

The Stellar Populations of dE Galaxies in Nearby Groups

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Abstract. In this contribution initial results from colour-magnitude diagrams for five dEs in the M81 group are presented. The colour-magnitude diagrams, derived from HST/ACS images, reach well below the red giant branch tip and allow evaluation of distances and mean metallicities. Further, the intermediate-age upper-AGB stars seen in the diagrams allow estimates of the epochs of the last significant episodes of the star formation in the dEs. These epochs, and the relative numbers of upper-AGB to red giant branch stars, vary significantly from dE to dE. Preliminary inferences from similar HST/ACS data for five early-type dwarfs in the Sculptor group are also discussed.

1. Introduction

One of the most important results in stellar populations research over the past decade or more has been the recognition that, at least for systems within the Local Group, the objects classified as dwarf Elliptical (dE) and dwarf Spheroidal (dSph) galaxies do not possess single old populations. Instead they exhibit a variety of star formation histories. This diversity is best documented for the Milky Way Galaxy's (MWG) 'classic' dSph companions, i.e. the well-studied objects as distinct from the numerous newly discovered, but as yet less well-studied, systems. For example, Ursa Minor is dominated by a single old stellar population but dSphs such as Carina, Fornax and Leo I have had complex star formation histories, and contain stars as young as ~ 1 Gyr. Extended star formation histories are also evident for the M31 dE and dSph companions.

At present there is no definitive understanding of what drives these variations in star formation histories, though there are hints that environment, as represented by, for example, proximity to a luminous galaxy, and the type of that galaxy, plays a role. These hints include the well known morphology-density relation in which the majority (but not all!) of the isolated dwarf galaxies in the Local Group are star-forming gas-rich dwarf irregulars, rather than dEs or dSphs, and that for the MWG and its classic dSph companions, there is a trend for the more distant systems to have more prominent intermediate-age populations. Clearly, to understand more fully the role of environment, the next step is to investigate the stellar populations of dEs beyond the Local Group. In this contribution initial results are presented for dEs in the M81 group, an environment somewhat denser than that of the Local Group, and for early-type dwarfs in the Sculptor Group, a low density loose aggregation of galaxies strung out along the line-of-sight. The results are based on images taken with the ACS instrument aboard HST under programs GO-9884 and GO-10503.

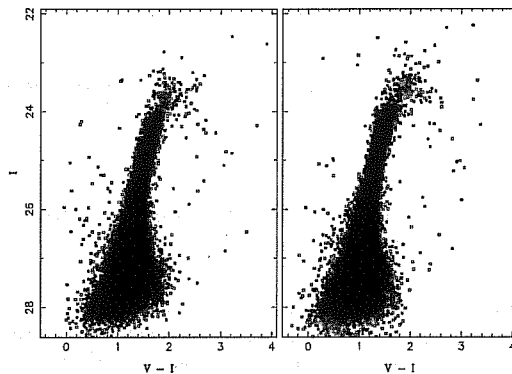


Figure 1. Colour-magnitude diagrams for the M81 group dEs F12D1(left) and Kar 64 (right) based on deep HST/ACS images. The tip of the red giant branch is apparent at $I \approx 24$ and there are numerous upper-AGB stars at magnitudes above the RGB tip. The CMDs for the other dEs observed with HST/ACS are similar.

2. The M81 Group

There are currently about a dozen known dE/dSph members of the M81 group (Karachenstev et al. 2002). Two, F8D1 and BK 5N, were studied in detail by Caldwell et al. (1998) using deep HST/WFPC2 images, and deep HST/ACS images have now been obtained for a further five objects: Kar 61, F6D1, Kar 64, F12D1 and DDO 71. These seven dEs cover a range of properties. For example, the projected distances from M81 vary between ~ 30 kpc and ~ 170 kpc, and the absolute magnitudes range from $M_V \approx -14.2$ to $M_V \approx -11.3$. The HST/ACS images were reduced with Stetson's DAOPHOT/ALLSTAR package (Stetson 1987, 1994) and calibrated using the procedures outlined in Sirianni et al. (2005). Fig. 1 shows the resulting colour-magnitude diagrams (CMD) for F12D1 and Kar 64. The CMDs for the other dEs are similar.

In these CMDs the red giant branch (RGB) tip is readily apparent at $I \approx 24$, as is the presence of numerous upper-AGB stars at I magnitudes above that of the RGB tip. Less obvious in these CMDs is a 'red clump' of core helium burning stars seen near the limit of the data at $I \approx 27.5$ ($M_I \approx -0.3$). Given the low metallicities of the dEs (see below), the presence of such a clump most likely indicates the existence of a population of stars with ages younger than the Galactic globular clusters. However, to recover information of this nature, 'population modelling' of the CMDs, in which the observed data are compared to synthetic CMDs generated for different star formation histories, needs to be undertaken. Such comparisons require knowledge of completeness corrections and errors as a function of magnitude and location, and this in turn requires substantial artificial star tests which have not yet been completed. Consequently, only results from the upper part of the CMDs where the errors are small and the completeness corrections are negligible are presented.

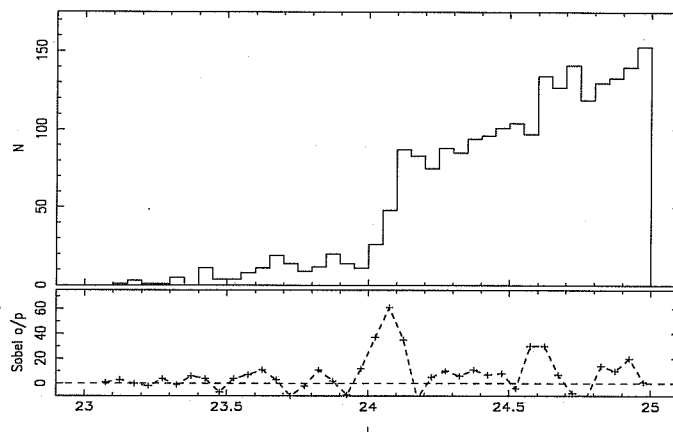


Figure 2. Upper panel: I -band luminosity function ($I < 25$ only) for the dE F12D1. Lower panel: output of a Sobel edge-detection filter applied to the data in the upper panel. The value of $I(TRGB)$ is well determined by this process.

2.1. Distances

The distances were determined by constructing I -band luminosity functions (LF) and measuring $I(TRGB)$, the I magnitude of the tip of the red giant branch. The process is illustrated in Fig. 2, which shows the I -band LF for F12D1. Application of a Sobel edge-detection filter to the LF data results in a well determined value for $I(TRGB)$. Then using reddenings from Schlegel, Finkbeiner & Davis (1998) and the calibration of $I(TRGB)$ from Da Costa & Armandroff (1990) (cf. Caldwell et al. 1998) values for the distances then follow. The mean distance of the 7 dEs is 3.70 Mpc, with a 1σ dispersion of only 140 kpc, consistent with that expected just from the uncertainties in the $I(TRGB)$ values. Indeed the difference in distance modulus between the 'nearest' and 'furthest' galaxies is only 0.24 ± 0.12 mag, so that it is only at the 2σ level that all the dwarfs being at the same distance can be ruled out. The mean distance closely matches that of M81, 3.63 Mpc (Freedman et al. 1994). Clearly, the 7 dEs lie within the 'core' of the M81 group, consistent with the morphology - density relation.

2.2. Abundances

Once the distances to the dEs are known, estimates of the mean abundance can be derived from the mean colour of the RGB compared to the colours of standard Galactic globular cluster giant branches (cf. Caldwell et al. 1998). Strictly, abundances derived in this way are lower limits on the actual mean abundance as, for fixed abundance, the RGB of a younger population is bluer. The effect is not large unless the bulk of the population is significantly younger ($\Delta t > \sim 6$ Gyr) than the Galactic globular clusters, which is unlikely to be the case here.

In Fig. 3 the mean abundances derived in this way are plotted against the absolute magnitudes of the systems. Also shown are the data for the two

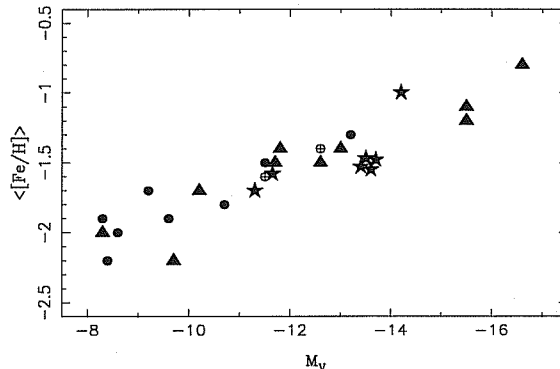


Figure 3. Mean abundances plotted against absolute visual magnitudes for dEs in the M81 group (star symbols), in the Cen A group (circled plus-signs) and the Local Group (Milky Way Galaxy companions filled circles; M31 companions filled triangles).

Cen A group dEs studied by Rejkuba et al. (2006) as well as similar data for the classic dSph companions to the Milky Way, and for dE and dSph companions to M31. The M81 group objects fall in with the Local Group systems, as do the Cen A group objects, outlining a well-defined relation. The existence of this well-defined relation indicates that the mass-metallicity relation for dE galaxies is not strongly dependent on environment, though clearly additional systems in other environments need to be added to this relation before it can be claimed as ‘universal’. The relationship is usually explained in terms of supernova-driven gas loss within dark matter halos (e.g. Dekel & Woo 2003).

2.3. Intermediate-Age Populations

All seven M81 group dEs show populations of stars above the RGB tip in their CMDs (cf. Fig. 1). Such stars are upper-AGB stars of intermediate-age (age $\sim 1 - 10$ Gyr). Two characteristics of these upper-AGB populations have been explored. The first is the mean luminosity of the three most luminous upper-AGB stars in each dE, $\langle M_3(bol) \rangle$. Since the tip of the AGB is more luminous for younger populations, this parameter is an indicator of the epoch of the most recent episode of significant star formation. Second, the number of upper-AGB stars has been compared to the number of RGB stars in a 0.3 mag interval just below the RGB tip. This parameter gives a first order indication of the relative importance of the intermediate-age population.

Based on the $\langle M_3(bol) \rangle$ values, and using the calibration of upper-AGB tip luminosity with age of Rejkuba et al. (2006), the inferred epochs of last significant star formation for the M81 group dEs vary from ~ 2.5 to ~ 8 Gyr. The diversity in these values is similar to that seen in the Local Group, though apparently as yet there are no M81 group dEs whose youngest significant populations are as young as those seen in the MWG dSph companions Fornax (< 1 Gyr) or Leo I (~ 1 Gyr). Although the most distant from M81 system (F8D1) is also the dE with the most luminous upper-AGB stars, there is no clear dependance of the $\langle M_3(bol) \rangle$ values on distance from M81, in contrast to the situation for the

MWG classic dSph companions. There the inner systems ($R_{GC} \approx 75$ kpc), such as Draco and Ursa Minor, lack upper-AGB stars and so have $\langle M_3(bol) \rangle$ values of order -3.6 , the RGB tip luminosity. On the other hand, the more distant systems such as Fornax at ~ 140 kpc and Leo I at ~ 250 kpc have $\langle M_3(bol) \rangle$ values of -5.0 and -4.9 , respectively, so that overall there is an apparent correlation between $\langle M_3(bol) \rangle$ and R_{GC} for the MWG classic dSph companions. This correlation is a manifestation of the suggestion originally by van den Bergh (1994) that the Milky Way galaxy has more strongly influenced its nearer neighbors compared to the more distant satellites. A comparable trend is much less obvious for the M31 dSph companions, though the only M31 dSph companion with an upper-AGB population is amongst the most distant of the satellites (cf. Da Costa et al. 2000). The situation for M81 is thus more similar to that for M31 than for the MWG.

As regards the relative numbers of upper-AGB stars compared to the number of RGB stars just below the tip, there are definite dE-to-dE variations. Again there is no clear correlation of the upper-AGB to RGB number ratio with distance from M81, though the most distant from M81 dE is once more the one with the highest value of this ratio. Full population synthesis models are needed to infer the proper intermediate-age population fractions but application of simple models (cf. Rejkuba et al. 2006) suggests that these fractions range from $\sim 15\%$ to perhaps $\sim 50\%$. Once again these values fall within those for MWG dSph companions which range from $\sim 0\%$ (e.g. Draco, Ursa Minor) to $\sim 70\text{--}80\%$ (Leo I; Gallart et al. 1999).

3. The Sculptor Group

The Sculptor group contains six early-type dwarf galaxies, one of which is the relatively luminous ($M_V \approx -15.3$) dS0 galaxy NGC 59 that will not be discussed here. Regarding the other five systems (ESO540-030, ESO540-032, ESO410-005, ESO294-010 and Scl-dE1) recent observations have detected neutral gas in four, with M_{HI}/L_B values between 0.08 and 0.18 in solar units (Bouchard et al. 2005). These systems may well be best regarded as ‘transition objects’ rather than as dE systems. The fifth galaxy, Scl-dE1 has $M(HI) < 10^5$ solar masses and $M_{HI}/L_B < 0.04$ in solar units (Bouchard et al. 2005).

In the past few months deep HST/ACS observations of the five dwarfs have been obtained. The images will allow generation of CMDs of similar quality to those for the M81 group dEs presented in the previous section. A first look at the data confirms that the five Scl group dwarfs have a significant spread in distance: Scl-dE1 is the most distant, ESO540-030 and ESO540-032 are at similar intermediate distances, and ESO294-010 and ESO410-005 are the closest. All 5 systems appear to contain upper-AGB stars, and there are apparent differences in the upper-AGB populations from system to system. While the CMD data are far from fully analyzed, it is likely that the red clump/horizontal branch is reached in the two nearer systems. The intention is to search the datasets for RR Lyrae variables to confirm the existence of a Galactic globular cluster aged population in the two dwarfs.

The above results must be considered preliminary as the initial CMDs are not yet calibrated, nor has there been any attempt to correct them for field con-

mination or to remove spurious or poorly measured stars. One issue though can be investigated directly from the ACS images. This the question of the existence of globular clusters associated with Scl-dE1. Sharina, Puzia & Makarov (2005) identified three candidate globular clusters based on relatively short exposure HST/WFPC2 'snapshot' images. All three candidates are contained within the field of the ACS images, which have better resolution and which go considerably deeper than the images available to Sharina, Puzia & Makarov (2005). Inspection of the images indicates that all three of the Sharina, Puzia & Makarov (2005) candidates are in fact background galaxies. Nevertheless, the ACS images also clearly show that Scl-dE1 does possess at least one apparently genuine globular cluster candidate. The cluster candidate lies $\sim 20''$ or 420pc to the NW of the galaxy centre and is ~ 50 pc in diameter.

It should be possible to produce a CMD for the cluster candidate which can then be compared with that for the dwarf. The ACS frames of the other dwarfs will also be surveyed for cluster candidates.

4. Conclusions

While fully exploiting all the information contained in the deep CMDs of dEs in the Scl and M81 groups remains a task to be completed, it is clear that essentially all of the systems studied so far contain indications of extended star formation histories. Stated in another way, it is becoming increasingly evident that dEs with stellar populations similar to that of the Local Group dEs Ursa Minor and Tucana, which lack upper-AGB stars and which have dominant old (age > 10 Gyr) populations, are not very common. "Classic" dEs, meaning objects consisting of a single ancient stellar population (cf. Baade Pop II) are apparently comparatively rare objects.

Acknowledgments. I would like to thank all my collaborators, particularly Nelson Caldwell, for their contributions to the material presented here. This research has been supported in part by the Australian Research Council through grant DP0343156.

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