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Astro 302 Research Project

Types and Colors of Galaxies in Galaxy Clusters

Group partner: Vadim Bernshteyn (he did most of the coding for me, I'm so glad he is my groupmate).

(Also, please go easy on us! Thank you so much!)

Types and Colors of Galaxies in Galaxy Clusters

Abstract

The purpose of this research is to classify the types of galaxies (elliptical and spiral) within galaxy clusters and identify the correlation between galaxies' types and their colors. To accomplish this goal, we picked two galaxy clusters: A2199 and A85 to observe, and do photometry and morphology on them. Despite many limitations in our data-taking and data-processing methods, we have concluded that the majority of the samples we have analyzed are elliptical galaxies. We also concluded that elliptical galaxies tend to be redder while spiral galaxies tend to be bluer.

Introduction

The two main types of galaxies that we focus on in our research are spiral and elliptical galaxies. According to Tojeiro et.al (2013), there could be red and blue spiral galaxies and red and blue elliptical galaxies. However, the quality that separates spiral and elliptical galaxies is their star formation. Spiral galaxies tend to have more active star formation compared to elliptical galaxies. Even the red spiral galaxies where star formation has largely slowed down compared to blue spiral galaxies (by a factor of 3), can still form stars about 17 times faster than red elliptical galaxies. These spiral galaxies over time, can also evolve to elliptical galaxies as their star formation decreases (Tojeiro et.al, 2013, p. 259). We also go through 2 other studies from Abell (1965) and Dressler (1984). These studies have noticed that for rich galaxy clusters, the galaxy population near the center would be predominantly elliptical (Abell, 1965, p. 189), or that the numbers of elliptical galaxies start to become less significant as we get closer to the center of the cluster (Dressler, 1984, p. 3).

Theory

Based on the studies we have gone through, we form a hypothesis that if the galaxy is elliptical, then it would be redder, and if the galaxy is spiral, it would be bluer. This is because star formation is more active within spiral galaxies, therefore bluer and newer stars will be created in spiral galaxies compared to elliptical ones, hence making the spiral galaxies bluer. We also form another hypothesis that if galaxies are in the same cluster, then they should be the same types, and if the galaxies are in the center of a cluster, then they are most likely elliptical galaxies.

Observation

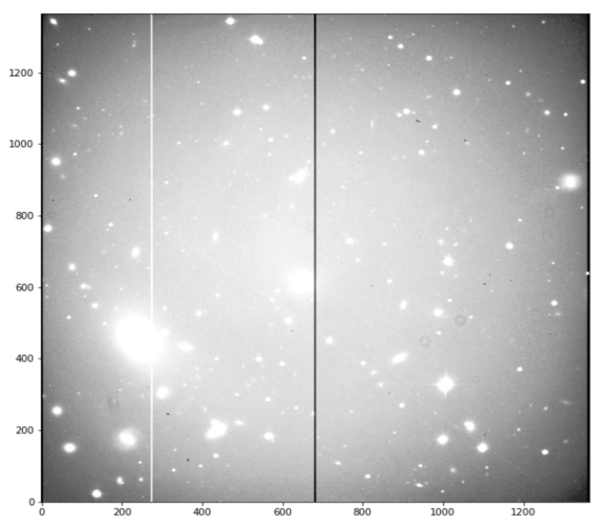
For the observational part of this research project, we decided to choose two targets for our observation: galaxy clusters A2199 and A85. We began to observe them on Saturday, September 23rd, 2023 at the Kuiper 61" telescope on Mt. Lemmon. Since the day is very close to the autumnal equinox, combined with nice weather and good seeing, it was very easy to observe our targets. Our observation procedures include these steps:

1. Take bias and flat field frames for each filter (R and V).
2. Starting with A85, take a 10-second exposure for the target in the R filter.
3. Pick 4-point sources (stars) that seem to be far apart from each other, then measure their full width half max (fwhm).
4. If the fwhm of the stars are not close to one another, increase the focus. Then repeat the 10-second exposure and the measurement of fwhm until their values are close. That means the focus is correct.
5. Start taking 200-second exposure for the target.
6. Repeat the process and take 5 more 200-second exposures for the target. Move the telescope in between exposures so the bad columns of the CCD do not stack on top of each other when we combine the images later on.
7. Repeat all steps for the V filter. Then do the same for A2199 later that night. In total, we have 24 200-second-exposure images for A2199 and A85, 12 for each galaxy and 12 for each filter.

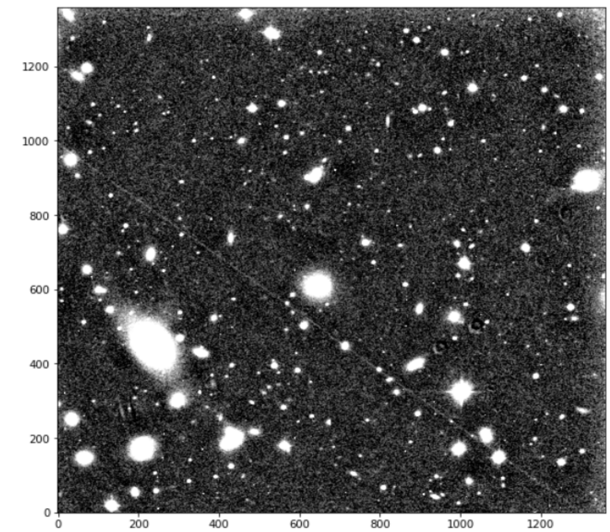
Data Processing

1. **Image Processing**

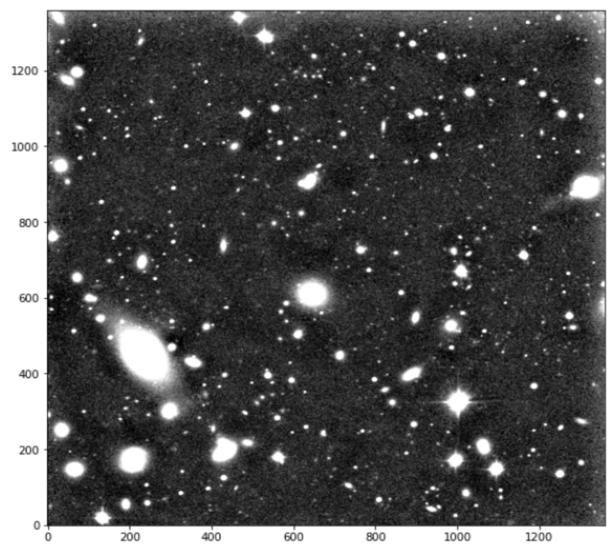
   This is the raw image from 1 of the 200-second exposures we took. As you can see, the bias, background, defection on the CCD, and the bad columns are still in this picture.



   Therefore, we need to do bias subtraction, flat fielding, sky subtraction, and blur the bad column to make the image look better. Now that all the defections are gone, but you can still see a mysterious crossline in our picture. That is a satellite that we accidentally captured when taking data. This will not affect our final results too much, fortunately.

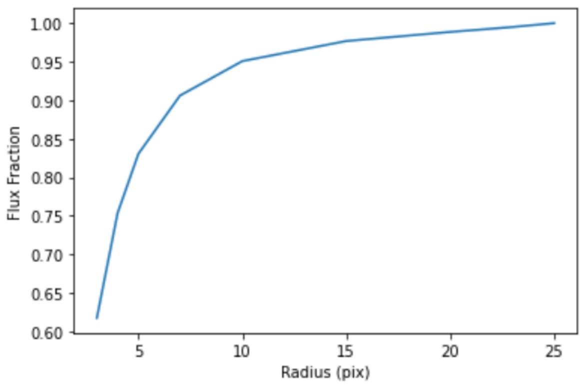


After cleaning all 24 images, we started to combine R images and V images. In total, we will have 4 combined images: 2 for A2199 in R and V and 2 for A85, also in R and V. The combined image looks way better now compared to the raw one.

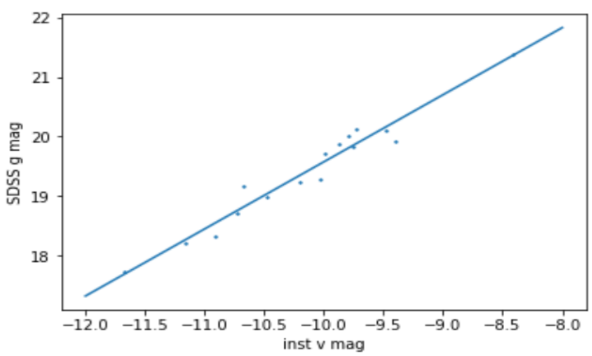


2. Calibration

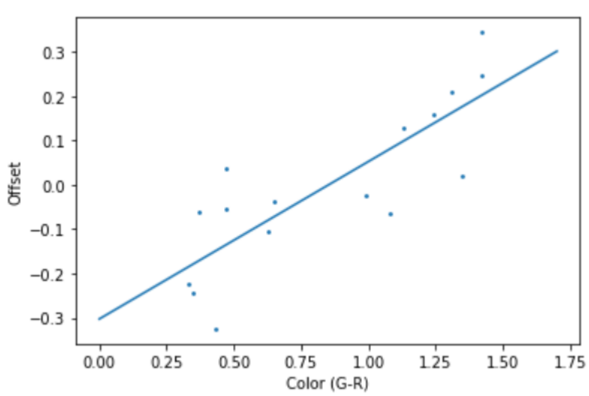
After cleaning the image, we start to calibrate our instrumental magnitude. We first pick out stars in our picture and take apertures of them. We want to pick stars because the light from stars is a point source, which is easier to correct than galaxies. After taking the aperture, we begin our aperture correction. After graphing flux vs aperture radius, we will have the graph below:



The aperture radius of 10-15 seems to be ideal since it covers the most flux of our object, so we pick the aperture radius 15 for our aperture correction. We then compare the flux we have for our stars and compare it with the Legacy survey data to correct for our magnitude. The graph below shows the correlation between our instrumental magnitude and the calibrated values in the Legacy survey data for the V filter (they only have G filter for the archival data but the data should be close enough).



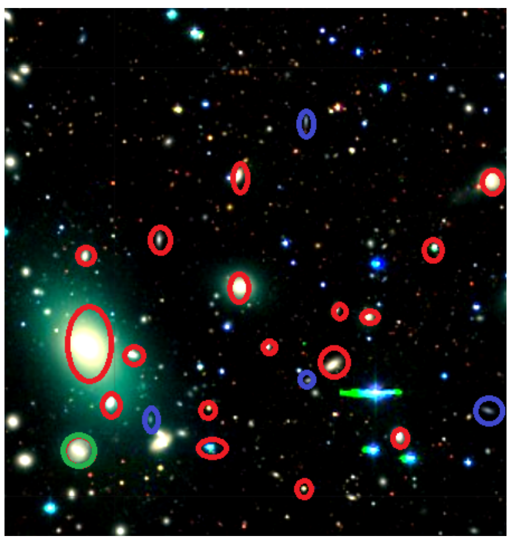
Lastly, we check for our color terms as different filters can affect the zero points differently. We first will find the offset by checking how far away our data points are from the line of best fit. Then we graph the offset with the color to check for the correlation between them. That will be our color term. We will add and subtract our color term into our final magnitude later to get our data a little bit more accurate.

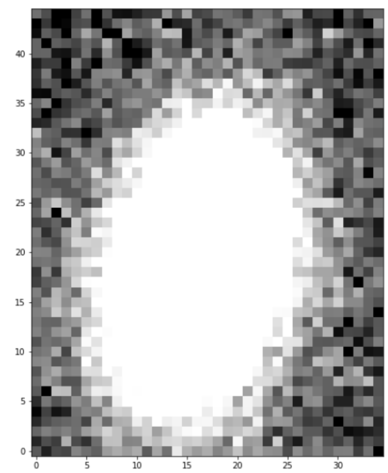


3. **Morphology (Galaxy Classification):**

After the calibration process is finished, we start to classify galaxies in our pictures using the corresponding area in the Legacy survey data as they have clearer pictures than us. We classify galaxies by eyes based on their looks and the classification criteria are:

- Is a light source a point source? If it is then it is not a galaxy.
- Does the galaxy look circular/elliptical? If it is then it might be an elliptical galaxy.
- Is the color of that galaxy uniform throughout? If it is then it might be an elliptical galaxy.
- Does the galaxy look bluer and fainter than the ones surrounding it? If it is then it might be a spiral galaxy.

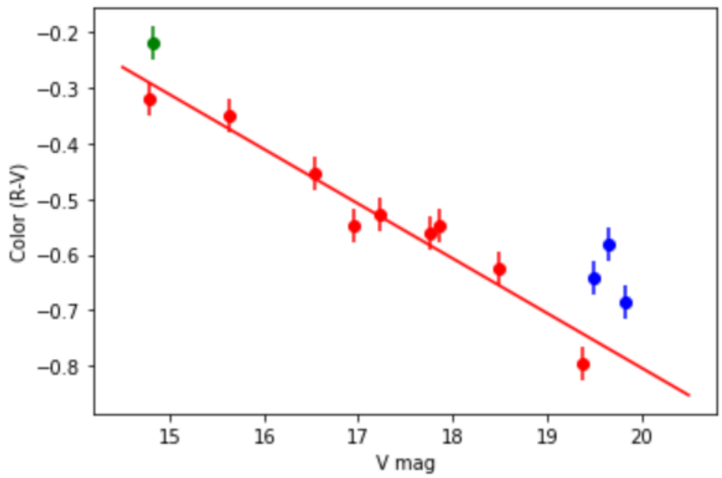




After finishing classifying by eyes, we took the "aperture" of these galaxies to measure their flux. However, since there is no code we know of that can take aperture of galaxies, we instead cropped each galaxy individually and measured the flux within the cropped area. We make sure our measured flux values are good by comparing them to the Legacy survey data. It is close, which is a good step in the right direction for us.

Results

Due to time limitations and how much the data processing took us, we unfortunately could not analyze the data for A85. However, we have finished analyzing the data for A2199. Here is our graphical result for A2199:

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Slope:-0.0981 +- 0.0001
Intercept:1.16 +- 0.03
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Our Chi-square for the graph is 0.993. We got this Chi-square because we purposely picked our error bars so that the Chi-square would be closer to 1, and we picked the same error bar values for all our data points. Although this method is not the best, since Professor Zaritsky said it is somewhat acceptable, we will use this as our Chi-square for this result.

The red dots are the ones we classified as elliptical galaxies, the blue dots are the ones we classified as spiral galaxies, and the green dot is our unknown galaxies. The x-axis in this graph represents the magnitude of the galaxies. The larger the magnitude, the dimmer the galaxies are. The y-axis in this graph represents the color of the galaxies. The higher the value, the redder the galaxies are. According to our data, you can see that all the spiral galaxies group themselves in one spot, while the elliptical galaxies distributed themselves in a linear. This shows the clear difference between elliptical and spiral galaxies, suggesting that we did a good job in our morphology process. All the elliptical galaxies also present as redder and brighter than the spiral galaxies (except the lowest red dot to the right). This confirms our hypothesis that elliptical galaxies are red. While the elliptical galaxies even though they are not necessarily red, are bluer than most elliptical galaxies according to our data, which also matches our hypothesis well. Since the region we took from A2199 is very close to the center, we can also confirm that the center region of A2199, a fairly rich galaxy cluster, contains predominantly elliptical galaxies.

Conclusion

Despite getting fairly satisfactory results, there are so many errors and limitations that we have in this research. Some of them are:

- Nearby stars/galaxies mess up the flux from the object.
- Gas/dust in line of sight that we didn't account for.
- Classification by eyes is not accurate.
- Cropping technique is not the best.
- Use the V filter while the catalog uses the G filter.

- We over-subtracted the sky by combining multiple sky subtraction images.
- Our methods of getting the error bars are also not the best.

To this day, we cannot find a way to improve our data on our over-subtracted sky and our error bars. One thing we could do for this is to compare how the flux varies between the combined image and the non-combined image where the sky is not overly subtracted to come up with better error bars, thus creating better uncertainties. However, such a method will take a lot of time as not only do we have many non-combined images to compare to, but we also have a lot of galaxies to check. We try to improve our graph by fixing our cropping for the galaxies by making the cropped area more focused on the galaxy to ignore as much background as possible. We also added the color terms, which makes our data a little bit better. There are still so many uncertainties in our data, but I am satisfied with what we have done so far. This is my very first "proper" astronomy work, and I have a really fun time with it. Thank you very much for an amazing opportunity! I cannot wait to do more things like this in the future. (Please pretend that the pictures make this 9 pages but the world is within 3 pages. I'm sorry!)

Works Cited

Abell, G. O. (1965). Clustering of galaxies. *Annual Review of Astronomy and Astrophysics*, *3*(1), 1-22.

Dressler, A. (1984). The evolution of galaxies in clusters. *Annual review of astronomy and astrophysics*, *22*(1), 185-222.

Tojeiro, R., Masters, K. L., Richards, J., Percival, W. J., Bamford, S. P., Maraston, C., ... & Thomas, D. (2013). The different star formation histories of blue and red spiral and elliptical galaxies. *Monthly Notices of the Royal Astronomical Society*, *432*(1), 359-373.