Does the One-Way Speed of Light Depend on the Distance Between the Emitter and Absorber?

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June 20, 2017

Abstract

We present a simple model of light propagation that allows for the one-way speed of light, or equivalently, the simultaneity convention, to depend on the distance between the emitter and the absorber. This is distinct from variable speed of light (VSL) theories that assume the two-way speed of light is variable. We show that this model predicts wavelength shifts that are consistent with wavelength shifts measured from light propagating on astrophysical scales, thus eliminating the need to propose ad hoc mechanisms, such as dark matter, dark energy, and cosmological expansion.

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It is well known that Einstein addressed the challenge of defining distant simultaneity in his groundbreaking paper on special relativity [1] by stipulating that the one-way speed of light is identical to the experimentally measured two-way speed of light [2]. This method of synchronizing distant clocks results in a simultaneity relation now commonly referred to as *standard simultaneity*. Einstein's examination of distant simultaneity has led to a long-standing, and still unresolved, debate in the literature regarding the conventionality of simultaneity [3, 4, 5, 6, 7, 8, 9, 10]. On the one hand, supporters of the conventionality thesis (e.g., [3, 4, 7, 8]) advocate that clock simultaneity is an arbitrary convention that permits different one-way speeds of light. According to this thesis, all simultaneity conventions that preserve the experimentally measured two-way speed of light are equivalent. On the other hand, opponents of the conventionality thesis (e.g., [5, 6, 9]) argue that standard synchrony defined by Einstein synchronization is the only clock synchronization convention that is permitted by fundamental physical laws. Furthermore, they argue that the one-way speed of light can be measured independently of the synchronization convention and is equal to the experimentally measured two-way speed of light. Although this topic has received significant attention throughout the years this debate remains unsettled. The absence of indisputable experimental evidence in favor of either interpretation has contributed to the prolongation of the debate.

Even though more than a century has passed since Einstein's seminal paper, all experimental efforts to measure the one-way speed of light independent of a synchronization scheme have failed. Indeed, there is no difference between stipulating the one-way speed of light and adopting a particular synchronization scheme, so the inability to measure the one-way speed of light independent of a synchronization scheme is consistent with Einstein's viewpoint [2]. However, whereas previous discussions on the conventionality of simultaneity assume a constant one-way speed of light, in the following we explore a model of light propagation that relaxes this assumption. In particular, we explore a model that incorporates a variation of the one-way speed of light with the distance between the emitter and absorber. Such a variation can be formulated such that the experimentally-measured two-way speed of light remains unchanged. As a result, the proposed model is not a variable speed of light (VSL) theory [11] and is therefore consistent with all predictions of special relativity.

We consider light propagating from a point A in space to an observer O in a straight line with phase given by:

$$\phi = \frac{2\pi}{\lambda}(r + ct), \tag{1}$$

where r is the radial coordinate according to observer O, and we have ignored an arbitrary phase constant. Under the following time transformation:

$$t \to t - \frac{b}{c}r, \tag{2}$$

the phase of the electromagnetic wave according to observer O is:

$$\phi = \frac{2\pi}{\tilde{\lambda}}(r + \tilde{c}t), \tag{3}$$

where

$$\tilde{\lambda} = \frac{\lambda}{1 - b} \tag{4}$$

and

$$\tilde{c} = \frac{c}{1 - b}. \tag{5}$$

We see that transformation (2) leads to a change in the wavelength observed by O at the point of absorption. It is important to note that the frequency of the wave remains constant, so that $\tilde{\nu} = \nu$. According to the conventionality thesis, b is an arbitrary constant that must be stipulated and cannot be measured. Standard relativity assumes $b = 0$.

We now consider the case, alluded to above, where b is a function of the distance, L, between the emitter and the observer. In particular, we consider a linear relation such that:

$$b = \frac{L}{L_0}, \tag{6}$$

where L_0 is a fundamental constant of nature that represents the largest possible distance of light propagation, i.e., the distance from the observer to the edge of the universe. In the limit $\frac{L}{L_0} \to 1$, the simultaneity convention predicted by Equation (6) approaches backward null cone simultaneity [12, 13, 14], which was briefly entertained by Einstein in his seminal paper [1]. According to backward null cone simultaneity, light propagates with infinite speed towards an observer and with speed $c/2$ away from an observer. In the opposite limit, $\frac{L}{L_0} \to 0$, the simultaneity convention according to Equation (6) reduces to standard simultaneity. Assuming $\frac{L}{L_0} \ll 1$, the shift in wavelength predicted by (6) is:

$$\frac{\Delta\lambda}{\lambda} \approx \frac{L}{L_0} + \left(\frac{L}{L_0}\right)^2. \tag{7}$$

We see that the simple model proposed above predicts wavelength shifts that are consistent with wavelength shifts currently observed from astrophysical sources. Therefore, we identify $L_0 = \frac{c}{H_0}$, where H_0 is the Hubble constant. It is important to point out that this model predicts wavelength shifts from stationary sources, thus eliminating the need to postulate the expansion of the universe. Also, the proposed model predicts that the frequency of light remains unchanged. In addition, for $\frac{L}{L_0} \to 1$, the model includes terms that would appear as an acceleration if the wavelength shifts were attributed to the expansion of the universe.

In conclusion, we relaxed the assumption that the one-way speed of light, or equivalently, the simultaneity convention, is independent of the distance between the emitter and the absorber. For a simple linear relationship this leads to wavelength shifts consistent with observation. We note that the linear relationship considered in Equation (6) is just one simple example, and the exact functional form can only be determined by experiment. It is the change in the one-way speed of light with separation distance that is observable, not the one-way speed of light itself.

The proposed model suggests a teleological interpretation of light such that the one-way speed of light in both directions is determined by the distance between the emitter and observer at the time of emission. While somewhat surprising from a classical viewpoint, such an interpretation is consistent with the strange behavior of light and particles in the quantum domain. Note that the one-way speed of light in both directions must preserve the experimentally-measured two-way speed of light, so that the one-way speed of light in both directions is encoded by nature at the time of emission based on the instantaneous emitter-absorber separation. In addition, the proposed model is consistent with current proposals related to the timelessness of physics (e.g., [15]). Indeed, the timelessness of special relativity, i.e., the elapsed time in the rest frame of a photon, is equivalent with the duration of time measured by O for light to propagate from L_0 to observer O. In other words, according to O, there is no past event of emission from L_0 so that both emission from the edge of the universe and absorption at O occur in the present according to O.

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