Relating bars with the environment in the nearby Universe

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ABSTRACT
We study the correlation between the fraction of barred spiral galaxies and environmental parameters of galaxies to understand in which environments the bars are more commonly found. For this purpose, we apply the Blanton et al. technique to a sample of spiral galaxies drawn from the Nair & Abraham catalogue. Our results agree with previous findings in which the fraction of barred galaxies is almost insensitive to environment.

Key words: galaxies: evolution – galaxies: fundamental parameters – galaxies: statistics.

1 INTRODUCTION
Bars are believed to be closely related with the dynamical evolution of disc galaxies and to play an important role in redistributing the angular momentum between dark and baryonic matter (Weinberg 1985; Debattista & Sellwood 1998). Athanassoula (2003) proposed that this exchange of angular momentum is closely related to the density and velocity dispersion of the host halo. Other roles that have been assigned to bars are (a) to transport material to the centre and ignite starbursts (Sheth et al. 2005) and/or feed the central black hole (Shlosman, Begelman & Frank 1990; Corsini, Debattista & Aguerri 2003); however no direct evidence of this is seen (Mulchaey & Regan 1997), (b) change chemical abundance gradient (Zaritsky 1992; Martin & Roy 1994) and (c) bars can trigger star formation along themselves, or have a lot of gas and no star formation (Kenney & Lord 1991; Sheth et al. 2002). Bars are also associated with circumnuclear star formation activity (Sérsic & Pastoriza 1967; Ho, Filippenko & Sargent 1997; Sheth et al. 2000), the formation of nuclear pseudo-bulges (Kormendy 1982; Kormendy & Kennicutt 2004), rings (Schwarz 1981; Buta 1986; Buta & Combes 1996) and, possibly, spiral arms (Lindblad 1960; Elmegreen & Elmegreen 1985).

For a fixed circular velocity, barred and unbarred galaxies have similar properties like luminosity, scalelengths, star formation and colour (Courteau et al. 2003), which does not necessary imply they have followed the same evolutionary paths (see Sheth et al. 2008). de Vaucouleurs (1963) using blue plates found that more than 60 per cent of nearby galaxies are barred. Similar fractions are observed in the near-infrared (Eskridge et al. 2000; Laurikainen, Salo & Buta 2004; Menéndez-Delmestre et al. 2007). In numerical simulations, bars appear naturally once the cold and rotationally supported disc is in place (see Athanassoula 2005, for a review), although the precise mechanisms that drive this phenomenon are not well established yet. Among the internal mechanisms that can produce bars is the instability of the disc (Sellwood & Wilkinson 1993; Heller, Shlosman & Athanassoula 2007; Athanassoula 2008).

It has also been suggested that environment could also be important in leading to the formation of bars, although results are contradictory. In some numerical simulations, bars are created in mergers and interactions (Walker et al. 1996; Mihos, McGaugh & de Blok 1997; Berentzen et al. 2004), it is transient in others (Gerin, Combes & Athanassoula 1990) and in some others bars are destroyed as the galaxy becomes an elliptical. Elmegreen, Elmegreen & Bellin (1990) analyse galaxies in binary and group systems and in the field and find a correlation between the bar fraction and environment for early-type spirals, with the highest fraction corresponding to binary systems. On the other hand, van den Bergh (2002) uses 930 galaxies from the Palomar Sky Survey and concludes that the bar fraction does not depend on the environment. An environment that has been particularly studied is that of galaxy clusters. Méndez-Abreu, Sánchez-Janssen & Aguerri (2010) study both, the centre and the infall regions of the Coma Cluster, in a wide range of magnitudes. They find that bars are hosted in galaxies in a tight interval of masses and luminosities ($10^9 \leq M_*/M_\odot \leq 10^{11}$ and $-22 < M_r < -17$, respectively). These authors do not find a significant difference in the fraction of bars between galaxies in the centre and in the infall regions, suggesting that the cluster environment plays a second-order role in the bar formation/evolution.

The purpose of this Letter is to evaluate different parameters that characterize the environment as possible generators of bars. We use the technique proposed by Blanton et al. (2005) and significance criteria introduced by Martínez, Coenda & Muriel (2008) to samples of galaxies drawn from the catalogue by Nair & Abraham(2010a, hereafter NA10). The Letter is organized as follows. Section 2 describes the sample of galaxies and the environmental properties we use throughout our work. Section 3 presents the results. Finally, we provide a discussion of our findings in Section 4. Throughout this Letter, we assume a flat cosmological model with parameters $H_0 = 70$ km s$^{-1}$ Mpc$^{-1}$, $\Omega_M = 0.3$ and $\Omega_\Lambda = 0.7$. 

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2 THE GALAXY SAMPLE

For the purposes of this Letter, we use a sample of galaxies drawn from the catalogue by NA10. This catalogue presents detailed visual classification for 14034 galaxies in the main galaxy sample (MGS; Strauss et al. 2002) of the Fourth Data Release of the SDSS (Adelman-McCarthy et al. 2006) that constitute a complete sample with 0.01 ≤ z ≤ 0.1 and down to a limiting extinction-corrected apparent magnitude of g = 16. Each galaxy in the catalogue has been morphologically classified by NA10 into T-types. Additionally, they recorded the existence of structures such as bars, rings, lenses, tails and warps.

In our analyses below, we include all galaxies classified as spirals (T-type ≥ 0) in the NA10 catalogue which have axial ratio b/a > 0.55. Below this cut-off, the fraction of barred galaxies drops dramatically (fig. 21 in NA10). There is no other important incompleteness regarding bar identifications in the NA10. Our sample has 5508 galaxies, among which 1841 are barred.

For the analysis of the correlation between the existence of bars and the environment in which galaxies are located, we selected four measures of environment quoted in the NA10 catalogue and also computed the projected distance to the nearest MGS neighbour brighter than \( M_r = -20 \) (that is, a volume-limited sample of galaxies up to \( z = 0.1 \)) and with \( c|\Delta z| \leq 1000 \text{ km s}^{-1} \) as another environment measure:

(i) \( L_{\text{group}}, g \): group luminosity \([9.5 \leq \log (L_{\text{group},g}/L_{\odot}) \leq 12.5]\) from Yang et al. (2007);

(ii) \( M_{\text{group}} \): group mass \([9.5 \leq \log (M_{\text{group}}/M_{\odot}) \leq 13.0]\) from Yang et al. (2007);

(iii) \( M_{\text{halo}} \): group halo mass \([11.5 \leq \log (M_{\text{halo}}/M_{\odot}) \leq 15.5]\) from Yang et al. (2007);

(iv) \( \Sigma_1 \): fifth neighbour projected density \([-0.8 \leq \log (\Sigma_1/\text{Mpc}^{-2}) \leq 1.8]\) from Baldry et al. (2006).

(v) \( r_{\text{NN}} \): projected distance to the nearest neighbour (0 \( \leq r_{\text{NN}}/\text{kpc} \leq 1500\)) computed in this work. We have not introduced corrections accounting for the well-known fibre loss incompleteness of the MGS; nevertheless, this should not bias our results since both barred and non-barred spirals should be affected in the same way.

All cut-offs in the lists above were imposed as a compromise between probing the largest possible volume in the space of parameters and, at the same time, having enough galaxies per bin to properly carry out the correlation analyses detailed in the next section.

3 RELATING BARS WITH ENVIRONMENTS

We explore the ability of different environment parameters to predict the fraction of barred galaxies by using the \( \sigma_X \) statistics as defined by Blanton et al. (2005). Briefly, given a set of environmental properties, \( X_1, \ldots, X_N \), the fraction of barred galaxies, \( f_{\text{bar}} \), will be, in principle, a function of them: \( f_{\text{bar}} = f_{\text{bar}}(X_1, \ldots, X_N) \). If we consider now a particular parameter \( X_I \) and marginalize \( f_{\text{bar}} \) over the remaining ones, we get the fraction of barred galaxies as a function of \( X_I \) alone, \( f_{\text{bar}}(X_I) \). The parameter \( X_I \) that correlates best with the fraction of barred galaxies will be the one that minimizes the variance \( \sigma_{X_I} \) of \( f_{\text{bar}}(X_I) \) after subtracting its global trend (for details, see Blanton et al. 2005; Martínez & Muriel 2006; Martínez et al. 2008).

The \( \sigma_X \) statistics provides the environmental parameter that predicts best the presence of bars. This does not mean, however, that the best ranked parameter is a good predictor of bars. To complement the \( \sigma_3 \) statistics, we use the significance criterion by Martínez et al. (2008) computed by using bootstrap resamplings.

Since we are dealing with a flux-limited galaxy sample in our analyses, we have weighted each galaxy in our statistics by \( 1/V_{\text{max}} \) (Schmidt 1968). Given that the fraction of barred galaxies depends on absolute magnitude (Sheth et al. 2008; Nair & Abraham 2010b), and that brighter galaxies tend to be located in higher density environments, the non-inclusion of such a weighting scheme can lead to systematics in our analyses.

In Fig. 1, we show the results of our analysis on the relationship between bars and environment. Panels are sorted from top to bottom according to increasing \( \sigma_X \) values. We quote next to each panel the \( \sigma_X \) value along with its significance. Each panel shows the fraction, \( f_{\text{bar}}(X) \), of barred galaxies as a function of the corresponding quantity \( X \). Error bars are 1σ bootstrap resampling error bars. Shaded areas represent the overall mean value of \( f_{\text{bar}}(X) \) ± 1σ from the bootstrap resamplings. We also show in the inferior part of each panel the \( 1/V_{\text{max}} \) weighted histograms of barred (shaded) and non-barred (empty) galaxies; all these histograms are normalized to have the same area. The best predicting parameter is the distance to the nearest neighbour, in the sense that galaxies with bars tend to have closer neighbours. This is followed by the projected galaxy density, the mass of the halo, the group luminosity and finally the group mass. Nevertheless, all the parameters have significance below 68 per cent, i.e. less that 1σ for Gaussian statistics; thus, none of them is significant according to our criterion.

Despite that none of the explored parameters is closely correlated to the presence of bars, the trends in Fig. 1 suggest that barred galaxies are slightly more common at higher densities, and in more massive haloes. Inspired in the results by Elmegreen et al. (1990), we also check whether the correlation of bars and the environment is stronger for early spirals, by repeating the \( \sigma_X \) computations only for galaxies classified as Sa, Sab and Sb by NA10. We find no evidence of significant correlation for those galaxies either. The results suggest, at best, a second-order environmental effect.

We have repeated our computations without the \( 1/V_{\text{max}} \) weighting scheme, resulting in a different ranking of parameters. In this case, we observe that (i) the overall \( f_{\text{bar}} \) is slightly higher since \( f_{\text{bar}} \) is an increasing function of luminosity, (ii) the trends as in Fig. 1 do not qualitatively change, (iii) however, the variances around the global trends, \( \sigma_X \), do change leading to a different ranking: the group mass ranks first and the remaining four parameters have almost identical \( \sigma_X \) values. This is no surprise since in this case the statistics is dominated by brighter galaxies, that tend to be located in more massive systems, and among them the fraction of bars is higher. Again, we find that significance levels are well below 68 per cent. The non-inclusion of a weighting scheme accounting for the fact that we are dealing with an essentially flux-limited galaxy sample can lead to wrong conclusions.

Although non-significant according to our criterion, the distance to the nearest neighbour is the environmental parameter that correlates best with the fraction of bars. The nearest neighbour in our analysis is, in all cases, a relatively bright object, \( M_r < -20 \), since we searched for it in a volume-limited (up to \( z = 0.1 \)) sample of galaxies drawn from the MGS to avoid biases with redshift. If the proximity to another galaxy is an important factor for the formation and/or stability of a bar, the mass ratio between a galaxy and its closest neighbour might be important as well. We have further explored the correlation between bars and neighbours in terms of the difference in absolute magnitude between the barred galaxies and their nearest neighbours, which is broadly related to their mass...
Figure 1. The fraction of barred galaxies as a function of different measures of the environment; quoted error bars are obtained by the bootstrap resampling technique. From upper to lower, panels are sorted according to increasing $\sigma_X$ values. Shaded areas are the mean values and $\pm 1\sigma$ error bars from the resamplings. We quote in the bottom the number of galaxies in each bin. Below each panel, we show the distributions corresponding to barred (shaded histogram) and non-barred galaxies (empty histogram), both normalized to have the same area.

4 CONCLUSIONS

We have studied the relationship between the fraction of barred spiral galaxies and a number of environmental parameters in the nearby Universe using a complete sample of spiral galaxies taken from the NA10 catalogue. For this purpose, we have applied the technique by Blanton et al. (2005) and the significance criterion by Martínez et al. (2008), to a sample of spiral galaxies taken from the NA10 catalogue. Once the range of a set of parameters is defined, this technique measures the ability of each parameter to predict an observable, in this case the bar fraction.

We have considered in our analysis five parameters characterizing the environment: group luminosity, group mass, group halo mass (the three of them computed by Yang et al. 2007), the projected galaxy density (computed by Baldry et al. 2006) and the projected distance to the nearest neighbour (computed in this work). Our results indicate that the latter parameter is the one that best predicts the existence of bars; however, the signal is only marginal. The small effect is in the sense that spiral galaxies with a nearest neighbour within 0.5 Mpc tend to have a slightly higher fraction of bars. We find no evidence of bars preferring systematically brighter or fainter neighbours. Our finding that the proximity to another galaxy could play a role in the formation of a bar can be related to the predictions of some numerical simulations in which interactions can trigger bars and/or influence bar properties (e.g. Noguchi 1987; Gerin et al. 1990; Mihos et al. 1997; Miwa & Noguchi 1998; Berentzen et al. 2004). However, due to the low significance we find, our results can also be in agreement with van den Bergh (2002) and Méndez-Abreu et al. (2010), in which the fraction of barred galaxies does not depend on the environment. Numerical simulations have shown that bars form naturally in discs (e.g. Athanassoula 2005, and references therein); thus, bars could be understood in terms of nature only, leaving for nurture, at best, a secondary role. A larger sample of barred galaxies is needed to shed more light on the relationship between environment and the presence of bars.

According to our results, the relation between environment and bars appears to be, at best, a second-order effect. Since the NA10 sample contains galaxies in a wide range of environments (see histograms in Fig. 1), it is worth emphasizing the fact that the presence of bars does not seem to depend on environment, while most galaxy properties do.

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REFERENCES

Adelman-McCarthy J. K. et al., 2006, ApJS, 162, 38
Athanassoula E., 2003, Celest. Mech. Dynamical Astron., 91, 9
Athanassoula E., 2008, MNRAS, 390, L69
Baldry I. K., Balogh M. L., Bower R. G., Glazebrook K., Nichol R. C., Bamford S. P., Budavari T., 2006, MNRAS, 373, 469
Barentzen I., Athanassoula E., Heller C. H., Fricke K. J., 2004, MNRAS, 347, 220
Blanton M. R., Eisenstein D., Hogg D. W., Schlegel D. J., Brinkmann J., 2005, ApJ, 629, 143
Buta R., 1986, ApJS, 61, 609
Buta R., Combes F., 1996, Fundamentals Cosmic Phys., 17, 95
Corsini E. M., Debattista V. P., Aguerri J. A. L., 2003, ApJ, 599, L29
Courteau S., Andersen D. R., Bershady M. A., MacArthur L. A., Rix H.-W., 2003, ApJ, 594, 208
de Vaucouleurs G., 1963, ApJS, 8, 31
Debattista V. P., Sellwood J. A., 1998, ApJ, 493, L5
Elmegreen B. G., Elmegreen D. M., 1985, ApJ, 288, 438
Elmegreen D. M., Elmegreen B. G., Bellin A. D., 1990, ApJ, 364, 415
Eskridge P. B. et al., 2000, AJ, 119, 536
Gerin M., Combes F., Athanassoula E., 1990, A&A, 230, 37
Heller C. H., Shlosman I., Athanassoula E., 2007, ApJ, 671, 226
Ho L. C., Filippenko A. V., Sargent W. L. W., 1997, ApJ, 487, 591
Kenney J. D. P., Lord S. D., 1991, ApJ, 381, 118
Kormendy J., 1982, ApJ, 257, 75
Kormendy J., Kennicutt R. C., Jr, 2004, ARA&A, 42, 603
Laurikainen E., Salo H., Buta R., 2004, ApJ, 607, 103
Lindblad P. O., 1960, Stockholm Obser. Ann., 21, 4
Martin P., Roy J.-R., 1994, ApJ, 424, 599
Martinez H. J., Muriel H., 2008, MNRAS, 391, 585
Menéndez-Abreu J., Sánchez-Janssen R., Aguerri J. A. L., 2010, ApJ, 711, L61
Menéndez-Delmestre K., Sheth K., Schinnerer E., Jarrett T. H., Scoville N. Z., 2007, ApJ, 657, 790
Mihos J. C., McGaugh S. S., de Blok W. J. G., 1997, ApJ, 477, L79
Miwa T., Noguchi M., 1998, ApJ, 499, 149
Mulchaey J. S., Regan M. W., 1997, ApJ, 482, L135
Nair P. B., Abraham R. G., 2010a, ApJS, 186, 427 (NA10)
Nair P. B., Abraham R. G., 2010b, ApJ, 714, L260
Noguchi M., 1987, MNRAS, 228, 635
Schmidt M., 1968, ApJ, 151, 393
Schwarz M. P., 1981, ApJ, 247, 77
Sellwood J. A., Wilkinson A., 1993, Rep. Progress Phys., 56, 173
Sérsic J. L., Pastoriza M., 1967, PASP, 79, 152
Sheth K., Regan M. W., Vogel S. N., Teuben P. J., 2000, ApJ, 532, 221
Sheth K., Vogel S. N., Regan M. W., Teuben P. J., Harris A. I., Thornley M. D., 2002, AJ, 124, 2581
Sheth K., Vogel S. N., Regan M. W., Thornley M. D., Teuben P. J., 2005, ApJ, 632, 217
Sheth K. et al., 2008, ApJ, 675, 1141
Shlosman I., Begelman M. C., Frank J., 1990, Nat, 345, 679
Strauss M. A. et al., 2002, AJ, 124, 1810
van den Bergh S., 2002, AJ, 124, 782
Walker I. R., Mihos J. C., Hernquist L., Bolte M., Mendes de Oliveira C., 1996, in Butta R., Crocker D. A., Elmegreen B. G., eds, ASP Conf. Ser. Vol. 91, Barred Galaxies. Astron. Soc. Pac., San Francisco, p. 486
Weinberg M. D., 1985, MNRAS, 213, 451
Yang X., Mo H. J., van den Bosch F. C., Pasquali A., Li C., Barden M., 2007, ApJ, 671, 153
Zaritsky D., 1992, ApJ, 390, L73

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