Dark Energy and the Expanding Universe

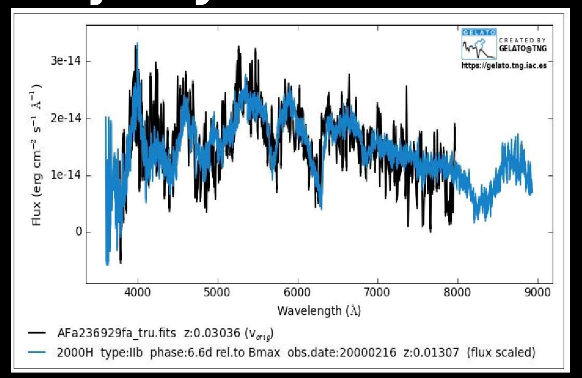
Austin Williams; Hereford High School, 2015

Abstract

Over the summer, I investigated the use of type 1a supernovae* to find the history of the expansion of the universe and the universe's composition which affected this. By analyzing published data on the magnitude* and redshift* of distant supernovae, I was able to make a rough relationship between time and expansion rate. The contents of the universe at different times can then be predicted based on how these expansion rates compare to simple mathematical models.

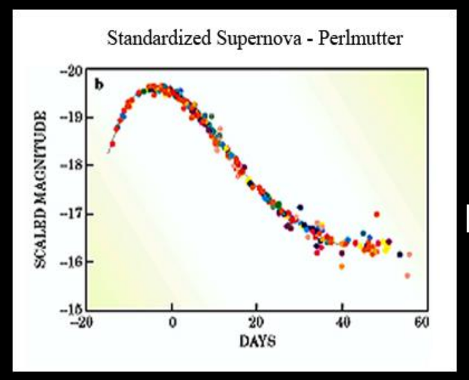
Introduction

The expansion should be decelerating due to gravity, but instead it is accelerating. This led to the discovery of dark energy, the pushing force that makes up the majority of our universe.



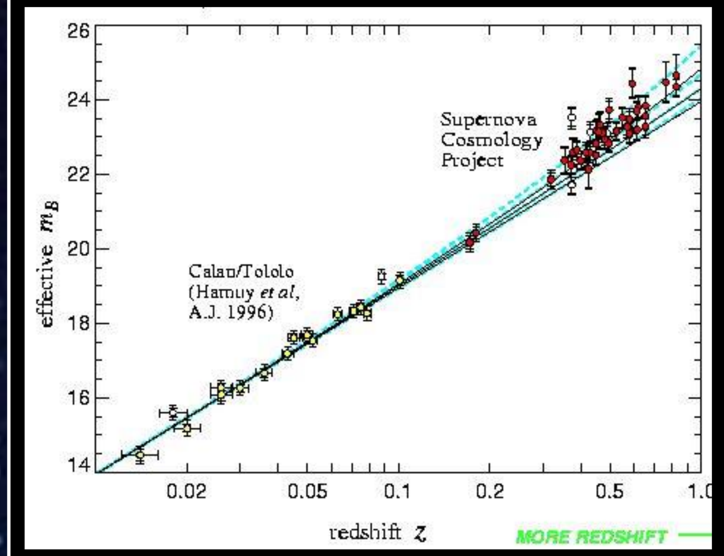
[9]

Wavelength vs. brightness shows redshift



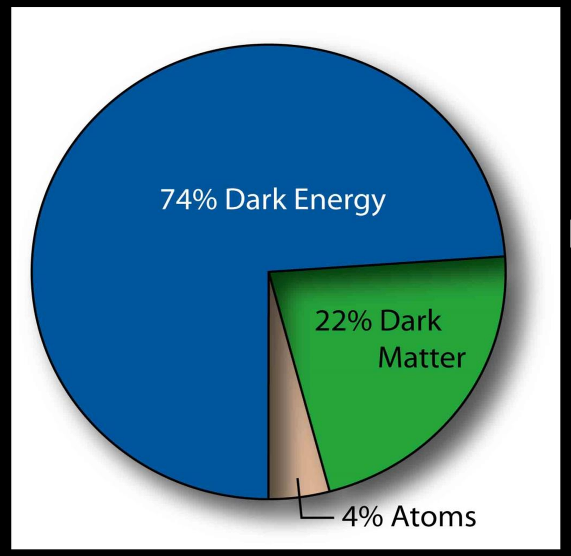
[8]

graph of the magnitude as a function of time



[5]

Redshift vs. magnitude relates to Velocity vs. distance



[4]

Composition of the Universe

My Research

The evidence for dark energy has come from a curve in the graph of redshift vs. distance (called a Hubble diagram). As we look farther away, we also look into the past. Therefore, if far off supernova appear to have lower z values per distance than closer supernova, it means that the expansion has sped up over time. If We look far enough into space, we can actually see the point where dark energy overtook the decelerating force of gravity.

Composition: Changes in acceleration of the universe correspond to different eras: radiation dominated, matter dominated, and dark energy dominated[14]. This led me to the Friedmann-Robertson-Walker equation, which describes the fate of the universe based on these three parameters.

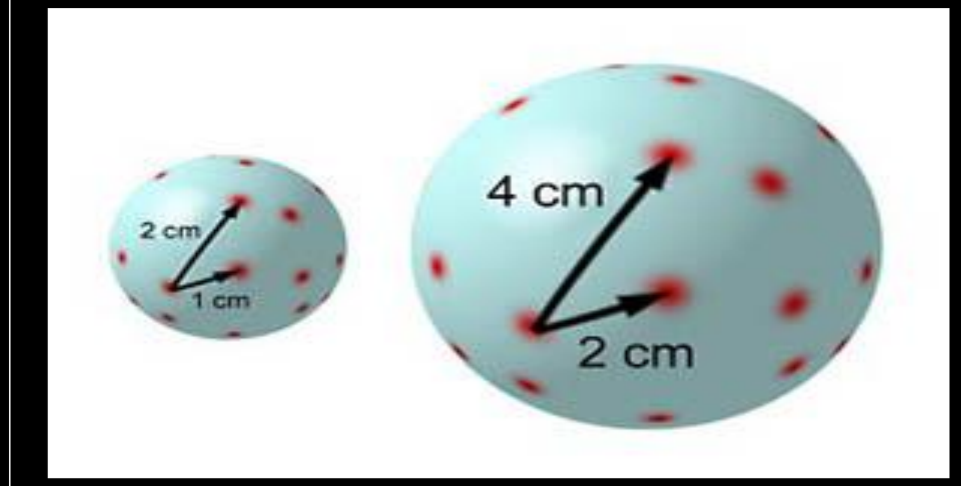
$$\left(\frac{\dot{R}}{R}\right)^2 = \frac{8\pi G\rho}{3} - \frac{k}{R^2} + \frac{\Lambda}{3}$$

$$\frac{\ddot{R}}{R} = \frac{\Lambda}{3} - \frac{4\pi G}{3}(\rho + 3p)$$

[12]

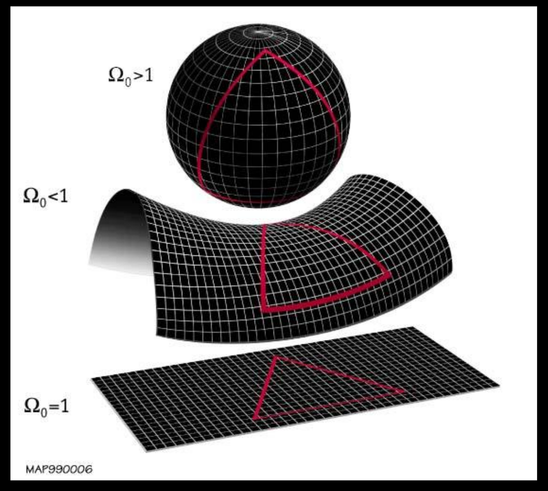
R: scaling factor of the universe
p: Energy Density
G: Gravitational Constant
k: Curvature of the universe
Λ: Cosmological Constant

Scaling Factor: This is the relative expansion of the universe as a function of time. As the universe expands, the galaxies get proportionally farther apart.



[10]

Curvature: Depending on the total energy density, (radiation density + matter density + dark energy density), the universe's curvature is either positive(k=1), negative(k= -1), or flat(k=0). [12]



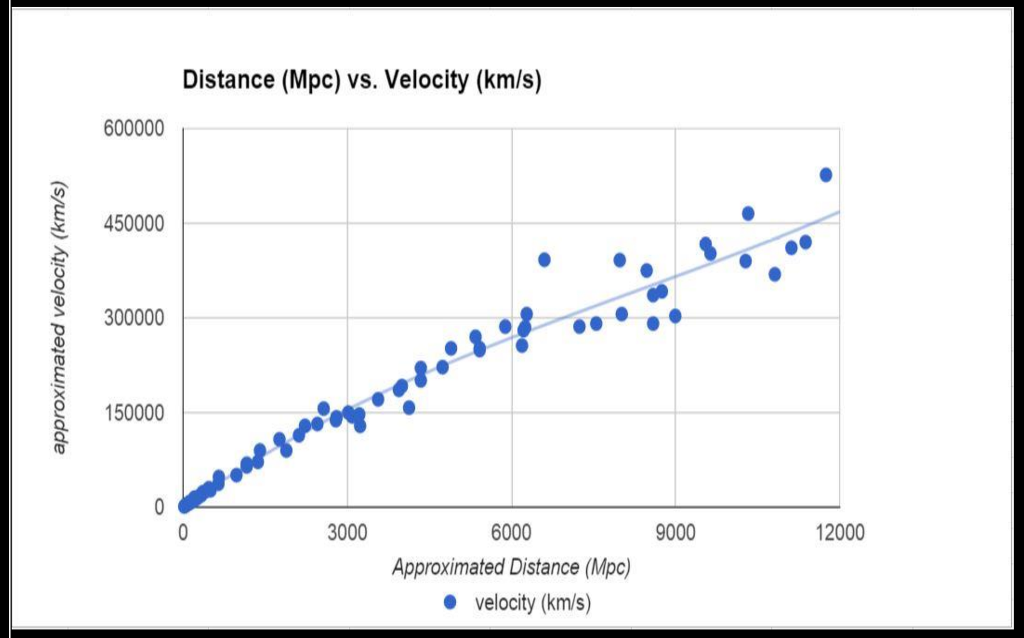
Astronomers have measured the universe to be extremely close to flat[12]

Cosmological Constant: First theorized by Einstein[13], the cosmological constant is a "negative pressure" that is evenly spread throughout the cosmos[6], stretching the space-time fabric, pushing galaxies apart. This energy of empty space keeps its same energy density throughout space and time. It is dark energy.

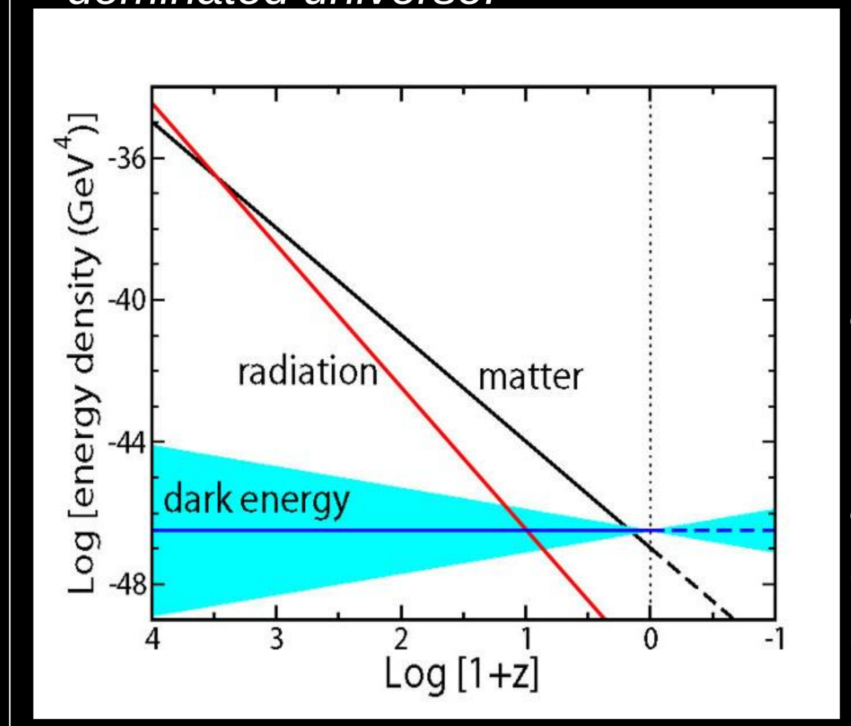
[2]

A coffee mug sized space anywhere in the universe contains about 10^{-28} j of dark energy.[3]

Results



After taking data points from multiple papers [6][7] by Dr. Adam Riess I plotted their rough equivalents of distance vs. velocity to show the transition from a decelerating matter dominated universe to an accelerating dark energy dominated universe.



[1]

This image depicts the energy densities of the various components as a function of redshift.

The point where matter and dark energy cross coincides with the point of inflection on the top graph.

SOME KEY TERMS

Magnitude: the apparent magnitude (m) and absolute magnitude (M) are the brightness of the star when the light reaches the earth and how bright it would be 32.6 light years away respectively.

Megaparsec (Mpc): one million parsecs; 3,261,633.44 light years

Redshift: the stretching of the wavelength of light due to an object's velocity away from the observer (Doppler) or the stretching of space-time(Cosmological); calculated using $z=(\lambda_o - \lambda_e)/\lambda_o$.

Type 1a Supernova: the explosion of a white dwarf star; astronomers can compare how bright it looks to how bright it actually is to determine distance, since they have very similar peak brightneses

Acknowledgments

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SOURCES

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