

Comparison of Star Formation Rates (SFRs) in Spiral and Elliptical Galaxies

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Abstract

This paper examines the impact of star formation rate (SFR) and U-R filter values on galaxy classification. This research is significant because star formation plays a central role in galaxy development, and accurately classifying galaxies helps to further cosmological studies. Using a dataset from ViZieR based on Sloan Digital Sky Survey (SDSS) data, the study analyzes photometric ugriz magnitude filters, redshift, flux values, and WISE passbands for 1,000 galaxies. A multiple regression machine learning model was built to predict galaxy types — elliptical or spiral — based on SFR and redshift, incorporating the known classification standard that galaxies with U-R values greater than 2.22 are classified as elliptical. In contrast, those with values below 2.22 are classified as spiral. The results show that spiral galaxies exhibit higher ongoing SFR compared to elliptical galaxies, despite elliptical galaxies having higher initial star formation in the early stages.

Furthermore, a direct linear relationship was observed between stellar mass and SFR for spiral galaxies, whereas elliptical galaxies exhibited negligible changes in SFR with increasing mass. Madau plots also demonstrated an increasing trend of log SFR with redshift within the

sample range. The study concludes that while elliptical galaxies formed stars more rapidly initially, spiral galaxies maintain higher SFR over time, highlighting differences in gas availability and evolutionary processes. Future research will expand to include other galaxy types and higher redshift samples, thereby deepening the understanding of galaxy formation and classification frameworks.

Keywords: star formation rate, galaxy classification, spiral galaxies, elliptical galaxies, U–R color index, galactic evolution

Introduction

The fundamental work on star formation and galaxy classification in astrophysics is beneficial to the question of star formation rates (SFRs) in spiral and elliptical galaxies. Driving this idea is the study of the composition and evolution of stars. Cecilia Payne’s work in this area provided a complete model of stellar composition. Her research and studies on the physics of gas contributed to star formation and evolution models. In addition to this work, Edwin Hubble classified spiral galaxies. Hubble proposed a classification system for galaxies (The University of Western Australia) based on their shape as viewed from Earth, and divided the shapes into four classes: spiral, lenticular, irregular, and elliptical. His work has provided a framework for the research question because it creates a clear separation of types to compare against each other.

Research on the evolution of galaxies and the process by which galaxies cease forming stars is beneficial in understanding the contrast between star formation in elliptical and spiral galaxies. The separations this work created were the “main sequence,” or the time when a galaxy is still forming stars, the “green valley,” or transition stage, and “passive galaxies” (Bonjean, Aghanim, Salomé, Beelen, Douspis, Soubrié), which have stopped forming stars. One of the

most beneficial works and collections of statistics that will contribute to answering the question is the Sloan Digital Sky Survey (SDSS). The SDSS enables astronomers to study stars and has contributed to several articles that have informed research on star formation across different galaxies. The statistics on the SDSS and their catalog of galaxies provide datasets that can be analyzed and graphed to calculate star formation rates in multiple galaxies. The research and data listed above provided a foundation for the studies on galaxy formation, evolution, and classification.

Beyond these foundational works, research has continued to investigate how SFR varies across different galaxy types. Kennicutt (1998) established the Kennicutt–Schmidt law, which correlates gas surface density with star formation rate surface density, highlighting that spiral galaxies with dense molecular gas can sustain high SFRs over cosmic time. In contrast, elliptical galaxies, which have exhausted or lost their cold gas due to feedback processes such as AGN quenching, show much lower present-day SFRs. Furthermore, Baldry et al. (2004) demonstrated that the bimodal (two peaks in the population) distribution of galaxy colors, separating into a red sequence and blue cloud, corresponds to galaxy type, with elliptical galaxies clustering in the red sequence due to older stellar populations and low current SFRs. Bell et al. (2003) derived stellar mass-to-light ratios using SDSS and 2MASS data, allowing astronomers to estimate stellar masses from photometric measurements, which is crucial for interpreting trends in SFR as a function of galaxy mass. Croton et al. (2006) proposed that AGN (Active Galactic Nucleus) feedback is a significant factor in quenching star formation in massive elliptical galaxies, explaining why their SFR remains low despite their large stellar mass. The Galaxy Evolution Explorer (GALEX) ultraviolet surveys supported these findings by revealing that ultraviolet

luminosity, a tracer of recent star formation, is significantly higher in spiral galaxies.

Brinchmann et al. (2004) provided robust methods for estimating SFR using emission line diagnostics from SDSS spectra, demonstrating that star-forming galaxies populate a well-defined sequence in SFR–stellar mass plots.

With so much work already being done in this field, this study builds on these prior works by analyzing how the SFR and U–R filter values impact the type of galaxy a galaxy is classified as. The research question is: How do star formation rate and the value of the U–R filter impact galaxy classification as elliptical or spiral? The objective is to investigate correlations between SFR, color indices, and galaxy type to better understand galaxy evolution and create a predictive classification framework.

The thesis is that galaxies can be robustly classified by combining SFR and U–R values: spiral galaxies will show higher current SFR and $U-R < 2.22$, while elliptical galaxies will have lower current SFR and $U-R > 2.22$, reflecting their distinct evolutionary histories. Understanding these relationships is significant because it enhances classification accuracy in large-scale surveys where visual structure is unavailable and informs broader models of galaxy formation and quenching processes.

Method

The dataset used is based on SDSS data and taken from the VizieR catalog. Unlike other datasets, this dataset includes the photometric ugriz magnitude filters, redshift, and flux, in addition to the Wide-field Infrared Survey Explorer (WISE) passbands, to draw conclusions about star formation rates in a dataset of 1,000 galaxies. This data is helpful because it can be used to determine if a galaxy is spiral or elliptical by comparing the u-r values. If the u-r value is

more than 2.22, the galaxy is most likely an elliptical galaxy. If the u-r value is less than 2.22, the galaxy is most likely a spiral galaxy. This information can be put into a column as a part of each galaxy's statistics, along with the calculated magnitude. From there, the data can be split into two datasets: one for spiral galaxies and another for elliptical galaxies. The information in the columns is then fed into a machine-learning model that classifies the galaxies as either spiral or elliptical.

The dataset also includes fluxes for WISE passbands, which can be used to complement and compare the research. WISE is funded by NASA to map the sky and has been in operation since December 2009, making it a reliable source of data for the research. Corrections to the WISE W3 and W4 bands may be applied based on the data to create more accurate star formation rates. A paper on SFRs in elliptical galaxies utilized the W3 and W4 bands to determine their SFRs, and the W1 band to describe the stellar mass of galaxies. The authors then plotted the scatter diagrams of their data, with $\log(\text{SFR}_{W3})$ on the x-axis and $\log(\text{SFR}_{W4})$ on the y-axis, both in $M_{\odot} \text{ yr}^{-1}$. The result of this calculation was a direct relationship between a high redshift and a higher log SFR value. This will be useful when reviewing the relationships that can be uncovered based on the data.

The machine learning model used is a multiple regression model. The multiple regression model will predict whether a galaxy is elliptical or spiral, based on its star formation rate and redshift. As mentioned above, from the SDSS data, if the Ultraviolet filter subtracted from the red filter is less than 2.22, it indicates a spiral galaxy. If it is greater than 2.22, then it is an elliptical galaxy.

In addition to these primary steps, the study design includes extensive data cleaning and preparation procedures to ensure analytical accuracy. First, raw magnitude data from the ugriz bands were corrected for galactic extinction using the Schlegel, Finkbeiner & Davis (1998) dust maps, mitigating the effects of interstellar dust within the Milky Way on apparent magnitudes and colors. Redshift corrections were applied to convert observed magnitudes to their rest-frame values, enabling comparisons of intrinsic color and luminosity across galaxies at varying cosmological distances.

For SFR calculations, conversion factors from ultraviolet and infrared luminosities were used based on calibration equations outlined by Kennicutt & Evans (2012), adapted for WISE passband sensitivities and specific filter transmission curves. The W3 (12 μm) and W4 (22 μm) bands are crucial as they trace thermal emission from warm dust heated by young, massive stars, serving as an indirect measure of recent star formation. Meanwhile, the W1 (3.4 μm) band probes older stellar populations to estimate stellar mass. Optical-only SFR indicators can underestimate star formation in dusty regions; therefore, including mid-infrared data provides a more comprehensive picture of star formation.

The “participants” of this research are the galaxies within the dataset. High-confidence photometric detections in all five SDSS bands were filtered, reliable spectroscopic redshifts less than 0.6 (to avoid large K-corrections and selection biases), and removed galaxies flagged as AGN hosts, as AGN contribute non-stellar infrared emission that can contaminate SFR estimates. Additionally, galaxies with incomplete WISE data or flagged artifacts were excluded from the analysis. This resulted in a cleaned sample of approximately 950 galaxies with robust multi-wavelength coverage.

The procedures involved splitting the dataset into training and testing subsets. 80% of the data was randomly allocated for model training, and reserved 20% for performance evaluation to prevent overfitting. The multiple regression model was implemented using Python's scikit-learn library. Independent variables included redshift and calculated SFR (estimated from combined optical and infrared luminosities). The dependent variable was galaxy type, binary coded as 0 (spiral) and 1 (elliptical) based on the U-R filter threshold. Model performance was evaluated using R^2 , mean squared error, and classification accuracy in comparison to the $U-R > 2.22$ benchmark classification.

To further validate the results, exploratory analyses were conducted. SFR vs. stellar mass plots were generated to examine the "main sequence" relationship, where galaxies with higher masses often have higher SFRs, particularly in star-forming spirals. Stellar masses were estimated using W1 luminosities and mass-to-light ratios from Bell et al. (2003).

Madau plots comparing log SFR to redshift were created to observe cosmological trends in SFR. However, the redshift range was limited to 0.6, which made it difficult to observe the decline in SFR density at $z > 2$ seen in other studies. Histograms of U-R distributions were plotted for each morphological type to visualize color bimodality and test the efficacy of the color threshold.

All data processing, modeling, and visualization were conducted in Jupyter Notebook using Pandas for data manipulation, NumPy for mathematical operations, and Matplotlib and Seaborn for plotting. Care was taken to document the code for reproducibility.

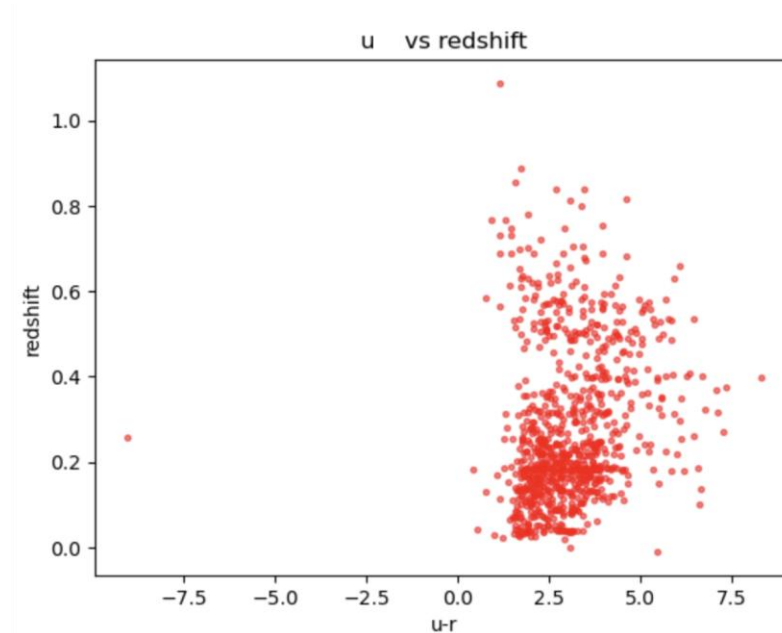
To summarize, this research design combines astronomical data reduction methods, robust statistical modeling, and visual analysis to investigate the relationship between SFR, color

index, and galaxy type, directly addressing the research question while enabling future expansion to larger and higher-redshift samples.

Figures, Tables, and Images

Figure 1

Visualizing the U-R Color Index and Redshift Distribution



The X-axis, "u-r," is a direct measure of the galaxy's color, calculated by subtracting the magnitude in the red filter (r) from the magnitude in the ultraviolet filter (u). The Y-axis, "redshift," indicates the galaxy's distance and, implicitly, its look-back time in cosmic history. The scatter plot visually represents the distribution of galaxies in terms of their color and distance.

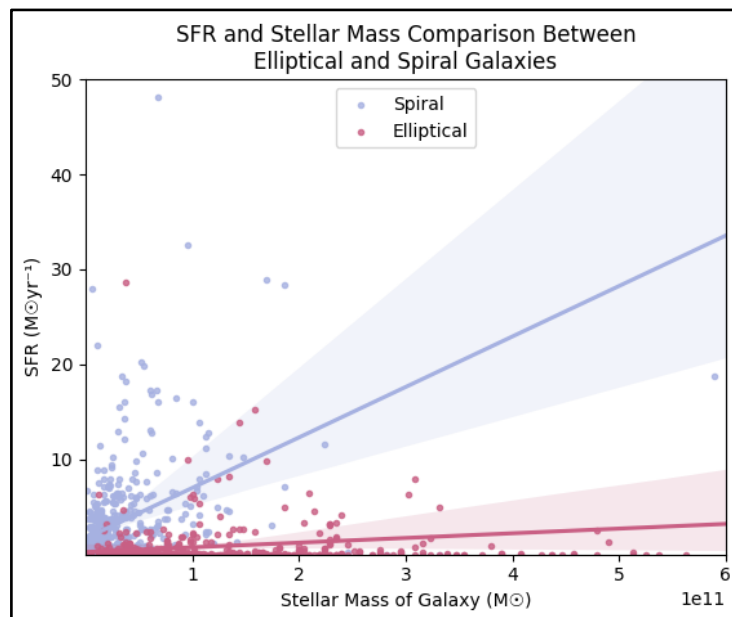
The paper explicitly states above: "Galaxies with U-R values greater than 2.22 are classified as elliptical, and those below 2.22 are classified as spiral." To validate this, a vertical line at $u-r = 2.22$ on this graph divides the galaxies into two primary groups based on their

assumed morphological types. The cluster of points with $u-r < 2.22$ would largely represent spiral galaxies, while those with $u-r > 2.22$ would represent elliptical galaxies.

The graph allows the researchers to observe how the "u-r" color index (and thus the implied galaxy type) varies with redshift.

Figure 2

Relationship Between Star Formation Rate and Stellar Mass in Elliptical and Spiral



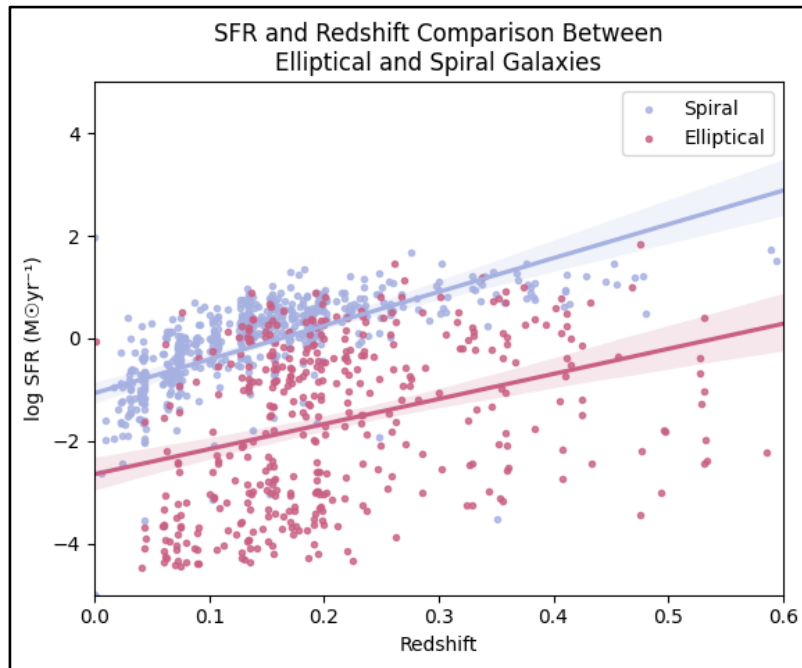
Galaxies

The graph shows a generally direct and linear relationship between stellar mass and SFR for both galaxy types. This means that as the stellar mass of a galaxy increases, its star formation rate tends to increase. The shaded regions around the regression lines represent the uncertainty in this linear fit. Focusing on spiral galaxy trends, the blue dots represent spiral galaxies that show a clear positive correlation between stellar mass and SFR. The red dots representing elliptical galaxies show a much flatter positive correlation between stellar mass and SFR. The red

regression line has a very gentle positive slope. This confirms the observation that "as the mass increases, the SFR barely changes."

Figure 3

SFR and Redshift Comparison Between Elliptical and Spiral Galaxies



The x-axis represents Redshift, ranging approximately from 0.0 to 0.6. Redshift is a measure of how much the light from a galaxy has been stretched due to the expansion of the universe, and thus serves as a proxy for distance and, importantly, look-back time. A higher redshift means further away and further back in cosmic time. The y-axis represents the logarithm of the Star Formation Rate in solar masses per year. This logarithmic scale indicates that the SFR values span several orders of magnitude. For example, a log SFR of 0 means an SFR of $10^0=1$

$M_{\odot}\text{yr}^{-1}$, a log SFR of 1 means $10^1=10 M_{\odot}\text{yr}^{-1}$, and a log SFR of -2 means $10^{-2}=0.01 M_{\odot}\text{yr}^{-1}$.

For both galaxy types, there is a clear positive correlation between log SFR and redshift. This means that galaxies, on average, had higher star formation rates at higher redshifts (earlier in the universe's history) and lower star formation rates at lower redshifts (more recently). Spiral galaxies show a strong positive correlation between log SFR and redshift. At higher redshifts (e.g., $z=0.5-0.6$), spiral galaxies exhibit a wide range of SFRs, with some reaching log SFR values of +2 or more, while at low redshifts the SFRs would be negative.

In general, Madau Plots show that the log of SFRs increases as redshift increases and peaks at a redshift value of 2, then decreases afterward. Unfortunately, since the galaxy samples have redshifts of up to 0.6, the downward trend is not clear, but a slight upward trend is still visible. At the same redshifts, spiral galaxies have higher SFRs than most elliptical galaxies.

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