Determining the Redshift of Galaxies Photometrically

ABSTRACT

Galaxies are clusters of stars, gas, and dust held together by a gravitational attraction. There are approximately one hundred billion galaxies known to exist, most of which are moving with the expansion of the universe. As galaxies travel away from Earth, the wavelength of their light is elongated towards the red end of the visible spectrum, hence the term redshift. Once the redshift of a galaxy is found, Hubble's Law can be used to calculate its distance from Earth.

The redshift of galaxies is usually calculated by analyzing their emission spectra, but it is impossible to view the spectra of every single one. This experiment is designed to determine whether photometric analysis can be used to accurately estimate redshift. Using the Sloan Digital Sky Survey, I collected data on the magnitude of light emitted from different galaxies through different lenses (u, g, r, i, z). I used this to create three scatter plots that compared those magnitudes based on redshift. Then, five test galaxies were selected from the Sky Survey using the same parameters, and using the plots, I was able to estimate their redshift.

The final redshift estimates yielded a minimum error of 0.99 percent and a maximum error of 13.4 percent. Therefore it can be concluded that photometric analysis provides a fairly reliable estimate of galaxies' redshift. This research could be applied to the billions of galaxies that cannot be analyzed spectrally. More data points and smaller redshift intervals could make this process more accurate.

INTRODUCTION

Redshift is one of the most important discoveries to ever occur in the field of astronomy. It revolves around the doppler effect, a phenomenon that describes how the frequency or wavelength of a wave changes as the source moves toward or away from an observer. In the case of astronomy, the universe is constantly expanding, so each galaxy is growing farther from Earth, and its waves are stretched toward the red end of the spectrum. Usually this is measured by looking at a light source's emission spectra, but with hundred of billions of galaxies in the universe, it is impossible to analyze each one.

The Sloan Digital Sky Survey, or SDSS, has collected data on millions of galaxies throughout the observable universe. Photometric data is obtained from pictures of the night sky, such as Hubble's Deep Field, and measured using wavelength filters (Figure A) — ultraviolet, green, red, near infrared, and infrared. By comparing the ratios of the magnitude of light through the aforementioned filters, I hoped to find a pattern in the data that could be used to estimate the redshift.

This research has numerous applications throughout astronomy, as already redshift has many uses. Astronomers use redshift to discover new planets, calculate the mass of those planets, and even determine the size of the ever-growing universe.

Figure A

Filter	Wavelength (Å)
Ultraviolet (u)	3540
Green (g)	4750
Red (r)	6220
Near Infrared (i)	7630
Infrared (z)	9050

Purpose: To determine if redshift can be estimated through photometric analysis

Hypothesis: By plotting the ratios of magnitudes of light measured through different filters, redshift of galaxies can be estimated

METHODS

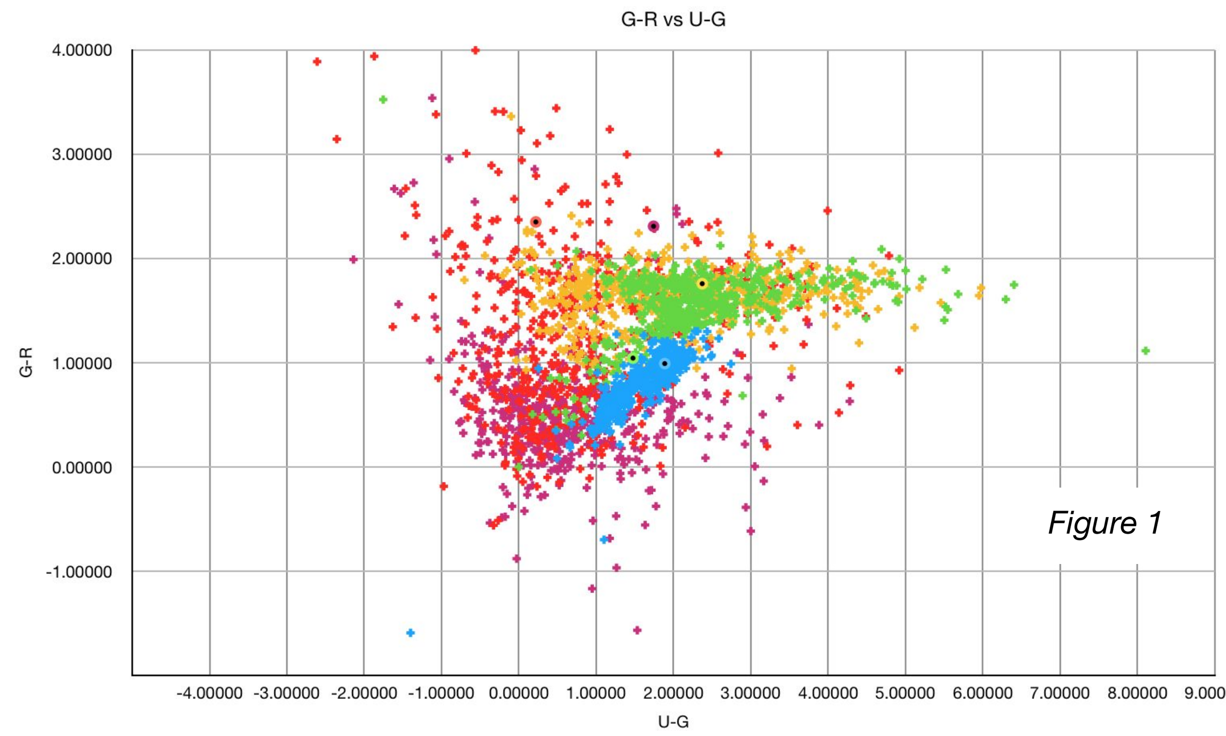
1. Create search query for SQL search on SDSS
2. Collect data for the different light magnitudes of 500 galaxies, and import it to a graphing utility, such as Excel
3. Make sure to select galaxies with a low zErr, which is the number that represents the amount of error for redshift
4. Separate the data into five sections based on redshift intervals of 0.2
5. Calculate the ratios of light magnitudes through the color filters. These ratios are u-g, g-r, r-i, and i-z
6. Create three separate scatter plots, graphing (in y vs x form) g-r vs u-g, r-i vs g-r, and i-z vs r-i. Make sure each redshift interval is given a different color
7. Create another search, this time only for 5 galaxies which will be used as test points
8. Determine where each point is in relation to the plotted data and record the position in a data table
9. Estimate the redshift based on the mode of the locations of the test points
10. Calculate percent error based on actual redshift from SDSS to determine if estimates are accurate

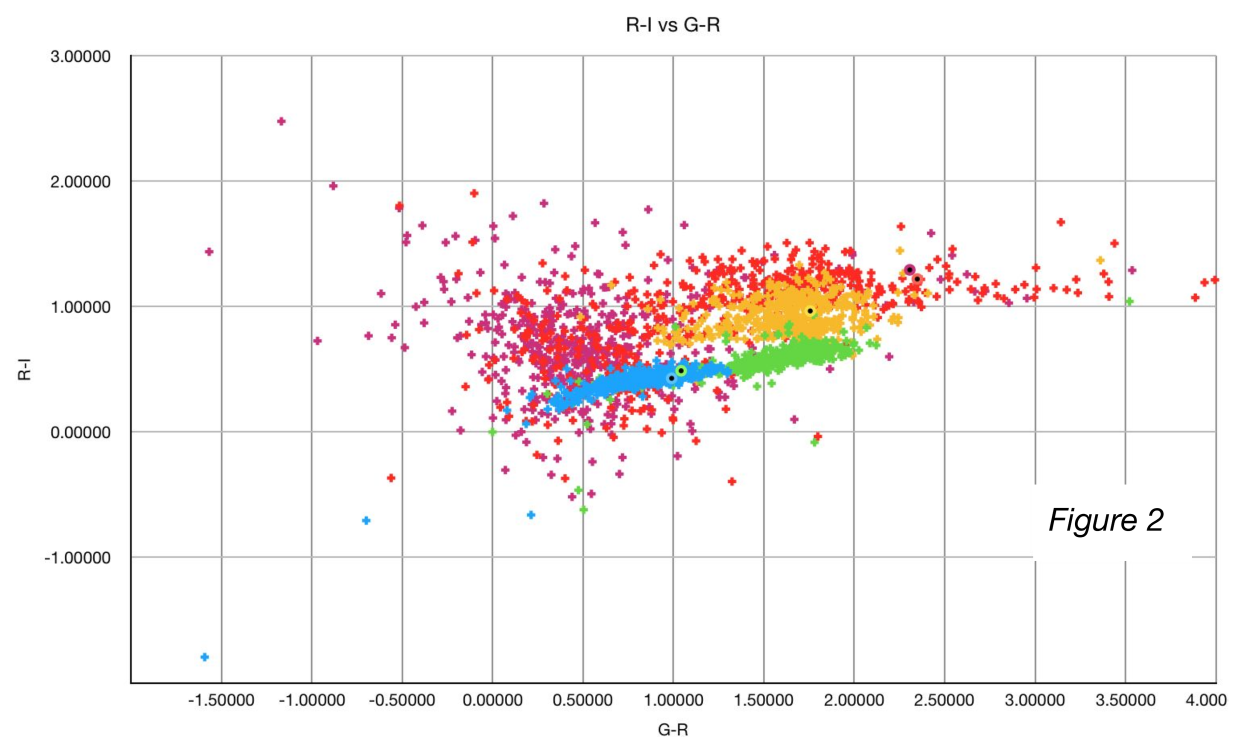
Sample SQL Search Query

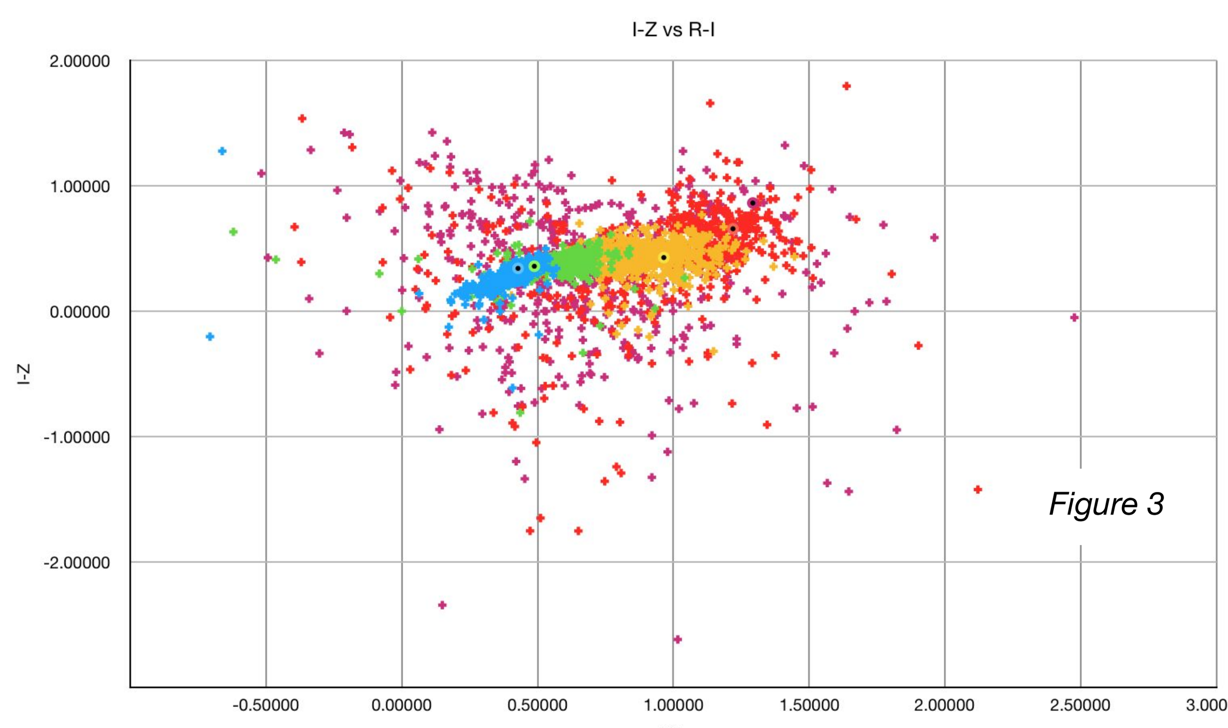
```
select top 500
objid, modelmag_u, modelmag_g, modelmag_r, modelmag_i,
modelmag_z, z

from
SpecPhoto

where
class='galaxy'
and z BETWEEN 0.2 and 0.4
and zErr BETWEEN 0 and 0.03
```

RESULTS

The photometric ratios of the galaxies are plotted below. Each color represents a different redshift interval.







Test Galaxies:

- Test A
- Test B
- Test C
- Test D
- Test E

Redshift Ranges:

- 0-0.2
- 0.2-0.4
- 0.4-0.6
- 0.6-0.8
- 0.8-1.0

Figure 4

Galaxy	Redshift from Figure 1	Redshift from Figure 2	Redshift from Figure 3	Mode of Redshifts	Photometric Redshift Estimate	Redshift from Spectral Analysis
A	(0-0.2)	(0-0.2)	(0-0.2)	(0-0.2)	0.1	0.097
B	(0-0.2) (0.2-0.4)	(0-0.2)	(0-0.2) (0.2-0.4)	(0-0.2)	0.2	0.231
C	(0.2-0.4) (0.4-0.6)	(0.4-0.6)	(0.4-0.6)	(0.4-0.6)	0.5	0.526
D	(0.4-0.6) (0.6-0.8)	(0.4-0.6) (0.6-0.8) (0.8-1.0)	(0.4-0.6) (0.6-0.8)	(0.4-0.6) (0.6-0.8)	0.6	0.606
E	(0.4-0.6) (0.6-0.8) (0.8-1.0)	(0.4-0.6) (0.6-0.8) (0.8-1.0)	(0.6-0.8) (0.8-1.0)	(0.6-0.8) (0.8-1.0)	0.8	0.920

Spectral Analysis

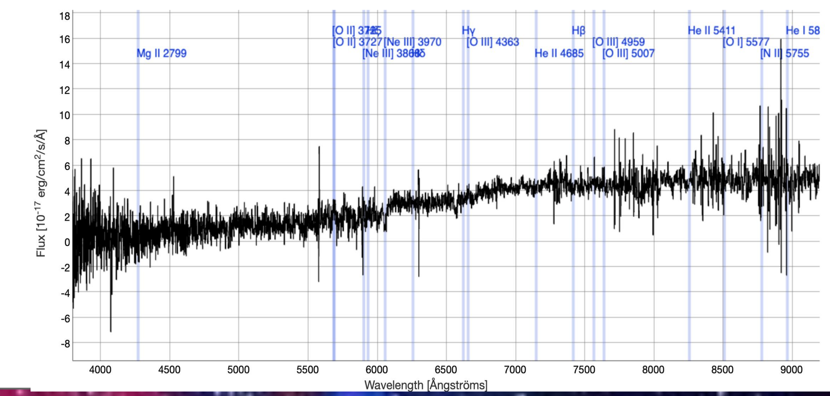
The formula for redshift is: $\frac{\text{Observed } \lambda - \text{rest } \lambda}{\text{Rest } \lambda}$

For this galaxy I will use the "O III" emission line to calculate the redshift.

$$\frac{7643 \text{ Å} - 5007 \text{ Å}}{5007 \text{ Å}} = 0.526$$

For reference, the redshift given by the SDSS search was also 0.526.

Emission Spectra - Galaxy 1237655693550813532



DISCUSSION

Galaxy	Estimate	Actual	Percent Error
A	0.1	0.097	3.09
B	0.2	0.231	13.42
C	0.5	0.526	4.94
D	0.6	0.606	0.99
E	0.8	0.920	13.04

Figure B

Before conducting this research, I hypothesized that the photometric analysis of galaxies would allow the redshift of galaxies to be estimated, but I did not believe it would be very accurate. As seen in *Figure B*, this method produced a minimum error of 0.99 percent, while the maximum error was 13.4 percent. Though this is not as accurate as spectral analysis, it still presents an important finding — with some improvement, photometry can be a viable option for determining the redshift of distant galaxies.

Photometric analysis has the potential to increase the accuracy of its redshift predictions with a few changes. First, more data points could be collected from the Sky Survey. My research only used 500 galaxies from each redshift interval, but SDSS has photometric data for millions of them. This would make the redshift regions on the plots more distinct, allowing for more confidence in estimates. Next, the range of the redshift intervals could be decreased. This project separated the galaxies into five sections, each spanning 0.2 units. Intervals of 0.1, 0.05, or even less would allow for more precise estimates. If I were to recreate this project, I would also include data from galaxies with a redshift higher than 1. Without those data points, it cannot be definitively concluded if this method of estimation can be used for all galaxies. This may also fill in the gaps left by the points with higher values already plotted on the graphs.

CONCLUSION

With this research, I wanted to determine if the redshift of galaxies could be estimated without spectroscopy. It can be concluded that photometric analysis is a viable option for estimating the redshift of galaxies. The average error from the experiment was 7.1 percent, while the minimum was 0.99 percent and maximum was 13.42 percent. Based on this information it is important to note that this method is not as accurate as spectral analysis, however it works for obtaining close estimates. With a few improvements, I believe its data may provide more accurate estimates. These may include collecting and plotting more data points, as well as decreasing the range of the redshift intervals. In the future, astronomers can use this method of photometric analysis to make accurate redshift estimations without the use of spectroscopy. It would be even more useful for those galaxies for which an emission spectra cannot be created.

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