Observational evidence of different evolutionary stages in galactic bars

I. Pérez, P. Sánchez-Blázquez and A. Zurita

Abstract We analyse the stellar line-strength index distribution along the bar of a sample of 20 early-type galaxies derived from optical long–slit observations along the bar major axis. The aim is to study the formation and evolution of bars in galaxies. We obtain age and metallicity distributions using stellar population models. We find that the mean bar values of age, metallicity and [E/Fe] correlate with central velocity dispersion in a similar way to that of bulges, pointing to a intimate evolution of both components. Galaxies with high stellar velocity dispersions ($>$170 kms^{-1}) host bars with old stars while galaxies with lower central velocity dispersion show stars with a large dispersion in their ages. We find, for the first time, gradients in both age and metallicity. We find three different types of bars according to their metallicity and age distribution along the radius: 1) Bars with negative metallicity gradients. They show mean young/intermediate population ($<$ 2 Gyr), and have amongst the lowest stellar velocity dispersion of the sample. 2) Bars with null metallicity gradients. The galaxies that do not show any gradient in their metallicity distribution along the bar have positive age gradients. 3) Bars with a mean older population and positive metallicity gradients, i.e. more metal rich at the bar ends. The results indicate that most bars are long–lasting structure. These derived gradients place strong constrains on models of bar evolution. All the galaxies show disk–like central components, implying a strong role played by bars in the bulge secular evolution.

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1 Introduction

In order to understand the role played by bars in secular evolution, such as the building-up of the central bulge, feeding the nuclear black hole, or , simply, understanding their role in the redistribution of material in the disk, it is crucial first to understand their own fate and evolution. Detailed analysis of the stellar populations in the bar region of local galaxies can shed some light to the formation and evolution of bars. We have carried out a project to analyse in detail the stellar populations in the bars of 20 early–type spiral galaxies. Long-slit spectra along the bar of our sample galaxies have been obtained at the 2.3m telescope at Siding Spring Observatory (RSAA, ANU, Australia) with the DBS spectrograph, and at El Roque de Los Muchachos Observatory (La Palma, Spain), where we used the IDS mounted on the Isaac Newton telescope (2.5m). Details of the observations, data reduction, and analysis is presented in Pérez, Sánchez-Blázquez & Zurita (2007) [2] and Pérez, Sánchez-Blázquez & Zurita 2008 (submitted to A&A), in the latter we present also the comparison between galaxy parameters such as the bar–strength, bar size and presence of nuclear activity and the age and metallicity radial distribution. Extreme care has been taken to remove the nebular emission from the spectra. We will present in the following sections the main results obtained from the analysis of the derived stellar populations parameters.

2 Results and discussion

Kinematics

From the study of the kinematics along the bar, we have found that all the galaxies in the sample show a disk–like component in their centers, showing as dips or plateaus in their central stellar velocity dispersion and as stellar rotating disks. Therefore, this implies that bars, as expected, have a strong influence in the building up and later evolution of the central component. We have derived ages and metallicities from Lick/IDS line-strength indices of single stellar population (SSP) (Trager et al. 1998) [4].

Mean stellar parameter values

We first calculate the mean stellar age, [E/Fe], and metallicity of the bar by averaging the derived values along the bar and weighting with the errors in these parameters. Mean stellar parameter values with respect to the central velocity dispersion are presented in Fig. 1 and Fig. 2. As can be seen, there is a trend in which galaxies with smaller central velocity dispersion are also the ones showing younger mean-ages. In the same way, galaxies with lower central velocity dispersion tend to have lower values of [E/Fe] and metallicity. In this Figure, we have separated the galaxies hosting a nuclear AGN from those without, there is no significant difference in the distribution of the two samples. It is interesting to notice that the trends shown in Fig. 1 and Fig. 2 are similar to those found for galaxy bulges (Proctor & Sansom 2002, Morthy & Holtzman 2006) [3] [1] with values of the metallicity and [E/Fe] slightly lower than those found in the bulges. This result points out to an intimate link between the evolution of the bar and the bulge.

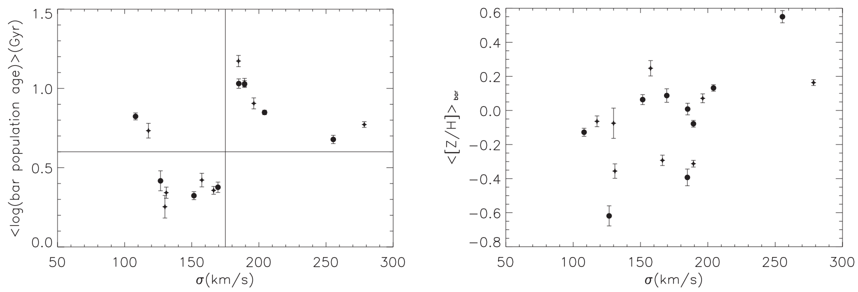

Fig. 1 Mean age, metallicity in the bar region against central velocity dispersion. The diamonds correspond to the galaxies classified as hosting and AGN, the circles are the galaxies with non-active nuclei. Notice that galaxies with lower central velocity dispersions are also the ones with younger ages and lower Z values, these trends are similar to those found for the bulge region

Fig. 2 Mean [E/Fe] in the bar region against central velocity dispersion. Symbols as in Fig. 1. Notice that galaxies with lower central velocity dispersions are also the ones with lower [E/Fe] values, these trends are similar to those found for the bulge region

Stellar parameter radial distribution

We have found three different types of bars according to their metallicity and age distribution along the bar, Fig. 3 shows SSP-equivalent age and metallicity along the radius for a few galaxies, as indicative of the type of results that have been obtained, of the sample showing very different age and metallicity trends:

1) Bar with negative metallicity gradient. These bars show a mean intermediate population (< 2Gyr) and have amongst the lowest central stellar velocity dispersion of the sample. They also tend to have positive age gradients (i.e. older population at the bar ends).

2) Bars with null metallicity gradients. The galaxies that do not show any gradient in their metallicity distribution along the bar have positive age gradients, that is, their ends of the bar are younger. These younger populations are linked to the bar ends (from the morphology) and therefore, star formation bursts must have happened after bar formation. Although, the population at the end of the bar is younger than the average bar value, it is still between 3 and10 Gyr, which implies that these bar are old. These low-age regions at the ends of the bar are clearly seen in simulations of barred galaxies (Wozniak 2007) [5], these regions are located at the apocenter of elliptical orbits along the bar, near the ultra–harmonic resonance.

3) Bars with an older population and positive metallicity gradients. In order to produce this metallicity gradient (opposite sign to the gradients found in disks), which has to be post–bar formation since it is morphologically related to the bar, the bar must have formed stars very quickly or for a long period of time. The ages in these bars are old, implying that these bars are long–lived. In the few cases where we reach information on the disk region, the metallicities are lower than those of the bar, implying a chemical enrichment of the bar region after bar formation. Therefore, for the galaxies with positive or zero metallicity gradient in the bar region, we can conclude that the bars are robust and old.

We conclude than the bars 2) and 3) have formed more than 5 Gyr ago. So, what about the galaxies with negative metallicity gradients? All the galaxies with a younger average population have negative metallicity gradients and a positive age gradient, similar to those found in the disk region. These galaxies have populations at the beginning of the bar and central regions of around 1.2 Gyr, while the population at the bar ends corresponds to ages of around 10 Gyr. If the bar formation is linked with a burst of star formation, the presence of the young population might be indicating a bar formed less than 2 Gyr ago. Although the presence of recent star formation might be indicating a recently formed bar this is not necessarily the only explanation, the amount of gas available in the system might also be determining the duration of the star formation period. Further study of the disks hosting the bars will help to better understand the results derived for the bar region. To this aim, we have already gathered deep GEMINI long–slit spectra of a sample of four barred galaxies.

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References

1. Moorthy B. K. & Holtzman J. A., MNRAS **371**, 583 (2006)
2. Pérez, I. Sánchez-Blázquez P. & Zurita A., A&A **465**, 9 (2007)

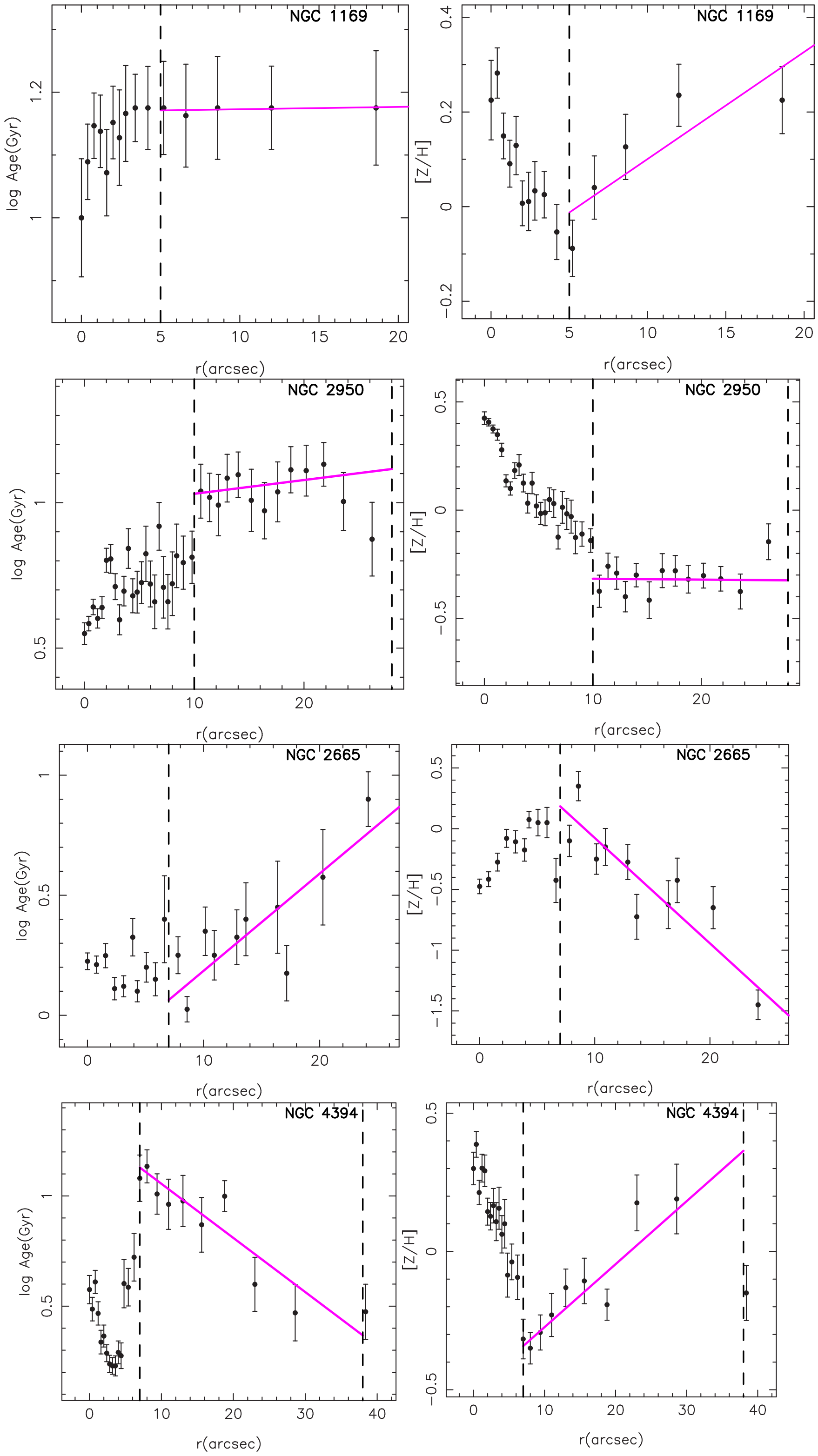

Fig. 3 SSP-equivalent age and metallicity along the radius for the bar region of a few of the sample galaxies as an example of the different age and metallicity distributions displayed by the galaxies. Dashed lines indicate the beginning and the end of the bar region. A linear fit to the bar region is also plotted.

3. Proctor R. N. & Sansom A. E., MNRAS **333**, 517 (2002)
4. Trager S. C., Worthey G., Faber S. M., Burstein D. & Gonzalez J. J., ApJ **116**, 1(1998)
5. Wozniak H., A&A **465**, 1 (2007)