VIREO ASSIGNMENT 1
Large Scale Structure of the Universe

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1 Introduction

Drawing a map: Two of the three dimensions required to make a 3-dimensional map of the positions of the galaxies in universe are actually fairly easy to determine. Those two dimensions are the two celestial coordinates, Right Ascension and declination, that tell us the location of a galaxy on the celestial sphere.More is needed, however. The two celestial coordinates just tell us in what direction to look to see a galaxy. A third number—the radial velocity of the galaxy—is necessary in order to produce a reliable map.

Hubble's Law: Hubble's Law states that a galaxy's recession velocity increases linearly with in- creasing distance from the observer. In mathematical terms, it can be written as:

$$v = H_0 D$$

This simple law is of profound importance in the fields of Cosmology and Astrophysics. H_0 is known as the Hubble's Constant and can be used to calculate physical quantities of immense importance like the age of the universe and the size of the observable universe. The primary calculation of the Hubble's Constant, as first performed by Edwin Hubble, is quite simple and is the technique we use in this experiment to determine its value.

Galactic Spectra: The spectra of regular galaxies show some prominent absorption lines that can be very easily identified upon visual examination of the spectrum. These lines can then be used to calculate the redshift, using the formula:

$$z = \frac{\lambda_0 - \lambda_e}{\lambda_0}$$

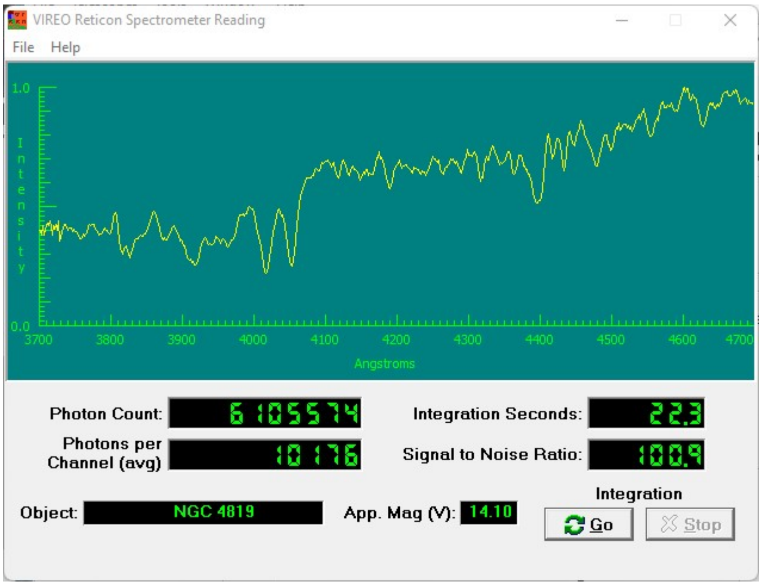
Here,
λ_0 : Observed Wavelength
λ_e : Emitted Wavelength
We use the H and K Ca II lines to calculate redshift in this experiment.

Calcium Doublet: The Ca H and K doublet corresponds to the fine structure splitting of the singly ionized calcium excited states Ca II at $\lambda_k = 3933.33$Å and $\lambda_h = 3968.33$ Å in the rest frame respectively, due to singly ionized calcium (Ca II). They are prominent in the spectrum of solar-type and cooler stars. Ca II also produces a triplet at 8498Å; 8542Å and 8662Å wavelengths. However, the H and K lines have been identified to be excellent probes.Galaxy spectra are typically characterized by a strong continuum component, caused by the combination of a range of blackbody emitters spanning a range in temperature.

2 Observations

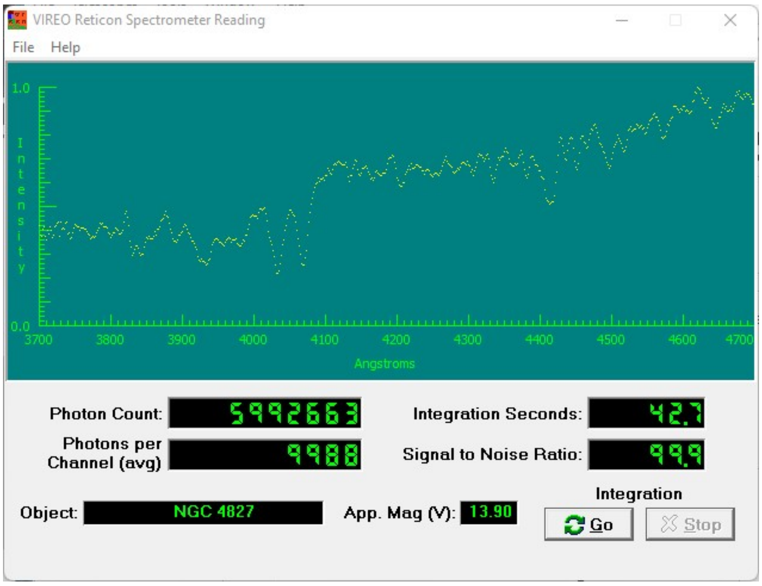
2.1 NGC 4819 -

Right Ascension: 12h 56m 28.4s
Declination: 26°59′17.0”



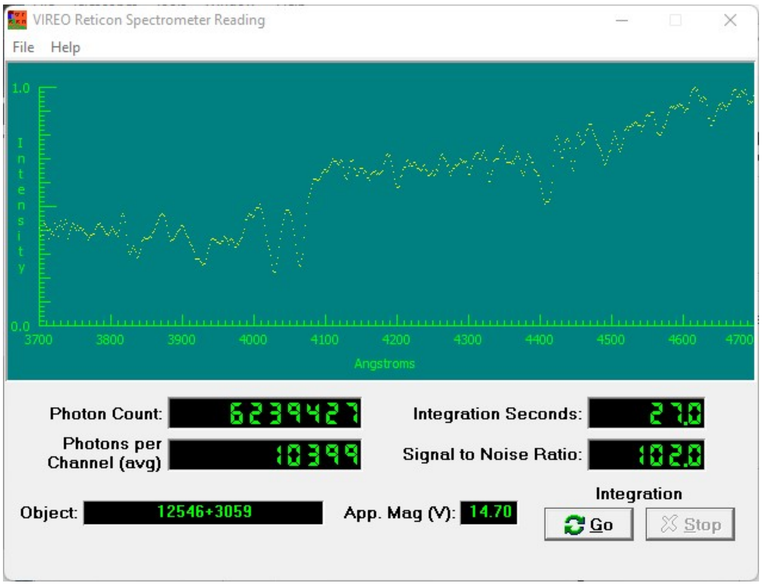
2.2 NGC 4827 -

Right Ascension: 12h 56m 43.4s
Declination: 27°10′47.0”



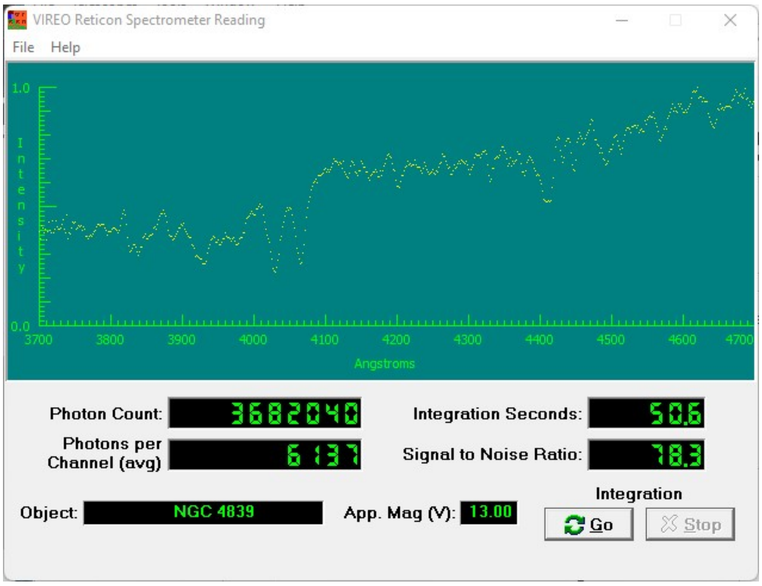
2.3 12546+3059 -

Right Ascension: 12h 57m 00.1s
Declination: 30°42′47.0”



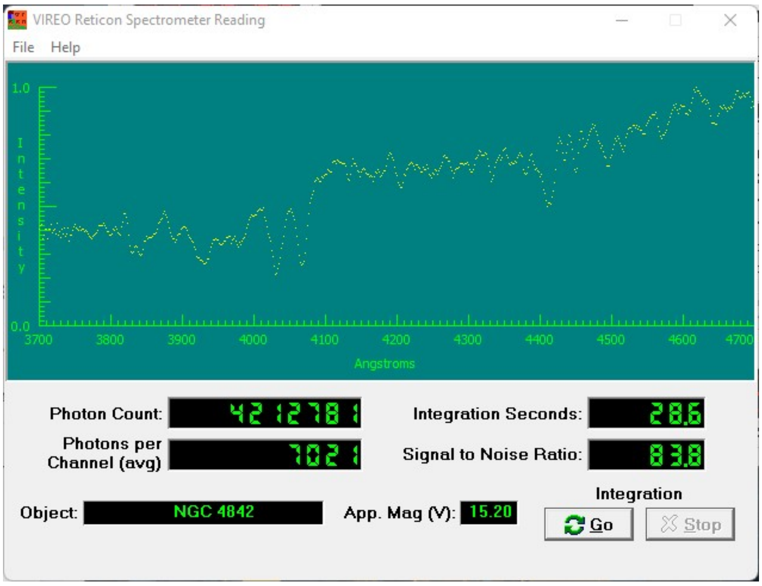
2.4 NGC 4839 -

Right Ascension: 12h 57m 24.2s
Declination: 27°29′54.0”



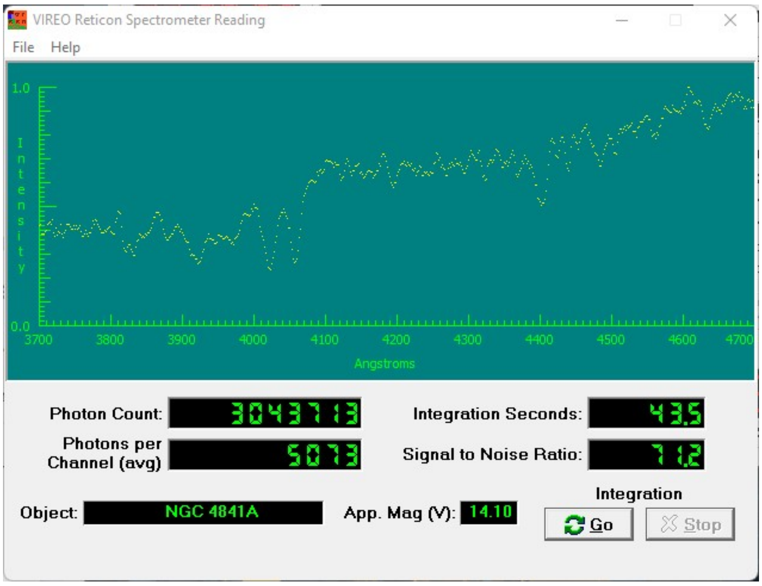
2.5 NGC 4842 -

Right Ascension: 12h 57m 25.2s
Declination: 27°32′48.0”



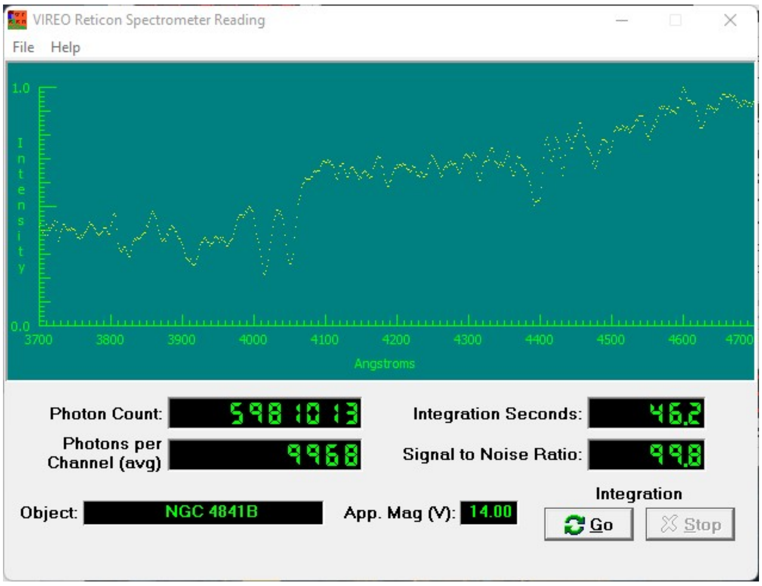
2.6 NGC 4841A -

Right Ascension: 12h 57m 32.2s
Declination: 28°28′38.0”



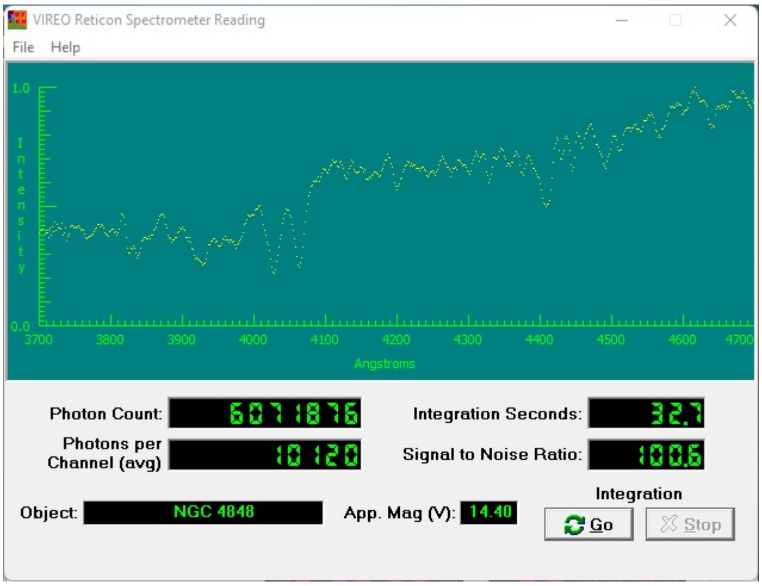
2.7 NGC 4841B -

Right Ascension: 12h 57m 34.4s
Declination: 28°28′56.0”



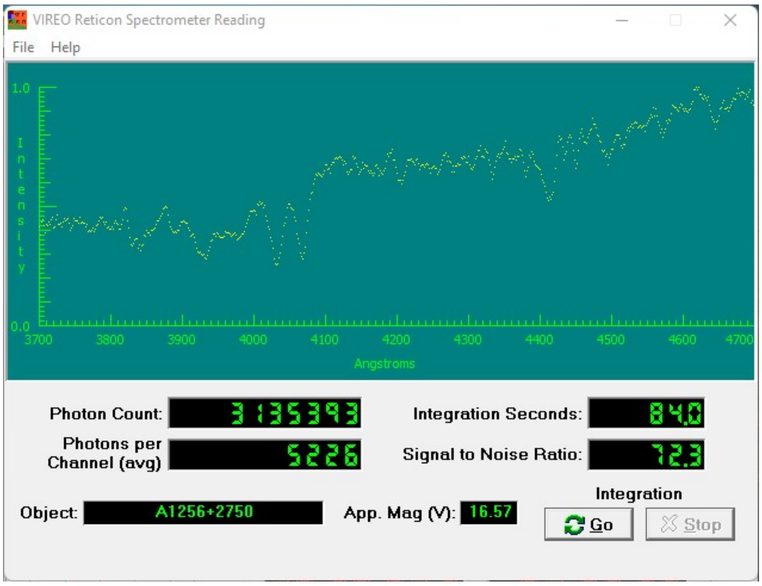
2.8 NGC 4848 -

Right Ascension: 12h 58m 05.7s
Declination: 28°14′41.0”



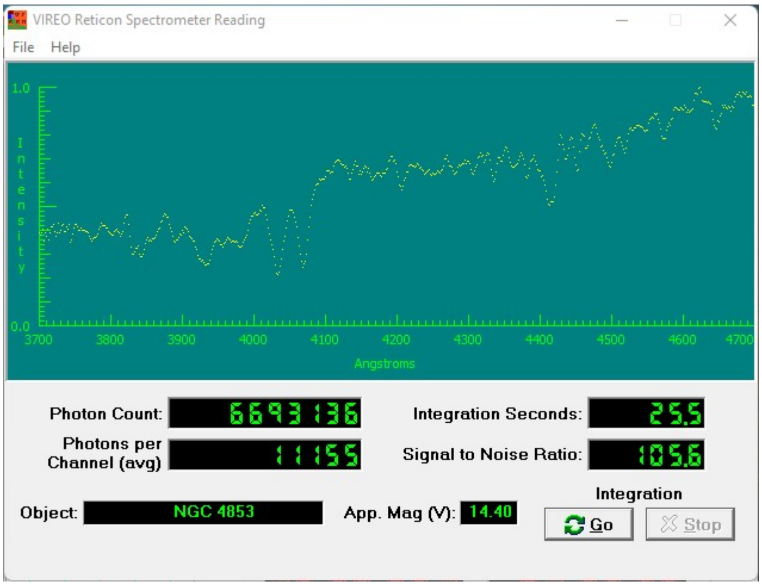
2.9 A1256+2750 -

Right Ascension: 12h 58m 29.5s
Declination: 27°33′55.0”



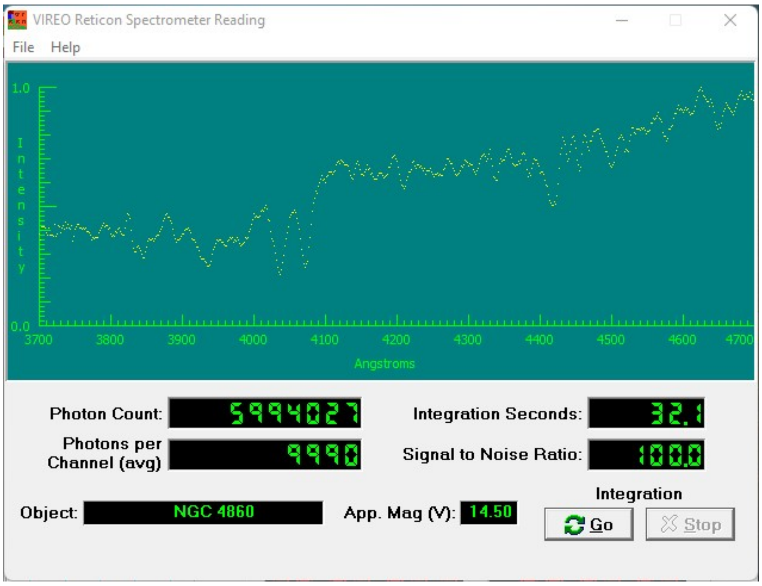
2.10 NGC 4853 -

Right Ascension: 12h 58m 35.4s
Declination: 27°35′52.0”



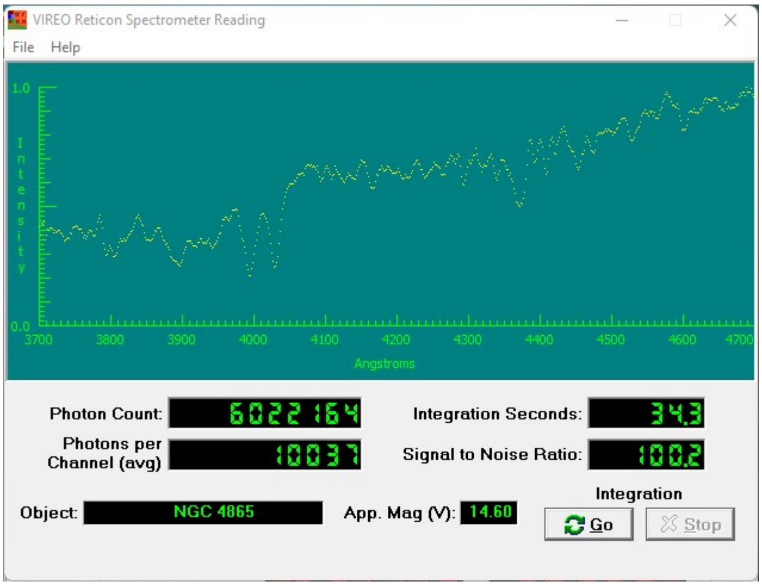
2.11 NGC 4860 -

Right Ascension: 12h 59m 04.1s
Declination: 28°07′21.0”



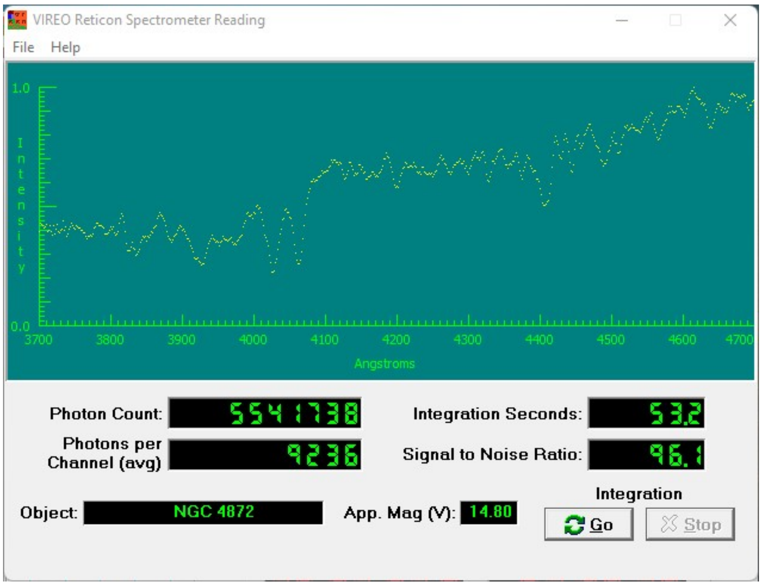
2.12 NGC 4865 -

Right Ascension: 12h 59m 19.8s
Declination: 28°05′04.0”



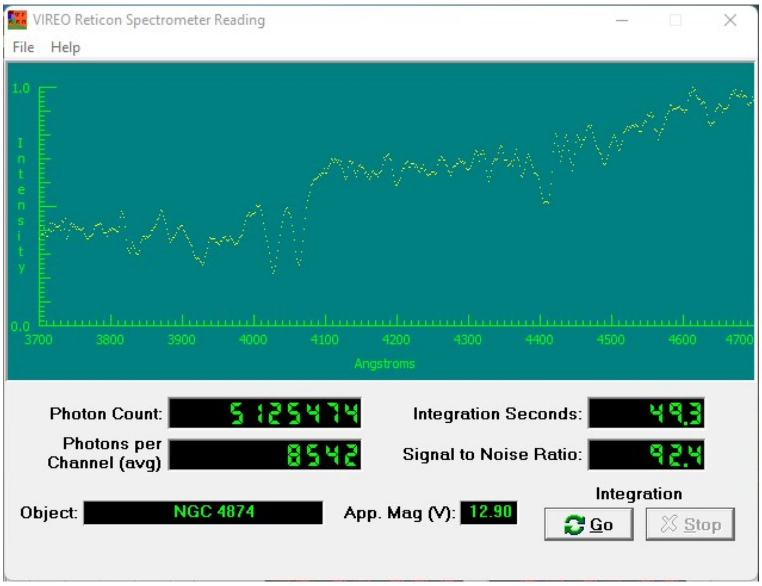
2.13 NGC 4872 -

Right Ascension: 12h 59m 34.0s
Declination: 27°56′46.0”



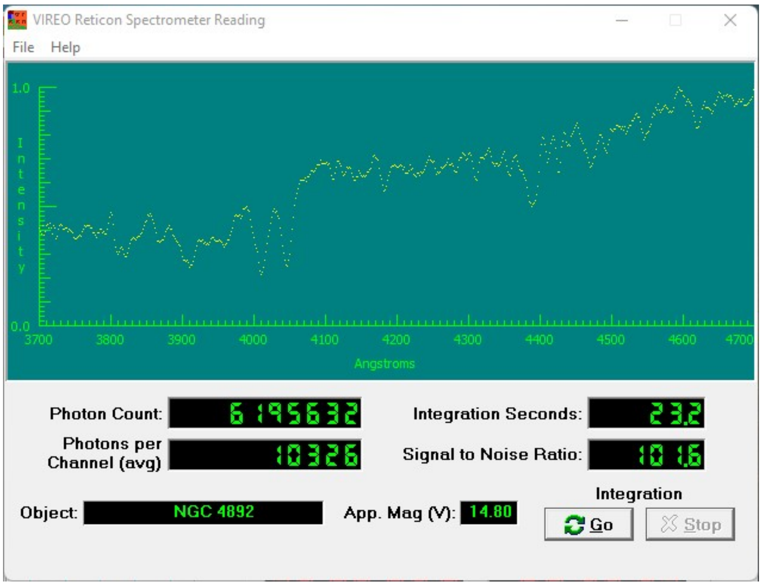
2.14 NGC 4874 -

Right Ascension: 12h 59m 35.2s
Declination: 27°57′35.0”



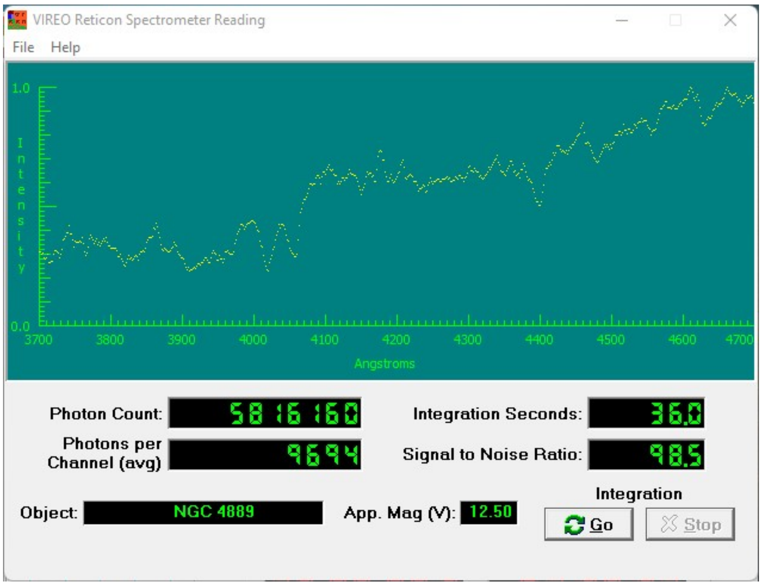
2.15 NGC 4892 -

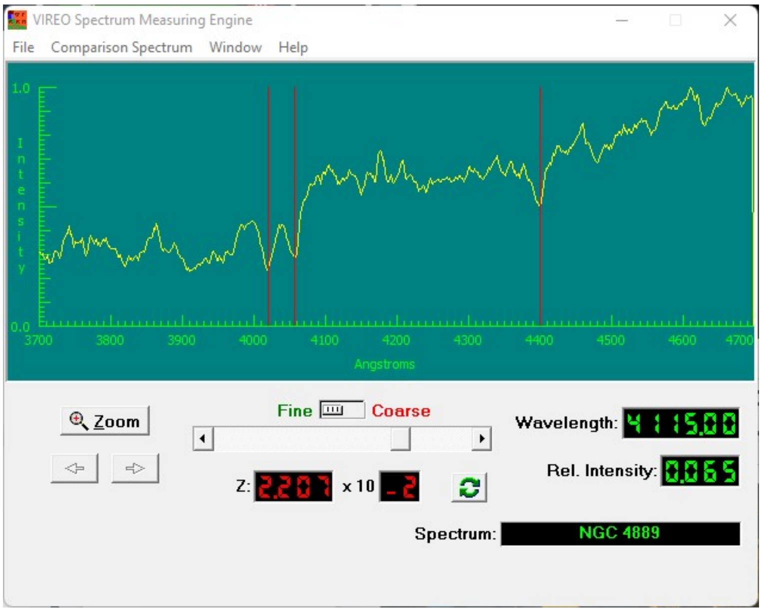
Right Ascension: 13h 00m 0.6s
Declination: 26°53′51.0”



2.16 NGC 4889 -

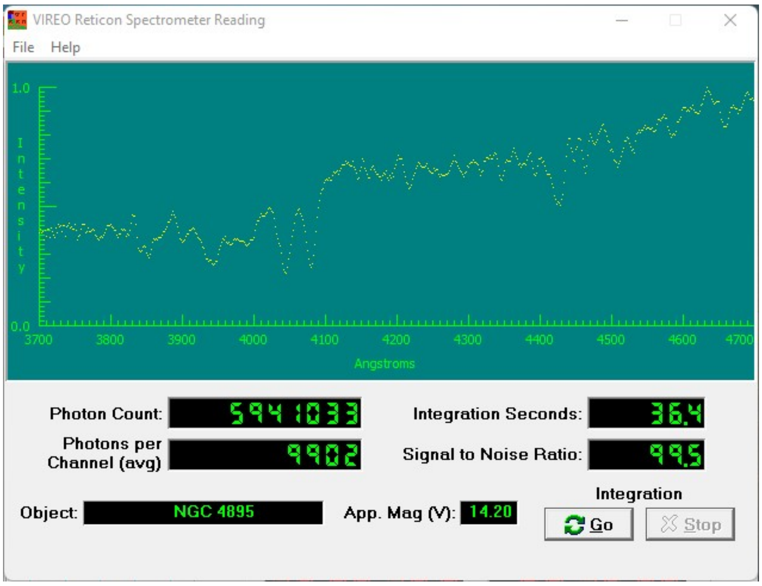
Right Ascension: 13h 00m 08.3s
Declination: 27°58′39.0”





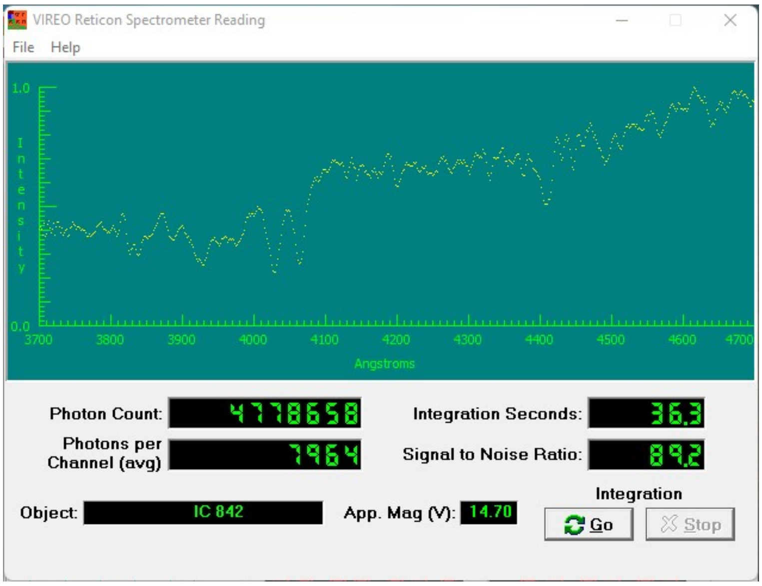
2.17 NGC 4895 -

Right Ascension: 13h 00m 18.0s
Declination: 28°12′06.0”



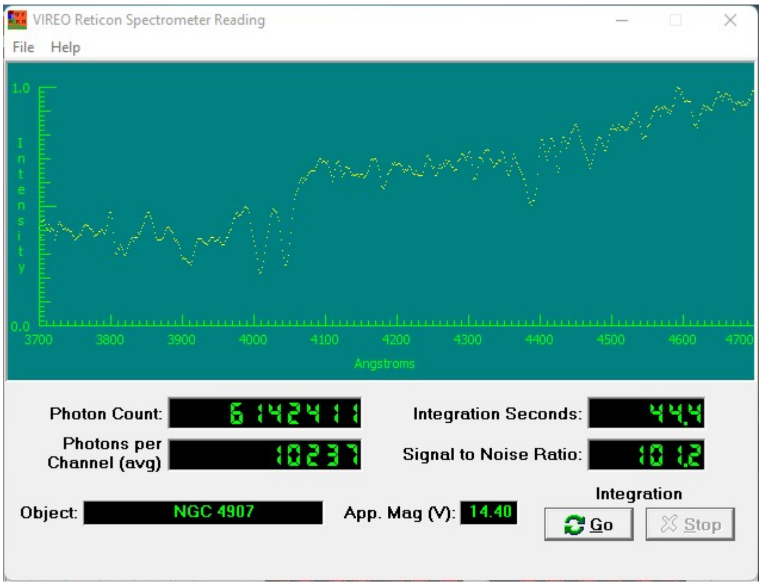
2.18 IC 842 -

Right Ascension: 13h 00m 39.2s
Declination: 29°01′09.0”



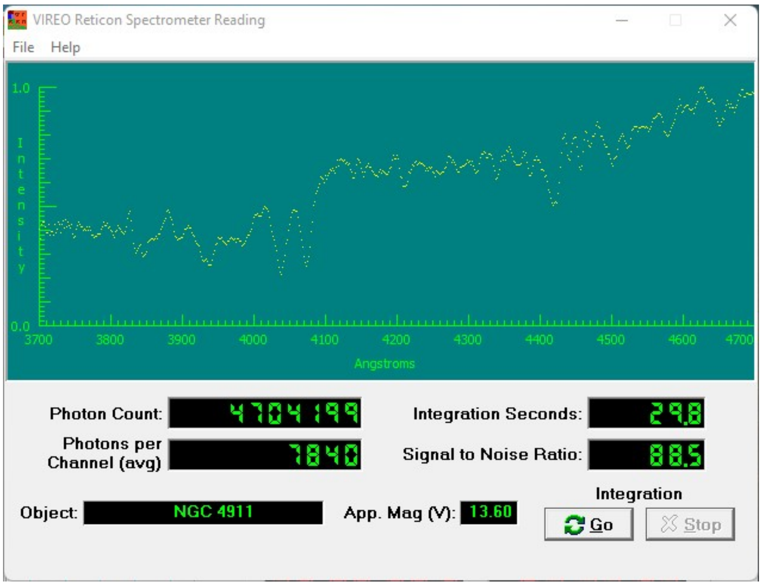
2.19 NGC 4907 -

Right Ascension: 13h 00m 48.0s
Declination: 28°09′24.0"



2.20 NGC 4911 -

Right Ascension: 13h 00m 56.30s
Declination: 27°47′34.0”



3 Results

There were 20 galaxies in the assigned sample. Using the redshift of Ca II (K line) and Ca II(H line) from spectroscopic data, we calculated the redshift of the galaxies individually. Using these redshift values, the respective velocities were calculated. Further, using the apparent magnitude values, the distances can be calculated. The formulae are as follows:

Velocity calculation:

$$v(inkm/s) = zc$$

where z is the redshift and c is the speed of light, $c = 3 * 10^5$km/s The rest frame wavelengths of Ca II lines are as follows:
K line:$\lambda_k = 3933.33$Å
H line:$\lambda_h = 3968.49$Å

3.1 Observation table:

Table 1: Recorded and calculated data

Object ID	MJD(Days)	RA	Dec	z	V(km/sec)
NGC 4819	9599.198611	12h56m28.4s	26°59'17"	$2.117 * 10^{-2}$	6.351E+03
NGC 4827	9599.199421	12h56m43.4s	27°10'47"	$2.523 * 10^{-2}$	7.569E+03
12546+3059	9599.200185	12h57m00.1s	30°42'47"	$2.387 * 10^{-2}$	7.161E+03
NGC 4839	9599.203218	12h57m24.2s	27°29'54"	$2.387 * 10^{-2}$	7.161E+03
NGC 4842	9599.206181	12h57m25.2s	27°32'48"	$2.477 * 10^{-2}$	7.431E+03
NGC 4841A	9599.207593	12h57m32.2s	28°28'38"	$2.252 * 10^{-2}$	6.756E+03
NGC 4841B	9599.209306	12h57m34.4s	28°28'56"	$2.072 * 10^{-2}$	6.216E+03
NGC 4848	9599.210926	12h58m05.7s	28°14'41"	$2.387 * 10^{-2}$	7.161E+03
A1256+2750	9599.212940	12h58m29.5s	27°33'55"	$2.477 * 10^{-2}$	7.431E+03
NGC 4853	9599.213981	12h58m35.4s	27°35'52"	$2.523 * 10^{-2}$	7.569E+03
NGC 4860	9599.215231	12h59m04.1s	28°07'21"	$2.568 * 10^{-2}$	7.704E+03
NGC 4865	9599.219005	12h59m19.8s	28°05'04"	$1.532 * 10^{-2}$	4.596E+03
NGC 4872	9599.220625	12h59m34.0s	27°56'46"	$2.342 * 10^{-2}$	7.026E+03
NGC 4874	9599.221782	12h59m35.2s	27°57'35"	$2.387 * 10^{-2}$	7.161E+03
NGC 4892	9599.234792	13h00m03.6s	26°53'51"	$1.937 * 10^{-2}$	5.811E+03
NGC 4889	9599.236991	13h00m08.3s	27°58'39"	$2.207 * 10^{-2}$	6.621E+03
NGC 4895	9599.239421	13h00m18.0s	28°12'06"	$2.793 * 10^{-2}$	8.379E+03
IC 842	9599.241690	13h00m39.2s	29°01'09"	$2.387 * 10^{-2}$	7.161E+03
NGC 4907	9599.243171	13h00m48.0s	28°09'24"	$1.892 * 10^{-2}$	5.676E+03
NGC 4911	9599.244722	13h00m56.3s	27°47'34"	$2.658 * 10^{-2}$	7.974E+03

In the above table,
RA: Right Ascension Dec: Declination V : Radial Velocity z: Cosmological Redshift

3.2 LSS Wedge plot:

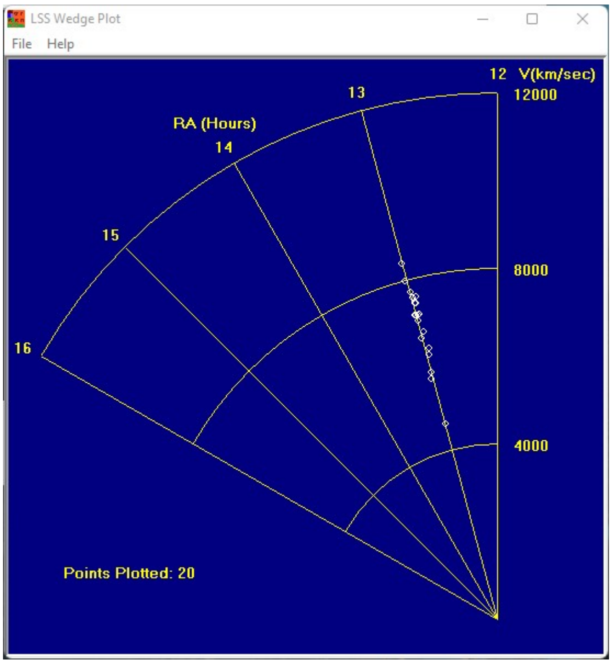
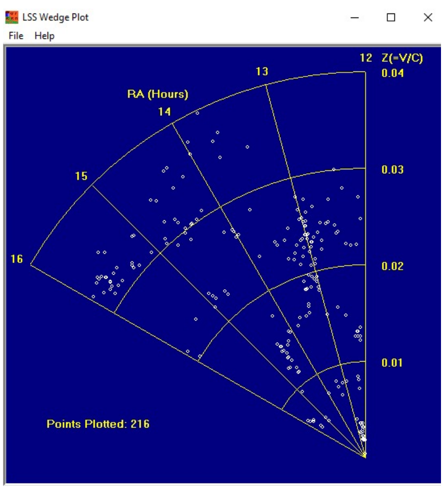
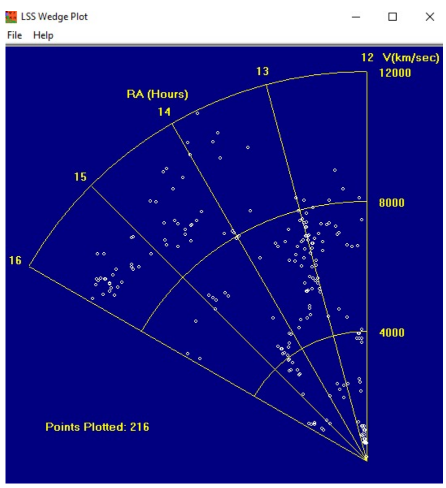


Figure 1: LSS Wedge Plot



(a) RA vs Redshift(z)



(b) RA vs Velocity

Figure 2: Wedge plot for class data

3.3 Interpreting the Wedge Plot -

1. Does matter in the universe appear to be randomly distributed on the large scale, or are there clumps and voids?

No, the distribution of matter is not random in the universe. It can be clearly observed from the above wedge plots that some regions are densely populated with galaxies, while other are much more scarcely populated. There is clear clumping of galaxies in matter dense regions, which are also called clusters, while galaxy/matter deficient regions are called voids.

2. The most densely populated region of the diagram (which appears like the stick figure of a human), is the core of the Coma Cluster of galaxies. What are the approximate Right Ascension and velocity coordinates of this feature?

For the core of the Coma Cluster of galaxies- RA $\approx$ 13h and Velocity $\approx$ 7000 km/s

3. You can use Hubble's redshift-distance relation to determine the distances of objects in the chart. $v = H \times D$ **where H is the Hubble constant which tells you how fast an galaxy at a given distance is receding due to the expansion of the universe. The value of H is not well known, and there is a great deal of dispute about it, but a value of 75 kilometers/sec/mpc is a reasonable figure. (1 mpc =** 10^6 **parsecs). Using this value of H, calculate the distance to the Coma Cluster.**

From Hubble's redshift-distance relation

$$D = \frac{v}{H}$$

Here,$v = 7000km/s \ and \ H = 75km/s/Mpc$

Then,

$$D = \frac{7000km/s}{75km/s/Mpc}$$

$$D = 93.33 \quad Mpc$$

Hence, the distance of the Coma cluster is about 93 Mpc.

4. Using the redshift-distance relation, how far is the farthest galaxy included in this study? How much smaller is this distance than the limit of the observable universe, which is about 4.6×10^9 **parsecs?**

The farthest galaxy in this study is NGC 5280 and it's distance is 145 Mpc. The observable universe is approximately 32 times more than that of the distance of the farthest galaxy in this study.

5. Discuss the problem of completeness of the sample, which is based on a catalog of galaxies identified on photographs. What sorts of objects might be missing from our survey? How could we improve the completeness?

If this data sample is collected through optical telescope then the objects which emits their peak radiation other than optical range are missing from this sample. To improve the completeness, we can observe the universe in multiple bandwidths and then combine them to get a much more comprehensive view of the observable universe, which itself is a fairly small portion of the total universe.

6. Beyond the Coma cluster there is a loose band of galaxies stretching from east to west across the entire survey volume. It is called the "Great Wall".
a. Using the Hubble redshift-distance relation, calculate the distance to the Great Wall.
b. One can use simple trigonometry to estimate the length of the Great Wall. If D is the distance of the Great Wall, and Θ is the angle it spans in the skies (in degrees), then

$$Length\ of\ the\ great\ wall = 2\pi \times D(\frac{\Theta}{360})$$

Use this formula to estimate the length of the Great Wall (which is just a lower limit, since it may extend beyond the boundaries of our survey.) Give your answer in mpc and ly (3.26 1y = 1 pc).

a). 9000 km/sec= 75 km/sec/mpc $\times$ D $\Rightarrow$ D=120mpc
b). L= $2\pi \times 120mpc \times \frac{30^\circ}{360}$= $62mpc \times 3.26$ yr/parsec=$2.05 * 10^8$ ly

4 Discussion

• The number of specimens used are too few to make a statistically robust declaration
• The range of redshifts used in the experiment is quite narrow. A broader range may provide a better estimate.
• The method of spectroscopic analysis for redshift calculation should be validated by other methods of redshift calculation such as the use of Cepheid variables and Type Ia supernovae.
• Several approximations were used in this experiment for brevity and ease of execution, such as the assumption of a fixed absolute magnitude M and the usage of the v = zc formula to approximate the recession velocity.

5 Acknowledgement

We thank the Department of Physics, Gettysburg College for the virtual observatory software VIREO which has been used in producing the diagrams shown in this report. We would also like to thank the various contributors to the python libraries which have been used to generate the required plots for this exercise.