Journal of Institute of Science and Technology, 27(2), 85-89 (2022)
ISSN: 2467-9062 (print), e-ISSN: 2467-9240
https://doi.org/10.3126/jist.v27i2.35312

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Research Article

STRUCTURAL PARAMETER OF A MERGING COMPACT DWARF GALAXY CG 0315

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(Received:** February 28, 2021; **Final Revision:** December 30, 2022; **Accepted:** December 31, 2022**)

ABSTRACT
Structural parameters like size, Sersic index, total luminosity and ellipticity are important tools to study galaxy formation and evolution. This work studies a compact dwarf galaxy CG 0315, originated from a merger, and performs a detailed analysis of morphological parameters. The galaxy size is derived by using two different methods, i.e., parametric and non-parametric. The parametric uses the Sersic modeling, but it is found that the observed light profile of CG 0315 cannot be modeled with a simple Sersic function. This is, however, common in merging feature galaxies. Therefore, for further analysis, the half-light radius derived from the non-parametric method can be used as the size of the galaxy. CG 0315 is far more compact than a typical galaxy. We measured its effective radius of 4.05 arcseconds and half-light radius of 2.60 arcseconds that corresponds to a physical value of 221 parsec. Its ratio between the minor and major axis is 0.82, and the position angle is 179 degrees to the North. The star formation rate of the galaxy is $0.051 M_{\odot}$ year^{-1}. We conclude from these observational data that CG 0315 will continue to be a compact dwarf galaxy when star formation stops and transforms into a well-known compact elliptical galaxy. Therefore, CG 0315 might be a progenitor of an elliptical galaxy.

Keywords: Compact dwarf galaxy, Galaxy merger, Sersic index, half-light radius

INTRODUCTION
Structural parameters; size, concentration, and ellipticity are important tools for studying galaxy formation and evolution. Galaxies follow a scaling relation between size and magnitudes that is continuous over the whole range of luminosities (Graham & Guzmán, 2003; Ferrarese *et al.,* 2006; Janz & Lisker 2008). The universality of this relation has been a subject of considerable debate because of the presence of outliers and the non-linearity of the relation (Kormendy 1985; Kormendy *et al.,* 2009; Chen *et al.,* 2010). The high redshift galaxies are noticeably more compact than the local ($z < 0.1$) galaxies, indicating that early formed galaxies are more compact than later produced galaxies. One of the enigmas of modern cosmology is the size, history, and formation of compact galaxies in the early universe.

Galaxies are three-dimensional objects, and we observe them in a projected plane of the sky. Their structures, in general, are quantified through the use of integrated light profiles along the major axis. These profiles are measured by averaging the observed intensity of a galaxy at a given radius in a concentric ellipse and then determining how this intensity varies as a function of radius. It was first formulated by de Vaucouleurs in 1948 (Buta, 1996), who used light measurements for elliptical galaxies. Surface photometry is a process of quantifying galaxy morphology. The colors of the galaxies derived from surface photometry through different passbands provide information about the ages and metallic contents of the stellar population of the galaxies. The measured light profile is called the surface brightness profile, which reduces observed two-dimensional isophotes to a 1D set of parameters. Galaxies' isophotes are closely approximated by ellipses which simply reflect the condition that underlying stellar orbits in galaxies are Keplerian. From the surface photometry, we can find the variation of intensity and ellipticity with a radius of the ellipses.

In this work, we present an analysis of the structural parameter of a compact merging dwarf galaxy CG 0315. We derive its size, Sersic index and position angle. We make comparative study between morphological and star-formation properties.

MATERIALS AND METHODS
Sample Selection
CG 0315 is taken from a catalog (Paudel *et al.*, 2018) of merging dwarf galaxies which shows compact visual morphology. It has a sky position R.A. = $10^h\ 01^m\ 14.38^s$, Dec. = + 37° 04'15.24", and a redshift of $z = 0.0048$. In the catalog, it is listed as a shell feature merging dwarf galaxy. It is located in an isolated environment where we identify no nearby companion within the 500 kiloparsec (kpc) sky projected radius with a line-of-sight relative radial velocity range of ± 500 km s^{-1}.

Figure 1 reveals the optical view of CG 0315, where we can see elongated low surface brightness tidal tail along the galaxy's major axis. The color image is a cutout of the Legacy sky-server images (Dey *et al.,* 2019), which is prepared by combining *g*-, *r*-, and *z*-band images. The field of view of the image is 1'×2'. For the distance of

CG 0315, it corresponds to a physical value of 28 × 56 kpc. We can see that the inner part is quite round and bluish, and the outer low surface brightness extended tidal tail is relatively reddish.

Figure 1. Optical image of CG 0315. Field of view of image is 1 × 2 arcmin, where the north is top and the east is left. The image is obtained from Legacy sky viewer which is prepared by combining the mono-color *g-r-z* filter images.

The basic photometric properties; R. A., Dec., red shift, *b*-band absolute magnitude, difference of *g* and *r* band magnitudes and star formation rate of CG 0315 are listed in Table 1. Located at 20.34 Megaparsec distance from us, it has an *b*-band absolute magnitude $M_B = -15.94$ magnitude (mag) and an overall $g - r$ color index of 0.14 mag, with a star-formation rate of 0.051 $M_\odot$ $year^{-1}$. This value of the star formation rate (SFR) is slightly less than the star formation rate of a newly formed, less metallic interacting dwarf galaxy NGC 2604 of value 0.057 $M_\odot$ $year^{-1}$ obtained from the spectroscopic calculation using Hα emission line flux (Chhatkuli *et al.,* 2020). The line-of-sight radial velocity of the galaxy obtained from NED is 1467 km s^{-1}.

Imaging Analysis

To perform image analysis, the Sloan Digital Sky Survey (SDSS) images are used which we obtained from the SDSS archive database (Ahn *et al.,* 2012). We primarily employed the *r*-band image from the SDSS to carry out surface photometry because of its higher signal-to-noise ratio. The Image Reduction and Analysis Facility (IRAF) task ellipse was used to extract the galaxy's major-axis light profile. IRAF is a collection of software, which is used to fit elliptical isophotes in an optical image of galaxies, and we can obtain several parameters like intensity, radial distance, ellipticity, etc. The IRAF reads the 2D image section and produces output in tabular form. The ellipse uses the methodology described in Jedrzejewski (1987), where for each semi-major axis length, the intensity I(ϕ) is azimuthally averaged along an elliptical path described by an initial guess for the isophote's center (X, Y), ellipticity (e), and semi-major axis position angle (θ). The intensity I(ϕ) is expanded into the following Fourier series to quantify how the intensity deviates from being constant along the fitted ellipse.

Table 1. Basic Physical Parameters of CG 0315

Parameters	R. A. (deg.)	Dec. (deg.)	*z*	M_B (mag)	*g-r* (mag)	SFR ($M_\odot year^{-1}$)
Value	150.309990	37.0709423	0.0048	-15.94	0.14	0.051

$$I(\phi) = I_o + \sum_k [A_k \sin(k\phi) + B_k \cos(k\phi)] \qquad (1)$$

Where I_0 is the intensity averaged over the ellipse and ϕ is azimuthal angle. A_k and B_k are the Fourier coefficients. If an isophote is a perfect ellipse, A_k and B_k will be exactly zero.

All foreground and background unrelated objects were masked. The masking was performed manually, where we visually identified the unrelated objects. The center of galaxies was derived using the imcentre task in the IRAF, which calculates a centroid of the provided image section. The centroid of the image is the arithmetic mean position of all points in the image. The upper panel of Figure 2 shows the *r*−band grayscale image where the green circled regions were masked before the fitting. While fitting the ellipse, position angle and ellipticity were allowed to vary freely, and the semi-major axis was increased logarithmically. The discrete radii of ellipses are specified by the rule that the different semi-major axis lengths are spaced by a factor of 1.1. The ellipse center was not allowed to wander by more than 3 pixels between consecutive isophotes.We show the derived surface brightness profile along the major axis in the bottom panel of Figure 2. It is clear that the surface brightness profile is not smooth, and we can see a steep rise in the middle and nearly constant at the outer radius. Figure 3 shows a variation of position (PA) angle and ellipticity (e) along the major axis. The position angle varies rapidly at the inner part, and it remains nearly constant beyond a five arcsecond radius. The ellipticity shows the same behavior in the central region. It continuously increases at the outer radius, which we also see in the overlay blue ellipse of Figure 2 at the top right panel.

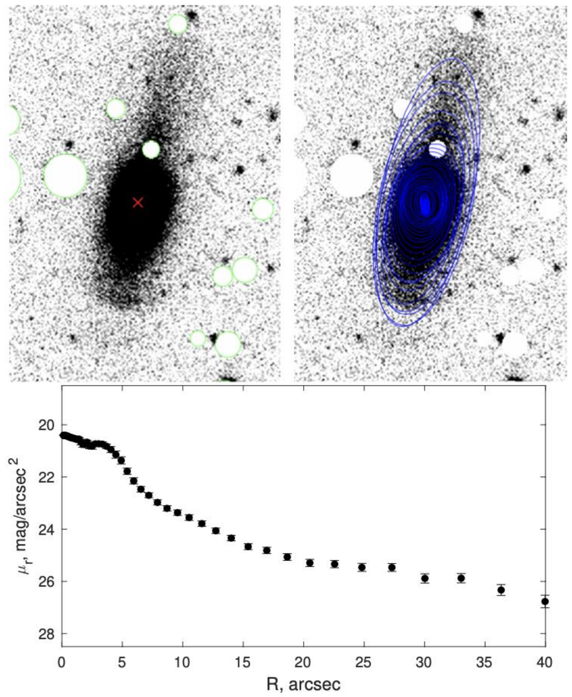

Figure 2. In the top left panel, we show SDSS r-band image, where we masked foreground and background unrelated objects, see green circle. The center of the galaxy is marked by a red cross. In top right, we overlay best fitted ellipse obtained from IRAF ellipse task. In the bottom panel, we show derived light profile along the major axis. The y-axis is the surface brightness in the unit of mag per arcsec².

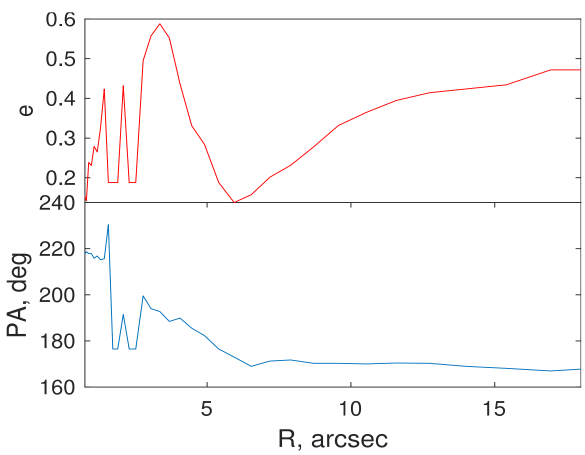

Figure 3. Variation of ellipticity and Position angle along the major axis in upper and lower panels respectively

Measurement of Galaxy Size

Galaxies never have an endpoint; therefore, a measurement of galaxy size is not a trivial task. In general, we use two different approaches to derive galaxy size, i.e., parametric and non-parametric. In the parametric approach, we first approximate the galaxy light profile into a parametric function such as exponential or de Vaucouleurs. In general, both exponential and de Vaucouleurs are the special cases of Sersic function (Sersic 1968) defined as

$$I(R) = I_e \exp\left\{-b_n\left[\left(\frac{R}{R_e}\right)^{1/n} - 1\right]\right\} \tag{2}$$

Where I_e is the intensity of the light–profile at the effective radius R_e and n is called Sersic index, which defines the 'shape' of the profile. The term b_n is simply a function of n and is chosen to ensure the radius R_e encloses half of the profile's total luminosity. In general, as a special case of the Sersic model, we use $n = 4$ for the early-type galaxy called de Vaucouleurs, and for the late-type galaxy, we use $n = 1$, which is exponential.

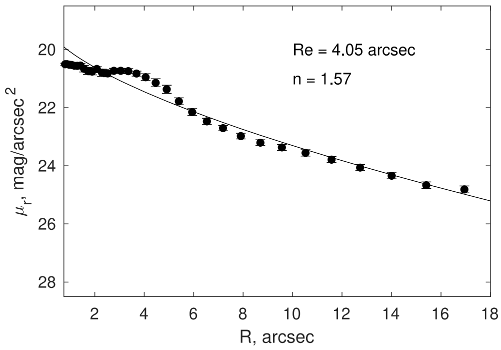

Figure 4. Modeling of observed light profile with a Sersic function. The black line represents a best fitted Sersic function to the data

The exponential function is generally used for late-type galaxies, and de Vaucouleurs functions are typically used for early-type galaxies. These analytic functions have free parameters such as effective radius R_e and effective surface brightness μ_e. We finally modeled the observed light profile with these functions and found the best-fit parameters. We do not need to know where the galaxy ends in this approach, and we simply use the best fit effective radius as a galaxy size.

On the other hand, non-parametric methods measure the galaxy size without the use of any analytic function. One simple method is called the Petrosian method; we first define an empirical radius from the observed intensity profile, called Petrosian radius a_p, (Blanton *et al.,* 2001; Petrosian 1976). To calculate this, we first derive the Petrosian index, which is the ratio of the surface brightness at R to the mean surface brightness within R, i.e.,

$$n(R) = \frac{\mu(R)}{\langle\mu(R)\rangle} \tag{3}$$

Where $\mu(R)$ is surface brightness at radius R, and $\langle\mu(R)\rangle$ is the average surface brightness within that radius, and Petrosian radius is defined where $n = 0.2$. Then it is assumed that the galaxy extension is at most out to $2a_p$, and the total flux in it is measured within a $2a_p$ aperture. Once we know the total flux, we can measure the distance where the flux becomes half and this galactocentric distance is called half-light radius (R_h).

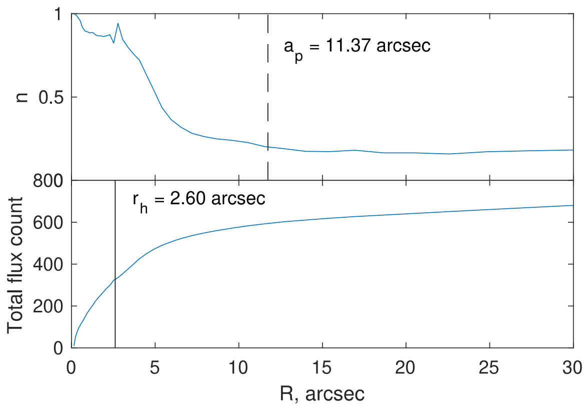

Figure 5. Top: we show variation of Petrosian index n along the major axis and the position of a_p, where n = 0.2, is marked by dashed line. Bottom: we show cumulative intensity profile along the major axis, and at r_h = 2.60 arcsec marked by the black line represents the radius at which the flux is half of its total value

We calculate the galaxy size using the non-parametric approach, i.e., the Petrosian method, as shown in Figure 5. We derive a half-light radius for the CG 0315 is 2.60 arcsec. We calculate the global value of PA and ellipticity of galaxy by averaging these values beyond the 5 arcsecond radius, which is well beyond the spatial resolution of the SDSS imaging data. The calculated values of position angle, ellipticity, effective radius, half-light radius and Sersic index are listed in second, third, fourth, fifth and sixth columns respectively in Table 2. The position angle and ellipticity are 179° and 0.18 respectively.

In Figure 4, we have tried to model the galaxy light profile with a Sersic function. It is clear that the modeled black line does not fit well with the data points. The derived Sersic index and effective radius are 1.57 and 4.05 arcsec, respectively. However, it is normal for galaxies like CG 0315, which possess tidal features like long extended tails.

Table 2. Global Structural Parameters of CG 0315

Parameter Name	Position Angle (deg.)	Ellipticity	Effective Radius (arcsec)	Half-light Radius (arcsec)	Sersic Index
Value	179	0.18	4.05	2.60	1.57

CONCLUSIONS

In this work, we perform a detailed morphological study of a compact dwarf galaxy, CG 0315. CG 0315 hosts a prominent shell feature and is listed in a merging dwarf galaxy catalog of Paudel *et al.,* (2018). We measured its half-light radius of 2.60 arcseconds using the Petrosian method that corresponds to a physical value 221 parsec and *b*-band absolute brightness $M_B = -15.94$ mag. However, the parametric modeling galaxy's light profile with a Sersic function gives an effective radius of 4.05 arcsecond. Its ratio between the minor and major axis is 0.82, and the position angle is 179 degrees to the North. Current star-formation rate derived using H_α emission line flux is 0.051 $M_\odot$/yr. This value of SFR is normal as compared to the normal star-forming galaxies. From these observational evidence, we conclude that CG 0315 will still be a compact dwarf galaxy once its star-formation ceases, and become well known compact elliptical galaxy. CG 0315 could therefore be a progenitor of elliptical galaxy.

ACKNOWLEDGEMENTS

D. N. Chhatkuli gratefully acknowledges the University Grants Commission of Nepal, for financial support by providing Ph. D. Fellowship and Research Support Grant (Award No.: PhD-75/76-S & T-13) to carry out this research.

AUTHORS CONTRIBUTION STATEMENT

DNC conceptualized the research project, led the data processing and prepared the manuscript. SP performed the candidate selection and contributed to the analysis and interpretation. AS contributed to proof reading of the manuscript. BA contributed to the interpretation.

CONFLICT OF INTEREST

The authors do not have any conflict of interest pertinent to this work.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author, upon reasonable request.

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