The origin of the relation between metallicity and size in star-forming galaxies

J. Sánchez Almeida
C. Dalla Vecchia

2018, ApJ, in press

Instituto de Astrofísica de Canarias





Outline

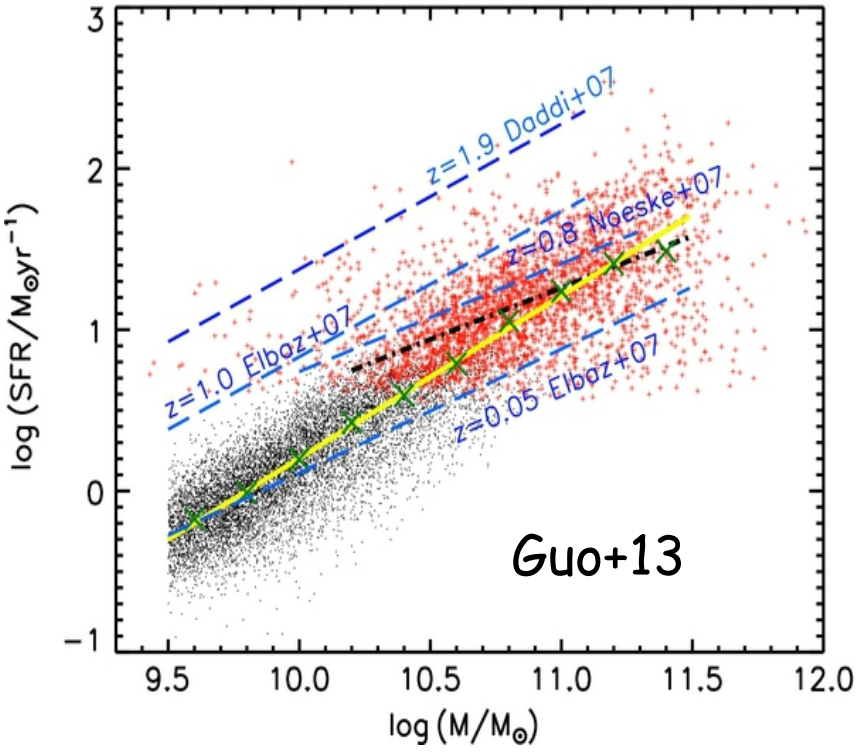
- Galaxy scaling relations involving metallicity
- Relation between metallicity and size in star-forming galaxies (Ellison+08)
- EAGLE numerical simulation
- Ellison+08 relation in EAGLE
- Summary: take away message

Galaxy scaling relations involving metallicity

Scaling relations : relations involving physical parameters characterizing bulk properties of galaxies.

Fundamental to understand how galaxies form and evolve, and to test whether our understanding of the process is correct.

Main sequence of star-formation
Noeske+07; Daddy+07

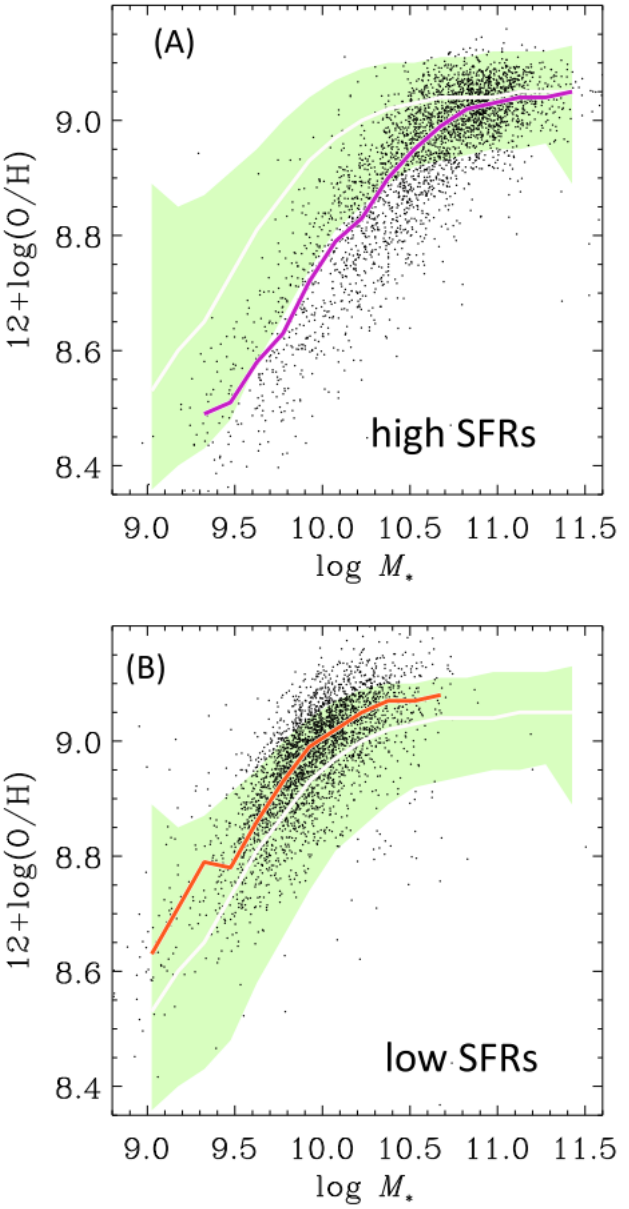


Fundamental Metallicity Relation

The larger the SFR the lower gas-phase metallicity

Discovered by
Mannucci+10, Lara-Lopez+10, Ellison+08

Salim+14, ApJ -->



Metallicity Lopsidedness Relation

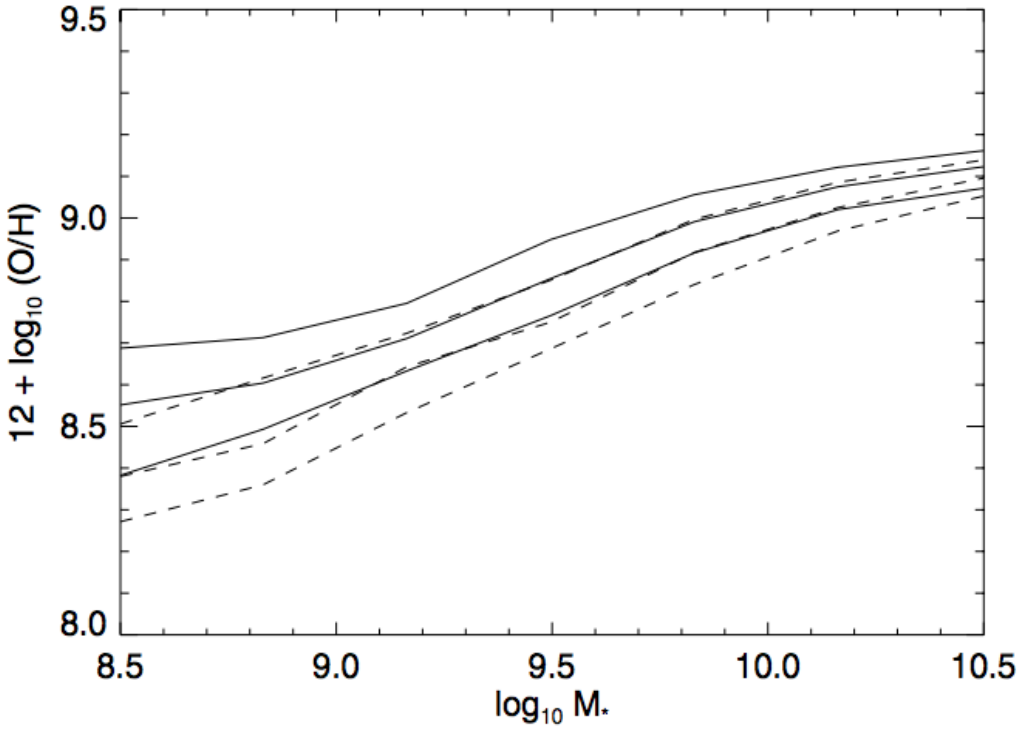


Figure 9. Mass–metallicity relation for the most ($A_1^i > 0.2$, *dashed lines*) and least lopsided ($A_1^i < 0.08$, *solid lines*) galaxies. The 25th, 50th, and 75th percentile lines are shown for each distribution. The most lopsided galaxies have a metallicity deficit of 0.05–0.15 dex compared to the least lopsided galaxies at the same mass. The deficit is greater at low mass than at high mass.

The more lopsided
the lower the gas metallicity



Reichard+09
Morales-Luis+11

Size-Metallicity relation

Ellison et al. (2008, ApJL)

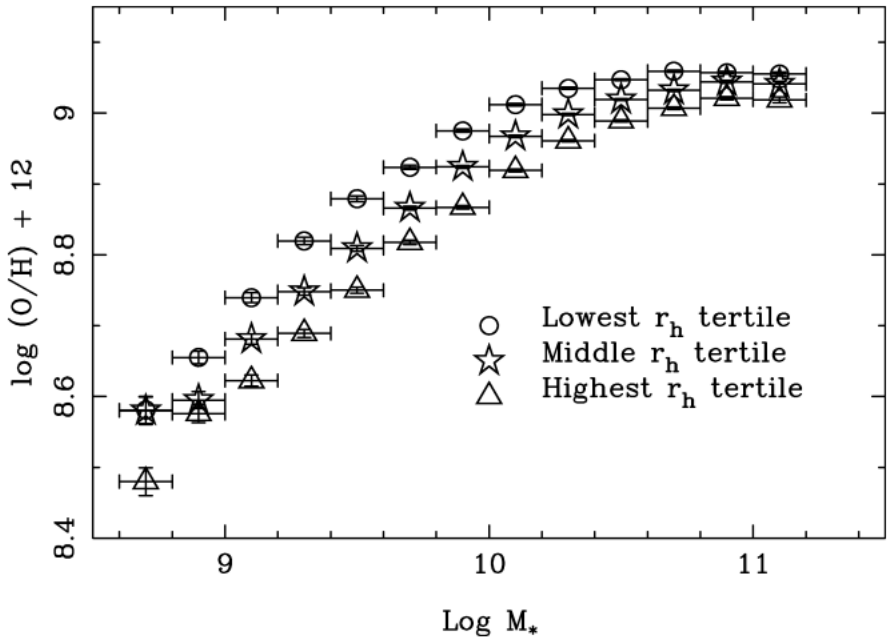


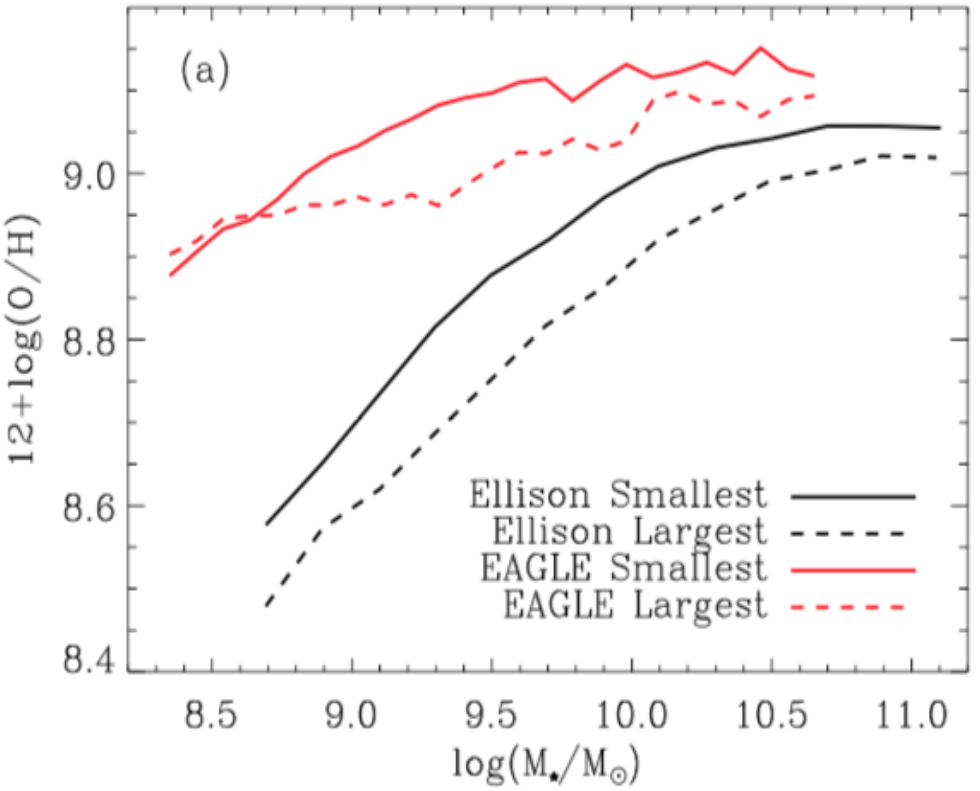
FIG. 2.—Binned mass-metallicity relation for ~44,000 SDSS galaxies from the DR4, divided by half-light radius (r_h) tertiles in each mass bin. Open circles, stars, and triangles represent the lowest, intermediate, and highest r_h, respectively. The divisions between the r_h tertiles are $r_h < 2.2\ h_{70}^{-1}$ kpc, $2.2\ h_{70}^{-1}$ kpc $< r_h < 3.3\ h_{70}^{-1}$ kpc, and $r_h > 3.3\ h_{70}^{-1}$ kpc for the mass bin centered at $\log M_* = 9.5\ M_\odot$; and $r_h < 4.0\ h_{70}^{-1}$ kpc, $4.0\ h_{70}^{-1}$ kpc $< r_h < 5.5\ h_{70}^{-1}$ kpc, and $r_h > 5.5\ h_{70}^{-1}$ kpc for the mass bin centered at $\log M_* = 10.5\ M_\odot$. The vertical error bars are the standard error on the mean.

Why this happens?

The work aimed at figuring this out

44000 SDSS galaxies

The EAGLE numerical simulation reproduces the size metallicity relation



EAGLE numerical simulation

Suite of numerical simulations of galaxy formation in a cosmological context (Schaye+15, Crane+15, McAlpine+16)

- Baryon physics included in a self consistent way.

* Pressure-based law for star formation (Schaye & Dalla Vecchia 2008),
* line cooling in photoionisation equilibrium (Wiersma et al. 2009a),
* stellar evolution (Wiersma et al. 2009b),
* thermal super- nova feedback (Dalla Vecchia & Schaye 2012),
* and black holes growth and feedback (Rosas-Guevara et al. 2015).

- Redshift range 100 □ 0

- We use the large cube (100 comoving Mpc)

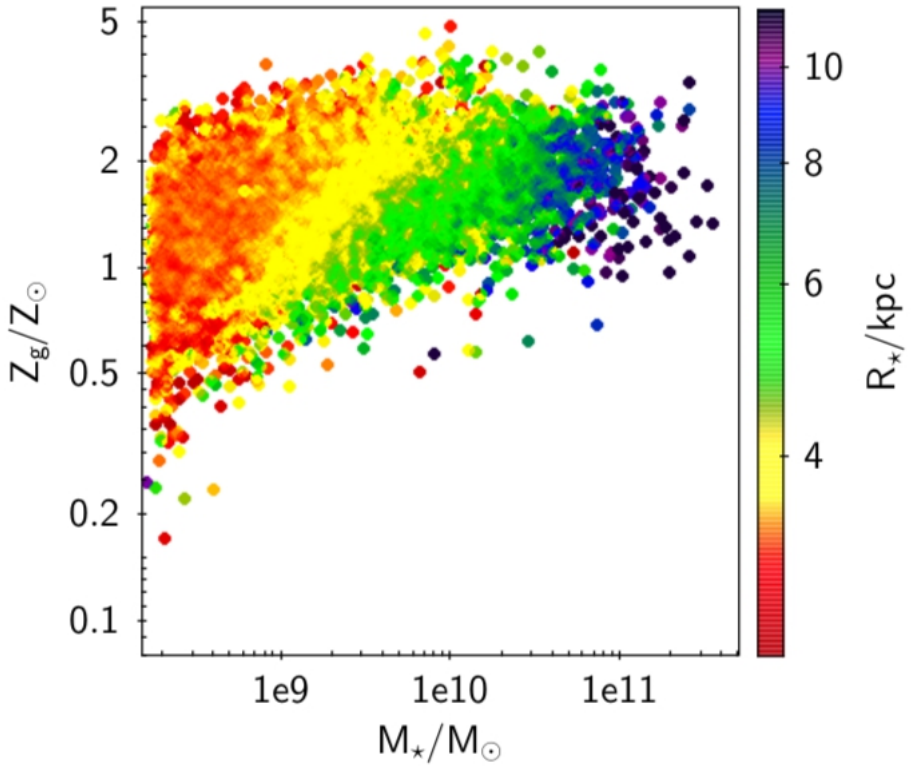
- Mass resolution 2×10^6 $M_\odot$ (gas) 1×10^7 $M_\odot$ (Dark Matter)

- Select central star-forming galaxies, at redshift zero.
  Corresponds to some 16000 galaxies



Ellison+08 relation in EAGLE

Assuming the physical mechanism responsible for the relation in EAGLE is also responsible for the observed relation, we use use the simulations in figure out the cause.



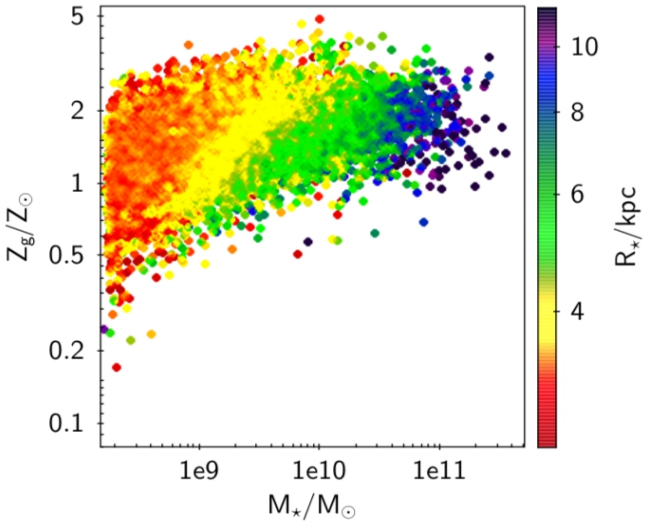
(1) metal-rich gas outflows particularly efficient in shallow gravitational potentials,

(2) enhanced efficiency of the star-formation process in compact galaxies, and

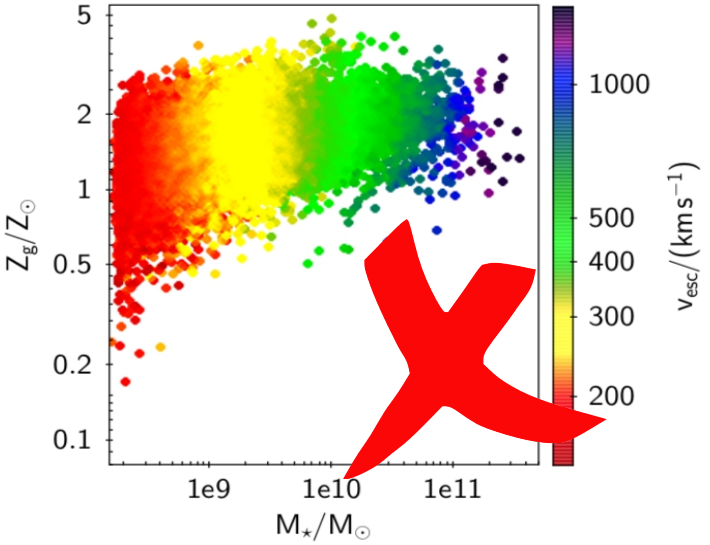
(3) metal-poor gas inflows feeding the star-formation process,

Metallicity versus Stellar Mass, color coded with:

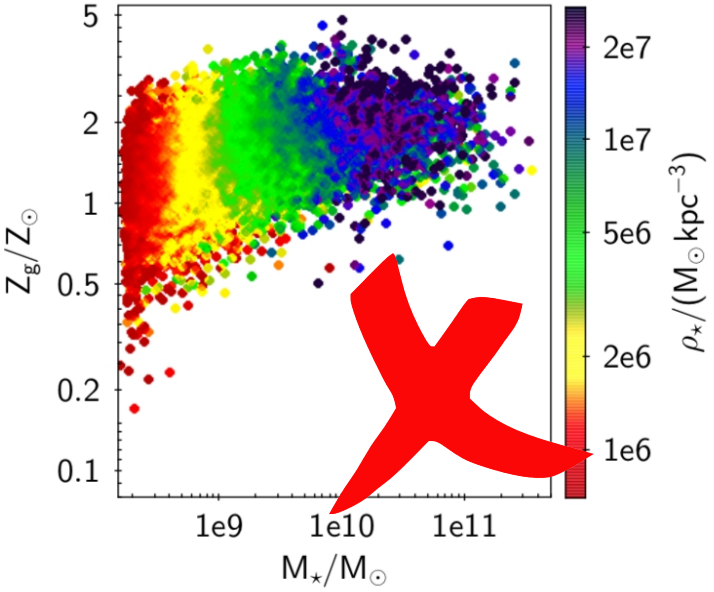
stellar radius



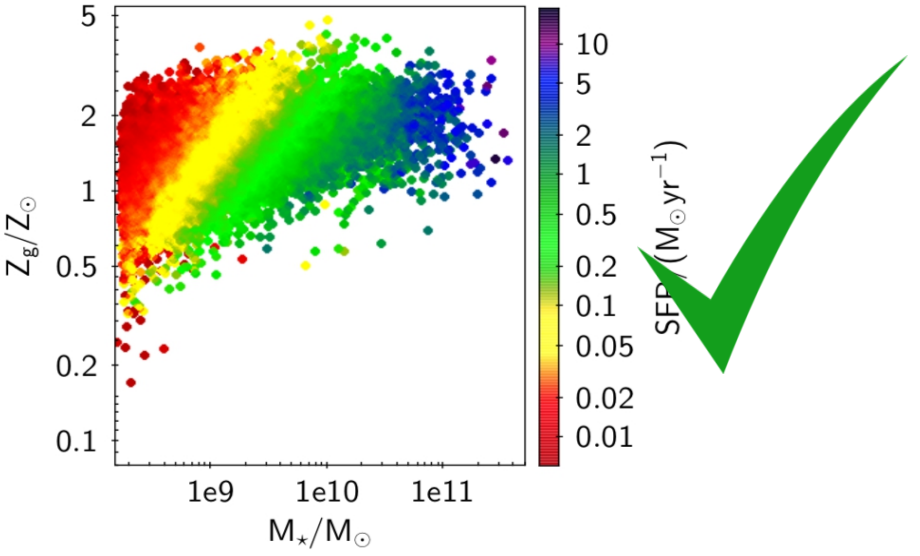
escape velocity



stellar density

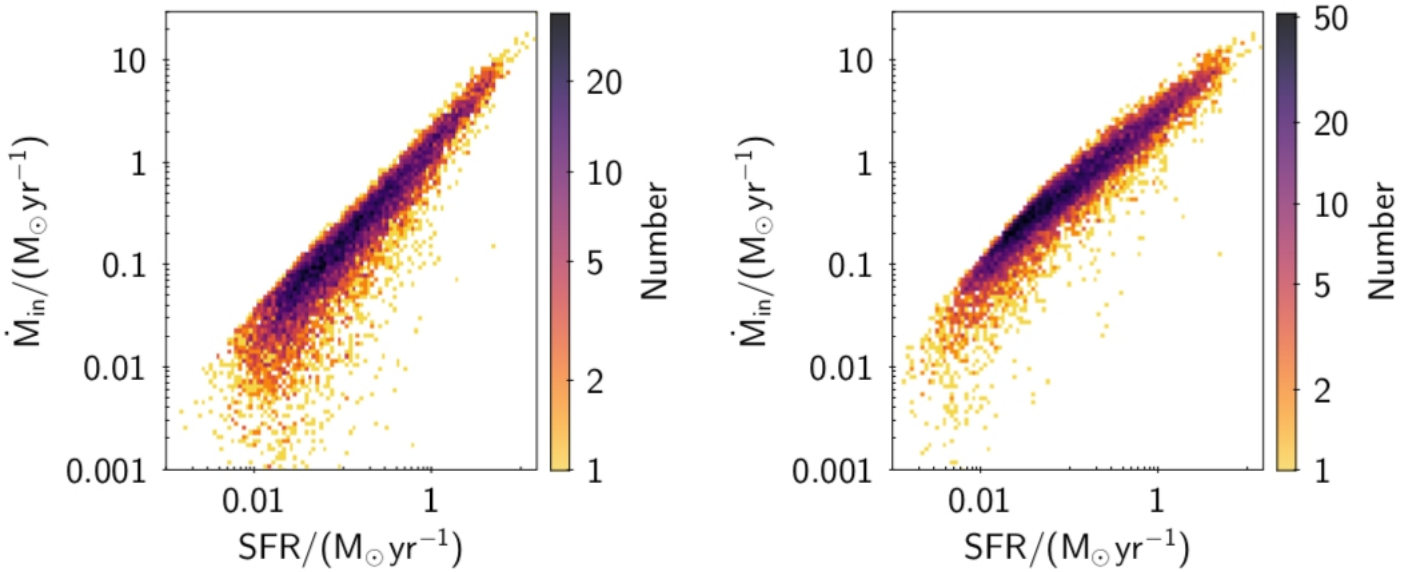


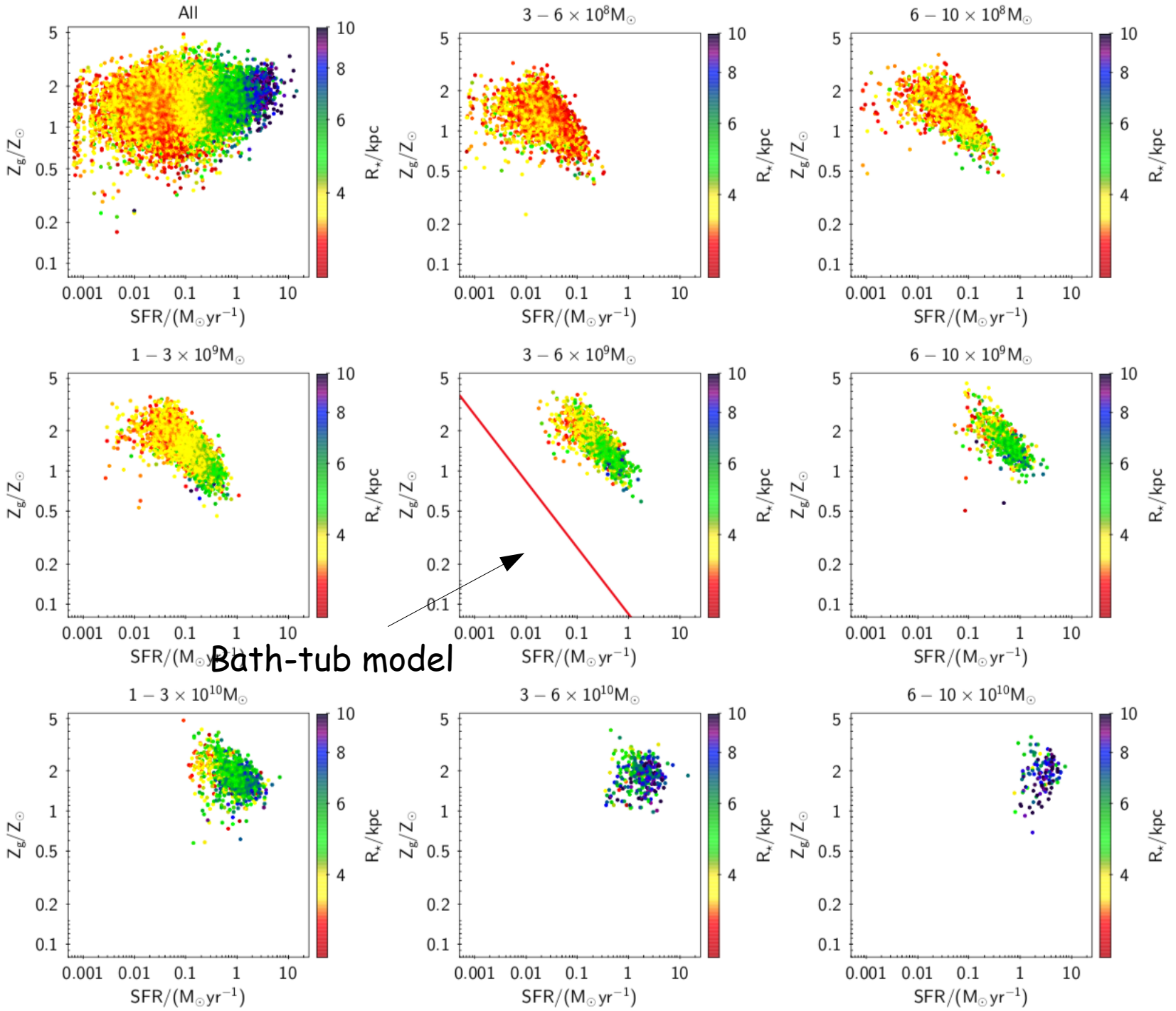
SFR ≡ Gas infall rate



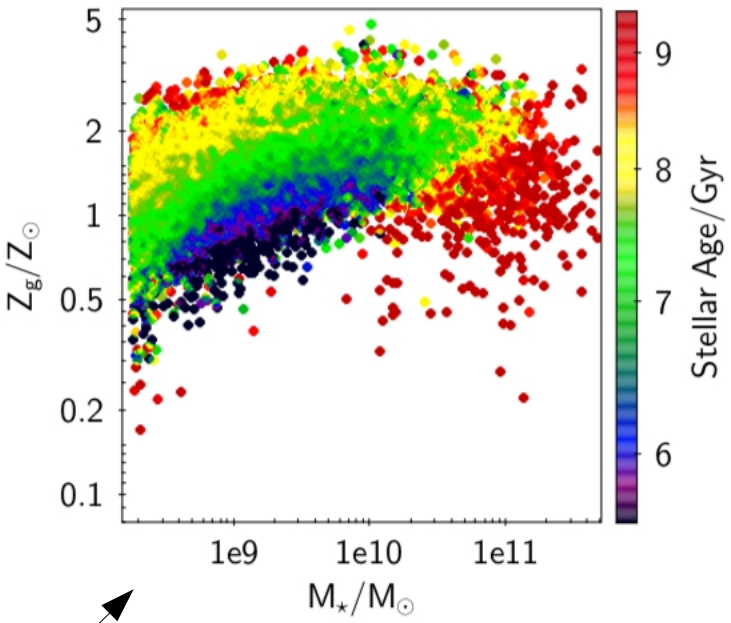
The SFR is a good proxy for the mass infall rate

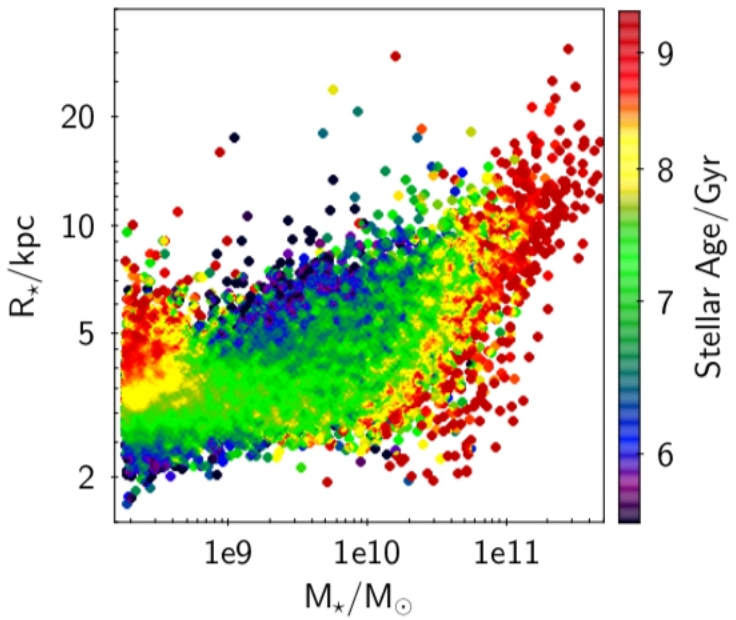
$$\dot{M}_{in} = \dot{M}_g + (1 - R + w)\,\mathrm{SFR},$$




All
$3-6\times10^{8}M_{\odot}$
$6-10\times10^{8}M_{\odot}$
$1-3\times10^{9}M_{\odot}$
$3-6\times10^{9}M_{\odot}$
$6-10\times10^{9}M_{\odot}$
$1-3\times10^{10}M_{\odot}$
$3-6\times10^{10}M_{\odot}$
$6-10\times10^{10}M_{\odot}$
$Z_g/Z_{\odot}$
R_*/kpc
$SFR/(M_{\odot}yr^{-1})$
Bath-tub model

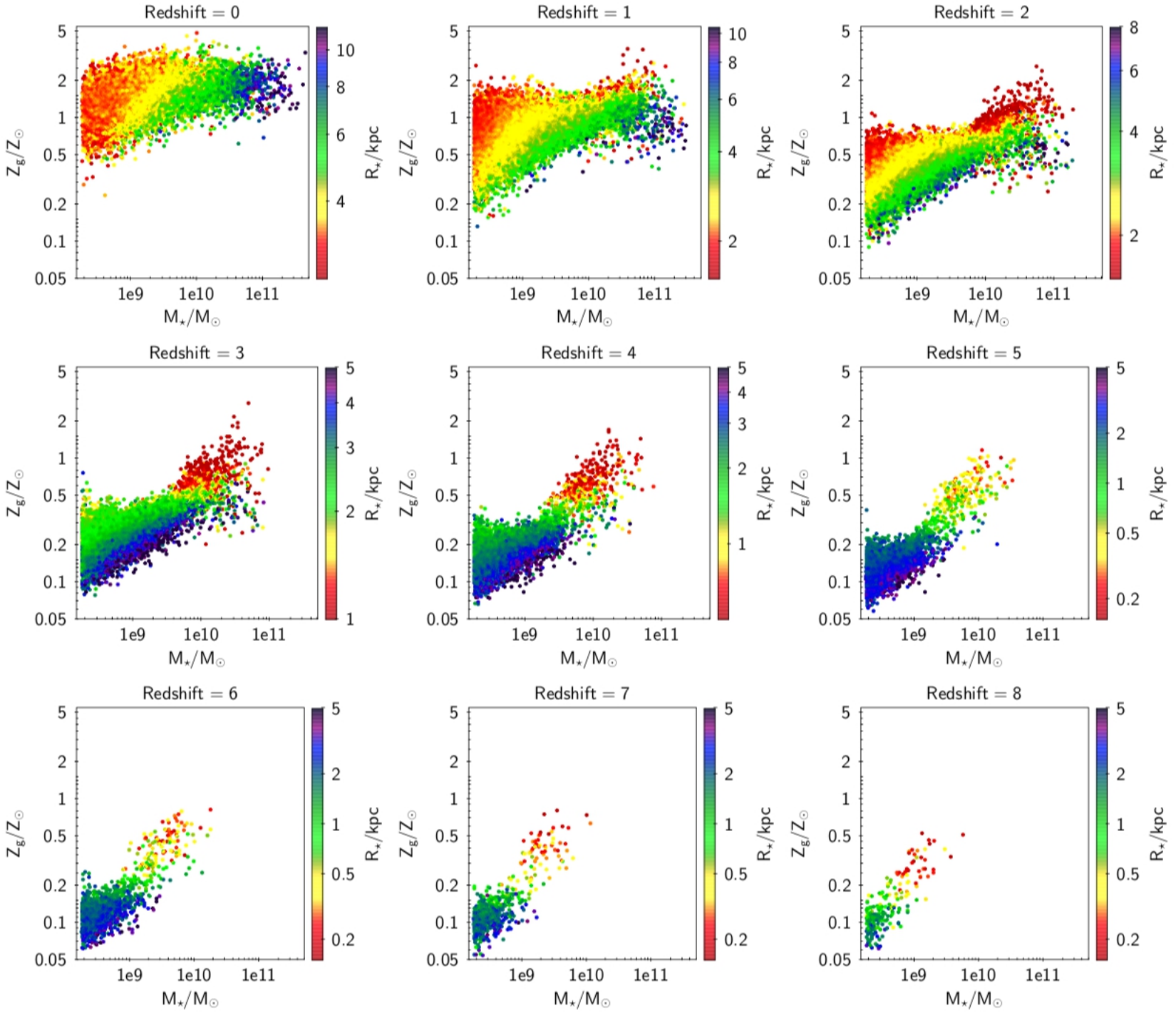
For the same stellar mass,
larger galaxies have younger
stellar populations





For the same stellar mass,
metal-poorer galaxies have younger
stellar populations

The anti-correlation between size and metallicity remains until redshift 8



Take-away message

1.- Given M_*, larger galaxies are metal poorer (Ellison+08)

2.- EAGLE galaxies of the local Universe show the trend

3.- **Assuming EAGLE grasps the essentials** of the physical mechanism, we concluded that the relation

- is not due to outflows en shallow potentials

- it is not due to enhanced efficiency in denser systems

- it is due to recent metal-poor gas accretion

4.- The relation remains until redshift 8