H0 using Standard candles, Cepheids & BTFR comparison with Virial Theorem

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1 Introduction

In 1929, Edwin Hubble discovered a linear correlation between the distance and recessional velocity measurements of galaxies. He proved that the universe, which was believed to be stationary, was in fact expanding. He found that the velocity of the farther objects is greater than the velocity of objects nearby. This led to the famous Hubble Diagram (see figure 1). He stated a the relation in

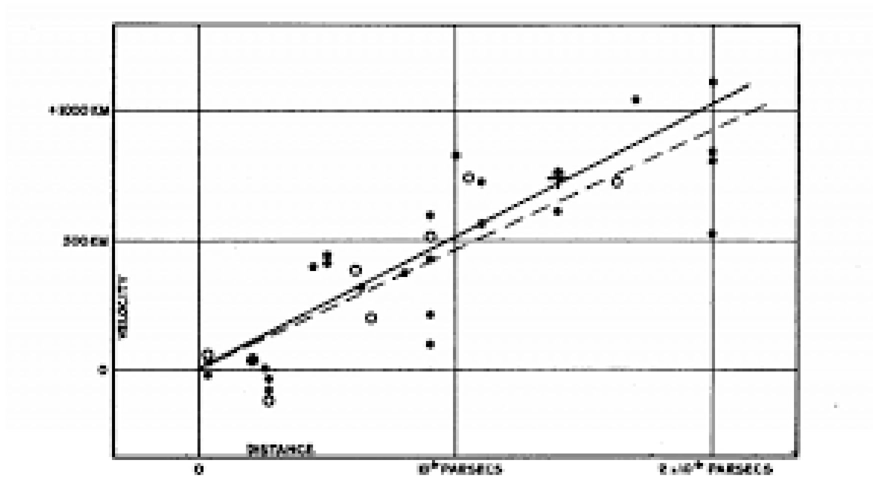


FIGURE 1
Velocity-Distance Relation among Extra-Galactic Nebulae.

Figure 1: Original Hubble Diagram

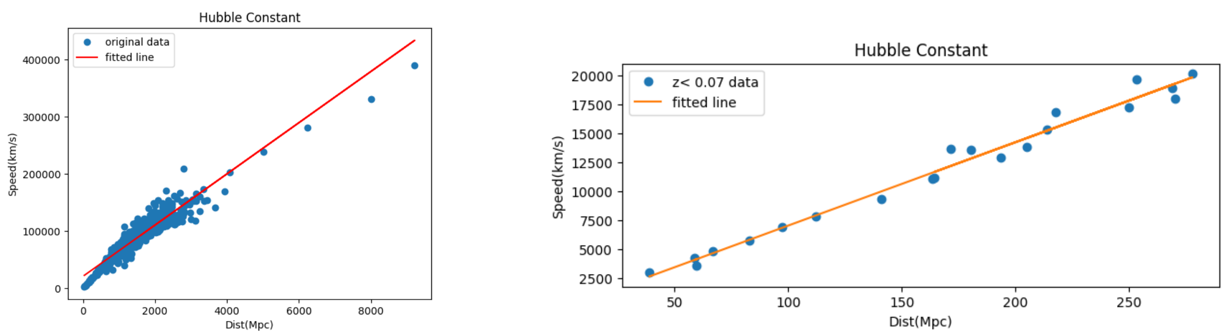
the form V = H_0 D, where H_0 is called the Hubble Constant. It is the slope of the line relating the distance of a galaxy to its velocity. Conversely, based on the value of H_0 and velocity calculated from the spectrum, distance to the galaxy can be calculated.

Since the discovery of Hubble Law, there have been continuous efforts to determine the value of Hubble Constant precisely. The values which were initially determined to be 625 km/s in 1927, 500 km/s in 1929, 100 km/s in 1970's, 50—90 km/s till 1996 have currently been restricted to the 65-74 km/s range in modern literature. But even today, the exact value of H_0 is not known. It has also been suggested that the expansion rate of the universe is not uniform, but distinct at various epochs, suggesting an accelerating universe. There are different 'Distance Ladders' used for the determination of H_0. Distance ladders are the methods by which the distance to an object can be determined.

In this work, We restrict this analysis to Cepheid and the Type I Supernovae approaches. The period- luminosity relation as well as direct recession velocity-distance relation are used for determination of H_0. Also, we validate our results of the sample field galaxies Baryonic Tully Fisher Relation (BTFR) with the corresponding Virial Theorem expectation.

2 Type Ia SN

Type Ia SN is a binary system supernova, in which one star is a white dwarf, and the second star can be of any type. These SN's are standard candles, with constant apparent magnitude. The redshift and the distance modulus were taken from [1] based on a joint analysis of the SNLS and SDSS-II SN Ia samples. This dataset includes 31 SNEs. To eliminate the low sample size bias, data samples were added from [2], also acquired from SDSS-II Supernova Survey. This sample included 751 SNEs, resulting in a total sample size of 782 SNEs.



(a) Linear fit for entire dataset

(b) Linear fit for $z < 0.07$

Figure 2:

The redshifts range from $0.01 < z < 1.3$, improving the zeropoint of Hubble-diagram. However the full dataset resulted into H_0 value of 44.826 km/s/Mpc, requiring additional analysis. To improve the value, the redshifts were binned in intervals consisting of successively increasing sample points. The resulting analysis showed an offset H_0 value at higher redshifts, and a literature matching value at lower redshifts of $0.05 < z < 0.07$, at 95% confidence interval. The reason is predicted to be absence of dark matter results in minimum acceleration of universe at lower redshift. The best redshift values obtained for the sample were 71.799 ± 4.76 km/s/Mpc for $z < 0.07$ & 69.962 ± 7.122 km/s/Mpc for $z < 0.05$ (see figure 2). Below z= 0.05 H_0 values were again offset.

3 Cepheids

Cepheids are a widely used distance ladder due to its periodic nature. Cepheid Variables are stars which brighten and dim periodically. The Period-Luminosity Relation (PLR) for a cepheid is determined by Leavitt's law.

The data of LMC cepheids was taken from [3], with Distances and absolute magnitudes along with Time stamps and radial velocities for RV curve plots. From the available sample, RV phase plots were constructed and filtered based on the quality of the plots. Periods were determined for the selected phase plots. The apparent magnitudes from V band were selected to construct PLRs using

$$M = a \cdot \log(P) + b \tag{1}$$

. The slope a and intercept b form a linear fit, approximating the actual M values. The distance modulus μ was calculated using

$$\mu = (m - M)_0 \tag{2}$$

. The distance in Mpc was calculated using

$$5 \log D = (m - M)_0 + 5 \tag{3}$$

. The distance values resulting after rearranging the equation as

$$D = 10^{\frac{(m-M)_0+5}{5}} \tag{4}$$

were within the 95% confidence interval agreement of the recorded distance by [3]. Finally, the H_0 value was found using

$$\log H_0 = \frac{5M_{0v} + 5a + 25}{5} \tag{5}$$

The resulting H_0 values were ranging in 50.6467-55.8102 km/s/Mpc, within the acceptable H_0 range, but not matching with the current literature value. The causes are expected to be sample size induced bias. The dataset contained only 36 cepheids significantly below z= 0.1. Building on the Type Ia SNEs results, we know that the Hubble Diagram shows a perfectly linear fit at $0.05 < z < 0.07$, whereas LMC being only at 50 Kpc, the redshifts were as low as 0.00093, way below the expected linearity range.

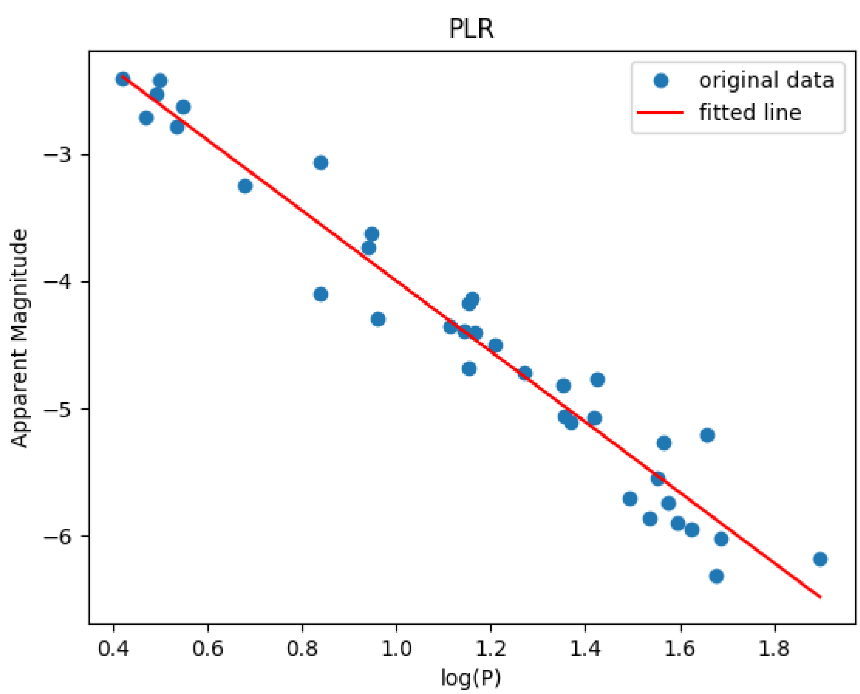


Figure 3: PLR for 36 LMC cepheids

4 BTFR

Tully fisher relation (TFR) distance ladder is another method used for distance determination. The TFR is given by

$$L \propto V^{\alpha} \tag{6}$$

forming a relation in Luminosity and Rotation speed of galaxies. A more accurate version of TFR is BTFR, forming a relation between Baryonic mass and rotation speed. Baryonic mass is calculated by adding the mass of stars (inferred from luminosity and mass-to-light ratio) and the gas mass (measured from the 21 cm hydrogen line for neutral hydrogen or CO lines for molecular gas). For this purpose, the data was taken from [4].

From this dataset of 152 galaxies, the galaxies with unknown rotational velocities were filtered out. A TFR template was created to test the linearity of the remaining 123 galaxies. The regression model was then trained on 100 of the datapoints, and the baryonic mass predictions of the remaining 23 points were compared with the actual values. A linear fit with minimum such error was selected. The BTFR relation is given as:

$$\log M_b = \alpha \log V_{\text{flat}} + \beta \tag{7}$$

where V_{flat} is the rotation velocity of galaxy. Similar to TFR, BTFR relation is given as

$$M = V^{\alpha} \tag{8}$$

The value of α should be equal to 3 according to Virial theorem [5], while the value obtained in this work is 3.4863.The result is consistent with Recent cold dark matter galaxy formation models.

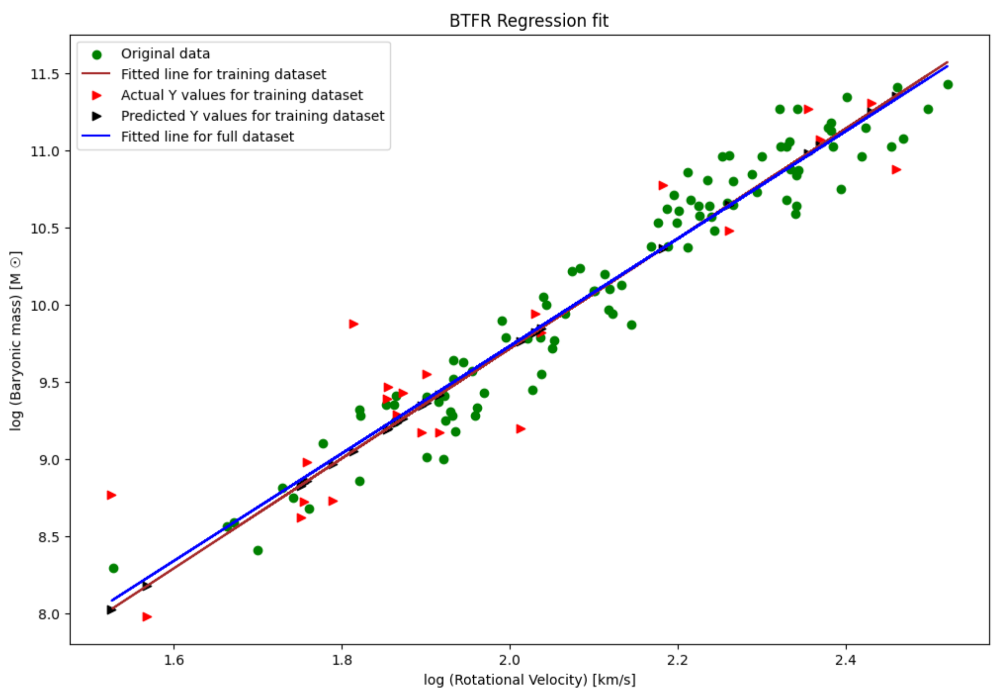


Figure 4: BTFR fit for 151 galaxies

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