An Analysis on the Distribution of the Hubble Parameter across the Sky

Verifying the Cosmological Principle

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Abstract

The purpose of this project is to investigate using Type Ia supernovae data to analyze the anisotropy of the expansion rate of the universe. Our process entails collecting supernovae data from online databases and finding their Hubble parameter values, plotting them, and cross-correlating with variations in the Cosmic Microwave Background. Due to large errors in our dataset, finding such correlations is a difficult and ultimately inconclusive task. As a result of which we also propose further use of technology and telescopes (WFIRST) to provide more robust data for future projects and studies.

Background and Question

Cosmology is the study of the origin, evolution, and nature of the Universe. The Cosmological Principle suggests characteristics of homogeneity and isotropy to the universe, such as all physical laws hold the same at any location in our Universe and appear the same in any frame of reference. A specific interest in cosmology is the expansion of the universe. Through an empirical relationship known as the “Hubble Law”, objects that are farther away from us appear to recede at greater velocities. This recession speed for relatively nearby objects is given by:

\[ v = H_0d \]

where \( v \) is the recession velocity for an object at a distance \( d \). \( H_0 \) is the Hubble Constant which is derived experimentally from observations. This equation is an approximation which holds only for objects of low redshift. It is derived from a simplified form of the Friedmann equation. In general, we consider some parameter \( H_0 \) where the constant is calculated at an arbitrary time. For us, we assume \( H_0 \) is its present time and for all objects observed.

Hubble’s Law has important implications to the field of cosmology; primarily, that spacetime is expanding. Our project investigates the relationship between Hubble’s Law and the Cosmological Principle. We ask: How strongly does the principle of isotropy hold along angular variations of our sky?

Methods

Type Ia Supernovae are events of known luminosity they can be used as standardizable candles as a measure of distance. Due to distances inferred from the Doppler effect, we can use these Supernovae to accurately measure these cosmological distances. Our process:

1. Compute Distance to Supernovae and respective redshift (to find the velocity or \( v \)).
2. Find Hubble Constant accurately.
3. Find Hubble Constant for supernovae at varied angles to find a spatial distribution.
4. Compare to CMB variation and analyze the parametrized error.

Analysis and Conclusions

The average variation (1σ error) in the Hubble constant for supernovae data is approximately 0.5σ/18 whereas the same value for CMB data (1σ error) is around 1.3σ/31. However, we must consider that a discrepancy in supernovae and CMB data of approximately 1000 points was found with CMB data vastly outnumbering supernovae data. It could be due to the lack of data points that we see a such a large margin of error. The average difference between the variations was 0.56σ after we removed the points where we did not have supernovae data. Inherent errors in each dataset should also be considered. Derived quantities exist within the dataset such as values of the distance derived from \( v \)-shifts values. As a result, the errors yield almost completely inconclusive analysis. In general, considering the amount of noise in the data due to the derivations required, building a reasonable conclusion is not feasible. It is for this reason that we need for more quality and quantity of data. There is also a possibility of a null result; there could be no correlations between CMB and HD data. This question be answered by using improved cross-correlation methods. Given that we have access to both the Planck’s CMB data and the supernova-derived Hubble constant data, we currently constructed a simple algorithm to take differences between the two datasets. However, a more statistically sound way would be cross-correlation, as it often yields better accuracy and is more thoroughly analyzed method.

![Figure 2: Hubble Law Variation](image)

References


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![Figure 3: CMB Variation](image)