IPMU

February 2015

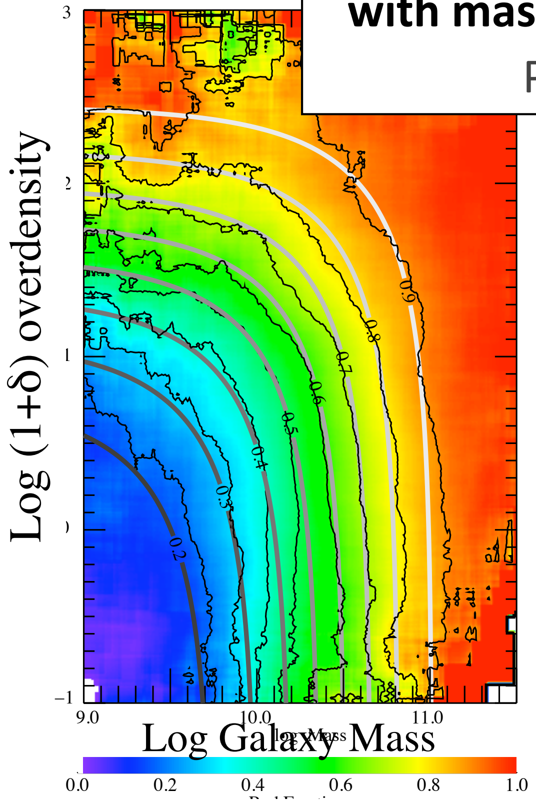
Galactic structure, quenching & environment.

Marcella Carollo

ETH Zurich

When Galaxies Switch Off

Separability
of the Quenched Fraction
with mass and environment
Peng+2010



Red Fraction

Two apparently independent quenching mechanisms

Environment-Independent
'Mass' Quenching

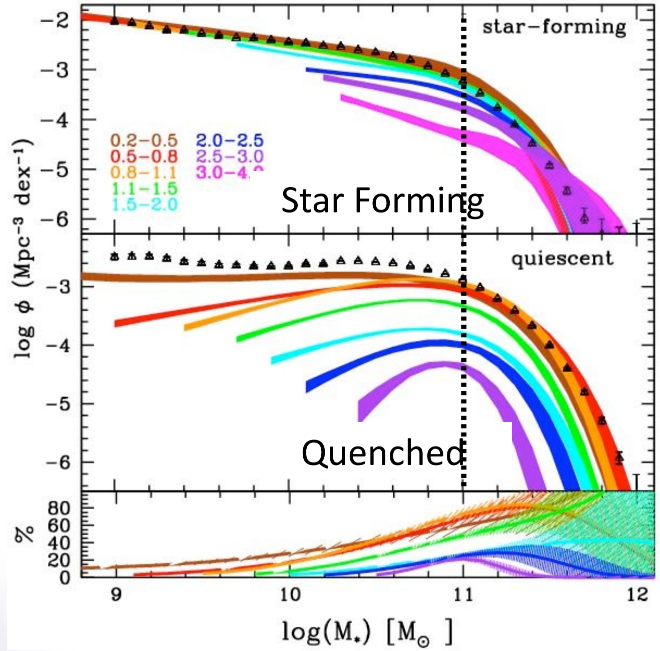
Mass-Independent
'Environment' Quenching

= ***Satellite*** *Quenching,*
more relevant at later epochs

vdBosch+2008; Peng+2012; Wetzel+2013

Remarkable constancy of M*

Ilbert+ 2013



How do *mass*- and *environment*-quenching affect galaxy structure at&around M*?

The Nature of the Quenched Galaxy Population at z=0

Binney&Tremaine 1987; Bender+1988,1992; Carollo+1993; Lauer+1995; Faber+1997; …….. Cappellari+2013;….

$\sim 10^{11} M_\odot$ ~M*

Quenched Bulges/ Spheroids

Fast Rotators
Cusps
Disky
Steep Z gradients
↓
"Dissipative"

Slow Rotators
Cores
Boxy
Flat Z gradients
↓
"Dissipationless"

The $>>10^{11} M_\odot$ Population <u>NEEDS</u> DISSIPATIONLESS (including major) MERGERS

THIS TALK FOCUSES ON HOW TO MAKE 'DISSIPATIVE' M* SPHEROIDS

$>>10^{11} M_\odot$ Population NOT discussed in this talk

Following analyses in bins of constant mass at&around ~M*

Zurich Environmental Study (ZENS): ~1600 Central and Satellite Galaxies at z~0 in Group Dark Matter Halos of mass $10^{12.5}$-$10^{14.5}$ $M_{\odot}$

Carollo, Cibinel et al 2013, ZENS I, ApJ 776, 71
Cibinel, Carollo et al 2013a, ZENS II, ApJ 776, 72
Cibinel, Carollo et al 2013b, ZENS III, ApJ 777, 113

Pipino, Cibinel et al 2014, ZENS V, ApJ 797, 127
(Environmental dependence of mergers)

PUBLIC CATALOG
OF ENVIRONMENTAL &
GALAXY MEASUREMENTS

This Talk focuses on the
SATELLITE POPULATION

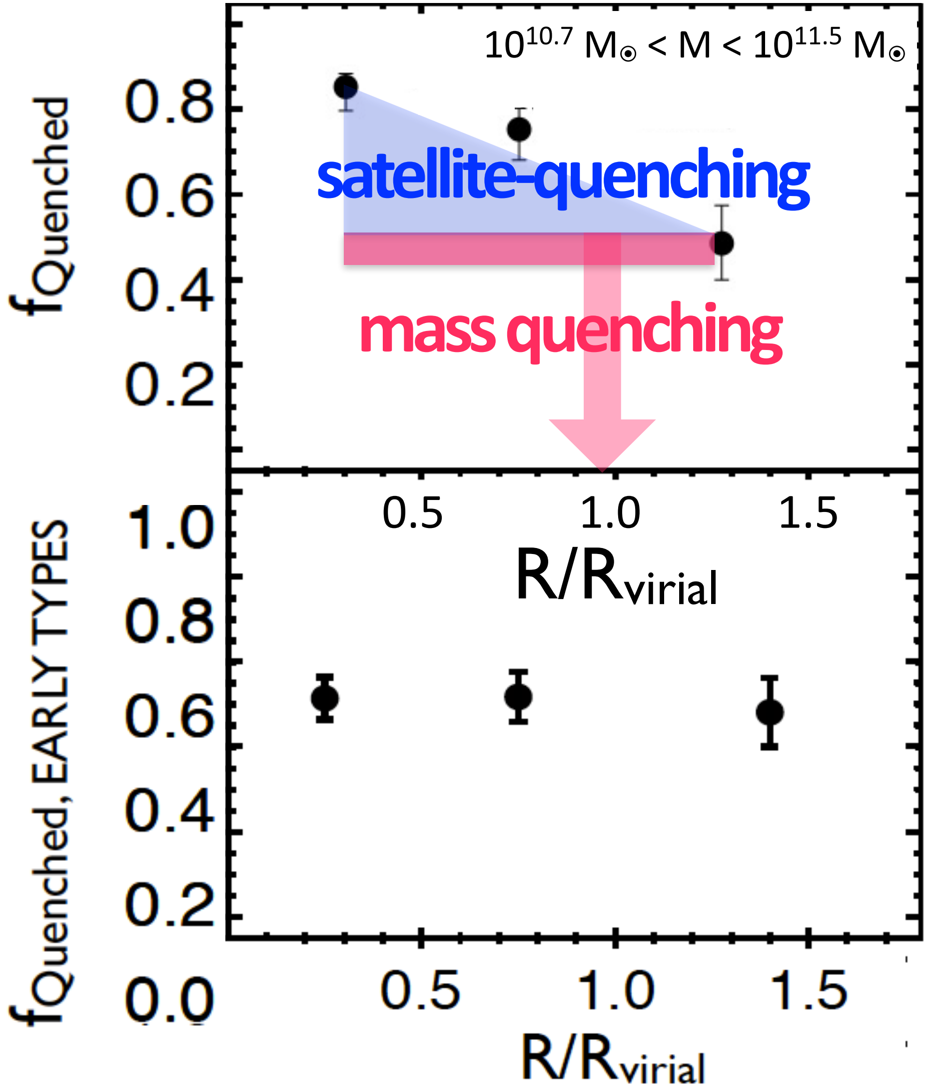
RESULTS PUBLISHED IN:
ZENS IV. Carollo+ 2014 arXiv 1402.1172 (on ApJ SOON)

Analysis of the Quenched Satellite Population in the *ZENS* sample

ZENS IV. Carollo+ 2014 arXiv 1402.1172

The morphological mix of quenched galaxies at a given mass is decoupled from the overall quenched fraction

The morphology-density relation results from the increasing *fraction* of quenched galaxies, *not* from changes in the morphological mix (bulge-to-total ratio) towards the centres of halos



Analysis of the Quenched Satellite Population in the *ZENS* sample

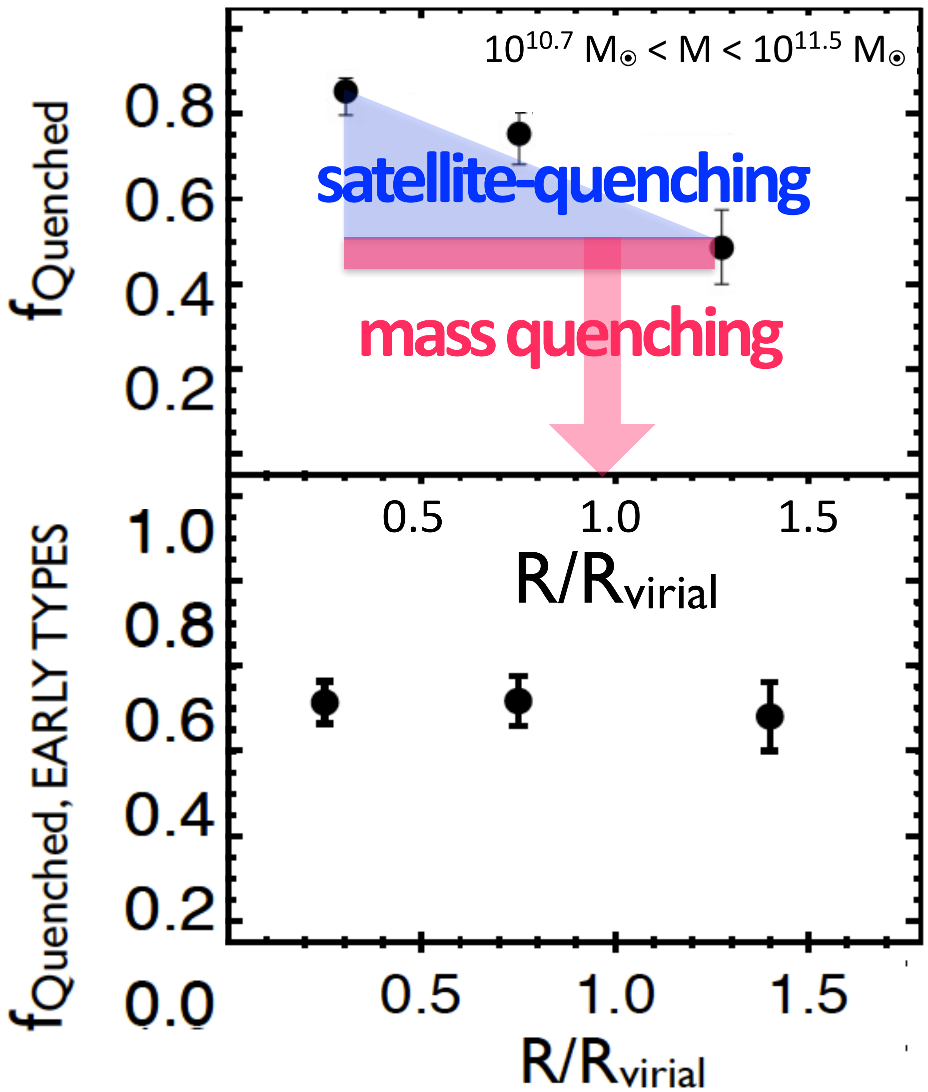
The overall quenched ***satellite*** fraction increases towards group centers.

(see also eg vdBosch+2008, Peng+2012, Wetzel+2012, Woo+2013,….)

The fraction of quenched satellites *with an early-type morphology* is constant with $R_{halocentric}$.

- Either both quenching channels produce *same morphological mix*, or
- Neither is associated with a morphological transformation.

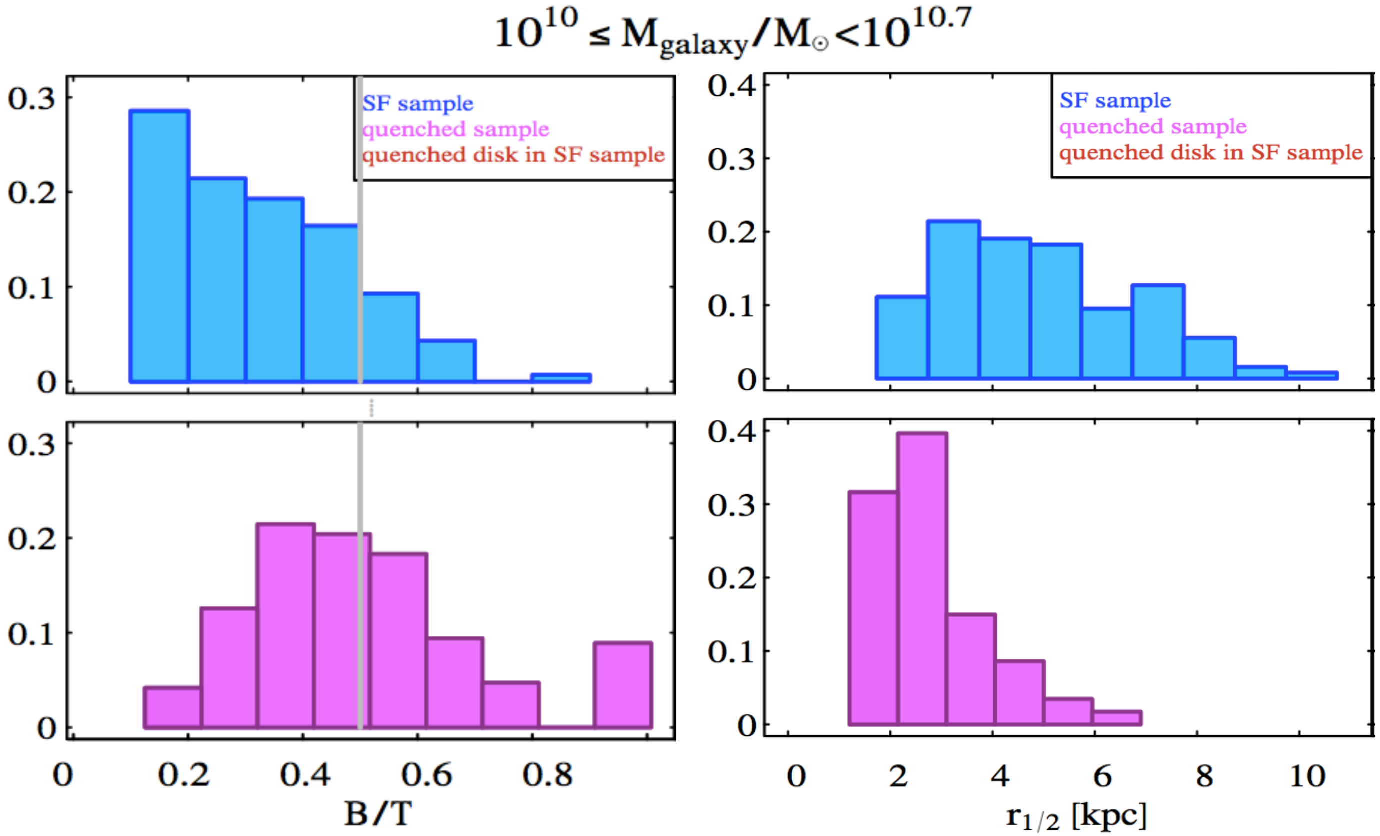
ZENS IV. Carollo+ 2014 arXiv 1402.1172



Comparison of Morphologies between Quenched and Star-Forming Satellites

- Despite no difference in the morphological outcomes of the two quenching processes, the morphologies of the quenched satellites differ systematically from their star-forming counterparts

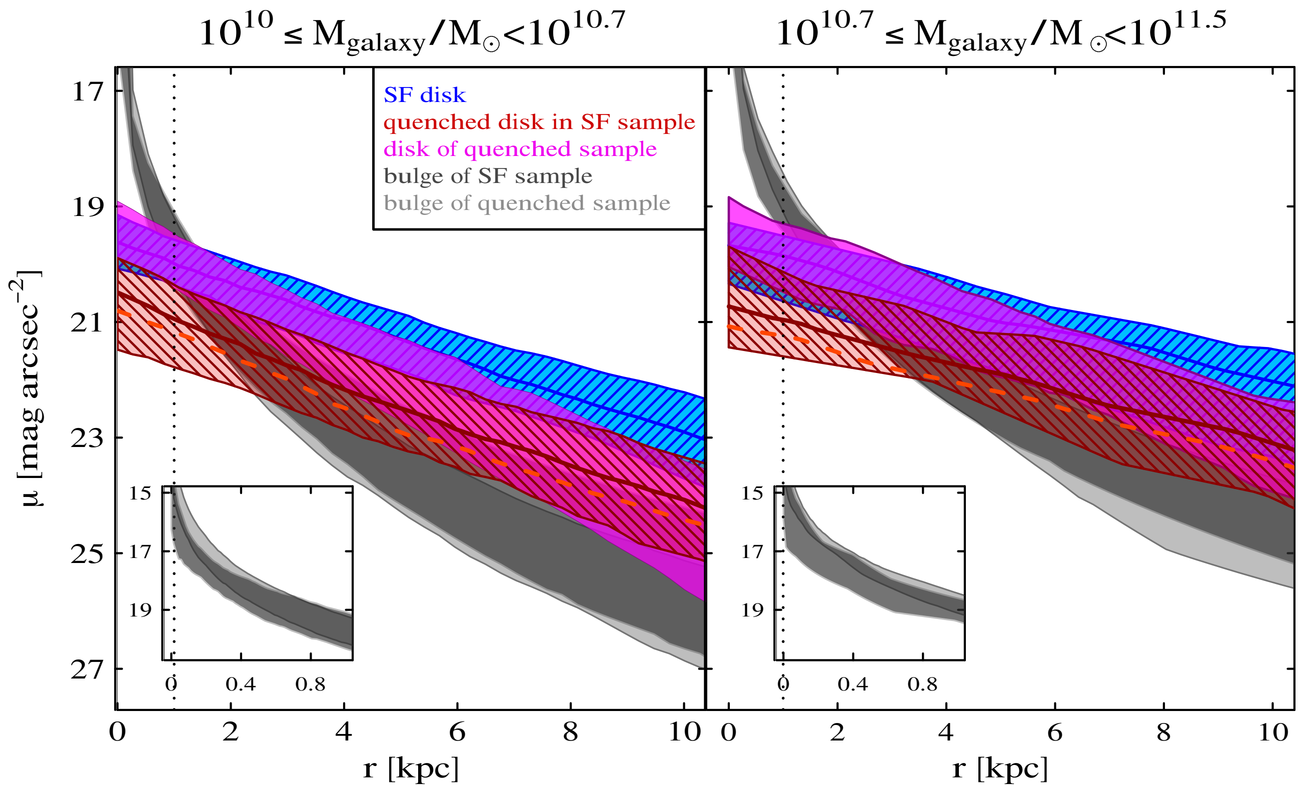
ZENS IV. Carollo+ 2014 arXiv 1402.1172



- Quenched satellites have larger B/T and smaller half-light radii than star-forming satellites

Comparison of Bulges and Disks between Quenched and Star-Forming Satellites

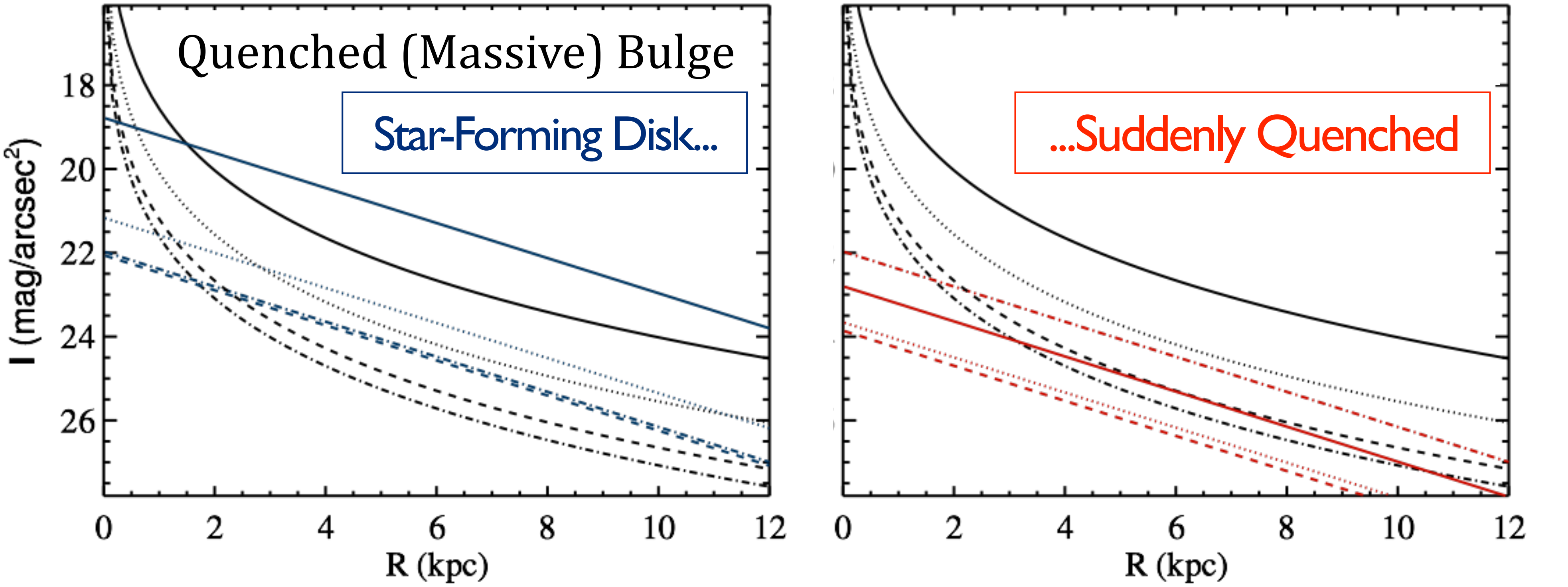
ZENS IV. Carollo+ 2014 arXiv 1402.1172



- The bulges in quenched and star-forming satellites have very similar luminosities and surface brightness profiles
- Any mass growth of the bulges associated with quenching cannot greatly change these quantities

The differences in B/T and in half-light radii are mostly due to differences in the disks, which have lower luminosities in the quenched galaxies

Star Formation in Disks ⇒ Quenching = *Disk* Quenching



➡ **Bulges emerge as Disks Fade**

Apparent Morphological Transformation Through Disk Fading

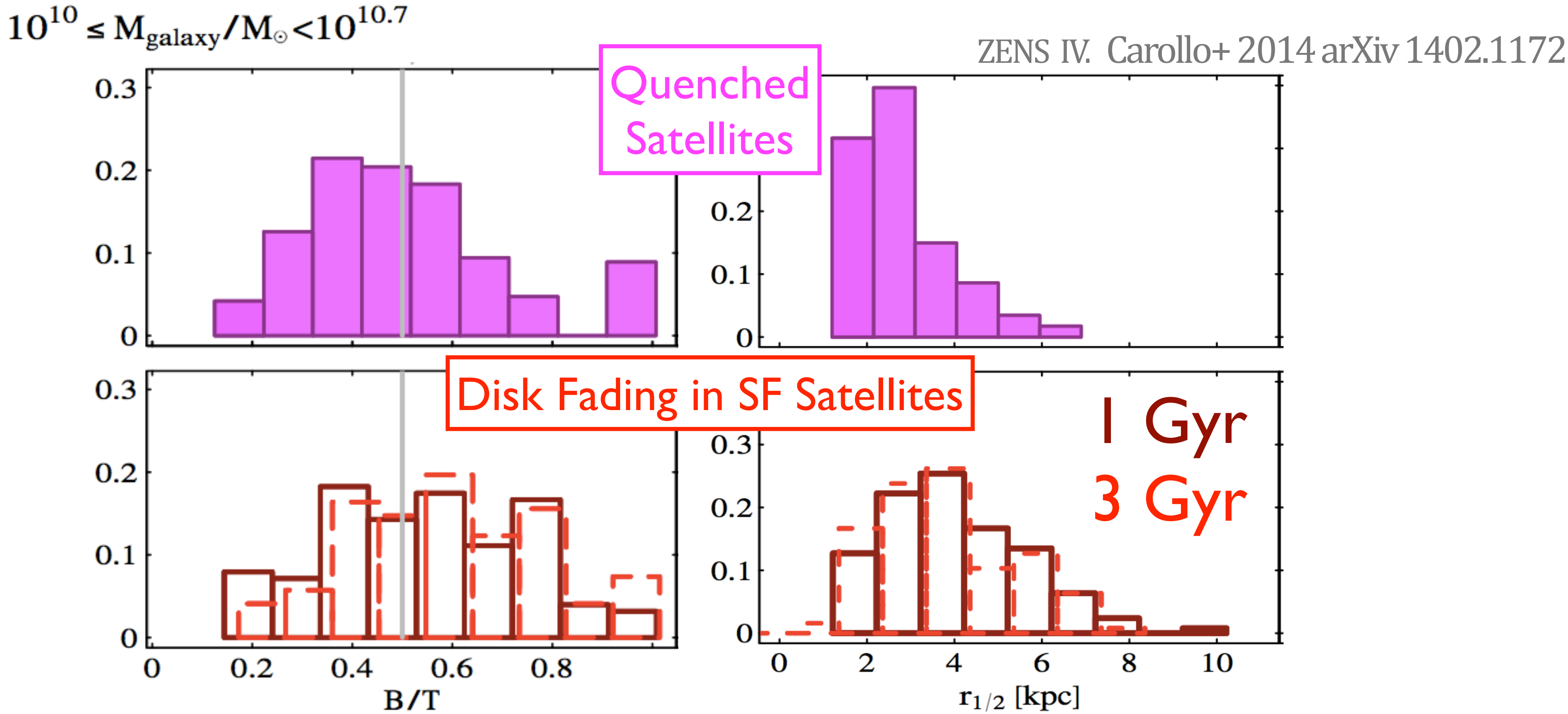
$\xi = D_Q/D_{SF} < 1$

$$(B/T)_{SF} = \frac{B}{B + D_{SF}}$$

$$(B/T)_Q = \frac{B}{B + D_Q} = \frac{(B/T)_{SF}}{\xi + (1 - \xi)(B/T)_{SF}}$$

Disk fading after quenching
increases the morphological B/T — and decreases the half-light radii,
even if there are ***no underlying structural changes in the stellar mass distributions***

Simulated B/T and $r_{1/2}$ of *Uniform* Disk Fading after Disk Quenching

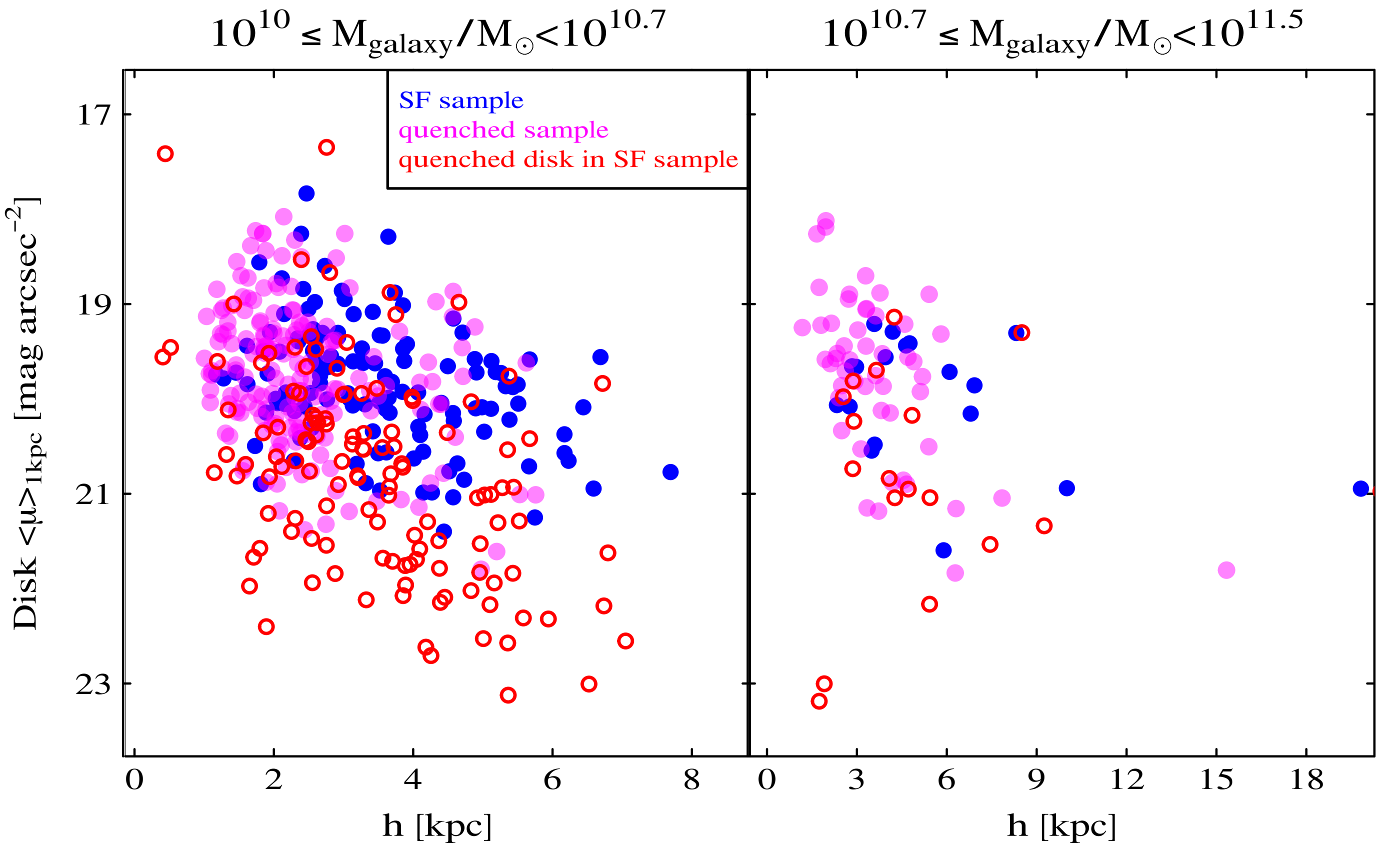


- Disk fading after quenching quantitatively explains the morphological differences in B/T between star-forming and quenched satellites
- The difference in galaxy half-light radii between quenched and star-forming satellites remains larger than can be explained by *uniformly* fading the disks following quenching

ETH
Eidgenössische Technische Hochschule Zürich
Swiss Federal Institute of Technology Zurich

Why ***Uniform*** Disk Fading fails: Disk Scale Lengths

ZENS IV. Carollo+ 2014 arXiv 1402.1172



▸The quenched disks have smaller scale lengths than in star-forming satellites

Expectations from inside-out growth of disks

ZENS IV. Carollo+ 2014 arXiv 1402.1172

➡ Radial age gradients within the disks, i.e., *differential* fading of the disks with radius

➡ disks generally smaller, at a given mass,

at earlier epochs, when the quenched satellites were actually quenched

Quantifying Differential Disk Fading

$$h_{fade} = \frac{h_{SF} h_Q}{h_{SF} - h_Q} = (h_Q^{-1} - h_{SF}^{-1})^{-1}.$$

With:

$$\mu_{SF}(r) = \mu_{SF,0} + 1.085 r h_{SF}^{-1}$$

and

$$\mu_Q(r) = \mu_{Q,0} + 1.085 r h_Q^{-1},$$

the fading $\Delta\mu(r)_{fade}$ at different radii will be given by:

$$\Delta\mu(r)_{fade} = (\mu_{Q,0} - \mu_{SF,0}) + 1.085 r (h_Q^{-1} - h_{SF}^{-1}).$$

With $h_Q \sim 0.5 h_{SF}$ (as observed):

➜ $h_{fade} \sim h_{SF}$

➜ $\mu_{Q,0} - \mu_{SF,0} \sim 0$

➜ $\Delta\mu(h_{SF})_{fade} = 1$ mag

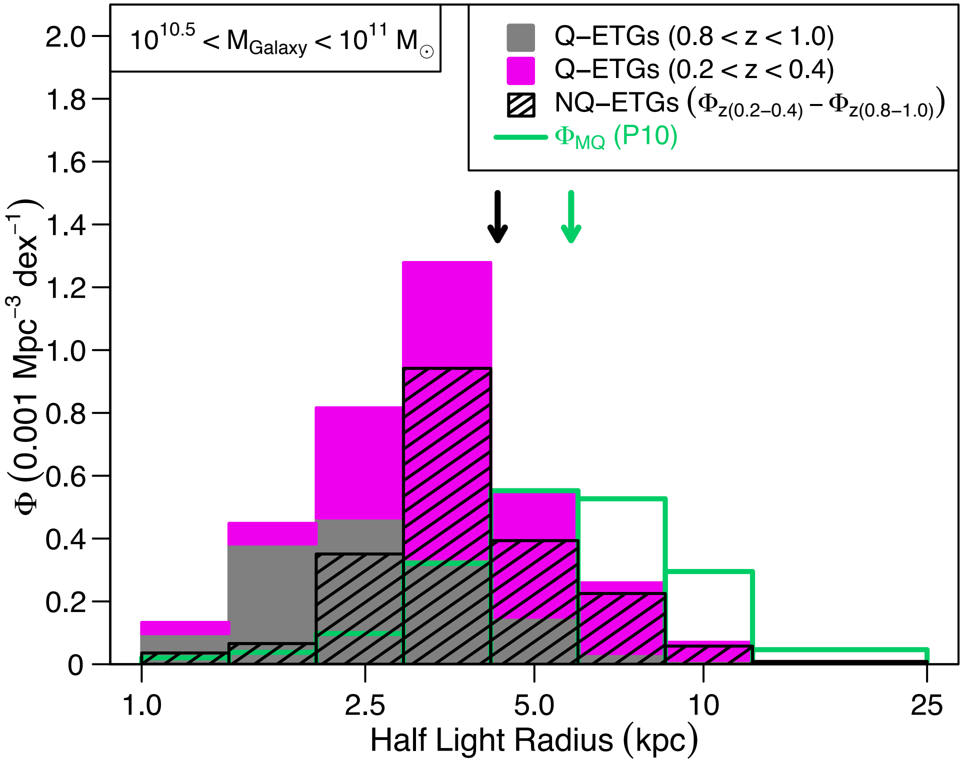
➜ About 3Gyr of age difference between older centres and younger outskirts, consistent with direct estimates of stellar population age gradients in disks.

~1-3 Gyr of passive evolution of disks leads to fading which fully explains the smaller sizes of quenched satellites relative to star-forming satellites

DISK FADING EXPLAINS ALSO ~30% SMALLER SIZES OF ~M* *NEWLY*-QUENCHED GALAXIES SINCE Z=1 RELATIVE TO PREDICTED SIZES OF QUENCHED (STAR-FORMING) PROGENITORS

COSMOS sample

Carollo+ 2013, ApJ 773, 112



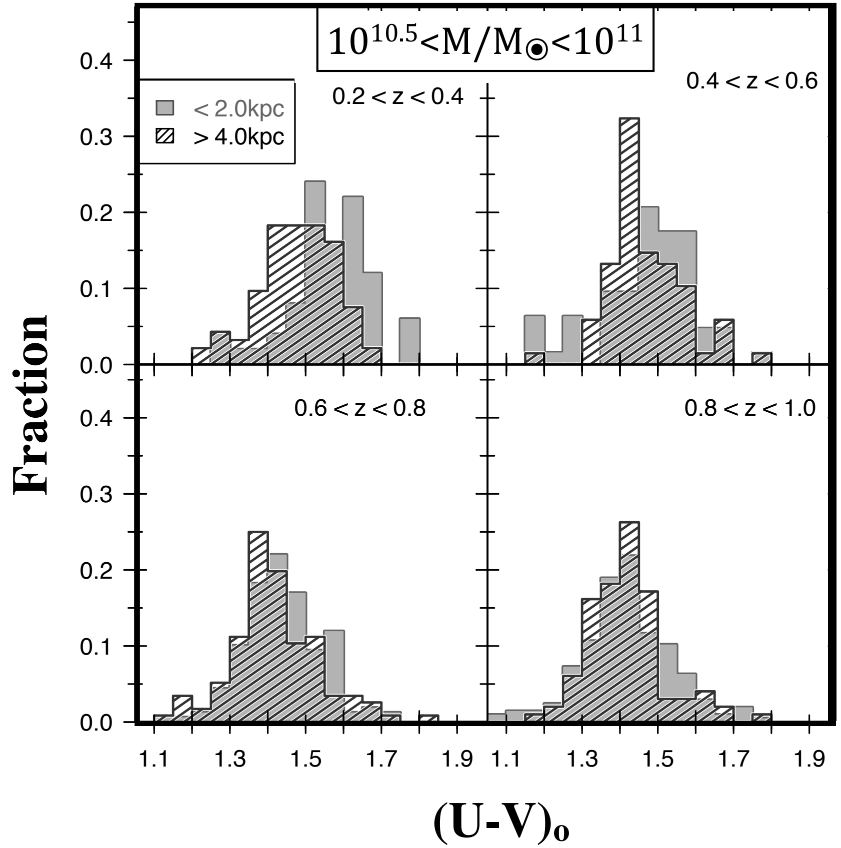
Predicted **Size-Function of Newly-Quenched Galaxies since z=1 (from observed Size-Functions of Star-Forming Galaxies and Peng+2010 quenching rates)**

Observed **Size-Function of Newly-Quenched Galaxies since z=1**

ETH Eidgenössische Technische Hochschule Zürich
Swiss Federal Institute of Technology Zurich

Stellar Populations of Compact & Large M* Quenched Early-Type Galaxies (Q-ETGs)

Carollo+ 2013, ApJ 773, 112



Increase with z→0 of the *average* size of Q-ETGs primarily caused by the addition at later epochs of larger and more diffuse Q-ETGs

- **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**

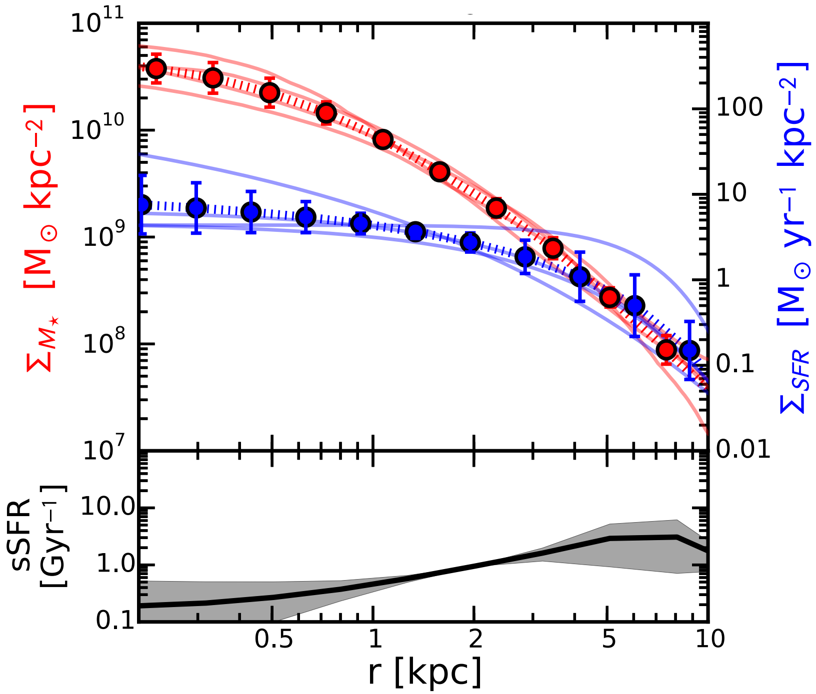
- **Larger Q-ETGs** have average rest-frame U-V colors **bluer than compact Q-ETGs**

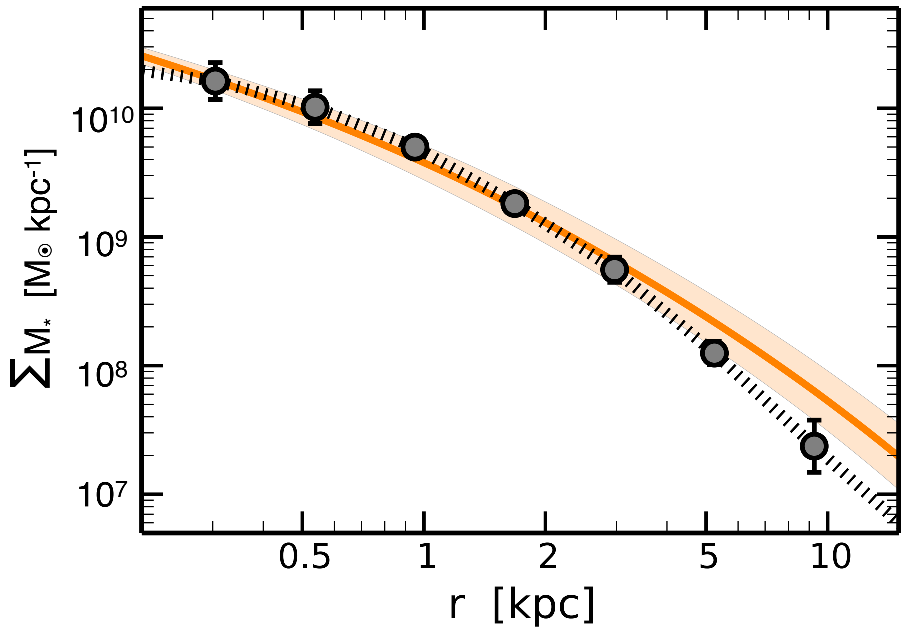
➡ **At any z<1, larger Q-ETGs younger than compact Q-ETGs**

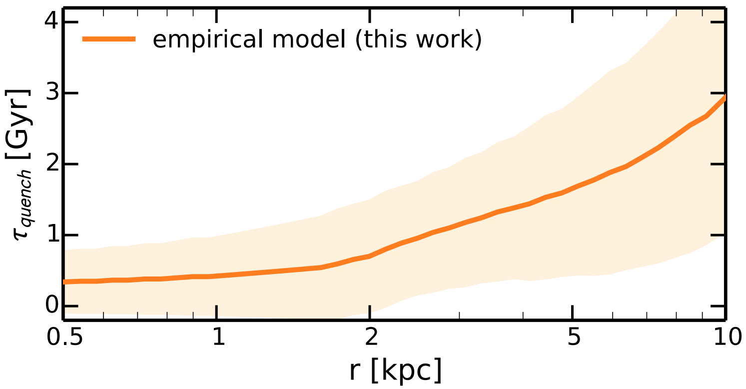
ETH Eidgenössische Technische Hochschule Zürich
Swiss Federal Institute of Technology Zurich

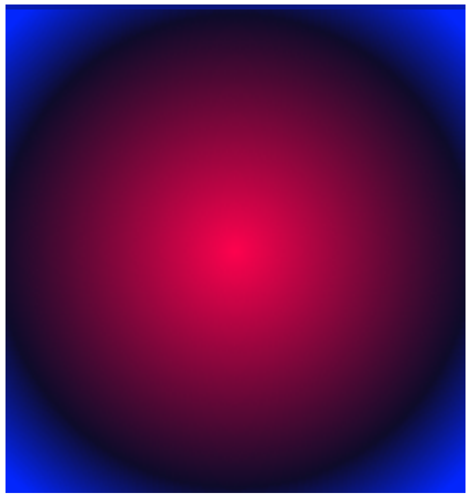
Inside-Out Disk Quenching+Fading of M* *Star-Forming Main Sequence Galaxies* at z~2

Sandro Tacchella, Carollo, Renzini, Forster Schreiber et al 2015, Submitted to Science









The emergence of 'dissipative' M* Spheroids

My perspective in 3 bullets

Focus on ~M* mass scale

1. **Mass- or satellite-quenching have a similar (if any) impact on morphologies: Likely two manifestations of a single physical process (eg, 'halo physics').**

2. **Fading of the disks after star-formation ceases can explain the change in the *observed (light-defined) B/T* and in the *mean half-light radii*, that are seen in quenched galaxies relative to a plausible set of star-forming progenitors, without the need for any substantial mass growth or other changes in the bulge components.**

3. **Quenching+fading of star-forming disks can explain the (size evolution and) emergence of ~M* quenched spheroids since at least z~2.**

My Contributed Questions for the Discussion

1. What causes quenching?
   If we will understand what 'does it' we will understand its consequences (also for the mass-size relation).

2. Is there mass formation in bulges involved in quenching?
   Direct impact on the evolution of sizes and on the relationship between the size evolution of Star-Forming and Quenched galaxies.

3. Is a 'blue nugget' phase essential to make 'red nuggets' later on?
   Some work I will show on Thursday suggests a 'NO'…