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The lives of double-barred galaxies: photometric properties.

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Abstract

Double-barred galaxies are structurally complex objects, as the two bars show random orientations and independent pattern speeds. This fact has greatly hampered the study of these objects, even though inner bars are considered a main driver of gas inflow to the central regions of galaxies, where it may feed the AGN and/or promote the secular formation of bulges. Over the past years our group has faced the problem of the observational study of double bars from different standpoints. Thus, we have studied in detail the stellar and gas content of double bars, their particular properties with respect to single- and non-barred galaxies, and even how to identify new double-barred systems previously unknown. This proceeding summarizes the most relevant knowledge we have so far about double-barred galaxies, and presents preliminar results about the structural characterization of double bars.

1 Double bars: background

Bar instabilities are considered the main drivers of the internal secular evolution of spiral galaxies [9]. The gravity torques linked to the presence of a non-axisymmetric structure such as a bar induce gas flows outwards and inwards. In the central regions of the galaxy, this gas accumulates, star formation may then be triggered, and new structures may eventually be formed.

It has been theoretically postulated that a system of two nested bars may efficiently transport gas to even more central regions, unreachable for the material flowing along a single bar. If this hypothesis was proved true, this would place double bars as the promising solution for the long-standing problem of AGN feeding. Double bars would indeed be able to promote secular evolution and keep the gas flowing towards the AGN, as suggested by [17] (although see e.g., [11] for other points of views).

Many double-barred systems have been found in the local Universe so far. In 2004, [7] published a catalog of 50 double-barred galaxies, and new 18 candidates have been identified by [10] in the NIRS0S survey. This means that approximately 20 % of all the local spirals host two bars. This number might even be considered as a lower bound, due to the difficulties inherent to the detection of inner bars.

Observational studies of double-barred systems have shown that the two bars rotate independently [1], having therefore random orientations between them. Moreover, the inner bar has around 12 % the length of the outer bar [6], and might be totally embedded in the light of the central bulge. These properties make the observational analysis of double-barred galaxies arduous, and while the literature shows a nice number of projects aiming at detecting new double-barred systems and analysing their photometry, there are only a few works relying on spectroscopic data.

In 2008 and 2013, our group studied in detail both the stellar and gas kinematics of double-barred galaxies by means of integral-field spectra (see [3] and [5]). We showed that, while the presence of an inner bar has a very subtle effect on the stellar line-of-sight velocity distribution of its host, it does modify the velocity dispersion (σ) map. Two local σ-minima appear exactly at the edges of the inner bars, with amplitudes ranging between 10 and 40 $\mathrm{km\,s^{-1}}$. This new feature is known as the σ-hollows and represents the first kinematic signature of the presence of an inner bar in a spiral galaxy.

The ionized gas distribution in double-barred galaxies analysed by [5] also showed promising results. The intensity maps present spiral structures pointing towards the ends of the inner bars, which can be interpreted as hints of gas inflows through the outer bars and entering the inner bar structure. This interpretation is furthermore supported by the gas velocity distributions, which show the clear counterparts of the spiral structures. The results presented in [5] may be seen as an additional argument in favour of the hypothesis of [17], although more detailed studies are needed to confirm or discard it.

Little is known about the stellar population content of double bars. In [4] and [5], our group carried out an analysis of the absorption line indices with high quality spectra of five double-barred galaxies in order to measure the mean luminosity ages and metallicities of these objects. We found that the inner bars show lower age and higher metallicity values than the outer bars, being however not absolutely young systems, as their ages range from approximately 4 to 6 Gyr.

The five galaxies analysed by [4] and [5] show positive age and negative metallicity gradients along the whole studied field-of-view. This result is in agreement with the work of [14] for single bars. Estimates of the α-enhancement point towards slightly lower values at the very central regions of the galaxies, which indicates that they have suffered a more time-extended star formation.

The pieces of evidence presented by [4] and [5] seem to indicate that inner bars might be formed secularly from gas inflow along the outer bars. This gas-rich scenario has been already introduced in the theoretical works of [8] and [15], among others. The possibility of a gas-free scenario, as that resulting from the simulations of [2] and [16], cannot be fully discarded though. The role that inner bars play in the secular evolution of their hosts once they are formed cannot be fully constrained with the published data neither, although no major evidences of young structures or central star formation are found in the five galaxies under study in [4] and [5].

2 Double bars: photometric properties

Most of the photometric studies of double-barred galaxies performed so far are based on ellipse fitting over galaxy images. They are therefore hampered by the overlapping of the different structures at place, namely bulge, disc, outer bar, and inner bar. Proper photometric decompositions, in which the size and other photometric properties of each individual structure are recovered, would provide a definitive characterisation of inner bars.

Photometric decompositions are a powerful technique to investigate the nature of the structural components and recover their formation histories, as the photometric properties keep the fingerprint of the evolutionary processes that have shaped the galaxies. In particular, photometric decompositions have been widely used to study bulges and distinguish between classical and disc-like bulges (see e.g., [13]), which can be considered as tracers of secular evolution. As introduced in Section 1, many double-barred systems most likely remain unknown, and even known inner bars are usually not taken into account in the photometric decompositions of the central regions of galaxies.

We are carrying out a project to perform photometric decompositions of double-barred galaxies, with special emphasis on the properties of inner bars. The goal is to derive, for the first time, intrinsic lengths and sizes of the bars, and to estimate the errors affecting bulge measurements when the inner bars are not included in the fitting procedure.

Our sample consists in the 23 double-barred galaxies included in the catalog of [7] that have been observed by the Sloan Digital Sky Survey (SDSS; [18]). We make use of the code GASP2D [12], that has been adapted to include an inner bar, as well as a truncated disc, bar, and bulge. An example of a fitting of a double-barred galaxy performed with GASP2D is shown in Figure 1.

A total of 9 galaxies have been analysed so far. We have discovered that two well known double-barred galaxies, NGC 1068 and Mrk 573, are not real hosts of inner bars. This conclusion has been double-checked with Hubble Space Telescope images. The structural complexity at the centres of these galaxies had led to the misleading result that inner bars are present, but no hints of small bars appear in our analysis and therefore we have removed these two galaxies from the sample. 7 galaxies are included in the preliminar results shown here: NGC 357, NGC 718, NGC 2950, NGC 3941, NGC 4340, NGC 4503, and NGC 7716.

Figure 2 shows the comparison of the bulge efective radii and Sérsic indices when fitted with two bars and with just one single, big bar. The results follow the identity relation fairly well, thus indicating that not including the inner bar in the fitting of a double-barred galaxy

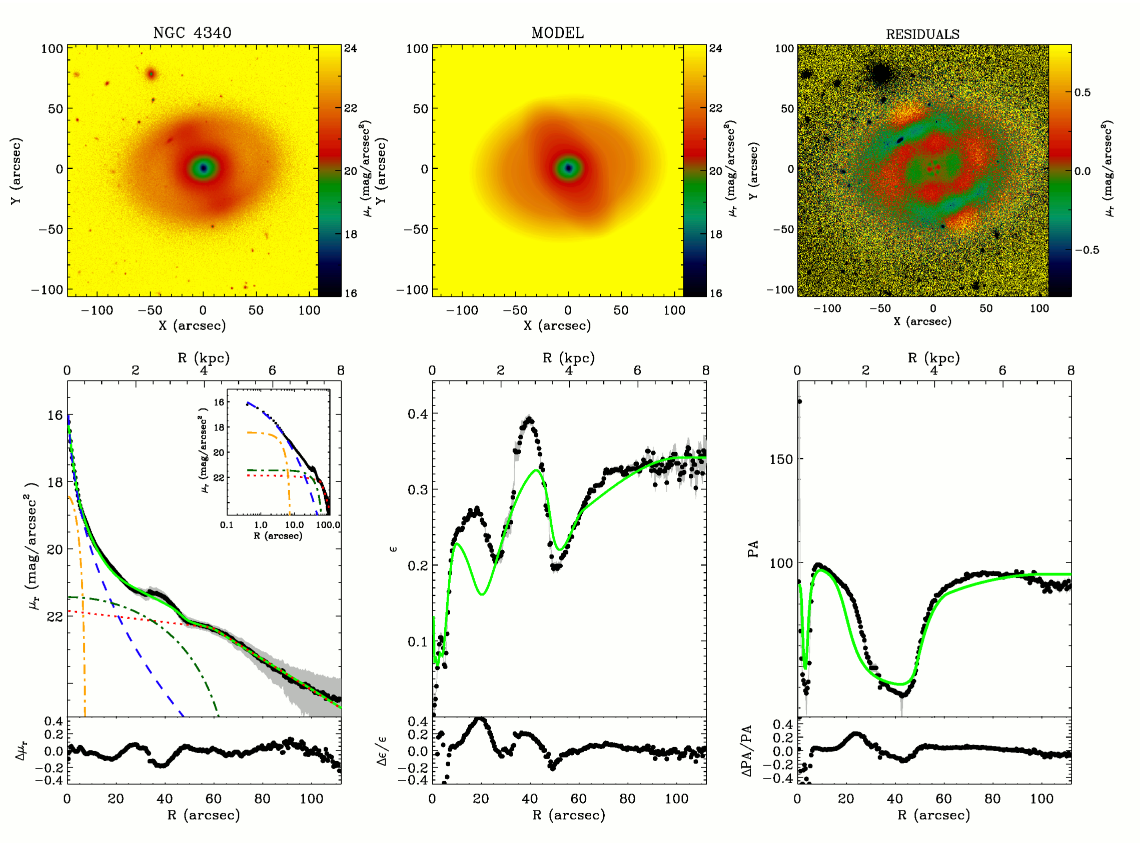

Figure 1: Photometric decomposition of the double-barred galaxy NGC 4340 performed with the modified version of GASP2D [12]. The top panels show the original SDSS image (left), the best 2D fit including a disc, bulge, and two bars (middle), and the residuals of the fit (right). Radial profiles are displayed in the bottom panels to show the accuracy of the fit: the left panel contains the original light profile (black dots), and the fitted disc (red dots), bulge (blue dashed line), outer bar (green dot-dashed line), and inner bar (yellow dot-dashed line). The black dots in the bottom middle and right panels show the original position angle (PA) and ellipticity profiles, respectively, with their fitted counterparts in green. Note that the bumps of the PA and ellipticity profiles in the very central regions (r∼4 arcsec), due to the presence of the inner bar, are well recovered in our fitted model.

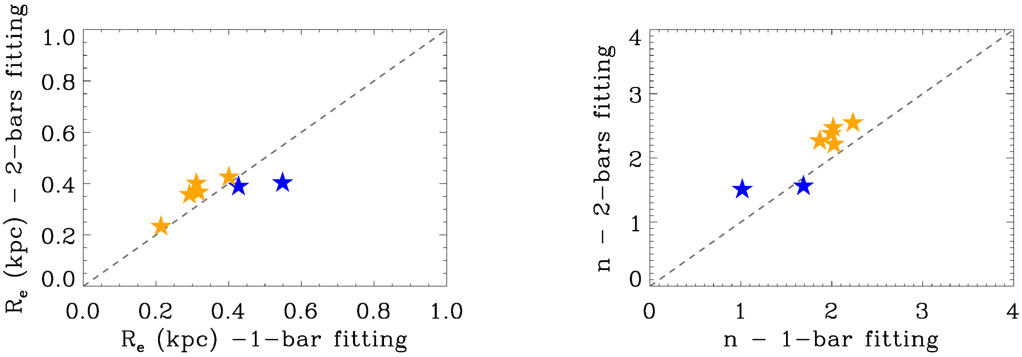

Figure 2: Comparison of bulge effective radii (left panel) and Sérsic index (right panel) derived with a fitting procedure including two bars (y-axes), and including only one, single bar (x-axes), for the 7 double-barred galaxies analysed with GASP2D. Blue stars indicate galaxies with bulge Sérsic index $n > 2$.

does not affect the measurement of the bulge parameters in a major way.

The previous conclusion is well understood when looking at the plots shown in Figure 3. The intrinsic lengths and bar-to-total (Bar/T) intensity ratios recovered for the inner and outer bars are shown. It is seen that inner bars contribute to only $\sim 2\,\%$ of the total galaxy light, and their sizes are ~11–30 % of the outer bar lengths. Inner bars are therefore small and faint structures with a mild effect on the photometric parameters of the bright bulges.

It is interesting to note that the intrinsic length ratio between inner and outer bars can reach up to $\sim 30\,\%$, as shown in Figure 3. This is a much larger value than the $\sim 12\,\%$ estimated through ellipse fittings (see Section1, [6]). This result was expected as the photometric decomposition derives the real intrinsic length of the bar structure, while the ellipse fitting needs to agree criterion for the length estimate that is usually taken where the bar is still bright, and not at its faint ends.

Further conclusions on the photometric properties of double-barred galaxies and the nature of its central structures will be published when the whole sample has been analysed.

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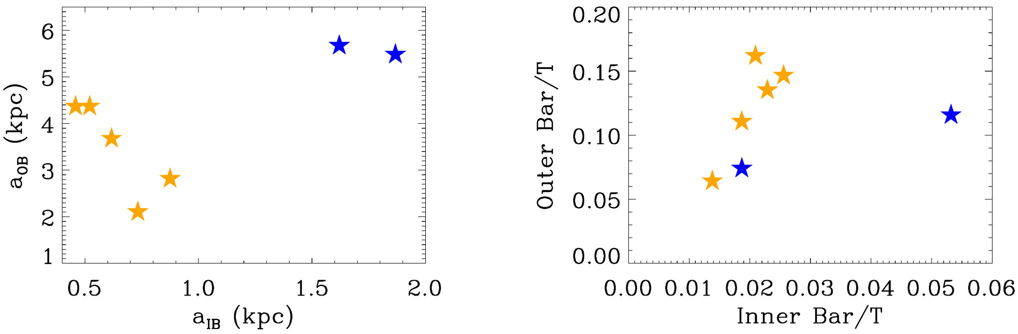

Figure 3: Comparison of the bar length (left panel) and the bar-to-total intensity ratio (Bar/T; right panel) for the outer (y-axes) and inner bars (x-axes), for the 7 double-barred galaxies analysed with GASP2D. Blue stars indicate galaxies with bulge Sérsic index $n > 2$.

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