Photometric Analysis and Morphological Classification of Nearby Galaxies

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Abstract

In this paper, we make an attempt to perform photometric analysis on galaxies and use the Sersic model to classify them. This caters primarily for an audience new to photometric analysis and classification of galaxies, but we hope to provide evidence for those trying to verify existing data as well. Three galaxies with prominent visual constitution are considered to measure the structural parameters by fitting single-Sersic model and double-Sersic model. We show that the Sersic index obtained by fitting the single-Sersic model to NGC 3982, NGC 2865, NGC 7773 do not show much deviation from the existing classification of them as spiral, elliptical and barred spiral galaxy respectively. Although, the Sersic index values are not accurate due to the foreground stars that alter the correlation between the data points. The results are compared to existing data and discussed to provide clarity on our research.

Keywords: Sersic model, NGC 3982, NGC 2865, NGC 7773, Astropy, Photutils, Galaxies.

I. INTRODUCTION

In 1926, Edwin Hubble developed a classification scheme of galaxies. It was published in 1936 as 'Tuning fork diagram' in his book called the "Realm of the Nebulae". Since then attempts have been made to refine the existing model or develop new models that best fit the wide variety of galaxies. As the technology has advanced, complex galaxies have been discovered which cannot be classified using simple models alone. Classification can be made based on many of their features such as luminosity, colour, spectra, star formation rate and using visible images. Data from sky surveys are been used to analyse and identify correlation between the features of galaxies and their shapes. This paper describes an attempt to classify NGC 3982 (New General Catalogue), NGC 2865, NGC 7773 based on the Sersic index obtained for each galaxy by fitting the Sersic model to its surface brightness profile. Photometry packages such as Astropy Python package, Photutils and Sersic1D functions have been used in this research. NGC 3982 is an intermediate spiral galaxy at redshift z=0.003699, NGC 2865 is an elliptical galaxy at z=0.008683 and NGC 7773 is a barred spiral galaxy at z=0.028300 (Redshifts taken from NASA/IPAC Extragalactic Database[1]). These galaxies were chosen to be analysed based on their visibility period and good visible morphology.

We have classified the galaxies using a parametric method, by fitting the light curve of a galaxy to the Sersic model and measuring parameters. This mathematical function defines the surface brightness distribution of galaxies. It was introduced by the astronomer Jose Luis Sersic in 1968. The Sersic model is given by,

$$I(R) = I_e exp\left\{-b_n\left[\left(\frac{R}{R_e}\right)^{1/n}-1\right]\right\} \text{ [3]} \tag{1}$$

Where I_e is the intensity at effective radius R_e (Radius at which fifty percent of the total light of the galaxy is emitted), n is the Sersic index and $b_n = 2n - 1/3$.

Another aspect to note is that the Sersic function assumes the surface brightness profile of every galaxy fits the model, which will have its implications on the results. In this paper, galaxies with Sersic index $n > 2.5$ are classified as "early-type" i.e. elliptical galaxies and Sersic index $n < 2.5$ are classified as "late-type" i.e. spiral galaxies [4]. Bulges with Sersic index n_b<2 are classified as pseudobulges (bulges with high star formation and rotational motion and higher correlation with the disk of the galaxy) and n_b>2 as classical bulges (bulges formed due to mergers of galaxies, has a more random motion)[2].

Note: The term light curve and surface brightness of a galaxy have been used interchangeably since they mean the same.

II. METHODOLOGY

This study utilised three face-on and three edge-on galaxies to compare their structural properties, highlighted by the Sersic model. The images of the galaxies were captured using MuSCAT3 instrument, a four channel simultaneous imager mounted on 2-meter Faulkes Telescope North at the Haleakala Observatory in Maui, Hawaii, in between 18.12.2023 to 31.12.2023 with an exposure time of 60 seconds. The files were then examined to check for any possible distortions. Suitable image of each galaxy was selected for analysis using photometry libraries in python mentioned in I.

model against the flux density versus radius curve. A user-defined function which accepts radius, intensity and Sersic index value as its parameters was created which returned the Astropy Sersic1D function. This was called as a parameter in the scipy optimisation function *'curve fit'* which finds the minimum difference between the data points and the model i.e. it finds the best fit parameter values which then can be passed into the user defined function containing the Sersic1D function. The single-Sersic model tries to fit data considering all the data points, including the data points of bulge and the disk. Carefully looking at the light curve, it

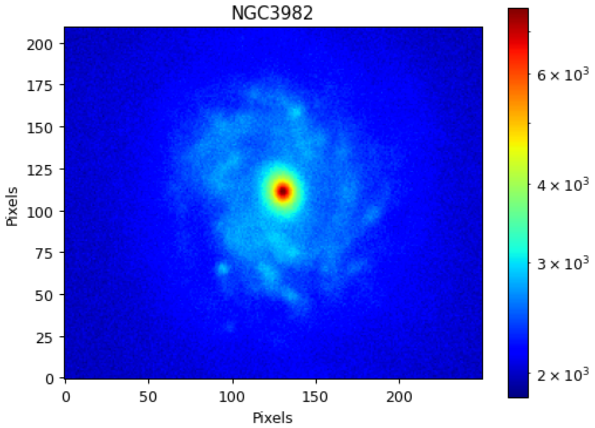

Figure 1: Observed image of NGC 3982.

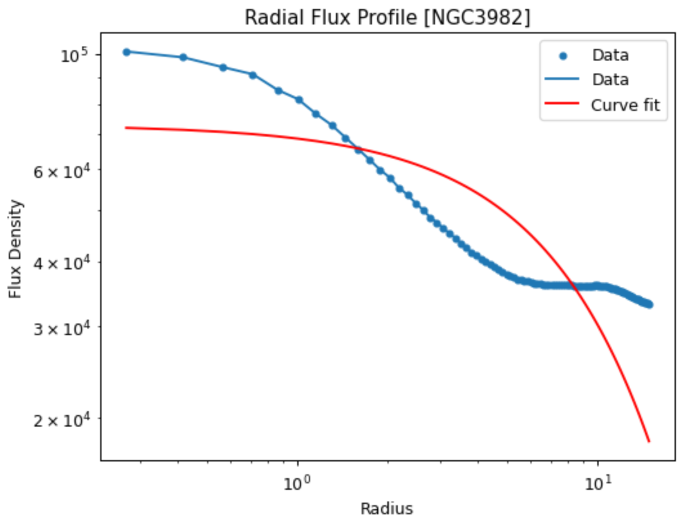

Figure 2: Single-Sersic model fit of NGC 3982.

Concentric apertures were used to generate the data points necessary for the light curve of NGC 3982. The pixel with a highest flux value was measured as it represents the center of the galaxy within this pixel array. Radii across the pixels were converted into arcseconds to plot the curve growth, showing radii versus flux value between each concentric aperture. Since the MuSCAT 2m Faulkes telescope has a pixel scale of 0.27 arcseconds per pixel, radii were multiplied to convert them into arcseconds. The Astropy functions such as *'CircularAperture'*, *'ApertureStats'* were used for this photometric analysis. *ApertureStats* function measures the flux value of each pixel within the circular apertures. To plot the light curve, flux densities had to be calculated from the flux values using the equation,

$$\text{Fluxdensity}(i+1, i) = flux/\{\pi(r_{i+1}^2 - r_i^2)\} \quad (2)$$

We had to subtract the flux values under one aperture from the consecutive aperture to measure the flux density accurately since flux values overlap with each concentric apertures being drawn from the center. Jansky (Jy) is the unit of flux density. Light curve can be obtained by plotting flux densities across the radius and also by plotting magnitude values across the radius. Magnitude is inversely proportional to flux density. But for this research we have chosen to fit the Sersic

is observable that the part of the curve at initial radii with subtle and wide peak corresponds to the bulge or the core of the galaxy. Conversely, sharper peak observed at higher radii indicate the presence of disk or the arms of the galaxy. However, it is evident that the Single-Sersic model cannot accommodate all the distributions in the data points. To address this limitation, a more effective approach involves the integration of two Sersic1D functions: one to fit the bulge data points and another to the disk, the light curve can be better fit to the model. An error made during this research was attempting to fit the Sersic1D function to the bulge and the disk separately and combining them both only during the plotting of the graph, which is not the approach for this task. Rather, the appropriate method involves adding the Sersic1D function for the bulge and the disk while the functions are executed and not after it has been performed separately as mentioned earlier. This method produced a model fit of the light curve, fitting both the bulge and the disk satisfyingly.

To ascertain whether the Sersic index value varies when a different image is used, additional image of the NGC 3982 with a exposure time of 60 seconds, was taken from the LCO archive. The process involved in the photometric analysis of the first image were replicated, yielding a slightly different result (Refer to the tableIII.3). This identical methodology was then employed to analyse NGC 2865 and NGC 7773, with the outcome nearly aligning with the known characteristics of the respective galaxies.

The edge on galaxy, NGC 4565 was analysed, drawing elliptical apertures and attempting to produce the light curve. However, due to its inclination, it is not possible to produce a light curve that accurately defines all the aspects of the galaxy's morphology. As a result, rest of the edge-on galaxies, NGC 891 and NGC 4013 were not analysed.

The images and plots of the other galaxies, which have not been displayed here, are available in Appendix A IV.

III. RESULTS AND DISCUSSION

III.1. NGC 3982

In Fig.3, the light curve of galaxy NGC 3982 has been plotted. The red coloured line fitting the dotted curve (data) represents the double-Sersic model fit. The orange coloured curve is the single-Sersic model fit. Blue and green curves represent the bulge and the disk of the galaxy respectively. The curve fitting the bulge has shifted down from the actual bulge data points indicating that it is influenced by the curve fitting the disk of the galaxy. The single-Sersic model produces a Sersic index of n=0.85856, which signifies that the galaxy is a spiral galaxy. The Sersic index of the bulge n_b=0.79089 signifies that it is a pseudobulge, which is a feature of a spiral galaxy. The Sersic index of the disk n_d=0.16668 indicates that the brightness profile is centrally concentrated and it is typically associated with spiral arms (Concluded from the general understanding of the Sersic index). Comparing the obtained results to the existing data ($n_b = 1.95 \pm 0.19$ from [2]), despite the difference in the numerical values, the galaxy can be classified under the same morphological classification. These difference in the Sersic index values might have happened because of the methods used, resolution of the image, accessibility to better technology.

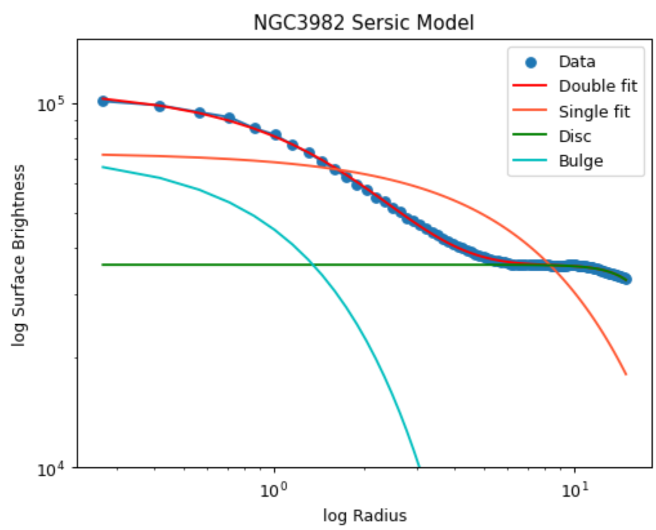

Figure 3: Single and Double Sersic model fit of NGC 3982.

III.2. NGC 2865

In Fig.4, the curve corresponding to the bulge has a sharper raise due to a foreground star. Even the curve of the disk has a noticeable peak that falls slightly different than the other two galaxy curves. The model fitting is influenced by data points of the external source. The Sersic index value from single-Sersic function n=2.2157 indicate that it is more likely to be an elliptical galaxy. The Sersic index is not above 2.5, it might be because of the deficiency in the accuracy of the measurement and the external source affecting the system. The Sersic index of bulge obtained here tell that it is a pseudobulge, but it is not usual for an elliptical galaxy to have pseudobulge. The bulge in an elliptical galaxy is composed predominantly of older stars, which is a classified as classical bulge.

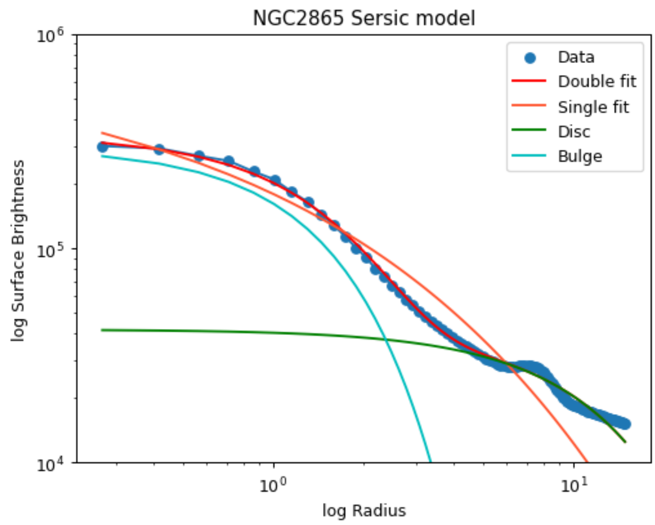

Figure 4: Single and Double Sersic model fit of NGC 2865.

III.3. NGC 7773

In Fig.5, the sharp peak seen in the disk region is the foreground star influencing the readings. Because of that external source the fitting of the model is heavily impacted. The model assumes the disk region as the bulge and tries to fit the data. The Sersic index value from the single-Sersic fit n= 1.7138 indicates that the galaxy is a spiral galaxy, which is what the existing data suggests. The double-Sersic model fit is heavily degraded by the object near the galaxy. There were no reliable existing data to be found on this galaxy which made it harder to compare the accuracy of the results obtained here.

There were other problems encountered during the research which lead to the decrease in the accuracy of the results produced. The bounds were affecting the model fit. Changing the bounds above the radius value for the curve fit should not a make difference while the model fits the data. However, the model showed different fit when bounds have been altered.

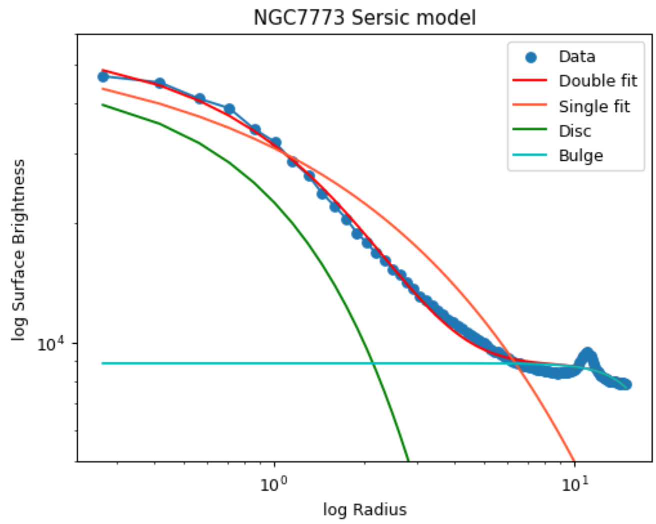

Figure 5: Single and Double Sersic model fit of NGC 7773.

Table 1: All the Sersic indices obtained through the analysis for easier comparison.

NGC 3982	Intensity (R_e)	18048.5801
	Sersic Index (Single Fit)	0.85856
	Sersic Index (Bulge)	0.79089
	Sersic Index (Disk)	0.16668
NGC 3982 (Second Image)	Intensity (R_e)	15786.364
	Sersic Index (Single Fit)	0.80725
	Sersic Index (Bulge)	0.89439
	Sersic Index (Disk)	0.0034
NGC 2865	Intensity (R_e)	12853.204
	Sersic Index (Single Fit)	2.215703
	Sersic Index (Bulge)	0.69926
	Sersic Index (Disk)	0.76127
NGC 7773	Intensity (R_e)	2643.0802
	Sersic Index (Single Fit)	1.71386
	Sersic Index (Bulge)	0.19795
	Sersic Index (Disk)	0.93624

III.4. Future Work

This research could have been more accurate, using better methodology and planned analysis, selections of better data to be analysed would enhance the results. The processes mentioned in this paper can be carried forward with the use of Sersic2D function. The function plots 2D model of a galaxy given the parameters. Other structural parameters of galaxies like total magnitude, position angle can be estimated like it has been carried out here to measure the Sersic index.

IV. CONCLUSIONS

We have demonstrated the effectiveness of classifying galaxies using the Sersic index. We have used galaxy structural parameter measured using photometry python packages which allowed us to analyse the morphological class of each galaxy. The unavailability of the data related to certain galaxies made it challenging to verify the results and assessing the measurement accuracy. In this paper, by considering a set of nearby galaxies, Sersic indices were measured to classify them. Out of the analysed galaxies, two galaxies were spiral galaxies with their Sersic index of bulges indicating pseudobulge. While the other galaxy showed the reading of an elliptical galaxy. The numerical discrepancies are been largely relaxed when we have made the conclusions. Three galaxies were not analysable due to their orientation. This research journey also involved intensive learning of Python program, the astronomical code packages and their various applications. Classifying galaxies are a complex process and there is no single definitive method for its execution. This paper presented an approach, using the Sersic model to measure the Sersic index, fitting it to the entire dataset as a whole and also fitting it separately to the bulge and the disk components which makes it a little more flexible.

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APPENDIX A

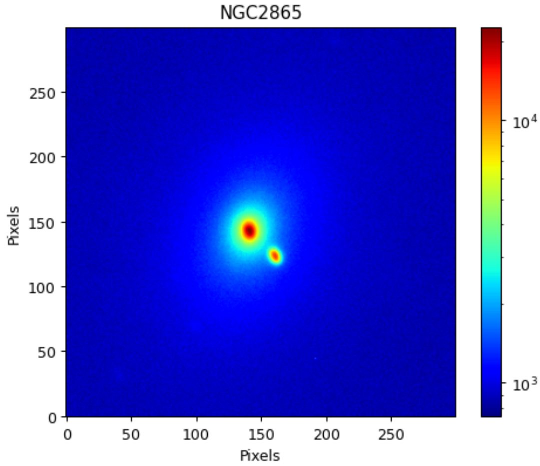

Figure 6: NGC 2865

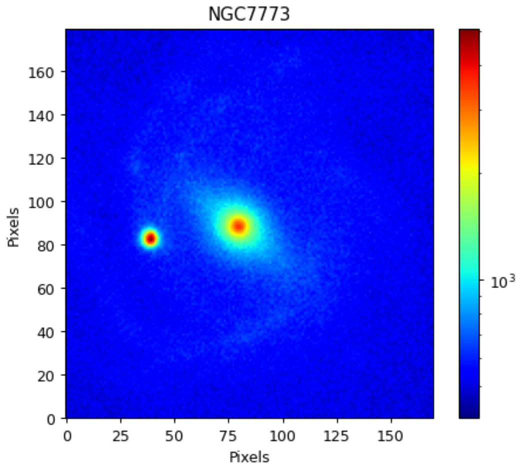

Figure 7: NGC 7773

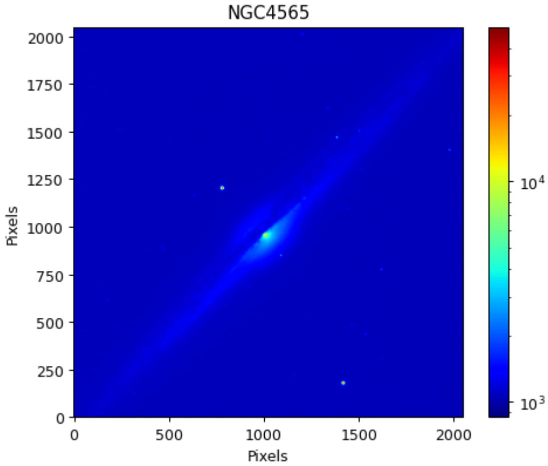

Figure 8: NGC 4565

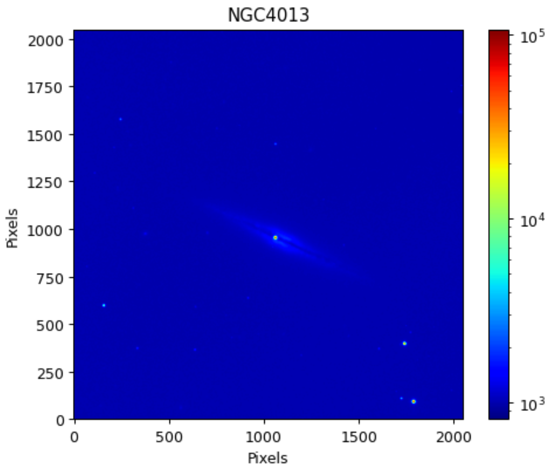

Figure 9: NGC 4013

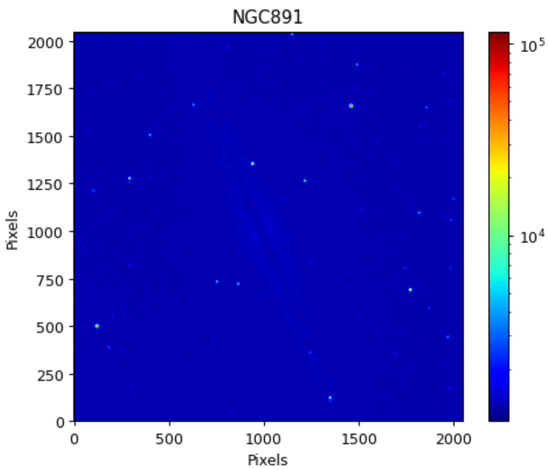

Figure 10: NGC 891