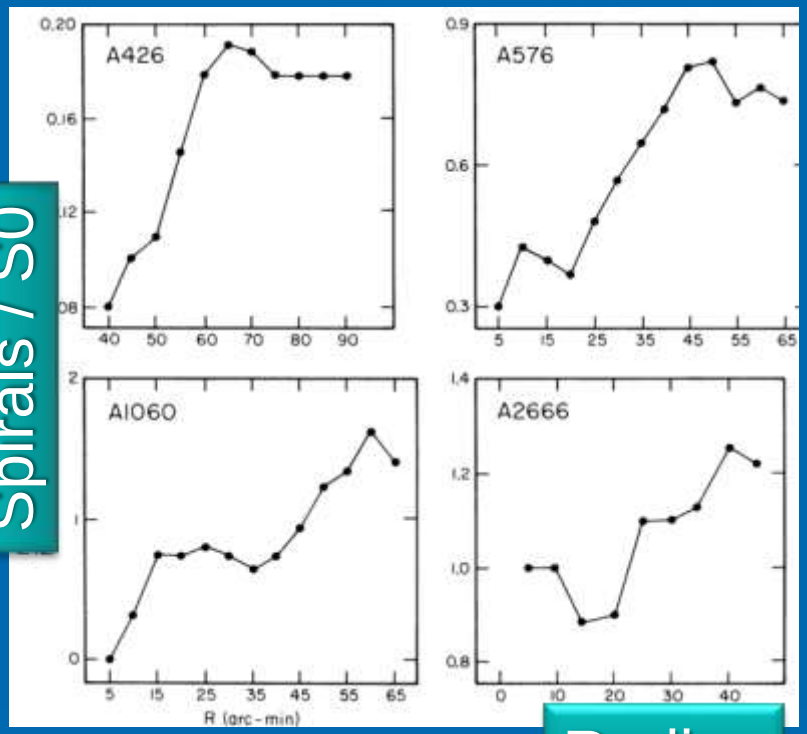
The roles of environment, galaxy mass and internal kinematics

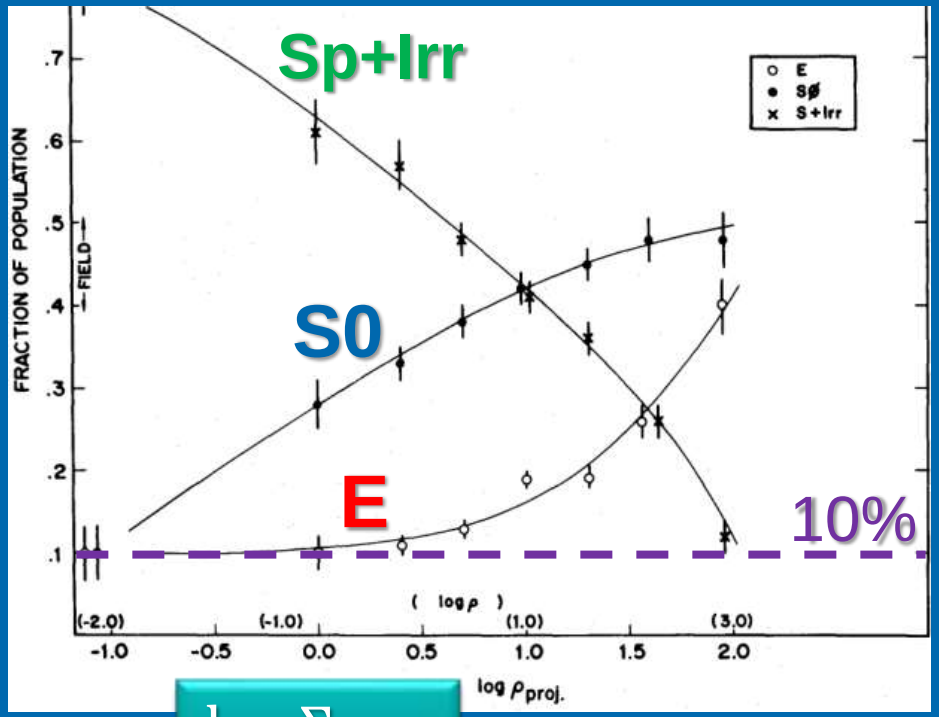
Michele Cappellari

Morphology-density ($T - \Sigma$)



(Melnick+Sargent77)

Radius



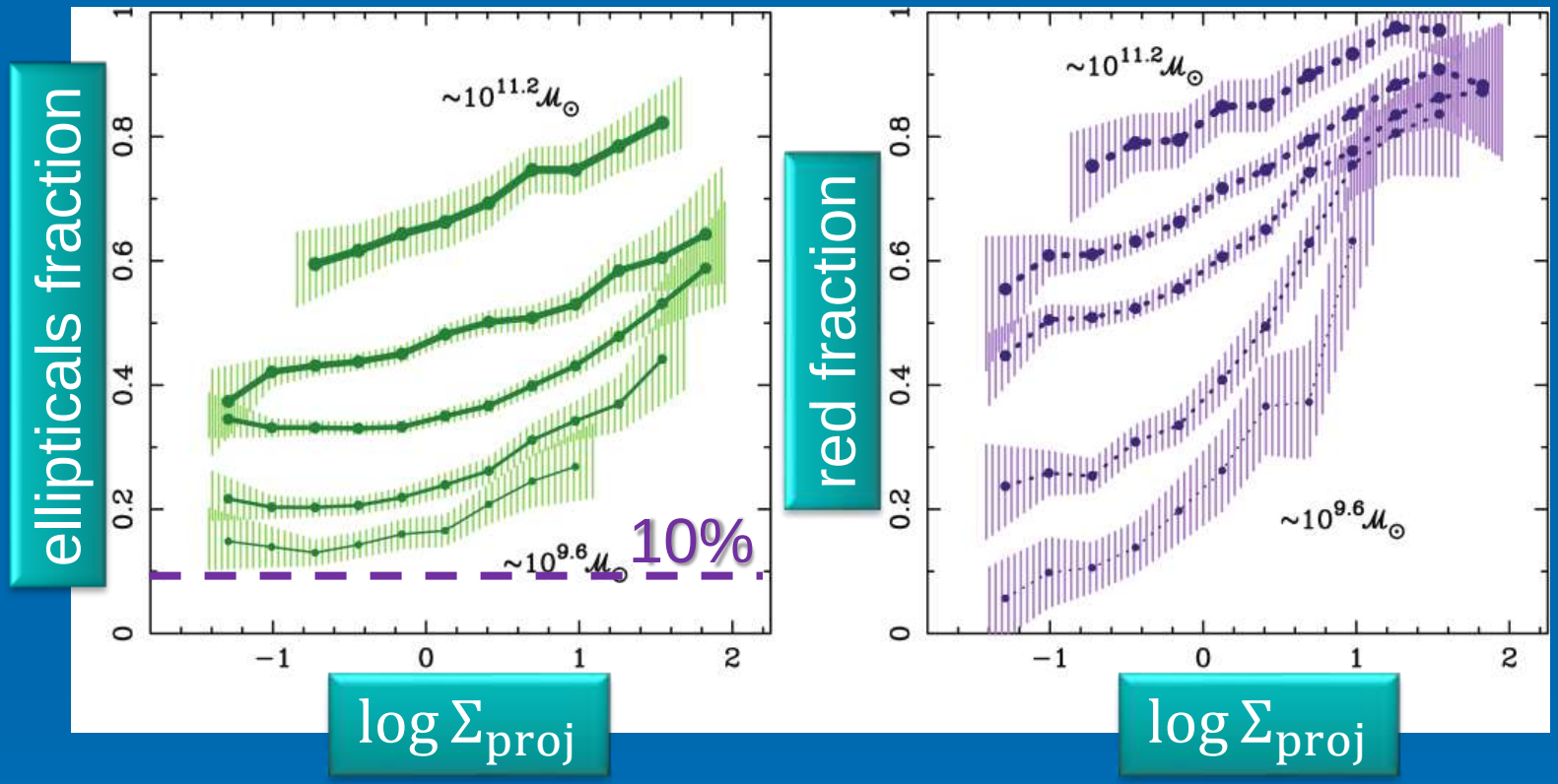
$\log \Sigma_{\rm proj}$

(Dressler-80)

(up to z~1: Dressler+97; Fasano+00; Treu+03; Smith+05; …)

- Morphology *T* dependence on num. dens. Σ
- Spirals segregate into E+S0 in clusters
- But 10% of E still present in the field!

Mass or environment (M_* or Σ)?



(Bamford-GalxyZoo+09)

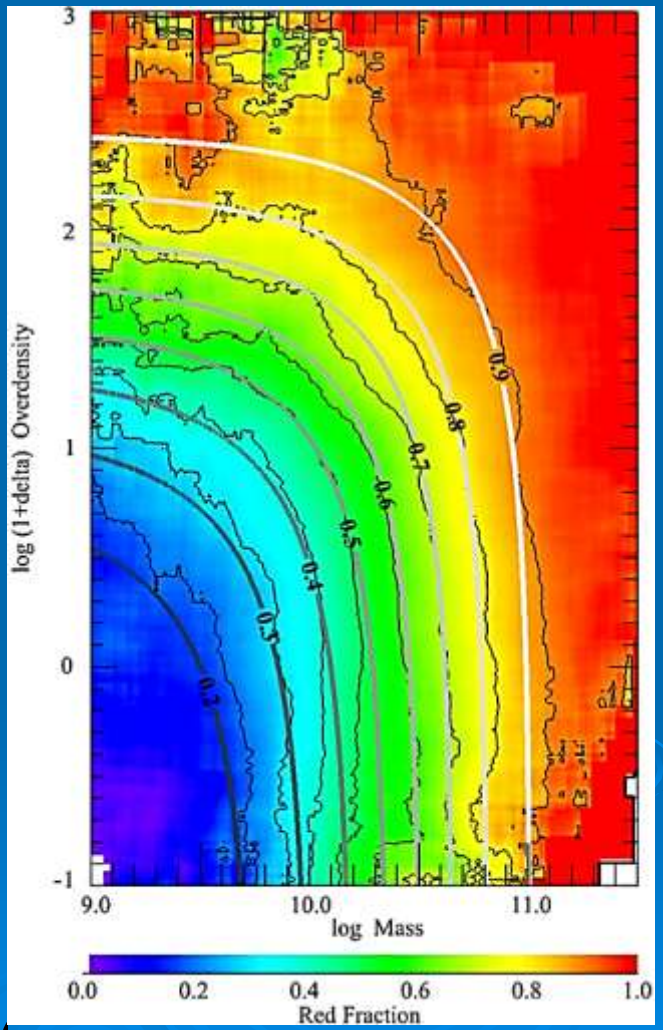
- Clear $T - \Sigma$ trends at fixed mass
- But strong $T - M_*$ dependence

See Courteau+13 for review on galaxy masses

"separable" M_* and Σ quenching

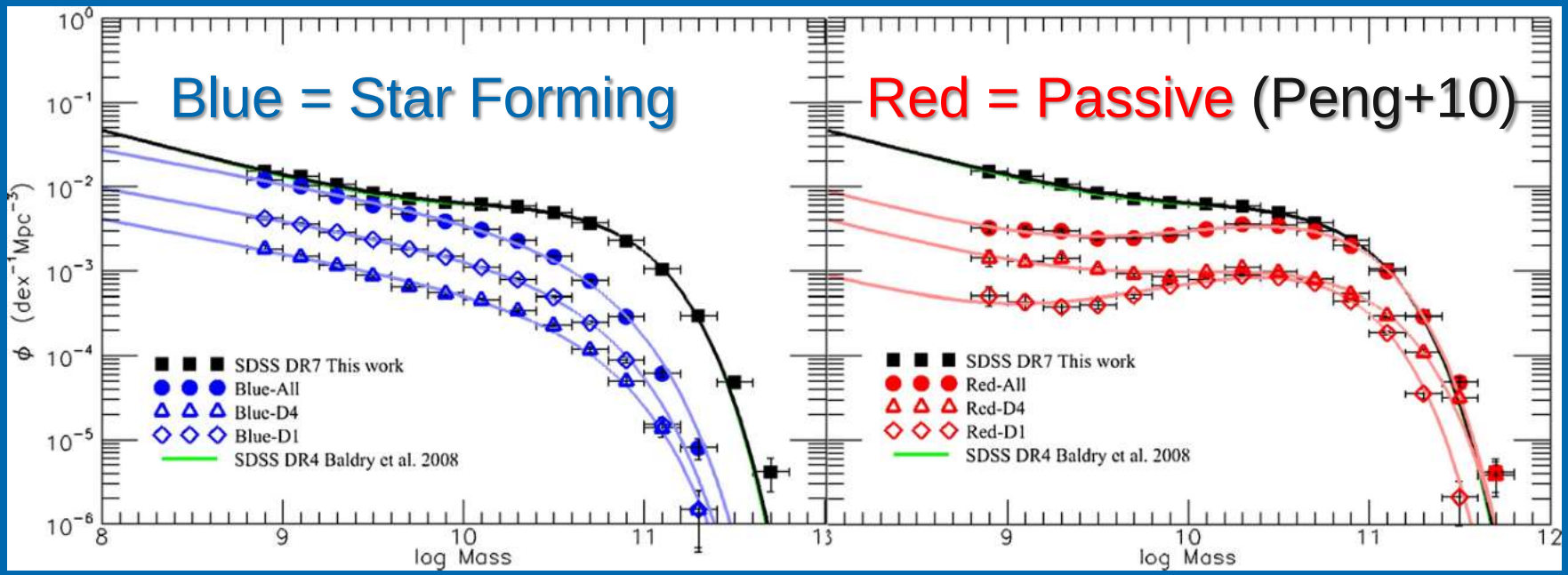
- At fixed Σ quenching driven by M_*: mass quenching
- At fixed M_* quenching driven by Σ: environment quenching
- Tested from $z \sim 0 \rightarrow 1$

(Kauffmann+04; Peng+10; Sobral+11; Smith+12; Muzzin+12; Quadri+12)

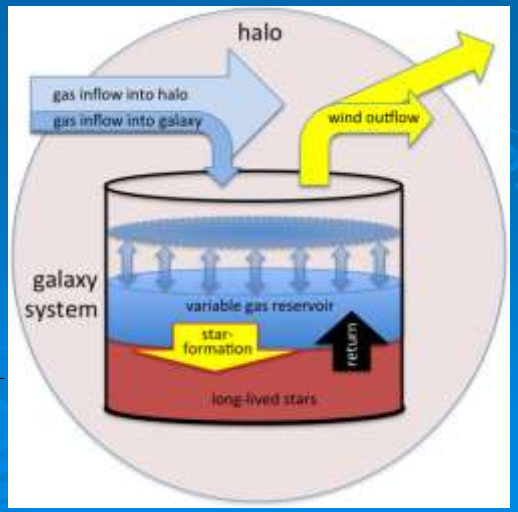


(Peng+10)

Quenching: not merging related

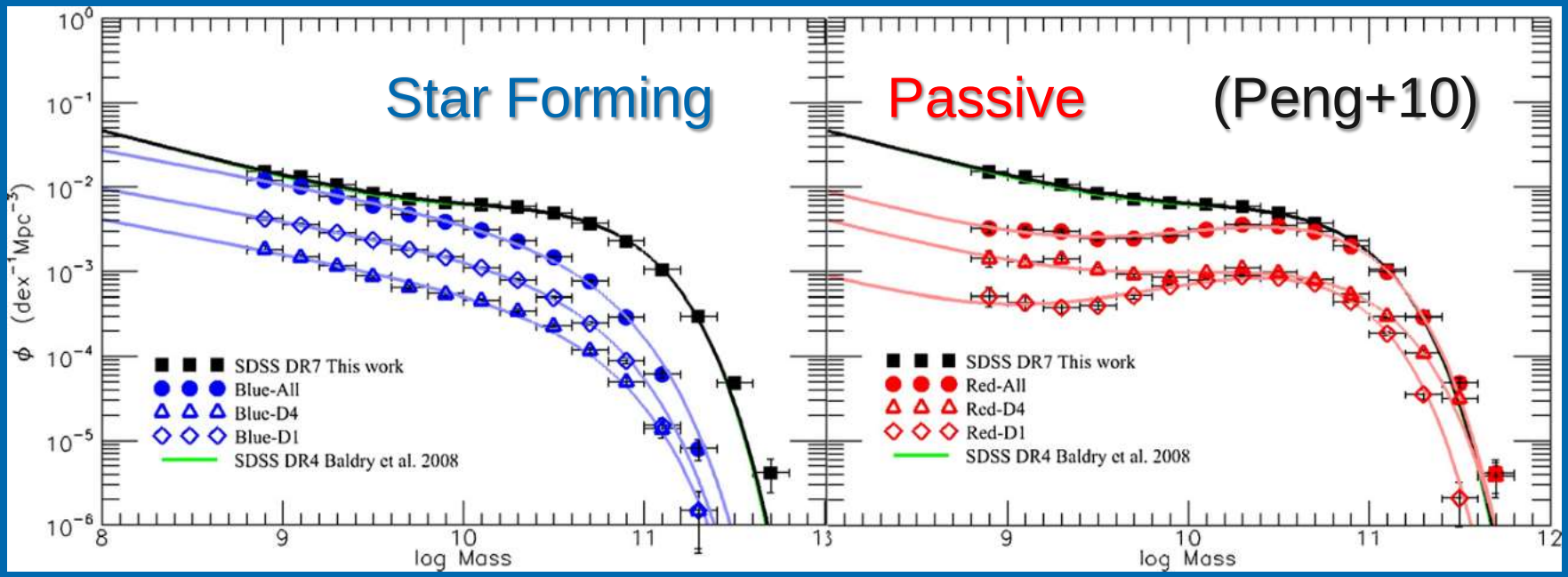


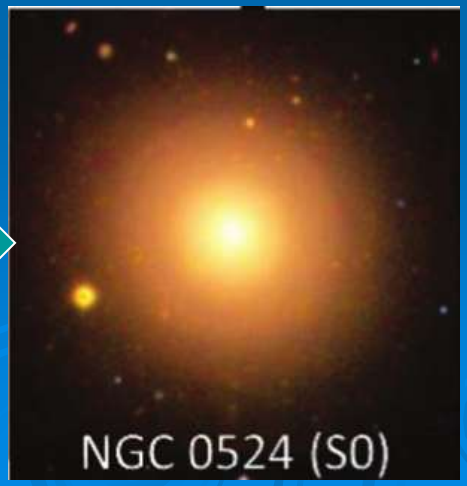
- Schechter for blue galaxies
- Red galaxies distribution can be predicted from blue galaxies
- Satisfy continuity equation



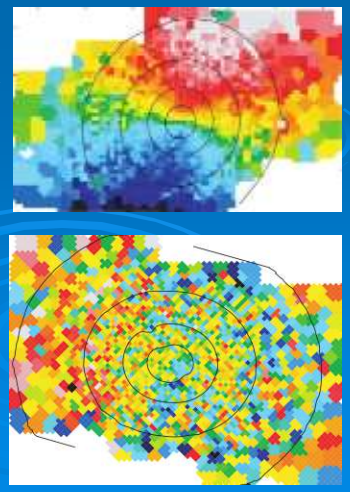
(Lilly+13)

How does quenching work?

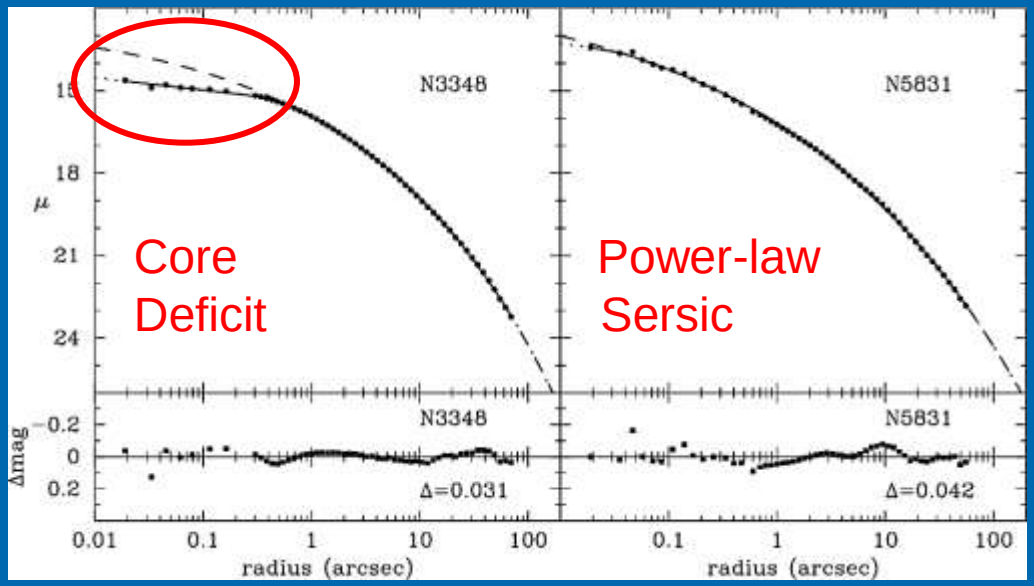




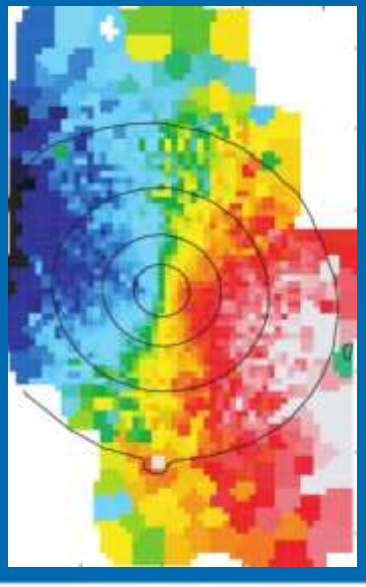
?

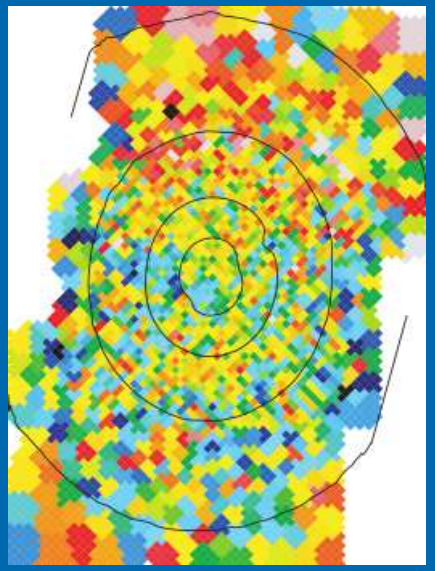


Recognizing merging history



(Graham+03)





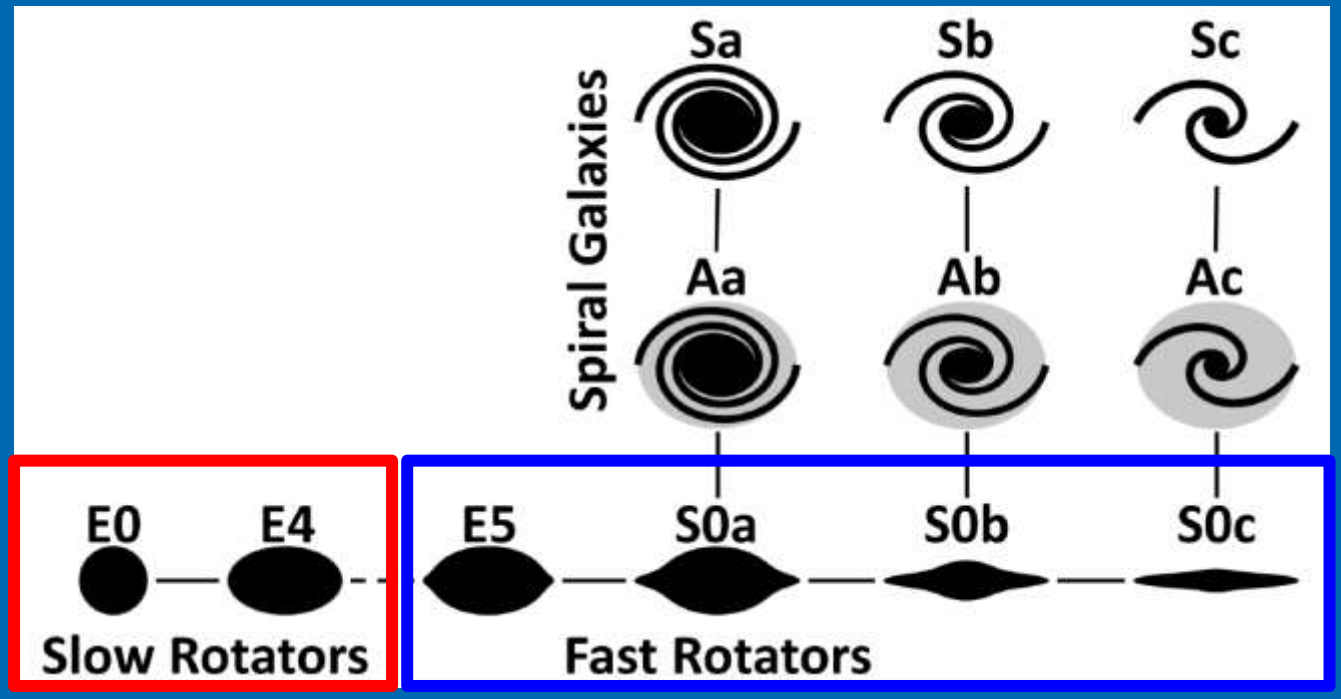
Fast-rotator | Slow-rotator

(Emsellem+04)

- Dry merger remnant
  - Core/deficit (e.g. Milosavljevic+01; Ferrarese+06; Kormendy+09)
  - Slow rotator (Emsellem+07,11; Cappellari+07)

  (See Lauer+12 and Krajnovic+13 for differences)
- Core AND slow-rotator = secure dry merger remnant

What are fast/slow rotators?



(Cappellari+11b: ATLAS^{3D}-7)

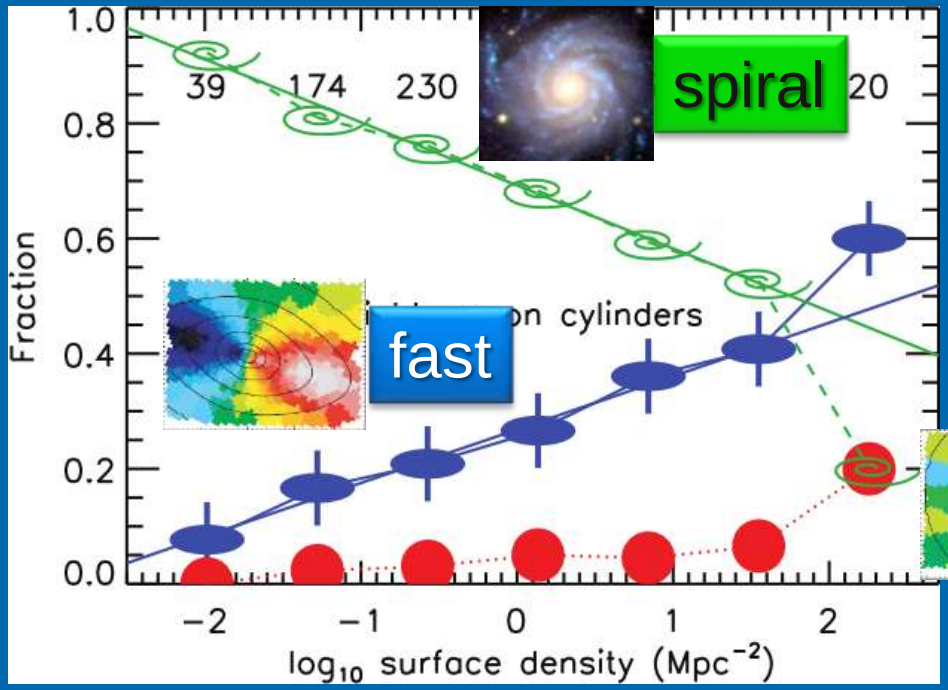
Slow rotators

- Weakly triaxial
- NO disks
- Elliptical isophotes from any direction

Fast rotators

- Axisymmetric
- With stellar disks
- Classified disky-E or S0 when seen edge-on

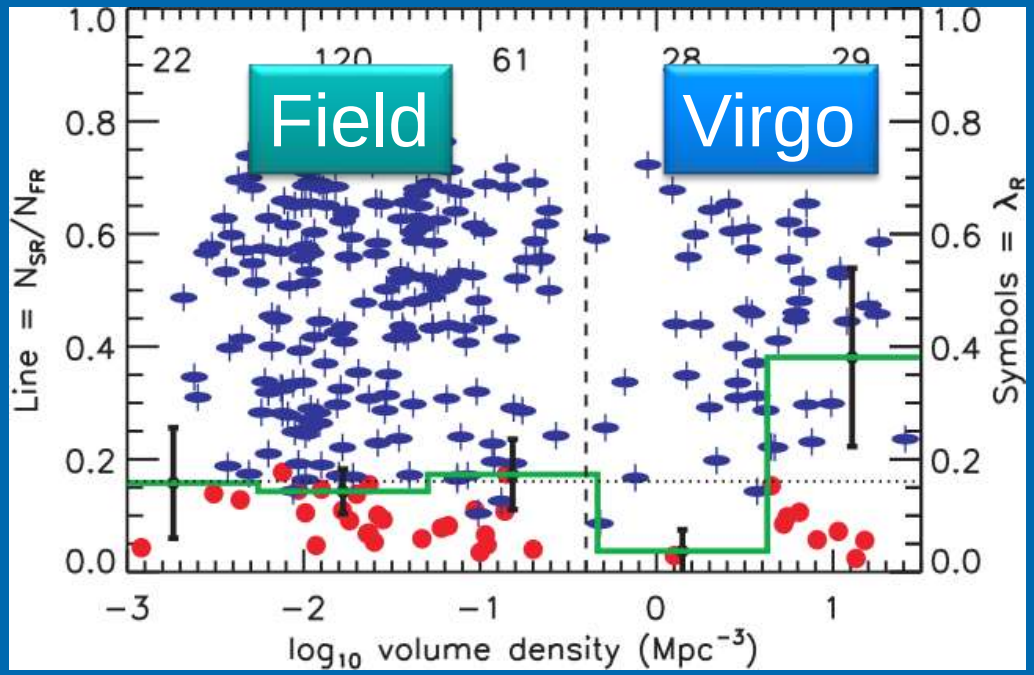
Kinematic morphology-density ($\lambda_R - \Sigma$)



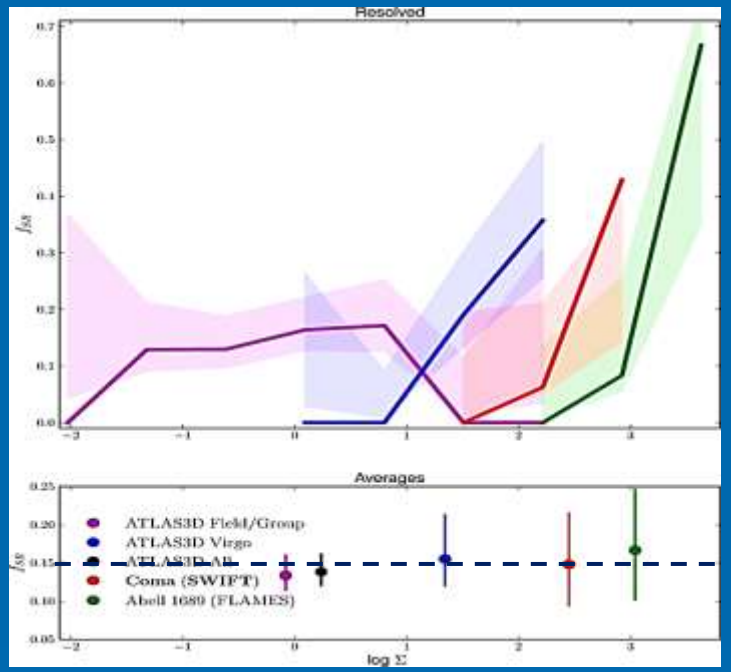
(Cappellari+11b: ATLAS^{3D}-7)

- Opposite trend spirals/fast rotators
- But NO slow rotators in the field (1%=2/200)!
- Field ellipticals → misclassified disk-like ETGs
- Sharp rise of slow rotators in cluster

Fast/slow-ETGs independent of Σ



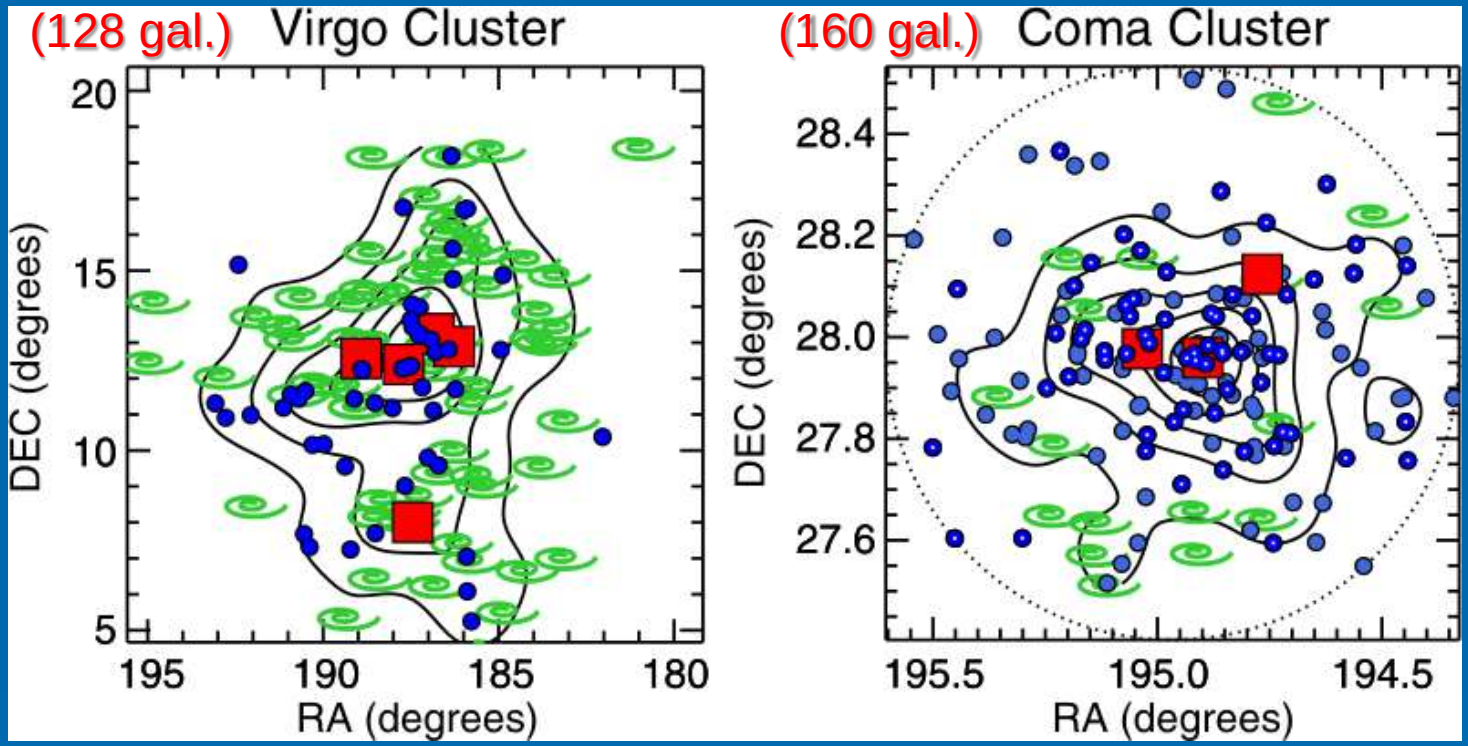
(Cappellari+11b ATLAS^{3D}-7)



(Houghton+13)

- No clear dependency on Σ
- For 3 orders of magnitude in Σ
- But slow rotators sit at centre of clusters

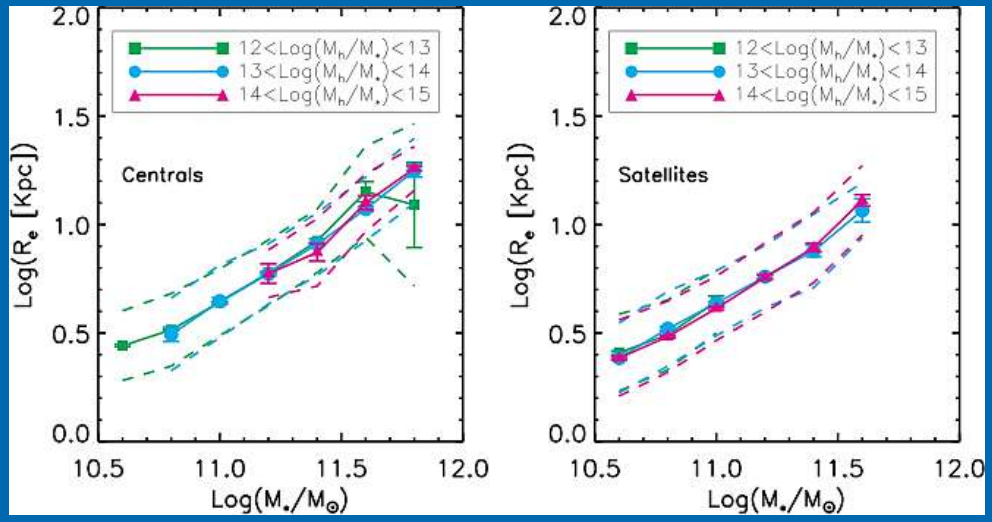
Core slow rotators in cluster centres



(Cappellari-13 ApJL)

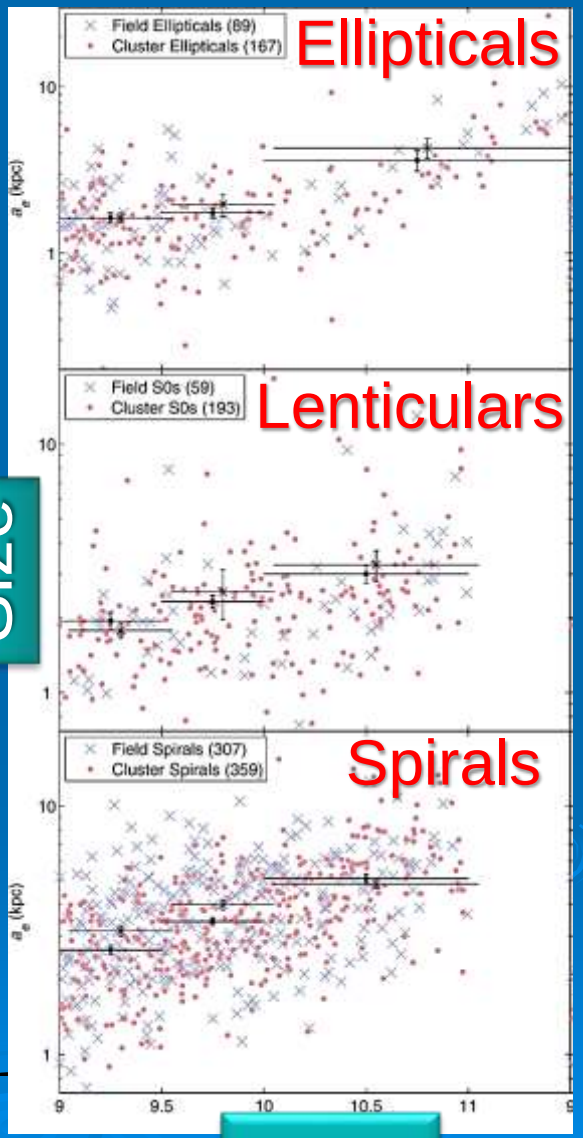
- Strong decrease of spirals in Coma
- Strong increase of fast rotators
- But less core slow rotators in Coma

$M - R_e$ universality at $z \sim 0$



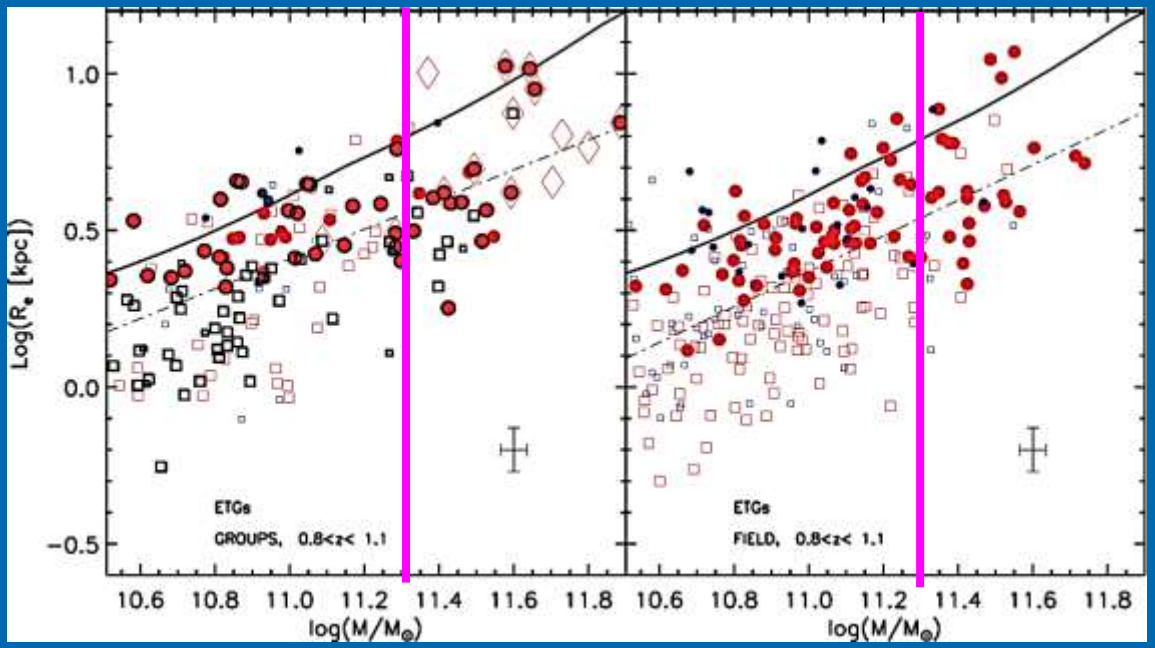
(Huertas-Company+13b)

- Same relation in cluster and field (Maltby+10)
- Independent of halo mass (Huertas-Company+13)
- Essential to select identical morphology/age

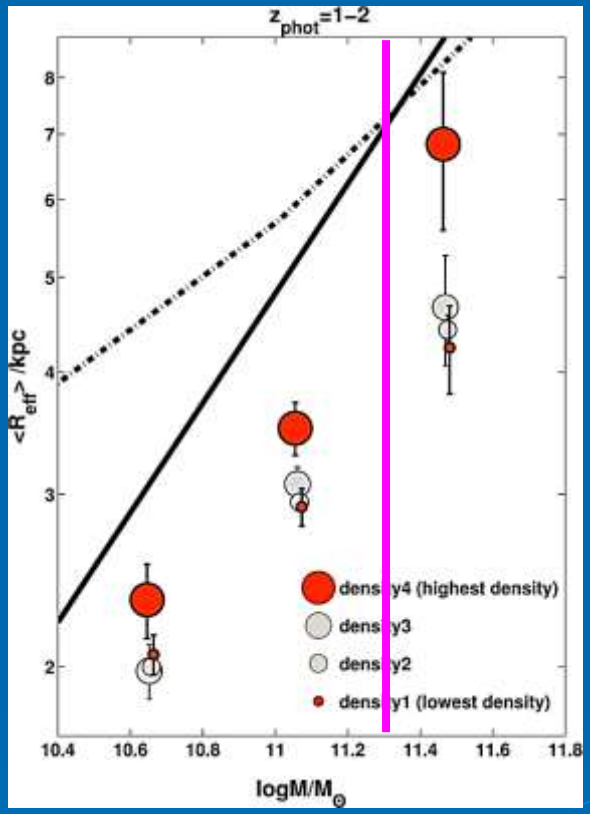


(Maltby+10)

$M - R_e$ universality up to $z \sim 1$



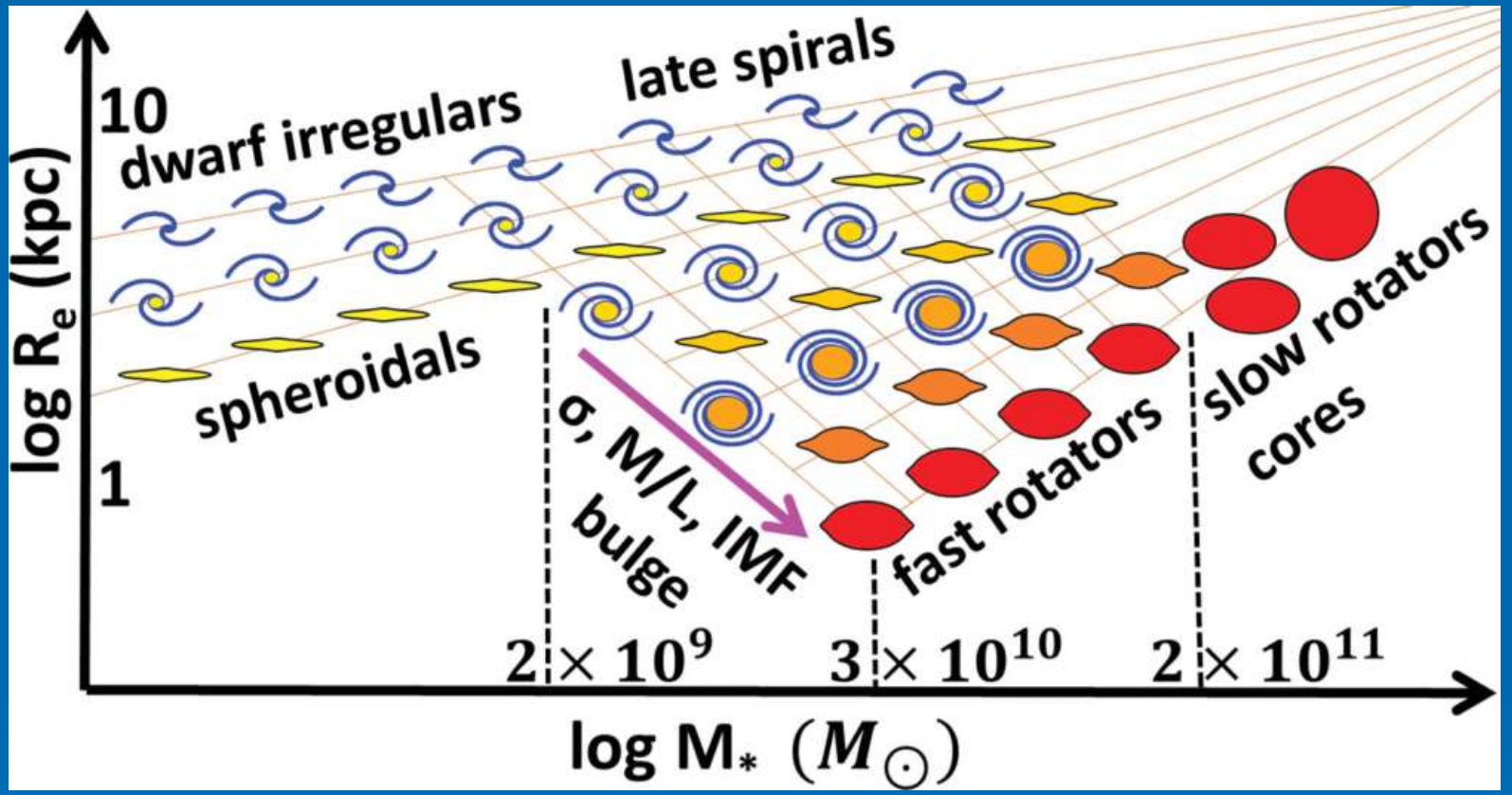
(Huertas-Company+13a)



(Lani+13)

- Unchanged in field/groups to $z \sim 1$ (Huertas-Company+13a)
- 25% larger sizes in groups to $z \sim 1$ (Cooper+12; Delaye+arXiv)
- 50% larger sizes in groups for $M_* \gtrsim 2 \times 10^{11} M_\odot$ (Lani+13)

Importance of global picture



(Cappellari+13b: ATLAS^{3D}-20)

- Bulge linked to quenching for $M_* \lesssim 2 \times 10^{11} M_\odot$

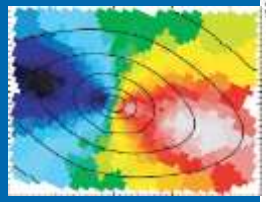
  (also Cappellari-11; Bell+12; Saintonge+12; Cheung+12; Fang+13)

- Three characteristic galaxy stellar masses

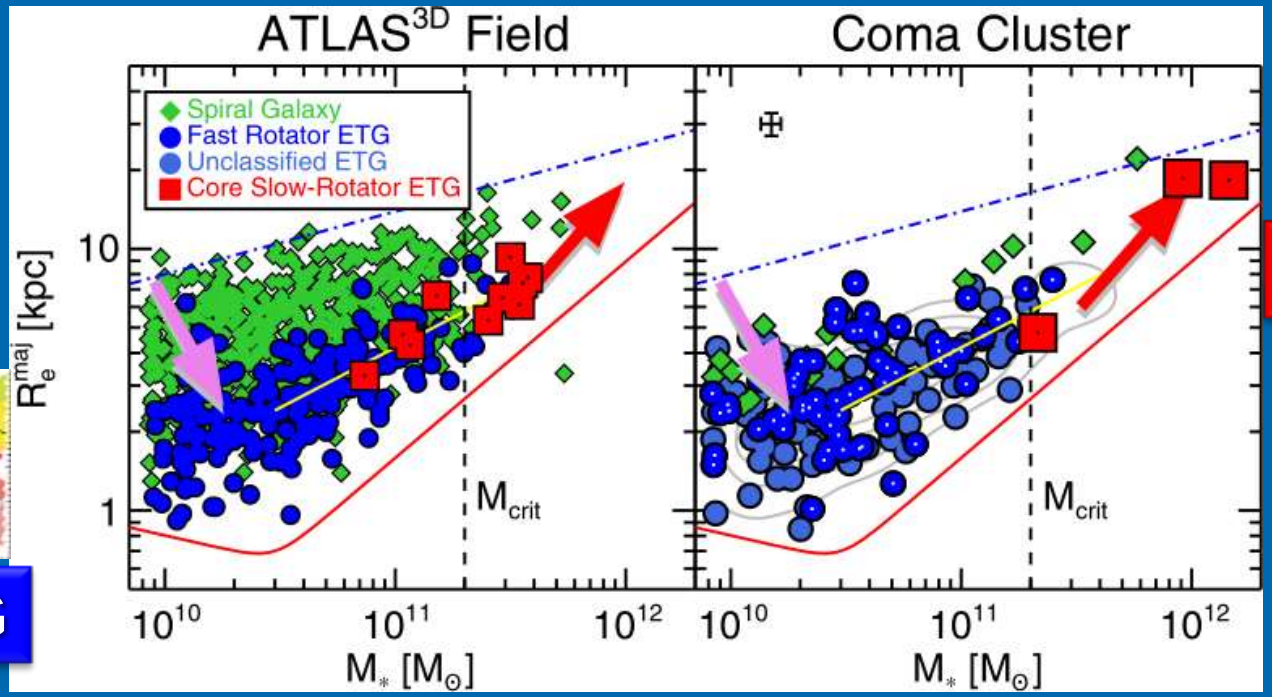
  (cfr. Faber+97; Kauffmann+03; van der Wel+09; Bernardi+11; Geha+12)

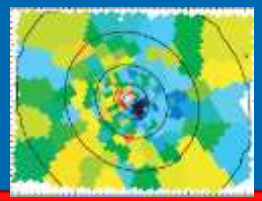
From outside-in to inside-out evolution

spiral



fast ETG





slow ETG

Coma dark halo:
$M \approx 1.4 \times 10^{15}\ M_\odot$
(Lokas+Mamon03)

$\Delta \log \Sigma_3 \sim 3$
increase in number density

(Cappellari-13 ApJL)

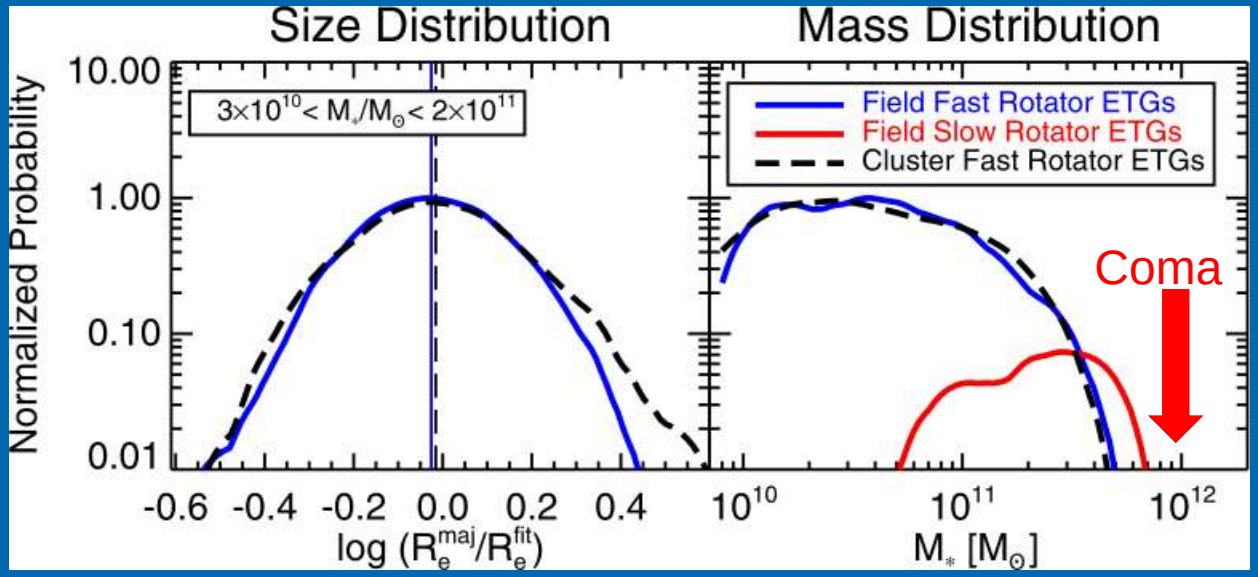
Spirals → Fast rotators

- NO mass change
- Environment quenching
- Bulge quenching
- outside-in evolution

Core slow rotators →

- Mass growth $M \propto R_e$
- Mass quenching
- Halo quenching
- Inside-out evolution

Mass and size distribution Coma/field



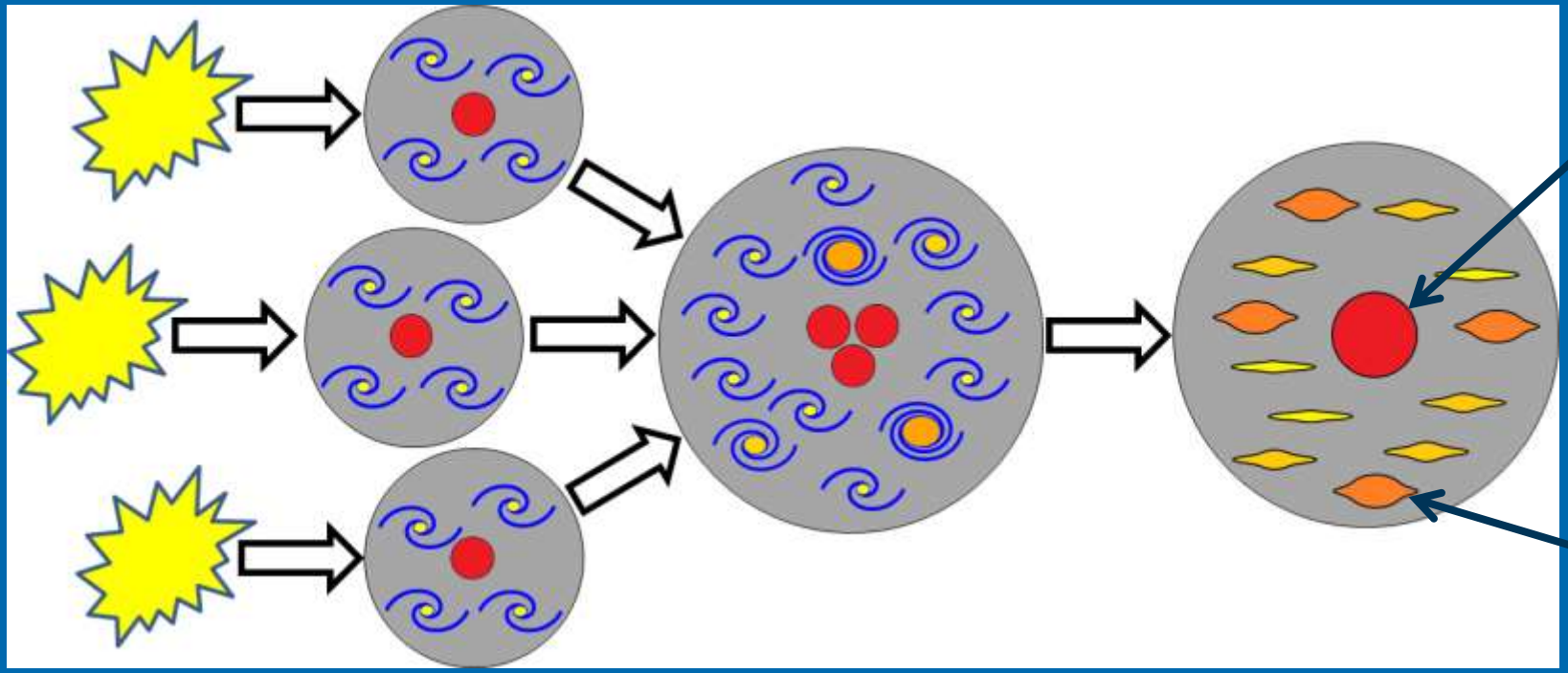
(Cappellari-13 ApJL)

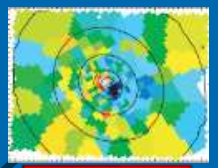
Spiral in the Field

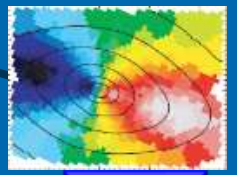
Red Spiral in Coma

- **Fast rotators**
  - Mass distribution unchanged
  - Mean sizes unchanged (within 4%)
    - But tail at larger sizes in cluster (also Delaye+13 arXiv)
    - Red spirals common in cluster (vanDenBergh-76; Wolf+09; Masters+10)
- **Core slow rotators** mass segregated in Coma
  - Inconsistent with Schechter extrapolation

Hierarchical morphology evolution







Fast rotators

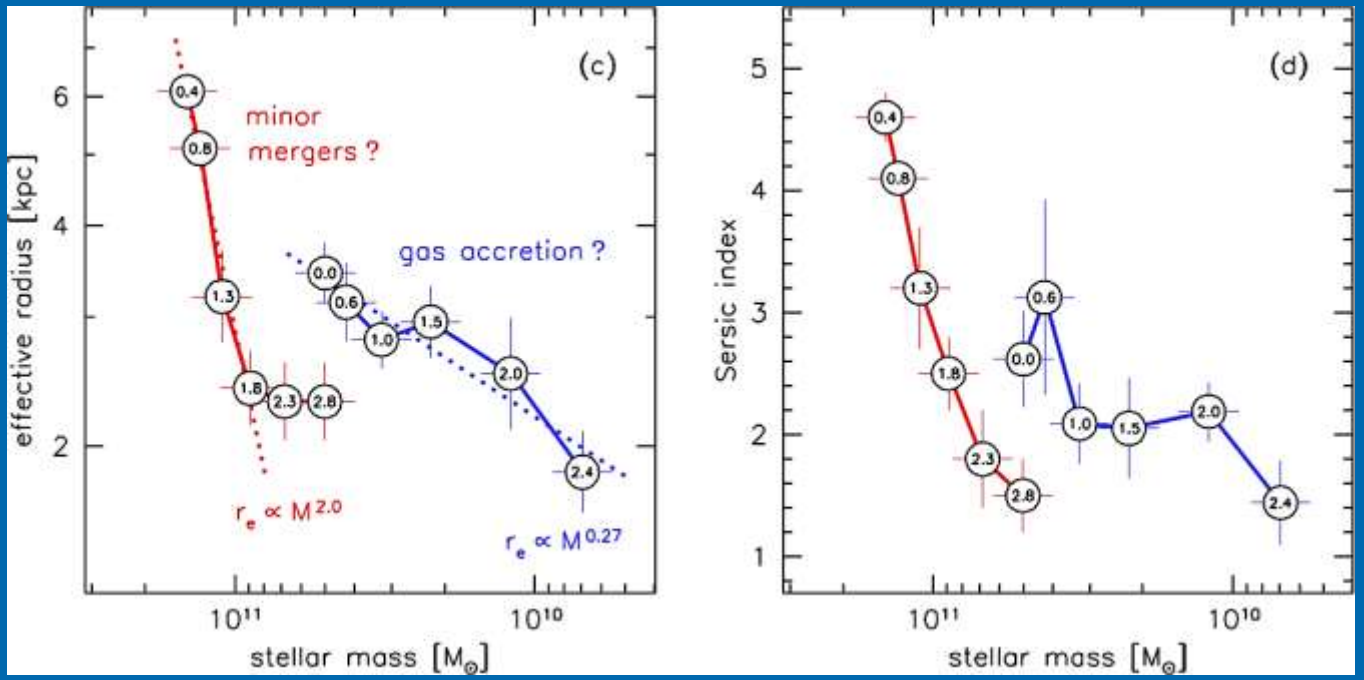
- Always satellites
- Quenched by environment
- Bulge grows with quenching

(also De Lucia+12; Wilman+Erwin-12)

Core slow rotators

- Always centrals
- Sink by dynamical friction
- ISM → No cold accretion
- Mass grows by dry mergers

$M - R_e$ redshift evolution



(vanDokkum+13)

$M \lesssim 2 \times 10^{11} M_\odot$

- Weak size increase
- Sersic $n \sim 2$

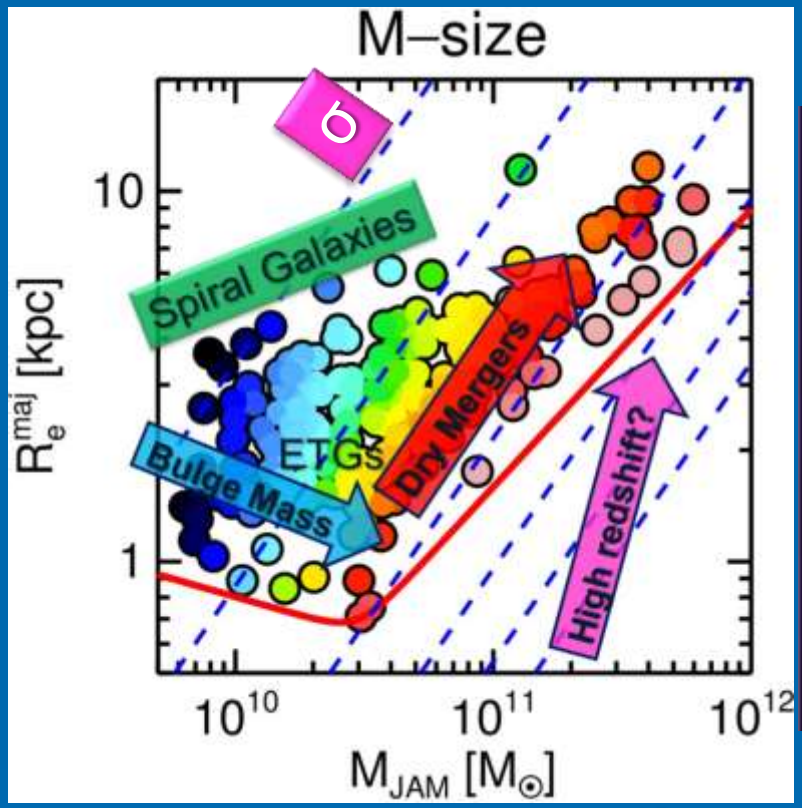
(e.g. Barden+05; Sargent+07; Nagy+11)

$M \gtrsim 2 \times 10^{11} M_\odot$

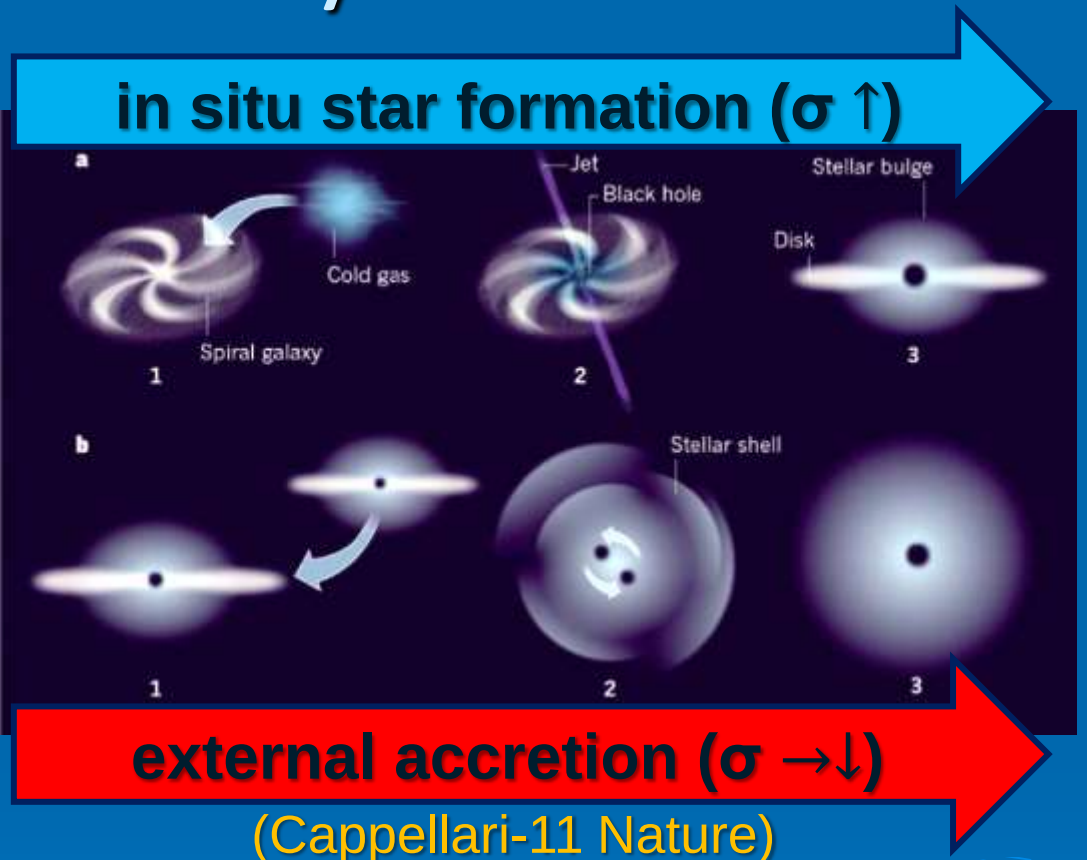
- Strong size increase
- Sersic varies $n \sim 1 \rightarrow 5$

(e.g. Daddi+05; Trujillo+06; van Dokkum+08; Saracco+09…)

Summary



(Cappellari+13b: ATLAS^{3D}-20)



(Cappellari-11 Nature)

$M \lesssim 2 \times 10^{11} M_\odot$

- Bulge growth + quenching
- Evolve from spirals
- Mergers unimportant

$M \gtrsim 2 \times 10^{11} M_\odot$

- Dry mergers + halo quenching
- Significant mass growth
- Driven by major/minor mergers