Evolution of Early-Type Galaxies in Groups

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Question

When, how, and it what order

morphological (structural) & photometric (color, SFR)

transformations of present day early-type galaxies?

- Role of mergers in these transformations?
- Impact of environment and environmental processes?
- What happens with the dense galaxies seen at high z?
- Differences between central and satellite galaxies?

A few clues (or more questions...)

Observations:

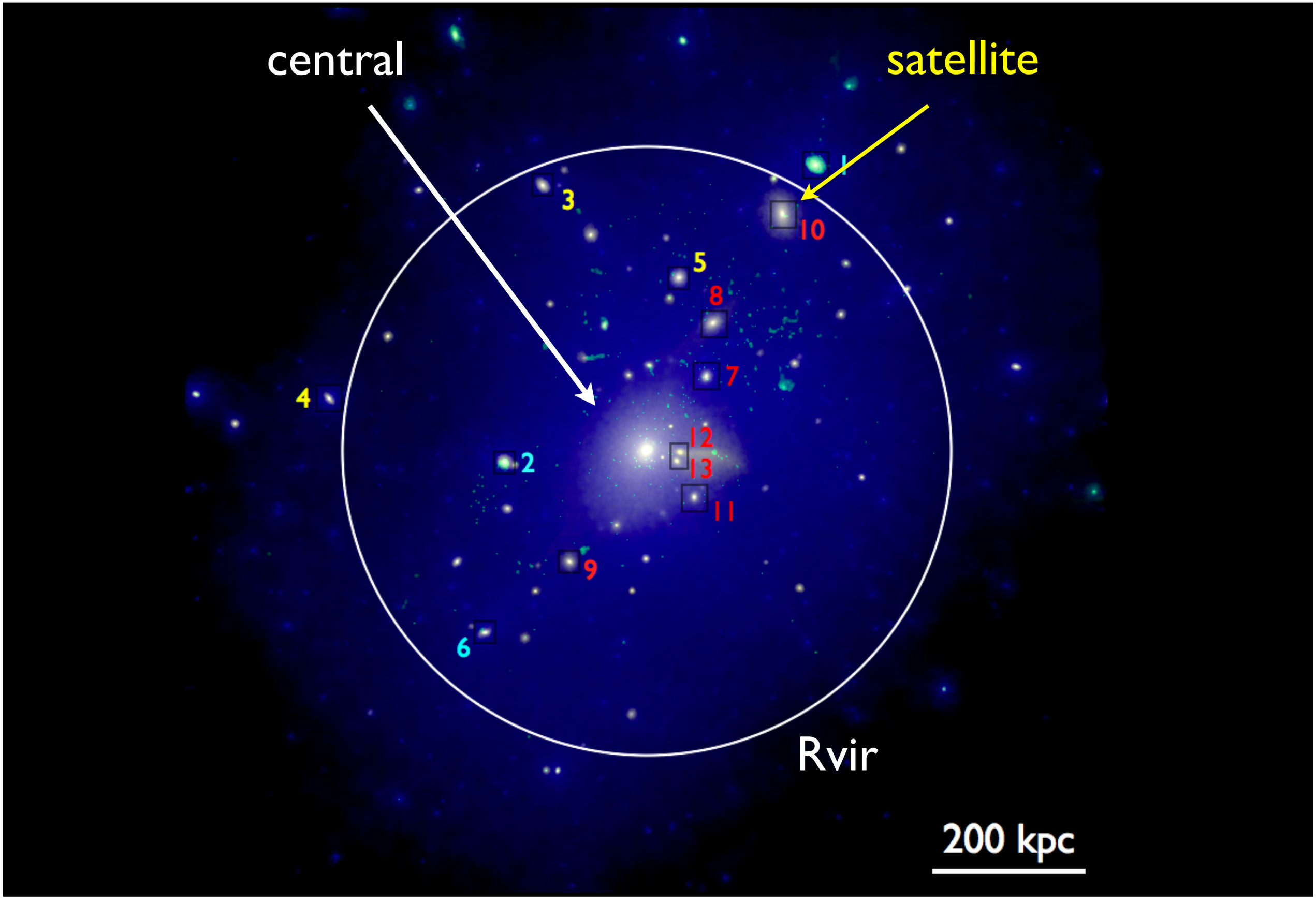
- morphology - density relation
- evolution of luminosity/mass functions of red/blue, early/late type galaxies
- quenching separable into stellar mass driven & environmentally driven (Peng+10)
- 2/3 local early types in the field have substantial gas reservoirs (e.g., Osterloo+11) - environment?
- 3/4 local early types are fast rotating, somewhat disky objects (e.g., Emsellem+07) - dissipative mergers?
- compact passive early types at high z, rare locally

...

Theory:

- high resolution numerical simulations of individual processes (binary mergers, ram-pressure stripping, tidal stripping, tidal stirring, harassment, ...)
- analytical & semi-analytical models for population studies
- challenge: predicting evolution of populations in ab-initio simulations

Why Groups?



Why Groups?

central

satellite

- Typical environments:
  - Many galaxies in the Universe live in groups,
  - many groups exist (compared to clusters)
  - significant fraction of local baryons is in groups
- Groups contain usually both spirals and early type galaxies
- Are believed to be places where galaxies preferentially merge
- High density environment; environmental effects: ram-pressure stripping, starvation, tidal stripping
- Allow to simultaneously study very massive centrals and lower mass (but still massive) satellite galaxies

200 kpc

Simulation details

Zoom-in simulations of 3 groups of $M_{Vir} \sim 10^{13}\ M_\odot$ in a 123 Mpc box

TreeSPH GASOLINE

Star formation: n>0.1 cm^{-3}, T < 15'000 K, convergent flow, ε=0.05,

$$\dot{\rho}_{\rm star} = \varepsilon \frac{\rho_{\rm gas}}{t_{\rm dyn}}$$

SN feedback: "Star" = Single Stellar Population, 4×10^{43} J of thermal energy/SN; SN Ia & II

UV background, tracking of metal production, mass loss by stellar winds

High resolution:

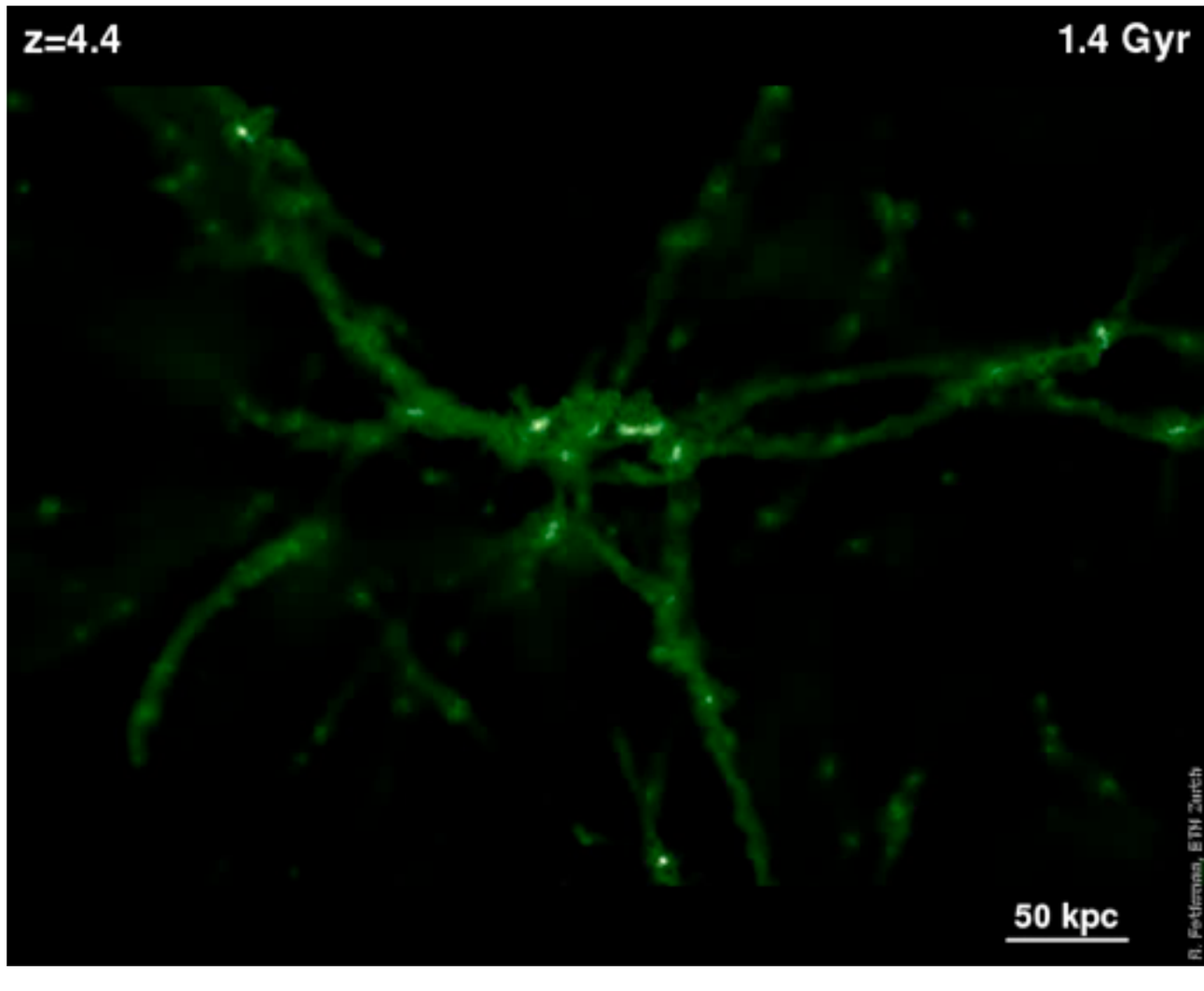
- resolve 13 satellites with $\sim10^5$ baryonic particles: **(~ 1 Million CPUh)**
- ~200 pc/h spatial resolution, SPH particle masses $\sim10^6\ M_\odot/h$

Low resolution:

- resolve central galaxies with $\sim10^5$ baryonic particles
- ~0.5 kpc/h spatial resolution, baryonic particle masses of $\sim8\times10^6\ M_\odot/h$

Similar physics & resolution previously used to study *individual* dwarf and MW galaxies

Evolution



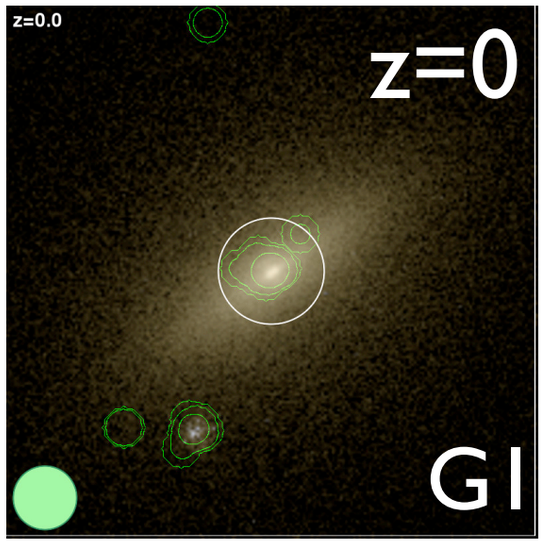
B, R, I band (stellar light)

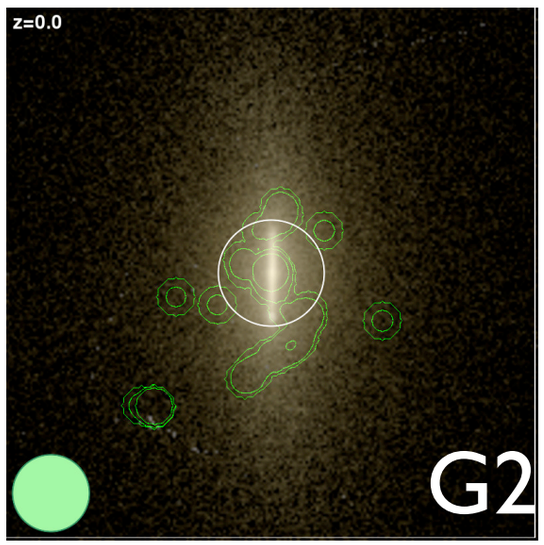
cold (green), hot (red)
gas surface density

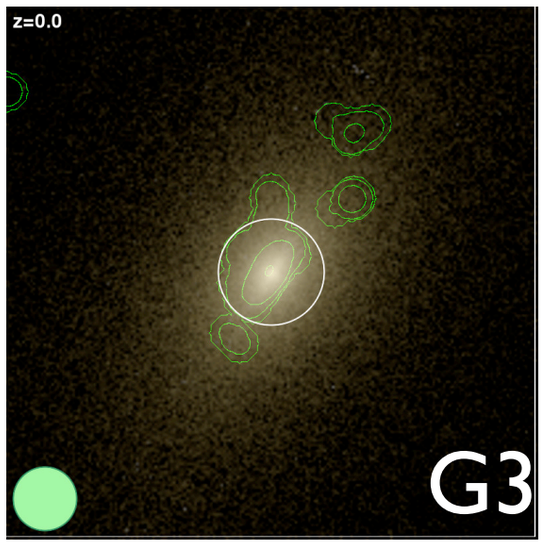
Central Galaxies

Feldmann et al. APJ, 709, 218 (2010)

Simulated Group Centrals at z=0







\+ • Massive galaxies (~few times 10^{11} $M_\odot$)

• Surface profile close to de Vaucouleurs (n~4)

• Supported by velocity dispersion (v_{rot} /σ_{cen}<1)

• little star formation outside central region

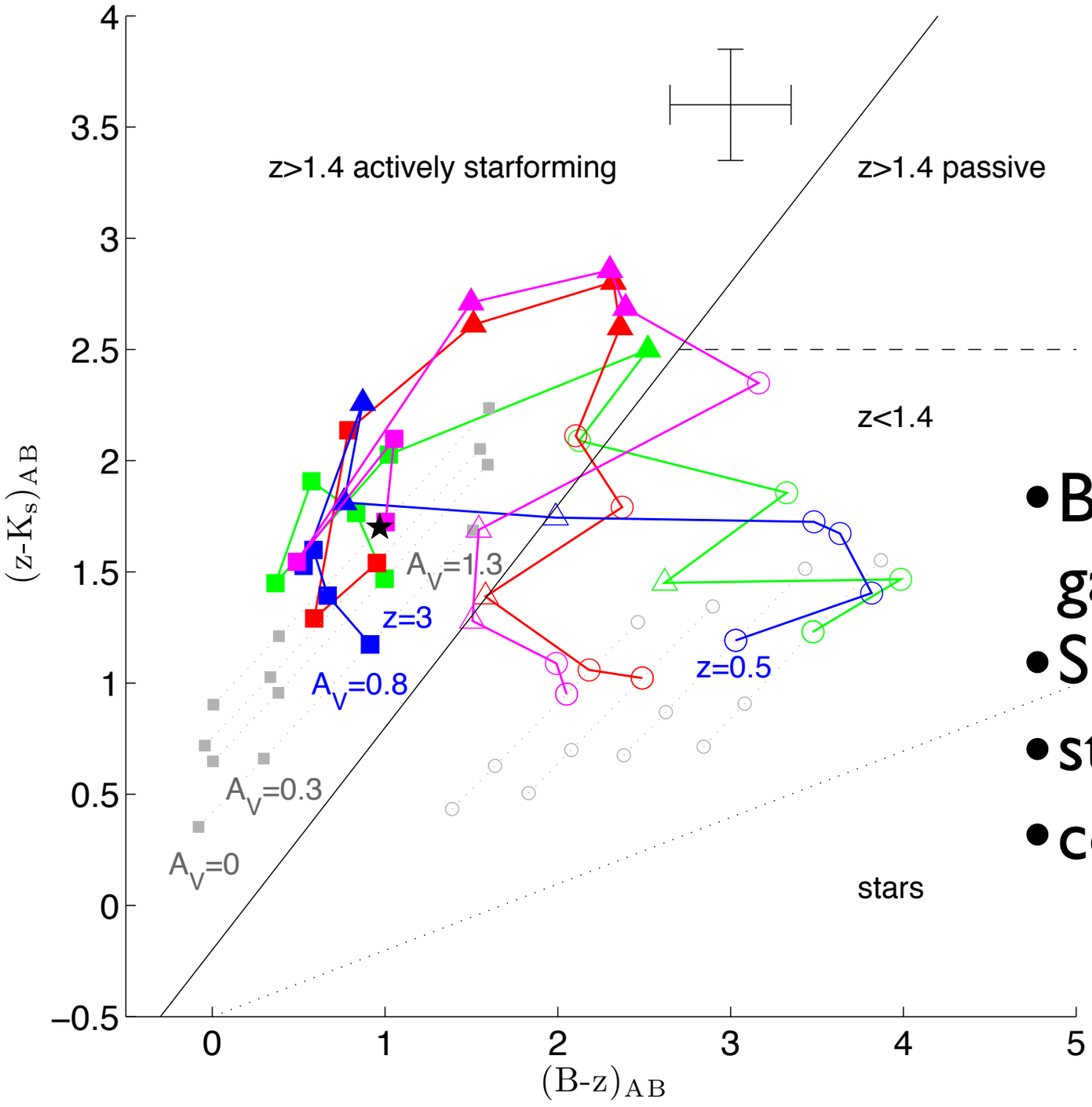
• almost no cold gas (f_{gas} <1%)

• red colors (g-r ~ 0.85)

No need for AGN feedback
(outside central ~few 100 pc)

\- • biased towards higher masses & smaller sizes w.r.t. average observed mass-size relation

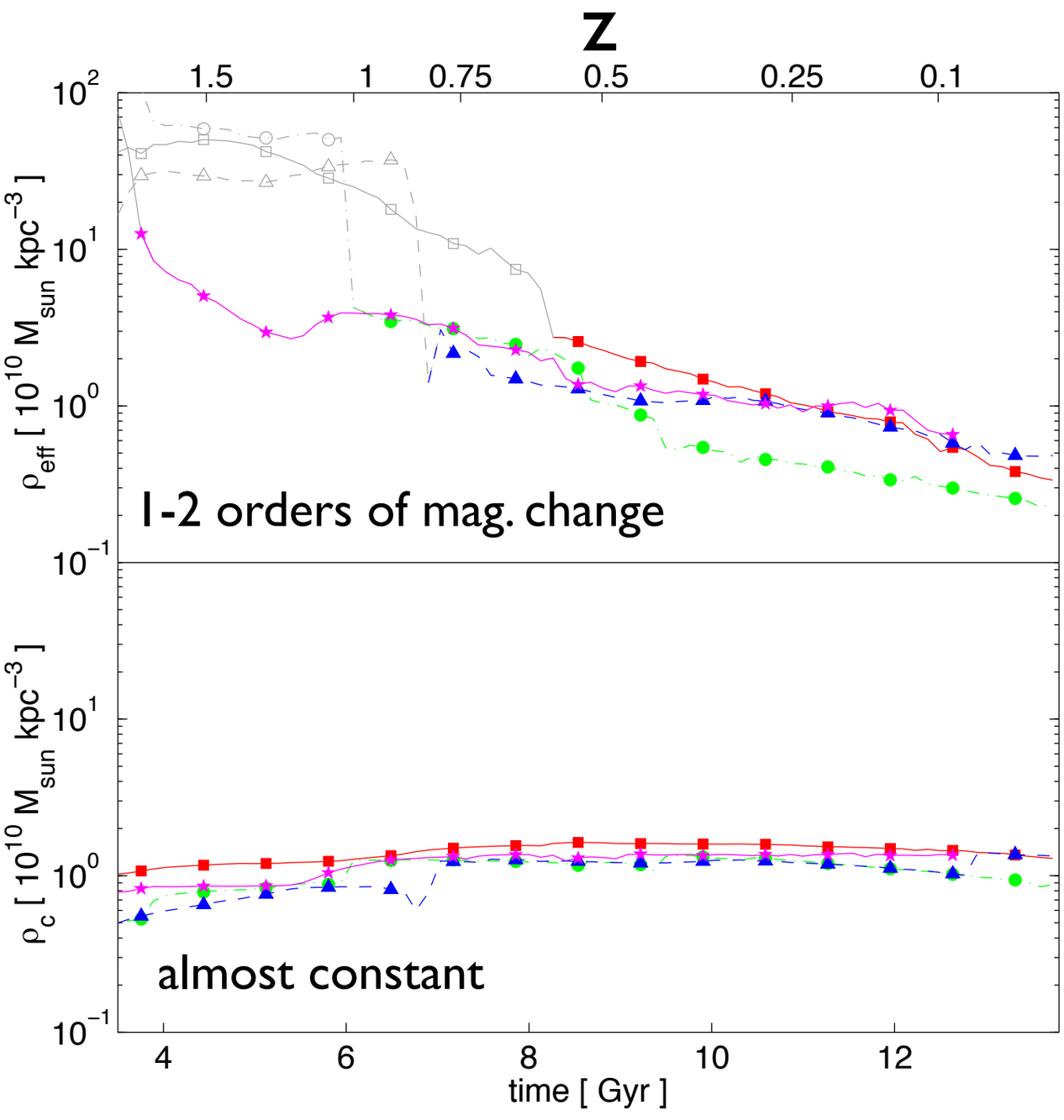
their ~2 progenitors



- BzK criterion: star forming galaxies
- SFR ~ 20-60 $M_\odot$/yr
- stellar masses ~0.5-1x10^{11} $M_\odot$
- compact: Reff ~ 1 kpc

Density evolution

How do these dense high-z galaxies evolve into local not-so-dense galaxies ?



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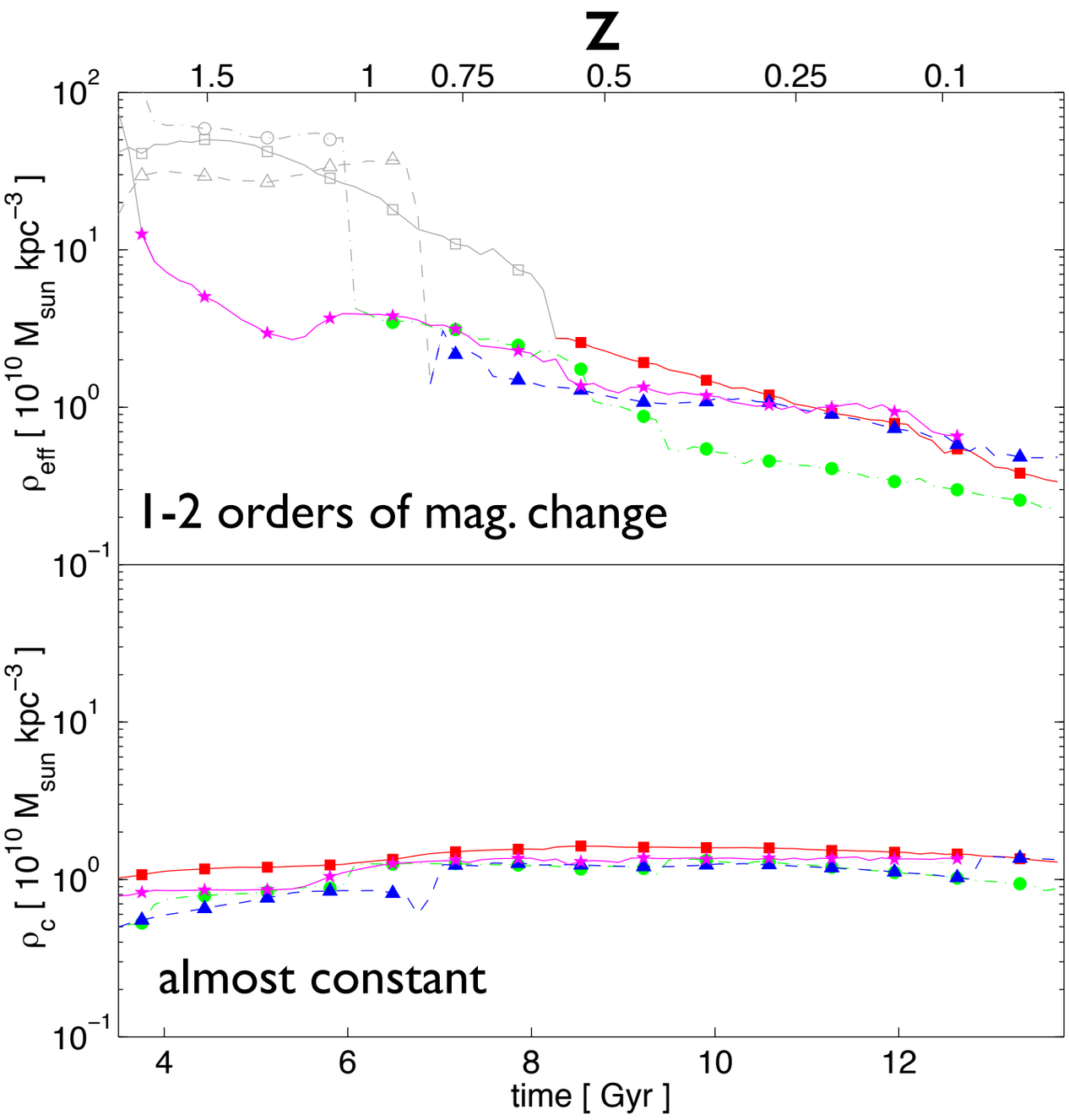
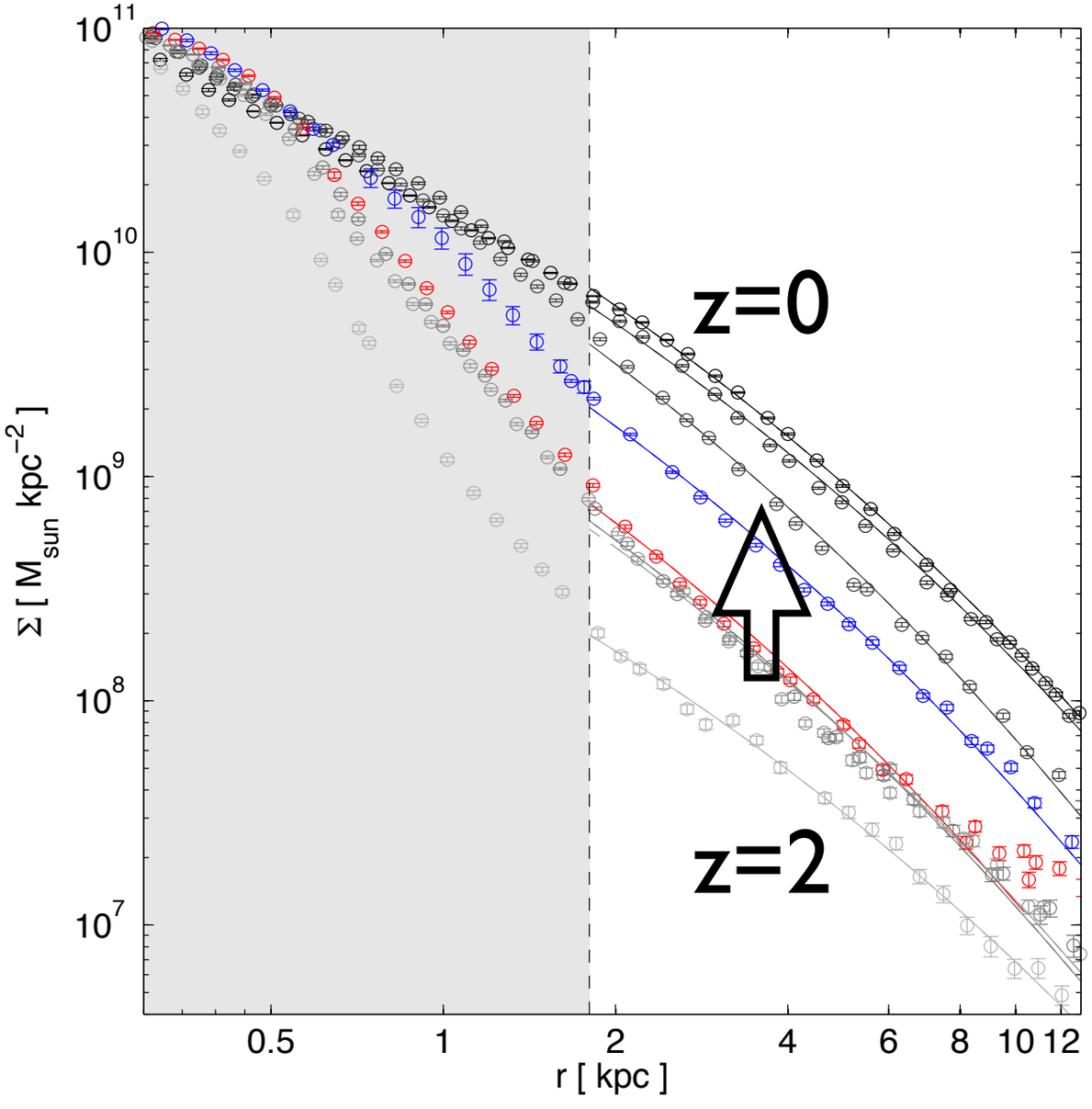
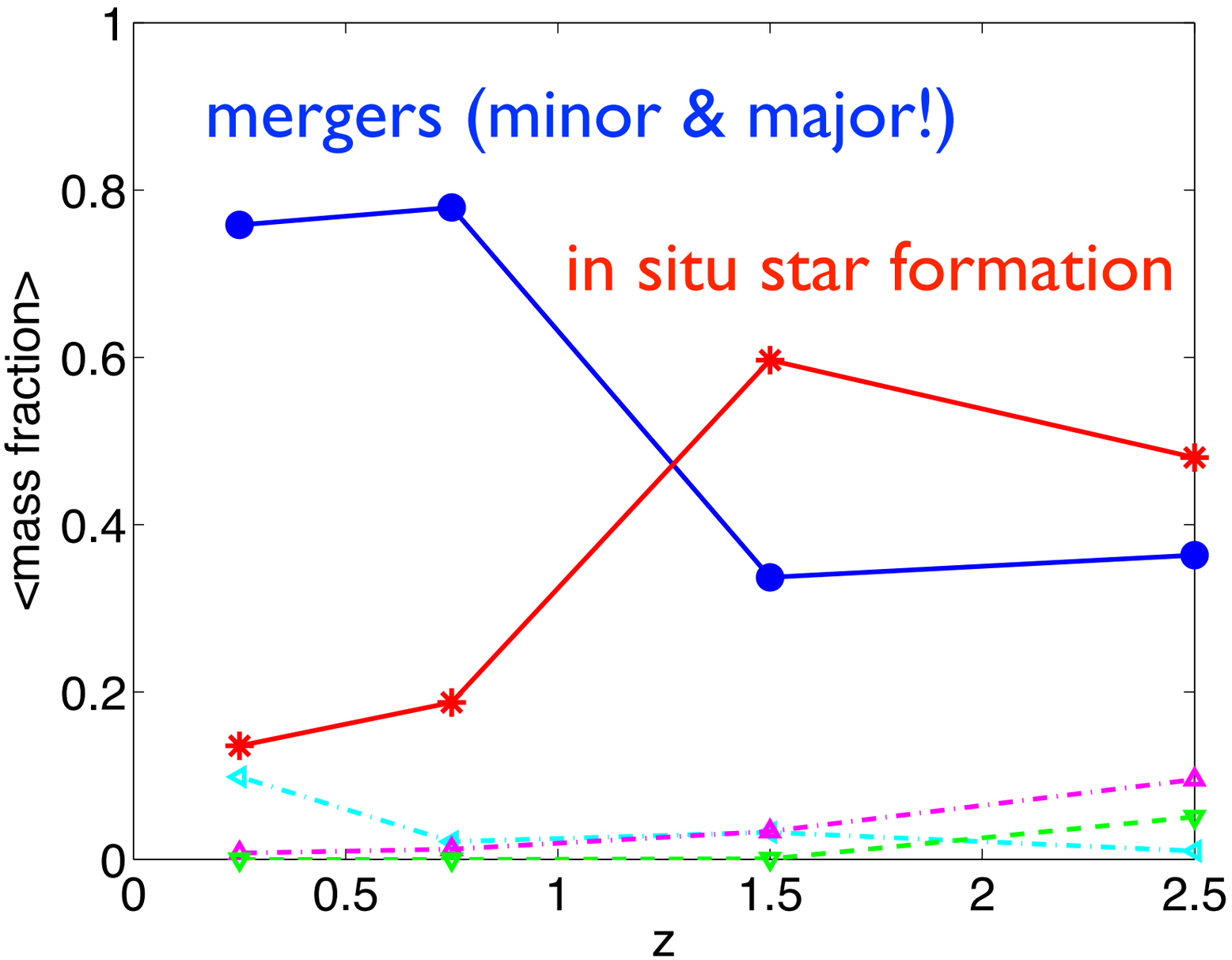




envelope due to merging (not only "minor")

cf., e.g., Naab+07,+09, Bezanson+09, many more

Stellar mass accretion history



accretion of stripped stars,
stars formed before z=4, ...

at z>1: mass growth by in-situ SF

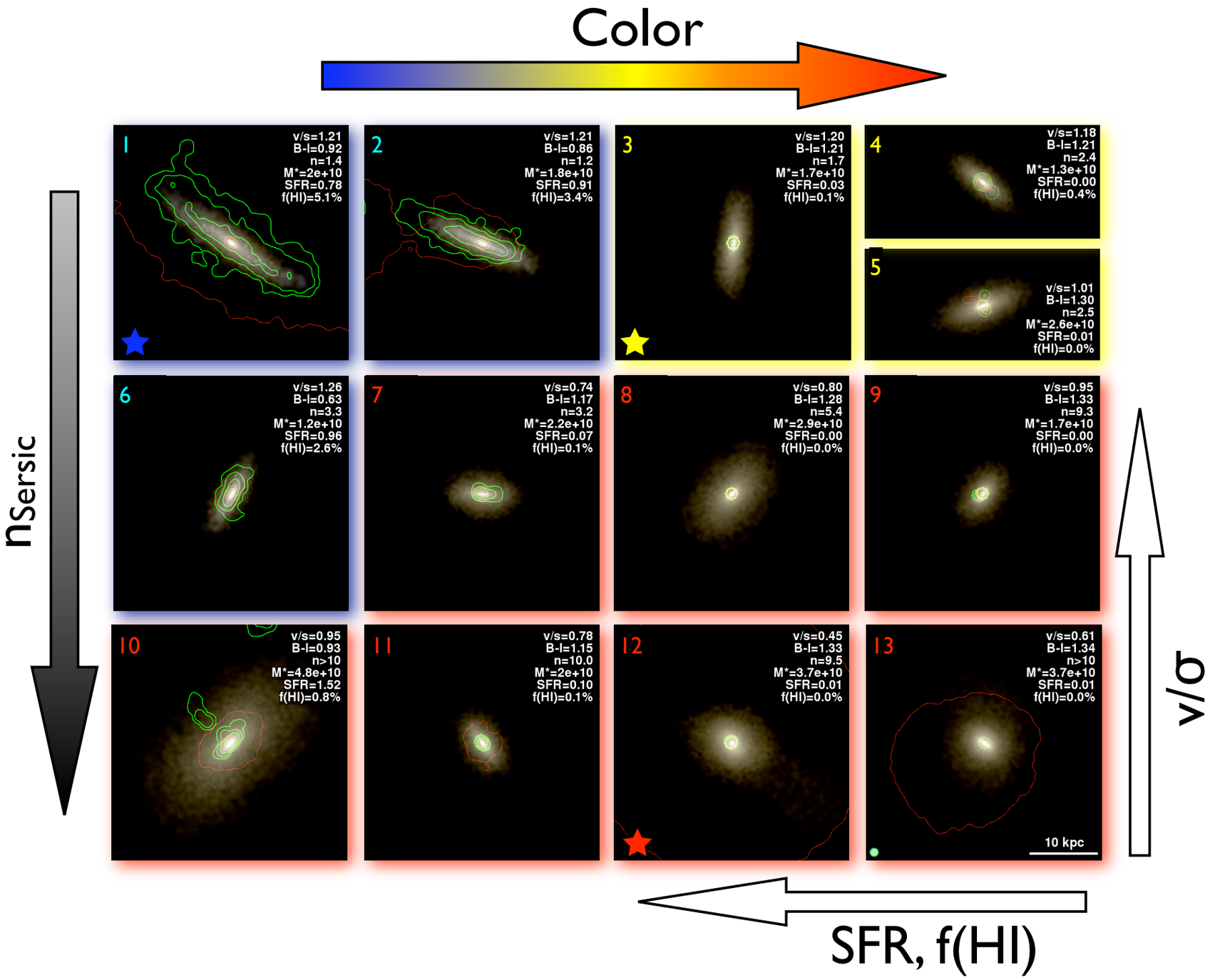
at z<1: mass growth by mergers

Satellites

(or in short "non-central group members within Rvir")

Feldmann et al. APJ,, 736, 88 (2011)

Hubble sequence in groups?



\+ Broad range in

- n_sersic
- color
- SFR
- gas fractions
- rotational support

\- Galaxies somewhat too compact

3 Classes: star forming disks, passive disks, ellipticals

Properties at z~2?

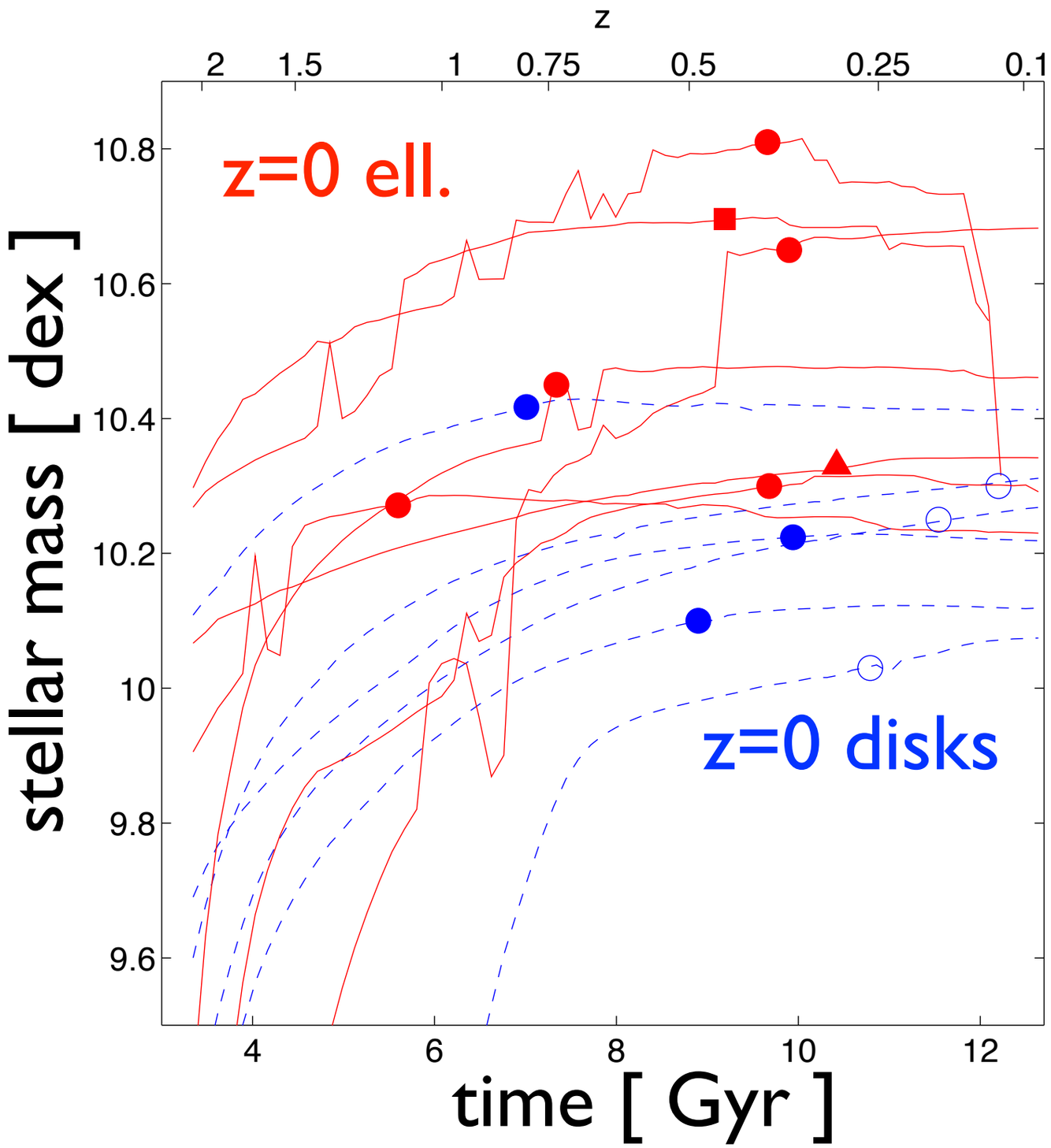
at z~2 all progenitors are:

- star forming
- blue
- gas-rich
- disky
- rotation-supported
- some not even born yet

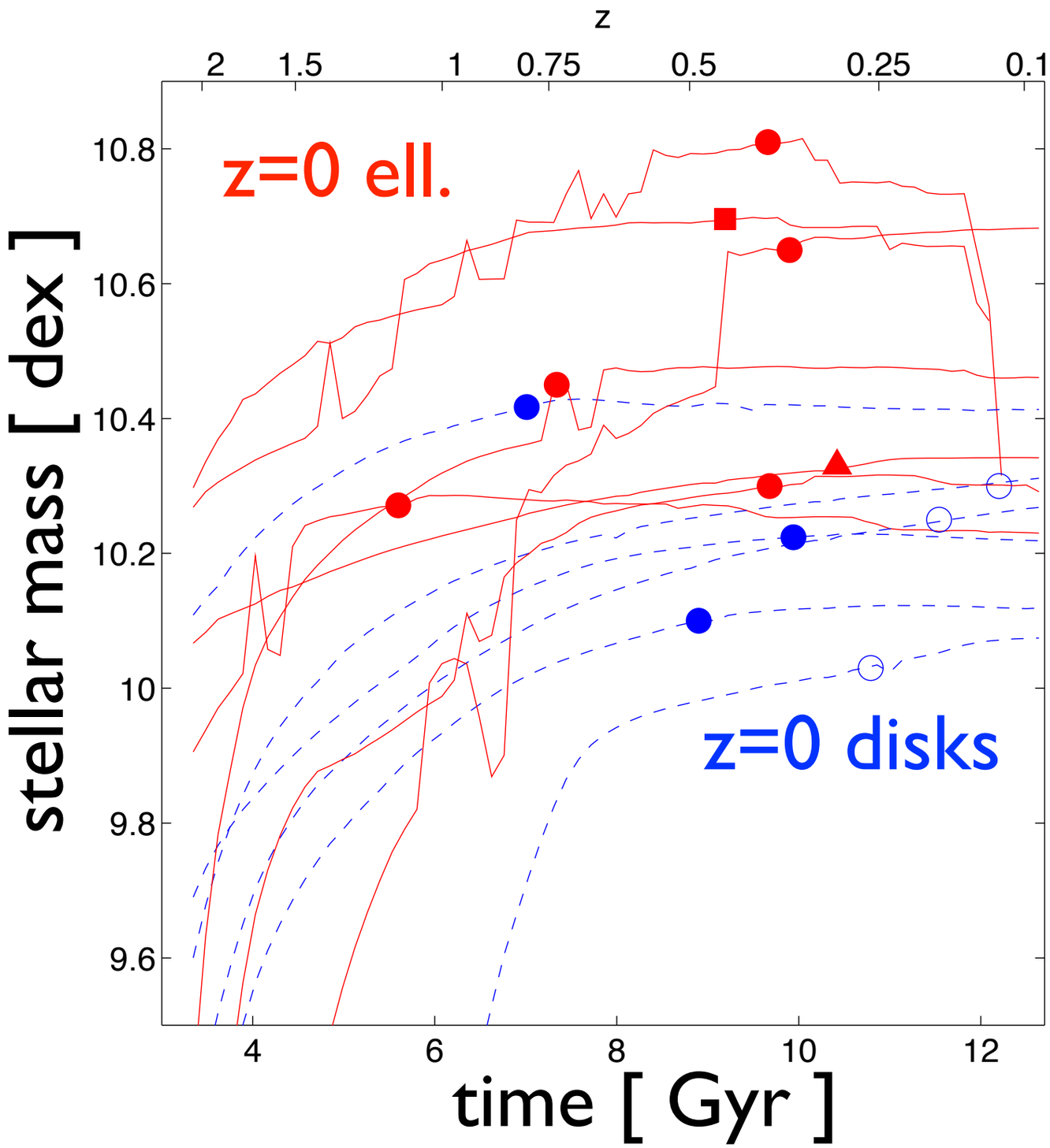
none of the progenitors is yet in the group
(typical infall time z~0.3-1)

How and why do morphology & color change with time?

Morphological transformations



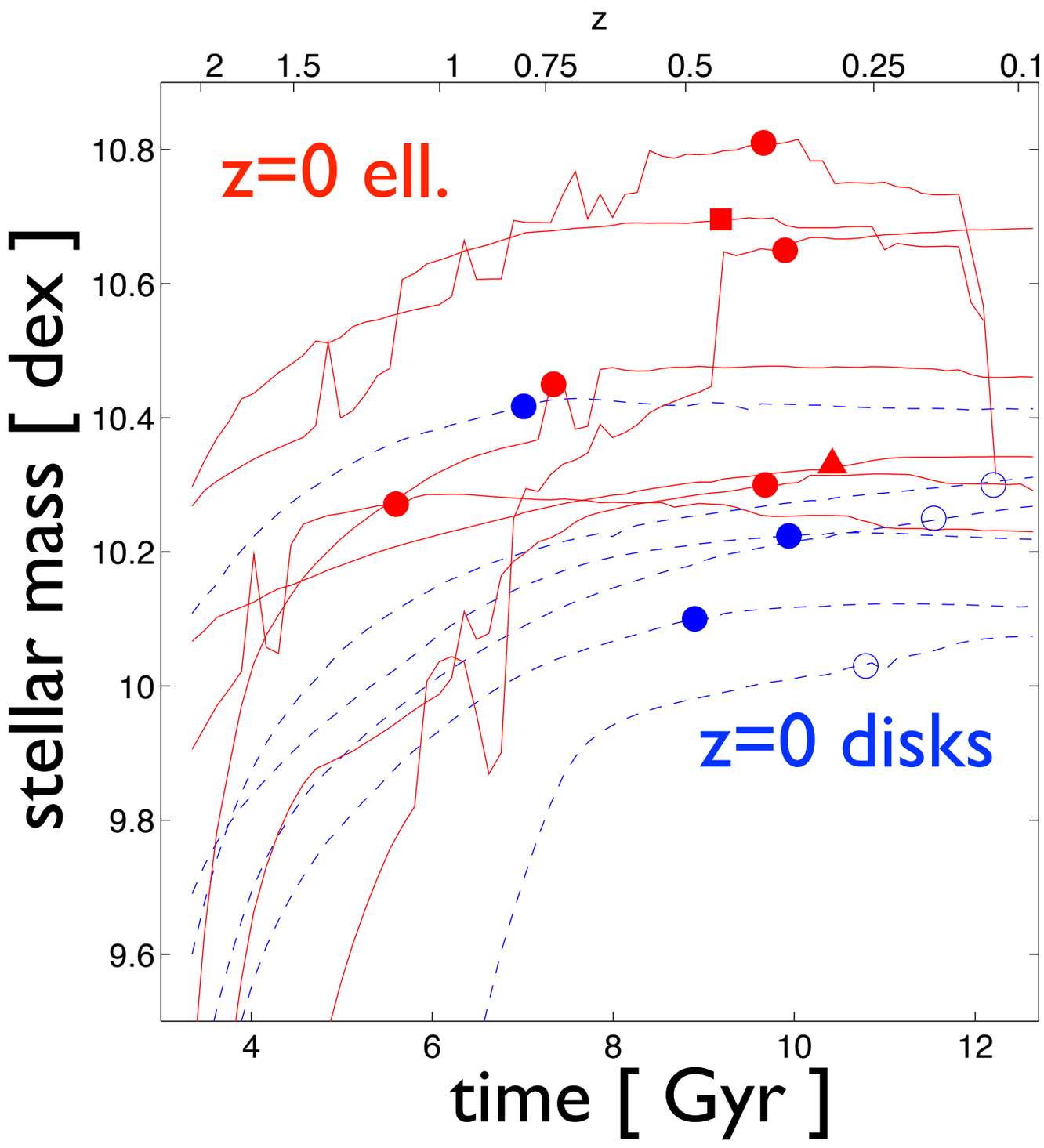
Morphological transformations



Due to merging, often before infall to the group

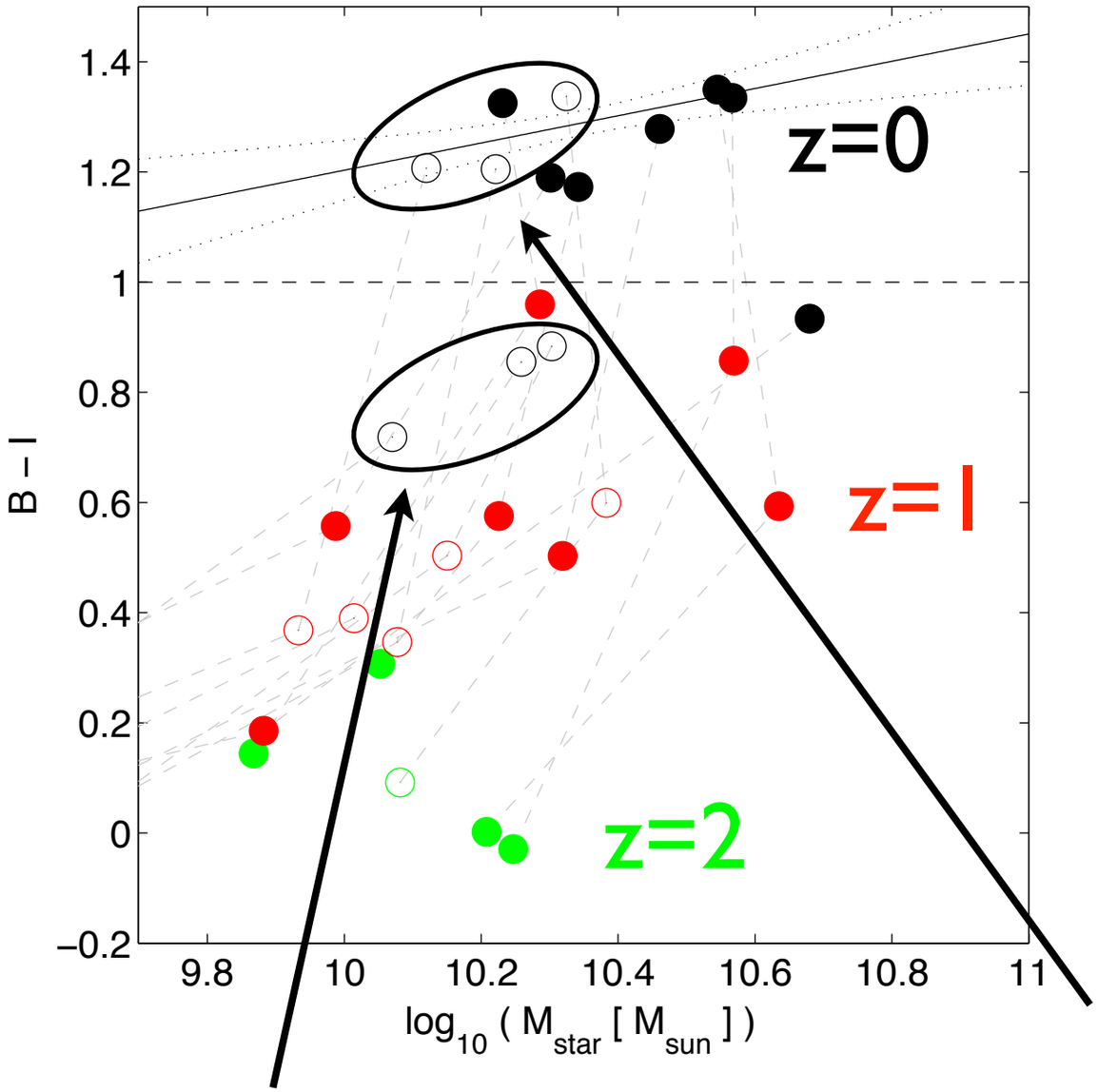
Morphological transformations

Groups are not the places where galaxies merge...



Due to merging, often before infall to the group

Color transformations



Overall decline in SFR

+

Environmental effects

- Shutdown of Accretion,
- Starvation,
- Ram-pressure (minor)

Star forming Disks

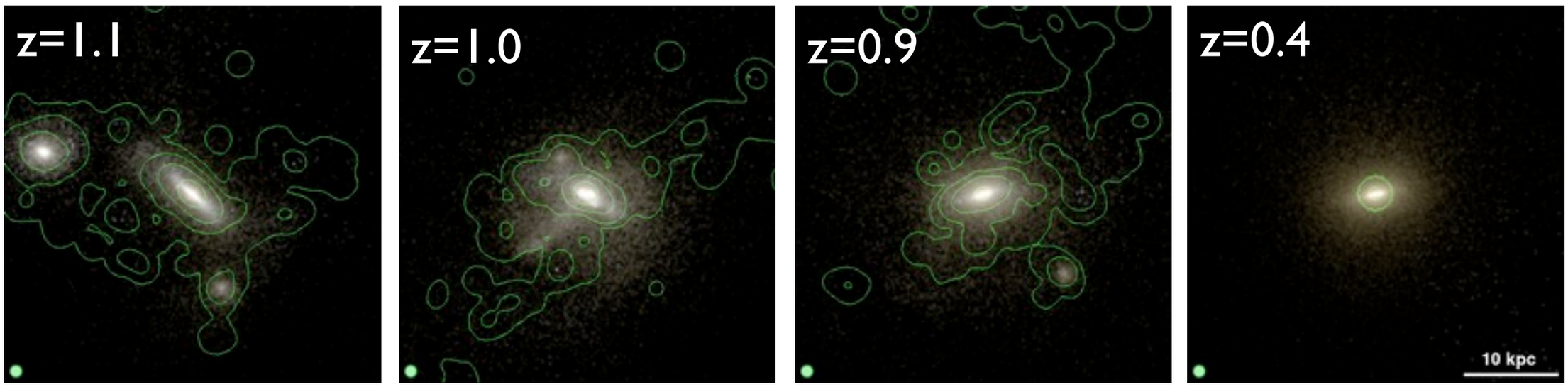
- Not yet exhausted cold gas reservoir
- Declining star formation
- Large Pericenter: lower ram-pressure (or tidal) stripping

Passive Disks

- Earlier Infall
- Longer Exposed to Group Environment
- Smaller Pericenters
- Preprocessing before group infall

The picture

outside group → within group

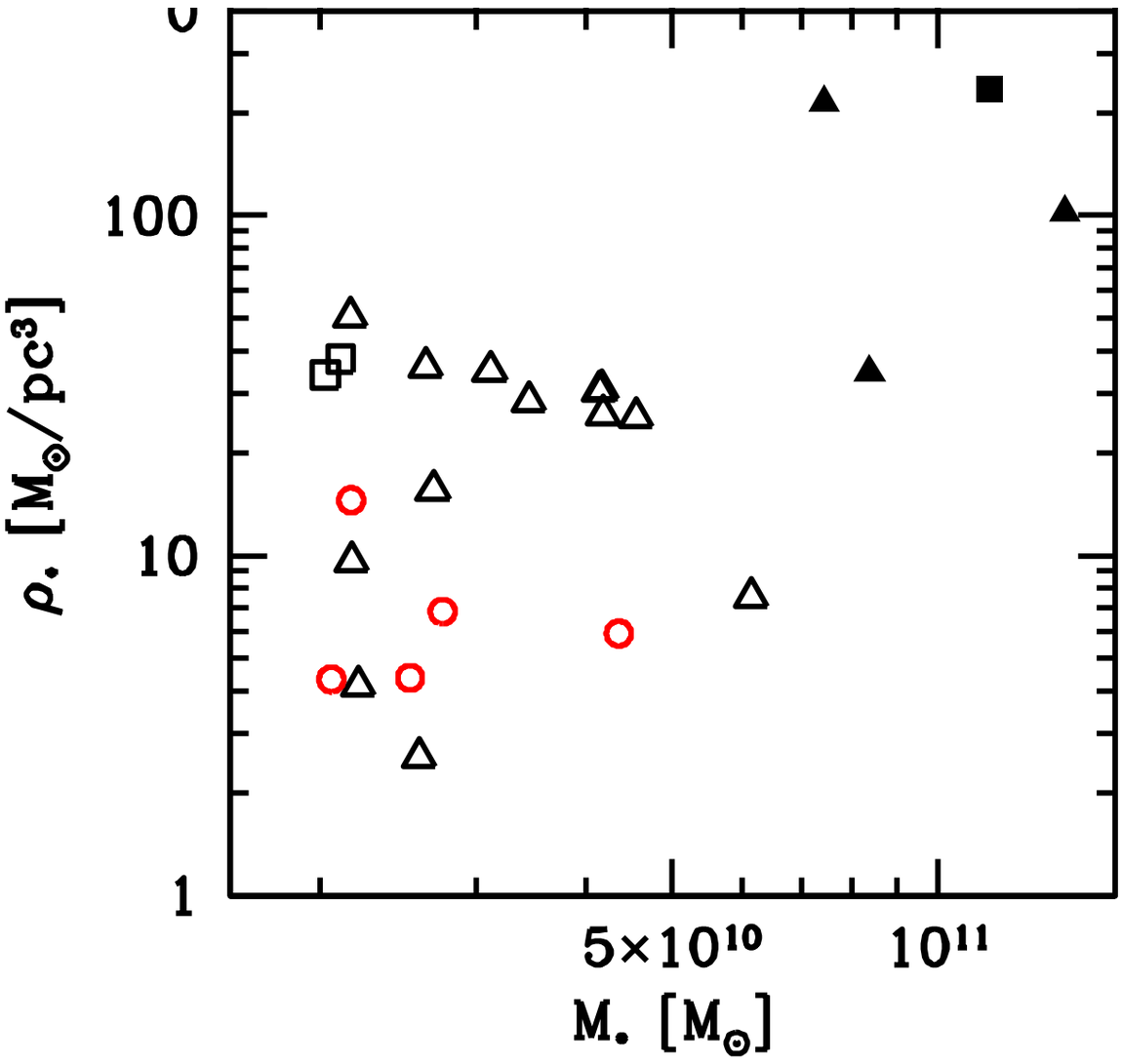


red elliptical:
- gas-rich disks merge
- form “gas-rich” elliptical
- enter high-dens environ
- over ~Gyr timescale become red & dead

red disk:
- same, but without the merger

Density transformations

What happens to dense satellites?



z=2 centrals

z=2 satellites

z=0 satellites

Kaufmann+, in prep

Density transformations

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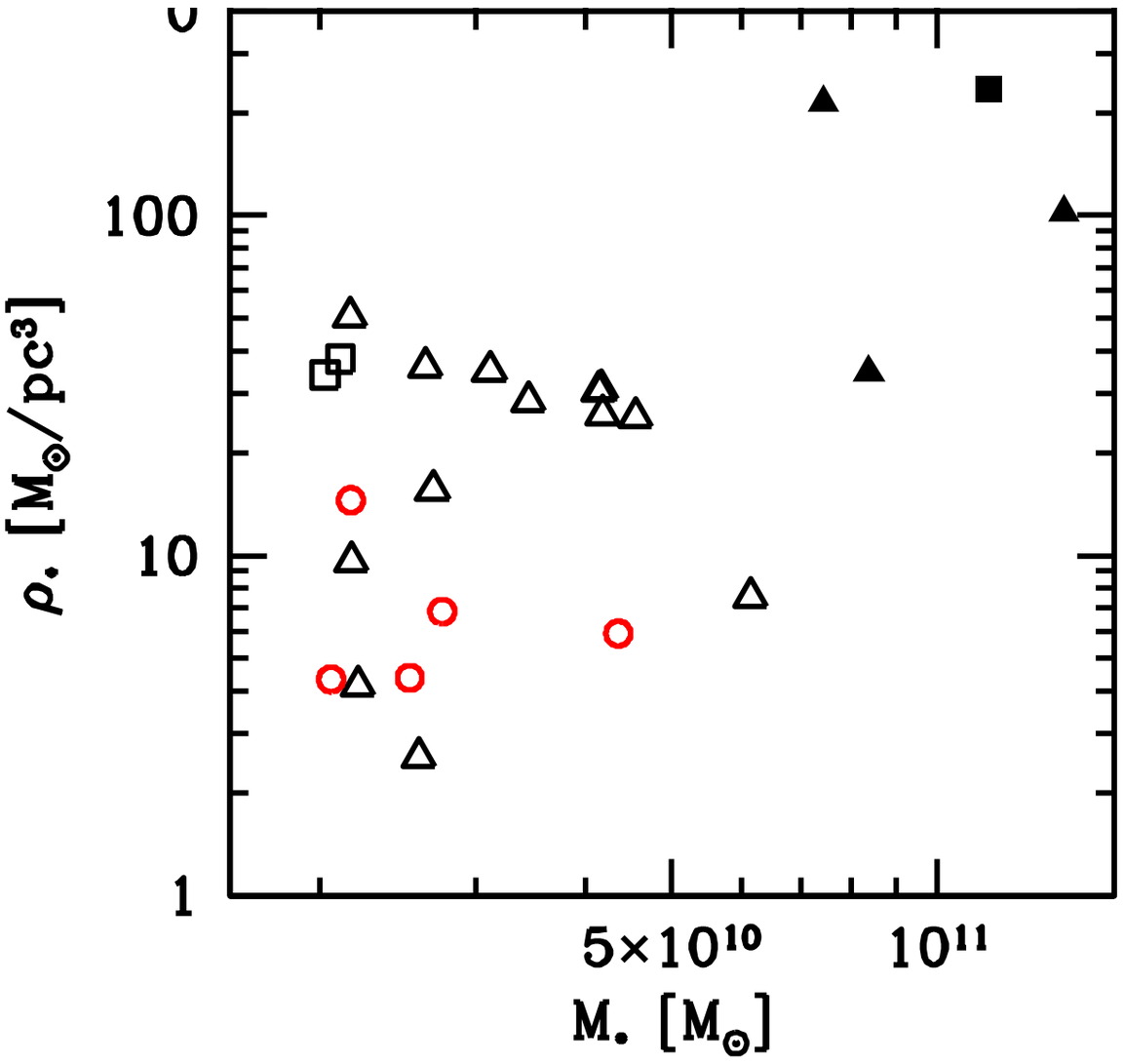

z=2 centrals

z=2 satellites

z=0 satellites

- dense satellites disappear (merge with central),
- later infalling satellites are born later
- are less dense

Kaufmann+, in prep

Conclusions

High mass (> 10^{11} $M_\odot$) centrals:

- red, low SF, early type galaxies
- mass growth by star formation (at z>1) & merging (z<1)
- size growth of envelope (merging, SF, migration) around dense core

Lower mass (~ few 10^{10} $M_\odot$) satellites:

- span of Hubble types incl. blue disks, red disks & ellipticals
- morphological transformation induced by merging before group infall & before photometric transformations
- environmental effects (primarily starvation) lead to SF quenching, gas removal and red colors
- field ellipticals predicted to retain their gas
- dense satellites disappear (merge with central)