Astron 1221 Project 2 Written Report

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1 Introduction

This is a written report for Astronomy 1221. In this project, we will calculate the Hubble constant using data from Type-1a Supernovae. We will use data from Tonry et al. 2003, plot a distance vs velocity graph, and fit the data using a linear equation. The slope of the graph is the Hubble constant for the data. We will then calculate the ago of our universe based on that Hubble constant.

2 Theory

The Hubble constant (H_0) is a fundamental parameter in cosmology that describes the rate of expansion of the universe. The relationship between a galaxy's recession velocity (v) and its distance from Earth (d) is given by Hubble's law:

$$v = H_0 d$$

Here, v is the galaxy's velocity due to cosmic expansion, and d is its distance. H0 is the Hubble constant, typically expressed in units of $km/s/Mpc$ (kilometers per second per mega-parsec). This means that for every mega-parsec of distance, the velocity increases by H_0 km/s. The discovery of this relationship in 1929 by Edwin Hubble led to the conclusion that the universe is expanding.

Type Ia supernovae play a crucial role in determining cosmological distances. These supernovae, also known as "standard candles," have a consistent peak luminosity. By comparing their observed brightness (apparent magnitude) with their intrinsic brightness (absolute magnitude), astronomers can calculate their distances. The combination of these distances with Redshift data allows for the determination of the Hubble constant.

Once the Hubble constant is measured, it can also be used to estimate the age of the universe. Under the assumption that the universe has been expanding at a constant rate, the inverse of the Hubble constant gives an approximation for the universe's age:

$$t_{\text{universe}} = \frac{1}{H_0}$$

This equation is simplified and assumes no changes in the expansion rate over time, though more precise calculations would incorporate the influence of dark energy, dark matter, and the curvature of space-time.

3 Methods

In this project, we utilized Python programming to perform calculations and generate plots related to the Hubble constant, age of the universe, and the rate at which the universe is expanding. The primary goal was to model the distance versus time of galaxies, fit the data using a linear equation, and calculate the effective Hubble constant.

3.1 Extracting the Data

The first step in obtaining our calculations was using the data from Tonry et al. (2003) to get actual data points of the rate of expansion of the universe.

The first group of data points we must extract is the distance plots. These were positioned in column 8 of the data. To make the data easier to use with our calculations, we converted the unit in the data to mega-parsecs. To this, we used the equation:

$$10^x/72$$

where x is each data point. We applied this equation to each point in the distance data to convert the data to mega-parsec.

The second group of data points we extracted was the velocity. The unit that the original velocity data was in was also converted to a different unit to make the calculations easier. In this case, we converted it to kilometers per second. The equation we used is the following:

$$10^y$$

where y represents each individual velocity data point. We applied this equation to each data point in the velocity data to convert the data to kilometers per second.

With this data extracted, we can move on to plotting it and making our calculations.

3.2 Plotting and Creating a Linear Fit

After obtaining all the data, we used the Matplotlib Python library to create a distance vs velocity graph of the data. The distance was used for the x scale and velocity was used for the y scale. This plot can be seen below in figure 1: After plotting the data, we can see that there is a very clear linear trend to the data. To

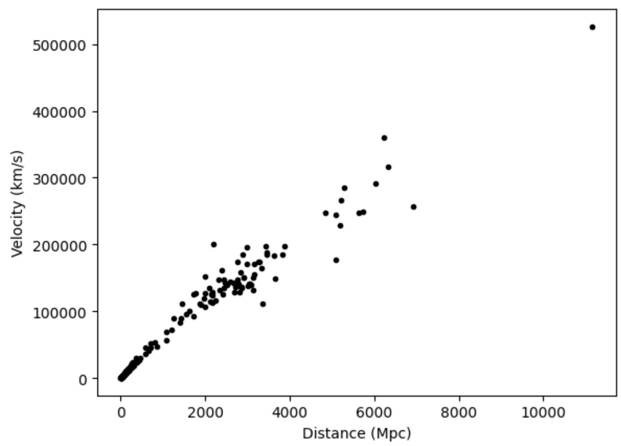

Figure 1: Distance vs Velocity graph representing the expansion of the universe

confirm this, we used the Numpy python library to create a linear fit of such data. This was done with the following lines of code:

```
import numpy as np
import astropy.units as u

z_linear_data = np.polyfit(distance.to(u.mpc).value, velocity.to(u.km / u.s).value, 1)
C_linear_data = z_linear_data[0] * distance.to(u.mpc).value + z_linear_data[1]
```

This uses a least squares polynomial fit to calculate the linear fit. The linear fit is represented in the *C_linear_data* variable. This is done by using slope of the linear fit, represented as *z_linear_data*[0], and then multiplying that by each distance point and adding the y-intercept of the linear fit (represented as *z_linear_data*[1]). Plotting this calculated linear fit produced the following graph (figure 2):

3.3 Calculating the Hubble Constant

Now that we have our linear fit of the data, we can calculate the Hubble constant and, by extension, the age of the universe. The Hubble constant can be calculate by simply observing the slope of the linear fit of the data. The age of the universe can then be calculated using the following equation:

$$A_u = \frac{1}{H_0}$$

where H_0 is the observed Hubble constant and A_u is the age of the universe.

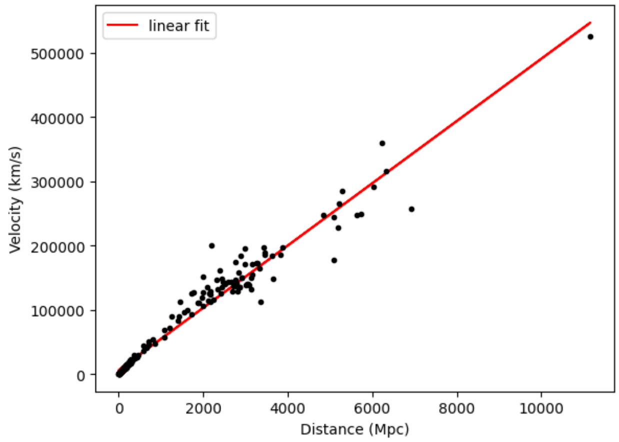

Figure 2: Distance vs Velocity graph representing the expansion of the universe with the linear fit

4 Results

4.1 Hubble Constant

As mentioned in the methods section, we could obtain the observed Hubble constant by looking at the slope of the linear fit we created. Initially, we calculated the Hubble constant to be 48.47 kilometers / second / mega-parsec. This results differs heavily from the currently estimated Hubble constant of around 68. After finding this, we made the decision to limit the x-range of the data given that most of the data is centered below the 5000 Mpc line. We can also see that the data beyond that point strays further from the linear fit and has higher error ranges. After making this adjustment, we found the observed Hubble constant of the data to be 67 km/s/Mpc which alligns much closer with the current estimated value.

4.2 Age of the Universe

After obtaining of adjusted Hubble constant of 67 km/s/Mpc, we then used the equation stated in the methods sections to obtain the estimated age of the universe. The result of this calculation is the following:

$$A_u = \frac{1}{67} km/s/Mpc$$

We then took this value and converted it to billions of year often referred to as the unit of gyr. This resulted in a value of $1.456e-8$ Gyr or 14.56 billion years. This aligns somewhat closely with the current estimated value of around 13.8 billion years.

4.3 Assumptions and Limitations

- **Linear Relationship**: We assumed that the expansion rate of the universe continues to have a linear relationship beyond the data that we have used and observed.
- **Data Accuracy**: We assumed that the data we used was collected accurately and also properly conveys the distance and velocity data points we used for our calculation of the age of the universe.

5 Conclusion

In this project, we used data from Tonry et al. (2003) to calculate the Hubble constant using observations of Type Ia supernovae. By fitting a linear model to the relationship between redshift and distance, we obtained an estimate for the Hubble constant. Based on this estimate, we calculated the approximate age of the universe.

We finally calculated the Hubble constant to be 67.48, which is consistent with our actual precise value, proving that our data is relatively accurate. The calculated age of the universe is roughly $1.45e10$ years, which is also close to the actual age of the universe.

6 AI Statement

We did not use AI to assist in any of our calculations or any other part of the project.

7 Contributions

Introduction, Theory, and Conclusion: Wentao Zhong
Methods and Results: Sam Grobelny
Presentation Slides: Sach Wible