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 supernova 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

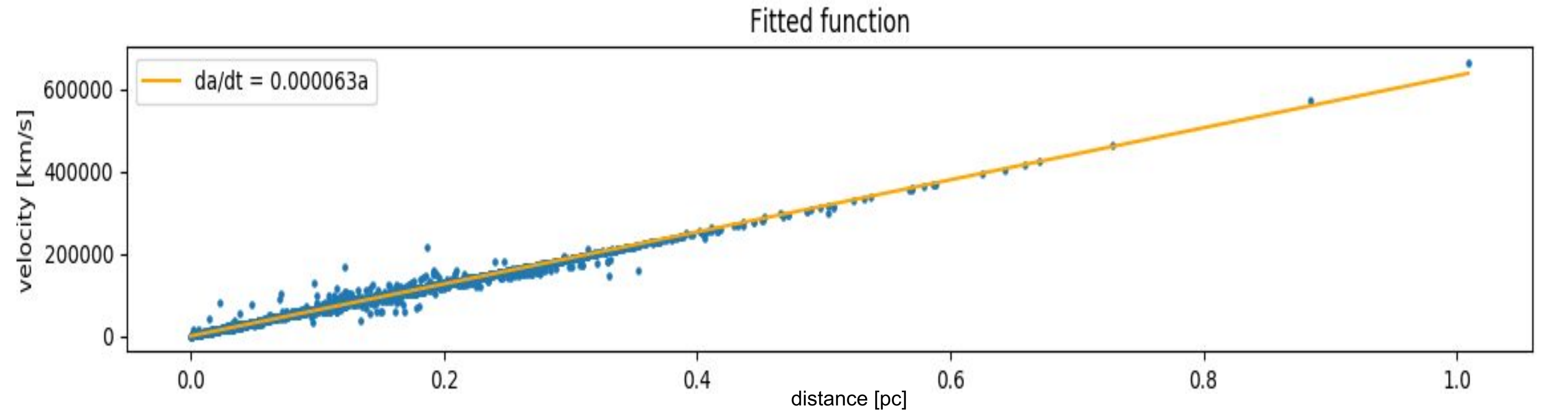
Cosmology is the study of the origin, evolution, and nature of the Universe. The Cosmological Principle suggests characteristics of homogeneity and isotropy to the universe, such that all physical laws hold the same at any location in our Universe and appear the same in any frame of reference.

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:

$$v = H_0 d\,,$$

where v is the recessional 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, as it is derived from a simplified form of the Friedmann equation. In general, we consider some parameter $H(t)$ where the constant is calculated at an arbitrary time t. For us, we assume $H(t) = H_0$, at the 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?



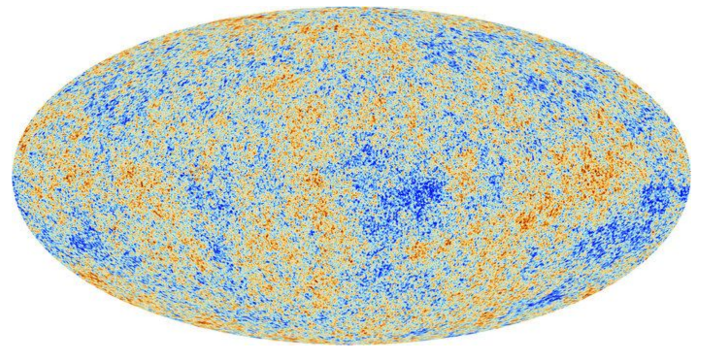
Methods

Type Ia Supernovae are events of known luminosity they can be used as standardizable candles as a measure of distance. Due to the Chandrasekhar Limit derived from electron degeneracy pressure, 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 a').
2. Find Hubble Constant accordingly.
3. Find Hubble Constant for supernovae at varied angles to find a spatial distribution.
4. Compare to CMB variation and analyze the parameterized error.

Data



We used data from the Open Supernovae Catalog. This data repository includes a comprehensive collection of data from several secondary data sources such as SNDB, SDSS, and CfA as well as many individual sources. Data was selected based on a series of criteria; primarily Type Ia Supernovae with information regarding right ascension, declination, redshift, reddening, and source.

Construction of a pipeline was necessary in order to compute the Hubble parameter for any arbitrary supernova. In doing so, we used the distance and velocity parameters to find the value across the night sky for as many points as possible. This leads to the process:

- Data from open catalog is processed and purified (empty points are filtered out).
- Plotted the data on a Mollweide projection with numpy, healpy, matplotlib, pandas, scipy, and astropy.
- Cross-correlation methods (parametrizing the difference between the temperature variation in the CMB and the Hubble parameter in our computations).

A 60 by 60 resolution was used to optimize for local Hubble Constant calculations. Using processed data, the program was able to filter through 8651 points and generate a plotted distribution on a mollweide projection. All projections in the Figures are in equatorial coordinates. 2458 data points (after sampling) contain both CMB and supernovae data. On both projections, we iterated through 3600 squares and produced an average Hubble Constant based on local calculations.

Average of Variation on H / H (average): 0.5438269534211051
Standard Deviation of H0: 1.28 km s^{-1} pc^{-1}
Average of Variation on H / H (average) for CMB: 1.3675347401968403
Average difference between (Temperature difference / average temp) and (Hubble difference / average H): 0.56

Figure 1: Supernovae Data

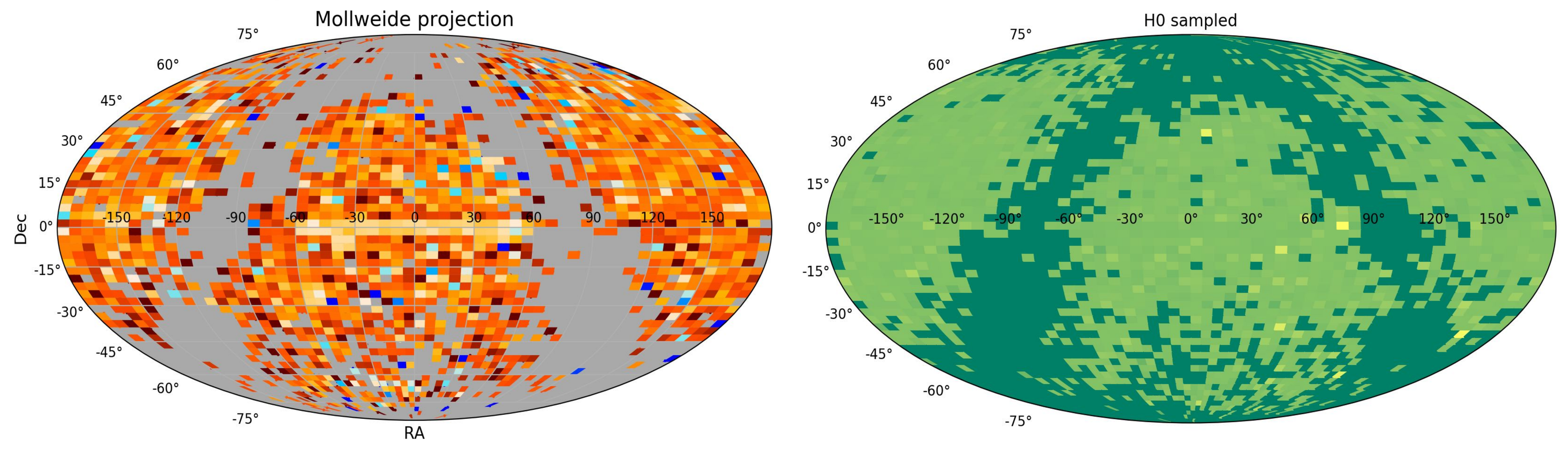
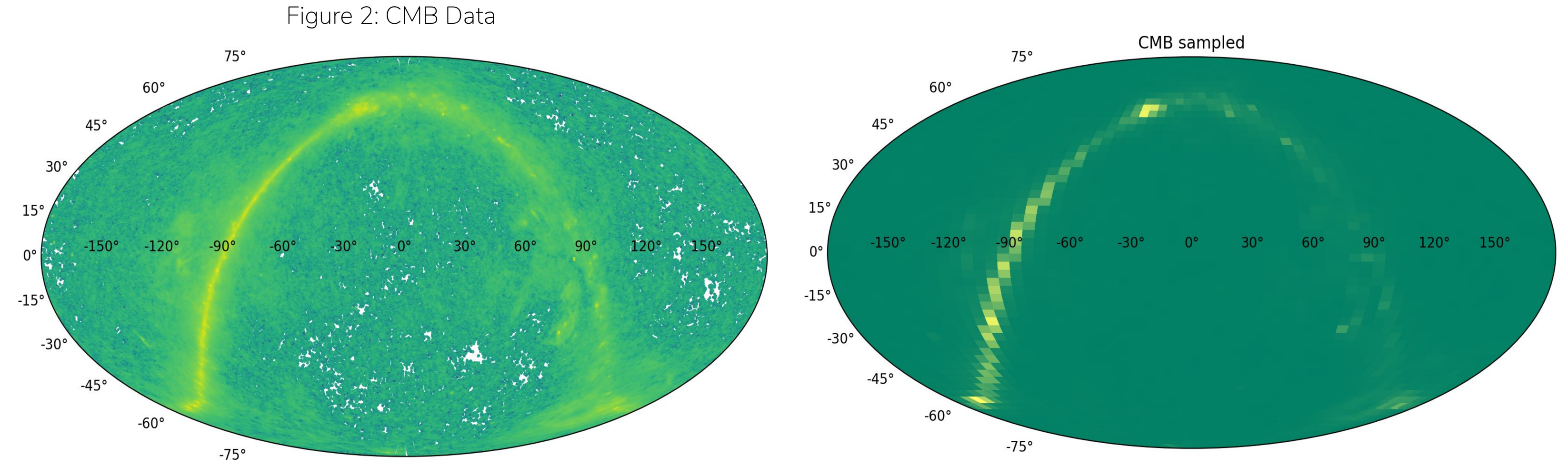


Figure 2: CMB Data

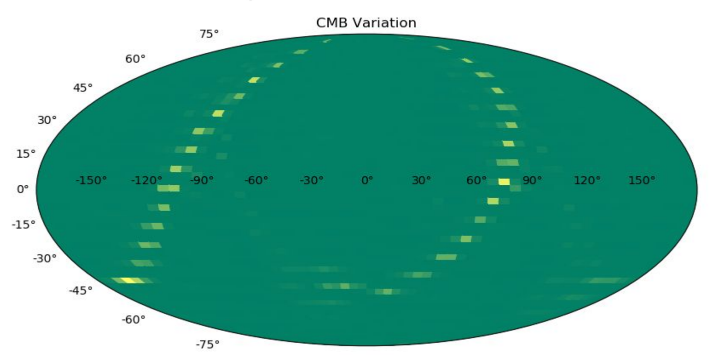


Analysis and Conclusions

The average variation (H/H avg) in the Hubble constant for supernovae data is approximately 0.5438 whereas the same value for CMB data (T/T data) is around 1.3673. 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 such a large margin of error. The average difference between the variations was 0.56, 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 z-shift values. As a result, the errors yield an 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 correlation between CMB and H0 data. This question be answered by using improved cross-correlation methods. Given that we have access to both the Planck CMB data and the supernovae-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 more accuracy and is a more thorough analytical method.

Figure 3: CMB Variation



It is difficult to argue whether isotropy holds based simply on our work. Rather, our project is a stepping stone to future research focused around looking at variations along the night sky. In order for this work to be of value, there is a need for higher-resolution data. With 12,000 type Ia supernovae collected with high uncertainty on each calculation, it is essential to gain more supernovae data as well as higher-resolution for each one.

In relation to our project, the WFIRST telescope is planned to be sent in the mid-2020s. According to NASA, "WFIRST has a 2.4m telescope, the same size as Hubble's, but with a view 100 times greater than Hubble's." Based on the results of our project, we argue that this mission is important for further research to find an accurate distance measurement. If we are to understand dark energy or any of the large-scale cosmological concepts, the best bet is high-quality data, and WFIRST seems like a very qualified and potentially strong option to attain such data.

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References

- Guillochon, J., Parrent, J., Kelley, L. Z., & Margutti, R. (2017). An Open Catalog for Supernova Data. *The Astrophysical Journal*, *835*(1). doi:10.3847/1538-4357/835/1/64.
- Planck Collaboration. (2018). Planck 2018 results. I. Overview and the cosmological legacy of Planck. https://arxiv.org/abs/1807.06205
- DES Collaboration. (2019). First Cosmology Results Using Type Ia Supernovae from the Dark Energy Survey: Constraints on Cosmological Parameters. The *Astrophysical Journal*, *872*(2). https://arxiv.org/pdf/1811.02374.pdf
- Gorski, Krzysztof M. et al. The Healpix Primer - astro-ph/9905275
- WFIRST Formulation Science Working Group. Further information on Wide Field Infrared Survey Telescope: http://wfirst.gsfc.nasa.gov/
- "White Dwarfs, Novae, and Type Ia Supernovae." Burro.case.edu, burro.case.edu/Academics/Astr221/LifeCycle/WDnovae.html.