The Morphology of Galaxies

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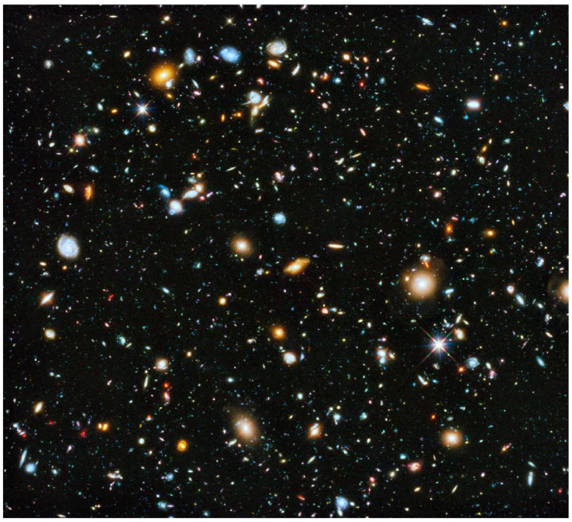
Conference Paper

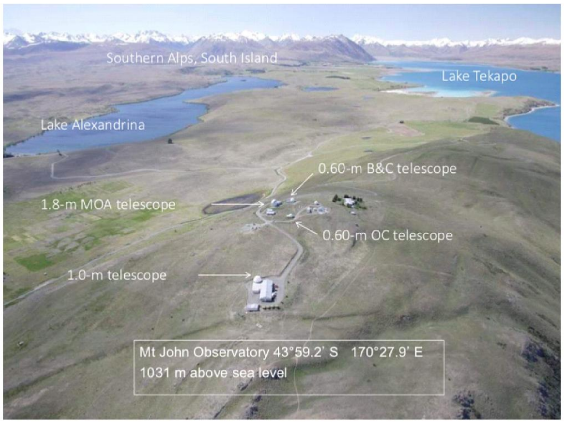
My name is Aayushi Verma, and I'm a second-year undergraduate student at the University of Canterbury studying Astronomy and Maths. During my previous semester, I took an Observational Astronomy course at university, where I did a research project on a topic that interests me. Over my summer vacation, I took my project a little bit further and did some extra analysis and have presented my work here.

My motivation for choosing a project stemmed from Hubble's Ultra Deep Field image, taken by the Hubble Space Telescope. This image, containing over 10,000 galaxies of varying sizes, colours, luminosities and shapes motivated me to learn more about the morphology, or structure, of galaxies and to understand how they are classified.



Hubble Ultra Deep Field

Being a student at Canterbury, I was able to use the telescopes at Mount John Observatory. In order to get started with my research project, I researched what galaxies would be observable at Mount John at that time of the year. Factors like the limiting magnitudes of the telescopes, the moon, and the rise/set times of the galaxies had to be taken into account. After my observing proposal was approved, I observed my galaxies using three telescopes at MJO: the 0.61m Optical Craftsmen telescope, the 0.6m Boller and Chivens telescope, and the 1.8m MOA telescope.

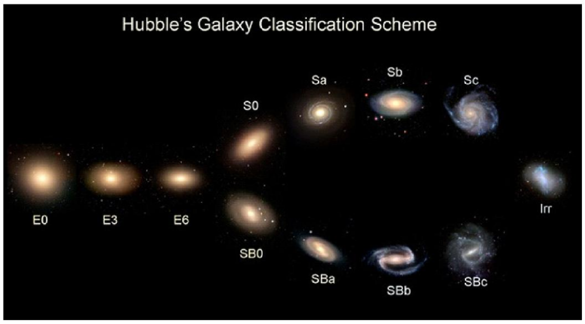


Mt John University Observatory

The next and most important step was to reduce and then analyse the raw CCD images. Since I used multiple filters on each telescope to observe my objects, I reduced the images for each filter for each object, as raw CCD images need to be calibrated first for excess noise and signals like bias, dark current, saturation, and more by first subtracting the biases and darks and then dividing by the flat-fields. I used the software AstroImage J to do this.

Once the images were reduced, I aligned the stacks of multiple exposures for each object for each filter, by aligning the WCS apertures, or bright stars, in AstroImage J. I then stacked the images together by an average intensity projection type to get one image for one object for every filter that it was imaged in. I took this a little bit further and did some extra work to stack these multiple filters together and create a coloured, combined image for many of the galaxies, and due to this, I now have an appreciation for astrophotography and am hoping to do more astrophotography of my own.

Now that I had visual CCD images for each galaxy that had been reduced and calibrated, I classified them according to Hubble's Tuning Fork diagram. The Tuning Fork diagram was devised by Edwin Hubble, who classified them according to shape. Elliptical galaxies have relatively large nuclei and no arms, and generally range on a scale of 0-9 based on their ellipticity. The top rung of the fork depicts spiral galaxies with relatively small nuclei and spiral arms. The lower rung depicts spiral galaxies with bars, known as Barred Spirals.



Hubble's Tuning Fork Diagram

Barred and unbarred spirals both range on a scale of a to c depending on how tightly wound the arms are. There is also a class of galaxies called irregular galaxies which cannot be classified as elliptical, barred or unbarred spiral galaxy.

Based on the visual images I had for each galaxy, I classified them according to Hubble's Diagram. Most of the galaxies that I classified were barred and unbarred spiral galaxies, however there was 1 elliptical and 1 irregular galaxy. One of the difficulties faced when using Hubble's method was distinguishing between an elliptical E9 and a spiral S0 galaxy. It was hard to tell what type of galaxy it is despite examining all the filters and under different scales and colours using the software. Perhaps using the Sérsic profile might shed some… light on this matter.

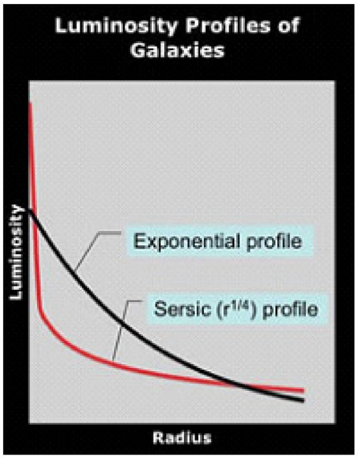
The next step was to use models to fit to the data and verify that my earlier visual classifications were correct, using the light-mass profiles of the galaxies. I used something called the Sérsic profile, which essentially classifies a galaxy according to its light-mass profile, which is the distribution of mass as a function of radius of a galaxy, measured by the surface brightness in this case.

This Sérsic profile is given as this equation, where $\mu(r)$ is the surface brightness at radius r, μ_0 is the brightness in the centre of the galaxy, r_e is the scale length, β is such that half of the total light of the galaxy is emitted inside r_e, and n is a number usually between ½ and 10.

$$\mu(r) = \mu_o * e^{-\beta * \frac{r}{r_e}^{1/n}}$$

It is worth noting that the Sérsic profile of a spiral galaxy is usually modelled by n=1. This shows that spiral galaxies are modelled by an exponential trend, hence in the context of Sérsic profiles, spiral galaxies are often referred to as 'exponential galaxies'.

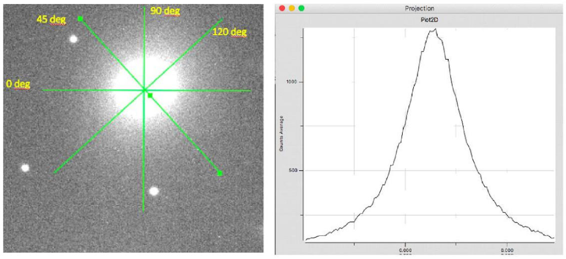
Elliptical galaxies, on the other hand, are usually modelled by n=4, which makes the Sérsic profile such that: *This shows that elliptical galaxies are modelled by what is known as the 'Sérsic' index (1/4), hence referred to as 'Sérsic galaxies'.*



Sérsic Profile

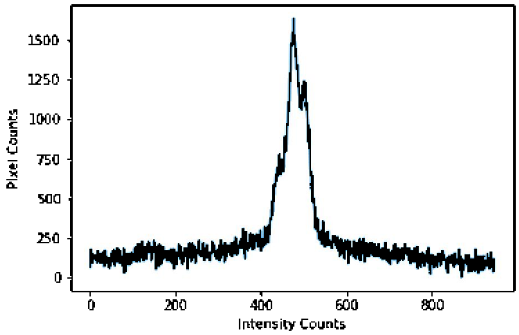
In theory, the Sérsic profiles of the galaxies should look something like the graph shown above, where the black curve represents spiral galaxies with an exponential profile, and the red curve represents elliptical galaxies, with a Sérsic profile.

Therefore, in order to use the Sérsic profiles to classify my galaxy data, I had to first extract a surface brightness profile for each filter for each galaxy. I did this using the software DS9 and drew a projection line at four different angles for each filter of each galaxy.



Surface Brightness Profile

I then wrote some code in Python to analyse the surface brightness profiles. First I normalised the plot, and then read off the values for 'r' and 'central_pixel' from the normalised plot and entered these as parameters in the function. The value of 'n' was estimated from the earlier galaxy classification using Hubble's diagram. For example, for NGC720, it was earlier estimated that it is an elliptical galaxy, hence the value of n=4 was used. Since this gave a good fit of the Sérsic profile to the data, this was the value used. For the galaxy NGC1291, which was estimated to be a spiral galaxy, initially the value of n=1 was used, however the resulting Sérsic profile did not fit the data very well, so the value of n=1.1, 1.2, … was used until the value of n=1.5 was found to be a good fit for the data.



Normalised surface brightness profile of a galaxy.

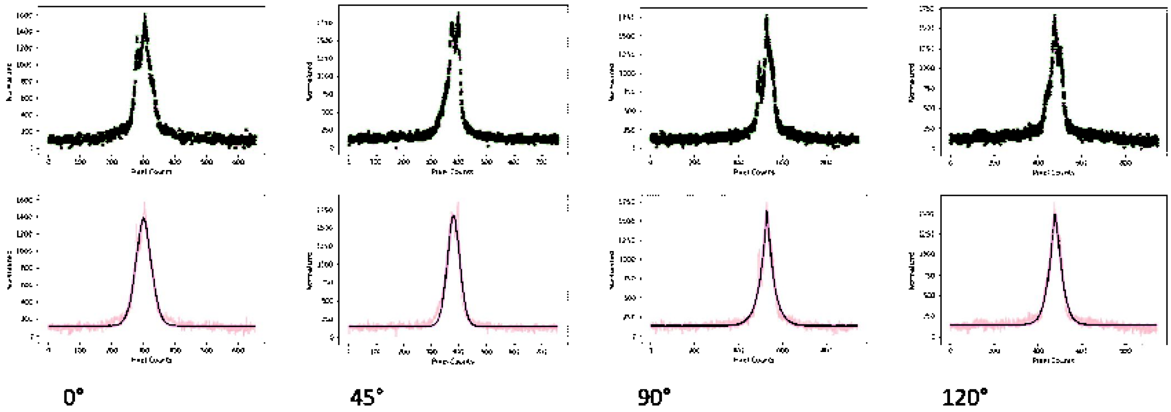
An example of my data analysis is presented using NGC 1097, which I earlier predicted to be a barred spiral galaxy, and so an estimate of n is n=1. For each angle that I extracted the light-mass profiles for in the green filter for this galaxy, I calculated the uncertainties in the data, indicated by the upper graph here, where the green stuff is the uncertainty and the purple stuff, which I'm not actually sure you can see, is the data. The pink curves in the lower graphs are the data, and the purplecurve on top is the fitted sersic profiles. We see that they look rather similar. Initially I tried n=1, but that did not give a good fit so I went up in intervals of 0.1 until I found n=1.5 to be a good fit. I repeated this process for the infrared and red filter data.

NGC 1097

Barred Spiral (SBb)

Green (G) filter

n = ~~1~~ = 1.5



Normalised data analyses for four angles across galaxy NGC1097.

I repeated this process for all the filters of all the other galaxies. I collated the data in some tables, where I've listed the galaxy and what I predicted them to be, and then what n-value was found to be a good fit for each of the filters. These galaxies were observed in the green, infrared and red filters on the B&C telescope, and in the broadband blue and narrowband green and infrared filters on the Optical Craftsmen telescope at Mt John.

Galaxy	Predicted Type	Green (G) Filter	Infrared (I) Filter	Red (R) Filter
NGC 613	SBb	1.1	1.2	1.2
NGC 720	E6	4	4	4
NGC 1097	SBb	1.5	1.1	1.1
NGC 1315	S0	1	1	1
NGC 1365	SBb	1.1	1	1.2
NGC 1549	S0	1.2	1.1	1.1
NGC 1553	E9/S0	1	1.1	1
NGC 7213	Sa	1.2	1.2	1
NGC 7552	SBa	1	1.1	1
PGC 2248	Irr	5	5	5

Results for Sérsic Method: Dataset #1

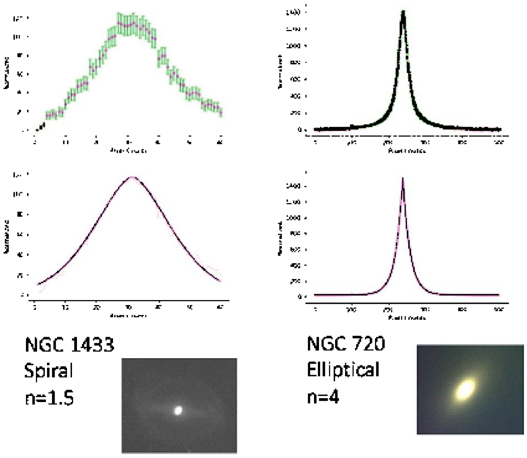
Galaxy	Predicted Type	Blue (B) Filter	Green (g) Filter	Infrared (I) Filter
NGC 1232	Sc	1.2	1.2	1.2
NGC 1365	SBb	1.1	1	1.1
NGC 1433	SBa	1	1	1.1
NGC 1512	SBb	1.2	1.1	1.1

Results for Sérsic Method: Dataset #2

It was not always possible to visually distinguish between E9 and S0 lenticular galaxies like NGC 1553. I used the Sérsic method to resolve this and tried both n=1 and n=4 to fit the Sérsic profile to the data. In theory if it was an elliptical, it would have a better fit with n=4, or if it was a spiral it would have a better fit with n=1. Using this seemed to resolve many of the unclear distinctions between E9 ellipticals and lenticular galaxies.

Another issue was that not all my predictions were correct. Despite classifying the galaxies first according to Hubble's method and then using Sérsic profiling, some of my galaxy classifications were wrong when I compared them to published literature values. This means that even by visual inspection, it may actually be hard to figure out the type of galaxy due to many factors.

Remember that the Sérsic model describes the light-mass distribution of mass as a function of radius of the galaxy, and that the Sérsic profiles I fitted showed either a bell-curve or a sharp spike shape. In the case of the bell-curve, it indicates that the mass (and hence light intensity) gradually increases as the centre is approached and then declines, showing that the



Bell-curve profile of a spiral galaxy vs sharp spike profile of an elliptical galaxy.

mass of that particular galaxy is distributed somewhat evenly across the entire galaxy. This is the Sérsic exponential profile which is predicted for spiral galaxies. Or the sharp spike graph shows that most of the mass is concentrated in the centre of the galaxy, which is the Sérsic n=4 profile which is predicted for ellipticals. However this theoretical trend was not noticed in the lightcurves produced for these galaxies. Some spiral galaxies displayed sharp spike-like profiles, which was theoretically not predicted.

As seen in the plots earlier, there seems to be no correlation or pattern between the shape of the Sérsic profiles of different types of galaxies, meaning that for example looking at the spiral galaxies, some display exponential-type profiles while others seem to have Sérsic profiles. Also due to limited data, it is hard to make a decisive inference for elliptical galaxies, except for a remark that in general elliptical galaxies have reasonable Sérsic fits at n=4. Additionally, there seems to be no trend to distinguish between barred and unbarred spirals.

One possible reason for no correlation could be the quality of the data. At the time of observing, the weather was not very agreeable and there was a full moon, which would affect the amount of light collected of the galaxy, therefore affecting the data.

The main reason for these inconclusive results is that there are several scientific factors which I had not considered, or assumed. For one, the orientation angles of the galaxies have not been taken into account. It is unknown whether the galaxies are edge-on or face-on to us. This affects the surface brightness profiles and therefore it is hard to infer a conclusive result.

Before this extra analysis, I didn't consider using different angles of galaxies and did not inspect the Sérsic profiles in different filters, so my previous results indicated a general distinction between barred and unbarred spirals, as I noticed in general that the spiral galaxies had n=1, while barred spirals usually had n=1.5. This wasn't always the case though, and this method was incorrect, which is why is discarded my previous analysis and started again.

Some possible improvements I am aiming to incorporate in my further research is to do follow-up observations of a wider variety of galaxies. With more elliptical, lenticular, barred and unbarred spirals and irregular galaxies, it is probable some sort of trend or conclusion can be drawn about the morphology of galaxies. Another improvement I am working on is trying to find an average surface brightness profile for many angles of the galaxy. One method I am trying is to simply plot the average surface brightness profile plot of all the angles and then fit a Sérsic profile to it. I am also reading a variety of publications which deal with different methods for classifying galaxies.

Despite the fact I couldn't find solid results, I still have learned a lot from this project. I was a first year at university when I did this course and only had the minimal amount of physics, mathematical and programming skills necessary. After finishing the course and doing some extra analysis, I am now a lot more knowledgeable about scientific computational methods, which is analysing the data, writing code to analyse the data, and understanding the physical meaning behind the results.

I also learned a lot about the scientific research process in astronomy, from coming up with ideas for a research project, planning how it's going to be done, carrying it out, collecting the data, analyzing it and presenting it. Speaking of which, I learned to present my data in a variety of formats like a written publication, a poster, a presentation, and so on. I also have an appreciation now for astrophotography and am excited to use my newly-gained astrophotography knowledge sometime.

I also now know how large-scale professional telescopes like the ones at Mount John Observatory work, and hope to someday be able to do a project where I can collect data from professional telescopes again.

As an aside, after this course and project, my passion for astronomy was further solidified and made me realise that I want to pursue this kind of career where I can work with data, think about how that relates to our understanding of the universe, and to communicate this data to my peers and you, the audience. Doing this also enabled me to seek an internship with a professor at Brown University in Rhode Island in the States, where I am working on a project on the study of the presence of dark matter in galaxy clusters with him.

I have also started experimenting with astrophotography and borrowed a friend's camera to take some cool shots of the cosmos from Lake Tekapo. I was also motivated to spread my passion for astronomy and space to people by co-founding the NZ Students' Space Association: Christchurch branch. I was also motivated to start a blog where I write articles about topics in astronomy and other sciences which interest me.

And finally, thanks to this project and this course, I have seriously started considering a variety of topics in astronomy which inspire me, which I can then pursue as a career. Attending the RASNZ Conference is always so useful in my pursuit of knowledge for my passion, and meeting really interesting and knowledgeable people from whom I learn a lot in the span of three days. I would like to thank Dr Karen Pollard for helping and encouraging me with this project, and Astronz for providing a grant so that I could attend this conference for the third year in a row and be able to talk about my work and my passion.