SDSS J150634.27+013331.6: the second compact elliptical galaxy in the NGC 5846 group

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ABSTRACT

We report the discovery of the second compact elliptical (cE) galaxy SDSS J150634.27 + 013331.6 in the nearby NGC 5846 group by the Virtual Observatory (VO) workflow. This object ($M_B = -15.98$ mag, $R_e = 0.24$ kpc) becomes the fifth cE where the spatially resolved kinematics and stellar populations can be obtained. We used archival HST WFPC2 images to demonstrate that its light profile has a two-component structure, and integrated photometry from GALEX, SDSS, UKIDSS and Spitzer to build the multiwavelength spectral energy distribution to constrain the star formation history (SFH). We observed this galaxy with the PMAS IFU spectrograph at the Calar-Alto 3.5-m telescope and obtained two-dimensional maps of its kinematics and stellar population properties using the full-spectral fitting technique. Its structural, dynamical and stellar population properties suggest that it had a massive progenitor heavily tidally stripped by NGC 5846.

Key words: galaxies: dwarf – galaxies: elliptical and lenticular, cD – galaxies: evolution – galaxies: stellar content – galaxies: kinematics and dynamics.

1 INTRODUCTION

In the magnitude–mean surface brightness diagram and the Fundamental Plane (FP, Djorgovski & Davis 1987), dwarf and giant early-type galaxies seem to form two distinct sequences joining at around $M_B = -18$ mag (see Kormendy et al. 2009 and references therein). However, this bi-modal distribution can be explained as a projection of the two known monotonous relations of other structural properties of early-type galaxies as functions of a galaxy luminosity on to this parameter space: (a) light profile concentration index and (b) central surface brightness (Graham & Guzmán 2003; Hilker, Mieske & Infante 2003; Karick, Drinkwater & Gregg 2003; Ferrarese et al. 2006). Only objects classified as compact elliptical (cE) or ultra-compact dwarf (UCD) galaxies strongly depart from these relations.

They represent the two classes of galaxies supposedly forming by tidal threshing of more massive progenitors (Bekki et al. 2001, 2003), i.e. they must have sharply decreased their stellar masses during the evolution. Both cE and UCD classes are represented by only a few dozen of known members including several transitional cE/UCD objects discovered recently (Chilingarian & Mamon 2008; Price et al. 2009). Since all these objects are very dense and small, much higher stellar velocity dispersions are required to keep them in equilibrium compared to dwarf elliptical (dE) or dwarf spheroidal (dSph) galaxies of similar luminosities, thus putting them above the locus of dEs on the $\sigma$ versus $M_B$ (Faber & Jackson 1976) relation. Stellar population properties of cEs and UCDs are very different from typical dE/dSph which are usually very old (with rare exceptions such as Messier 32) and notably more metal-rich.

Among the known compact elliptical galaxies, only M 32 (Local group), NGC 4486B (Virgo cluster), NGC 5846A (NGC 5846 group) and possibly ACO 3526 J124853.91 – 411905.8 (Centaurus cluster) reside sufficiently nearby to allow spatially resolved studies of their kinematics and stellar populations using ground-based telescopes. They were considered unique objects until the recent discovery (Mieske et al. 2005; Chilingarian et al. 2007a, 2009a; Price et al. 2009) of cEs located at a distance...
from the Coma cluster or further, which are, however, spatially unresolved for ground-based optical observations.

In this Letter we report the detection of the fifth near-by cE galaxy made by the Virtual Observatory (VO)-fed workflow, which became the second object of this class in the NGC 5846 group. We study its internal properties using 3D-spectroscopy and data sets at different wavelength domains available in the VO and data archives.

2 DATA AND TECHNIQUES USED

Chilingarian et al. (2009a) describe a VO workflow constructed to search cE galaxies in nearby clusters. We extended it in order to detect cE candidates also in nearby groups, which would have higher extent on the sky because of smaller distances and, therefore, require different settings of the SExtractor software (Bertin & Arnouts 1996). To test the modified workflow, we decided to use HST images of the central part of the Virgo cluster and the NGC 5846 group, known to contain ‘legacy’ cEs, NGC 4486B and NGC 5846A. Surprisingly, the workflow detected a new compact object in the HST WFPC2 images of the NGC 5846 group, 3.1 arcmin south-east of the group centre, which turned to have a spectrum in the Sloan Digital Sky Survey Data Release 7 (SDSS DR7, Abazajian et al. 2009), proving its membership in the group. The galaxy has a small size on the sky, therefore we used other search workflow to studying the internal structure of NGC 5846cE.

The NGC 5846 group, the third massive structure in the local Universe after the Virgo and Fornax clusters, has been intensively studied in the past and, therefore, numerous complementary data sets in different wavelength domains are available in the VO. The Universe after the Virgo and Fornax clusters, has been intensively studied in the past and, therefore, numerous complementary data sets in different wavelength domains are available in the VO. The galaxy is classified as an UCD. The NGC 5846A. Surprisingly, the workflow detected a new compact object in the HST WFPC2 images of the NGC 5846 group, 3.1 arcmin south-east of the group centre, which turned to have a spectrum in the Sloan Digital Sky Survey Data Release 7 (SDSS DR7, Abazajian et al. 2009), proving its membership in the group. The galaxy is classified as an UCD. The NGC 5846A. Surprisingly, the workflow detected a new compact object in the HST WFPC2 images of the NGC 5846 group, 3.1 arcmin south-east of the group centre, which turned to have a spectrum in the Sloan Digital Sky Survey Data Release 7 (SDSS DR7, Abazajian et al. 2009), proving its membership in the group. The galaxy has a small size on the sky, therefore we used other search workflow to studying the internal structure of NGC 5846cE.

2.1 Photometric data

We used the calibrated optical WFPC2 HST images in F555W and F814W (total integration times 2200 and 2300 s, respectively) available from the Hubble Legacy Archive 1 and found by the cE search workflow to studying the internal structure of NGC 5846cE. The galaxy has a small size on the sky, therefore we used other data sources only for the integrated photometric measurements. All photometric data provided in this Letter are corrected for the Galactic extinction (Schlegel, Finkbeiner & Davis 1998).

The NGC 5846 group is included in the footprints of (1) the GR4 Data Release of the Medium Imaging Survey (MIS) by the Galaxy Evolution Explorer (GALEX) and (2) the Data Release 6plus (DR6+) of the Large Area Survey (LAS) of the UKIRT Infrared Deep Sky Survey (UKIDSS, Lawrence et al. 2007), thus providing photometric measurements in far-UV, near-UV and four near-IR broad-band filters YJHK in addition to the five-band optical ugriz photometry from SDSS DR7. We took Petrosian magnitudes from SDSS and UKIDSS, applying Vega-to-AB zero-point correction for the latter ones according to Hewett et al. (2006), and total FUV and NUV magnitudes from GALEX.

There are publicly available archival Spitzer Space Telescope images obtained with the Infrared Array Camera (IRAC) in four photometric bands centred at 3.6, 4.5, 5.8 and 8.0 μm. We obtained total AB magnitudes of NGC 5846cE in the IRAC bands using SExtractor (MAG_AUTO and MAGERR_AUTO parameters).

Several central pixels of the galaxy image in all HST WFPC2 frames are saturated, therefore no analysis of the inner region is possible. The images were background-subtracted using SExtractor. Then we obtained light profiles of NGC 5846cE in both photometric bands by fitting elliptical isophotes with free orientation, ellipticity and disky/boxy parameters using the STSDAS ANALYSIS ISOPHOTE ELLIPSE task in the IRAF data processing environment.

In Fig. 1 we present the radial behaviour of ellipticity $e = 1 - b/a$, and positional angle (top and middle panels) and the F555W – F814W colour profile. The positional angle remains stable at $PA = 127$ deg at all radii. The galaxy has very round outer isophotes ($e < 0.05$) becoming significantly prolate inwards with the ellipticity reaching ($e = 0.3$) at $r = 0.125$ kpc = 1 arcsec. Closer to the centre the ellipticity starts to decrease; however, we could not measure it at $r < 0.3$ arcsec due to the saturation mentioned above. The radial behaviour of $PA$ and $e$ is identical in the two photometric bands. The isophotes remain purely elliptical without any signature of diskyness/boxinesses.

The reconstructed colour profile is completely flat having a value of $F555W - F814W = 0.90$ mag. We computed a two-dimensional colour map of NGC 5846cE applying the Voronoi adaptive binning (Cappellari & Copin 2003) with a target signal-to-noise ratio 100 in F555W. It contains no statistically significant deviations from the same constant level. The unsharp masking technique using the elliptical Gaussian smoothing kernel with the parameters corresponding to the inner isophotes did not reveal any embedded structures in NGC 5846cE.

Figure 1. Radial behaviour of the major axis positional angle (top), ellipticity (middle) of the isophotes of NGC 5846cE from the HST WFPC2 F555W and F814W-band images shown in black and green, respectively. The bottom panel displays the reconstructed F555W – F814W colour profile.


1 The preliminary data analysis (Smith Castelli et al. 2008) for the two candidate cEs in the nearby Antlia cluster (Smith Castelli et al. 2008) at $d ≈ 35$ Mpc confirms their membership in the cluster, thus extending the sample of nearby cEs to seven objects.

2 http://hla.stsci.edu/
Table 1. NGC 5846cE F555W-band light profile decomposition using the two-component model.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Sérsic$_{in}$</th>
<th>Sérsic$_{out}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$r_e$, kpc</td>
<td>$0.038 \pm 0.012$</td>
<td>$0.291 \pm 0.009$</td>
</tr>
<tr>
<td>$r_e$, arcsec</td>
<td>$0.30 \pm 0.10$</td>
<td>$2.33 \pm 0.07$</td>
</tr>
<tr>
<td>$n$</td>
<td>$1.56 \pm 0.26$</td>
<td>$1.41 \pm 0.02$</td>
</tr>
<tr>
<td>$\mu_e$ mag arcsec$^{-2}$</td>
<td>$17.48 \pm 1.05$</td>
<td>$19.86 \pm 0.13$</td>
</tr>
<tr>
<td>$(\mu_e)$ mag arcsec$^{-2}$</td>
<td>$16.56 \pm 1.05$</td>
<td>$19.00 \pm 0.13$</td>
</tr>
<tr>
<td>$M_\text{F555W}$ mag</td>
<td>$-14.92$</td>
<td>$-16.91$</td>
</tr>
</tbody>
</table>

Figure 2. The two-component NGC 5846cE light profile decomposition. The top panel displays the brightness profile shown with black diamonds, and the two components represented by the blue dashed and green dotted lines for inner and outer Sérsic profiles correspondingly. The bottom panel shows the fitting residuals.

The light profile in the outer part ($r > 2.0$ arcsec) is perfectly approximated by the Sérsic (1968) profile having $n \approx 1.5$, but in this case there is a light excess in the inner part of the galaxy. Therefore, we performed the structural decomposition of the light profile using two Sérsic components and fitting their parameters non-linearly. We used a modified version of the algorithm presented in Chilingarian et al. 2009b. The obtained structural parameters of NGC 5846cE in the F555W band are presented in Table 1. Parameters of the inner component are badly constrained because of the saturated nucleus. The light profile and its components are shown in Fig. 2, the scale is set logarithmic on the $r$ axis in order to emphasize the inner component which becomes barely visible in linear scale. The total reconstructed absolute magnitude of NGC 5846cE is $M_\text{F555W} = -17.07 \pm 0.10$ mag. In order to transform these measurements into the Johnson $B$ band, the $B - F555W = 0.92$ mag transformation should be applied according to Jordi, Grebel & Ammon (2006) and $g - r = 0.78$ mag from SDSS DR7. The absolute $B$ band magnitude computed from the SDSS DR7 photometry is $M_B = -15.98$ mag.

### 2.2 Spectroscopic data

We observed NGC 5846cE with the Potsdam Multi-Aperture Spectrograph (PMAS, Roth et al. 2005) mounted at the 3.5-m telescope of the Calar-Alto Observatory on 2009-Apr-22 in the framework of our observing programme ‘3D-spectroscopy of dE galaxies with kinematically decoupled cores’ (P.I.: GB). NGC 5846cE was an extra target observed in the morning. We made three 30-min-long exposures in the LArr mode with the Integral-Field Unit (IFU) having $16 \times 16$ square $1 \times 1$ arcsec lenses. The FWHM seeing was about 1.8 arcsec. We used the V1200 grism providing the resolving power $R \approx 2800$ in the wavelength range of 4720–5420Å.

For the data reduction, we used the generic IFU data reduction pipeline implemented in IRAF. A brief description of the data reduction steps can be found in Chilingarian et al. (2007c). We performed the flux calibration using the observations of the HZ44 spectrophotometric standard star. The night sky spectrum was reconstructed from the lenses located in the outer parts of the field of view ($r > 6$ arcsec). For the analysis we used only the inner $8 \times 8$ arcsec fragment of the field of view centred on NGC 5846cE. We applied the Voronoi adaptive 2D binning to the final sky-subtracted and flux-calibrated data cube.

We exploited the NBURSTS full spectral fitting technique (Chilingarian et al. 2007b) to fit the binned PMAS data set, and derived maps of stellar radial velocity, velocity dispersion, age and metallicity of stellar populations presented in Fig. 3. We used the grid of simple stellar populations (SSPs) computed with the PEGASE.HR code (Le Borgne et al. 2004), therefore the derived stellar population parameters are SSP-equivalent. The target signal-to-noise ratios of 10 and 15 per pixel were used for computing kinematical and stellar population maps, respectively.

Despite its almost round outer isophotes, the galaxy exhibits a regular velocity field with a significant major-axis rotation ($v, \sin i = 40 \text{ km s}^{-1}$). We are probably reaching the maximum of rotation already at $r = 3–4$ arcsec comparable to M32 (e.g. Simien & Prugniel 2002); however, deeper observations with higher spatial resolution are required to give decisive conclusions about this point.

The velocity dispersion distribution has a pronounced bump in the centre reaching $\sigma_0 = 118 \text{ km s}^{-1}$ with the values smoothly decreasing outwards down to 75–85 $\text{ km s}^{-1}$ at $r = 3$ arcsec. Due to the limited spatial resolution of our data, the real value of the central velocity dispersion is probably underestimated and it can be much higher as in other nearby cEs (Davidge, Beck & McGregor 2008).

Stellar population of the galaxy is very old ($t = 15 \pm 4$ Gyr) and metal-rich ([Z/H] = $-0.04 \pm 0.06$ dex). The metallicity...
distribution slightly decreases outwards; however, the change is only $-0.1$ dex. The age map does not exhibit any statistically significant details.

We also used the flux-calibrated SDSS DR7 spectrum of NGC 5846cE ($R = 1800$) obtained in a 3-arcsec-wide circular aperture. We applied the NBURSTS technique to this spectrum in the wavelength range of 3900–6800 Å in order to perform the cross-check of the kinematical and stellar population parameters in the central region of the galaxy. The values ($v_0 = 1537 \pm 2 \text{ km s}^{-1}$, $o_0 = 119 \pm 2 \text{ km s}^{-1}$, $r = 15.3 \pm 0.6$ Gyr, $[Z/H] = -0.04 \pm 0.02$ dex) agree remarkably well with those obtained from the PMAS data. No emission lines are detected, ruling out the ongoing star formation (SF) in the galaxy as well as the presence of ionized gas in any form.

We also used the measurements of Lick absorption line strength indices ( Worthey et al. 1994) for Mg$b$, Fe5270 and Fe5335 provided by the SDSS and models of Thomas, Maraston & Bender (2003) in order to estimate the level of $\alpha$/Fe enhancement of stellar population. We derived $[\text{Mg/Fe}] = 0.34 \pm 0.05$ dex.

### 3 DISCUSSION

In Fig. 4 we demonstrate the multiwavelength spectral energy distribution (SED) of NGC 5846cE constructed from the integrated photometric data described in the previous section. We overplot the low-resolution SSP model computed with PEGASE.2 (Fioc & Rocca-Volmerange 1997) for the age and metallicity of stars close to those obtained from the full spectral fitting of the SDSS DR7 spectrum of NGC 5846cE. No internal extinction is assumed. One can see a perfect agreement between the SSP model and the observed galaxy SED at all wavelengths from 1500 Å to 8 μm. The absence of the UV excess clearly rules out any possibility of having extended SFH and residual recent SF, the agreement of all SED details at such a wavelength basis proves the lack of dust. All this, in addition to the high value of $[\text{Mg/Fe}]$ abundance ratios suggest (Matteucci 1994) that the star formation history of NGC 5846cE contained only one very short and intense starburst in the remote past.

The structural properties and low luminosity place NGC 5846cE between M 32 and A496cE (Chilingarian et al. 2007a) on the FP and its projections. At the same time, its stellar population properties, in particular the very Mg/Fe overabundance, make it resembling extreme cases like A496g1 and NGC 4486B. Indeed, NGC 5846cE exhibits a two-component light profile. However, the important difference between this object and most cE (Graham 2002; Chilingarian et al. 2007a) and transitional cE/UCD galaxies (Chilingarian & Mamon 2008; Price et al. 2009) is that even its outer component is compact and bright.

Chilingarian et al. (2009a) demonstrate using numerical simulations that the tidal stripping of a disc (possibly barred) galaxy by the cluster cD potential is the most plausible formation scenario of cE galaxies. In case of NGC 5846cE, the role of a cD is played by NGC 5846, a very massive non-rotating (Emsellem et al. 2004) elliptical galaxy. The isophote ellipticity increasing towards the centre, important major axis rotation, and at the same time, very regular elliptical isophotes and the absence of embedded structures, support the scenario of a tidally stripped bar suggested by simulations by Chilingarian et al. (2009a) and presented in their Fig. 3. From the luminosity–metallicity relation presented in the lower panel of Fig. 1 from the same paper, we can estimate the luminosity of the NGC 5846cE’s progenitor to be about $M_B = -19$ mag, hence the mass loss due to the tidal stripping should be a factor of 15.

We can compare the present day stellar mass of NGC 5846cE computed in case of two different stellar initial mass functions (IMFs) similarly to what we did for UCDs (Chilingarian et al. 2008). We use the total luminosity of the galaxy from SDSS DR7, age and metallicity of its stellar population from the full spectral fitting and corresponding mass-to-light ratios provided by PEGASE.2. The results are different by a factor of almost two: $(4.2 \pm 0.4) \times 10^9$ $M_\odot$ and $(2.2 \pm 0.3) \times 10^9$ $M_\odot$ for the Salpeter (1955) and Kroupa (2001) IMFs, correspondingly. At the same time, using a simple virial mass estimate $10 R_c \sigma_c^2/G$ (Spitzer 1969) which will probably underestimate the mass, we get $(5.5 \pm 0.6) \times 10^9$ $M_\odot$ for the dynamical mass assuming the global velocity dispersion $\sigma_r = 100 \pm 5$ km s$^{-1}$. Hence, our galaxy may contain about 60 per cent of dark matter if we adopt the Kroupa IMF, whereas it becomes almost dark matter free in case of the Salpeter IMF, making it similar in this respect to UCDs which are also believed to be tidally stripped objects.

Hence, all observed properties of NGC 5846cE suggest that it was probably formed by tidal stripping of a massive disky (probably barred) galaxy by NGC 5846, similarly to compact elliptical galaxies in nearby clusters. Unlike M 32, NGC 5846cE is an excellent example of a cE very similar to those observed in galaxy clusters; however, located relatively nearby. It will thus hopefully allow us to study in detail its internal dynamics and mass distribution using available observational facilities in order to better understand tidal stripping of galaxies.

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**Figure 4.** Multiwavelength SED of NGC 5846cE constructed from the integrated photometry found in the VO, and the Spitzer Space Telescope archive. Horizontal bars denote the FWHM of corresponding photometric bands. Dotted black line is a PEGASE.2 SSP model without internal extinction corresponding to the $t = 15$ Gyr and $[\text{Fe/H}] = 0.0$ dex.

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3 Stellar population parameters remain virtually the same for the SSP models computed using two different IMFs. All values provided in the previous section are computed for the Salpeter IMF based SSP models.
The 2nd cE galaxy in the NGC 5846 group

Smith Castelli A. V. et al., 2010, BAAA, in press (arXiv:1002.3830)

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