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The properties of a large sample of low surface brightness galaxies from SDSS

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Abstract. A large sample of low surface brightness (LSB) disk galaxies is selected from SDSS with B-band central surface brightness μ_0(B) from 22 to 24.5 mag arcsec^{-2}. Some of their properties are studied, such as magnitudes, surface brightness, scalelengths, colors, metallicities, stellar populations, stellar masses and multiwavelength SEDs from UV to IR etc. These properties of LSB galaxies have been compared with those of the galaxies with higher surface brightnesses. Then we check the variations of these properties following surface brightness.

Keywords. galaxies: abundances, galaxies: evolution, galaxies: spiral, galaxies: starburst

1. Introduction

Low Surface Brightness Galaxies (LSBGs) are important populations in galaxy field. However, their contributions to galaxy population have been underestimated for a long time since they are hard to find owing to their faintness compared with the night sky. An initial quantitative study was made by Freeman (1970), who noticed that the central surface brightness of their 28 out of 36 disc galaxies fell within a rather narrow range, μ_0(B) = 21.65 ± 0.3 mag arcsec^{-2}. This could be caused by selection effects (Disney 1976).

Since then, many efforts have been made to search for large number of LSBGs from surveys (Bothun & Impey 1997; Impey & Bothun 1997; Zhong *et al.* 2008 and references therein). One of the important ones is the APM survey, i.e., Impey *et al.* adopted the Automated Plate Measuring (APM) mechanism to scan UK Schmidt plates and discovered 693 LSBGs which forms the most extensive catalog of LSBGs to that date (Impey *et al.* 1996). O'Neil *et al.* (1997, in "Texas survey") firstly found the red LSBG populations. Monnier Ragaigne *et al.* (2003) selected a sample of about 3800 LSBGs from the all-sky near-infrared 2MASS survey, and then made HI observations for a sub-sample.

The modern digital sky survey, such as the Sloan Digital Sky Survey (SDSS), certainly provide a wonderful chance for us to find much more LSBGs. Kniazev *et al.* (2004) developed a method to search for LSBGs from SDSS images and used the APM sample to test their method. They recover 87 same objects and 42 new LSBGs. Recently, our group (Zhong *et al.* 2008) successfully select a large sample of LSBGs from SDSS-DR4 main galaxy sample, which includes 12,282 nearly face-on disk galaxies with low surface brightness μ_0(B) $\geqslant$ 22 mag arcsec^{-2}, and another 18,051 high surface brightness galaxies (HSBGs) with μ_0(B) < 22 mag arcsec^{-2} are also selected for comparisons. This will be a very efficient sample to study the properties of LSBGs, and to check the variation of these properties with surface brightnesses if there exists. We have studied some properties of this large sample. Zhong *et al.* (2008) presented the sample selection criteria, and their magnitudes, surface brightness, scalelengths and colors etc. The metallicities (Liang *et al.* 2009, in preparation) and stellar populations (Chen *et al.* 2009, in preparation) are also studied from optical spectra, i.e. the emission lines, continua and absorption lines. In addition, the modern digital sky surveys have been made in wide wavelength ranges, such as GALEX-UV, SDSS-optical, 2MASS-NIR, IRAS-IR etc. These allow us to construct the multi-wavelength SEDs for our sample galaxies (Gao *et al.* 2009, in preparation), which are very useful and efficient to study their star formation history. In this paper, we summarize the interesting results we obtained for this large sample of galaxies, which will be presented in detail in the series work mentioned above. Especially, we try to check the varying trends of their properties following surface brightness. A cosmological model with $H_0 = 70$ km s^{-1} Mpc^{-1}, $\Omega_M = 0.3$ and $\Omega_\lambda = 0.7$ is adopted in this paper.

2. The sample, the correlations between M_B and log$h$, log$D$ and log$h$

We select 30,333 nearly face-on disk galaxies from the SDSS-DR4 main galaxy sample. They have been estimated the reliable surface brightness values and minimize the effect of dust extinction inside the galaxies. The selection criteria are given below.

(a) $fracDev_r < 0.25$ ($fracDev_r$ indicates the fraction of luminosity contributed by the de Vaucouleurs profile relative to exponential profile in the r-band, and this low value for limit can also minimize the effect of bulge light on the disk galaxies);

(b) $b/a > 0.75$ (for nearly face-on galaxies, where a and b are the semi-major and semi-minor axes of the fitted exponential disk respectively);

(c) $M_B <$ -18 (this excludes the few (6%) dwarf galaxies contained in the sample).

Taking μ_0(B)=22 mag arcsec^{-2} as criterion, 12,282 objects are confirmed as LSBGs and other 18,051 objects are confirmed as HSBGs. The properties of this large sample of LSBGs have been studied carefully by Zhong *et al.* (2008). Specially, these LSBGs show clear correlations between M_B and log$h$, and between log$D$ and log$h$, which mean that the brighter galaxies tend to have larger scalelengths and the galaxies with larger scalelengths have the benefit to be detected and observed in the more distant universe.

Furthermore, both of the LSBGs and HSBGs can be divided into two sub-groups following μ_0(B), which will allow us to study their properties in a sequence of surface brightness. The criteria for $\mu_0(B)$ (in mag arcsec^{-2}) are following McGaugh (1996): sLSBGs (2,815) with 22.75-24.5, ISBGs (9,467) with 22.0-22.75, sHSBGs (10,989) with 21.25-22.0, VHSBGs (7,062) with <21.25. Fig.1a shows the relations of M_B vs. log$h$ for the samples in these four sub-groups. Fig.1b shows that for log$D$ vs. log$h$. All the four sub-groups show clear correlations. However, the comparisons among these four show that, at a given disk scalelength, the galaxies having higher μ_0(B) are brighter, and could be observed at a farther distance. There are gradually varying trends following surface brightnesses of the galaxies.

3. The metallicities

Metallicity is an important parameter of galaxy and a good tracer for their evolution history. The metallicities of this large sample of nearly face-on disk galaxies can be estimated from optical emission lines. To select the target galaxies with good quality spectroscopic observations, we adopt the criteria below (following Liang *et al.* 2006 and Tremonti *et al.* 2004).

(a) Cross correlating between our sample and the SDSS-DR4 spectroscopic database.

(b) The fluxes of the emission lines of the galaxies have been measured for [O II], Hβ, [O III], Hα, [N II], and the line Hβ, Hα, and [N II]6584 are detected with S/N ratios

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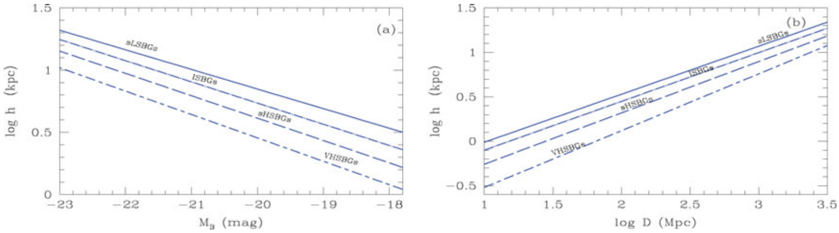

Figure 1. (a) Correlation of disk scale length and luminosity for the whole sample galaxies with $\mu_0(B)$ from 18.0-24.5 mag arcsec^{-2}, (b) correlation of disk scale length and distances for them: sLSBGs (24.5-22.75, the solid line); lSBGs (22.75-22.0, the dot-long dash line); sHSBGs (22.0-21.25, the long-dash line); VHSBGs (<21.25, the short-long dash line).

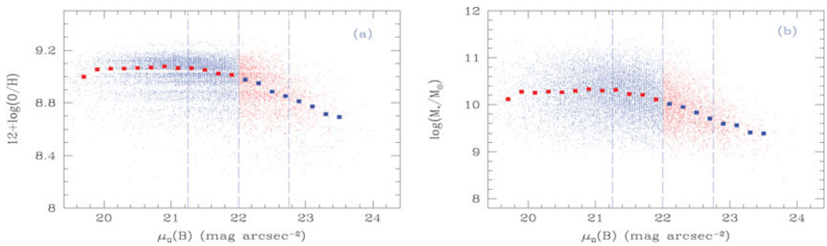

Figure 2. (a) The relations of 12+log(O/H) vs. $\mu_0(B)$ for the star-forming galaxies, (b) the relations of stellar mass vs. $\mu_0(B)$ of them. The median values in each of the bins of 0.2 in $\mu_0(B)$ are also given as the big squares. The three vertical long-dashed lines at 22.75, 22.0 and 21.25 mark the ranges of $\mu_0(B)$ for the four sub-groups of sLSBGs, lSBGs, sHSBGs, VHSBGs.

greater than 5σ. Then the selected sample in the four sub-groups are 1,364 in sLSBGs, 6,055 in lSBGs, 9,107 in sHSBGs are 6,231 in VHSBGs.

(*c*) Selecting the star-forming galaxies by using the diagnostic diagram of [N II]/Hα vs. [O III]/Hβ following Kauffmann *et al.* (2003a). Now we obtain 1,299 of sLSBGs, 5,551 of lSBGs, 8,310 of sHSBGs, and 5,872 of VHSBGs. This also means that the AGN fractions of these sub-groups are quite small.

The 12+log(O/H) abundances of these star-forming galaxies are taken from the MPA/JHU database (Tremonti *et al.* 2004). The median values in the four sub-groups are 8.77 for sLSBGs, 8.94 for lSBGs, 9.03 for sHSBGs, and 9.06 for VHSBGs. This means that the galaxies have lower surface brightness generally have lower metallicity.

Fig. 2a shows the relations of 12+log(O/H) vs. $\mu_0(B)$ of the star-forming galaxies in the four sub-groups. The median values in each of the bins of 0.2 in $\mu_0(B)$ are also given (the big squares), as well as the three vertical long-dashed lines at $\mu_0(B)$=21.25, 22.0 and 22.75 to mark the ranges of $\mu_0(B)$ for the four sub-groups. A general varying trend shows that, for the sLSBGs, lSBGs and sHSBGs, the galaxies with lower surface brightness have lower metallicity. We further obtain the stellar masses of these sample galaxies from the MPA/JHU database (Kauffmann *et al.* 2003b), and present their relations with $\mu_0(B)$ in Fig. 2b. It shows that, for the sLSBGs, lSBGs and sHSBGs, the galaxies with lower surface brightness have smaller stellar mass generally. These are in agreement with the stellar mass-metallicity relations of the galaxies.

4. The stellar populations and multiwavelength SEDs

We study the stellar populations of this sample of star-forming galaxies by using the software STARLIGHT (Cid Fernandes *et al.* 2005; Chen *et al.* 2009) to fit the optical spectral absorptions and continua. The template for spectral synthesis analysis are the simple stellar populations from Bruzual & Charlot (2003). We combined the spectra of

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all the objects to be one spectrum in each of the sub-samples, then we synthesize these combined spectra. The results show that the importance of young populations increases from sLSBGs to ISBGs, sHSBGs, and to VHSBGs (more details in Chen *et al.* 2009, in preparation).

Since the multiwavelength modern digital sky surveys have observed and released a very large sample of objects to public, such as GALEX-UV, SDSS-optical, 2MASS-NIR and IRAS-IR (the Spitzer/SWIRE survey also release their IR data, but in a much smaller sky coverage). Therefore, we cross correlate our such large sample of nearly face-on disk galaxies selected from optical with the observations at UV, NIR and IR, and then construct their multiwavelength SEDs. We extend the SDSS-DR4 to the DR7 main galaxy sample here, which expands to be 21,666 LSBGs and 30,898 HSBGs by following the same criteria given in Sect.2. Finally we obtain about 280 LSBGs and 300 HSBGs with reliable observations from UV to IR. If without considering IR, there are about 2100 LSBGs and 7300 HSBGs having multiwavelength observations from UV to NIR. These will be good samples to study the multiwavelength SEDs and stellar formation history of galaxies. One of the useful model to analyze their SEDs is GRASIL (Silva *et al.* 1998). This model could produce the multiwavelength SEDs of galaxies, such as M51 (nearly face-on disk), M82 (starburst) and NGC 6090 (strongly interacting galaxy) etc. Our sample could be compared with these SEDs and hopefully they will be similar to those of M51 and/or M82.

In summary, we have selected a large sample of LSBGs from SDSS, which could provide interesting and important results for understanding the properties of this kind of galaxies. Also it must be very useful to better understand their contribution to the local galaxy population. Their effects on the number density, light density and light functions of galaxies in the local universe will be further studied.

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