Mass-density and quenching: a cautionary story of cause and effect and the importance of progenitor effects

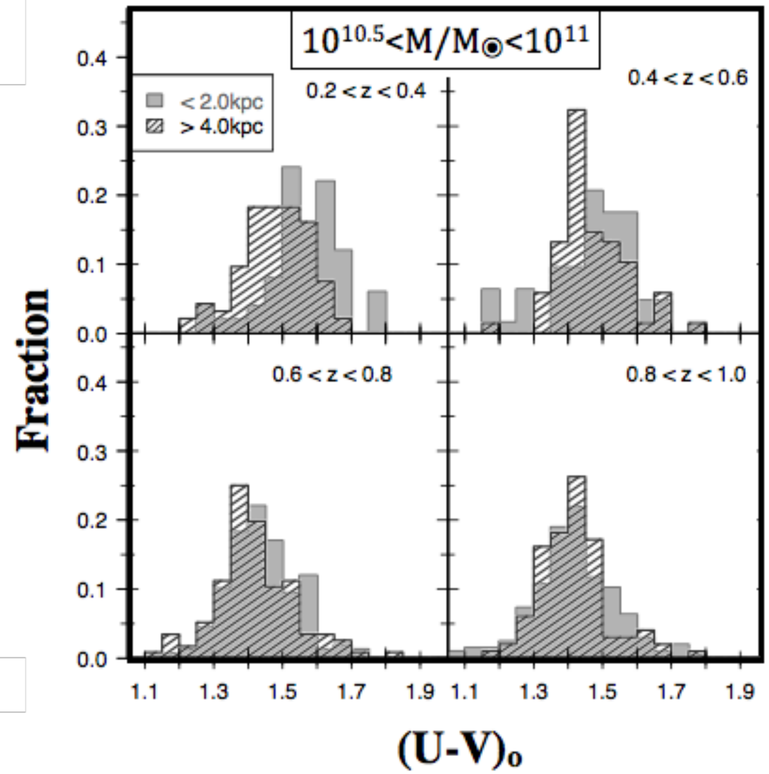
(Mostly)
On Behalf of Simon Lilly

Lilly & Carollo 2015, soon on astroph

Stellar Population Ages of Compact & Large M* Q-ETGs

➡ The average size of quenched galaxies scales as (1+z)-1,
i.e., same scaling of virial radius of DM halos (of a given mass).

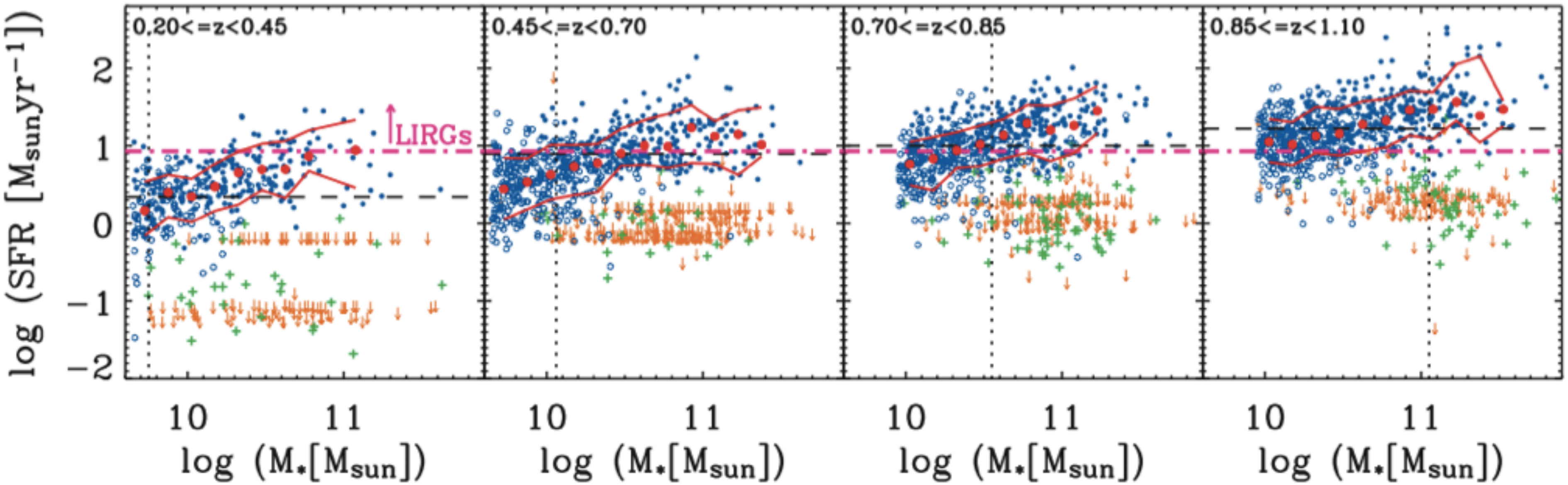
Carollo+2013, ApJ 773, 112



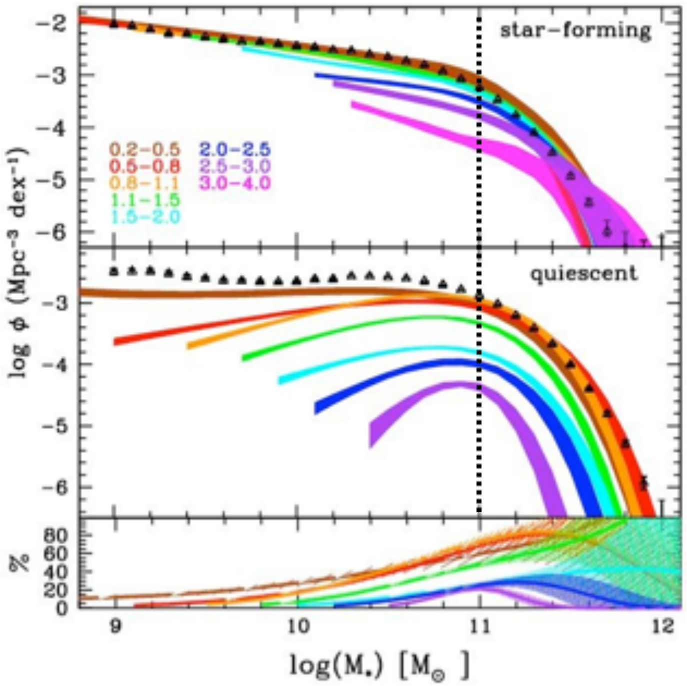
- Compact Q-ETGs become systematically redder towards later epochs
- U–V color difference consistent with a passive evolution of their stellar populations
- ➢ Stable population that does not appreciably evolve in size

- Larger Q-ETGs have average rest-frame U-V colors bluer than compact Q-ETGs
- ➢ At any z<1, larger Q-ETGs younger than compact Q-ETGs

The Star-Forming Main Sequence and the Quenched Populations

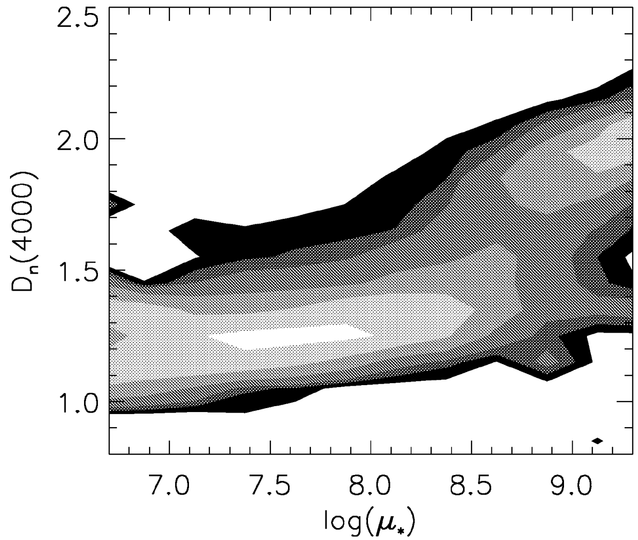


Remarkable constancy of M*



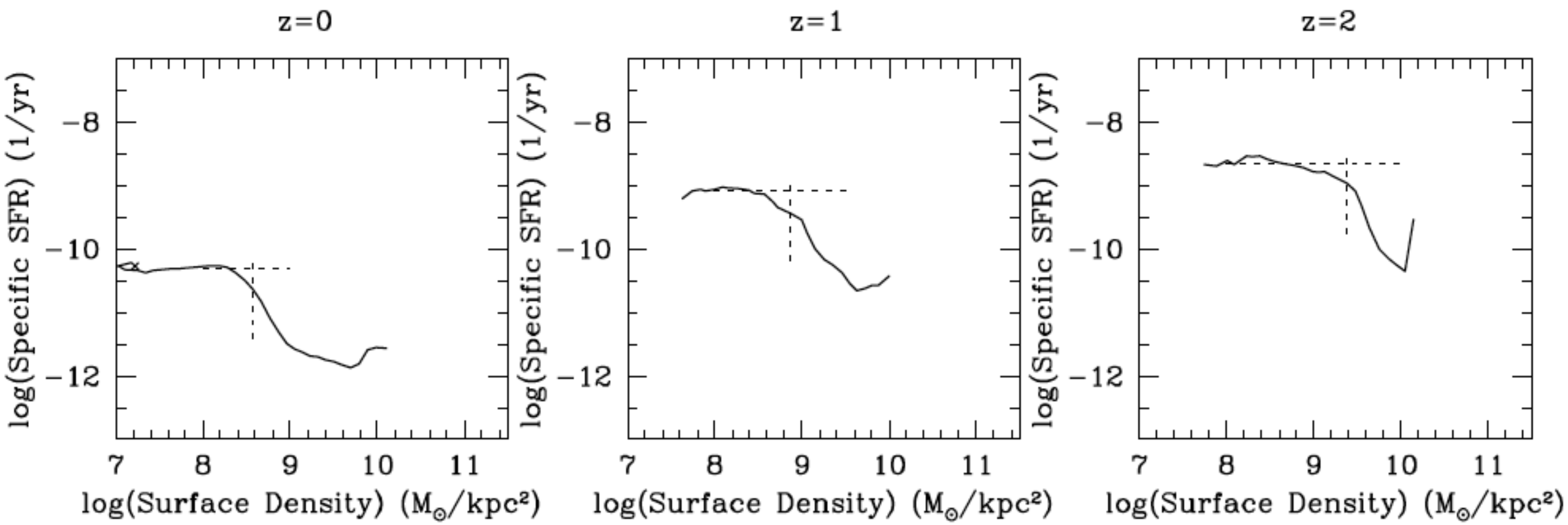
Apparent importance of stellar density in quenching

Kauffmann et al 2003



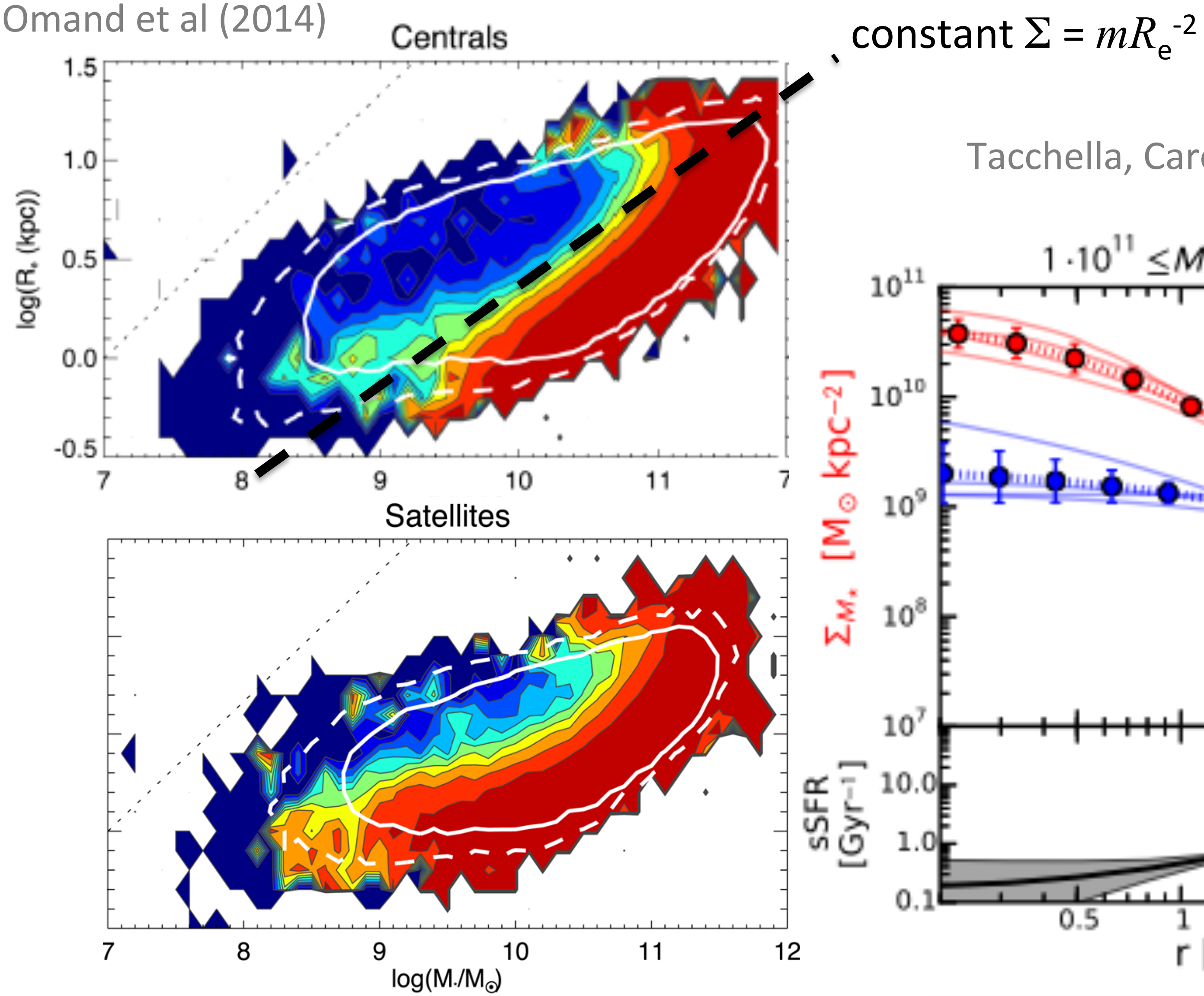
There is a characteristic surface mass density in SDSS, above which galaxies are quenched and below which they are not

Franx et al 2008

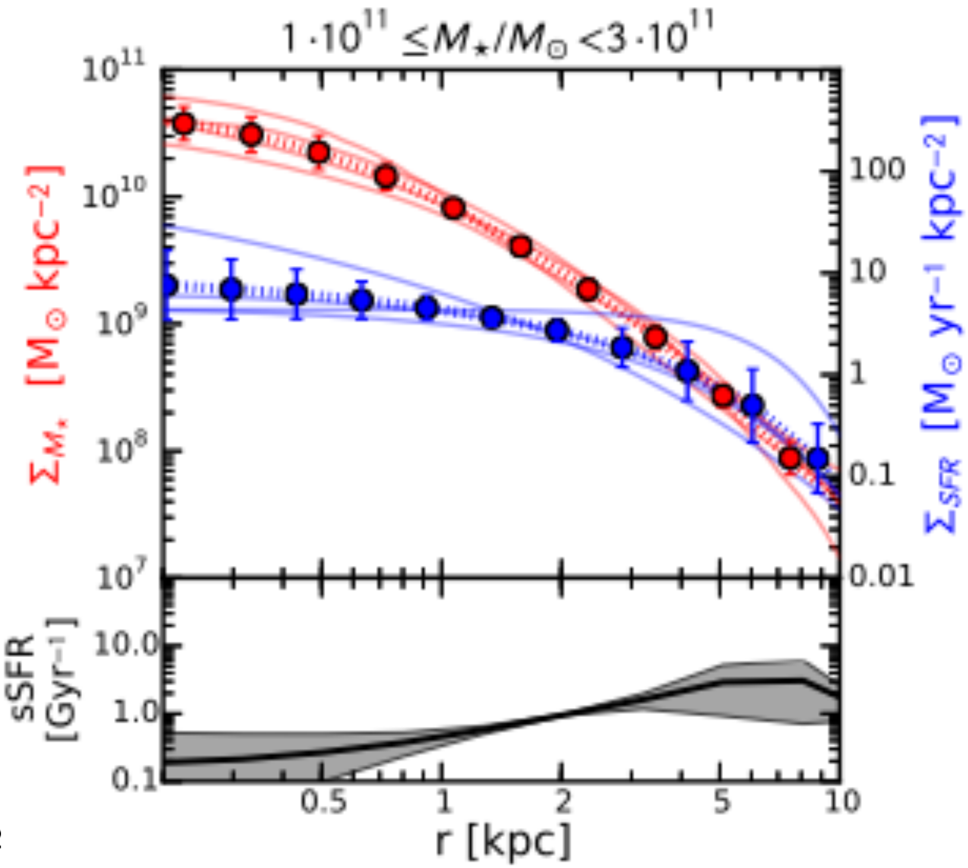


Apparent importance of stellar density in quenching

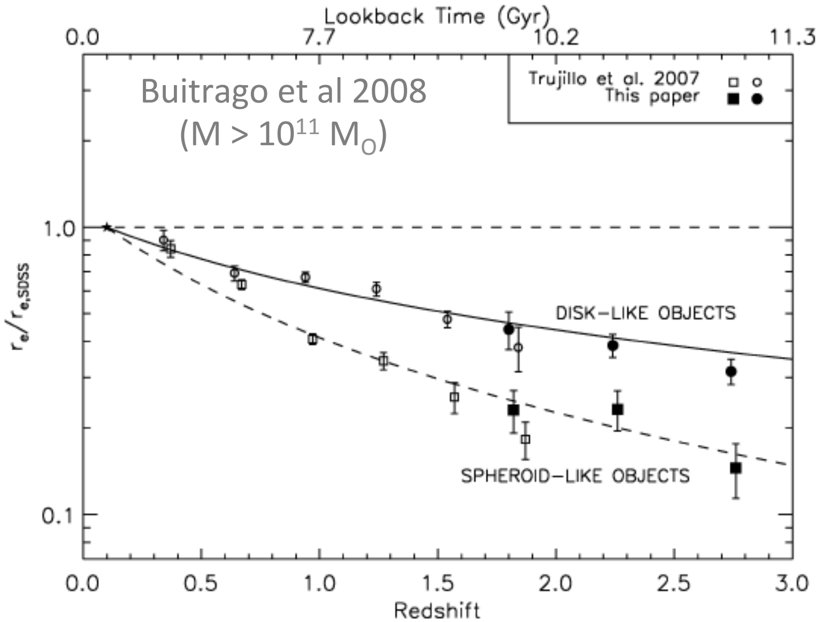
Omand et al (2014)

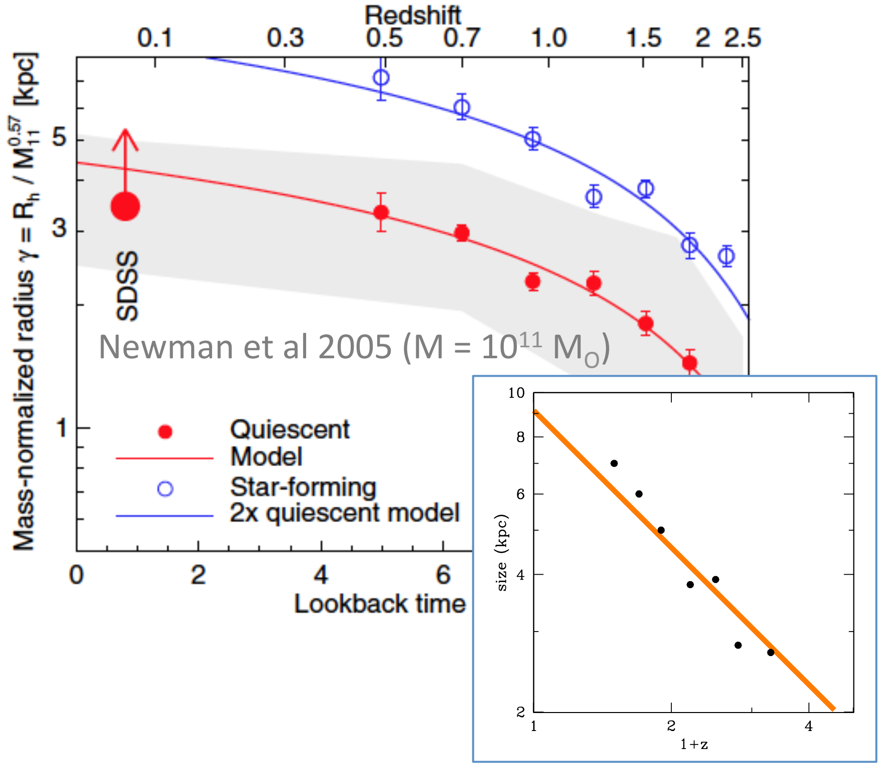


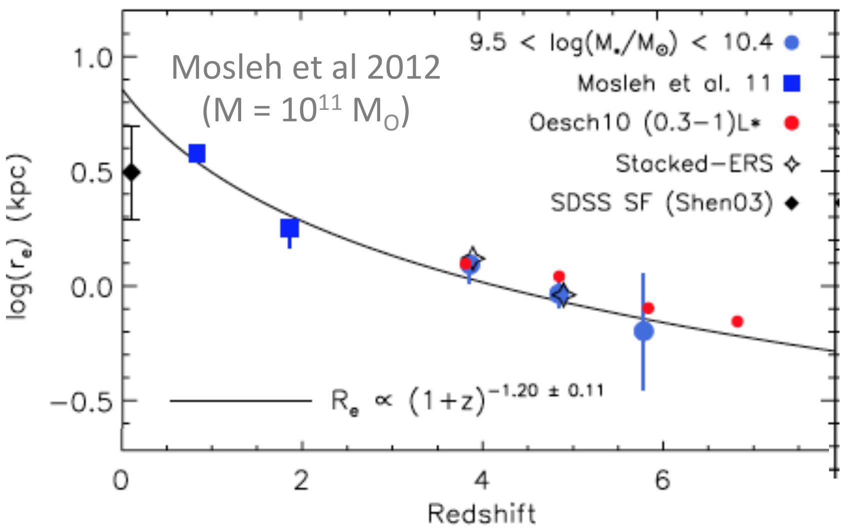
Tacchella, Carollo et al (2014)



Sizes of star-forming "disks" at a given mass scale roughly as $(1+z)^{-1}$







At a given stellar mass, the size of star-forming galaxies scales roughly as $(1+z)^{-1}$

By definition, the scaling of the virial radius of DM haloes at a given mass

A Simple Toy Model to explore this effect

Addition of new stars

Galaxies form stars at a rate given by their existing mass and the Main Sequence sSFR(m,z):

$$sSFR_{MS} = 0.07\left(\frac{m}{3\times10^{10}}\right)(1+z)^2\ \ \mathrm{Gyr}^{-1}$$

New mass is added to galaxy in an exponential disk with scale length given by:

$$h_{SF} = 5\left(\frac{m}{3\times10^{10}}\right)^{1/3}(1+z)^{-1}\ \mathrm{kpc}$$

Both $sSFR_{MS}$ and h_{MS} have a small gaussian scatter added to produce some dispersion in the population

Quenching

Galaxies then quench probabilistically according to the Peng et al (2010) prescription which may be written as

$$Pdm = \frac{dm}{M*}$$

Satellites have an additional probability of quenching given by

$$P_{sat}dm = \varepsilon_{sat}\frac{dm}{m}(1+z)^{-1}$$

Note: Nothing to do with surface mass density!

Recovery of size evolution

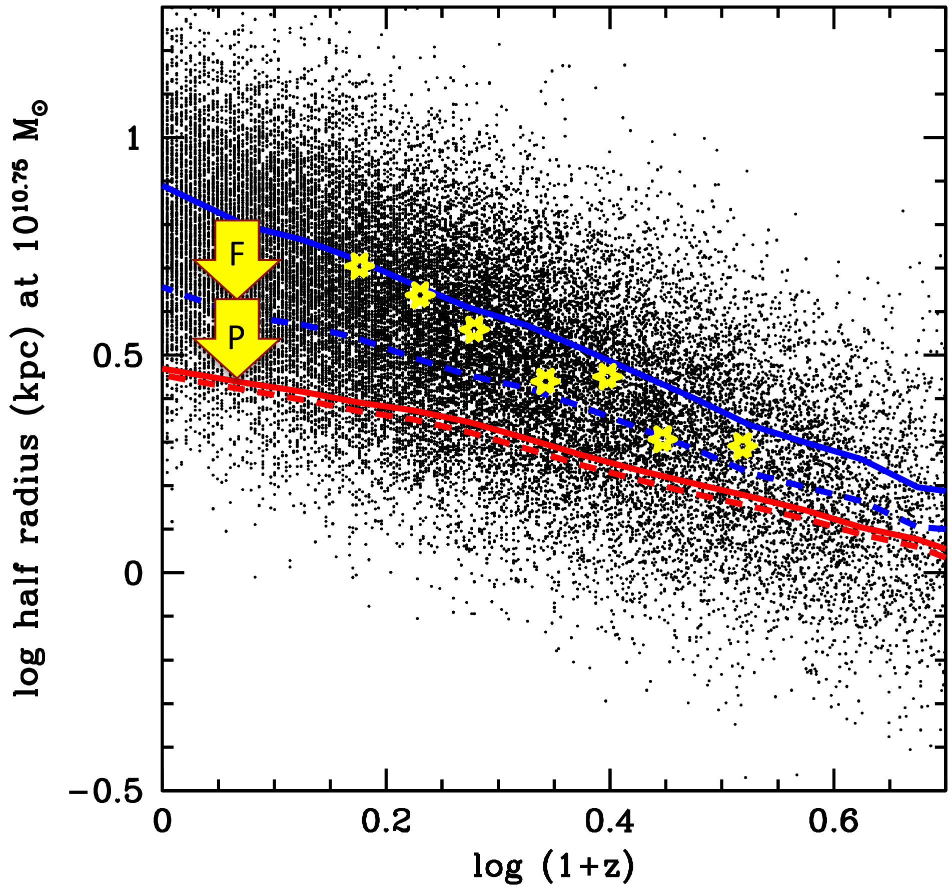
Size of star-forming in light: $(1+z)^{-1}$
Size of star-forming in mass: $(1+z)^{-0.85}$
Size of cumulative passive population (i.e. from "progenitor bias" alone) $(1+z)^{-0.6}$

Passive galaxies are typically factor of two smaller than star-forming ones.

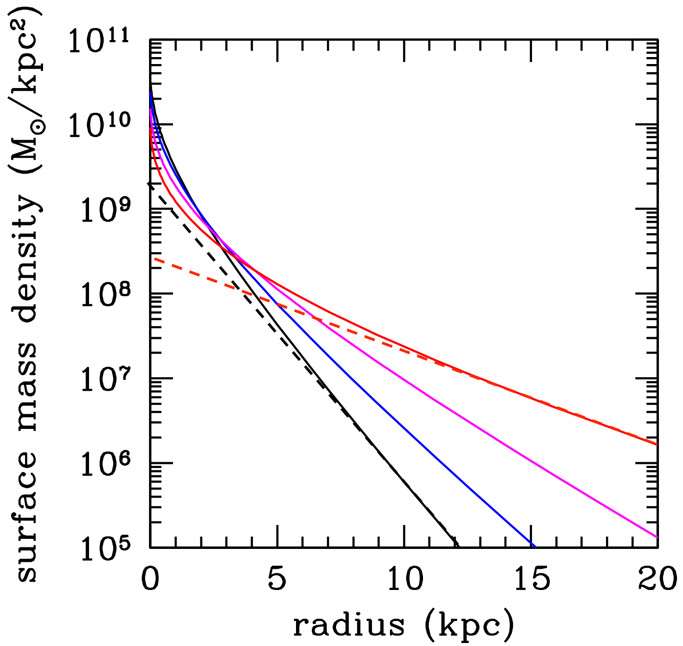
Due to both fading of disks (F) and "progenitor bias" (P)

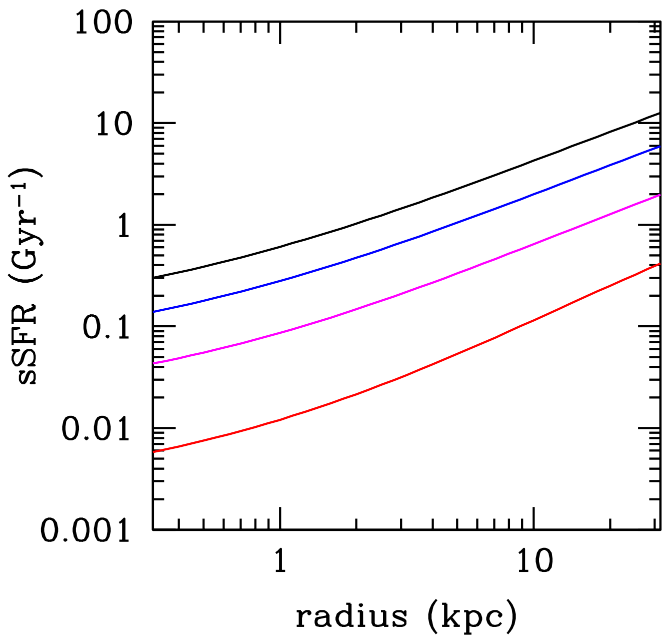
Progenitor Bias (P):
Valentinuzzi et al (2010),
Carollo et al (2013),
Poggianti et al (2013),
+++

Carollo et al (2014), astroph 1402.1172 for Disk Fading (F)



Surface mass profiles and apparent "inside-out" quenching





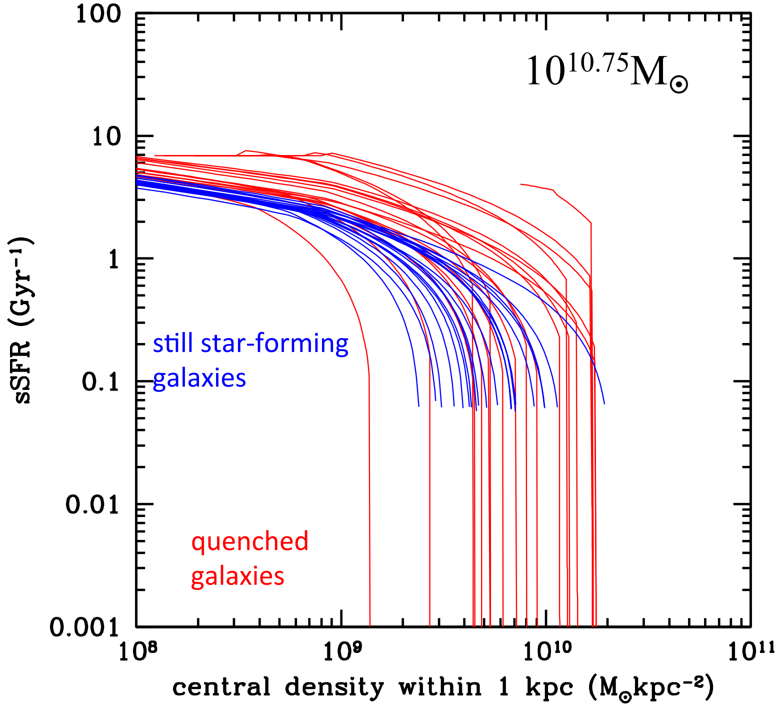
Galaxies have central concentrations above the disks (="bulges")

sSFR increases from inside-out

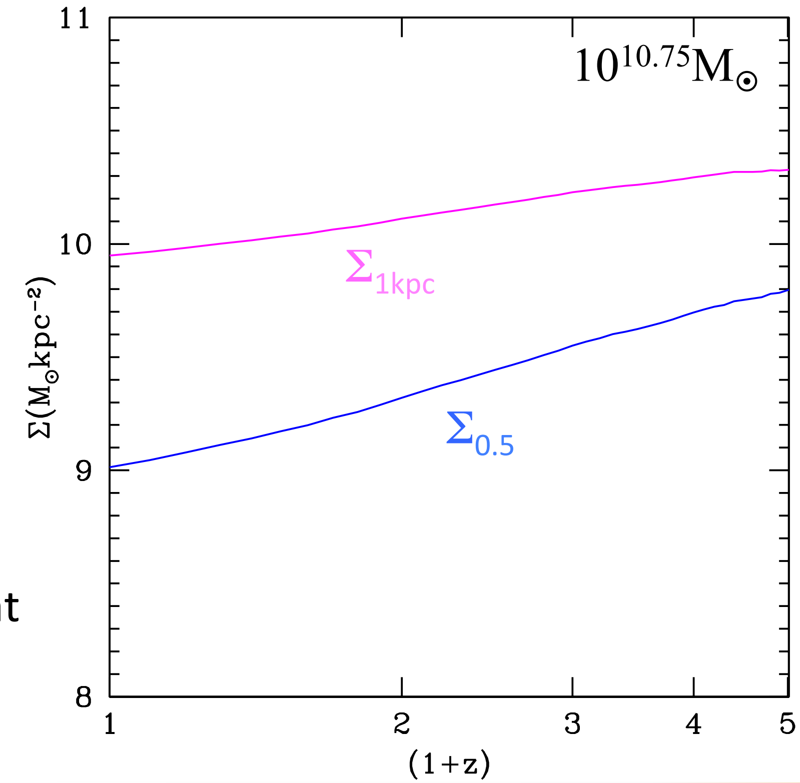
(see e.g. Tacchella et al 2015)

Both arise from the stars that formed earlier when the galaxy was smaller

Surface mass densities in the model

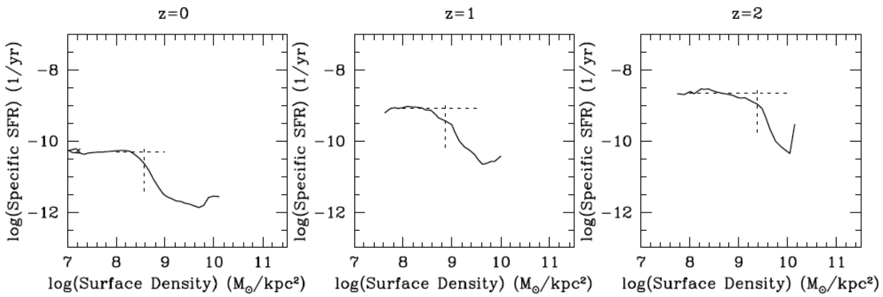


Histories of representative galaxies:
Note the apparent characteristic quenching density of Σ_{1kpc}~$10^{10}M_\odot kpc^{-2}$

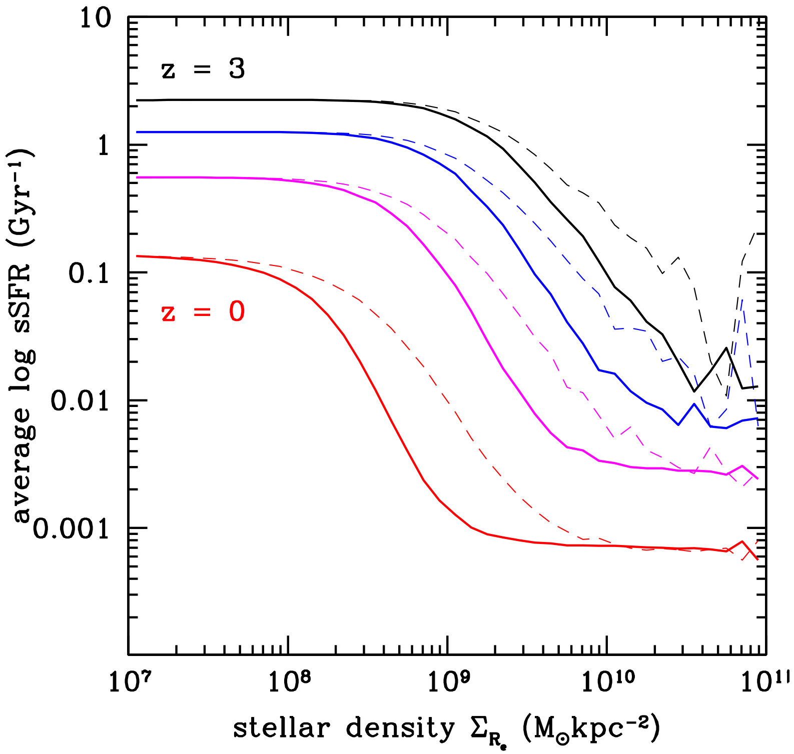


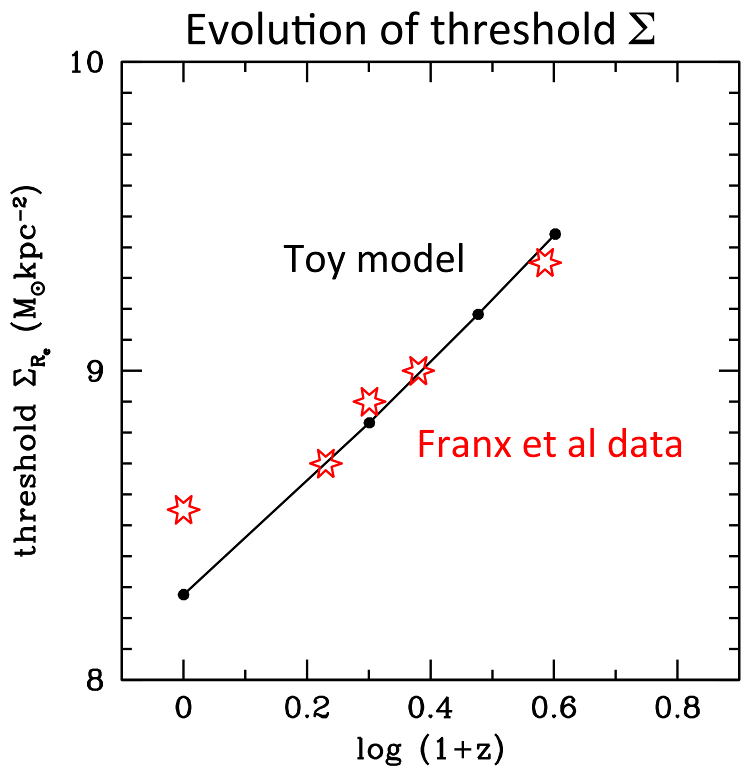
Evolution of central and half-mass densities for the cumulative passive population:
Note the shallow evolution of Σ_{1kpc} relative to that of $\Sigma_{0.5}$, i.e. producing an apparent "inside-out" growth

The quenching stellar density thresholds follow from size evolution…

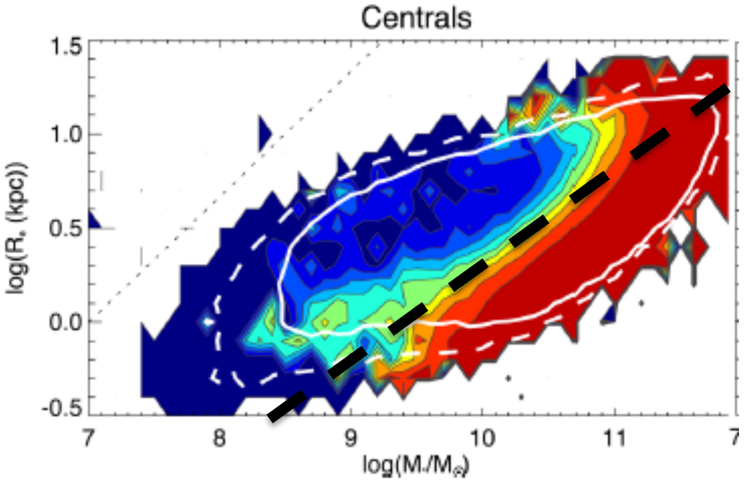


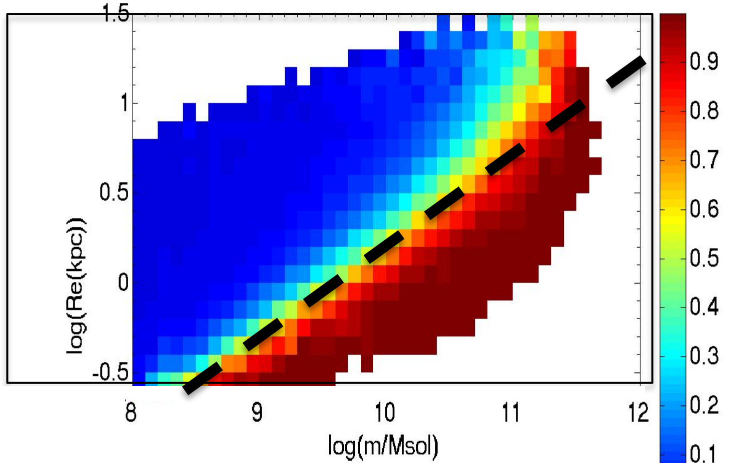
Franx et al (2008)



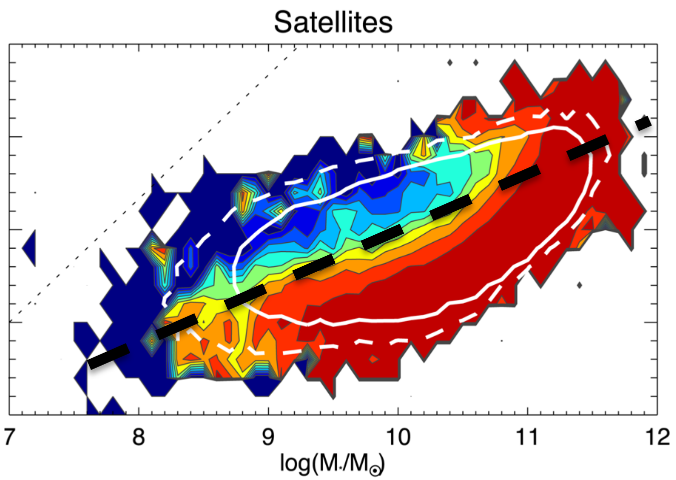


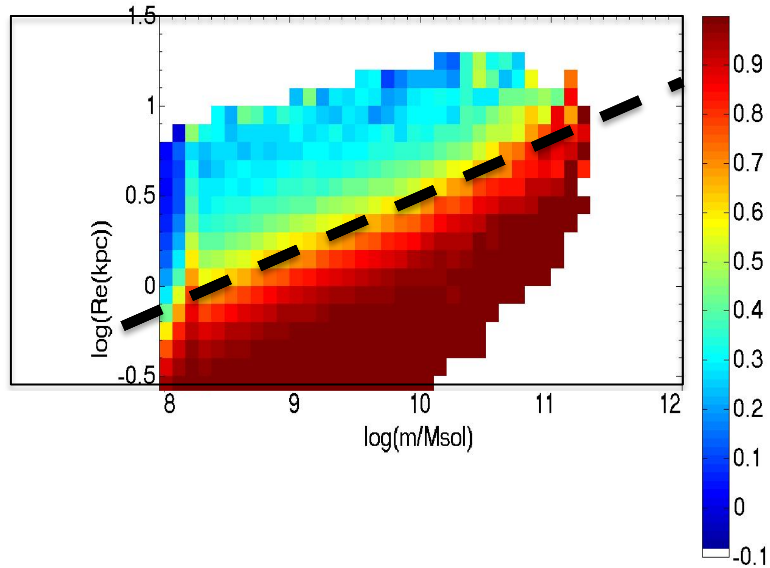
… and the apparent role of stellar density arises naturally





With a very naïve effect of mergers on quenched galaxies: Δm = +0.2 dex, ΔR_e = +0.2 dex





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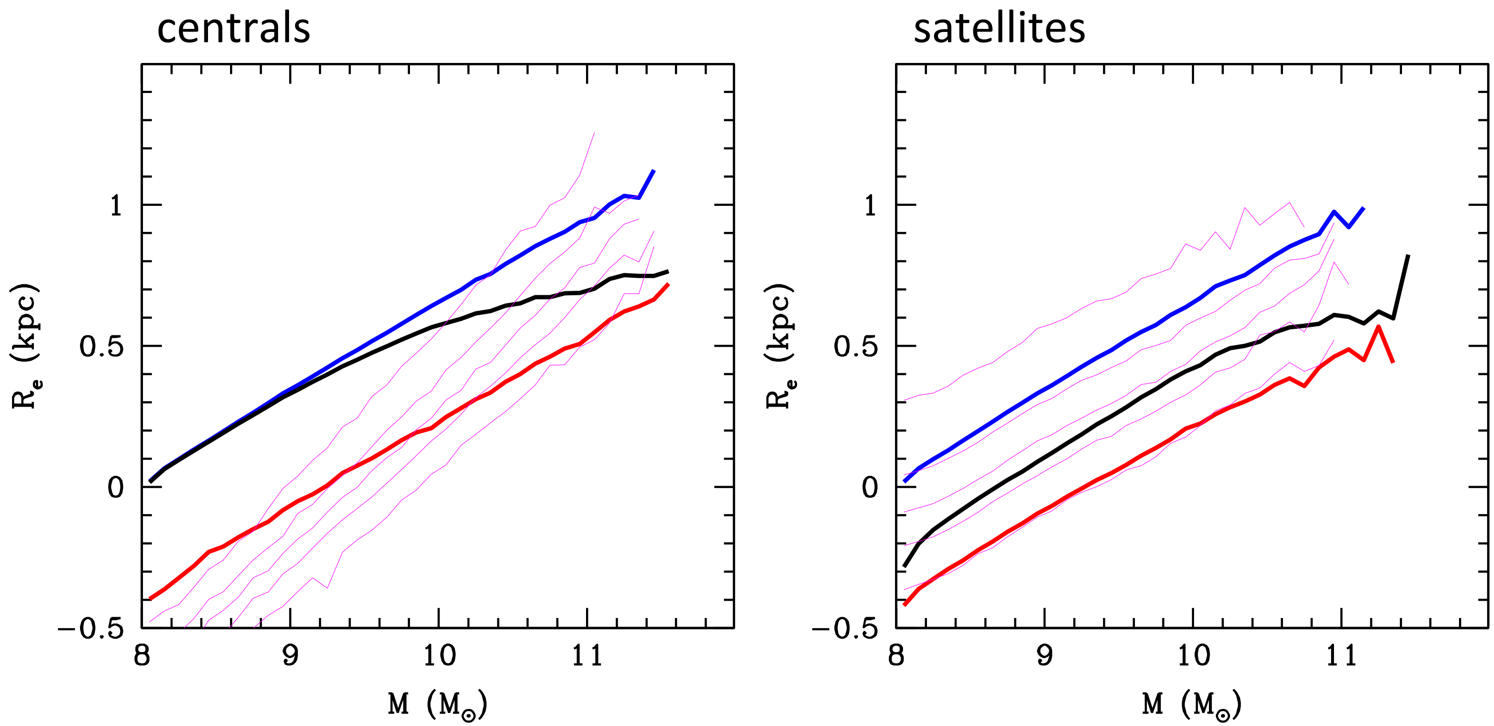

average star-forming $R_e(m)$

average all $R_e(m)$

average quenched $R_e(m)$

i.e. a consequence of (a) parallel but displaced loci in $R_e(m)$ for SF and quenched due to fading and progenitor effects

(b) different relative numbers along these loci due to $\phi(m)$ from mass- and environment quenching

Factual points to take away

A simple model in which added stellar mass scales as $m^{0.3}$ and $(1+z)^{-1}$,
Plus Peng et al (2010) quenching laws, naturally produces:

- passive galaxies that are half the size of star-forming ones.
  50% of this effect is due to fading and 50% due to progenitor bias

- the apparent "ceiling" in surface mass density above which growing galaxies quench

- the apparent inside-out growth of passive galaxies with redshift
  (in that the mass density within 1 kpc changes less than that within Re)

- the redshift evolution of the surface mass density threshold between
  passive and SF galaxies as in Franx et al (2008)

- the variation of quenched fraction with surface mass density and mass
  as in Omand et al (2014) for both centrals and satellites.