A Non-Morphological Method to Isolate Red Spiral Galaxies

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A means of selecting reddened spiral galaxies was devised using both a color cut and a cut based on hydrogen-α emission line strength. The combination of the methods proved to be 80% effective (with the other 20% being red ellipticals) over the first 25 identifiable galaxies. Spectroscopic differences between red- and blue-type spiral galaxies were observed using morphologically-classified lists and color data obtained from The Sloan Digital Sky Survey (SDSS). The ugriz values for the different galaxies were transformed to u-g, g-r, and r-i colors before being graphed three-dimensionally. A plane was used to separate the two types of galaxies. The corresponding equation of the plane, $2 \times (u-g) + 2.05 \times (g-r) + 0.75 \times (r-i) = 5$, was used to select a random assortment of galaxies from SDSS with the goal of isolating reddened spirals. It was found that also requiring the objects to have an H-α emission line equivalent width larger than 10 Å could improve the efficiency from the 40% success rate observed using either method alone.

I. INTRODUCTION

As the universe is ever expanding, so, too, is the wealth of astronomical data available for observation and study. One of the observatories focused on imaging the sky around us is the Sloan Digital Sky Survey (SDSS) operating out of the Apache Point Observatory in New Mexico. SDSS was established in 2000 with the goal of imaging 25% of the night sky while providing this data to the public. (1)

Sloan operates with a 2.5 m telescope to collect photometric data by imaging the sky over five distinct bandpasses. Measurements are made in the ultraviolet, visible (both green and red), and near-infrared, as shown in Table 1. (1) For more luminous objects, a spectrum of the chemical composition is also obtained. SDSS images have been noted to contain some of the most distant (and therefore oldest) quasars and galaxies ever observed. (2)

As can be imagined, the amount of objects contained in these images must be quite vast, creating issues when the data needs to be analyzed. Many galaxies have been classified morphologically by hundreds of thousands of volunteers. However, this method is obviously quite tedious and could never occur without the generous nature of the amateur astronomers who donate their time. It would be more efficient if a method of classifying objects based on their spectroscopic properties could be devised.

Specifically, this study focuses on identifying red spiral galaxies from a random smattering of objects obtained via SDSS. Considering most spiral galaxies are bluer, star-forming structures, red spirals are an ideal subject due to their inherent rarity. (3) Several different aspects must come together at once in order to achieve this goal, however. First, the objects must obviously be galaxies. Second, they must be spiral galaxies. Third, they must be reddened. As such, a means of combining these properties will be explored.

TABLE I Different bandpasses used by Sloan and their corresponding wavelengths.

Type	Region	Wavelength
u	Ultraviolet	354 nm
g	Green	475 nm
r	Red	622 nm
i	Near-infrared	763 nm
z	Near-infrared	905 nm

II. THEORY

The purpose of this study is to devise a means of identifying red spiral galaxies without morphology. Red spirals were chosen based on their relative scarcity. The anomalous nature of spirals that have been reddened has several proposed explanations. Suggestions include that the galaxy has been stripped of most of its gases by a neighboring galaxy or most of the gas has been funneled in by especially efficient spiral arms, both of which would represent a starvation or strangulation event. (4; 5) A connection between the density of the gases present during the formation of a galaxy and its resulting color has been made, although it has also been surmised that environment alone cannot be used as an indication of color, which defies the typical color-morphology relation. (4; 6) Another proposed explanation is simply that some process has aged the galaxy to a point where star formation has ceased, although there has been research to the contrary. (6; 7)

Morphological sample data sets of blue and red spiral galaxies can be used to determine fundamental differences between the two galactic types. The photometric data needed for such an analysis can be obtained using the Sloan Digital Sky Survey (SDSS). The magnitudes of the ugri color data of the galaxies can be manipulated into u-g, g-r, and r-i colors. These colors can be simultaneously graphed to determine a relation between the two types. The maximum separation of the two types can be found via this plot. Once this difference between the two is found, the equation relating them can then be used to obtain a random data set from SDSS. To ensure the objects obtained are galaxies of identifiable type, limits on the redshift and luminosity can be enforced.

The set of galaxies obtained with this color cut method can then be classified into different types of varying redness. The method can be further improved by also noting key spectral properties of the galaxies in question and then applying these observations to the search as well. By combining both a color cut and a spectral qualifier, reddened spiral galaxies can be isolated and identified using spectroscopy and photometry alone.

III. PROCEDURE

Photometric data was obtained using a list of morphologically identified red spirals and a standard list of typical bluer spirals (4) over a set of five established bandpasses (u, g, r, i, and z) covering the ultraviolet, visible, and infrared portions of the spectrum (1). Each data set contained about 300 galaxies, and the values for the magnitudes were found using the Object Explorer function of the latest release of data (DR7) from SDSS.

The magnitudes for each were used to find differences between consecutive bands. For example, u-g would correspond to the difference in magnitude between the ultraviolet portion and the green portion of the spectrum. These differences in magnitude were then plotted against one another in the same consecutive manner (i.e. u-g vs. g-r, etc.) to observe any separation in the properties of the blue and red galaxies, an example of which is shown in Fig. 1. All of the graphs showed at least a reasonable separation except for the r-i vs. i-z plot.

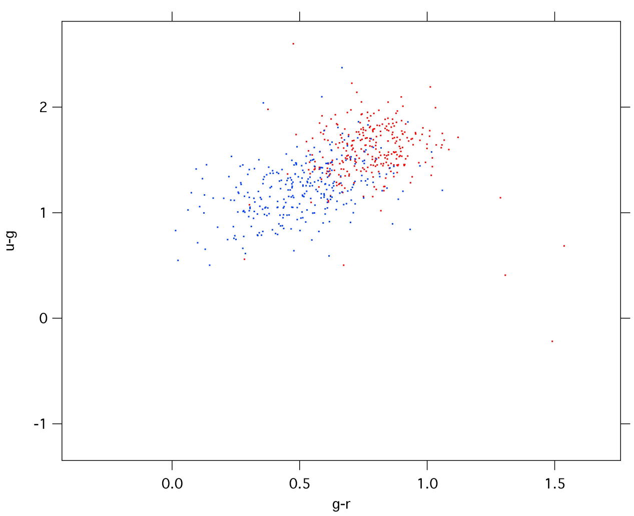

FIG. 1 Two-dimensional example plot of the difference of the ultraviolet and green spectrum portions and the difference of the green and red spectrum portions.

However, simply separating the points with a line would have proven less effective than using a three-dimensional plot of the data to distinguish differences. As a result, a 3D plot of u-g, g-r, and r-i values for each data set was constructed and a plane was visually fit to provide the most separation between the two galactic types, as shown in Fig. 2 and Fig. 3.

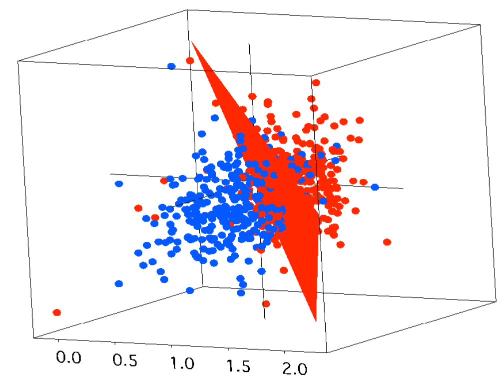

FIG. 2 Side view of the three-dimensional plot of the different photometric differences of the red- and blue-type spiral galaxies with their separation shown as a plane.

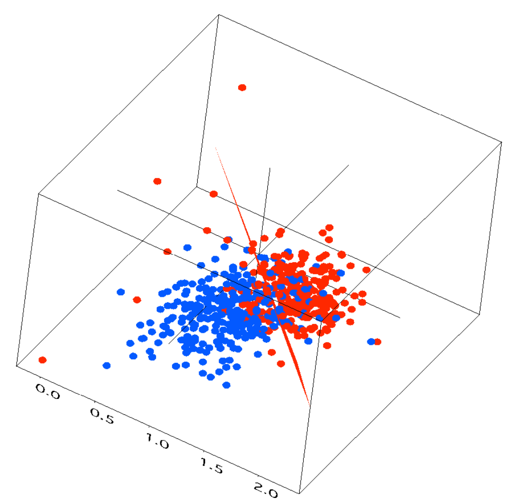

FIG. 3 Top view of the three-dimensional plot of the different photometric differences of the red- and blue-type spiral galaxies to better show the separation of the galaxies.

The values for the apexes of the plane were then used to calculate the formula of the plane, which was found to be

$$2\times(u-g)+2.05\times(g-r)+0.75\times(r-i)+0.05=0. \quad (1)$$

Although this equation didn't provide a distinct enough separation when used to search for galaxies using SDSS. So, to further improve the fit, histograms as shown in Fig. 4 and Fig. 5 of the blue and red values were constructed. It was noted that the population distribution of galaxies at a value of about 5 should ensure a larger likelihood of a given galaxy being red than being blue. As a result, the equation was modified to

$$2 \times (u - g) + 2.05 \times (g - r) + 0.75 \times (r - i) = 5. \quad (2)$$

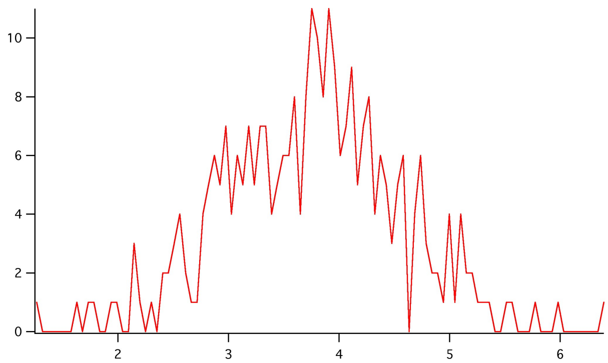

FIG. 4 Histogram showing the distribution of blue spiral galaxies. Note how the values vary widely with a maximum at about 4 and a much smaller proportion at 5.

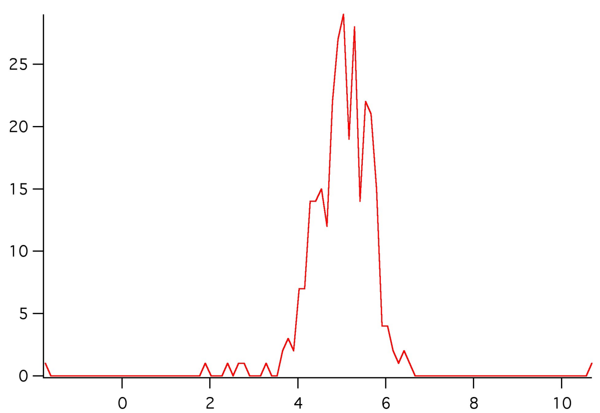

FIG. 5 Histogram showing the distribution of red spiral galaxies. Note how the values have a more narrow range with a maximum peak at about 5.

This equation was then used in a search of the latest data set (DR7) of SDSS to obtain a list of 100 random objects that possessed spectroscopic properties that resulted in a value for Eqn. 2 greater than 5. The redshift of the samples was limited to $0.001 < z < 0.05$ to ensure the objects would in fact be galaxies only. The overall magnitude of the objects was limited to ensure the brightness and angular size would be high enough to facilitate morphological classification. The first 25 identifiable samples were observed visually using the Object Explorer function of SDSS to determine the efficiency of the devised color classification method.

By observing the spectra of the spiral galaxies obtained using Eqn. 2, it was noted that they all seemed to have markedly intense peaks corresponding to a form of hydrogen known as H-α. Following up on this observation, a search was performed to determine the role limiting the H-α line parameter has on the results. The equivalent width of the emission line peak was forced to be larger than 10 Å . Another search was performed combining the two methods.

IV. RESULTS AND ANALYSIS

In order to isolate and identify reddened spiral galaxies non-morphologically, three different searches of DR7 of SDSS were performed using a structured query language (SQL) search. Each search used a different method to obtain the data set. All searches had a redshift limit of $0.001 < z < 0.05$ to ensure selection of galaxies.

The data sets obtained were morphologically analyzed until 25 identifiable spiral or elliptical galaxies were obtained. Due to this simplicity, samples deemed unclassifiable or as irregular galaxies were discarded. However, edge-on spiral galaxies were retained for classification. This could produce false-positives on the reddening scale due to the high levels of dust present in the line-of-sight measurements. (8)

One search relied solely upon the color cut devised here from the morphological red and blue sample galaxies. As shown in Fig. 6, this method provided red galaxies in a 2:3 ratio between spirals and ellipticals. This ratio can be explained by considering the fact that elliptical galaxies are essentially older, non-star-forming (and therefore reddened) structures and are much more profuse. The samples obtained in this trial were by far the most straightforward to classify.

A second used a limit on the equivalent width of the emission line peaks of hydrogen-α. This method also produced spirals to ellipticals in a 2:3 ratio, as seen in Fig. 7. However, the samples were measurably less reddened, with only three galaxies that would barely pass the color cut. Overall, the galaxies collected this way were also the most difficult to identify, having nearly two unidentifiable and/or irregular galaxies for each labeled one.

The third approach combined these two methods. As shown in Fig. 8, the probability of finding a red spiral galaxy increased from about 40% to 80%. The identifiability of the samples was intermediate between the two individual methods.

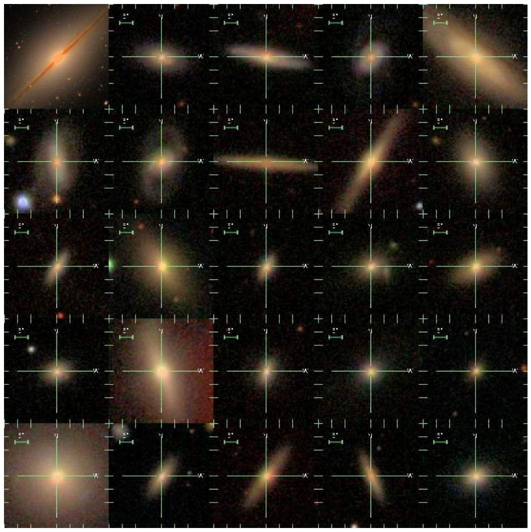

FIG. 6 Categorized results of only the color cut method. The first two rows are spirals whereas the bottom three rows are elliptical galaxies.

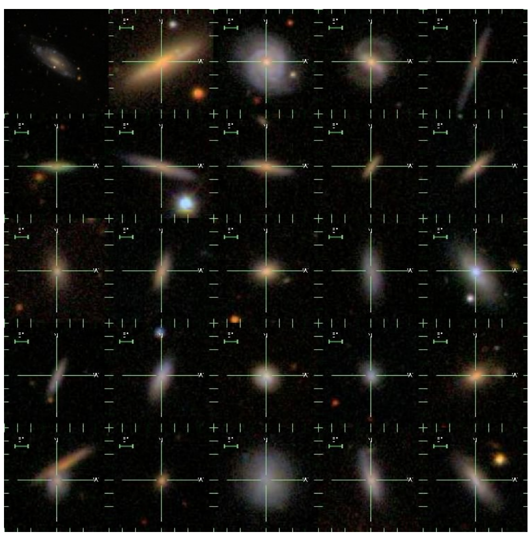

FIG. 7 Classified galaxies of the H-α method alone. Again, the first two rows are spirals and the bottom three rows are ellipticals.

V. CONCLUSION

Groups of known red and blue spirals were obtained from Masters *et al.* and used to determine what fundamental photometric properties differentiate the two types of galaxies. This was done using data collected and reported by the Sloan Digital Sky Survey (SDSS). A three-dimensional plot was visually fit with a plane to maximize the separation between the red and blue values. The equation of the plane was found and then improved via use of histogram plots.

This version of the equation was used as part of a color-cut system to select a list of random objects, which resulted in a 2:3 ratio between spiral and elliptical galaxies. The benefit of this method was the fact that all of the galaxies observed were, in fact, reddened. A second search with limits on the H-α emission line peak size was performed which resulted in a 40% success rate of finding a spiral galaxy. The samples obtained weren't reddened enough to pass the color cut though. In order to improve the results, one last search was conducted to combine the two methods. The success rate of finding a red spiral galaxy was twice as large as finding a spiral (reddened or not) using either of the individual methods.

As a result, it can be concluded that coupling the two methods can produce the desired red spirals with reasonable success. Numerically, the likelihood doubles when both parameters are included in a search. This combination method is far from foolproof, but it could eventually be further adjusted and refined into a more effective means of classifying astronomical objects without relying solely upon morphology.

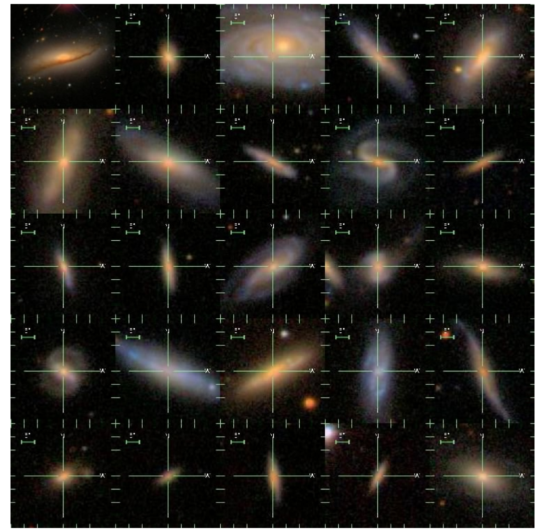

FIG. 8 Distribution of spiral and elliptical galaxies corresponding to the joint search. Here the first three rows are spiral galaxies and the last two rows are elliptical galaxies.

References

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Appendices

A-1. SDSS SQL SEARCH PARAMETERS

This appendix contains the actual search code used in the Structured Query Language search of DR7 of SDSS.

A. Color cut

```
SELECT TOP 100
 p.objid,p.ra,p.dec,p.psfmag_u-extinction_u as
umag,p.psfmag_g-extinction_g as gmag,p.psfmag_r-extinction_r as
rmag,p.psfmag_i-extinction_i as imag,p.psfmag_z-extinction_z as zmag,
2*((p.psfmag_u-extinction_u)-(p.psfmag_g-
extinction_g))+2.05*((p.psfmag_g-extinction_g)-(p.psfmag_r-
extinction_r))+0.75*((p.psfmag_r-extinction_r)-(p.psfmag_i-extinction_i))
as color,
s.specobjid, s.specClass, s.z
FROM PhotoObj AS p
 JOIN SpecObj AS s ON s.bestobjid = p.objid
WHERE
(2*((p.psfmag_u-extinction_u)-(p.psfmag_g-
extinction_g))+2.05*((p.psfmag_g-extinction_g)-(p.psfmag_r-
extinction_r))+0.75*((p.psfmag_r-extinction_r)-(p.psfmag_i-
extinction_i)))>5.0
AND s.z>0.001 and s.z<0.05
```

B. H-α cut

```
SELECT TOP 100
 p.objid,p.ra,p.dec,p.psfmag_u-extinction_u as
umag,p.psfmag_g-extinction_g as gmag,p.psfmag_r-extinction_r as
rmag,p.psfmag_i-extinction_i as imag,p.psfmag_z-extinction_z as zmag,
2*((p.psfmag_u-extinction_u)-(p.psfmag_g-
extinction_g))+2.05*((p.psfmag_g-extinction_g)-(p.psfmag_r-
extinction_r))+0.75*((p.psfmag_r-extinction_r)-(p.psfmag_i-extinction_i))
as color,
s.specobjid, s.specClass, s.z, l.ew
FROM PhotoObj AS p
 JOIN SpecObj AS s ON s.bestobjid = p.objid
 JOIN SpecLine as l ON l.specobjid = s.specobjid
WHERE
s.z>0.001 and s.z<0.05 and l.lineid = 6565 and l.ew>10
```

C. Both color and H-α cuts

```
SELECT TOP 100
 p.objid,p.ra,p.dec,p.psfmag_u-extinction_u as
umag,p.psfmag_g-extinction_g as gmag,p.psfmag_r-extinction_r as
rmag,p.psfmag_i-extinction_i as imag,p.psfmag_z-extinction_z as zmag,
2*((p.psfmag_u-extinction_u)-(p.psfmag_g-
extinction_g))+2.05*((p.psfmag_g-extinction_g)-(p.psfmag_r-
extinction_r))+0.75*((p.psfmag_r-extinction_r)-(p.psfmag_i-extinction_i))
as color,
s.specobjid, s.specClass, s.z, l.ew
FROM PhotoObj AS p
 JOIN SpecObj AS s ON s.bestobjid = p.objid
 JOIN SpecLine as l ON l.specobjid = s.specobjid
WHERE
(2*((p.psfmag_u-extinction_u)-(p.psfmag_g-
extinction_g))+2.05*((p.psfmag_g-extinction_g)-(p.psfmag_r-
extinction_r))+0.75*((p.psfmag_r-extinction_r)-(p.psfmag_i-
extinction_i)))>5.0
AND s.z>0.001 and s.z<0.05 and l.lineid = 6565 and l.ew>10
```