Mon. Not. R. Astron. Soc. **000**, 000–000 (0000) Printed 15 October 2010 (MN LaTeX style file v2.2)

Bar fraction in lenticular galaxies: dependence on luminosity and environment

Sudhanshu Barway [1]⋆, Yogesh Wadadekar [2]†, and Ajit K. Kembhavi [3]‡
[1]*South African Astronomical Observatory, P.O. Box 9, 7935, Observatory, Cape Town, South Africa;*
[2]*National Centre for Radio Astrophysics, Post Bag 3, Ganeshkhind, Pune 411007, India;*
[3]*Inter University Centre for Astronomy and Astrophysics, Post Bag 4, Ganeshkhind, Pune 411007, India.*

15 October 2010

ABSTRACT

We present a study of bars in lenticular galaxies based on a sample of 371 galaxies from the SDSS-DR 7 and 2MASS in optical and near-infrared bands, respectively. We found a bar in 15% of the lenticular galaxies in our sample, which is consistent with recent studies. The barred galaxy fraction shows a luminosity dependence, with faint lenticular galaxies ($M_K > -24.5$, total absolute magnitude in K band) having a larger fraction of bars than bright lenticular galaxies ($M_K < -24.5$). A similar trend is seen when $M_r = -21.5$, the total absolute magnitude in SDSS r band is used to divide the sample into faint and bright lenticular galaxies. We find that faint galaxies in clusters show a higher bar fraction than their counterparts in the field. This suggests that the formation of bars in lenticular galaxies not only depends on the total luminosity of galaxy but also on the environment of the host galaxy.

Key words:
galaxies: elliptical and lenticular - fundamental parameters galaxies: photometry - structure - bulges galaxies: formation - evolution

1 INTRODUCTION

The presence of bars has important implications for disk galaxies due to their deep connection with the dynamical and secular evolution of such galaxies (Kormendy & Kennicutt 2004). N-body simulations and many theoretical studies predict that bars transfer angular momentum to the outer disk, which causes the stellar orbits in the bar to become elongated and the bar amplitude to increase (Pfenniger & Friedli 1991; Sellwood & Wilkinson 1993; Athanassoula 2003). The growing bar becomes more and more efficient in driving gas in towards the centre of the disk, which can trigger star-bursts (Hunt & Malkan 1999; Sakamoto et al. 1999; Regan & Teuben 2004) and contribute to the formation of disky bulges or pseudo bulges (Kormendy & Kennicutt 2004; Debattista et al. 2004; Athanassoula et al. 2005; Jogee et al. 2005; Sheth et al. 2005; Debattista et al. 2006). Bars are typically dominated by evolved stellar populations (Gadotti & de Souza 2006) but sometimes they are also associated with enhanced nuclear and circumnuclear star formation (Ho et al. 1997). Barred galaxies are observed to have larger reservoirs of molecular gas in their centres relative to unbarred galaxies (Sakamoto et al. 1999, Sheth et al. 2005). A recent study by Barazza et al. (2008), with a large sample, found that the bar fraction is higher in blue, lower-luminosity, late-type disks compared to more massive, red, early-type galaxies. However, bars in early-type galaxies tend to be stronger, more elongated and longer, both in an absolute sense and relative to the size of the disk (Elmegreen & Elmegreen 1985; Erwin et al. 2005; Menendez-Delmestre et al. 2007). There have been a few studies on the relation between the bar fraction and environment of the host galaxy which suggest that the frequency of bar formation does not depend significantly on host galaxy environment (Aguerri et al. 2009, Barazza et al. 2009; Marinova et al. 2009; van den Bergh 2002). On the other hand, some studies have suggested that barred galaxies are more concentrated towards cluster centers than unbarred disks in rich clusters like Coma and Virgo (Barazza et al. 2009; Thompson 1981; Andersen 1996).

Optical and near-infrared imaging has revealed bars (both prominent and weak) in a majority (50-70%) of local disk galaxies, including lenticular galaxies and irregulars, with a wide range of bulge-to-total luminosity ratio and mass (de Vaucouleurs 1963; Eskridge et al. 2000 Whyte et al. 2002; Marinova & Jogee 2007; Menendez-Delmestre et al. 2007; Barazza et al. 2008). A substantial population of bars exists in lenticular galaxies (Nair & Abraham 2010; Aguerri et al. 2009) which are not dynamically cool, indicating that the mechanism responsible for the formation of the bar is more complex than the accepted mechanism based on dynamical

---

⋆ E-mail: barway@saao.ac.za (SB)
† E-mail: yogesh@ncra.tifr.res.in (YW)
‡ E-mail: akk@iucaa.ernet.in (AKK)

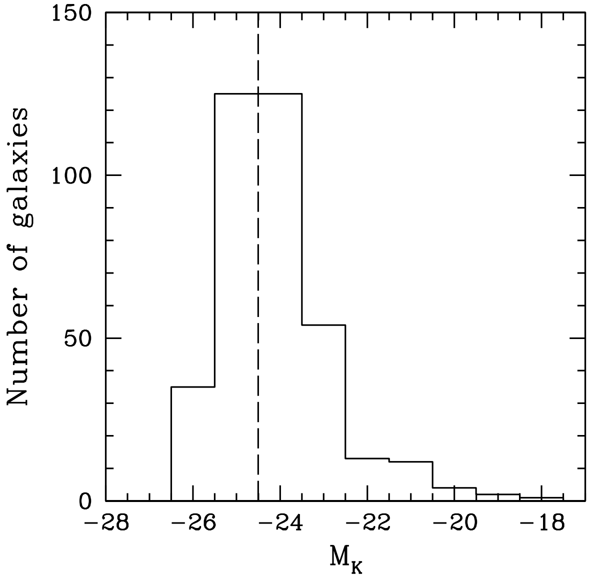

Figure 1. Distribution of total K band absolute magnitude (M_K). The vertical dashed line corresponds to total absolute magnitude M_K = -24.5, which we use to divide low- and high-luminosity lenticular galaxies in the near-IR.

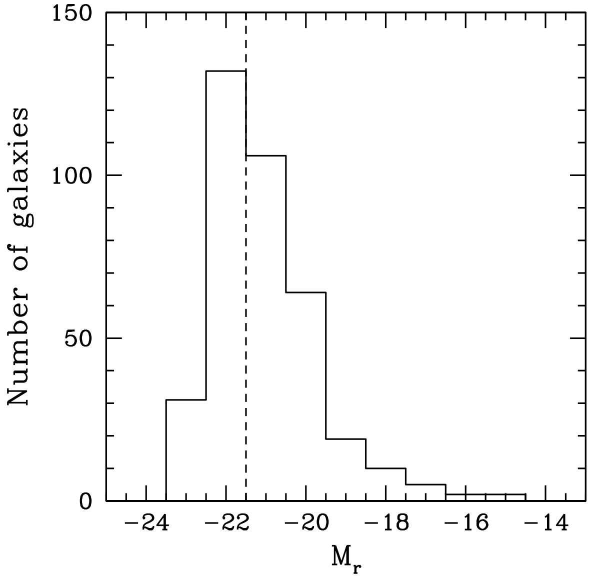

Figure 2. Distribution of total r band absolute magnitude (M_r). The vertical dashed line corresponds to total absolute magnitude M_r = -21.5, which we use to divide low- and high-luminosity lenticular galaxies in the optical.

instabilities in cold stellar systems (Bournaud & Combes 2002). The lenticular galaxies introduced by Hubble (1936) as a morphological transition class between elliptical and early-type spiral galaxies, which have most the massive bulges among disk galaxies, may have formed in several different ways as suggested by theoretical and numerical simulation studies (Bekki 1998; Abadi et al. 1999).

Barway et al. (2009, 2007) have presented evidence to support the view that the formation history of lenticular galaxies depends upon their luminosity. According to this view, luminous lenticulars are likely to have formed their bulges at early epochs through a rapid collapse followed by rapid star formation, similar to the formation of elliptical galaxies (Aguerri et al. 2005). On the other hand, low-luminosity lenticular galaxies likely formed by the stripping of gas from the disc of late-type spiral galaxies, which in turn formed their pseudo bulges through secular evolution processes induced by bars. If this is true there must be signatures of the formation mechanism imprinted in the light profile (correlated bulge disk sizes), stellar populations (as traced by colours), stellar kinematics (as traced by 3D spectroscopy) and more evidently in the presence of a kinematic structure such as a stellar bar.

In this Letter, we present evidence for a significantly enhanced probability of the existence of a bar in fainter lenticular galaxies relative to brighter ones. We focus on the variation of the bar fraction in lenticular galaxies with total luminosity, in K band as well as r band, using 2MASS and SDSS data, respectively. We use a sample of 371 lenticular galaxies in the local Universe in the present study. Throughout this Letter, we use the standard concordance cosmology with $\Omega_M = 0.3$, $\Omega_\Lambda = 0.7$, and $h_{100} = 0.7$.

2 THE SAMPLE AND DATA

We aimed for a sample, from the field as well as cluster environments, which is a fair representation of the lenticular (S0) galaxy population in the near-by universe and has a statistically meaningful number of galaxies spanning a large range of luminosities. We began by selecting all galaxies with apparent blue magnitude brighter than $m_B = 14$ and classified as lenticular in the Uppsala General Catalogue of Galaxies (UGC; Nilson 1973). The UGC is essentially complete to a limiting major-axis diameter of 1 arcmin, or to a limiting apparent magnitude of 14.5 on the blue prints of the Palomar Observatory Sky Survey for the sky north of declination -2°.5. This provides a sample of 635 lenticular galaxies. Next, we searched the Sloan Digital Sky Survey Data Release 7 (SDSS-DR7; Abazajian et al. 2009) to get data from that survey on our sample of lenticular galaxies. We found that 387 lenticular galaxies have SDSS-DR7 imaging in five bands (u, g, r, i, z). All of these galaxies except two (which are affected by artifacts in the 2MASS scans) have near-infrared data from 2MASS in J, H and K bands as well. We also use the *Hyperleda*[1] database and *NASA Extragalactic Database (NED)*[2] for distance measurements and morphological classifications. For four galaxies we do not have distance measurements and 10 galaxies are classified as either elliptical or spiral in both *NED* and *Hyperleda* databases. After excluding these galaxies, we are left with a final sample of 371 lenticular galaxies for which we report our analysis in this Letter. We have not applied any inclination cut on our sample galaxies. The sample, while not complete, is representative of lenticular galaxies in the nearby universe and with the availability of multi-wavelength data is an unprecedented resource to study lenticular galaxy properties.

We retrieved the data for all sample galaxies in the form of images and photometric/spectroscopic measurements from SDSS and 2MASS data archives. The magnitudes reported here are not corrected for galactic extinction and K-correction (which will be small because all galaxies have $z \leq 0.05$). In Figure 1 we show the distribution of total absolute magnitude (M_K) in the K_s band

---

[1] http://leda.univ-lyon1.fr/

[2] http://nedwww.ipac.caltech.edu/

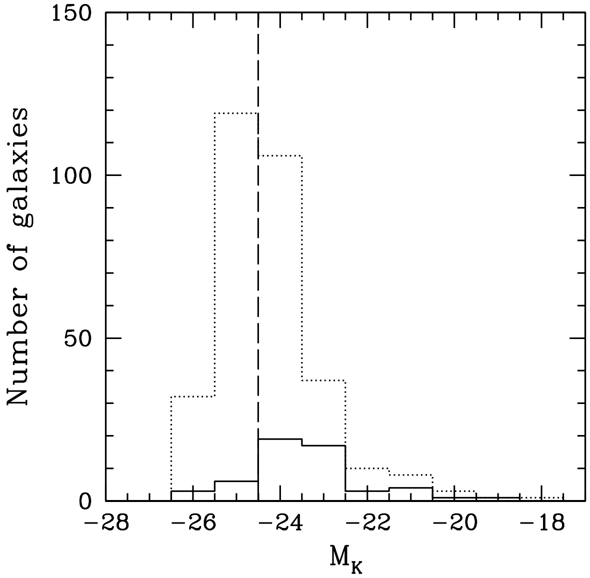

Figure 3. Distribution of barred (solid line) and unbarred galaxies (dotted line) as a function of total absolute magnitude (M_K). The vertical dashed line corresponds to total absolute magnitude M_K = -24.5, which we use to divide low- and high-luminosity lenticular galaxies. 54 galaxies are classified as barred in the *HyperLeda* database.

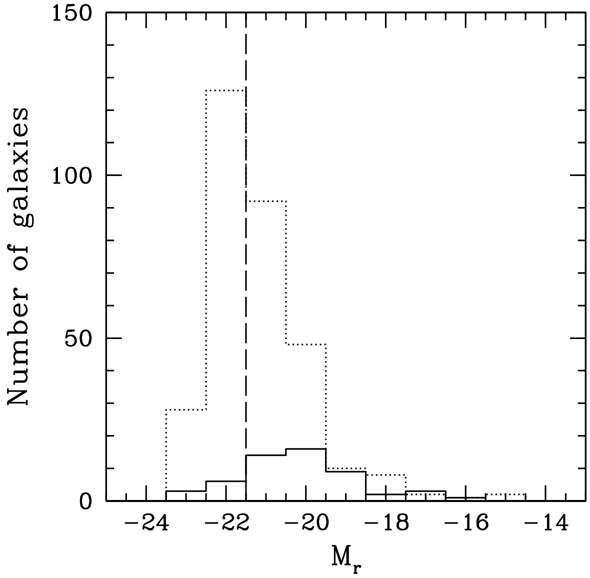

Figure 4. Distribution of barred (solid line) and unbarred galaxies (dotted line) as a function of total absolute magnitude (M_r). The vertical dashed line corresponds to total absolute magnitude M_r = -21.5, which we use to divide low- and high-luminosity lenticular galaxies. 54 galaxies are classified as barred in the *HyperLeda* database.

for the sample, which is seen to span a wide range in luminosity ($-26.5 < M_K < -17.5$). We divide the sample into faint and bright groups, using $M_K = -24.5$ as a boundary following Barway et al. (2007;2009). The boundary at $M_K = -24.5$ is somewhat arbitrary but our results do not critically depend on small (~ 0.5 mag) shifts in the dividing luminosity. The bright group has 160 (43 %) lenticular galaxies while the remaining 211 (57 %) lenticular galaxies belong to the faint group. Using a typical colour of $r - K = 3.0$ for early-type galaxies (Fukugita et al. 1995; McIntosh et al. 2006) this luminosity division in K band corresponds to $M_r = -21.5$ in SDSS r band. Using this, we divide the sample into faint and bright groups in the optical as well. According to this luminosity division the bright group has 163 (44 %) lenticular galaxies while 208 (56 %) lenticular galaxies belong to the faint group (Figure 2), with absolute r magnitudes being in the range $-23.5 < M_r < -14.5$.

3 ANALYSIS AND RESULTS

Historically, bars were identified by eye, by experts using a variety of criteria (de Vaucouleurs 1963, Eskridge et al. 2000). The most widely adopted quantitative technique for identifying bars is the ellipse-fitting method, in which a bar must exhibit a characteristic signature in both the ellipticity and position angle profiles (Marinova & Jogee 2007; Barazza et al. 2008; Sheth et al. 2008; Knapen et al. 2000). A simplified version of this technique measures the difference in the axial ratio and position angles of a best-fit ellipse to one interior and exterior isophote (Whyte et al. 2002). In general, the visual and ellipse-fitting methods agree about 85% of the time, with egregious disagreement only 5% of the time (Menendez-Delmestre et al. 2007, Sheth et al. 2008). In edge-on galaxies, as Combes & Sanders (1981) first pointed out, bars result in boxy- or peanut-shaped bulges (Athanassoula 2005, Bureau et al. 2006). Studying the Fourier modes of the light distribution (Aguerri et al. 1998, 2000; Laurikainen et al. 2005), or fitting the different structural components to the surface brightness distribution (Prieto et al. 2001; Aguerri et al. 2005; Laurikainen et al. 2005; Weinzirl et al. 2009) have also been used to reveal the presence of a bar.

In the present study, we used two methods to identify a galaxy as barred: (1) we checked if each galaxy was classified as barred in the *HyperLeda* and *NED* databases and (2) we independently, visually, classified each lenticular galaxy as barred or unbarred using SDSS images in optical and 2MASS images in the near-infrared. In order to reach a higher S/N than that of the individual images in different filters, we produced a combined image, as described in Lisker et al. (2006), by co-adding the g, r, and i for SDSS and J, H, and K for 2MASS by applying weights to each image, following Kniazev et al. (2004). The visual inspection of these co-added SDSS and 2MASS images was carried out by us to look for the presence of a bar. The two classification methods were in close agreement with a consistency level better than 98%. A caveat in using this approach is that our methods do not make any distinction between strong, weak and nuclear bars. In the few cases of conflict between our classification and the Hyperleda classification, we use the Hyperleda one. It must be remembered that bar identification is highly subjective because (a) one might miss weak bars during visual classification if the images are too shallow or (b) one might miss some bars because of inclination effects that we have not considered. Nevertheless, the consistency between our visual classification and that in Hyperleda was very good, indicating that only obvious, strong bars were being identified in both cases .

A bar was found in 15% of the lenticular galaxies in our sample i. e., 54 galaxies were classified as barred in *HyperLeda* and *NED* database as well as from our visual inspection of SDSS and 2MASS co-added images. This should be taken as a lower limit of detection of bars in lenticular galaxies as the fraction of galaxies classified as barred strongly depends on the techniques used to detect the bars (Aguerri et al. 2009). Our detected bar fraction agrees well with a recent study by Nair & Abraham (2010) based on a catalogue of detailed visual classification for 14,034 galaxies in the SDSS DR4. Out of 966 lenticular galaxies in the Nair & Abraham (2010) sample, 117 (12%) were classified as barred which is also consistent with the RC3 visual strong bar fractions in the local universe. These authors have adopted the bar classification scheme in which all the bar types are viewed as definite bars and is more conservative than that of the RC3, where systems classified as weakly barred include objects that only possibly contain bars. The bar fractions reported by these authors as well as from our study are low compared to some previous studies which quote bar fractions as high as 60% (de Vaucouleurs 1963; Aguerri et al. 2009) in lenticular galaxies.

Our analysis finds that the bar fraction in lenticular galaxies depends on the luminosity. In Figure 3 and Figure 4 we show the distribution of barred and unbarred lenticular galaxies as a function of luminosity in 2MASS K and SDSS r band, respectively. The distribution for barred lenticular galaxies in both optical and near-infrared bands reveals that 83% of the barred lenticular galaxies belong to the faint group while the bright group has 17 % barred lenticular galaxies out of 54 barred lenticular galaxies in our sample. Bars are found in 21% of fainter lenticular galaxies while they are found in only 6% of more luminous lenticular galaxies. This suggest that bars occur preferentially in faint lenticular galaxies pointing to a possible fundamental difference in the way in which faint and bright lenticular galaxies are formed as suggested by Barway et al. (2009;2007).

It would be particularly interesting to know whether environment plays a role in the dichotomy in bar fraction for the bright and faint lenticular galaxies that we found in our investigations. This is important because lenticular galaxies are more common in high density environments (i. e. , groups and clusters) where the influence of environment greatly affects galaxy disks (Aguerri et al. 2004). To investigate this issue, we examine the environment of our sample of lenticular galaxies and divide our sample into field and group/cluster environment using data from Tago et al. 2010 which uses the FoF (friends-of-friends) group search method to search for groups in the SDSS Data Release 7 (DR7). Out of 371 lenticulars that we have in our sample, 108 galaxies are in the field and 263 are members of a group/cluster, which reflects the fact that a majority of lenticular galaxies are located in dense environments. This is true also for the barred lenticular galaxies in our sample. Only nine barred lenticular galaxies are found in field and remaining 45 barred lenticular galaxies are members of group/cluster. We do not see a significant environment dependence for the bright and faint class of our sample lenticular galaxies. However, barred lenticular galaxies show a significant environment dependence if one divides galaxies into bright and faint classes (see Table 1). For barred lenticular galaxies, our analysis suggests that faint barred galaxies occur more frequently in group/cluster environments than their brighter counterparts. This is well supported by the fact that there is no environment bias for bright and faint class of our lenticular sample as the fraction of galaxies are same in field and group/cluster environments is about the same in both classes. From Table 1 it is clear that for the bright class, we have 44% galaxies in the field and group/cluster. This is also true for faint class where a comparable 56% galaxies are in the field and group/cluster.

Table 1. Environment dependence for our sample.

Galaxy Type		All S0's	Barred S0's
Bright	field	48/108 (44%)	04/09 (44%)
	group/cluster	115/263 (44%)	08/45 (18%)
Faint	field	60/108 (56%)	05/09 (56%)
	group/cluster	148/263 (56%)	37/45 (82%)

Notes. group/cluster membership determined by Tago et al. (2010).

4 DISCUSSION AND CONCLUSION

Many observations of disk galaxies, combined with results of simulations, strongly suggest that the rearrangement of disk mass into rings and bars funnels gas and stars to the centre of the galaxy which is an important driver for the secular evolution process (see Kormendy & Kennicutt 2004; Athanassoula 2005 and references therein for reviews). Recent studies of the distribution of bar strength has shown that lenticular galaxies on average have weaker bars than spiral galaxies in general, and even weaker than early-type spirals (Knapen 2010). Barazza et al. (2009) found evidence that the bar fraction is related to the morphological structure of the host galaxies in the sense that the bar fraction rises from early- to late-type disk galaxies (i. e. , from bulge-dominated galaxies to disk-dominated galaxies) and does not change with redshift. These authors also suggest that bars are typically formed or destroyed during processes in which the morphology of the disk is emerging or changing. In other words, bars are not dissolved in, for instance, lenticular galaxies, but can be destroyed during the processes in which a disk galaxy is transformed into a lenticular. Gadotti et al. (2003) have proposed, from the study of two lenticular galaxies without disks using N-body simulation, an alternate scenario in which bars can be formed in lenticular galaxies through the dynamical effects of nonspherical halos.

For lenticular galaxies, our investigations suggest that the formation of bars is a complex process. It not only depends on the total luminosity of galaxy but environment of the host galaxy also plays a crucial role in bar formation and the question whether internal or external factors are more important for bar formation and evolution are not easy to answer definitively.

Barway et al. 2009 (also see Boselli & Gavazzi 2006) have suggested that faint lenticular galaxies in clusters might be the result of ram pressure stripping of disk galaxies, where fading of the disc causes a change of morphology. Their results obtained using only photometric data are consistent with the spectroscopic results of Barr et al. (2007), which support the theory that lenticular galaxies are formed when gas in normal spirals is removed, possibly when well-formed spirals fall into a cluster. If lenticular galaxies in clusters are indeed transformed spirals, it is likely that they preserve other signatures of their earlier existence, and the presence of a bar could be a natural expectation if disk galaxies are transforming into faint lenticular galaxies due to an interaction with the cluster medium and with other galaxies in the cluster. This is also consistent with a scenario in which bars are rather stable and long-lived structures.

Recent studies have shown that fainter, bluer and less massive disk galaxies have higher bar fractions (Barazza et al. 2008; Aguerri et al. 2009). Our study finds that a higher bar fraction in lenticular galaxies occurs at luminosities $M_r > -21.5$ or $M_K > -24.5$. At this point, it should be noted that the *relative* change in bar fraction between bright and faint lenticular galaxies (not the absolute value of the fraction) is the relevant parameter, because bar detection fraction can vary substantially when different techniques are used to identify a bar. At poorer signal-to-noise ratio, i. e. , for faint galaxies, it should get more difficult to detect a bar. The fact that we find a larger fraction of bars in faint galaxies indicates that the effect is real, and may be even stronger, if the bias introduced by the poorer signal-to-noise ratio is accounted for.

Our results are supported by the study of Mendez-Abreu et al. (2010) which suggests that bars are hosted by galaxies in a tight range of luminosities ($-22 < M_r < -17$) and mass using measures of the bar fraction in the Coma cluster, a rich environment, from HST-ACS observations. However, in all above studies lenticular galaxies are treated as disk galaxies and no effort has been made to study the luminosity and environment dependence of host galaxy on bars for disk galaxies and lenticular galaxies separately. Detailed analysis of bar properties and correlations between bars and various observed properties of lenticular galaxies in optical and in near-infrared will appear in a forthcoming paper (Barway et al. 2010), where we discuss the results in the context of galaxy evolution scenarios within the framework of N-body simulations and possible links to the formation of classical bulges and pseudobulges in lenticular galaxies.

ACKNOWLEDGEMENTS

SB thanks Petri Vaisanen for helpful discussions. We thank an anonymous referee for insightful comments that have greatly improved both the content and presentation of this Letter. This publication makes use of data products from the Two Micron All Sky Survey, which is a joint project of the University of Massachusetts and the Infrared Processing and Analysis Center/California Institute of Technology, funded by the National Aeronautics and Space Administration and the National Science Foundation. Funding for the SDSS and SDSS-II has been provided by the Alfred P. Sloan Foundation, the Participating Institutions, the National Science Foundation, the U.S. Department of Energy, the National Aeronautics and Space Administration, the Japanese Monbukagakusho, the Max Planck Society, and the Higher Education Funding Council for England. The SDSS Web Site is http://www.sdss.org/. The SDSS is managed by the Astrophysical Research Consortium for the Participating Institutions. This research has made use of the NASA/IPAC Extragalactic Database (NED) which is operated by the Jet Propulsion Laboratory, California Institute of Technology, under contract with the National Aeronautics and Space Administration. We also acknowledge use of the HyperLeda database.

REFERENCES

Abadi, M. G., Moore, B., Bower, R. G. 1999, MNRAS, 308, 947

Abazajian, K. N. et al. 2009, ApJS, 182, 543

Aguerri, J. A. L., Beckman, J. E., Prieto, M. 1998, AJ, 116, 2136

Aguerri, J. A. L., Munoz-Tunon, C., Varela, A. M. et al. 2000, A&A, 361, 841

Aguerri, J. A. L., Iglesias-Paramo, J. et al. 2004, AJ, 127, 1344

Aguerri, J. A. L., Elias-Rosa, N., Corsini, E. M. et al. 2005, A&A, 434, 109

Aguerri, J. A. L., Mendez-Abreu, J., Corsini, E. M. 2009, A&A, 495, 491

Andersen, V. 1996, AJ, 111, 1805

Athanassoula, E. 2003, MNRAS, 341, 1179

Athanassoula, E., Lambert, J. C., Dehnen, W. 2005, MNRAS, 363, 496

Barazza, F. D., Jogee, S., Marinova, I. 2008, ApJ, 675, 1194

Barazza, F. D., Jablonka, P., Desai, V. et al. 2009, A&A, 497, 713

Barr, J. M., Bedregal, A. G. et al. 2007, A&A, 470, 173

Barway S., Kembhavi A., Wadadekar Y. et al. 2007, ApJ, 661, L37

Barway, S., Wadadekar, Y., Kembhavi, A. K. et al. 2009, MNRAS, 394, 1991

Barway, S., Wadadekar, Y., Kembhavi, A. K. 2010 (in preparation)

Bekki, K. 1998, ApJ, 502, 133

Boselli, A. & Gavazzi, G. 2006, PASP, 118, 517

Bournaud, F. & Combes, F. 2002, A&A, 392, 83

Bureau, M. et al. 2006, MNRAS, 370, 753

Combes, F., Sanders, R. H. 1981, A&A, 96, 164

Debattista, V. P., Carollo, C. M., Mayer, L. et al. 2004, ApJ, 604, L93

Debattista, V. P. et al. 2006, ApJ, 645, 209

de Vaucouleurs, G. 1963, ApJS, 8, 31

Elmegreen, B. G., Elmegreen, D. M. 1985, ApJ, 288, 438

Eskridge, P. B. et al. 2000, AJ, 119, 536

Erwin, P., Beckman, J. E., Pohlen, M. 2005, ApJ, 626, L81

Fukugita, M., Shimasaku, K., Ichikawa, T. 1995, PASP, 107, 945

Gadotti, D. A., de Souza, R. E. 2003, ApJ, 583, L75

Gadotti, D. A. & de Souza, R. E. 2006, ApJS, 163, 270

Ho, L. C., Filippenko, A. V. & Sargent, W. L. W. 1997, ApJ, 487, 591

Hubble, E. P. 1936, The Realm of the Nebulae (New Haven: Yale Univ. Press)

Hunt, L. K. & Malkan, M. A. 1999, ApJ, 516, 660

Jogee, S., Scoville, N., Kenney, J. D. P. 2005, ApJ, 630, 837

Knapen, J. H., Shlosman, I., Peletier, R. F. 2000, ApJ, 529, 93

Knapen, J. H. 2010, arXiv1005.0506

Kniazev, A. Y. et al. 2004, AJ, 127, 704

Kormendy, J. & Kennicutt, R. C., Jr. 2004, ARA&A, 42, 603

Laurikainen, E., Salo, H., Buta, R. 2005, MNRAS, 362, 1319

Lisker, T., Grebel, E. K., Binggeli, B. 2006, AJ, 132, 497

Marinova, I., & Jogee, S. 2007, ApJ, 659, 1176

Marinova, I., Jogee, S. 2009, ApJ, 698, 1639

McIntosh, D. H., Bell, E. F., Weinberg, M. D. et al. 2006, MNRAS, 373, 1321

Mendez-Abreu, J., Sanchez-Janssen, R., Aguerri, J. A. L. 2010, ApJ, 711, L61

Menendez-Delmestre, K., Sheth, K. et al. 2007, ApJ, 657, 790

Nair, P. B.; Abraham, R. G., 2010, ApJS, 186, 427

Nilson, P. 1973, Uppsala General Catalogue of Galaxies (Uppsala: Uppsala Astron. Obs.)

Pfenniger, D. & Friedli, D. 1991, A&A, 252, 75

Prieto, M., Aguerri, J. A. L., Varela, A. M. et al. 2001, A&A, 367, 405

Regan, M. W. & Teuben, P. J. 2004, ApJ, 600, 595

Sakamoto, K., Okumura, S. K., Ishizuki, S. et al. 1999, ApJ, 525, 691

Sellwood, J. A. & Wilkinson, A. 1993, RPPh, 56, 173

Sheth, K. et al. 2005, ApJ, 632, 217

Sheth, K. et al. 2008, ApJ, 675, 1141

Thompson 1981, ApJ, 244, 43

Tago, E., Saar, E., Tempel, E. et al. 2010, A&A, 514, 102

van den Bergh, S. 2002, AJ, 124, 782

Whyte, L. F. et al. 2002, MNRAS, 336, 1281

Weinzirl, T., Jogee, S., Khochfar, S et al. 2009, ApJ, 696, 411