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Central Surface Brightness Profiles in Brightest Cluster Galaxies

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Abstract

We present results from an HST WFPC2 I-band imaging study of the centers of 81 brightest cluster galaxies (BCGs). The images show a rich variety of morphological features. We were able to derive surface brightness profiles for 60 galaxies. Of those, 88% have well-resolved cores. The remaining twelve percent have "power-law" profiles. Therefore, the central structure of even the brightest galaxies shows a bimodality. A correlation between the power-law BCGs and the so-called α parameter, related to the slope of the surface brightness profile at a large radius, suggests a scenario in which elliptical galaxies evolve from power-law profiles to core profiles through accretion and merging. This is consistent with theoretical scenarios which invoke the formation of massive black hole binaries during merger events.

1.1 Introduction

By their very definition, brightest cluster galaxies (BCGs) are highly luminous elliptical galaxies. Their high luminosities and their central location in galaxy clusters suggest that the processes which shape the centers of giant ellipticals should be most easily observable in these systems. Due to their high luminosities, and the strong correlation between galaxy luminosity and central black hole mass (Kormendy & Gebhardt 2001), BCGs are expected to harbor the most massive black holes. Due to their central location in galaxy clusters, we expect them to cannibalize other cluster galaxies even at the current epoch. The great homogeneity in the global properties and in the environment of the BCGs gives us perhaps the best opportunity to understand the central structures found in elliptical galaxies. Therefore, we have chosen to study a large sample of BCGs to learn more about the physical processes that shape the centers of bright elliptical galaxies. Further details of this work can be found in Laine et al. (2003).

1.2 Sample

Our final sample is a subsample of the Lauer & Postman (1994) and Postman & Lauer (1995) sample of 119 galaxies. BCGs were picked randomly from this sample for *HST* snapshot observations. In all, 75 galaxies were observed. One of these turned out to be a foreground galaxy. We added seven BCGs from the *HST* archive. The observations were taken with the F814W filter, which is close to the *I*-band.

1.3 Results

We have discovered the following features in our images:

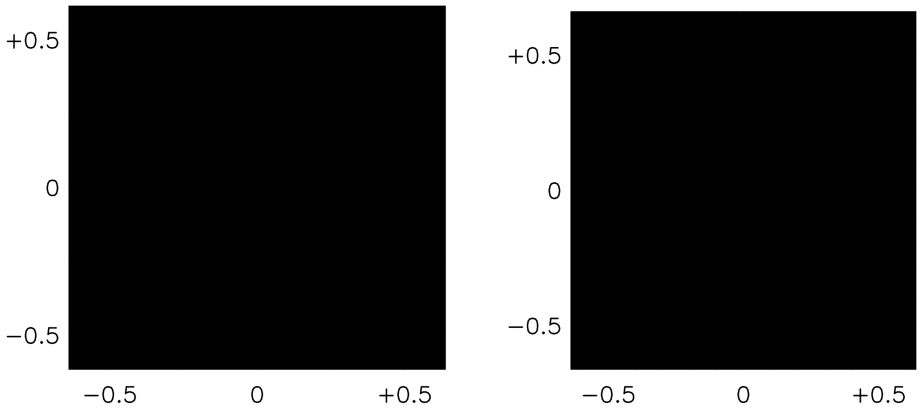

Fig. 1.1. Examples of double nuclei. BCGs of Abells 347 and 3526.

- **Multiple nuclei.** 40% of our sample BCGs have a second nucleus within the area imaged by the PC chip. In two cases, we have detected double nuclei (see Fig. 1.1). However, a large fraction of the secondary nuclei may be foreground or background projections.
- **Dust features.** We have found dust features in 38% of our sample. These features include nuclear dust disks, dust filaments, dust rings, dust spirals and patchy dust (see Fig. 1.2).
- **Nuclear stellar disks.** We found two BCGs that have an edge-on disk morphology in the nucleus, revealed by their high ellipticity.
- **Central point sources.** We identified ten BCGs with bright point sources near the center. Such point sources are likely to be related to AGN-like nuclear activity, and were discarded from the fits to the surface brightness profiles.
- **Central surface brightness depressions.** Six galaxies in the sample have surface brightness profiles that decrease towards the center (see Fig. 1.3; the sixth galaxy is the BCG of Abell 347, shown in Fig. 1.1).

We fitted the surface brightness profiles, derived from deconvolved images, with the Nuker law.

$$I(r) = I_0\,(r/r_{\mathrm{b}})^{-\gamma}\,(1+[r/r_{\mathrm{b}}]^{\tau})^{\frac{\gamma-\beta}{\tau}} \tag{1.1}$$

We allowed for both positive and negative γ values. The fits were generally performed over the radial range from 0.02 arcsec (i.e., the central pixel) to 10 arcsec from the galaxy center. We define the quantity $\Gamma_{0.05}$, which is the power-law slope $-\mathrm{d}\log I/\mathrm{d}\log r$ at 0.05 arcsecs from the galaxy center. This is the last reliable radius outside the *HST* resolution limit in the deconvolved profiles, and it offers the best view of the cusp slope as the radius approaches zero. Examples of the fits are shown in Fig. 1.4, and some of the resulting parameters are in Table 1.1.

Out of the 60 galaxies for which we have fitted surface brightness profiles, 52 have $\Gamma_{0.05} \leq 0.3$ and $r_{\mathrm{b}} \geq 0.15$ arcsecs. These are core galaxies with well-resolved cores. Another six galaxies have $\Gamma_{0.05} \geq 0.5$. These are power-law galaxies. The remaining galaxy is an intermediate type galaxy. We also estimated upper limits to the radius of any true break in the power-law galaxies.

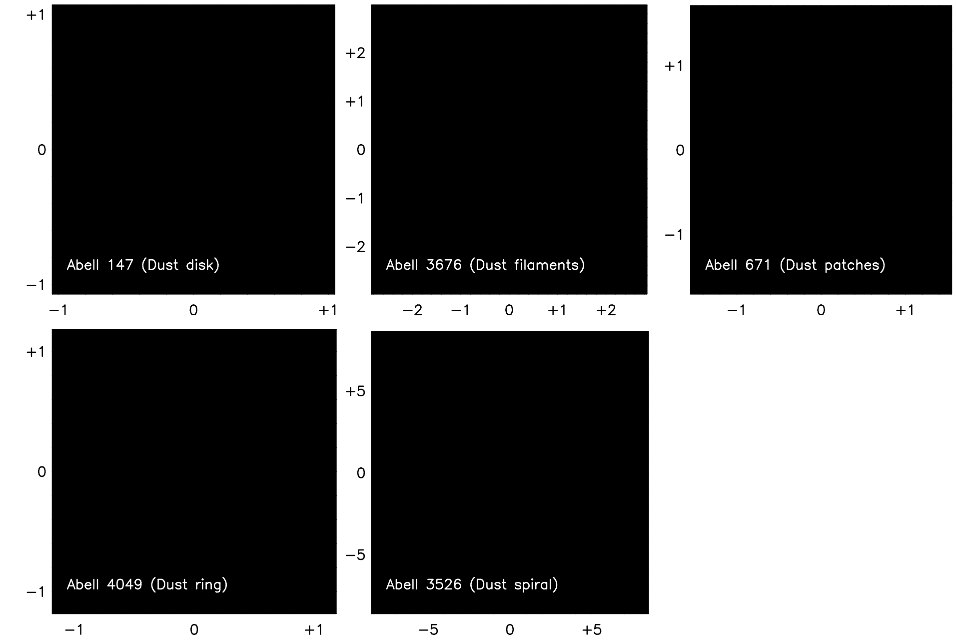

Fig. 1.2. Examples of the different dust features.

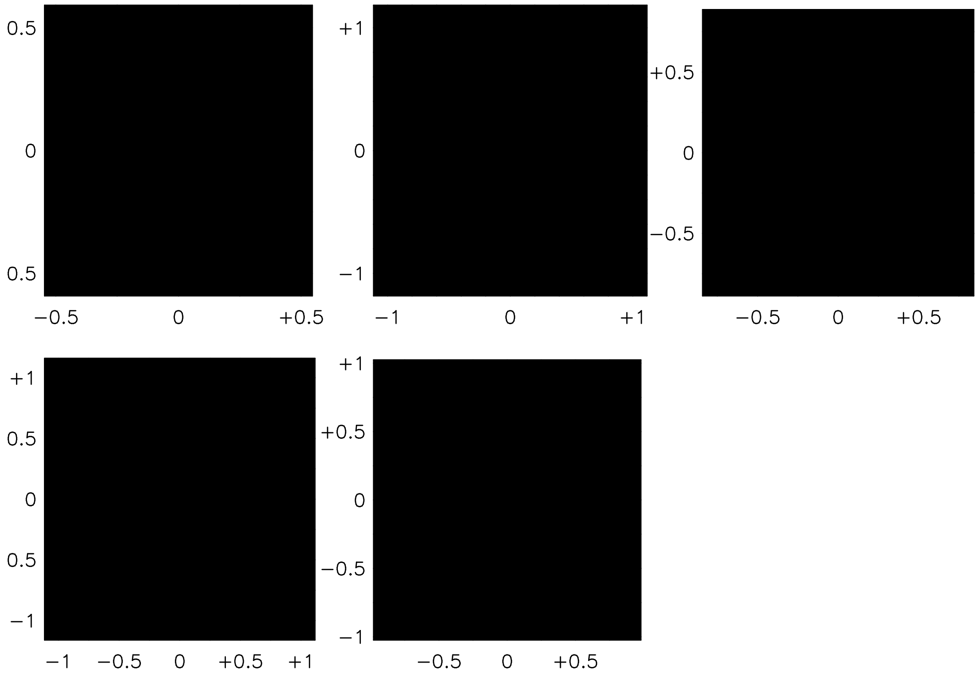

Fig. 1.3. Examples of galaxies with central light depressions.

Table 1.1. *Nuker fit parameters.* $\Gamma_{0.05}$ *is the power-law slope at 0.05 arcsec,* $\cap$ *is a core profile,* $\backslash$ *is a power-law profile and "i" is an intermediate profile. Upper limits for the break radius* r_b *(in arcsec) are shown in parenthesis.*

ABELL	r_b	$\Gamma_{0.05}$	Profile	ABELL	r_b	$\Gamma_{0.05}$	Profile
76	0.28	-0.03	$\cap$	2040	0.39	0.19	$\cap$
119	0.80	0.06	$\cap$	2147	2.21	0.18	$\cap$
168	0.06	0.19	$\cap$	2162	1.04	0.02	$\cap$
189	0.65 (<0.05)	0.85	$\backslash$	2197	0.78	0.02	$\cap$
193	0.39	0.23	$\cap$	2247	1.99 (<0.03)	0.85	$\backslash$
194	0.70	0.10	$\cap$	2572	0.18	0.21	$\cap$
195	0.49	0.10	$\cap$	2589	0.25	0.05	$\cap$
260	0.75	-0.01	$\cap$	2877	0.98	0.01	$\cap$
261	0.98 (<0.05)	0.76	$\backslash$	3144	0.39	0.11	$\cap$
295	0.63	0.13	$\cap$	3193	0.26	0.20	$\cap$
347	0.39	-0.03	$\cap$	3376	1.95	0.05	$\cap$
376	0.68	0.20	$\cap$	3395	0.37	0.04	$\cap$
397	1.06	0.07	$\cap$	3526	1.40	0.10	$\cap$
419	0.47 (<0.1)	0.60	$\backslash$	3528	0.61	0.18	$\cap$
496	0.73	0.10	$\cap$	3532	0.43	0.18	$\cap$
533	0.31	0.10	$\cap$	3554	0.52	0.04	$\cap$
548	0.40	0.16	$\cap$	3556	0.47	0.10	$\cap$
634	0.23	-0.04	$\cap$	3558	1.73	0.05	$\cap$
779	1.04	0.03	$\cap$	3562	1.15	0.03	$\cap$
912	0.21 (<0.08)	0.55	$\backslash$	3564	0.24	0.20	$\cap$
999	0.62	0.05	$\cap$	3570	0.26	0.17	$\cap$
1016	0.23	0.25	$\cap$	3571	1.15	0.02	$\cap$
1142	0.19	0.12	$\cap$	3574	0.76	-0.02	$\cap$
1177	0.57	0.14	$\cap$	3656	0.99	0.09	$\cap$
1228	0.27 (<0.08)	0.60	$\backslash$	3677	0.27	0.13	$\cap$
1314	1.19	0.17	$\cap$	3716	0.44	-0.02	$\cap$
1367	0.93	0.12	$\cap$	3736	0.92	0.13	$\cap$
1631	0.20	0.12	$\cap$	3742	0.22	0.11	$\cap$
1656	2.10	0.03	$\cap$	3747	0.18	0.05	$\cap$
1983	0.10	0.44	i	4038	0.33	0.17	$\cap$

We found that the power-law galaxies exist only among BCGs that are less bright than $M_V = -22.6$. Figure 1.5 shows the break radius r_b for the BCGs, in physical units, vs. the absolute galaxy magnitude M_V. As reported previously, there is a correlation between r_b and M_V in the sense that lower-luminosity galaxies have smaller break radii. The only other significant correlation that we found is between the central slope and the parameter α, which measures the logarithmic slope of the metric luminosity at 10 kpc.

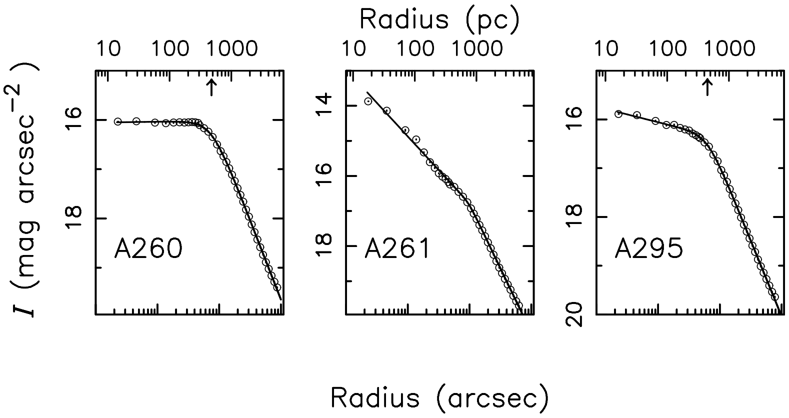

Fig. 1.4. Examples of Nuker-law fits to our surface brightness profiles. The break radius is shown with an arrow.

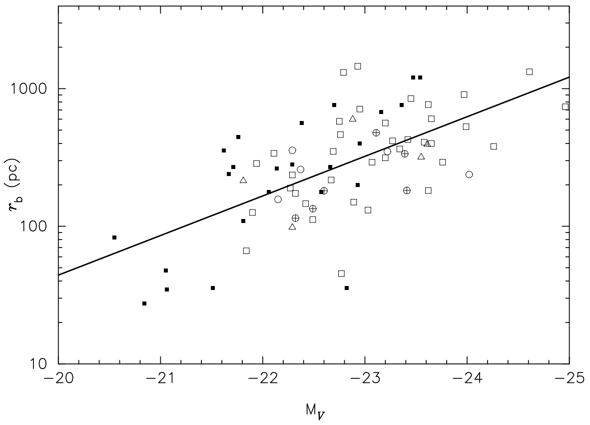

Fig. 1.5. The total luminosity vs. the break radius in pc. A best fitting line to the combined BCG + Faber et al. (1997) sample is also shown.

1.4 Discussion

Our results support scenarios in which elliptical galaxies evolve from power-law profiles to core profiles through accretion and merging. As two galaxies merge, the formation and coalescence of a binary black hole system creates a core-type surface brightness profile. More massive galaxies have undergone more accretion events, and this causes core-type profiles to be more common amongst the most luminous galaxies. If there is no central massive black hole, any dense nucleus cannibalized may settle into the core of the luminous galaxy without being disrupted, creating a central power-law profile.

1.5 Conclusions

- Among 60 BCGs, 88% have "core-type" profiles, and the rest have either "power-law" or intermediate-type profiles.

- We suggest that BCGs with low luminosities and low α values have had the least pronounced accretion histories.
- We interpret our results as evidence that elliptical galaxies evolve from power-law to core profiles through accretion and merging. Such an evolution is naturally explained in theoretical studies where the merging progenitors both have central black holes.

References

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