Bars in field and cluster galaxies at intermediate redshifts

Fabio D. Barazza¹, Pascale Jablonka¹,², and the EDisCS collaboration

Abstract. We present the first study of large-scale bars in clusters at intermediate redshifts ($z = 0.4 - 0.8$). We compare the properties of the bars and their host galaxies in the clusters with those of a field sample in the same redshift range. We use a sample of 945 moderately inclined disk galaxies drawn from the EDisCS project. The morphological classification of the galaxies and the detection of bars are based on deep HST/ACS F814W images. The total optical bar fraction in the redshift range $z = 0.4 - 0.8$, averaged over the entire sample, is 25%. This is lower than found locally, but in good agreement with studies of bars in field environments at intermediate redshifts. For the cluster and field subsamples, we measure bar fractions of 24% and 29%, respectively. In agreement with local studies, we find that disk-dominated galaxies have a higher bar fraction than bulge-dominated galaxies. We also find, based on a small subsample, that bars in clusters are on average longer than in the field and preferentially found close to the cluster center, where the bar fraction is somewhat higher than at larger distances.

1. Introduction

Bars are believed to be very important with regard to the dynamical and secular evolution of disk galaxies, particularly in redistributing the angular momentum of the baryonic and dark matter components of disk galaxies. Theory and $n$-body simulations predict that this redistribution is characterized by the transfer of angular momentum to the outer disk. As a result, gas is driven inside the corotation toward the center of the disk, which can trigger starbursts (Sakamoto et al. 1999; Bournaud & Combes 2002; Jogee et al. 2005) and contribute to the formation of disky bulges (Kormendy & Kennicutt 2004).

While it is still unknown why a specific disk galaxy hosts a bar and an apparently similar galaxy is unbarred, it is clear that a significant fraction of bright disk galaxies appears barred in optical observations (Eskridge et al. 2000; Reese et al. 2007; Marinova & Jogee 2007; Barazza et al. 2008). This result is mainly based on samples of disk galaxies in field environments, whereas studies of bars in cluster galaxies are rather rare. In general it is found that the fraction of barred disks in clusters or groups is roughly the same as in the field (van den Bergh 2007; Marinova et al. 2009), suggesting that the denser environment does not significantly affect bar formation. On the other hand, Thompson (1981) and Andersen (1996) present evidence that barred galaxies in the Coma

¹Laboratoire d’Astrophysique, EPFL, Observatoire de Sauverny, CH-1290 Versoix, Switzerland
²Université de Genève, Observatoire de Sauverny, CH-1290 Versoix, Switzerland
and Virgo clusters are more concentrated toward the cluster centers than unbarred disks.

We present results of the first study of bars in clusters at intermediate redshifts and investigate the impact of the cluster environment on bar formation and evolution. We use a sample of disk galaxies from the ESO distant cluster survey (EDisCS, White et al. 2005). Using the available I-band HST/ACS images we identify and characterize bars, based on quantitative criteria. We look for relations between barred and unbarred galaxies and their environment for a subsample, for which spectroscopic redshifts and reliable cluster membership determinations are available.

2. Sample and method

The EDisCS project has assembled three-band optical VLT deep photometry, deep NTT/SOFI near-infrared imaging, and optical VLT/FORS2 spectroscopy for 26 optically selected and spectroscopically confirmed galaxy structures between redshifts 0.39 and 0.96 (Halliday et al. 2004; Milvang-Jensen et al. 2008). Additional HST/ACS images in the F814W filter were acquired for 10 fields containing the most distant clusters. Galaxies in these 10 fields, regardless of whether they are cluster members or group/field galaxies, and with $I < 23$ mag constitute our basic sample. From this sample we select all galaxies with Hubble types S0–Sm/Im based on visual classification (Desai et al. 2007) and in the redshift range $z = 0.4 – 0.8$, which ensures to remain in the rest-frame optical (1906 objects). Results based on the separation between cluster and field galaxies are based on a subsample, for which spectroscopic redshifts and therefore a reliable cluster or field allocation is available (459 objects).

Our method to find bars relies on the fact that the isophotes of bars in moderately inclined disk galaxies (i.e. with disk inclination $i < 60^\circ$) have much higher ellipticities than the isophotes of the underlying disk. The ellipticities of the isophotes are derived by fitting ellipses to the surface brightness distribution of the disks using the IRAF task ‘ellipse’. The corresponding profiles of ellipticity ($\epsilon$) and position angle (P.A.) are investigated based on two quantitative criteria: (1) $\epsilon$ increases steadily to a global maximum higher than 0.25, while the P.A. value remains constant (within 10°), and (2) $\epsilon$ then drops by at least 0.1 and the P.A. changes at the transition between the bar to the disk region. Galaxies meeting these two criteria have been classified as barred.

3. Results

The optical bar fraction of the entire sample (including field and cluster galaxies) is $\sim 25\%$. This is significantly lower than is typically found in optical studies of local galaxies (Eskridge et al. 2000; Reese et al. 2007; Marinova & Jogee 2007; Barazza et al. 2008), but in good agreement with studies of galaxies in field environments at intermediate redshifts (Jogee et al. 2004; Elmegreen et al. 2004; Sheth et al. 2008). For the spectroscopically confirmed cluster sample, we obtain $\sim 24\%$, and for the corresponding field sample, we derive $\sim 29\%$. These values agree within the uncertainties with the result for the complete sample and indicate that the frequency of bars in clusters is almost identical to that in the
Figure 1. top left: The number of barred and unbarred galaxies in the entire sample as a function of Hubble type and the corresponding bar fraction. top right: The bar fraction as a function of Hubble type for two redshift bins. bottom left: The number of barred and unbarred galaxies in the entire sample as a function of effective radius ($r_e$). bottom right: The bar fraction as a function of $r_e$ for two redshift bins.

field. Figure 1 shows the optical bar fraction of the entire sample as a function of Hubble type (top left) and effective radius ($r_e$, bottom left). The effective radius defines the area, which contains half of the total galaxy light. The bar fraction increases towards later Hubble types and disks with larger effective radii. This indicates that disk-dominated galaxies are more likely to be barred than bulge-dominated galaxies. This results is in good agreement with two recent SDSS studies also based on Hubble types and effective radius (Barazza et al. 2008; Aguerri et al. 2008). The right panels of Figure 1 show the same as the left panels, but separated into a low and high redshift bin. The relations remain roughly the same showing that the relative bar fractions of the different Hubble types do not change significantly with look-back time. The distribution of the barred galaxies within the clusters shows two interesting features represented
Figure 2. *left:* The bar size as a function of normalized clustercentric distance for the spectroscopic cluster subsample ($R_{200}$ is a measure of the virial radius). The dashed line indicates the mean bar size for this sample of 3.68 kpc. *right:* The distribution of the disk galaxies with respect to the clustercentric distance (left) and the normalized clustercentric distance (right) for the spectroscopic subsample.

in Figure 2. The left panel shows that the largest bars are preferentially found close to the cluster centers and the right panel indicates that the bar fraction is somewhat larger near the cluster centers than at larger radii. For the $R_{CC}$ distribution, the bar fraction declines from 31% in the central bin to 18% at $\sim 1$ Mpc. For the $R_{CC}/R_{200}$ distribution, the corresponding values are 29% in the central bin and 22% at $R_{200}$. We have to stress though that the sample used is rather small, but we can safely say that barred galaxies do not avoid the cluster center.

The question whether internal or external factors are more important for bar formation and evolution cannot be answered definitely. On the one hand, the bar fraction and properties of cluster and field samples of disk galaxies are quite similar, indicating that internal processes are crucial for bar formation. On the other hand, we find evidence that cluster centers are favorable locations for bars, which suggests that the internal processes responsible for bar growth are supported by the typical interactions taking place in such environments.

References

Andersen, V. 1996, AJ, 111, 1805
Aguerri, J. A. L., Mendez-Abreu, J., Corsini, E. M., 2009, A&A, in press
Barazza, F. D., Jogee, S., & Marinova, I. 2008, ApJ, 675, 1194
Bournaud, F., & Combes, F. 2002, A&A, 392, 83
Desai, V., et al. 2007, ApJ, 660, 1151
Elmegreen, B. G., Elmegreen, D. M., & Hirst, A. C. 2004, ApJ, 612, 191
Eskridge, P. B., et al. 2000, AJ, 119, 536
Halliday, C., et al. 2004, A&A, 427, 397
Jogee, S., Scoville, N., & Kenney, J. D. P. 2005, ApJ, 630, 837
Jogee, S., et al. 2004, ApJ, 615, L105
Bars in field and cluster galaxies at intermediate redshifts

Kormendy, J., & Kennicutt, R. C., Jr. 2004, ARA&A, 42, 603
Marinova, I., & Jogee, S. 2007, ApJ, 659, 1176
Marinova, I. et al. 2009, ApJ, in preparation
Milvang-Jensen, B., et al. 2008, A&A, 482, 419
Reese, A. S., Williams, T. B., Sellwood, J. A., Barnes, E. I., & Powell, B. A. 2007, AJ, 133, 2846
Sakamoto, K., Okumura, S. K., Ishizuki, S., & Scoville, N. Z. 1999, ApJ, 525, 691
Sheth, K., et al. 2008, ApJ, 675, 1141
Thompson, L. A. 1981, ApJ, 244, L43
van den Bergh, S. 2007, AJ, 134, 1508
White, S. D. M., et al. 2005, A&A, 444, 365