Surface Brightness Profiles of Spiral and Elliptical Galaxies

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Introduction:

As a general rule, anything that changes the way electrons move and interact influences the properties of the light emitted and how they observed and quantified. This rule holds true for galaxies, which are, in essence, galactic bodies of moving light. This paper will explore the relationship between the intrinsic properties of spiral and elliptical galaxies and their surface brightness profiles and confirm that this relationship can be quantified by the Sersic bulge equation:

$$I(R) = I_0 e^{\left(\frac{-R}{h_R}\right)^{1/n}} \tag{1}$$

where I(R), in our project, was measured in magnitudes/arcseconds^2. Based on their properties, spiral and elliptical galaxies will fit this Sersic Bulge equation differently.

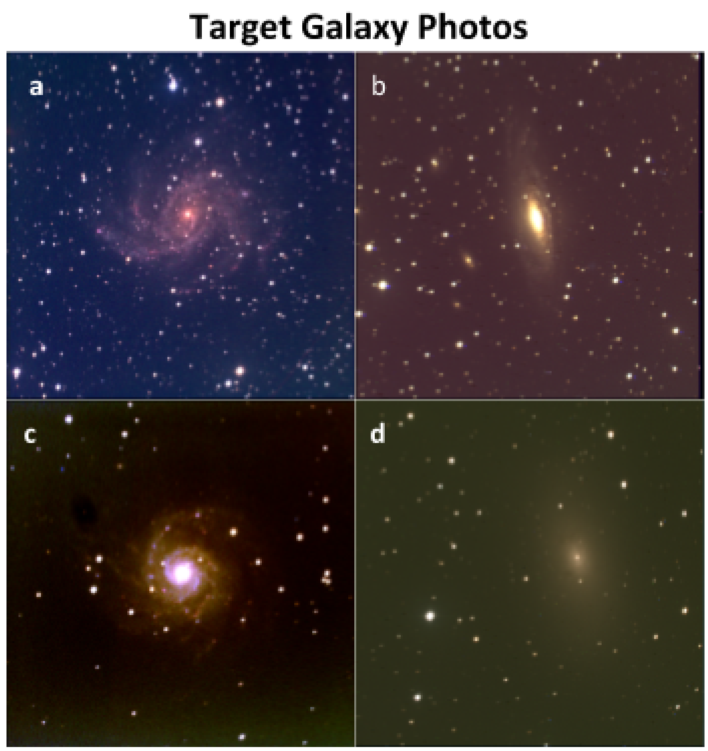

Figure 1: Above are pictures depicting NGC-6946 (a), NGC-7331 (b), M74 (c), and NGC-205 (d) respectively. Figures 1a., 1b., and 1c. can all be classified as structurally as spiral galaxies, while 1d. can be classified as an elliptical galaxy. Images were created in AIJ.

What are Spiral and Elliptical Galaxies?
Spiral galaxies are much like our Milky Way in that their rotation around a central axis, creates a curved edge in the shape of a spiral. At the central axis, there is a region called a bulge that contains the highest density of stars on the entire galaxy. This collection of stars surround a central black hole and is called a cusp. The rest of the disk surrounding the cusp is called an envelope. Much of the anatomy of the envelope is made of red nebulous gas, indicating that stars are in the process of being made and that the galaxy is young.[1] In imaging cameras mounted onto telescopes, spiral galaxies can appear to be blue at the center from the hot stars and redder on the envelope due to the red gas. This can be seen in figure 1c. On the galaxy M74. Elliptical galaxies on the other hand, are much older than spiral galaxies and have lost their nebulous gas to stars that fill up most if not all of the disk. In this way, they are like globular clusters. They are far more uniform than spiral galaxies, yet the

[1] Elmegreen, D. M. (1198). GALAXY Classification/Elliptical Galaxies. In A. Reeves (Ed.), *Galaxies & Galactic Structure* (pp. 14-15). Upper Saddle River, NJ: Siman & Schuster/A Viacom Company.

density of stars at the is still at a peak on the center.[2] Three of our targets NGC- 6946, NGC - 7331, and M74 qualify as spiral galaxies while our fourth galaxy, NGC - 205 is better described as an elliptical galaxy. Figure 1 display the individual structure of each of the galaxies.

By measuring and comparing the magnitude across the radii of these galaxies to one another, we were able to make a quantitative assessment about whether or not our spiral and elliptical galaxies fit the sersic bulge equation (1) and explain how structural elements within each galaxy, such as star density and color composition, influence the way the Sersic bulge function will behave.

Methods:

Observing:

NGC-6946, NGC-7331, NGC-205 and M74 were observed Wellesley College Whitlin Observatory's 24" telescope, and images were taken on the CCD (charge-coupled device, gain 2.6e-/DN) camera on four separate nights. The targets were found using the World Coordinate System (WCS), and the CCD camera was operated with a program called MaxIm, We had 4 - 5 minute exposures in blue, visual, and red light filters (B,V, and R respectively) for each of our images. 20 biases frames, 10 second flats, and 300 second darks were taken at sunset for each of the galaxies. The exposure times per color band filter are summed up in table 1. The raw images in addition to the bias, dark, and flat frames would be used later in the calibration step.

Total Exposure Lengths (minutes)				Biases, Darks, and Flats Exposure Length		
Galaxy	B Filter	V Filter	R Filter	Biases (frames)	Darks (sec/dark)	Flats (sec/flat)
NGC - 6946	110	75	75	20	300	10
NGC - 7331	80	40	40	20	300	10
NGC - 205	30	15	15	20	300	10
M74	75	45	45	20	300	10

Table 1: This table shows the total exposure length per filter, per galaxy as well as exposure time for bias, dark, and flat frames per frame per galaxy.

Calibration:

Once the observing step was complete, the next step was to reduce them. Images were opened in the CCD Data Processor tool in a program called Astro ImageJ (AIJ) where dark, bias, and flat frames to remove dark current, camera impurities and correct for electronic noise, or "hot pixels" that were detected by the camera. After calibration, pixel values, measured in DNs or counts, were able to reflect the true value of the number of photons originally received by our CCD camera from the targets.[3] After the images were reduced, images with corresponding filters were combined to create a final image that were used to get data in a program called DS9 and were analyzed in another program called Python.

Analysis

Post - Reduction Data Retrieval and Analysis

In the CCD camera, the amount of DNs in every pixel is directly proportional to the total number of photons that reach the camera during an exposure. The amount of photons received

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[2] Elmegreen, D. M. (1198). GALAXY Classification/Elliptical Galaxies. In A. Reeves (Ed.), *Galaxies & Galactic Structure* (pp. 17). Upper Saddle River, NJ: Siman & Schuster/A Viacom Company.

[3] AIJ: http://www.astro.louisville.edu/software/astroimagej/guide/AstroImageJ_User_Guide.pdf

can be influenced by anything from stars to clouds in the night sky.[4] Because the center of all galaxies have the highest concentration of stars within the galaxy, the peak count in AIJ could be used to infer where the center of each galaxy was located while doing data analysis. The same value was found in DS9 and used as the starting point of the measurement regions.

The next step was to select a value for the radii of the galaxies to measure. This was relatively easy for the NGC - 6946 and M74, which appear to be circular in shape on the images produced by the CCD camera. The baseline radius was chosen by stretching a circular annulus in DS9 across the galaxies and generating a radius in pixels for the resulting circle using functions in the DS9 program. Each of our samples, or "cuts" were clicked in dragged on the images until the desired length and and angle were achieved. An example of the cuts made are displayed in green in figure 2. Approximately 16 cuts were made in each filter, separated by the same angle.

Unlike the previous two, NGC - 7331, and NGC - 205 appear to be more oval shaped in the images received. So, an ellipse annulus was used to measure the major and minor axis of the galaxies and than the ellipse equation was used to find the other radii lengths. The value of R was measured by:

$$r = \frac{ab}{\sqrt{(bcos(\theta))^2 + (asin(\theta))^2}} \qquad (2)$$

where a = major axis, b = minor axis θ = angle from the major axis. Since it would take far too long to adjust the individual cuts for these galaxies, an excel sheet was used to make this calculation. The same sheet was used to generate points for the cuts by using the starting, (X,Y) fits point at the center, the r - values from equation 2, the desired angles, and the skinny triangle formula. Then, these points were typed into DS9 to generate the cuts seen in figure 2b. Once all the projections were made, measurements were taken using the "Get Information" function in DS9. The data was given in DNs per pixel per the radius (also in pixels). From this a surface brightness profile can be generated in units from the image (counts per pixel). These counts were then imported into an excel sheet and a program called Python was

Example Projections: NGC - 6946 and NGC - 205

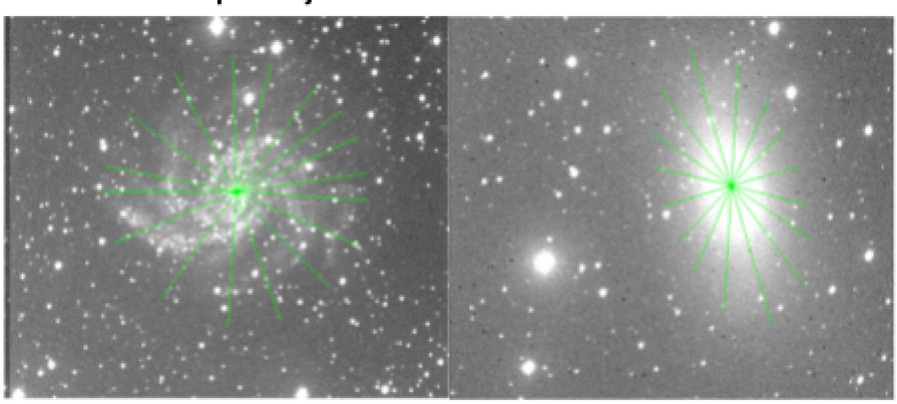

Figure 2: Projections from NGC - 6946 (a) and NGC - 205 (b) respectively in the program DS9. NGC - 6946 cuts were made by clicking and dragging the cuts. NGC-205 projections were made by using equation 2 and an excel sheet. Both had about 16 cuts, about 22.5 and 30 degrees apart respectively.

[4] Elmegreen, D. M. (1198). GALAXY Classification/Elliptical Galaxies. In A. Reeves (Ed.), *Galaxies & Galactic Structure* (pp. 87-88). Upper Saddle River, NJ: Siman & Schuster/A Viacom Company.

used to convert this value to magnitudes per square arcsecond and create graphs.[5] From there, we made our final assessment.

Results:

Surface Brightness and the BVR Filters

If the surface brightnesses profiles of NGC - 6946, NGC - 7331, NGC - 205 and M74 can be described by the Sersic bulge equation, then certain trends are expected when it comes to the relationship between the number of photons being emitted, and the distance from the center at which they were emitted.

Photons of light come in different wavelengths, and wavelengths of light from galaxies can vary based on their age dependent characteristics. As stated in the introduction, spiral galaxies have a cusp at their central axis that contains the highest density of stars throughout the entire disk. The high density causes the magnitude of the center to be low because the amount of light produced has higher amounts of energy. It's no surprise that the magnitude will be especially low in B band images which have high energy wavelengths.

Estimated Rmax Values (kpc)			
Galaxy	B	V	R
NGC - 6946	1.28	2.56	3.18
NGC -7331	1.41	2.21	3.01
M74	0.52	1.04	1.3
NGC - 205 (Re)	0.96	0.96	0.96

Table 2: The table above displays Rmax values for the spiral galaxies and an Re value for NGC - 205 in ecah filter. As the wavelength of the filtered light is stretched from B to V to R, the estimated values increase accordingly for the spiral galaxies. For the elliptical galaxy, the value of Re remains constant regardless of the light that is being filtered.

As the distance from the center of the galaxy increases, the magnitude increases accordingly because red nebulus gas of the young galaxy is more popular on the envelope of the spiral galaxies and is not as luminous as the stars at the center. So as the distance from the center increases, the wavelength of light from the photons emitted from these regions will become more elongated. Table one displays estimated Rmax values (in kiloparsecs) that indicate the radius where the exponential part of the galaxy ends. The Re value for the elliptical galaxy NGC - 205 is also displayed, which shows at the distance at which the surface brightness is half its total.[6]

For the spiral galaxies that were tested, the Rmax values increased from B to V to R. This means that the radius at which the cusp end is closer to the center for the B filter and gets farther away as lower energy photons are filtered through to the CCD camera. M74 in figure 1c., for example, can be seen with blue light coming from center of the galaxy, while red light surrounds it.

As for the elliptical galaxies we tested, the Re value, or effective radius value is the same across all the filters, indicating that half the total amount of light in each filter is contained within the same distance from the center. Because the structure of an elliptical galaxy is mostly uniform and doesn't have significant BVR color band variance (as seen in figure 1d. on the galaxy NGC - 205), it makes sense that the Re values would be the same across the filters.

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[5] DS9: http://www.faulkes-telescope.com/files/faulkes-telescope.com/archive/projects/galaxies/bright_profiles/ds9_profiles.pdf

[6] Definition of Rmax and Re: http://astroweb.case.edu/ssm/ASTR620/Dubinski_SB.pdf

These trends confirm the expected relationship between the structural characteristics of the galaxies and the amount of light that is being measured across particular radius, in that the composition of the galaxy influence the magnitude and type of light that can be detected from each color band.

Profiles and Sersic Bulge Equation Models

Once our data was compiled in a program called Python, there was a clear quantitative difference in each of the galaxies that seems to fit the sersic bulge equation. For the spiral galaxies, the surface brightness seemed to rise at increasing rate over the central bulge, then that rate flattens out after a certain radius. As seen in figure 3., the surface brightness profile in the B filter increased at an increasing rate and then continues to increase at a steady rate as the

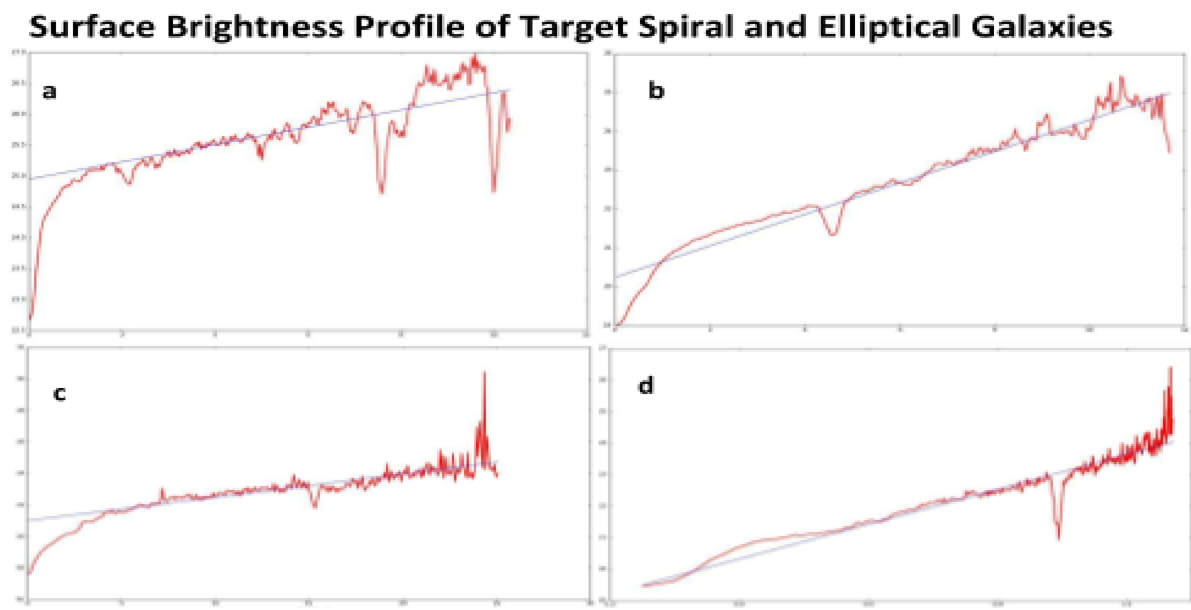

Figure 3: Surface brightness profile for NGC - 6946 (a), M74 (b), NGC-7331 (c), and NGC - 205 (d) in the B filter, measured in magnitudes per arcsecond squared/radius(kpc.)The surface brightness increases exponentially in a-c until Rmax their respective Rmaxs (estimated values in table 2). Surface brightness in d is increasing at a constant rate (estimated Re value in table 2). A line of best fit was added to each piece of data.

radius rises to multiple kpc. However, in the elliptical galaxy NGC - 205, the surface brightness of the galaxy seems to decrease at a relatively constant rate over the full length of the radii measured (figure 4). Thus following the trend estimated by the Rmax and Re values.

So, by completing this project, it can be confirmed that NGC 6946, NGC 7331, M74 fit the sersic bulge equation when n=1 and that their structures had a hand in this. The model used to describe the data received from the spiral galaxies matches the exponential disk equation:

$$I(R) = I_0 e^{\frac{-R}{hr}} \qquad (2)$$

Where I_0 is the central surface brightness, measured in magnitudes per arcsecond squared, R is a measured radius in kpc, and h_r is some scale length. The scale length is mostly likely about ⅓ to ⅕ times the estimated Rmax values.[7] ed

The model used to describe data received from the NGC - 205 is called de Vaucouleurs model:

$$I(R) = I_0 e^{(-R/Re)^{1/4}} \tag{3}$$

Where I_0 is the central surface brightness, measured in magnitudes per arcsecond squared, R is a measured radius in kpc, and Re is the effective radius measured in kpc.[8] Profiles of elliptical galaxies can be described using this R^¼ law. In short, the R^¼ law explains how the magnitude of NGC - 205 increases over a much smaller distance in elliptical galaxies than it does for spiral galaxies.

In comparison, the surface brightness was growing exponentially as the distance from the center was increased in the spiral galaxies, while the surface brightness of the elliptical galaxy was uniform across the center; all of which are dependent on the composition of the galaxies, which is dependent on their age. Furthermore, the increase in the surface brightness value according to the kpc value allowed a conclusion to be drawn; that is, regardless of the color band being observed, the surface brightness of spiral galaxies increases exponentially across the cusp while the surface brightness remains constant and changes over a much smaller distance, giving it it’s uniformity. The exponential disk model and de Vaucouleurs model of the sersic bulge function can therefore be applied to spiral and elliptical galaxies respectively.

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[7] Equation 2: http://jila.colorado.edu/~pja/astr3830/lecture15.pdf

[8] Equation 3: http://jila.colorado.edu/~pja/astr3830/lecture15.pdf