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Galaxy evolution through resolved stellar populations in the nearby Centaurus A group

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Abstract. The CenA group is a nearby dense complex ($\sim$ 4 Mpc) dominated by an active elliptical galaxy, hosting more than 60 dwarf companions with a variety of morphological types and stellar contents. We study the resolved stellar populations of a sample of dwarfs using optical and near-infrared data from ACS/HST and ISAAC/VLT. We characterize their recent star formation histories and metallicity content, and compare them to what is known for Local Group dwarfs, underlining similarities and differences. Our results probe the fu ndamental interplay between nature and nurture in the evolution of dwarfs in such a dense environment. We further present the results of the first deep survey of resolved stellar populations in the remote outer halo of our nearest giant elliptical, CenA (VIMOS/VLT optical data). Tracing its halo structure (radial profile, extent and metallicity) out to a remarkable $\sim$ 85 kpc and comparing the halo stellar populations to those of CenA's dwarf companions enables us to constrain the mechanisms that contributed to the build-up of CenA in the context of cosmological galaxy formation models.

Key words. Galaxies: dwarf – Galaxies: elliptical and lenticular – Galaxies: stellar content – Galaxies: photometry – Galaxies: groups: individual: Centaurus A – Galaxies: evolution

1. Introduction

The questions we would like to (partially) answer in this contribution are: 1. do dwarf galaxies in external groups show different star formation histories and/or physical properties with respect to Local Group dwarfs of similar luminosities, i.e., what is the role played by environment in the evolution of these low-mass systems? and 2. how does the build-up of the outer halo in a giant galaxy proceeds in a cosmological context, i.e. what are the properties of its stellar populations and how can they be related to the galaxy's dwarf satellites?

In order to tackle these questions, we targeted the nearby (∼ 4 Mpc) Centaurus A (CenA) group, the only closeby agglomerate dominated by an active elliptical (E) galaxy, and inhabited by several tens of dwarf galaxies. This is thus an ideal environment where to investigate the mutual interactions of dwarf and giant galaxies in a great level of details. This can be achieved by studying the resolved stellar populations of our targets, which contain precious information about the global properties of their host galaxies.

2. Evolution of dwarf galaxies

We concentrate on a sample of six dwarf spheroidal (dSph) companions of CenA. We analyse Hubble Space Telescope (HST) images taken with the Advanced Camera for Surveys (ACS), performing PSF-photometry with the DOLPHOT package (Dolphin, 2002).

The resulting color-magnitude diagrams (CMDs) for all the studied dSphs show predominantly old populations ($\gtrsim$ 1 Gyr), as indicated by their red giant branch (RGB; Fig. 1). In absence of a significant age spread, the color and width of the RGB give a measure of the metallicity and metallicity spread in a stellar system. Given the absence of CMD features indicating a significant young/intermediate-age stellar component, we can assume a single old age for RGB stars and individually assign them a metallicity value by comparing them to stellar evolutionary models (Dotter et al., 2008). We thus derive photometric metallicity distribution functions (MDFs) for the dSphs. The resulting MDFs show a relatively metal-poor content for the studied dwarfs ([Fe/H] ~ -1.5 to -1.0 dex), with large spreads amounting to as much as $\sim$ 0.4 dex (Crnojević et al., 2010). These results, together with the shapes of the MDFs themselves, are in good agreement with what is known from (photometric *and* spectroscopic) studies of LG dwarfs of comparable luminosity. For example, gradients in metallicity as a function of radius are found for some of the observed dSphs, and two of them also host statistically distinct subpopulations (metal-poor and metal-rich, with different spatial distributions). Furthermore, CenA's

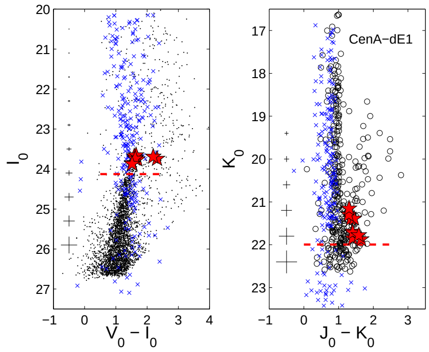

Fig. 1. CMDs for CenA-dE1 (a dSph companion of CenA), showing the same sample of stars belonging to the observed target field (black dots) as observed at different wavelenghts (optical HST in the *left panel*, and near-IR ISAAC in the *right panel*). Blue crosses represent the predicted position of Galactic foreground contaminants (Besançon models, Robin et al. 2003). The optical CMD is heavily contaminated by foreground objects in the region where luminous AGB stars indicative of an IAP are found (above the TRGB, the latter being indicated with a dashed red line). In the near-IR CMD it is easier to disentangle foreground stars from the stars belonging to the dSph. The final candidate luminous AGB stars for this dSph, selected by cross-correlating the two sets of observations, are shown as red stars (Crnojević et al., 2011).

dSph companions lie on the same luminosity-metallicity relation defined by LG dSphs (e.g. Grebel et al., 2003). This evidence suggests that the ability to form metals in dSphs is mainly regulated by their mass.

For a subset of three dSphs within our HST sample, and for two additional dSphs around CenA, near-IR data from the Very Large Telescope (VLT), Infrared Spectrometer And Array Camera (ISAAC) were further used to investigate luminous asymptotic giant branch (AGB) stars in more detail (Rejkuba et al., 2006; Crnojević et al., 2011). These are found above the tip of the RGB and are indicative of intermediate-age populations (IAPs, $\sim 1-8$ Gyr). The optical CMDs suffer from a heavy contamination from foreground Galactic contaminants (due to CenA group's low galactic latitude, $b \sim 20^o$), particularly in the luminous

AGB region. On the other hand, the sequence of Galactic contaminants is much narrower and well separated from the target's AGB stars at near-IR wavelengths (e.g. Gullieuszik et al., 2008, see also Fig. 1). By matching the optical and near-IR datasets, we are thus able to fully exploit the advantages of both: an easier foreground decontamination in near-IR, and a higher resolution with optical HST images, which allows us to reject background galaxies from our CMDs.

From the luminosity of the brightest candidate luminous AGB stars, we can estimate the latest epoch of significant star formation for our targets, by using an empirical relation between the absolute bolometric magnitude of the AGB candidates and their age (see Rejkuba et al., 2006). More importantly, by comparing the observed numbers of AGB and RGB stars to stellar evolutionary models (Maraston, 2005, based on the fuel consumption theorem), we assess the fraction of IAPs for our dSphs. We intriguingly find that these are particularly low (at most $\sim$ 15%) in comparison to Milky Way companions of comparable luminosity (i.e., mass), which reach IAP fractions of up to $\sim$ 50% (e.g. Orban et al., 2008). On the other hand, M31 satellites with lower masses similarly show a lack of star formation at intermediate-ages (e.g. Harbeck et al., 2004), which still remains unexplained.

This preliminary trend clearly indicates an environmental component severly affecting the evolution of the studied dwarfs (e.g., the presence of an active E host), and deserves further investigation by means of a larger sample of targets. We thus conclude that the study of dSph companions of CenA underlines the tight interplay between nature and nurture in the evolution of dwarf galaxies.

3. The outer halo of the elliptical Centaurus A

CenA is the closest E galaxy to us, and has long been the topic of studies investigating its AGN and its disturbed central regions (the prominent dust lane suggests a recent merger event, for a review see Israel 1998). Several HST pointings in these central regions exists to date and analyse the resolved stellar populations of this E, but they reach at most $\sim$ 40 kpc in the halo (see Fig. 2). However, with a luminosity of $M_V \sim -21.5$ and a mass of $\sim 0.5-1\times10^{12}$ $M_\odot$ (Woodley et al., 2007), CenA is a typical field E, and deserves more attention beyond its central regions in order to delve deeper into its global properties and formation history.

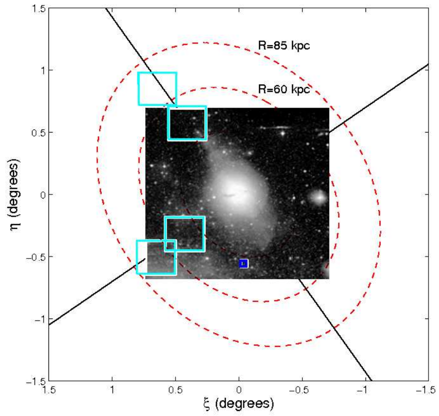

Fig. 2. Projected position on the sky (with respect to the center of Cen A, standard coordinates) of our four VIMOS fields (cyan rectangles). A UKST photographic plate image of the central regions of CenA is also shown. Red ellipses are drawn at projected radii of 65 kpc and 85 kpc, adopting b/a= 0.77 and PA= 35° (values from the RC3). Black solid lines indicate major and minor axis. Finally, we show the outermost deep HST/ACS pointing to date (see Rejkuba et al., 2005, at 40 kpc) in CenA's halo with a blue square.

We thus targeted two pointings along each of the major and minor axis with the optical imager of the VIsible MultiObject Spectrograph (VIMOS) at VLT. This is the first wide-field survey ($\sim$ 0.25 deg^2) of resolved stellar populations in CenA's outer halo, and reaches a remarkable galactocentric distance of $\sim$ 85 kpc (corresponding to $\sim 14R_{eff}$, see Fig. 2). Probing the haloes of giant galaxies to such large radii is observationally very challenging due to their intrinsic faintness, thus CenA is a unique target for this kind of studies due to its proximity.

We perform PSF-photometry with the DAOPHOT and ALLFRAME suites of programs (Stetson, 1987, 1994), and analyse the resulting CMDs as a function of projected elliptical radius (Crnojević et al., MNRAS submitted). Our findings can be summarized as follows: we detect a prominent old RGB component out to the furthermost radii probed, which demonstrates the large extent of this system. Interestingly, the RGB stellar density profile is higher along the major axis than along the minor axis over the whole radial range, and in particular we find a strong overdensity at radii $\lesssim$ 55 kpc. By inspection of an extended UKST photographic plate, we indeed find our inner major axis VIMOS field to overlap with an elongated substructure (also visible in Fig. 2) that might be originating from the recent merger event. The observed overdensity is moreover observed also for intermediate-age AGB stars. The radial profiles additionally suggest an increase in ellipticity with radius, and become shallower at radii $\gtrsim$ 70 kpc.

As already done for our dwarf targets (see previous section), we derive photometric MDFs for CenA. We find a relatively high mean metallicity for the RGB populations even at these large distances ([Fe/H] ~ -0.9 to -1.0 dex), which shows only a mild variation from the innermost to the outermost fields observed (at most Δ[Fe/H] $\sim$ 0.2 dex). The fraction of metal-poor stars (i.e., [Fe/H] $\lesssim -1.0$ dex) never exceeds $\sim$ 50%. Combined with previous results from HST pointings at smaller galactocentric radii (see Rejkuba et al., 2005), this indicates that CenA's outer halo never displays a metal-poor break in its stellar populations at least out to $\sim$ 85 kpc (as might be expected, see e.g. Harris et al. 2007). Given the low metallicity content of its dwarf satellites studied so far, the outer halo must have built-up by the accretion of more massive companions, and/or by in-situ star formation. Detailed theoretical models tailored to explore such large galactocentric distances are needed to give a more quantitative explanation for our results.

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References

Crnojević, D., Grebel, E. K., & Koch, A. 2010, A&A, 516, A85
Crnojević, D., et al. 2011, A&A, 530, A58
Dolphin, A. E. 2002, MNRAS, 332, 91
Dotter, A., Chaboyer, B., Jevremović, D., et al. 2008, ApJS, 178, 89
Grebel, E. K., Gallagher, III, J. S., & Harbeck, D. 2003, AJ, 125, 1926
Gullieuszik, M., Held, E. V., Rizzi, L., et al. 2008, MNRAS, 388, 1185
Harbeck, D., Gallagher, III, J. S., & Grebel, E. K. 2004, AJ, 127, 2711
Harris, W. E., et al. 2007, ApJ, 666, 903
Israel, F. P. 1998, A&A Rev., 8, 237
Maraston, C. 2005, MNRAS, 362, 799
Orban, C., Gnedin, O. Y., Weisz, D. R., et al. 2008, ApJ, 686, 1030
Rejkuba, M., et al. 2006, A&A, 448, 983
Rejkuba, M., Greggio, L., Harris, W. E., Harris, G. L. H., & Peng, E. W. 2005, ApJ, 631, 262
Robin, A. C., et al. 2003, A&A, 409, 523
Stetson, P. B. 1987, PASP, 99, 191
Stetson, P. B. 1994, PASP, 106, 250
Woodley, K. A., Harris, W. E., Beasley, M. A., et al. 2007, AJ, 134, 494