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MORPHOLOGICAL CLASSIFICATION OF GALAXIES: IMPACT FROM SPATIAL RESOLUTION AND DATA DEPTH ON NON-PARAMETRIC METHODS

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Abstract. We analysed the impact of survey depth and spatial resolution on some of the most used morphological parameters for classifying galaxies through non-parametric methods. We selected three different non-local datasets, ALHAMBRA and SXDS, as examples of deep ground-based surveys, and COSMOS, as an example of deep space-based surveys. We used a sample of 3000 local, visually classified galaxies. We first measured their morphological parameters at their real redshifts (z$\sim$0). Secondly, we simulated them to match the redshift and magnitude distributions of galaxies in the selected non-local surveys. From the comparisons of the two sets we were able to put constraints on the use of each parameter for morphological classification, in each survey, at different magnitude cuts, and to evaluate the effectiveness of the commonly used morphological diagnostic diagrams.

1. INTRODUCTION

Morphology is one of the main characteristics of galaxies, and the morphological classification has been central to many advances in the picture of galaxy formation and evolution. The basic classification schemes come from early 20s (Reynolds 1920; Hubble 1926), dividing all galaxies into four main types: elliptical, lenticular, spiral, and irregular. Hereafter, when we speak about early-type galaxies (ET) we will refer to ellipticals and lenticulars, while in late-type (LT) galaxies we include spirals and irregulars. Moreover, LT_et and LT_lt include spirals Sa-Sbc and later than Sbc, respectively.

Non-parametric methods are based on measuring the different galaxy parameters that correlate with the morphological type, usually with light distribution: concentration of light within the galaxy, galaxy shape, or presence of small-scale structures. For intermediate- and high-redshift, low resolution, galaxy samples, and large data sets, typical for current (and future) deep photometric surveys, the application of automated non-parametric methods is very often the only way to obtain information about the morphology. Over the past years different diagnostic diagrams were developed, related to the use of two or more parameters to separate between ET and LT galaxies and to select mergers. However, each of the analysed parameters, and therefore the diagnostic diagrams constructed with a combination of them, can suffer important changes depending on the data quality, mainly spatial resolution and data depth, so special care should be taken into account when applying the same criteria on different datasets.

Here we present a systematic study on how spatial resolution and depth affects the most used morphological diagnostic diagrams based on the six commonly used parameters: Abraham concentration index (CABR; Abraham et al. 1994, 1996), Gini coefficient (GINI; Abraham et al. 2003), Conselice-Bershady concentration index (CCON; Bershady et al. 2000; Conselice et al. 2000), M20 moment of light (M20; Lotz et al. 2004), Asymmetry index (ASYM; Abraham et al. 1994), and Smoothness (SMOOTH; Conselice et al. 2000). We used a visually classified sample of local galaxies and simulated them to map the observational conditions of three different ground- and space-based deep surveys. Comparing the parameters of local galaxies measured before and after moving them in redshift and magnitude, we were able to put constraints on the main morphological diagnostic diagrams, observing how the position and shape of the regions typical of ET and LT galaxies change in local and simulated conditions. Moreover, comparing the diagrams between the ground-based and space-based surveys, and at different magnitude cuts, we quantified how strong is the impact from spatial resolution and survey depth.

2. DATA

Local sample

We used a sample of 3000 local galaxies at $0.01 \leq z \leq 0.1$ (mean redshift of 0.04), observed in the Sloan Digital Sky Survey (SDSS) Data Release 4 (DR4) down to an apparent extinction-corrected magnitude $g < 16$, and visually classified by Nair & Abraham (2010; hereafter N&A), using the g and r bands.

Non-local sample

We selected three non-local surveys for our analysis: The Advanced Large Homogeneous Area Medium Band Redshift Astronomical survey (ALHAMBRA) and Subaru/XMM-*Newton* Deep Survey (SXDS), that provide representative samples for deep ground-based surveys (ALHAMBRA being shallower than SXDS, but with a large covered area, and SXDS as an example of the deepest available ground-based data). The Cosmic Evolution Survey (COSMOS) is used as a reference of deep space-based surveys.

ALHAMBRA is described in Moles et al. (2008), while photometric and photometric redshift catalogues are described in Molino et al. (2014). SXDS is described in Sekiguchi et al. 2004, used images and photometric catalogues in Furusawa et al. (2008), and photometric redshift catalogues in Simpson et al. (2013). COSMOS survey, images, photometric, and photometric redshift catalogues are described in Scoville et al. (2007), Koekemoer et al. (2007), Leauthaud et al. (2007), and Ilbert et al. (2009), respectively. We selected only objects with magnitudes F613W ≤ 23.0, $i' \leq 24.5$, and F814W < 24.0 in the ALHAMBRA, SXDS, and COSMOS surveys, respectively, since above these magnitude limits the photo-z accuracy decreases significantly.

3. METHODOLOGY

We used a sample of local galaxies with available detailed visual classification and measured their morphological parameters in two cases:

1) at their real redshifts (magnitudes), ie. at $z \sim 0$, and

2) moving them to higher redshifts (therefore to fainter magnitudes) and lower resolution, to simulate the conditions of galaxies on deep, ground- and space-based non-local surveys.

In both cases all parameters are measured in a completely consistent way. Finally, we compared the results obtained in cases 1) and 2) to quantify the impact from data depth and spatial resolution on each morphological parameter, for each of the three analysed surveys.

We measured all parameters, in both cases 1) and 2), using the public code of galaxy classification galSVM (Huertas-Company et al. 2008). To simulate the conditions of non-local surveys, we first randomly redshifted and scaled in luminosity the selected sample of local galaxies to match the distributions of non-local ones. Moreover, we re-sampled the local galaxies with the corresponding pixel scale for each selected non-local survey, and convolved with its PSF to match the spatial resolution. Secondly, we dropped the simulated galaxies, obtained in the first step, into the real background of the high-redshift survey images. Third, we measured CABR, GINI, CCON, M20, ASYM, and SMOOTH of the simulated (at higher redshifts) and local sample (at their true redshifts). We took care of the k-correction effect introduced by redshift, and depending on the band selected in each survey, and also depending on the redshift to which the local galaxy was moved, we measured the morphological parameters using the corresponding SDSS rest-frame band image (in both cases for simulated and local samples). Since the morphological classification directly depends on the source brightness, in each survey we analysed the observational bias at the three different magnitude cuts: mag1_cut ≤ 20.0, mag2_cut ≤ 21.5, and mag3_cut ≤ 23.0 in the F613W band in ALHAMBRA; ≤ 21.0, ≤ 23.0, and ≤ 24.5, in the i' band in SXDS; and ≤ 21.0, ≤ 23.0, and ≤ 24.0, in the F814W band in COSMOS. In all surveys we chose the first magnitude cut as that at which we have a sufficient number of sources to perform our analysis; the cut at which our selected photometric/photometric redshift sample is complete, is the last one; and we chose a cut intermediate to these two.

Figure 1 shows examples of LT local galaxies, after being scaled to the conditions of the ALHAMBRA (top), SXDS (middle), and COSMOS (bottom) surveys. In each survey, we show the galaxies being redshifted to the corresponding magnitude cuts, as explained above, providing for each cut the simulated values of magnitude and redshift. We can observe in each survey how the galaxy information changes when going from brighter to fainter magnitudes (from lower to higher redshifts), but even more, how important role the spatial resolution has when classifying galaxies. In COSMOS survey the galaxy information can be conserved up to much higher redshifts in comparison with the studied ground-based surveys.

4. RESULTS

We analysed some of the most commonly used diagnostic diagrams, and measured their effectiveness for each survey and magnitude cut in Pović et al. (2014). Here we

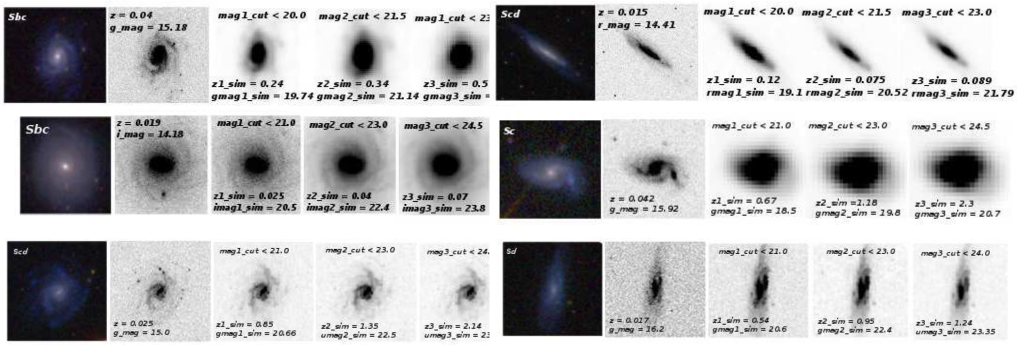

Figure 1: Example of simulated images of local LT galaxies after being scaled to map the conditions of the ALHAMBRA (top), SXDS (middle), and COSMOS (bottom). For each galaxy (in each row) we present the following (from left to right): colour image, used rest-frame image, and simulated high-redshift images at three magnitude cuts (as written on the top of each redshifted image). The real redshift and magnitude of the galaxy are noted on the corresponding rest-frame band image(s), while the simulated high-redshift and magnitude are noted on the scaled images of each magnitude cut.

present two of these diagrams: the relation between the CABR and ASYM (Fig. 2, left), commonly used to distinguish between ETs and LTs, and that between M20 and GINI (Fig. 2, right), mainly used for classifying mergers. In both figures, when observing the true parameters for local galaxies, we can clearly separate the regions typically occupied by ET, LT_et, and LT_lt galaxies, as expected. On the other side, we can observe how the position and the shape of the same regions change once we go to fainter magnitudes (higher redshifts). We measured the level of contamination for the highest density population (50%) of each analysed morphological group (ET, LT_et, and LT_lt) with the other two types, for the morphological diagrams presented (see Tab. 2 in Pović et al. 2014). We observed that the contamination levels in the morphological types increase with the data depth in all three surveys, being however significantly lower in the case of COSMOS.

5. CONCLUSIONS

Our main findings are:

- All six analysed morphological parameters suffer from significant changes in relation with both, the spatial resolution and the data depth.

- The impact of the spatial resolution on the morphology is much stronger than that of the data depth. Spatial resolution is therefore the most responsible for changing the parameters in the ground-based surveys, making in general galaxies to appear less concentrated and more symmetric.

- In surveys similar to ALHAMBRA, when analysing the highest density population regions of ET and LT galaxies in the main morphological diagnostic diagrams, spatial resolution and data depth introduces contamination levels of 5 - 30% for ET and 5 - 40% for LT galaxies (depending on the diagram), for the brightest galaxies with F613 ≤ 20.0. The diagrams that seem to work the best in this case are (CABR - ASYM), (CCON - GINI), and (CABR - GINI), while (CCON - SMOOTH) and (M20 -

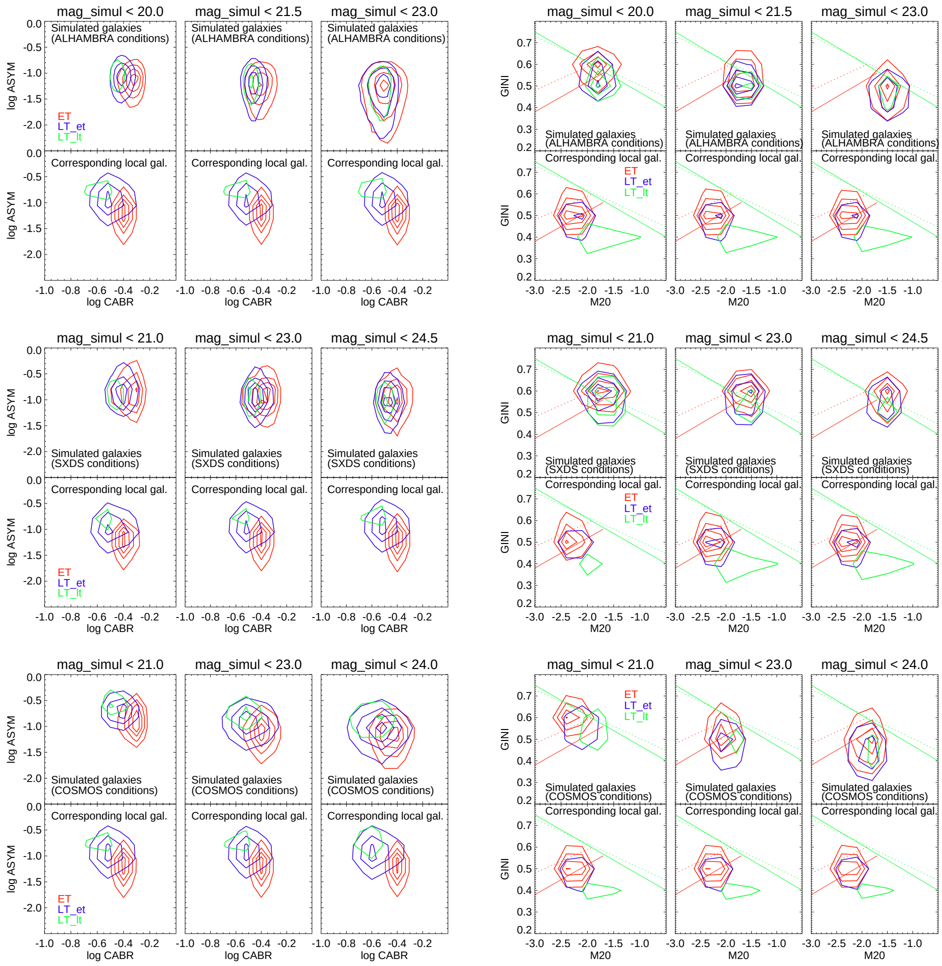

Figure 2: Left: Relation between CABR and ASYM, in the three analysed non-local surveys: ALHAMBRA *(top plots)*, SXDS *(middle plots)*, and COSMOS *(bottom plots)*. In each survey, the *top rows* represent the morphological parameters of the simulated sample obtained after moving the local galaxies to higher redshifts, considering three magnitude cuts (the first and last columns show the lowest and the highest analysed magnitude cut, respectively), while *bottom rows* show the corresponding true (local) values. Red, blue, and green contours represent ET, LT_et, and LT_lt galaxies, respectively. Right: Same as left, but for the relation between the M20 and GINI. The green (red) dotted and solid lines present the limits by Lotz et al. (2008) to distinguish between the normal galaxies and mergers (ET and LT galaxies), in the local universe and at $0.2 < z < 0.4$, respectively. In their classifications, mergers occupy the regions above the green lines, and ETs (LTs) are located below the green lines and above (below) the red ones.

Gini) are less efficient. At the faintest analysed magnitudes ($F613 \leq 23.0$) the contamination levels increase significantly, being as high as 60 - 100%, making each of the diagnostics useless if used separately. Similar results are obtained in the case of

SXDS, but at higher magnitude cuts (of order 1 - 2). Taking all this into account, when dealing with ground-based data sets, we suggest to avoid the use of 2 - 3 parameter diagnostic diagrams in morphological classification, and to apply instead the use of all morphological parameters simultaneously, and to use statistical approaches based on probability distributions for galaxies to be ET or LT. We applied this kind of methodology to classify galaxies in ALHAMBRA survey (see Pović et al. 2013).

- In space-based surveys similar to COSMOS, even at the highest magnitude cuts ($F814 \leq 24.0$), the contamination levels are significantly lower than those at the brightest magnitudes in the ground-based surveys. The observational bias is insignificant for all parameters at magnitudes brighter than $F814 = 21.0$ (except for the LT_lt galaxies). However, when going to fainter magnitudes the contamination increases, and depending on the diagram it changes from 2 - 20% at $F814 \leq 23.0$, to 10 - 30% for ET, and 20 - 70% for LT galaxies at $F814 \leq 24.0$. In surveys similar to COSMOS, we again suggest to use several diagnostics to classify galaxies when going to magnitudes fainter than $F814 = 23.0$.

The results presented in this paper can be directly applied to any survey similar to ALHAMBRA, SXDS and COSMOS, and also can serve as an upper/lower limit to take into account when classifying galaxies using shallower/deeper data sets, including the future large photometric surveys like LSST, EUCLID, J-PAS, or DES.

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References

Abraham, R. G. et al.: 1994, *ApJ*, **432**, 75.
Abraham, R. G., van den Bergh, S., Nair, P.: 2003, *ApJ*, **588**, 218.
Bershady, M. A., Jangren, A. & Conselice, C. J.: 2000, *AJ*, **119**, 2645.
Conselice, C. J. et al.: 2000, *ApJ*, **529**, 886.
Furusawa, H. et al.: 2008, *ApJS*, **176**, 1.
Hubble, E. P.: 1926, *ApJ*, **64**, 321.
Huertas-Company, M. et al.: 2008, *A&A*, **478**, 971.
Ilbert, O. et al.: 2009, *ApJ*, **690**, 1236.
Koekemoer, A. et al.: 2007, *ApJS*, **172**, 196.
Leauthaud, A. et al.: 2007, *ApJS*, **172**, 219.
Lintott, C. J. et al.: 2008, *MNRAS*, **389**, 1179.
Lotz, J. M., Primack, J., Madau, P.: 2004, *AJ*, **128**, 163.
Lotz, J. M. et al.: 2008, *ApJ*, **672**, 177.
Moles, M. et al.: 2008, *AJ*, **136**, 1325.
Molino, A. et al.: 2014, *MNRAS*, **441**, 2891.
Nair, P. B. & Abraham, R.: 2010, *ApJS*, **186**, 427.
Pović, M. et al.: 2013, *MNRAS*, **435**, 3444.
Pović, M. et al.: 2014, submitted to *MNRAS*, **453**, 1644.
Reynolds, J. H.: 1920, *MNRAS*, **80**, 746.
Scoville, N. et al.: 2007, *ApJS*, **172**, 1.
Sekiguchi, K. et al.: 2004, *Annual Rep. of the Nat. Astron. Obs. of Japan*, **5**, 40.
Simpson, C. et al.: 2013, *MNRAS*, **433**, 2647.
Saas-Fee Advanced Course 20, Berlin: Springer – Verlag.