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Effects Of Galaxy Environment On The Concentration Index Classification Tool

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Abstract
The morphological classification of galaxies is crucial for understanding their formation and evolution over time. There are various galaxy parameters, such as structural features, light profiles, and the concentration index (C_r) that serve as proxies for galaxy morphological types that can be used to classify galaxies effectively. These galaxy parameters have been proposed for classifying galaxies in the large galaxy samples, where visual classification becomes labor-intensive and impractical. This work report on the the effect of galaxy environment on the use of concentration index tool for classifying galaxies. The archival data for this work was obtained from the Sloan Digital Sky Survey-AMIGA catalog SDSS-DR16. The low density population is constrained to a redshift range $0.005 \leq z \leq 0.080$ and r-band magnitudes range $11 \leq M_r \leq 15.7$, while the dense environment sample obtained from the Coma Cluster for sources to within $3000 \leq cz \leq 10500$ kms^{-1} at a redshift range of $0.01 \leq z \leq 0.035$. To investigate the effect of galactic environment, the galaxy population was constrained to a mass range of $10 \leq logM \leq 12$ and a redshift range of $0.02 \leq z \leq 0.04$. The derived C_r values against the galaxy environments show that C_r values increases from less-dense to high-dense environments.
Keywords: *galaxies-classification, galaxies-concentration index*

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I. Introduction

The morphological classification of galaxies endevours to account for how galaxies are formed, their evolution over time as well as the underlying physical processes that drive these changes (Shimasaku et al. 2001a). Recent advancements in observational techniques and data analysis have led to increased interest in galaxy classification, prompting the development of new classification tools and methodologies.

The galaxies are known to be roughly divided into two groups; the early-type population predominantly comprising of elliptical and lenticular (S0) galaxies and late-type populations which consists of spiral and irregular galaxies. Late-type galaxies are characterized by ongoing star formation activities rendering them blue in color, whereas early-type galaxies predominantly harbor older stellar populations resulting in a redder hue (Zucca et al. 2009). Traditionally, morphological classification of galaxies has been done by eye (e.g. de Vaucouleurs et al. 1991, Fukugita et al. 2007). However, this is a very time-consuming exercise. A widely used classifying alternative is the use of central concentration selection index, a parameter that is able to reliably distinguish between early-type (E, SO) and late-type (Sa, Sb, Sc, Irr) galaxies. For the SDSS galaxies, the concentration index is defined as $C_r = R90/R50$, where R90 and R50 are the radii enclosing 90% and 50% of the Petrosian flux in the r−band, respectively (e.g. Shimasaku et al. 2001b, Strateva et al. 2001a, Nakamura et al. 2003). The Petrosian flux is the flux contained within twice the Petrosian radius, the circular radius at which the local surface brightness μ(r) is equal to 20% of the enclosed mean surface brightness (Blanton et al. 2001). Shimasaku et al. (2001b) and Strateva et al. (2001a) found that separating galaxies using C_r gives automated samples of early and late types with about 15−20% contamination from the opposite class.

There has been studies aimed at understanding the correlation of galaxy parameters with concentration index (e.g. Muñoz-Cuartas et al. 2011, Busha et al. 2011). However, in the local universe (i.e. $z \leq 0.1$), the population of galaxies that are concentrated in virialised groups and clusters amount to 54% (Courtois et al. 2013). The sample located in collapsing regions around groups and clusters amount to ∼20% (Tully & Fisher 1987, Crook et al. 2007, Makarov & Karachentsev 2011). The remaining 26% of the populations are field galaxies, with a fraction of which are found in loose pairs and compact groups (Karachentsev et al. 2011). These variations implies the need to constrain the concentration index tool to specific galaxy parameters such as environment, masses and redshift. In the previous work, we have reported on the effect of stellar mass and redshift on the morphological galaxy classification.

The paper is organized as follows; in section 2, we review the archival data and sample analysis. We present the results and discussion section 3 and our conclusions given in section 4.

II. Archival Data And Sample Analysis

The low density population sample

The low density galaxy sample considered is part of the (AMIGA) catalog that hosts Isolated Galaxies which consists of 3702 Singly Isolated Galaxies (SIG), 1240 Singly Isolated Pairs (SIP), and 315 Singly Isolated Triplets (SIT) samples (Argudo-Fernández et al. 2015). The AMIGA catalogue uses SDSS data with the sample being composed of galaxies within the r-band model magnitudes in the range $11 \leq M_r \leq 15.7$ and a redshift ranging from 0.005 to 0.080 (Buta et al. 2019) which is considered to be sufficient for developing a homogeneous isolation.

In this study, we used photometric data from SDSS-DR16 (the Sloan Digital Sky Survey, data release sixteen, Ahumada et al. 2020). The catalogue provide the positions, redshifts, and the degrees of relation with the galaxy's physical and large-scale environments are provided (Argudo-Fernández et al. 2015). The galaxies' median stellar masses were derived from the stellarMassPCAWiscBCO 3 table in CasJobs query.

To separate our isolated galaxy sample into early and late galaxy types by concentration index, histogram distribution of concentration index was generated and the seperation value (C_r = 2.66) was determined by fitting double gaussian curves to the distribution as the point of intersection of the curves. The sample contamination was found to be 46.4% from the area of overlap of the double gaussian. The singly isolated sample that was classified consisted of 3699 galaxies after leaving out three galaxies with high concentration indices. The galaxies with $C_r \leq 2.66$ were classified as late-type galaxies while those with $C_r \geq 2.66$ represented the early-type galaxies. From the sample, 1895 (51.2) were late-types while 1804 (48.8%) were classified as early-type galaxies. By comparing our concentration classifications with the visual classification from galaxy zoo, 3528 isolated galaxies were classified with 2414 galaxies identified as isolated spirals and 1114 galaxies classified as isolated ellipticals. The completeness of the sample was found to be 67.77% for the selected isolated spirals and 90.12% for the selected isolated ellipticals.

A plot of the redshift-stellar mass diagram for the singly isolated galaxy sample that was classified using the concentration index is shown in figure 1, where late-type galaxies (blue filled circles) and early-type galaxies are represented by the red filled circles. The top panel shows the distribution of the stellar mass distribution of the sample where the red line shows that of the early-type galaxies population which are predominantly massive galaxies, while the blue histograms shows the distribution of stellar mass for the late-type galaxy population which are generally low mass galaxies in agreement with Kauffmann et al. (2003). The right hand side panel shows the distribution of the redshift for the two galaxy populations where both galaxy types are observed to span the entire redshift range with both types having the highest number density of galaxies at around a redshift of z = 0.045.

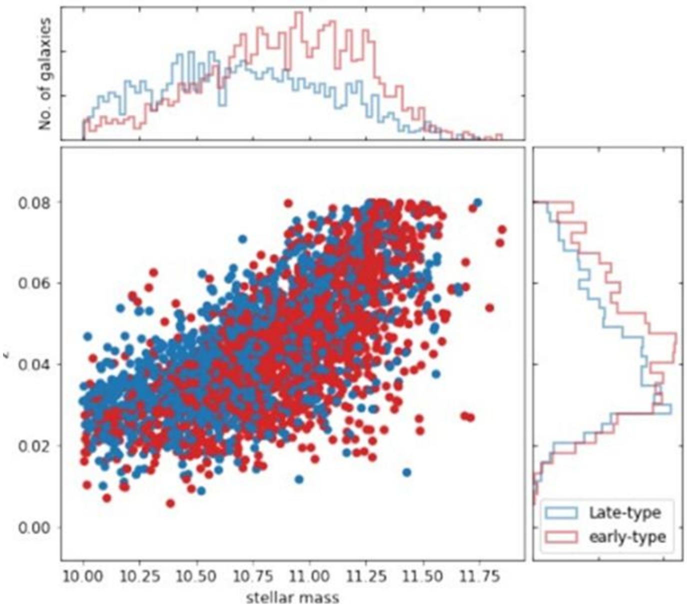

Figure 1. The SIG galaxy sample redshift (z) against the log of stellar mass (logM⊙).

The high density population sample

The sample galaxies inhabiting dense environments was obtained from the Coma Cluster. The redshift data for the galaxies within the Coma Cluster were sourced from (Healy et al. 2021), with a significant portion obtained from the Sloan Digital Sky Survey Data Release 13 (SDSS DR13) (Albareti et al. 2017). Using the VizierR astronomical data base (Ochsenbein et al. 2000) data in the published catalogues within a 2 degree radius centered on the coma cluster was querried. By merging the SDSS redshifts with those obtained from VizierR a large master catalogue was created and to construct the catalogue of unique sources associated with the coma cluster, sources within $3000 \leq cz \leq 10500$ kms^{-1} , and $0.01 \leq z \leq 0.035$ redshift range were considered. This range of velocity was selected based on the expected velocity dispersion of galaxies in the coma cluster which would help in selecting only those galaxies in the coma cluster which have velocities consistent with expected velocity dispersion of the cluster.

III. Results And Discussion

Determination of concentration index of galaxies

We retrieved SDSS petroR90 r and petroR50 r from the SDSS DR16 database which we used to obtain the concentration index of the galaxies as C r = R90/R50. By calculating the concentration index of the galaxies and displaying it's distribution using the histogram, we obtained a bimodality of the distribution of concentration index, and by fitting a double gaussian in the distribution, a concentration index value (value that corresponds to the point of intersection of the two gaussian curves) was obtained as a separator value to automatically separate the late-type from the early type galaxy population *Figure 2*. The observed bimodality in the distribution of concentration index is in agreement with earlier studies on the distribution of color of galaxies in the SDSS (Strateva et al. 2001B; Shimasaku et al. 2001a and Mateus et al. 2006).

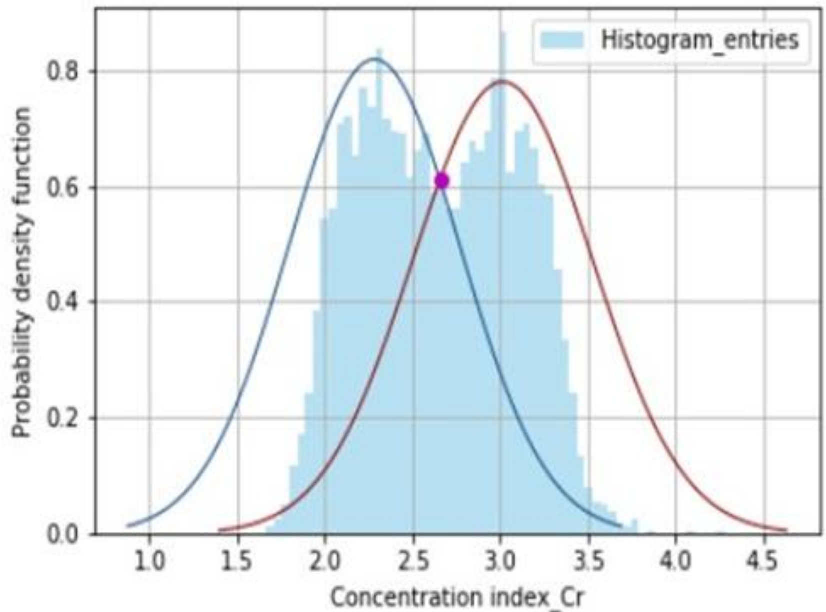

Figure 2. The Cr distribution for the SIG galaxy sample. The blue gaussian curve fits the late- type, while the red gaussian curve fits the early-type galaxy population. The overlap region gives the amount of contamination from the two galaxy groups, while the magenta-cloured point indicates the concentration index separator for the two galaxy populations.

Analysis of environment-concentration index relationship

The effect of galactic environment was investigated by constraining the galaxies in both low-density and high -density population to a mass range of $10 \leq \log M_{\odot} \leq 12$ and a redshift range of $0.02 \leq z \leq 0.04$. From the double Gaussian fits into the concentration index distribution of galaxies in the different galactic environments (SIG, SIP, SIT, and the coma cluster) shown in figure 3. The derived concentration index values obtained for the different galactic environments were 2.704, 2.727, 2.809, and 3.044 for SIG, SIP, SIT and coma cluster respectively.

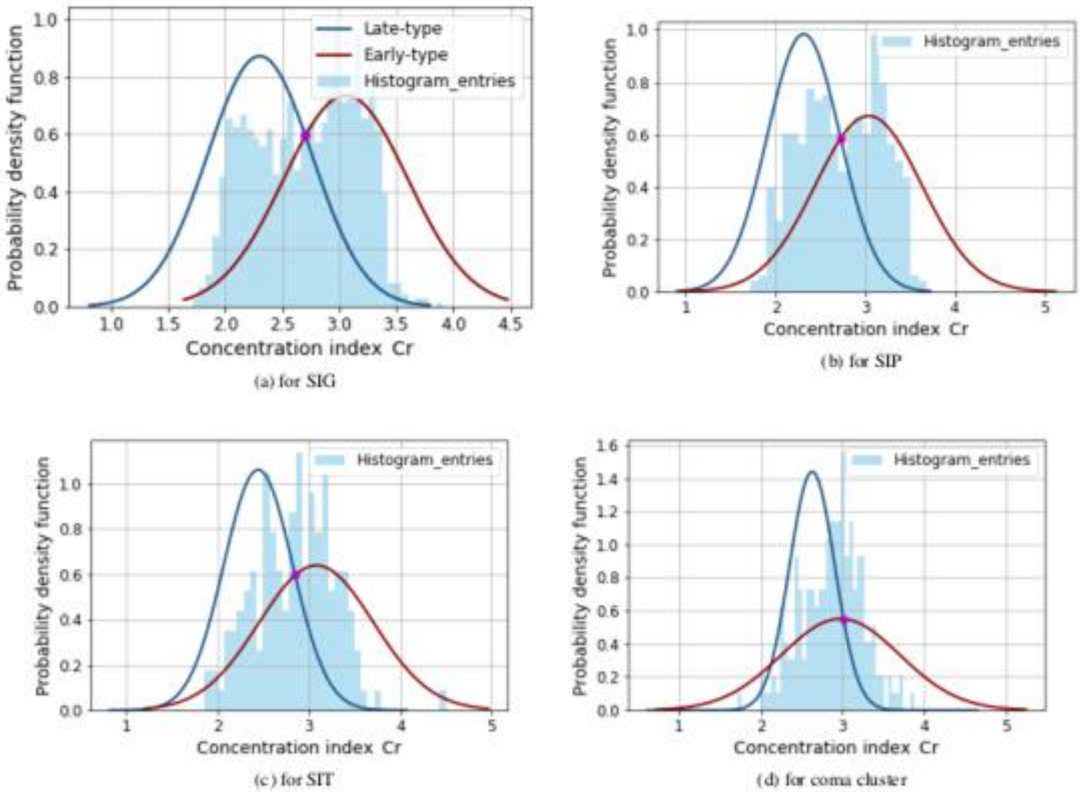

Figure 3. The distribution of the concentration index values for the different galactic environments for the sample of galaxies analyzed in this work. The blue gaussian curves show the distribution of the late- type galaxies, the red Gaussian curves show the distribution of the early-type galaxies, and the magenta point at the point of intersection of the double gaussian indicates the concentration index values for the different galactic environments.

Table 1: A summary of the concentration indices for each galaxy population/environment sample

	Population	Concentration index, C_r
0	SIG	2.654
1	SIP	2.728
2	SIT	2.850
3	Coma cluster	3.044

The C_r dependence on galaxy environment was explored by comparing the concentration indices for the low-density to those of the high-density galaxies. The galaxies were constrained to a redshift range of $0.02 \leq z \leq 0.04$ and a stellar mass range of $10 \leq \log M_{\odot} \leq 12$. The mass constrain to smaller bin across the environments at the redshift range was a challenge due reduced late-type number statistics in the COMA cluster. The COMA cluster sample galaxies used are concentrated at the cluster core (z =0.030), a region known to host early-type galaxies (Kauffmannet al. 2003). The derived C_r values in different environments is shown in figure 3(a - d). A plot to the derived C_r values against the environment denoted as 0, 1, 2, 3 for SIG, SIP, SIT and COMA cluster respectively is shown in figure 4. From the plot, the C_r is seen to scale linearly with galaxy density. The derived concentration index values increases from less-dense to high-dense environments. The trend is attributed to predominance of early-type galaxies in dense environments which have higher values of the concentration index than the late-type galaxies.

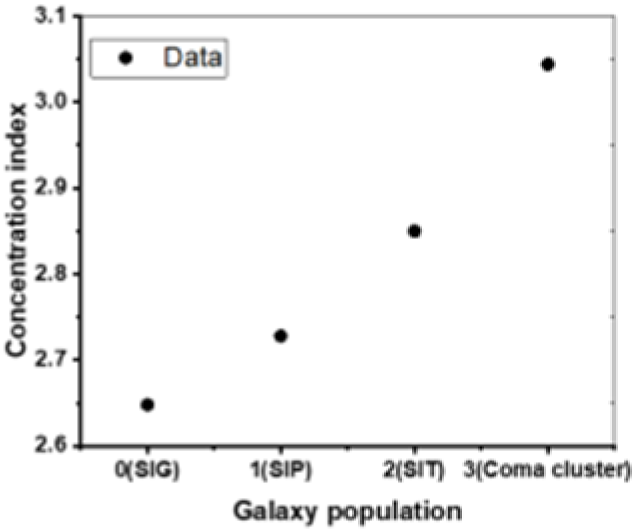

Figure 4. A graph of concentration index dependence on galaxy environment

IV. Conclusion

We report on the effect of galactic environment on the concentration index tool. The archival data was obtained from the Sloan Digital Sky Survey - AMIGA catalog SDSS-DR16 that consists of 3702 Singly Isolated Galaxy (SIG), 1240 Singly Isolated Pairs (SIP), and 315 Singly Isolated Triplets (SIT). The low density population is constrained to a redshift range $0.005 \leq z \leq 0.080$ and an r-band model magnitudes in the range $11 \leq M_r \leq 15.7$. The dense environment sample was obtained from the Coma Cluster sources that are within $3000 < cz < 10500$ kms^{-1} at a redshift range of $0.01 < z < 0.035$.

The effect of galactic environment was investigated by constraining the galaxies in both low-density and high-density population to a mass range of $10 \leq \log M_{\odot} \leq 12$ and a redshift range of $0.02 \leq z \leq 0.04$. The derived C_r values at different environments is seen to scale linearly with galaxy density with concentration index values increasing from less-dense to high-dense environments. The trend is attributed to predominance of early-type galaxies in dense environments which have higher values of the concentration index than the late-type galaxies.

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