Black Holes from Stars to Galaxies – Across the Range of Masses
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The nuclear properties of early-type galaxies in the Virgo and Fornax clusters

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Abstract. We summarize findings from imaging surveys of 143 early-type galaxies in the Virgo and Fornax Clusters. Using deep HST images in the F475W (g) and F850LP (z) band-passes obtained with the Advanced Camera for Surveys (ACS), we have examined the central structure of the program galaxies, finding clear evidence for a compact stellar nucleus in $\sim 75\%$ of the sample. The formation of early-type galaxies of low- and intermediate-mass is often – but not always – accompanied by the formation of a compact stellar nucleus.

Keywords. galaxies: clusters – galaxies: elliptical and lenticular – galaxies: nuclei

1. Introduction

The ACS Virgo and Fornax Cluster Surveys [5,11] consist of HST imaging for 143 early-type (E, S0, dE, dE,N or dS0) members of the Virgo and Fornax Clusters, supplemented by imaging and spectroscopy from WFPC2, Chandra, Spitzer, Keck, VLT, Magellan, KPNO, and CTIO. All HST images were taken with the ACS [9] using a filter combination equivalent to the g and z band-passes in the SDSS photometric system. The images cover a $200'' \times 200''$ field with $\approx 0.1''$ resolution (corresponding to a physical resolution of 8 pc).

2. Results from the ACS Virgo and Fornax Surveys

For each galaxy, azimuthally averaged surface brightness profiles were derived as described in [6,7]. Nuclei were identified through a direct inspection of the ACS images and by fitting the surface brightness profiles, where nuclei appear as an "excess" over the inward extrapolation of the best-fitting galaxy model [10,15] (see Figure 1). Our main findings can be summarized as follows:

□ The frequency of nucleation in early-type galaxies brighter than $M_B \approx -15$ falls in the range $66 \lesssim f_n \lesssim 82\%$, roughly three times higher than previous estimates [1]. Earlier ground-based surveys missed significant numbers of nuclei due to surface brightness selection effects, limited sensitivity and poor spatial resolution.

□ A search for nuclei offset from the photo-centers of their host galaxies reveals only a handful of candidates (i.e., $\lesssim 7\%$ of the sample) with displacements of $0.5''$ (40 pc) or larger, all in dwarf galaxies. In each case, though, the evidence suggests that these "nuclei" are, in fact, globular clusters projected close to the galaxy photo-center.

□ The nuclei have a median half-light radii of $r_h = 4.2$ pc, with the sizes of individual nuclei ranging from 62 pc down to $\leqslant 2$ pc (i.e., unresolved in our images). Excluding the half dozen unresolved objects, the nuclei sizes are found to depend on nuclear luminosity according to the relation $r_h \propto \mathcal{L}^{0.50\pm0.03}$.

□ The large majority of nuclei are resolved, so we can rule out low-level, non-thermal AGN as an explanation for the central luminosity excess in almost all cases.

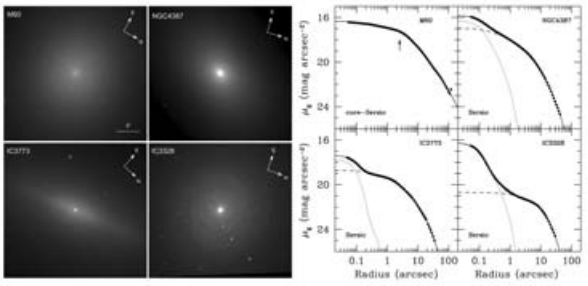

Figure 1. Left Panels: F475W images of the central regions of four galaxies from the ACS Virgo Cluster Survey. Right Panels: Azimuthally-averaged g-band surface brightness profiles for these same four galaxies. M60 is an example of a non-nucleated "core-Sérsic" galaxy; the best core-Sérsic model is shown as a solid curve. The vertical arrow shows the radius, r_b, at which the outer Sérsic profile "breaks" to an inner power-law. For the remaining galaxies, we show the best-fit model which consists of a central King model for the nucleus (dotted curve) and a Sérsic model for the underlying galaxy (dashed curve). The solid curve shows the composite model.

□ The colors of the nuclei in galaxies fainter than $M_B \approx -17.6$ are tightly correlated with their luminosities, and less so with the luminosities of their host galaxies, suggesting that their chemical enrichment histories were governed by local or internal factors.

□ Comparing the nuclei to the "nuclear clusters" found in late-type spiral galaxies [2-4,12-14,16] reveals a close match in terms of size, luminosity and overall frequency. A formation mechanism that is rather insensitive to the detailed properties of the host galaxy is required to explain this ubiquity and homogeneity.

□ The mean of the frequency function for the nucleus-to-galaxy luminosity ratio in our nucleated galaxies is indistinguishable from that of the black hole-to-bulge mass ratio calculated in 23 early-type galaxies with detected supermassive black holes: i.e., $\approx 0.2\%$ by mass; [6,8,17]. The compact stellar nuclei found in our program galaxies may thus be low-mass counterparts to the supermassive black holes detected in the bright galaxies.

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