Galaxies: Elliptical galaxies

ASTR 505

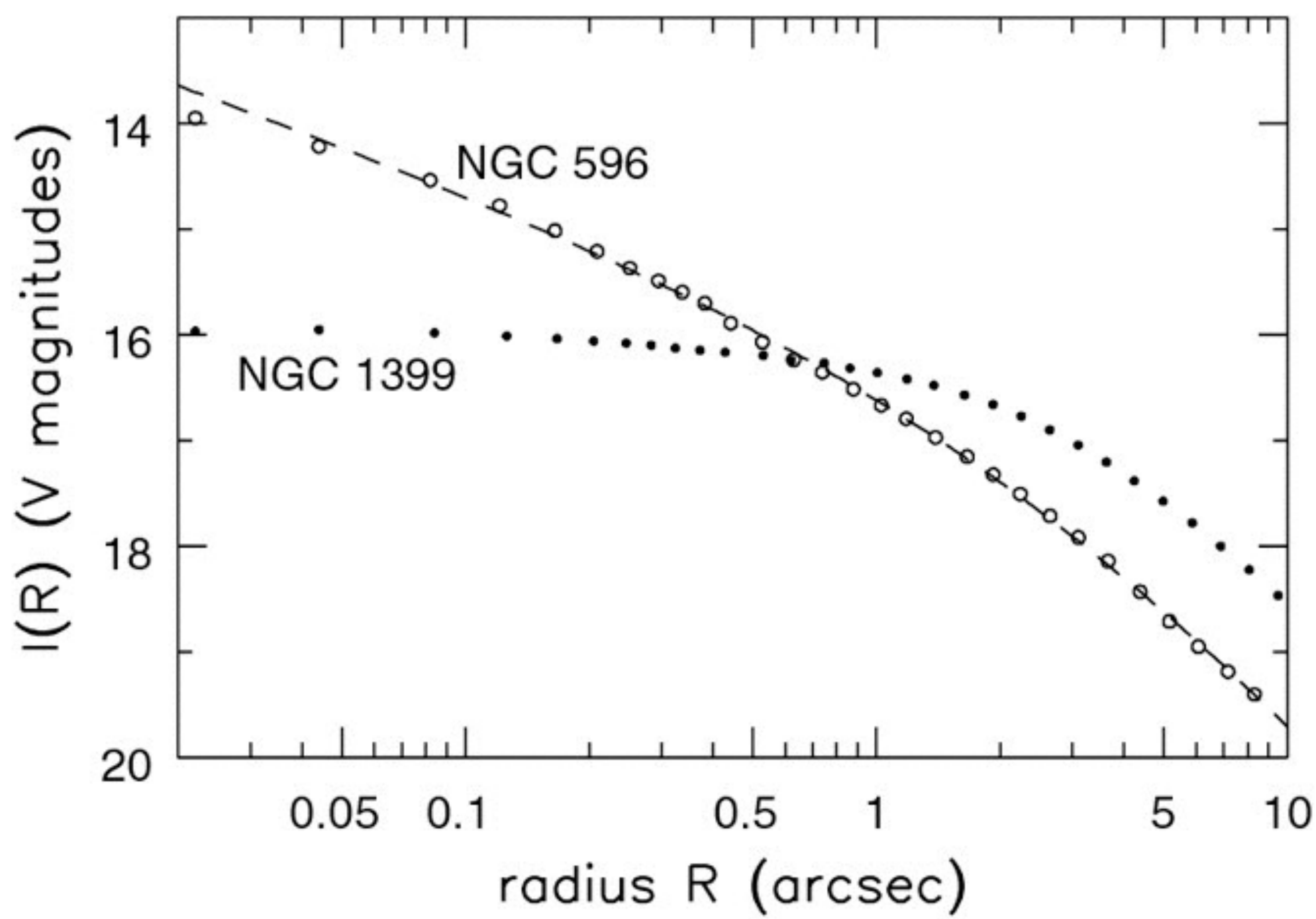
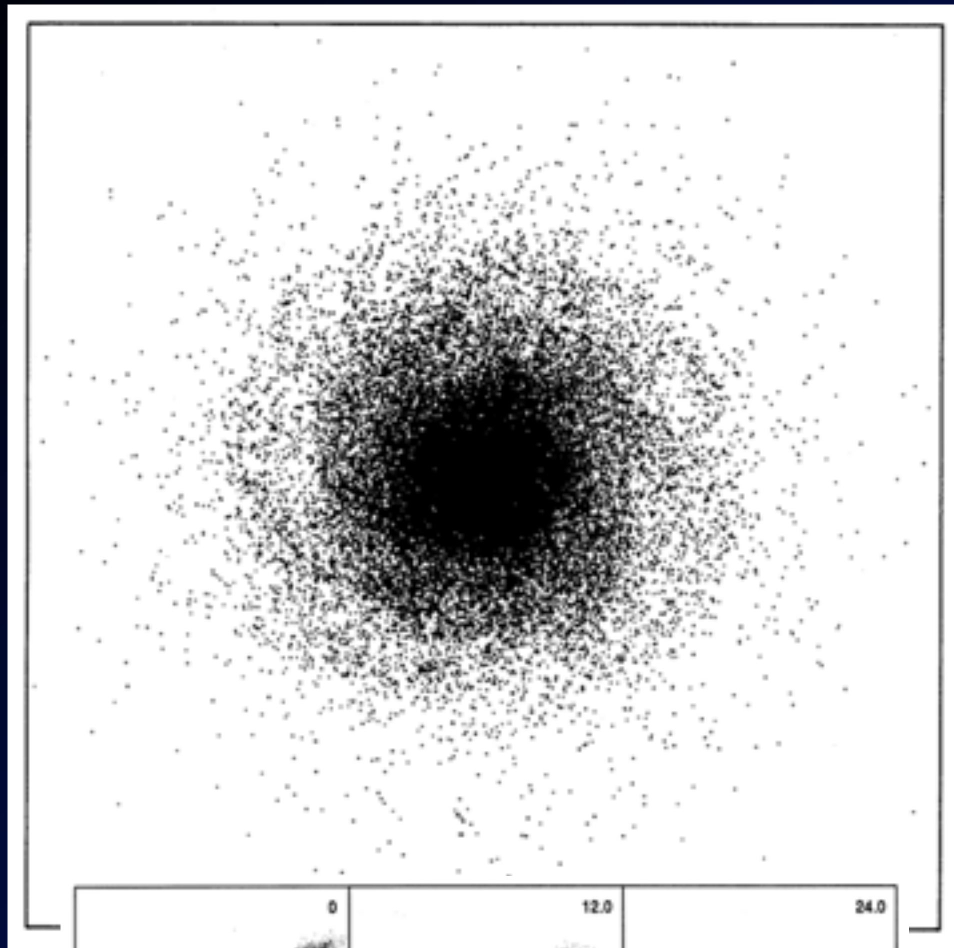
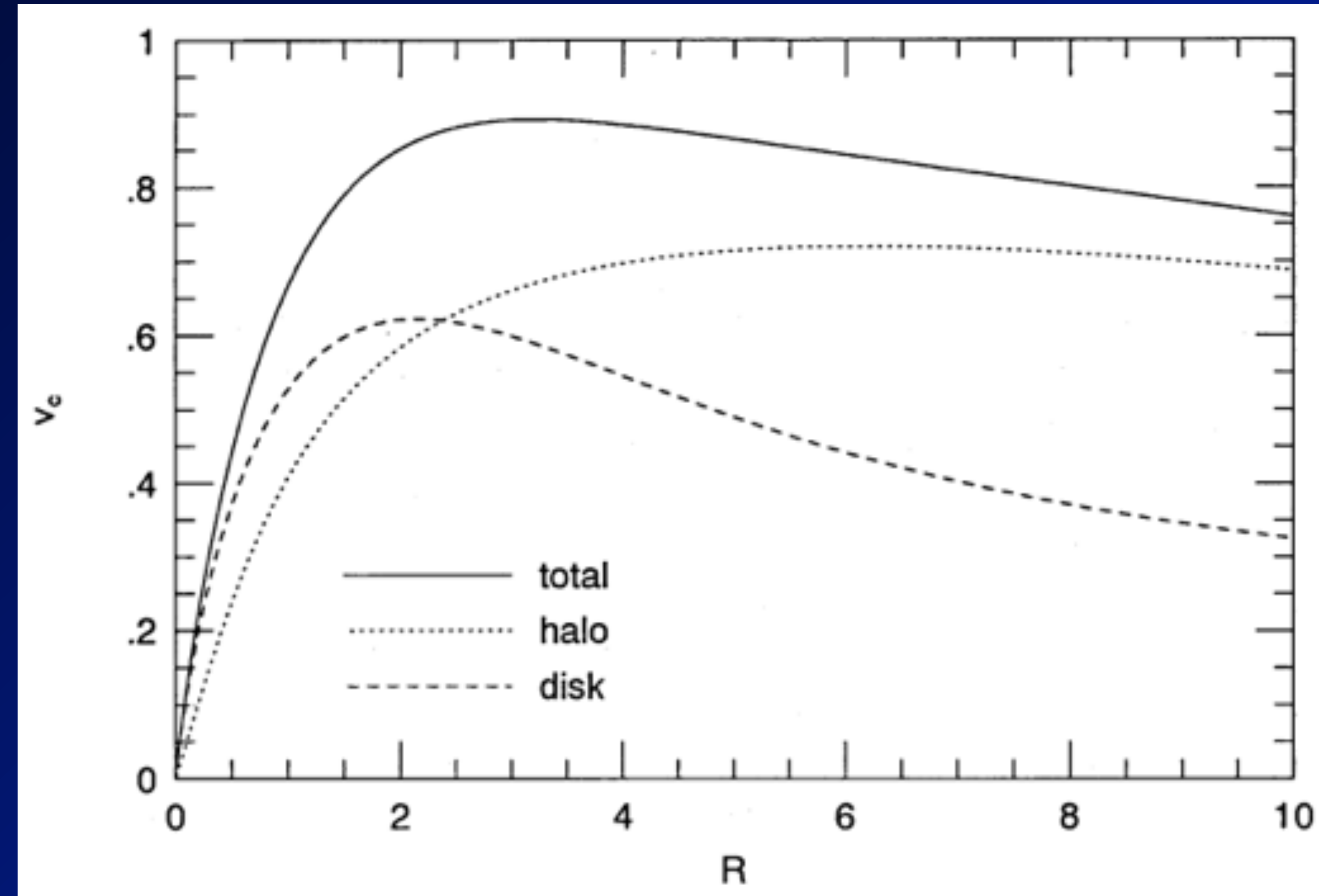


Fig 6.7 (T. Lauer) 'Galaxies in the Universe' Sparke/Gallagher CUP 2007





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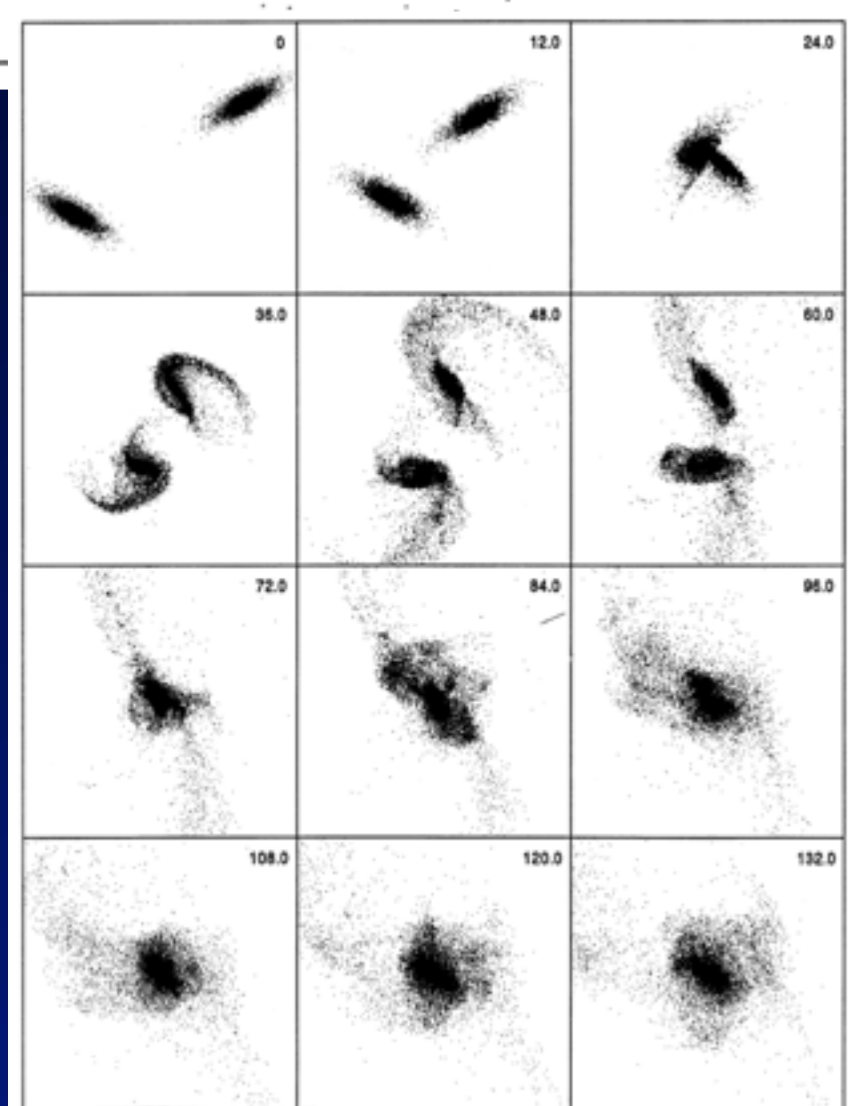

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72.0
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96.0
108.0
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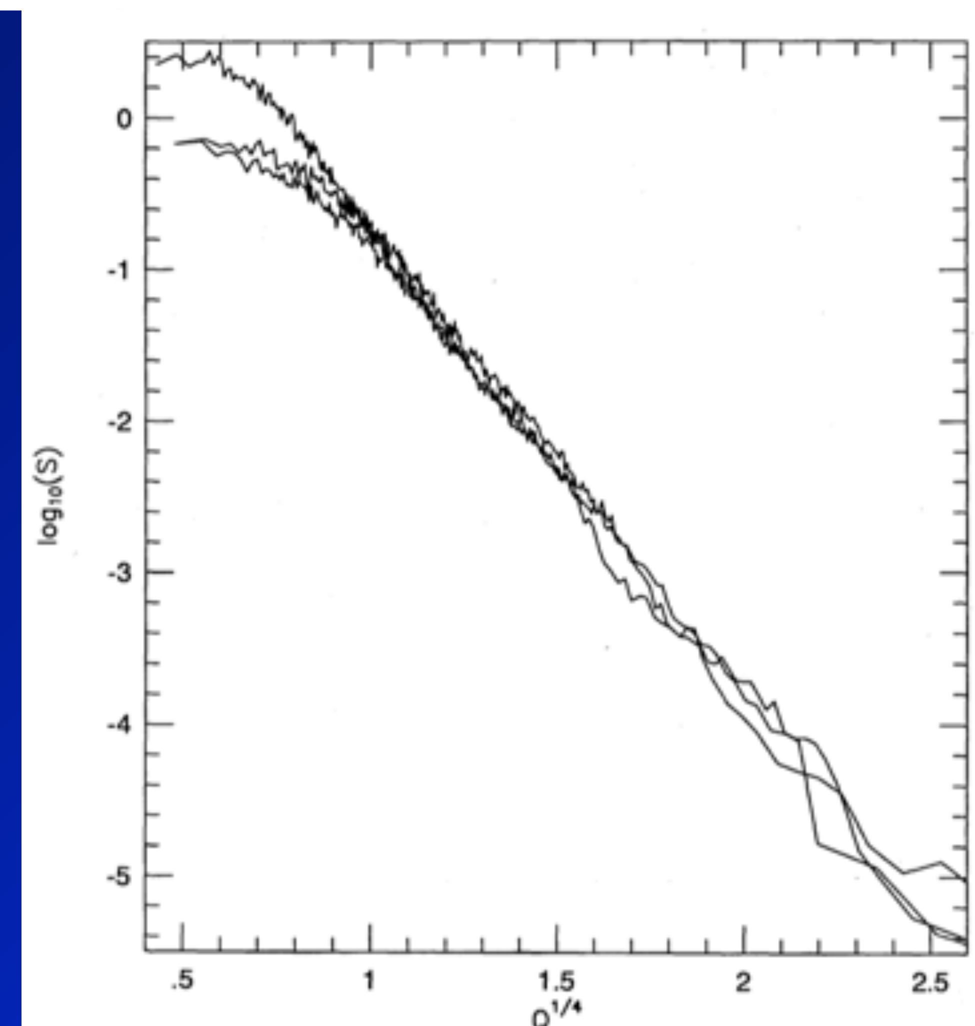
132.0



0
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1
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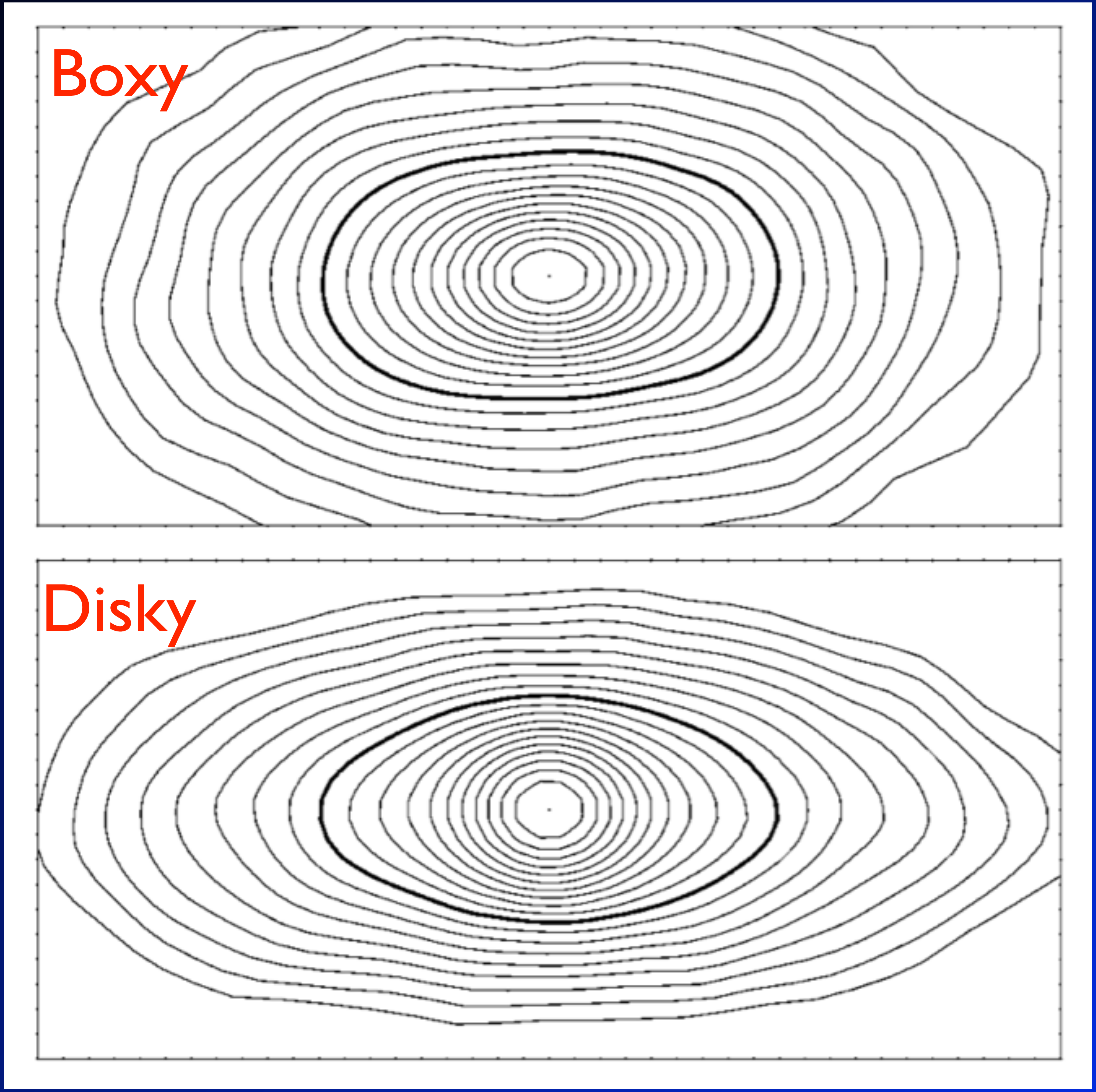
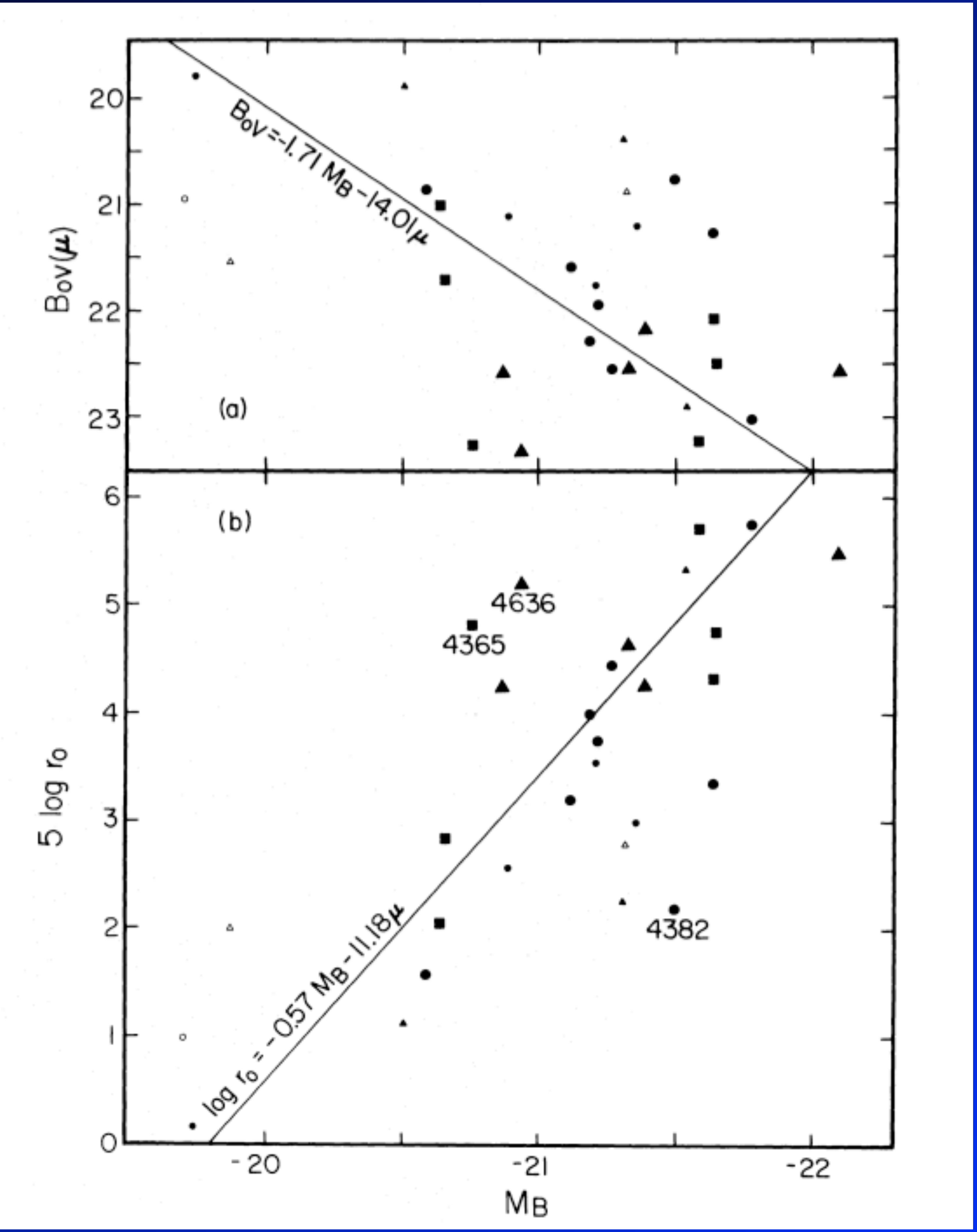
2
2.5
$\log_{10}(S)$
$Q^{1/4}$


Boxy
Disky

Kormendy (1977)



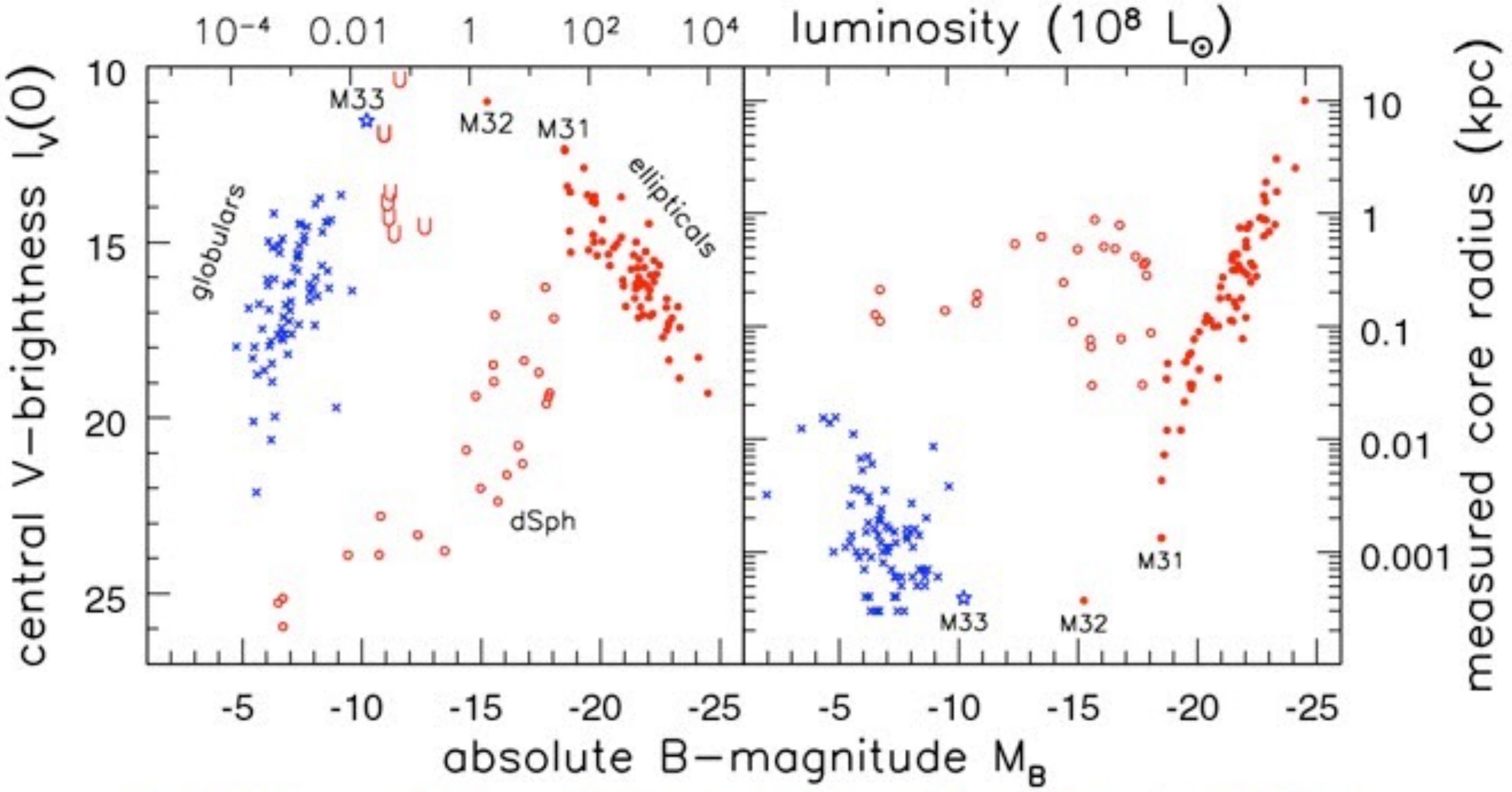


Fig 6.6 (Kormendy, Philipps) 'Galaxies in the Universe' Sparke/Gallagher CUP 2007

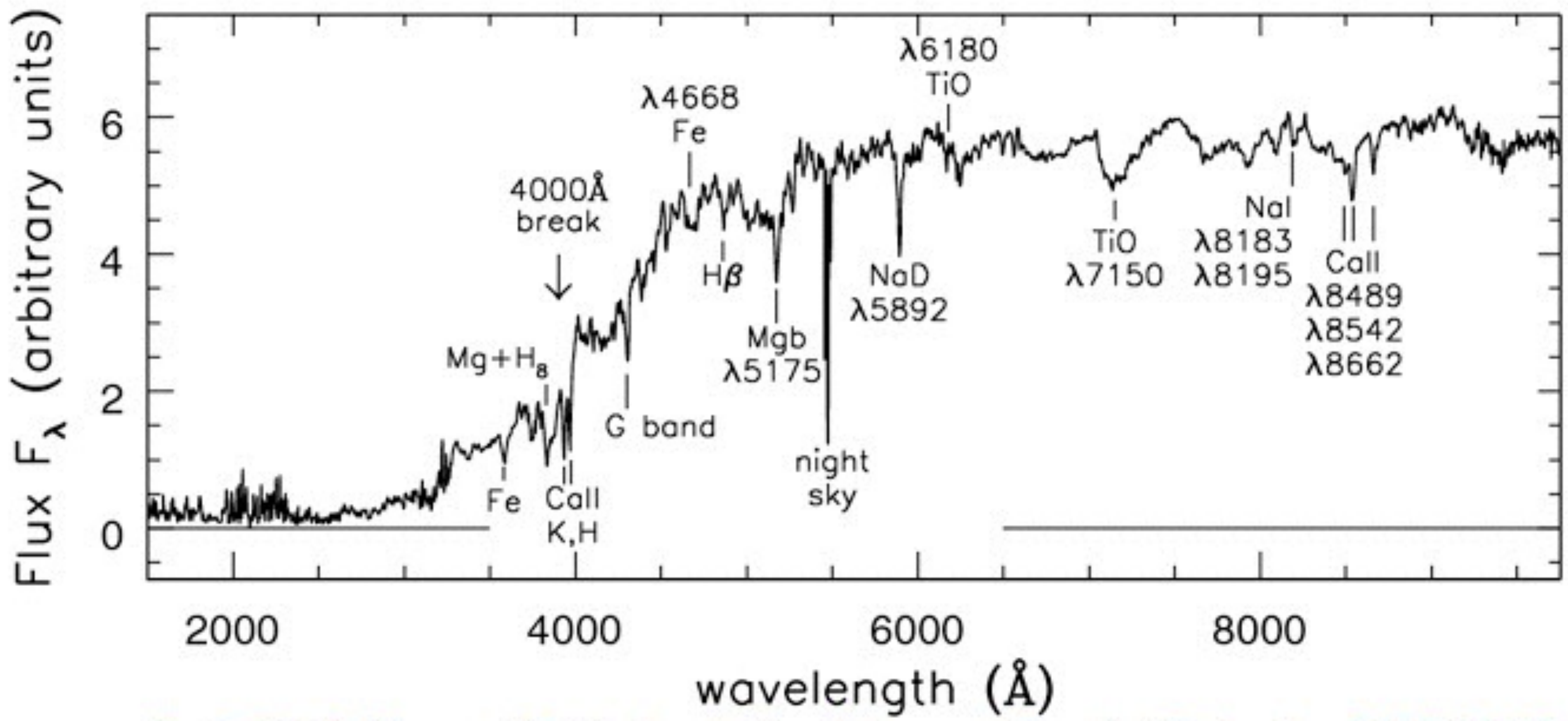


Fig 6.17 (A. Kinney) 'Galaxies in the Universe' Sparke/Gallagher CUP 2007

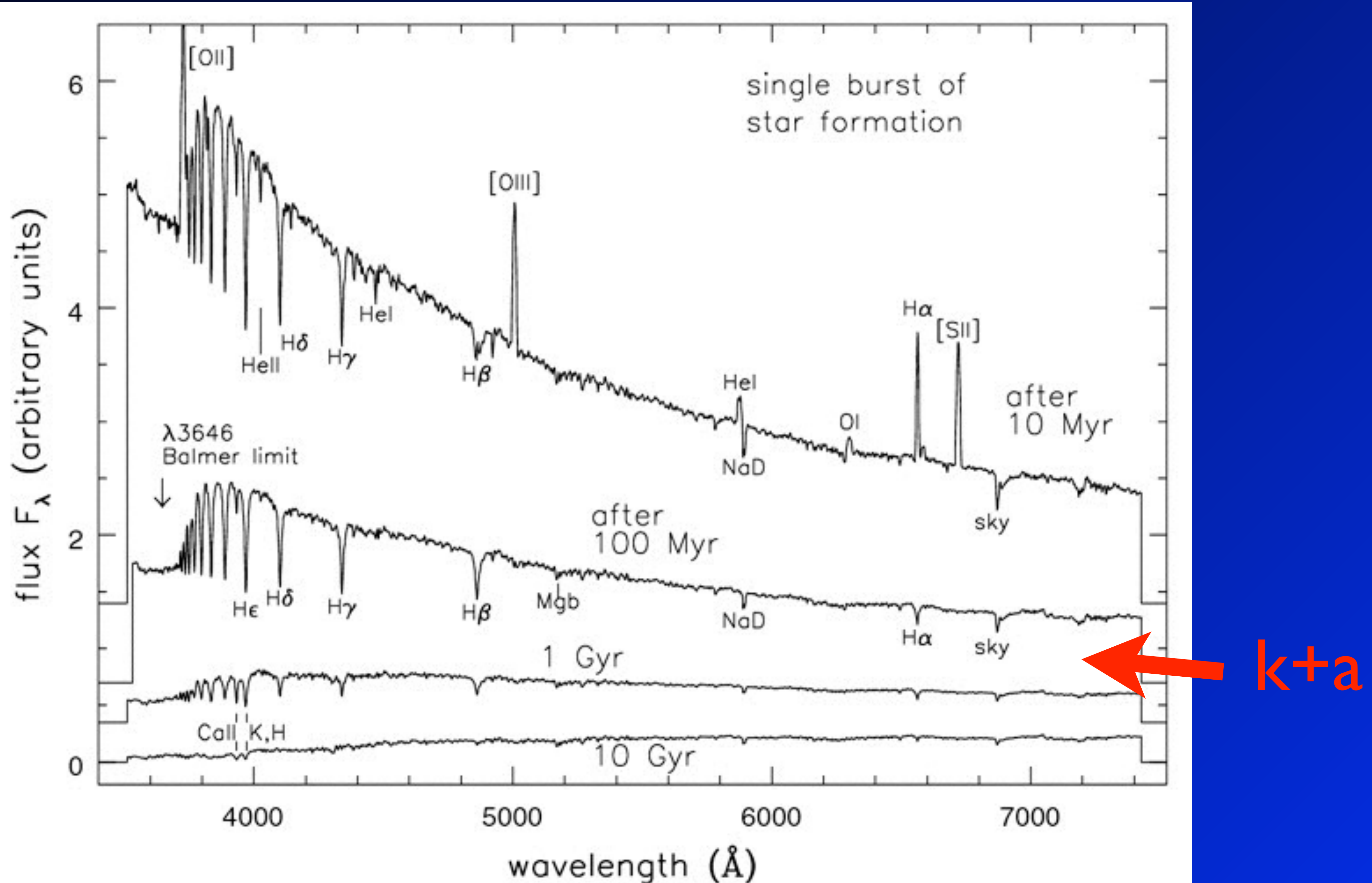


Fig 6.18 (B. Poggianti) 'Galaxies in the Universe' Sparke/Gallagher CUP 2007

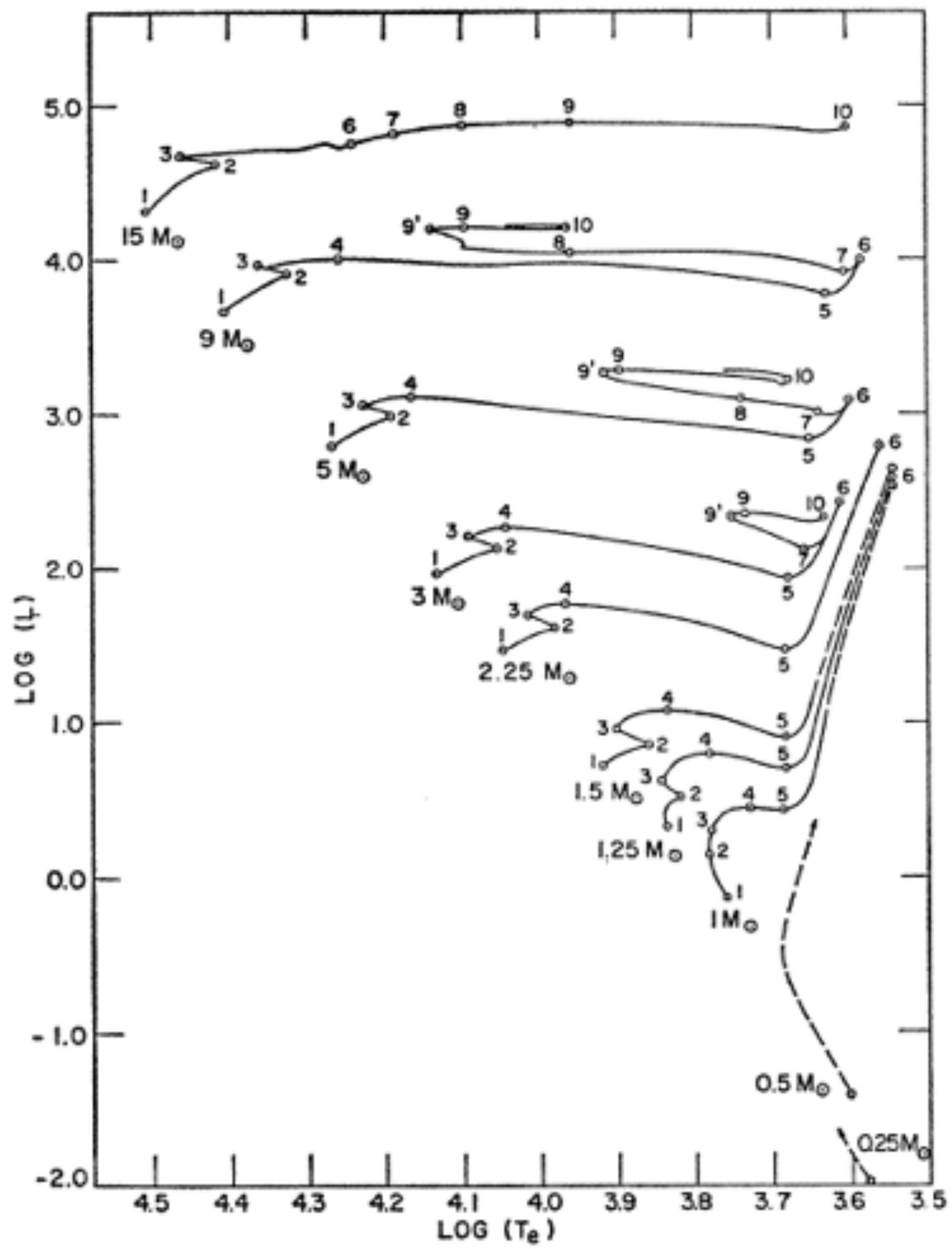


FIG. 3. Paths in the H-R diagram for metal-rich stars of mass $(M/M_{\odot})=15$, 9, 5, 3, 2.25, 1.5, 1.25, 1, 0.5, 0.25. Units of luminosity and surface temperature are the same as in Figure 1. Traversal times between labeled points are given in Tables III and IV. Dashed portions of evolutionary paths are estimates.

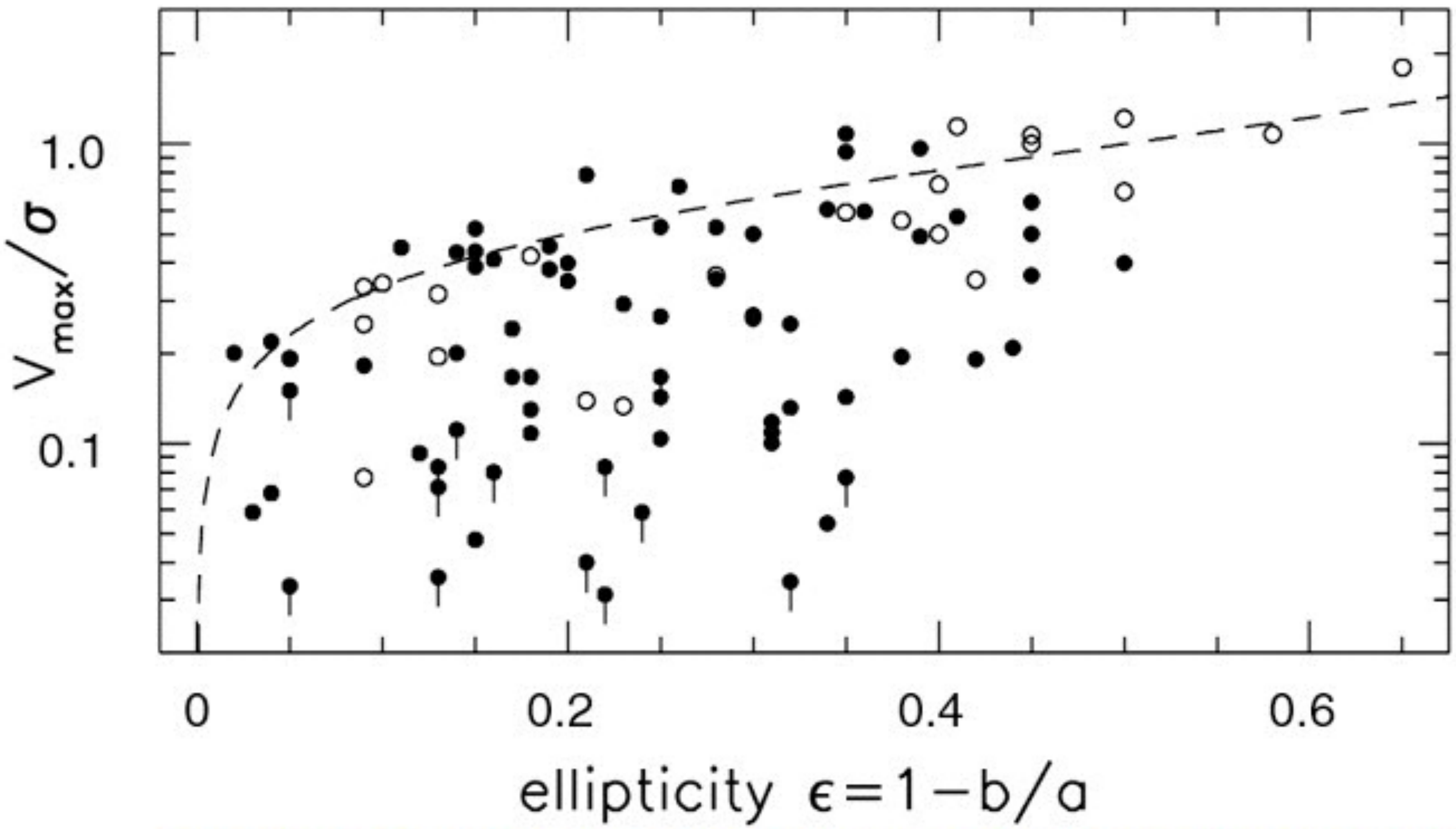


Fig 6.14 (R. Bender) 'Galaxies in the Universe' Sparke/Gallagher CUP 2007

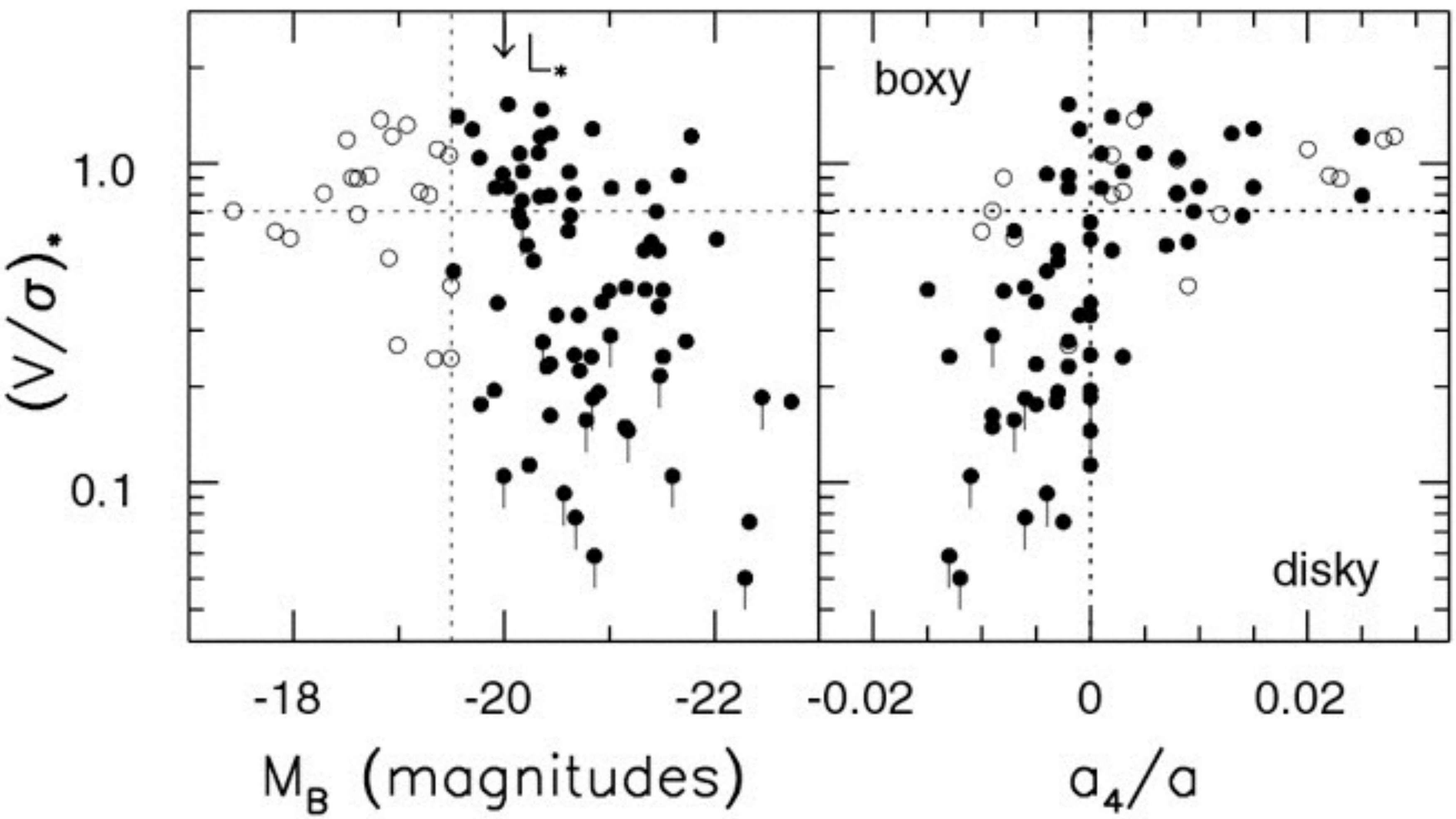
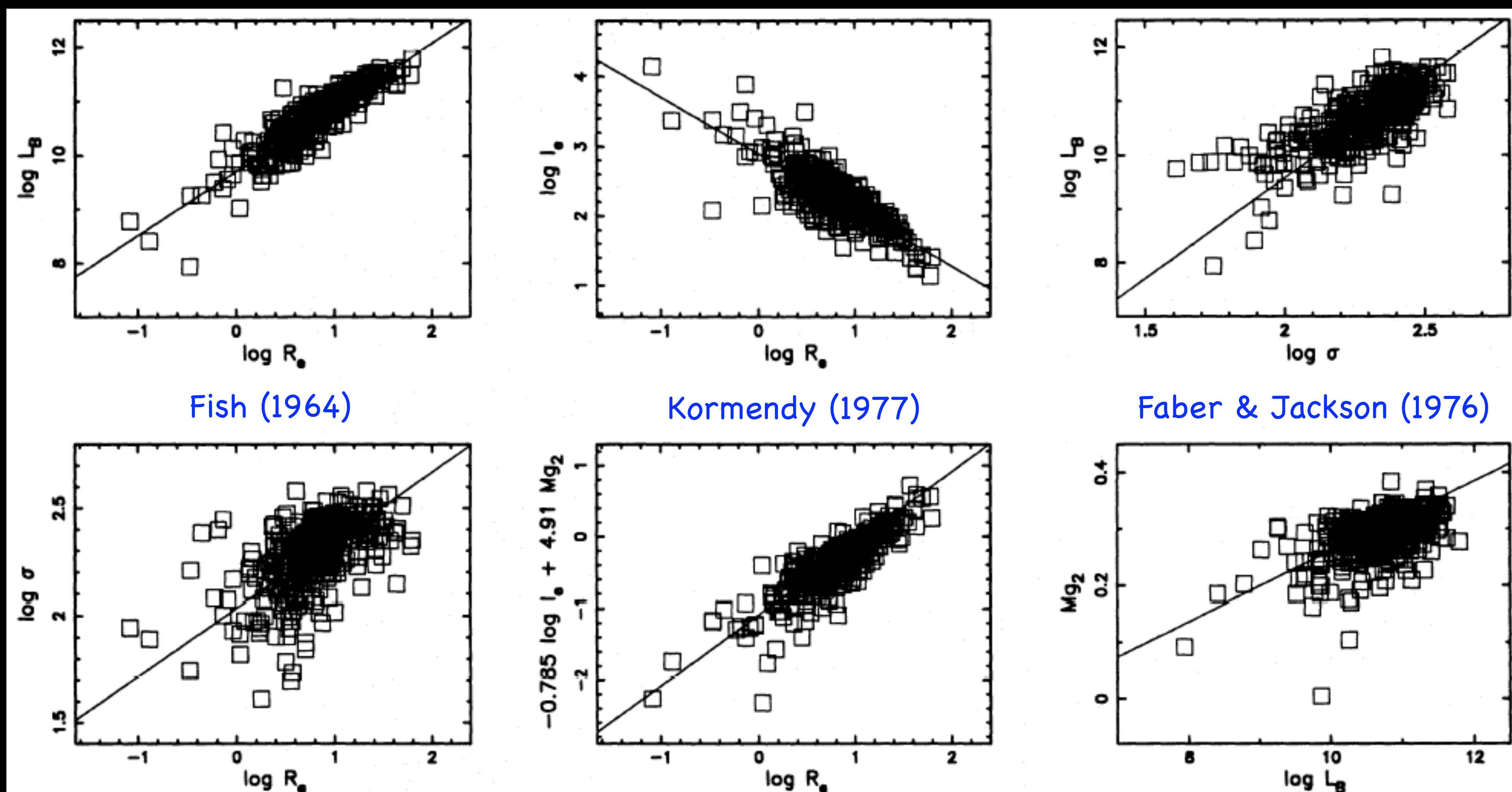


Fig 6.15 (R. Bender) 'Galaxies in the Universe' Sparke/Gallagher CUP 2007

To Summarize....

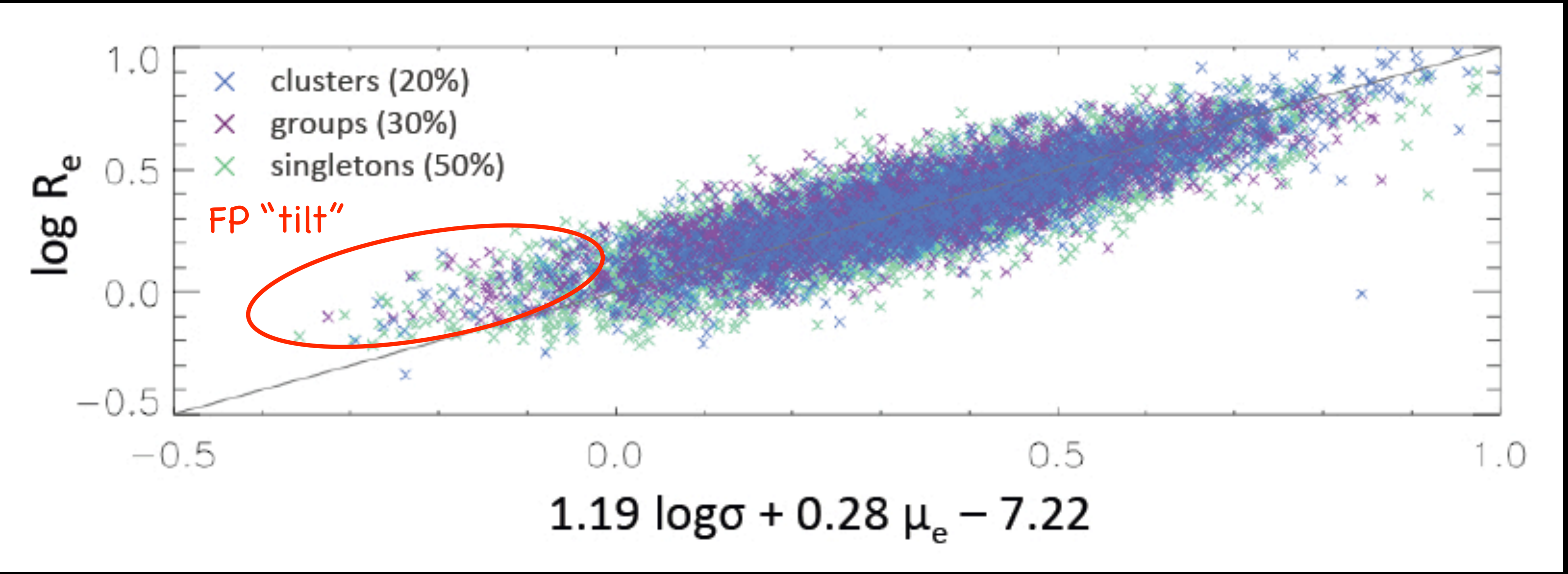
- Luminous ("giant" = "normal" = "ordinary") galaxies obey a well-defined set of scaling relations between their photometric (and kinematic) structural parameters: e.g., Fish (1964), Faber & Jackson (1976), Kormendy (1977), Binggeli, Sandage & Tammann (1984), Dressler et al. (1987), Djorgovski & Davis (1987), and many, many others. [See Cappellari et al. 2006 for the very latest results.] Late-types usually considered separately, and dwarfs, usually not at all.

Guzman et al. (1993)



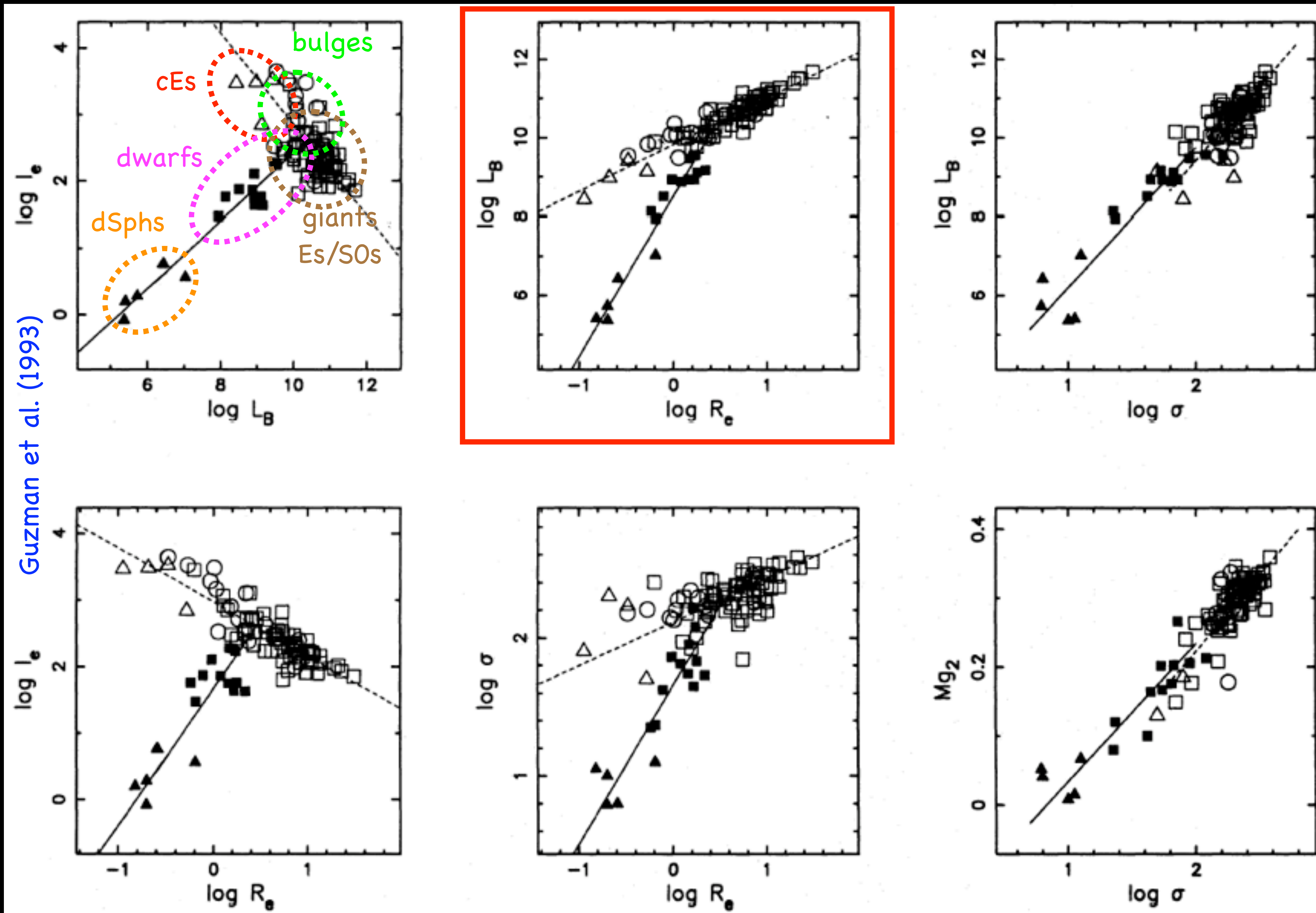
Es/S0s and the Fundamental Plane

- Edge-on projection of the Fundamental Plane for 10K early-type galaxies from the 6dFGS (Colless et al. 2009; www.aao.gov.au/6dFGS).



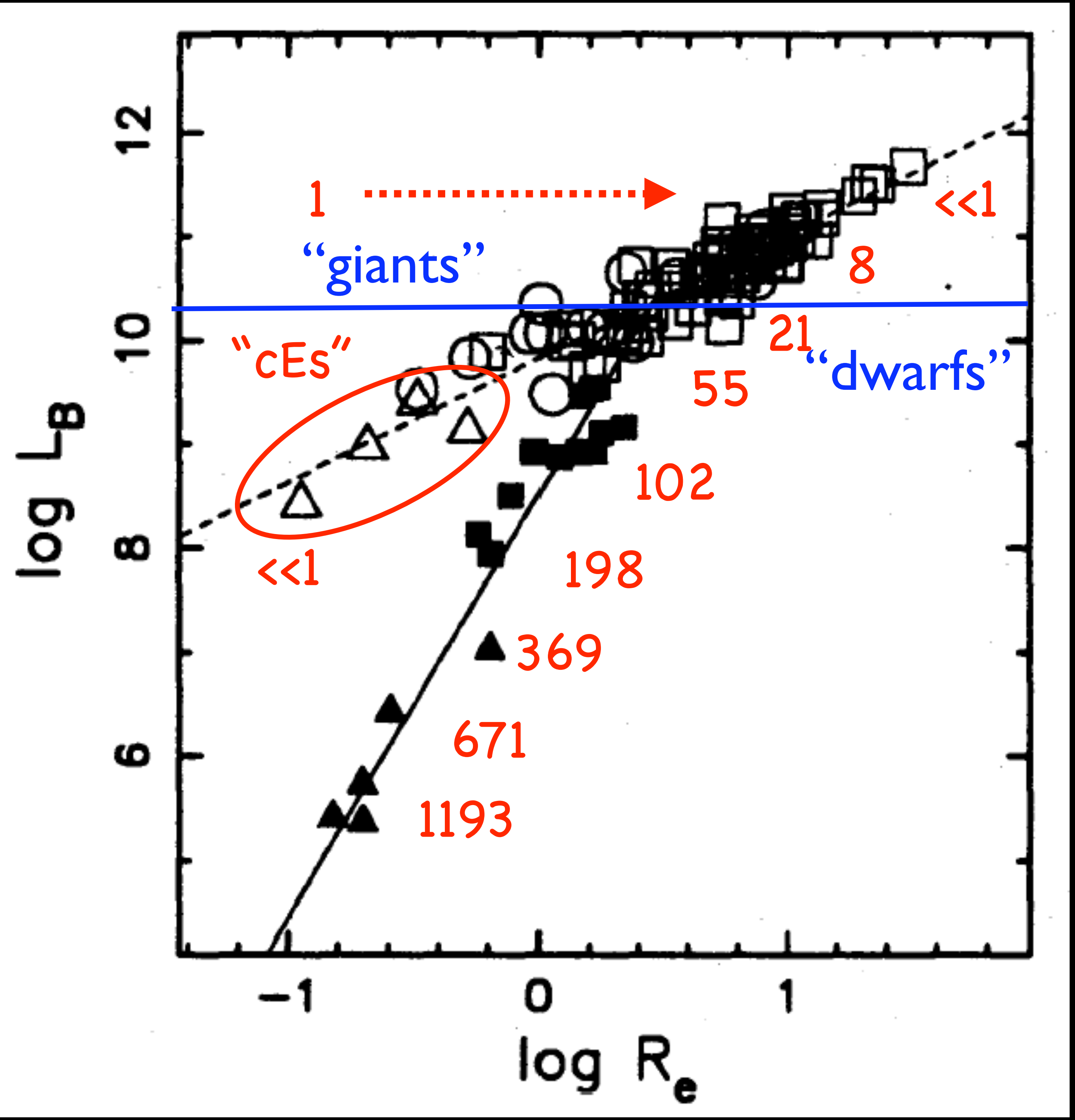
- Note: does not include "dwarfs" (i.e., the sample has a mass cutoff of $10^{10.5}$ solar masses).

The Extension From "Giants" to "Dwarfs"



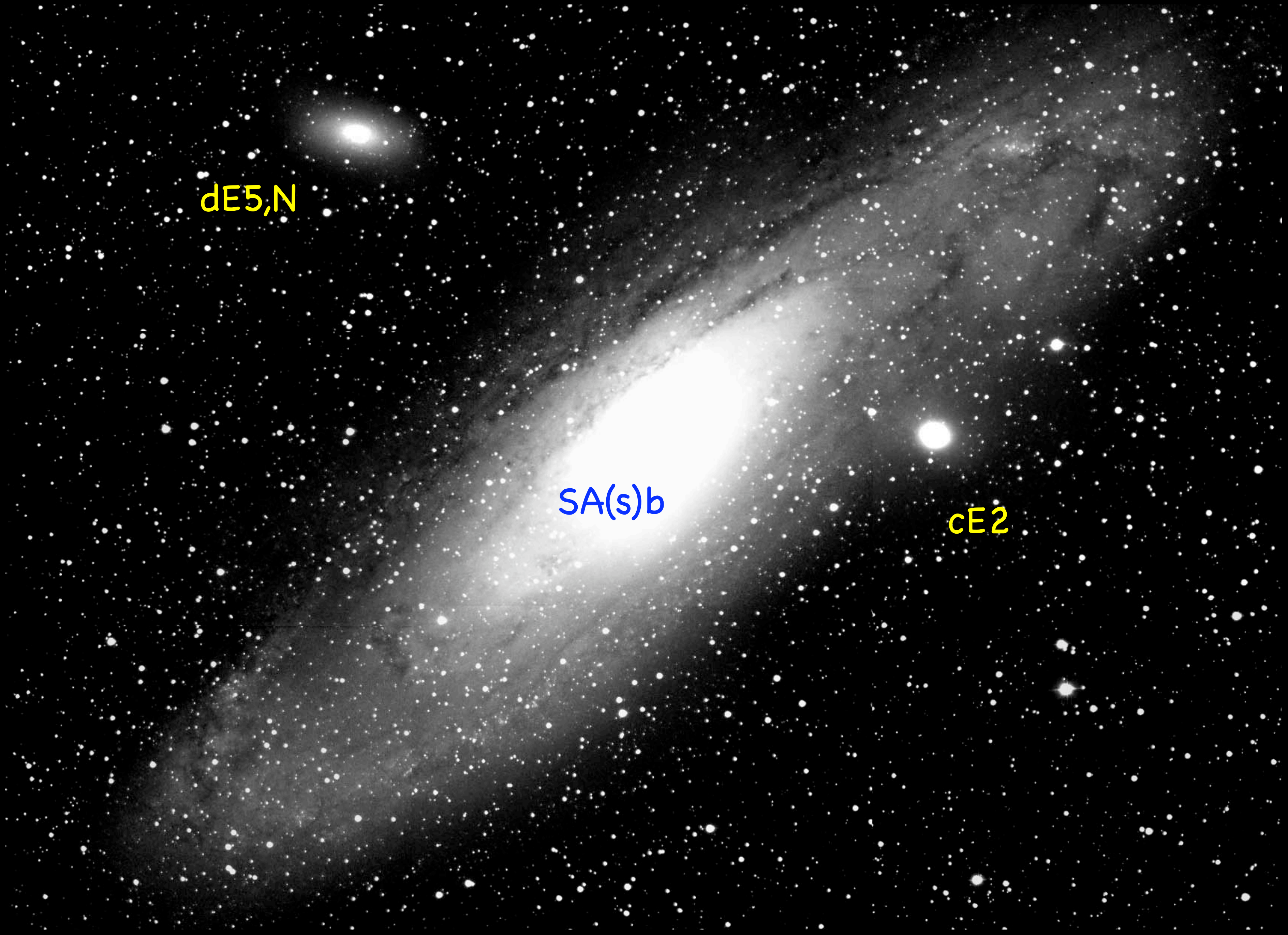
The Importance of Complete and Representative Samples

- "Classical" scaling relations represented with figures of this sort (e.g., TF, FJ, etc).
- However, there is a third dimension to such figures: the relative number of galaxies in volume-limited samples.
- Use the galaxy counts from Binggeli, Sandage & Tammann (1985) and normalize the distribution to 1 galaxy per cluster at $L_B = 10^{11.5}\ L_\odot$



Guzman et al. (1993)

M32 and NGC205: Low-Mass E Galaxies

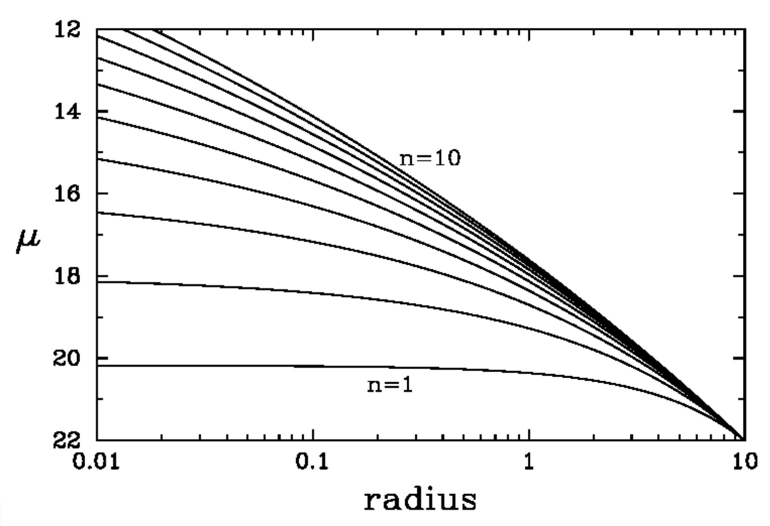


Andromeda, M32 and NGC205 - Ground-Based - 1.5X2

Parameterization of the Surface Brightness Profiles

- Sérsic law (Sérsic 1968):

$$I(R) = I_e \exp(-b_n[R/R_e]^{1/n} - 1])$$

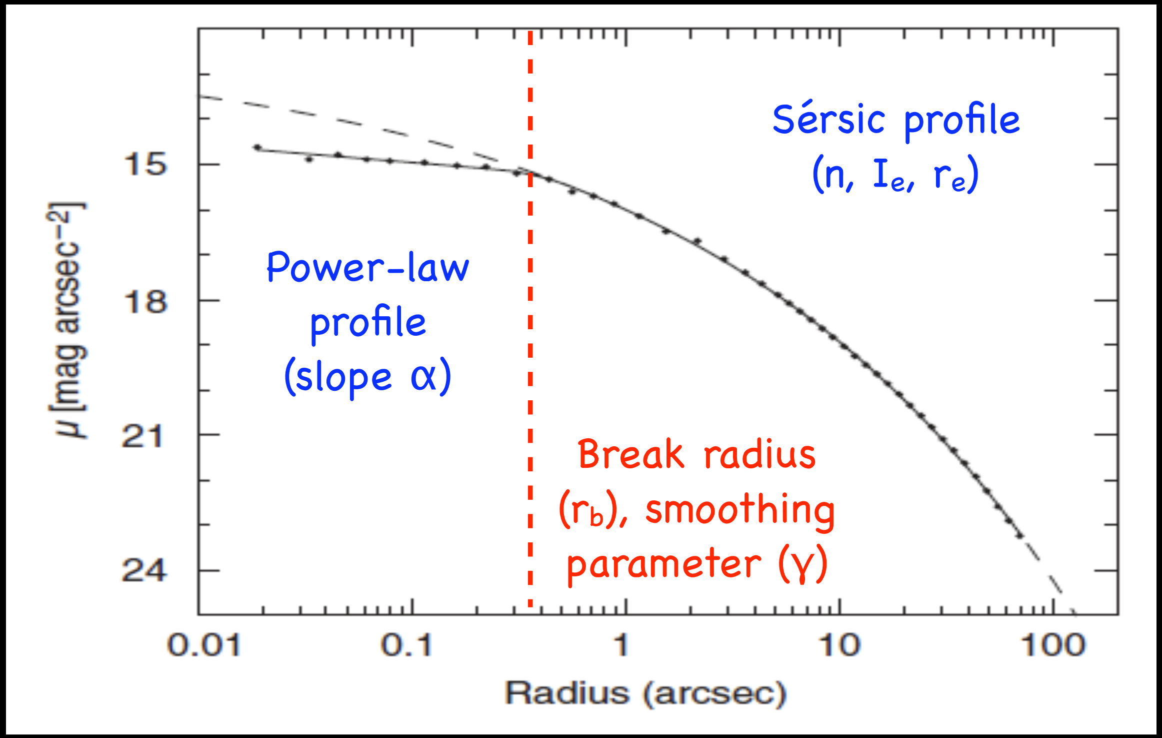


- Has a number of attractive features for parameterizing both the small- and large-scale profiles of E/dE galaxies:
  - Accounts for the profiles' curvature on kpc-scales
  - Parameters are robust against radial range of data (Graham et al. 2003)
  - Integrals for $r \rightarrow \infty$ converge (c.f., Nuker law)
  - Might have applicability to CDM halos (e.g., Merritt et al. 2005)
  - Concentration is a free parameter, giving the flexibility to fit the profiles of both high- and low-mass galaxies (i.e., galaxies are not assumed to be homologous).

A Modification of the Sérsic Model

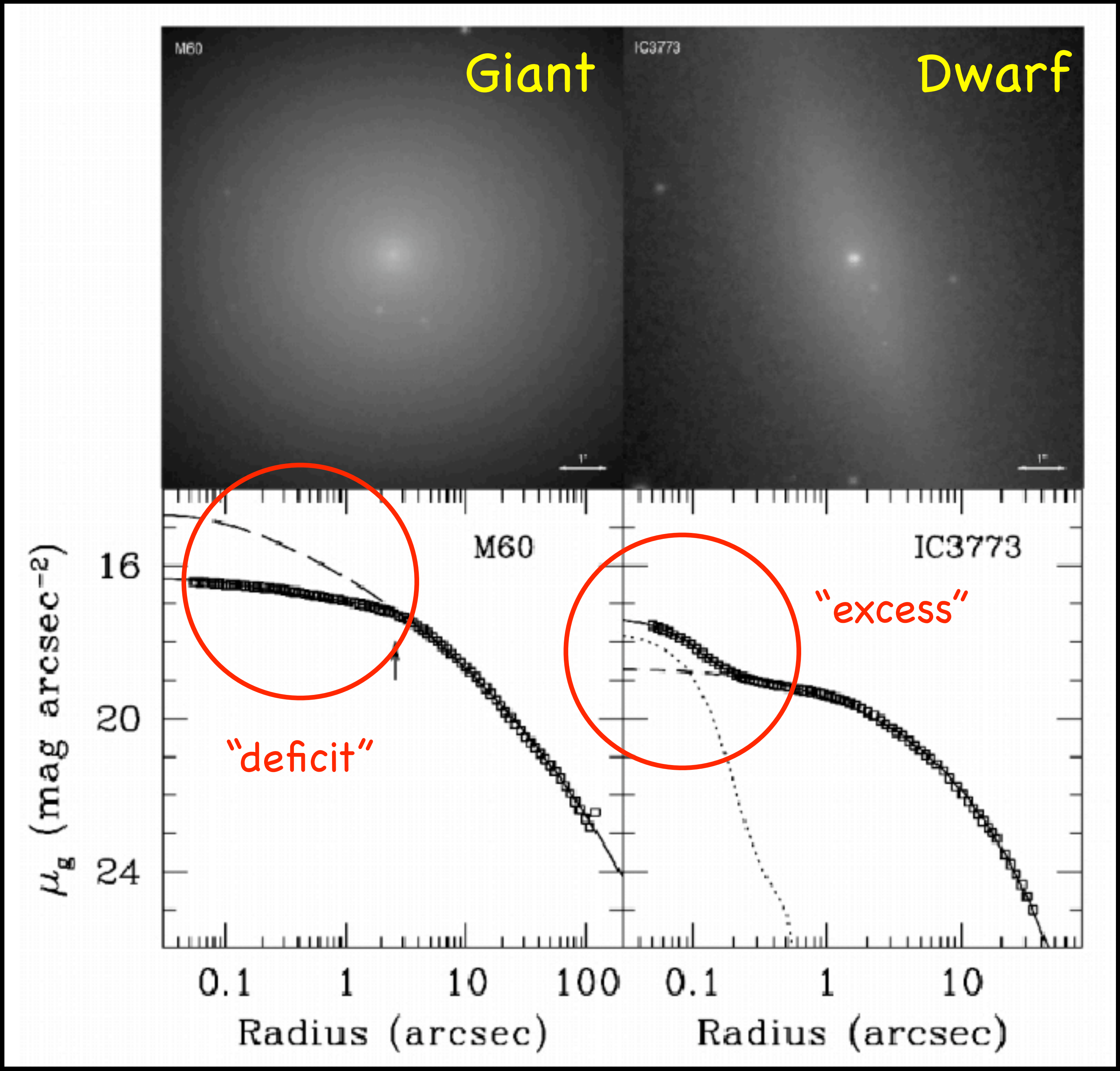
"core-Sérsic" law (Graham et al. 2003)

$$I(r) = I' \left[1 + \left(\frac{r_b}{r}\right)^{\alpha}\right]^{\gamma/\alpha} \exp\left[-b_n \left(\frac{r^{\alpha} + r_b^{\alpha}}{r_e^{\alpha}}\right)^{1/(\alpha n)}\right]$$



Motivation for the Core-Sérsic Parameterization: VCC1978 (M60)

core-Séric models

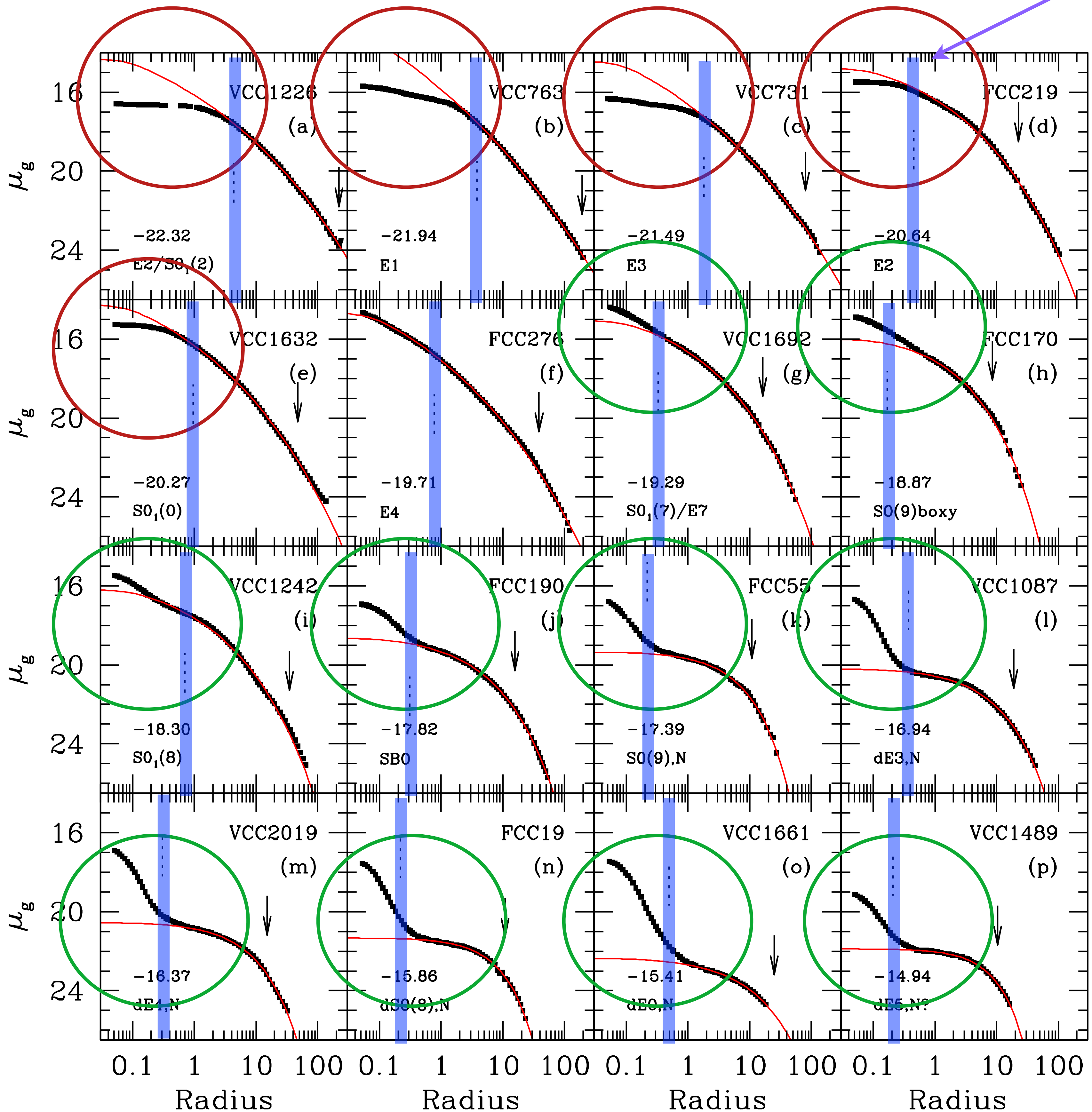


double Séric models

Ferrarese et al. (2006)

Global and Core Structure

2%R_e



Ferrarese et al. (2006a,b); Côté et al. (2006,2007)

Luminosity "Deficit"

For "giant" galaxies, a separation into core and "power-law" classes reported and discussed extensively in (Ferrarese et al. 1994, Lauer et al. 1995, Gebhardt et al. 1996, Faber et al. 1997, Rest et al. 2001, Ravindranath et al. 2001, etc).

Transition from Central Luminosity Deficit to Excess:

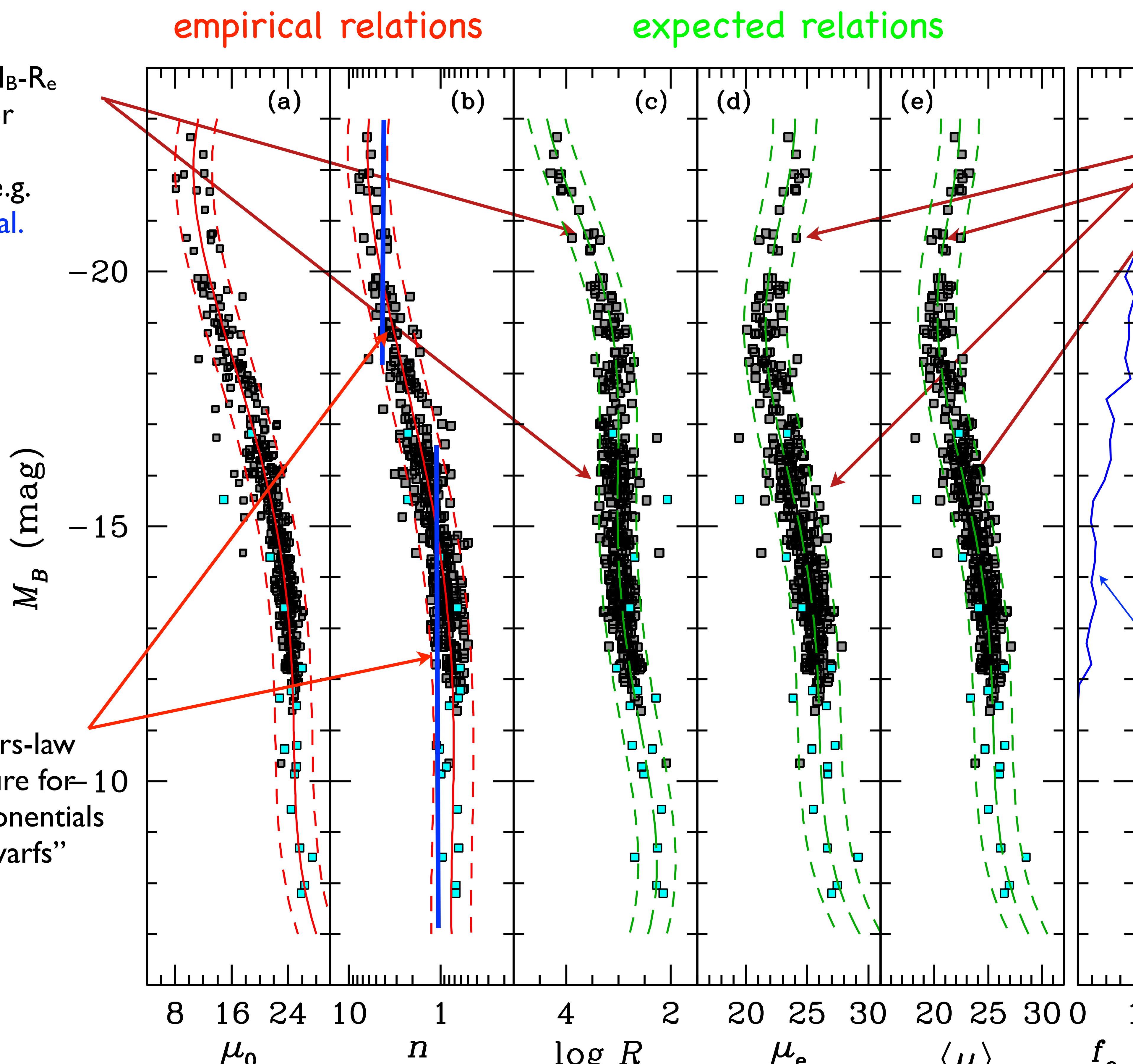
$M_B \approx -20$ mag

Luminosity "Excess" (a.k.a. Nuclei)

Deviations wrt Sersic models noted in ACSVCS confirmed by Kormendy et al. (2009) using ACSVCS data. See also Binggeli & Jerjen (1998), Kormendy et al. (1999), Stiavelli et al. (2001), Graham & Guzman (2003).

Scaling Relations of RS Galaxies

Different M_B-R_e relations for "giants" & "dwarfs" (e.g. Binggeli et al. 1984).



Different M_B-μ scaling relations for "giants" and "dwarfs" (K ormendy 1977, 1985)

de Vaucouleurs-law (n=4) structure for "giants", exponentials (n=1) for "dwarfs"

Virgo and Fornax completeness

Mergers

- Although the scaling relations extend continuously over a factor of 10^6 in mass, the most massive galaxies in the Universe appear to be ellipticals or "spheroids". Why should this be the case?

- Stars in an (idealized) equilibrium system should form in a disk and stay in a relatively disk-like structure. At the same time, the stars in mergers (either the pre-existing ones or those formed during the merger) should undergo violent relaxation and be redistributed in spheroidal components.

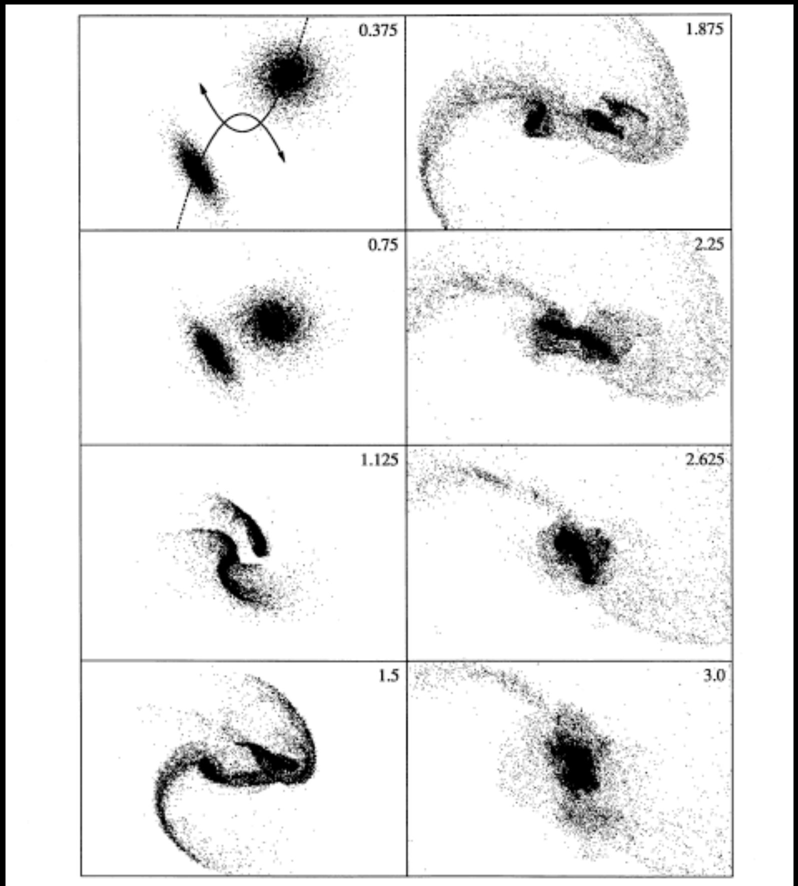
  violent relaxation: rapid evolution of a stellar system that has formed out of equilibrium. Orbits can rapidly due to the rapid changes in the underlying gravitational potential. [See Chap. 4 of Binney & Tremaine 1987.]

- CDM cosmologies are "bottom up" in the sense that the larger systems are formed hierarchically from repated mergers of low-mass ones.

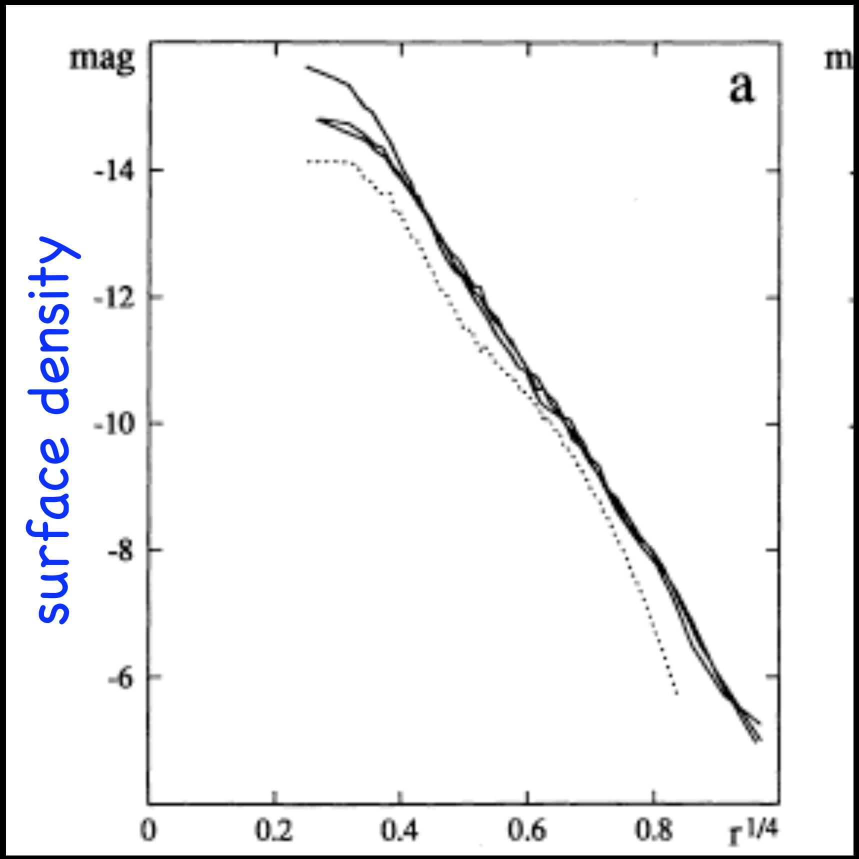
- Simulations predict that most massive (spheroidal) galaxies should indeed have experienced many mergers in their lifetime, including several major mergers after star formation was largely complete.

Mergers: Stellar Disks

- Mergers of (equal-mass) stellar disks generally give rise to roughly spheroidal-like profiles (i.e., ≈ $R^{1/4}$-law surface brightness profiles).
- But these simulations fail to reproduce the central structure of spheroidal galaxies: i.e., the central (phase space) densities are too low. Suggests that gas is required.
- phase space density: $f(\mathbf{r},\mathbf{v},t)$ = the number of stars at **r** with **v** at time t in the range $d^3\mathbf{r}$ and $d^3\mathbf{v}$.

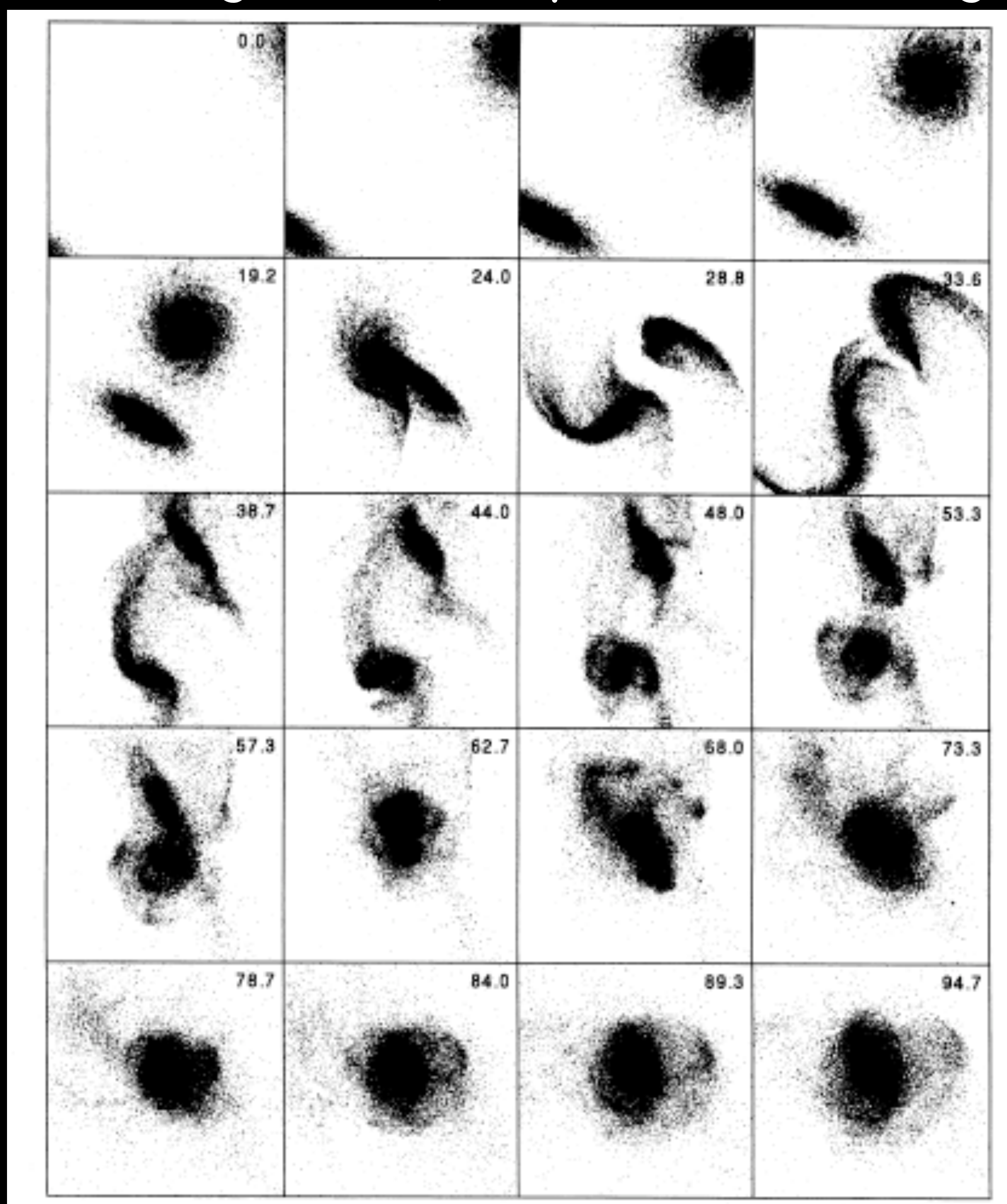


Barnes (1992)



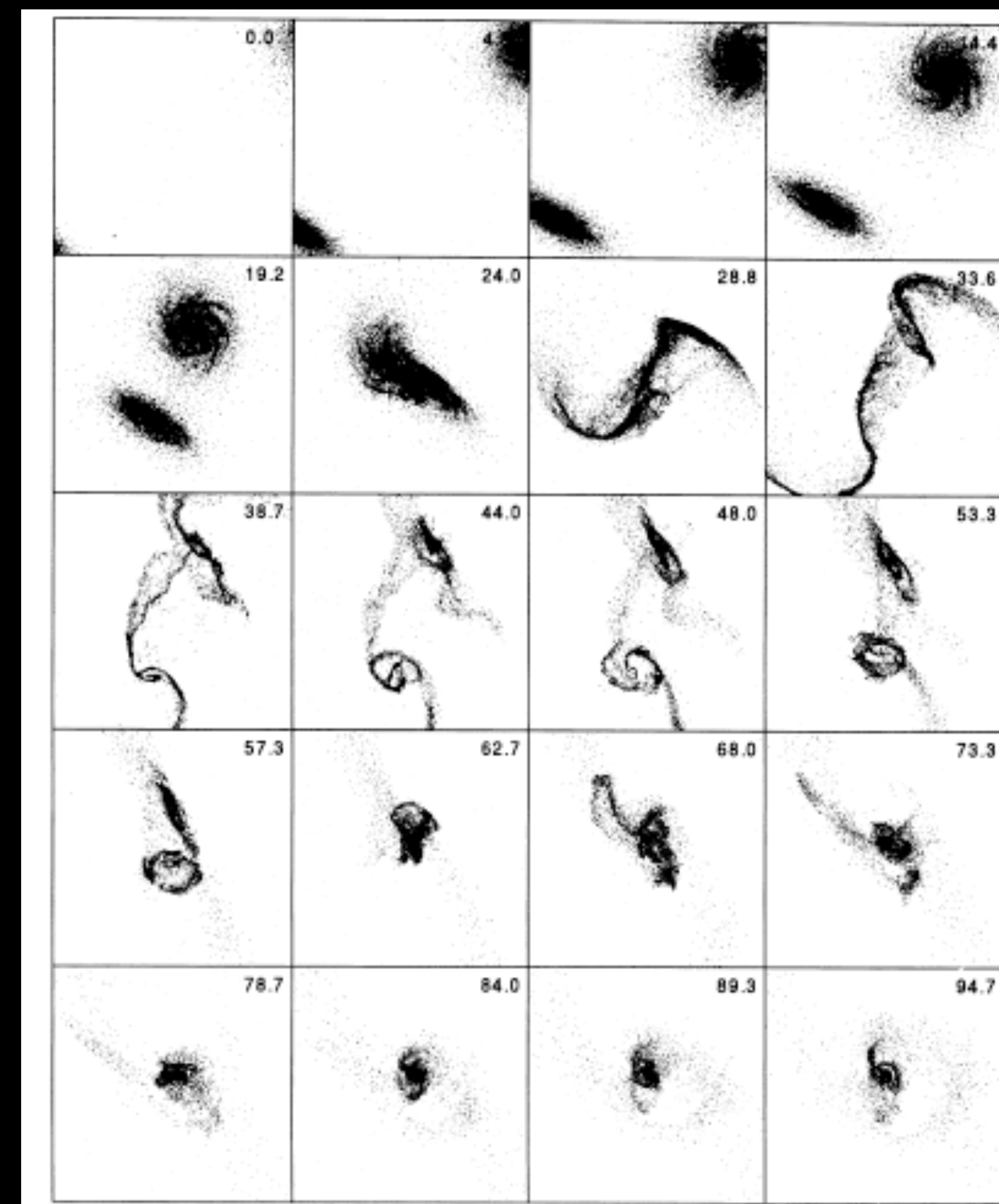
Mergers: Addition of Gas

- If gas is added to the simulations, some gas undergoes a rapid inflow from angular momentum loss caused by gravitational and hydrodynamic torques (which generally depend on the alignment/orbits/structure of the progenitors).



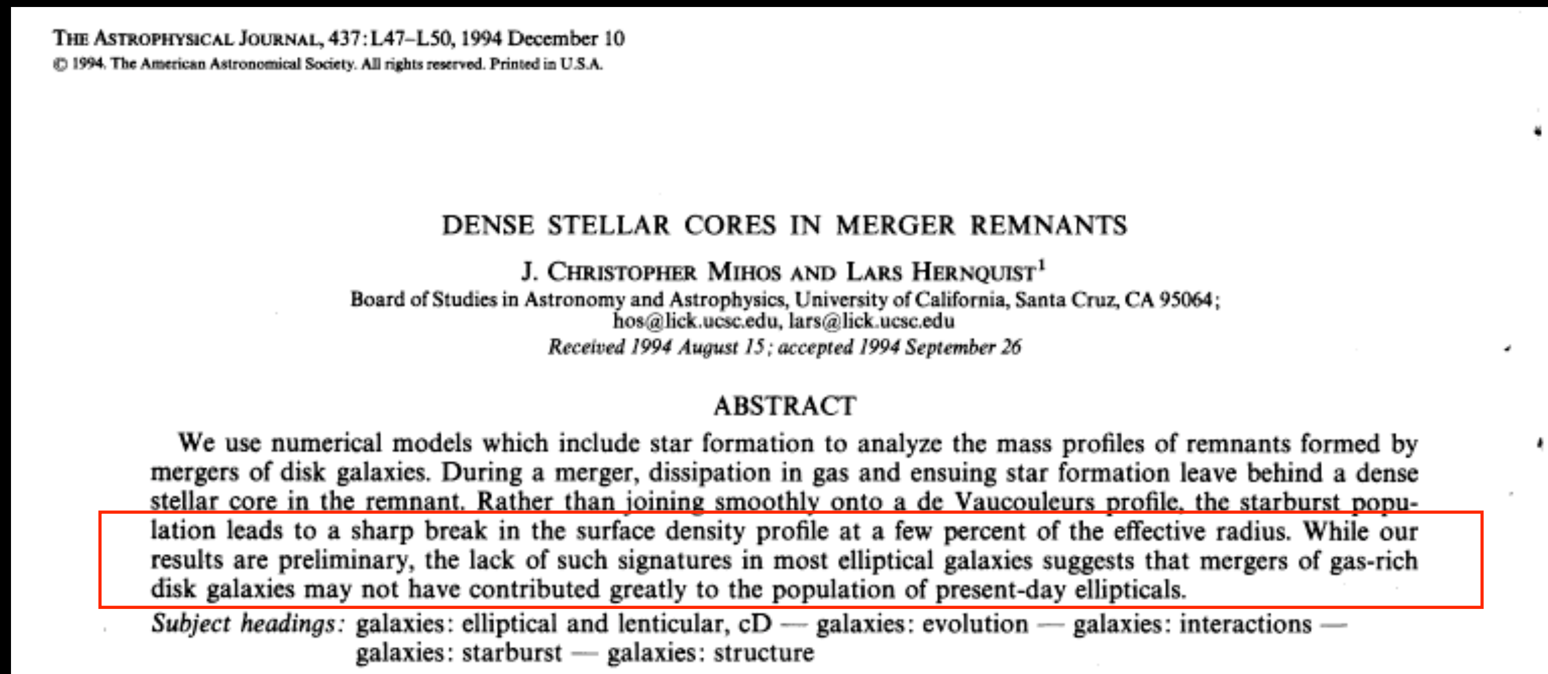
old stellar disk component

Mihos & Hernquist 1996)



gas and young stellar disk component

Mergers: Addition of Gas


THE ASTROPHYSICAL JOURNAL, 437: L47–L50, 1994 December 10

DENSE STELLAR CORES IN MERGER REMNANTS

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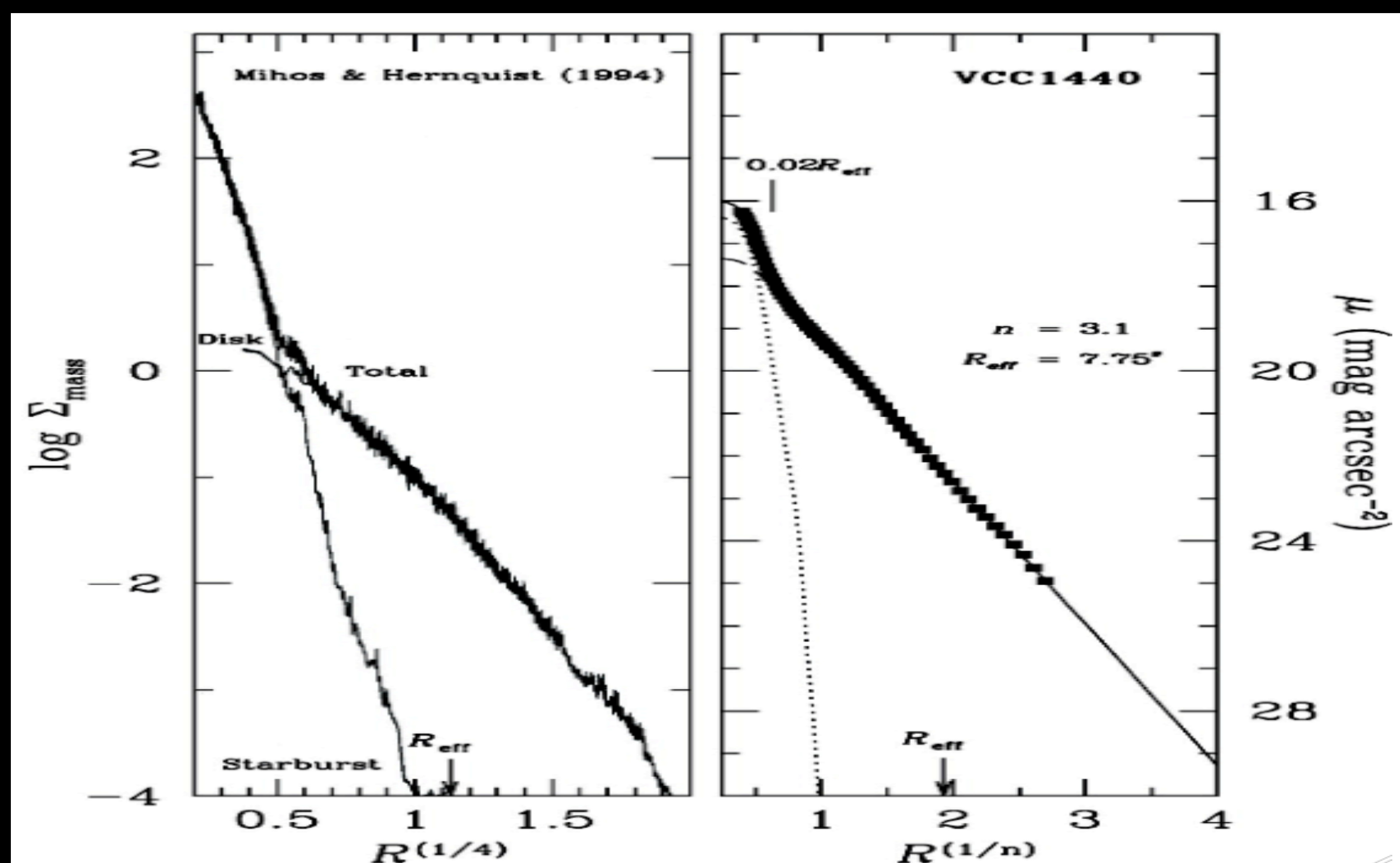
Received 1994 August 15; accepted 1994 September 26

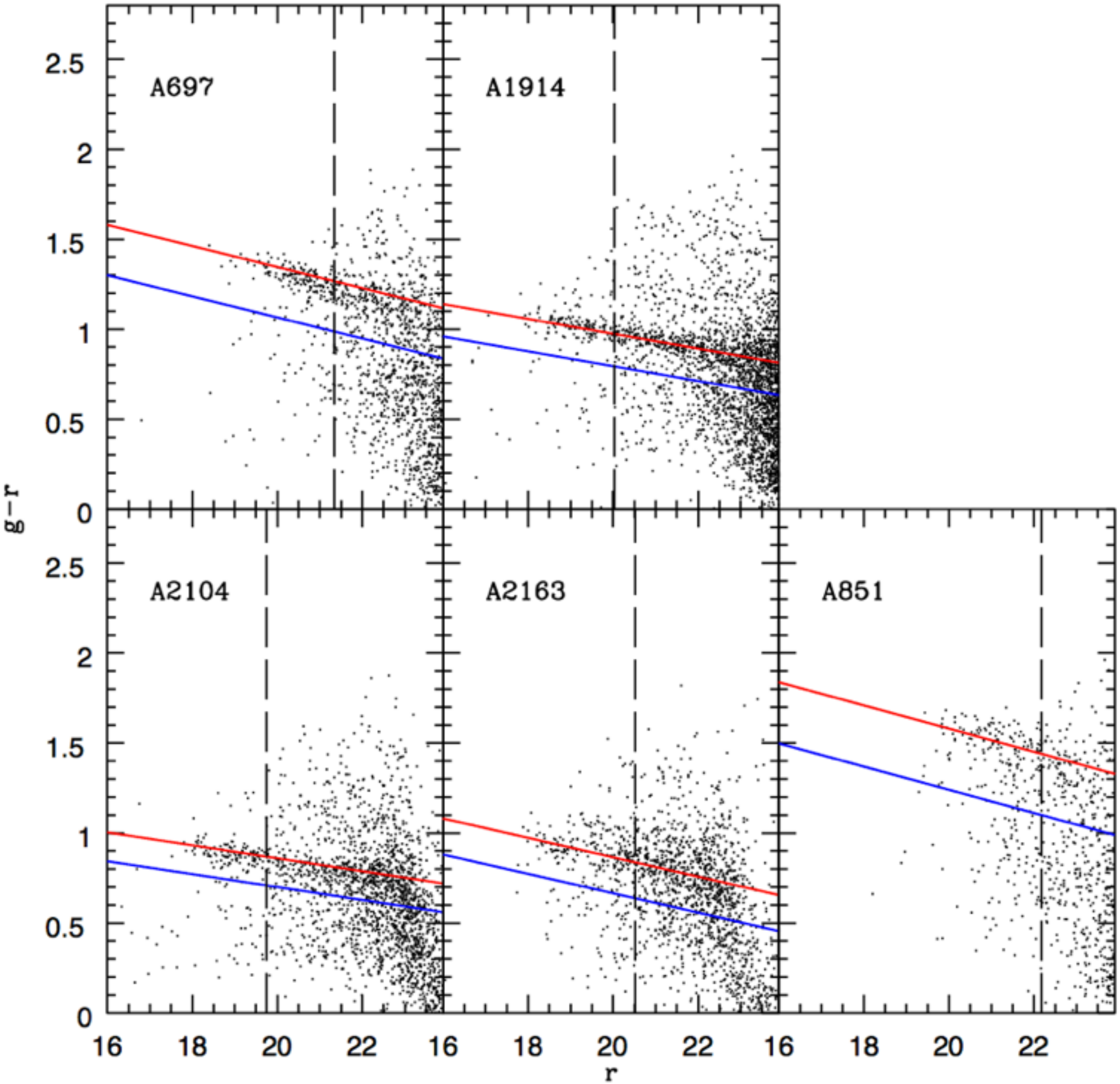
ABSTRACT

We use numerical models which include star formation to analyze the mass profiles of remnants formed by mergers of disk galaxies. During a merger, dissipation in gas and ensuing star formation leave behind a dense stellar core in the remnant. Rather than joining smoothly onto a de Vaucouleurs profile, the starburst population leads to a sharp break in the surface density profile at a few percent of the effective radius. While our results are preliminary, the lack of such signatures in most elliptical galaxies suggests that mergers of gas-rich disk galaxies may not have contributed greatly to the population of present-day ellipticals.

Subject headings: galaxies: elliptical and lenticular, cD — galaxies: evolution — galaxies: interactions — galaxies: starburst — galaxies: structure

Cote et al. (2007)

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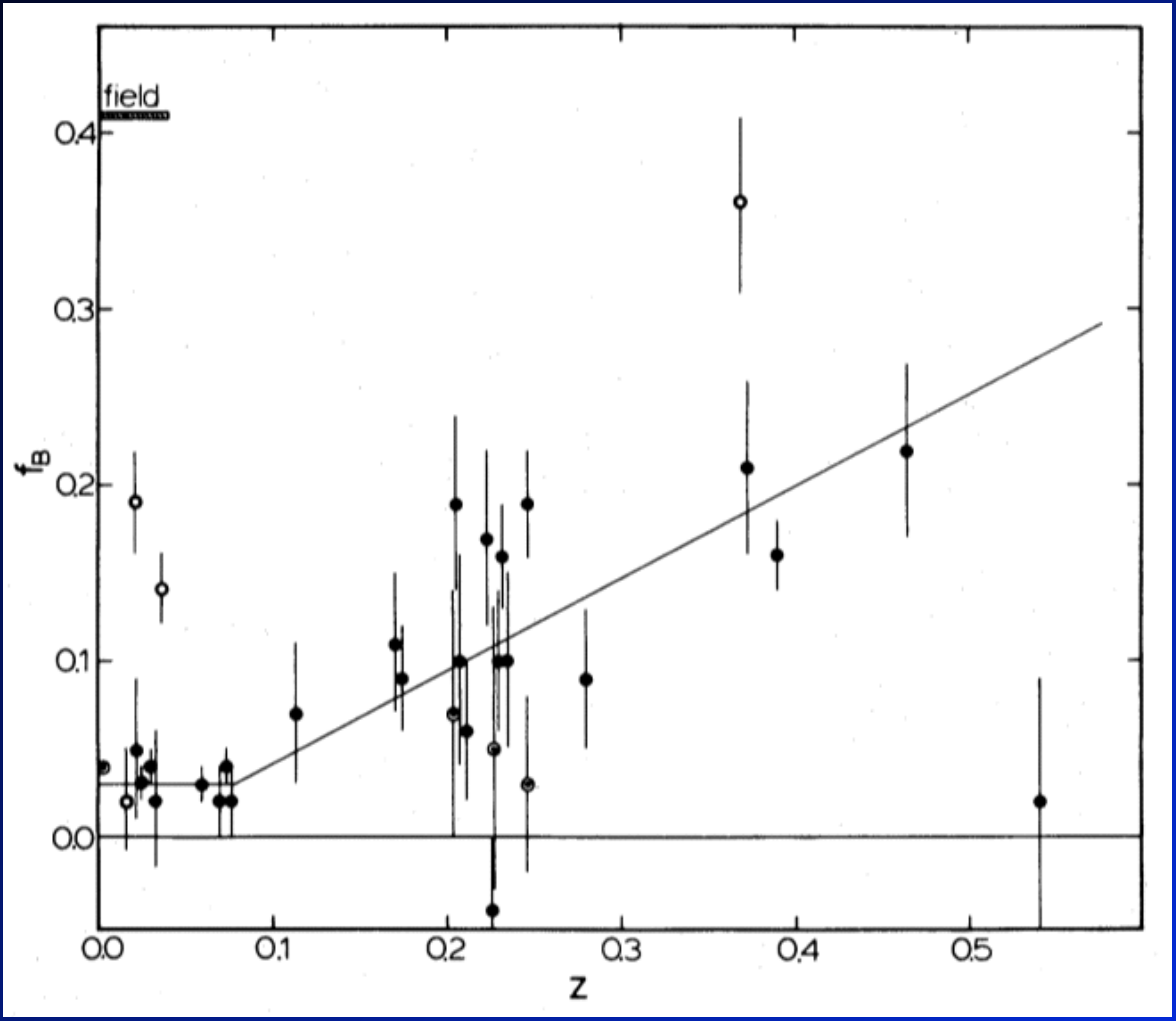
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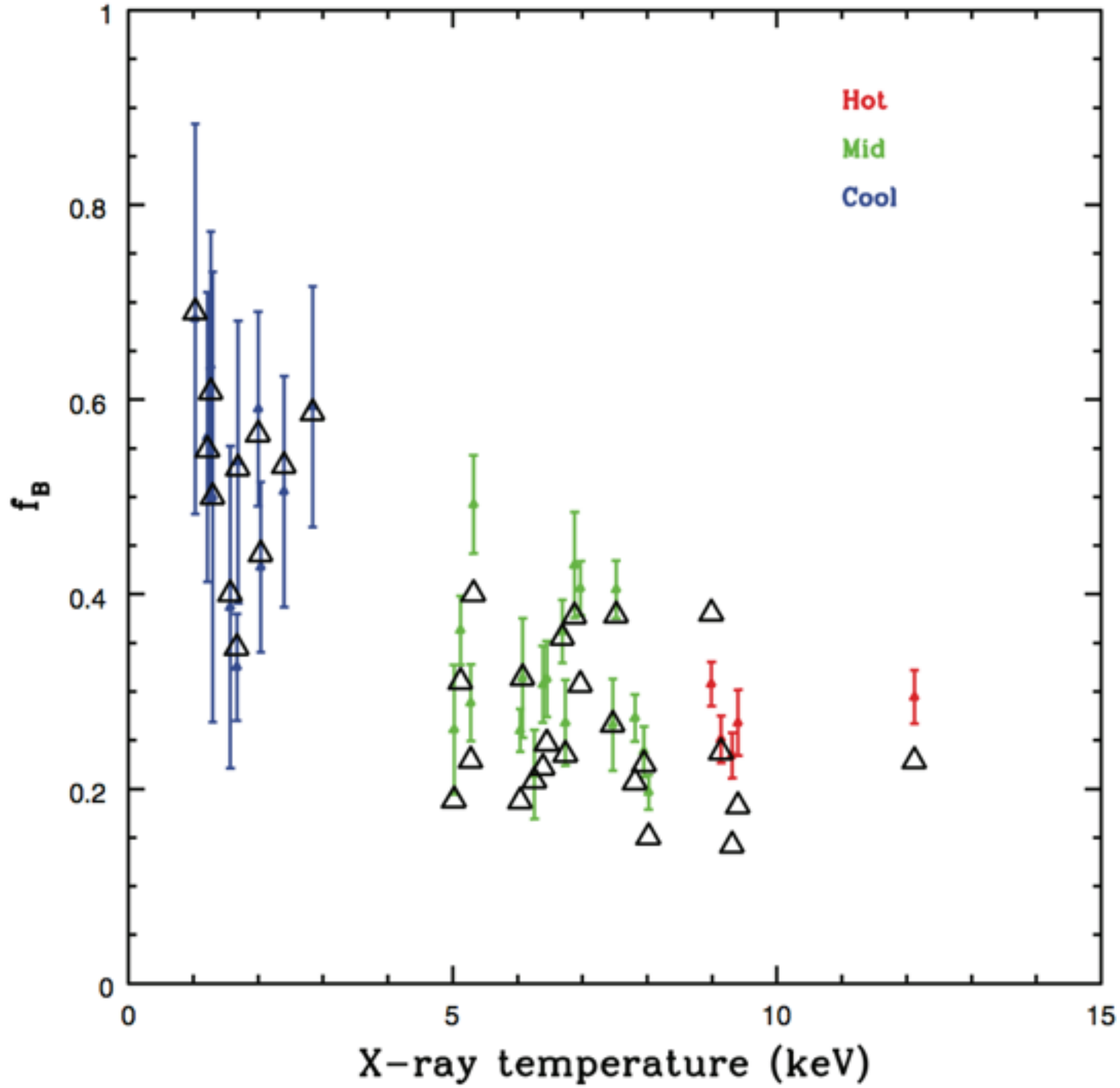

Figure 12. Cluster blue fraction as a function of X-Ray temperature. The black points indicate the result of correcting the original blue fraction values to a common epoch at $z = 0.3$.