The Low Surface Brightness Universe, IAU Col. 171
ASP Conference Series, Vol. 170, 1999
J. I. Davies, C. Impey and S. Phillipps, eds.

The Fornax Spectroscopic Survey — Low Surface Brightness Galaxies in Fornax

M.J. Drinkwater

Physics, University of New South Wales, Sydney 2052, Australia

S. Phillipps, J.B. Jones

Physics, University of Bristol, Tyndall Avenue, Bristol BS8 1TL, UK

Abstract. *The Fornax Spectroscopic Survey* is a large optical spectroscopic survey of *all* 14 000 objects with $16.5 < B_J < 19.7$ in a 12 deg^2 area of sky centered on the Fornax Cluster. We are using the 400-fibre Two Degree Field spectrograph on the Anglo-Australian Telescope: the multiplex advantage of this system allows us to observe objects conventionally classified as "stars" as well as "galaxies". This is the only way to minimise selection effects caused by image classification or assessing cluster membership.

In this paper we present the first measurements of low surface brightness (LSB) galaxies we have detected both in the Fornax Cluster and among the background field galaxies. The new cluster members include some very low luminosity ($M_B \approx -11.5$ mag) dwarf ellipticals, whereas the background LSB galaxies are luminous ($-19.6 < M_B < -17.0$ mag) disk-like galaxies.

1. Introduction: The Fornax Spectroscopic Survey

Several remarks have already been made at this Colloquium about the difficulty of performing optical redshift surveys of low surface brightness (LSB) galaxies, in particular using fibre-fed spectroscopy, despite the pressing need for redshifts for these objects. It is hard to obtain optical spectra of LSB galaxies at the best of times. The limited apertures of fibre spectrographs and problems with sky subtraction would normally be thought to make matters even worse. However by using a system with a very large number of fibres like the 400-fibre Two Degree Field (2dF) on the Anglo-Australian Telescope (AAT) these limitations are outweighed by the multiplex advantage of the system.

The Fornax Spectroscopic Survey (FSS) is designed to sample the largest possible range in surface brightness, including high surface brightness (HSB) as well as LSB galaxies. It does this by targeting *all* objects in a region of sky centred on the Fornax Cluster. No morphological information is used in the target selection, so objects conventionally classified as "stars" are included as well as "galaxies". Such a complete survey of all objects is the only way to minimise selection effects caused by image classification or assessing cluster membership. Previous attempts at "all-object" surveys have been limited to

https://doi.org/10.1017/S0252921100054191 Published online by Cambridge University Press

small areas. Morton, Krug & Tritton (1985) obtained spectra of all 606 star-like objects brighter than $B = 20$ in an area of 0.31 deg^2 and Colless et al. (1991) extended their galaxy survey by measuring spectra of 117 compact objects with $21 < B_J < 23.5$ in a 0.1 deg^2 area. *The Fornax Spectroscopic Survey* will cover four 2dF fields (totaling 12 deg^2) centered on the Fornax Cluster. It will include all 14,000 objects in the magnitude range of $16.5 < B_J < 19.7$ (and somewhat deeper for unresolved images).

We selected our targets from an APM (Irwin et al. 1994) scan of the blue and red sky survey plates which provided accurate positions, image classifications and photographic B_J and R magnitudes (optimised for stellar profiles). The galaxy B_J magnitudes were taken from Davies et al. (1988), as were estimates of the surface brightness and image scale length.

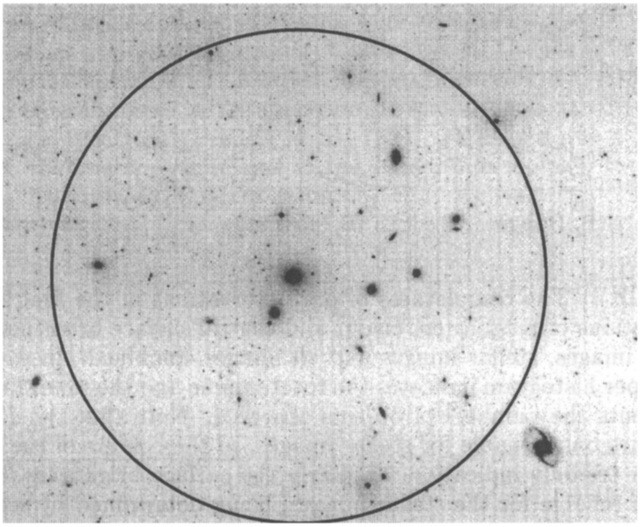


Figure 1. The first 2dF Fornax field observed. We measured spectra of 2500 "stars" and "galaxies" with $B_J < 19.7$ inside the 2 degree diameter circle shown. The field is centred at R.A. $03^h\ 38^m\ 29^s$, dec. $-35° \ 27' \ 01''$ (J2000).

In this paper we present some preliminary results from the FSS based on the first season of observing in which we have almost completed our first field, shown in Figure 1. Here we concentrate on the LSB galaxies and in a companion paper (Drinkwater et al., this volume) we present the detection of HSB galaxies from the survey.

https://doi.org/10.1017/S0252921100054191 Published online by Cambridge University Press

2. Observations

The spectroscopic data were obtained with the 2dF in 1996 and 1997. Full details of the observations and the other objects observed are given in Drinkwater et al. (1999). In the limited time available during these initial observations, we successfully observed 1041 (80%) of the resolved objects to a limit of $B_J = 19.7$ and a total of 1123 (45%) of the stellar objects to the deeper limit of $B_J = 20.3$. Most of the observations were 2 hour exposures for the galaxies and about 45 minutes for the stars.

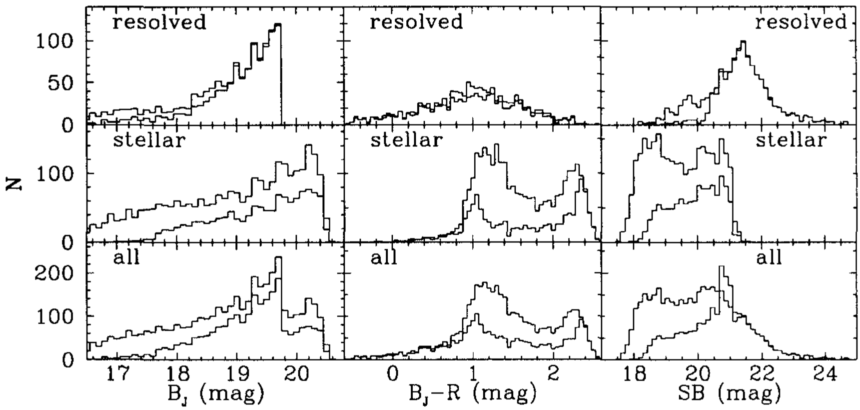


Figure 2. The completness of our observations in the first 2dF field as functions of magnitude, colour and central surface brightness for resolved images, stellar images and all images combined. In each panel the upper histogram indicates the total sample and the lower histogram represents the numbers of objects observed. Note that the R magnitudes are only reliable for stellar images, so the colours of the resolved objects are only indicative. Similarly the surface brightness estimates are not reliable for the stellar images, being determined by seeing and saturation effects.

The numbers of objects observed are shown in Figure 2 as functions of their magnitude, colour and surface brightness for the resolved and stellar image classes and for the whole sample combined. The star–galaxy classification is taken from the APM catalogue. The colours $(B_J - R_F)$ were derived using the R magnitudes from the APM catalogue data. These have not been independently calibrated and are optimized for stellar images so the galaxy colours are only indicative. However the stellar objects show the normal colours with the classic bimodal distribution of blue halo and red disk populations (Kron 1980).

The selection functions in Figure 2 show that, as discussed above, we observed the stellar images to a fainter magnitude limit than the resolved objects, with some bias not to observe the brightest stars. The selection by colour was fairly uniform for resolved objects, but the stellar objects were chosen with a

https://doi.org/10.1017/S0252921100054191 Published online by Cambridge University Press

bias to extreme colours so as preferentially to include unusual objects. There is a slight bias to faint surface brightness for all images classes. We will complete this first field during out next observing run to remove these biases.

3. Analysis

We reduced the data using standard IRAF routines for multi-fibre spectroscopy, although an automated pipeline reduction package is now also available at the AAT. We then cleaned the spectra by interpolating across the strongest sky line residuals and correcting for atmospheric absorption. We analysed all the spectra with the RVSAO (Kurtz & Mink 1998) cross-correlation package to identify the objects and measure their radial velocities. Instead of the normal selection of galaxy templates for the cross-correlations, we used a set of ten stellar templates from the Jacoby, Hunter & Christian (1984) library plus one emission line galaxy template. These templates were capable of identifying and measuring galaxy redshifts as well as a set of galaxy templates, but had the advantage, when applied to Galactic stars, of giving a good first estimate of the stellar type. The object identifications were accepted if the Tonry & Davis (1979) "R" coefficient was greater than 3, although all the identifications were checked by visual inspection. If an object was not identified and there were any signs of broad emission lines in the spectrum, it was subsequently tested against a QSO template spectrum (Francis et al. 1991). We used the same process to analyse all the spectra regardless of the image morphology, to give object identifications based on the spectra alone.

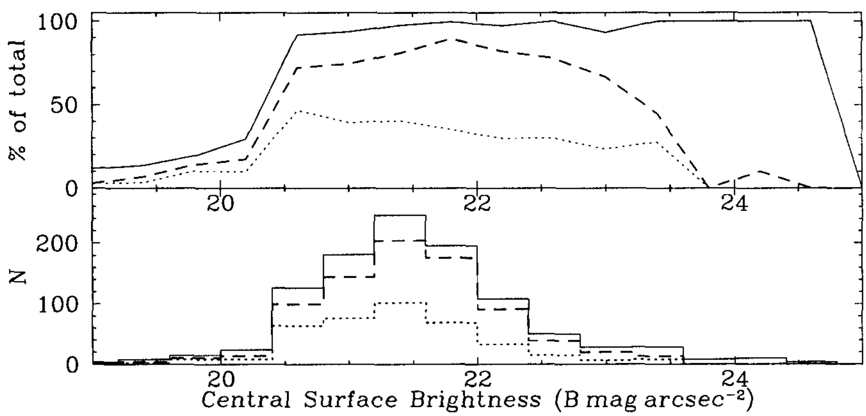


Figure 3. The galaxies observed (solid), with measured redshifts (dashed), and with strong emission lines (dotted) plotted as a fraction of the total sample (upper panel) and as histograms of the actual numbers (lower panel), both as a function of surface brightness.

Figure 3 indicates the success rate of the identifications for galaxies in the sample (i.e. fraction of objects with measured redshifts) as a function of surface

https://doi.org/10.1017/S0252921100054191 Published online by Cambridge University Press

brightness. This is fairly constant at about 90% except for the extremely LSB objects: the success rate drops below 50% fainter than 23 B mag arcsec^{-2}. We plan to extend our survey to fainter surface brightness limits in future observations with one long (order 6 hour) exposure in each field. This should permit us to get a reasonable completeness to 23.5 Bmag arcsec^{-2}. The Figure also shows that about half the identified galaxies have strong emission lines. This fraction increases to lower surface brightness, demonstrating the bias against identifying absorption line spectra at low signal-to-noise ratios.

4. Results

In this section we summarise the initial results of the survey, concentrating on the low surface brightness galaxies, but briefly reviewing the other objects. Most of the galaxy results are summarised in Figure 4 which shows the surface brightness plotted against redshift for all the galaxies measured so far. Note that we use the spectra to define which objects are galaxies: those with redshifts greater than 700 km s^{-1}, irrespective of morphology.

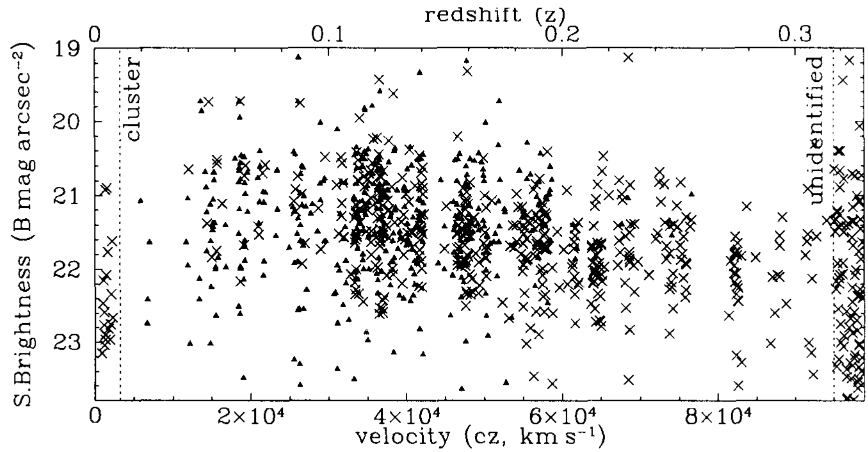


Figure 4. The distribution in surface brightness and redshift of all the galaxies observed so far. The triangles represent objects measured with strong emission lines; all others are indicated by crosses. Note that at redshifts above 55,000 km s^{-1} the Hα emission line is shifted out of the 2dF spectra, so very few galaxies are flagged for emission. Galaxies for which we could not measure a redshift are plotted at the right of the figure.

4.1. Galactic stars

In addition to the galaxies shown in Figure 4, we also have a large sample of stars. These will be used for studies of Galactic structure in later papers.

https://doi.org/10.1017/S0252921100054191 Published online by Cambridge University Press

4.2. Cluster galaxies

Our galaxy observations were limited in both magnitude and surface brightness, so only 20 galaxies classified as cluster members by Ferguson (1989, FCC) were observed. Of these, 4 were actually found to be background galaxies, the remaining 16 being confirmed as members.

We detected 5 more members of the Fornax Cluster that were not listed as cluster members in the FCC. Two of these new members were listed in the FCC as background galaxies because they had relatively high surface brightness (reported by Drinkwater & Gregg, 1998). Examples of these galaxies are shown in the top row of Figure 6. All the cluster members observed, most of which have central surface brightness $\mu_0 > 22.5B\,\mathrm{mag\,arcsec^{-2}}$, were identified by absorption line spectra, having no strong emission lines. The remaining 3 new members were not listed at all in the FCC, presumably because they were too faint. These new galaxies have red colours ($1.1 < B_J - R < 1.7\,\mathrm{mag}$) and appear to be very small (scale lengths less than 200 pc), low luminosity dwarf ellipticals ($-11.9 < M_B < -11.3\,\mathrm{mag}$). We use 15.4 Mpc as the Fornax cluster distance and 30.9 mag as the distance modulus (Bureau et al. 1996). Some of the brighter new cluster dwarf galaxies are shown in the middle row of Figure 6.

The detection of new cluster members like these weakens the correlation between magnitude and surface brightness proposed by Ferguson & Sandage (1988) and refuted by Irwin et al. (1990). We have replotted the data for this correlation in Figure 5 with the new cluster members plotted. The scatter in the relation is significantly increased, but the relation may still exist. We hope to resolve this with further observations.

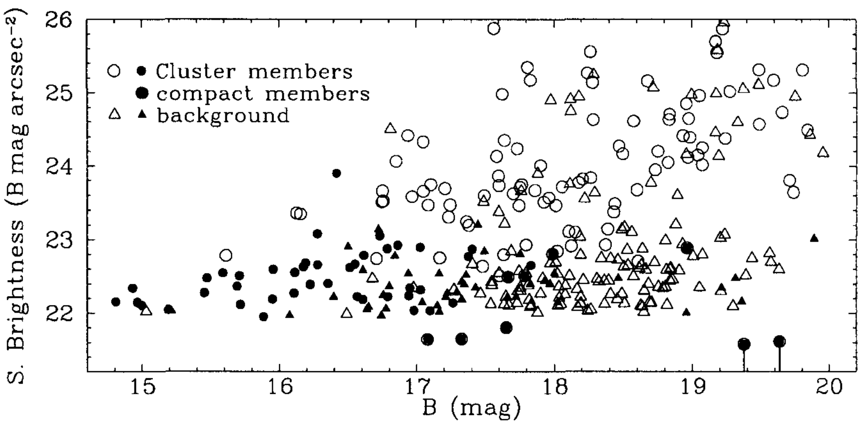


Figure 5. Magnitude–surface brightness relation for galaxies in the Fornax Cluster. The B band central surface brightness is plotted against B magnitude. The membership classifications are taken from the FCC (open symbols), except where they are now spectroscopically confirmed (closed symbols). The two new compact galaxies indicated at the lower right have surface brightnesses of 20.9.

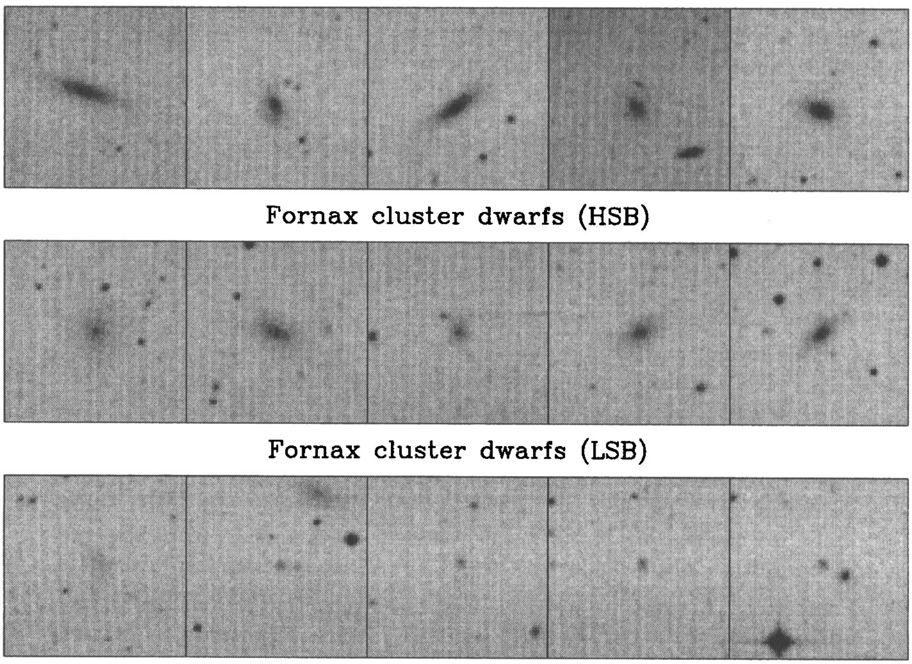
https://doi.org/10.1017/S0252921100054191 Published online by Cambridge University Press

4.3. Field galaxies

We denote as "field galaxies" all those galaxies beyond the Fornax cluster (i.e. $cz > 3500\,\mathrm{km\,s^{-1}}$ but excluding those identified as QSOs by having very broad emission lines. The field galaxies include several high surface brightness compact emission line galaxies which we have identified among the unresolved "stellar" objects. These are discussed in more detail by Drinkwater et al. (this volume).

It is apparent from Figure 4 that there is a tail of LSB galaxies extending below the main galaxy population at all redshifts. If we select the galaxies with central surface brightness $\mu_0 > 22.5\,\mathrm{B\,mag\,arcsec^{-2}}$ and redshift $cz < 50,000\,\mathrm{km\,s^{-1}}$ (so Hα is detectable), we note that they *all* have emission line spectra and have bluer colours ($-0.4 < B_J - R < 0.7\,\mathrm{mag}$) than the cluster LSBs. These field LSBs are luminous ($-19.6 < M_B < -17.0\,\mathrm{mag}$ for $H_0 = 75\,\mathrm{km\,s^{-1}Mpc^{-1}}$) and have relatively large scale lengths (2–5 kpc) making them more like local spirals (de Jong 1996) than dI galaxies. A selection of these LSB galaxies is shown in the bottom row of Figure 6.

We also note from Figure 4 that there remains a large number of LSB galaxies not yet identified (at the right edge of the Figure). These galaxies are very interesting: if cluster members they represent a significant new addition to the cluster luminosity function. On the other hand if they are background field galaxies they must include some very large galaxies.



Fornax cluster dwarfs (HSB)

Fornax cluster dwarfs (LSB)

background LSB galaxies

Figure 6. B_J-band images of the new galaxies. Each is 2′ across.

https://doi.org/10.1017/S0252921100054191 Published online by Cambridge University Press

4.4. QSOs

We have so far identified 52 QSOs in the first field to a limit of $B_J = 20.3$, generally consistent with published QSO number counts. We will eventually generate a large QSO sample relatively free of selection bias compared to other QSO surveys: for instance the current sample covers a redshift range of $0.3 < z < 3.1$.

5. Conclusions

In this paper we have presented results from the first 2500 spectra measured for *The Fornax Spectroscopic Survey*. We are continuing this project with more observations scheduled in 1998 November when we plan to extend the observed sample to fainter limits of surface brightness. When complete the survey will comprise a unique sample of the spectra of all 14,000 objects with $16.5 < B_J < 19.7$ in this $12\,\mathrm{deg}^2$ area of the Fornax Cluster. The ability to record spectra through 400 fibres simultaneously allows long exposures to be used while still sampling large numbers of galaxies. It is therefore possible to measure redshifts for the many low surface brightness galaxies observed in the direction of the Fornax Cluster, including both cluster members and background objects. Already new cluster members have been found, while other objects have been shown to be large field LSBGs in the background.

References

Bureau, M., Mould, J.R., Staveley-Smith, L., 1996, ApJ, 463, 60

Colless, M., Ellis, R.S., Taylor, K., Shaw, G. 1991, MNRAS, 253, 686

Davies, J.I., Phillipps, S., Cawson, M.G.M. , Disney, M.J., Kibblewhite, E.J. 1988, MNRAS, 232, 239

Drinkwater, M. J., Gregg, M. D. 1998, MNRAS, 296, L15

Drinkwater, M. J., Phillipps, S., Davies, J. I., Gregg, M. D., Jones, J. B., Parker, Q. A., Sadler, E. M., Smith, R. M. 1999. In preparation.

Ferguson, H. C., 1989, AJ, 98, 367 (FCC)

Ferguson, H. C., Sandage, A. 1988, AJ, 95, 1520

Francis, P.J., Hewett, P.C., Foltz, C.B., Chaffee, F.H., Weymann, R.J., Morris, S.L. 1991, ApJ, 373, 465

Irwin, M.J., Davies, J.I., Disney, M.J., Phillipps, S., 1990, MNRAS, 245, 289

Irwin, M., Maddox, S., McMahon, R. 1994, Spectrum, 2, 14

Jacoby, G.H., Hunter, D.A., Christian, C.A. 1984, ApJS, 65, 257

de Jong, R.S. 1996, A&A, 313, 45

Kron, R.G. 1980, ApJS, 43, 305

Kurtz, M.J., Mink, D.L., 1998, PASP, 110, 934

Morton, D.C., Krug, P.A., Tritton, K.P. 1985, MNRAS, 212, 325

Tonry, J., & Davies, M. 1979, AJ, 84, 1511