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Deconstructing bulges in lenticular galaxies using CALIFA

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Abstract

Bulges play a key role in the evolution of disk galaxies and their influence on the fate of lenticular galaxies (S0s) is still more manifest. We present preliminary results on the photometric and kinematic properties of S0 bulges drawn from the CALIFA survey. We find that S0 galaxies usually deviate from their *archetypal* view of simple systems composed by a bulge and disk structure. In fact, most of S0 galaxies ($\sim$ 65%) host bars or non-single exponential profiles, making compulsory the use of multi-component photometric decompositions to properly address the bulge properties. We confirm previous results present in the literature showing S0 galaxies as a complete photometric and kinematic sequence of galaxies.

1 Introduction

The relevance of galaxy bulges as central pieces in the study of galaxy formation is nowadays well settled. This role is still more manifest in lenticular (S0) galaxies where, by definition, bulges account for a significant fraction of the galaxy mass [14, 17]. Recently, several studies [7, 15] have shown that bulges of S0 galaxies exhibit a great diversity of properties, some of them being similar to small-scale ellipticals (i.e., classical bulges) and others to late-type, more disk-like, spiral bulges (i.e., pseudobulges). This could reinforce the idea of S. van den Bergh [25] that S0s encompass galaxies with different origins and evolutionary paths, only being similar in their morphology. Despite the huge amount of literature on S0 galaxies [3], several basic questions still need to be answered. Are S0 galaxies a well-defined and homogeneous class of galaxies, or do they have different origins and/or evolutions? Are S0 galaxies formed by major mergers of galaxies, or did they form through slow galaxy processes including minor satellite accretion or secular evolution? Are they the final steps in the evolution of late-type galaxies due to environmental mechanisms?

From an observational perspective, integral field spectroscopic (hereafter IFS) data are now providing a new look to the puzzle of S0s formation and evolution. Their ability to spatially constrain the kinematic and stellar population properties of the underlying stellar populations, as well as the continuously growing number of galaxies observed using this technique is given new light to the topic. In this paper, we present the first results of a project devoted to study the properties of the bulges of S0 galaxies using the IFS survey CALIFA [24]. The sample used in this paper comprise a subsample of 20 low-inclined and non-disturbed S0 galaxies extracted from the CALIFA observed sample until February 2014.

2 Multi-component photometric decomposition

The *photometric* definition of a bulge as the light excess above an exponential disk is nowadays the most used. Therefore, adopting this as a general definition it is clear that the study of galaxy bulges always involves to get rid of the light contamination produced by other structural components present in the center of galaxies. This task is usually performed by applying a photometric decomposition to the galaxy surface brightness distribution (SBD).

The structural parameters of the sample galaxies were derived by applying a parametric two-dimensional photometric decomposition to the $g-$, $r-$, and $i-$band Sloan Digital Sky Survey (SDSS-DR7; [1]) galaxy images. We used the GASP2D algorithm developed by [19]. The galaxy SBD was initially assumed to be the sum of a bulge and disk. A bar component was then introduced in the fitting process when necessary. Details about the properties of these three components as well as the main characteristics of GASP2D are given in [22]. In addition, the three different types of disk profiles observed in galaxies [10], i.e., Type I single exponential, Type II downbending brightness beyond a break radius, and Type III upbending brightness beyond a break radius were also included in GASP2D to properly fit the disks of S0 galaxies.

The SBD of the disk component was assumed to be given by

$$I_{\rm disk}(r_{\rm disk}) = I_0 \exp\left(\frac{-r_{\rm disk}}{h_i}\right)\Theta + \exp\left[-r_{\rm break}\left(\frac{h_i - h_o}{h_i\, h_o}\right)\right]\exp\left(\frac{-r_{\rm disk}}{h_o}\right)(1-\Theta) \qquad (1)$$

where I_0, h_i, and h_o are the central surface brightness and scale-length of the inner and outer disks, respectively. $r_{\rm break}$ is the transition radius between the two exponentials and Θ is given by

$$\begin{aligned} \Theta &= 1 \qquad if\, r_{\rm disk} < r_{\rm break} \\ \Theta &= 0 \qquad if\, r_{\rm disk} \geq r_{\rm break} \end{aligned} \qquad (2)$$

We performed a careful case-by-case analysis of the photometric decomposition finding that only 7 out of 20 S0 galaxies have a *archetypal* bulge + type I disk. This result highlights the importance of multi-component photometric decomposition even when dealing with initially *simple* systems such as S0 galaxies.

12 galaxies in our sample are best fitted by adding a bar component thus implying a bar fraction of $60^{+9.6}_{-11.4}\%$. This is in good agreement with previous measurements in larger

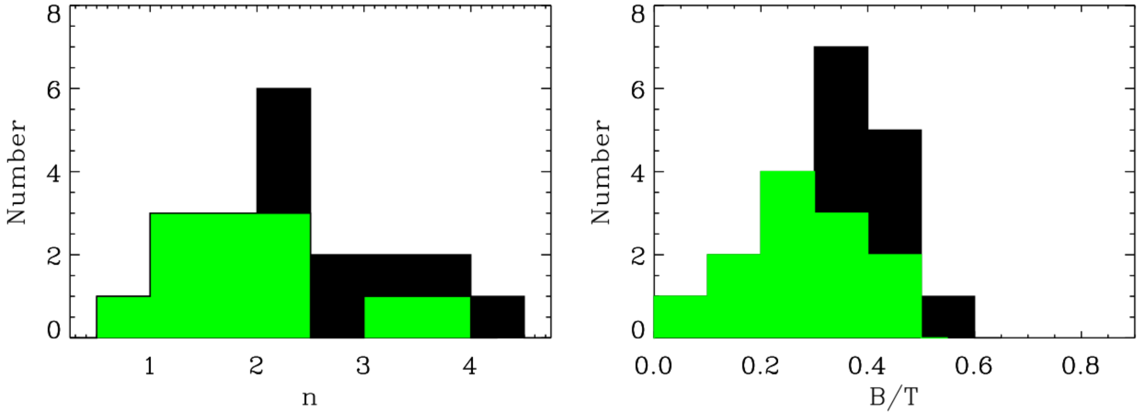

Figure 1: *Left* panel: distribution of bulge Sérsic index (n) in our sample. *Right* panel: distribution of B/T in our sample. In both panel the green and black histograms represent barred and unbarred systems.

galaxy samples ($\sim$ 50%; [4]) but much higher than the 29% presented by [2] for the same galaxy type. The actual bar fraction in S0 galaxies is still matter of debate [18] and several factors such as galaxy mass [20] or environment [21] can be biasing the results.

In addition, 4 galaxies show a type II disk profile with 3 of them being also barred galaxies. This result is compatible with the previous measurements by [13] where they found $\sim$ 20% of the early type disks hosting a type II profile. Nevertheless, we did not find any type III profile in our sample in contrast with the $\sim$ 45% predicted by [13].

3 Photometric properties of the S0 galaxies

Figure 1 show the distribution of bulge Sérsic index (n) and bulge-to-total (B/T) luminosity ratio of our S0 sample. The Sérsic index span from $0.8 < n < 4.1$ in agreement with previous results [16, 17]. Similarly, the B/T distribution also covers a large range of values from $0.1 < B/T < 0.52$. These results point towards S0 galaxies being a complete sequence of galaxies with different properties and, likely, with different formation and evolutionary paths as suggested by [15].

The presence of bars and their proper addition to the photometric decomposition procedure have a strong impact on the final measurements [11]. The green shaded histograms in Fig. 1 show how, in general, barred galaxies host bulges with both shallower SBD, i.e., lower Sérsic index, and smaller size, i.e., lower B/T values. These results remark again the importance of carrying out accurate multi-component photometric decomposition on the study of galaxy bulges.

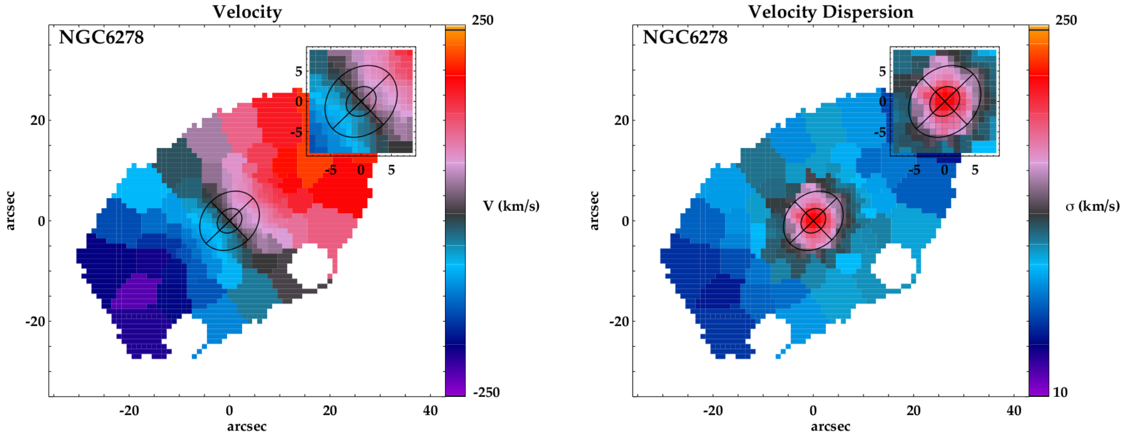

Figure 2: Velocity (*left* panel) and velocity dispersion (*right* panel) maps of NGC 6278. The inner and outer ellipse in each panel represents the effective radius (r_e) and r_bd (see text) of the corresponding bulge. The insets show a zoom in the central region of the galaxy.

4 Stellar kinematics of the S0 bulges

The stellar kinematic of the galaxies was measured from the spectral datacubes observed with the V1200 grating of the CALIFA survey [24]. The full description of the procedure will be detailed in Falcón-Barroso et al. (in prep.). For the sake of clarity, we give here a brief summary of the process. In the first step the spaxels of the datacube were Voronoi binned to achieve a limiting signal-to-noise ratio $S/N > 20$ [6], while spectra with $S/N < 3$ were not considered. The values of the line-of-sight (LOS) velocity and velocity dispersion were obtained by fitting the binned spectra using the penalised pixel-fitting method (pPXF) from [5]. An example of the kinematic maps produced with this procedure can be seen in Fig. 2.

We used the previously mentioned photometric parameters to define the apertures on the CALIFA kinematics maps where to extract the bulge properties (see Fig. 2). To this aim, we used the bulge effective radius (r_e) and the radius where the bulge and disk give the same contribution to the total SBD (r_bd; [23]).

Using the angular momentum (λ_r) definition by [8] we estimated the dynamical support within 1 r_e of the S0 bulges. The results are shown in Fig. 3 where the λ_r vs. ϵ (apparent ellipticity of the bulge) diagram is represented. Figure 3 show how the kinematic of some of our bulges can be compared with the slow rotators defined by [9] whereas others are fast rotators. However, it is clear that there is also a continuity in the kinematic properties of bulges similar to what found with their photometric properties. Further analysis on the relation between the photometry and kinematics of bulges will be the scope of a future paper.

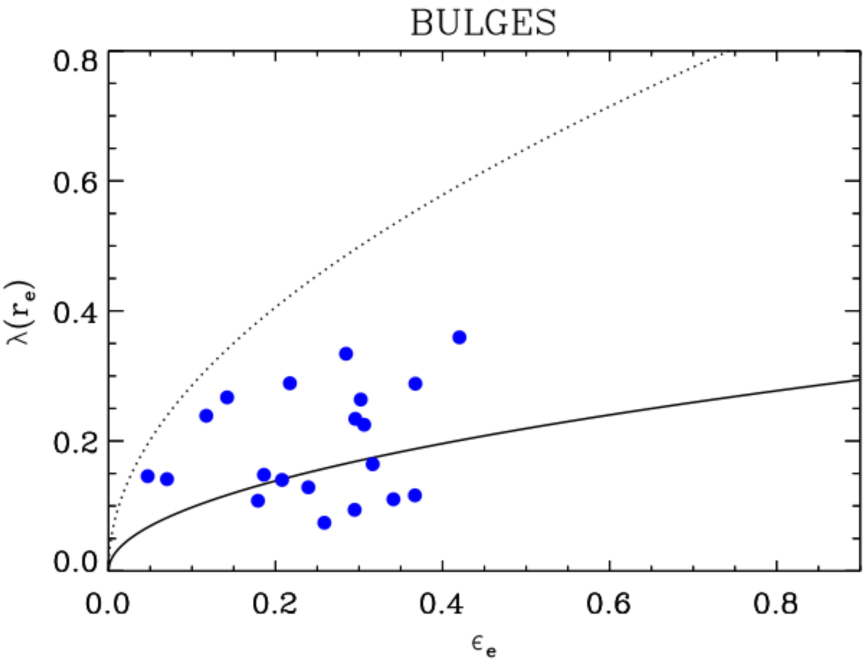

Figure 3: Angular momentum (λ_r) computed at 1 effective radius (r_e) vs. bulge apparent ellipticity (ϵ_e). The black solid line represents the empirical separation between slow and fast rotators given by [9]. The dotted black line represents the isotropic oblate systems seen edge-on.

5 Conclusions

Our preliminary analysis of the CALIFA S0 galaxies confirm previous results arguing that S0 galaxies represent a complete sequence of galaxies in both their photometric and kinematic properties. Therefore they are not just a homogeneous class of object at the transition point between elliptical and spiral galaxies.

It is worth noting that the results presented in Fig. 3 are subject to systematics due to the limited spatial resolution of the CALIFA datacubes [12]. Preliminary experiments to understand how this problem can affect the measurements of λ_r indicate that they are always understimated. However, the bias is strongly dependent on the SBD of the underlying population thus changing from galaxy to galaxy. On the other hand, the identification of composite bulges [22] is also hampered by the limited spatial resolution and therefore our results do not account for multiple bulges coexisting within the same galaxy.

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