What is the Age and Size of the Universe
ASTR 102

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1 Objective

The objective of this lab report is two answer two questions: What is the age of the universe, and what is the size of the universe. Through these questions, I will also demostrate how the Hubble Law can be calculated by observing distance galaxies and how it can be used to calculate the size and age of the universe.

2 Introduction

We all live in a house. That house is in a city, in a province, in a country, in a continent, on Earth. Earth is in a solar system, in a galaxy, in a cluster of galaxies, in the Universe. Just for the scope of things. But how big and how old is that scope? Back in 1905, Einstein's special relativity [1] hit the scene showing that Light is the fastest moving matter and will always move at the same speed. This insight will eventually lead us down the path to how big the universe is. Einstein also came up with his infamous cosmological constant [5] which allowed the universe to stay the same size. He would later state this was the biggest mistake of his career.

Later, Edwin Hubble came along and discovered the Hubble Constant [6] , a remnant of Einstein's cosmological constant (he was sort of right), a figure that shows the relationship to how distant two obejcts are and their velocities. Through this constant, and Einstein's special relativity, Hubble was able to make general predictions of how big the observable universe was and how old it was leading up to the big bang.

While we generally take for granted the results of these experiements and calculations of universe size and age, very few people know how it is calculated. This report will demostrate how using spectroscopy on distant galaxies, we can find the hubble constant and thus determine the size of the universe and its age.

3 Equipment

For this report, the following list of equipment was used. The "Contemporary Laboratory Experience in Astronomy" which is a Windows program developed by Larry Marshall's group at the Department of Physics at Gettysburg College. A SHARP-EL510R calculator. A single sheet of opaque graph paper. A blue pen for drawing on the graph paper. Finally, Google Calculator [1] was also used.

4 Procedure

The procedure preformed in this report is broken down into the following two sections: Measruements, and Calculations

4.1 Measruements

For the following procedure, the Windows program "Contemporary Laboratory Experience in Astronomy" (CLEiA) was used. First, CLEiA was run from a Windows personal computer. From here, a number of steps in the CLEiA simulation had to be preformed for the use inside this lab. First the virtual dome was opened by clicking the Dome button. Next, star tracking was turned on by clicking the Tracking button. Finally, the slew rate was set to 16 to allow faster movements of the telescope by clicking the Slew Rate button twice. The next procedures were preformed for 3 galaxies inside each of the given fields of the CLEiA program.

The chosen galaxy was centered in the telescope's field of view. Next, the Change View button was clicked to get a magnified view of what the telescope's field of view was pointed at. From here, the galaxy was once again centered on the cross hair. This time however, the cross hair were two parallel lines. These lines were placed over the middle of the galaxy where the best measruement could be taken. Next, the Take Reading button was placed which opened up a new window that had a spectroscopy graph on it. From here, the Start Count button was pushed. This button started the spectroscopy readings of the galaxy and their K and H calcium absorbption lines. For most galaxies, the readings continued until the Signal/Noise was at least 20.0 (some were stopped at 10.0 for time). After the Signal/Noise level was appropriate, the Stop Count button was pushed to stop the reading. Now, the object's name, the apparent magnitude and K calcium absorption lines were read and placed in Table 1. To measure the K calcium line, the cursor was used to click on the lowest point of the line and then measure the wavelength that was given. These steps were repeated

[1] http://www.google.ca/help/features.html

for 3 galaxies in each of the 6 fields given by the CLEiA program.

4.2 Calculations

Once all measurements had been taken, a series of calculation was preformed. For each row inside of Table 1, the following calculation were preformed.

First, the change in K calcium wavelength was computed using Equation 1. Nest, the velocity of the object was calculated using Equation 2. And finally, the distance of the object from Earth was calculated using Equation 3.

After each of the latter equations were used on each row in Table 1, Three final calculations were used to calculate the Hubble Constant (Equation 4, the slope of Figure 1), the size of the observable universe (Equation 5), and the age of the universe (Equation 6).

5 Observations

All observations for thie report were made on the day of 2013-Mar-18. Since the result of any given observation did not depend on time of day or weather, they have been omitted from this report. All spectroscopy measurements made in this report were made using the "Contemporary Laboratory Experience in Astronomy" (CLEiA) and can be found in Table 1. These are the only observations made for this report.

6 Tables and Measurements

The following table corrsponds to the spectroscopy measurements and various other details of distance galaxies using CLEiA. The later columns correspond to calculations made using Equation 1, Equation 2, and Equation 3.

Galaxy	magnitude	lambda	delta	v(km/s)	D(Mpc)
Coma1	12.30	4012.0	78.0	5944	72.4
EDW	13.45	4050.0	116.0	8839	123.0
LAM	11.15	3973.0	39.0	2972	42.7
PRC	13.36	4051.0	117.0	8916	118.0
CrBor2	15.43	4209.0	275.0	20956	306.2
CrBor1	15.08	4208.0	274.0	20880	260.6
CrBor3	15.35	4208.0	274.0	20880	295.1
Boot2	16.76	4446.0	512.0	39017	564.9
Boot3	16.72	4445.0	511.0	38941	554.6
Boot1	16.52	4444.0	510.0	38864	505.8
Coma3	12.45	4012.0	78.0	5944	77.6
Coma2	12.55	4012.0	78.0	5944	81.3
uma1-3	14.49	4130.0	196.0	14936	198.6
uma1-1	14.62	4130.0	196.0	14936	210.9
uma1-2	14.52	4130.0	196.0	14936	201.4
uma2-1	16.87	4484.0	550.0	41913	594.3
uma2-3	16.89	4484.0	550.0	41913	599.8
uma2-2	16.67	4484.0	550.0	41913	542.0

Table 1: Spectroscopy measurements of galaxies in CLEiA.

7 Graphs

The graph of meassured galaxy Speed(km/s) vs. Distance(Mpc) can be found at the back of this lab report labelled as Figure 1.

8 Calculations

The following equation was used to calculate all values in Table 1 under column delta. This equation gives the difference between an at rest body's K calcium absorbtion line wavelength and a moving body's K calcium absorbtion line wavelength.

$$\Delta\lambda_K = \lambda' - \lambda \tag{1}$$

The following equation was used to calculate all values in Table 1 under column velocity. This equation gives the speed at which a galaxy is moving away from the Earth at.

$$v = c * \frac{\Delta\lambda}{\lambda} \tag{2}$$

The following equation was used to calculate all values in Table 1 under column distance(Mpc). This equation gives the distance in megaparsecs of how far away a galaxy is from Earth. Here we assume the absolute magnitude, M = -22.0.

$$D = 10^{\frac{m-M-25}{5}} \tag{3}$$

The following equation was used to calculate the slope of the graph in Figure 1.

$$H = \frac{(18000 - 6000)}{(240 - 80)} = 75km/s \tag{4}$$

The following equation was used to calculate the size of the observable universe.

$$size = \frac{c}{H} = 3997Mpc = 13,000,000,000lyr. \tag{5}$$

The following equation was used to calculate the age of the universe.

$$age = \frac{1000}{H} = 13,300,000,000years \tag{6}$$

9 Results

The results of this report can be found by examining the results of Equation 5 and Equation 6. Here we find that the size of the observable universe was found to be 13 Billion ligh years in radius from the Earth. The age of the universe was found to be 13.3 billion years old.

These results were found by using the intermediate result of the found Hubble Constant which was found to be 75km/s/Mpc. The accepted results for these two primary questions and one intermediate step are as follows. The accepted size of the observable universe 14.3 billion parsecs [2]. The accepted age of the universe 13.77s billion years old [3]. The accepted value of the Hubble constant is 69.32km/s/Mpc [4].

10 Threats to Validity

The main threat to validity in this lab report is the reliance on the CLEiA Windows program. Here all values into the program have been somewhat precomputed and are therefore subject to any errors in the initial collection of data by the creators of CLEiA and the astronomers who supplied the data. The other issue with CLEiA that causes a threat to validity is the measurements preformed on the spectroscopy printout of each galaxy as seen in Table 1. Each of the K calcium absorption lines were done by attempting to read the perfect center location of the line. These measurements are subject to error as the exact center of the line may not have been selected.

A secondary thrate to validity is the calculation of the Speed vs. Distance graph found in the back of this lab report labelled as Figure 1. Here the line used to create the graph was done by hand and was a best fit line. The slope therefore does not fully represent the true slope of the points plotted on the graph. This could have been preformed better with graphing software.

11 Conclusions

This report has shown how to calculate three items using the CLEiA Windows program. First, the Hubble Constant was calculated by determining the speed and distance of galaxies. Next, the hubble Constant was used in order to determine both the size of the observable universe as well as the age of the universe. In this report, reasonable answers were found that closely related to the true accepted values for the main questions posed in this report.

12 Evaluation

I found this lab extermely interesting for the demostration of the universe size and age. I have always wondered how these ages were precisely calculated and how the Hubble Constant came about. The Hubble Constant seems interesting to me as it looks like it closely relates to both inflation and Einstein's infamous cosmological constant. I had lots of questions after this lab was over however but would take too long to ask. If space can expand faster than light can move then how does this not violate special relativity [1]. Among others. I would have also liked to see an explination of the difference between the observable universe and the entire universe, or some explination of the possible shape of the entire universe.

References

[1] Albert Einstein (1905) "Zur Elektrodynamik bewegter Krper", Annalen der Physik 17: 891

[2] Gott III, J. Richard; Mario Juri, David Schlegel, Fiona Hoyle, Michael Vogeley, Max Tegmark, Neta Bahcall, Jon Brinkmann (2005). "A Map of the Universe"

[3] Bennett, C.L.; Larson, L.; Weiland, J.L.; Jarosk, N.; Hinshaw, N.; Odegard, N.; Smith, K.M.; Hill, R.S. et al. (December 20, 2012). Nine-Year Wilkinson Microwave Anisotropy Probe (WMAP) Observations: Final Maps and Results

[4] http://map.gsfc.nasa.gov/ (WMAP website)

[5] Urry, Meg (2008). The Mysteries of Dark Energy. Yale Science. Yale University.

[6] Lematre, Georges (1927). "Un univers homogne de masse constante et de rayon croissant rendant compte de la vitesse radiale des nbuleuses extragalactiques". Annales de la Socit Scientifique de Bruxelles A47: 4956