Hunting for Field LSB Galaxies in Deep CCD Surveys

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Abstract

We present results from our analysis of public, deep, multicolor CCD mosaic images centered on the Hubble Deep Field South. Our resulting sample of LSB galaxies extends to smaller scale length, smaller total magnitude, and fainter surface brightnesses than earlier CCD and photographic surveys and implies a higher surface density of these galaxies. The presence of this population has immediate implications e.g. for the faint end of the local galaxy luminosity function. We also discuss our search technique and present a new method to select the local LSB galaxies against the background of cosmologically dimmed normal galaxies.

1 Introduction

During the last years, it has become more and more obvious that Low Surface Brightness (LSB) galaxies contribute an important part to the galaxy population – possibly up to 50 % (McGaugh, 1996). This high number of LSB galaxies implies that LSB galaxies also represent a large part of the baryonic dark matter in the local universe. For example this fraction could reach more than 40 % expecting constant number density out to 26 mag arcsec^{-2} (O'Neil 2000). If the number density is constant out to much fainter surface brightness LSB galaxies represent a much larger fraction of the baryonic dark matter.

With the availability of large CCDs and (now even) CCD mosaics conditions improved dramatically for observers to find and study LSB galaxies. More sensitive observations show that selection effects lead to missing a whole populations of galaxies (Disney & Phillipps, 1983, Davies, 1990). These selection effects resulted in the Freeman Law (Freeman, 1970), which implied a typical central surface brightness for disk galaxies of about $\mu_{0,\mathrm{B}} \sim 21.65 \pm 0.3$ mag arcsec^{-2}. For example the analysis of the Texas Survey, a CCD survey which covers a 10 deg^2 field- and 17 deg^2 cluster-region derived a field galaxy density of 4 galaxies deg^{-2} (O'Neil et al. 1997a,b). Therefore a major correction of the galaxy luminosity function is necessary, especially at the very faint end (Sprayberry et al. 1997). If so, LSB galaxies might constitute a significant reservoir of baryonic matter in the universe, and manifest a crucial class of galaxies for cosmology.

LSB galaxies are defined as galaxies with a central surface brightness fainter than $\mu_{\mathrm{B}}(0) \geq$ 22.0 mag arcsec^{-2} in the Johnson B-Band (Bothun et al. 1997). Their blue colors indicate that they are not simply faded remnants of High Surface Brightness (HSB) galaxies (McGaugh & Bothun 1994). They are also not necessarily HI poor dwarf galaxies. A LSB galaxy population of gas rich disk galaxies exist, which contains the largest and HI richest objects known (Bothun et al. 1987).

Until now not much is known about the formation and the evolution processes of this population of galaxies. We know that the star formation of these galaxies propagate with much lower rate as in HSB galaxies (van den Hoek et al. 2000). One reason of this reduced star formation could be the low HI surface densities which mostly reaches not the threshold above star formation occur (Bothun et al. 1997).

"Dwarf Galaxies and their Environment"; Bad Honnef, Germany, 23-27 January 2001; Eds. K.S. de Boer, R.-J.Dettmar, U. Klein; Shaker Verlag

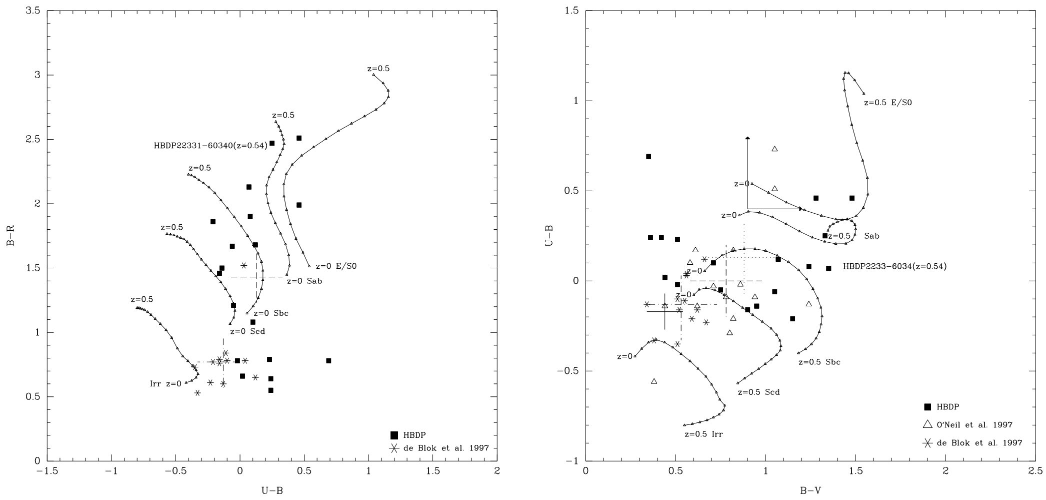

Figure 1: Color-Color (left: B-R vs. U-B , right: U-B vs. B-V) diagrams with the redshift tracks of the five standard galaxy types E/S0, Sab, Sbc, Scd, Irr(starburst) from Liu & Green (1998). Our objects are indicated by squares. For comparison we plot the samples from O'Neil et al. (1997a) (triangles) and de Blok (1997) (stars). Due to the larger color basis in the B-R vs. U-B diagram, in comparison to the U-B vs. B-V diagram, we have better separation between the LSB and the HSB galaxies.

2 Results and Conclusions

Here we present the results of a search for LSB galaxies in a 0.76 $\deg^2$ large field including the Hubble Deep Field South (HDF-S). We use very sensitive public multicolor data from the NOAO Deep Wide-Field survey (Dell'Antonio et al. 1999) and similar data provided by the Goddard Space Flight Center/STIS team. Our search uses a combination of two methods. For the brighter LSB galaxies (up to $\mu_0 \sim 24.5$ mag arcsec^{-2}) we scanned the images with the source extractor program SExtractor (Bertin & Arnouts, 1996) using a search filter optimized for faint and large objects. For the faintest objects ($\mu_0 \geq 24.5$ mag arcsec^{-2}) we adopted the electronical filter method from Armandroff et al. (1998). We filtered the images with a 25 pixel (10.75 arcsec) median filter and visually inspected the images for LSB galaxies. The relative large filter (25 pixels) was adapted in order to avoid being swamped by redshifted galaxies, cosmological dimmed into the LSB range. Note that this 25 pixel diameter aperture poses a selection criteria against much smaller and much larger objects.

The search results in a sample of 37 LSB galaxy candidates fainter than 22 mag arcsec^{-2}. A subsample of 18 galaxies was also measured on the smaller and less deep "Goddard" field. To select the LSB galaxies from the higher redshifted galaxies in our sample we used a variant of photometric redshifts (e.g. Koo, 1985), improving our observation, that LSB galaxies have different location in some color-color diagrams in comparison to normal galaxies.

We compare the location of our 18 galaxies (located also in "Goddard" field) in the color-color diagram (see Fig.1), with the location of five typical galaxy types (E/S0,Sab, Sbc, Scd, Irr(starburst)) adopted from Liu & Green (1998). LSB candidates show up in a different location of the U, B, V, R color space than HSB galaxies (see Fig.1). This indicates a different stellar population and evolution of these galaxies.

We have identified 9 galaxies as LSB galaxies (50%) due to their location in these color-color diagrams and 3 very faint candidates ($\mu_0 \geq 25$ mag arcsec^{-2}) which were detected only in the NOAO field.

Our search results in a number surface density of about 24 LSB galaxies deg^{-2} which is a factor of 6 higher in comparison to the Texas Survey (O'Neil et al. 1997a). The sensitivity of the used data and the small diameter of the galaxies in our sample could result in a distribution over a much larger volume as in other surveys. In this case our search would not effect the volume number density in the local Universe. Still, the morphology of many of these LSB candidates appears consistent with intrinsically small galaxies without spiral structure, supporting the presence of a local population of small LSB galaxies.

The distribution of the sample (see Fig.2) show a maximum at $\mu_0 \sim 23$ mag arcsec^{-2}. In spite of the higher sensitivity in comparison to other surveys (O'Neil et al. 1997a) this maximum is not shifted to much fainter central surface brightnesses. After inclination correction we find a broader distribution with a maximum around 23 -24 mag arcsec^{-2}. However there exists a second peak at much fainter central surface brightness which could be the result of the combination of two search methods and maybe indicates a second population of LSB galaxies.

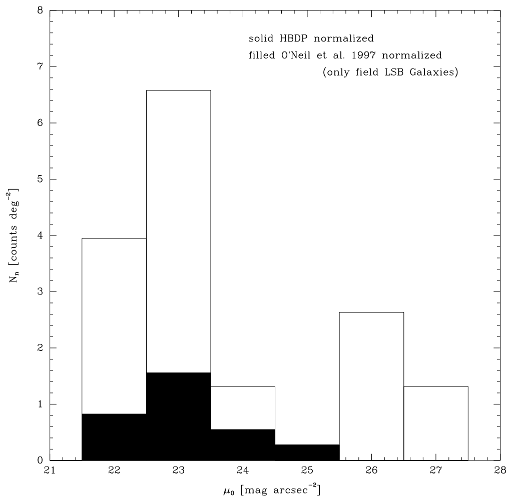

Figure 2: Central surface brightness distribution of our LSB galaxy sample. Both distributions have a maximum at $\mu_0 \sim 23$ mag arcsec^{-2} and a second peak at 26 mag arcsec^{-2}. After inclination correction we obtain a much broader distribution with a maximum around 23-24 mag arcsec^{-2} and also a second peak at 27 mag arcsec^{-2}. For comparison the field LSB galaxies distribution of O'Neil et al. (1997a) is plotted.

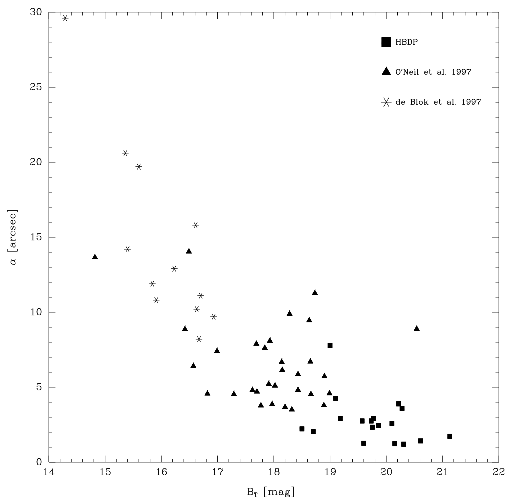

Figure 3: We plot the scale length against the central surface brightness. For comparison we use the LSB galaxy samples of O'Neil et al. (1997a, triangles) and de Blok (1997, stars). Our data are indicated with squares.

With this search we found galaxies with total, optical diameters between $12'' \leq d \leq 36''$ and scale length between $0.93'' \leq \alpha_{\rm B_W} \leq 6.31''$. The comparison of our galaxies with the LSB sample of O'Neil et al. (1997a) and de Blok (1997) show that we preferentially found galaxies with much smaller scale lengths (see Fig.3). These galaxies are possible missed in other survey because they are too small and too faint to be detected.

Depending on the search volume covered by our method, the data seem to imply the presence of a large population of intrinsically small low surface brightness galaxies, a population previously hinted at by LSB counts outside the Fornax cluster (Kambas et al. 2000). The other major result of our study is the detection of a population of very low surface brightness galaxies with central surface brightness of 27 mag arcsec^{-2}, which could have significant impact on the baryon content of the local universe.

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