

Research Article

Beyond Conventionalism: Testing the One-Way Speed of Light via Classical Entanglement Synchronization

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The conventionalist thesis holds that all internal clock synchronization procedures are equivalent to Einstein's, that the one-way speed of light is conventional (i.e., not measurable), and that the Lorentz transformations (LT) and Lorentz transformations with absolute simultaneity (LTA) are empirically equivalent. In this paper, we challenge these claims by presenting a rotating rod synchronization procedure that operates independently of light signals or information transport. This procedure is a priori not equivalent to Einstein synchronization and can be used to experimentally discriminate between LT and LTA by measuring the one-way speed of light. We analyze Sagnac-type optical effects —including the linear Wang-Sagnac effect and its reciprocal variant—showing that only the LTA preserve spacetime continuity along closed non-simply connected contours. We further examine Faraday induction from moving electrified bodies and equilibrium paradoxes in relativistic electromagnetism, showing that the LTA resolve these paradoxes. The implications for quantum entanglement synchronization and variable speed of light (VSL) cosmology are briefly explored. Our analysis indicates that the claimed LT-LTA equivalence is not general, and that experimental tests of the one-way speed of light are feasible, potentially favoring the LTA framework. In particular, we find that the reciprocal linear Sagnac effect preserves reciprocity—a hallmark of the relativity principle—under the LTA, whereas the LT fail to do so, indicating that the LTA offer a more consistent description of relativistic phenomena across a wider class of physical scenarios.

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1. Introduction

Positioned within the wider context of relativistic theories and their relations to modern physics, we review the advances made in the interpretation of relativity theory spanning more than a century. In this exploration, we consider the main theoretical merits and limitations of the Lorentz and alternative relativistic transformations, address presumed difficulties and paradoxes, and examine the interpretations of experiments alongside their impact on modern physics.

The primary purpose of this article is to revise the controversial status of Special Relativity (SR) in light of recent experimental and theoretical advances.

Following the null result of the Michelson-Morley experiment (1887), several experimental developments have tested light-speed invariance. Optical tests—such as the Sagnac effect (1913) [1], the Michelson-Gale experiment (1925) [2], the linear Wang et al. effect (2005) [3][4], and routine measurements of Earth's rotation variations by Schreiber (2014) [5]—indicate non-null results favoring light-speed variance. These experiments are generally considered equivalent to Sagnac-type effects [6][7].

Theoretical advances involve re-evaluating SR's second postulate and the development of ”conventionalism” based on the generalized relativistic transformations of Mansouri and Sexl (1977) [8], [9][10][11][12][13][14][15][16][17][18][19][20][21][22][23][24][25][26][27][28][29][30][31]. This controversy, initiated by Sagnac, was furthered by several physicists including Selleri [32][33][34], Gift [35][36], Kipreos [37][38][39], Lundberg [40][41], Field [42][43], Spavieri et al. [6], [7], [44][45][46][47][48][49][50][51][52][53], and Engelhardt [54].

We acknowledge that special relativity, as formulated with the Lorentz transformations (LT), has been extensively tested and verified across a wide range of phenomena with precision experiments. The empirical success of SR is not in question. However, the conventionalist thesis asserts that what is observable and has been measured is the average two-way speed of light c and not the one-way light speed supporting the LT [10], [9][10][11][12][13][14][15][16][17][18][19][20][21][22][23][24][25][26][27][28][29][30][31]. Then, the LT based on relative simultaneity and the Lorentz transformations based on absolute simultaneity (LTA) are empirically equivalent, meaning that the same body of evidence supports both frameworks equally. Our aim is not to challenge the experimental foundation of SR but to examine the limits of this claimed equivalence. We identify specific physical scenarios—including Sagnac-type optical effects, the reciprocal linear Sagnac effect, Faraday induction from moving electrified bodies, and

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equilibrium paradoxes—where the LT and LTA diverge in their predictions or interpretations. By exploring these cases, we seek to determine whether the conventionalist equivalence holds generally or whether experimental discrimination between the two frameworks is, in principle, possible.

Paper Organization:

- Section 2: Summarizes the current status of the controversy.
- Section 3: Presents a new, linearized version of the Wang-Sagnac effect using observers in inertial frames to dismiss arguments regarding non-inertiality.
- Section 4: Discusses classical entanglement as a synchronization procedure non-equivalent to Einstein's, thereby challenging the conventionality of the one-way speed of light. Specific physical scenarios are explored indicating that the LT and LTA differ in their experimental predictions.
- Section 5: Concludes that, for non-simply connected topologies, experimental and theoretical evidence favors light-speed variance and the necessity of coordinate transformations based on the conservation of simultaneity, as highlighted by Sagnac [1], Selleri [32], Spavieri [44][45][46][47][48][49][50][51][52][53], and several other authors.

2. Revision of the Controversy: One-Way Light Speed Invariance

A. The Foundations: Einstein and Conventionalism vs. conservation of simultaneity

- **Standard SR (1905):** Assumes light propagates at a constant one-way speed c in all inertial frames, as defined by Lorentz Transformations (LT).
- **Einstein Synchronization:** To synchronize clocks A and B separated by distance L, Einstein assumed the one-way speed equals the average round-trip speed: $c = 2L/T$. Clock B is set to $t = L/c$ when the signal arrives.
- **Modern Mainstream View:** Many journals now argue that the one-way speed of light is conventional (arbitrary) because only the round-trip speed is directly observable [10]. Several authors favor coordinate transformations based on conservation of simultaneity.

B. Generalized Transformations (Mansouri & Sexl, 1977 [8]). To account for different synchronization choices, the arbitrary synchronization parameter ε is introduced:

$$
\begin{aligned}
t' &= \frac{t}{\gamma} - \frac{\varepsilon x'}{c^2} = \gamma[t(1+\frac{\varepsilon v}{c^2} - \frac{v^2}{c^2}) - \frac{\varepsilon x}{c^2}] \\
x' &= \gamma(x - vt) \; y' = y \qquad z' = z \\
c' &= \frac{dx'}{dt'} = \frac{c}{1 + \frac{v}{c} - \frac{\varepsilon}{c}}
\end{aligned} \tag{1}
$$

Transformation	Parameter	Simultaneity	Light Speed
Lorentz (LT)	$\varepsilon = v$	relative	Invariant ($c' = c$)
LTA	$\varepsilon = 0$	absolute	Variant ($c' \neq c$)

The transformations (1) from frame S to $S^{'}$ in relative motion with velocity v take on different names depending on the chosen value of the parameter ε. The LTA have been used by many physicists, although under different names and, originally, they have been denoted as the Tangherlini [55] or Selleri [32] transforms, and later as ALT [37][38][39], or LTA [40][41][42][43][44][45][46][47][48][49][50][51][52][53][54], etc., where the letter A indicates that the (Lorentz) transformations adopt conservation of simultaneity (i.e., absolute simultaneity).

C. The Core of the Conflict

1. **The Conventionalist Argument**: Supporters of conventionalism claim LT and LTA are physically equivalent because they differ only by the ”arbitrary” synchronization parameter ε. They argue that any ”internal” synchronization is conditioned by time dilation/length contraction effects (like clock transport) and must eventually default to Einstein’s results. Hence, even in the Sagnac-type experiments indicating light-speed variance, the local one-way light speed is c and the related non-integrability of light speed along closed loops represent a mathematical artifact of the theory that does not disprove the validity of the LT.
2. **The Counter-Argument (This Paper)**: Under the standard LT, if we synchronize clocks around a closed loop of length L, an observer in motion with velocity v along the loop finds that upon returning to the start, the ”time” has jumped by $\Delta t' = -(vL/c^2)$.

Non-Integrability: Mathematically, for a physical quantity to be ”integrable,” the integral around a closed loop should be well-defined. Since the LT force a coordinate ”step” at the closure point, the physical quantity effectively sees a discontinuity. These difficulties emerging with the LT have been theoretically and experimentally exposed with the optical effects of the Sagnac type, reflecting topologies non-simply connected.

Concerning the alleged equivalence, we contend that LT and LTA may represent different physical realities and, in Section 4, provide a list of examples where the LT and LTA predict different observable results and, thus, are not equivalent.

- **The "Entanglement" Solution:** Instead of Einstein sync, we use the recently proposed [53] "preset classical entanglement"- based synchronization —simultaneous events at A and B that do not require moving a signal or clock between them.
- **Result:** This bypasses the time dilation/length contraction errors inherent in standard synchronization and, in principle, allows us to measure the "true" one-way speed and test if space is isotropic.

D. Experimental Scope

This interpretation can be applied to several phenomena where light speed variance appears:

- *Circular:* Sagnac Effect, Michelson-Gale, GPS satellite timing.
- *Linear:* Wang-Sagnac effect, discussed in detail in Section 3.
- *Geophysical:* Variations in Earth's rotation (Schreiber).
- *Astrophysics and Cosmology*: Models where light speed is variant are being discussed in the literature as possible alternatives to the Standard Model.

3. Interpreting light propagation in a closed loop to determine the synchronization consistent with observation

In all the effects of the Sagnac type, the invariant proper time interval T measured by a clock for a counterpropagating photon leaving the clock and returning to it after covering the contour length $2\gamma L$, is:

$$T = \frac{2\gamma L(1 - v/c)}{c} = \frac{2\gamma L}{\gamma^2(c+v)}, \tag{2}$$

where c is the one-way light speed in the inertial reference frame S and v is the velocity of the measuring device relative to S. The interval T is independent of the initial position of the measuring device C* (a clock) and is valid even when C* changes its velocity direction.

Possible interpretations of the one-way result (2):

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The result (2) is generally derived within a single inertial reference frame, where the one-way speed of light is assumed to be c, in agreement with the two-way Einstein synchronization. As long as there is no specific evidence of spatial isotropy or anisotropy, the choice of the "preferred" single frame is arbitrary and does not alter the invariant result (2). In fact, for both the LT and LTA, the average two-way speed in the chosen frame is the constant c, consistent with the convention that what is constant is the two-way speed rather than the one-way speed—a point correctly highlighted by Lee [10]. What we show below to differ between the LT and LTA is the internal consistency of the transformations when used to assess the local light speed along a closed contour whose sections are in relative motion.

What can be inferred from result (2): In the interval T the photon traveling at the average speed c can cover only the distance $2\gamma L(1-v/c) < 2L$. For the set of inertial observers along the closed contour, the contour length is $2\gamma L$ [44][45][46][47][48][49][50][51][52][53]. It is impossible that at speed c the photon can cover the whole length $2\gamma L$ in the interval T. In the interval T the photon can cover the whole distance $2\gamma L$ only if traveling at the average supraluminal speed $\gamma^2(c+v)$.

Although these obvious interpretations exclude the possibility that the local one-way light speed can be the invariant c along the whole contour $2\gamma L$, conventionalists [9][10][11][12][13][14][15][16][17][18][19][20][21][22][23][24][25][26][27][28][29][30][31] claim that the local speed is c. As already shown in several descriptions of the linear effect [6], [7], [44][45][46][47][48][49][50][51][52][53], we show once more below that conservation of spacetime continuity along the whole contour requires the local speed to be variant: $c' = c(v)$.

Figure 1. A photon travels along an optical fiber of length $\simeq 2L$ and is emitted by the stationary clock C*, which measures the total time of flight $T = T''_{out} + T''_{ret}$, with T''_{out} the out-trip interval from C* to point B and T''_{ret} the return interval from B to C*. a) Initial relative position of C* and point B. b) The origins of frame S$'$ and S$''$ coincide at $t' = t'' = 0$ when the photon has reached B as simultaneously seen in frame S$''$. Due to relative simultaneity, in frame S$'$ the photon is seen at K, closer to the origin O$'$ of S$'$ at $t' = 0$. The section KB $= c\,\delta t' \simeq 2\gamma(v/c)L$ has not been covered by the photon in the interval $T''_{ret} > 0$. It has been covered in the past ($t' < 0$). c) The photon is back to C* after the interval T.

We wish to check the internal consistency of the LT and LTA in describing the optical experiment shown in Fig. 1, where light propagates along an optical fiber. A photon is emitted from the stationary clock C*, which measures the total time of flight $T = T''_{out} + T''_{ret}$ taken in the out trip to traverse the distance from C* to the moving point B in the interval T''_{out} and return to C* in the interval T''_{ret}. Although this problem

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can be presented and discussed independently from the linear Wang-Sagnac effect (LSE), we may recognize its analogy with the LSE by considering that, as seen from the pulleys rest frame S, the optical fiber of length $2\gamma L$ may be thought of as sliding on the two pulleys at A and B forming a closed contour, as shown in Fig. 1-c by the sections of the fiber forming a closed loop.

We choose the frame S$^{''}$ where C* is at rest as the preferred frame where for both the LT and LTA the one-way light speed is c and use the transformations (1) with the initial conditions defined in frame S$^{''}$. As seen from frame S, the fiber is sliding at speed v on the pulleys and the following kinematical relations hold: $\gamma_w = \gamma^2(1+v^2/c^2)$, $w = 2v/(1+v^2/c^2)$, where w is the relative velocity between S$^{'}$ and S$^{''}$ [53].

To check the internal consistency of the transformations we need to verify that the observable time intervals in the out trip in S$^{''}$ and return trip in S$^{'}$ correspond to the photon traversing—while preserving spacetime continuity—the total fiber length $2\gamma L$ in the interval T at the local light speed foreseen by the chosen transformations (LT or LTA).

The details of the calculations for the LT and LTA are:

1) **LT and LTA**: Performing the calculations in the preferred frame S$^{''}$, the results obtained are the same for both the LT and LTA.

With reference to Fig. 1-c, for the section C*B we find,

$$\begin{gathered} D + vT''_{out} + vT''_{ret} = (L/\gamma)\ D = \gamma L(1-v/c)^2 \\ \frac{L}{\gamma} + \frac{\gamma_w L}{\gamma} \ = \ 2\gamma L.\ \text{(contour length)} \end{gathered} \tag{3}$$

In the out trip from C* to B the equation of motion of the photon is $ct'' = D + vt''$ and,

$$T''_{out} = \frac{\gamma L(1-v/c)}{c} = \frac{\gamma L}{\gamma^2(c+v)}. \tag{4}$$

In the interval T''_{out} the length covered from C* to B is (Fig.1-b),

$$L''_{out} = cT''_{out} = \gamma L(1-v/c). \tag{5}$$

Since B is at the distance $x''_B = cT''_{out}$ from C*, the photon's return equation of motion in S$^{''}$ is $cT''_{out} - ct'' = 0$. Then,

$$T''_{ret} = T''_{out} = \frac{\gamma L(1-v/c)}{c} = \frac{\gamma L}{\gamma^2(c+v)} \tag{6}$$

$$T''_{tot} = T''_{out} + T''_{ret} = \frac{2\gamma L(1-v/c)}{c} = \frac{2\gamma L}{\gamma^2(c+v)} \tag{7}$$

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in agreement with (2).

2) **Checking the internal consistency of the theory.**

2.1) *Using the LT.* **Fiber length covered by the photon at the local speed $c' = c$ in the return trip in frame S':**

The LT are,

$$x' = \gamma_w(x'' - wt''); \quad t' = \gamma_w(t'' - wx''/c^2) \\ w = 2v/(1 + v^2/c^2) \simeq 2v \quad \gamma_w = \gamma^2(1 + v^2/c^2). \tag{8}$$

In the return trip along the fiber comoving with frame S$'$, we wish to calculate the length L'_{ret} covered by the photon traveling at speed $c' = c$ in S$'$ in correspondence to the observable interval T''_{ret} elapsed in S$''$.

The expected fiber effective length to be covered in S$'$ in the return trip is,

$$L'_{ret-eff} = 2\gamma L - L''_{out} = 2\gamma L - \gamma L(1 - v/c) = \gamma L(1 + v/c). \tag{9}$$

For the clock C$'$ suitable for determining L'_{ret} in S$'$, we choose the clock at the origin O$'$. This clock meets the photon returning to C* at the instant when O$' \equiv$ C$'$, the photon, and C* coincide (Fig. 1-c). To start with, we consider the origin O$''$ of S$''$ coinciding with the origin O$' \equiv$ C$'$ as shown in Fig. 1-b and, correspondingly, set the origins of time $t'' = t' = 0$. At $t'' = 0$, the point O$' \equiv$ C$'$ is placed to the left of C* at the distance,

$$\Delta x''_{C'} = \mathrm{O'C*} = wT''_{ret} = \frac{w}{c}\gamma L(1 - \frac{v}{c}). \tag{10}$$

Next, we use the LT to find the position x'_{0-ph} of the photon in S$'$ at $t' = 0$. The time interval $T'_{ret} = T''_{ret}/\gamma_w$ taken by the photon to traverse the fiber from x'_{0-ph} to $O' \equiv C'$ is observable and corresponds to the reading of C$'$ when reached by the photon in its return trip. The interval T'_{ret} is related to the fiber length $L'_{ret} = cT'_{ret}$ covered at speed $c' = c$ in frame S$'$. Relative to the origin O'' and at $t'' = 0$, the photon at B is located at (Fig. 1-b):

$$x''_{0-ph} = \Delta x''_{C'} + cT''_{out} = wT''_{ret} + cT''_{out} = (1 + w/c)\gamma L(1 - v/c) \\ = \frac{\gamma}{\gamma_w} L(1 + v/c). \tag{11}$$

According to the time transform of the LT, the event E($t'' = 0$; $x'' = x''_{0-ph}$) occurs in S$'$ at

$$t' = -\delta t' = \gamma_w(0 - wx''_{0-ph}/c^2) = -\gamma_w wx''_{0-ph}/c^2 \\ = \gamma\frac{w}{c^2}L(1 + v/c) \simeq 2\frac{v}{c^2}L \tag{12}$$

at the position,

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$$L'_{ret-eff} = x'_{ph}(-\delta t') = \gamma_w(x'' - wt'') = \gamma_w x''_{0-ph} = \gamma L(1+v/c). \tag{13}$$

It follows that at the present time $t' = 0$ the photon has moved to:

$$\begin{aligned} x'_{0-ph} &= x'_{ph}(t'=0) = x'_{ph}(-\delta t') - c\,\delta t' = \gamma_w x''_{0-ph} - \gamma_w w x''_{0-ph}/c \\ &= \gamma L(1+v/c) - w(1+v/c)\gamma L/c = \gamma L(1+v/c)(1-w/c) \\ &= \frac{\gamma}{\gamma_w} L(1-v/c) = L'_{ret} = cT'_{ret}. \end{aligned} \tag{14}$$

This result indicates that, traveling in the return trip at the local speed $c' = c$, in the interval T'_{ret} $(t' > 0)$ the photon has not covered the expected fiber effective length $L'_{ret-eff} = x'_{ph}(-\delta t') = \gamma L(1+v/c)$ of Eq. (13) but only the section L'_{ret} of Eq. (3). Thus, if with the LT in the return interval T'_{ret} the photon is bound to travel at the local speed c in S$^{'}$, there is a "missing" uncovered section of length:

$$L'_{ret-eff} - L'_{ret} = x'_{ph}(-\delta t') - x'_{ph}(t'=0) = c\,\delta t' \simeq 2\gamma(v/c)L. \tag{15}$$

Therefore, spacetime continuity does not hold with the imposed constraint of an invariant light speed c.

Some unfounded criticisms to the conclusion that the LT foresee the "missing" uncovered section of length $c\delta t' \simeq 2\gamma(v/c)L$:

Some authors [31], [30] claim that the use of the LT does not imply the spacetime discontinuity reflected by Eq. (15). Applying their argument to the linear effect of this paper, it is referring to the nonconservation of simultaneity of the LT that foresees the covered fiber length $L'_{ret-eff} = \gamma L(1+v/c)$ of Eq. (13) in the photon return trip in frame S$^{'}$. These authors argue that the total length covered is $L_{tot} = L''_{out} + L'_{ret-eff} = 2\gamma L$ and thus spacetime continuity is conserved with the LT.

However, the point is that, at the local speed c, the length $L'_{ret-eff}$ used by these authors is covered in the interval,

$$(T'_{ret})_{authors} = \frac{L'_{ret-eff}}{c} = \frac{L'_{ret} + c\,\delta t'}{c} = T'_{ret} + \delta t' \tag{16}$$

and not in the interval $T'_{ret} = T''_{ret}/\gamma_w$ of Eq. (3) consistent with observation. In fact, with the ad hoc addition of $\delta t'$ in (16)—claimed by Mamone Capria [30] and Lambare [31]— we find

$$T''_{tot} = T''_{out} + \gamma_w (T'_{ret})_{authors} = \gamma L(1-v/c)/c + \gamma_w \gamma L(1+v/c)/c \simeq 2L/c, \tag{17}$$

in complete disagreement with the observed result (2) and thus ruling out the validity of the criticisms [52].

2.2) *Using the LTA.* **Fiber length covered by the photon at the local speed $c' = \gamma_w^2(c+w)$ in the return trip in frame S':**

We use the generalized transformations (1) with $v \Rightarrow w$.

At $t' = t'' = 0$, as seen from S$^{''}$ the distance O$^{'}$B to be traversed by the photon in the return trip is: $wT''_{out} + cT''_{ret} = (1 + w/c)\gamma L(1 - v/c) = x''_{0-ph}$ as in (3). As seen from S$^{''}$, this distance is traversed by the photon as predicted by the equation $wt'' = x''_{0-ph} - ct''$, which gives $T''_{ret} = \gamma L(1 - v/c)$ as in (6) and (10). If spacetime continuity is conserved, the same distance seen from S$^{'}$ is,

$$L'_{ret} = L'_{ret-eff} = \gamma_w x''_{0-ph} = \gamma L(1 + v/c). \tag{18}$$

For the time intervals T'_{ret} and T''_{ret} evaluated at the position ($\Delta x' = 0$) of clock C$^{'}$ the time transform of (1) yields,

$$\gamma_w(\Delta t' + \frac{\varepsilon \Delta x'}{c^2}) = \Delta t \ \Rightarrow \ \gamma_w T'_{ret} = T''_{ret} \tag{19}$$
$$T'_{ret} = T''_{ret}/\gamma_w = \frac{\gamma L(1 - v/c)}{c\gamma_w},$$

independent of ε. For the return trip the light velocity changes sign and from the expression (1) with $v \to w$ and with the help of (8) we find the one-way light speed that conserves spacetime continuity:

$$c' = c'(\varepsilon) = \frac{c}{1 - w/c + \varepsilon/c} = \frac{L'_{ret}}{T'_{ret}} = \frac{c\gamma_w(1 + v/c)}{(1 - v/c)} \tag{20}$$
$$= \gamma_w^2(c + w) = \frac{c}{1 - w/c} \ \Rightarrow \varepsilon = 0,$$

in agreement with the velocity composition of the LTA.

The fiber's length covered at the corresponding local speed c' is

$$L_{tot} = cT''_{tot} = cT''_{out} + c'T'_{ret} = L''_{out} + L'_{ret} \tag{21}$$
$$= \gamma L(1 - v/c) + (1 + v/c)\gamma L = 2\gamma L.$$

Confirming spacetime continuity, the whole fiber length has been covered in the observed interval $T = T''_{tot}$.

4. Classical Entanglement as a Synchronization Procedure for Measuring the One-Way Speed of Light

Let us review the claims of conventionalists [8][9][10][25][26][27] and provide more detailed rebuttals. The claims are:

- Any internal synchronization procedure is equivalent to Einstein's;
- Synchronization is arbitrary;

- The one-way speed of light is conventional; therefore, since the synchronization parameter ε is not observable, the Lorentz Transformations (LT) and Lorentz Transformations with Absolute Simultaneity (LTA) are equivalent. Being equivalent to Einstein's, any internal synchronization will show the local one-way light speed to be c and, because of the LT-LTA equivalence, the LT are not disproved by Sagnac-type experiments.

Our response to the conventionalism approach:

a) We highlight the recent procedure by Spavieri et al. [51][53], consisting of a rod of length AB $= L$ stationary on an inertial frame and rotating uniformly about its symmetry axis L parallel to the x axis. When the rod is not rotating, on the two cross sections of the rod, we can identify two points, point A* at A and point B* at B, which are in phase being aligned on the AB line parallel to the x axis. In the absence of torsional stresses, when the rod is in uniform rotation, points A* and B* remain in phase [51][53]. Thus, the built-in synchrony of the rod implies that the rotating points A* and B* will cross any axis perpendicular to the AB direction simultaneously. This preset simultaneity can be exploited to internally synchronize two clocks, one at A and the other at B.

Crucially, this rotating rod synchronization procedure does not rely on the transport of physical information or light signals. It is therefore operationally independent of the Einstein synchronization convention, which—as epistemologists and conventionalists have noted—functions not as a physical synchronization but as a clock coordination that imposes the invariance of the one-way speed of light by fiat [8][9][10]. In contrast, the rod synchronization can be applied separately in any inertial frame without presupposing the relationship between synchronizations in different frames. That relationship is not postulated a priori but is instead determined experimentally.

If the rod synchronization is applied in frame S and the result of the measurement yields the standard two-way speed c, then applying the same procedure in a relatively moving frame S' will likely yield either c (consistent with Lorentz invariance) or $c' = c \pm v$ (consistent with the LTA prediction of variable light speed). The outcome thus provides an empirical test of whether the one-way speed of light is invariant or frame-dependent. Consequently, this synchronization procedure represents an internal synchronization that is not equivalent to Einstein's a priori; it offers a means to experimentally discriminate between the LT and LTA frameworks without assuming consistency across frames.

Because its preset instantaneous synchrony can be associated with the LTA, the rotating rod synchronization demonstrates that not every internal synchronization is equivalent to Einstein's. The conventionalist claim that all internal synchronizations are equivalent therefore rests on an unexamined presupposition. By enabling a direct measurement of the one-way speed of light, this procedure opens the possibility of falsifying Lorentz invariance or, alternatively, confirming the LTA description of optical effects such as the Sagnac-type experiments discussed in this paper.

With reference to Quantum Entanglement and Synchronization, we know that, to validate the precision of quantum clock synchronization between two points (A and B), a classical information channel is required to establish the timing of coincidences [56][57][58]. This channel uses protocols such as Einstein synchronization or GPS. It may be suggested that the observed ”non locality” would not be a property of the quantum system alone, but rather a joint property of the quantum system and the classical communication framework used. Within the framework of Long-Distance Scenarios, research aims to conduct tests between satellites or stars so that the effects of the synchronizations adopted—Einstein (LT) or GPS and the classical entanglement-based synchronization (LTA)—become more evident. Hence, for astronomical-scale testing, it may be possible to determine whether the strength of correlations violating Bell's inequalities depends on the choice of synchronization method—a test that could discriminate between the LT and the LTA.

b) **Where and why the LT are considered to fail.**

Going back to the theme of the equivalence and confirming that synchronization is not arbitrary, we mention that there are other methods that can lead to the measurement of the one-way speed of light, as shown in Refs. [46][48][49].

Well-known failure of Einstein synchronization along closed moving contours has been discussed by several authors [1][32][33][34][35][36][37][38][40][41][42][43][44][45][46][47][48][49][50][51][52][53][54][59][60]. Klauber [59] has shown that applying it to a closed moving contour it amounts to a clock being out of synchronization with itself.

Moreover, the fact that the Sagnac results favor the LTA over the LT is not due to rotating frames being non-inertial, as in the case of the GPS and the circular Sagnac effect (a point highlighted also by Engelhardt [54]). Indeed, the mentioned difficulties of the LT emerge even when dealing with strictly inertial systems as in the case of the linear Wang-Sagnac (Wang et al. [3][4]) effect, as discussed in detail in Section 3.

Note that the problem arising from using Einstein's procedure for synchronizing clocks and using the LT along a closed contour was pointed out more than 50 years ago by Landau and Lifshitz [61], who stated:

"... However, synchronization of clocks along a closed contour turns out to be impossible in general. In fact, starting out along the contour and returning to the initial point, we would obtain for dx^o a value different from zero ..." .

However, Landau and Lifshitz clarify that "*The impossibility of synchronization of all clocks is a property of the arbitrary coordinate system, and not of the spacetime itself.*" Hence, although adopting the LT means that the impossibility of synchronization along a closed contour does not necessarily reflect a problem with spacetime itself, the adoption of the LTA allows for the possibility of synchronizing all clocks without the difficulties arising from the LT. Thus, as shown in the case of the linear effect in Fig. 1, the requirement of spacetime continuity for a photon covering the total fiber length $2\gamma L$ in the interval T, supports the conservation of simultaneity (LTA) versus relative simultaneity (LT).

c) **The symmetry of transformations.**

The role of symmetry represents an important theoretical argument endorsing the view that, in general, relative simultaneity (and the LT) is not compatible or exchangeable with absolute simultaneity (and the LTA). In the literature, we have found no authors –adhering to the conventionalist view– discussing this fundamental aspect. Regarding the LT, we know that the Thomas-Wigner rotation is present whenever a pair of Lorentz transformations involving non-collinear velocities is composed. In the context of atomic physics, by exploiting the symmetry of the transformations along the electron orbit, Jackson [62] applies these successive Lorentz transformations in his derivation of the Thomas precession, showing that it is predicted by the LT. Yet, in Ref. [50] Spavieri and Haug take into account the different symmetries of relative and absolute simultaneity and, following Jackson's derivation using the LTA, show that the LT and LTA provide different results. This outcome confirms the idea that the LT and LTA are in general not physically equivalent: fundamentally, the LT form a symmetry group, a Lie group of symmetries of Minkowski spacetime, while the LTA form a different group of symmetry [33].

Our claim is that the contended equivalence between relative (LT) and absolute simultaneity (LTA) has no general validity and seems to be limited to simply-connected topologies with arbitrary synchronization involving two spatially separated clocks where Einstein synchronization procedure is applicable. However, Einstein synchronization is not applicable to non-simply connected topologies –such as in Sagnac effects– where a single clock may be used to measure the round-trip time interval. Considering that the conventionalist view has limits and the LT and LTA are not interchangeable in general, whenever the LTA are successfully used to solve paradoxes of standard SR, several authors [7][32][33][34][35][36][37][38]

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[39][40][41][42][43][44][45][46][47][48][49][50][51][52][53][54] consider it a conceptual error the conventionalist claim [9][10][27] that the LT are also validated.

d) **Other considerations showing the non-equivalence of the LTA and the LT.**

1) **The reciprocal linear Wang-Sagnac effect.**

In the standard linear (Wang-Sagnac) effect the measuring device moves back and forth along the stationary contour. In the reciprocal effect, the measuring device is stationary and the contour is moving back and forth. The analysis by Spavieri and Haug [50], [7] of the reciprocal linear effect indicates that the LT and LTA foresee different results for the invariant round-trip observable T. If X is the initial distance of the clock C* from the pulley A, T is independent of X in the standard linear effect. However, for the reciprocal effect, these authors find that $T = T(X)$ is X-dependent for the LT, while T is invariant and X-independent for the LTA. Therefore, by predicting different results, the two transformations are not equivalent and represent different physical realities in this case, invalidating the argument of general equivalence claimed by conventionalists.

There exists a vast class of physical phenomena for which the relativity principle and the LT are compatible and, moreover, the LT and LTA are equivalent. It is therefore surprising that in the case of the reciprocal linear Sagnac effect, reciprocity is fully preserved under the LTA but not under the LT. Reciprocity—the symmetry that exchanging the roles of ”moving” and ”stationary” frames should yield equivalent physical descriptions—is a fundamental consequence of the relativity principle. The fact that the LT break reciprocity in this scenario while the LTA preserve it indicates a significant conceptual advantage of the LTA.

In the interpretation of Sagnac-type effects using the LT, the imposed constraint of an invariant local one-way speed c impedes the photon from traversing the whole contour in the observed interval T, producing a kind of spacetime discontinuity. By relaxing this restriction to allow for a variant one-way light speed under the LTA, spacetime continuity is conserved. Thus, for the wider class of phenomena that includes effects such as the reciprocal linear Sagnac effect, compatibility with the relativity principle requires the use of the LTA rather than the LT. Consequently, the set of phenomena for which reciprocity and the relativity principle are compatible with the LTA appears to be wider than that corresponding to the LT.

The reciprocal linear effect stands to be a new relativistic optical effect: being sensitive to velocity changes, it might have relevant technological applications in inertial guidance systems by detecting velocity variations and the corresponding direction [50], [7].

2) **Faraday Law for a Moving Electrified Body**

According to special relativity based on the Lorentz transformations (LT), an electrified body in motion—such as a small, charged sphere at rest in frame S—produces a time-varying magnetic field in a relatively moving frame S$^{'}$. Faraday's law then predicts an observable electromotive force (emf) and induced electric current in a closed conducting wire at rest in S$^{'}$. The origin of this effect lies in the LT's mixing of space and time: the time transformation $t' = \gamma(t - vx/c^2)$ couples spatial and temporal coordinates. When the electrostatic field E (with $\nabla \times \mathbf{E} = 0$ in S) is transformed to S', its curl no longer vanishes, yielding $\nabla' \times \mathbf{E}' = -c^{-1}\partial_{t'}\mathbf{B}' \neq 0$ and consequently a non-zero induction field $\mathbf{B}'$.

By contrast, the Lorentz transformations with absolute simultaneity (LTA), given by $t' = t/\gamma$ with no space-time mixing, preserve simultaneity across inertial frames. Puccini [63] and Bonaura [64] have derived the electromagnetic field transformations under the LTA starting from the same Maxwell equations used in special relativity. For the case of an electrified body at rest in S, using the results of Puccini and Bonaura, we find that in S$^{'}$ one obtains $\nabla' \times \mathbf{E}' = 0$ and $\mathbf{B}' = 0$. Thus, under the LTA, no magnetic induction field appears, and Faraday's law predicts no induced emf or current.

It is important to distinguish this scenario from that of a closed current loop stationary in the lab frame S. For such a loop, the magnetic field $\mathbf{B}$ in S is identical under both the LT and LTA. In a moving frame S$^{'}$, both transformations predict the existence of a transformed field $\mathbf{B}'$. The difference arises specifically for the case of an electrified body with no intrinsic magnetic field in its rest frame: the LT predict a non-zero magnetic field in moving frames, while the LTA predict none.

Historically, the experimental verification of induction from moving electrified bodies has been contentious. Indorato and Massotto [65] revisit the early 20th-century controversy over electric convection involving Poincaré, Crémieu, and Pender, concluding that the evidence for such effects remains inconclusive. Notably, the Rowland experiment, which purported to detect the magnetic induction field from a rotating electrified disk, is unreliable because the predicted field is approximately 50,000 times smaller than the Earth's magnetic field [65].

Nevertheless, the LT and LTA yield distinct predictions for the magnetic induction produced by a moving electrified body. This divergence indicates that the two transformations represent different physical realities, further undermining the conventionalist claim of their general equivalence.

3) **The equilibrium paradoxes of standard special relativity.**

”Paradoxes” of equilibrium are old and date back to the Tolman-Lewis’ right-angle lever paradox [66]. The equilibrium paradox of the right angle lever discussed by Tolman and Lewis consists of a lever in equilibrium under the action of external forces in the reference frame S where the lever is at rest. In a moving frame S′, the transformation of forces is such that an extra non-vanishing external torque is introduced, making the lever seem forced to rotate.

One of the viable approaches to the ”solution” of the equilibrium paradoxes is the one developed by Cavalleri, Spavieri, and Spinelli [67] who applied it to the equilibrium of a current loop in 1979. These authors recognize that the standard approach using the Maxwell tensor $\Theta^{\mu\nu}$ does not solve the equilibrium paradoxes of electromagnetism and mechanics. Then, Maxwell’s theory is incomplete and needs to be complemented by the introduction of the stress tensor $S^{\mu\nu}$ [67]. Using the total stress-energy tensor,

$$T^{\mu\nu} = \Theta^{\mu\nu} + S^{\mu\nu} \tag{22}$$

and the continuity equation,

$$\partial_\nu T^{\mu\nu} = 0 \tag{23}$$

reflecting the equilibrium of the physical system, these authors show that the paradoxes of equilibrium of standard relativistic electromagnetism based on the LT are solved.

The paradox is ”solved” within standard special relativity by complementing relativistic electromagnetism and Maxwell’s electromagnetic tensor $\Theta^{\mu\nu}$ with the stress tensor $S^{\mu\nu}$. In fact, the internal stresses of the lever now balance in frame S′ the external torque, and no net torque acts on the lever, which stays in equilibrium.

Hence, we may say that the relativistic electromagnetism based on the LT is incomplete without the introduction of the tensor $S^{\mu\nu}$ that solves the equilibrium paradoxes. However, following the works of Bonaura [64] and Puccini [63], it can be shown that if the LTA are used instead than the LT, the transformation of forces is such that no extra external torque is introduced, and the lever stays naturally in equilibrium in every inertial frame without the need for the additional stress tensor $S^{\mu\nu}$. Therefore, with the LTA, the relativistic electromagnetism is complete and there are no equilibrium paradoxes.

4) **Variable speed of light in cosmology and astrophysics.**

Since the LTA provide a consistent interpretation of optical effects within electromagnetic interactions, it cannot be excluded that they may also be applicable in microscopic and astrophysical scenarios.

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The variable light speed predicted by the LTA could support cosmological models based on a variable speed of light (VSL). In such VSL scenarios, a light speed greater than c in the early universe would have allowed distant regions to remain in thermal contact without requiring exponential inflation, thereby offering an alternative solution to the horizon problem [68] while also addressing the flatness and horizon problems without inflation [69]. If both the speed of light c and Newton's gravitational constant G vary in tandem, such correlated variations could preserve the successes of standard cosmology while modifying early-universe dynamics, consistent with constraints from the cosmic microwave background (CMB) and big bang nucleosynthesis (BBN) [70].

5. Conclusions

One of the merits of conventionalism has been to show that, owing to the claimed equivalence between the Lorentz transformations (LT) and the Lorentz transformations with absolute simultaneity (LTA), most experiments corroborating the LT corroborate the LTA equally well. After analyzing more than 40 basic experiments across different physical scenarios, Kipreos [38][39] has shown that both the LT and LTA provide the same, or equivalent, meaningful interpretations. The only differences arise for optical effects of the Sagnac type [38][39], where the LTA are favored.

We do not dispute the extensive experimental support for special relativity. Rather, we argue that the claimed LT-LTA equivalence is not general: there exist specific physical scenarios—such as Sagnac-type effects, the reciprocal linear Sagnac effect, and Faraday induction from moving electrified bodies—where the two frameworks diverge in their predictions or interpretations. Identifying these scenarios is essential for testing the limits of the conventionalist thesis and, more broadly, for clarifying whether the one-way speed of light is conventional or physically measurable.

The LTA have applications in electromagnetism, resolving equilibrium paradoxes that have challenged standard relativistic formulations. In this context, the LTA can be tested against the LT in experiments involving Faraday's law of induction applied to electrified bodies in motion. Furthermore, within the framework of the "Joint Entanglement" Hypothesis for astronomical-scale testing, it may be possible to determine whether the strength of correlations violating Bell's inequalities depends on the choice of synchronization method—a test that could discriminate between the LT and the LTA. Moreover, astrophysical observations may provide evidence of the validity of variable speed of light as assumed in some cosmological models.

By utilizing internal synchronization procedures, such as the one based on ”classical entanglement” described in Ref. [53]—which is a priori not equivalent to Einstein synchronization—it becomes theoretically possible to test Lorentz invariance and light-speed invariance. Such tests could confirm, or refute, the contended equivalence between relative and absolute simultaneity.

The primary distinction between the LT and the LTA lies in their divergent light speed predictions in the frame of the measuring clock, as evidenced in the case of the GPS [71][72], the circular Sagnac effect [1], the linear Wang-Sagnac effect [3][4], and particularly the reciprocal linear Sagnac effect [7][50]. The result that in the interpretation of the linear Wang-Sagnac effect the LT imply a spacetime continuity breach that is not reflected by the LTA, represents a strong argument favoring the LTA versus the LT. Ignoring the LTA's superior consistency in handling synchronization and spacetime continuity in non-simply connected topologies is not merely a matter of convention, but a risk to the logical coherence of future relativistic frameworks.

Coordinate transformations form a fundamental aspect of any physical model or theory. They should be valid generally, including in the treatment of optical effects. We therefore propose that the scientific community give rigorous consideration to the position advanced by Sagnac and his followers. The interpretational challenges of optical effects, the Selleri paradox [32], and the advances made within the conventionalist discourse are seldom mentioned in papers dealing with the Standard Model—either because they are not widely known or because they are assumed to have been historically resolved. While modern science has made significant progress in prominent mainstream research, it is important to recognize that the challenges facing the Standard Model extend beyond dark energy and dark matter to include the fundamental viability of the Lorentz transformations. By persisting in the assumption of the LT-LTA general equivalence, the mainstream risks overlooking a fundamental phase shift or timing bias that could be misattributed to new physics or noise.

In conclusion, we have highlighted several phenomena where compatibility with the relativity principle, a consistent interpretation of light speed propagation in non-simply connected topologies, and conservation of spacetime continuity all require the use of the LTA rather than the LT. The LTA are less restrictive than the LT in that, with their light speed variance, they relax the LT-imposed constraint of light speed invariance when passing from frame S to the relatively moving frame S' while describing light propagation.

A particularly significant finding is that in the reciprocal linear Sagnac effect, reciprocity—a fundamental feature of the relativity principle—is preserved by the LTA but not by the LT. This suggests that the set of physical phenomena for which the LTA provide a consistent description is wider than that corresponding to the LT. The road of physics research based on the LTA may therefore encompass dimensions and landscapes not foreseen by the LT. In this wider scenario, the exploration of physical reality—besides offering innovative theoretical models—may even lead to technological applications such as the reciprocal linear effect.

Notes

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The authors declare no conflict of interest.

Data Availability

Not applicable (this manuscript does not report data generation or analysis).

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