TITLE
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The INT-WFS + 2dFGRS: The Local Space & Luminosity Density.

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Abstract. We discuss the quantification of the local galaxy population and the impact of the "New Era of Wide-Field Astronomy" on this field, and, in particular, systematic errors in the measurement of the Luminosity Function. New results from the 2dFGRS are shown in which some of these selection effects have been removed. We introduce an INT-WFS project which will further reduce the selection biases. We show that there is a correlation between the surface brightness and the luminosity of galaxies and that new technologies are having a big impact on this field. Finally selection criteria from different surveys are modelled and it is shown that some of the major selection effects are surface brightness selection effects.

1. Introduction

Galaxy populations were first studied by Hubble (1926), who developed the familiar Tuning Fork diagram of Ellipticals, Spirals and Barred Spirals. Most bright galaxies can be morphologically classified by their Hubble type. However, many types of galaxy have been found that don't fit the Tuning Fork. These occur both at low redshift and at high redshift where the galaxies can be intrinsically different due to evolution. Some of these galaxies are shown in Fig. 1. The Tuning Fork can be extended to include these new types of galaxy as shown in Fig. 2.

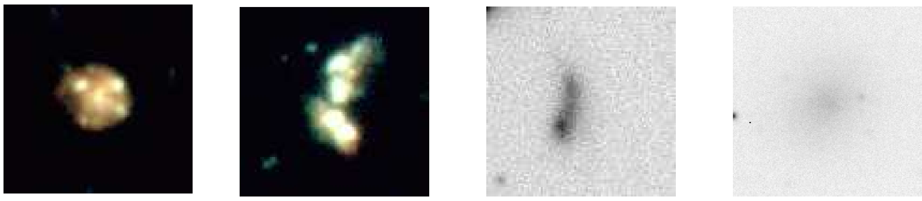

Figure 1. Some peculiar galaxies. The two on the left hand side are high redshift galaxies in the Hubble Deep Field North. The two on the right are low redshift galaxies from the Millennium Galaxy Catalogue. The farthest right galaxy is a Low Surface Brightness Galaxy.

However, morphological classification only tells us what type of galaxies there are. It does not tell us what proportion are of each type or whether

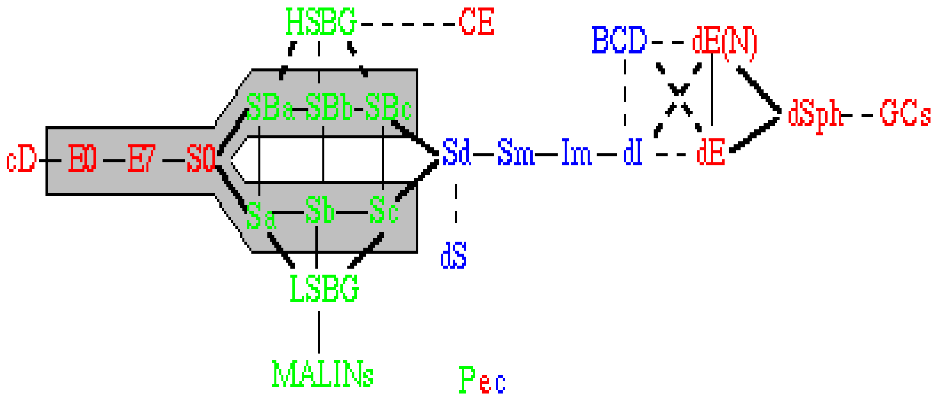

Figure 2. The various different classes of galaxies that astronomers have named over the years. The classes are positioned roughly in order of magnitude from bright on the left to faint on the right and in surface brightness from high surface brightness at the top to low surface brightness at the bottom. The Hubble Tuning Fork types make up most of the bright galaxies.

this varies over time. Galaxy formation and evolution is a relatively new field and so far very little is known about what produced the galaxy population we see today. To understand this process it is first necessary to have some quantitative information about the local galaxy population. The luminosity is an easy to measure quantity which can be used to classify galaxies. The Luminosity Function (LF) (Peebles & Hauser 1974) measures the space density of galaxies as a function of luminosity. This can be convolved with different evolutionary models and compared to number - magnitude counts (Driver et al. 1994). However, recent surveys have produced a large range in the measured LF, Fig. 3, with the variation between the surveys much greater than random errors. The systematic errors causing this wide variation must be understood before any progress is going to be made.

Disney (1976) pointed out that surface brightness selection effects are important to take into account when measuring the luminosity function. Phillipps & Disney (1986) and Phillipps, Davies & Disney (1990) went on to calculate the effects of surface brightness. These calculations take into account light lost below the isophote, Malmquist bias and surface brightness dimming due to cosmological expansion.

Here, we will discuss how we have used the "Two Degree Field Galaxy Redshift Survey" (2dFGRS) to produce a Bivariate Brightness Distribution (BBD), which corrects for these effects. Then we will describe some of the results and some of the selection effects that we have not corrected for. We will then briefly describe the Millennium Galaxy Catalogue (MGC), one of the projects in the Isaac Newton Telescope Wide Field Survey (INT-WFS). The MGC is a deep, imaging survey designed to remove some of the remaining selection effects. The selection effects are then modelled by convolving the BBD with different functions based on the visibility theory of Phillipps, Davies & Disney 1990) adopting parameters appropriate for the ESO Slice Project (ESP) (Zucca et al. 1997),

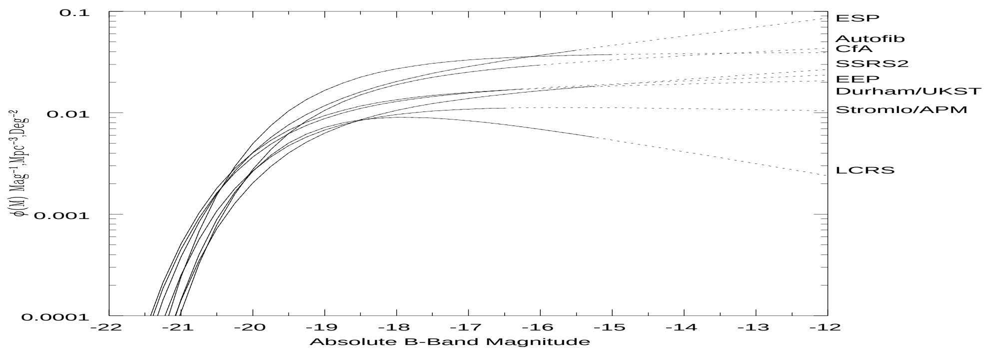

Figure 3. This is a plot of eight recent Galaxy Luminosity Functions. The variation at the M* ($M \approx -19.5$) point is a factor of 2 and at $M = -14.5$ the variation is a factor of 10. The M^* point is where the statistics are best. The variation would be expected to be of the order 10% if it where due to random errors. For more details see Cross et al. (2000).

the Las Campanas Redshift Survey (LCRS) (Lin et al. 1996) and the Second Southern Sky Redshift Survey (SSRS2) (Marzke et al. 1998).

2. The 2dFGRS

The 2dFGRS is a 2000□° redshift survey of the North Galactic and South Galactic Polar (NGP, SGP) regions. When it is complete it will have redshifts for 250,000 galaxies with $B < 19.45$. At present more than 100,000 redshifts have been measured, making this the largest survey to date by a factor of 4. The input catalogue is the APM catalogue (Maddox et al. 1990a,b). For more details on the 2dFGRS see the article in these proceedings by Bridges et al.

2.1. The Bivariate Brightness Distribution (BBD).

One method to remove surface brightness selection effects is to construct a BBD. This is a plot of the space density of galaxies versus the absolute magnitude, AND the effective surface brightness. This is a simple extension of the LF, whereby galaxies of different surface brightnesses are treated separately. In Cross et al. (2000), we describe how to construct the BBD for the 2dFGRS. Throughout this work, we make corrections based upon the data as much as possible. The data has been corrected for light lost below the isophote, Malmquist bias, redshift incompleteness and clustering. In each case these corrections were functions of both absolute magnitude AND effective surface brightness. The BBD was produced from 50,000 galaxies in the SGP.

2.2. Results

Fig. 4 shows the final Malmquist corrected space density of galaxies as a function of M_B and μ_e. There is a strong luminosity-surface brightness relation. L-

Σ relations are also seen in Driver (1999), Binggeli (1993) and de Jong and Lacey (2000). The shaded region on Fig. 4b shows where the volume is less than 10,000Mpc^3. This plot suggests that luminous LSBGs such as Malin 1 are extremely rare. Faint HSBGs such as M32 are likely to be rare as they are far from the L-Σ axis.

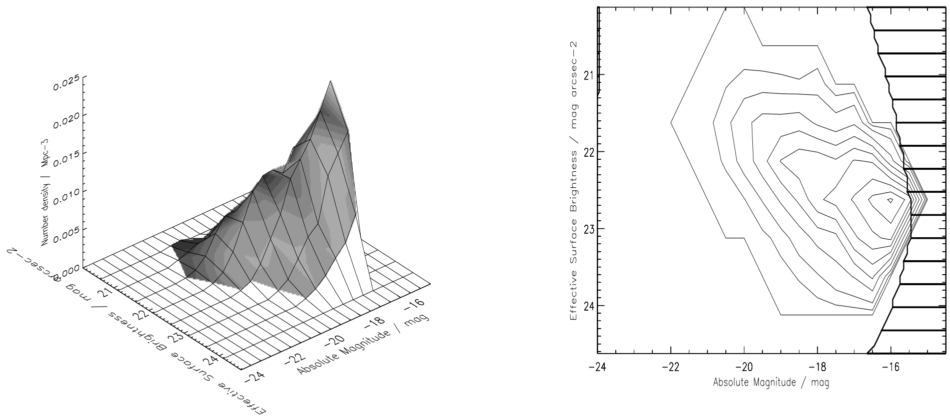

Figure 4. The 2dFGRS space density. These plots are reproduced from Cross et al. (2000). The contour levels are 1.0×10^{-7}, 1.0×10^{-3}, 2.5×10^{-3}, 5.0×10^{-3}, 7.5×10^{-3}, 1.0×10^{-2}, 1.25×10^{-2}, 1.5×10^{-2}, 1.75×10^{-2}, 2.0×10^{-2}, and 2.25×10^{-2} galaxies Mpc^{-3}bin^{-1} in the right hand plot.

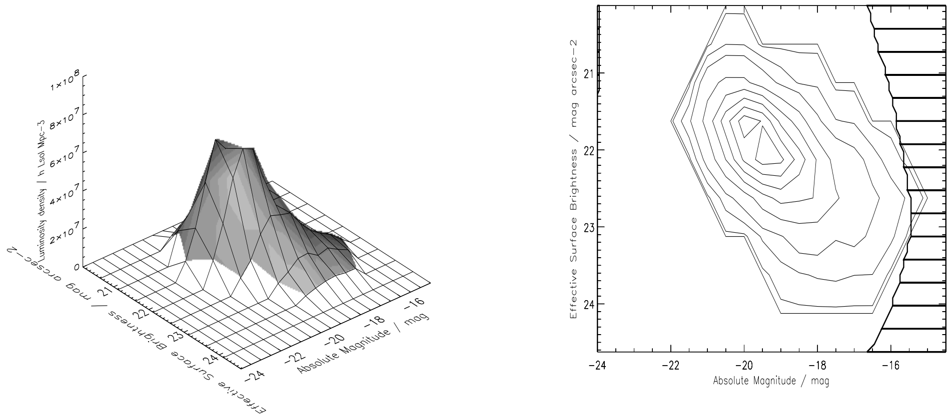

Figure 5. The 2dFGRS luminosity density. These plots are reproduced from Cross et al. (2000). The contour levels are 100, 1.0×10^{6}, 5.0×10^{6}, 1.0×10^{7}, 2.0×10^{7}, 3.0×10^{7}, 4.0×10^{7}, 5.0×10^{7}, and 6.0×10^{-2}L$_\odot$Mpc^{-3}bin^{-1} in the right hand plot.

The luminosity density $j = 2.62 \pm 0.20 \times 10^8 h_{100} L_\odot$Mpc^{-3}. The luminosity density is plotted as a function of absolute magnitude and surface brightness in Fig. 5. This shows clearly that the luminosity density is decreasing well before the selection boundaries imposed by the survey. This implies that we are indeed seeing the majority of the light emitted by local galaxies.

2.3. Problems with the 2dFGRS BBD.

The input catalogue completeness is a complex function of both surface brightness and magnitude. The curve on Fig. 4b shows where the volume, over which a galaxy can be detected, is equal to 10,000Mpc^3. Outside this region, the detection of galaxies becomes increasingly difficult. The input catalogue is only complete in regions determined by the detection isophote (24.7mag arcsec^{-2}), the apparent magnitude limit (19.45mag) and the smallest isophotal radius (3.6$''$). The smallest isophotal radius depends on the seeing ($> 2''$ for the APM).

The APM suffers from less than ideal photometry which is only accurate to $\sim$ 0.2mag. The data does not contain information on the light profiles of the galaxies such as disc-bulge separation parameters.

3. The Millennium Galaxy Catalogue.

To remove these problems we have undertaken a deep equatorial CCD survey over part of the 2dFGRS Northern Galactic Polar region. This survey is described in more detail in these proceedings by Lemon et al. It will push the boundaries of the $M - \mu_e$ plane that can be studied, giving us a quantitative measure of the population that we may have missed with the 2dFGRS. It will also improve the photometry of the galaxies we have already observed and allow us to do morphological classification and disc-bulge separation.

4. Modelling Selection Effects

Fig. 6 shows the Schechter function fits to three LFs shown in Fig. 3. These are the LCRS (Lin et al. 1996), the SSRS2 (Marzke et al. 1998) and the ESP (Zucca et al. 1997). The LCRS and ESP show the largest variation amongst the surveys. Also plotted are three lines showing the LFs produced when the 2dFGRS BBD is convolved with three different visibility functions. The parameters used for the LCRS are $\mu_{lim} = 23.3$Bμ, m$_{lim}$ = 19.2B, and d$_{min}$ = 4.0, calculated using a B-r colour of 1.5 (Driver et al. 1994). The parameters used for the ESP are $\mu_{lim} = 25.0$Bμ, m$_{lim}$ = 19.4B, and d$_{min}$ = 4.0. The parameters used for the SSRS2 are $\mu_{lim} = 25.0$Bμ, m$_{lim}$ = 15.5B, and d$_{min}$ = 4.0. This plot shows that the LFs can be reproduced well at the faint end. This demonstrates that surface brightness selection effects are a major systematic error in determining luminosity functions.

5. Conclusions

To understand the effects of evolution, it is essential to have a good quantitative knowledge of the local galaxy population.

It is apparent from Fig. 4 that our knowledge of the local galaxy population is limited by systematic errors rather than random errors.

A major systematic error is caused by surface brightness selection effects. These can be removed using a Bivariate Brightness Distribution.

The new technologies in this "New Era of Wide Field Astronomy" allow us to detect larger numbers of galaxies with higher precision. These new technologies are the multi-fibre spectrometers such as 2dF and the large format CCDs

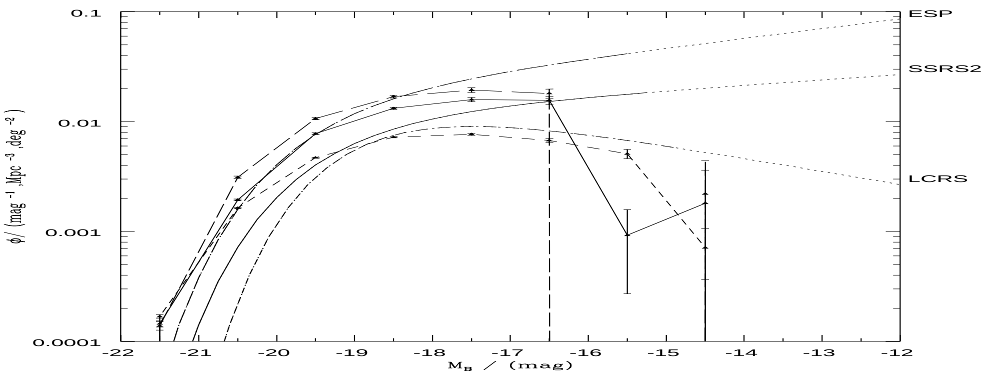

Figure 6. Plot of LFs of recent surveys. The smooth curves are the Schechter Function fits to the original surveys. The connected triangular points with error-bars are the luminosity distributions calculated by convolving the BBD with various selection functions. The SSRS2 is the solid line, the LCRS is the short-dashed line and the ESP is the long-dashed line. The dots represent where the data runs out for each survey.

such as those in the INT Wide Field Camera. These new surveys allow us to properly tackle the selection effects that have dogged our surveys and therefore will allow us to finally pin down the space and luminosity densities of galaxies.

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