Dark energy is due to a math error from 1930

A Preprint

Logan P. Evans
loganpevans@gmail.com

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Abstract

Light from distant objects, such as supernovae and galaxies, is dimmed due to three phenomena associated with redshift: energy levels per photon, spectral bandwidth, and time dilation. Observed magnitudes are reported with k-corrections that should correct for these dimming effects, but since 1930, the equations used to perform these k-corrections have been missing the correction factor for time dilation. When observations of Type Ia supernova are corrected for this missing factor, the relationship between luminosity distance and redshift for Type Ia supernova becomes linear. This indicates that the expansion rate of the universe is not accelerating and there is no need for dark energy to explain observational data.

Keywords Cosmological Parameters · Dark Energy · Luminosity Distance

1 Introduction

Observations of Type Ia supernova are fundamental to the study of cosmology. These measurements are necessary to calibrate models that measure redshift and estimate distance. This relationship, often called the Hubble-Lemaître law, [TODO: find citation] describes how quickly the universe is expanding. However, Riess et al. [1998] and Perlmutter et al. [1999] presented evidence that there isn't a linear relationship between redshift and distance, but instead, distant objects are farther away than their redshift would predict (see Figure 1). This phenomenon is referred to as dark energy.

Type Ia supernova are used to explore the relationship between distances and redshifts because these events always happen in similar ways, so the absolute brightness is roughly always the same. An analogy is to imagine someone walking in the dark and lighting matches. As long as we know how brightly a match burns at a known distance, we can estimate the distance to any match by measuring the appearant brightness before applying some geometry.

It turns out that measuring the apperant brightness of a Type Ia supernova is non-trivial. The aspect of the process that we will explore here concerns how redshift affects the light we observe. This problem is often referred to as k-corrections, and one of the first mathematical treatments of the problem was performed by Tolman [1930]. However, when Tolman made his derivation, he did not consider the effects of a spectra that is stretched out due to redshift.

A few years later, de Sitter [1934], discussed all three issues that would reduce the observed magnitude of a distant observation. The correction for each of these issues is identical: take a measurement for luminosity and multiply it by the factor $1 + z$.

A year later, Hubble and Tolman [1935] published a similar set of calculations for k-corrections, but these equations used $(1 + z)^2$ instead of the $(1 + z)^3$ correction term used by de Sitter. They started their derivation by copying the incorrect equation from 1930. After their derivation, they noted,

> It should be specially noted that this expression differs from the correction to m proposed by de Sitter, which contains the term $(1 + z)^3$ instead of $(1 + z)^2$. Expression (28), however, would seem to give the proper correction to use in connection with our equation (21), since it has been derived in such a way as to make appropriate allowance, first, for the double effect of nebular recession in reducing both the individual energy and the rate of arrival of photons, and then for the further

> circumstance that a change in spectral distribution of the energy that does arrive will lead to changes in its photographic effectiveness.

The Hubble k-corrections with the incorrect correction term have been used ever since.

By Oke and Sandage [1968], the two factors of $(1+z)$ were attributed to the change in energy and to the spectral bandwidth elongation, which leaves time dilation as the factor that was omitted.

In 1935, the correction of $(1+z)^2$ empirically lined up the data so that there seemed to be a linear relationship between redshift and distance. It wasn't until Riess et al. [1998], sixty-eight years later, that the omission of a third $(1+z)$ correction factor resulted in faulty conclusions.

Those faulty conclusions, however, have been the basis for a substantial amount of scientific interest. In 2011, three physicists received the Nobel Prize in Physics for discovering that the expansion rate of the universe is accelerating Straumann and Zürich [2012]. The papers Riess et al. [1998] and Perlmutter et al. [1999] have each received over 20000 citations. It's not clear how much cosmology work will need to be revisited with corrected distance measurements, but it is a non-trivial amount.

2 The dimming effects of redshift

The magnitude measurements for Type Ia supernova goes through a long chain of data processing. The data used here was collected by the Dark Energy Survey Collaboration, as summarized in DES-Collaboration et al. [2024] and described in more detail by Vincenzi et al. [2024]. However, the data processing does not explicitly correct for either redshift or time dilation.

In the big bang model, there are multiple phenomena associated with redshift that we might expect to reduce the apparent magnitude of a Type Ia supernova.

2.1 Recessional velocity redshift

The energy carried by a photon is inversely proportional to wavelength, given by the Planck relation

$$E = \frac{hc}{\lambda} \tag{1}$$

where E is energy, h is the Planck constant, c is the speed of light, and λ is the wavelength.

As redshift increases the wavelength of a photon, the energy decreases.

The supernova data collected by the DES Collaboration used a CCD camera, a photon counting device, as described by Flaugher et al. [2015]. Kim et al. [1996] noted that photometric measurements that depend on bolometers will need to be corrected for the reduced energy level of redshifted light, but with a photon counting device, this correction is not necessary.

While the redshift phenomenon should impact the light detected from distant supernova, it should not impact the magnitude measurements so it does not need to be explicitly corrected.

2.2 Time dilation

The second phenomenon is that time dilation for objects moving quickly relative to our observational rest frame will reduce the rate at which photons are being emitted. Instead of changing the properties of individual photons, time dilation reduces the count of photons by a factor of $\frac{1}{1+z}$ where z is the redshift.

This phenomenon will not be addressed by the nuances of any measuring device, so it must be explicitly corrected.

2.3 Stretching of space

If space itself is stretching, it will both increase the wavelength of photons and also reduce the density of those photons. If space is stretching at a constant rate, the effect would be indistinguishable from the redshift and time dilation created by high relative recessional velocities. However, an accelerating expansion of the universe may indicate a non-constant rate of stretching. This would manifest by distant objects having a greater distance per redshift than nearby objects.

This non-linear streching-of-space model would be indistinguishable from a scenario where a constant force is pushing all objects away from each other.

2.4 Tired light

An alternative to the big bang theory is the tired light hypothesis, as described by Zwicky [1929] and Shao [2013]. The idea is that distant objects are mostly stationary relative to us, but the energy of light is lost as it travels through space. A feature of the tired light hypothesis is that since distant objects do not have a high relative velocity to us, they should not show time dilation.

However, as shown by Blondin et al. [2008] and White et al. [2024], distant supernova do experience time dilation. Based on this, we can reject the tired light hypothesis and assume the big bang model.

3 Correcting magnitude for time dilation

Luminosity distance D_L, is the apparent distance of an object based on the observed luminosity, also known as the flux F. This does not take into account any movement of the observed object between the time when the light was emitted and the light is observed.

To derive the luminosity distance from these measurements, we start by computing the flux F. Magnitude m is defined on a logarithmic scale where magnitude 1 has 100 times the brightness of magnitude 6, leading to

$$F = \frac{1}{\sqrt[5]{100}^{m-1}}. \tag{2}$$

This is proportional to the number of photons detected by a telescope. We can find the corrected flux F^* by multiplying by $k(z)$, the redshift correction factor. Time dilation of quickly moving objects reduces the number of photons by a factor of $\frac{1}{1+z}$, so we have

$$\begin{aligned} F^* &= F \times k(z) \\ &= F(1+z). \end{aligned} \tag{3}$$

To compute the corrected magnitude m^*, we can solve

$$\begin{aligned} F^* &= \frac{1}{\sqrt[5]{100}^{m^*-1}} \\ m^* &= m - \frac{\ln(z+1)}{\ln(\sqrt[5]{100})}. \end{aligned} \tag{4}$$

From here, we can use the standard distance modules μ defined as

$$\mu = m^* - M \tag{5}$$

where M is the absolute magnitude. The luminosity distance D_L in parsecs can then be calculated as

$$D_L = 10^{1+\frac{\mu}{5}}. \tag{6}$$

4 Linear distance vs redshift relationship

The theory of an accelerating expansion is based on there being a non-linear relationship between redshift and distance. More specifically, old objects (the ones that are more distant) should have more distance per redshift than newer objects.

As shown in Figure 1, this non-linear relationship is only observed when $k(z) = 1$, meaning that magnitude is not corrected for time dilation.

In contrast, when $k(z) = 1 + z$, time dilation is accounted for and there is a linear relationship between redshift and distance. A linear model rules out an accelerated expansion.

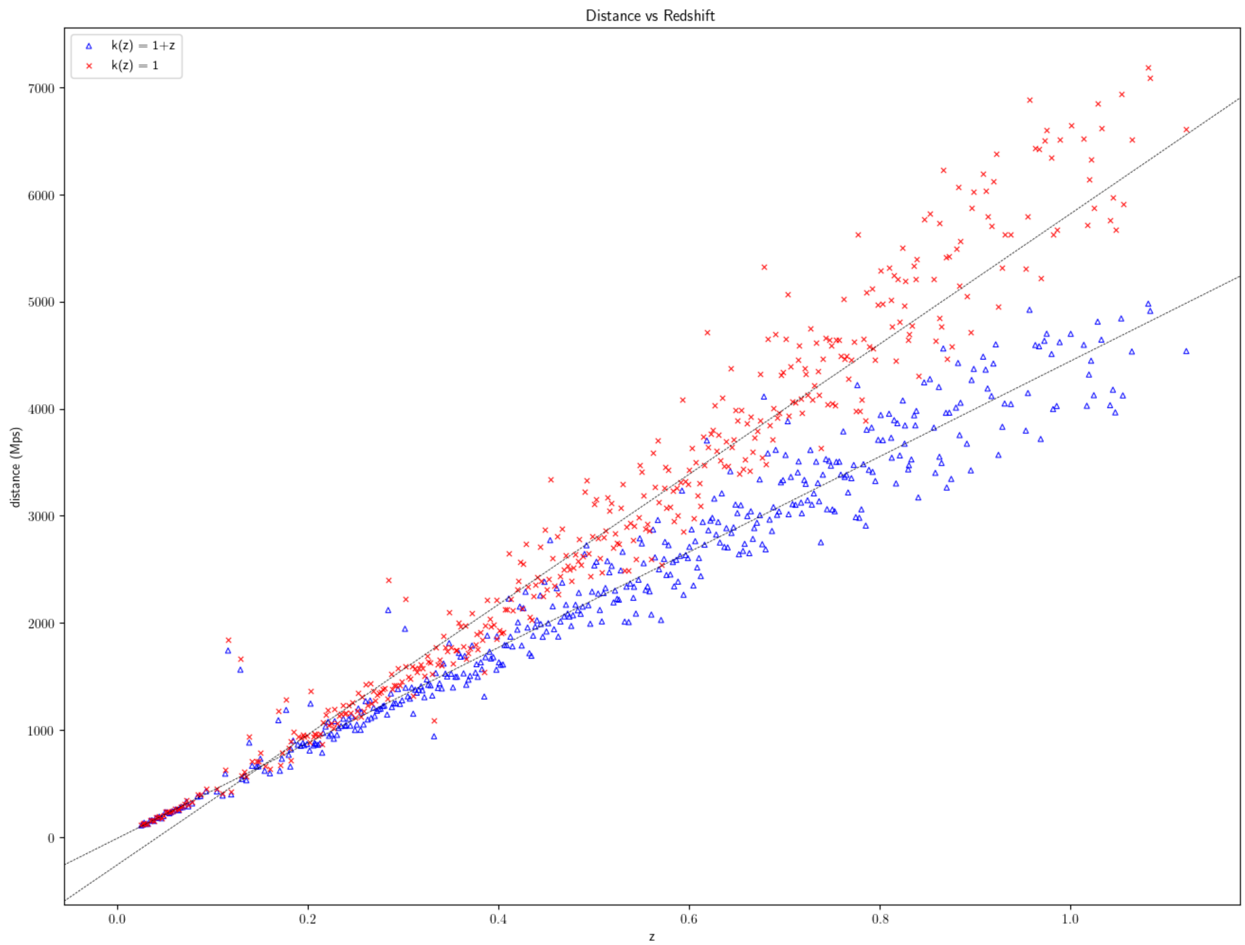

Figure 1: The relationship between distance and redshift for two treatments of magnitude data. The displayed points are roughly a third of the values in the full DES dataset, selected evenly to aid visibility. The $k(z) = 1$ treatment is clearly non-linear while the $k(z) = 1 + z$ treatment appears to be linear.

5 Disagreement with existing research

Previous studies use F instead of $F*$. To the best of our knowledge, no studies that depend on the distance of Type Ia supernova, reaching back at least to Kim et al. [1996], Riess et al. [1998], and Perlmutter et al. [1999], have accounted for time dilation.

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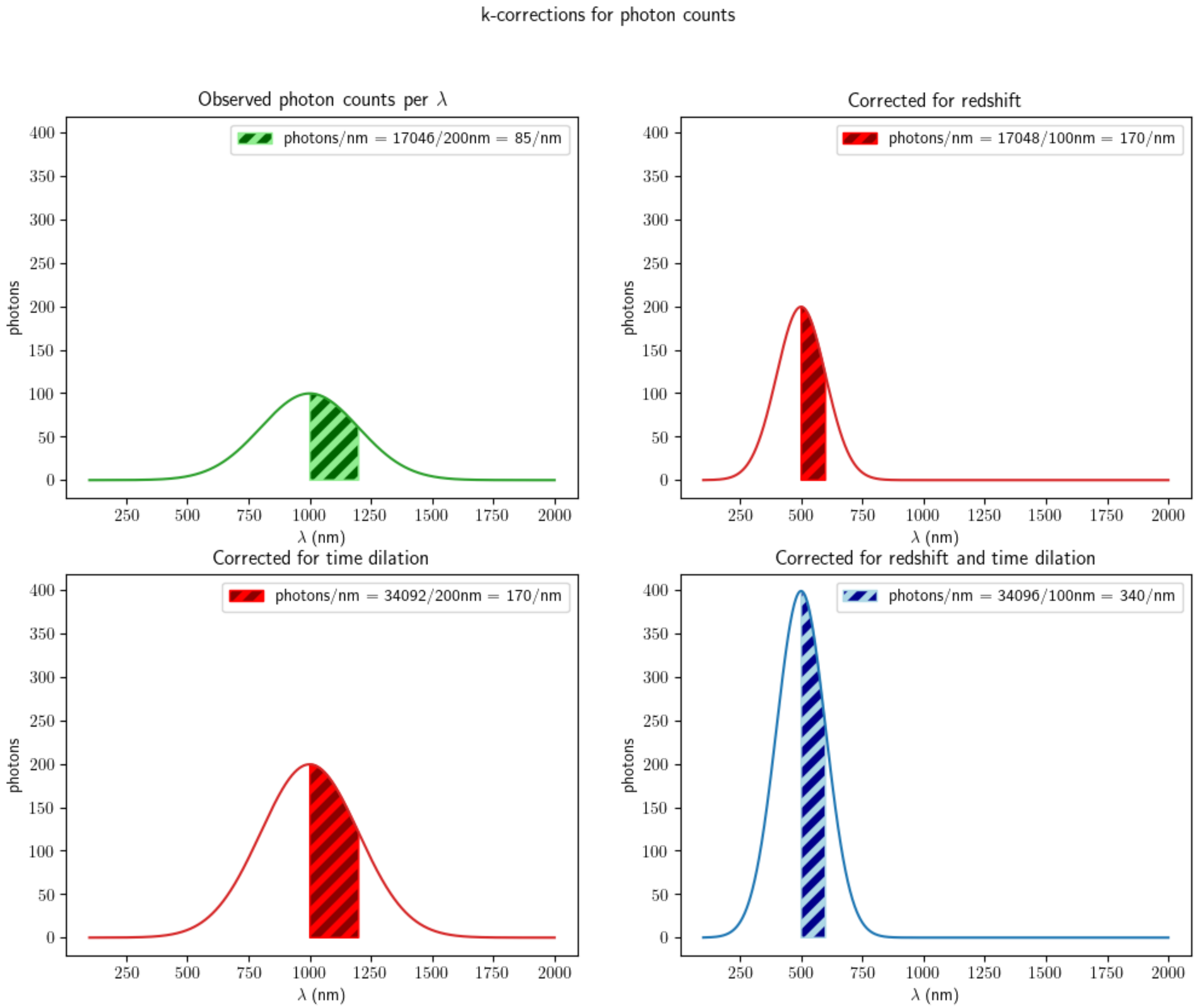

Figure 2: An example of how k-corrections take an observed spectrum and produce a rest-frame spectrum. [TODO]

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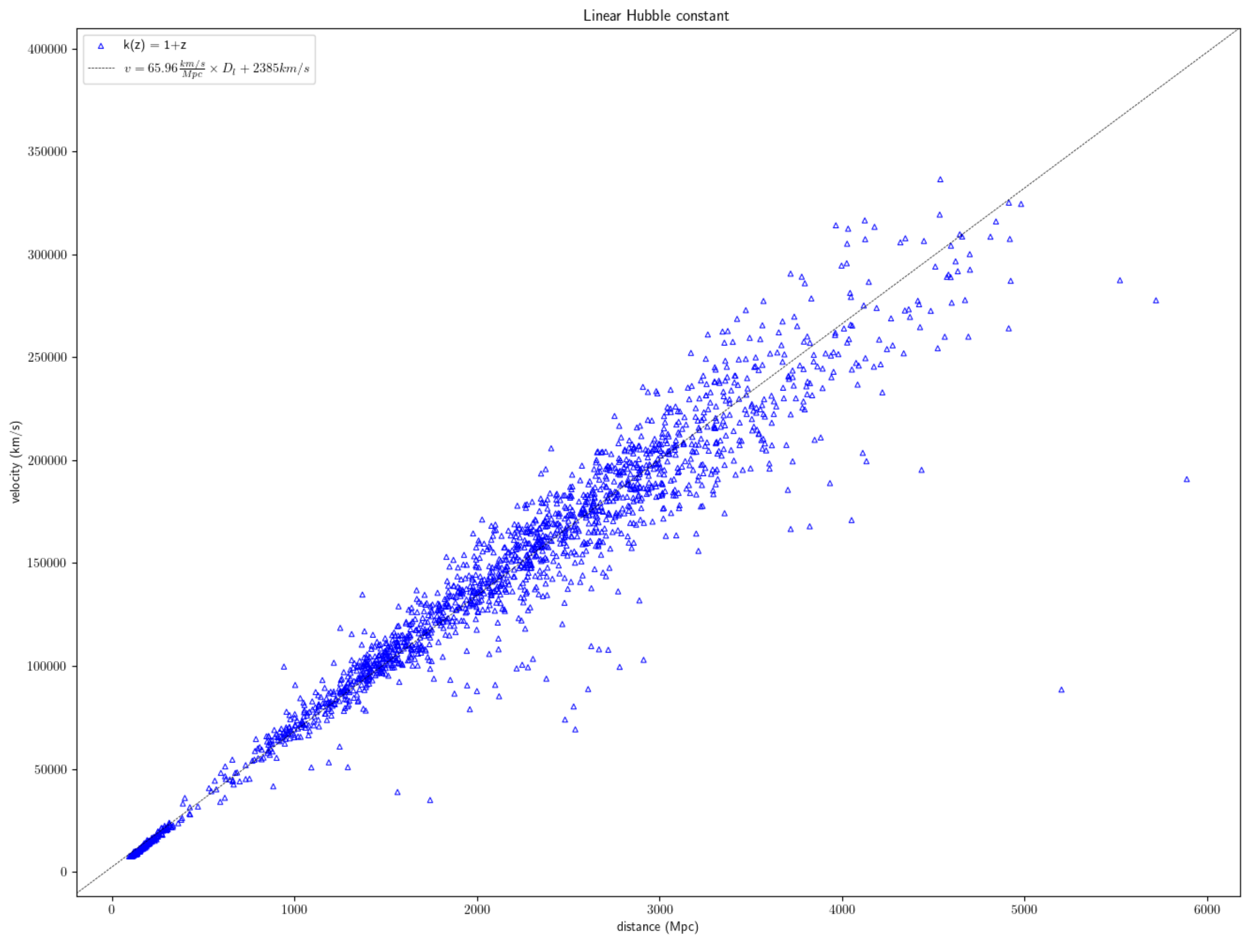

Figure 3: The relationship between expansion velocity and distance. The slope of this graph demonstrates the Hubble constant.

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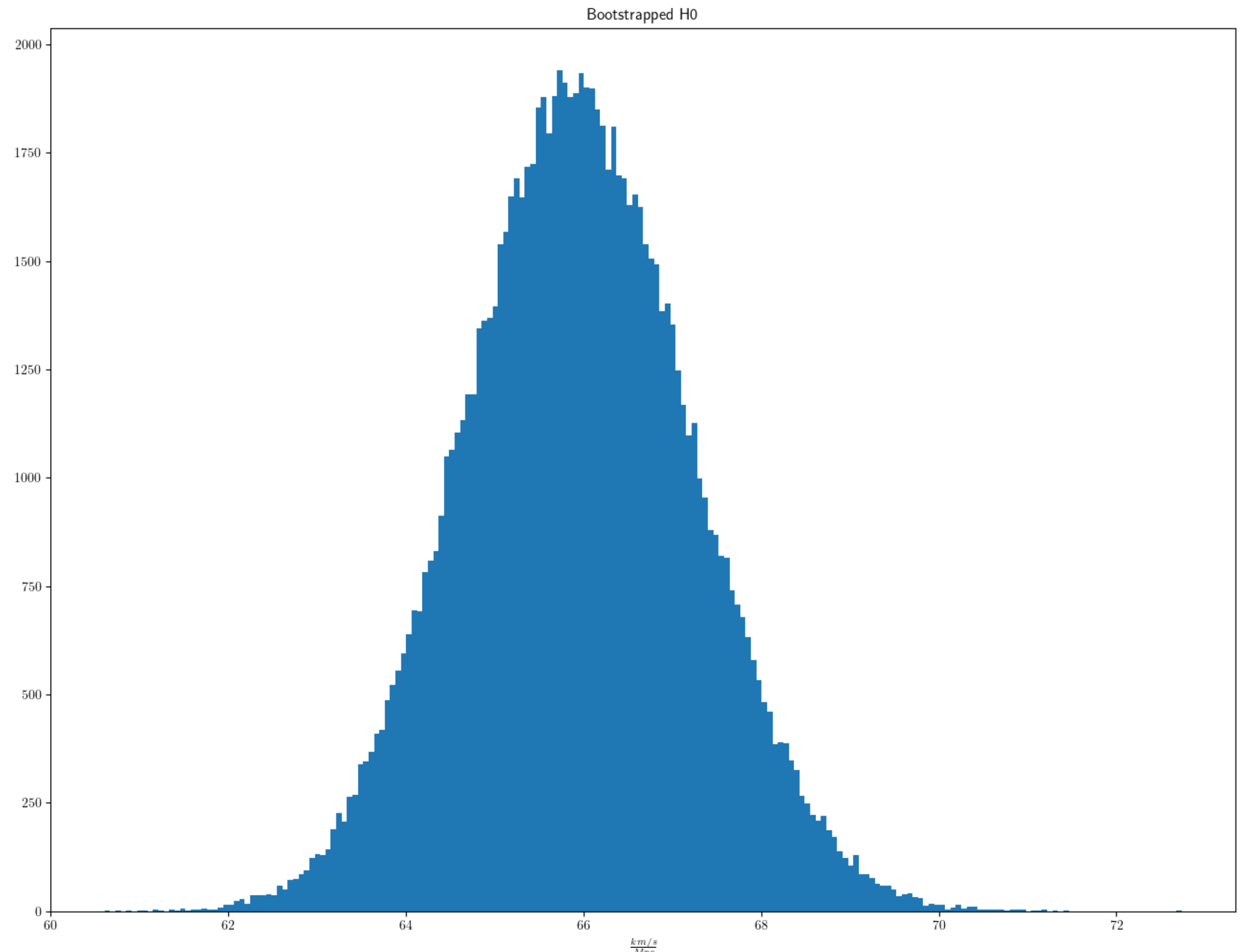

Figure 4: A histogram of 100000 bootstrap trials measuring the Hubble constant $H0$. Each trial samples an absolute Type Ia magnitude $M \sim Norm(-19.2334, 0.0404)$ based on data published by Camarena and Marra [2020]. It then samples, with replacement, a population of supernovae from the dataset published by DES-Collaboration et al. [2024]. Finally, it uses the non-parametric linear regression technique described by Siegel [1982]. The result of the bootstrap is $H0 \sim Norm(65.94, 1.29)$.