Highlights of Spanish Astrophysics VIII, Proceedings of the XI Scientific Meeting of the Spanish Astronomical Society held on September 8–12, 2014, in Teruel, Spain. A. J. Cenarro, F. Figueras, C. Hernández-Monteagudo, J. Trujillo Bueno, and L. Valdivielso (eds.)

Primordial (pseudo)bulges in isolated galaxies

M. Fernández Lorenzo[1], J. Sulentic[1], L. Verdes-Montenegro[1], J. Blasco-Herrera[1], M. Argudo-Fernández[1], P. Ramírez-Moreta[1], J. Garrido[1], J.E. Ruiz[1], S. Sánchez-Expósito[1] and J.D. Santander-Vela[2]

[1] Instituto de Astrofísica de Andalucía-CSIC
[2] SKAO

Abstract

Important clues about spiral galaxy formation lie in the nature of their central bulges. In this sense, properties of bulges in isolated galaxies best reflect their origin because of their minimized environmental evolutionary effects. We report here the structural parameters and $(g-i)$ bulge/disk colors for a sample of 189 isolated galaxies selected from the AMIGA project (Analysis of the interstellar Medium of Isolated GAlaxies). A 2D bulge/disk/bar decomposition of SDSS i-band images was performed in order to identify the pseudobulges in our sample. We derived $(g-i)$ bulge colors using aperture photometry. Pseudobulges in our sample show median colors $(g-i) \sim 1.06$, while their associated disks are much bluer, $(g-i) \sim 0.77$. Moreover, 64 % (113/177) of pseudobulges follow the red sequence of early-type galaxies. The bluer pseudobulges in our sample tend to be located in those galaxies more affected by the tidal interactions. The red bulge colors and low B/T values for AMIGA isolated galaxies are consistent with an early formation epoch. The results found here suggest that environment could be playing a role in rejuvenating the pseudobulges.

1 Introduction

According to the properties observed in the central parts of galaxies, we can distinguish two main stellar systems: classical bulges are composed by old stellar populations, are dinamically supported by velocity dispersion and follow the same relations than early-type galaxies. On the other hand, disk-like bulges or pseudobulges are characterized by young stellar populations, are dinamically supported by rotation motions and present disky structures, such as spiral arms. The surface brightness profile of pseudobulges is better represented by a sérsic function with sérsic index lower than 2 while the profile of classical bulges is more close to a De Vaucouleurs function (see [7] for a review).

Different formation mechanisms have been proposed for classical and pseudobulges. A rapid and violent process is expected to form the classical bulges because their similarity with early-type galaxies. In the case of pseudobulges, a more slowly formation is expected because they preserve some memory of their disky origin. Gravitational instabilities have been also proposed to build bulges via clump migration [4], but the type of bulges formed by this process remains unclear. On the other hand, the role of the environment in the formation of both kind of bulges is far from being unraveled. Understanding the main properties of central parts in isolated galaxies is therefore important in the sense that their evolution is mainly driven by internal processes.

Here, we studied the structural parameters and $(g - i)$ bulge/disk colors for a sample of 189 isolated AMIGA (Analysis of the interstellar Medium of Isolated GAlaxies) galaxies [11].

2 Sample selection and data analysis

The AMIGA sample is based on the catalog of isolated galaxies (CIG; [5]). Two complementary isolation parameters were defined in AMIGA to select the most isolated galaxies in the CIG: the tidal force ($Q_{\rm kar}$) and the local number density (η_k). The isolation parameters have been recently improved [2] for the 636 AMIGA galaxies in the Sloan Digital Sky Survey (SDSS; [1]). To select the sample, we applied the isolation criteria of [2], $Q_{\rm kar} < -2$ and $\eta_k < 2.7$, which ensures that the galaxies have been unperturbed by major neighbors in the last 5 Gyr. We applied also a completeness condition [11] resulting in a final sample of 279 spiral ($T = 1$–8) galaxies.

We downloaded the images of these galaxies from the SDSS in g, r, and i-bands. A bulge/disk/bar decomposition was performed using `galfit` [10] in the i-band images, with the aim to identify classical bulges and pseudobulges. We judged a fit to be acceptable when the residuals in the central part were lower than 10 % of the flux. This happened for 189 galaxies.

In the left pannel of Fig. 1 we represented the bulge Sérsic index versus the bulge-to-total luminosity ratio. We used a cut in sérsic index of 2.5 to separate classical and paseudobulges. We found that 94 % of bulges in the AMIGA sample are classified as pseudobulges. High-BT and low-BT pseudobulges are represented with different colors to check in the following analysis if high-BT can represent more evolved pseudobulges. In the right panel we represented the Kormendy relation [6] for AMIGA early-type galaxies and each kind of bulge in our sample. Classical bulges follow the Kormendy relation of early-type galaxies. In the case of pseudobulges, they tend to be located below the relation with high-BT pseudobulges forming an upper envelope, in the region consistent with the Kormendy relation. This seems to indicate some similarity with classical bulges.

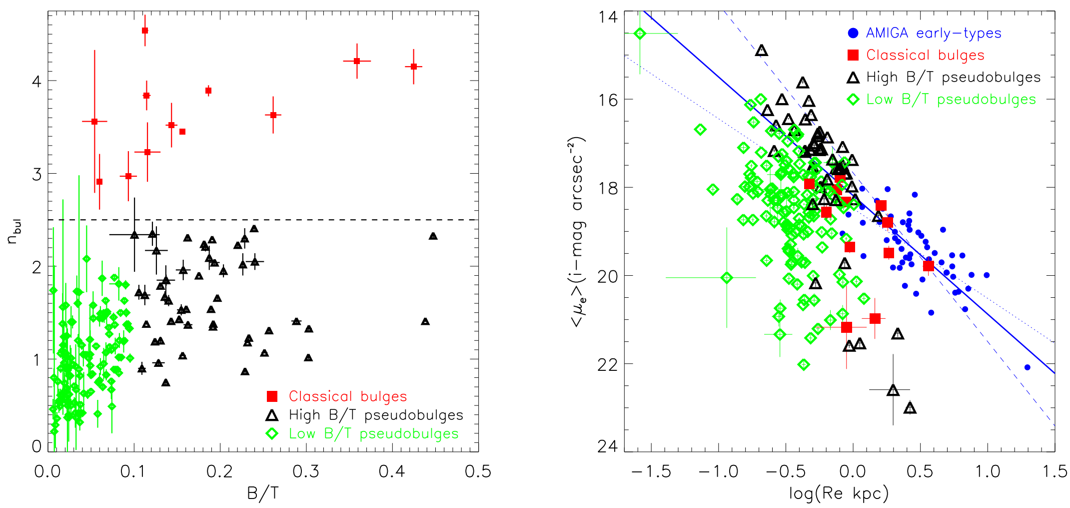

Figure 1: Structural parameters in the i-band for the bulges in our sample. Left panel: bulge Sérsic index versus bulge-to-total luminosity ratio. Right panel: the Kormendy relation for classical bulges (red squares), low-B/T (green diamonds), and high-B/T pseudobulges (black triangles). As comparison, the Kormendy relation for the AMIGA early–type galaxies is represented (blue points) [3].

3 Stellar populations for bulge and disks

We used $(g-i)$ colors as indicative of the stellar population for bulge and disks in our sample. Using the structural parameters obtained in the i-band, we made the decomposition in the g and r band. For disks, we use the magnitudes derived from the `galfit` fit in g and i-bands since they are the same whether fixing or not the parameters fitted in the i-band. In the case of the bulges, the magnitudes given by `galfit` result in colors more than 3-σ redder than the red sequence of early-type galaxies. This happened overall for the later types where the contribution of the disk inside the bulge is larger. The reason of this anomalous bulge colors can be a change in the disk inside the bulge which is not taken into account when we are extrapolating the disk obtained outside the bulge. Since we cannot trust the bulge colors obtained with `galfit`, we decided to use aperture photometry with ellipse. Galaxies were fitted in the i-band and then we calculated the aperture magnitudes in r and g-bands, fixing the ellipticity and position angle of each isophotal aperture to be equal to the i-band values.

In Fig. 2, we represent the $(g-i)$ color obtained respectively for bulges and disks versus the total i-magnitude of our galaxies. As comparison, we represent the color-magnitude relation obtained for the galaxies in the Nair & Abraham sample [9]. A 63% of our bulges are located in the red sequence fitted to E/S0 galaxies of [9] sample. Regarding different bulges type, we found a 58 % of high-BT pseudobulges and a 66 % of low-BT pseudobulges in the red sequence, while their disks are much more bluer. There is no difference in colors between high and low-BT pseudobulges although disks of high-BT pseudobulges are redder

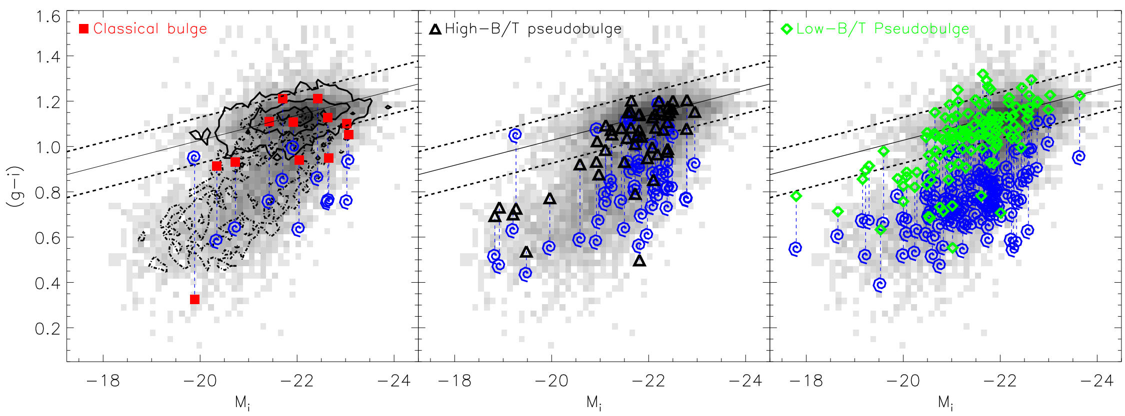

Figure 2: $(g - i)$ color for bulges and the disks (blue spirals) versus the absolute magnitude in the i-band of the host galaxy (M_i). Different bulge types are represented with different symbols following Fig. 1. The grey-scale represents the density diagram obtained from the Nair & Abraham sample [9] at $0.01 < z < 0.05$. The solid and dashed lines are the linear fit and its $2\,\sigma$ for the early-type galaxies. In the first panel, we represent the contours of equal density for these galaxies (solid) and for Sbc–Sd spirals (point-dash) [3].

than those of low-BT pseudobulges, probably because high-BT pseudobulges are located in earlier spiral types. We also applied a full reddening correction using the SDSS spectra and found that 60 % of our pseudobulges are still in the red sequence.

4 Discussion

Colors of pseudobulges obtained here are consistent with old stellar populations. To check whether a bulge with such red colors could be formed through continuous star formation, we did a test with `starburst99` [8]. The mean stellar mass of our bulges is $3 \times 10^9\,\mathrm{M}_\odot$. Then we simulated the color of a bulge which formed half of its mass in an instantaneous burst 8 Gyr ago and half through continuous star formation during 8 Gyr. The burst after 8 Gyr has a color of $(g - i) = 1.13$, while the stellar mass formed through continuous SF has a color of $(g - i) = 0.49$. When both models are combined we can see that the color is still very blue (0.59), indicating that the continuous star formation dominates the final color. These results contrast with pseudobulge formation through continuous star formation. Therefore, if secular evolution is the formation mechanism, it should have stopped a long time ago.

In order to check the effects of the environment in the pseudobulge stellar population, we represent the pseudobulge color versus the tidal force exerted on the galaxy by the companions. We found a tendency for bluer pseudobulges to show higher values of tidal force (more affected by the environment), indicating that interactions could be rejuveneting the pseudobulges.

The red bulge colors and low B/T values for AMIGA isolated galaxies are consistent with an early formation epoch and not much subsequent growth. Properties of bulges in isolated galaxies contrast with a picture where pseudobulges grow continuously via star formation.

5 Conclusions

We have performed a 2D bulge/disk/bar decomposition for a sample of 189 isolated galaxies. We used the Sérsic index to separate between classical bulges ($n_b > 2.5$) and pseudobulges ($n_b < 2.5$). We found 12 classical bulges and 177 pseudobulges in our sample. Our pseudobulges fall below the $\langle\mu_e\rangle$–R_e plane of early-type galaxies, i.e. they are less dense, with the region closest to the Kormendy relation populated by those pseudobulges with larger values of B/T.

We derived the $(g-i)$ colors of our bulges using aperture photometry. We found that a 64 % of our pseudobulges follow the red sequence of early-type galaxies: they have colors similar to those presented by early-type galaxies as luminous as their host galaxies (redder for brighter galaxies). These red colors suggest a predominant old stellar population. The bluer bulges in our sample tend to be located in those galaxies more affected by the tidal interactions. The properties of the majority of bulges in isolated galaxies suggest that pseudobulges formed most of their mass in an early epoch, and that specific environmental events could rejuvenate the pseudobulges. In our sample of isolated galaxies, these events were minimized, which would explain our large fraction of late-types and the red colors of their (pseudo)bulges.

Acknowledgments

This work has been supported by Grant AYA2011-30491-C02-01 and the Junta de Andalucía (Spain) P08-FQM-4205 and TIC-114.

Funding for SDSS-III has been provided by the Alfred P. Sloan Foundation, the Participating Institutions, the National Science Foundation, and the U.S. Department of Energy. The SDSS-III web site is http://www.sdss3.org/.

References

[1] Aihara, H., et al. 2011, ApJS, 193, 29

[2] Argudo-Fernández, M., Verley, S., Bergond, G., et al. 2013, A&A, 560, A9

[3] Fernández Lorenzo, M., Sulentic, J., Verdes-Montenegro, L., et al. 2014, ApJL, 788, LL39

[4] Genzel, R., Burkert, A., Bouché, N., et al. 2008, ApJ, 687, 59

[5] Karachentseva, V. E. 1973, Astrofizicheskie Issledovaniia Izvestiya Spetsial'noj Astrofizicheskoj Observatorii, 8, 3

[6] Kormendy, J. 1977, ApJ, 218, 333

[7] Kormendy, J., & Kennicutt, R. C., Jr. 2004, A&A, 42, 603K

[8] Leitherer, C., Schaerer, D., Goldader, J. D., et al. 1999, ApJS, 123, 3

[9] Nair, P. B., & Abraham, R. G. 2010, ApJS, 186, 427

[10] Peng, C. Y., Ho, L. C., Impey, C. D., & Rix, H.-W. 2010, AJ, 139, 2097

[11] Verdes-Montenegro, L., Sulentic, J., Lisenfeld, U., Leon, S., Espada, D., Garcia, E., Sabater, J., & Verley, S. 2005, A&A, 436, 443