How Quickly Can Compact Galaxies Grow through Merging?

ANDREW NEWMAN, Caltech | RICHARD ELLIS, Caltech | KEVIN BUNDY, UCB | TOMMASO TREU, UCSB

Can mergers account for the size evolution of compact quiescent galaxies?

Many massive quiescent galaxies at high redshift have much smaller radii – a factor of ~5 at z~2 – than comparable galaxies today [1]. Early compact galaxies may naturally form as a consequence of greater gas content and thus more dissipative mergers [2]. But the absence of comparable galaxies at low redshift [3] implies that these compact "nuggets" must grow in size substantially.

Secular processes, such as adiabatic expansion by AGN or stellar winds, appear unlikely to explain the dramatic growth, leaving mergers as the most viable explanation. Similar-mass ("major") mergers alone are insufficient, being both too stochastic and inefficient as a means of expansion [4]. Minor mergers are thought to provide a more efficient route and may play a key role.

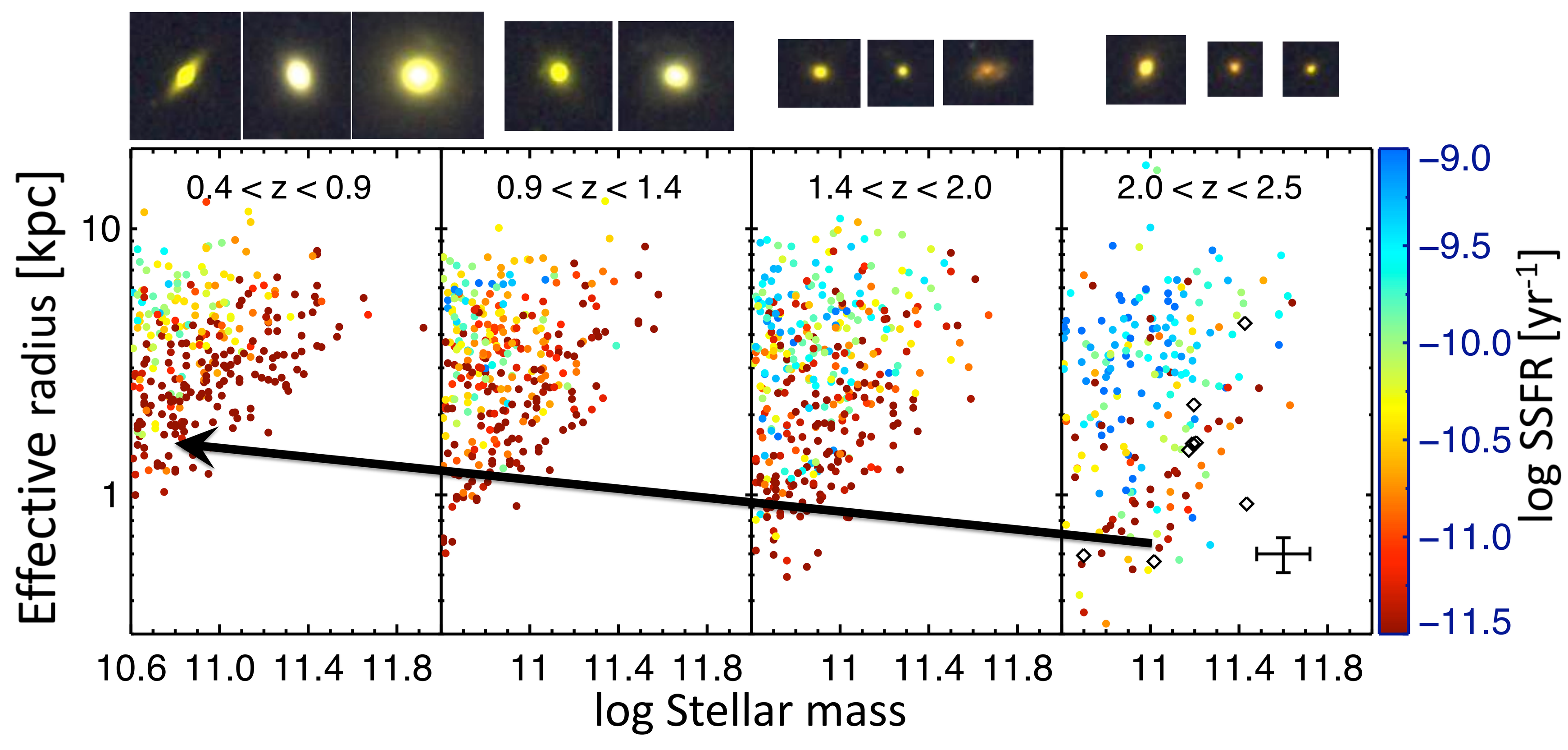
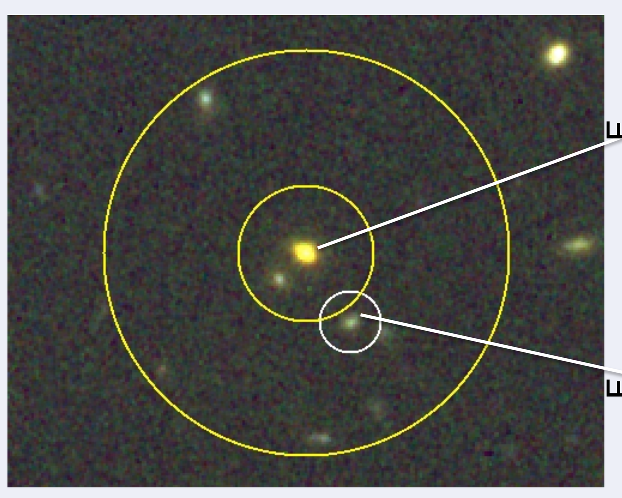
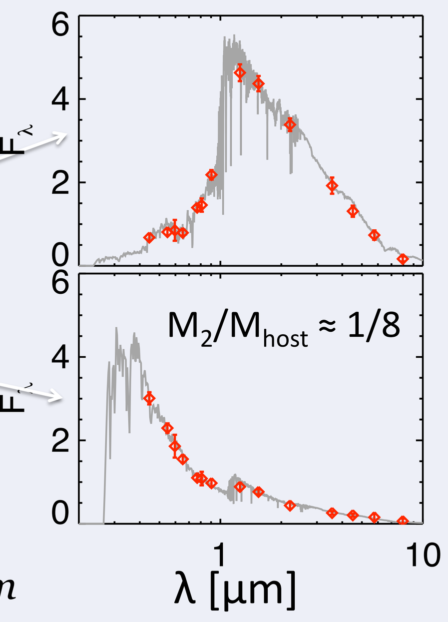


Fig. 1: *Size growth of massive galaxies from z=0.4-2.5. At each epoch, quiescent galaxies (red) are the most compact, and the size of the smallest galaxies found at a given mass increases with time. Radii are measured along the major axis in WFC3/F160W.*

Searching for Satellites

Redshift and mass estimates from ground- and space-based 0.4-8 μm photometry

- Using WFC3/IR imaging in the UDS and GOODS-S CANDELS fields, we searched for close neighbors to massive (>$10^{10.6}$ $M_\odot$) quiescent galaxy hosts at $1 < z < 2$ within $10 < R < 30$ kpc/h annuli and the same redshift interval.
- After subtracting chance alignments, (21±4)% of the host sample is associated with a nearby galaxy of mass ratio >1:10. *The mean stellar mass in satellites as a fraction of the host is 0.070 ± 0.013.*

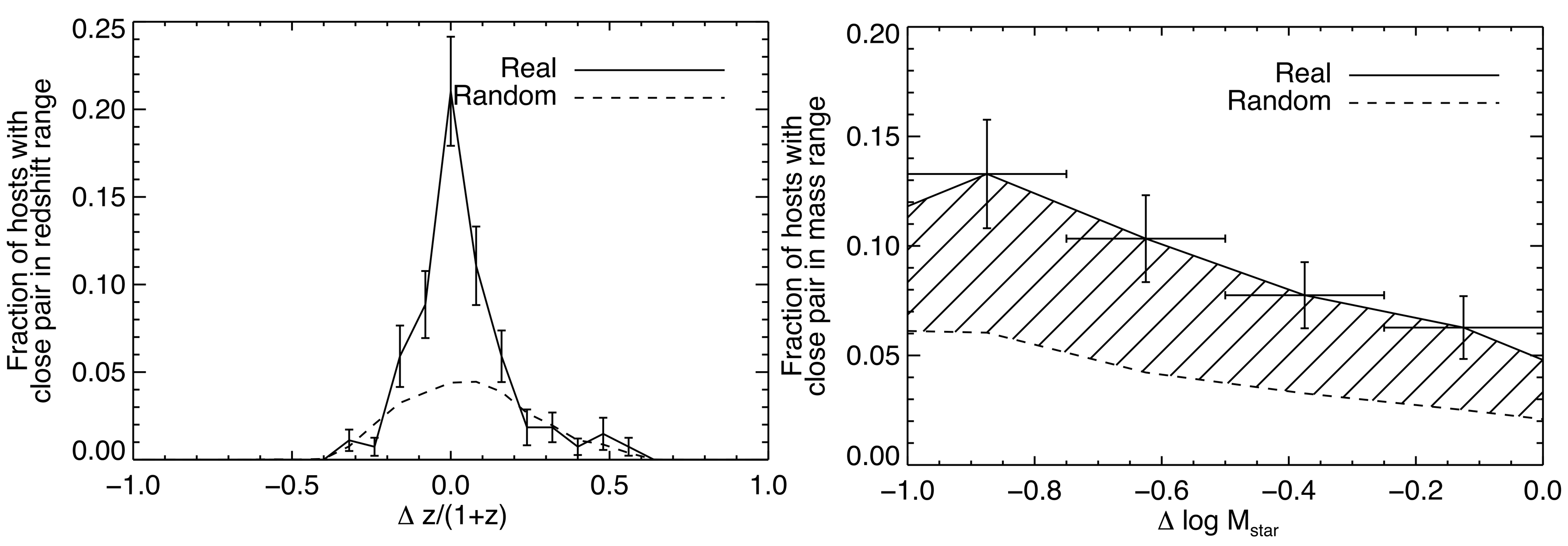


Fig. 2: *Fraction of massive, quiescent host galaxies with a close neighbor within a given redshift (left) or stellar mass (right) range relative to the host, as compared to random apertures (dashed). "Close pairs" are required to have a stellar mass ratio $0.1 < M_2/M_{host} < 1$. There is a clear excess of galaxies proximate to the host sample; many of these will soon merge with their host.*

Size Evolution from Mergers

- To convert the mass in satellites to a merger rate, a timescale is required. Below we assume τ=800 Myr based on simulations in Lotz et al [5]. With this timescale the mass growth rate from mergers nearly reproduces the evolution of the mass function [6].
- The typical size growth per merger is estimated as Δlog R/Δlog M ≈ 1.5, based on simulations in [7].
- We can then evolve the $2 < z < 2.5$ quiescent galaxies forward and check that they move to occupied regions of the mass-size plane at a sufficient rate. *Mergers may account for the size growth of most compact galaxies, if their descendants are also among the most compact at each redshift*:

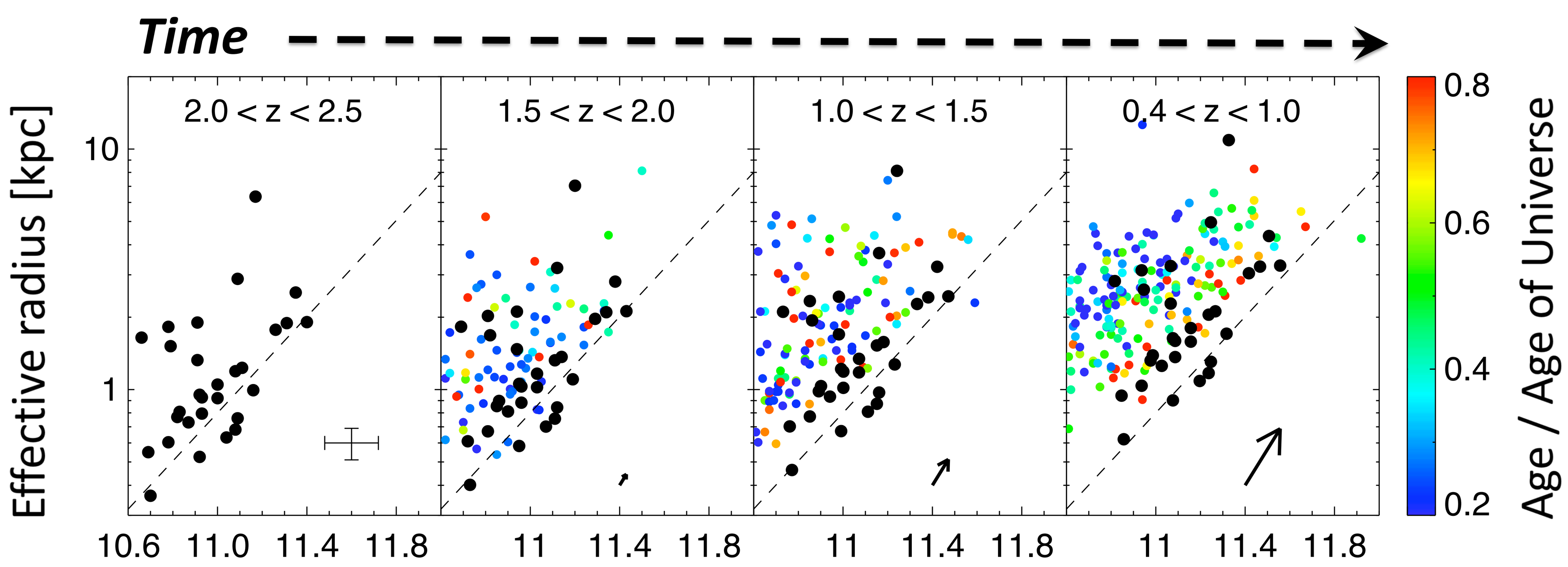


Fig. 3: *Modeled size evolution of massive, quiescent galaxies. Black points in each bin show the $2 < z < 2.5$ population evolved according to the mean merger rate; arrows in each panel indicate the magnitude and direction of the shift.*

- *Key uncertainty is the merger timescale*: if instead τ=2.8 Gyr, as in Kitzbichler & White [8], then >1:10 mergers are much rarer and have little role in the observed size evolution.

Conclusions

Mergers may explain most of the size evolution of compact, quiescent galaxies, but *only if* the merger timescale is at the short end of published estimates (<~ 1 Gyr) *and* the most compact galaxies remain the most compact galaxies at each epoch.

If the latter is true, a correlation between size and age at fixed mass is expected, with the oldest galaxies being the smallest. This is indeed seen at z~0 [9] and is also visible in the present sample to z~1 (right).

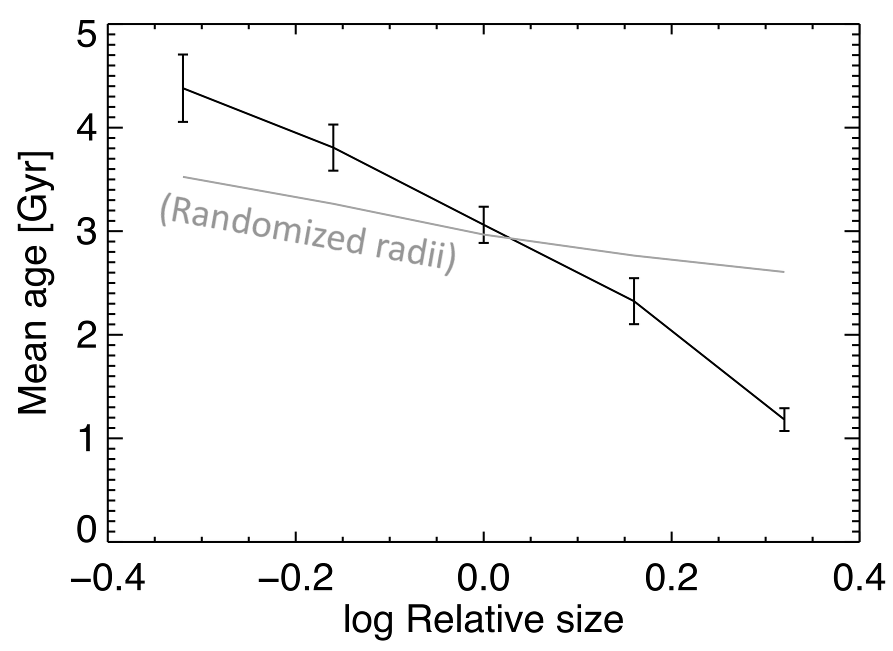


Fig. 4: *Stellar age of massive, quiescent galaxies at 0.4<z<1 versus residual size after dividing out mean trends with stellar mass, redshift, and SFR. The most compact galaxies are the oldest.*

References

[1] van Dokkum et al 2008, ApJ 667, L5
[2] Khochfar & Silk 2006, ApJ 648, L21
[3] Taylor et al 2010, ApJ 720, 723
[4] Bezanson et al 2009, ApJ 697, 1290
[5] Lotz et al 2010, MNRAS 404, 575
[6] van Dokkum et al 2010, ApJ 709 1018
[7] Oser et al 2011, arXiv:1106.5490
[8] Kitzbichler & White 2008 MNRAS 391, 1489
[9] van der Wel et al 2009, ApJ 698, 1232