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Cosmic Redshift as the Time Dilation of Electromagnetic Waves

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ABSTRACT

If the time dilation observed in a distant supernova is considered to be real, rather than an effect of expanding space, then the oscillations of an electromagnetic wave emitted from that distance should be equally time dilated, elongating the wave's period and redshifting it. A hypothesis motivated by that interpretation of the evidence is shown to be a better fit to the Type 1a supernovae data than the current standard model of cosmology. The possible geometric foundations of such a hypothesis are examined, recalling de Sitter's original spatially static coordinates.

Key words: galaxies: distances and redshifts

1 INTRODUCTION

The mounting observational and theoretical challenges to the standard model of cosmology, ΛCDM, (Melia (2022), Aluri (2023)) are accompanied by a renewed interest in nonexpanding models of space, such as the proposal that particles had a higher mass in the past (Lombriser (2023)). A nonexpanding model has also been shown to be a better fit for the cosmic distance duality relation for radio sources than the familiar expanding models (Pengfei (2023)).

An elegant nonexpanding hypothesis is developed in this paper by starting with the simplifying interpretation of redshift in electromagnetic waves as a fundamentally identical phenomenon to the time dilation of supernovae.

The hypothesis, which is first proposed in an ad hoc way, is shown to be a better fit to the Pantheon+SH0ES dataset than ΛCDM. The spacetime requirements of the hypothesis suggest that a suitable geometrical foundation for the hypothesis may be de Sitter's spatially closed, spatially static spacetime from 1917.

2 INTERPRETING THE EVIDENCE

The most direct pieces of evidence for the expansion of space are the redshifts in light from distant galaxies and the time dilation of distant supernovae. Light is redshifted when its wavelength increases, and time dilation is an increase in duration. So the observations include a stretching of length, and a stretching of time:

- The elongated wavelength of an electromagnetic wave
- The elongated duration of supernovae

Light, an electromagnetic wave, would also be redshifted were the wave's period to increase somehow. Since the observed duration of a distant supernovae is stretched, then it would follow that the duration of all similarly distant phenomena would be equally stretched, including the oscillations of electromagnetic waves emitted from that distance.

Consider the interpretation that the observed redshifts are a change in the electromagnetic wave's period. The evidence could then be stated as:

- The elongated period of an electromagnetic wave
- The elongated duration of supernovae

As a consequence of interpreting redshift like this, the two points of evidence appear to be fundamentally one-in-the-same, with the suggestive hint that it has to do with some kind of dynamic of time, rather than of space.

3 CONJECTURE

The time dilation of supernovae is traditionally considered to be an effect of the expansion of space. Each photon coming from the supernova will have to travel farther than the one before it, causing its observed duraton to be stretched.

The hypothesis developed in this paper asks the reader to consider the possibility that what we are observing to happen, is actually happening. Distant supernovae don't just appear time dilated; they are time dilated. The observed time dilation isn't an effect of expanding space, because the expansion of space won't be necessary in a universe with time that possesses this dynamic characteristic. The conjecture can be summarized as **"the past is time dilated."**

4 AN AD HOC HYPOTHESIS

The scale factor $a(t)$ plays a very important role in describing an expanding universe.

$$ds^2 = -c^2dt^2 + a(t)^2(dx^2 + dy^2 + dz^2) \tag{1}$$

A length L in the past is its current length times the scale factor:

$$a(t) = \frac{L_{then}}{L_{now}} = \frac{\lambda_{emit}}{\lambda_{obs}} = \frac{1}{1+z} \tag{2}$$

And in a universe that expands very simply, such as a dark energy only universe:

$$a(t) = e^{H_0 t} \tag{3}$$

Consider what happens when a scale factor is applied to time instead of space.

$$ds^2 = -b(t)^2c^2dt^2 + dx^2 + dy^2 + dz^2 \tag{4}$$

The "time scale factor", $b(t)$, describes the relationship between a duration T in the past and how it would be observed in the present. Given that frequency is the inverse of period:

$$b(t) = \frac{T_{then}}{T_{now}} = \frac{f_{obs}}{f_{emit}} = \frac{1}{1+z} \tag{5}$$

And we'll use the same function to evaluate the time scale factor as we would in a simply expanding universe.

$$b(t) = e^{H_0 t} \tag{6}$$

This metric form has no curvature and amounts to a transformation of the time coordinate in Minkowski spacetime. It cannot be claimed to produce the effects of time dilation, or explain why it happens, which is why a geometrical solution is pursued in the next section. For now, we just need to assume that the time dilation that is observed is really happening, and that the t coordinate measured by an observer shows those effects. Under those assumptions, we can use the following transformation to produce a time coordinate τ that excludes the effects of time dilation:

$$\tau = \frac{1}{H_0}(e^{H_0 t} - 1) \tag{7}$$

It is important to note that $t = 0$ will always represent the present, and that all the measured time coordinates used will be negative since cosmological observations are dealing with the past. Therefore $\tau \leq 0$ too. This means the exponent in the equation should always be zero or negative.

Distances, on the other hand, should be regarded as positive values. Since τ gives us the "un-time dilated" time coordinate, we know that the physical distance d to a source of light is $d = -c\tau$. The time scale factor in terms of redshift z from equation (5) can be substituted into equation (7), giving:

$$\tau = \frac{1}{H_0}\left(\frac{1}{1+z} - 1\right) \tag{8}$$

$$\tau = -\frac{z}{1+z}\frac{1}{H_0} \tag{9}$$

$$d = \frac{z}{1+z}\frac{c}{H_0} \tag{10}$$

The light travel time distance, $d_t = -ct$, will be longer than the physical distance due to the effects of time dilation, and can be related to z by solving equation (7) for t:

$$H_0\tau + 1 = e^{H_0 t} \tag{11}$$

$$t = \frac{1}{H_0}\log(H_0\tau + 1) \tag{12}$$

And due to the time scale factor's relationship with redshift z, equation (11) becomes:

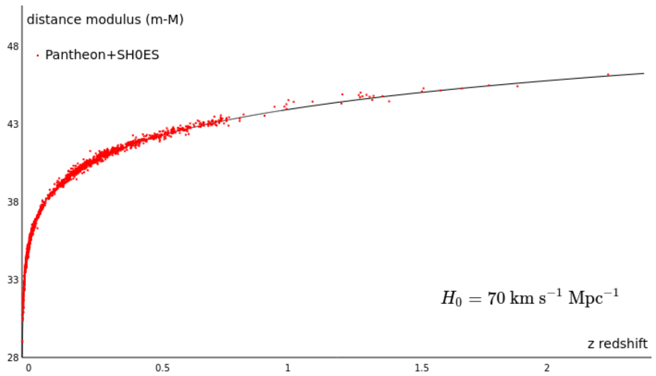

Figure 1. The hypothesis' prediction for distance modulus from z compared to the Pantheon+SH0ES dataset

$$H_0\tau + 1 = \frac{1}{1+z} \tag{13}$$

$$H_0\tau = \frac{1}{1+z} - 1 \tag{14}$$

If we substitute the right hand side for $H_0\tau$ in equation (12) we get:

$$t = \frac{1}{H_0}\log\left(\frac{1}{1+z} - 1 + 1\right) \tag{15}$$

$$t = \frac{1}{H_0}\log\left(\frac{1}{1+z}\right) \tag{16}$$

$$-ct = \frac{c}{H_0}\log(1+z) \tag{17}$$

$$d_t = \frac{c}{H_0}\log(1+z) \tag{18}$$

In this hypothesis, H_0 no longer represents the expansion rate of the universe, but it still plays a familiar role in relating redshift to distance.

4.1 Compared to data

To test the hypothesis against the Pantheon+SH0ES dataset (Scolnic (2022)), a distance modulus needs to be calculated from the redshift. A distance modulus can be obtained from a luminosity distance, for which we will use $-ct(1+z)$, which accounts for the effects of time dilation in the flux of the light source. The result is shown in Fig. 1

To calculate a best fit for the hypothesis to determine a value for Hubble's constant, H_0, we'll use this equation for the sum of squared errors (SSE):

$$\chi^2 = \Sigma_i(\mu_i^d - \mu_i^m)^2 \tag{19}$$

where μ_i^d is the distance modulus of the i-th supernova in the dataset, and μ_i^m is the distance modulus predicted by the model from the redshift z. The best fit to the data is the model with the lowest SSE. When an SSE is calculated for the hypothesis over a range of H_0, the best fit is 70.4 km/s/Mpc, as can been seen in Fig. 2.

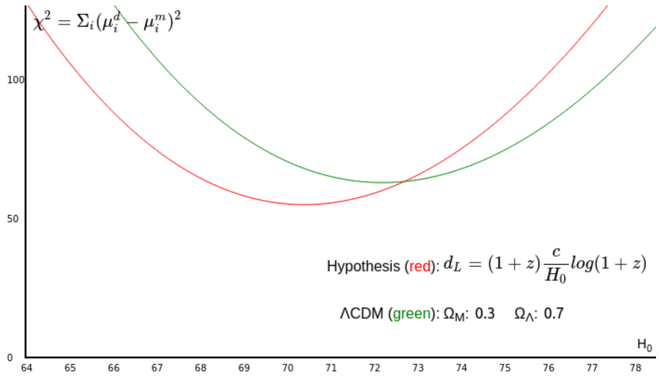

Figure 2. The sum of squared errors for the hypothesis (red) and ΛCDM (green) to the Pantheon+SH0ES dataset over a range of H_0.

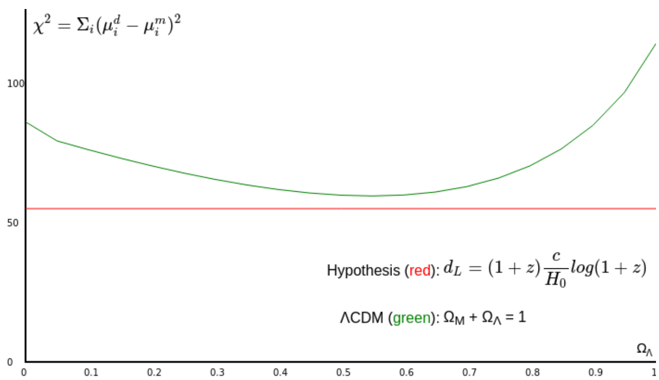

Figure 3. The SSE for a flat FLRW model (green) all possible values of Ω_Λ. For each model an SSE over a range of H_0 is calculated, and the lowest value is shown. The lowest SSE for the hypothesis (red) is shown for comparison.

The hypothesis is also shown in Fig. 2 to be a better fit to the data than the concordance model of cosmology, ΛCDM. In fact, these calculations show that the hypothesis is a better fit to the supernovae data than any "flat" FLRW model ($\Omega_\Lambda + \Omega_M = 1$), for any value of H_0, shown in Fig. 3.

5 A GEOMETRICAL FOUNDATION

The dimension of time is commonly considered to be the real number line, $t \in \mathbb{R}$. Let's suppose the dimension of time is instead curved in a circle, perhaps something like $t \in \mathbb{S}^1$, where $\mathbb{S}^1 = \{(x, y) \in \mathbb{R}^2 : x^2 + y^2 = R^2\}$.

As time passes in circular time, events that occur at a regular interval are evenly spaced along the circle's circumference. From a point on the circle, the distance to each event in the 2D space by way of the Pythagorean theorem, however, will not be evenly spaced. Events on the other side of the circle from the observer will have increasingly similar distances to the observer. Their distances, when compared in 1D causing them to bunch up, which is depicted on the left side of Fig. 4. Were the time that we observe acting this way, it would be time contracted and light would be blueshifted.

Since those effects are the opposite of what we observe, consider time on the surface of a hyperbola rather than a circle. This is depicted on the right side of Fig. 4. Hyperbolic time, then, would seem to be able to produce time dilation and redshift of the past when observed from the present.

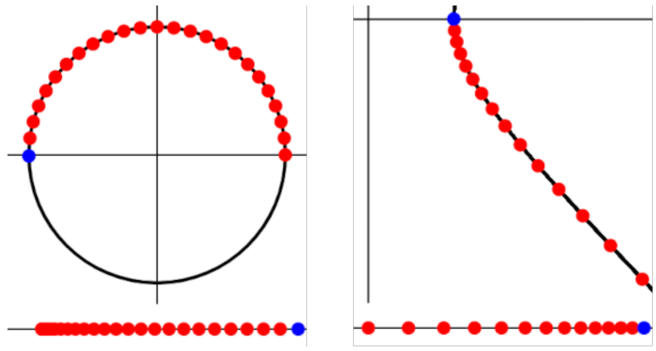

Figure 4. Circular time (left) and hyperbolic time (right). Regularly occuring events (red dots) are spaced evenly along the curves. Their distance to an observer (blue dot) in 2D space is shown underneath.

As seen from equation (10) for physical distance, as z approaches infinity, d approaches c/H_0. This means there is a cosmological horizon at that distance. A spacetime that fits the description of closed, static space in which time dilates along hyperbolic geodesics, is de Sitter's original coordinates, which he calls "system B", and is defined by the line element (equation (8B), de Sitter (1917)) with a $(- - -+)$ signature:

$$ds^2 = -dr^2 - R^2 \sin^2 \frac{r}{R}[d\psi^2 + \sin^2 \psi d\theta^2] + \cos^2 \frac{r}{R} c^2 dt^2 \qquad (20)$$

A modern version of that line element with a $(-+++)$ signature is given by:

$$ds^2 = -\left(1 - \frac{r^2}{\alpha^2}\right) dt^2 + \left(1 - \frac{r^2}{\alpha^2}\right)^{-1} dr^2 + r^2 d\Omega_2^2 \qquad (21)$$

de Sitter says (p. 18) that system B "does not appear to admit of a simple physical interpretation." However, the interpretation of "a time dilated past" may be applicable.

Consider a 3D hyperboloid with a radius of α in 3D Euclidean space (x_0, x_1, x_2) given by:

$$-x_0^2 + x_1^2 + x_2^2 = \alpha^2 \qquad (22)$$

Now let's say stationary clocks are placed along the "neck" of the hyperboloid at different angles θ so $x_0 = 0, x_1 = \alpha \cos\theta, x_2 = \alpha \sin\theta$, as shown in Fig. 5.

The worldline of each clock is given by the intersection of a 2D plane with the hyperboloid, where x_1 and x_2 are constant, and the plane contains the origin and the clock. If the hyperboloid is oriented so the x_0 axis is vertical, the 2D plane would be vertical as well.

It is helpful here to make an unusual interpretation of the passage of time. It is commonly understood that the clock will move along its worldline as time passes, that is traveling up the x_0 axis. As time passes and the clock ticks, the clock will travel upwards (forwards in time) leaving a trail of clock tick events behind it.

Alternatively, consider that as time passes, and the clock ticks, it stays where it is on the manifold, and it is the clock tick events that are moving downward, into the past. This is analogous to relative motion in Galilean relativity. An observer in a sailing ship dropping pieces of paper off the side of the ship may reason that the ship is stationary, and the pieces of paper are moving backwards from it.

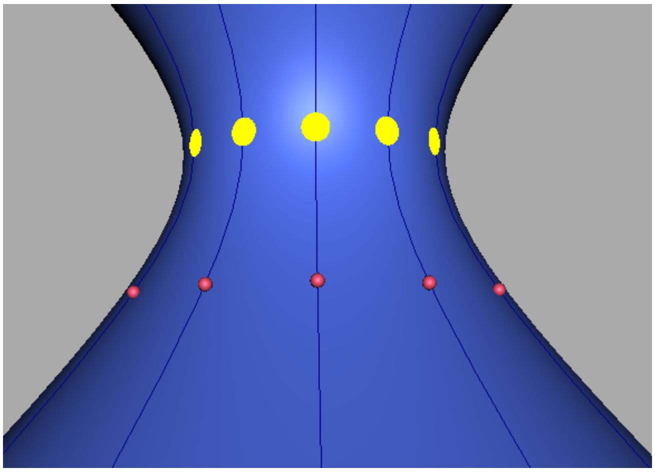

Figure 5. Stationary clocks (yellow discs) are placed on the manifold in the present. As time passes, the clock tick events (red balls) move downward, into the past, while the clock remains in the present.

This can be interpreted as the clocks always existing in the present, $t = 0$, and their tick events moving further into the past as time passes. Were Fig. 5 animated, the yellow discs would represent clocks that stay where they are, and the red spheres represent clock tick events that occur at the clock and then move downward along the clock's worldline.

As the clock tick events follow the hyperbolic worldline into the past, they intercept the past light cones of the other clocks at a diminishing rate, producing time dilation and redshift.

6 COSMOLOGICAL IMPLICATIONS

Time dilated supernovae and redshifted light are just two of the pieces of cosmological evidence we have available to us, and the Pantheon+SH0ES dataset is just one dataset. As a redshift-distance relationship, the hypothesis is shown to be a better fit to that dataset than the current standard model of cosmology. But for the broader body of cosmological evidence, the hypothesis is unsatisfyingly silent.

6.1 The Cosmic Microwave Background

The cosmic microwave background in particular has no immediate explanation in a universe that isn't expanding, and thus has no conceivable beginning.

As the hypothesis sets a cosmological horizon at $d = c/H_0$, the horizon itself could be a source of a thermal black body spectrum due to Hawking radiation. The temperature of this radiation, though, is estimated to be far too low to be considered as the source of the CMB.

7 CONCLUSION

It may turn out that the challenges faced by ΛCDM are resolvable within that framework, or within an alternative expanding framework, and that any interest in nonexpanding models will be short-lived. One consequence of exploring this particular hypothesis, however, is that an interesting question has been raised: who is to say that we as observers are moving forward through time, or whether the observer is at "rest" and time moves against it?

While the expanding dynamic of space has been favored for quite some time, other dynamics such as the mass of particles or the speed of the light, have been and are being investigated. Yet a dynamic of time, which at first doesn't seem intuitive, correlates closely to what is actually observed, and may be a promising alternative to the standard model of cosmology.

DATA AVAILABILITY

The data used in the work is publicly available.

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