Determining the Hubble Constant of the Universe

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Objective

In this experiment, we analyzed the images and spectra of multiple galaxies and found the velocity and distance from Earth of each galaxy. Plotting the velocity against distance, we found a value for the Hubble constant using the slope of the trendline. This value was used to compute the age of the universe. Both the Hubble constant and the age of the universe were compared to the currently accepted values for consistency.

Background

- In the 1920's, Edwin Hubble surmised that the universe was expanding uniformly.[1]
- This was discovered by his observation of the recessional velocity of galaxies relative to their distance, expressed as

$$v = H_0 d \tag{1}$$

where v is the recessional velocity, H_0 is the Hubble constant, and d is the distance.
- The Hubble constant is one of the most significant numbers in astronomy because it sets the rate of expansion and its reciprocal gives the age of the universe.
- Though highly disputed, the currently accepted value for Hubble's constant is 70 km/s/Mpc and the accepted age of the universe is 13.77 billion years.[2]

Theory

- Rearranging Eqn. 1 gives an expression for the Hubble constant,

$$H_0 = \frac{v}{d} \tag{2}$$

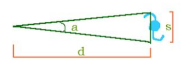
- The recessional velocity of a galaxy is expressed, via the Doppler formula, as

$$v = zc \tag{3}$$

where z is the redshift and c is the speed of light, 3×10^6 km/s
- Galaxies experience a perceived shift in their wavelength due to the motion of the expansion of space. Redshift gives a percentage of the shift, expressed as

$$z = \frac{\lambda - \lambda_0}{\lambda_0} \tag{4}$$

- For this experiment, we measured the redshift for three spectral lines and calculated the average redshift for each galaxy.
- Using Figure 1: Trigonometric Model of Distance to a Galaxy



- and small angle approximation, the distance to a galaxy is

$$d = \frac{s}{a} \tag{5}$$

where a is the angular distance and s is the galaxy's size.
- All the galaxies in this experiment were spiral galaxies so we used a standard candle assumption[3]; s=22 kpc for every galaxy.

$$d = \frac{22\ kpc}{a} \tag{6}$$

- To obtain the Hubble constant, the recessional velocities of galaxies are plotted in relation to their distances on a scatter plot. A trendline is taken with a starting point at the origin, representing a starting point in the Milky Way galaxy with no velocity.

Theory Continued

- According to Eqn. (2) where the velocity over distance gives Hubble's constant, the slope m is equal to Hubble's constant.
- The uncertainty in the value for Hubble's constant was found using the LINEST function to get the standard error in the slope of the linear function.
- The Hubble constant gives the rate at which the universe expands so its reciprocal gives a value for how long it has been expanding, or the maximum age of the universe.

$$maximum\ age = \frac{1}{H_0} \tag{7}$$

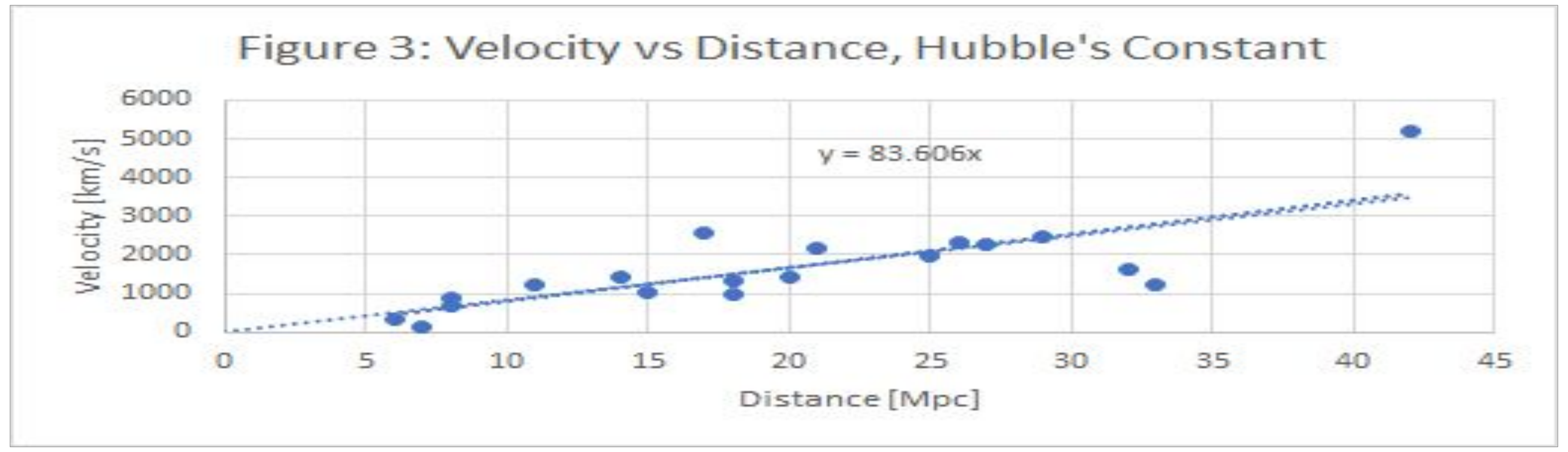
- The standard error in the maximum age of the universe is given by calculating the product of the standard error of the Hubble constant and the partial derivative of the maximum age with respect to the Hubble constant.

$$SE(maximum\ age) = (SE(H_0))\left(\frac{\partial H_0}{\partial (maximum\ age)}\right) \tag{8}$$

Experimental Data

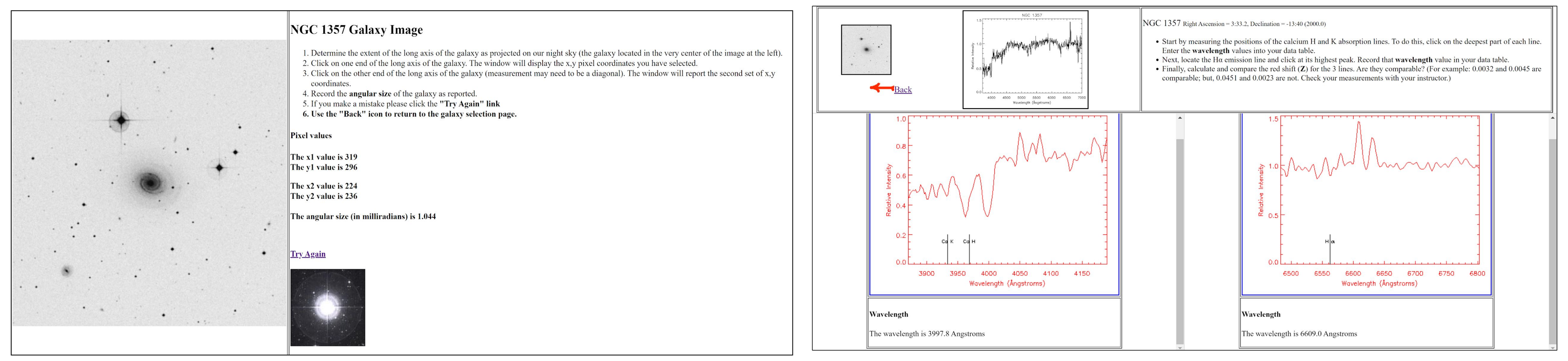
Table 1: Experimental Values for Angular Size, Distance, Redshift, and Velocity

Galaxy ID (NGC number)	Angular Size (milli-radians)	Distance (Mpc)	Redshifted Wavelength Values						Average Redshift	Velocity (km/s)
			Calcium (CaII) K		Calcium (CaII) K		Hydrogen (Halpha)			
			Measured	Redshift (z)	Measured	Redshift (z)	Measured	Redshift (z)		
1357	1.04	21	3962.9	0.0074	3997.8	0.0074	6608.2	0.0069	0.0072	2172
1832	0.87	25	3959.8	0.0066	3994.7	0.0066	6605.9	0.0066	0.0066	1980
2276	0.84	26	3966	0.0082	3996.2	0.0070	6614.4	0.0079	0.0077	2305
2775	1.62	14	3953.6	0.0051	3986.9	0.0046	6592	0.0044	0.0047	1414
2903	3.53	6	3937.4	0.0009	3971.5	0.0008	6573.4	0.0016	0.0011	331
3034	3.26	7	3935.8	0.0005	3970.7	0.0006	6563.3	0.0001	0.0004	116
3147	1.31	17	3968.4	0.0088	4000.9	0.0082	6620.6	0.0088	0.0086	2579
3227	1.1	20	3948.2	0.0037	3983.8	0.0039	6606.7	0.0067	0.0047	1423
3368	2.04	11	3945.1	0.0029	3980	0.0029	6605.1	0.0064	0.0041	1224
3623	2.89	8	3939.7	0.0015	3975.3	0.0017	6600.5	0.0057	0.0030	898
3627	2.77	8	3942	0.0021	3977.6	0.0023	6577.3	0.0022	0.0022	661
4775	0.68	32	3957.5	0.0061	3989.3	0.0052	6595.1	0.0049	0.0054	1621
5248	1.19	18	3945.9	0.0031	3981.5	0.0033	6585	0.0034	0.0033	976
5548	0.52	42	4000.9	0.0171	4039.6	0.0179	6673.3	0.0168	0.0173	5184
6181	0.83	27	3966	0.0082	3998.6	0.0076	6609	0.0070	0.0076	2284
6217	0.67	33	3949.8	0.0041	3984.6	0.0041	6588.9	0.0040	0.0040	1213
6643	1.22	18	3952.1	0.0047	3985.4	0.0043	6592.7	0.0046	0.0045	1349
6764	0.77	29	3963.7	0.0076	4007.9	0.0099	6609.8	0.0072	0.0082	2472



Experimental Procedure

Figure 2: Sample Images of Experimental Galaxy Imaging and Spectral Analysis [NGC 1357][4]



Results and Conclusion

- Our value for Hubble's constant was **H_0= 84±7 km/s/Mpc**.
- Our value for the maximum age of the universe was **maximum age= 12±1 billion years**.
- Our Hubble constant and age of the universe are consistent with the accepted value as the accepted values just within two standard errors of our values. As our Hubble constant was larger than the accepted value, our age of the universe was smaller than the accepted age.
- Compared to the age of the Sun (5 billion years), our age is plausible but compared to some of the oldest stars in the Milky Way (12.5 billion years), our age is inconsistent. According to our calculations, stars in the Milky Way are older than the universe which is impossible and suggests that our value for the Hubble constant is incorrect. A possible source of error may have been in our standard candle assumption we utilized to find distance. We assumed every galaxy to be the same size but they are not the same size so this assumption added error to our values.
- Another issue with the standard candle is dark energy. Dark energy is a theoretical energy that keeps gravity from slowing the acceleration of the universe and accelerates the expansion of the universe. Some standard candles may be in the decelerating part of the universe while others are in the accelerating part of the universe, meaning that there is no "standard" because these candles result in differing Hubble constants that are both correct. This ultimately brings into question whether the accepted age of the universe is correct because according to dark energy the rate at which the universe expands is not a constant value. If the universe is expanding at an accelerated rate, its age cannot be predicted solely via the Hubble constant.[5 6]

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