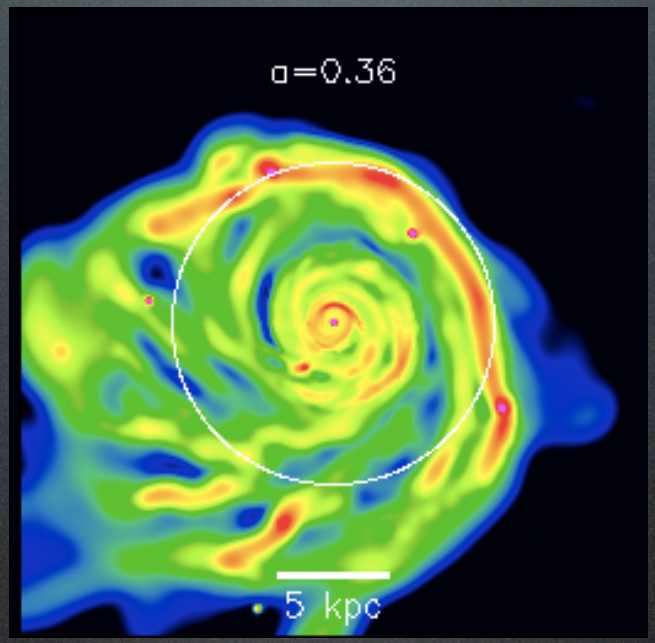
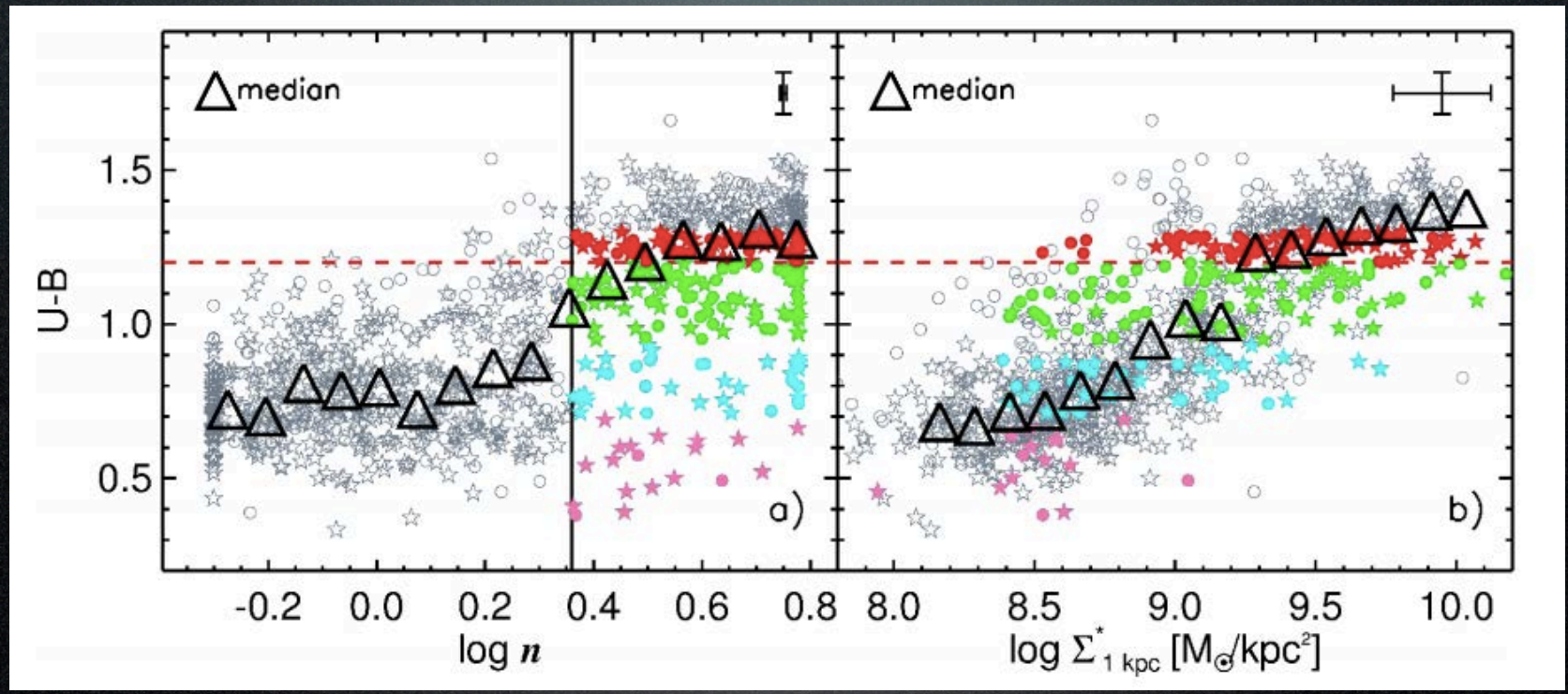
Compaction & Quenching of hi-z Galaxies



Adi Zolotov / Hebrew University

Daniel Ceverino, Avishai Dekel, Nir Mandelker, Dylan Tweed, Joel Primack

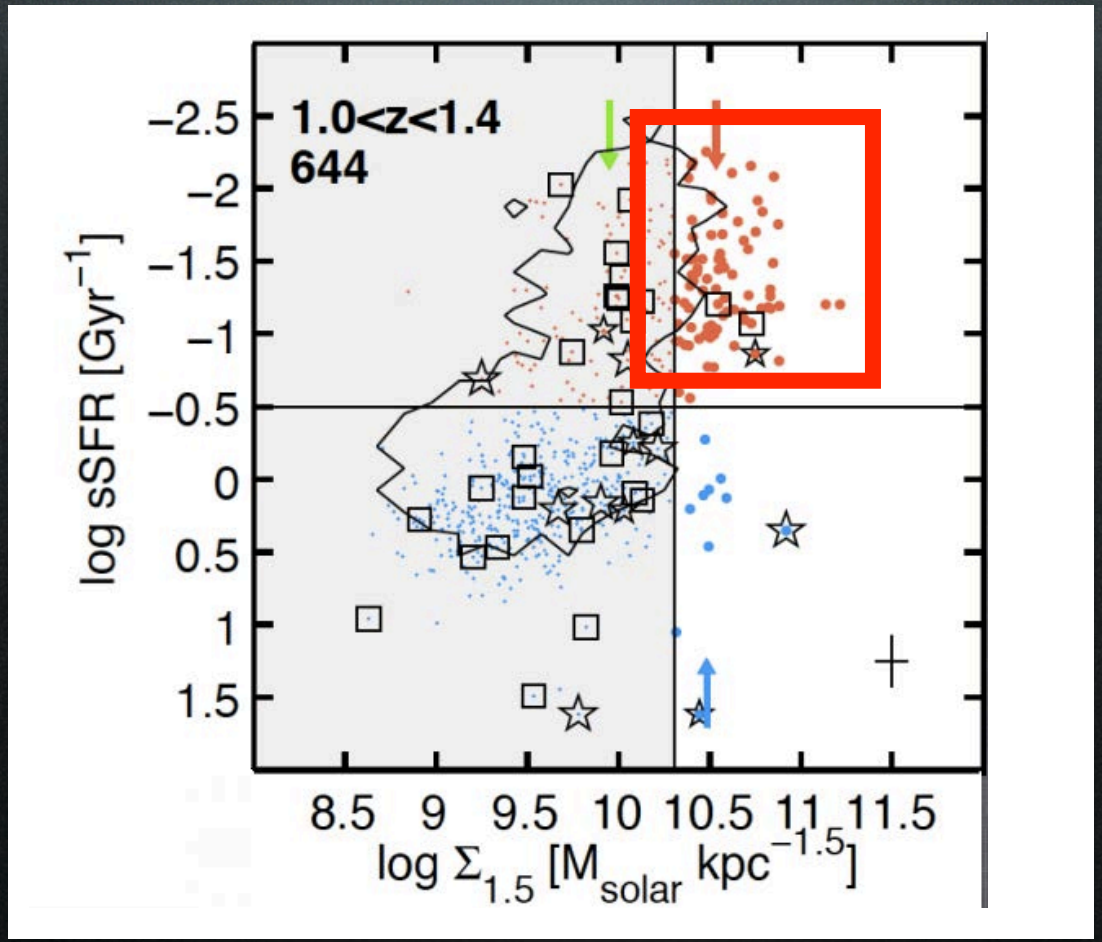
Galaxy Structure & Star Formation



Σ_{1kpc} corrects the outliers

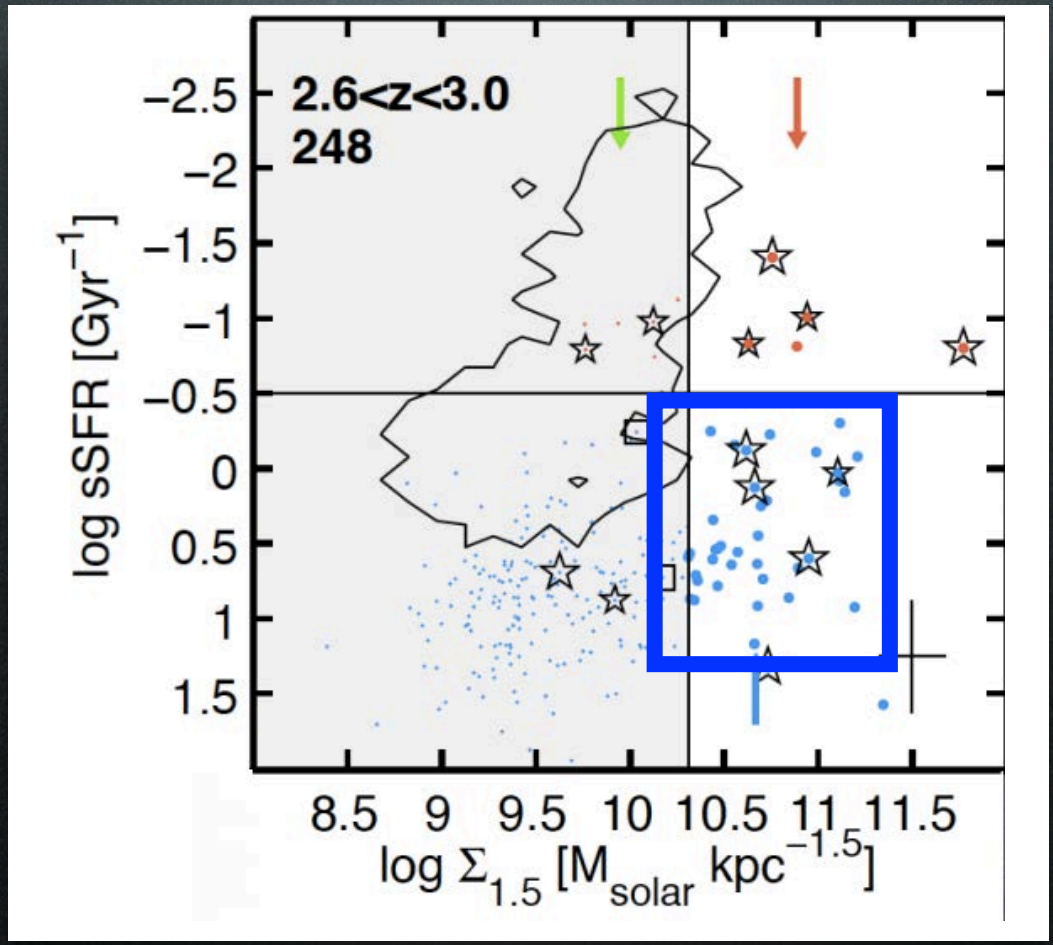
Cheung et al. (2012)

Observations of Compact Galaxies: "Nuggets"



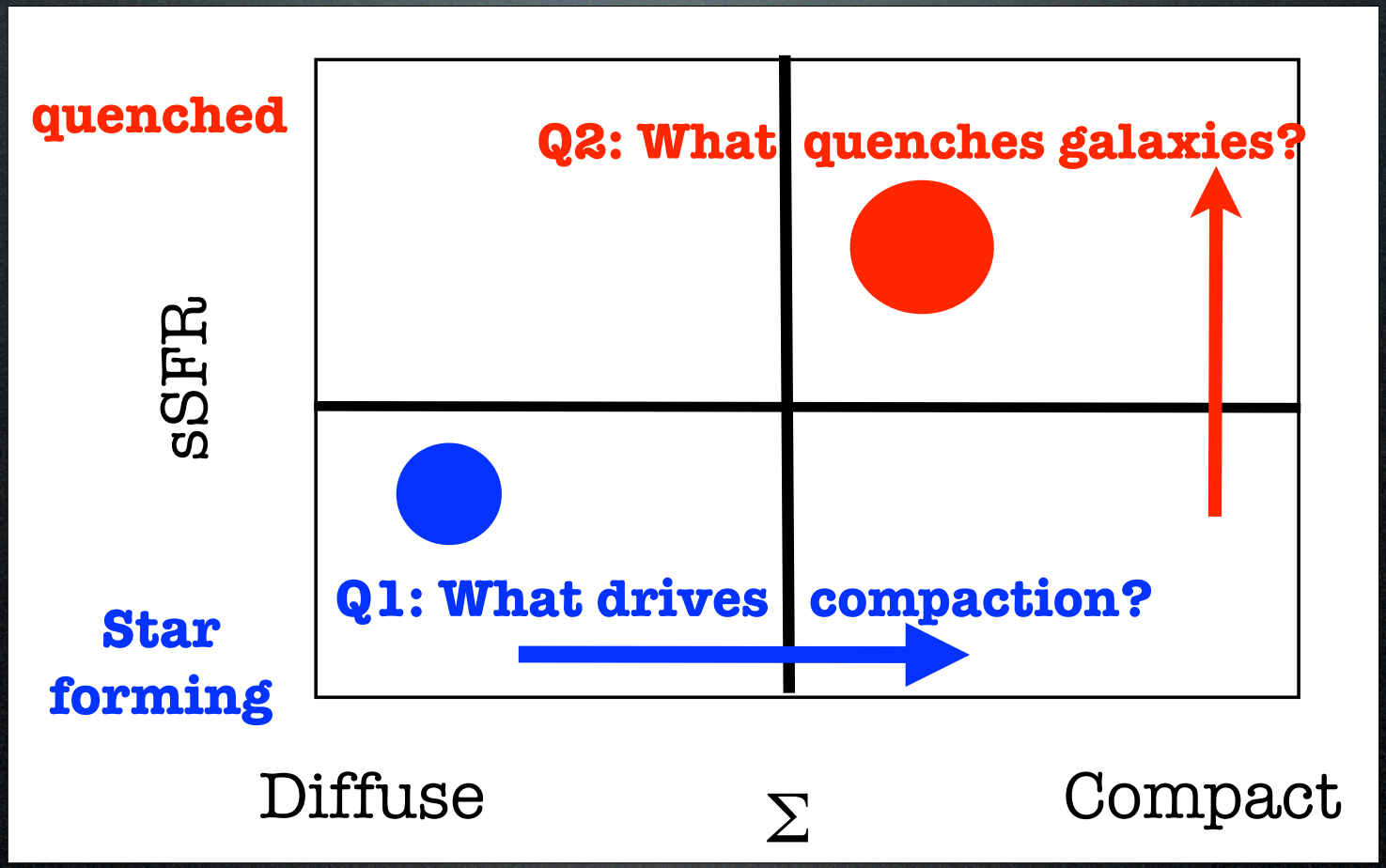
Barro et al. (2013)

Observations of Compact Galaxies: "Nuggets"



Barro et al. (2013)

Open Questions



Q3: What is the evolutionary path?

simulation sample

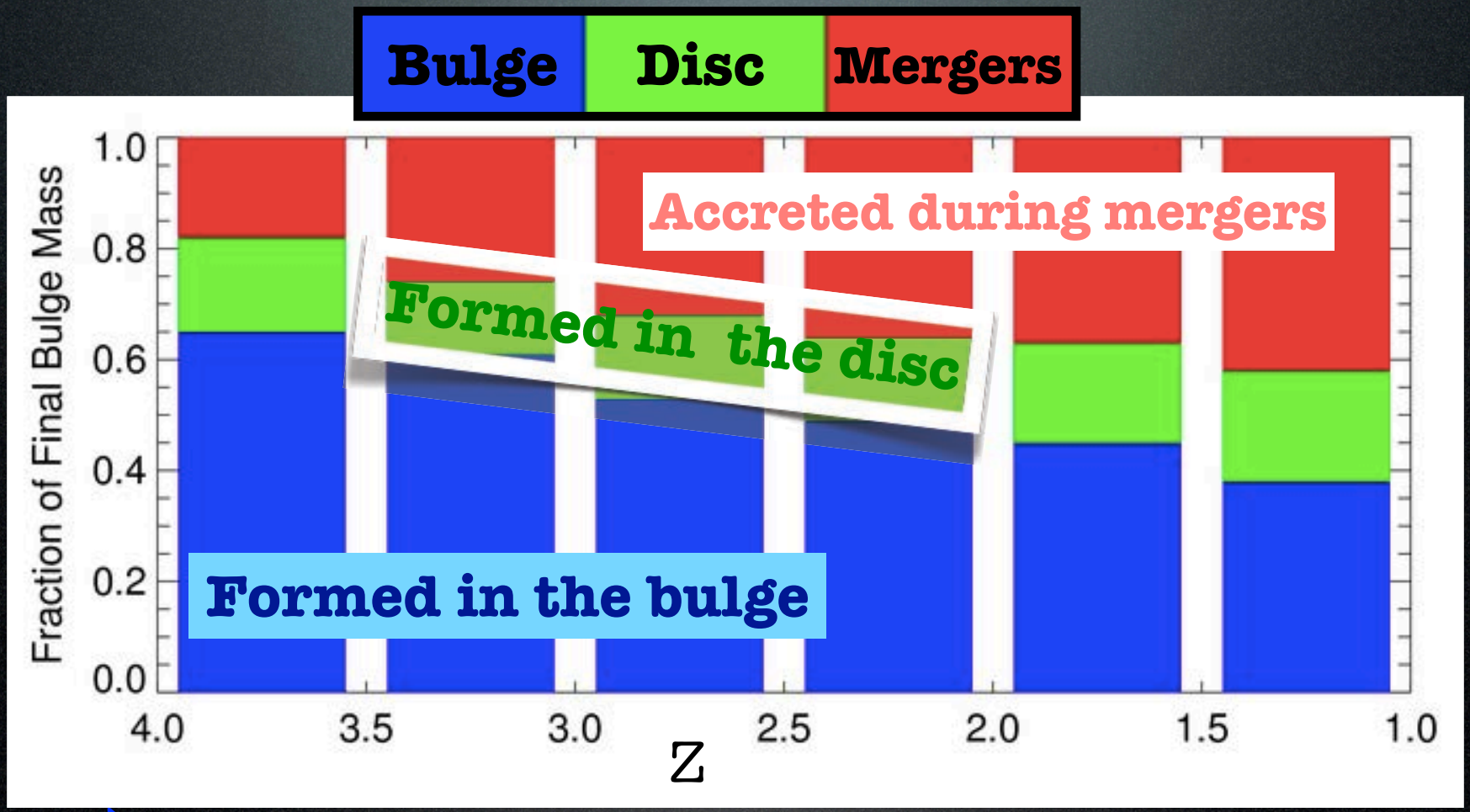
★ HydroART simulations: Kravstov, Klypin, Ceverino

★ Zoom-in cosmological simulations of 30 massive galaxies (M_{vir} ~ 0.2 - 1 x 10^{12} $M_{\odot}$ at z=2)

★ High-resolution: ~ 20 - 50 pc spatial resolution

★ SNe feedback + radiative pressure ("Generation 3")

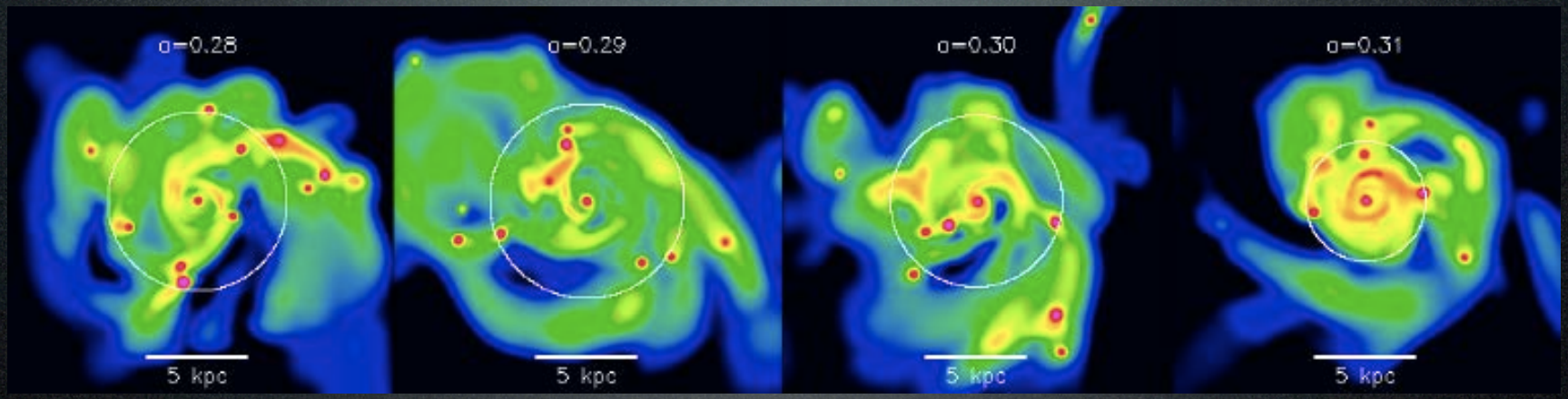
Stellar Bulge Formation



A lot of stars form in situ in the bulge!

Zolotov et al. (2014)

What fuels in situ star formation in bulges?



1. Gas from wet mergers

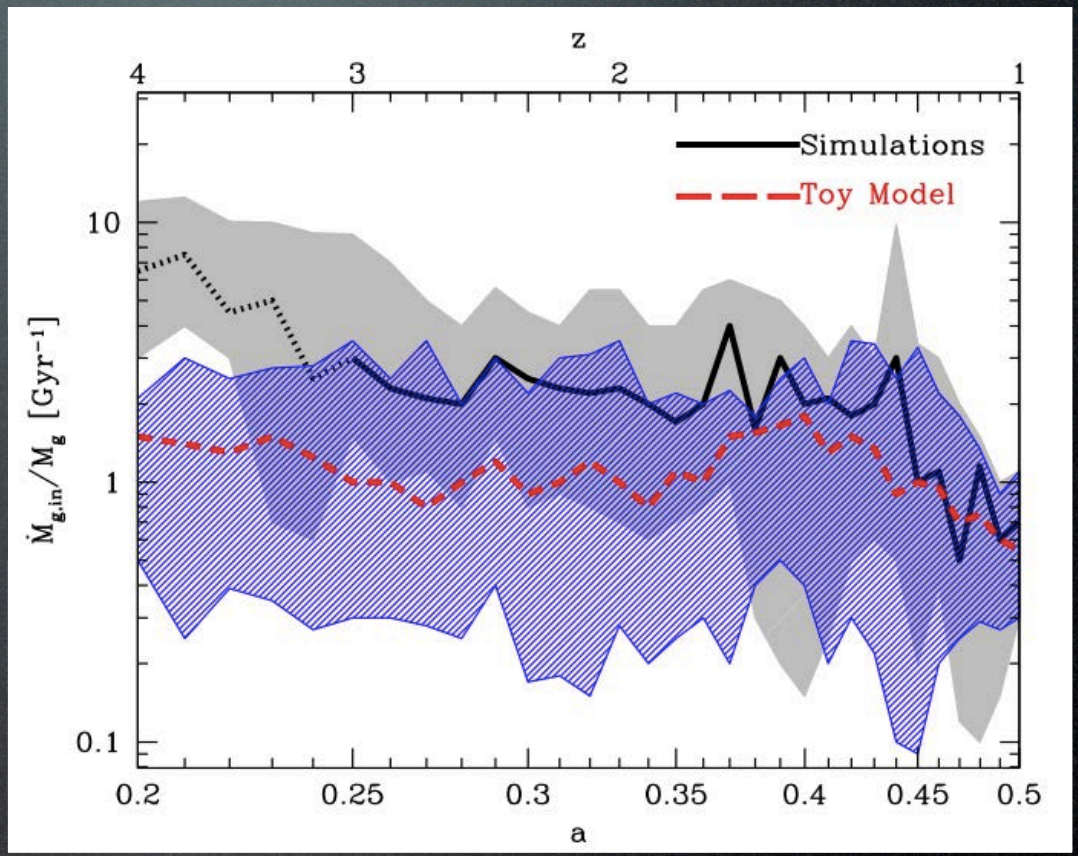
- and/or -

2. Disk instability → Inflow of gas, stars, & clumps to center

Inflow of gas within the disk

Torques between perturbations drive AM out and bring mass in

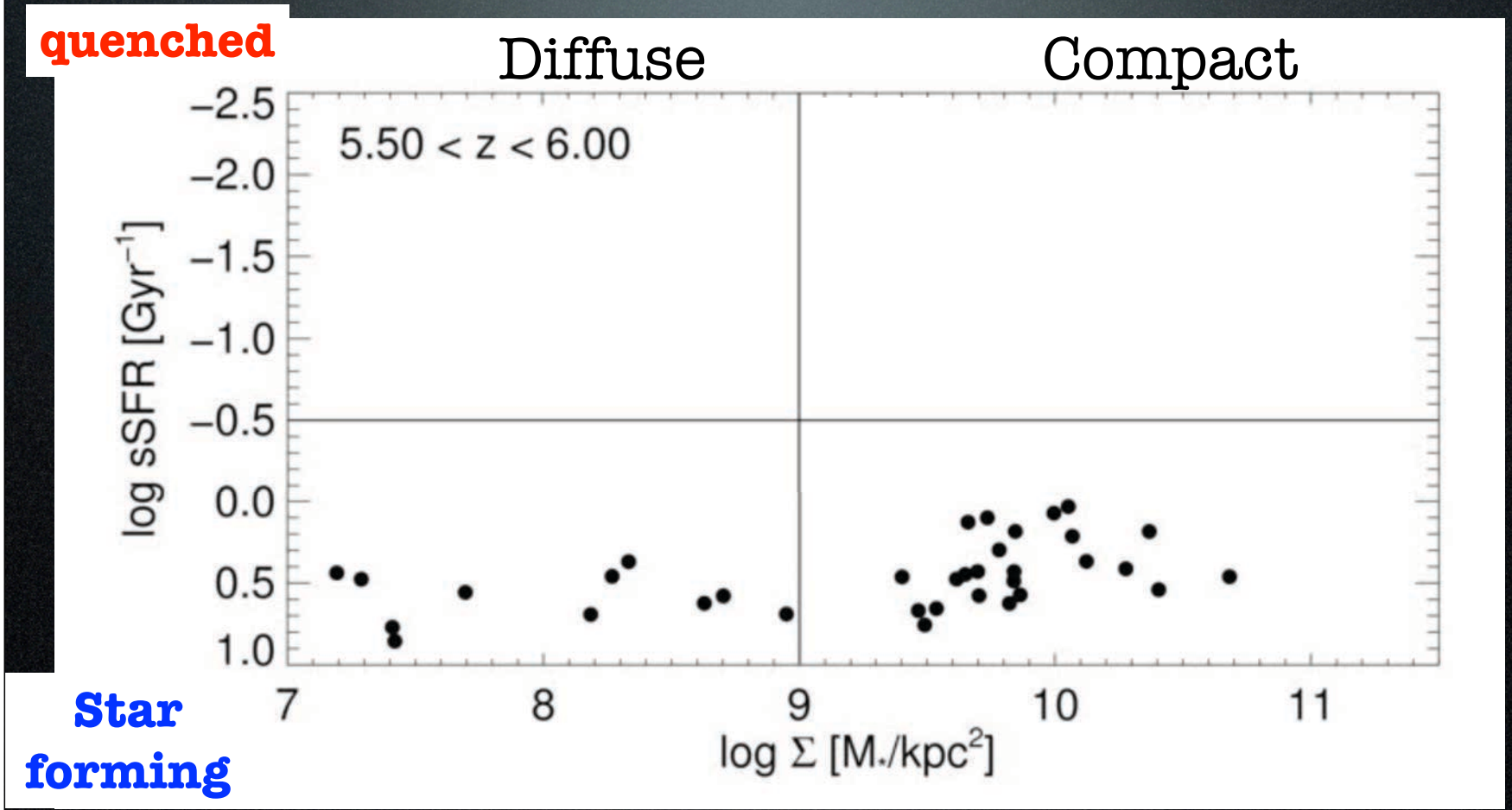
$$\left\langle \dot{M}_{\text{inf } low} \right\rangle \sim 25 M_{\odot}/yr$$



Dekel, Zolotov + 13

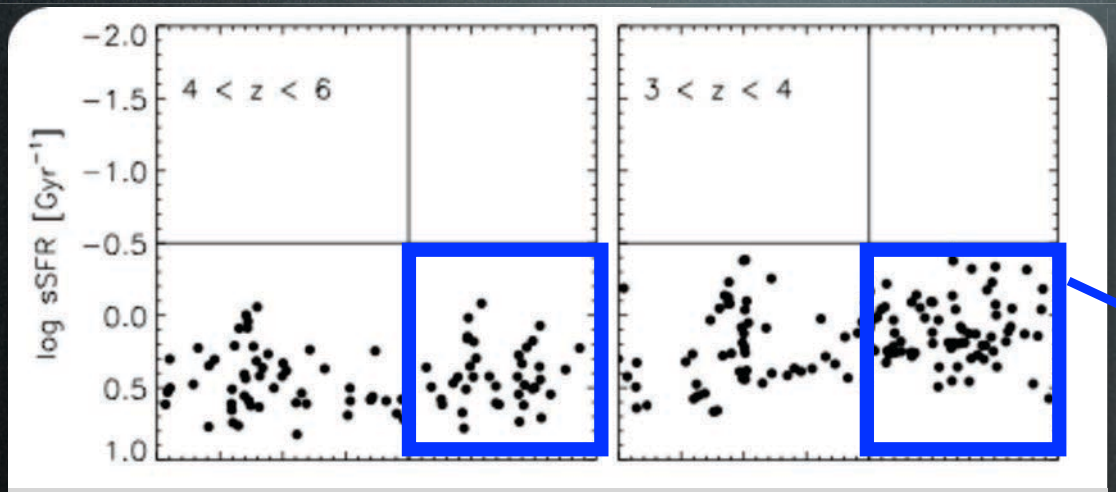
also: Gammie + (2001), Dekel + (2009), Krumholz + (2010), Cacciato + (2011)
observations: Genzel + 2006, 2008, 2011 Elmgreen + 2004, 2005, Guo +2013

The Formation of Compact Galaxies
1 < z <6



Zolotov + 2014, see also: Porter + 2014a,b

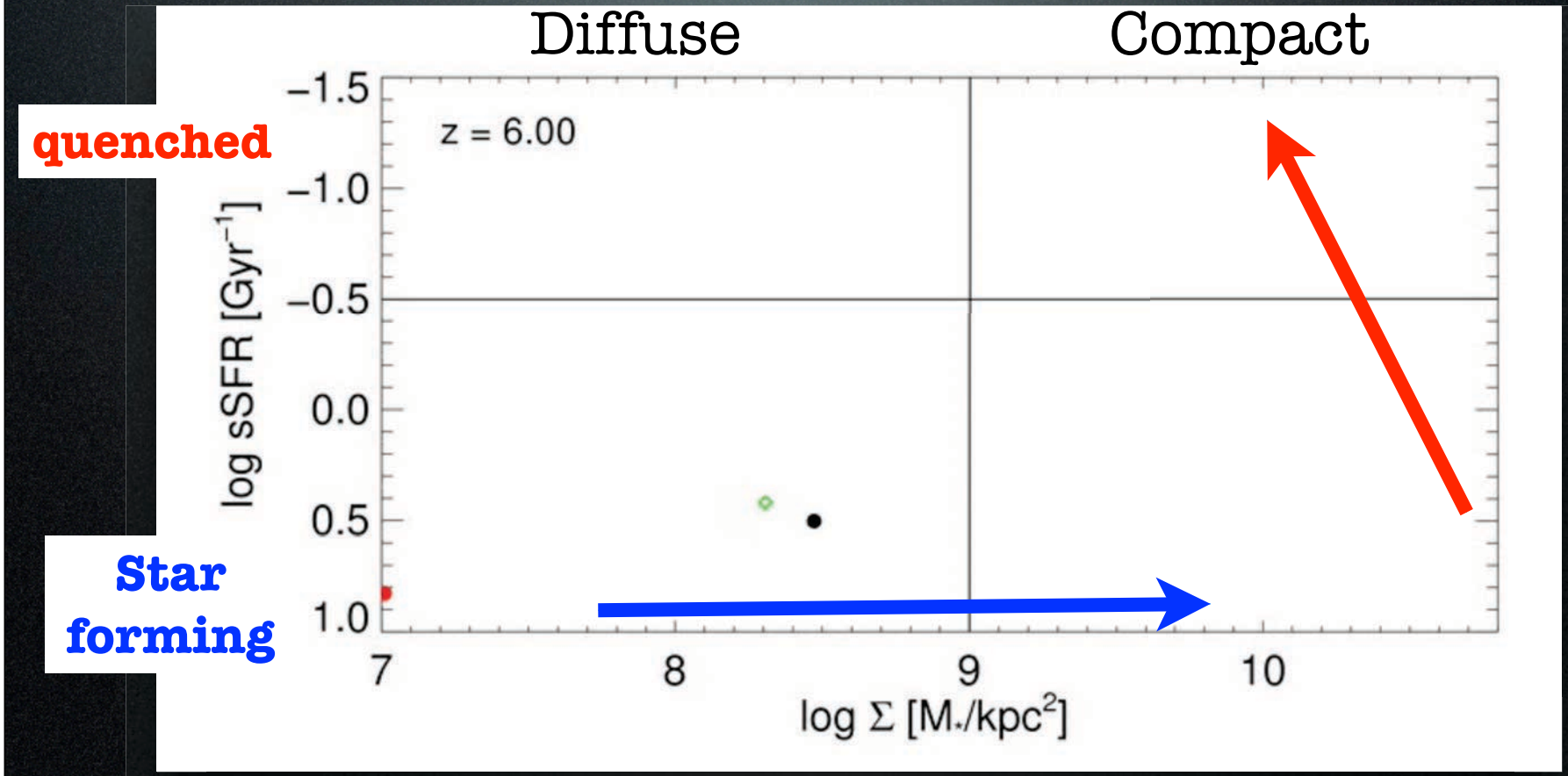
Zolotov +14



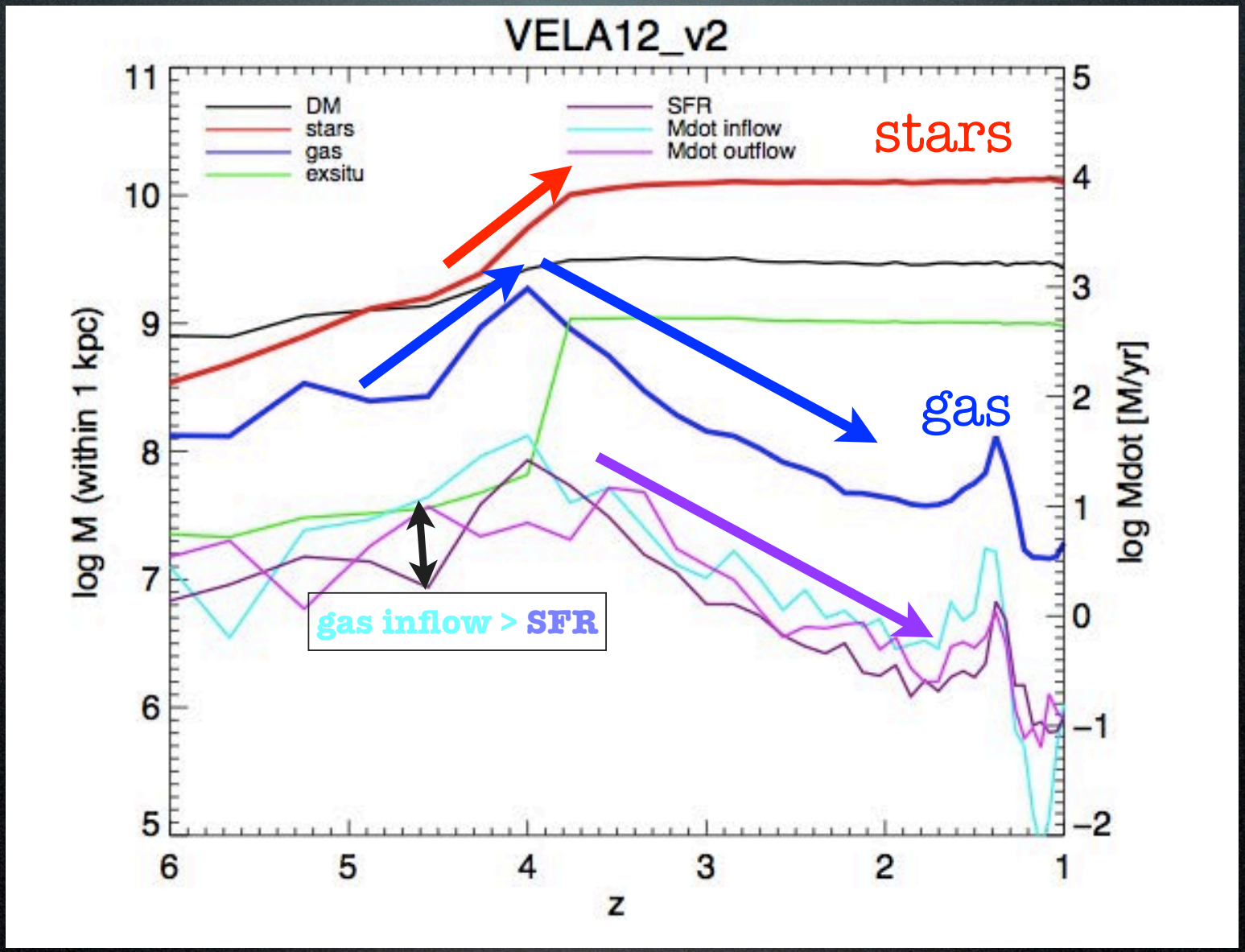
compact, SF galaxies at hi-z

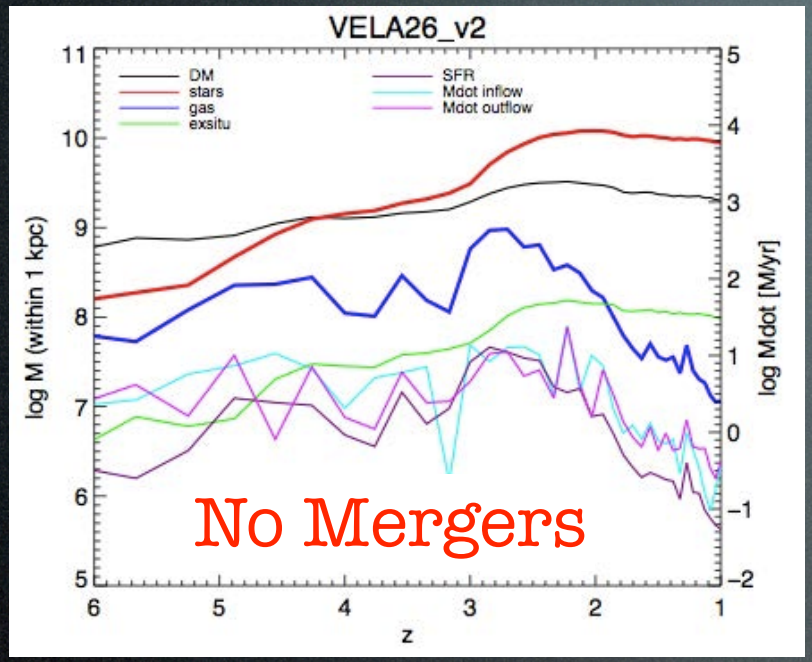
compact, quiescent galaxies at low-z

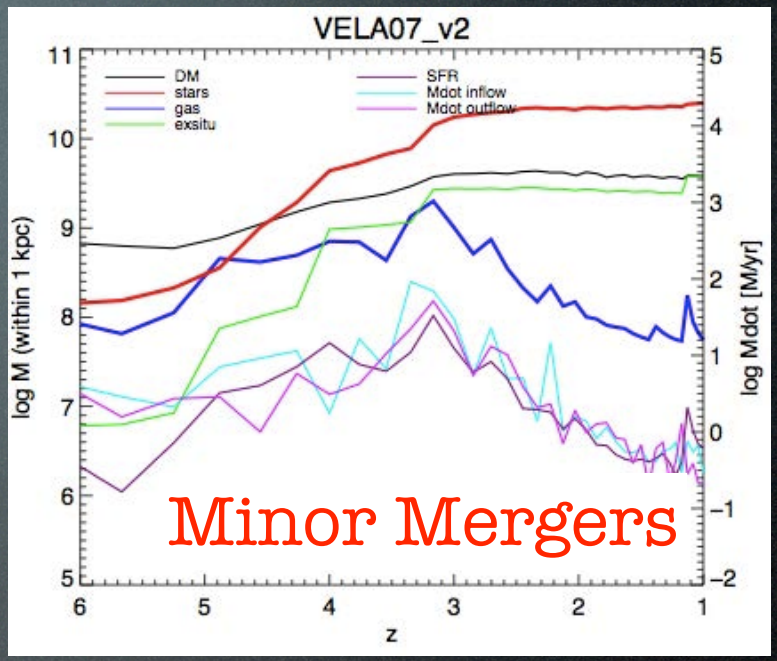
3 individual cases

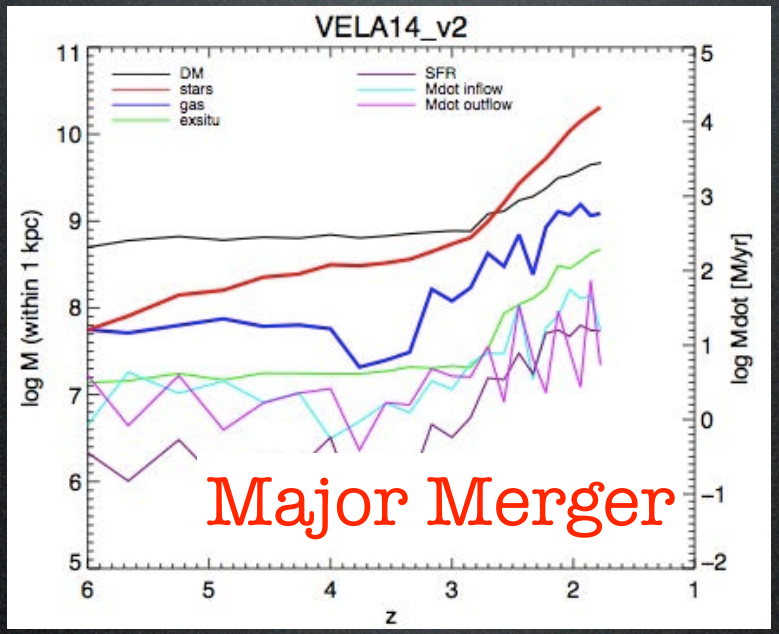


Zolotov + 2014

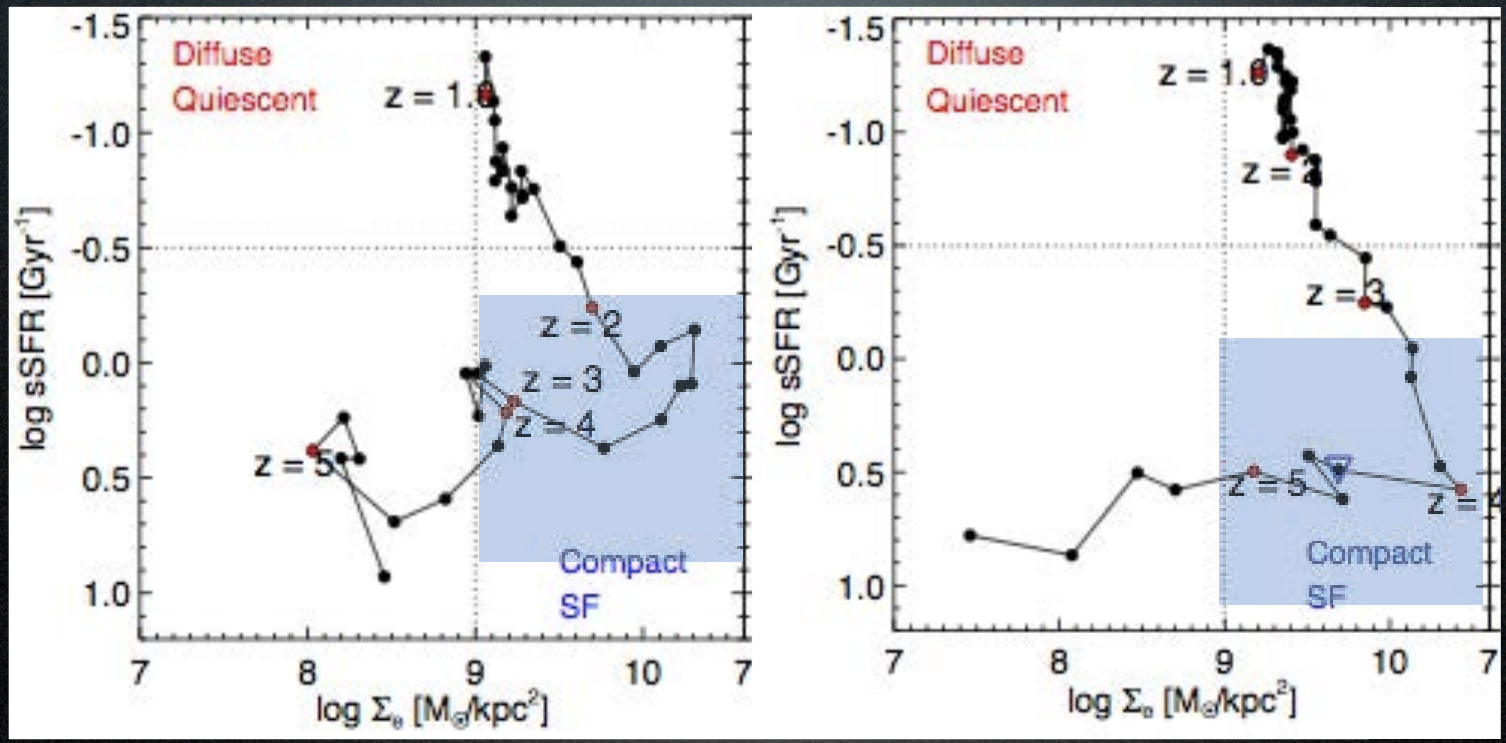

VELA12_v2
DM
stars
gas
exsitu
SFR
Mdot inflow
Mdot outflow
stars
gas
gas inflow > SFR
log M (within 1 kpc)
log Mdot [M/yr]
z
11
10
9
8
7
6
5
6
5
4
3
2
1
5
4
3
2
1
0
−1
−2

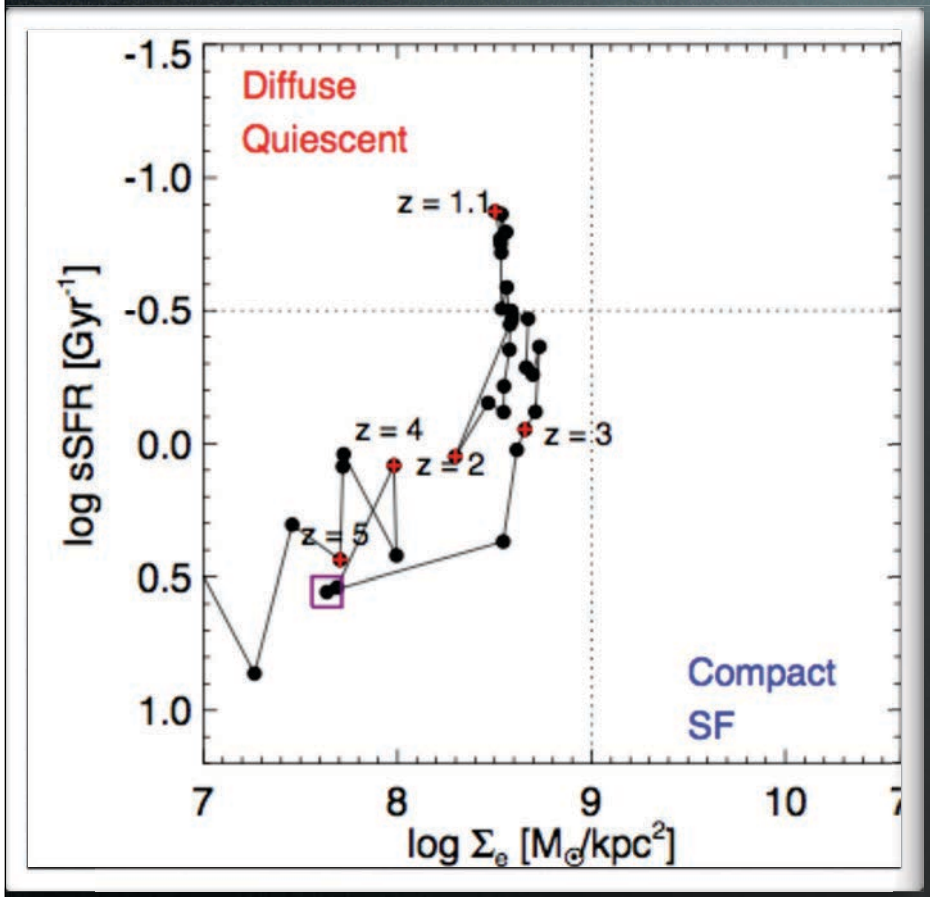

VELA26_v2
DM
stars
gas
exsitu
SFR
Mdot inflow
Mdot outflow
log M (within 1 kpc)
log Mdot [M/yr]
z
No Mergers

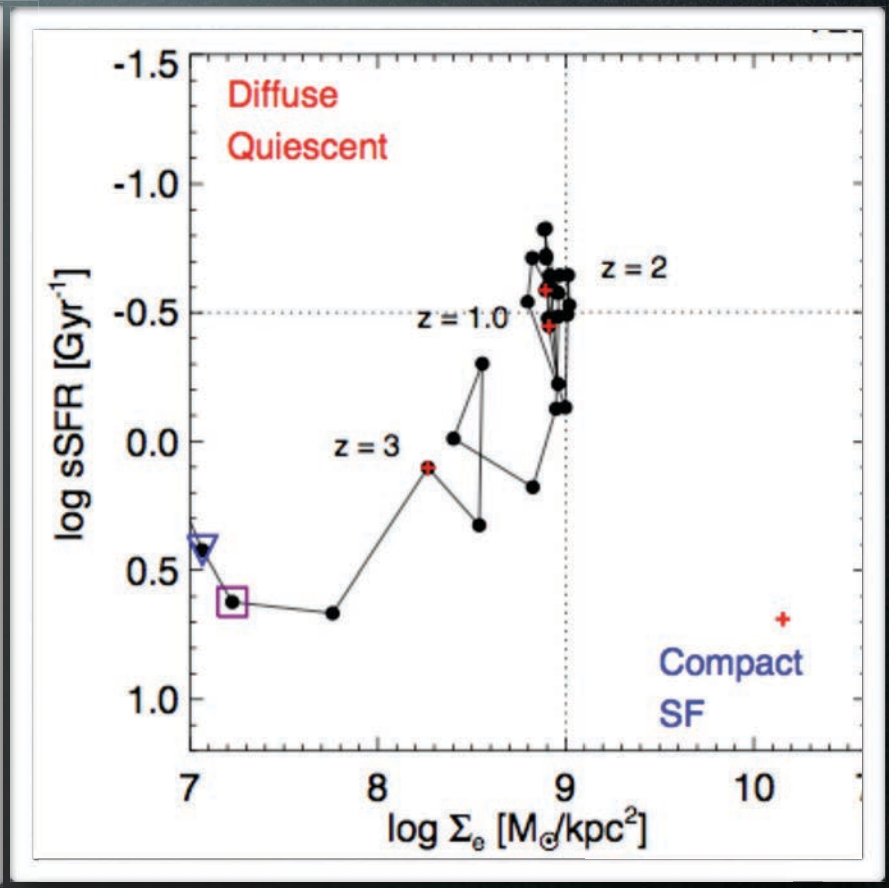

VELA07_v2
DM
stars
gas
exsitu
SFR
Mdot inflow
Mdot outflow
log M (within 1 kpc)
log Mdot [M/yr]
z
Minor Mergers


VELA14_v2
DM
stars
gas
exsitu
SFR
Mdot inflow
Mdot outflow
log M (within 1 kpc)
log Mdot [M/yr]
z
Major Merger

Counterparts to the observed blue nuggets: Compact & Star Forming at hi-z

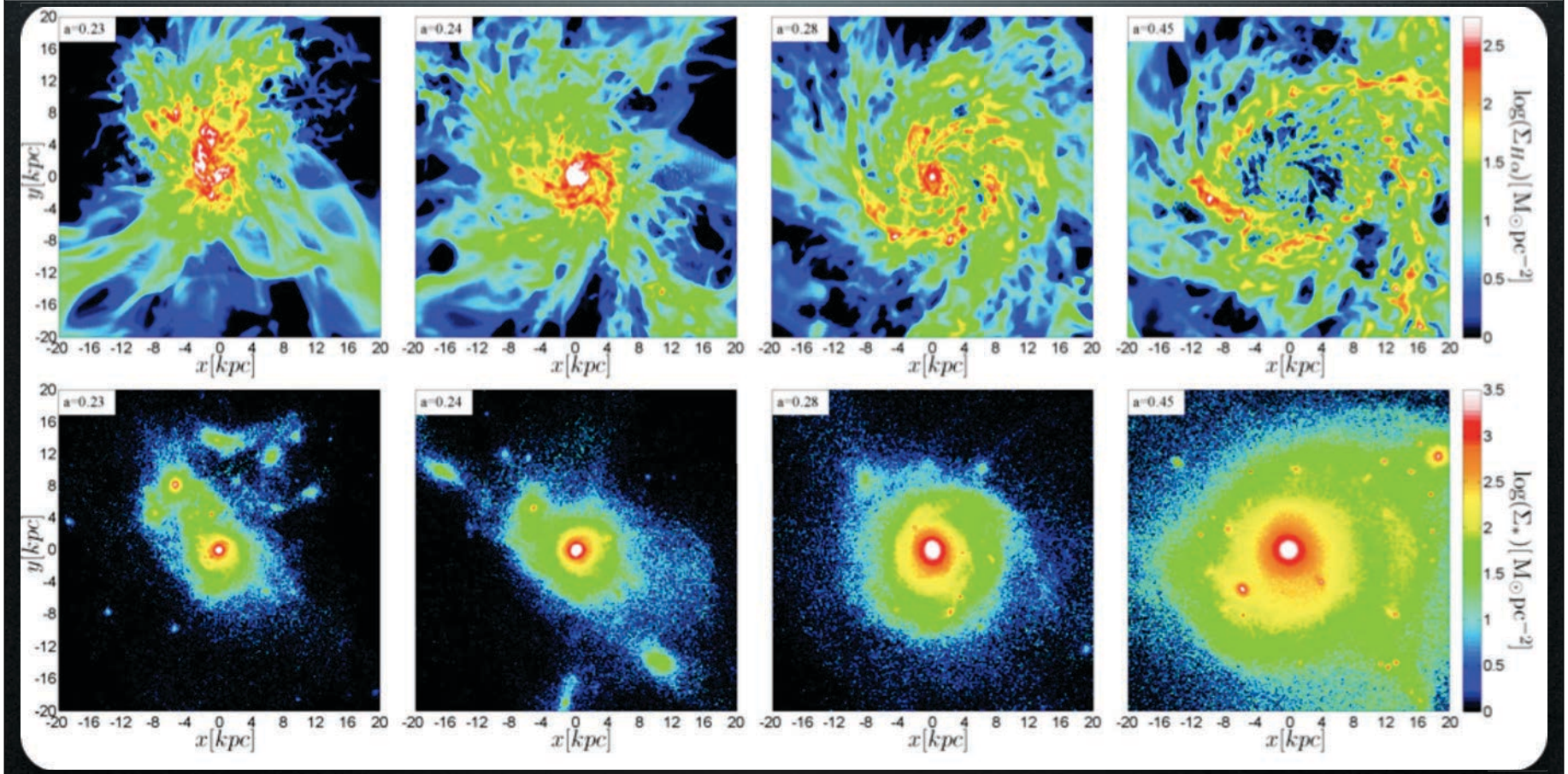






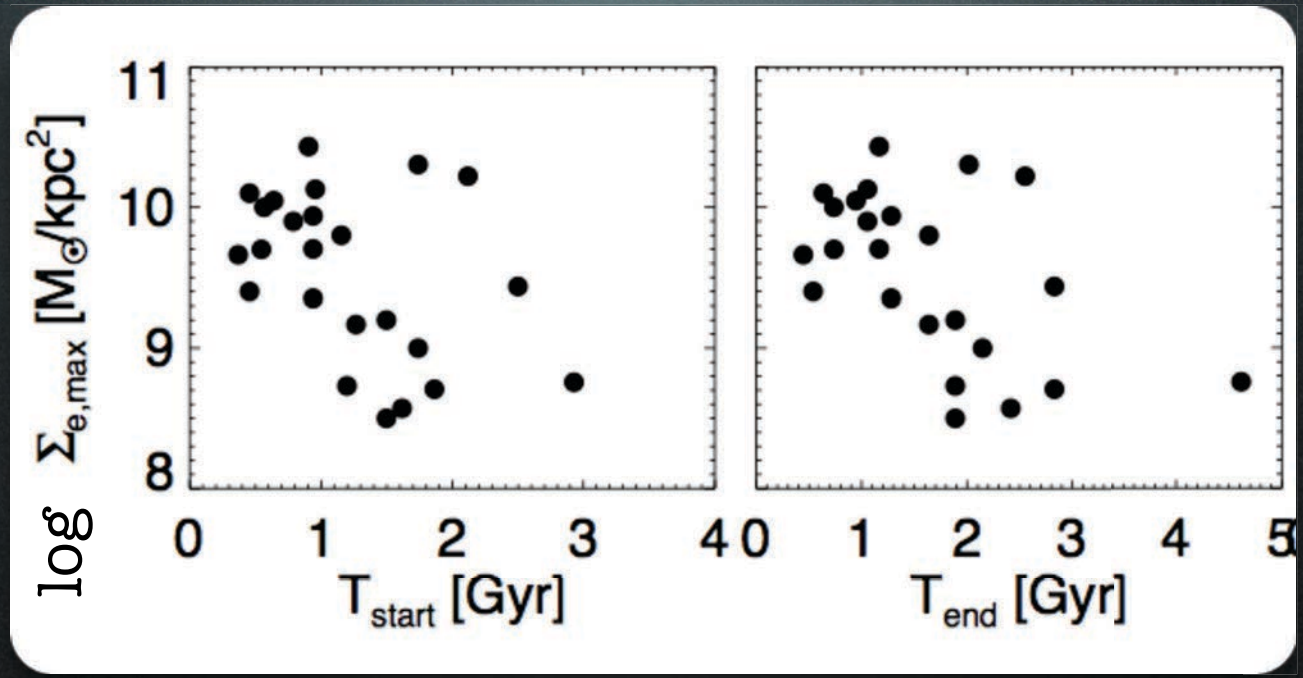
low-sigma galaxies

Wet Inflow Blue Nugget VDI SFR ring



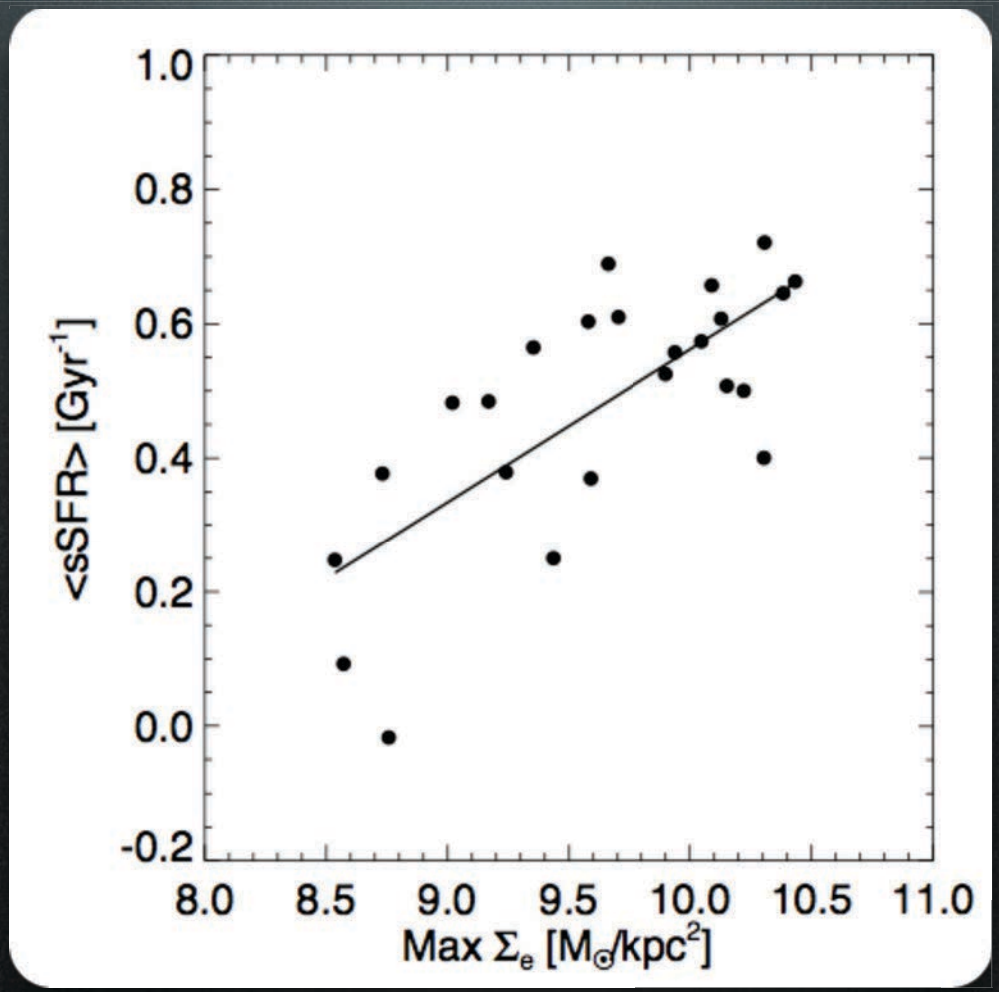
Red Nugget

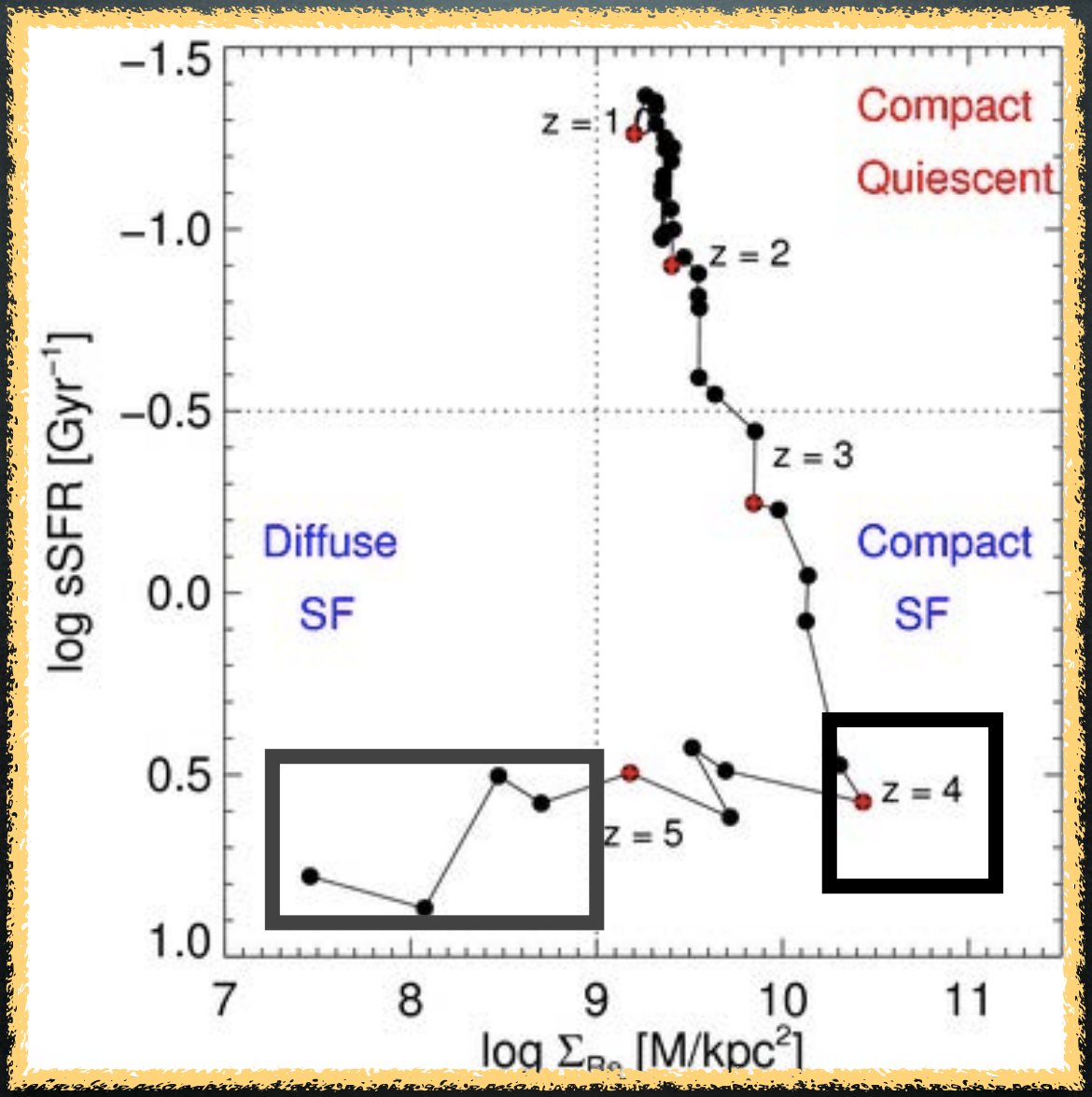
Mosiacs by Nir Mandelker



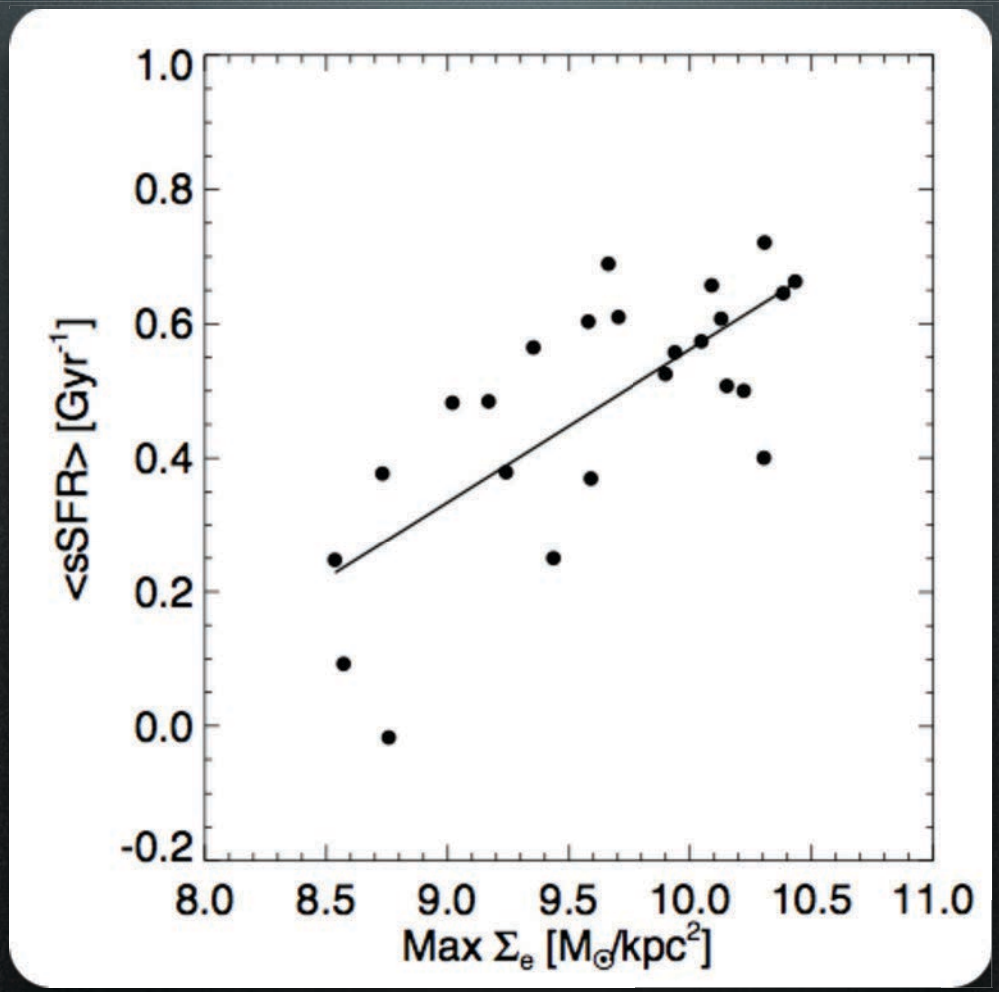
Galaxies that reach high-Σ do so at higher z, and more quickly than galaxies that only reach low-Σ

What Drives high-sigma compaction?

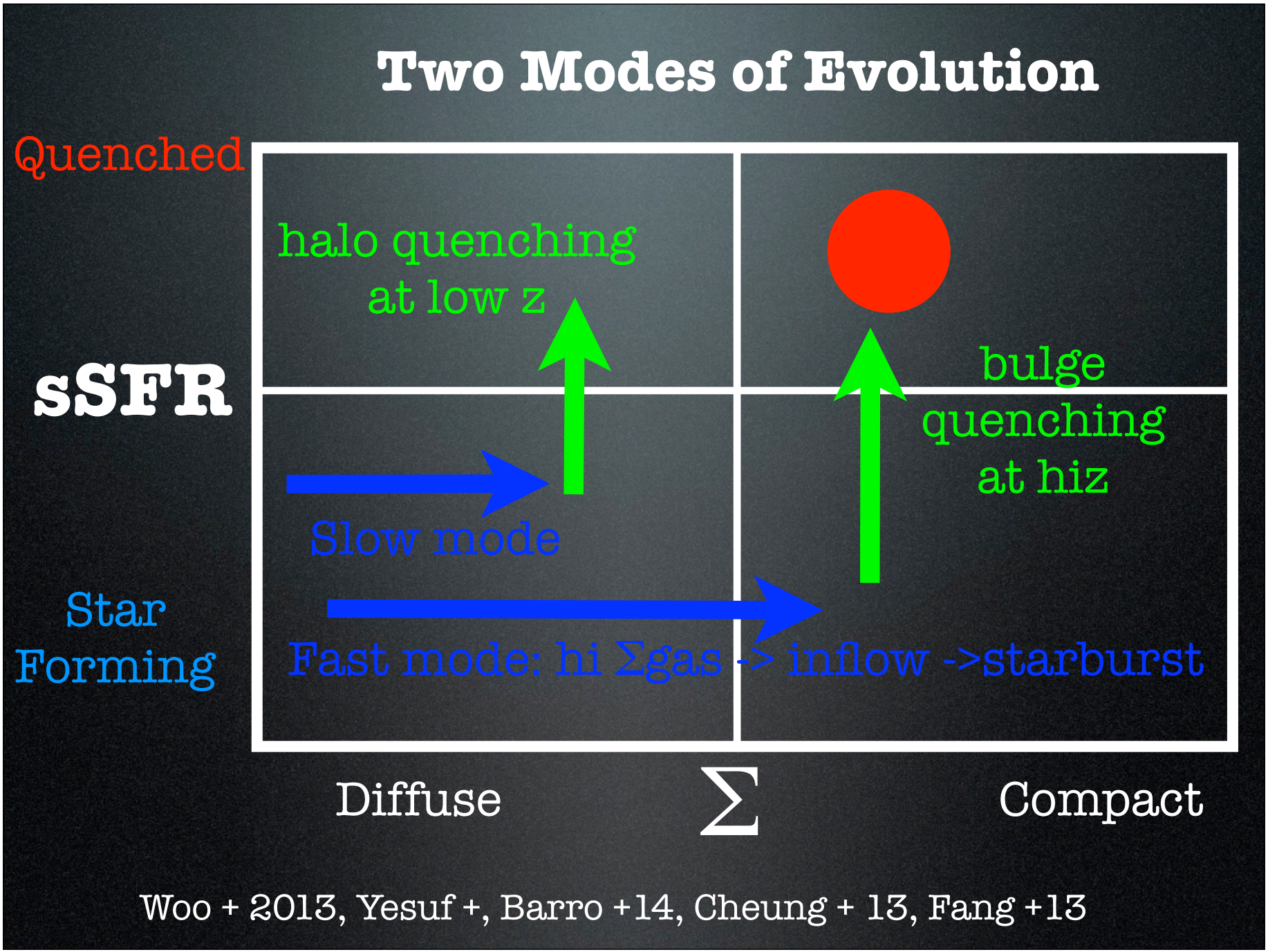



Compact
Quiescent
Diffuse
SF
Compact
SF
z = 1
z = 2
z = 3
z = 4
z = 5
−1.5
−1.0
−0.5
0.0
0.5
1.0
7
8
9
10
11
log sSFR [Gyr^{-1}]
log Σ_{R_e} [M/kpc^2]

What Drives high-sigma compaction?

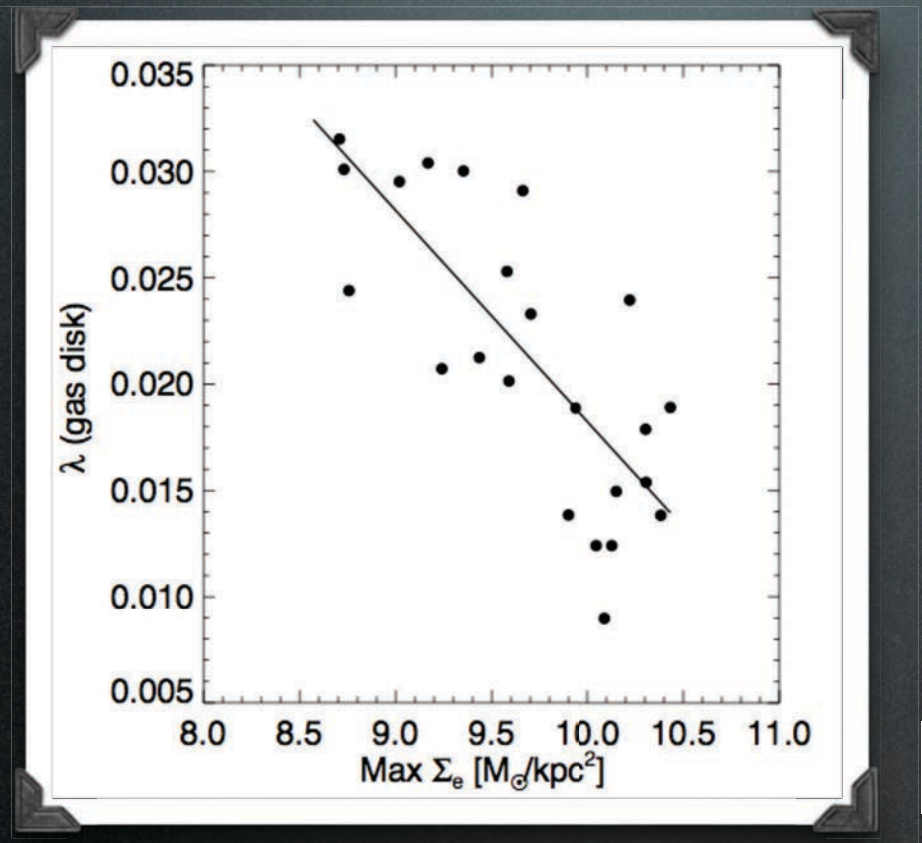


Two Modes of Evolution



Woo + 2013, Yesuf +, Barro +14, Cheung + 13, Fang +13

What Drives high-sigma compaction?



Zolotov + 2014

low spin disk -> high Σ_{max} high sSFR-> high Σ_{max}

Dekel & Burkert 2014

Dissipative Inflow

Dekel & Burkert 2014

★ To form a compact stellar spheroid, you need dissipative inflow

★ Inflow will be "wet" if $t_{inflow} << t_{sfr}$

$$w \equiv \frac{t_{sfr}}{t_{inf}} \sim \frac{\delta^2}{\epsilon},$$

$$\varepsilon_{sfr} \leq 0.02 \quad \delta \geq 0.2$$

$$\frac{M_{cold}}{M_{tot}} \equiv \delta$$

When to expect compact "nuggets":

★ At high z, when **f_{gas} is high**

★ For galaxies with **low spin**, where R_{gas} is low

Summary

- A characteristic sequence of events at hi-z in almost every galaxy:
- Dissipative compaction fueled by mergers and VDI leads to compact SFGs (“blue nuggets”)
- Fast quenching to compact ellipticals (“red nuggets”) + SF ring (sometimes)
- Slow quenching to diffuse ellipticals by hot massive halo