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Secular Evolution in Disk Galaxies: Pseudobulge Growth and the Formation of Spheroidal Galaxies

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Abstract. Updating Kormendy & Kennicutt (2004, ARA&A, 42, 603), we review internal secular evolution of galaxy disks. One consequence is the growth of pseudobulges that often are mistaken for true (merger-built) bulges. Many pseudobulges are recognizable as cold, rapidly rotating, disky structures. Bulges have Sérsic function brightness profiles with index $n \gtrsim 2$ while most pseudobulges have $n \lesssim 2$. Recognition of pseudobulges makes the biggest problem with cold dark matter galaxy formation more acute: How can hierarchical clustering make so many pure disk galaxies with no evidence for merger-built bulges? E. g., the giant Scd galaxies M 101 and NGC 6946 have rotation velocities of $V_{\rm circ} \sim 200$ km s^{-1} but nuclear star clusters with velocity dispersions of 25 to 40 km s^{-1}. Within 8 Mpc of us, 11 of 19 galaxies with $V_{\rm circ} > 150$ km s^{-1} show no evidence for a classical bulge, one may contain a classical plus a pseudo bulge, and 7 are ellipticals or have classical bulges. So it is hard to understand how bulgeless galaxies could form as the quiescent tail of a distribution of merger histories.

Our second theme is environmental secular evolution. We confirm that spheroidal galaxies have fundamental plane correlations that are almost perpendicular to those for bulges and elliptical galaxies. Spheroidals are not dwarf ellipticals. Rather, their structural parameters are similar to those of late-type galaxies. We suggest that spheroidals are defunct late-type galaxies transformed by internal processes such as supernova-driven gas ejection and environmental processes such as secular harassment and ram-pressure stripping.

Minus spheroidals, the fundamental plane correlations for ellipticals and bulges have small scatter. With respect to these, pseudobulges are larger and less dense. They fade out by becoming fluffy, not by becoming compact, like nuclei. Pseudobulges and nuclear star clusters appear to have different origins.

1. Internal and Environmental Secular Evolution

Internal, slow (secular) evolution of galaxy disks occurs when nonaxisymmetries such as bars and spiral structure redistribute energy and angular momentum and rearrange disk structure. Environmentally driven evolution can also be secular (e. g., galaxy harassment), although better known processes are rapid (mergers). We concentrate on one consequence of environmental secular evolution. It is one of several processes that can transform late-type dwarfs into “spheroidals”, i. e., galaxies that are morphologically similar to ellipticals but that have different structural parameter correlations indicative of different formation physics. Figure 1 puts these galaxy formation processes into a more general context.

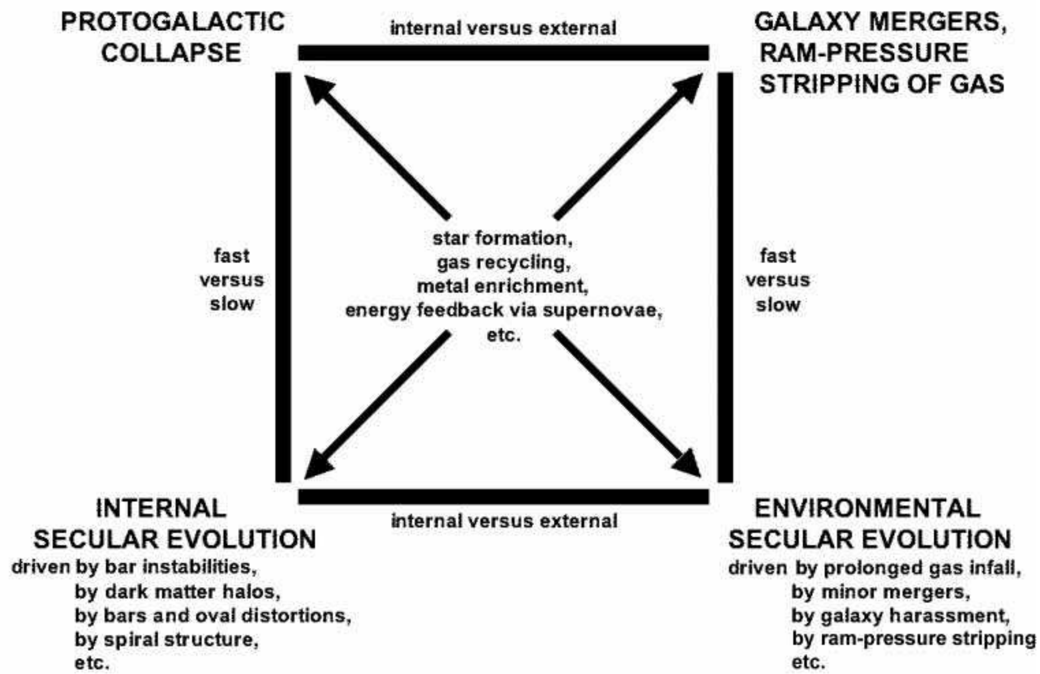

Figure 1. Summary of galactic evolution processes (Kormendy & Kennicutt 2004: KK04). Processes are divided vertically into fast (top) and slow (bottom). Fast evolution happens on a free-fall timescale, $t_{\rm ff} \sim (G\,\rho)^{-1/2}$, where ρ is volume density and G is the gravitational constant. Slow means many galaxy rotation periods. Ram-pressure stripping is likely to be fast for dwarf galaxies and slow for giant galaxies. Processes are divided horizontally into ones that happen internally in one galaxy (left) and ones that are driven by environmental effects such as galaxy interactions (right). The processes at center affect all types of galaxy evolution. This paper reviews internal secular evolution in galaxy disks (lower-left) and the nature of spheroidal galaxies as defunct late-type galaxies transformed (right) by galaxy harassment, ram-pressure stripping, and other processes.

2. Internal Secular Evolution and the Growth of Pseudobulges

Aspects of internal secular evolution have long been thriving "cottage industries" (an early review is in Kormendy 1982). Kormendy & Kennicutt (2004) provide a synthesis of these many lines of research, both observational and theoretical. Other reviews are in Sellwood & Wilkinson (1993), Kormendy (1993), Buta & Combes (1996) Kormendy & Cornell (2004), Kormendy & Fisher (2005), Athanassoula (2007), Peletier (2008), and Combes (2007, 2008). With limited space, this paper concentrates on new observations of pseudobulge properties.

Whatever the engine, internal evolution has similar consequences. Like all self-gravitating systems, galaxy disks tend to spread – the outsides expand and the insides contract (Tremaine 1989). This is as fundamental to disk evolution as core collapse is to globular clusters, as the production of hot Jupiters and colder Neptunes is to the evolution of planetary systems, and as evolution to red giants containing proto-white-dwarfs is to stellar evolution (Kormendy & Fisher 2005; Kormendy 2008). In galaxy disks, gas infall and star formation builds dense central components that get mistaken for bulges but that were not made by galaxy mergers. They come in several varieties depending on what drives the evolution. Pseudobulges made from disk gas are often but not always disky (Kormendy 1993; KK04; Fisher & Drory 2008a). Box-shaped bulges also are disk phenomena: they are parts of edge-on bars (Combes & Sanders 1981; Combes et al. 1990; Pfenniger & Friedli 1991; Raha et al. 1991; Kuijken & Merrifield 1995; Merrifield & Kuijken 1999; Bureau & Freeman 1999; Bureau, Freeman, & Athanassoula 1999; Athanassoula 2005, 2007). Nuclear bars are connected with disky pseudobulges (they rotate rapidly) and may be a subset of them. Other morphology that identifies pseudobulges includes nuclear star formation rings and spiral structure. It is convenient to have one name – "pseudobulges" – for all central, high-density products of disk secular evolution.

How to identify pseudobulges is discussed in KK04. Prototypical examples that are more disky than classical bulges were first recognized by their rapid rotation (Figure 2). Disks have large $V_{\max}/\sigma$ and plot above the oblate line when seen at inclinations other than edge-on. Early identification of very disky (e. g., NGC 4736, NGC 3945) and moderately disky (e. g., NGC 2950, also a nuclear bar) pseudobulges have recently been augmented as shown in Figure 2.

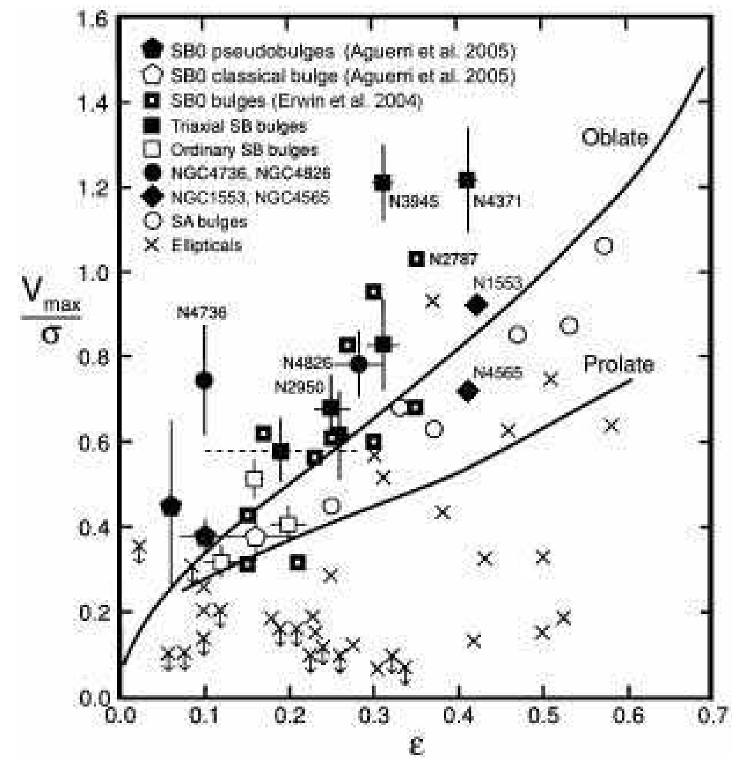

Figure 2. Relative importance of rotation and random velocity as a function of observed ellipticity $\epsilon = (1 - \text{axial ratio})$ for various kinds of stellar systems. Here $V_{\max}/\sigma$ is the ratio of maximum rotation velocity to mean velocity dispersion interior to the half-light radius. The "oblate" line approximately describes oblate-spheroidal systems that have isotropic velocity dispersions and that are flattened only by rotation; it is a consequence of the tensor virial theorem (Binney & Tremaine 1987). This figure is updated from KK04.

Figure 2 is an approximate analysis based on long-slit, major-axis spectra. Integral-field spectroscopy from the SAURON team now provides beautifully detailed detections of rapidly rotating, disky pseudobulges. Often (Figure 3), it is exactly the high-surface-brightness center – where the projected brightness profile rises above the inward extrapolation of the outer disk profile – that shows rapid rotation and a corresponding inward decrease in velocity dispersion. Many of these kinematically decoupled components are also younger than the rest of the inner galaxy. Some counter-rotate (McDermid et al. 2006) and presumably are made from accreted material. But the phenomenon is common in barred and oval galaxies in which secular evolution is expected to be rapid. Besides NGC 4274 in Figure 3, excellent examples include NGC 3623 (SABa in the optical but clearly SB(r) in 2MASS JHK images: Jarrett et al. 2003), and NGC 5689 (SB0). These results are discussed in Ganda et al. (2006), Falcón-Barroso et al. (2006), Peletier et al. (2007a); see Peletier (2008) and Peletier et al. (2007b, c) for reviews. Quoting Peletier et al. (2007c): "SAURON observations show that 13 out of 24 Sa and Sab galaxies [and a similar fraction of late-type spirals] show a central local minimum in the velocity dispersion ... The sigma-drops are probably due to central disks that formed from gas falling into the central regions through a secular evolution process."

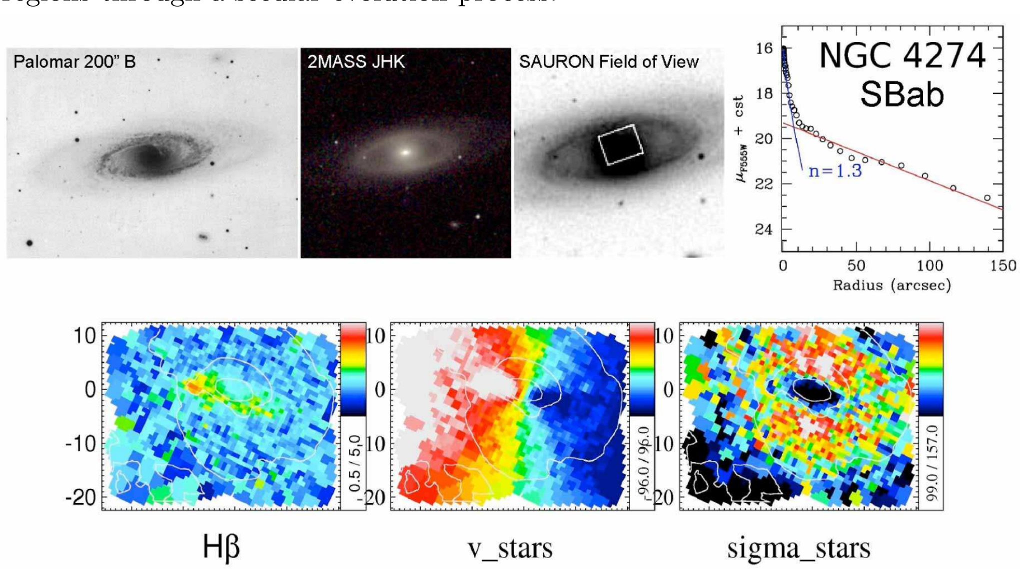

Figure 3. SAURON integral-field spectroscopy of the disky pseudobulge in the Sa galaxy NGC 4274 (adapted from Peletier et al. 2007c). The images show that NGC 4274 is a highly inclined barred galaxy; the bar is foreshortened, because it is oriented nearly along the minor axis. It fills an inner ring, as is normal in SB(r) galaxies (Kormendy 1979). The brightness profile (upper-right) is decomposed into a Sérsic (1968) function plus an exponential disk. The Sérsic function has $n = 1.3$, i.e., $n < 2$, as in other pseudobulges (Figure 5). The pseudobulge dominates the light at radii $r \lesssim 10''$. The kinematic maps (Falcón-Barroso et al. 2006) show that this light comes from a disky component that is more rapidly rotating (center), lower in velocity dispersion (right), and stronger in Hβ line strength (left, from Peletier et al. 2007a) and hence younger than the rest of the inner galaxy.

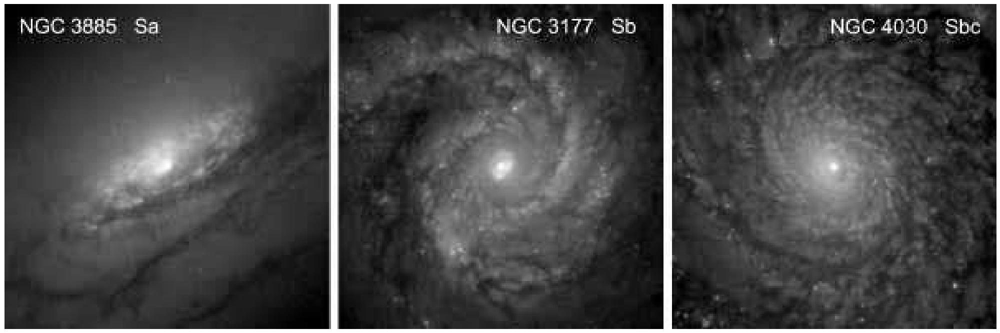

Figure 4. Sa – Sbc galaxies with disky pseudobulges shown in $18'' \times 18''$ regions centered on the galaxy nucleus and extracted from *Hubble Space Telescope* (HST) WFPC2 F606W images kindly provided by Carollo et al. (1997, 1998). Displayed intensity is proportional to the logarithm of the surface brightness. Mean and minimum (pseudo)bulge-to-total luminosity ratios B/T observed by Simien & de Vaucouleurs (1986) are 0.35 and 0.13 for Sas, 0.22 and 0.10 for Sbs, and 0.18 and 0.05 for Sbcs. These galaxies contain nuclear star clusters but no E-like component with the above B/T values.

Pseudobulges were also recognized photometrically in Kormendy (1993); progress since then has been rapid (KK04). In many galaxies, the "bulge" is essentially as flat as the disk and/or shows clearcut spiral structure. Both are signatures of high-density disks – classical bulges are dynamically hot and cannot have small-scale spiral structure. These features are spectacular in HST surveys of the centers of spiral galaxies (Carollo et al. 1997, 1998, 2001, 2002; Carollo 1999). Figure 4 shows examples. These are Sa – Sbc galaxies, so they should contain substantial bulges. Instead, their centers look like star-forming spiral galaxies. Contrast the definition of a classical bulge (Renzini 1999 following Sandage 1961): A bulge is nothing more nor less than an elliptical galaxy that happens to live in the middle of a disk.

Classical and pseudo bulges can coexist (KK04; Kormendy et al. 2006; Erwin 2007), but the morphology in Figure 4 is not due to nuclear disks embedded in classical bulges that are hidden by the display parameters. Bulges have steep brightness profiles, so bulge light would dilute the contrast in the spiral structure very strongly at smaller radii. But the strength of the spiral structure depends little on radius: essentially all of the pseudobulge participates.

The imaging survey authors generally interpret disky bulges as consequences of secular evolution. Courteau, de Jong, & Broeils (1996) observe "spiral structure continuing into the central regions" and "invoke secular dynamical evolution and ... gas inflow via angular momentum transfer and viscous transport" as the explanation. Carollo et al. (2001) conclude that "exponential-type bulge formation is taking place in the local universe and that this process is consistent with being the outcome of secular evolution ... within the disks".

A "proof of concept" is largely in hand, so studies of secular evolution now concentrate on star formation (reviewed in Fisher & Drory 2008b) and on pseudobulge statistical properties. In § 4, we compare the fundamental plane parameter correlations of pseudobulges, classical bulges, and ellipticals. First, we need to define what we mean by an elliptical. This leads to our second theme on environmental secular evolution and the formation of spheroidal galaxies (§ 3).

3. Environmental Secular Evolution: Origin of Spheroidal Galaxies

Figure 5 shows fundamental plane projections (Djorgovski & Davis 1987; Faber et al. 1987; Djorgovski et al. 1988) and Sérsic index versus total magnitude for various kinds of stellar systems (adapted from Kormendy et al. 2008: KFCB).

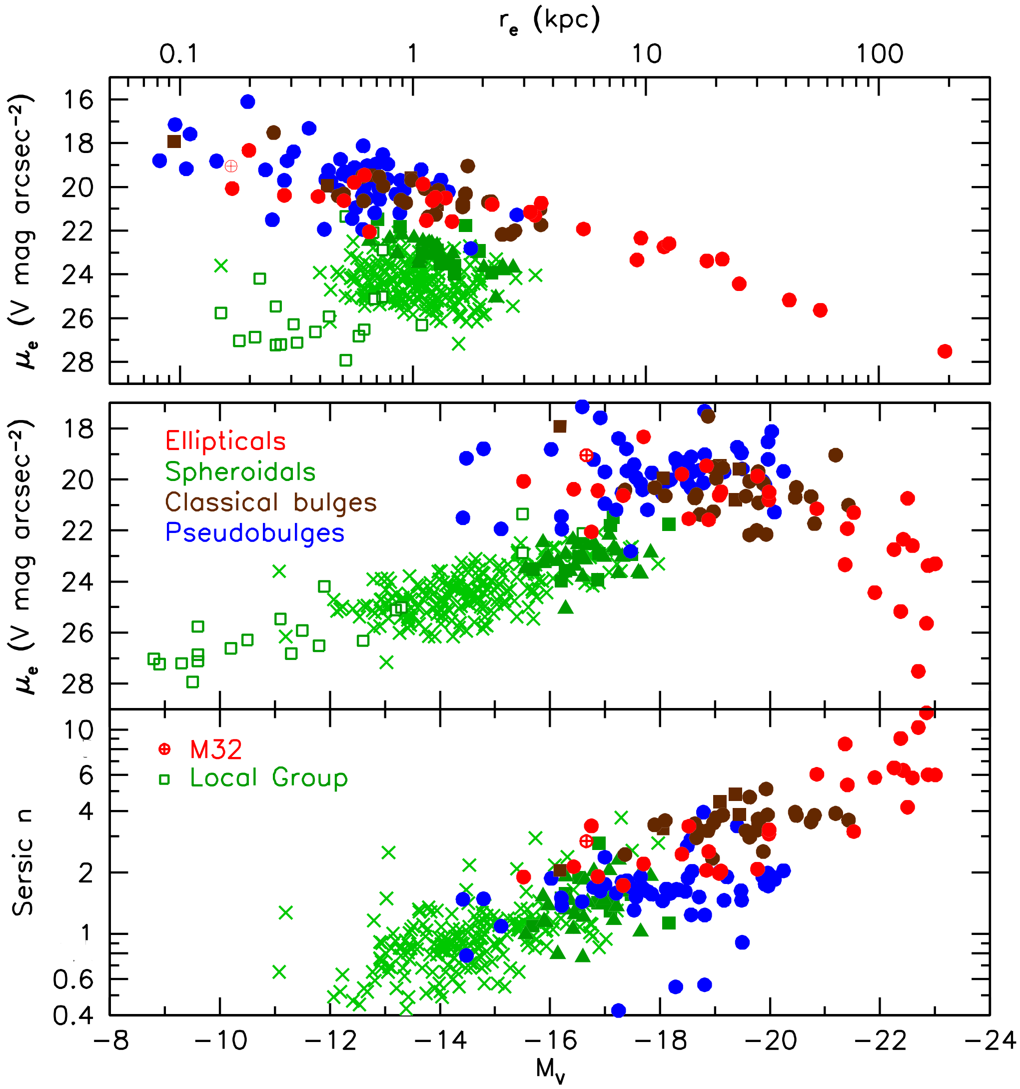

Figure 5. Global parameter correlations for pseudobulges (blue), classical bulges (brown), ellipticals (red), and spheroidal galaxies (green). Pseudobulge and most bulge points are from Fisher & Drory (2007a). The ellipticals, five bulge points, and the green squares are from Kormendy et al. (2008: KFCB). Green triangles show all spheroidals from Ferrarese et al. (2006) that are not in KFCB. Crosses show all spheroidals from Gavazzi et al. (2005) that are not in KFCB or in Ferrarese et al. (2006). Open squares are Local Group spheroidals (Mateo 1998; McConnachie & Irwin 2006). The bottom panels show major-axis Sérsic index n and effective surface brightness μ_e versus total galaxy absolute magnitude. The top panel shows μ_e vs. effective radius r_e (the Kormendy 1977 relation, which shows the fundamental plane almost edge-on).

Critical to the interpretation of this figure is high-accuracy photometry of all known E and selected Sph galaxies in the Virgo cluster from KFCB. Composite HST and ground-based profiles over large radius ranges provide accurate Sérsic parameters. Then the intrinsically small scatter of the fundamental plane (Saglia et al. 1993; Jørgensen et al. 1996) is seen in the top panel, which shows the plane almost edge-on. Figure 5 confirms the results of Kormendy (1985, 1987), Binggeli & Cameron (1991), and Bender, Burstein, & Faber (1992) that E and Sph galaxies satisfy different parameter correlations. This result has been criticized by Jerjen & Binggeli (1997), Graham & Guzmán (2003), Gavazzi et al. (2005), and Ferrarese et al. (2006) in part because the $n - M_V$ correlation is continuous. We agree. But the observation that n is not sensitive to the difference between E and Sph galaxies does not mean that they are related. The fundamental plane correlations (top panels and Figure 6) show that lower-luminosity Es are monotonically higher in density, whereas lower-luminosity Sphs are monotonically lower in density. Spheroidals are not faint ellipticals. Instead, Kormendy (1985, 1987) showed that they have similar parameter correlations to dwarf spiral and irregular galaxies. Spheroidals and ellipticals almost certainly had very different formation processes. We believe that Es formed via major galaxy mergers. Evidence discussed in KFCB suggests that spheroidal galaxies are defunct late-type galaxies transformed by internal processes such as supernova-driven gas ejection (Dekel & Silk 1986) and environmental processes such as secular galaxy harassment (Moore et al. 1996, 1998) and ram-pressure gas stripping (e. g., Chung et al. 2008).

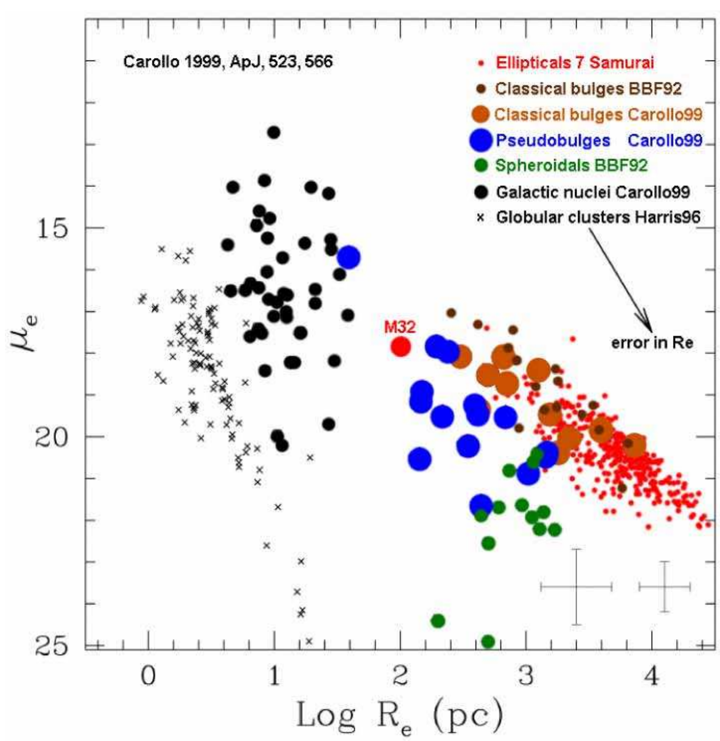

Figure 6. Effective surface brightness versus effective radius for various kinds of stellar systems (adapted from Carollo 1999; colors as in Figure 5).

4. Fundamental Plane Correlations for Bulges and Pseudobulges

Figures 5 and 6 compare parameter correlations for ellipticals, classical bulges, and pseudobulges. Sérsic parameters of (pseudo)bulges are less accurate than those of Es, because deriving them requires a decomposition of brightness profiles into (pseudo)bulge and disk contributions. We have reduced leverage on bulge parameters, and they are strongly coupled to the disk parameters. Nevertheless, Figures 5 and 6 show that classical bulges are indeed indistinguishable from elliptical galaxies, consistent with our definition. Many pseudobulges are not very different, either; this is one reason why they got confused with bulges. To find the difference between pseudobulges and classical bulges, we need to look beyond fundamental plane parameters and consider properties such as flattening and V/σ. Nevertheless, in Figures 5 and 6, pseudobulges also show larger scatter than classical bulges, and they have smaller Sérsic indices. Consistent with Courteau et al. (1996), MacArthur, Courteau, & Holtzman (2003), and the Carollo team papers, Fisher & Drory (2007a) find a relatively clean separation between classical bulges with $n \gtrsim 2$ and pseudobulges (mostly) with $n \lesssim 2$. Note that this conclusion would not be clear if we believed that spheroidals are faint ellipticals. In the above, the bulge-pseudobulge distinction is based on morphological criteria listed in KK04 and not on profile shape. We do not understand galaxy formation well enough to predict n for either type of bulge, but the distinction is clearcut enough to be a classification aid.

Figure 6 shows that pseudobulges fade out by becoming low in density, not by becoming compact, like nuclear star clusters (black filled circles). This suggests that pseudobulges and nuclei are fundamentally different.

5. How can hierarchical clustering make so many bulgeless galaxies?

Hierarchical clustering in a cold dark matter universe (White & Rees 1978) is a remarkably successful theory of galaxy formation. The struggle now is with baryonic physics. The most serious problem has been emphasized many times, both by observers (e. g., Freeman 2000; KK04; Kormendy & Fisher 2005; Carollo et al. 2007; Kormendy 2008) and by modelers (e. g., Steinmetz & Navarro 2002; Abadi et al. 2003). Given so much merger violence, how can hierarchical clustering produce so many pure disk galaxies with no signs of merger-built bulges? This problem gets harder when we realize that many of what we used to think are small bulges are really pseudobulges made by secular evolution. We know of no Sc or later-type galaxy with a classical bulge (KK04). So the solution to the above problem is not to hope that bulgeless disks are rare enough that they can be explained as the tail of a distribution of formation histories that included a few fortuitously mergerless galaxies.

This section provides new examples and better statistics on bulgeless disks.

The bulgeless disks that most constrain our formation picture are those that live in high-mass dark halos – say, ones in which circular-orbit rotation velocities are $V_{\rm circ} \sim 200$ km s^{-1}. Kormendy et al. (2009) have used the Hobby-Eberly Telescope to obtain high-resolution (instrumental dispersion $\sigma_{\rm instr} \simeq 8$ km s^{-1}) spectroscopy of the nuclear star clusters in M 101 and NGC 6946. M 101 is an Scd galaxy with $V_{\rm circ} = 210 \pm 15$ km s^{-1} (Bosma et al. 1981). But its nucleus has a velocity dispersion $\sigma = 25 \pm 7$ km s^{-1} like that of a big globular cluster. NGC 6946 is a similar Scd with $V_{\rm circ} = 210 \pm 10$ km s^{-1} (Tacconi & Young 1986; Sofue 1996) and $\sigma = 38 \pm 3$ km s^{-1}. IC 342 is a third such galaxy with $V_{\rm circ} = 192 \pm 5$ km s^{-1} (Rogstad, Shostak, & Rots 1973; Sofue 1996) and $\sigma = 33 \pm 3$ km s^{-1} (Böker et al. 1999; $\sigma_{\rm instr} = 5.5$ km s^{-1}). All three galaxies show small central upturns in their JHK brightness profiles (Jarrett et al. 2003) and NGC 6946 and IC 342 also show rapid rises in their central CO rotation curves $V(r)$ (Sofue 1996). But their small dispersions $\sigma \ll V$ show that these are pseudobulges. How did these halos grow so large with no signs of major mergers?

Could bulgeless disks be rare enough to have formed as the quiescent tail of a distribution of merger histories? We believe that the answer is "no". Consider first the Local Group. Only our Galaxy has uncertainty in its bulge classification. The box-shaped structure implies a pseudobulge. The low velocity dispersion of the bulge merges seamlessly with that of the disk (Lewis & Freeman 1989). The central σ profile derived by Tremaine et al. (2002) implies a pseudobulge. Only the old, α-element-enhanced stellar population is suggestive of a classical bulge (KK04 discusses these caveats). In agreement with Freeman (2008), we conclude that there is no photometric or dynamical evidence for a classical bulge. Then the Local Group contains one elliptical, M 32, and one classical bulge, in M 31. In the most massive three galaxies, there is only one classical bulge.

Looking beyond the Local Group, the most distant bulgeless disk discussed above is M 101. Its Cepheid distance modulus is $m - M = 29.34 \pm 0.10$; i. e., distance $= 7.4 \pm 0.3$ Mpc (Ferrarese et al. 2000), and $V_{\rm circ} = 210 \pm 15$ km s^{-1}. We will be conservative and look for all galaxies with $V_{\rm circ} > 150$ km s^{-1} or central $\sigma > 106$ km s^{-1} and $m - M < 29.5$. HyperLeda and Tonry et al. (2001) provide 19 such galaxies. M 101, NGC 6946, and IC 342, are 3/19 of the big galaxies in our sample volume. Of the rest, 8 are dominated by pseudobulges with no sign of a classical bulge. One more, NGC 2787, has a dominant pseudobulge but could also have a small classical bulge component. Three galaxies in the above volume are ellipticals, Maffei 1, NGC 3077 (probably), and NGC 5128. Three galaxies are known to have classical bulges, M 31, M 81, and NGC 4258. NGC 5195, the companion of M 51, has an uncertain classification but $\sigma = 157$ km s^{-1}; we include it among the classical bulges. This leaves us with the following statistics: Within 8 Mpc of us, 11 of 19 galaxies with $V_{\rm circ} > 150$ km s^{-1} show no evidence for a classical bulge, one may contain both a classical bulge and a pseudobulge, and 7 of 19 are either ellipticals or contain classical bulges. Big galaxies with evidence for a major merger are less than half of the sample.

In contrast, in the Virgo cluster, about 2/3 of the stellar mass is in elliptical galaxies and some additional mass is in classical bulges (KFCB). So the above statistics are a strong function of environment.

We therefore restate the theme of this section: What is special about galaxy formation in low-density, Local-Group-like environments that allows $> 1/2$ of the galaxies with halo $V_{\rm circ} > 150$ km s^{-1} to form with no signs of major mergers?

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References

Abadi, M. G., Navarro, J. F., Steinmetz, M., & Eke, V. R. 2003, ApJ, 591, 499
Aguerri, J. A. L., Elias-Rosa, N., Corsini, E. M., & Muñoz-Tuñón, C. 2005, A&A, 434, 109
Athanassoula, E. 2005, MNRAS, 358, 1477
Athanassoula, E. 2007, in Mapping the Galaxy and Nearby Galaxies, ed. K. Wada & F. Combes (New York: Springer), in press (astro-ph/0610113)
Bender, R., Burstein, D., & Faber, S. M. 1992, ApJ, 399, 462
Binggeli, B., & Cameron, L. M. 1991, A&A, 252, 27
Binney, J., & Tremaine, S. 1987, Galactic Dynamics (Princeton: Princeton Univ. Press)
Böker, T., van der Marel, R. P., & Vacca, W. D. 1999, AJ, 118, 831
Bosma, A., Goss, W. M., & Allen, R. J. 1981, A&A, 93, 106
Bureau, M., & Freeman, K. C. 1999, AJ, 118, 126
Bureau, M., Freeman, K. C., & Athanassoula, E. 1999, in The Formation of Galactic Bulges, ed. C. M. Carollo et al. (Cambridge: Cambridge Univ. Press), 115
Buta, R., & Combes, F. 1996, Fund. Cosm. Phys., 17, 95
Carollo, C. M. 1999, ApJ, 523, 566
Carollo, C. M., Stiavelli, M., de Zeeuw, P. T., & Mack, J. 1997, AJ, 114, 2366
Carollo, C. M., Stiavelli, M., & Mack, J. 1998, AJ, 116, 68
Carollo, C. M., et al. 2002, AJ, 123, 159
Carollo, C. M., et al. 2001, ApJ, 546, 216
Carollo, C. M., et al. 2007, ApJ, 658, 960
Chung, A. et al. 2008, in Formation and Evolution of Galaxy Disks, ed. J. G. Funes, S. J. & E. M. Corsini (San Francisco: ASP), 127
Combes, F. 2007, in IAU Symposium 245, Formation and Evolution of Galaxy Bulges, ed. M. Bureau et al. (Cambridge: Cambridge University Press), in press
Combes, F. 2008, in Formation and Evolution of Galaxy Disks, ed. J. G. Funes, S. J. & E. M. Corsini (San Francisco: ASP), 325
Combes, F., Debbasch, F., Friedli, D., & Pfenniger, D. 1990, A&A, 233, 82
Combes, F., & Sanders, R. H 1981, A&A, 96, 164
Courteau, S., de Jong, R. S., & Broeils, A. H. 1996, ApJ, 457, L73
Dekel, A., & Silk, J. 1986, ApJ, 303, 39
Djorgovski, S., & Davis, M. 1987, ApJ, 313, 59
Djorgovski, S., de Carvalho, R., & Han, M.-S. 1988, in The Extragalactic Distance Scale, ed. S. van den Bergh & C. J. Pritchet (San Francisco: ASP), 329
Erwin, P. 2007, in IAU Symposium 245, Formation and Evolution of Galaxy Bulges, ed. M. Bureau et al. (Cambridge: Cambridge Univ. Press), in press
Erwin, P., Beckman, J. E., & Vega Beltran, J. C. 2004, in Penetrating Bars Through Masks of Cosmic Dust, ed. D. L. Block et al. (New York: Springer), 775
Faber, S. M., et al. 1987, in Nearly Normal Galaxies: From the Planck Time to the Present, ed. S. M. Faber (New York: Springer), 175
Falcón-Barroso, J., et al. 2006, MNRAS, 369, 529
Ferrarese, L., et al. 2000, ApJS, 128, 431
Ferrarese, L., et al. 2006, ApJS, 164, 334
Fisher, D. B., & Drory, N. 2008a, AJ, 136, 773
Fisher, D. B., & Drory, N. 2008b, in Formation and Evolution of Galaxy Disks, ed. J. G. Funes, S. J. & E. M. Corsini (San Francisco: ASP), 309
Freeman, K. C. 2000, in Toward a New Millennium in Galaxy Morphology, ed. D. L. Block et al. (Dordrecht: Kluwer), 119
Freeman, K. C. 2008, in Formation and Evolution of Galaxy Disks, ed. J. G. Funes, S. J. & E. M. Corsini (San Francisco: ASP), 3
Ganda, K., et al. 2006, MNRAS, 367, 46
Gavazzi, G., et al. 2005, A&A, 430, 411
Graham, A. W., & Guzmán, R. 2003, AJ, 125, 2936
Jarrett, T. H., et al. 2003, AJ, 125, 525

Jerjen, H., & Binggeli, B. 1997, in The Second Stromlo Symposium: The Nature of Elliptical Galaxies, ed. M. Arnaboldi, et al. (San Francisco: ASP), 239
Jørgensen, I., Franx, M., & Kjærgaard, P. 1996, MNRAS, 280, 167
Kormendy, J. 1977, ApJ, 218, 333
Kormendy, J. 1979, ApJ, 227, 714
Kormendy, J., 1982, in Morphology and Dynamics of Galaxies, Twelfth Saas-Fee Course, ed. L. Martinet & M. Mayor (Sauverny: Geneva Observatory), 113
Kormendy, J. 1985, ApJ, 295, 73
Kormendy, J. 1987, in Nearly Normal Galaxies: From the Planck Time to the Present, ed. S. M. Faber (New York: Springer), 163
Kormendy, J. 1993, in IAU Symposium 153, Galactic Bulges, ed. H. Dejonghe & H. J. Habing (Dordrecht: Kluwer), 209
Kormendy, J. 2008, in IAU Symposium 245, Formation and Evolution of Galaxy Bulges, ed. M. Bureau et al. (Cambridge: Cambridge Univ. Press), 107
Kormendy, J., & Cornell, M. E. 2004, in Penetrating Bars Through Masks of Cosmic Dust, ed. D. L. Block et al. (New York: Springer), 261
Kormendy, J., et al. 2006, ApJ, 642, 765
Kormendy, J., Drory, N., Bender, R., & Cornell, M. E. 2009, ApJ, in preparation
Kormendy, J., & Fisher, D. B. 2005, RevMexA&A (Serie de Conferencias), 23, 101
Kormendy, J., Fisher, D. B., Cornell, M. E., & Bender, R. 2008, ApJS (arXiv:0810.1681)
Kormendy, J., & Kennicutt, R. C. 2004, ARA&A, 42, 603 (KK04)
Kuijken, K., & Merrifield, M. R. 1995, ApJ, 443, L13
Lewis, J. R., & Freeman, K. C. 1989, AJ, 97, 139
MacArthur L. A., Courteau, S., & Holtzman, J. A. 2003, ApJ, 582, 689
Mateo, M. 1998, ARA&A, 36, 435
McConnachie, A. W., & Irwin, M. J. 2006, MNRAS, 365, 1263
McDermid, R. M. et al. 2006, MNRAS, 373, 906
Merrifield, M. R., & Kuijken, K. 1999, A&A, 345, L47
Moore, B., et al. 1996, Nature, 379, 613
Moore, B., Lake, G., & Katz, N. 1998, ApJ, 495, 139
Peletier, R. F. 2008, in Pathways Through an Eclectic Universe, ed. J. H. Knapen, T. J. Mahoney, & A. Vazdekis (San Francisco: ASP), 232
Peletier, R. F., et al. 2007a, MNRAS, 379, 445
Peletier, R. F., et al. 2007b, in IAU Symposium 241, Stellar Populations as Building Blocks of Galaxies, ed. A. Vazdekis & R. Peletier (Cambridge Univ. Press), 485
Peletier, R. F., et al. 2007c, in IAU Symposium 245, Formation and Evolution of Galaxy Bulges, ed. M. Bureau et al. (Cambridge: Cambridge Univ. Press), in press
Pfenniger, D., & Friedli, D. 1991. A&A, 252, 75
Raha, N., Sellwood, J. A., James, R. A., & Kahn, F. D. 1991, Nature, 352, 411
Renzini, A. 1999, in The Formation of Galactic Bulges, ed. C. M. Carollo et al. (Cambridge: Cambridge Univ. Press), 9
Rogstad, D. H., Shostak, G. S., & Rots, A. H. 1973, A&A, 22, 111
Saglia, R. P, Bender, R., & Dressler, A. 1993, A&A, 279, 75
Sandage, A. 1961, The Hubble Atlas of Galaxies (Carnegie Institution of Washington)
Sellwood, J. A., & Wilkinson, A. 1993, Rep. Prog. Phys., 56, 173
Sérsic, J. L. 1968, Atlas de Galaxias Australes (Cordoba: Obs. Astr., Univ. de Cordoba)
Simien, F., & de Vaucouleurs, G. 1986, ApJ, 302, 564
Sofue, Y. 1996, ApJ, 458, 120
Steinmetz, M., & Navarro, J. F. 2002, NewA, 7, 155
Tacconi, L. J., & Young, J. S. 1986, ApJ, 308, 600
Tonry, J. L., et al. 2001, ApJ, 546, 681
Tremaine S. 1989, in Dynamics of Astrophysical Disks, ed. J. A. Sellwood (Cambridge: Cambridge Univ. Press), 231
Tremaine, S., et al. 2002, ApJ, 574, 740
White, S. D. M., & Rees, M. J. 1978, MNRAS, 183, 341