"Re-discovering the Expansion of the Universe"

Dominique Holiday, Bria McClain, and Vernell McCoy

Dunbar Vocational Career Academy

The University of Chicago

Introduction

In 1929, Hubble showed that the Universe is expanding by discovering that galaxies are moving faster the further away they are, in all directions. Hubble used special types of variable stars called Cepheid variables to measure distances to galaxies. By measuring galaxy redshifts (how much light shifts when a galaxy moves along with the expansion of the Universe) he was able to obtain their velocities. Our approach differs as we will use light from distant supernovae to determine distances to their host galaxies instead. We will achieve this by using data from the Sloan Digital Sky Survey (SDSS).

What are Supernovae?

There are two types of supernovae. One type occurs when massive stars (8-20 times the mass of our Sun) run out of nuclear fuel, their cores collapse, and a star explodes. The other, called Type Ia occurs when a white dwarf (itself a star which has died) accretes matter from a companion star and reaches a mass limit of 1.4 solar masses, known as the Chandrasekhar limit. This results in a thermonuclear fireball. The explosion is often as bright as the host galaxy itself, and can be seen up to 10 billion light years. Supernovae can therefore reveal how the Universe changes over several billion years.

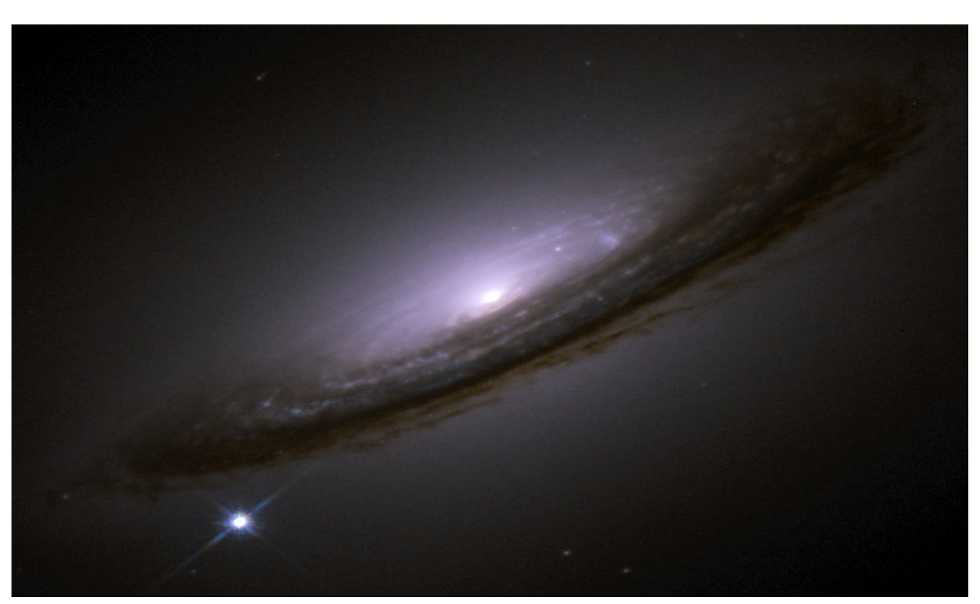

Figure 1: Supernovae Type Ia (1994D) in the galaxy NGC 4526 can be seen in the bottom left hand corner. Image Credit: NASA, ESA,The Hubble Key Project Team, and The High-Z Supernova Search Team.

About SDSS

The Sloan Digital Sky Survey (SDSS) provides a three dimensional picture of the Universe by observing one quarter of the sky and mapping the positions of hundreds of millions of objects. It measures more than a million distances to galaxies, stars, and quasars. It also carried out a Supernova Survey. It targeted Type Ia supernova in the redshift range between 0.05 < z <0.35. The SDSS telescope is located at Apache Point Observatory (APO) in New Mexico, sitting atop a mountain 9,200 feet above sea level, where there are less pollutants and water vapor in the atmosphere.

SDSS Camera and Photometry

The SDSS telescope uses a complex camera (shown in Fig. 2) that is made up of 30 electronic light sensors called charge-coupled devices (CCDs) arranged in 6 columns Each column has five filters that select certain wavelengths of light. The camera captures the light from an astronomical source, and gives the measure of the brightness of the object in each of the five filters. The five filters are u, g, r, i and z. They allow through different wavelengths of light such as ultra violet for the u filter, green for g, red for r, infrared for i, and far infrared for the z filter. The transmission of each filter is shown in Fig 3.

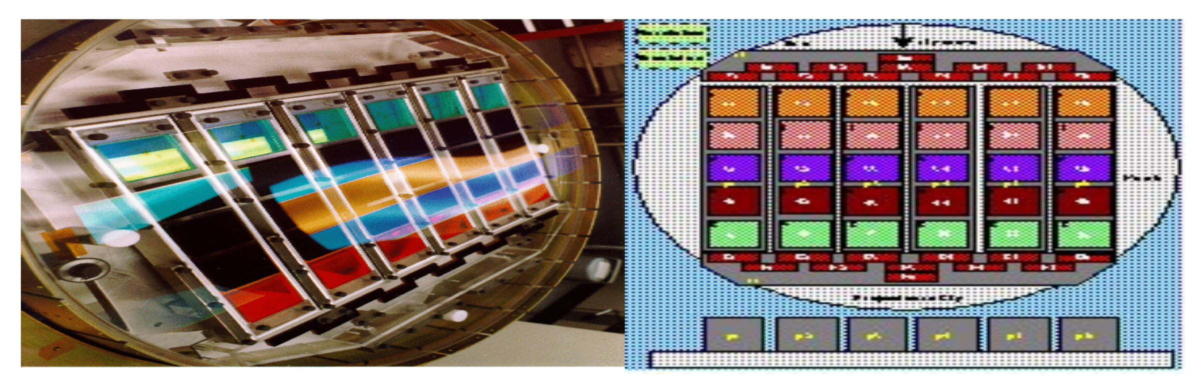

Figure 2 : Actual picture (left) and diagram (right) of arrangement of CCDs. The image of the CCD Camera and the filter transmission plot courtesy of SDSS.

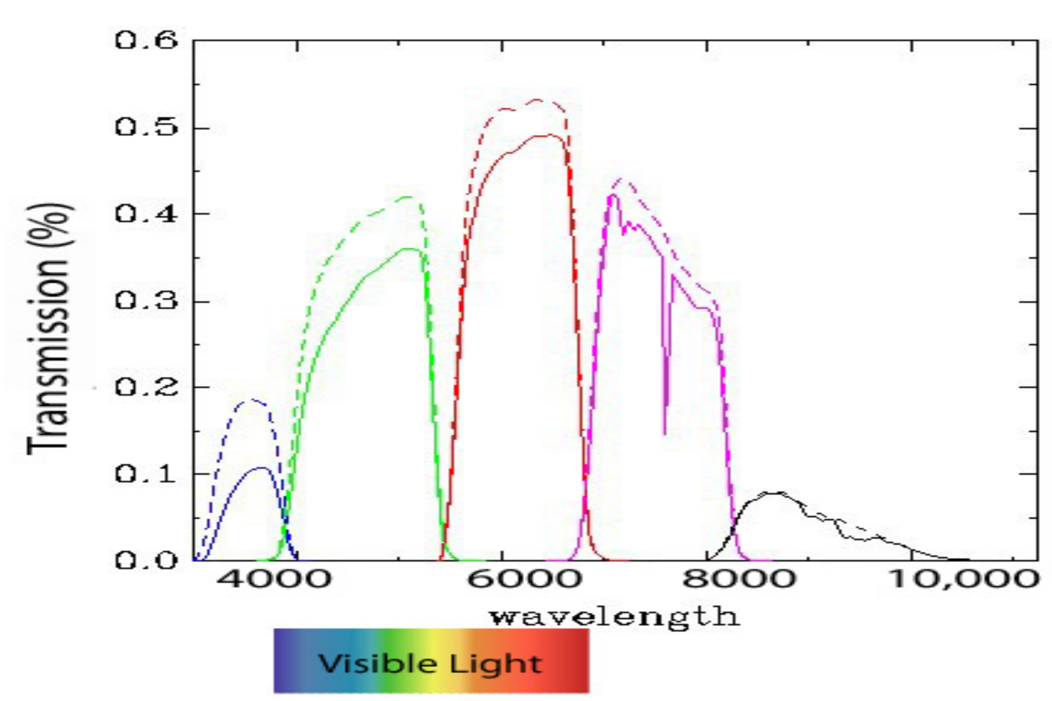

Figure 3: Wavelengths of the ugriz bandpasses at which they are sensitive.

Light Curves

We measured the apparent magnitudes (how bright an object appear in the sky) of 15 supernovae, a subset of the SDSS Supernovae Survey. For each of the five filters *ugriz*, we show the supernovae light curves by plotting the apparent magnitude vs. time, as measured by the Modified Julian Date (MJD). Shown in Fig. 4 is a light curve supernova SN2635.

Light Curves (cont.)

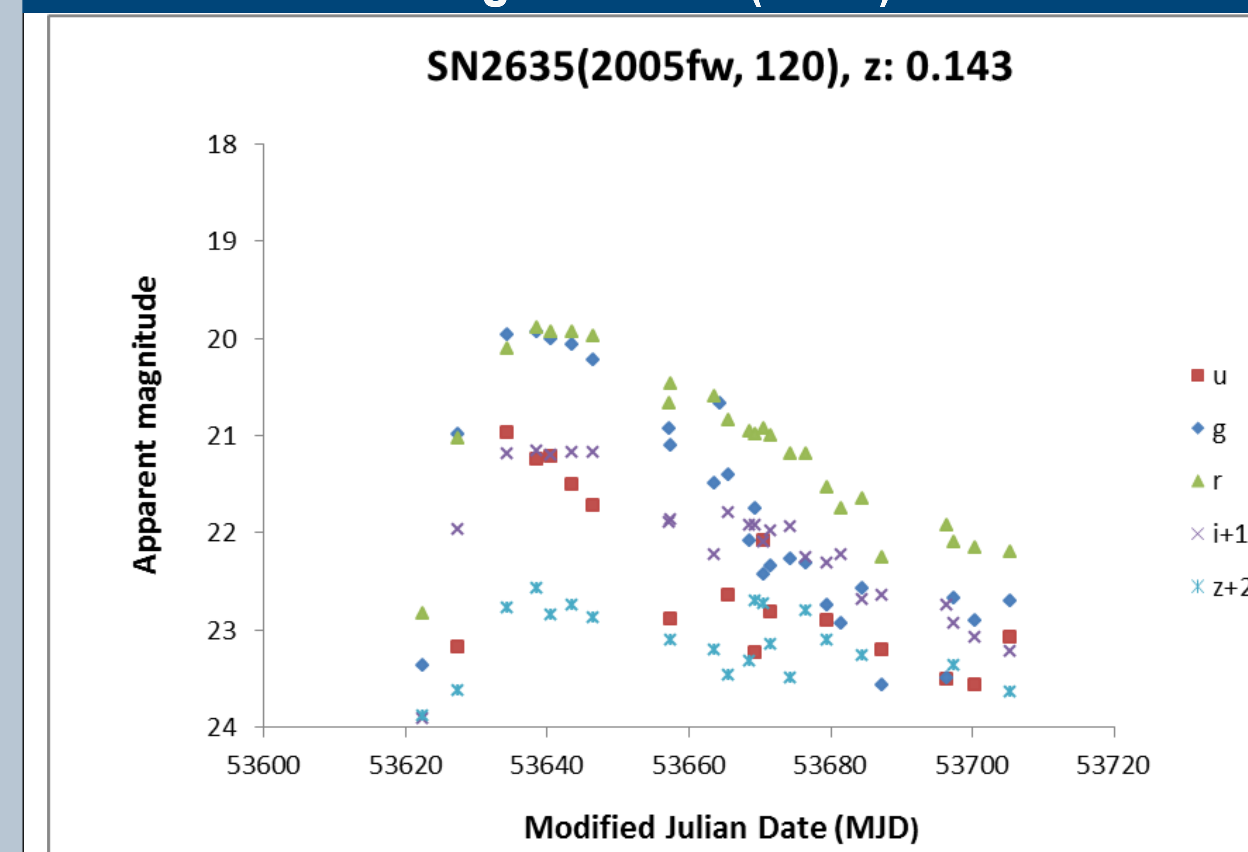

Figure 4: In the light curve graph above, each colored point represents a different filter. Together the points forms a curve, with a rise and fall demonstrating the brightness of light over time.

We then took 15 supernovae peak magnitudes in the g and r band in order to work out how far away they are. To do this we used the distance modulus,

$$m-M=5\log d-5$$

where m is the apparent magnitude of an object, M is the absolute magnitude (how bright it would appear if it was 10 parsecs away) and d is distance in parsecs. Since we don't know the absolute magnitude of the Type Ia supernovae ourselves, we use a previously published result for the absolute magnitude of SN1998bu equal to -19.42 in the V band. The V band in the UBVRI photometric system does not completely correspond to the Sloan g and r bands. We will therefore look at both g and r bands using the same absolute magnitude. This will naturally create a source of error that we will investigate at the end of our project.

Results

Having calculated the velocities of host galaxies and distances to supernovae we obtained plots of velocity vs. distance for 5 magnitude filters. The plot below shows a linear relationship between the two quantities for the r magnitude, and we measured its slope. We obtained a slope of 48 km/sec/Mpc in the r band. This slope is actually equal to the Hubble constant H_0, that appears in the Hubble Law, $V=H_0\ d$. V is the galaxy's radial velocity measured in km/sec and d is the galaxy's distance from the Earth in megaparsecs. The Hubble constant is very important because it can be used to estimate the size, age and shape of the Universe. It indicates the rate at which the Universe is expanding. It is not really a constant because it changes with time. That is why it carries the subscript "0" to indicate that it is the value at the present time.

Results

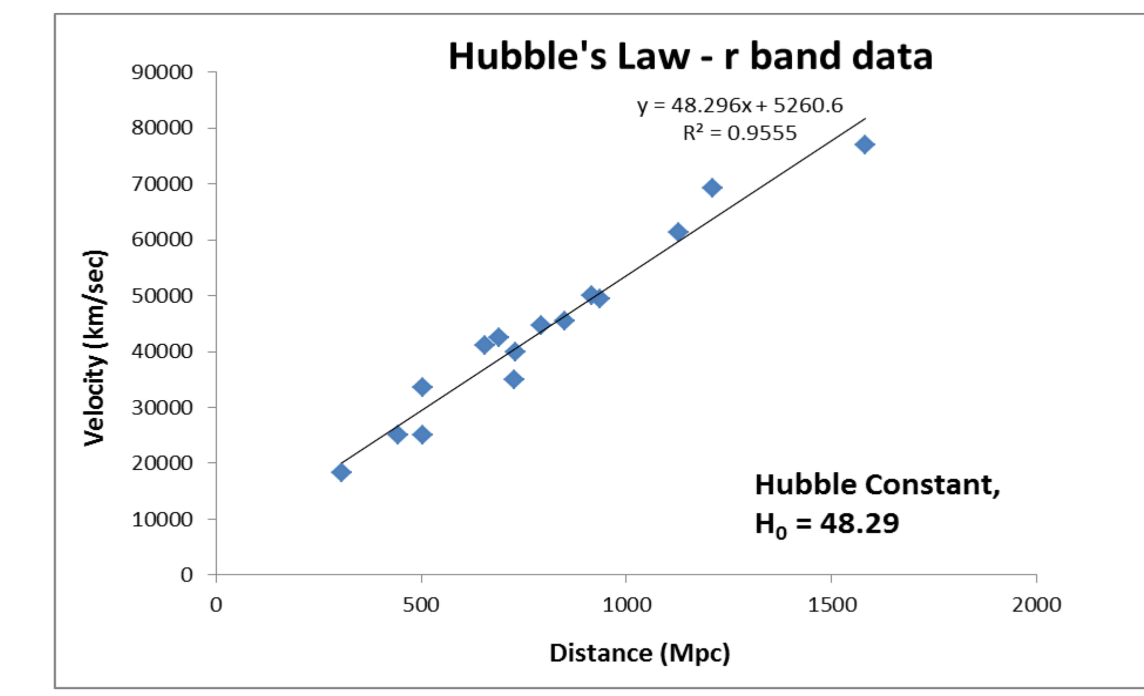

Figure 5: Plot of the relationship between distance and velocity, demonstrating the expansion of the Universe. The slop of the graph give the value of the Hubble constant and is equal to 48.3 km/sec/Mpc.

The current accepted value of H_0 is 71.2 km/sec/Mpc from measurements of the Cosmic Microwave Background (CMB). Our measured values differ for two reasons:

1) We used only 15 of the 146 supernovae from the Supernovae Survey, which will introduce some scatter.
2) We used the V band magnitude in the UBVRI photometric system. Sloan uses the *ugriz* system and the absolute magnitude of a supernova in either the r band or the g band is not going to be -19.42.

Absolute Magnitude SN 1A	g band Hubble Constant	r band Hubble Constant
-18.42	66.63	76.54
-19.42	42.04	48.29
-20.42	26.52	30.47

Figure 6: Shown is the variation of the Hubble constants in the g and r bands when the absolute magnitude is varied from -18.42 to -20.42. We obtain a range of values for the Hubble constant of 30.5 to 76.5.

Conclusion and Acknowledgements

We measured 15 supernovae magnitudes and obtained distances to them by assuming an absolute magnitude of -19.42, allowing us to estimate the Hubble constant of 48. Given the uncertainty in the absolute magnitude, we varied it between -18.42 and -20.42, giving a range of values for the Hubble constant of 30.5 to 76.5. We would like to acknowledge our instructors, Dr. Donald York, Professor Richard Kron, Alan Zablocki, Justin Johnsen, Julia Brazas, Mitch Marks, Russ Revzan, Terry Jones and our teacher Mr. Cartman.

References:

1) The Type Ia Supernova 1998 M96 and the Hubble Constant, Jha et.al
2) The Sloan Digital Sky Survey- II: Photometry and Supernova Ia Light Curves From 2005 data. Holtzman et.al