Reply to “Isotropy of Speed of Light” by Castaño and Hawkins, arXiv:1103.1620

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In “Isotropy of Speed of Light” by Castaño and Hawkins, arXiv:1103.1620, it is claimed, using a flawed theoretical argument, that the speed of light must necessarily be isotropic, independent even of experiment. The key false assumption made is that the round trip time must always be invariant wrt change of direction of the light path. This is shown to be false. More importantly the anisotropy of the speed of light has been repeatedly detected in experiments, beginning with Michelson and Morley in 1887, and with the most recent data being from spacecraft earth-flyby Doppler shift data. Similar misunderstandings critically affect the designs for LIGO and LISA.

1 Introduction

In “Isotropy of Speed of Light” by Castaño and Hawkins, arXiv:1103.1620 [1], it is claimed, using a flawed theoretical argument, that the speed of light must necessarily be isotropic, independent even of experiment. The key false assumption made is that the round trip time must always be invariant wrt change of direction of the light path, although no reasons for that assumption are given. This is shown to be false. More importantly the anisotropy of the speed of light has been repeatedly detected in experiments, beginning with Michelson and Morley in 1887 [2, 3, 4], and with the most recent data being from spacecraft earth-flyby Doppler shift data [5, 6]. Other experiments were reported in [7, 8, 9, 10, 11, 12, 13, 14]. It is also noted that the misunderstanding of the physics associated with the anisotropy of the speed of light explains why LIGO and related instruments have failed to detect gravitational waves, while the planned LISA space-based detector will be excessively sensitive.

2 Light Travel Times

Fig. 1 shows photon bounce trajectory in reference frame fixed in space, and so the light has speed $c$, and with source and retroreflector in motion through space with velocity $v$. Define $t_{AB} = t_B - t_A$ and $t_{BC} = t_C - t_B$. The distance $AB$ is $vt_{AB}$ and distance $BC$ is $vt_{BC}$. The total photon travel time is $t_{AC} = t_{AB} + t_{BC}$. In the case of there being no rod supporting the source and retroreflector, so that they are merely co-moving through space, then the distance between source and retroreflector is $L$. Applying the cosine theorem to triangles $ABB'$ and $CBB'$ we obtain

$$t_{AB} = \frac{vL \cos(\theta) + \sqrt{v^2L^2 \cos^2(\theta) + L^2(c^2 - v^2)}}{(c^2 - v^2)}$$ (1)

$$t_{BC} = \frac{-vL \cos(\theta) + \sqrt{v^2L^2 \cos^2(\theta) + L^2(c^2 - v^2)}}{(c^2 - v^2)}$$ (2)
Fig. 1: Photon bounce trajectory in reference frame of 3-space, so speed of light is $c$ in this frame. The source is at successive locations $A$, $B$, $C$, at times $t_A, t_B, t_C$, and the retroreflector is at corresponding locations $A', B', C'$ at the same respective times $t_A, t_B, t_C$. Source-retroreflector separation distance is $L$, and has angle $\theta$ wrt velocity $v$ of source and reflector, and shown at three successive times: (i) when photon pulse leaves $A$ (ii) when photon pulse is reflected at retroreflector at $B'$, and (iii) when photon pulse returns to source at $C$.

The round trip time depends on whether the retroreflector is support by a rod, of rest-length $L$, or not, as the rod is subject to Fitzgerald-Lorentz contraction. The round trip time is only independent of $\theta$ in the case of a rod supporting the source-retroreflector separation, and then only if the light propagates through a vacuum.

Then to $O(v^2/c^2)$

$$t_{AC} = \frac{2L}{c} + \frac{Lv^2(1 + \cos^2(\theta))}{c^3} + \ldots$$  \hspace{1cm} (3)

Hence we see that the round-trip travel time depends on orientation, contrary to the false assumption in [1]. However if there was a solid rod separating source and reflector, as in one arm of a vacuum-mode Michelson interferometer, then there would be a Lorentz contraction of that rod, and in the above we need to make the replacement $L \rightarrow L\sqrt{1 - v^2\cos^2(\theta)/c^2}$, giving $t_{AC} = \frac{2L}{c} + \frac{Lv^2}{c^3}$ to $O(v^2/c^2)$. And then there is no dependence of the travel time on orientation.

If, as well as a rod separating the source and retroreflector, a gas is present, and if we use the approximation $c \rightarrow c/n$, with $n$ the refractive index, but only in the light propagation terms, but not in the Lorentz contraction, we obtain

$$t_{AC} = \frac{2Ln}{c} + \frac{L(n^2 + (n^2 - 1)\cos^2(\theta))v^2}{c^3} \quad \text{to} \quad O(v^2/c^2)$$

and then an angle dependence is restored, but only when $n \neq 1$. Further if we have two orthogonal arms of a gas-mode Michelson interferometer, the travel time in the 2nd arm is, using $\theta \rightarrow \theta + \pi/2$ for this arm,

$$t_{\perp AC} = \frac{2Ln}{c} + \frac{Ln(n^2 + (n^2 - 1)\sin^2(\theta))v^2}{c^3} \quad \text{to} \quad O(v^2/c^2)$$

and then the difference in travel times, as measured by fringe shifts, is

$$\Delta t = t_{AC} - t_{\perp AC} = \frac{Ln(n^2 - 1)\cos(2\theta)v^2}{c^3} \quad \text{to} \quad O(v^2/c^2)$$  \hspace{1cm} (4)

However the above analysis does not correspond to how the interferometer is actually operated. That analysis does not actually predict fringe shifts, for the field of view would be uniformly illuminated, and
the observed effect would be a changing level of luminosity rather than fringe shifts. As Michelson and Miller knew, the mirrors must be made slightly non-orthogonal with the degree of non-orthogonality determining how many fringe shifts were visible in the field of view. Miller experimented with this effect to determine a comfortable number of fringes: not too few and not too many. Hicks developed a theory for this effect - however it is not necessary to be aware of the details of this analysis in using the interferometer: the non-orthogonality reduces the symmetry of the device, and instead of having period of 180° the symmetry now has a period of 360°, so that to (6) we must add the extra term $a \cos(\theta - \beta)$ in

$$\Delta t = k^2 \frac{L(1 + e\theta) v_P^2}{c^3} \cos(2(\theta - \psi)) + a(1 + e\theta \cos(\theta - \beta) + f \quad (5)$$

where $k^2 = n(n^2 - 1)$. The term $1 + e\theta$ models the temperature effects, namely that as the arms are uniformly rotated, one rotation taking several minutes, there will be a temperature induced change in the length of the arms. If the temperature effects are linear in time, as they would be for short time intervals, then they are linear in $\theta$. In the Hick’s term the parameter $a$ is proportional to the length of the arms, and so also has the temperature factor. The term $f$ simply models any
offset effect. Michelson-Morley and Miller took these two effects into account when analysing their data. Fig. 2 shows just such fringe shifts, clearly demonstrating the \( \cos(2\theta) \) signature, in both the Michelson-Morley and Miller gas-mode interferometer experiments.

Applying the above to a laboratory vacuum-mode Michelson interferometer with \( n = 1 \), as in [15], implies that it is unable to detect light-speed anisotropy. This is a basic design flaw in laboratory vacuum-mode Michelson interferometers. The “null” results from such devices are usually incorrectly reported as proof of the invariance of the speed of light in vacuum [15], when they are actually confirming the Lorentz contraction effect for physical objects, such as rods and resonant cavities. This flaw explains the null results from LIGO and related gravitational detectors, despite the fact that other experimental techniques, such as the gas-mode laboratory Michelson interferometers and the one-way RF coaxial cable experiment by DeWitte [13], have repeatedly detected the space velocity fluctuations - the phenomena underlying gravitational waves. The design flaw can be overcome by using a gas or other dielectric in the light paths, as first reported in 2002 [3]. However LISA, which is essentially a space-based vacuum-mode Michelson interferometer, and so without rods forming the arms, does not experience a Lorentz contraction of the “arms”. Repeating the above analysis gives for the difference in travel times, assuming for simplicity equal length arms,

\[
\Delta t = t_{AC} - t_{\perp AC} = \frac{L \cos(2\theta)v^2}{c^3} \text{ to } O(v^2/c^2)
\]

Then, because \( L \) is planned to be some \( 5 \times 10^6 \) km, LISA will be ultra-sensitive, with excessive effective fringe shifts overwhelming the detection system.

Fortunately early experiments had a gas present, so that \( n \neq 1 \), albeit very close to 1. As well some used air while others used helium, and only by taking account of the different refractive indices does the data become consistent, see [3]. For dielectrics with \( n \) not near 1, the Fresnel drag effect must be taken into account, see [16] for a derivation of this effect, and [17] for an early discussion of its role in interferometers.

The results from the laboratory gas-mode Michelson interferometers are only consistent with the spacecraft earth-flyby Doppler shift data if the Lorentz contraction involves the speed of the rods wrt to space, as in Lorentz Relativity, of some 480km/s [5], and not the speed of the rods wrt the observer, as in Einstein Special Relativity. So together these experiments distinguish the very different Lorentzian and Einsteinian accounts of relativistic effects.

3 Conclusions

Misunderstandings about the anisotropy of the speed of light have confounded physics for more than 100 years. That happened because Michelson, understandably, assumed the correctness of Newtonian physics in calibrating his interferometer. Later Fitzgerald and Lorentz introduced the notion of a physical length contraction of rods when in motion through space, but did not re-calibrate the interferometer in order to understand the significance of the small but not null data. Only in 2002 [3] was this oversight of the contraction effect first corrected in analysing data from the early gas-mode interferometers. In the case of [11] assumptions contrary to known experimental outcomes were made, leading to a spurious and false claim. The existence of a dynamical space has lead to a major development of a new physics [17 18 19].
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