The ACS Virgo Cluster Survey

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The Advanced Camera for Surveys (ACS on the Hubble Space Telescope) Virgo Cluster Survey is a program to observe images of 100 early-type galaxies in the Virgo cluster, in the F475W and F850LP band passes (SDSS g and z). In terms of depth, spatial resolution, sample size and homogeneity, this represents the most comprehensive imaging survey to date of early-type galaxies in a cluster environment. The scientific goals of this survey include an exploration of the three-dimensional structure of the Virgo Cluster and a critical examination of the usefulness of the globular cluster luminosity function as a distance indicator. In this article, we present some preliminary science results from the survey.

1. Introduction

The Virgo Cluster is the dominant mass concentration in the Local Supercluster and the largest collection of elliptical and lenticular galaxies in the nearby universe. The Advanced Camera for Surveys (ACS; Ford et al. 1998) Virgo Cluster Survey is a project based on observations with the ACS on the *Hubble Space Telescope* (HST), aimed at the exploration of the properties of 100 early–type galaxies in the Virgo Cluster, the study of their globular cluster systems, and the reconstruction of Virgo's three dimensional structure.

Coté et al. (2004) described the program galaxies, and their ensemble properties, the choice of filters, the field placement and orientation, the limiting magnitudes of the survey, coordinated parallel observations of 100 "intergalactic" fields with WFPC2, and supporting ground-based spectroscopic observations of the program galaxies. Details on the data reduction procedures may be found in Jordán et al. (2004a) and Mei et al. (2005a).

In terms of depth, spatial resolution, sample size, and homogeneity, this represents the most comprehensive imaging survey to date of early-type galaxies in a cluster environment.

2. Surface Brightness Fluctuation distance measurements

Our survey aims to measure accurate distances for the full sample of 100 program galaxies. To do so, we use the method of Surface Brightness Fluctuations (SBF). The SBF method was first proposed by Tonry & Schneider (1988) and it is based on the fact that the variance of normalized poissonian fluctuations of the galaxy stellar population depends on galaxy distance (for reviews see Jacoby et al. 1992 and Blakeslee et al. 1999). At present, SBF measurements have been used to determine galaxy distances out to ≈ 7000 km s^{-1}, using data from ground–based telescopes and the HST (Ajhar et al. 1997, 2001; Tonry et al. 1997, 2001; Jensen et al. 1999, 2003; Blakeslee et al. 2001, 2002; Mei et al. 2001, 2003; Liu et al. 2001, 2002; Mieske et al. 2003, Mei et al. 2005a, Mei et al. 2005b).

The feasibility of measuring accurate SBF distances from ACS Virgo Cluster Survey F850LP imaging was studied in detail in Mei et al. (2005a). As is well known, the ACS exhibits significant geometrical distortions due to its off-axis location in the *HST* focal plane; correcting for these distortions by resampling the pixel values onto an undistorted frame results in pixel correlations that depend on the nature of the interpolation kernel used for the resampling. This poses a major challenge for the SBF technique, which normally assumes a flat power spectrum for the noise. Mei et al. (2005a) investigated a number of different interpolation kernels and showed through an analysis

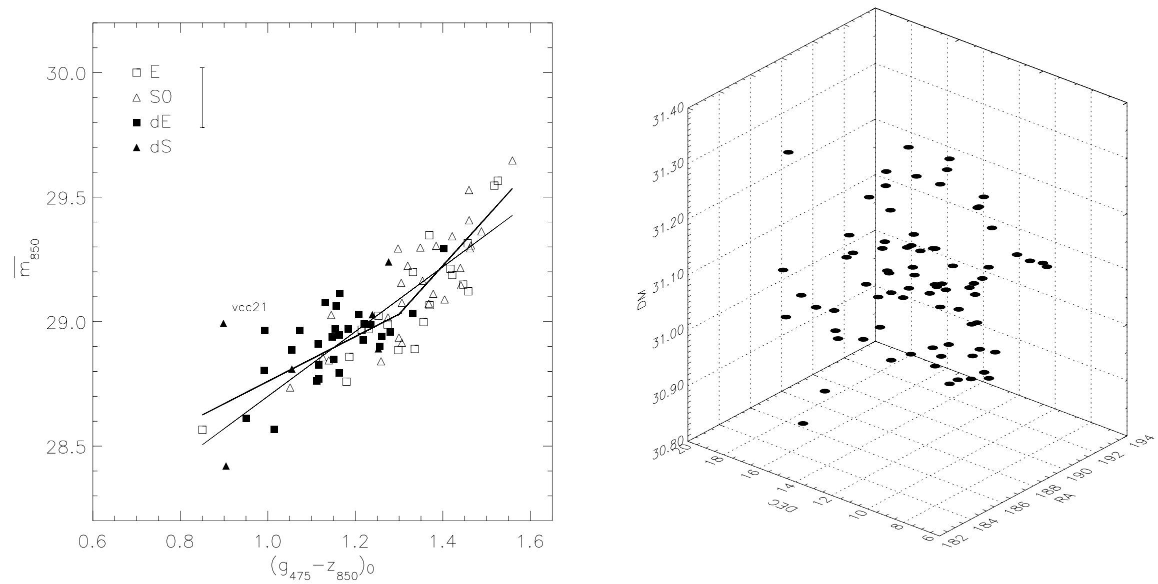

Figure 1: Our final calibration sample (81 galaxies, plus VCC 21; left) is shown, together with the fitted relations. Elliptical galaxies are represented by open squares, S0 by open triangles, dwarf ellipticals by filled squares, and dwarfs S0 by filled triangles. The straight line is the fit to the full sample, while the thick continuous lines are, respectively, fits for the red and blue ends. At the top left, the typical SBF magnitude error (0.12 mag, including the uncertainty due to the Virgo cluster depth and intrinsic SBF dispersion) is shown. On the right, the Virgo three dimensional structure as derived from our SBF measurements.

of simulated galaxy images with realistic noise properties that it is possible — depending on the kernel — to measure SBF distances using distortion-corrected ACS images without introducing significant additional error from the resampling. This study also showed examples of real image power spectra from the survey.

Since the absolute magnitude of the SBF varies as a function of the stellar population age and metallicity, SBF distance measurements in a given observational bandpass must be carefully calibrated in terms of stellar population observables, typically the galaxy color. Mei et al. (2005b) presents the first SBF calibration for the bandpasses of the survey: the first SBF measurements in the F475W and F850LP bandpasses.

Galaxy stellar population variations were quantified by galaxy color $(g_{475}-z_{850})_0$, where g_{475} and z_{850} are the galaxy magnitudes in the two ACS filters. We derived the following calibration for the absolute SBF magnitude $\overline{M}_{850}$:

$$\overline{M}_{850} = -2.06\pm0.04+(2.0\pm0.2)\times[(g_{475}-z_{850})_0-1.3] \quad (1)$$

in the range $1.3 < (g_{475}-z_{850})_0 \leq 1.6$, and

$$\overline{M}_{850} = -2.06\pm0.04+(0.9\pm0.2)\times[(g_{475}-z_{850})_0-1.3] \quad (2)$$

in the range $1.0 \leq (g_{475}-z_{850})_0 \leq 1.3$. The quoted zero-point uncertainty here includes all sources of internal error; there is an additional *systematic* uncertainty of ~ 0.15 mag, due to the uncertainty in the distance scale calibration.

Our calibration is shown in Fig. 1, together with the derived distances for the galaxies in our sample (Mei et al., in preparation). Physically, the two different color regimes correspond to different galaxy types: giant ellipticals and S0s at the red end, and early-type dwarfs at the blue end. For the first time in SBF studies, we are able to provide a firm empirical calibration of SBF in early–type dwarf galaxies. Our results agree with stellar population model predictions from Bruzual & Charlot (2003) in the range $1.3 < (g_{475}-z_{850})_0 \leq 1.6$, while our empirical slope is somewhat steeper than the theoretical prediction in the range $0.9 \leq (g_{475}-z_{850})_0 \leq 1.3$.

3. Low mass X-ray binaries in M87

In Jordán et al. (2004b), we used the ACIS instrument on board the Chandra X-Ray Observatory to carry out the first systematic study of low-mass X-ray binaries (LMXBs) in M87 — the giant elliptical galaxy near the dynamical center of the Virgo Cluster. These images, with a total exposure time of 154 ks-are the deepest X-ray observations yet obtained of M87, and offer a striking contrast to the view from our ACS imaging. We identified 174 X-ray point sources, of which ≈ 150 are likely LMXBs. This LMXB catalog is combined with deep F475W and F850LP images taken with ACS to examine the connection between LMXBs and globular clusters in

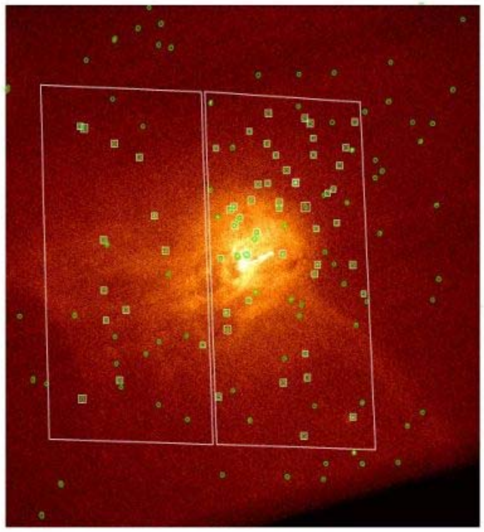

Figure 2: Chandra ACIS image ($5' \times 5'$) of M87 with the ACS field of view overlaid (rhomboids). The detected X-ray point sources are shown by the green ellipses. White squares indicate the 60 X-ray sources that coincide with globular cluster candidates.

M87. Of the 1688 globular clusters in our catalog, a fraction of $3.6\% \pm 0.5\%$ contain an LMXB. Dividing the globular cluster sample by metallicity, the metal-rich clusters are 3 ± 1 times more likely to harbor an LMXB than their metal-poor counterparts.

In agreement with previous findings for other galaxies based on smaller LMXB samples, we found the efficiency of LMXB formation to scale with both cluster metallicity and luminosity, in the sense that brighter, more metal-rich clusters are more likely to contain an LMXB. For the first time, however, we were able to demonstrate that the probability that a given cluster will contain an LMXB depends sensitively on the dynamical properties of the host cluster (i.e., core radius and central density).

4. Globular cluster sizes as a function of color

Most observations of the projected half-light radii of metal-rich globular clusters in a variety of galaxies have shown them to be 20% smaller than those of their metal-poor counterparts. In agreement with previous studies, Jordán (2004) found the cluster half-light radii to scale with cluster color (or metallicity), and showed that this could be the result of mass segregation combined with the dependence of stellar lifetimes with metallicity, under the assumption that the half-mass radii do not vary with metallicity. Fig. 3 show the size-metallicity relation for globular clusters in M87.

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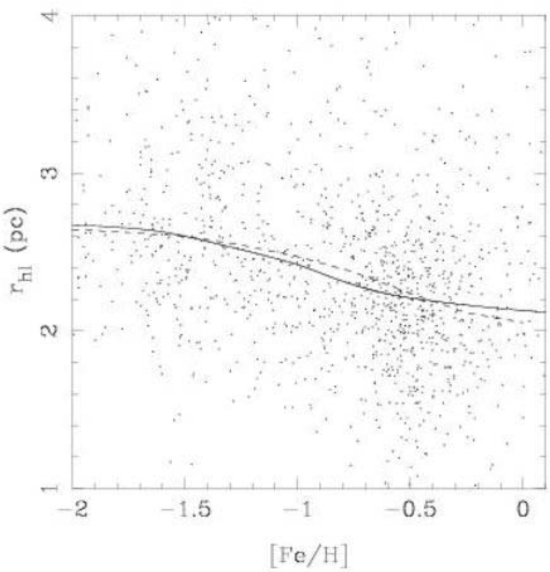

Figure 3: Projected half light radii for a globular clusters in M87 measured from our ACS images. The solid curve represents a robust estimate of the mean half light radius as a function of [Fe/H], and the dashed line is the predicted theoretical behavior of this quantity from Jordán et al.(2004).

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