High surface brightness dwarf galaxies in the Fornax cluster

Michael J. Drinkwater$^1$, and Michael D. Gregg$^2$

$^1$School of Physics, University of New South Wales, Sydney 2052, Australia
$^2$University of California, Davis, and Institute for Geophysics and Planetary Physics, Lawrence Livermore National Laboratory, L-413, Livermore, CA 94550, USA

To appear in Mon.Not.R.Astron.Soc.

ABSTRACT

We describe a search for compact dwarf galaxies in the Fornax cluster using the FLAIR spectrograph on the UK Schmidt Telescope. We measured radial velocities of 453 compact galaxies brighter than $B_T \approx 17.3$ and found seven new compact dwarf cluster members that were not classified in previous surveys as members of the cluster. These are amongst the most compact, high surface brightness dwarf galaxies known.

The inclusion of these galaxies in the cluster does not change the total luminosity function significantly but they are important because of their extreme nature; one in particular appears to be a high (normal) surface brightness dwarf spiral. Three of the new dwarfs have strong emission lines and appear to be blue compact dwarfs (BCDs), doubling the number of confirmed BCDs in the cluster. We also determined that none of the compact dwarf elliptical (M32-like) candidates are in the cluster, down to an absolute magnitude $M_B = -13.2$. We have investigated the claim of Irwin et al. (1990) that there is no strong relation between surface brightness and magnitude for the cluster members and find some support for this for the brighter galaxies ($B_T < 17.3$) but fainter galaxies still need to be measured.

1 INTRODUCTION

The determination of galaxy luminosity functions (LFs) is subject to a number of selection effects. This is particularly true for the faint end of the LF in clusters where cluster membership is often necessarily assigned without recourse to redshifts. One of the parameters relied upon to guide visual assignments of membership is surface brightness (SB). Disney (1976; see also Davies et al. 1988) argues that most magnitude-limited galaxy surveys are sensitive to a limited range of surface brightness: high SB galaxies being unresolved and rejected as ‘stars’ and low SB galaxies falling below the detection threshold even though their total magnitude is brighter than the nominal limit. Low SB galaxies have been studied in detail by Phillips et al. (1987) and Davies et al. (1988); in this paper we concentrate on the high SB galaxies.

Normal galaxies with relatively high SB are typically 3 magnitudes brighter than detection limits in photographic sky surveys and there is rarely any problem resolving them and distinguishing them from stars. In some surveys, however, a selection bias against the very highest SB compact objects can still occur. We have been conducting a spectroscopic survey of the Fornax cluster using the UK Schmidt Telescope (UKST) FLAIR multi-object spectrograph. Our aim is to establish the true cluster luminosity function over as great a range in luminosity and galaxy types as possible. It is crucial to understand any SB selection effects and to look for compact dwarf galaxies (Holman et al. 1995, Drinkwater et al. 1997) in particular. Our starting point for the spectroscopic survey is the Fornax Cluster Catalog (FCC) of Ferguson (1989) which lists 2678 galaxies in an area of 40 deg$^2$. The galaxies are classified as ‘members’ or ‘background’ according to a number of visual criteria, including morphology and SB, on large scale, high quality DuPont 2.5m Telescope plates. Broadly speaking, galaxies of faint apparent magnitude are classified as members if they have low SB and background if they have high SB. This type of visual classification was used successfully by Binggeli & Sandage (1984) in their Virgo Cluster Catalog; in both clusters it works well because there are voids behind the clusters.

Drinkwater et al. (1996) tested the classifications in the Virgo cluster using spectroscopy and found none of the 300 galaxies measured were incorrectly assigned. In the present paper we present results from a similar, more extensive survey of the Fornax cluster, having measured 453 galaxy redshifts with FLAIR to determine membership. The galaxy sample and observations are described in Section 2; we found seven new compact dwarfs in the cluster. Their properties are presented in Section 3 and in Section 4 we discuss the implications of our results. Throughout this paper we use a distance to the Fornax cluster of 15.4 Mpc and a distance modulus of 30.9 mag (Bureau, Mould & Staveley-Smith 1996).
2 GALAXIES OBSERVED

Our motivation was to search for any compact cluster members which had previously been misidentified as background galaxies. The possible bias against compact cluster members in the FCC is demonstrated in Fig. 1 which shows—as expected—that the new cluster members are much less compact (lower SB) than the background galaxies (confirmed: crosses; unconfirmed: dots). The new compact dwarf cluster members are plotted as filled triangles.

M32 candidates of $B_T=17$ corresponds to an absolute magnitude of $M_B = -13.9$, considerably fainter than M32 itself ($M_B = -15.5$ (Sandage & Tammann, 1987)).

Figure 1. Image classification diagrams of galaxies in the Fornax Cluster Catalog. Each point gives the parameters of an image on the UKST $B_j$ sky survey plate measured by the Automated Plate Measuring (APM) facility (see Drinkwater et al. 1996). The upper and lower panels respectively plot image area and the classification parameter ‘sigma’ against apparent magnitude. In both cases the smaller the parameter at a given magnitude, the more stellar in appearance the image. Stars are also plotted in the upper panel: these form a well-defined locus of images with minimum area. The ‘sigma’ parameter simply measures how many standard deviations a given image lies above the stellar locus. The FCC-classified members (confirmed: filled squares; unconfirmed: open squares) are less compact (lower SB) than the background galaxies (confirmed: crosses; unconfirmed: dots). The new compact dwarf cluster members are plotted as filled triangles.

3 PROPERTIES OF THE NEW DWARF MEMBERS

Fig. 1 shows—as expected—that the new cluster members are amongst the most compact galaxies in the cluster. This is also apparent from the images shown in Fig. 2. Several have disk-like structure, so it is not surprising they were classified as giant background galaxies, especially when they are compared to galaxies like FCC 333 (also shown in Fig. 2) that were classified as members but we have now shown are background galaxies.

We obtained CCD images of B2144 on the ANU 40-inch Telescope. An exponential fit to the $B$ band radial profile has a central SB of $21.8$ $B$ mag arcsec$^{-2}$ and a scale length of...

© 0000 RAS, MNRAS 000, 000–000
Table 1. Details of Observed Dwarf Galaxies

| RA (B1950) Dec | FCC | M   | Type         | $B_T$ | $M_B$ | SB  | $B_J$ | $cz$ (km s$^{-1}$) | Comment |
|----------------|-----|-----|--------------|-------|-------|-----|-------|----------------|---------|
| 3:29:40.00 -38:13:54.0 | B0729 | 3   | *dS0 or S0  | 16.5  | -14.4 | -   | -     | 1797 ± 75      |         |
| 3:32:00.40 -34:46:38.0 | B0905 | 4   | ?            | 17.0  | -13.9 | -   | 16.6  | 1278 ± 50      | emission|
| 3:34:51.70 -33:37:24.0 | B1108 | 3   | dS0 or S0   | 16.6  | -14.3 | 22.2| 15.9  | 1941 ± 95      |         |
| 3:36:21.60 -35:40:07.0 | B1241 | 3   | *dE3 pec?   | 17.3  | -13.6 | -   | 16.9  | 1997 ± 78      |         |
| 3:37:56.80 -33:12:43.0 | B1379 | 3   | dE6 pec    | 16.9  | -14.0 | 22.0| 16.3  | 708 ± 17       | emission|
| 3:40:04.60 -35:30:21.0 | B1554 | 5   | E           | 17.5  | -13.4 | -   | 16.7  | 1735 ± 50      |         |
| 3:47:55.00 -32:24:30.0 | B2144 | 3   | E or dE(M32?) | 16.5  | -14.4 | 21.8| 16.1  | 1155 ± 18      | emission|
| 3:48:05.80 -36:14:14.0 | 333  | 1   | E or S0    | 16.8  | -14.1 | -   | 16.4  | 13629 ± 67     | background|

Notes: FCC, M, Type $B_T$ and $M_B$ are the catalogue number, membership flag (1=definite member, 3=possible member, 4=likely background, 5=definite background) classification, total magnitude and absolute magnitude (assuming a distance modulus of 30.9 mag) from the FCC; SB is the B central surface brightness from our data for B2144 and from Irwin et al. (1990) for the others. The photographic $B_J$ magnitude is an estimate from our APM data, $cz$ is the heliocentric velocity from our observations.

Figure 2. Images of the seven new dwarf galaxies from the Digitized Sky Survey in the $B_J$ band. The final image is of FCC 333 a galaxy classified as a member which we have determined is actually a background galaxy. The images are all 4 arcmin across with North to the top and East to the left.

4.4 arcsec (0.33 kpc). Two of the galaxies, B1108 and B1379, are in the Irwin et al. (1990) sample with measured SB values of 22.2 and 22.0 $B$ mag arcsec$^{-2}$ respectively. These values are typical of compact BCDs (see e.g. Drinkwater & Hardy 1991) and confirm the compact nature of these galaxies.

The fibre spectra of the new dwarfs in Fig. 3 are not flux-calibrated, but they do show that three (B0905, B1379 and B2144) have prominent emission lines of H$\beta$, H$\alpha$, and [OIII] 500.7, indicative of ongoing or recent star formation. The flux-calibrated long-slit spectra (Fig. 4) reveal that both B2144 and B0905 have blue continua, and B2144 has strong [OII] 372.7, again pointing to star formation. We therefore classify both as BCDs and infer that the other object with emission lines, B1379, is also a BCD. The absorption line objects are all very weak lined, indicative of sub-solar abundances, consistent with their dwarf nature.

4 DISCUSSION

4.1 Compact dwarf ellipticals

One of the aims of this project was to test the hypothesis that if compact dwarf ellipticals form through tidal stripping of ordinary ellipticals, an idea originally due to King (1962), then they should always be found in association with large companions and should be rare or non-existent in the outskirts of clusters or as isolated objects. We observed 70 of the possible cdEs (Ferguson’s Table XIII plus additional objects from the background list tagged as ‘M32?’) in the FCC to see if they occur preferentially in dense environs. Somewhat surprisingly, we found only a single cluster member in this subsample; all the rest are background ellipticals. The one new cluster member from this sample is B2144, whose spectrum (Fig. 5) shows it to be not a cdE but a BCD, underscoring the uncertainty of classifying objects from imag-
are found near large companions and 4 are relatively isolated (Ferguson 1989), tidal stripping appears to be an unlikely mechanism for the production of cdEs. This is supported by the theoretical analysis of Nieto & Prugniel (1987).

4.2 Blue compact dwarfs

In the FCC, a total of 9 candidate BCDs were listed: 4 ‘definite’, one ‘likely’ and 4 ‘possible’ members according to morphological classification. Our new observations show that three of these (FCC 24, B0037 and B0801) are background galaxies and that FCC 35 is a member. Along with the previously confirmed members FCC 32 and FCC 33, this gives only 3 BCD members listed in the FCC with spectroscopic confirmation. The mean absolute magnitude of these is $<M_B> \approx -16$ (for a distance modulus of 30.9 mag). These BCDs comprise 1% of the cluster members, less than the 3% BCD fraction listed for Virgo catalogue (Binggeli & Sandage, 1984). Our observations have detected an additional 3 new BCDs, effectively doubling the number of confirmed BCDs although we defer any calculation of the BCD luminosity function until we can determine an objective (e.g. spectroscopic) definition of the type. Notably, the new BCDs are significantly fainter than the FCC BCDs with $<M_B> \approx -14$.

One of the new BCD galaxies, FCC B0905, has a bulge plus disk morphology and is probably a dwarf spiral (dS) type. Pending future CCD imaging of the galaxy we estimate its central SB as $\approx 23B$ mag arcsec$^{-2}$ and scale length as $\approx 5$ arcsec (0.4 kpc) from our APM data (used in Fig. 1). This is the first high (normal) surface brightness dS to be found. It is distinguished from spirals in conventional samples by its very small scale length; the 86 spirals measured by de Jong (1996) have scale lengths in the range 1–7 kpc. The discovery of dwarf spirals was previously announced by Schombert et al. (1995) in an HI survey of field galaxies, but these were much more luminous ($M_B \approx -16.5$) and more extended (scale length=1–3 kpc, SB$=23$–$24B$ mag arcsec$^{-2}$) than FCC B0905, and would have been included in the de Jong (1996) sample. Schombert et al. inferred that dS types are not found in clusters: we suggest rather that the cluster environment may influence the formation and/or stability of dS types so that only the smaller, high SB dS types like FCC B0905 can survive in clusters.

4.3 Magnitude - surface brightness relation

Ferguson & Sandage (1988) found a strong correlation between surface brightness and magnitude for galaxies they classified as early type cluster members (SB decreasing with total luminosity). Ferguson & Sandage claim that a report of no correlation by Davies et al. (1988) was due to contamination by background galaxies. However Irwin et al. (1990) repeat the claim that the correlation does not exist but is caused by selection effects in the FCC that cause the faintest, high SB galaxies and the brightest, low SB galaxies to be excluded. This disagreement could be resolved with redshifts of the galaxies to determine unambiguous cluster membership, but the low SB galaxies are hard to measure.

In Fig. 1 we have replotted the Irwin et al. surface brightness and magnitude data for their sample of 321 relatively low SB galaxies in the Fornax cluster. As a result...
of our observations, we now have velocities to confirm 29 of their sample as members and 37 as background galaxies: these are indicated on the diagram. Our data show that at least for magnitudes brighter than 17.3 the cluster members display the full range of SB and no tight relationship with magnitude. Ferguson & Sandage (1988) claim their correlation is only for galaxies they classify as dE and dS0 cluster members: we have plotted these on the diagram as open circles which do indeed appear to show a correlation. However the correlation depends on their having correctly classified all galaxies in the lower right-hand corner as background giants. We plan to resolve this issue finally by measuring these galaxies with 2dF.

5 CONCLUSIONS

We have confirmed the presence of a number of high (or ‘normal’) surface brightness dwarf galaxies in the Fornax cluster. These are among the most compact cluster members and one appears to belong to a new type of high SB dwarf spiral galaxy, distinct from the dwarf spirals identified in the field by Schombert et al. (1995) which are 2.5 mag more luminous and have SB at least 2 mag fainter. Although these new dwarfs are quite different to the dS types found by Schombert et al., the same approach of an HI survey might be used to find more of them: Barnes et al. (1997) found a new, high SB cluster dwarf with $M_B = -15.8$ in their HI survey of Fornax.

Additionally, we found no new M32-like (cdE) cluster members in our survey; all but one of the 78 targets are background objects while the single member (B2144) is an emission line object with blue colours and therefore not an M32-like elliptical but a BCD with ongoing star formation. The distribution of cdEs in the cluster, with 4 of the 7 being relatively isolated, suggests that they are not formed by tidal stripping by large, nearby companions.

ACKNOWLEDGMENTS

We particularly thank M. Brown, B. Holman and S. Ryder for making some of the observations. The 2dF data were used by kind permission of our collaborators R. Dickens, Q. Parker, S. Phillipps, E. Sadler, R. Smith and J. Davies (who also provided the data used in Fig. 1). Part of this work was done at the Institute of Geophysics and Planetary Physics, under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under contract No. W-7405-Eng-48. The NASA/IPAC Extragalactic Database is operated by the Jet Propulsion Laboratory, Caltech, under contract with NASA. IRAF is distributed by the National Optical Astronomy Observatories, operated by the Association of Universities for Research in Astronomy, Inc. under cooperative agreement with the NSF. The Digitized Sky Survey was produced at the Space Telescope Science Institute under US Government grant NAG W-2166.

REFERENCES

Barnes, D.G., Staveley-Smith, L., Webster, R.L., Walsh, W., 1997, MNRAS, 288, 307
Binggeli, B., Sandage, A., 1984, AJ, 89, 919
Bureau, M., Mould, J.R., Staveley-Smith, L., 1996, ApJ, 463, 60
Davies, J.I., Phillipps, S., Cawson, M.G.M., Disney, M.J., Kibblewhite, E.J., 1988, MNRAS, 232, 239
de Jong, R.S. 1996, A&A, 313, 45
Disney, M.J., 1976, Nature, 263, 573
Drinkwater, M.J., Hardy, E., 1991, AJ, 101, 94
Drinkwater, M.J., Currie, M.J., Young, C.K., Hardy, E., Yearsley, J.M., 1996, MNRAS, 279, 595
Drinkwater, M.J., Gregg, M.D., Holman, B.A., 1997 in The Second Stromlo Symposium: The Nature of Elliptical Galaxies, Eds. M. Arnaboldi, G.S. Da Costa, P. Saha, p. 287
Faber, S.M. 1973, ApJL, 179, 423
Ferguson, H.C. 1989, AJ, 98, 367 (FCC)
Ferguson, H.C., Sandage, A., 1988, AJ, 96, 1520
Holman, B., Drinkwater, M., Gregg, M., 1995, in IAU Colloquium 148: The Future Utilisation of Schmidt Telescopes, eds. J. Chapman, R. Cannon, S. Harrison, B. Hidayat, ASP Conf. Ser. 84, p. 107
Irwin, M.J., Davies, J.I., Disney, M.J., Phillipps, S., 1990, MNRAS, 245, 289
King, I.R. 1962, AJ, 67, 471
Kurtz M.J., Mink D.J., Wyatt W.F., Fabricant D.G., Torres G., Kriss G.A., Tonry J.L., 1991, in Worrall D.M., Biemesderfer C., Barnes J., eds., Astronomical Data Analysis Software and Systems I, ASP Conf. Ser., Vol. 25, p.432
Nieto, J.-L., Prugniel, P. 1987, A&A, 186, 30
Phillipps, S., Disney, M.J., Kibblewhite, E.J., Cawson, M.G.M., 1987, MNRAS, 229, 505
Sandage, A., Tammann, G.A., 1987, A revised Shapley-Ames catalog of bright galaxies. Carnegie Institution of Washington, Washington, D.C.
Schombert, J.M., Pildis, R.A., Eder, J.A., Oemler, A, 1995, AJ, 110, 2067