The Formation of Massive, Compact Galaxies at $z = 2$ in the Illustris Simulation

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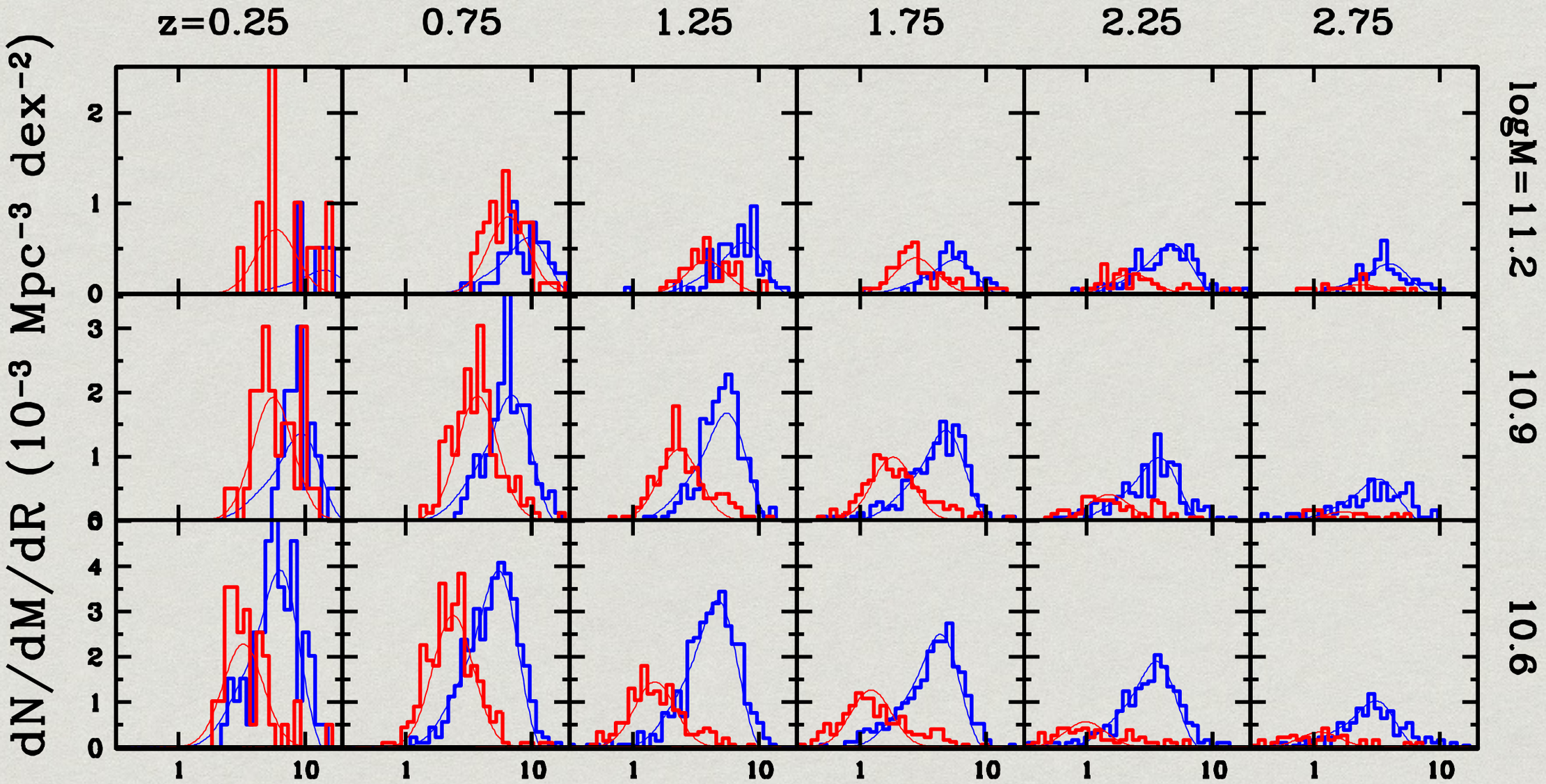
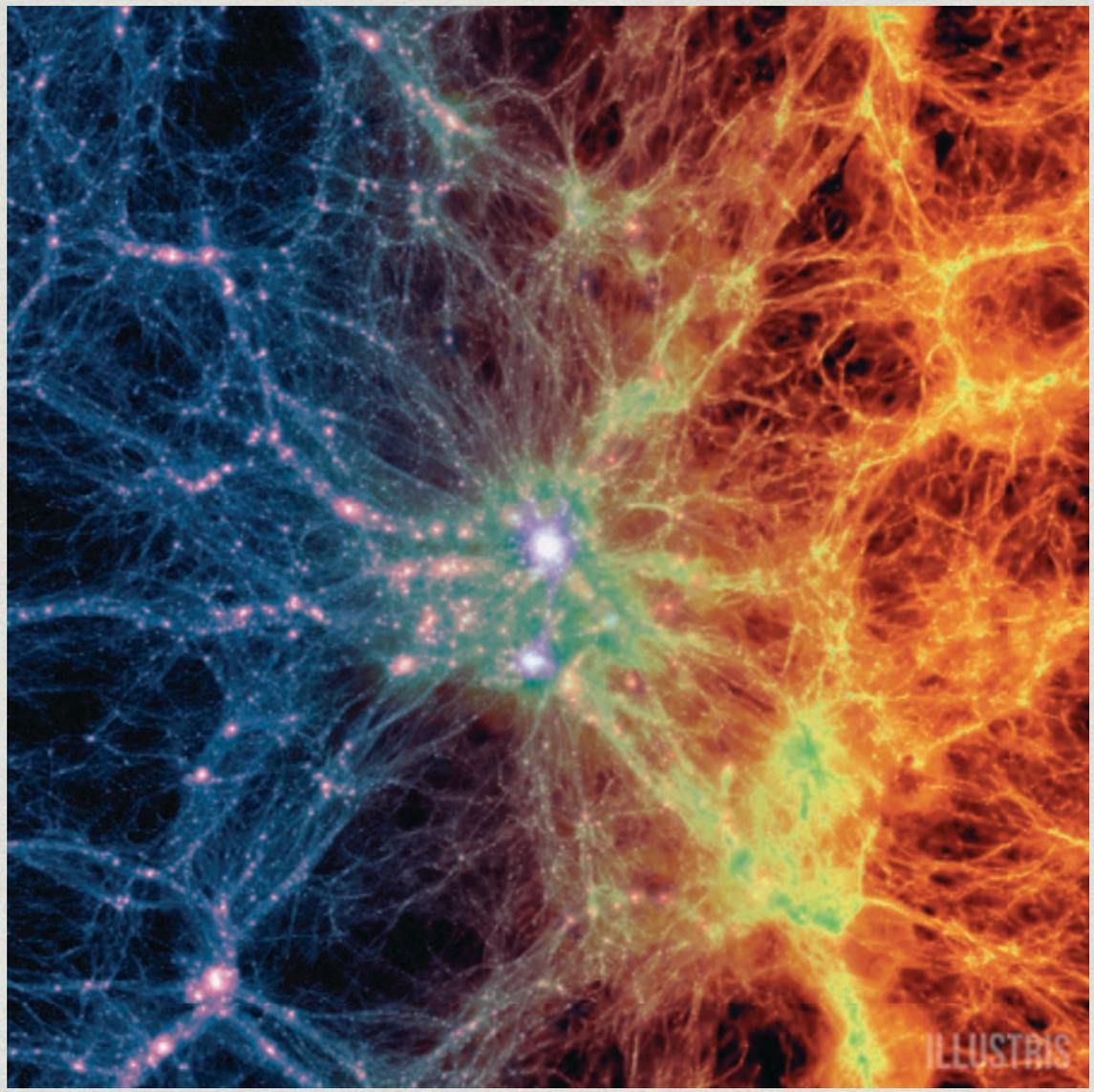
Strong size evolution of quiescent galaxies



van der Wel et al. 2014, 3D-HST+CANDELS

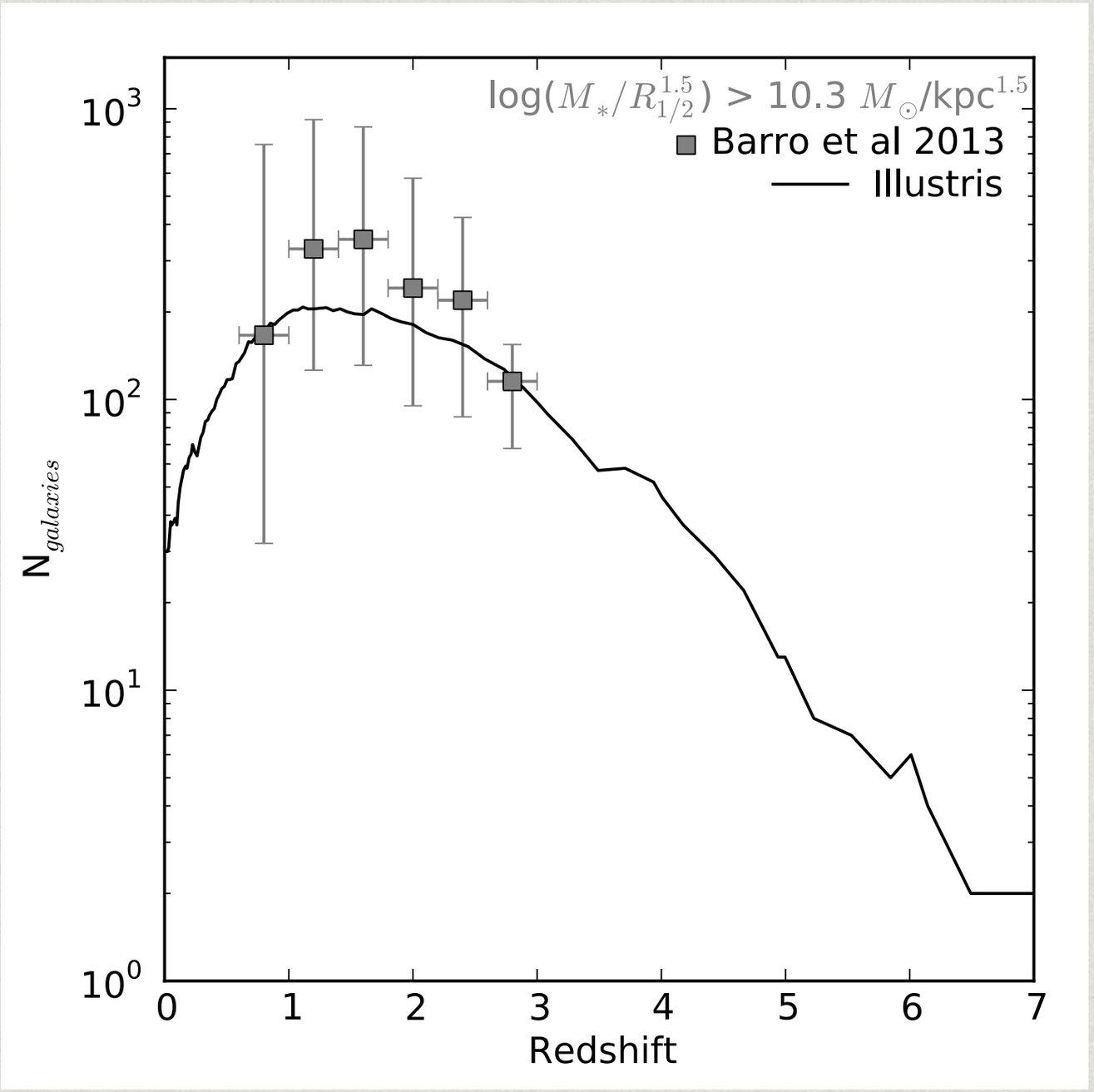
Illustris simulation

- Simulation volume of $(106.5\ \mathrm{Mpc})^3$
- Baryonic resolution elements have mass $1.3 \times 10^6\ M_\odot$
- Gravitational softening length 0.35-0.5 kpc at $z = 2$-3
- N-body + hydro (using moving-mesh code AREPO)
- Includes phenomenological models for star formation and evolution, gas cooling, stellar and black hole feedback

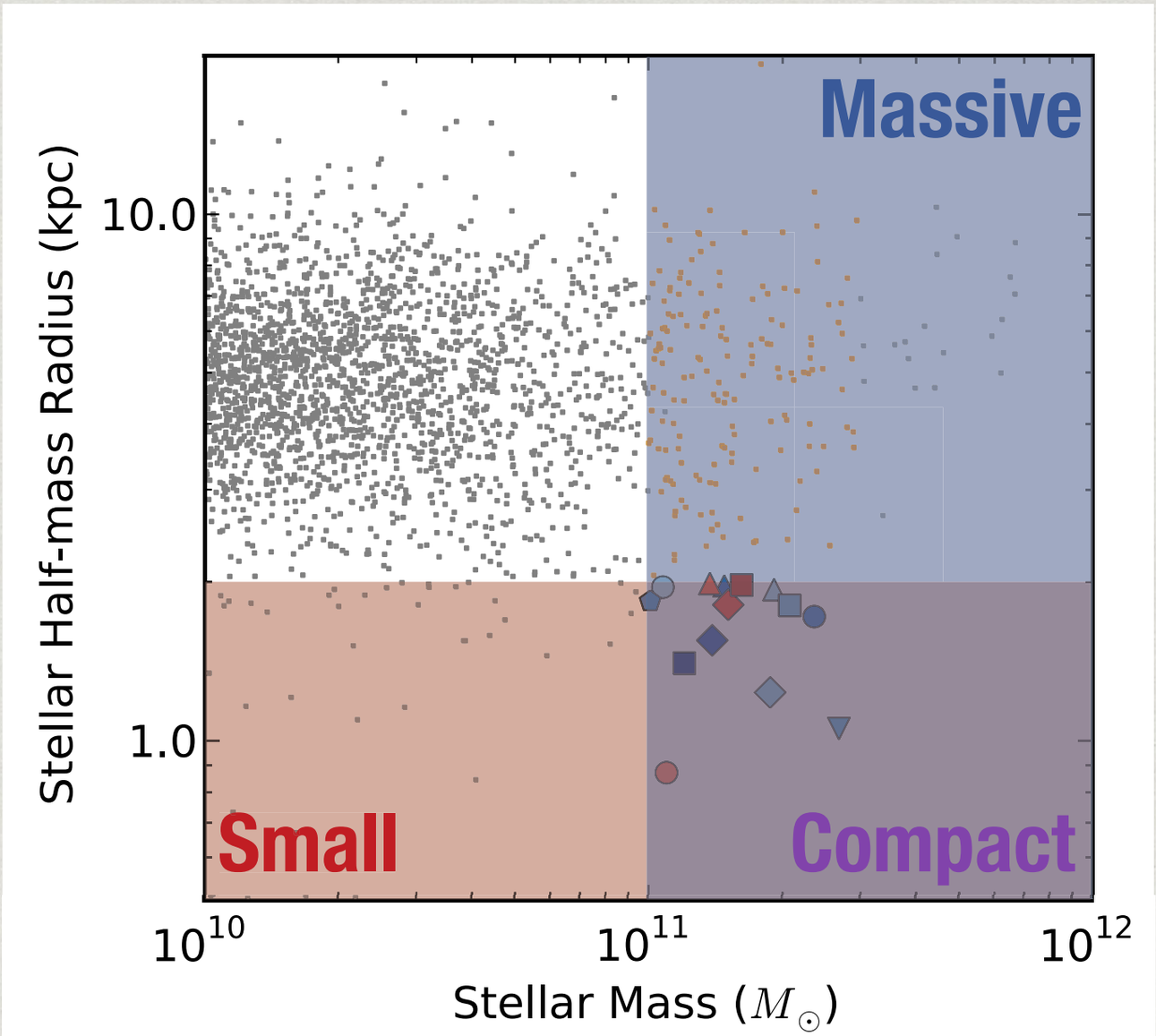


Number density evolution of compact systems

- Abundance of compact galaxies peaks at z = 1-2, then drops
- Number densities agree reasonably well with observations when same selection criteria is used



“Compact” selection criteria



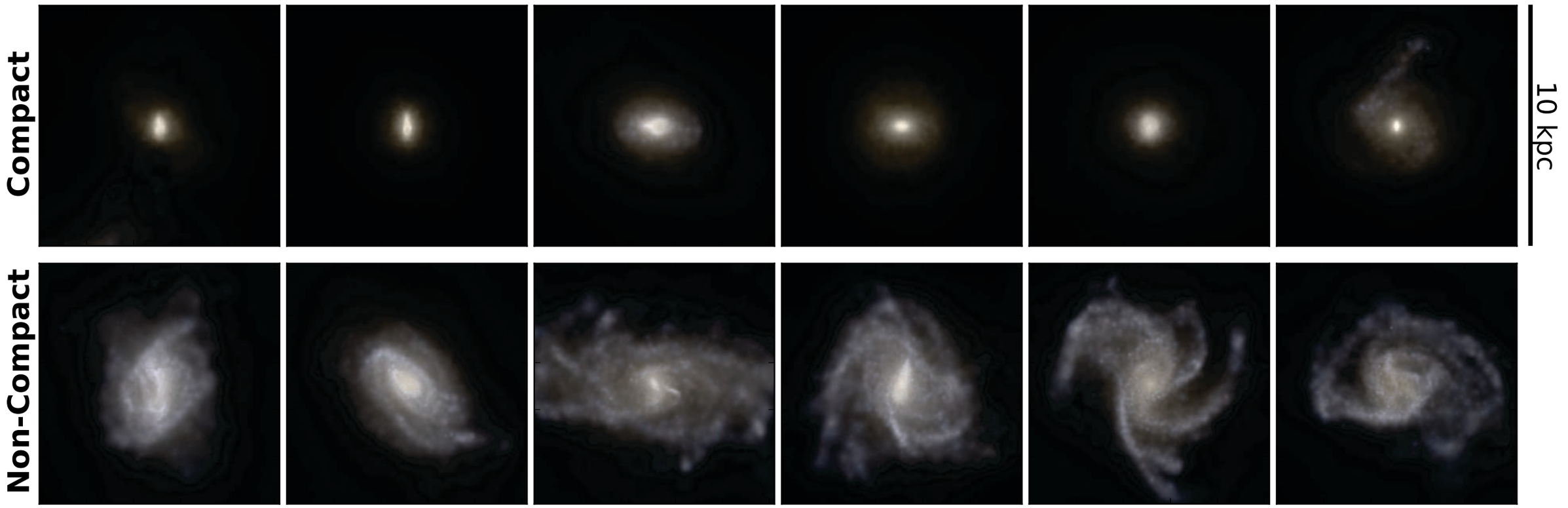
Select for galaxies with:

- stellar mass > 10^{11} $M_\odot$
- half-mass radius < 2 kpc

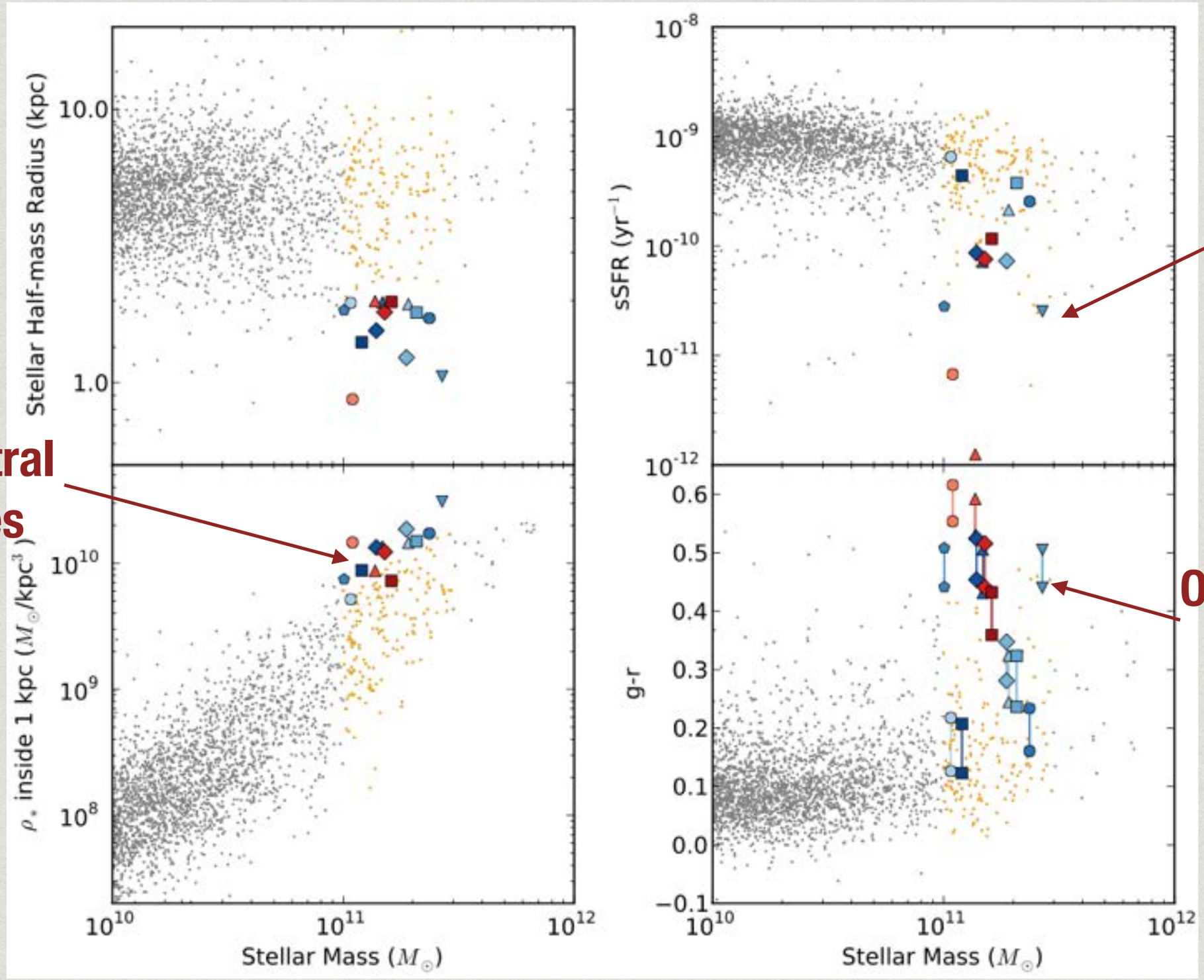
↓

14 massive, compact galaxies

Mock images



Properties of compact population



High central densities

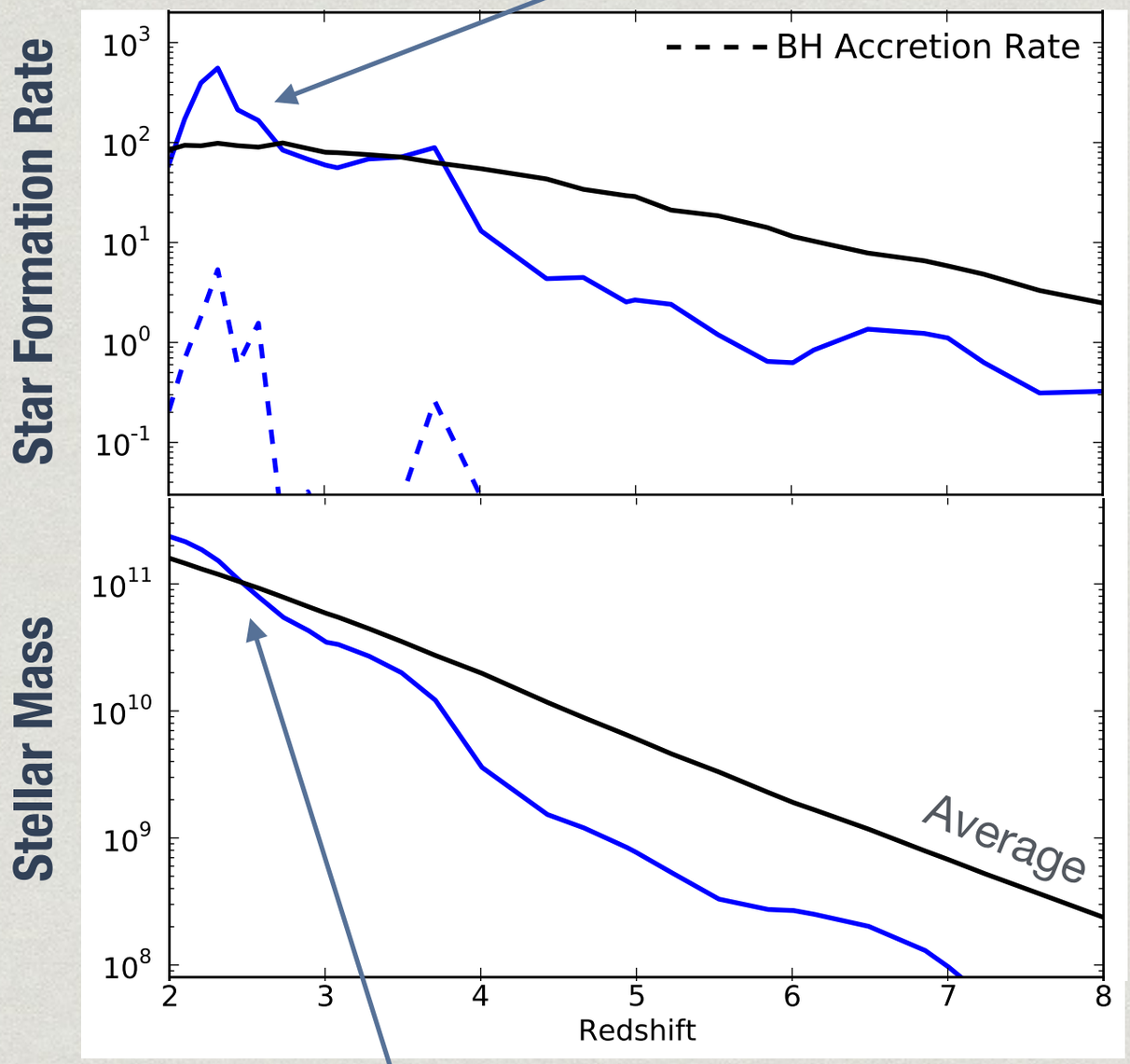
Star formation often quenched

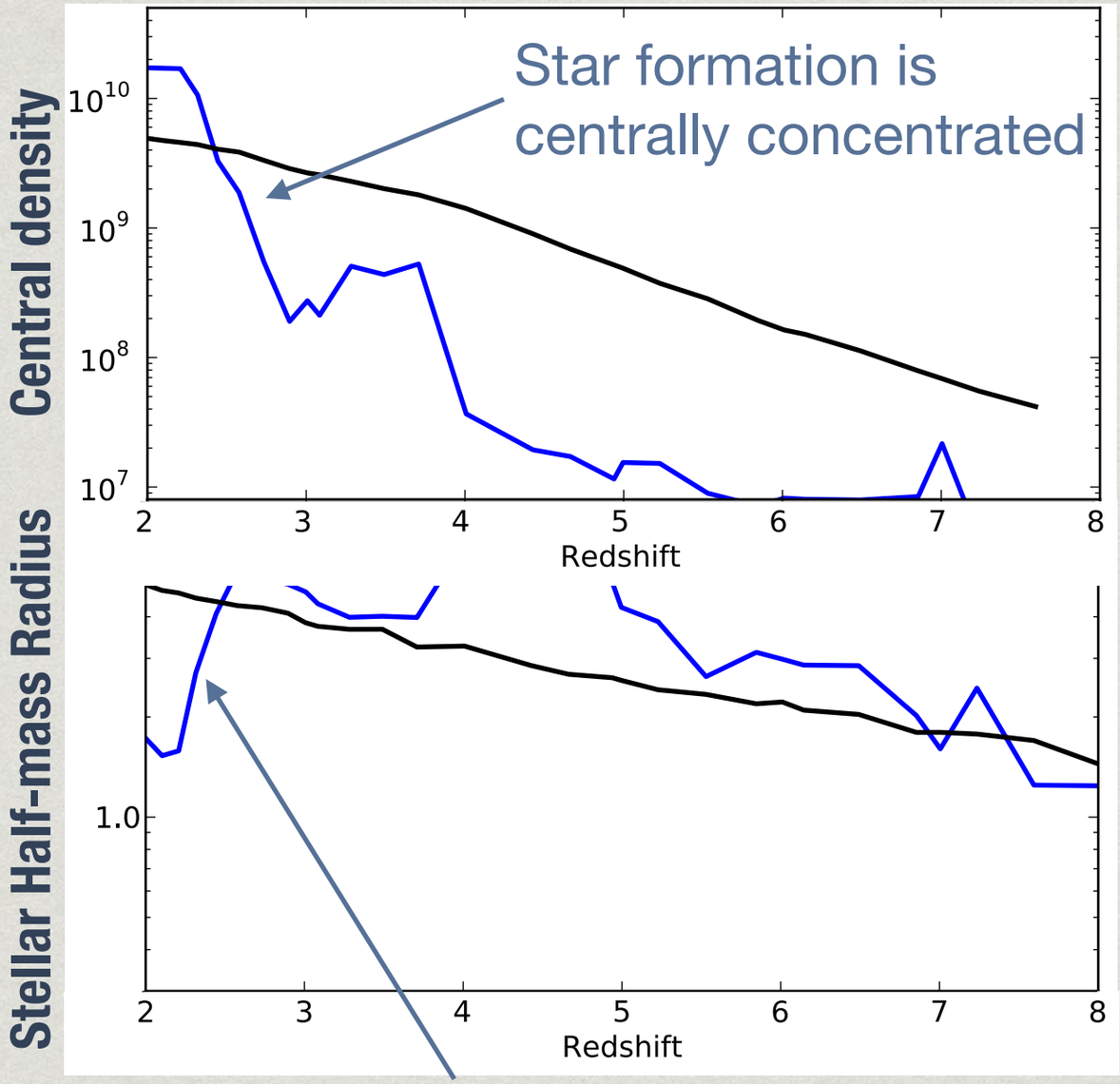
Often redder in color

Formation channels

Example #1:

Major merger is accompanied by burst of star formation





Stellar mass is assembled quickly at $z \sim 2.5$

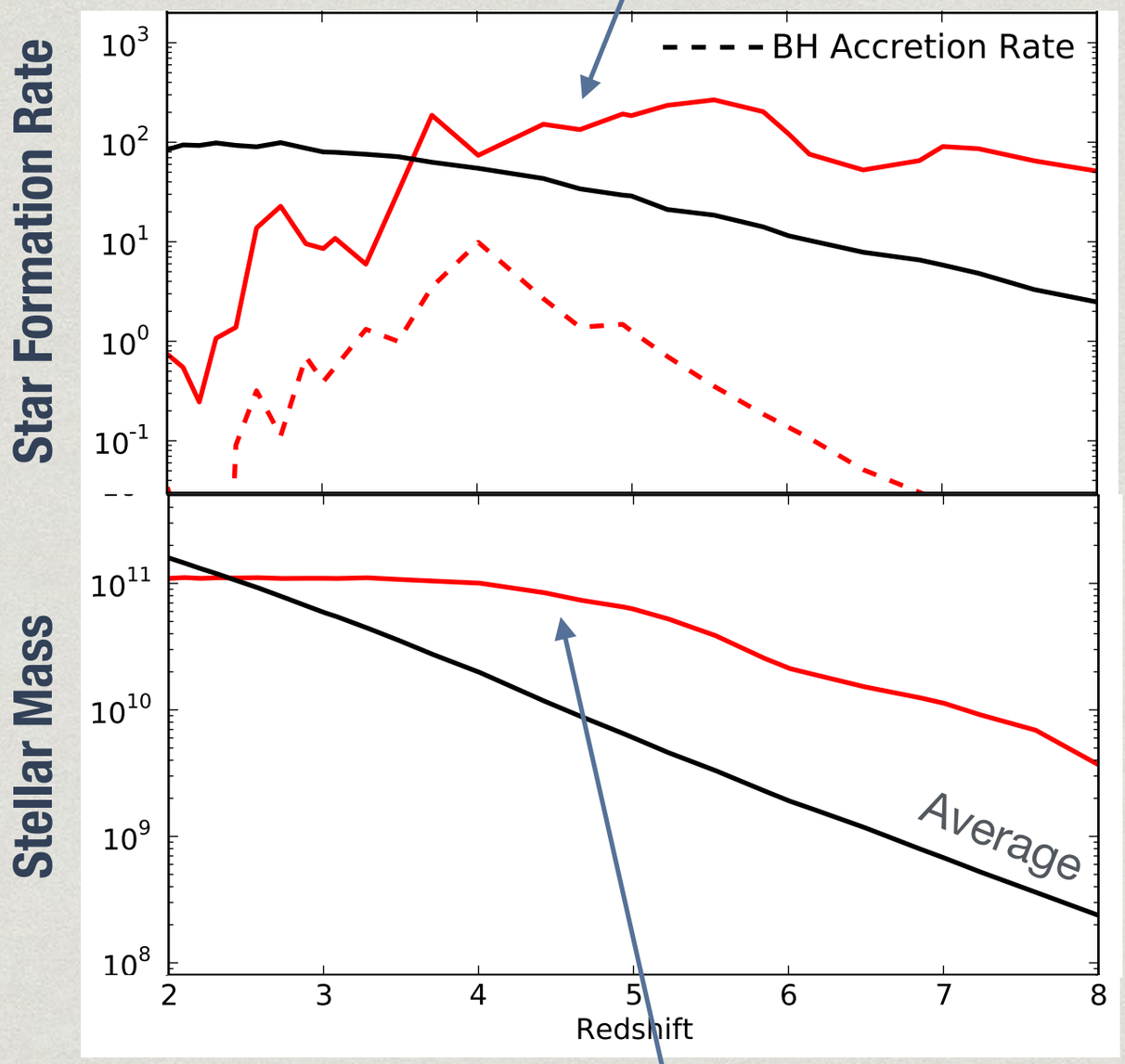
Increase in central density drives down half-mass radius

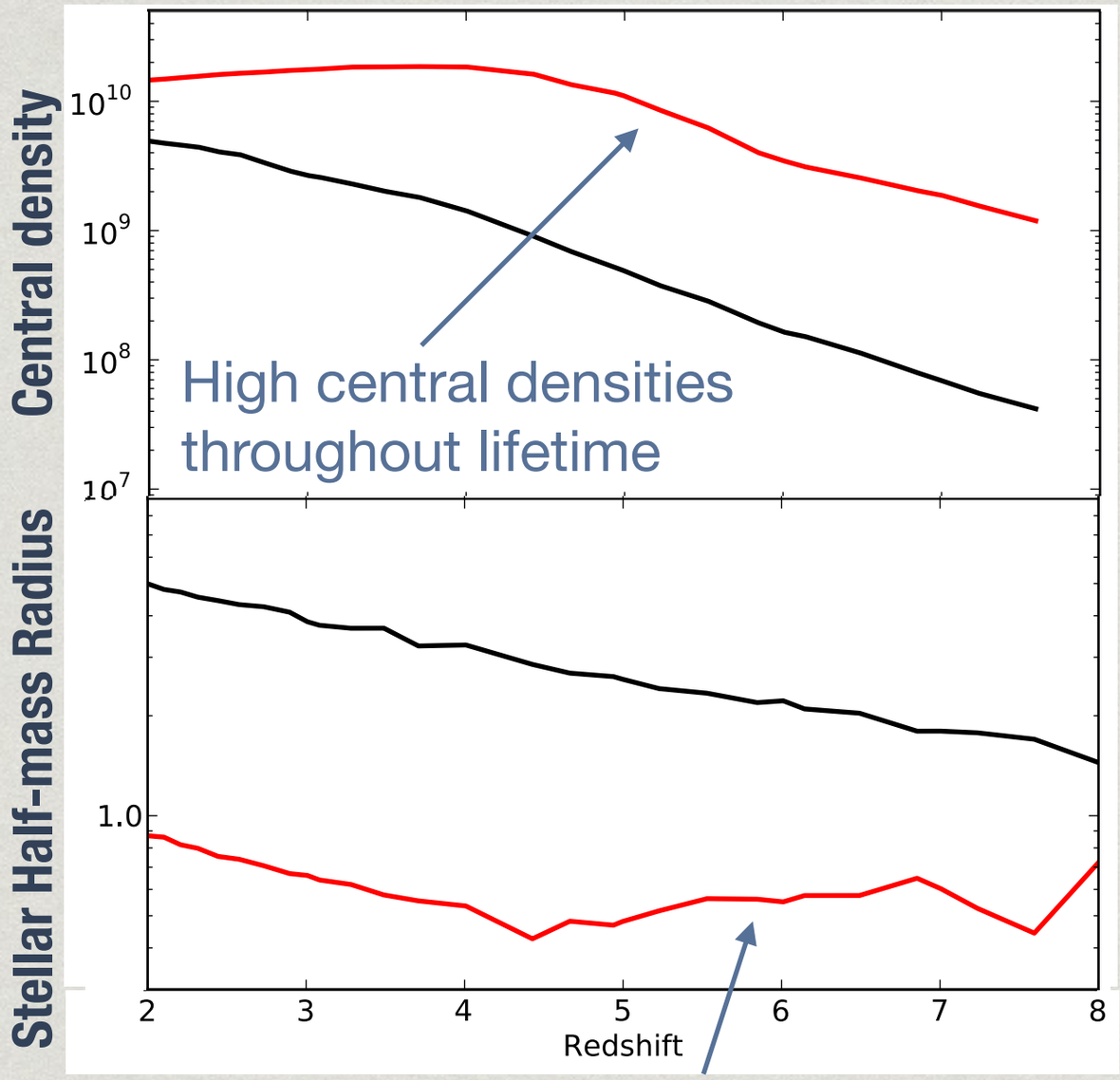
→ Major gas-rich merger drives intense central starburst

Formation channels

Example #2:

SFR an order of magnitude higher at early times, then quenches at z=4



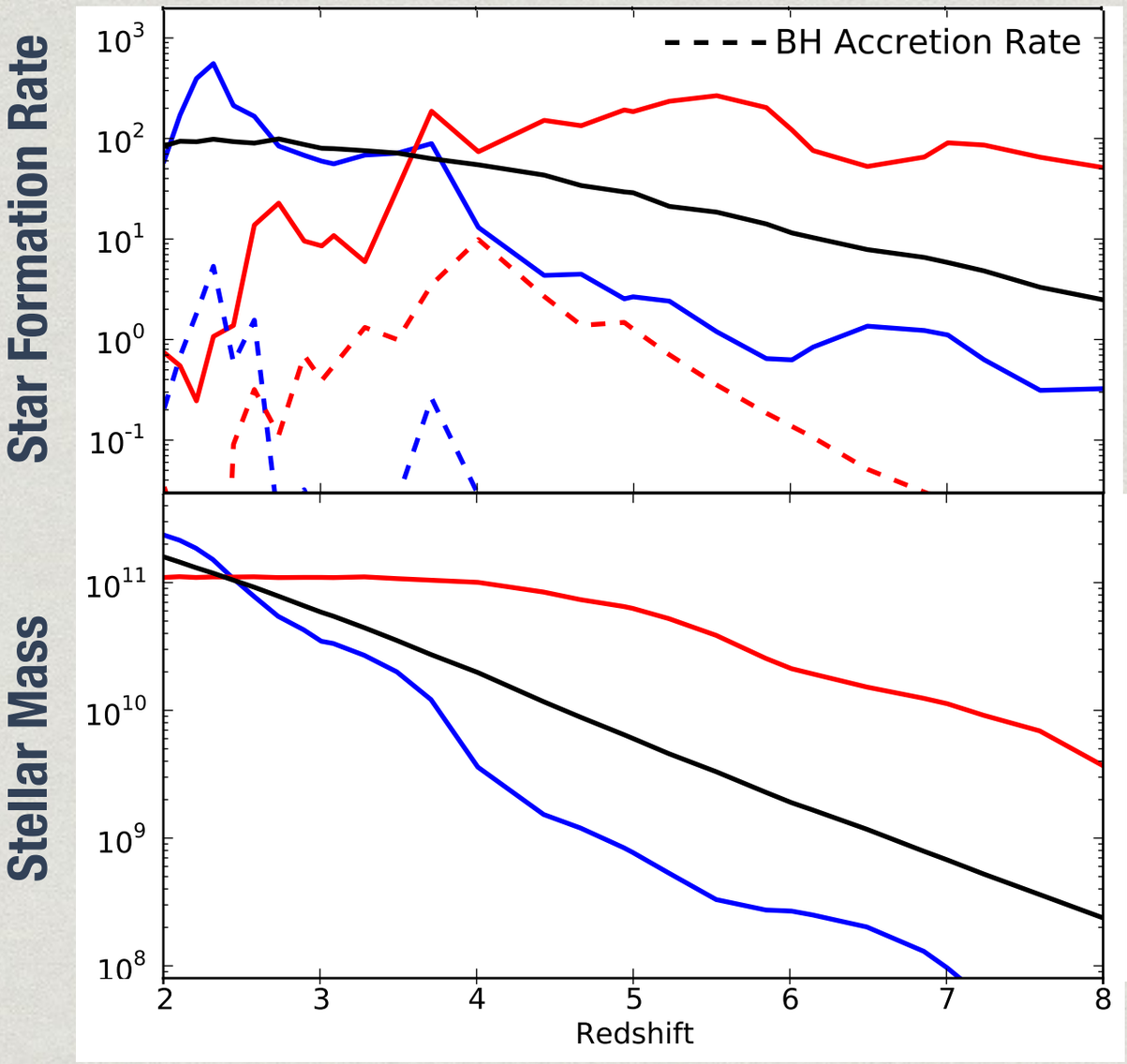


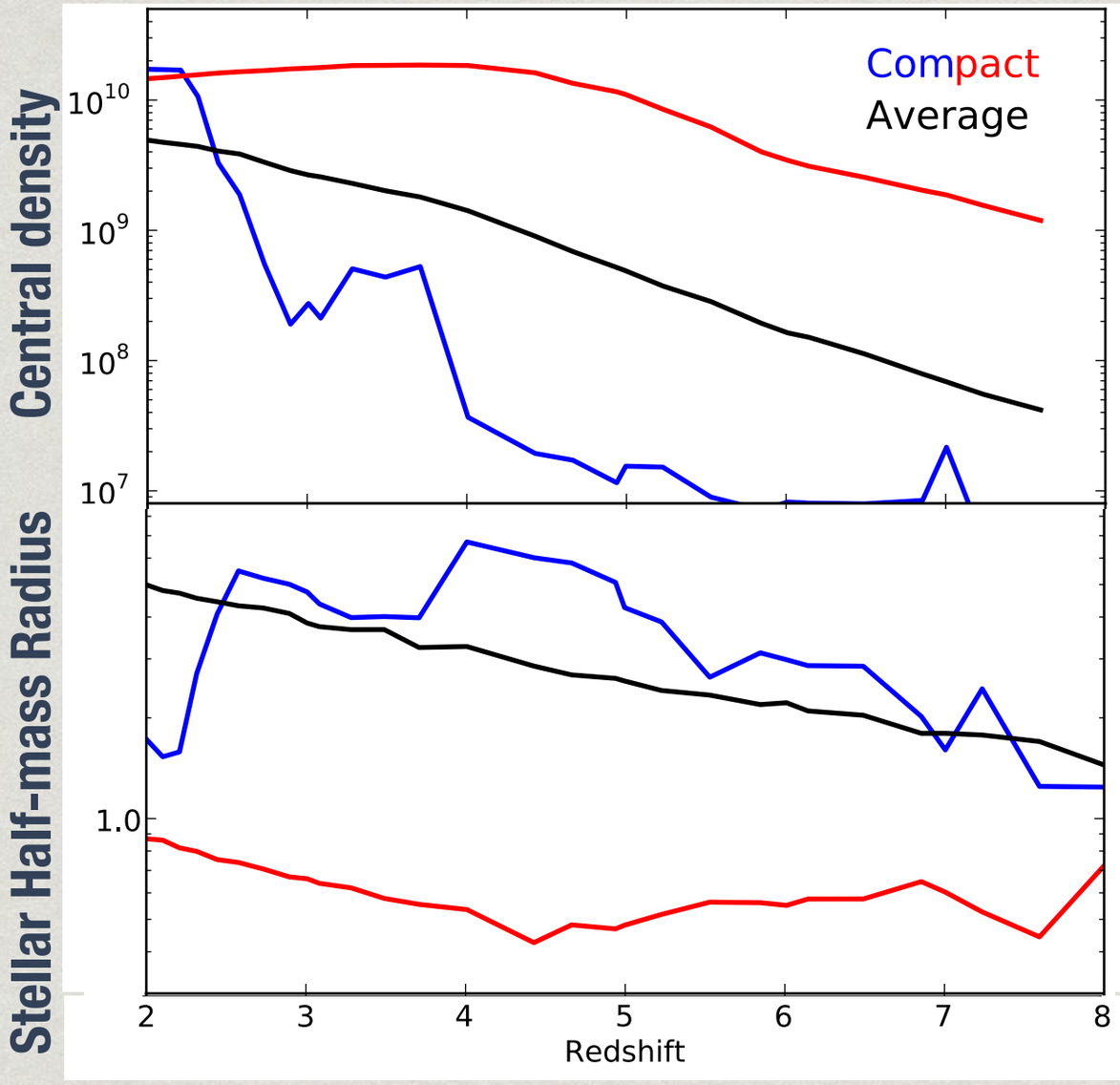
Stellar mass is assembled early and gradually

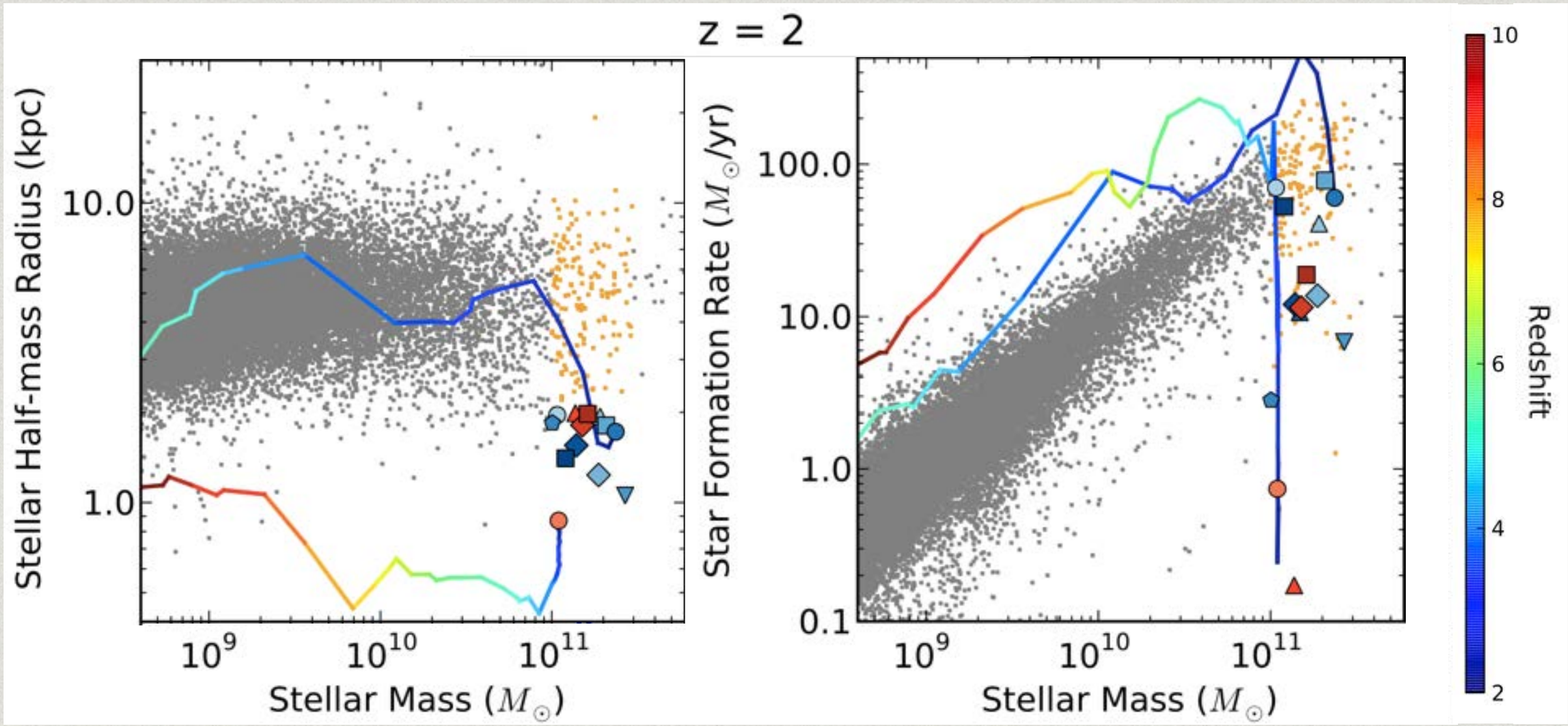
Early formation → small size

Forms with, and maintains, small size

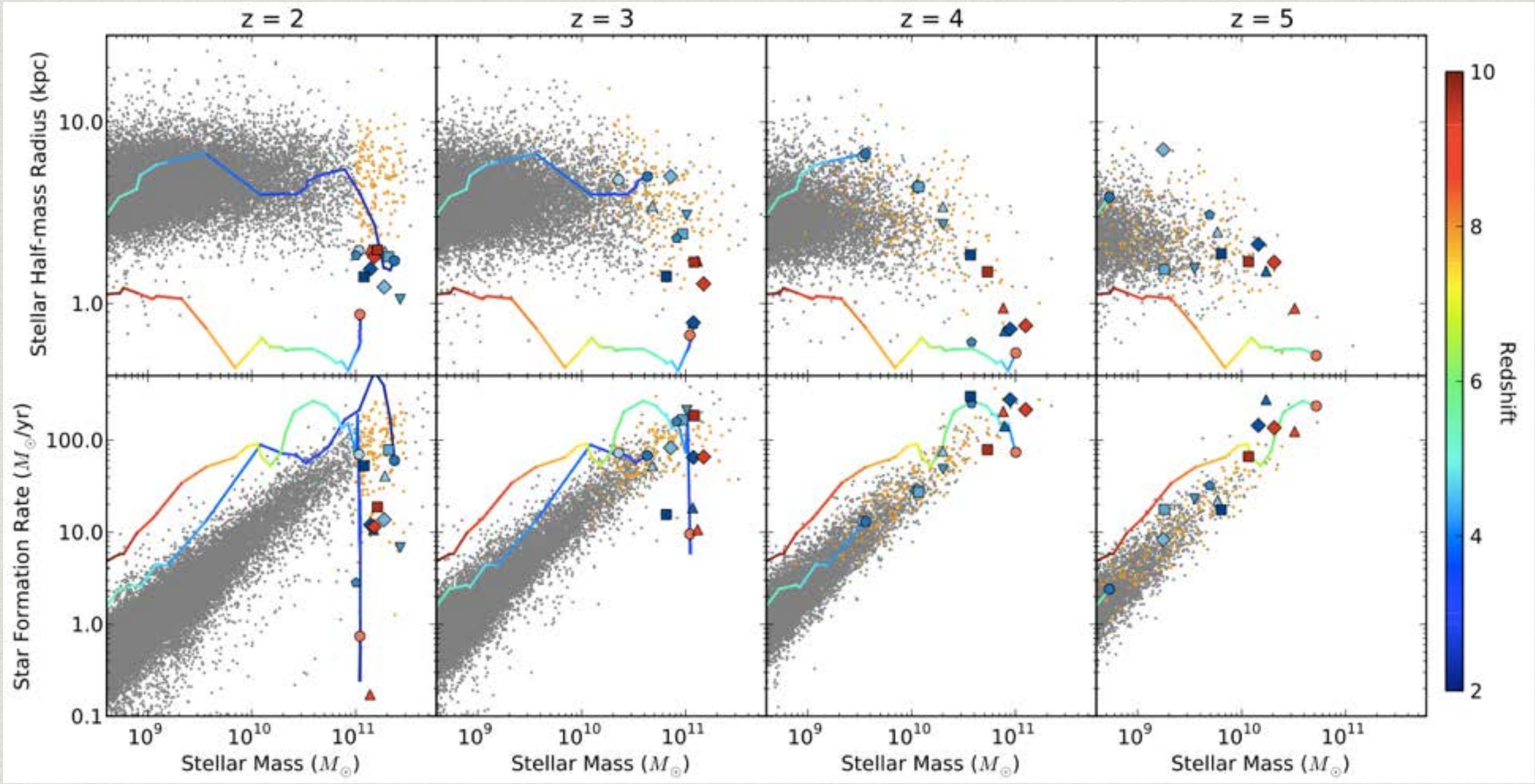
Two distinct formation mechanisms:
Central starbursts & Early assembly





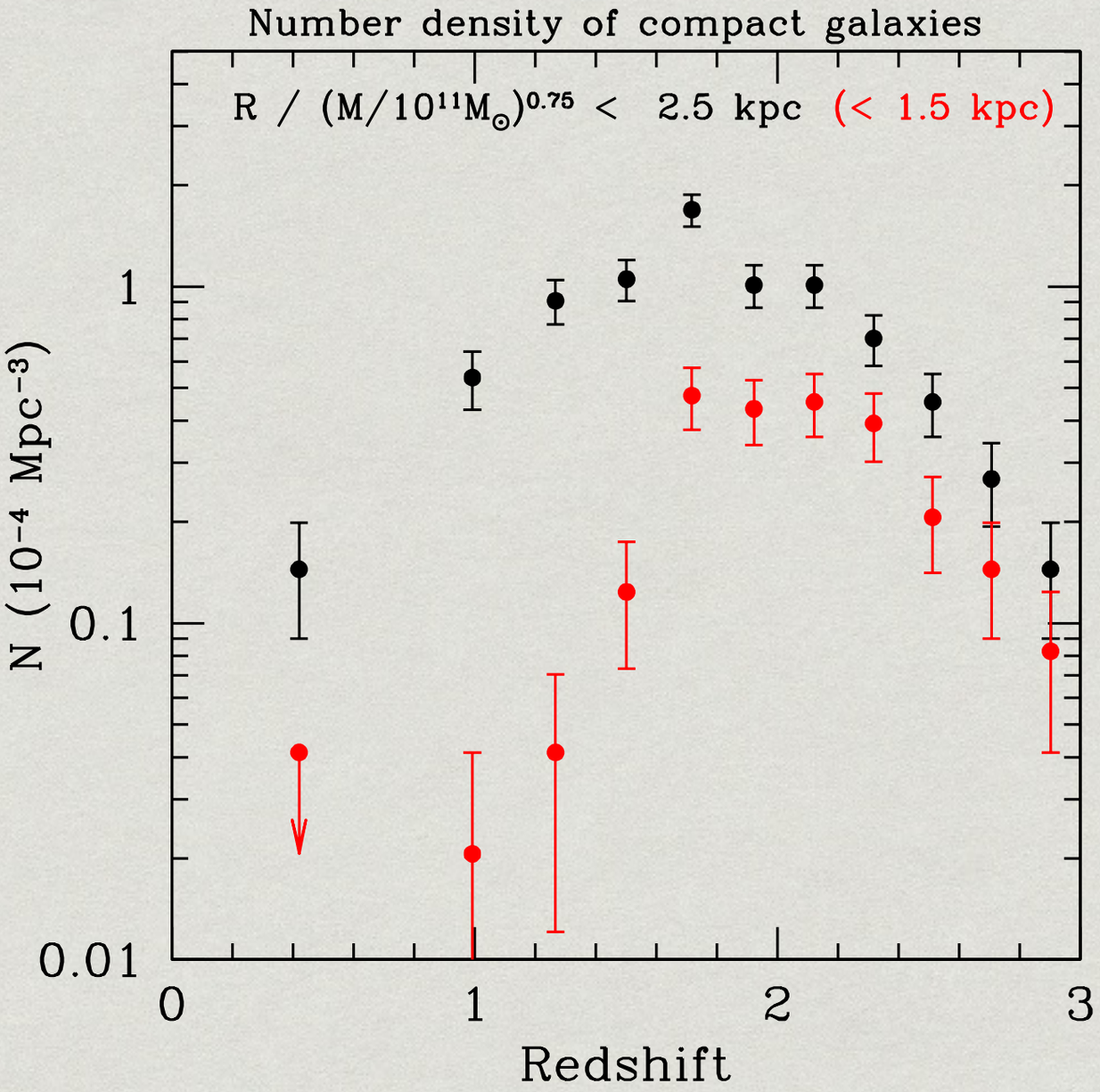

z = 2
Stellar Half-mass Radius (kpc)
10.0
1.0
10^9
10^{10}
10^{11}
Stellar Mass ($M_\odot$)
Star Formation Rate ($M_\odot$/yr)
100.0
10.0
1.0
0.1
10^9
10^{10}
10^{11}
Stellar Mass ($M_\odot$)
Redshift
10
8
6
4
2

All of the 14 compact galaxies form in ways that resemble these two paths



4 early formers, 10 central starbursts

Both of these mechanisms require high-*z* conditions



van der Wel et al. 2014, 3D-HST+CANDELS

Central starbursts:

Frequency depends on abundance of cold gas

Early formation:

Size of galaxy depends on scale factor

Number density will decrease at low redshift

Summary

- We search in the Illustris volume for massive, compact galaxies at z=2
- 14 galaxies have stellar mass > 10^{11} $M_\odot$ and half-mass radius < 2 kpc
- Each galaxy formed early, experienced a central starburst, or some combination thereof
- These formation mechanisms are most effective at high-z, leading to a decrease in number density thereafter