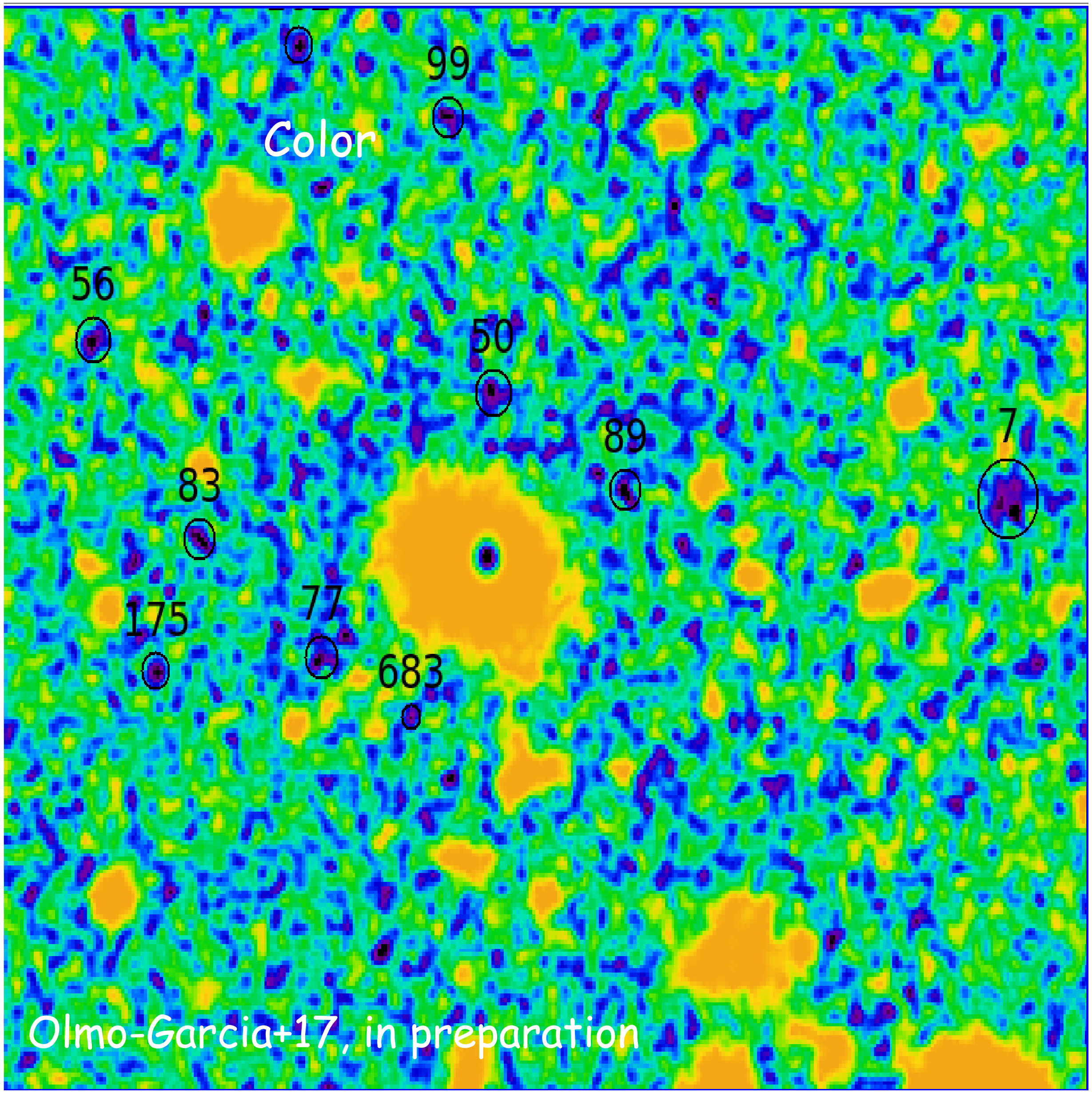
Proof of concept observation with 10m-GTC
8' x 8' FOV
Hα measurement (medium band filter) OSIRIS
8 hour integration
28 mag/arcsec2 or 10^{-18} erg s^{-1} cm^{-2} $arcsec^{-2}$

Olmo-Garcia+17, in preparation

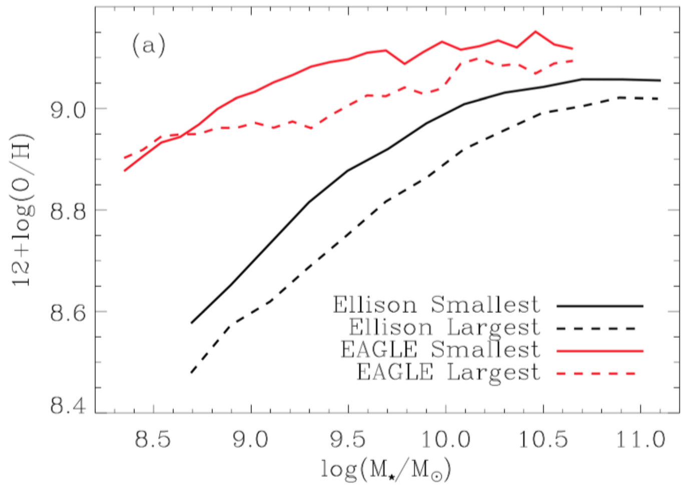

8 hours in GTC, 28 mag/arcsec2

log(Flux Ha): color map

- halo around the XMP galaxy
- clumps throughput the FOV

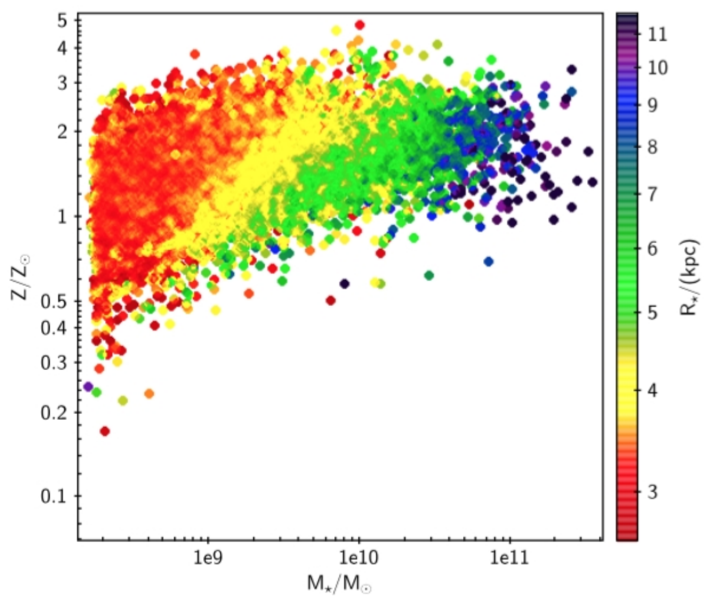


Size-Metallicity-Mass relation set by gas accretion in cosmological numerical simulations



At fixed M*, the smaller the galaxy the higher the gas-phase metallicity (Ellison+08)

Holds to high redshifts (1.4; Yabe+12)



This anti-correlation R_* and Z_{gas} is in the galaxies of the EAGLE numerical simulations (Schaye+15, Crain+15, McAlpine+16)

SA+2017, in prep

Assuming that the physical mechanism is the same for observations and numerical simulations, what is the process that is responsible for the relation between size and metallicity?

Options:

- Metal rich outflows: depth of the gravitational potential, deeper in the smaller systems.

  No relation metallicity vs Vscp (scape velocity)

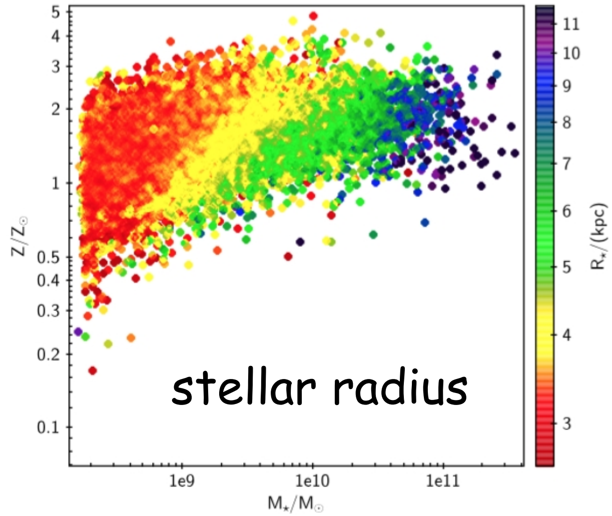
- Increase of star-formation efficiency in denser systems., which become metal richer sooner.

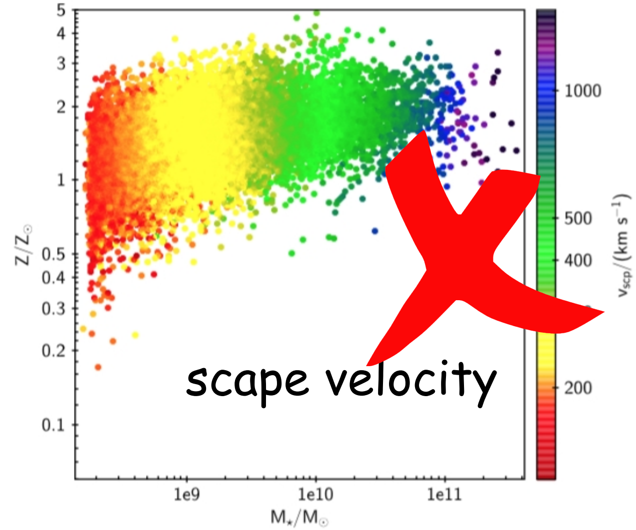
  No relation metallicity vs *(stellar mass density)

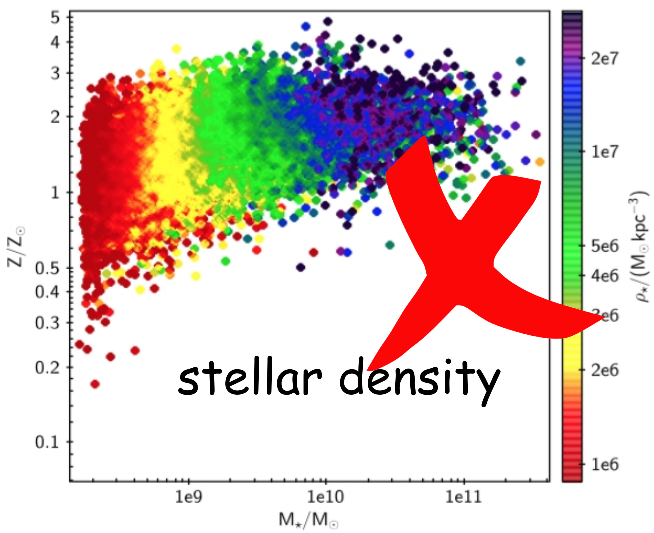
- Late metal-poor gas inflows: all galaxies grow in time so those that receive the gas later are both larger and metal-poorer.

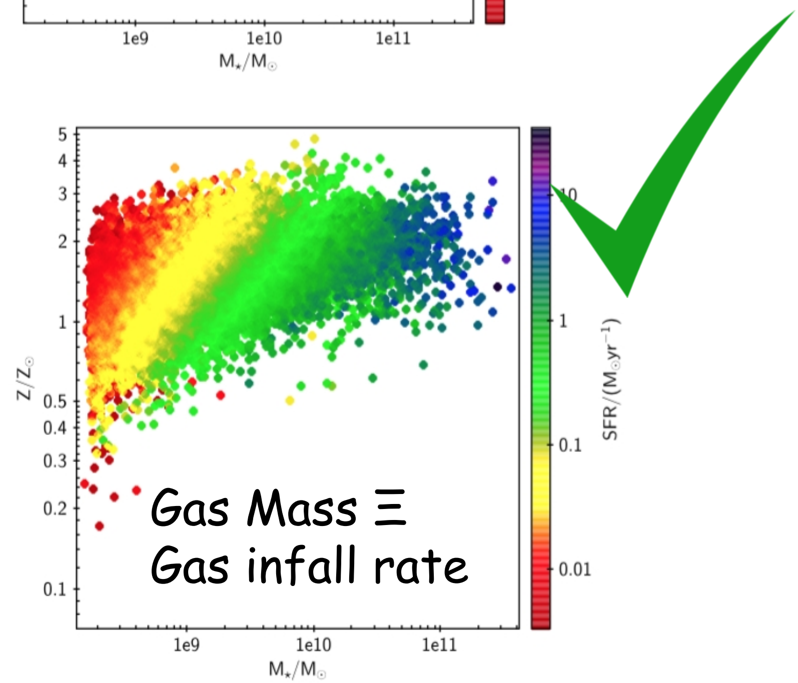
  Good relation metallicity vs gas infall rate, as parameterized either by SFR or M_{gas}

Metallicity versus Stellar Mass, color coded with:

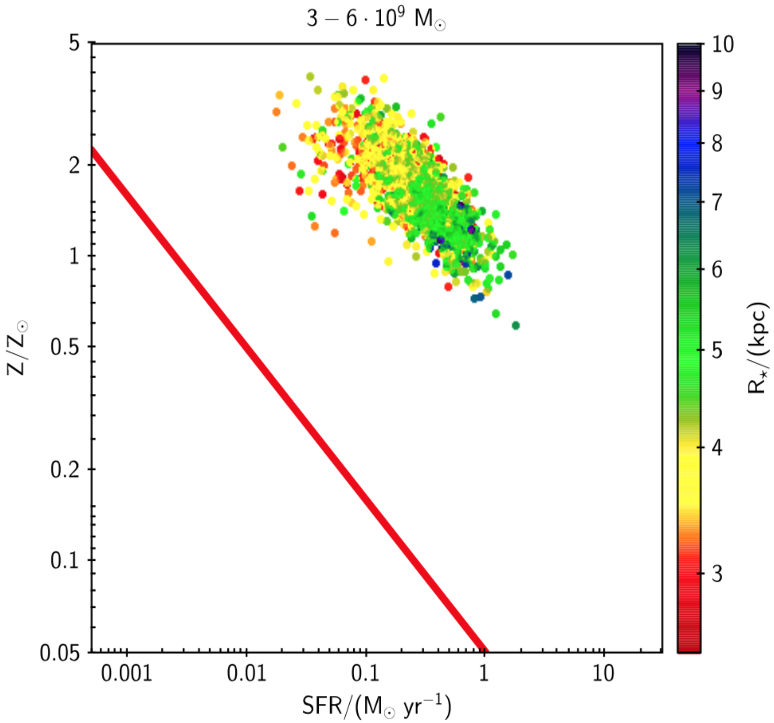




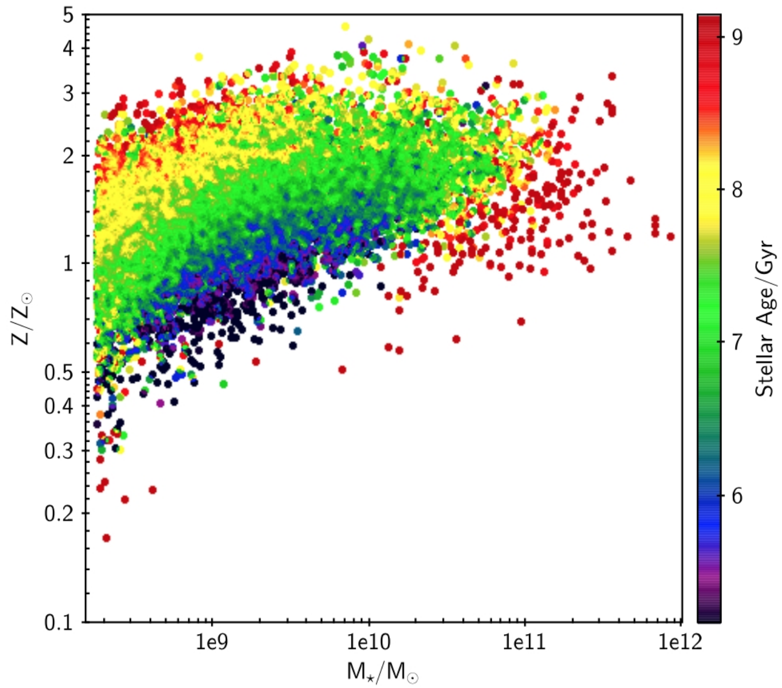




High SFR galaxies are larger

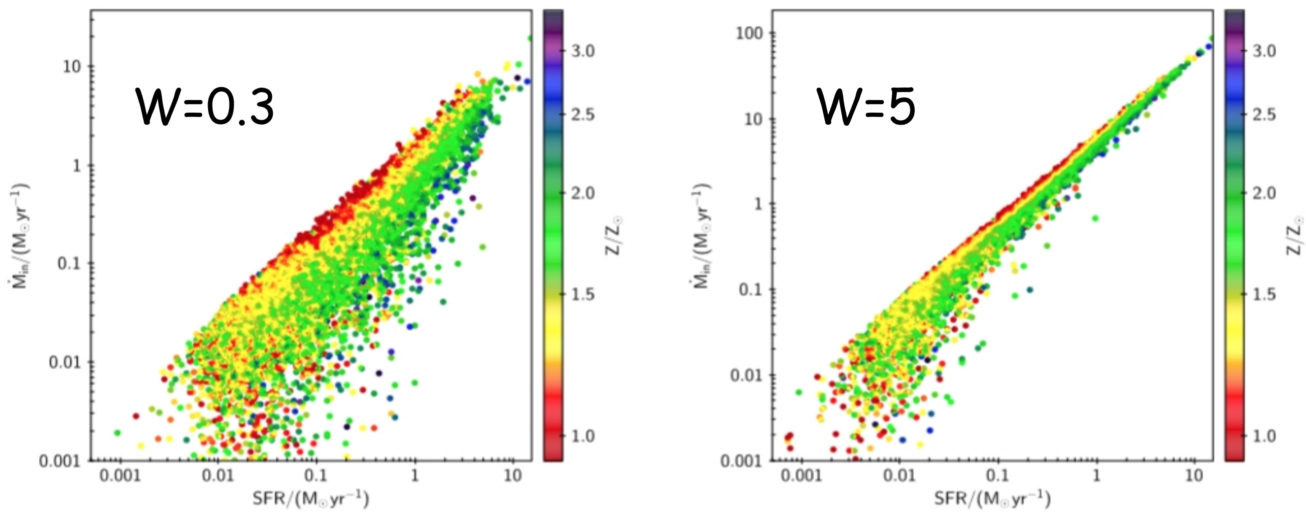


High SFR galaxies have younger stellar populations (mass-weighted age)



The anti-correlation between metallicity and size is due to difference in recent gas accretion rates

Mass infall rate is proportional to SFR



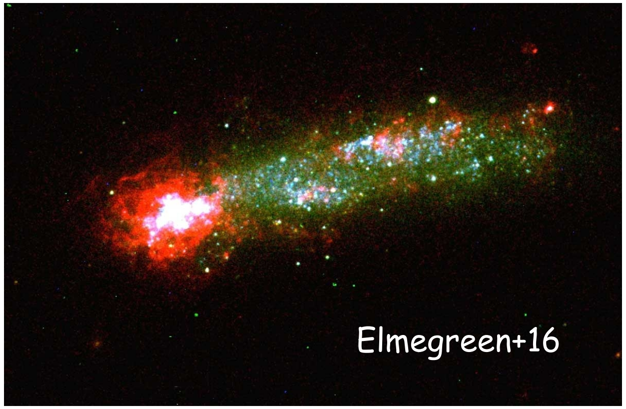
$$\dot{M}_g = -(1-R)\,\mathrm{SFR} + \dot{M}_{in} - \dot{M}_{out},$$

$$\dot{M}_{out} = w\,\mathrm{SFR},$$

$$M_g(t) = \int_0^t \dot{M}_{in}(t')\,\mathrm{e}^{-(t-t')/\tau_{in}}\,dt',$$

M_{gas} is just a time average of the gas accretion rate.

Summary

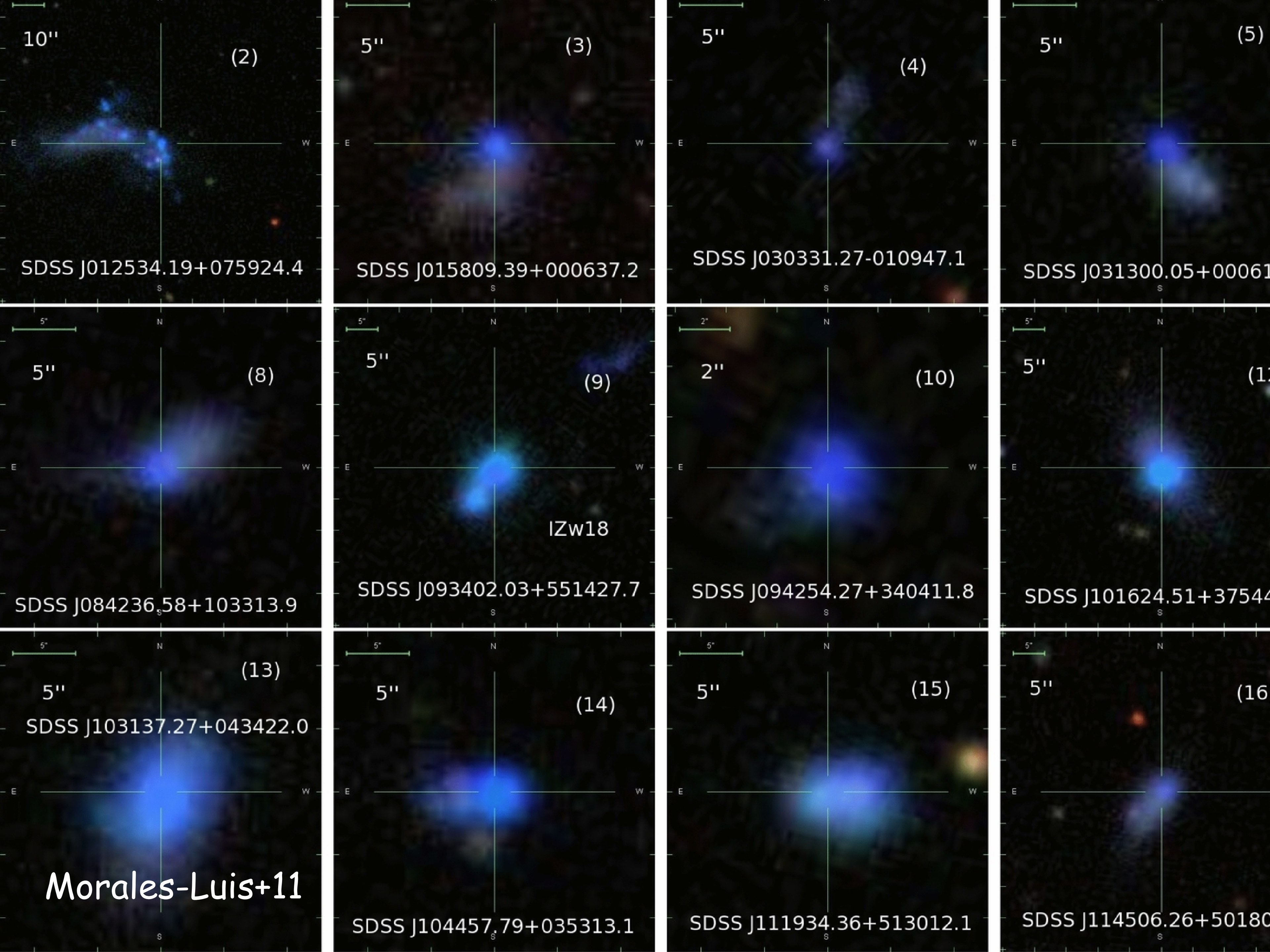


1.- Most of the star-formation is driven by gas accretion from the cosmic web. Solid theoretical prediction. Happens at all redshifts.

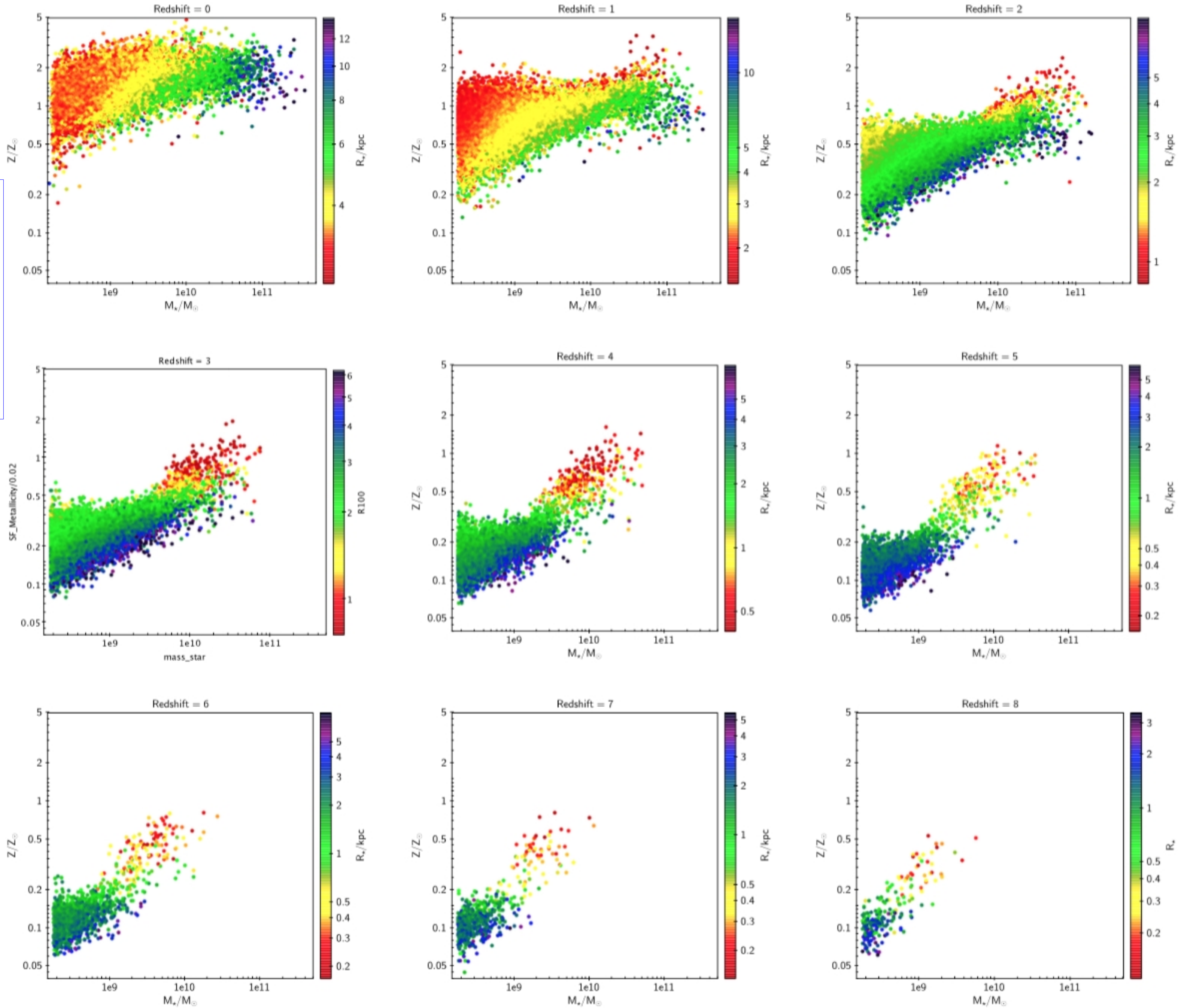
2.- XMP galaxies seem to be going through one episode of metal-poor gas accretion. (Cosmological?) Ideal to look for in-falling gas, in their GCM but also in their IGM.

3.- We are exploring various possibilities to detect this CGM -IGM elusive gas.

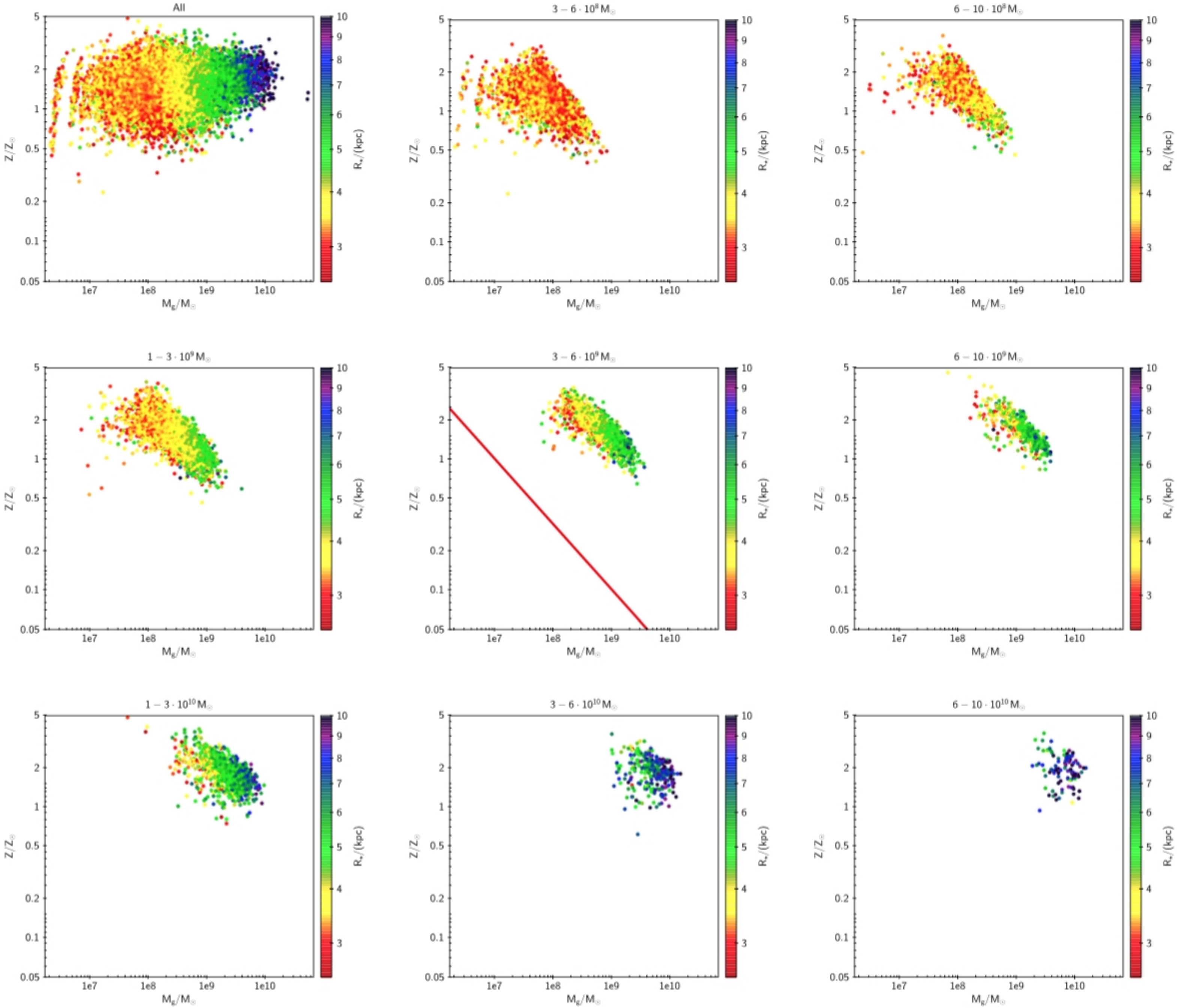
4.- The anti-correlation between gas metallicity and galaxy size (at constant M*; Ellison+08) is set by recent metal-poor gas accretion episodes in EAGLE galaxies.


10''
(2)
SDSS J012534.19+075924.4
5''
(3)
SDSS J015809.39+000637.2
5''
(4)
SDSS J030331.27-010947.1
5''
(5)
SDSS J031300.05+00061
5''
(8)
SDSS J084236.58+103313.9
5''
(9)
IZw18
SDSS J093402.03+551427.7
2''
(10)
SDSS J094254.27+340411.8
5''
SDSS J101624.51+37544
(13)
5''
SDSS J103137.27+043422.0
Morales-Luis+11
5''
(14)
SDSS J104457.79+035313.1
5''
(15)
SDSS J111934.36+513012.1
5''
SDSS J114506.26+50180

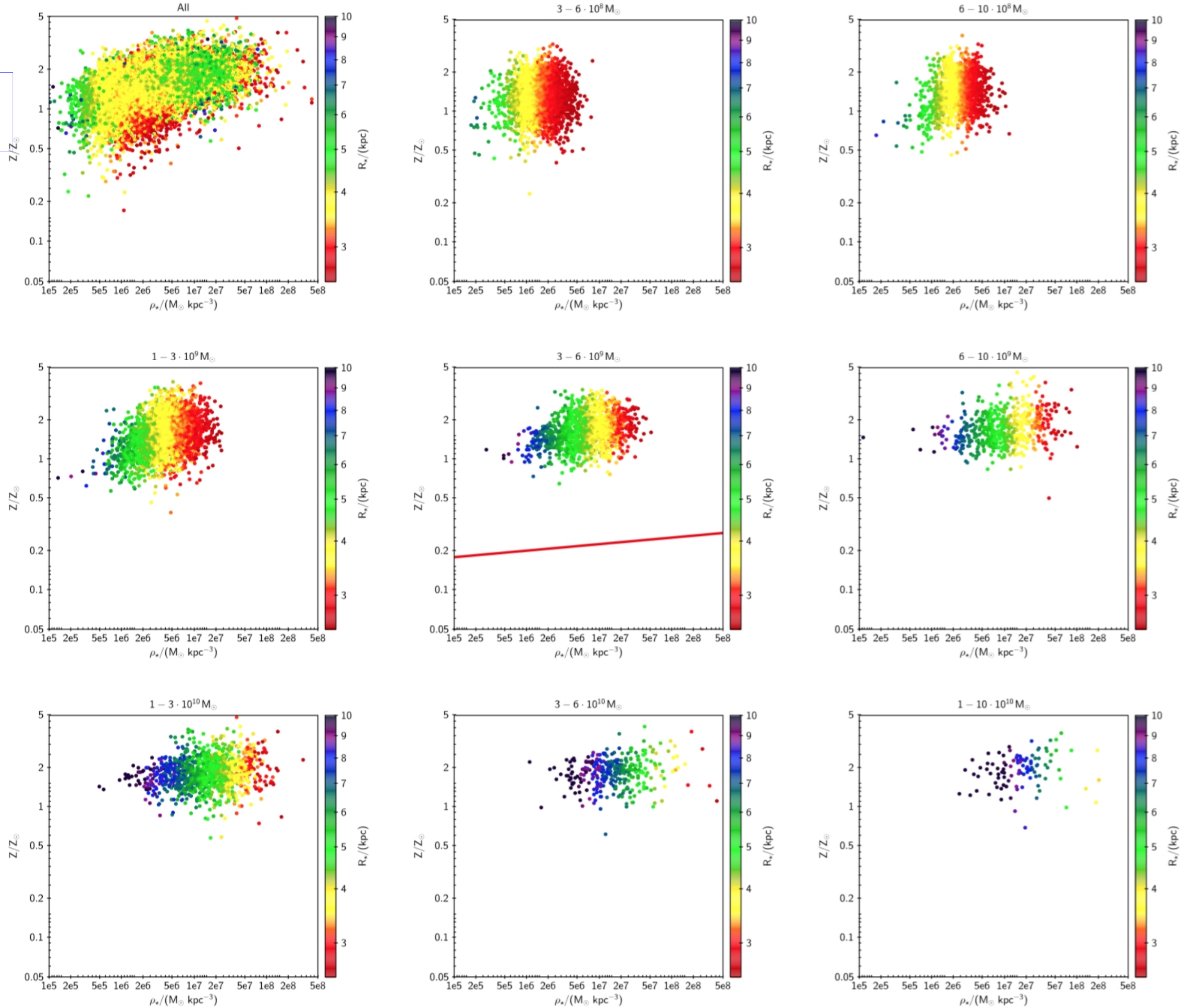
Z vs M_* Variation with redshift



Z vs M_g


All
$3-6\cdot10^8 M_\odot$
$6-10\cdot10^8 M_\odot$
$1-3\cdot10^9 M_\odot$
$3-6\cdot10^9 M_\odot$
$6-10\cdot10^9 M_\odot$
$1-3\cdot10^{10} M_\odot$
$3-6\cdot10^{10} M_\odot$
$6-10\cdot10^{10} M_\odot$
$Z/Z_\odot$
$M_g/M_\odot$
$R_*/(kpc)$
0.05
0.1
0.2
0.5
1
2
5
1e7
1e8
1e9
1e10
3
4
5
6
7
8
9
10

Z vs ρ_*



All
3 − 6 · 10^8 M☉
6 − 10 · 10^8 M☉
1 − 3 · 10^9 M☉
3 − 6 · 10^9 M☉
6 − 10 · 10^9 M☉
1 − 3 · 10^10 M☉
3 − 6 · 10^10 M☉
1 − 10 · 10^10 M☉
Z/Z☉
ρ*/(M☉ kpc^−3)
R*/(kpc)
0.05 0.1 0.2 0.5 1 2 5
1e5 2e5 5e5 1e6 2e6 5e6 1e7 2e7 5e7 1e8 2e8 5e8
3 4 5 6 7 8 9 10

Searching for the gas around XMP galaxies: II

Can it be observed in absorption in the spectrum of background?

We tried CaII H&K and NaI on background galaxies with SDSS spectrum (Filho+17,18 in prep). Got a CaII signal in UGCA 20

$N_{CaII} \sim 10^{12}$ cm^{-3}