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The Role of Stellar Mass in Shaping Galaxy Morphology: A Data Science Approach

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Abstract: ***This study is an investigation of the relationship between the stellar mass of galaxies and their morphological classification (the shape of the galaxy). Understanding this relationship provides insight on the mechanisms behind galaxy formation and evolution. The main objective of this research paper to analyse in what ways, if any, do variations in mass of galaxies influence their classification – focusing on key morphological characteristics such as spiral and elliptical structures. Utilizing astronomical data from several official large-scale galaxy surveys, correlations between stellar mass and certain morphological features are identified. By leveraging data science approaches such as machine learning techniques and statistical methods, this study aims to uncover patterns and trends that can enhance our understanding of galaxy morphology, an important factor determining several features of a galaxy such as its age, population, interactions with other galaxies and more. Preliminary results indicate a strong correlation between higher stellar mass and the definition of galaxy structures, suggesting that stellar mass does play a role in shaping a galaxy. Not only do these findings offer new insights on the mechanisms that drive evolution of galaxies, but also provide a foundation for future research utilizing advanced data science approaches.***

Keywords: Stellar Mass, Galaxy Morphology, Descriptive Statistics, Correlation Analysis

1. Introduction

The universe can be defined as an ever-expanding vastness of nothing but matter and energy. It is a dynamic and intricate system - a boundless expanse of everything we know. Among the countless celestial bodies, it is filled with, there are galaxies – some of the most fundamental structures that shape the cosmos, and home to everything from stars to planetary systems. Galaxies differ from each other – from the spirals of the milky way to the smoother and elliptical forms of older galaxies – they exhibit a variety of shapes, sizes and structures (morphology). One of the most significant reasons to this variation in morphology is stellar mass, which is central to not just galaxy luminosity and force of gravitation but also influences its shape, and hence evolution.

Stellar mass (denoted as M⊙) refers to the amount of matter that a star or galaxy contains, typically measured in terms of mass of the sun. Mass of a galaxy impacts the way the galaxy distributed its matter (Newton's law of gravitation), star formation rate as well as interaction with other galaxies. Since high stellar mass corresponds to a more active star formation rate, understanding the relationship between the mass of the galaxy and its morphological classification gives us information into the evolution of galaxies and how they change over billions of years. An understanding of this relationship does not just lead to more theoretical knowledge. It has practical implications for astrophysics, helping scientists refine models of galaxy formation, predict future galaxy behaviour, and understand the distribution of dark matter in the universe, all just by the morphology of the galaxy. The connection between stellar mass and morphology is vital for improving the accuracy of galaxy classification systems.

By applying techniques of data science to large galaxy datasets, this work investigates whether high stellar mass correlates with certain morphological traits such as ellipticity or spirality of a galaxy, guiding the question:
How does the stellar mass of a galaxy influence its morphological classification?

2. Approach

A sample of galaxies with varying stellar masses will be analysed. Data will be utilized from existing astronomical surveys to categorize galaxies based on their morphological features (ellipticity, spirality, irregularity). Statistical analysis will be performed to assess whether there is a significant relationship between higher/lower stellar masses and specific morphological features. The research will take into account potential influencing factors such as star formation rates in order to provide a comprehensive understanding of how stellar mass influences a galaxy's shape.

3. Literature Review

The study of galaxy morphology and impact of factors such as stellar mass on it is a topic extensively covered in the field of astronomy.

Table 1: Literature Review

Study	Summary	Information Gained
Peng et al. (2010)	Peng et al. conducted a study involving stellar mass and star formation rates. The study analysed the mass growth of galaxies over long periods of time. A correlation was found between stellar mass and galaxy morphology; that more massive galaxies, containing more stars, the more elliptical a galaxy is. The study suggested that "stellar mass quenching" -> the process in which a rate of star	Limitations on Data Modelling and extensive use of qualitative data encourage me to use more advanced data science techniques and rely more on quantitative data.

	formation ceases massive galaxies played a critical role in evolution of these galaxies.	
Conselice (2014)	The study provided valuable insights on the correlation between stellar mass and galaxy morphology as well. This study emphasized the importance of galaxy morphology in understanding the history of the cosmos. This study classified the shapes of galaxies structurally, based on asymmetry, concentration, heavy and clumpy-ness. Conselice found out that galaxies with lower mass have a tendency of displaying irregular morphologies, whereas higher mass galaxies tend to have more defined, elliptical shapes.	The structural classifications of galaxies and the finding that higher-mass galaxies tend to be elliptical are highly relevant to my investigation.
Blanton & Moustakas (2009)	Over various different time period in the history of the cosmos (cosmic epochs), Blanton and Moustakas explored the relationship between stellar mass, galaxy morphology as well as star formation rate. They showed that the shape of a galaxy varies greatly with different masses as well as different environments. They pointed out that galaxies with higher mass (particularly elliptical and lenticular) tend to have older stellar populations and are commonly found in dense environments such as galaxy clusters	This study supports my use of SDSS data for stellar mass and morphology research. It encourages me to apply more sophisticated data science techniques to capture nuances in galaxy morphology.

3.1 Gap in the Literature

Generally, previous research has shown that there is a relationship between star mass and galaxy morphology. What makes my study different is that it will deep dive into the subject by using modern data science techniques, such as machine learning. Unlike other studies that rely on observational correlations, I will quantify the influence of stellar mass more precisely using models of data science. This in turn may allow for a more nuanced understanding of the role played by stellar masses in shaping galaxies' evolution. The findings could potentially refine existing models of galaxy formation and provide a more detailed framework for classifying galaxies based on their stellar mass.

4. Experimental Overview

The relationship between stellar mass and galaxy morphology will be determined through a series of steps. To begin with, data will be extracted from official astronomical databases available on the internet, such as the Sloan Digital Sky Survey (SDSS). A standard data cleaning process will be followed to ensure accuracy and consistency among the data. Furthermore, the data would be classified in a tabular format. Descriptive statistics such as mean, median and mode of the stellar mass would be calculated to summarise the stellar mass distributions across morphological types. The data would be effectively be visualised as well, through the use scatter plots, in order to clearly understand the correlation between the variables in play. The relationship will be quantified using correlation analysis methods. In summary, the findings will provide insights on how the mass of a galaxy influences its morphological classification.

5. Background Theory

5.1 Galaxy Morphology

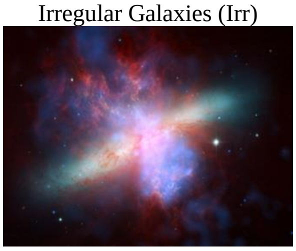
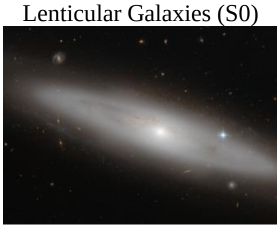
"Galaxy" is a name given to massive systems existing in the universe composed of stars, dust and gas – bound together by the force of gravity. **Galaxy Morphology** is the study of the structure and shape of galaxies.

The primary goal of the morphological classification of galaxies is to understand how galaxies form and evolve. It includes analysing the qualities and quantities of the various components making up a galaxy, as well as properties of galaxies such as its brightness, arrangement of their components and size. Through the observation of distribution of different types of galaxies (spiral galaxies with active star formation vs elliptical galaxies with comparatively little active star formation for example), astronomers can interpret how and when these galaxies formed and matured. Scientists can also develop an understanding in newer topics with unestablished relationships such as dark matter by the study of galaxy morphology. This is because dark matter plays a crucial role in determining a galaxy's shape. By studying the shape of galaxies, along with its motion, scientists can infer the distribution of dark matter.

Although the study of galaxy morphology may seem a topic much distant from real life, it actually has indirect impacts on our everyday lives, and how the world around us works. Research on galaxy morphology has driven development of new imaging and data processing technologies, leading to innovations in fields such as imaging technology, data storage, processing algorithms and machine learning. Such technologies benefit in fields like medical imaging, satellite imaging as well as security surveillance.

The classification of galaxies based on their morphology has been a central aspect of astronomy since the early 20th century, when Edwin Hubble developed the Hubble Sequence, often referred to as the Hubble Tuning Fork diagram.

Table 2: Hubble's Classification of Galaxies

Galaxy Type	Description
Spiral Galaxies (S)  Figure 1: Image of Spiral Galaxy	Spiral galaxies are large systems that rotate, and are characterized by rotating system characterized by a flat, disk-like structure with prominent spiral arms radiating from a central bulge; The arms, containing young, bright and blue stars, are rich in gas and dust and are fuelling ongoing star formation and giving the galaxy its characteristic "spiral" appearance. The central bulge is typically made up of older, redder stars and sits at the galaxy's core and is surrounded by a halo of older stars and globular clusters.
Barred Spiral Galaxies (SB)  Figure 2: Image of Barred Spiral Galaxy	Type of spiral galaxy distinguished by a central bar-shaped structure composed of stars, which extends across its core and connects to the spiral arms that radiate outward from the ends of the bar; This bar feature is thought to channel gas from the outer regions toward the galaxy's core, often fuelling active star formation and sometimes even enhancing the growth of a central supermassive black hole. The bar structure itself plays a key role in the galaxy's dynamics, possibly emerging from instabilities in the disk over time. Barred spiral galaxies, like our own Milky Way, are found in a variety of environments and are believed to evolve differently from their regular spiral counterparts due to the presence of the bar, which significantly influences their internal structure and star formation patterns.
Elliptical Galaxies  Figure 3: Image of Elliptical Galaxy	These galaxies can be identified by their smooth ellipsoidal shape and their lacking distinctive disks and spiral arms that are found in the spiral galaxies. Their structure is typically round or oval, appearing featureless and uniform, which gives them a smooth, symmetric appearance. These galaxies are composed mostly of older, red stars, with little to no gas or dust, leading to minimal or no new star formation. This makes them appear redder and more homogeneous compared to other galaxy types.
Irregular Galaxies (Irr)  Figure 4: Irregular Galaxy	Galaxies that lack a defined shape, structure, or symmetry, setting them apart from the more orderly elliptical and spiral galaxies. These galaxies do not fit into the standard categories of the Hubble Sequence because they have chaotic, disorganized appearances with no central bulge or spiral arms. Irregular galaxies are often rich in gas and dust, making them active sites for star formation and causing them to appear bright and blue due to the presence of young, hot stars.
Lenticular Galaxies (S0)  Figure 4: Image of Lenticular Galaxy	Type of galaxy that exhibits features intermediate between elliptical and spiral galaxies. They have a disk-like structure similar to spiral galaxies but lack the distinctive spiral arms. Lenticular galaxies have a central bulge surrounded by a flattened disk, giving them a smooth, lens-like appearance (hence the name "lenticular"). However, unlike spiral galaxies, they contain very little gas and dust, resulting in minimal or no new star formation and an older, redder stellar population similar to that of elliptical galaxies.
Peculiar Galaxies  Figure 5: Image of Peculiar Galaxy	Galaxies with unusual or irregular features that set them apart from the standard categories of elliptical, spiral, or lenticular galaxies. They often exhibit strange shapes, disrupted structures, or atypical characteristics that result from external influences, such as gravitational interactions, mergers, or tidal forces from nearby galaxies. Peculiar galaxies are frequently chaotic in appearance, with asymmetrical forms, extended tails, warped disks, and other unique features created by these interactions.

5.2 Stellar Mass

Stellar Mass refers to the sum of the masses of all the stars within a galaxy. Stellar mass plays a huge role in defining a galaxy's morphology. Stellar mass is determined by the amount of gas that is available during the formation period of the galaxy. More the available gas, higher the mass of the galaxy. Additionally, the galaxy' mass determines the gravitational potential of the galaxy, and thus, its ability to bind stars, gas and even dark matter.

Methods to Calculate Stellar Mass

1) Direct Observation:
2) Luminosity to Mass Ratio
3) Stellar Population Synthesis Model

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Relationship between Stellar Mass and Galaxy Morphology: Higher stellar mass typically translates into more stable and structured galaxy shapes, according to the relationship between stellar mass and galaxy morphology. Because there is less gas available for new star formation, massive galaxies typically have elliptical shapes, smooth, rounded surfaces, and older stars. Because they have enough gas left over for continuous star formation, intermediate-mass galaxies frequently have a spiral shape with distinct spiral arms and a mixture of young and old stars. Because of their weaker gravitational pull, low-mass galaxies tend to be less organized and appear irregular, which hinders their capacity to retain gas and take on a stable shape. As a result, a galaxy's appearance and classification are greatly influenced by its stellar mass.

5.3 Descriptive Statistics

Descriptive statistics will help summarise the key features of my data set of stellar mass and galaxy morphology

1) Mean, median, mode: Indicate the central/most typical values in the dataset: will show whether most galaxies are high/low in mass

$$Mean = \sum_{i=1}^{n} x_i \quad (1)$$

Where x_i is each value of the data set and n is the total no. of values
Median:
If n is an odd value, median value is at position $\frac{n+1}{2}$ (2)
If n is an even value, median value is the average of 2 middle values at position $\frac{n}{2}$ and $\frac{n}{2}+1$ (3)
Mode = most frequently occurring value

2) Range, Standard Deviation, Variance: Reveal the spread or variability in stellar mass across galaxies -> shows how diverse the sample is

$$Range = Maximum\ Value - Minimum\ Value \quad (4)$$

$$Standard\ Deviation\ (s) = \sqrt{\frac{\sum_{i=1}^{n}(x_i - x)^2}{n-1}} \quad (5)$$

Where s is the sample standard deviation, x is the sample mean and n is total number of values in the sample

$$Variance\ (s^2) = \frac{\sum_{i=1}^{n}(x_i - x)^2}{n-1} \quad (6)$$

Where s^2 is sample variance (square of standard deviation)

3) Skewness: Shows shape of the distribution; tells whether certain shapes of galaxies are associated with certain mass ranges

$$g_1 = \frac{n}{(n-1)(n-2)} \frac{\sum_{i=1}^{n}(x_i - x)^3}{s^3} \quad (7)$$

Where g_1 is skewness of the data set
If skewness > 0 -> distribution is positively skewed
If skewness = 0 -> distribution is symmetrical
If skewness < 0 -> distribution is negatively skewed

Correlation analysis allows the assessment of the strength and direction of the relationship between stellar mass and galaxy morphology.

- Using Spearman's correlation coefficient, it can be determined whether an increase in stellar mass is associated with a specific change in galaxy morphology
- Positive, negative or no correlation will determine if relationship between stellar mass and galaxy morphology is meaningful

Spearman's correlation coefficient is more suitable for this research as morphological classification is done categorically rather than continuous numerical values, so spearman's method would allow me to measure the strength and direction of association based on ranks rather than raw values.

$$p = 1 - \frac{6\sum d_i^2}{n(n^2-1)} \quad (8)$$

where p is spearman's correlation coefficient, n is the number of data points and d_i is the difference between ranks of each pair of observations

If the data turns out to be continuous, Pearson's correlation coefficient can be used instead of Spearman's.

$$r = \frac{\sum_{i=1}^{n}(x_i - x)^1(y_i - y)}{\sqrt{\sum_{i=1}^{n}(x_i - x)^2 \sum_{i=1}^{n}(y_i - y)^2}} \quad (9)$$

r is the Pearson's correlation coefficient
x and y are the means of x values and y values
n is the total number of data points

<u>Interpretation</u>
r = 1: Perfect correlation between (as X increases, Y increases linearly)
r = -1: Perfect negative correlation (as X increases, Y decreases linearly)
r = 0: No linear correlation between X and Y

6. Variables

Table 3: Independent, Dependent and Controlled Variables

	Independent Variable
Identification	Stellar Mass of Galaxies
Manipulation	Since the data is observational, the stellar mass would not need to be manipulated – galaxies will be analysed with their natural values of stellar mass. The galaxy mass data will be categorized into different mass ranges, including low, medium and high stellar mass. The units of the stellar mass recorded would be in terms of (a multiple of) solar mass (M☉) which is 1.989 x 10^{30} kilograms
	Dependent Variable
Identification	Galaxy Morphology
Measurement	The measurement of galaxy morphology involves classifying the galaxies into broad categories based on shapes:

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	• Elliptical • Spiral • Barred Spiral • Lenticular • Irregular • Peculiar
	Controlled Variables
Identification & Ensuring Consistency	1. Galaxy Redshift (Distance) - Redshift is related to a galaxy's distance from Earth, which can affect how we perceive its properties (e.g., brightness, morphology). By controlling for redshift, observational biases caused by distance would be minimized. - Dataset would be restricted to galaxies within a similar redshift range. This would be done by applying a filter to the dataset during the data cleaning stage. 2. Galaxy Luminosity - Luminosity can affect both stellar mass estimates and the visibility of morphological features. Controlling luminosity ensures that the variations in morphology observed are more likely due to stellar mass differences rather than differing brightness levels. - Only galaxies within a specific luminosity range would be included in the dataset. 3. Galaxy Age - Galaxy age affects both stellar mass (younger galaxies may have lower masses) and morphology (older galaxies tend to be more elliptical). Controlling for age ensures that differences in morphology aren't just due to age-related structural evolution but rather linked to stellar mass. - If age data is available, a filter would be applied for galaxies of similar ages.

7. Hypothesis

If a galaxy has a higher stellar mass, then it is more likely to have an elliptical or lenticular morphology because higher stellar masses are often associated with galaxies that have undergone multiple mergers and structural evolution, leading to smoother and more spheroidal shapes.

8. Methodology

Table 4: Methodology

S no.	Step
1.	Obtain galaxy data from Sloan Digital Sky Survey (SDSS). Ensure the dataset includes measurements for stellar mass and galaxy morphology classifications
2.	Filter out any entries with missing values for stellar mass or morphology to ensure accuracy in analysis
3.	Limit the dataset to galaxies within a similar redshift range, luminosity range, and age range to ensure only one variable is independent, so that the findings are valid and reliable
4.	Identify and remove any extreme outliers in stellar mass values that may skew results
5.	Calculate descriptive statistics for stellar mass within each morphological type. This will give a solid understanding of the distribution of values of stellar mass across different galaxy types
6.	Create a scatter plot with galaxy morphology on the x-axis (and stellar mass on the y-axis. The visualization will help observe any potential patterns between stellar mass and galaxy morphology
7.	Calculate the correlation coefficient (Pearson or Spearman's based on the type of data) between stellar mass and morphological type to quantify the strength and direction of the relationship.
8.	Examine the results of the visualizations and correlation analysis to determine if there is a proper trend between stellar mass and galaxy morphology.
9.	Compare the average stellar mass across different morphological types to assess if higher masses are associated with certain galaxy morphologies, and evaluate the hypothesis
10.	Summarize the findings of the study, highlighting any significant trends or correlations observed between stellar mass and galaxy morphology.
11.	Discuss potential limitations, such as observational biases or limitations in the dataset, evaluating the methodology.

9. Data Collection & Analysis

The different morphological classifications of galaxies were assigned numerical codes to make the data easier to work with. Numerical values allow simplified data entry and enable quantitative analysis.
1 for Elliptical
2 for Spiral
3 for Lenticular
4 for Irregular

Table 5: Raw Data Collection

Galaxy ID (self-assigned)	Stellar Mass (M⊙)	Morphological Code	Morphological Type
G1	5.3×10^{9}	1	Elliptical
G2	2.1×10^{10}	2	Spiral
G3	7.5×10^{8}	3	Lenticular
G4	3.2×10^{9}	4	Irregular
G5	1.1×10^{10}	2	Spiral
G6	9.6×10^{9}	1	Elliptical
G7	4.8×10^{10}	2	Spiral
G8	3.4×10^{9}	4	Irregular
G9	1.9×10^{8}	3	Lenticular
G10	2.8×10^{10}	1	Elliptical
G11	6.7×10^{9}	2	Spiral
G12	5.0×10^{8}	4	Irregular

G13	1.2 x 10^{10}	1	Elliptical
G14	7.3 x 10^{9}	3	Lenticular
G15	3.6 x 10^{10}	2	Spiral
G16	4.5 x 10^{9}	4	Irregular
G17	9.8 x 10^{9}	1	Elliptical
G18	2.2 x 10^{8}	3	Lenticular
G19	1.5 x 10^{10}	2	Spiral
G20	6.0 x 10^{8}	4	Irregular

9.1 Statistical Analysis for Stellar Mass of Full Sample Data

Mean M⊙ = 1.11 x 10^{10}
This high average mass suggests that the sample contains galaxies with substantial stellar masses. This can be due to the presence of many large elliptical or spiral galaxies in the dataset.

Median M⊙ = 7 x 10^{9}
The fact that the median is lower than the mean suggests that the data is skewed to the right. There are a few galaxies with very high stellar masses that are pulling the mean upwards.

Standard Deviation M⊙ = 1.29 x 10^{10}
The standard deviation is quite large, even larger than the mean. This indicates that there is significant variability in stellar masses within the sample. The reason for this is that galaxies in this dataset vary widely in mass, from relatively low-mass galaxies to very high-mass ones.

Variance M⊙ = 1.67 x 10^{20}
The variance, which is the square of the standard deviation, further emphasizes the extent of variability in stellar masses. A high variance confirms the presence of considerable spread in the stellar mass values across the sample.

9.2 Statistical Analysis for Stellar Mass for each Morphological Classification

Table 6: Statistical Analysis of Stellar Mass for each morphological classification

Code	Mean M⊙	Median M⊙	Standard Deviation M⊙	Variance M⊙
1	1.294 x 10^{10}	9.8 x 10^{9}	8.76 x 10^{9}	7.67 x 10^{19}
	The mean stellar mass for elliptical galaxies is higher than the full sample mean. This suggests that elliptical galaxies in the sample tend to have larger stellar masses on average compared to the overall galaxy population.	The median is slightly below the mean for elliptical galaxies, which indicates a slightly right-skewed distribution. Few very massive elliptical galaxies are pulling the mean up. This median is still higher than the overall median of reinforcing the idea that elliptical galaxies generally have higher masses	The high standard deviation, nearly as large as the mean, indicates considerable variability in the stellar mass of elliptical galaxies.	-
2	2.295 x 10^{10}	1.8 x 10^{10}	1.59 x 10^{10}	2.54 x 10^{20}
	The mean stellar mass for spiral galaxies is notably higher than the mean for the full sample, suggesting that spiral galaxies in this dataset are quite massive on average.	The median for spiral galaxies is lower than the mean, indicating a right-skewed distribution.	The standard deviation is relatively large, indicating considerable variability in stellar mass among spiral galaxies.	-
3	2.115 x 10^{9}	4.85 x 10^{8}	3.46 x 10^{9}	1.2 x 10^{19}
	The mean is significantly lower than the full sample mean indicating that lenticular galaxies in this dataset tend to have lower stellar masses on average compared to other galaxy types.	The median is much lower than the mean, suggesting a right-skewed distribution with a few more massive lenticular galaxies pulling up the average	The standard deviation is high relative to the mean	-
4	2.44 x 10^{9}	3.2 x 10^{9}	1.79 x 10^{9}	3.2 x 10^{18}
	The mean stellar mass is relatively low compared to the full sample mean indicating that irregular galaxies tend to have smaller stellar masses on average.	The median is close to the mean, suggesting a more symmetrical distribution of stellar masses within irregular galaxies, without significant skewing by extreme values.	The standard deviation is moderate, showing some variability in mass but less than other galaxy types, reflecting a narrower range of stellar masses among irregular galaxies.	-

9.3 Scatter Plot Representing Data

- The x axis of the plot represents the 4 different galaxy types present in the data set (1 – Elliptical, 2 – Spiral, 3 – Lenticular, 4 – Irregular)
- The Y axis represents stellar mass. The scatter plot is plotted on a logarithmic scale for stellar mass in order to show the wide range of stellar masses

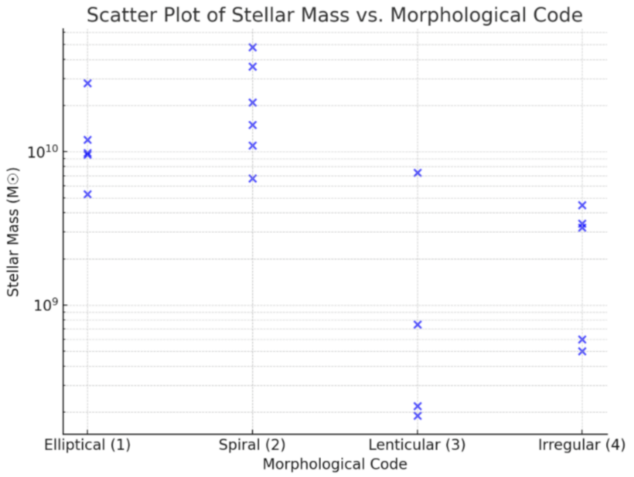

Figure 6: Scatter Plot (Stellar mass vs. Morphological Code)

The scatter plot shows unique patterns in stellar mass across different galaxy morphological types. Elliptical galaxies and spiral galaxies are shown to have higher stellar masses, with several points clustered around 10^{10} ⊙ or above, suggesting that these galaxy types tend to be more massive. Lenticular galaxies show a much lower range of stellar masses, indicating that they are generally smaller or less massive than ellipticals and spirals. One of the lenticular galaxy can be considered an outlier, as it has a mass close to 10^{10} ⊙, but the rest have lower masses. Irregular galaxies (code 4) display the widest spread in stellar mass, but they generally cluster at lower values, suggesting that these galaxies are typically lower in mass. This distribution aligns with the expectation that more structured galaxies (like ellipticals and spirals) tend to have higher stellar masses than less structured or irregular types.

Spearman's coefficient is the better choice for this study (in comparison to Pearson's coefficient) as morphological code is a categorical variable

Value of Spearman's coefficient: -0.664

−0.664 indicates a moderate negative relationship between stellar mass and morphological code, which means that that as the morphological code increases (from elliptical to irregular), stellar mass decreases.

10. Evaluation of Hypothesis

Table 7: Strengths & Weaknesses of Hypothesis

Strengths	Weaknesses
1) Aligns with understanding that high-mass galaxies tend to evolve into more spheroidal shapes	1) Hypothesis does not account for other influences such as environmental factors and interaction history which also impact morphology 2) Hypothesis states, high mass galaxies would be elliptical or lenticular, however lenticular galaxies had low mass, and spiral galaxies had one of the highest masses

11. Evaluation of Methodology

Table 8: Strengths & Weaknesses of Methodology

Strengths	Weaknesses
1) Results align with the established theory that galaxies with higher stellar mass are elliptical in shape. 2) The trend roughly applied to all the 20 galaxies in the sample, so the research can be considered valid and reliable	1) The study does show a correlation, but it cannot be confirmed that a factor apart from stellar mass does not cause this specific correlation 2) Treating the morphological codes as linear variables (1 to 4) can be regarded an oversimplification

12. Improvements

- Use of more sophisticated data analysis models such as machine learning classification models and multiple regression analysis for more reliable results
- More detailed morphological classifications instead of grouping galaxies basis just 4 groups
- Include additional variables that impact galaxy shape such as galaxy age or redshift, for a more comprehensive analysis

13. Extension

Instead of stellar mass as the independent variable, another factor can be tested such as the angular velocity of the galaxy. The alternative research question would be "How does the angular velocity of a galaxy impact its morphological classification"

14. Conclusion

The study concludes by confirming the hypothesis that elliptical or lenticular morphologies are more common in galaxies with higher stellar masses. Galaxies appear to be more spheroidal in shape as their mass increases, according to the statistically significant negative correlation found between stellar mass and morphological code. This result is consistent with well-established astronomical theories that associate particular galaxy types with high mass and structural evolution. Mass is a significant factor, but it is not the only one that determines galaxy morphology; other factors, such as environmental influences, also play a part.

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