Mapping the Hidden Universe
ASP Conference Series, Vol. 999, 2000
R.C. Kraan-Korteweg, P.A. Henning and H. Andernach, eds.

Hidden Galaxies in the Fornax Cluster

M. Drinkwater, M. Waugh, R. Webster
School of Physics, University of Melbourne, Victoria 3010, Australia

D. Barnes
Australia Telescope National Facility, PO Box 76, Epping, NSW 1710, Australia

M. Gregg
University of California, Davis, and Institute for Geophysics and Planetary Physics, Lawrence Livermore National Laboratory, L-413, Livermore, CA 94550, USA

S. Phillipps, J.B. Jones
Department of Physics, University of Bristol, Tyndall Avenue, Bristol, BS8 1TL, England

Abstract. We are using the Multibeam 21cm receiver on the Parkes Telescope combined with the optical Two degree Field spectrograph (2dF) of the Anglo-Australian Telescope to obtain the first complete spectroscopic sample of the Fornax cluster.

In the optical the survey is unique in that all objects (both “stars” and “galaxies”) within our magnitude limits ($16.5 \leq B_J \leq 19.7$) are measured, producing the most complete survey of cluster members irrespective of surface brightness. We have detected two new classes of high surface brightness dwarf galaxy in the cluster. With 2dF we have discovered a population of very low luminosity ($M_B \approx -12$) objects which are unresolved from the ground and may be the stripped nuclei of dwarf galaxies; they are unlike any known galaxies. In a survey of the brighter ($16.5 \leq B_J \leq 18$) galaxies with the FLAIR-II spectrograph we have found a number of new high surface brightness dwarf galaxies and show that the fraction of star-forming dwarf galaxies in the cluster is about 30%, about twice that implied by earlier morphological classifications.

Our radio observations have greatly improved upon the sensitivity of the standard Multibeam survey by using a new “basket weave” scanning pattern. Our initial analysis shows that we are detecting new cluster members with HI masses of order $10^8 M_\odot$ and HI mass-to-light ratios of $1–2 M_\odot/L_\odot$. 
## Introduction: Selection Effects

It has long been suggested that optical selection effects limit the galaxies in optical surveys to a narrow range of surface brightness (Disney & Phillipps 1983 and references therein). The idea is that very low surface brightness (LSB) galaxies are lost in the sky noise and compact, high surface brightness galaxies would be confused with stars. It now seems unlikely that there are large numbers of undetected giant LSB galaxies (Driver, these proceedings) and the number of unresolved giant galaxies missed in photographic surveys is small (Drinkwater et al. 1999). However the situation for dwarf galaxies may be different.

Most flux-limited galaxy surveys are dominated by giant galaxies, so the only way to study significant samples of dwarf galaxies is to observe nearby galaxy clusters where the galaxy density is so elevated that many dwarfs can be detected. The advantage of cluster samples is that cluster membership can often be assigned on morphological grounds, avoiding the need for spectroscopy. This has been done very effectively in surveys of the Virgo and Fornax Clusters which now form the basis of our knowledge of dwarf galaxies (Binggeli, Sandage & Tammann 1985; Ferguson 1989=FCC). However the lack of spectroscopy becomes a serious handicap when it comes to unusual types of dwarf galaxy: these may not be included on morphological grounds.

**Figure 1.** New galaxies detected in the Fornax Cluster. These B-band photographic images (from the DSS: see acknowledgements) are all 3 arcminutes across with North at the top and East to the left.

| FCC (old) | FLAIR (new) | FCC (old) | 2dF (new) |
|-----------|-------------|-----------|-----------|
| ![Image](image1) | ![Image](image2) | ![Image](image3) | ![Image](image4) |
| B=13.7    | B=17.0      | B=16.6    | B=19.7    |

| Parkes (new) | FLAIR (new) | FCC (old) | 2dF (new) |
|--------------|-------------|-----------|-----------|
| ![Image](image5) | ![Image](image6) | ![Image](image7) | ![Image](image8) |
| B=15.3       | B=16.5      | B=17.7    | B=19.8    |
In this paper we present results from an extensive multi-wavelength spectroscopic survey of the Fornax Cluster. We are obtaining the most complete spectroscopic sample of cluster galaxies ever made, detecting new types of galaxy missed in the previous morphological surveys. In the optical we are using the Two degree Field spectrograph (2dF) of the Anglo-Australian Telescope (AAT) to make a complete survey of faint objects in the core of the cluster and the FLAIR-II spectrograph of the UK Schmidt Telescope (UKST) to measure brighter compact galaxies over a six degree field. In the radio we are making a blind spectroscopic survey of an even larger ten degree field with the Multibeam 21cm receiver on the Parkes Telescope. In Fig. 1 we show images of a selection of the cluster galaxies observed; these are described in more detail below.

2. “Hidden” Galaxies Found by Optical Spectroscopy

2.1. High Surface Brightness Dwarf Galaxies

The main difficulty with the morphological studies of dwarf galaxies in clusters is the possibility that only a subset of cluster members with familiar properties is selected. In particular, high surface brightness compact dwarfs may be overlooked because they are misclassified as giant background galaxies. If such a population were found it would help explain the evolution of the more compact dwarfs such as blue compact dwarfs (BCDs) (Drinkwater & Hardy 1991).
We have just completed a spectroscopic search for new compact cluster dwarfs using FLAIR-II on the UKST (Drinkwater et al. in preparation). We measured 526 brighter ($16.5 \leq B_J \leq 18$) galaxies of compact appearance and found ten new cluster members that were previously classified as background objects. These objects are all high surface brightness dwarfs, most with strong H-α emission indicative of star formation. Two of these are shown in Fig. 1 labelled as “FLAIR (new)” and are very different to the “normal” LSB dwarfs (“FCC (old)”). We measured spectra of a total of 108 cluster members including previously known galaxies. These data showed that star formation as indicated by H-α emission is not just limited to the dwarf galaxies which were morphologically classified as late-type, but is also evident in many of the early-type dwarfs. We find a ratio of star-forming to non-star-forming dwarfs of 1:2 compared to a late-type to early-type ratio of 1:5 according to the FCC morphological classifications. We also find that the star-forming galaxies are significantly more extended across the cluster than those not forming stars actively.

2.2. Compact Stellar Systems

We have extended our optical spectroscopy to fainter limits ($16.5 < B_J < 19.7$) using the 2dF spectrograph on the AAT. This is almost a “blind” survey in that we have observed all objects both “stars” and “galaxies” in these limits. The sample (about 3600 objects in the first field) is therefore dominated by foreground Galactic stars and background field galaxies—but we can afford to use this complete strategy given the high efficiency of the 2dF system.
Hidden Galaxies in the Fornax Cluster

Apart from confirming the identification of several “normal” dwarf galaxies in the Fornax cluster we have also discovered a new population of very compact objects in the centre of the cluster (Drinkwater et al. 2000). These objects are unresolved in ground-based imaging (see Fig. 1 where they are labelled as “2dF (new)”) and have absolute magnitudes of $-11 < M_B < -13$. They have spectra typical of old stellar populations but they are brighter than any known globular clusters, as is shown in Fig. 2. The luminosities of these compact objects overlap those of the fainter known dwarf ellipticals in the cluster, but they are morphologically distinct, being much more compact. The only objects they do resemble are the nuclei of nucleated dwarf ellipticals: perhaps they are the remnants of nucleated dwarfs which have been stripped in the cluster potential. These objects are unlike any known type of galaxy or stellar system and occupy a region of the surface brightness-magnitude plane (Fig. 3) that was previously empty. We have been awarded Hubble Space Telescope time to obtain high-resolution images of these objects to determine what they are.

3. “Hidden” Galaxies Detected in 21 cm Radio Spectroscopy

In order to extend our survey to larger radii and also to search for galaxies with high ratios of neutral hydrogen to optical luminosity, we have made a deep, wide-field survey of the Fornax Cluster with the Parkes Multibeam receiver. Previous observations with the Parkes Telescope in “single beam” mode (Barnes et al. 1997) detected one new cluster member (“Parkes (new)” in Fig. 1). This galaxy was outside the region covered by the FCC.

Our new survey covers an even larger 10 square degree region of sky centred the Fornax Cluster with 4 times the exposure time of the standard HI Parkes All-Sky Survey (HIPASS) survey which also covers this region (see Waugh et al. in these proceedings). Unlike the standard HIPASS survey which uses a single set of North-South scans we made four sets of scans with half of them in the East-West direction—hence the term “basket weave” we adopt for the new scanning pattern. We also displaced the field centre by about half the offset between scans for the second pair of scan sets. The average noise per pixel scales with the square root of the exposure time as expected: about 7 mJy for the basket weave cube compared to 13 mJy for HIPASS. However the mean and RMS number of scans contributing to each pixel in the final basket weave cube is $153 \pm 7$ compared to $42 \pm 6$ for HIPASS, so the fluctuations in sampling rate from pixel to pixel have been decreased from 15% to 5% making the noise properties much more uniform. This is shown by comparing the basket weave data in Fig. 4 with the HIPASS data presented by Waugh et al. (these proceedings).

We have made a preliminary analysis of the basket weave data, making strong detections of a number of new galaxies at the 30 mJy level ($M_{HI} \approx 1 \times 10^8 M_\odot$ for a Fornax distance of 15.4 Mpc) which were not detected in the corresponding HIPASS data. We present examples of three HI detections in Fig. 5; in each case there is a probable optical identification. We find no evidence for a large population of dark neutral hydrogen clouds at the $10^8 M_\odot$ limit in the Fornax cluster. The first galaxy shown in Fig. 5 (FCC308) is a relatively bright known cluster member also detected in HIPASS. The two other galaxies were not detected in HIPASS and are new cluster members: the first (FCC120)
Figure 4. Deep basket weave HI map of the Fornax Cluster. The image measures the maximum signal in the velocity range 400–3000 km/s at each point in the map. The dark circles are sources. The pale blobs are caused by continuum sources.
Figure 5. Some of the smaller HI sources detected in our basket weave observations. The upper row shows B1-band photographic DSS (see acknowledgements) images centred on the radio detections, all 10 arcminutes across with North at the top and East to the left. The lower row show the radio spectra of the detections.
was classified as a cluster member in the FCC but without a confirmed velocity and the second (APMBGC 301+004-025) was not listed because it was outside the region surveyed for the FCC. At this stage it is premature to estimate the total mass of the cluster in HI, but we do note that these new detections all have high ratios of HI mass to optical luminosity (see Fig. 5) and that the cluster HI detections (see Fig. 4) are distributed over a much larger region than the optical galaxies (core radius of only 0.7 degrees).

4. Summary

We have shown that our approach of making complete spectroscopic surveys has overcome the selection effects evident in previous cluster samples of dwarf galaxies. The “new” members we find are not difficult to detect optically, but in each case have been excluded from existing compilations because of their high surface brightness or large distance from the cluster centre. We have detected unresolved compact objects, high surface brightness dwarf galaxies and radio galaxies. When it comes to clusters, galaxies do not have to be optically faint to be “hidden”, they just have to be unusual.

Apart from the compact objects, most of the galaxies we found show evidence of high rates of star formation. In the complete FLAIR-II sample our data show that star formation is about twice as common in the dwarf galaxies as would have been implied by the earlier morphological classifications. Star formation is still important in the Fornax cluster dwarfs, but not in the cluster core where the density of star-forming galaxies is reduced. This is consistent with the radio data which show that the neutral hydrogen in the cluster is much less centrally concentrated than the optical luminosity.

Acknowledgments. We wish to thank Virginia Kilborn for use of her galaxy detection software and Ivy Wong for assistance with some of the Parkes observing. The Digitized Sky Surveys (DSS) were produced at the Space Telescope Science Institute under U.S. Government grant NAG W-2166. The images are based on photographic data obtained using the UK Schmidt Telescope.

References

Barnes D.G., Staveley-Smith L., Webster R. Walsh W. 1997, MNRAS, 288, 307
Binggeli, B., Cameron, L.M., 1991, A&A, 252, 27
Binggeli, B., Sandage, A., Tammann, G.A., 1985, AJ, 90, 1681
Bridges, T.J., Hanes, D.A., Harris, W.E., 1991, AJ, 101, 469
Disney, M.J., Phillipps, S., 1988, MNRAS, 205, 1253
Drinkwater, M.J., Hardy, E., 1991, AJ, 101, 94
Drinkwater, M.J., Jones, J.B., Gregg, M.D., Phillipps, S., 2000, PASA, 17, in press
Drinkwater, M.J., Phillipps, S., Gregg, M.D., Parker, Q.A., Smith, R.M., Davies, J.I., Jones, J.B., Sadler, E.M., 1999, ApJ, 511, L97
Ferguson, H.C., 1989, AJ, 98, 367 (FCC)
Ferguson, H.C., Binggeli, B., 1994, A&ARv, 6, 67
Harris, W.E., 1996, AJ, 112, 1487