Families of Stellar Systems and the Origin of Spheroidal Galaxies

Spheroidals are not small ellipticals. They are defunct (“red and dead”) S+Irr galaxies.

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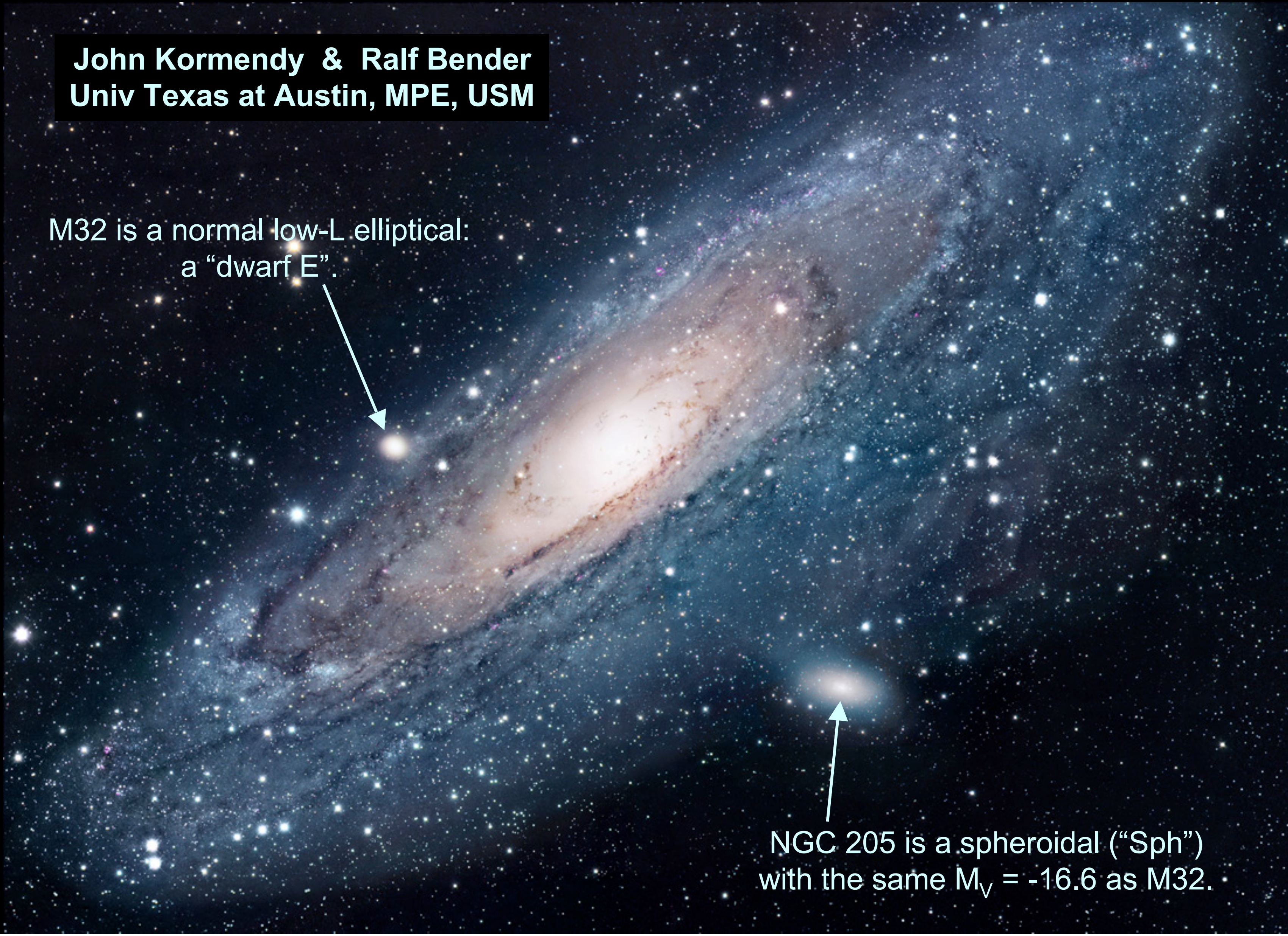
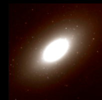


What is an elliptical galaxy?

Sandage & Bedke 1994, Carnegie Atlas of Galaxies:

Es have (1) smooth, elliptically-symmetric luminosity profiles,

(2) no prominent disk by inspection in flattened objects ( not ) and

by inference in rounder objects:

no shallow-gradient outer disk envelope

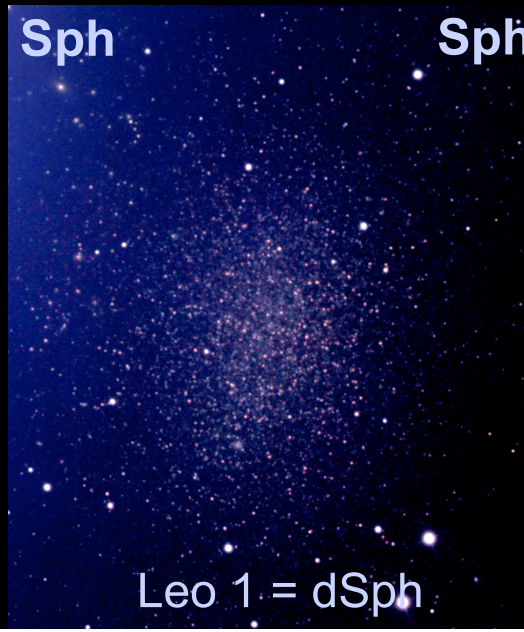
( not ),

(3) no recent star formation.

Problem: “Sph = E”, but these prove to have very different formation mechanisms.

E ≠ Sph Sph ≈ S,Im

M 87 = E



Leo 1 = dSph

Sgr = dIm

Who does not belong?

Dolphins are mammals.
Convergent evolution happens.

Why did we believe that Sph galaxies <u>are</u> Es? Hubble said so. Also:

STUDIES OF THE VIRGO CLUSTER. I. PHOTOMETRY OF 109 GALAXIES NEAR THE CLUSTER CENTER TO SERVE AS STANDARDS

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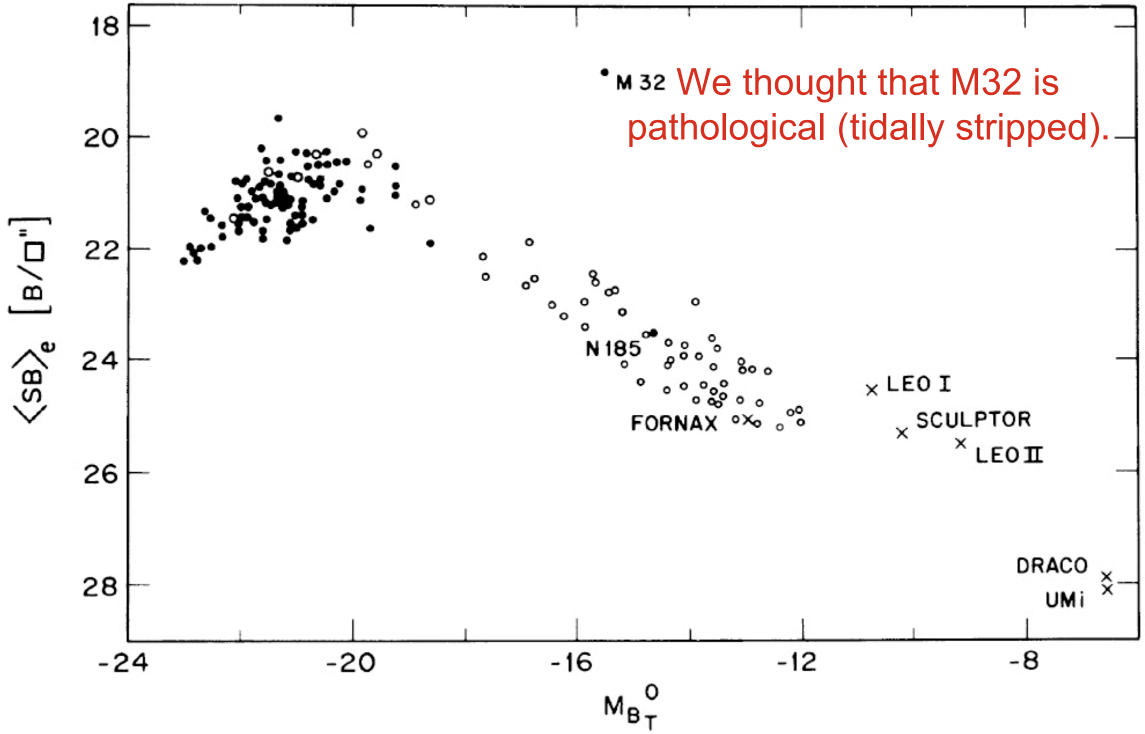
ABSTRACT

Photometry is given for 109 galaxies near the center of the Virgo Cluster. These are to be used as standards for the Virgo Cluster catalog in Paper II. Various types of radii and surface brightnesses have been measured for ~50 E and dE galaxies in the sample that range in absolute magnitude from $M_{B_T} = -20$ to -12. These data are combined with data in the literature for giant E and for dwarf E galaxies in the Local Group to study the systematic properties of E galaxies over a range of 10^6 in luminosity. The effective radius r_e is shown to decrease with decreasing luminosity over the range $-23 < M_{B_T} < -8$. <u>The resulting effective surface brightness $\langle SB \rangle_e$ follows two different scaling laws which change sign near $M_{B_T} \simeq -20$.</u>



We should have worried:

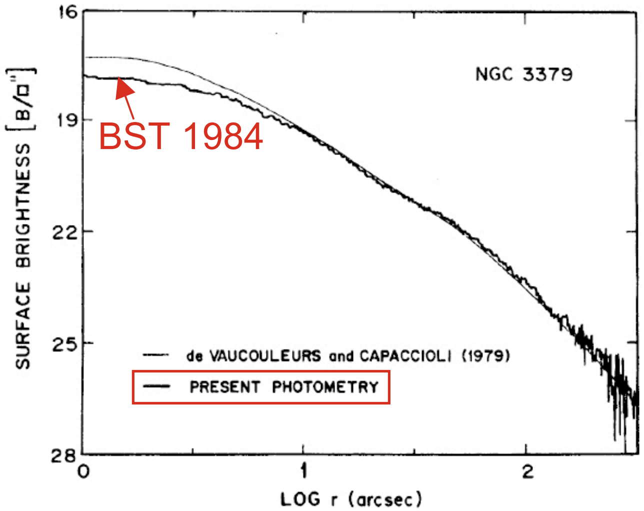


FIG. 1. Test of the calibration procedure by comparing our present photometry of NGC 3379 with that of de Vaucouleurs and Capaccioli (1979).

Sph galaxies are not Es (Wirth & Gallagher 1984).

THE FAMILIES OF ELLIPTICAL-LIKE GALAXIES

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THE ASTROPHYSICAL JOURNAL, **282**:85–94, 1984 July 1

very few!

ABSTRACT

We hypothesize that M32-like classical dwarf ellipticals, and not the more diffuse NGC 205-like systems, represent the true low-luminosity extension of the classical giant elliptical galaxy family. A review of fundamental properties illustrates significant structural and stellar population characteristics which differentiate these two types of low-luminosity elliptical galaxies. While the well-known classical dwarf ellipticals are all companions to giant galaxies, a survey of nearby galaxy groups has produced a few relatively isolated classical elliptical dwarfs, indicating that their structure properties are not due solely to the tidal effects of near neighbors.

b) Diffuse Ellipticals

The diffuse ellipticals are a distinct structural family of spheroids whose properties begin to diverge from those of the classical ellipticals at an absolute magnitude of $M_B \sim -18$. At $M_B = -15$, these two families differ in mean surface brightness by nearly two orders of magnitude.

Brighter than $M_B = -17.5$, nearly all spheroidal galaxies are of the classical, high central light concentration type, while below that limit, the fraction of diffuse systems increases rapidly until, at $M_B = -15$, they probably comprise >95% of all spheroidal galaxies (see also discussions of galaxy populations in the Fornax Cluster by Reaves 1967, 1983 and Hodge 1971). The key point to note for this discussion, however, is that in the range $-18 \lesssim M_B \lesssim -15$, *both* structural classes of elliptical galaxies coexist, and most probably there is a continuum of brightness structures from high to low central concentration forms.

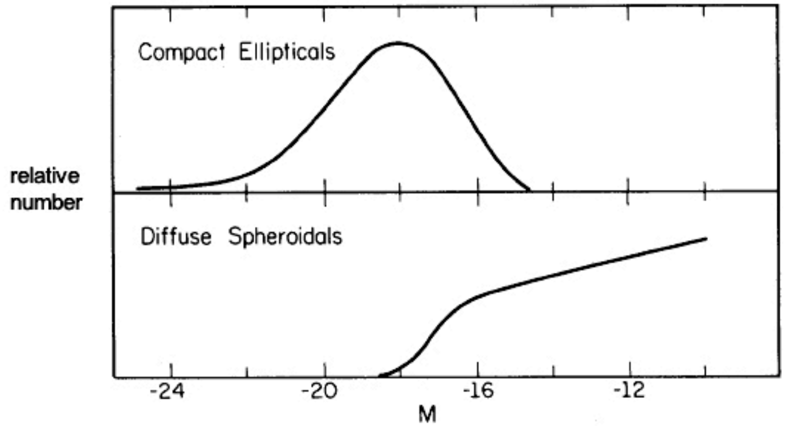
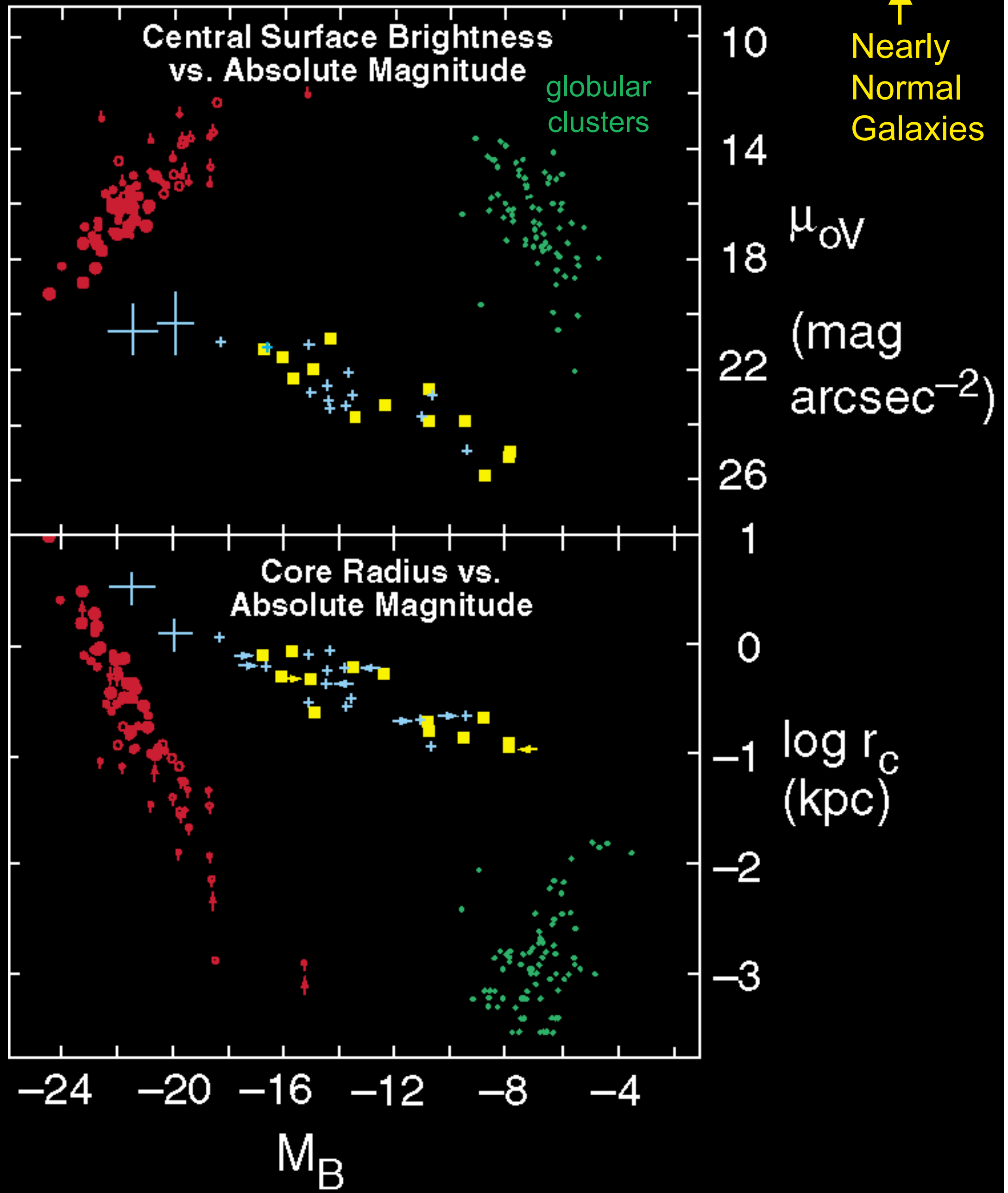


FIG. 7.—Schematic luminosity functions are shown for a variety of galactic structural families. The relative normalizations and perhaps also the forms of the luminosity functions are dependent on galactic environments.

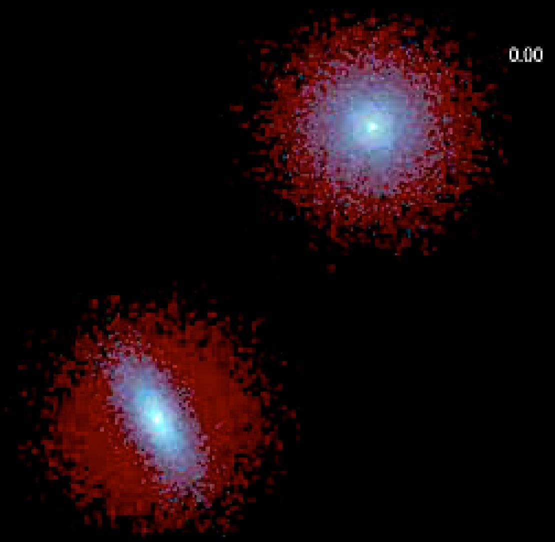
Sph galaxies are not Es (Kormendy 1985, 1987).

Nearly Normal Galaxies

Core or global "fundamental plane" relations define what it means to be an E galaxy.



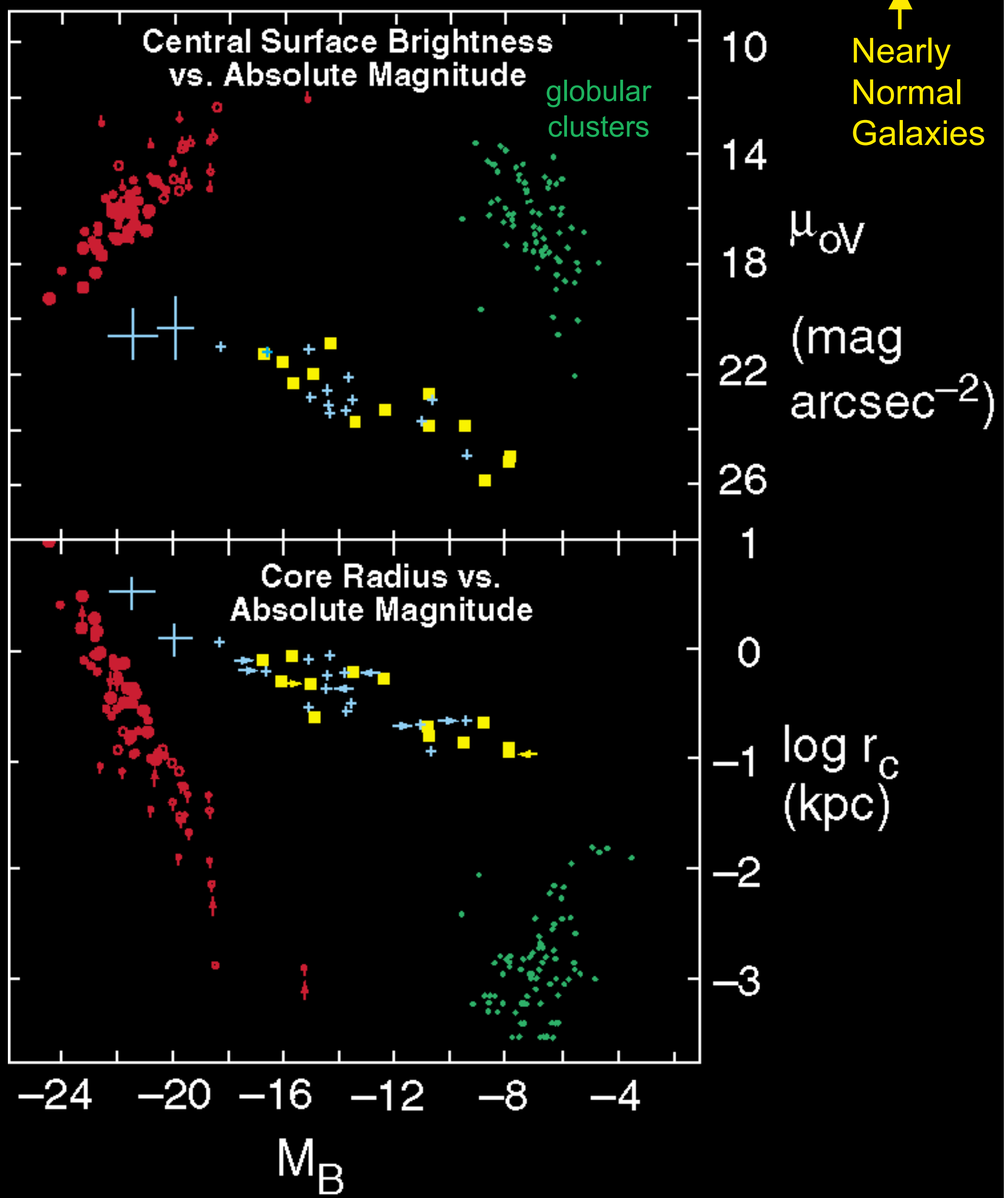
Es form by mergers



Josh Barnes

Sph galaxies <u>are not</u> Es (Kormendy 1985, 1987).

Core or global "fundamental plane" relations define what it means to be an E galaxy.



Sph ≈ defunct S,Im

"Dwarf elliptical galaxies cannot form by mergers" (Tremaine 1981).

Most contain intermediate-age stellar populations ⇒
1 – 8 Gyr ago they were still Im
(e. g., Mateo 1998).

“Sph Galaxies Are Not Es” – Mixed Reactions

Yes:

Sandage, Binggeli & Tammann 1985;
Dekel & Silk 1986;
Binggeli, Sandage & Tammann 1988, ARAA:
“The distinction [between] Es and dEs must almost certainly mean that the two classes are of different origin [K85, DS86]”;
Binggeli & Cameron 1991:
“There are no true intermediate types between E and dE. The classical-dwarf dichotomy … is *model-independent*.”;
Bender, Burstein & Faber 1992;
Tolstoy et al. 2009, ARAA; etc.

No:

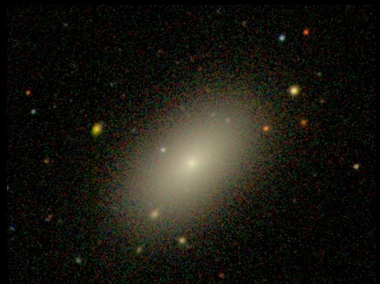
Sandage, Binggeli & Tammann 1985;
Jerjen & Binggeli 1997: “The [n–M_B] relation for Es and that for dEs are continuous.”;
Graham & Guzmán 2004;
Gavazzi et al. 2005: “Core Es deviate from continuous FP correlations of E + Sph galaxies.”;
Ferrarese et al. 2006 and this meeting: “ditto; small sample; biased sample”;
De Rijke et al. 2005, 2009;
Côté et al. 2007 and this meeting, etc.

A Note on Terminology:

is a dwarf

is a dwarf

But



NGC 4482 “dE” ≡ Sph M_V = -18.35

is not a dwarf

NGC 4464 E M_V = -18.40

Therefore we do not call “dE galaxies” dwarf ellipticals. We call them “spheroidal (Sph) galaxies”.

The Sérsic (1968) Function

$$\mu_{ser} = \mu_0 \exp\left[-\left(\frac{r}{r_0}\right)^{\frac{1}{n}}\right]$$

n = 1 ⇒ exponential (many disks)

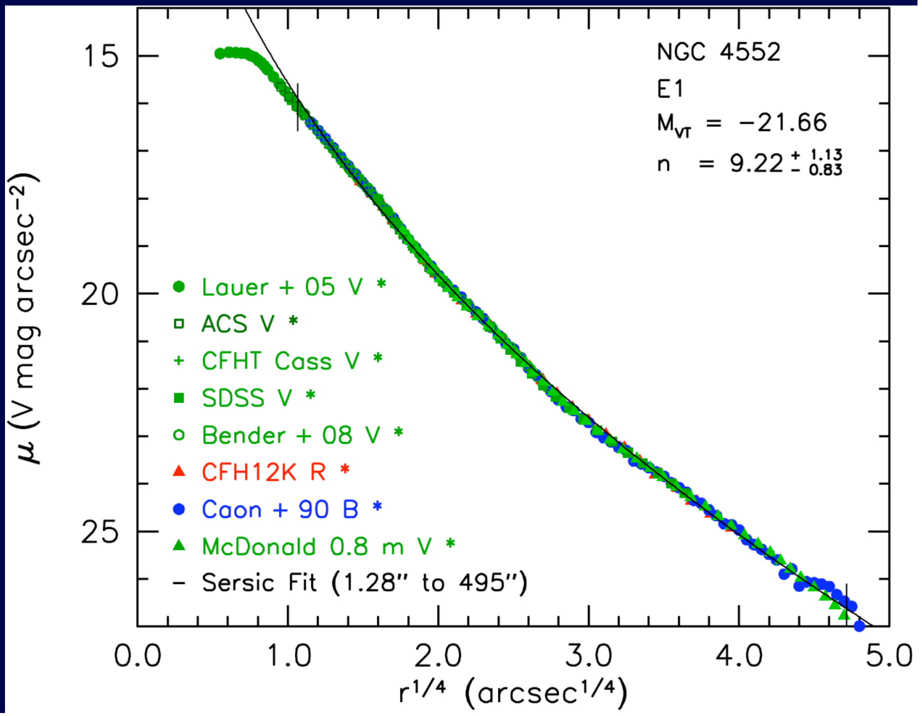
n = 4 ⇒ de Vaucouleurs law

KFCB

Kormendy et al. 2009, ApJS, 182, 216 ⇒ brightness profiles of Virgo Es are <u>very</u> accurately Sérsic. Our median fit RMS = 0.040 mag arcsec^{-2}.

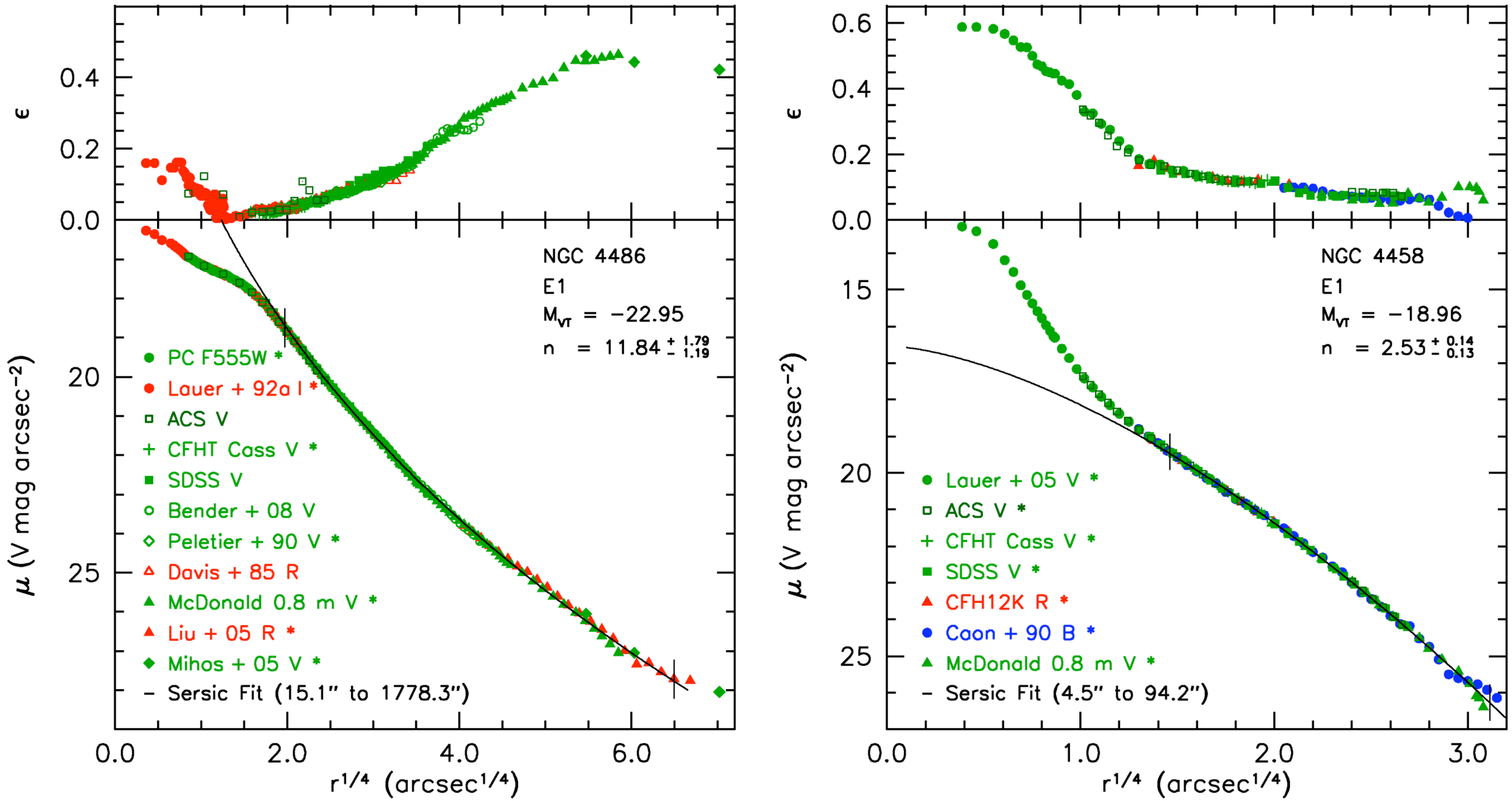
Caon et al. (1993) showed that residuals of Sérsic fits are systematically smaller than residuals of $r^{1/4}$-law fits. They suggested that n is physically meaningful because it correlates with effective radius.

This is confirmed by many people, including Schombert, D'Onofrio, Graham, Trujillo, Ferrarese, et al.

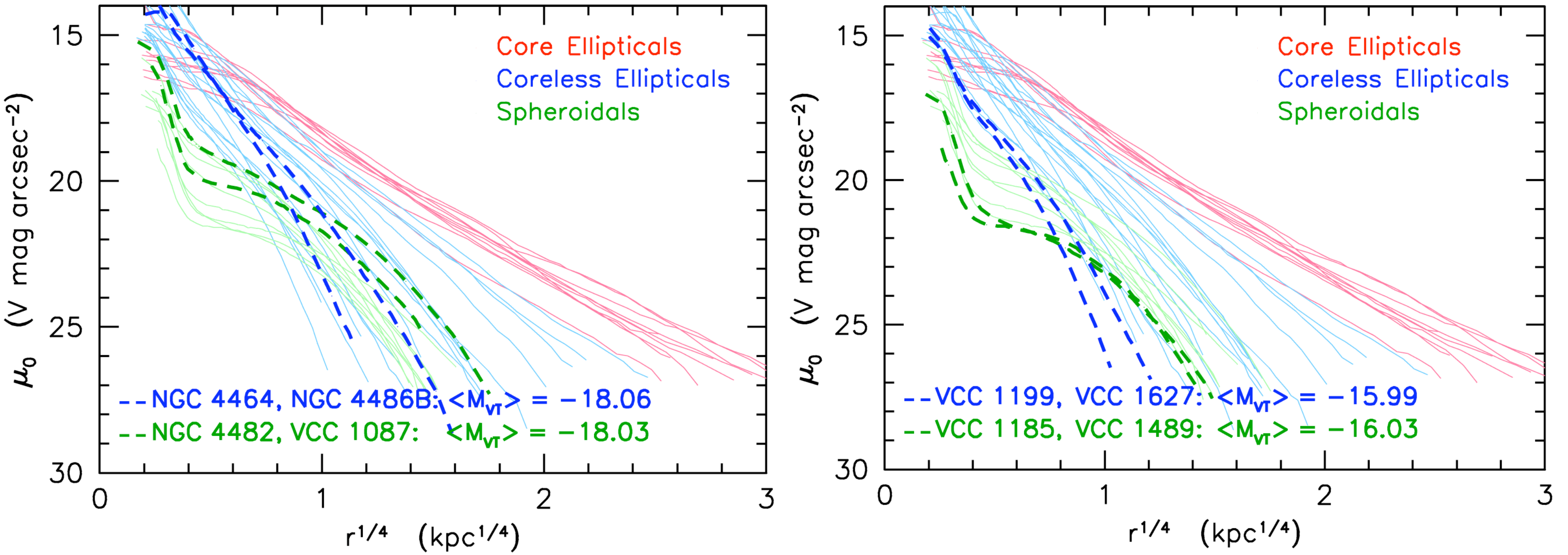


KFCB 2009 derive composite surface brightness profiles for "all" Es, 5 bulges, and 10 Sphs in the Virgo Cluster from published photometry + our photometry.

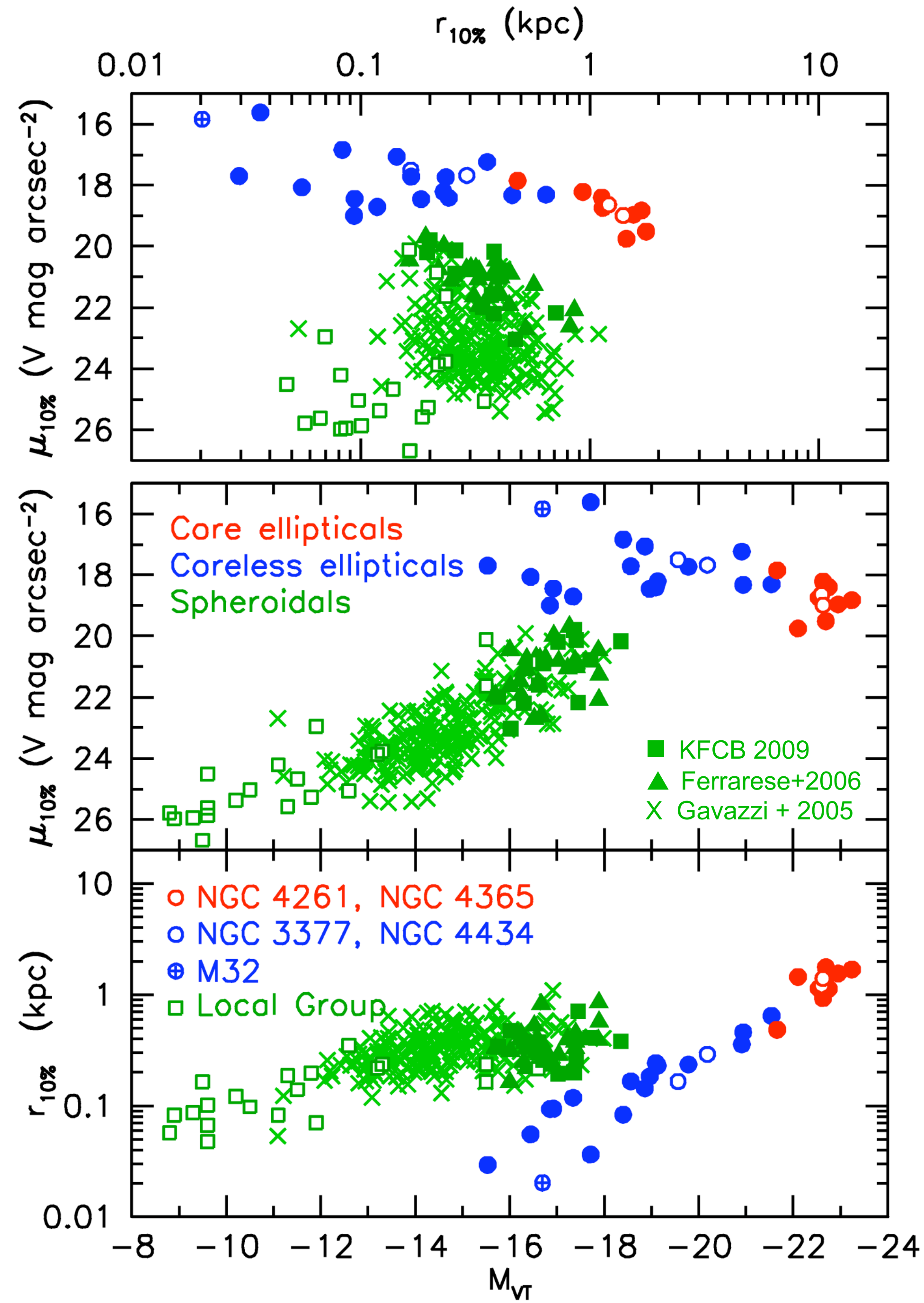
Emphasis:
Multiple measurements → high accuracy, high dynamic range



Profiles of E and Sph galaxies are fundamentally different.



All E and Sph profiles from KFCB (2009);
See also Kormendy (1987, Nearly Normal Galaxies) for a similar comparison.



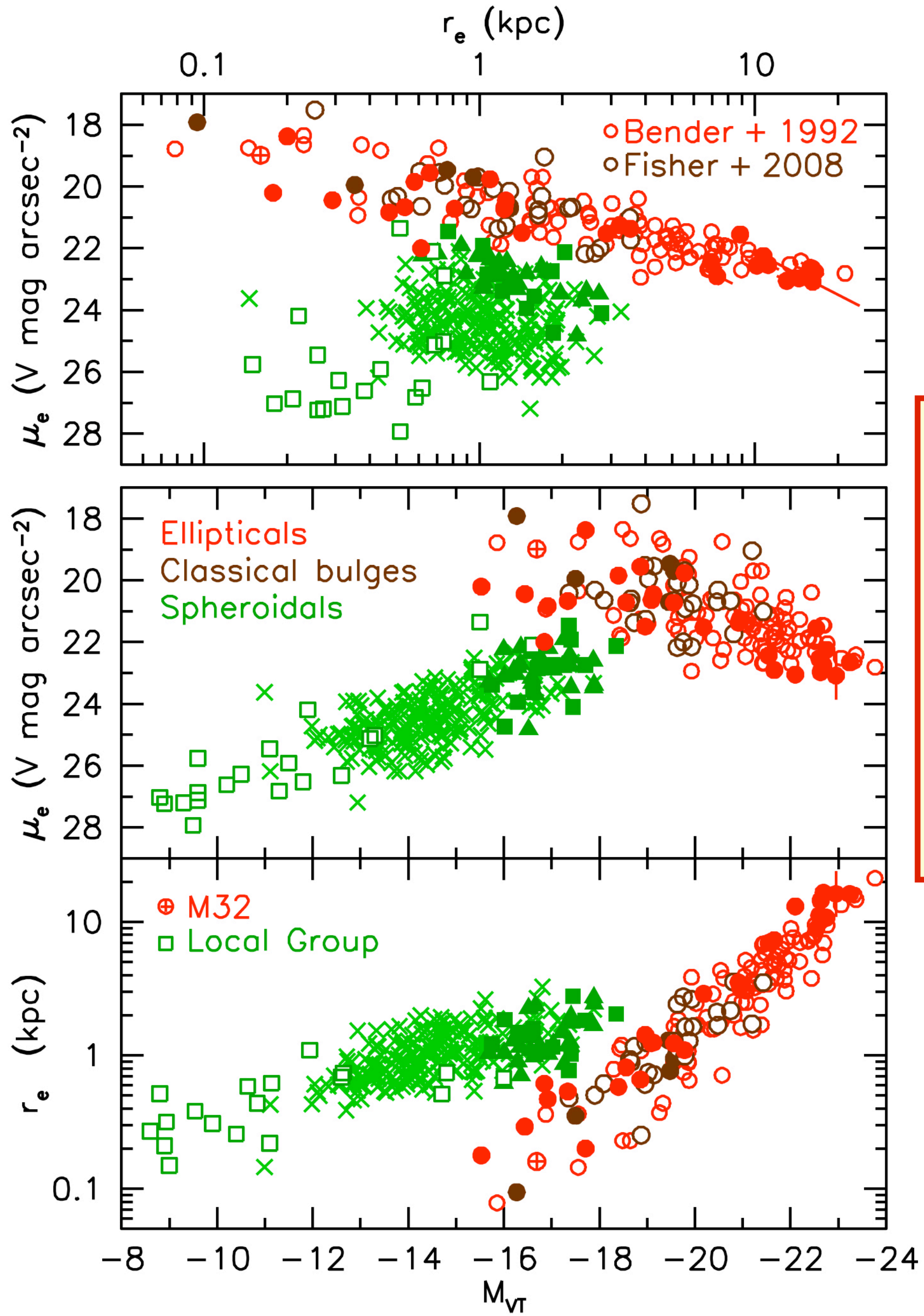
KFCB (2009) confirm that E ≠ Sph.

Here $r_{10\%}$ is the radius that contains 10% of the light of the galaxy and $\mu_{10\%}$ is the surface brightness at $r_{10\%}$.

Note:
Our Sph galaxies (■) are biased in favor of those that are most like ellipticals.

Classification tweaks are done with these correlations.

Global Parameter FP Projections (parameters from integrating 2-D profile)

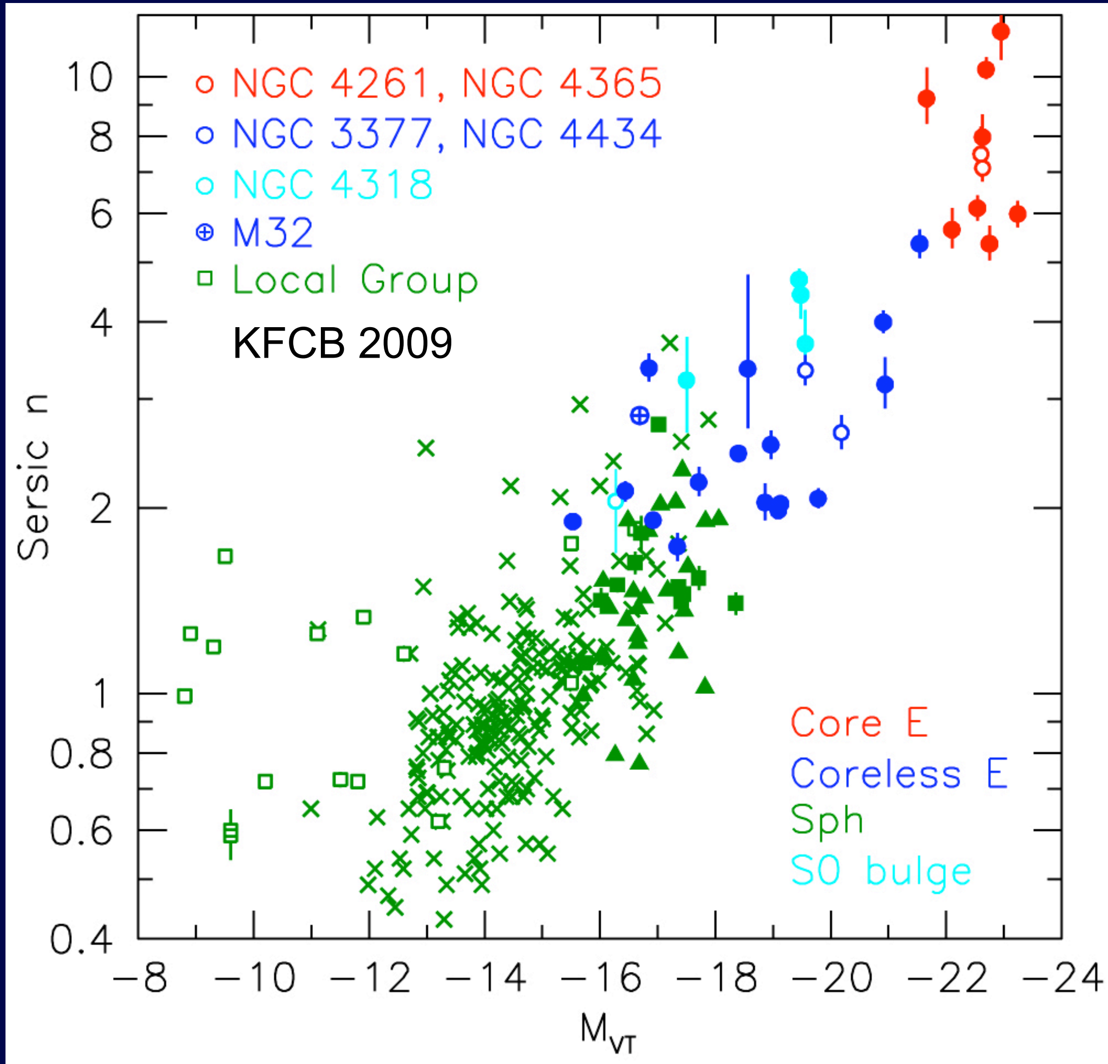


Kormendy (1977) $\mu_e - r_e$ correlation ≈ edge-on FP has small scatter (Saglia et al. 1992; Jørgensen et al. 1996).

KFCB (2009) confirm the E – Sph dichotomy presciently guessed by Wirth & Gallagher (1984) and demonstrated by Kormendy (1985, 1987).

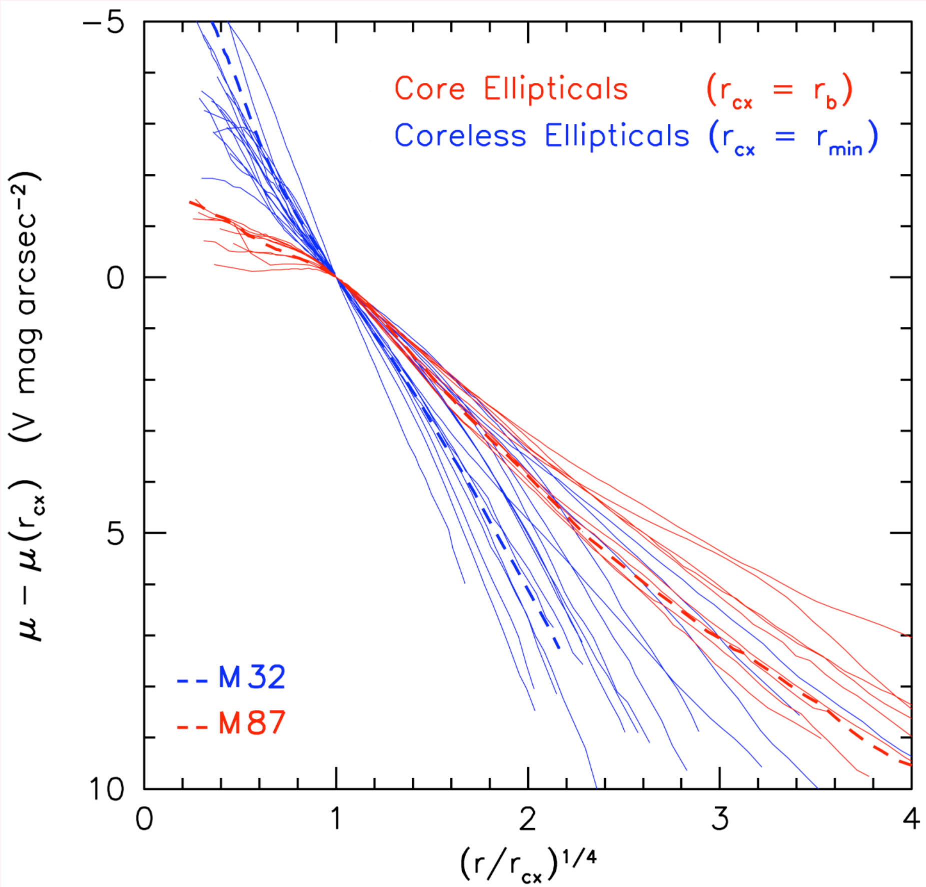
Jerjen & Binggeli 1997:

“The [n–M_B] relation for Es and that for dEs are continuous.”



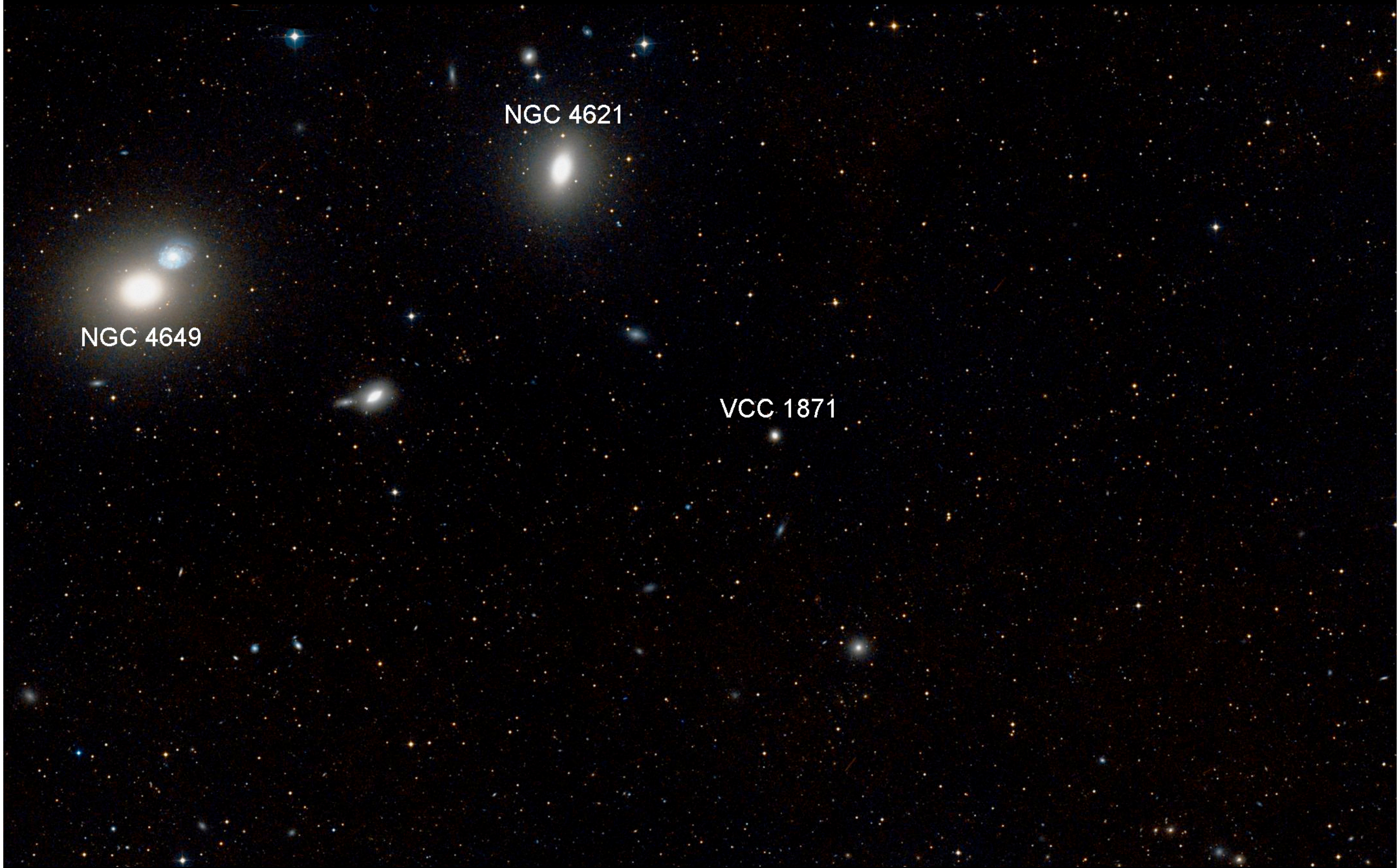
But this is not the only relevant correlation.

M32 is not pathological.

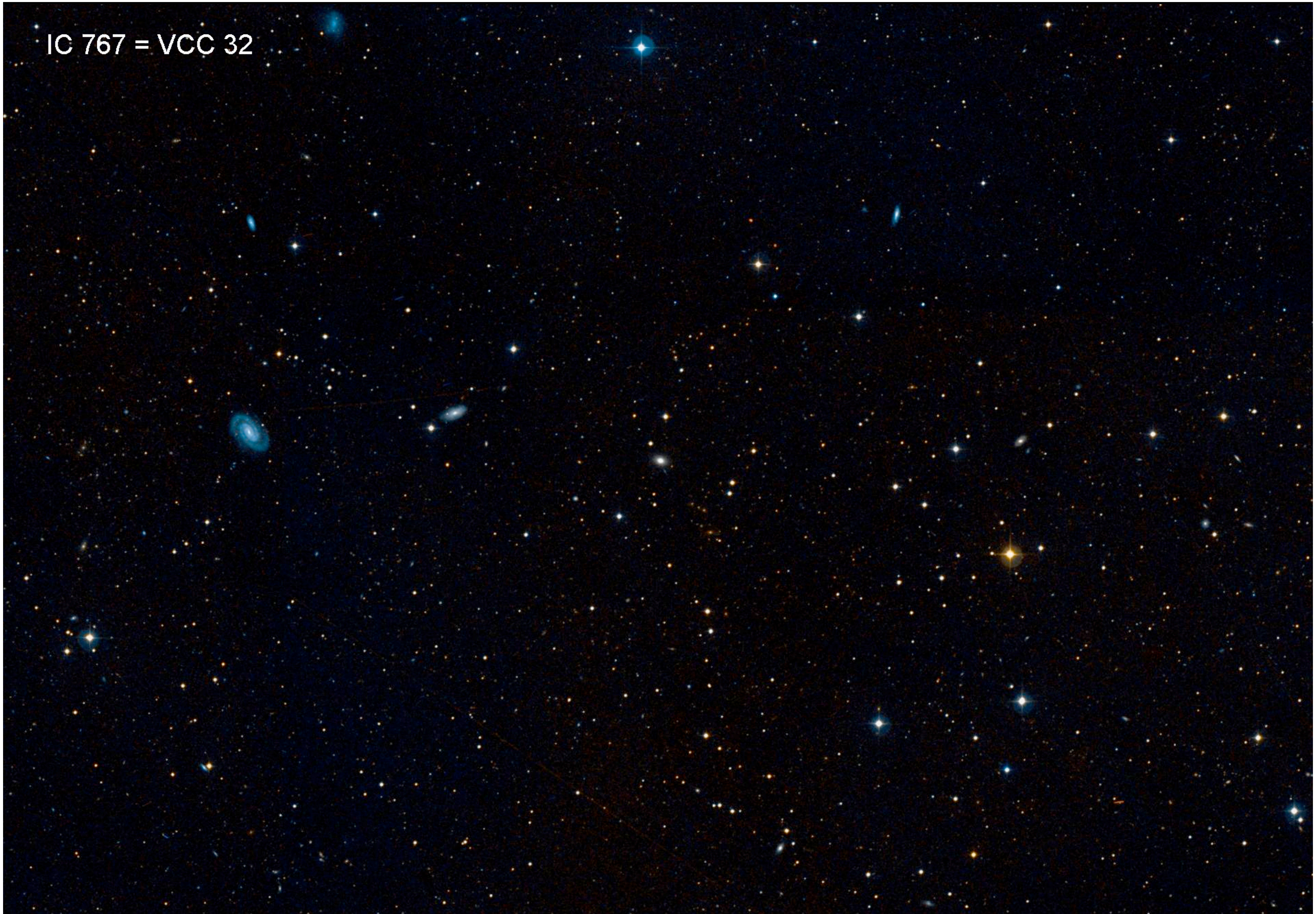


The profiles of M32 and of other low-L, compact Es in Virgo are closely similar to those of bigger, isolated extra light Es. The Sérsic index n = 2.8 of M32 is larger than the median for extra light Es. There is no sign that it and other compact Es in Virgo are tidally truncated.

Compactness is not a disease: it is normal for low-L Es.

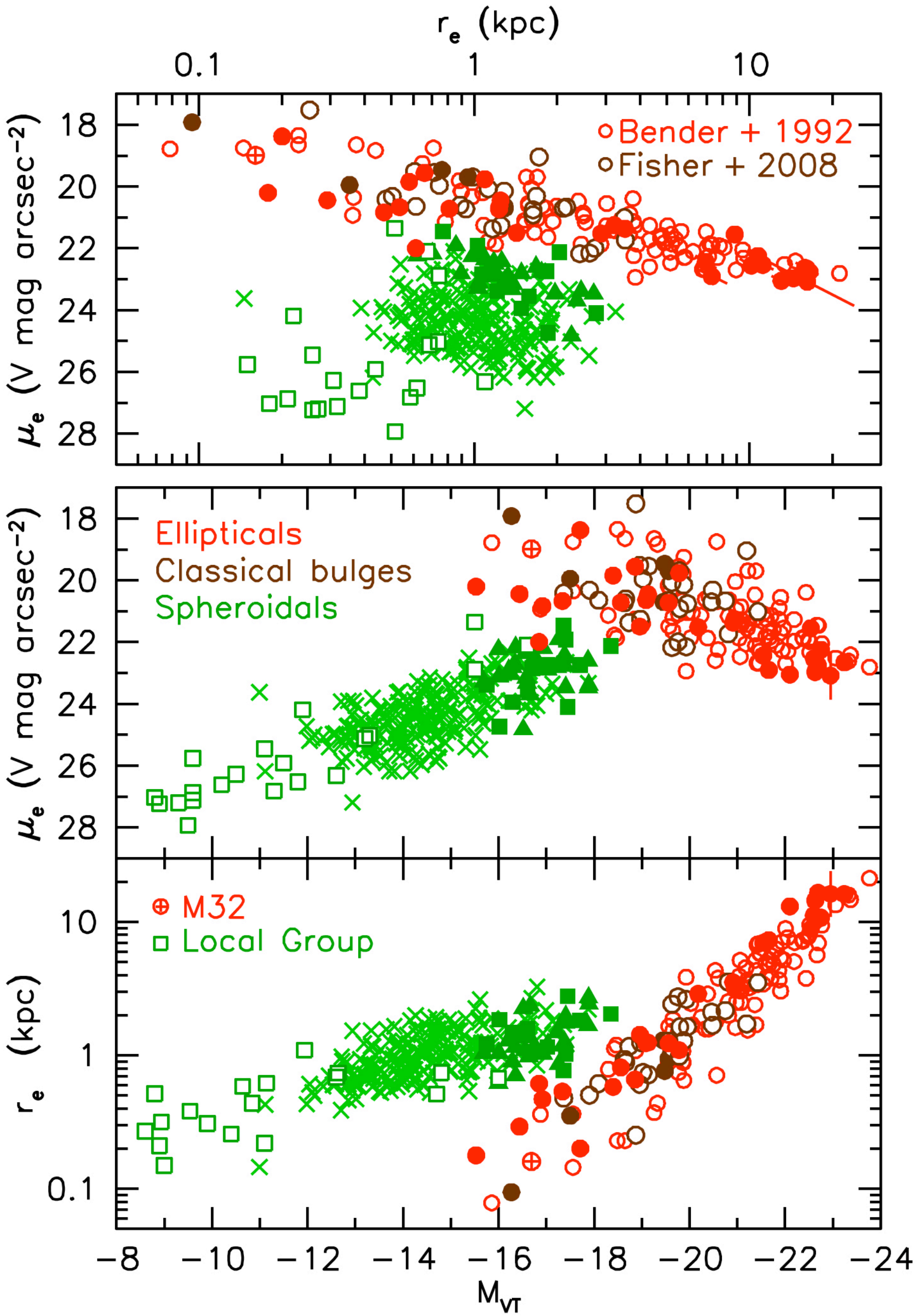


Not all tiny, compact Es are companions of bright galaxies. Some are quite isolated.
VCC 1871's separation from NGC 4621 is ~ 80 kpc in projection = 12 r_e of NGC 4621.



Not all tiny, compact Es are companions of bright galaxies. Some are quite isolated.

Why the compact end of the E sequence is probably not made by tidal truncation.



1 -- Not all cEs are companions of bright galaxies. Some are relatively isolated.

2 -- cEs have the same Sérsic indices n ~ 2.5 as brighter Es that are certainly not tidally truncated. In particular, M32 has n = 2.8, bigger than the mean for extra-light Es. These n values are exactly as found in n-body simulations of major galaxy mergers (van Albada 1982, …, Hopkins et al. 2009).

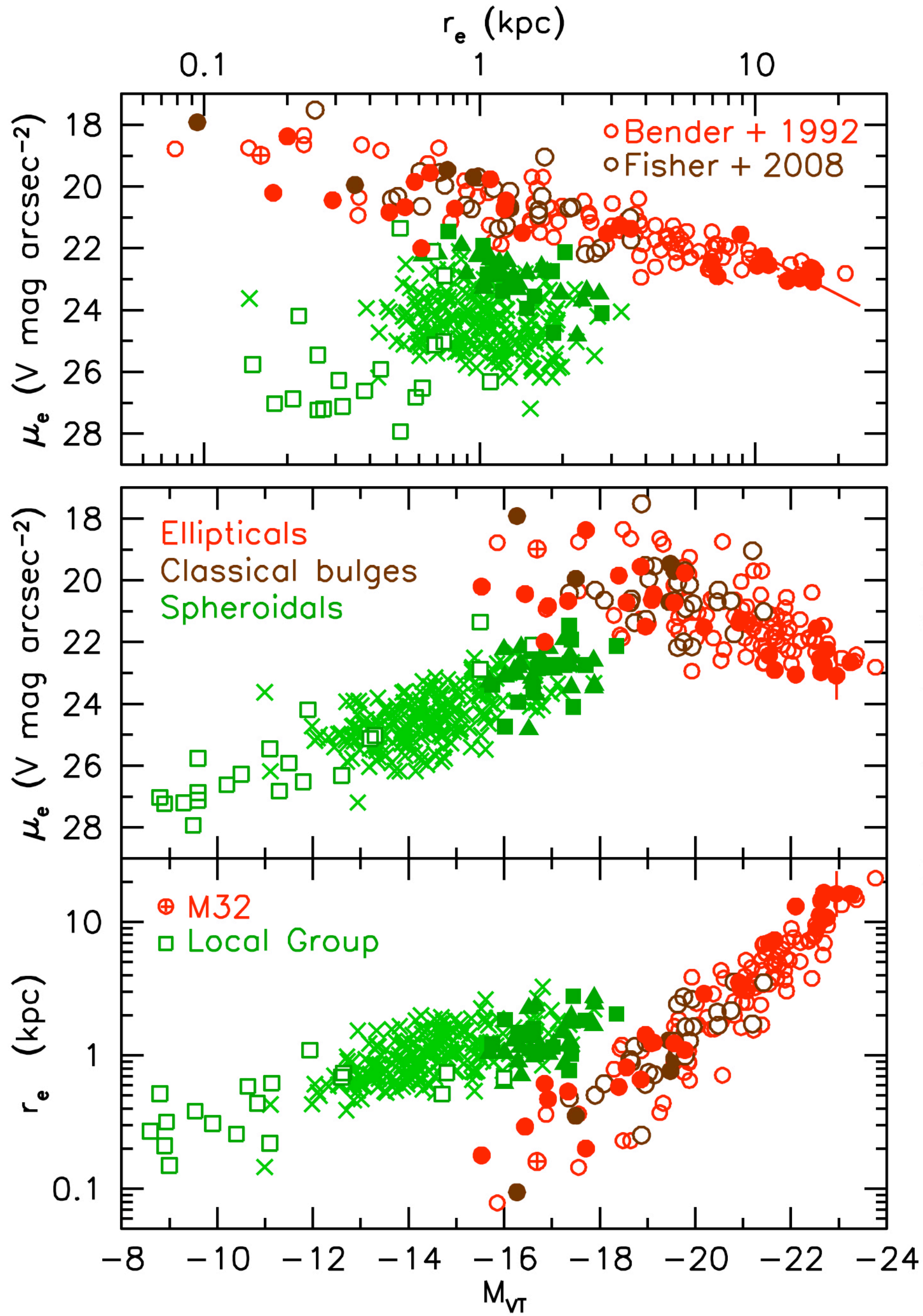
3 -- The compact end of the E sequence is also defined by tiny bulges. Classical bulges and ellipticals have closely similar FP parameter correlations.

4 -- Some Sph galaxies are companions to bright galaxies, but we do not argue that they have been truncated to be compact objects. E.g., NGC 205 is within the distribution of points for Virgo Sphs.

5 -- Our intuition about tidal truncation comes from experience with globular clusters. They have no dark matter halos, and the truncator is overwhelmingly more massive than the victim.

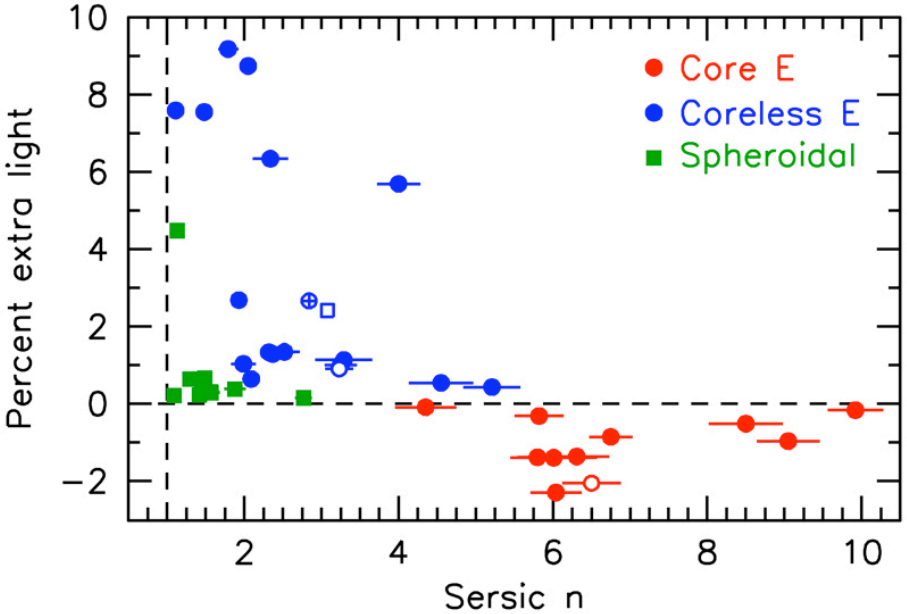
So it is not clear that small, already compact Es get truncated by larger, more fluffy Es.

Global Parameter FP Projections (parameters from integrating 2-D profile)

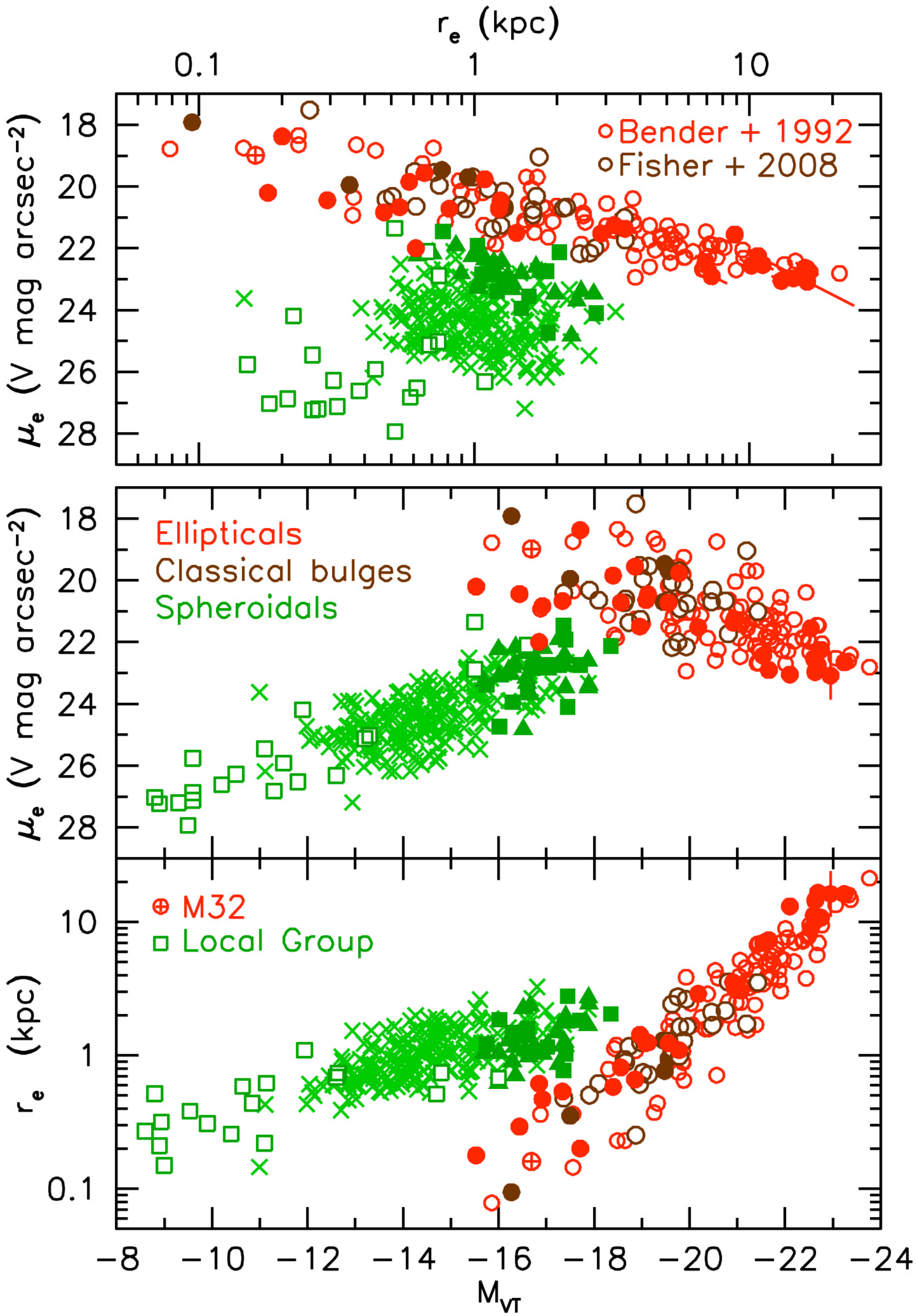


It is unrealistic to argue (Graham & Guzmán 2003, 2008; Gavazzi et al. 2005) that core Es deviate from a Sph+Power-Law-E FP only because of the light missing in cores.

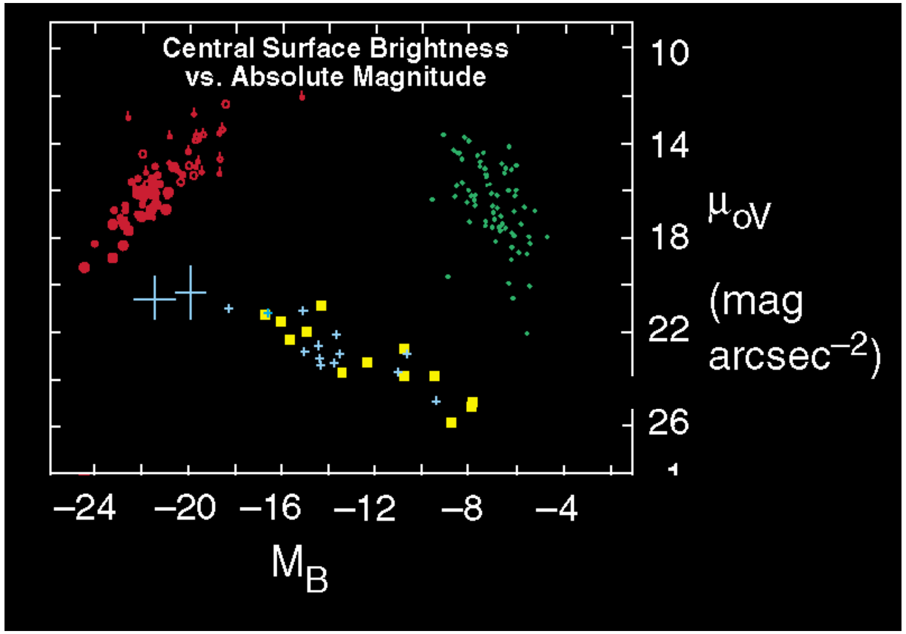
A central "deficit" of 0 – 2 % of the total light has negligible effect on global parameters.



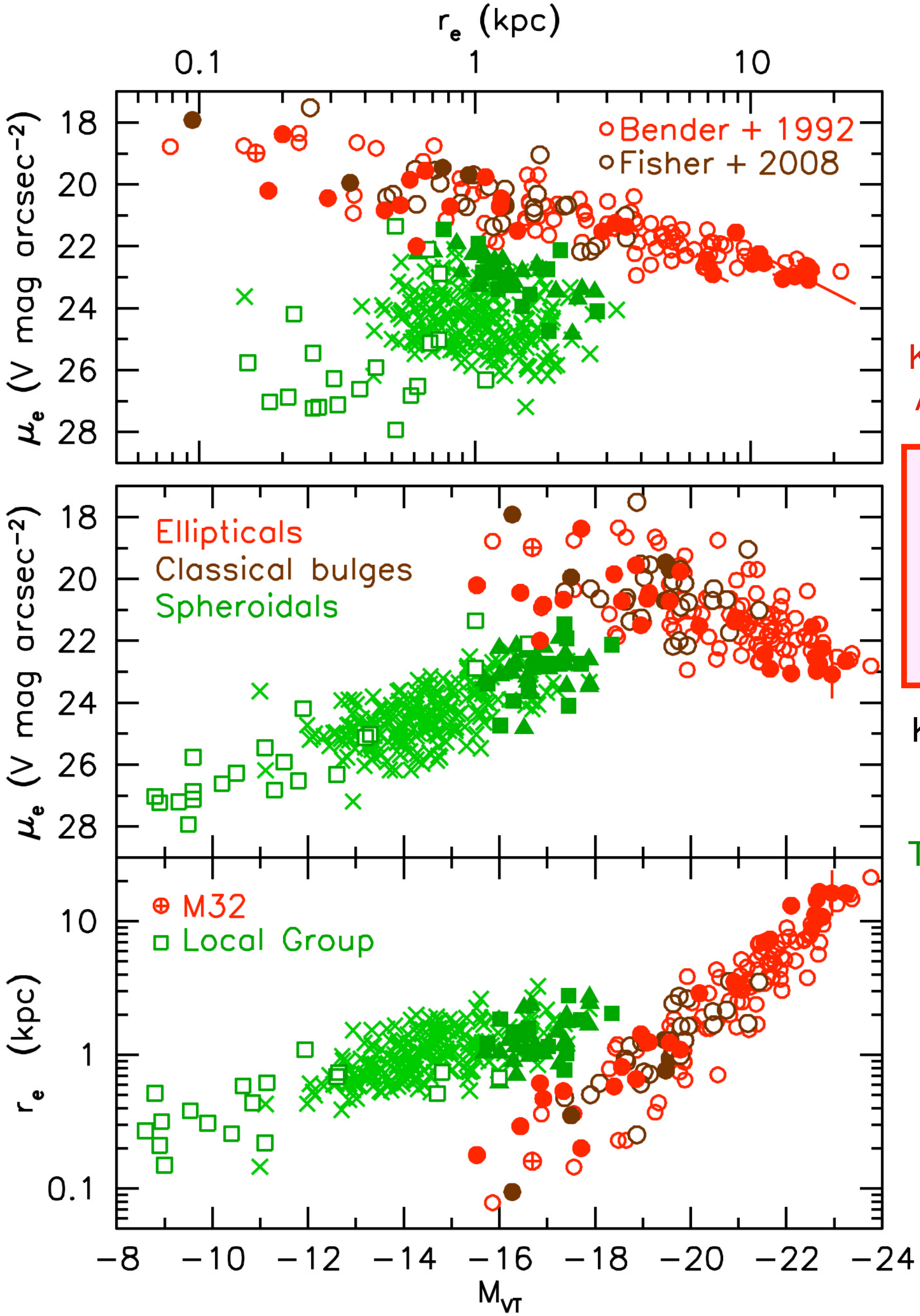
Global Parameter FP Projections (parameters from integrating 2-D profile)



It is unrealistic to argue
(e. g., Binggeli 1994; Graham & Guzmán 2003, 2008;
Gavazzi et al. 2005; Ferrarese et al. 2006) that
"the striking dichotomy observed by Kormendy (1985)
could partly be due to the lack, in Kormendy's sample,
of galaxies in the
-20 mag < M_B < -18 mag range, corresponding precisely to
the transition region between the two families."



Criticism of KFCB: Some Galaxies in the HST ACS Survey Were Omitted



E.g., Glass et al. 2011, ApJ, 726, 31:

"K09 excluded 60% of the ACSVCS sample—in particular, the vast majority of galaxies in the $-21.5 \lesssim M_B \lesssim -18.5$ range, and, unlike C07, included none of the Fornax cluster galaxies."

Sample size is surely not an issue here.
But:

KFCB did not omit 60 galaxies in Ferrarese + 2006.
KFCB omitted 3 pec Es, 26 S0s, 2 dS0s in Ferrarese+2006.
Also, Ferrarese did not get parameters in 2 galaxies (dust).

Reason: For S0 galaxies,
it is necessary to decompose surface brightness profiles into bulge and disk parts and
to plot bulge and disk parameters separately.
This was not done by Ferrarese + 2006.

KFCB was about Es and was already 94, ApJS pages long.
We postponed discussion of S0s to a future paper.

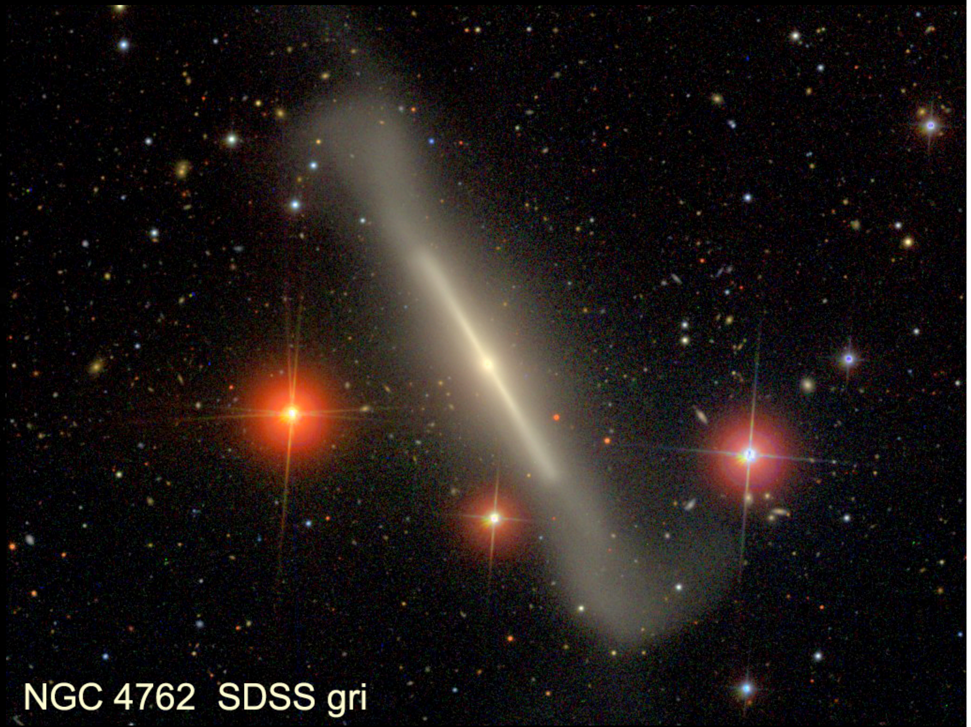
Turns out that the 3 omitted "Es", 3 "S0s", 1 "dS0" are Sphs.
They are added in green to the following plots.

Also, 5 dwarfs in Ferrarese + 2006 are dIm or dSph/dIm, as they correctly recognized.
They are shown in blue in the following plots.

In the following, 5 formerly discarded S0s
(5 more have bulge-disk decompositions in KFCB)
are shown as examples of bulge-disk decomposition & all Ferrarese galaxies with derivable parameters are plotted.

Bulge-Disk Decomposition is Necessary

(Kormendy 1977, ApJ, 217, 407)



The Sombrero is an Sa galaxy with
B/T = 0.93 ± 0.01.

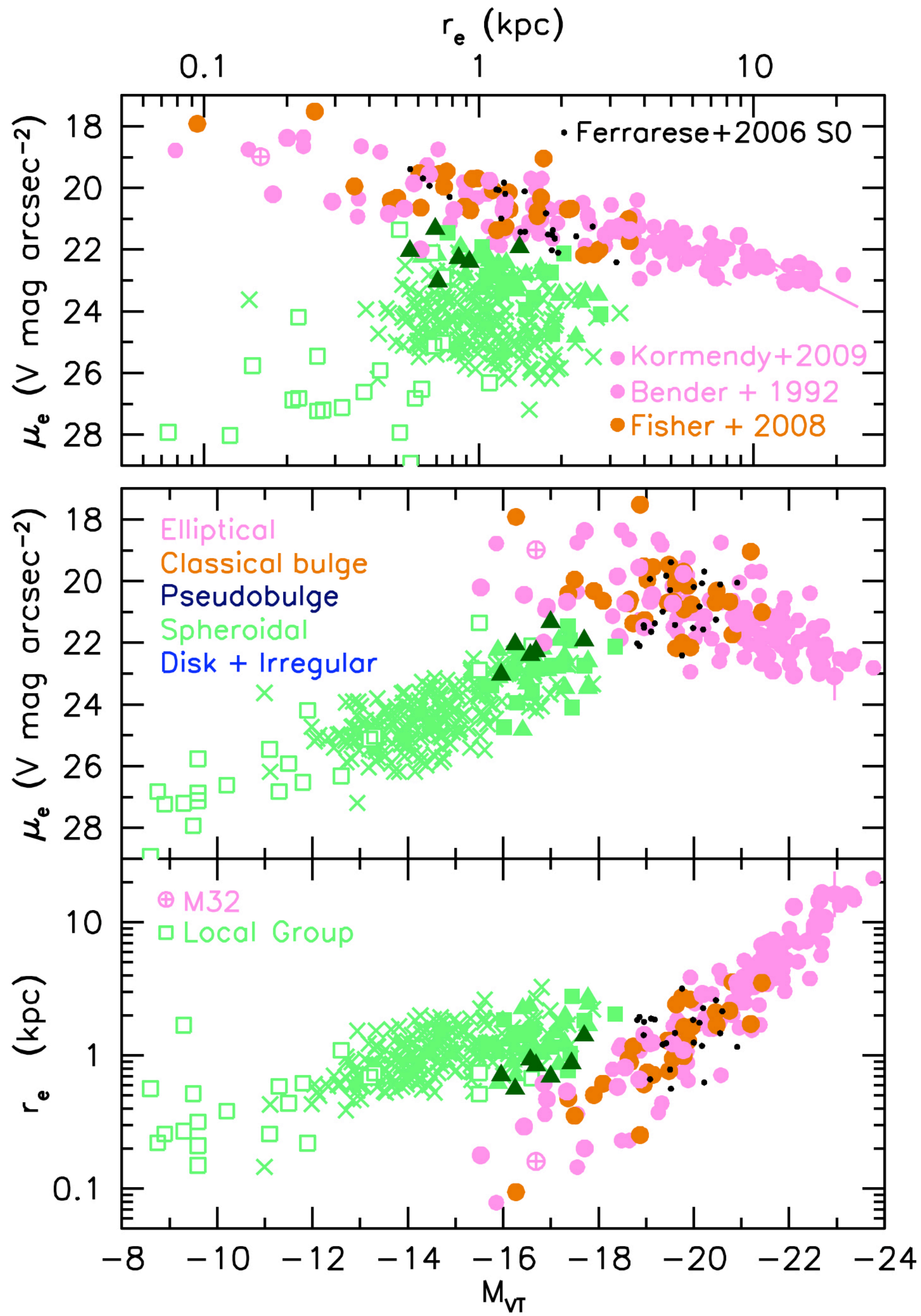
Without photometric decomposition,
we measure essentially only the bulge.
We learn nothing about the disk.

NGC 4762 is an SB0 galaxy in the ACS Virgo survey.
It has with B/T = 0.13 ± 0.02.

Without photometric decomposition:
We measure essentially only the disk.
We learn nothing about the bulge.

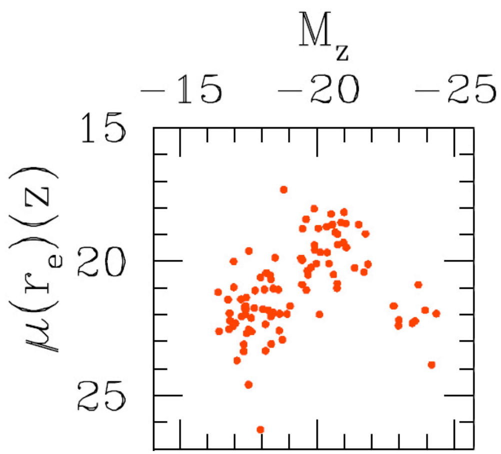
Also, azimuthally averaged parameters for edge-on disks are hard to interpret.

By combining parameters for galaxies like these, one is guaranteed to find continuity between bulge and disk parameters.



The 23 formerly omitted S0s that are not Sphs (black dots) are consistent with the E + bulge sequence.

But they contribute to the feeling that Sph and E galaxies are continuous, if pink, green, and black points are not distinguished.



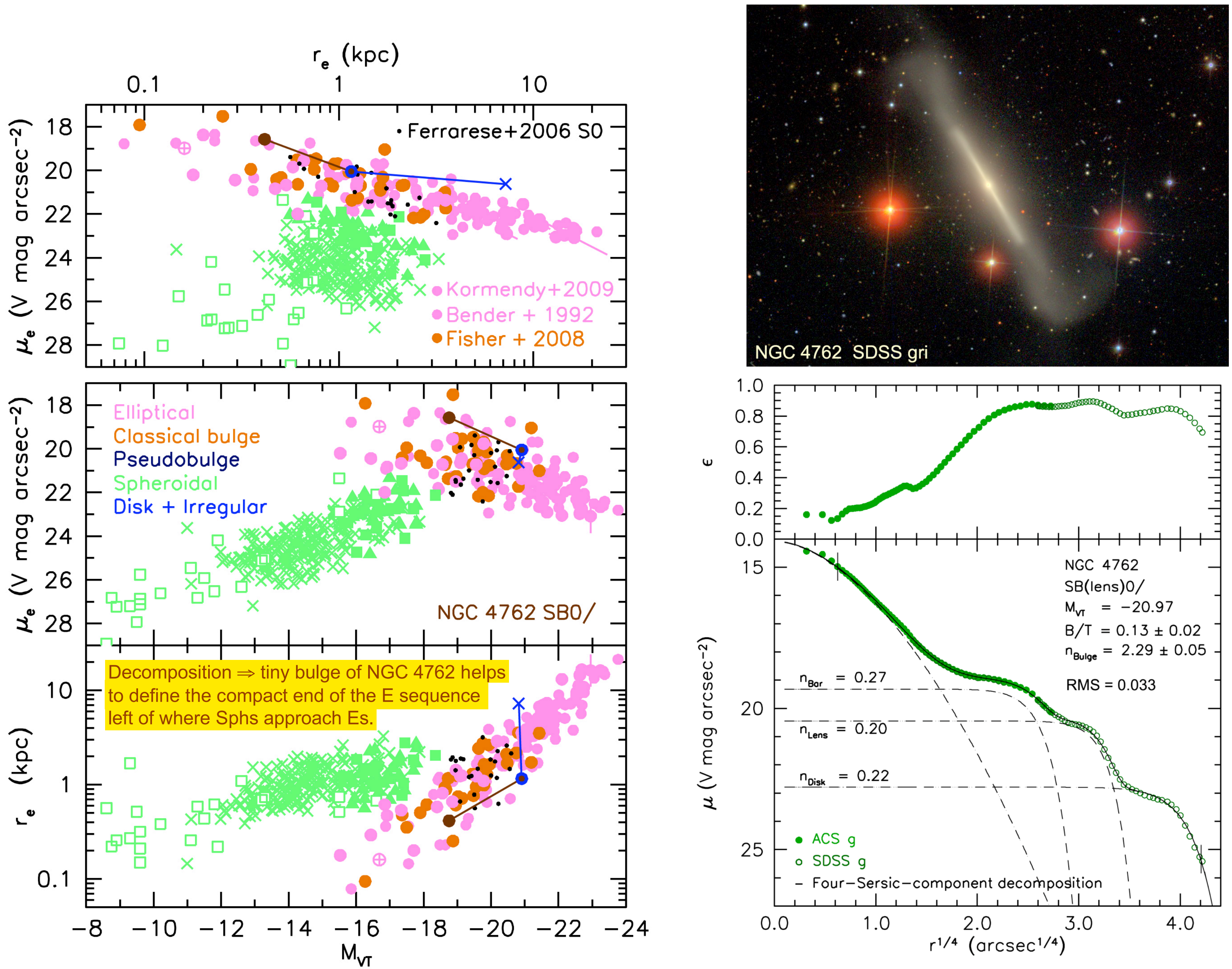
Ferrarese + 2006

It turns out that the main effect of not decomposing S0s is that the extension of the E + bulge sequence toward objects that are more compact than Sphs (i. e., to the left of the Sph sequence) is less evident.

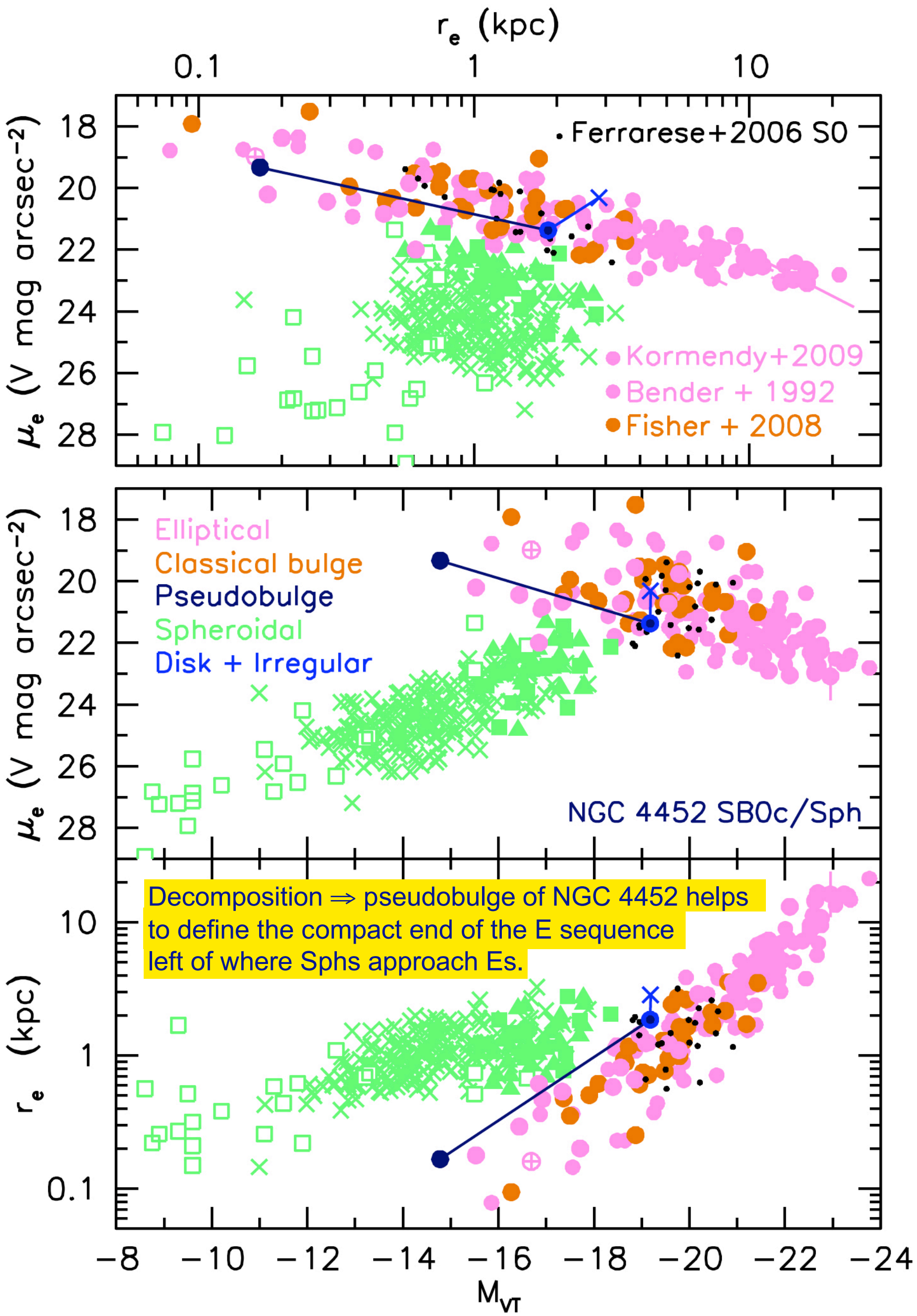
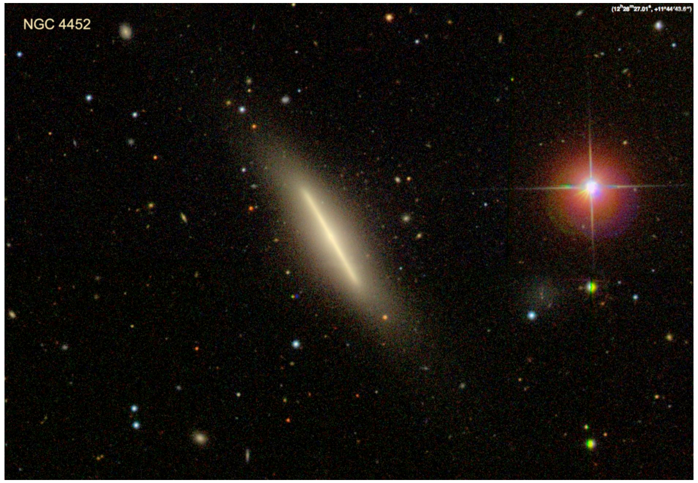
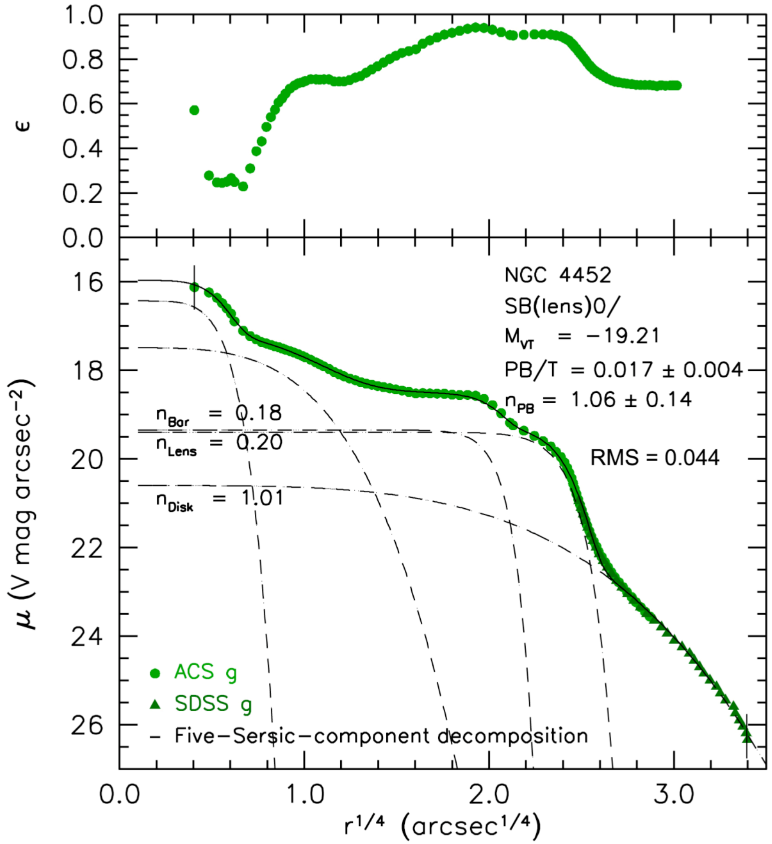
The 7 new Sphs that were omitted in KFCB because they were typed E, S0, or dS0 are added in dark green. They appear as normal Sphs in all subsequent plots.

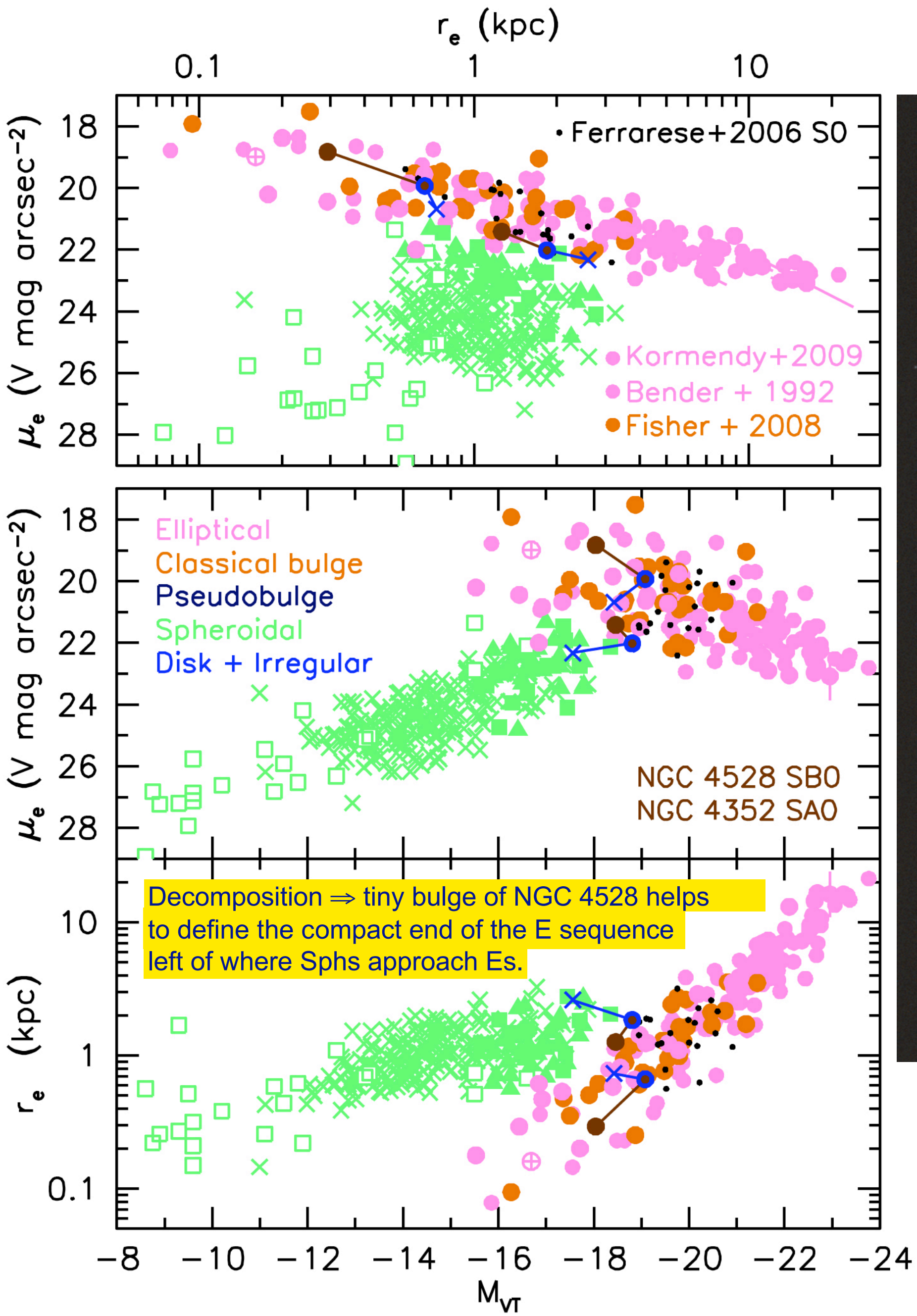
Local Group Sphs are updated with new discoveries.

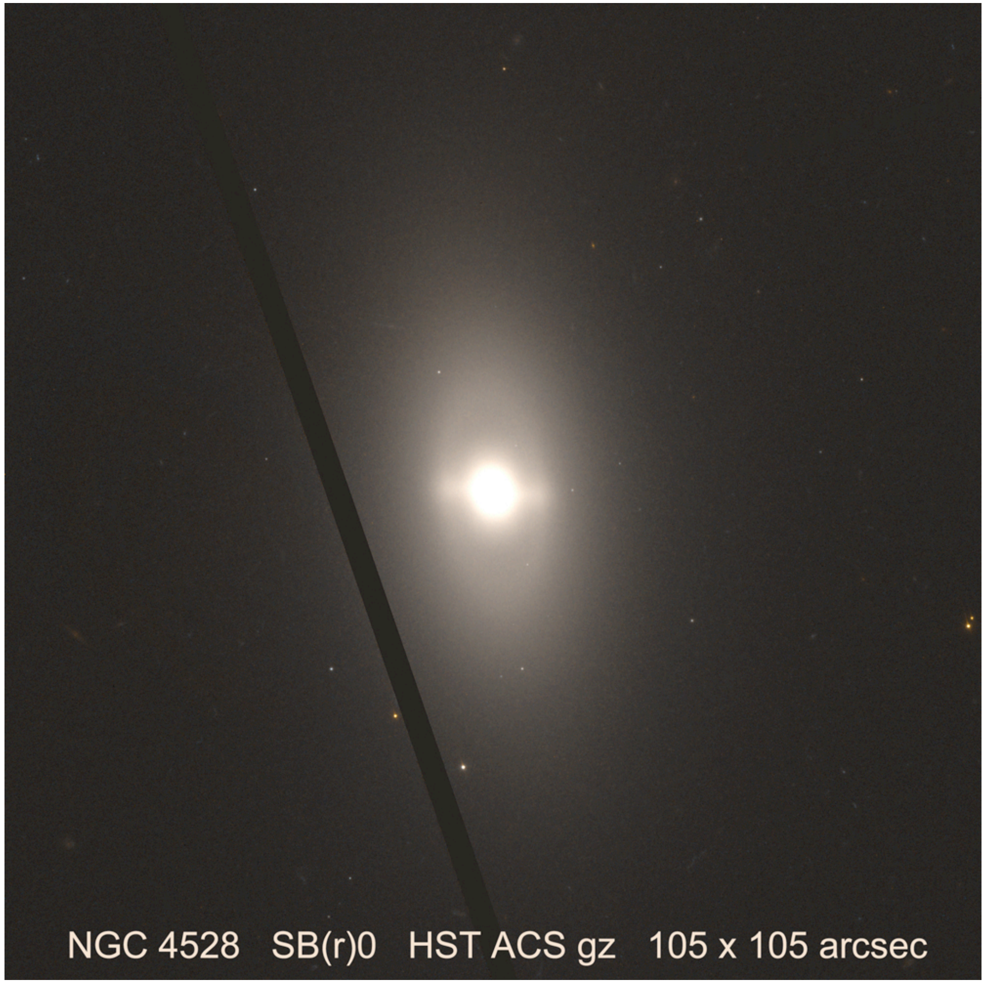
NGC 3945 SB(lens)0



r_e (kpc)
• Ferrarese+2006 S0
Kormendy+2009
Bender + 1992
Fisher + 2008
μ_e (V mag arcsec^{-2})
Elliptical
Classical bulge
Pseudobulge
Spheroidal
Disk + Irregular
NGC 4762 SB0/
Decomposition ⇒ tiny bulge of NGC 4762 helps to define the compact end of the E sequence left of where Sphs approach Es.
r_e (kpc)
M_{VT}
NGC 4762 SDSS gri
ε
NGC 4762
SB(lens)0/
M_{VT} = −20.97
B/T = 0.13 ± 0.02
n_{Bulge} = 2.29 ± 0.05
RMS = 0.033
n_{Bar} = 0.27
n_{Lens} = 0.20
n_{Disk} = 0.22
ACS g
SDSS g
Four−Sersic−component decomposition
μ (V mag arcsec^{-2})
$r^{1/4}$ (arcsec$^{1/4}$)

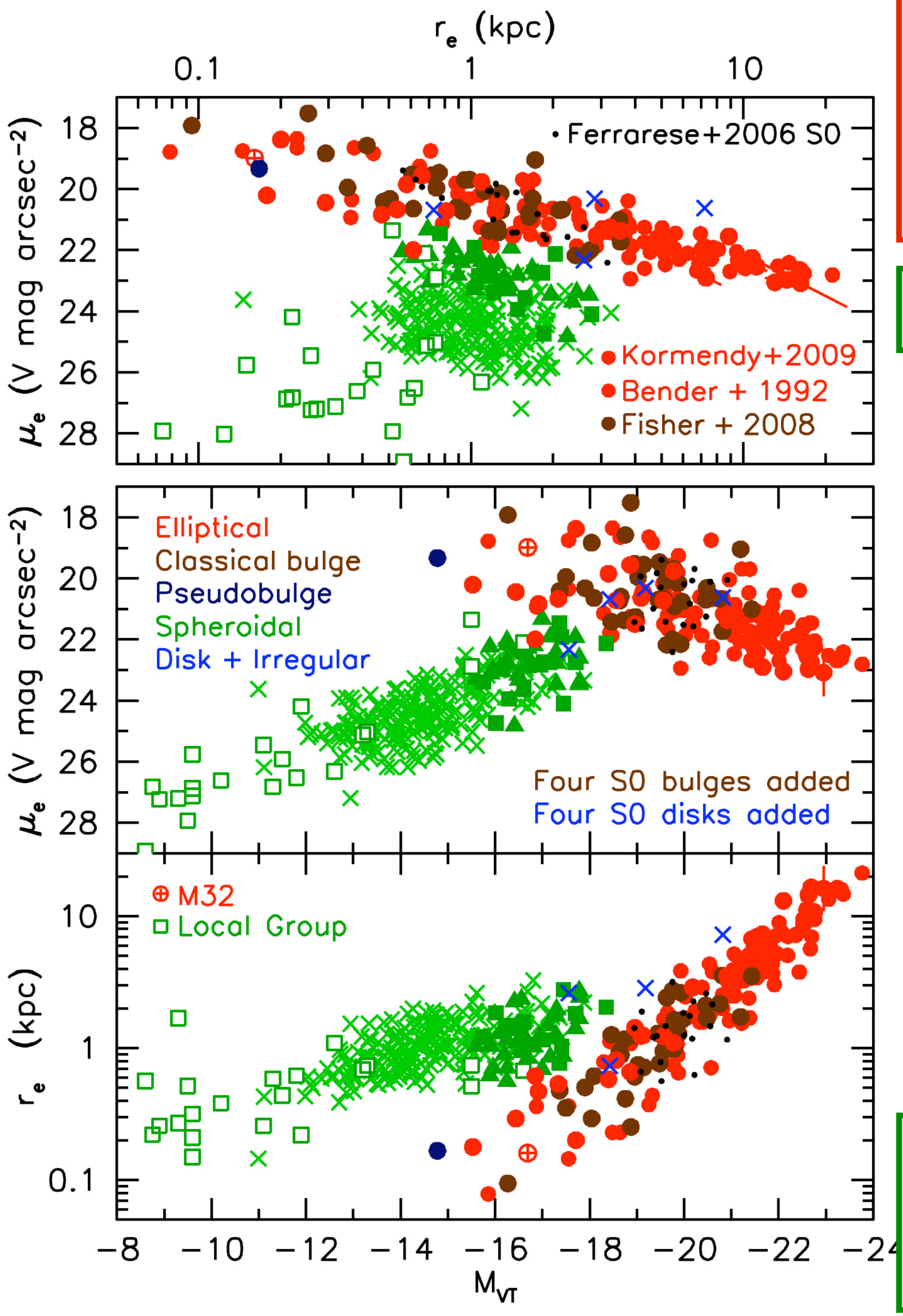

r_e (kpc)
0.1
1
10
Ferrarese+2006 S0
Kormendy+2009
Bender + 1992
Fisher + 2008
μ_e (V mag arcsec^−2)
Elliptical
Classical bulge
Pseudobulge
Spheroidal
Disk + Irregular
NGC 4452 SB0c/Sph
Decomposition ⇒ pseudobulge of NGC 4452 helps
to define the compact end of the E sequence
left of where Sphs approach Es.
r_e (kpc)
M_VT

NGC 4452

ε
NGC 4452
SB(lens)0/
M_VT = −19.21
PB/T = 0.017 ± 0.004
n_PB = 1.06 ± 0.14
n_Bar = 0.18
n_Lens = 0.20
n_Disk = 1.01
RMS = 0.044
ACS g
SDSS g
Five−Sersic−component decomposition
μ (V mag arcsec^−2)
r^1/4 (arcsec^1/4)





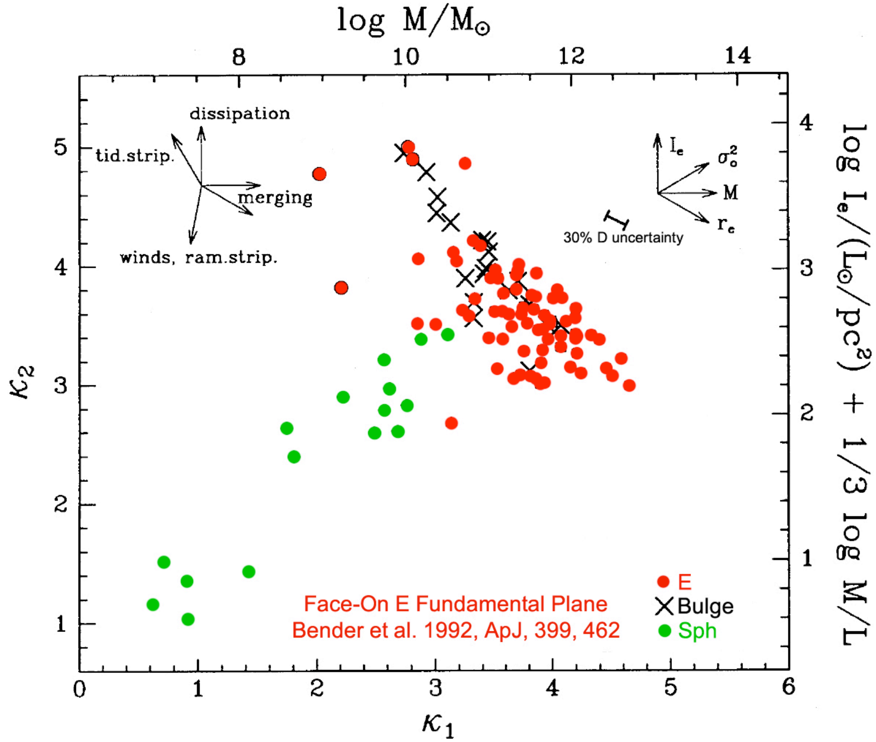
NGC 4528 B/T = 0.38 ± 0.02; n = 2.55 ± 0.40 ⇒ classical

NGC 4352 B/T = 0.69 ± 0.03; n = 2.88 ± 0.32 ⇒ classical

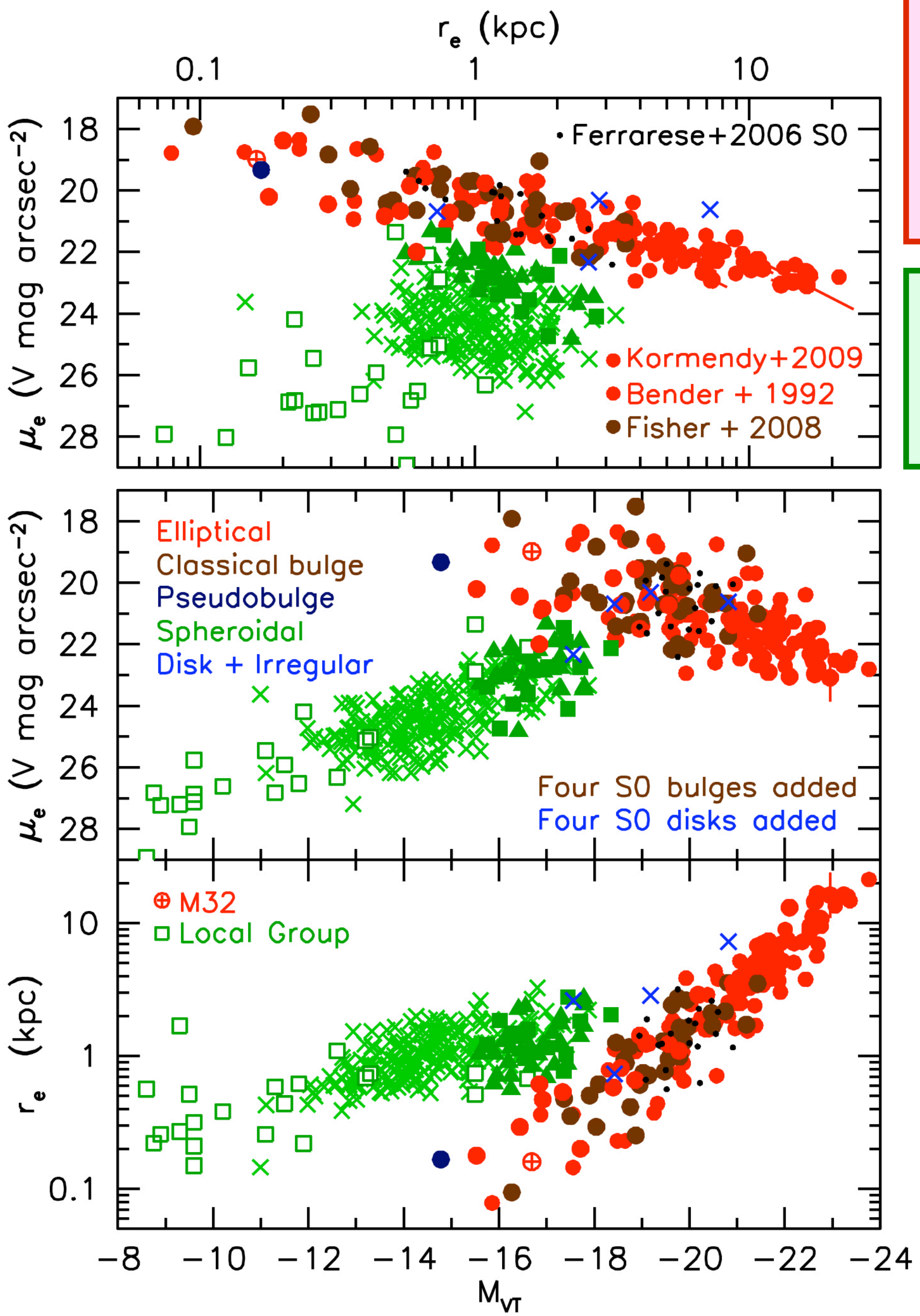


Our augmented sample (including the remaining 19 Ferrarese S0s without bulge-disk decompositions) confirms the E – Sph dichotomy.

So do many other authors:

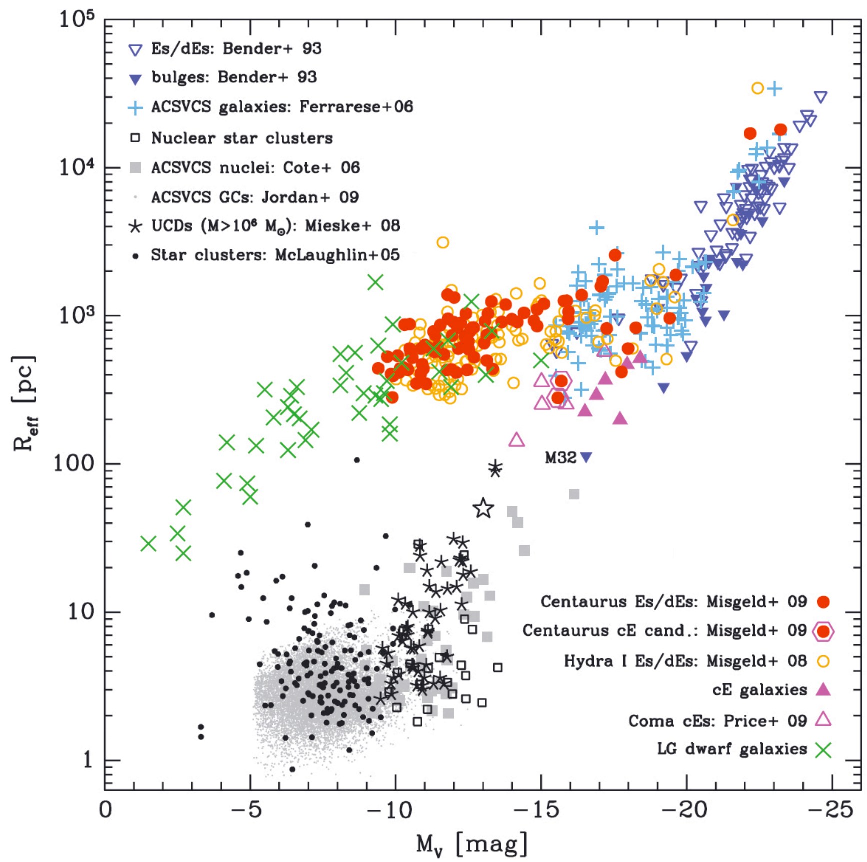


"Dwarf ellipticals and dwarf spheroidals … populate an elongated locus running at right angles to the main elliptical locus."



Our augmented sample (including the remaining 19 Ferrarese S0s without bulge-disk decompositions) confirms the E – Sph dichotomy.

So do many other authors (even when they don't say so). Misgeld & Hilker 2011, MNRAS, in press:



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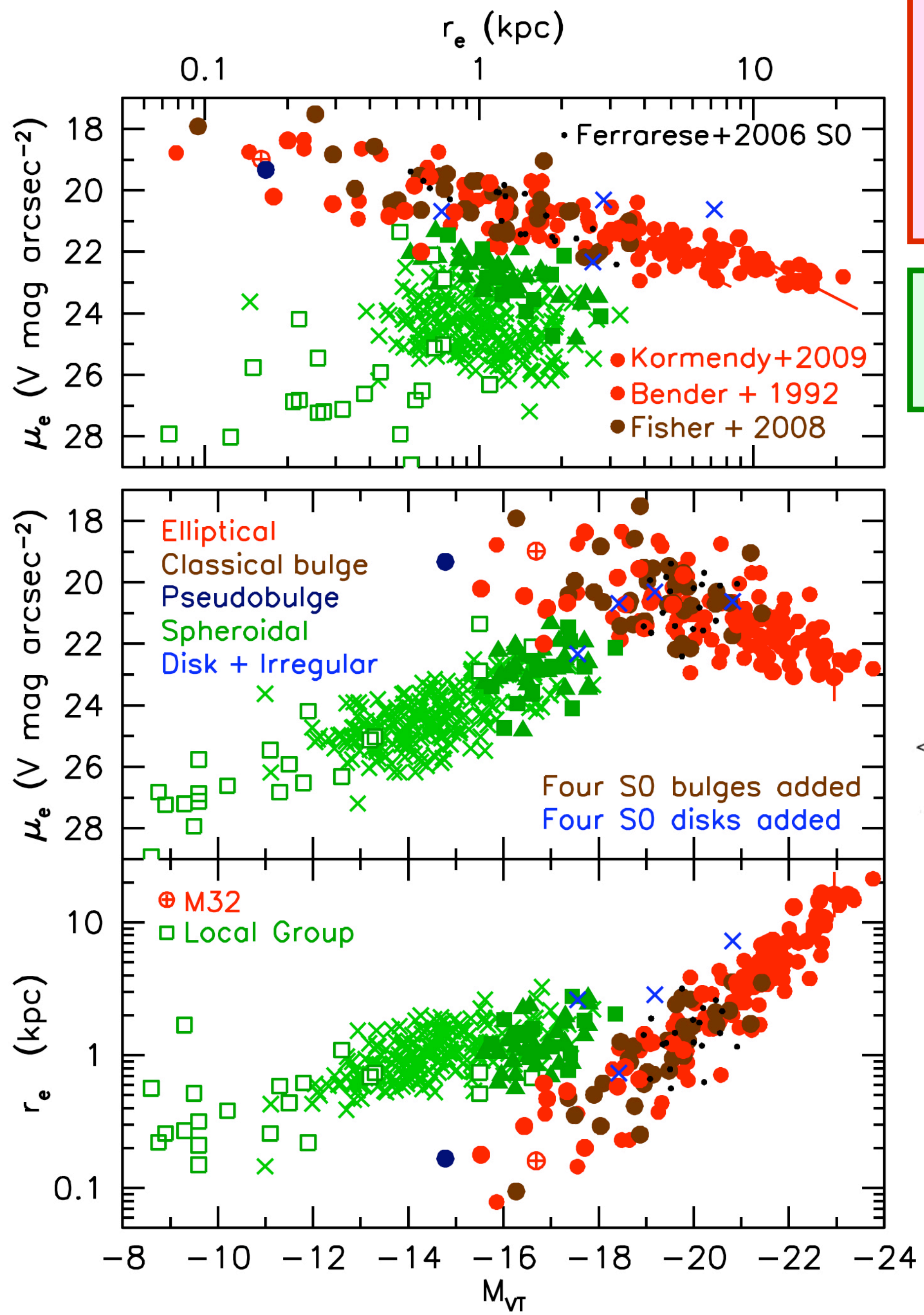
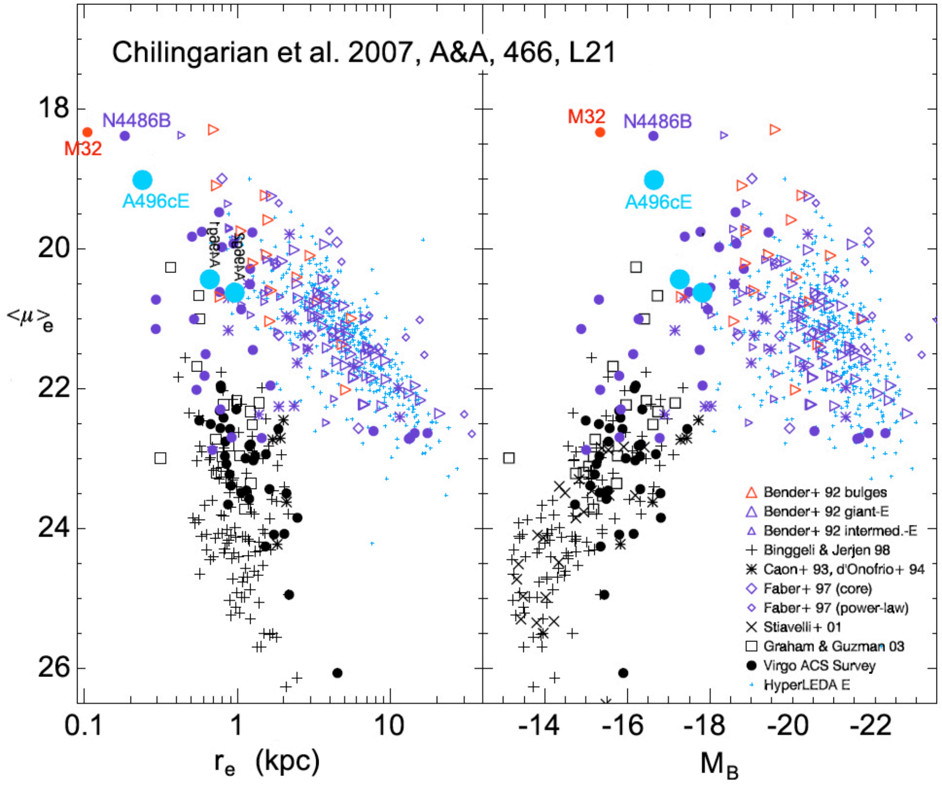
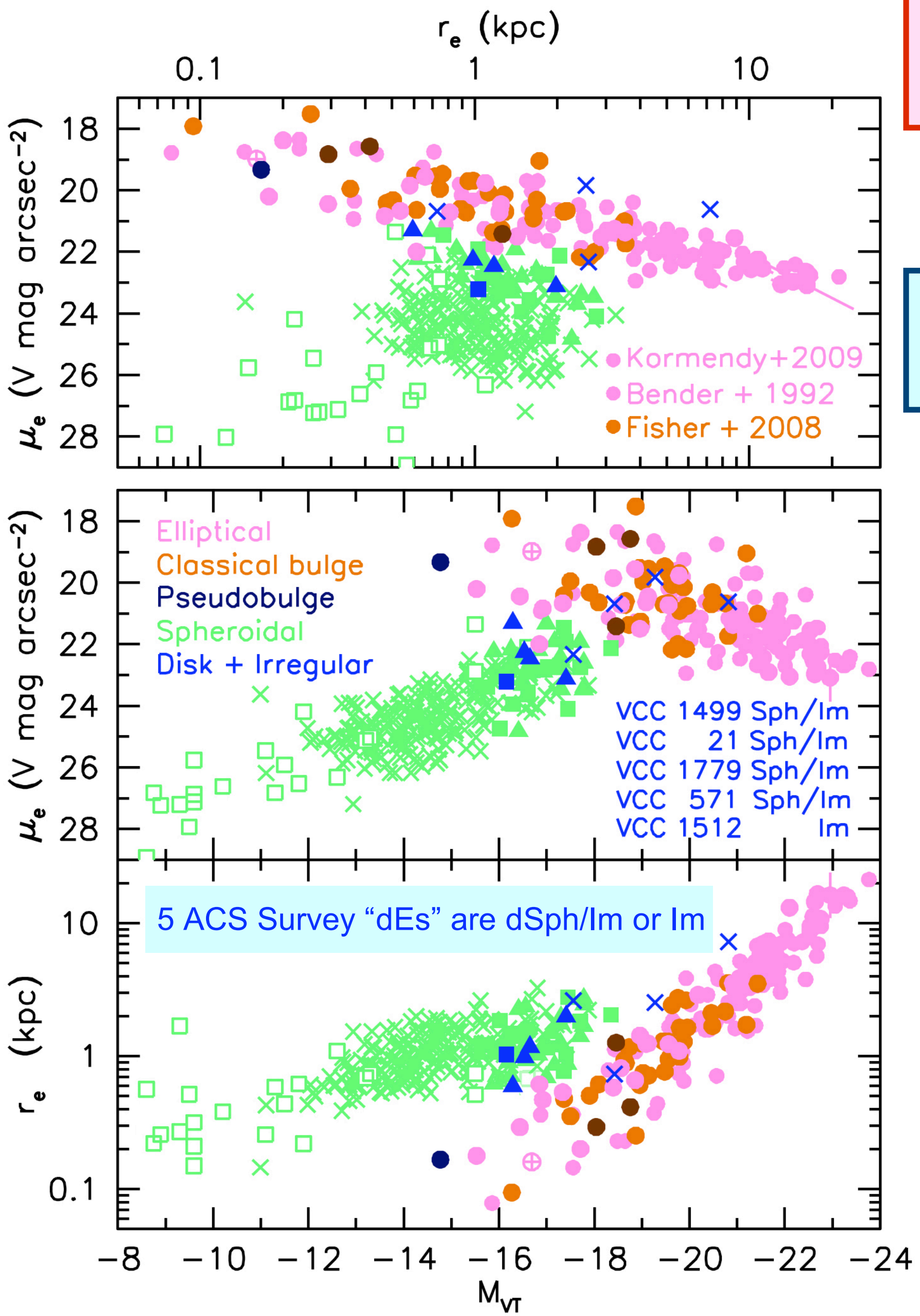


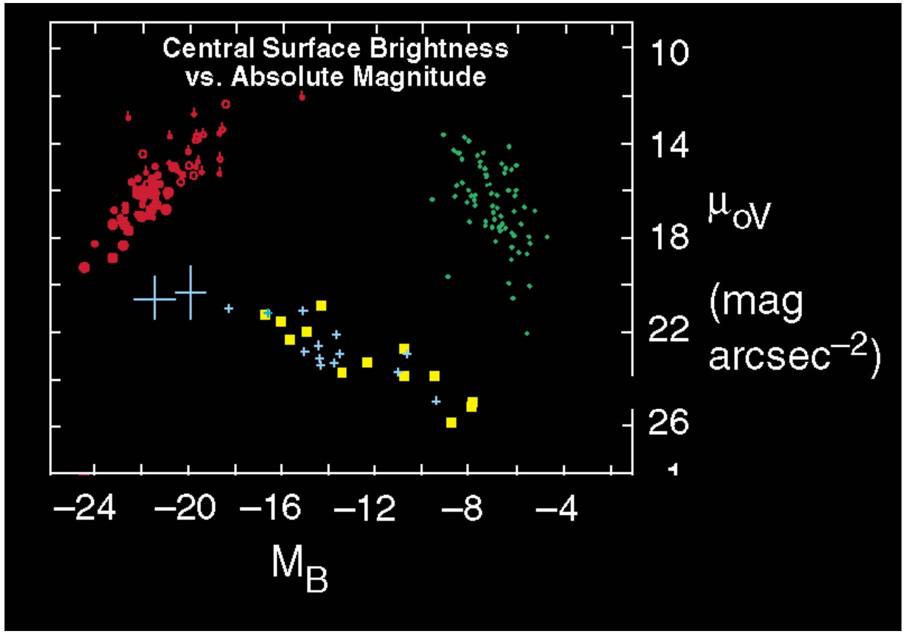
So do many other authors
(even when they only partly agree):

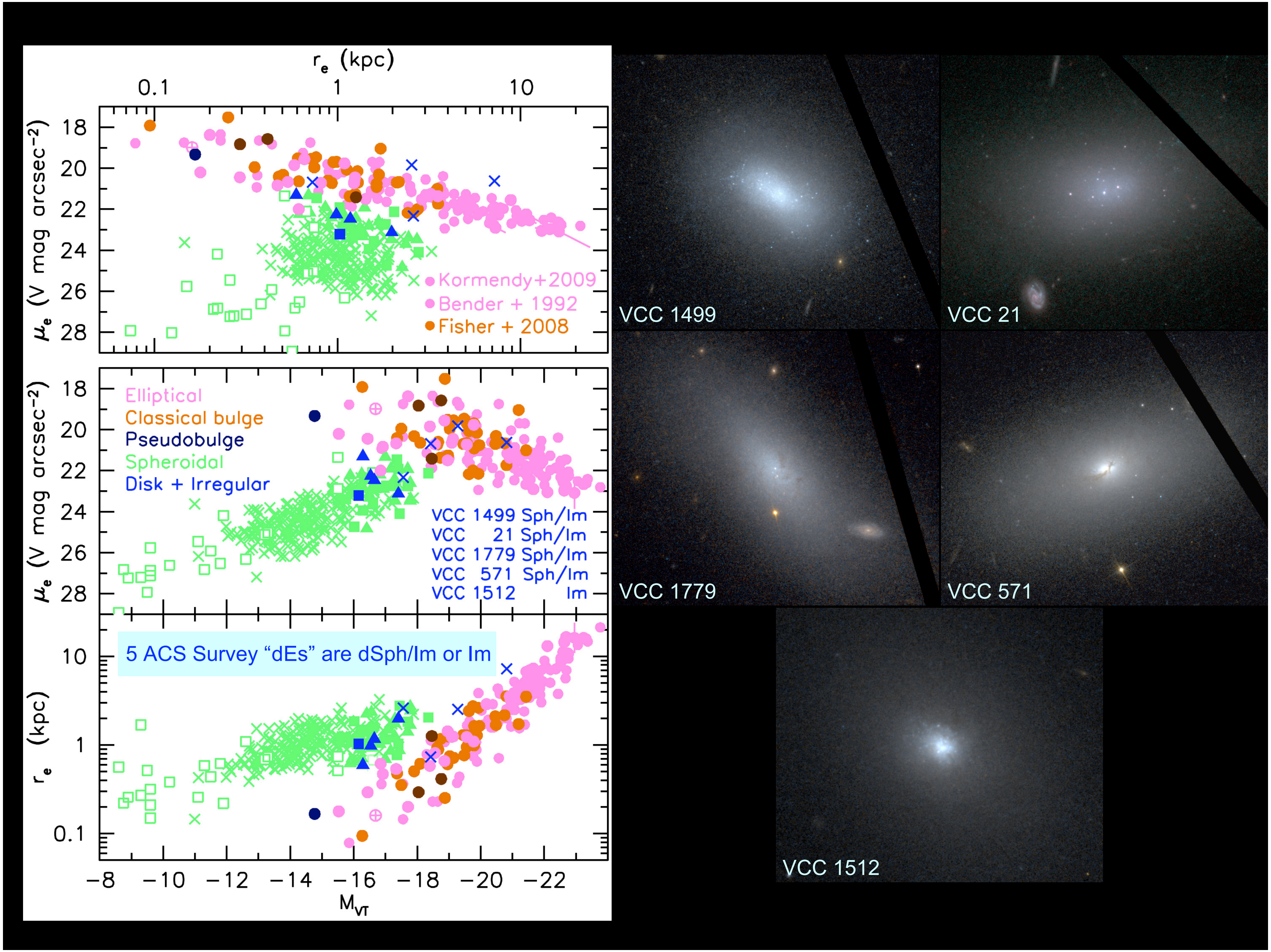


Our augmented sample confirms the E – Sph dichotomy.



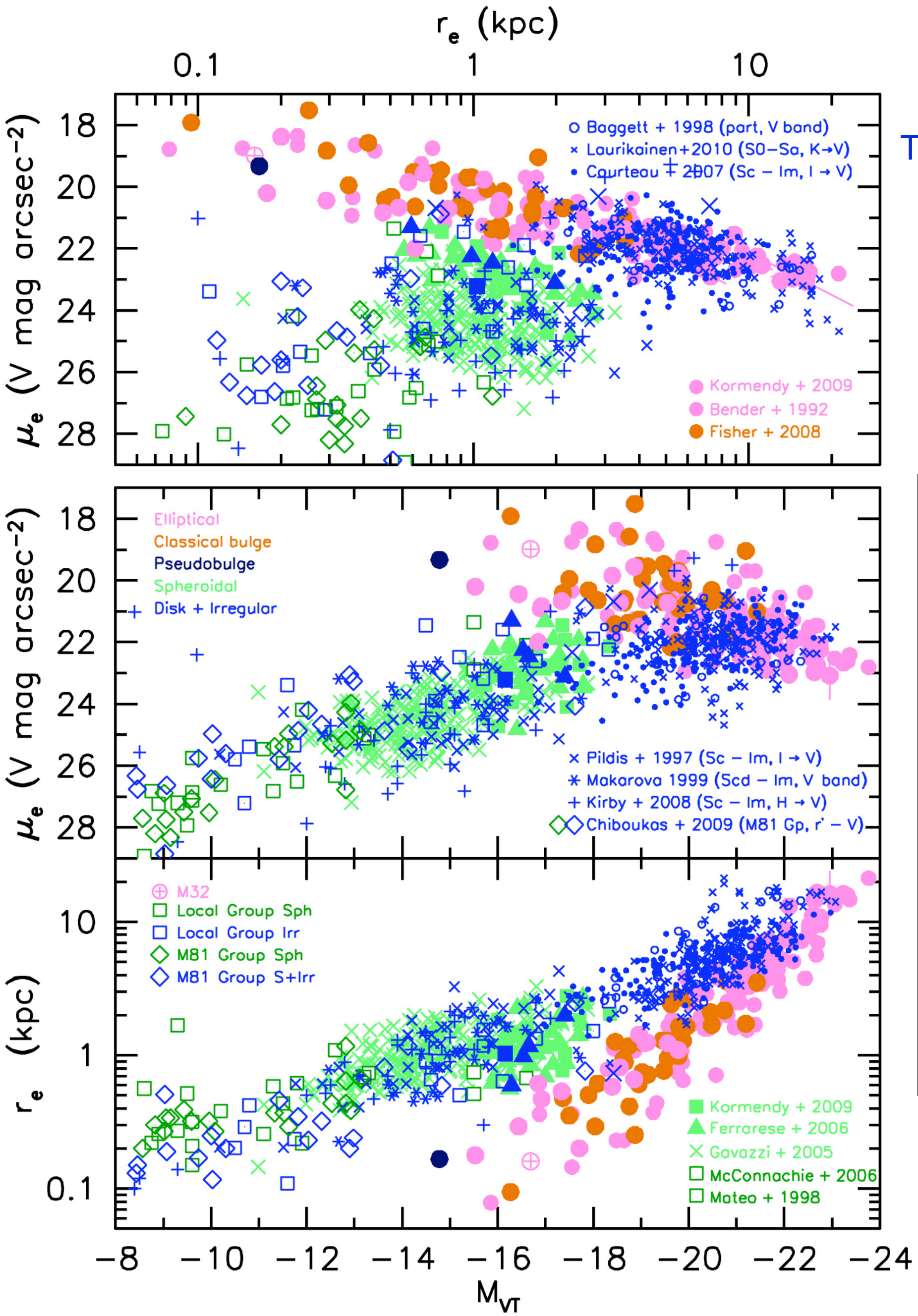
Do we also confirm that Sph sequence ~ S+Im sequence?



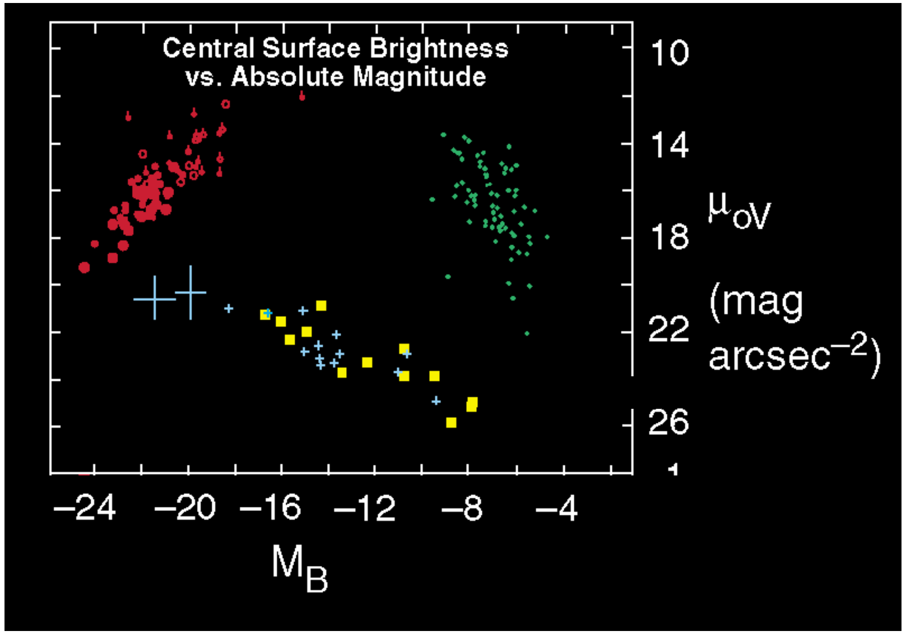


r_e (kpc)
0.1
1
10
μ_e (V mag arcsec^-2)
Kormendy+2009
Bender + 1992
Fisher + 2008
Elliptical
Classical bulge
Pseudobulge
Spheroidal
Disk + Irregular
VCC 1499 Sph/Im
VCC 21 Sph/Im
VCC 1779 Sph/Im
VCC 571 Sph/Im
VCC 1512 Im
5 ACS Survey "dEs" are dSph/Im or Im
r_e (kpc)
M_VT
VCC 1499
VCC 21
VCC 1779
VCC 571
VCC 1512

Global Parameter FP Projections (parameters from integrating 2-D profile)

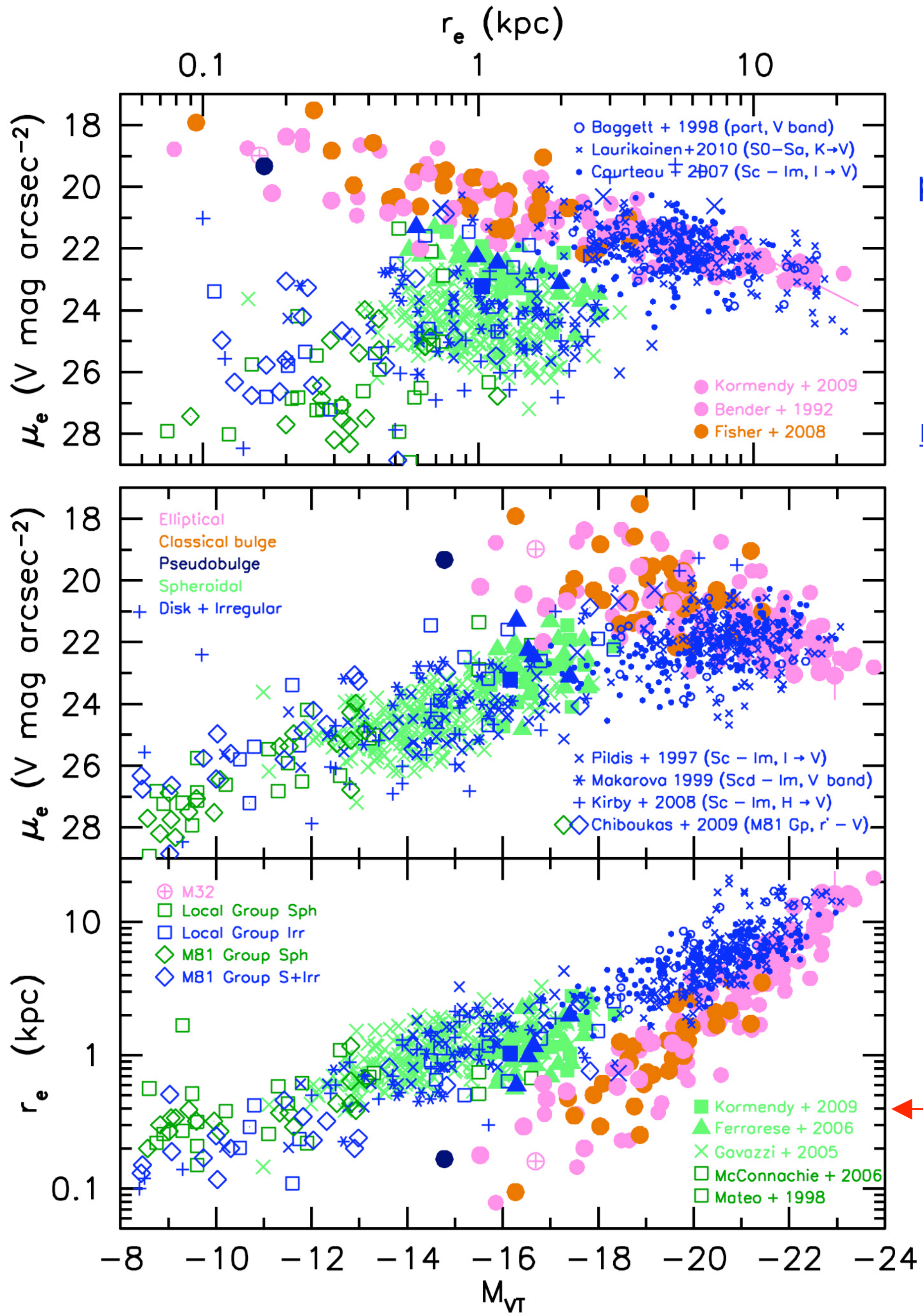


To our augmented sample of classical bulges and ellipticals, we add galaxy parameters from bulge-disk decompositions (for early-type galaxies) or from Sérsic fits (for late-type galaxies) for 509 galaxies from 9 independent sources.



This confirms that Sph galaxies have the same parameter correlations as disks & irregulars and supports our suggestion that Sphs are defunct dS+Im systems.

In galaxy mergers, dissipation is a strong function of (progenitor or remnant) luminosity.



Note that present-day, giant disks can merge to become present-day giant ellipticals with relatively little dissipation. This is plausible: present-day giant disks contain relatively little gas.

Making present-day small ellipticals out of present-day progenitors requires more dissipation as galaxy luminosity decreases.

Shen et al. 2003, MNRAS, 343, 978

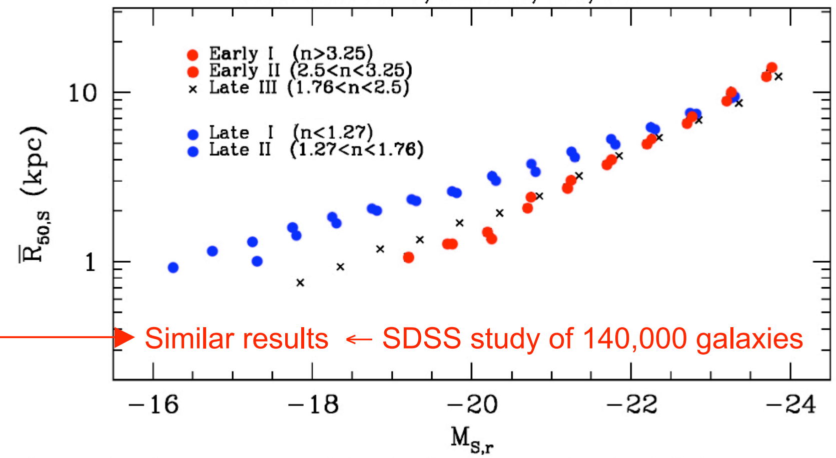
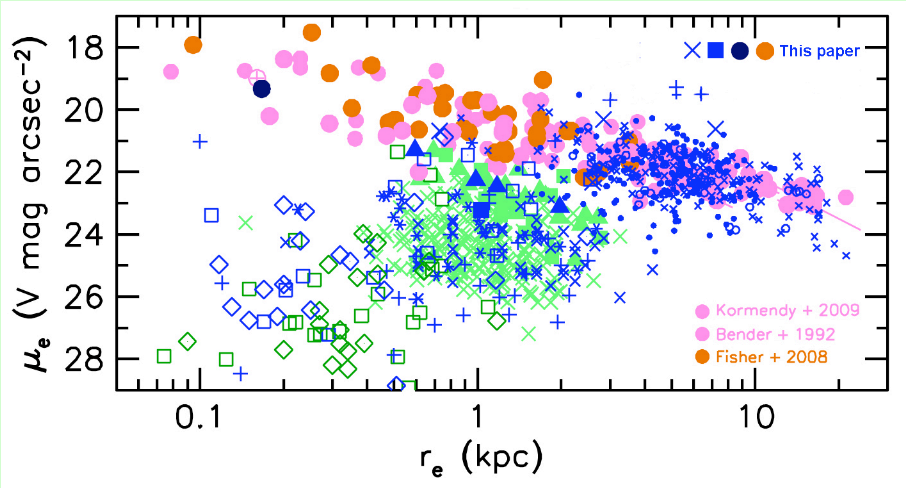


Figure 7. The median and of the distributions of Sérsic half-light radius, $R_{50,S}$, as function of r-band absolute Sérsic magnitude, for galaxies in fine bins of the Sérsic index n.

The E–Sph Dichotomy: Perspective



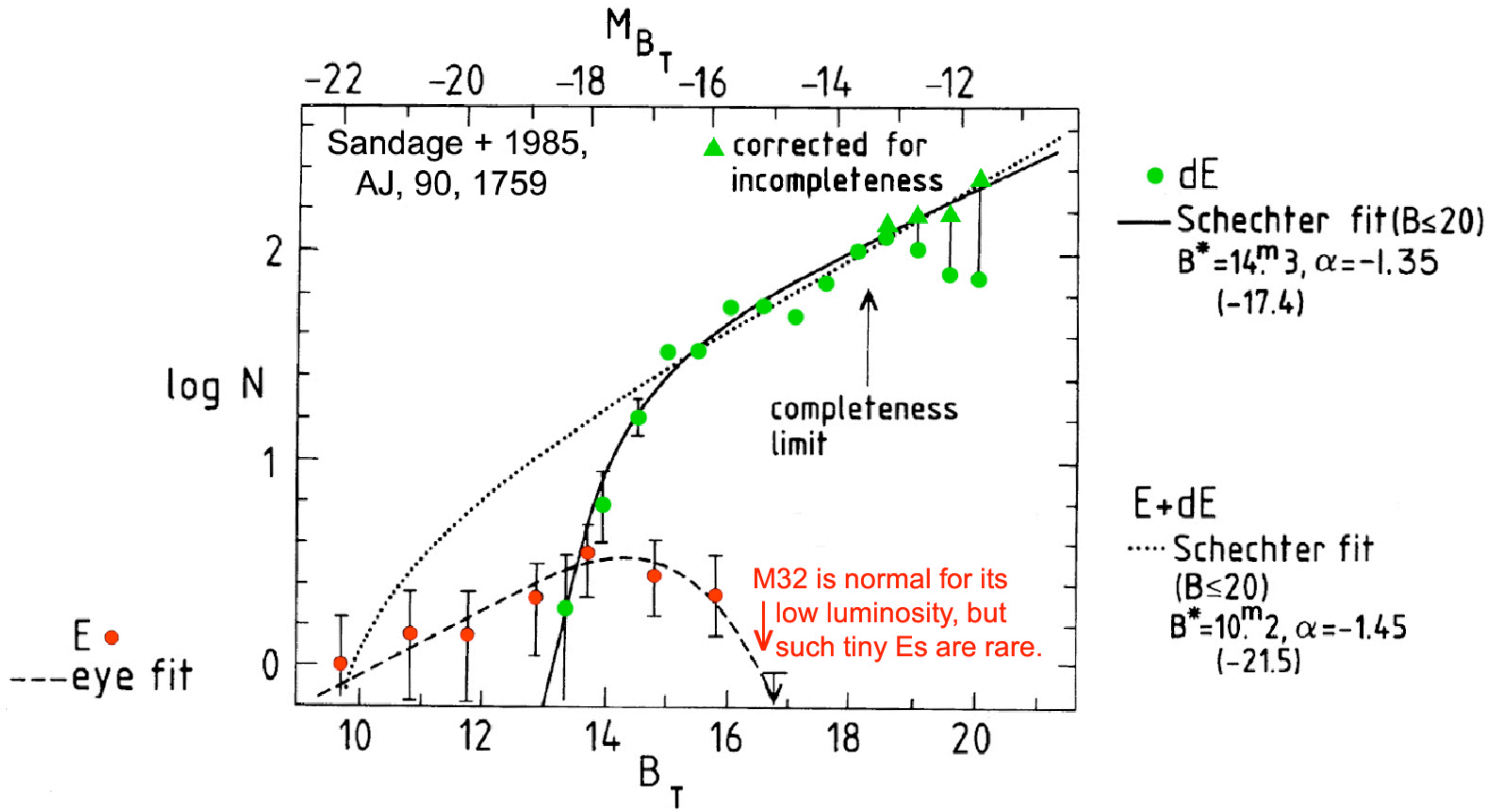
An E – Sph dichotomy is "necessary"
if Es form via major mergers and
if Sphs are defunct late-type galaxies.

Merger simulations predict the observed FP of ellipticals
(Robertson et al. 2006, ApJ, 641, 21; Hopkins et al. 2008, ApJ, 689, 17),
not an E+Sph+S+Im FP from which core Es deviate.

Ellipticals form a sequence of increasing dissipation
at decreasing L.
Spheroidals form a sequence of decreasing baryon retention
at decreasing L.

The E and Sph sequences overlap in r_e and luminosity.

The luminosity function of elliptical galaxies = remnants of major mergers is strongly bounded.

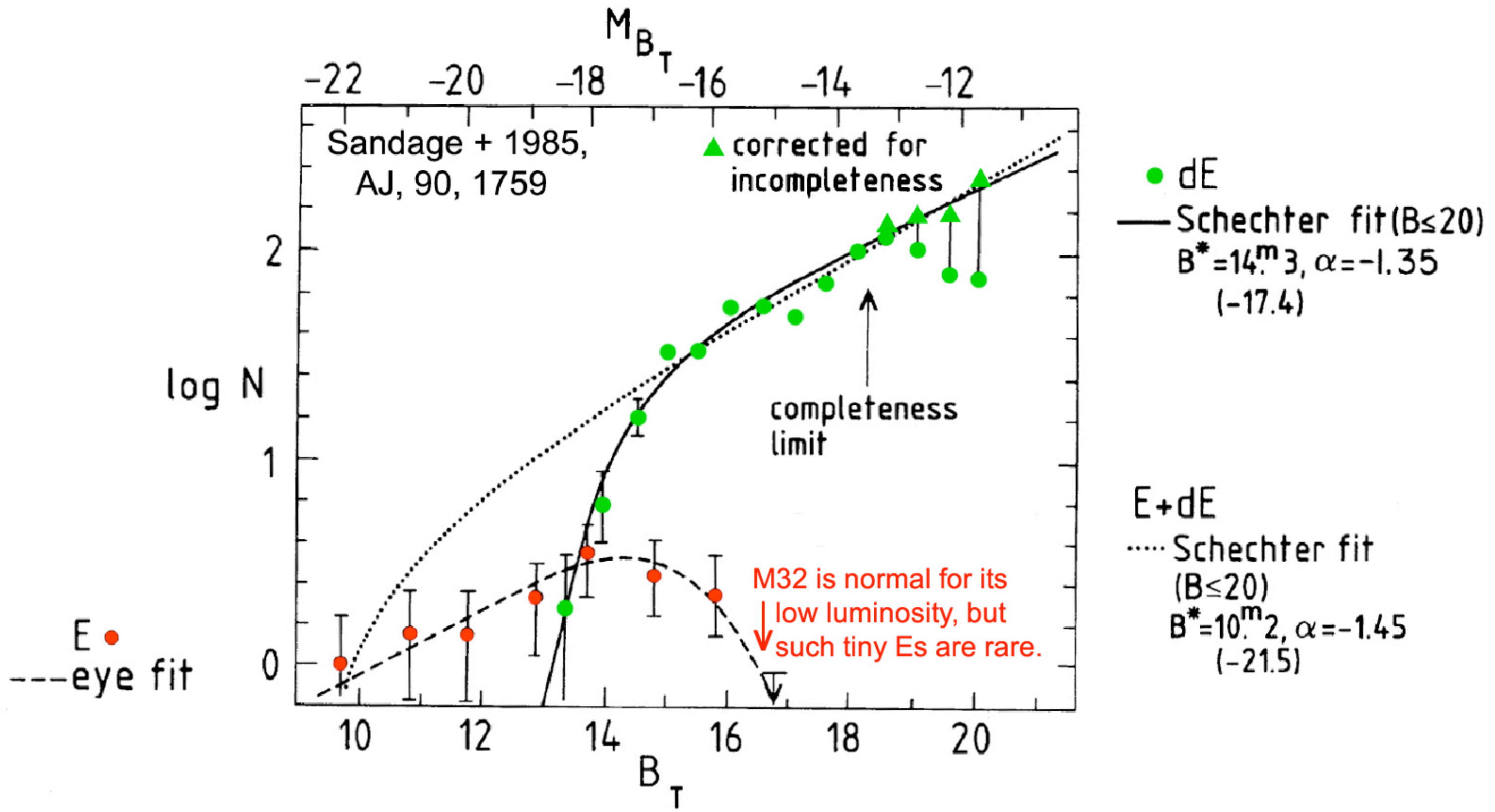


Luminosity function for E and dE types. The Schechter fit to all data brighter than $B = 20$ is poor, predicting too many galaxies at the bright end.

Binggeli, Sandage & Tammann 1988, ARAA, 26, 509:
"The distinction [between] Es and dEs must almost certainly mean that the two classes are of different origin [Kormendy 1985, Dekel & Silk 1986]. This is also supported by the fact that the LFs of Virgo Es and dEs [are different]."

Note that Sandage can (usually) distinguish between E and Sph galaxies of the same B_T.

The luminosity function of elliptical galaxies = remnants of major mergers is strongly bounded.



Luminosity function for E and dE types. The Schechter fit to all data brighter than $B = 20$ is poor, predicting too many galaxies at the bright end.

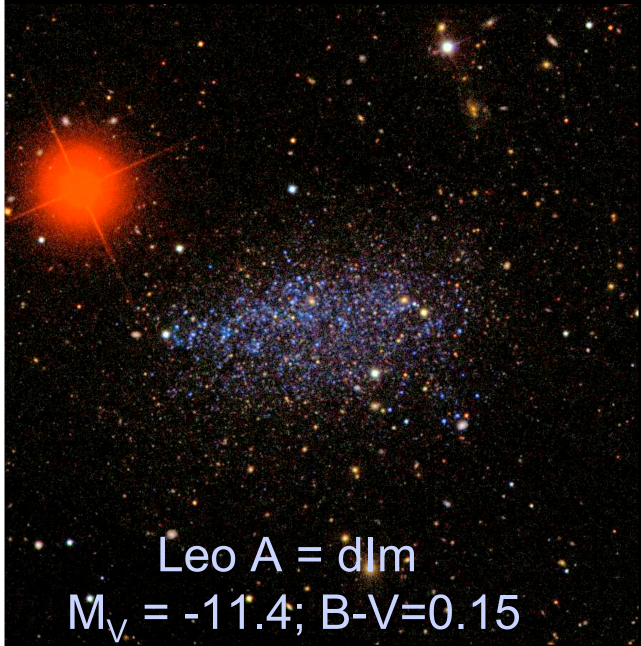
Because supermassive black holes (BHs) correlate tightly only with ellipticals and classical bulges

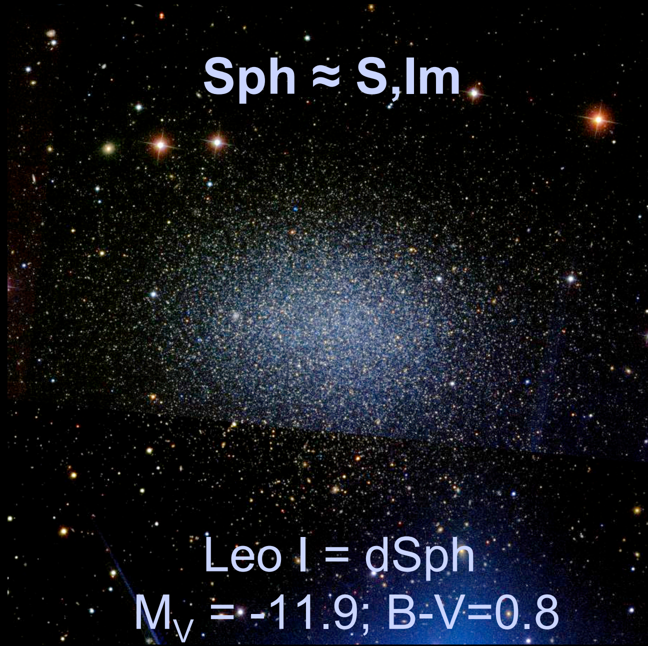
(Kormendy, Bender, & Cornell 2011, Nature, 469, 374: Bender talk at this meeting),

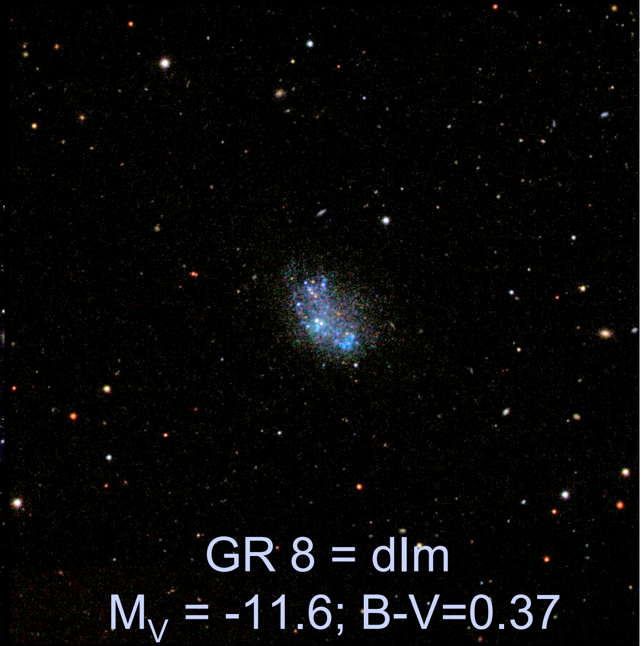
co-evolving BHs and their hosts are bounded in mass and few in number compared with BHs in disks and pseudobulges that grow via local processes and that do not co-evolve with their hosts.

But co-evolving BHs account for most BH mass!

Sph and Im galaxies have similar, low surface brightnesses.







E ≠ Sph

Suggested explanation 1 (Saito 1979, PASJ, 31, 193; Dekel & Silk 1986)

THE ORIGIN OF DWARF GALAXIES, COLD DARK MATTER, AND BIASED GALAXY FORMATION

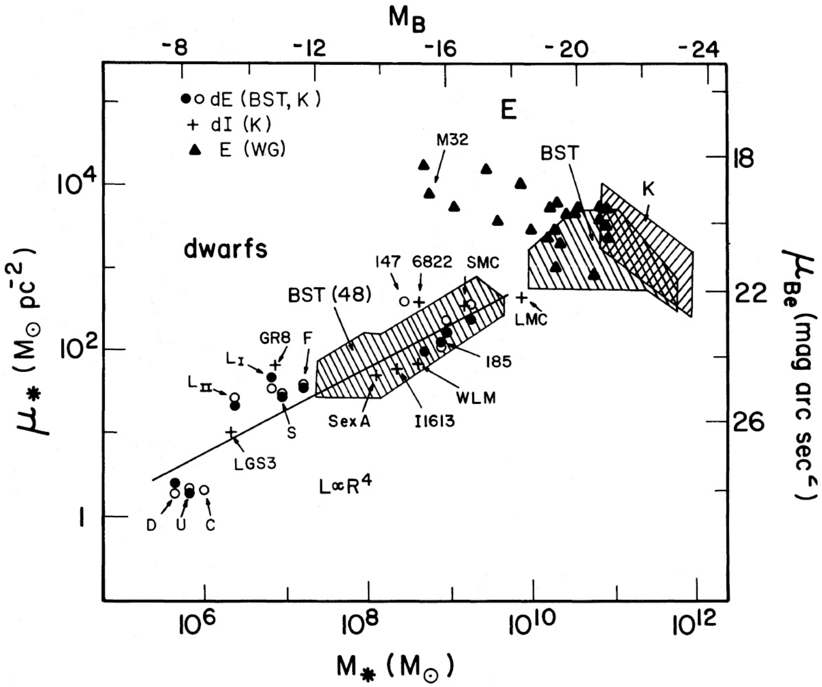
AVISHAI DEKEL AND JOSEPH SILK

THE ASTROPHYSICAL JOURNAL, 303:39–55, 1986 April 1

ABSTRACT

The formation of dwarf, diffuse, metal-poor galaxies as a result of supernova-driven winds is reexamined in view of the accumulating data on the systematic properties of dwarfs in the Local Group and in the Virgo Cluster. The observed luminosity-radius-metallicity relations, which are easily understood if the gaseous proto-galaxies are self-gravitating, are found to be produced naturally inside dominant halos, with a mass-radius relation that resembles the predictions of the "cold" dark matter cosmological scenario. The theory predicts for the least luminous galaxies a mass-to-luminosity ratio that increases with decreasing luminosity up to $\sim$10–100, and only a slow decrease of velocity dispersion with decreasing luminosity down to $\sim$5–10 km s^{-1}.

The critical condition for global gas loss as a result of the first burst of star formation is that the virial velocity be below a critical value on the order of 100 km s^{-1}. In any hierarchial scenario for galaxy formation, this condition leads to two distinct classes of galaxies as observed: (*a*) the diffuse dwarfs (including the dwarf irregulars that have retained some gas), which mostly originate from typical ($\sim 1\,\sigma$) density perturbations; and (*b*) the normal, brighter galaxies (including compact dwarfs) which can originate only from the highest density peaks (~ 2–$3\,\sigma$). This provides a statistical biasing mechanism for the preferential formation of bright galaxies in denser regions (clusters and superclusters), enhancing the clustering among the high–surface-brightness galaxies relative to the diffuse dwarfs.



The crucial observation is that both types of diffuse dwarfs seem to follow similar radius-luminosity-metallicity relations (K; Hunter and Gallagher 1985; Thuan 1986; M. Aaronson, private communication).

This similarity between dI's and dE's introduces the more crucial, general question of the origin of low surface brightness in all the diffuse dwarfs.

We suggest that *both the dI's and the dE's have lost most of their mass* in winds after the first burst of star formation, and that this process determined their final structural relations. The dI's somehow managed to retain a small fraction of their original gas, while the dE's either have lost all of their gas at the first burst of star formation or passed through a dI stage before they lost the rest of the gas and turned dE.

Suggested explanation 2
(Faber & Lin 1983; Lin & Faber 1983; Kormendy 1985, 1987)

IS THERE NONLUMINOUS MATTER IN DWARF SPHEROIDAL GALAXIES?

S. M. FABER AND D. N. C. LIN

THE ASTROPHYSICAL JOURNAL, **266**:L17–L20, 1983 March 1

ABSTRACT

Evidence from tidal masses indicates that mass-to-light ratios of dwarf spheroidal galaxies are roughly one order of magnitude larger than those of globular clusters. We tentatively infer that dwarf spheroidal galaxies contain large amounts of nonluminous matter and in this regard resemble bigger galaxies. The luminosity profiles of dwarf spheroidal galaxies are also shown to be consistent with exponential laws, possibly indicating a closer evolutionary link to spiral-irregular galaxies than to elliptical galaxies.

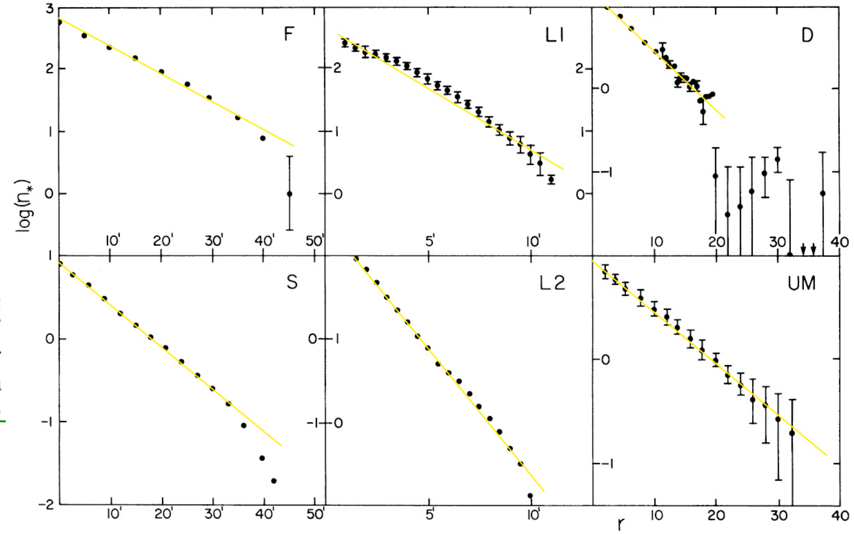


FIG. 2.—Hodge's star counts, n_*, versus radius, r, for six dwarf spheroidal galaxies plotted in semi-log coordinates. The individual counts are plotted whenever available, otherwise the smoothed counts are shown. An exponential would be a straight line.

SOME IMPLICATIONS OF NONLUMINOUS MATTER IN DWARF SPHEROIDAL GALAXIES

D. N. C. LIN AND S. M. FABER

THE ASTROPHYSICAL JOURNAL, **266**:L21–L25, 1983 March 1

ABSTRACT

Strong constraints are placed on the nature of nonluminous matter if it dominates the gravitational potential of dwarf spheroidal galaxies. In particular, the phase-space constraint in small galaxies sets a lower limit of several hundred eV on particle mass if the dark matter consists of noninteracting fermions. This limit is sufficiently strong to rule out neutrinos. Difficulties of a fundamental nature are also encountered even with more massive noninteracting particles. In scenarios where black holes comprise the nonluminous matter, they have to be less massive than $\sim 100\ M_\odot$.

The quasi-exponential light profiles and dark matter in dwarf spheroidal galaxies may indicate a possible evolutionary link to dwarf irregular galaxies. Evidence is presented which supports the view that dwarf spheroidal galaxies are former dwarf irregular galaxies which lost their gas near the Milky Way via ram pressure sweeping.

We suggest:
Both processes are important
(Kormendy 1987; KFCB)

The Morphology – Density Relation

GALAXY MORPHOLOGY IN RICH CLUSTERS: IMPLICATIONS FOR THE FORMATION AND EVOLUTION OF GALAXIES

ALAN DRESSLER

THE ASTROPHYSICAL JOURNAL, 236:351–365, 1980 March 1

ABSTRACT

A study of the galaxy populations in 55 rich clusters is presented together with a discussion of the implications for the formation and/or evolution of different morphological types. A well-defined relationship is found between local galaxy density and galaxy type, which, in agreement with previous studies, indicates an increasing elliptical and S0 population and a corresponding decrease in spirals with increasing density.

Three lines of evidence are presented which contradict the interpretation that these gradients in population result from the production of S0 galaxies when spirals are swept of their disk gas by an IGM. (1) The relation between density and morphological type is a very slow function of density, so that a significant percentage of S0 galaxies exists in regions where gas density and temperature are too low to effect removal of the gas from spirals by evaporation or ram pressure stripping. (2) The relation between density and morphological type is virtually identical in irregular clusters of low concentration which are presumably not yet relaxed, and regular, high concentration clusters which are thought to be relaxed, despite the expectation that S0 production by gas ablation from spirals should only be important in the latter. (3) The bulges and bulge/disk ratios of S0 galaxies are systematically larger than those of spiral galaxies in all density regimes. Since the tightly bound inner bulges should be unaffected by ablation, the dissimilarity in the bulge and bulge/disk distributions in all density regimes is inconsistent with the idea that most S0 galaxies result from the removal of disk gas from a spiral by ram pressure stripping or evaporation.

As an alternative to the hypothesis of spiral sweeping, it is suggested that the local density/morphological-type relation reflects the long time scale associated with the formation of the disk component of galaxies. If this time scale is comparable to or greater than several billion years, an increase in local galaxy density may slow or even halt the growth of the disk components.

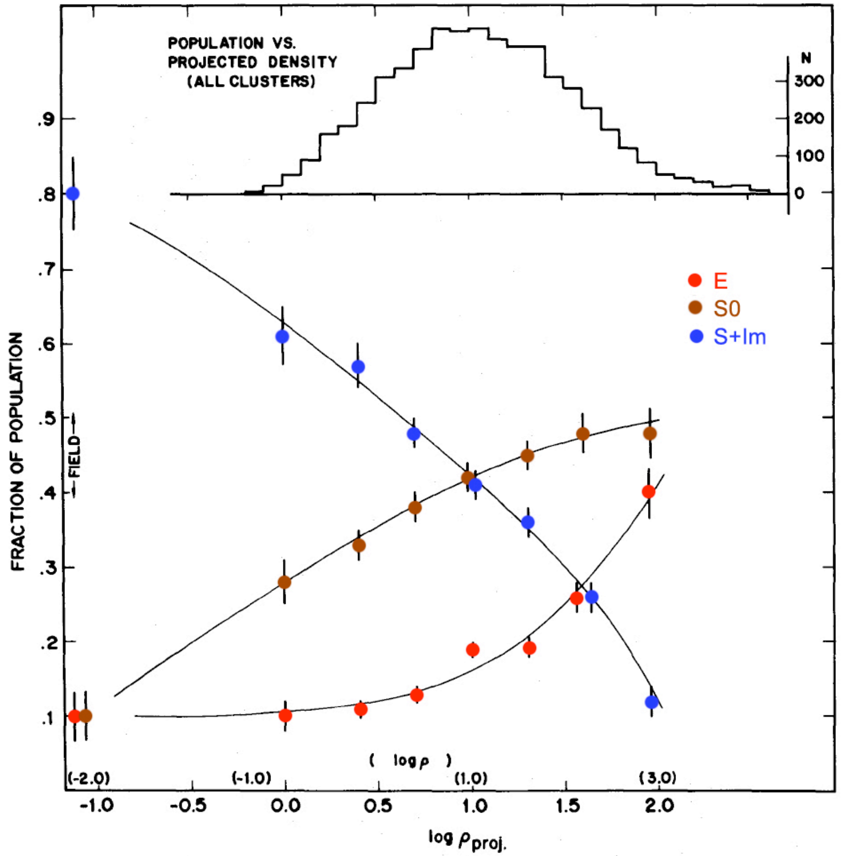


FIG. 4.—The fraction of E, S0, and S+I galaxies as a function of the log of the projected density, in galaxies Mpc^{-2}. The data shown are for all cluster galaxies in the sample and for the field. Also shown is an estimated scale of true space density in galaxies Mpc^{-3}. The upper histogram shows the number distribution of the galaxies over the bins of projected density.

Suggested explanation 3 (for S0s):
E, S0, S+Im origin is determined by environmental processes ≠ stripping.
(He suggests: choking disk formation at high ρ_{proj}. We are agnostic.)

The Morphology – Density Relation

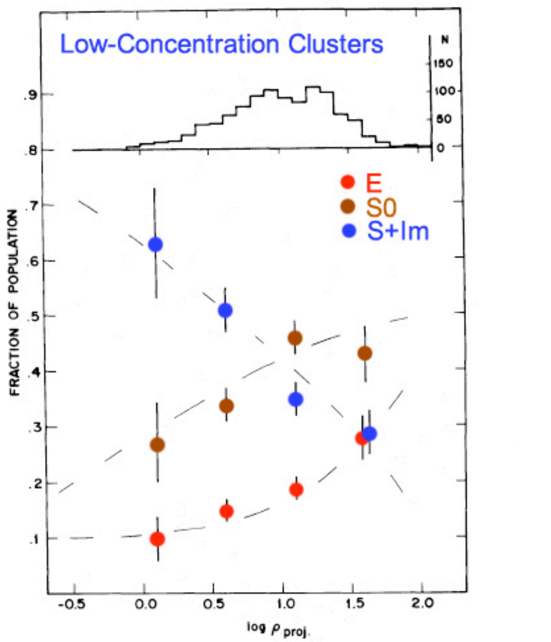


FIG. 9.—Low-concentration clusters (A76, A119, A168, A978, A979, A1644, A1736, A2151, 0030 − 50).

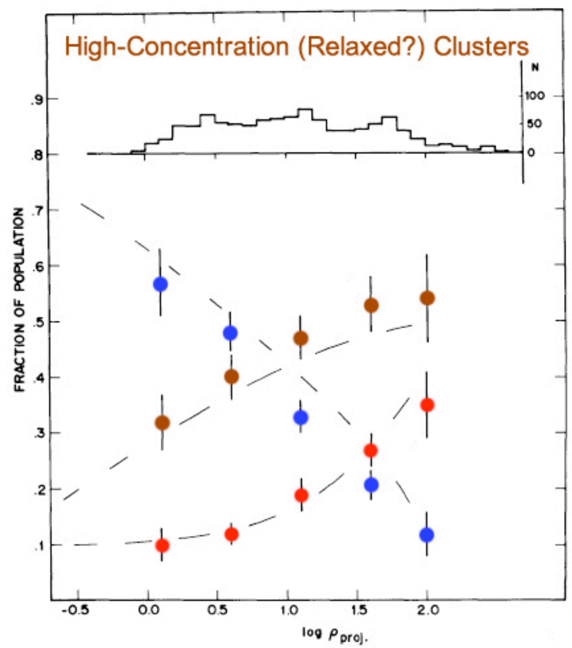


FIG. 8.—High-concentration clusters (A151, A539, A957, A1656, A1913, A2040, A2063, 0247 − 31, 0428 + 53, 1842 − 63).

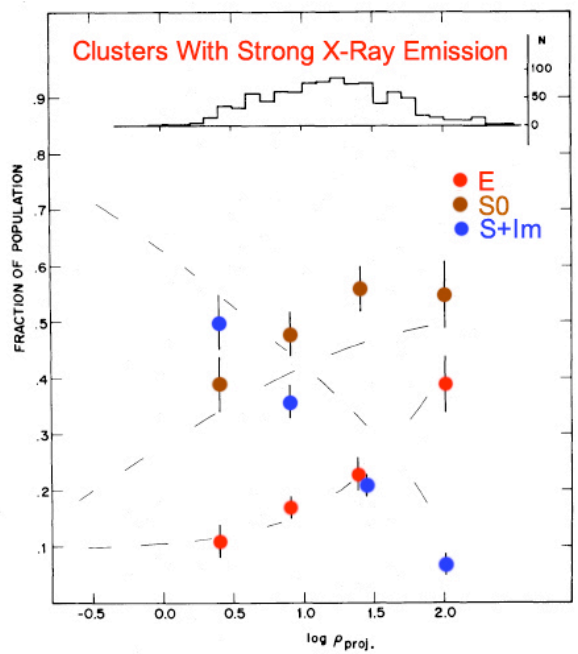


FIG. 10.—Strong X-ray emitters ($Lx \gtrsim 10^{44}$ ergs s^{-1}) (A119, A496, A539, A754, A1656, A2256, A2589, 2345 − 28).

1 – E: Same behavior in all clusters ⇒ origin is an intrinsic* f(local density).

2 – S/S0 is larger in less "mature" clusters for all local densities

⇒ Evolution is also partly a f(cluster "maturity").

This is more consistent with stripping than with baryon blowout.

3 – But gross trend of S/S0 is similar in all clusters

⇒ E, S0, S+Im origin is at least partly an intrinsic* f(local density).

Conclude: All 3 types of evolution are important.

*NB: This is not the same as Dressler's suggestion!

VIRGO GALAXIES WITH LONG ONE-SIDED H I TAILS

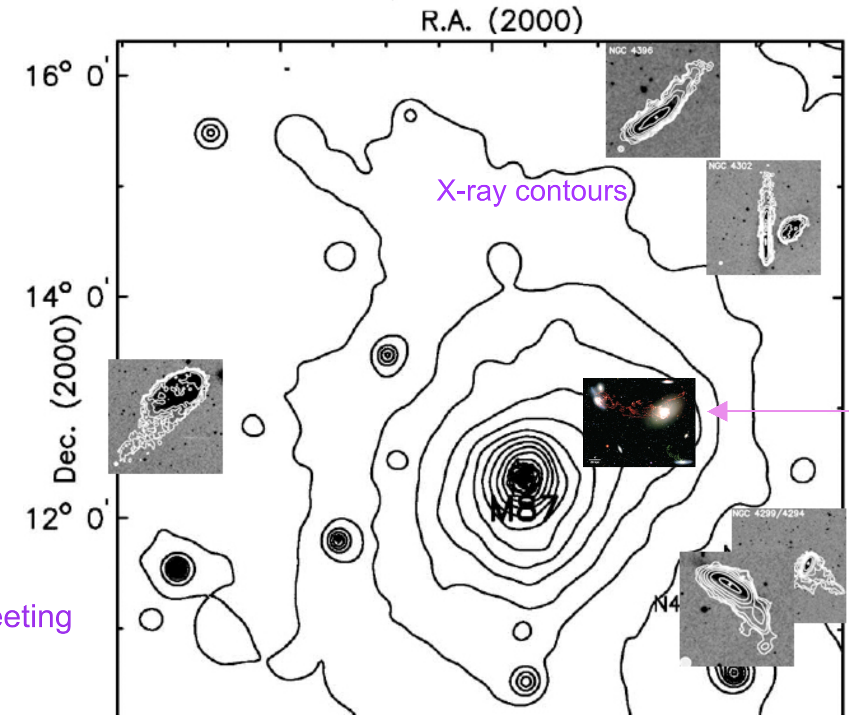
Aeree Chung, J. H. van Gorkom, Jeffrey D. P. Kenney, and Bernd Vollmer

The Astrophysical Journal, 659:L115–L119, 2007 April 20

ABSTRACT

In a new H I imaging survey of Virgo galaxies (VIVA: VLA Imaging of Virgo galaxies in Atomic gas), we find seven spiral galaxies with long H I tails. The morphology varies, but all the tails are extended well beyond the optical radii on one side. These galaxies are found in intermediate- to low-density regions (0.6–1 Mpc in projection from M87). The tails are all pointing roughly away from M87, suggesting that these tails may have been created by a global cluster mechanism. While the tidal effects of the cluster potential are too small, a rough estimate suggests that simple ram pressure stripping could have indeed formed the tails in all but two cases.

We conclude that these one-sided H I tail galaxies have recently arrived in the cluster, falling in on highly radial orbits. It appears that galaxies begin to lose their gas already at intermediate distances from the cluster center through ram pressure or turbulent viscous stripping and tidal interactions with their neighbors, or a combination of both.



Hα filaments trailing NGC 4438 and NGC 4388 (Kenney + 2008, ApJ, 687, L69; Yoshida + 2004, AJ, 127, 90;

Cf. Coma galaxies: Komiyama, This meeting)

Also: X-ray wakes: Forman, this meeting

Chung, van Gorkom et al. 2009, AJ, 138, 1741

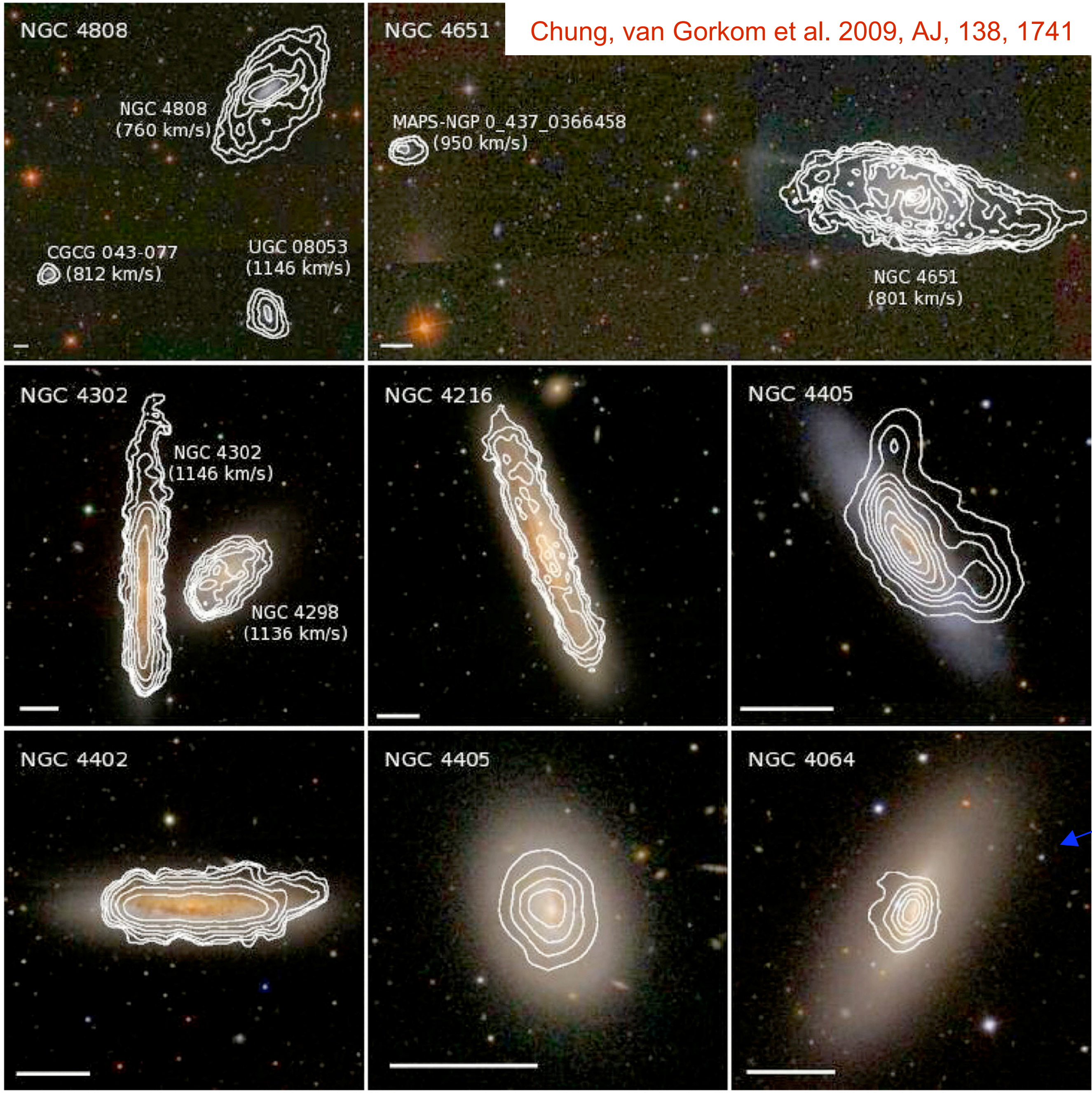


Figure 8. Examples of the different H I morphologies found in the survey. Total H I images are shown in white contours overlaid on the SDSS images. The thick white bar in the bottom-left corner indicates 1 arcmin in each panel. The top row shows examples of gas-rich galaxies in gas rich environments in the outskirts, the middle row shows galaxies at intermediate distances, while the bottom row shows examples of severely truncated H I disks at a range of projected distances from M87.

"We confirm that galaxies near the [Virgo] cluster core have HI disks that are smaller compared to their stellar disks ($D_{HI}/D_{25} < 0.5$).

Most of these galaxies in the [cluster] core also show gas displaced from the disk which is either currently being stripped or falling back after a stripping event."

The mean absolute magnitude of NGC 4402, NGC 4405, & NGC 4064 is $M_V = -19.4 \pm 0.2$.

Virgo Sph galaxies are fainter.

If even the deep gravitational potential wells of still-spiral galaxies suffer HI stripping, then the shallow potential wells of dS+Im galaxies are more likely to be stripped.

Tentative Conclusion:

All 3 types of evolution are important:

– Biased galaxy formation = $f(\rho_{proj}) \rightarrow$ importance of merger remnants vs disks.

(We observe an "embarrassingly large" fraction of giant, bulgless galaxies in the field but not in clusters like Virgo: Kormendy + 2010, ApJ, 723, 54.)

– Baryon blowout → surface brightness ↓ as L ↓ for both dS+Im and dSph.

– Transformation processes (both internal and environmental) convert some S galaxies into S0s and some dS+Im galaxies into Sphs.

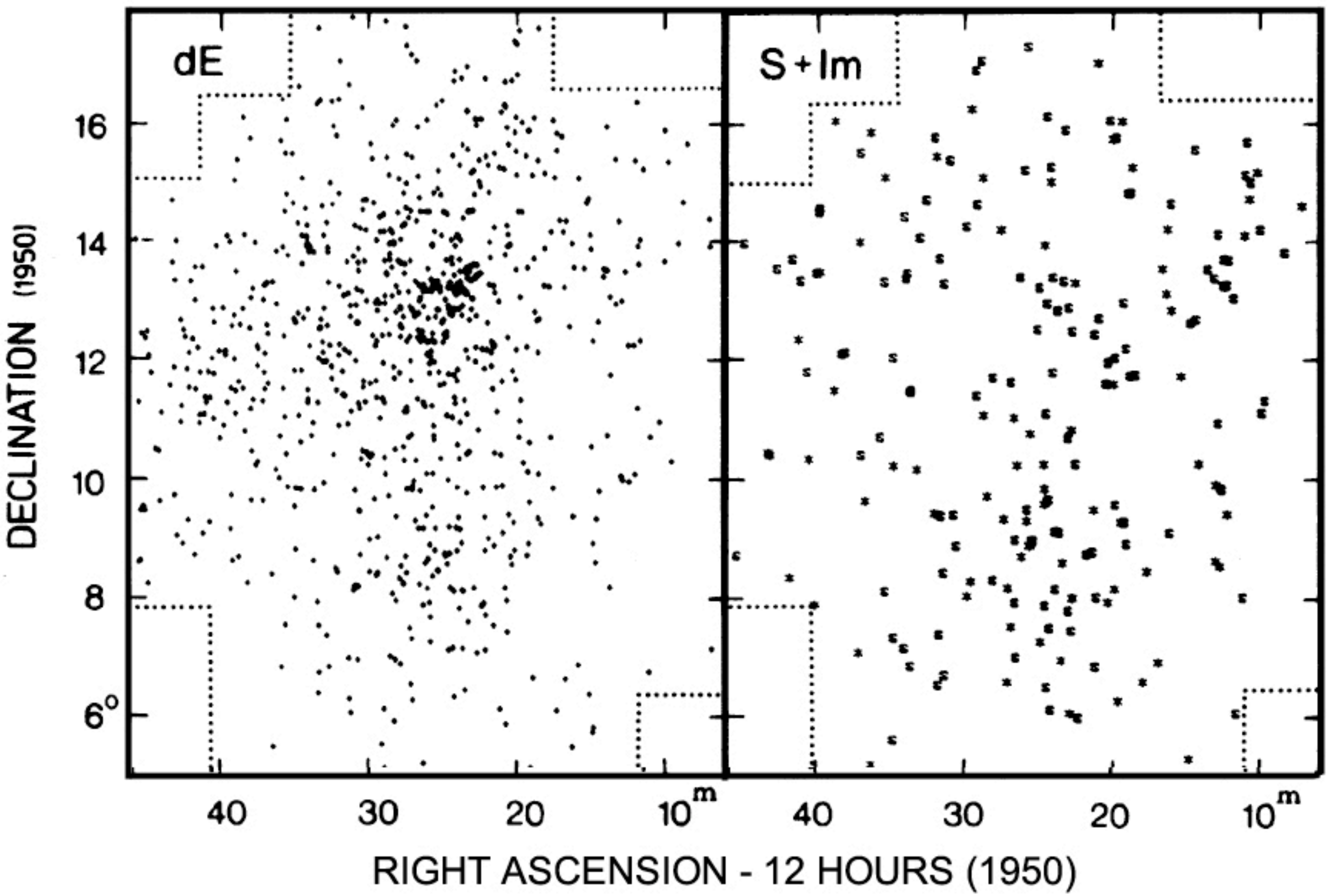
Now check other kinds of observational evidence that Sphs are related to S+Im galaxies:

Stellar populations ⇒ Sphs have long, heterogeneous histories of star formation, like S+Ims.
Dynamics 1: Some Sphs are rotationally flattened. (Others are not.)
Dynamics 2: Some Sphs show spiral structure ⇒ disks!
Structure: VCC 2048 is an edge-on Sph with a disk embedded in a Sph (not bulge) halo.
Also: Some S0 galaxies in Virgo have $B/T \approx 0$, like Scs!
Clustering: Sphs are concentrated in dense environments; dS+Im galaxies are not.

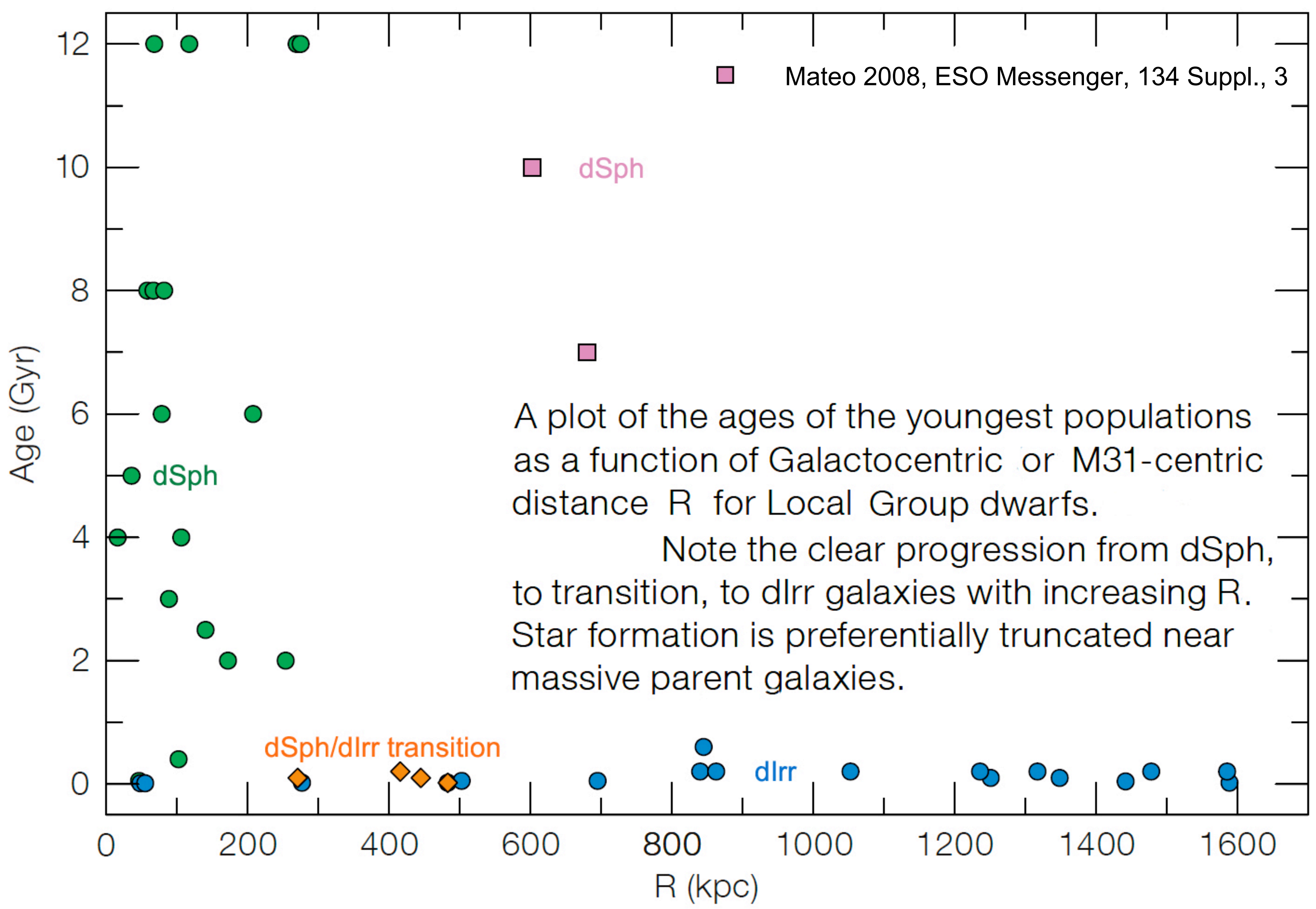
Conclusion will be: Sphs are defunct S+Im galaxies exactly as some S0s are defunct S galaxies.

STUDIES OF THE VIRGO CLUSTER. VI. MORPHOLOGICAL AND KINEMATICAL STRUCTURE OF THE VIRGO CLUSTER

Binggeli, Tammann, & Sandage 1987, AJ, 94, 251



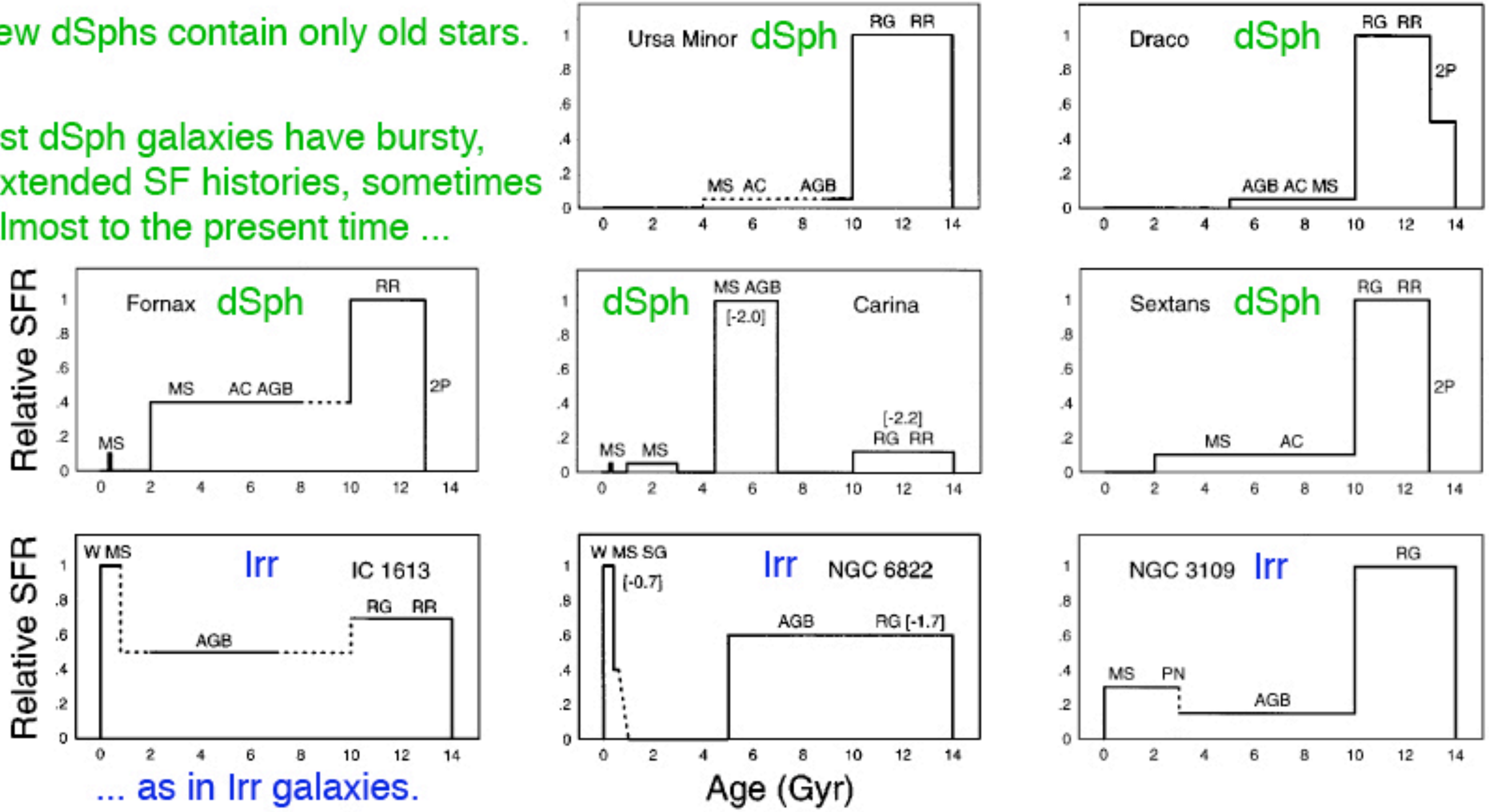
Irr → Sph transformation happens mostly near giant galaxies & in clusters of galaxies.



Extended, bursty star formation histories of many dSph galaxies ⇒ they were Irr galaxies not long ago (Kormendy & Bender 1994, KFCB).

A few dSphs contain only old stars.

Most dSph galaxies have bursty, extended SF histories, sometimes almost to the present time ...



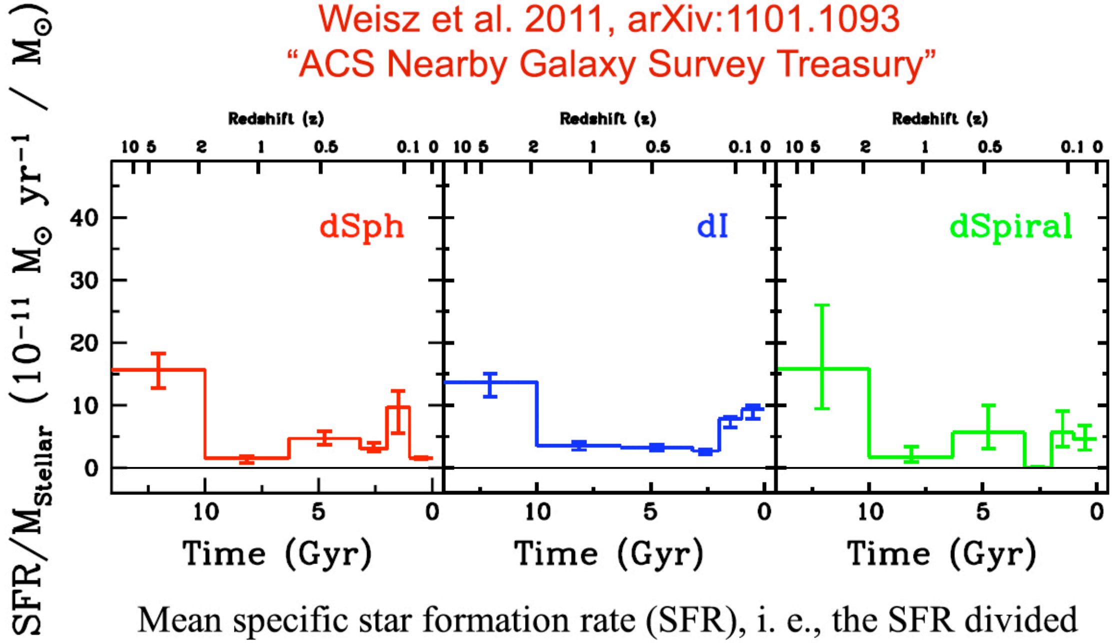
... as in Irr galaxies.

Figure 8 Schematic plots of the star-formation histories of all Local Group dwarfs with sufficient data. The *labels within the individual panels* specify the nature of the stellar indicators used to infer the presence of a given age component: MS = main-sequence stars; AGB = asymptotic giant branch stars; RG = red giants; RR = RR Lyr variables; AC = anomalous Cepheids; SG = blue and red supergiants; W = Wolf-Rayet stars; PN = planetary nebulae.

From Mateo 1998, ARA&A, 36, 435

Intermediate-age stellar populations in dSph galaxies were discovered long ago (e. g., Da Costa 1994, ESO Workshop on Dwarf Galaxies).

Weisz et al. 2011, arXiv:1101.1093
"ACS Nearby Galaxy Survey Treasury"



Mean specific star formation rate (SFR), i. e., the SFR divided by the integrated stellar mass, for each morphological type.

Dwarf galaxies had a high level of SF at ancient times (> 10 Gyr ago), with a low level of SF at intermediate times (1–10 Gyr ago). There are noticeable differences in the sSFHs among the morphological types within the most recent 1 Gyr.

we find three significant results: (1) the average dwarf galaxy formed $\gtrsim$ 50% of its stars by z ∼ 2 and 60% of its stars by z ∼ 1, regardless of current morphological type; (2) the mean SFHs of dIs, dTrans, and dSphs are similar over most of cosmic time, and only begin to diverge a few Gyr ago, with the clearest differences between the three appearing during the most recent 1 Gyr; and (3) the SFHs are complex

The sample shows a strong density-morphology relationship, such that the dSphs in the sample are less isolated than dIs. We find that the transition from a gas-rich to gas-poor galaxy cannot be solely due to internal mechanisms such as stellar feedback, and instead is likely the result of external mechanisms, e.g., ram pressure and tidal stripping and tidal forces.

IC3328: A “dwarf elliptical galaxy” with spiral structure

H. Jerjen, A. Kalnajs, and B. Binggeli

Astron. Astrophys. 358, 845–849 (2000)

Abstract. We present the 2-D photometric decomposition of the Virgo galaxy IC3328. The analysis of the global light distribution of this morphologically classified nucleated dwarf elliptical galaxy (dE1,N) reveals a tightly wound, bi-symmetric spiral structure with a diameter of 4.5 kpc, precisely centered on the nucleus of the dwarf. The amplitude of the spiral is only three percent of the dwarf’s surface brightness …

Barazza, Binggeli, & Jerjen 2002, A&A, 391, 823:
“This is unambiguous evidence for the presence of a disk in [IC 3328] …”

However, they correctly caution that,
when spiral structure is weaker, features in ε(r) and PA(r)
that are not spiral structure
“can indeed produce amazingly spiral-like twisting isophotes
and thus mimic a genuine spiral structure.”
The weakest spiral signals should be interpreted cautiously,
but the large number of detections ⇒ the phenomenon is real.

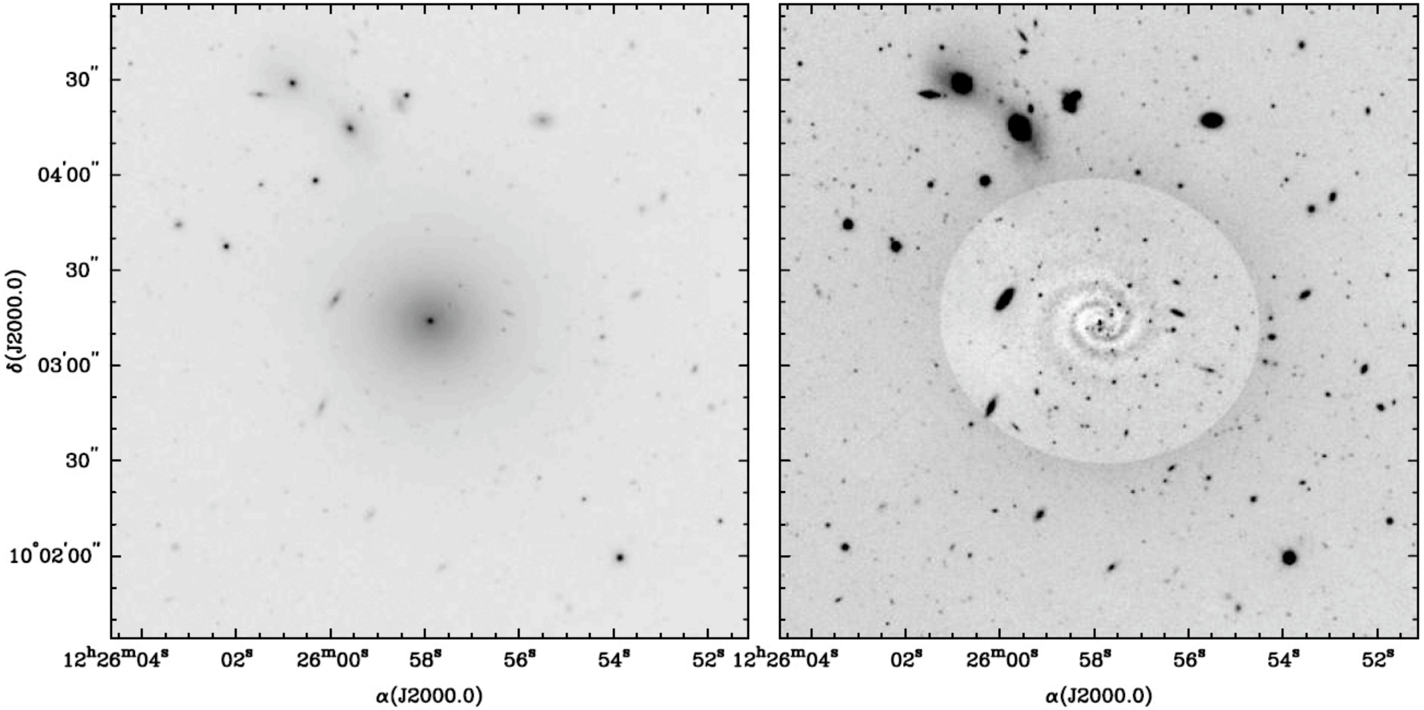
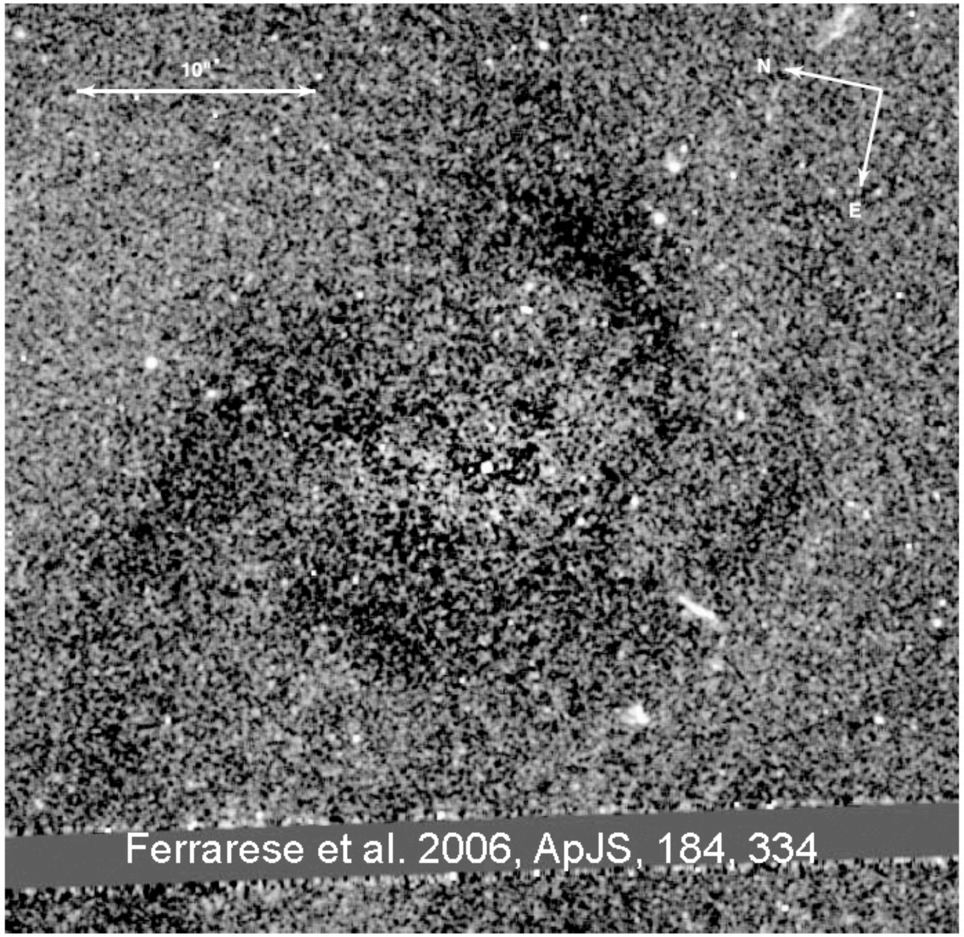


Fig. 1. The deep R-band CCD image of IC3328 (left panel) illustrates the overall morphology of this as dE1,N classified galaxy: a smooth radially decreasing light distribution with a centrally located nucleus. After the subtraction of the axis symmetric component, the residual image (right panel) reveals a prominent 2-armed spiral structure with a possible central bar.



The "spiral structure" in VCC 1199 does not look significant.

KFCB show that VCC 1199 is an M32-like elliptical.

IC 3586 (dS0:) **E1 in KFCB**

FIG. 110.—Residual images of VCC 1695 (*left*) and VCC 1199 (*right*), obtained by subtracting the best-fitting isophotal model from the *g*-band images. Both galaxies appear to display a spiral pattern. Each image is 40″ on the side.

"We confirm the existence of a face-on spiral pattern in VCC 856 (IC 3328), a galaxy formally classified as a dE1,N. The pattern was first noticed by Jerjen et al. (2000). Since then, evidence of spiral patterns or disk/bar structures have been found in a handful of Virgo, Fornax, and Coma dwarf ellipticals (Jerjen et al. 2001; De Rijcke et al. 2003; Graham et al. 2003; Barazza et al. 2002); these objects have been interpreted as late-type galaxies in the process of being transformed to an early-type morphology by harassment within the cluster environment."

Also:
Lisker et al. 2006, AJ, 132. 497;
Lisker et al. 2007, ApJ, 660, 1186;
Lisker et al. 2009, AN, 330, 966

A few Sph galaxies rotate like disks, i. e., $(V/\sigma)^* > 1$;
Many Sphs rotate like low-L ellipticals, i. e., $(V/\sigma)^* \sim 1$, with bigger $(V/\sigma)^*$ at higher L;
At least a few Sphs have anisotropic velocity distributions, i. e., $(V/\sigma)^* << 1$.

Internal kinematics of low-luminosity ellipsoidal galaxies

R. Bender and J.-L. Nieto

Astron. Astrophys. 239, 97–112 (1990)

Abstract. We present spectroscopic observations of 10 low-mass ellipsoidal galaxies having luminosities in the range where the luminosity functions of luminous ellipticals and low surface-brightness dwarf ellipticals overlap. The sample covers a large range in effective surface brightness, from values typical of genuine dwarfs to those of compact, M 32-like, ellipticals.

In contrast to what may be expected from the extrapolation of the result of Davies et al. (1983), about half of our objects are not rotationally flattened. However, only objects fainter than $M_T = -18.0$ mag ($H_\circ = 50$ km/s/Mpc) and having *low* surface brightness are considerably anisotropic, indicating that:
(a) the result of Davies et al. (1983) still describes the overall trend between kinematics and luminosity for elliptical galaxies brighter than $M_T = -18$ mag in the correct way, and
(b) low surface brightness dwarf ellipsoidals may be in general NOT rotationally flattened.
For the latter objects we find indications that their kinematical structure may be partially connected to supernova-driven galactic winds and inefficient star formation.

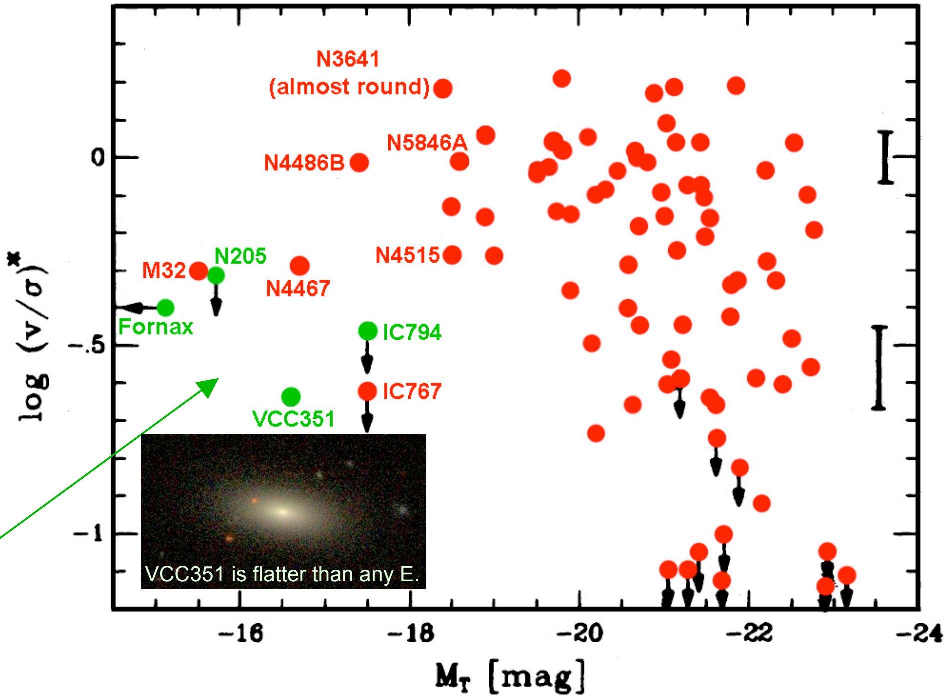


Fig. 2. Anisotropy parameter $(v/\sigma)^*$ against absolute magnitude M_T in the B-band ($H_\circ = 50$ km/s/Mpc). Objects with $\log(v/\sigma) \gtrsim -0.15$ owe their shape predominantly to rotation, while objects with smaller $(v/\sigma)^*$ values have anisotropic velocity dispersions. Some of the lower $(v/\sigma)^*$ values are upper limits.

Bender et al. 1991, A&A, 246, 349: the Local Group Sphs NGC 147, NGC 185, NGC 205 are anisotropic.

De Rijcke et al. 2006, MNRAS, 359, 1321 fit deeper kinematic data with 3-integral dynamical models ⇒ anisotropy is moderate.

Geha et al. 2006, AJ, ,131, 332: NGC 205 is somewhat anisotropic but clearly is tidally stretched.

A few Sph galaxies rotate like disks, i. e., $(V/\sigma)^* > 1$;
Many Sphs rotate like low-L ellipticals, i. e., $(V/\sigma)^* \sim 1$, with bigger $(V/\sigma)^*$ at higher L;
At least a few Sphs have anisotropic velocity distributions, i. e., $(V/\sigma)^* << 1$.

ROTATIONALLY SUPPORTED VIRGO CLUSTER DWARF ELLIPTICAL GALAXIES: STRIPPED DWARF IRREGULAR GALAXIES?

Liese van Zee
Evan D. Skillman
and
Martha P. Haynes

The Astronomical Journal, 128:121–136, 2004 July

ABSTRACT

New observations of 16 dwarf elliptical galaxies (dEs) in the Virgo Cluster indicate that at least seven dEs have significant velocity gradients along their optical major axis, with typical rotation amplitudes of 20–30 km s^{-1}. Of the remaining nine galaxies in this sample, six have velocity gradients of less than 20 km s^{-1} kpc^{-1}, while the other three observations had too low a signal-to-noise ratio to determine an accurate velocity gradient. Typical velocity dispersions for these galaxies are $\sim 44 \pm 5$ km s^{-1}, indicating that rotation can be a significant component of the stellar dynamics of Virgo dEs. When corrected for the limited spatial extent of the spectral data, the rotation amplitudes of the rotating dEs are comparable to those of similar-brightness dwarf irregular galaxies (dIs). Evidence of a relationship between the rotation amplitude and galaxy luminosity is found and, in fact, agrees well with the Tully-Fisher relation. The similarity in the scaling relations of dIs and dEs implies that it is unlikely that dEs evolve from significantly more luminous galaxies. These observations reaffirm the possibility that some cluster dEs may be formed when the neutral gaseous medium is stripped from dIs in the cluster environment. We hypothesize that several different mechanisms are involved in the creation of the overall population of dEs and that stripping of infalling dIs may be the dominant process in the creation of dEs in clusters like Virgo.

Also:

de Rijcke et al. 2001, ApJ, 559, L31 (Sph F76 = isotropic rotator)
de Rijcke et al. 2003, A&A, 400, 119 (caution: galx may be S0s)
Simien & Prugniel 2002, A&A, 384, 371 (many Sphs rotate)
Pedraz et al. 2002, MNRAS, 332, L59 (many Sphs rotate)
Geha et al. 2003, AJ, 126, 1794 (most Sphs are anisotropic)
Geha et al. 2006, AJ, 131, 332 (tidal stretching in NGC 205 !)
Thomas et al. 2006, A&A, 445, L9 (VCC 510 is anisoptropic)
Elisa Toloba, this meeting

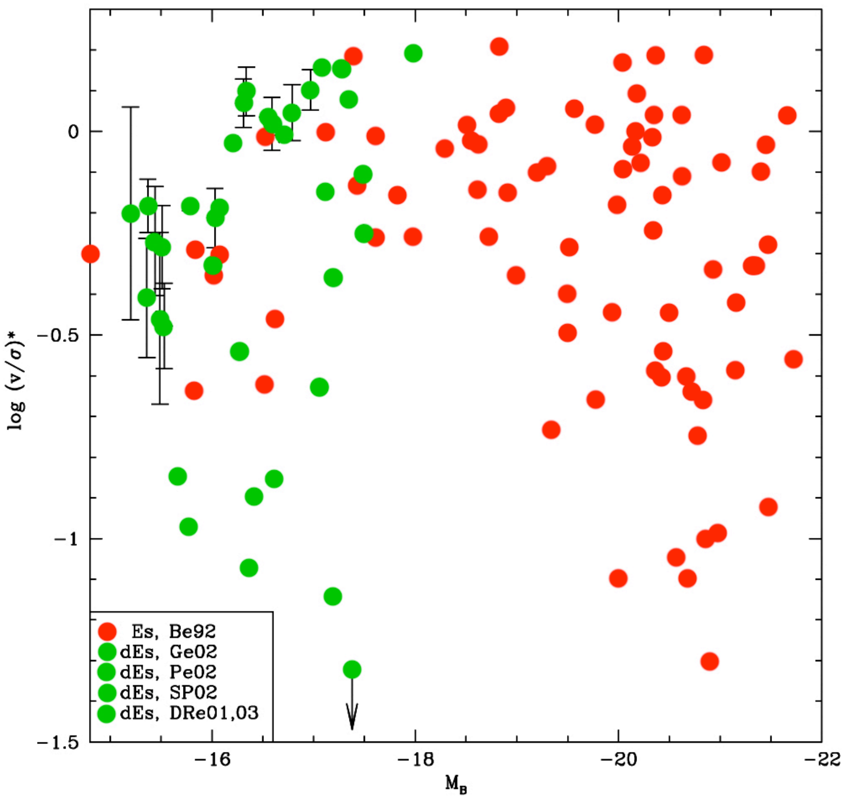
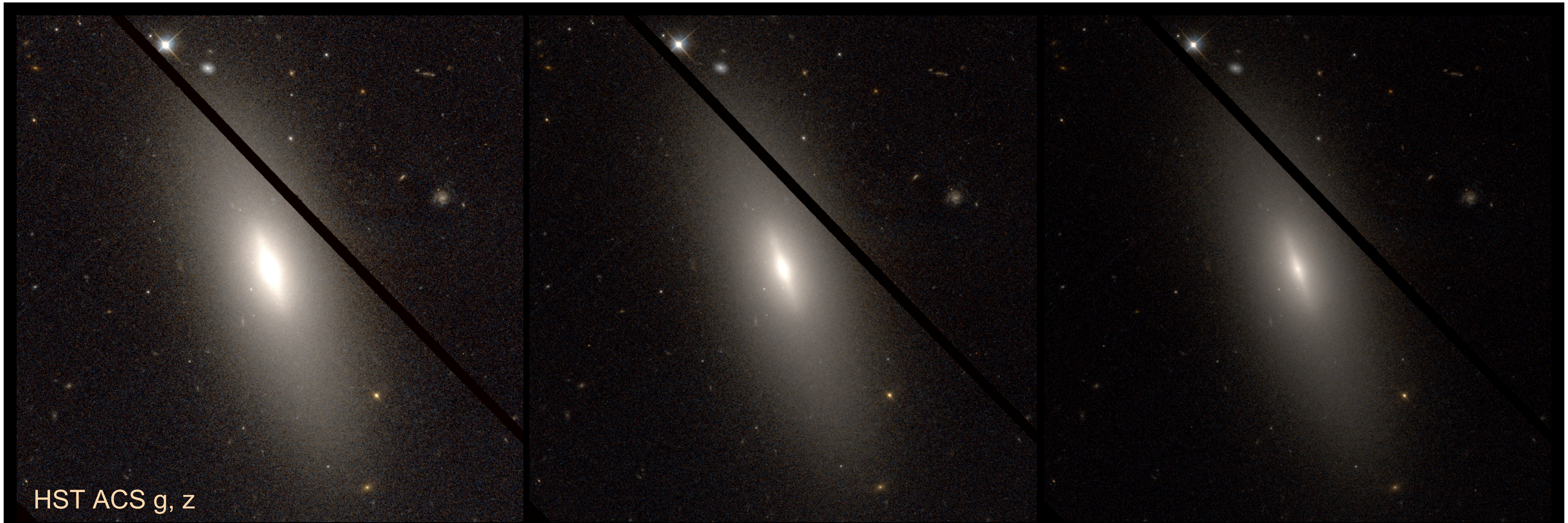


Fig. 5.—Anisotropy parameter $(v/\sigma)^*$ vs. absolute magnitude for dEs and elliptical galaxies showing dEs from the present study (*filled hexagons*), Geha et al. (2002; *plus signs*), Pedraz et al. (2002; *crosses*), Simien & Prugniel (2002; *triads*), and De Rijcke et al. (2001, 2003; *stars*). The location of VCC 1261 is shown as an upper limit since the observed velocity gradient was consistent with zero rotation. Elliptical galaxies and dEs from Bender et al. (1992; *circles*) are also shown. Many of the dEs in the present sample are rotationally flattened.

Conclusion 1: Some Sphs are (or contain) disks.
Conclusion 2: Large range of anisotropy with generally more rotation and more disk-like kinematics at higher L is roughly consistent with anisotropic heating during Im → Sph transformation.

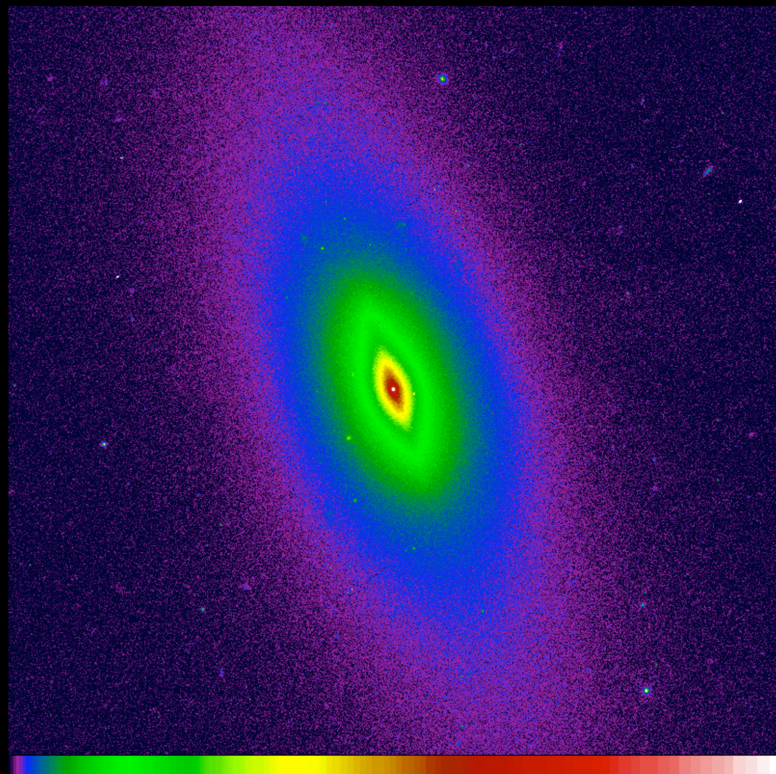


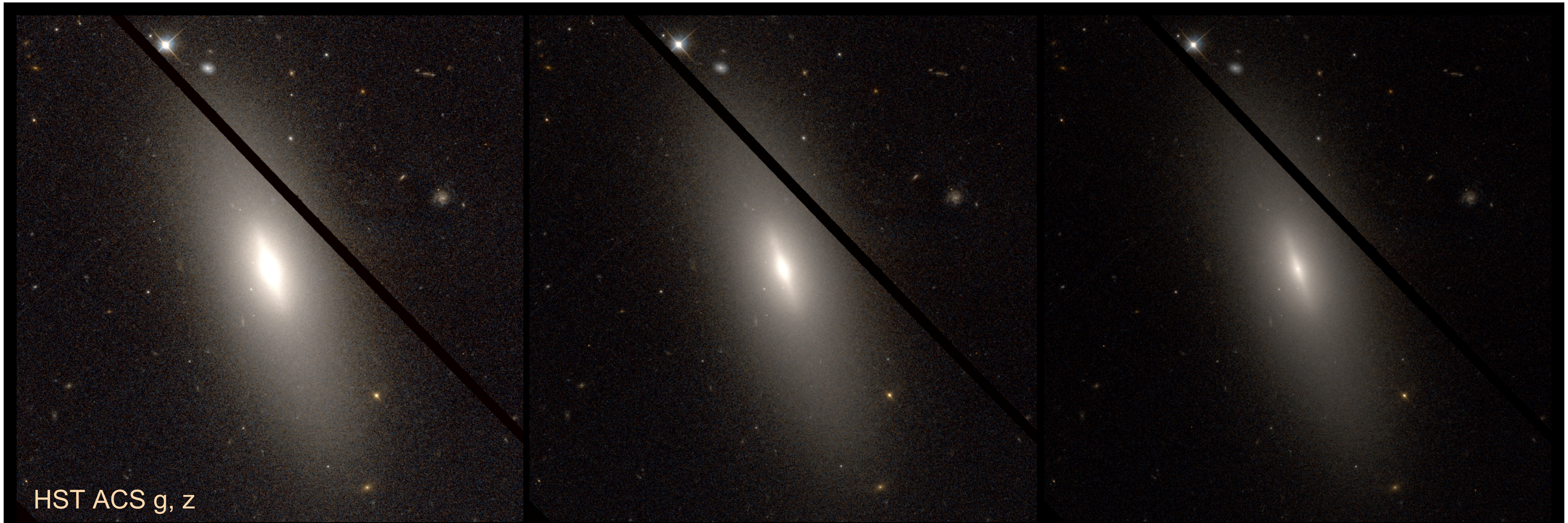
“Rosetta Stone” Galaxy VCC 2048:
An edge-on Sph that “still” contains a disk

Finding a high-luminosity, edge-on Sph →
more evidence that Sphs are related to disks.

The isophotes are disky-distorted at almost all radii.
Also, <u>VCC 2048 is flatter than any elliptical.</u>

Derive “bulge”-disk decompostion as in Scorza & Bender (1990, A&A, 235, 49; 1995, A&A, 293, 20):
calculate the almost-edge-on, thin-disk profile that, when subtracted from the image, generates residual isophotes that are exactly elliptical.





"Rosetta Stone" Galaxy VCC 2048:
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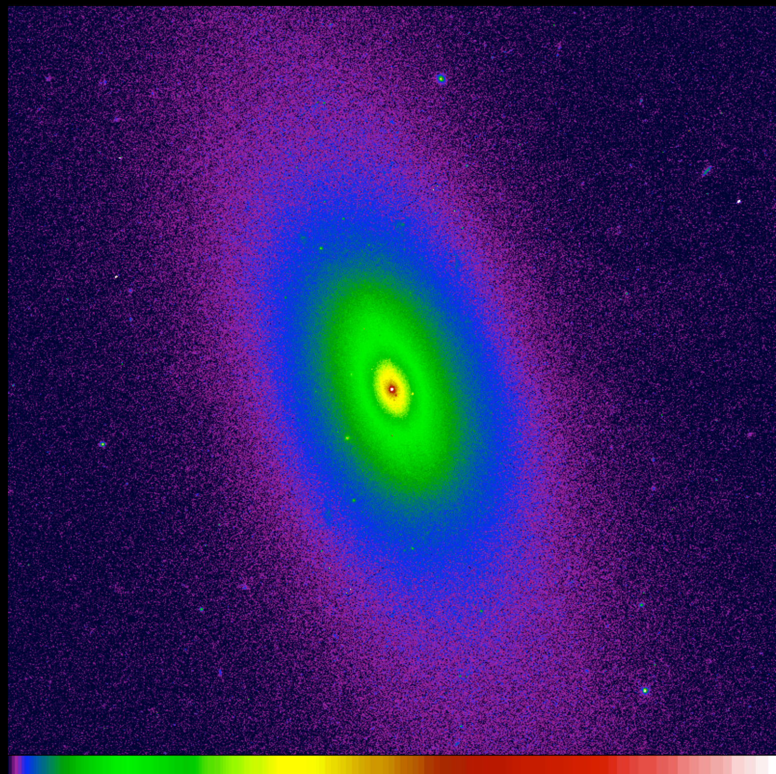

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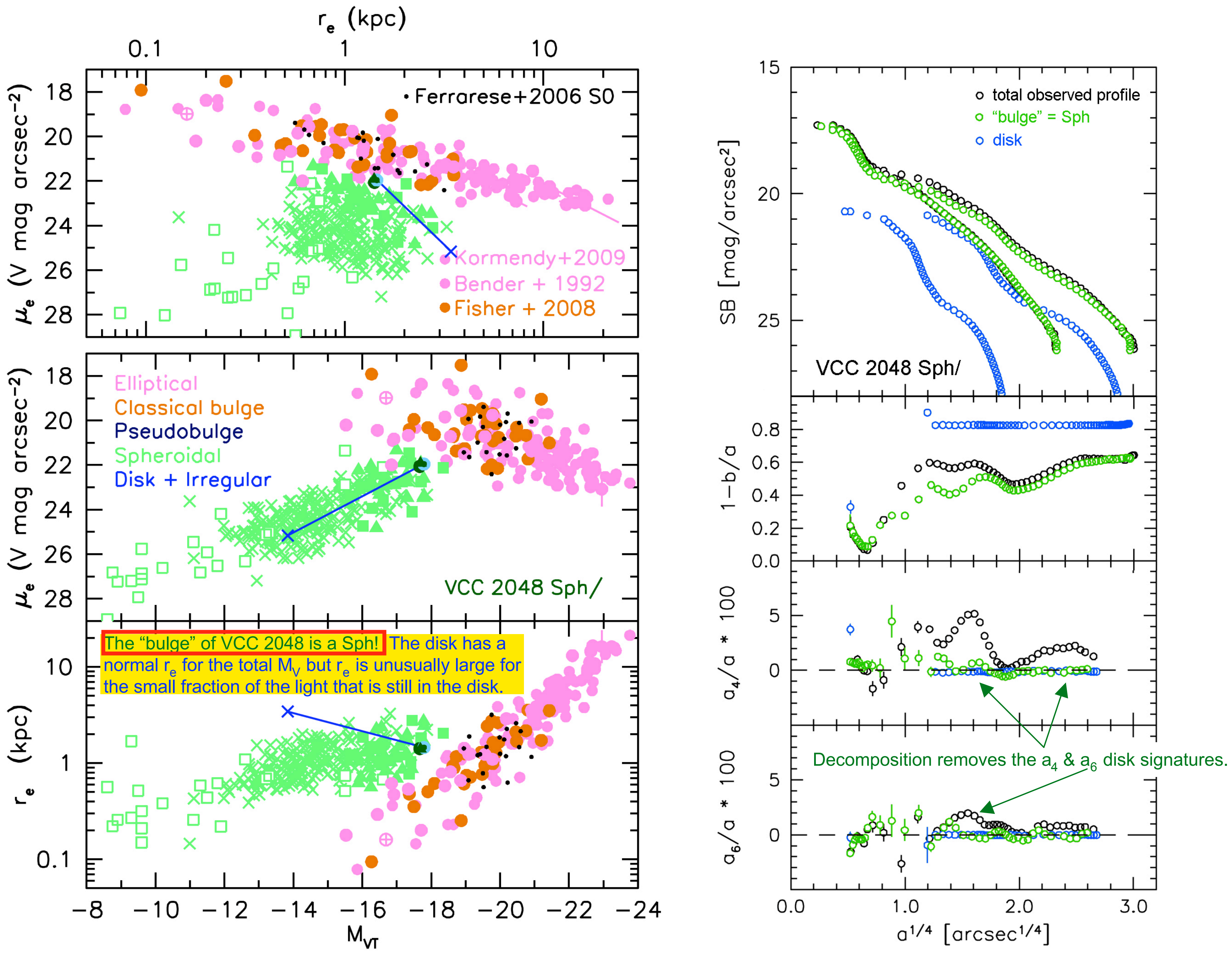


r_e (kpc)
0.1
1
10
• Ferrarese+2006 S0
Kormendy+2009
Bender + 1992
Fisher + 2008
μ_e (V mag arcsec^{-2})
Elliptical
Classical bulge
Pseudobulge
Spheroidal
Disk + Irregular
VCC 2048 Sph/
The "bulge" of VCC 2048 is a Sph! The disk has a normal r_e for the total M_V but r_e is unusually large for the small fraction of the light that is still in the disk.
r_e (kpc)
M_{VT}
total observed profile
"bulge" = Sph
disk
SB [mag/arcsec^2]
VCC 2048 Sph/
1 − b/a
a_4/a * 100
Decomposition removes the a_4 & a_6 disk signatures.
a_6/a * 100
$a^{1/4}$ [arcsec$^{1/4}$]

We confirm that
E and Sph galaxies are physically unrelated
but that Sph and S+Im galaxies are closely related.

Formation of Sph galaxies was almost certainly different from the formation of E galaxies:

Es were formed by major galaxy mergers.

Sphs are defunct S+Im galaxies transformed
by internal processes
like supernova-driven baryon ejection (Dekel & Silk 1986)
and by environmental processes
including reionization in the early Universe,
ram-pressure gas stripping (Chung et al. 2007, 2009; van Gorkom here),
galaxy harrassment (Moore et al. 1996, 1998),
tidal tickling (Mayer et al. 2001 & this meeting; Kazantzidis et al. 2011),
resonant tidal stripping (D'Onghia et al. 2009), etc.

Similarly, some S0 galaxies are defunct Sa – Sc galaxies.

A NEW CLASSIFICATION SYSTEM FOR GALAXIES

Sidney van den Bergh
David Dunlap Observatory, University of Toronto

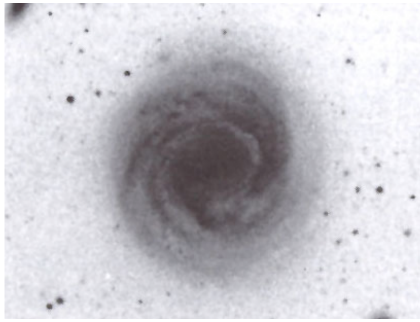
The Astrophysical Journal, 206:883–887, 1976 June 15

ABSTRACT

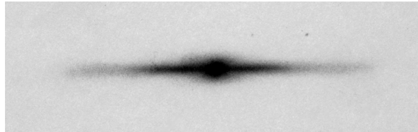
1) A new galaxy classification system is proposed in which normal spirals and lenticulars form parallel sequences within which "early" and "late" systems are distinguished by means of their disk-to-bulge ratios.

2) A sequence of "anemic spirals," which occur most frequently in rich clusters, is found to have characteristics that are intermediate between those of vigorous gas-rich normal spirals and gas-poor systems of type S0.

3) The differences between normal spirals (Sa-Sb-Sc), anemic spirals (Aa–Ab–Ac), and lenticulars (S0a–S0b–S0c) are tentatively interpreted in terms of the influence of environment on the evolution of flattened galaxies.



NGC 4921 (Ab) in Coma



NGC 4762 (S0b) in Virgo

This classification recognizes the important observation that the distribution of integral structural properties for S0 galaxies is similar to the distribution for Sa — Sbc galaxies combined. That is, some S0 galaxies are structurally more similar to Sbc galaxies than to any Sa or E.

Until now no S0 galaxy was known to be structurally similar to any Sc — Im galaxy.

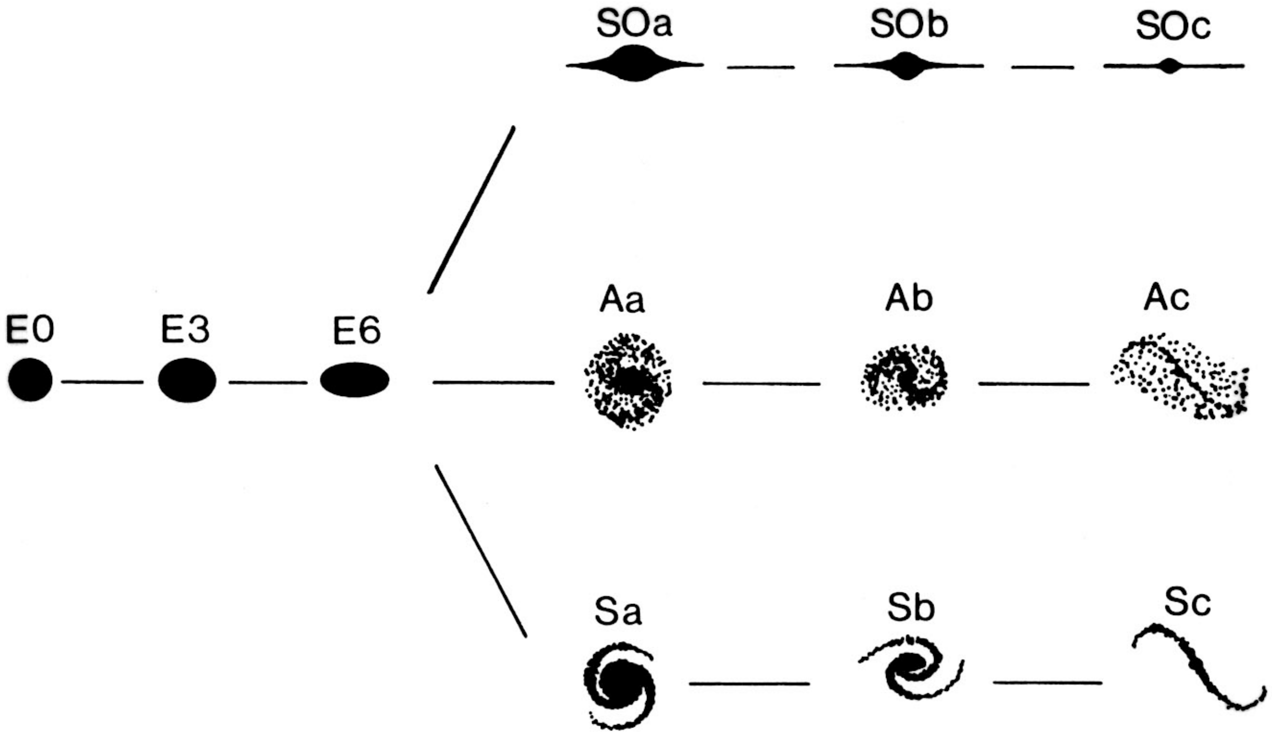
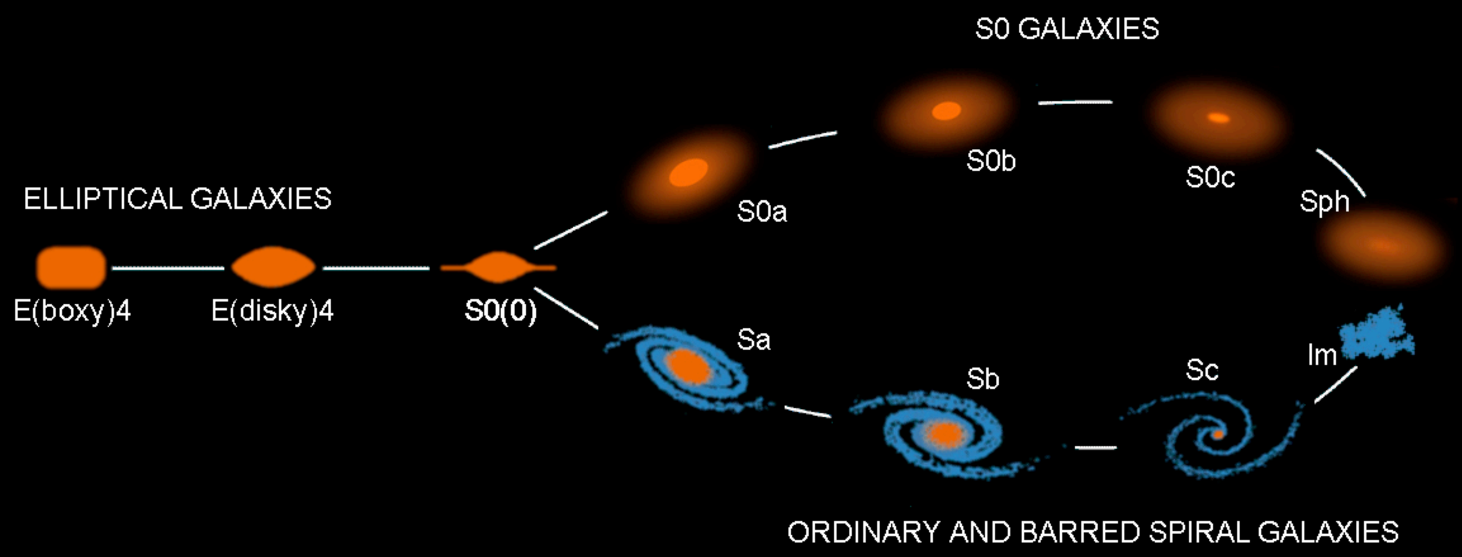


Fig. 2.—Schematic representation of the proposed new galaxy classification system

Revised Parallel Sequence Hubble Classification



This classification recognizes that some S0s — that is, the S0(0)s — are intermediate between E and S galaxies.

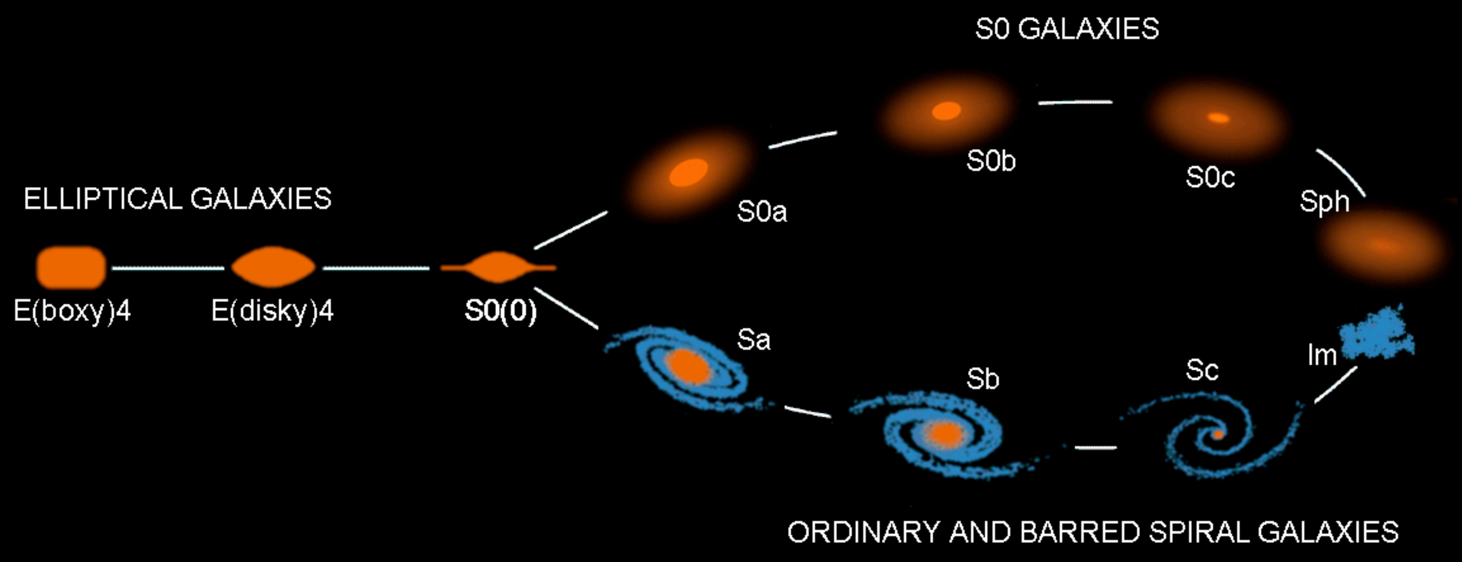
It recognizes that the distribution of structural properties for S0 galaxies is similar to that for Sa — Sc galaxies combined (van den Bergh 1976) → a sequence of S0a – S0b – S0c galaxies parallels the sequence of spirals.

Now we know a few S0 galaxies that are structurally similar to Sc — Sm galaxies. For example:
NGC 4762 (B/T = 0.13) is an SB0bc; i. e., the latest Hubble type of S0 that still has a partly classical bulge.
NGC 4452 (PB/T = 0.017) is an SB0c.

The completely bulgeless galaxies in the S0 sequence are the spheroidals.

The E(boxy) – E(disk) – S0 part of the above tuning-fork diagram is based on Kormendy & Bender 1996, ApJ, 464, L111.

Revised Parallel Sequence Hubble Classification



The disk sequence is continuous from where it overlaps Sphs to where it is similar to the E sequence;
The S0c – Sph sequence is continuous ⇒ <u>The E – Sph distinction does not depend on seeing a discontinuity or strict separation between E and Sph galaxies in parameter space.</u>

Like the classical Hubble sequence, galaxy luminosity is not constant along the S0 sequence.
Luminosity tends to decrease from S0(0) – S0a – S0b – S0c and then <u>decreases dramatically</u> to the Sphs.

The number of galaxies <u>drops</u> from S0a – S0b – S0c and then <u>increases dramatically</u> to the Sphs.
Suggested reason = (Difficulty of transforming galaxies into S0s) * (numbers of progenitors)
That is: Later-type giants have more gas to remove. But there are many dwarf, bulgeless Ims.

Evidence that E and Sph galaxies are physically unrelated and that Sphs are "red and dead" dS+Im galaxies.

Sphs define a sequence in $M_V - r_e - \mu_e$ (and especially $M_V - r_0 - \mu_0$) parameter space that is distinct from and (in some projections) roughly perpendicular to the sequence of E galaxies. The Sph sequence approaches the E sequence near its middle, not near its faint end.

Sph galaxies are distinguishable from ellipticals of the same luminosity because of their shallower brightness profiles (smaller Sérsic n) and fainter central surface brightnesses. (Caution: Es and Sphs overlap slightly in Sérsic n. Need to use other parameters, too.)

This makes it possible to show that E and Sph galaxies have very different luminosity functions:
Es are bounded in luminosity L, whereas Sphs become much more numerous as L ↓ for all L.

The Sph parameter sequence is closely similar to the parameter sequence for S+Im galaxies for all Sph luminosities.

Some Sphs are rotationally flattened, like disks. (Others are hot and anisotropic ← environmental heating mechanisms are anisotropic.)

Some Sphs show spiral structure. Therefore these <u>must</u> <u>be</u> mostly disks.

The "rosetta stone" Sph VCC 2048 is flatter than any elliptical and <u>contains an edge-on, thin disk</u>. But the decomposed "bulge" plots in the Sph parameter sequence. This is consistent with our suggestion that the biggest Sphs have disk-galaxy progenitors and got heated during the S → Sph conversion.

Stellar populations ⇒ the star formation histories of Sph and Im galaxies are closely similar: Both had repeated bursts of star formation. The difference is that, when the <u>current</u> rate of star formation is zero, we call the object a Sph.

The similarity of the dS+Im and Sph parameters sequences is consistent with the Dekel & Silk 1986 suggestion that both lost more baryons at lower L via supernova-driven winds.

Higher globular cluster specific frequencies in tinier dSphs (Harris, this meeting) is qualitatively consistent with baryonic blowout.

Sph and S+Im galaxies differ strongly in clustering properties: Sphs concentrate around giant galaxies and toward the center of the Virgo cluster; S+Im galaxies avoid such environments. This suggests that environmental processes converts late-type galaxies into Sphs. E.g., galaxy harrassment (Moore et al. 1996, 1998) and ram-pressure gas stripping (Chung et al. 2007, 2009; van Gorkom, this meeting).

The morphology-density relation suggests that S+Im galaxies get converted into S0+Sph galaxies, more so in denser environments. The dependence of the morphology-density relation on cluster maturity ⇒ both internal and environmental processes are important.

The strongest argument that ram-pressure stripping converts dS+Im → Sph galaxies is that HI observations show stripping in progress in giant galaxies in the Virgo cluster. It is much easier to strip dwarf galaxies with shallow gravitational potential wells.

Emphasize: 1. <u>Compactness in small Es is not a disease.</u> Compact ellipticals form the natural extension of the E sequence to low L.
2. <u>The fundamental difference between galaxy types is not dwarfs vs giants.</u> Rather, it is remnants of major mergers vs galaxies that form gently like disks. These fundamentally different kinds of galaxies overlap in luminosity.

Which Components Have Continuous Parameter Sequences? Which ones do not?

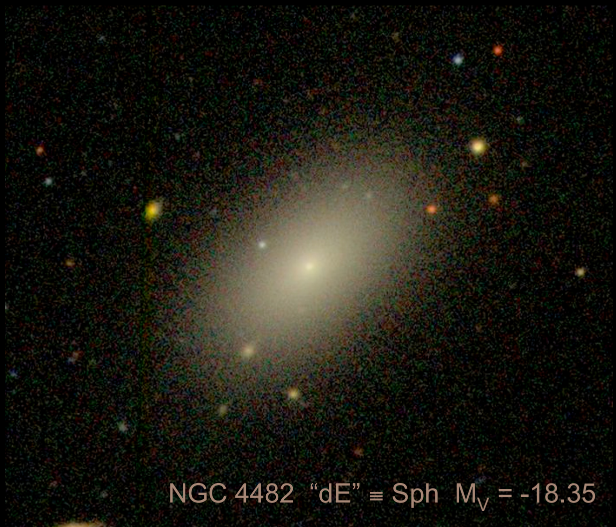
Ellipticals are continuous from cDs to tiny, compact Es like M32. Classical bulges are like Es.

Spiral galaxy disks + Irregular galaxies are continuous from M101 to tiny, HI dwarfs like M81 dwarf A.

Sph galaxies are similar in parameters to dS+Im galaxies; S0 disks are similar to S disks where they overlap in L.

Sph galaxies are continuous with S0 disks.

Sph galaxies are not continuous with Es at any L.



is <u>not</u> continuous with