

Lab Report 8

Properties of Galaxies

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1 **Experiment (XV)**: Morphological Properties of Galaxies (Elliptical, Spiral, Lenticular, Peculiar and Interacting Galaxies)

1.1 **Task (I)**: Grouping Galaxies Based on Appearance

1.1.1 Mohammad's Mosaic

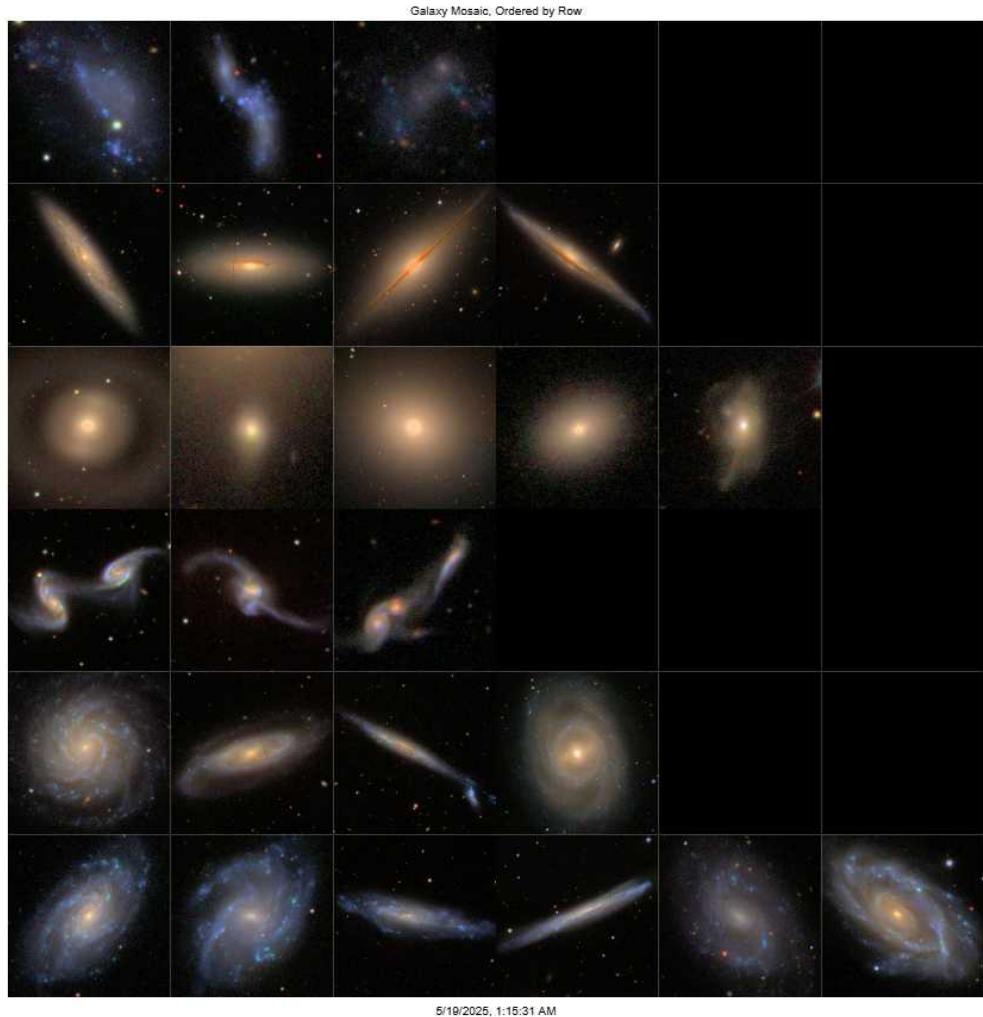


Figure 1: Mohammad's Grouping of Galaxies

- Row 1: Peculiar Galaxies
- Row 2: Lenticular Galaxies
- Row 3: Elliptical Galaxies
- Row 4: Merging Galaxies
- Row 5: Older (Reddish) Spiral Galaxies
- Row 6: Younger (Bluish) Spiral Galaxies

1.1.2 Hazem's Mosaic

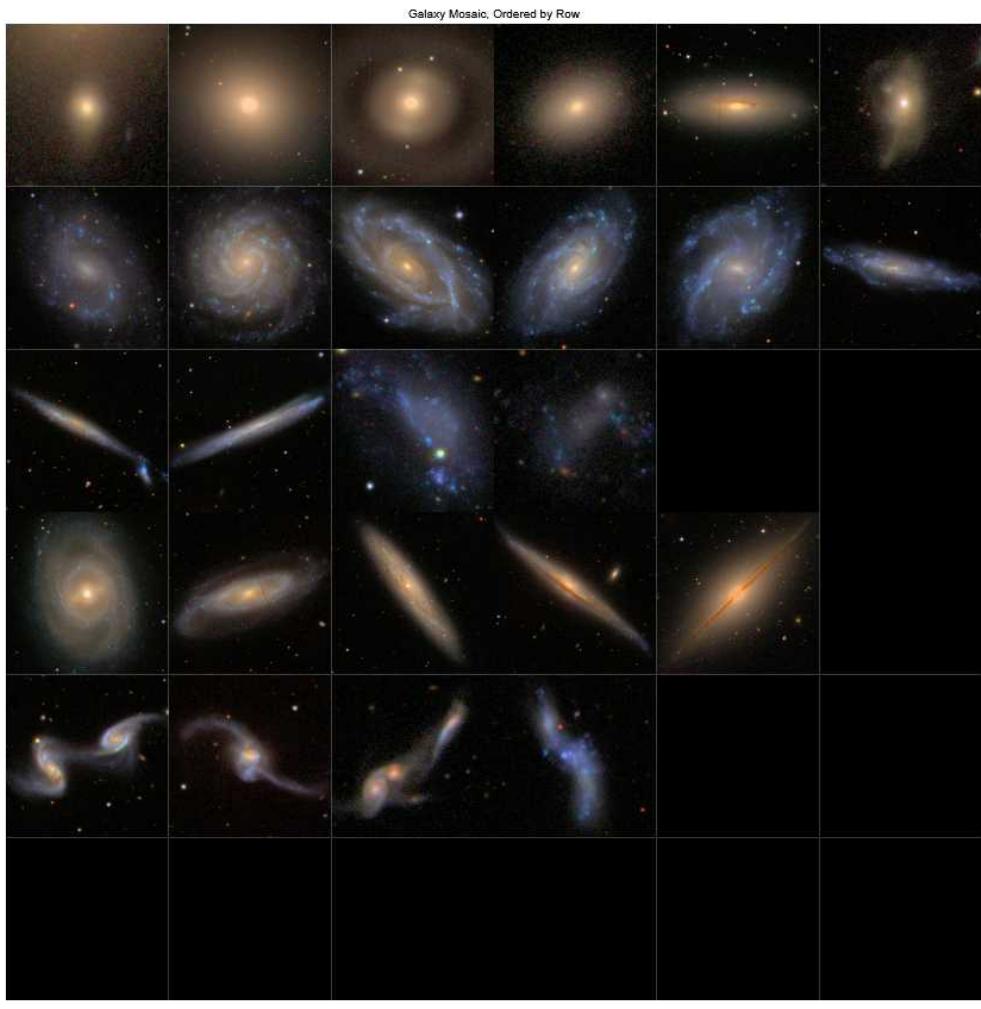


Figure 2: Hazem's Grouping of Galaxies

- Row 1: Galaxies with a golden hue
- Row 2: Spiral Galaxies with bluish spirals
- Row 3: Bluish Galaxies
- Row 4: Spiral Galaxies with reddish spirals
- Row 5: Interacting Galaxies

1.2 Comparison of Mosaics

When forming rows to classify the galaxies, we primarily focused on their visual appearance, such as the presence of spiral arms, the color of the galaxy, and any peculiar features like merging or interacting structures. For example, galaxies with bluish hues were grouped together as younger galaxies, while those with reddish or golden hues were classified as older galaxies. This approach allowed us to categorize galaxies based on their observable characteristics, although some classifications may have been influenced by the orientation or visibility of certain features. Overall, in classifying the galaxies, neither of us had particularly different approaches.

1.3 Task (II): Galaxy Morphology Questions

1. A galaxy emitting lots of blue light must contain many (hot / cool), (high- / low-) mass (short- / long-) lived stars. The stellar classification of these blue stars is (O and B / A, F and G / K, M and L).
2. Galaxies which appear more disturbed tend to have (higher / lower) asymmetry indices, and (bluer / redder) colors.
3. Elliptical galaxies tend to be (bluer / redder), (more / less) massive, and contain (more / less) gas than spiral galaxies. Their concentration indices are (higher / lower), while their asymmetry indices are (higher / lower).
4. The Milky Way is a spiral galaxy, with a sub-classification of (Sa / Sb / Sc (It is between Sb and Sc; Sbc) / Sd). It also has a central barred bulge.
5. It is much easier to trace the spiral arm structure on a(n) (face-on / edge-on) spiral galaxy than on a(n) (edge-on / face-on) one.
6. The force which binds all of the stars and gas in a galaxy together is the gravitational force.

1.4 Task (III): Measuring Galaxy Properties from Images

1.4.1 Galaxy #1

1. Note the “ripples” that appear at large radii in the radial counts profile. What do you think causes them?

Answer: The initial ripples are caused by the spiral arms of the galaxy, further out than the galaxy, the ripples are caused by the background stars and galaxies.

Galaxy #1 Comments:

The position angle of the galaxy is 16 degrees, and the axial ratio is 0.63. There is some flux from the galaxy left outside the ellipse, since the galaxy is not perfectly symmetric around the semi-major axis. The galaxy is a spiral galaxy, and the color is somewhat golden (0.72 B-V), with the spirals having bluish spots. Indicating that it is an older galaxy, with new stars forming in the spiral arms. The classification of this galaxy is Sb, decided by the shape and the spectrum. The asymmetry index is 13.9 % which is expected from how it looks. The concentration index is 19.8 %, not that high, but expected for a spiral galaxy. There seems to be a faint bar in the center of the galaxy.

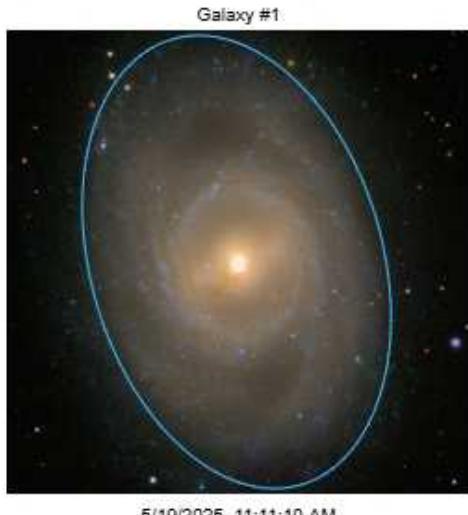


Figure 3: (a) Galaxy #1

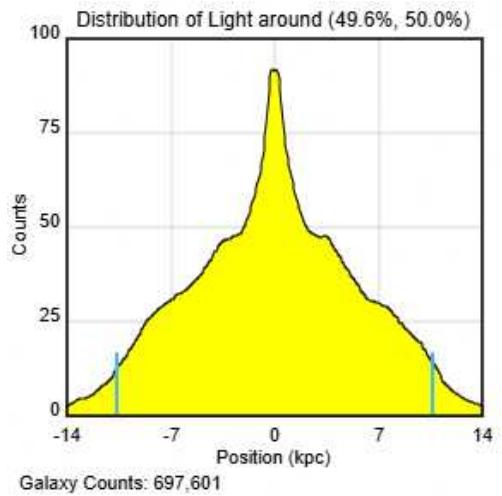


Figure 4: (b) Counts Graph for Galaxy #1

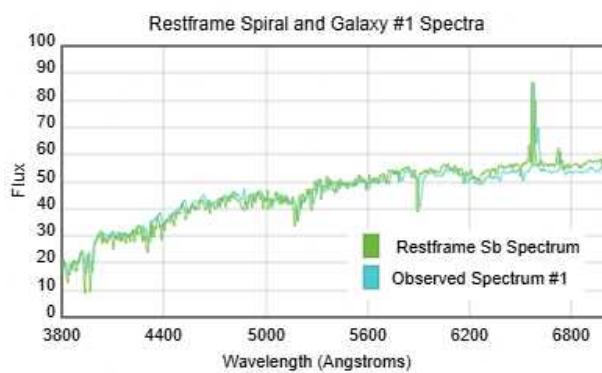


Figure 5: (c) Spectrum Analysis for Galaxy #1

1.4.2 Galaxy #2

1. This galaxy is far less luminous than our Milky Way. How many galaxies of this luminosity would you need to match the light output of the Milky Way? (1 point)
Answer: The Flux of this galaxy is 0.07 compared to that of the Milky Way. So, we would need $\frac{1}{0.07} \approx 14.3$ galaxies to match the light output of the Milky Way.
2. Notice how the light profile (the radial plot of counts) can be divided into an inner region and an outer region (with a change of slope between them). The names for the two galaxy components that these two regions represent are the bulge and the disc.
3. What do you think causes the patches of blue in the outer regions of this galaxy? (1 point)
Answer: The patches of blue are regions of concentrated star dust and gas, where new stars are forming. This is a sign of a young galaxy, which is still forming stars.

Galaxy #2 Comments:

The position angle of the galaxy is 43 degrees, and the axial ratio is 0.72. The flux of the galaxy is 0.07 of the Milky Way's which is very faint. The galaxy is a very young spiral galaxy, which is evident from its color being bluish, especially the spirals ($B-V=0.59$). The classification of this galaxy is Sc, having a dull bulge and from the spectrum. The asymmetry index is 29.1 % which is very high and expected from how it looks. The concentration index is 19.9 %, not that high, but expected for a spiral galaxy. There seems to be no bar in the center of the galaxy.

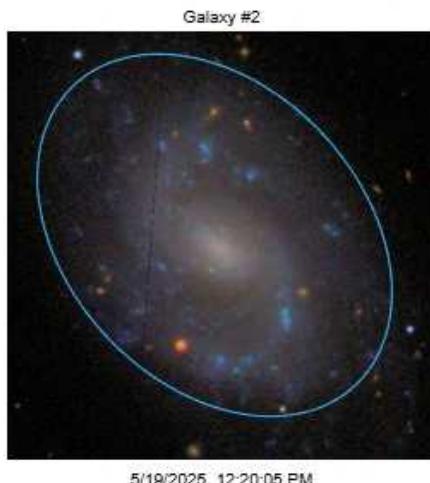


Figure 6: (a) Galaxy #2

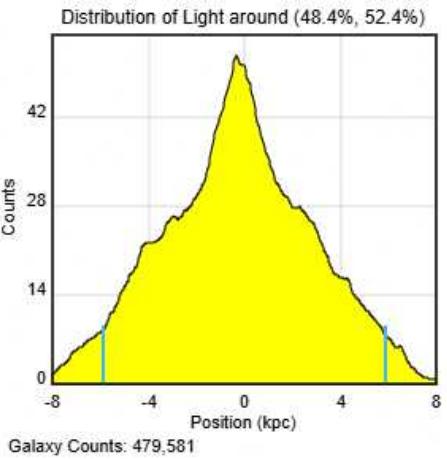


Figure 7: (b) Counts Graph for Galaxy #2

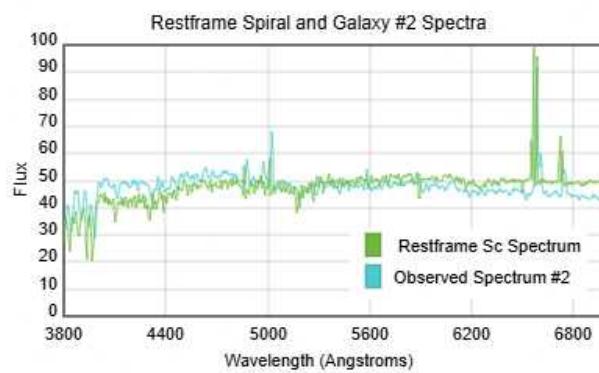


Figure 8: (c) Spectrum Analysis for Galaxy #2

1.4.3 Galaxy #3

1. Does this galaxy have a fairly uniform color? (yes / no)

Galaxy #3 Comments:

The color of the galaxy is very uniform, and the color is golden ($B-V=1.01$). The counts graph is very smooth (indicating that the distinction between bulge and disc is almost not there), and the galaxy is very symmetric. The position angle of the galaxy is -62 degrees, and the axial ratio is 0.70. The galaxy is an elliptical galaxy, and the classification is E3, which is evident from the spectrum. The asymmetry index is 10.7 % which is very low and expected from how it looks. The concentration index is 41.5 %, which is very high and expected from an elliptical galaxy. There is no bar in the center. The flux of the galaxy is 0.22 of the Milky Way's which is faint.

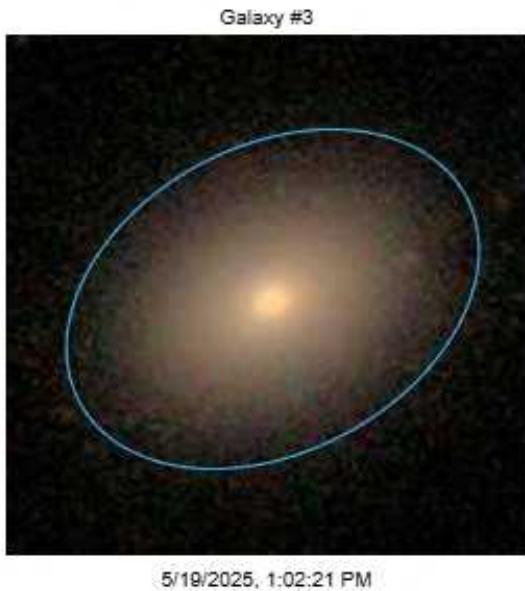


Figure 9: (a) Galaxy #3

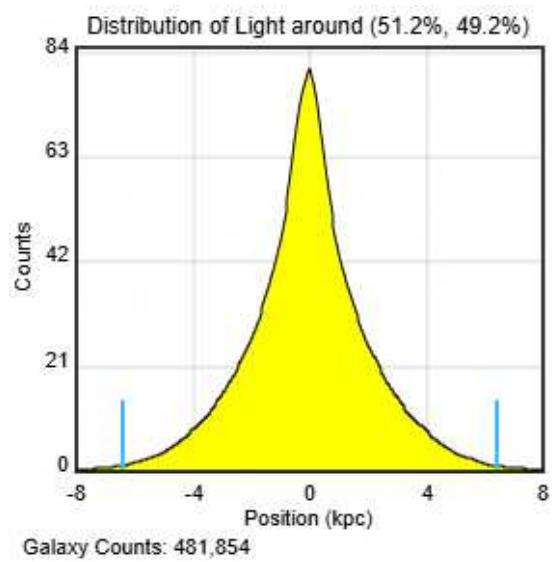


Figure 10: (b) Counts Graph for Galaxy #3

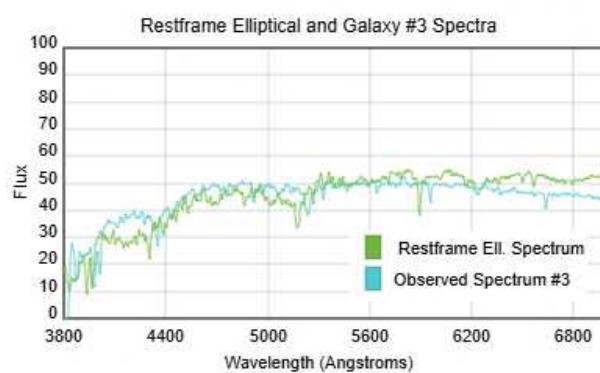


Figure 11: (c) Spectrum Analysis for Galaxy #3

1.4.4 Galaxy #4

1. Consider the total B-V color measured across the entire galaxy. What value do you find if you reduce the size of the ellipse to contain just the bright golden nucleus of the galaxy? What types of galaxies have this B-V color overall?

Answer: The B-V color of the entire galaxy is 0.80, and the B-V color of the nucleus is 1.45. The B-V color of the nucleus is similar to that of an elliptical galaxy. This indicates that the core is much older and doesn't contain many new stars, indicated by the redness of the core.

Galaxy #4 Comments:

The position angle of the galaxy is -67 degrees, and the axial ratio is 0.39. The flux of the galaxy is 1.09 of the Milky Way's which is relatively bright. The galaxy is a spiral galaxy, and it has blue spots in the spiral arms and a reddish core, indicating that new stars are forming in the spiral arms. The galaxy is classified as a Sb galaxy, which is evident from the spectrum. The asymmetry index is 24.4 % which is somewhat high and expected from how it looks. The concentration index is 23.9 %, which is high for a spiral galaxy. There is no bar in the center of the galaxy.

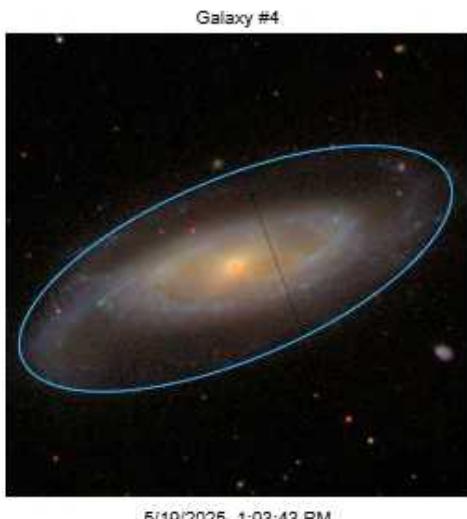


Figure 12: (a) Galaxy #4

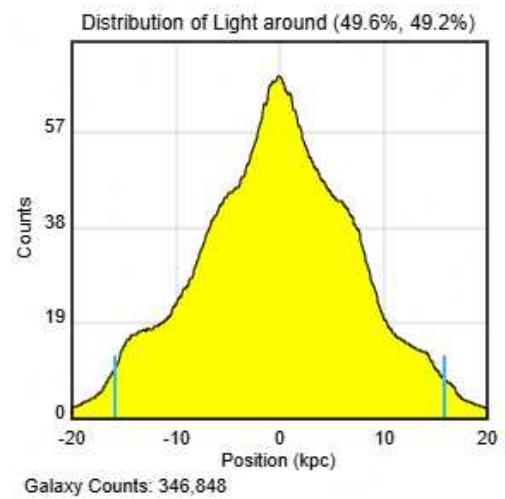


Figure 13: (b) Counts Graph for Galaxy #4

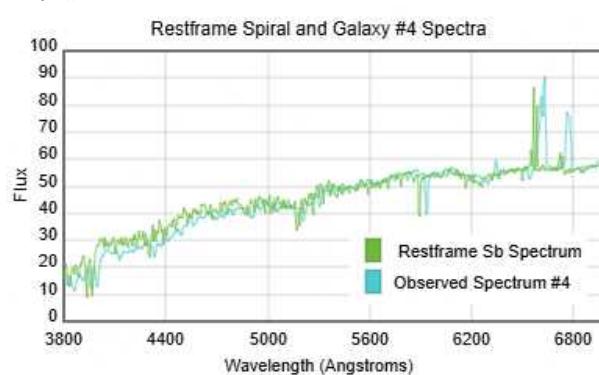


Figure 14: (c) Spectrum Analysis for Galaxy #4

1.4.5 Galaxy #5

- What do you think this object might have looked like a few billion years ago?

Answer: Two separate galaxies that later crashed into each other, and are now merging.

Galaxy #5 Comments:

Galaxy #5 is a peculiar galaxy, it seems to be a merger of two galaxies. The nuclei seem to have started to merge, and the galaxy is in the process of merging. The colors of the nuclei seem to be different, with the upper one being more golden and the lower one being more bluish. It seems like it's the product of a merger between two galaxies, one old and the other young. The position angle of the merger is 66 degrees, and the axial ratio is 0.38. The flux of the galaxy is 1.29 of the Milky Way's which is bright and expected, since it is in a violent process. The spectrum of the galaxy seems to contain the spectrum of an Sc indicating that at least one of the galaxies might have been a spiral galaxy. The asymmetry index is 66.8 % which is very high and expected from how it looks. The concentration index is 31.4 %, which is high as expected since most of the galaxy seems to be concentrated in the nuclei. It has a B-V = 0.48 which is the bluest of the 10 galaxies, this is probably since the violent crashing caused the formation of a lot of new stars. There is no bar visible in either of the nuclei.

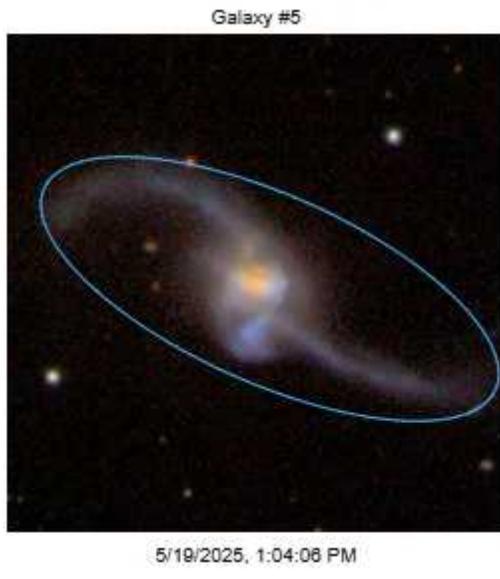


Figure 15: (a) Galaxy #5

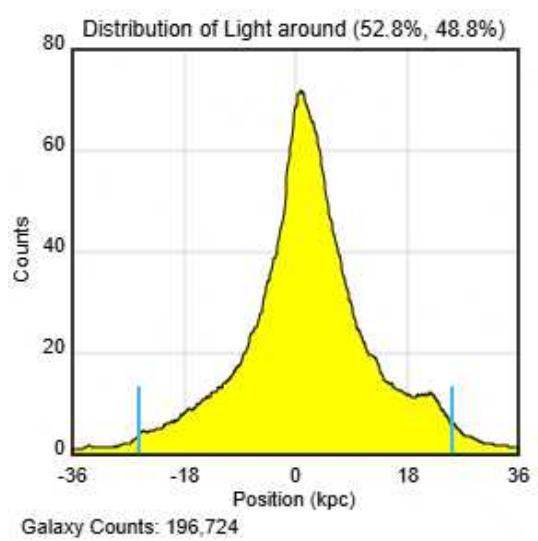


Figure 16: (b) Counts Graph for Galaxy #5

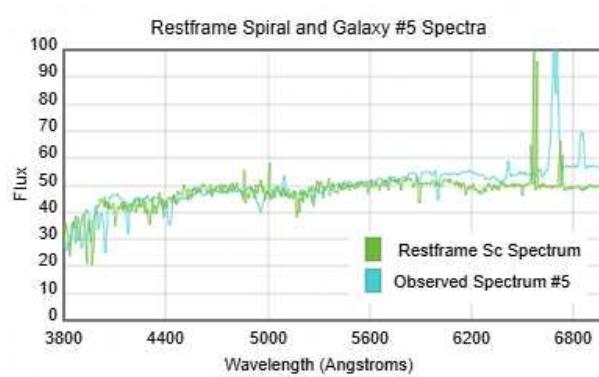


Figure 17: (c) Spectrum Analysis for Galaxy #5

1.4.6 Galaxy #6

1. Note the dark band running along this galaxy disk, and the bright splotch slightly offset from the center as defined by the rest of the galaxy. These factors will lead to a (higher / lower) asymmetry index.

Galaxy #6 Comments:

The position angle of the galaxy is 53 degrees, and the axial ratio is 0.15 (very edge on). The flux of the galaxy is 1.61 of the Milky Way's which is very bright. I assume this is due to the large size of the galaxy. The color is yellowish/reddish ($B-V=0.78$) implying it is an older galaxy. The asymmetry index is 32.1 % which is high and expected from how it looks, it being edge on and from the presence of the dust lane and the bright splotch mentioned above. The concentration index is 20.9 %, which is expected for a lenticular or elliptical galaxy. There is no bar in the center of the galaxy. The dark band running along the galaxy is a dust lane, which is common in spiral and lenticular galaxies. The bright splotch is a region of star formation, which is also common in spiral and lenticular galaxies. The galaxy has a well defined bulge and disc. These features indicate that the galaxy might be a spiral galaxy, but the spectrum indicates that it is an elliptical galaxy. The lack of a strong $H\alpha$ line is due to the dust lane, so the spectrum would actually fit better to an Sb spectrum, had the $H\alpha$ line not been obstructed (as explained again later in part II). Its classification is somewhat ambiguous, but I would classify it as an Sb (Spiral) galaxy.

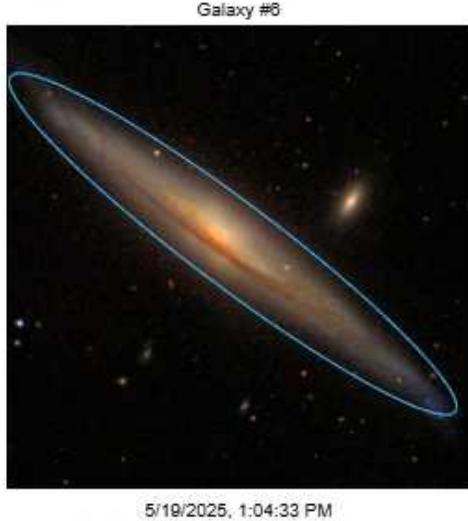


Figure 18: (a) Galaxy #6

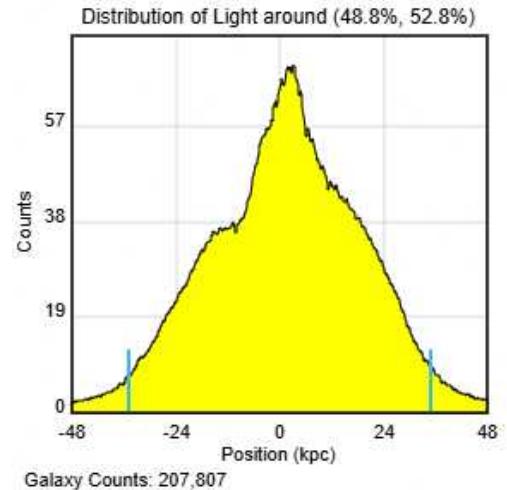


Figure 19: (b) Counts Graph for Galaxy #6

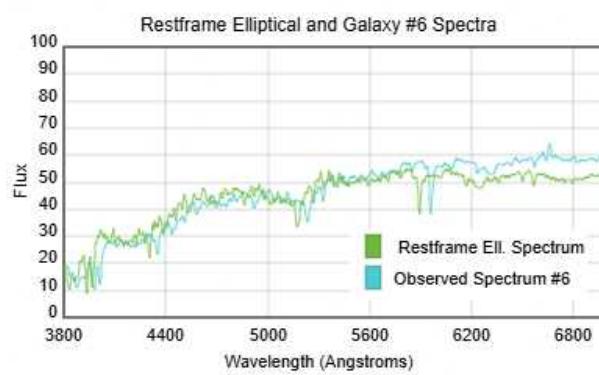


Figure 20: (c) Spectrum Analysis for Galaxy #6

1.4.7 Galaxy #7

- Does the edge-on orientation of this galaxy make it more difficult for us to calculate an asymmetry index and to define a morphological type?

Answer: Yes, the edge-on orientation makes it difficult to calculate the asymmetry index objectively, since there will be asymmetry just due to the orientation of the galaxy. The morphological type is also difficult to define, since the galaxy is edge-on, and we can't see the presence of spiral arms or the bulge clearly.

Galaxy #7 Comments:

The position angle of the galaxy is 38 degrees, and the axial ratio is 0.22 (edge on). The flux of the galaxy is 0.21 of the Milky Way's which is faint. The color is reddish ($B-V=0.73$) implying it is an older galaxy. The asymmetry index is 22.4 % which is high and expected from its axial ratio, it being edge on. The concentration index is 19.7 %. There is no bar in the center of the galaxy. The galaxy has a well defined bulge and disc. The galaxy is classified as an Sc (spiral) galaxy, which is evident from the spectrum.

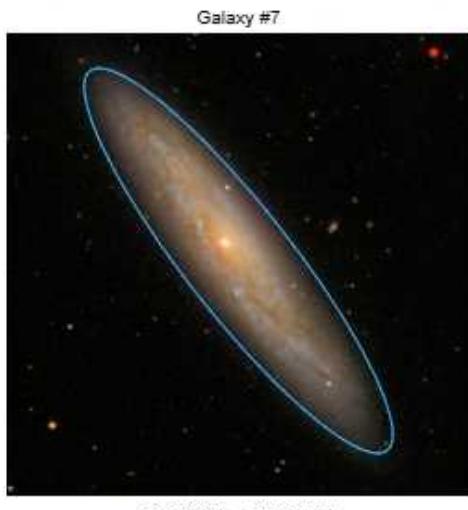


Figure 21: (a) Galaxy #7

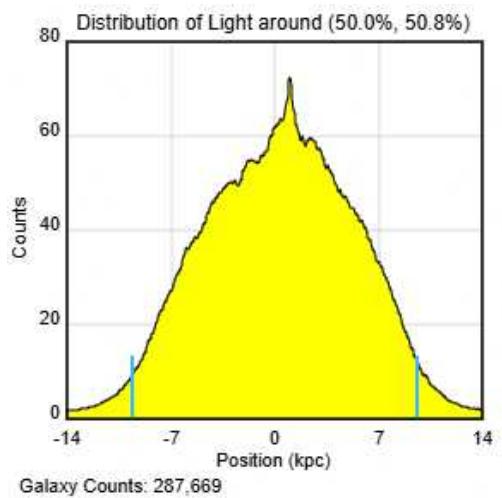


Figure 22: (b) Counts Graph for Galaxy #7

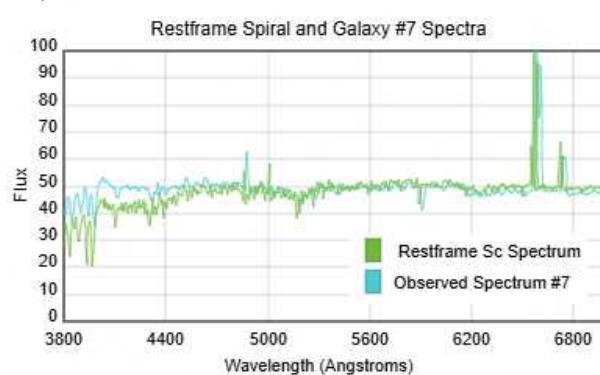


Figure 23: (c) Spectrum Analysis for Galaxy #7

1.4.8 Galaxy #8

1. A larger neighboring galaxy above our target scatters light across this entire image. Because of this, the (left / right) side of the radial profile is slightly higher than it should be.

Galaxy #8 Comments:

The position angle of the galaxy is 0 degrees, and the axial ratio is 0.37. The flux of the galaxy is 0.15 of the Milky Way's which is faint. The color is golden (B-V=1.24) implying it is a much older galaxy. The asymmetry index is 12.6 % which is high and expected from how it looks. The concentration index is 36.5 %, which is expected for an elliptical galaxy. There is no bar in the center of the galaxy. The galaxy is classified as an Elliptical (E6) galaxy, which is evident from the spectrum. The galaxy has a large neighbor above it, which is scattering light across the entire image. This is causing the left side of the radial profile to be slightly higher than it should be and generally distorting the features of the galaxy.



Figure 24: (a) Galaxy #8

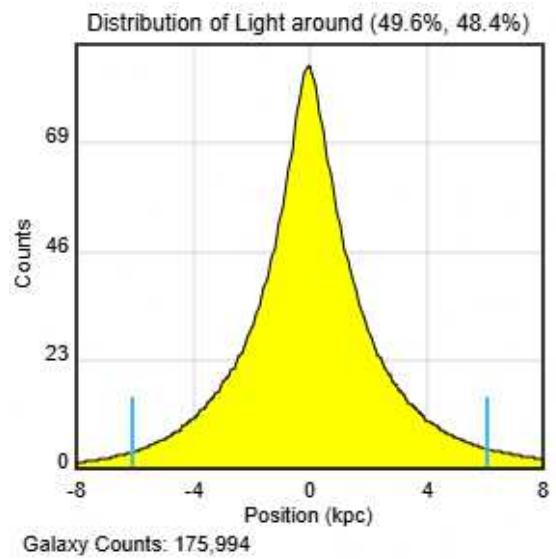


Figure 25: (b) Counts Graph for Galaxy #8

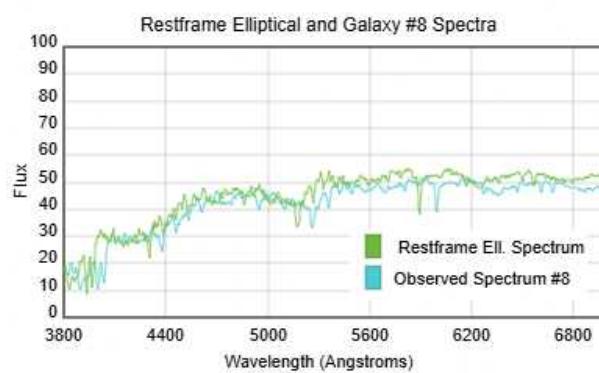


Figure 26: (c) Spectrum Analysis for Galaxy #8

1.4.9 Galaxy #9

Galaxy #9 Comments:

The position angle of the galaxy is 90 degrees, and the axial ratio is 0.38. The flux of the galaxy is 0.13 of the Milky Way's which is faint. The color is golden ($B-V=0.93$) implying it is an older galaxy and likely elliptical or lenticular. The asymmetry index is 14.2 % which is not that high and expected from the axial ratio. The concentration index is 29.0 %, which is expected for an elliptical or lenticular galaxy. There is no bar in the center of the galaxy. The counts graph is very smooth (indicating that the distinction between bulge and disc is almost not there), and the galaxy is very symmetric. The galaxy seems elliptical, but has some structure similar to that of a spiral galaxy. The galaxy is classified as a lenticular galaxy (S0), which is evident from the spectrum.

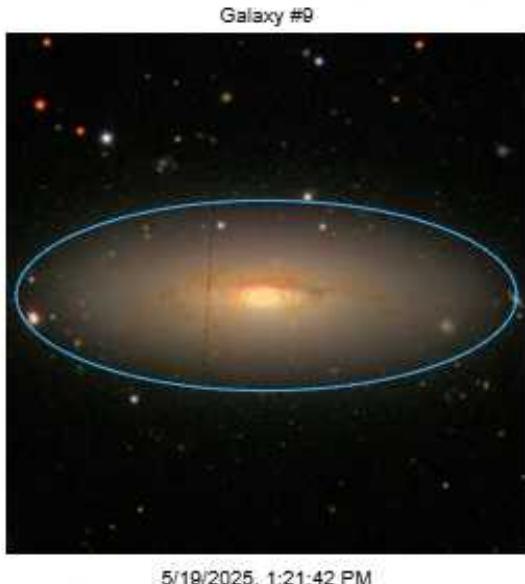


Figure 27: (a) Galaxy #9

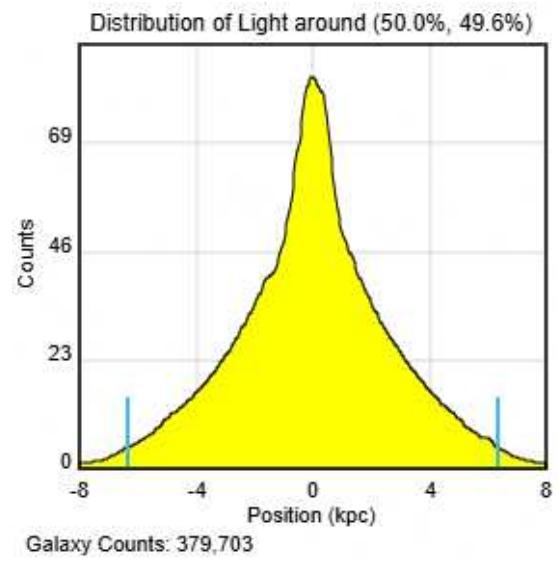


Figure 28: (b) Counts Graph for Galaxy #9

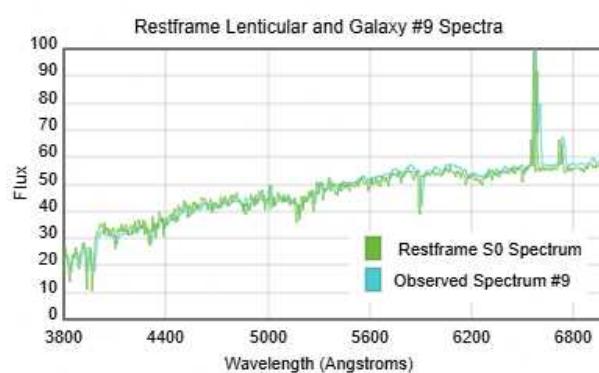


Figure 29: (c) Spectrum Analysis for Galaxy #9

1.4.10 Galaxy #10

Galaxy #10 Comments:

The position angle of the galaxy is -35 degrees, and the axial ratio is 0.66. The flux of the galaxy is 0.28 of the Milky Way's which is faint. The color is very bluish ($B-V=0.48$) implying it is a younger galaxy. The asymmetry index is 32.6 % which is high and expected from the shape of the galaxy and the spiral arms. The concentration index is 21.3 %. There is no visible bar in the center of the galaxy. The galaxy is classified as spiral (Sd), which is evident from the spectrum. The galaxy has a well defined bulge and disc. The galaxy has a very well defined spiral arm structure.

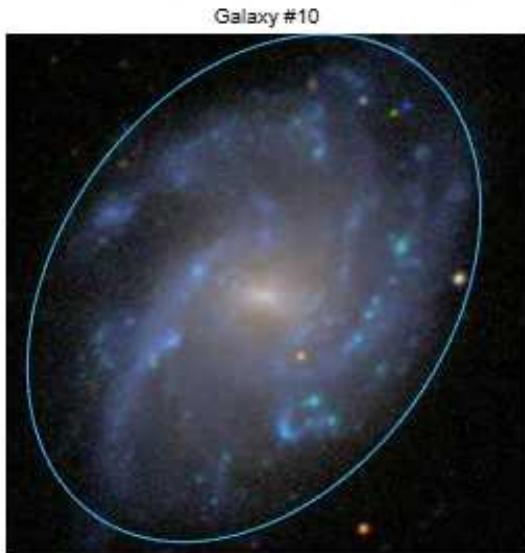


Figure 30: (a) Galaxy #10

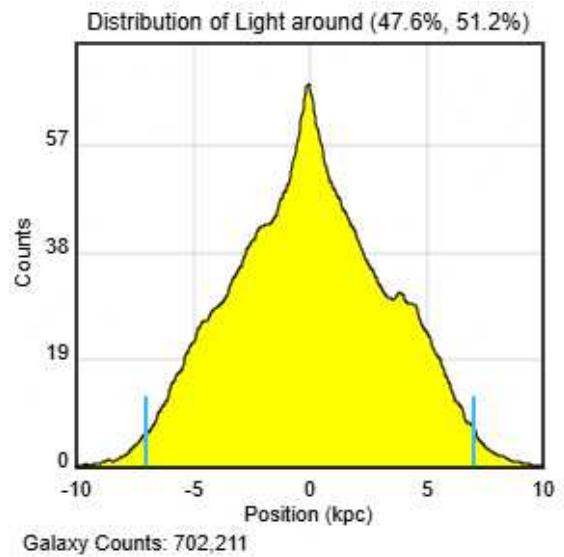


Figure 31: (b) Counts Graph for Galaxy #10

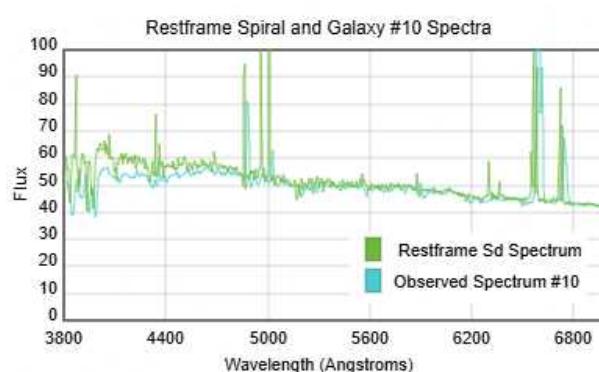


Figure 32: (c) Spectrum Analysis for Galaxy #10

Question: Which of the ten galaxies posed the largest challenge to fit? Which was the easiest to analyze? Explain your choices.

Answer: The galaxy that posed the largest challenge to fit was Galaxy #8, since it is barely visible due to the large neighbor above it, which is scattering light across the entire image. Galaxy #5 was also difficult to analyze, since it is a merger and has two nuclei, which makes it difficult to analyze the galaxy as a whole. The easiest galaxies to analyze were numbers 1, 2, 4, and 10 since they were largely head on and their features were very clear.

The following table summarizes the properties of the ten galaxies analyzed in this experiment:

Galaxy Image Properties								
#	Pos Ang. (deg.)	Axial Ratio	Size (kpc)	Flux (MW)	Color (B-V)	C.I. (%)	A.I. (%)	Type
1	16	0.63	10.6	0.59	0.72	19.8	13.8	Sb
2	43	0.72	5.9	0.07	0.59	19.9	29.1	Sc
3	-62	0.70	6.4	0.22	1.01	41.5	10.7	E3
4	-67	0.39	15.9	1.09	0.80	23.9	24.4	Sb
5	66	0.38	25.2	1.29	0.47	31.4	66.8	Sc
6	53	0.15	34.8	1.61	0.78	20.9	32.1	E9
7	38	0.22	9.6	0.21	0.73	19.7	22.4	Sc
8	0	0.37	6.1	0.15	1.24	36.5	12.6	E6
9	90	0.38	6.4	0.13	0.93	29.0	14.2	S0
10	-35	0.71	7.0	0.29	0.50	21.3	32.6	Sd

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Figure 33: Table of Galaxy Properties

2 Experiment (XVI): Galactic Spectra as a Probing Tool for Galactic Types and Velocities.

The following table summarizes galactic spectra and their properties:

Galaxy Spectrum Properties				
#	Vel. (km/sec)	Dist. (mpc)	Corr. (%)	Type
1	800	11.1	98.6	Sb
2	800	11.1	66.8	Sc
3	3300	45.4	91.5	Ell.
4	2050	28.4	98.1	Sa
5	5600	76.4	87.3	S0
6	3350	46.1	98.5	Sb
7	800	11.1	79.0	Sc
8	5100	69.7	99.6	Ell.
9	650	9.1	97.9	S0
10	1200	16.7	60.4	Sd

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Figure 34: Galactic Spectra Properties Summary

2.1 Galaxy #1

- The presence of which very strong emission line in this spectrum rules out the 'E' (for elliptical) morphological class?
Answer: The presence of the H α emission line rules out the Elliptical morphological class.
- Is it the presence or absence of key absorption or emission lines, or the poorly fitting shape of the continuum (the overall shape of the spectrum, ignoring emission and absorption features) which rules out the Sc, Sd, and interacting galaxy types?
Answer: The poorly fitting shape of the continuum rules out the Sc, Sd, and interacting galaxy types.
- Describe the general pattern formed by the galaxy spectrum and the type-specific spectra when the correlation coefficient drops below 0 (-3.1%). For which galaxy types does this occur, for this galaxy?
Answer: The pattern formed is an X-shape, where the underlying spectrum is rising and the underlying type-specific spectrum is falling. This occurs for the Int type as shown in figure 34.

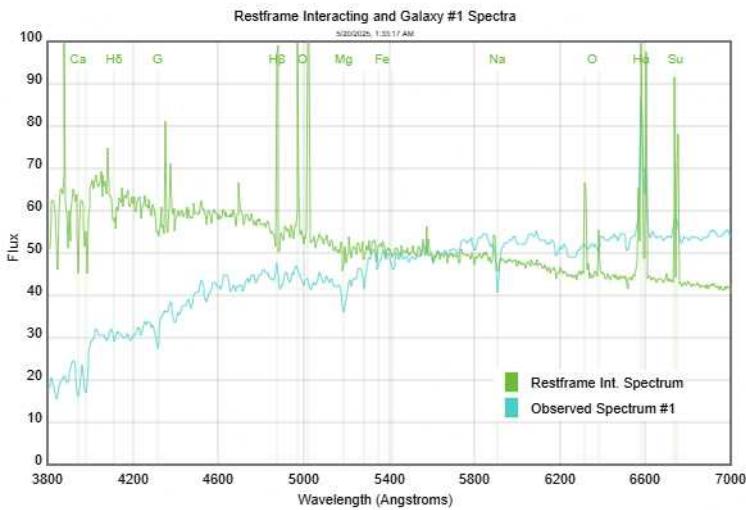


Figure 35: Figure 34: Correlation Coefficient for Galaxy #1

- What morphological type yields the second-highest correlation coefficient? Can you point to a feature shown in the accompanying galaxy image which also suggests that this is not the correct type? Answer: The morphological type that yields the second-highest correlation coefficient is the S0 type. The feature that suggests that this is not the correct type is the strength of the H α emission line, it would be much stronger in an S0 galaxy.

Galaxy #1 Comments:

The recessional velocity of the galaxy that gives the highest correlation coefficient is 800 km/s. Indicating a distance of 11.1 MPC. The maximum correlation coefficient is 98.6%, which is very good. The galactic type that fits the spectrum best is the Sb type.

2.2 Galaxy #2

1. More distant galaxies appear (smaller / larger) on the images, and their observed spectra are shifted to the (left / right) to (shorter / longer) wavelengths.
2. If we took a second spectrum of this galaxy and sampled a small region near the galaxy edge rather than the nucleus, how would you expect the spectrum to change? The (absorption / emission) lines would become much stronger, indicating (increased / decreased) star formation in this region of the galaxy.

Galaxy #2 Comments:

The recessional velocity of the galaxy that gives the highest correlation coefficient is 800 km/s. Indicating a distance of 11.1 MPC. The maximum correlation coefficient is 66.8%, which is not very good, but is the best achievable with the types given. The galactic type that fits the spectrum best is the Sc type, but the correlation is not that good due to the galaxy having a much weaker H α line than expected for an Sc galaxy.

2.3 Galaxy #3

1. The redshift measured for this galaxy confirms that it appears so small in the image because it is (very far away / an intrinsically small galaxy).

Galaxy #3 Comments:

The recessional velocity of the galaxy that gives the highest correlation coefficient is 3300 km/s. Indicating a distance of 45.4 MPC. The maximum correlation coefficient is 91.5%, which is very good. The galactic type that fits the spectrum best is the Elliptic type. The galaxy is very small, and the redshift confirms that is because it is very far away (45.4 MPc).

2.4 Galaxy #4

We observe both strong emission features (H α and the longer wavelength sulfur line) and strong absorption features (sodium, the calcium doublet at 3950Å) in this spectrum.

Galaxy #4 Comments:

The recessional velocity of the galaxy that gives the highest correlation coefficient is 2050 km/s. Indicating a distance of 28.4 MPC. The maximum correlation coefficient is 98.1% for the galaxy type Sa, however there is also a very good fit for the Sb type with a correlation coefficient of 97.8% and for the S0 type with a correlation coefficient of 97.4%. This indicates that the best galaxy specification is most probably an Sab galaxy.

2.5 Galaxy #5

1. This galaxy was very easy to type based on its image, but should give us a different answer based on its core spectra alone. Why is this the case?

Answer: The galaxy is a merger of two galaxies, and the spectrum seen is the combination of the two spectra.

Galaxy #5 Comments:

The recessional velocity of the galaxy that gives the highest correlation coefficient is 5600 km/s. Indicating a distance of 76.4 MPC. The higher wavelength lines give very good agreement with the S0 type, but the lower wavelength lines give a very good agreement with the Sc type, suggesting that these may have been the two types of the galaxies that are merging. The maximum correlation coefficient is 87.3% for the galaxy type S0, however there is also a very good fit for the Sc type with a correlation coefficient of 73.0%.

2.6 Galaxy #6

Galaxy #6 Comments:

The recessional velocity of the galaxy that gives the highest correlation coefficient is 3350 km/s. Indicating a distance of 46.1 MPC. The maximum correlation coefficient is 98.5% for the galaxy type Sb, however it lacks the strong H α emission line, which is expected for a galaxy of this type giving a good correlation coefficient also with Elliptical type (97.6%). However, the color and shape strongly suggest that it is a spiral galaxy. The galaxy is classified as an Sb galaxy, and the lack of the strong H α emission line is expected to be due to the dust lane running across the galaxy, and for the galaxy being edge on.

2.7 Galaxy #7

1. Many galaxies of this morphological type have (bluer / redder) disks.

Galaxy #7 Comments:

The recessional velocity of the galaxy that gives the highest correlation coefficient is 800 km/s. Indicating a distance of 11.1 MPC. The maximum correlation coefficient is 79% for the galaxy type Sc, even though its color is redder than expected for a galaxy of this type.

2.8 Galaxy #8

1. Are both of the galaxies in this image of the same type? (yes / no)

Galaxy #8 Comments:

The recessional velocity of the galaxy that gives the highest correlation coefficient is 5100 km/s. Indicating a distance of 69.7 MPC. The maximum correlation coefficient is 99.6% for the galaxy type Elliptical, which is easily expected from the image.

2.9 Galaxy #9

Galaxy #9 Comments:

The recessional velocity of the galaxy that gives the highest correlation coefficient is 650 km/s. Indicating a distance of 9.1 MPC. The maximum correlation coefficient is 97.9% for the galaxy type Lenticular (S0), as expected from the image.

2.10 Galaxy #10

1. Can you identify a single feature which is very strong in this observed spectrum but much weaker in the reference spectrum for this type of galaxy? How would you expect this to affect the correlation coefficient?

Answer: The H α emission line is very strong in this observed spectrum, and much weaker in the reference spectrum for this type of galaxy. This would decrease the correlation coefficient, since the reference spectrum would not match the observed spectrum as well.

Galaxy #10 Comments:

The recessional velocity of the galaxy that gives the highest correlation coefficient is 1200 km/s. Indicating a distance of 16.7 MPC. The maximum correlation coefficient is 60.4% for the galaxy type Sd. This is the type we expected from the image, however the corellation os very weak. Since Sd galaxies are much younger and very active, their spectrum is largely variable, and the reference spectrum is not a good match for the observed spectrum. The H α emission line is very strong in this observed spectrum, and much weaker in the reference spectrum for this type of galaxy.

2.11 Final Review:

Which of the ten galaxies posed the largest challenges in determining redshifts? Which was the easiest to fit? Explain your choices.

Answer: The galaxy that posed the largest challenge in determining redshifts was Galaxies #2, #5, and #10. These were the galaxies that had the most ambiguous spectra (weak correlation for all types), and the ones that were the most difficult to classify. Also, galaxy #5 was difficult to classify since it is a merger of two galaxies, and the spectrum is a combination of the two spectra. The easiest galaxies to fit were #1, #8, and #9. These galaxies had very good correlation coefficients and were very easy to classify. The spectra of these galaxies were very clear and easy to analyze.

3 *Bonus Part*

- Given what you now know, describe how you grouped galaxies together initially. (To which galaxy properties were you most sensitive?)

Answer: We focused on general structure (unstructures, merging, regular galaxy). Then we focused on the color of the galaxy, and the visual presence of spiral arms. We however might have ignored the presence of some spiral arms due to them being edge on.

- If you were to resort these galaxies now, what would you change? Are there aspects which you emphasized which you now think are unimportant? Are there properties which you dismissed which now seem more important, in view of what you have learned?

Answer: We emphasized them being edge on or not, and somewhat ignored the tightness of the spiral arms. We would resort by focusing on sorting them into their morphological types.

- What are the basic observed properties of elliptical galaxies, in images and in spectra? What does this tell us about the distribution of stars and gas in these galaxies?

Answer: Elliptical galaxies are very smooth and have no structure. They have a very golden color, and their spectra are very smooth. This indicates that they are very old galaxies, and that they have no gas or dust. The stars in these galaxies are very old, and there is no star formation. The stars are very uniformly distributed, and there seems to be little to no gas.

- What are the basic observed properties of spiral galaxies, in images and in spectra? What does this tell us about the distribution of stars and gas in these galaxies?

Answer: Spiral galaxies have a very well defined structure, with spiral arms and a bulge. They usually have bluish spots on their spiral arms. Their spectra have a bump that distinguishes between the disc and the bulge. This indicates that they are young galaxies (relative to ellipticals). The stars are not uniformly distributed, the stars are concentrated in the spiral arms, and there is a lot of gas and dust in the spiral arms, hence a lot of star formation.

- Which of the ten galaxies in our sample is the best match to the Milky Way galaxy, and why?

Answer: Galaxy #4 is the best match to the Milky Way galaxy, since both are spiral galaxies and it has a well defined bulge and disc, and it has a lot of star formation in the spiral arms. The color is also similar to that of the Milky Way, and the spectrum is also similar. The galaxy is classified as an Sa galaxy, while Milky Way is Sbc (still somewhat close). However, the Milky way has a bar, while this galaxy does not.

- Compare your derived morphological types based first on images and then from spectra for the ten sampled galaxies. For which galaxies did you estimate different morphological types from the image and from the spectrum? Where your type estimates differed, did they differ by one step (Sb versus Sc), or by several steps (E versus interacting)?

Answer: The galaxies that I estimated different morphological types from the image and from the spectrum were galaxies #4, and #5. Galaxy #4 was classified as an Sb galaxy from the image, but as an Sa galaxy from the spectrum, so only one step not a big difference. However, we landed on labeling it as an Sab galaxy, as both types were very close. Galaxy #5 the merger, only one of the galaxies was

classified as an Sc galaxy from the image, but the spectrum was a combination of the two galaxies, so it was classified as being a merger of and Sc and S0 galaxies.

7. Consider the galaxies for which you found the greatest disagreement between image-based types and spectrum-based types. Discuss the cause(s) of the differences, and explain which type classification you think is the most accurate in each case.

Answer: The galaxy for which I found the greatest disagreement between image-based types and spectrum-based types was galaxy #5. The cause of the differences is that during a merger, it is very difficult to classify the galaxy using the images. So the spectrum classification seems to be much more accurate.