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On the Selleri Transformations: Analysis of Recent Attempts by Kassner to Resolve Selleri's Paradox

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Dedicated to the memory of Franco Selleri, 1936-2013

Abstract

This paper is a response to recent attempts by Kassner (2012) to resolve Selleri's paradox, a construction involving light speeds on a rotating disc that undermines the validity of special relativity. Kassner's first approach employed Einstein synchronization and failed as it led to an unphysical time discontinuity. His second approach ironically involved the introduction of the Inertial (or Selleri) transformations which explain the associated Sagnac effect using light speed anisotropy but preserve the paradox. His core methodology based on his belief that a clock synchronization procedure can be freely chosen is shown to be without foundation and therefore the paradox stands unresolved.

Keywords: Sagnac Effect, Selleri's paradox, Selleri transformations, Einstein synchronization, clock synchronization, GPS

1. Introduction

The well-known Sagnac Effect is the difference in transmission times of light travelling in opposite directions around a rotating disc. Selleri (1997, 2010) considered this effect to be unexplainable within the context of special relativity theory and used it to develop a paradox which appears to undermine the theory. He deduced that forward and backward light speeds c_+ and c_- of light moving in opposite directions around the rotating disc have a ratio

$$q \equiv \frac{c_+}{c_-} = \frac{c - \omega R}{c + \omega R} \neq 1 \tag{1}$$

where R is the radius of the disc and ω is the angular speed. If R goes to infinity and ω goes to zero such that the product $\omega R = v$ which is the tangential speed of the rim of the disc remains constant, then the system approaches an inertial system in which the forward and backward light speeds are unequal. This is contrary to the light speed invariance postulate of special relativity which requires

$$q \equiv \frac{c_+}{c_-} = 1 \tag{2}$$

in inertial systems. There have been several attempts to resolve this contradiction (Rizzi & Tartaglia, 1998; Rizzi & Tartaglia, 1999; Budden, 1998; Minguzzi, 2002; Ghosal et al., 2004) but Selleri (2004a) has persuasively defended the validity of the result in (1). The most recent attempts are in a paper by Kassner (2012) who claimed to resolve Selleri's paradox using two approaches. In this paper we examine these approaches and show that contrary to Kassner they both fail to resolve the paradox.

2. Kassner's First Approach

In Kassner's first attempt he considered local comoving observers in the rotating frame who may be treated at any instant as being in local inertial frames (Rindler, 2006). In such frames clocks can be Einstein synchronized in which case Kassner argued that since the two-way velocity of light is c, then the one-way velocity on the rotating disc must also be c. Earlier in the paper however he determined the average one-way speed of light observed by the commoving observer in the direction of rotation to be

$$c_+ = \frac{c}{1+\omega R/c} \tag{3}$$

and in the opposite direction to be

$$c_- = \frac{c}{1-\omega R/c} \tag{4}$$

It is interesting to note that these speeds satisfy Selleri's ratio (1) since for them

$$q \equiv \frac{c_+}{c_-} = \frac{\frac{c}{1+\omega R/c}}{\frac{c}{1-\omega R/c}} = \frac{c-\omega R}{c+\omega R} \neq 1 \tag{5}$$

This apparent contradiction by Kassner regarding the speed of light on a rotating platform immediately raises suspicion about the validity of his ensuing argument.

Following his determination of (3) and (4) he stated, "It may surprise that light needs different times to orbit the disk in the two directions. This is the Sagnac effect and it was taken by its discoverer as a sign for a failure of special relativity. Indeed, the result seems difficult to reconcile with a universal speed of light." It is in attempting to provide this reconciliation that Kassner asserted, despite his finding in (3) and (4), that "the one-way velocity of light must also be c"! Such a declaration is effectively a statement of the light speed invariance postulate of special relativity and cannot be considered a legitimate counter to (3) and (4) which contradict it.

Kassner continued in his effort to explain the Sagnac effect in the frame of the commoving observer by utilizing Minkowski analysis. He concluded by acknowledging that "Einstein synchronization fails when performed along a path around a full circle" i.e. on a closed path on the rotating disc. This failure has also been observed by Weber (1997) and earlier by Anandan (1981). Weber analyzed the situation using an invariant line element described by cylindrical coordinates in an inertial frame given by

$$ds^2 = c^2dt^2 - dr^2 - r^2d\phi^2 - dz^2 \tag{6}$$

Following Weber's approach and transforming the line element from the coordinate system (t, r, ϕ, z) in an inertial frame to a coordinate system (t', r', ϕ', z') in the rotating frame yields the well-known Langevin metric given by

$$-ds^2 = -(1-\frac{\omega_E{}^2 r'^2}{c^2})(cdt')^2 + 2\omega_E r'^2 d\phi' dt' + d\sigma'^2 \tag{7}$$

where

$$d\sigma'^2 = dr'^2 + r'^2 d\phi'^2 + dz'^2 \tag{8}$$

is the square of the coordinate distance. Applying equation (7) to the propagation of light around the rotating disc at a fixed radius by setting $ds^2 = 0$ in (7) yields a quadratic equation for dt' which when solved gives (Ashby, 2003; Gift, 2013)

$$cdt' = \frac{\omega_E r'^2 d\phi'}{c} + d\sigma', v << c \tag{9}$$

This reduces to

$$dt' = \frac{d\sigma'}{c} + \frac{2\omega_E}{c^2} dA'_z \tag{10}$$

where $dA'_z = r'^2 d\varphi' / 2$ is the infinitesimal area in the rotating frame that is swept out by a line between the axis of rotation and the light signal in the plane of the disc. From (10) the total time for light to travel a given path as measured in the rotating frame is given by (Ashby, 2003; Gift, 2013)

$$\int_{path} dt' = \int_{path} \frac{d\sigma'}{c} + \frac{2\omega_E}{c^2} \int_{path} dA'_z \tag{11}$$

Using (11), the time for light to travel around the disc at a fixed radius in the direction of rotation is given by

$$t'^{+} = \frac{2\pi R}{c} + \frac{2\pi v R}{c^2} = \frac{2\pi R}{c}(1+\frac{v}{c}) \tag{12}$$

and the time for light travel in the opposite direction around the disc is given by

$$t'^{-} = \frac{2\pi R}{c} - \frac{2\pi vR}{c^2} = \frac{2\pi R}{c}(1 - \frac{v}{c}) \tag{13}$$

The times (12) and (13) are to first order equal to those derived by Kassner given by

$$t'^{+} = \frac{2\pi R}{c}\left(\frac{1+v/c}{1-v/c}\right)^{1/2} \tag{14}$$

and

$$t'^{-} = \frac{2\pi R}{c}\left(\frac{1-v/c}{1+v/c}\right)^{1/2} \tag{15}$$

Now following Weber (1997) in order to Einstein synchronize a clock on the disc with itself, a light signal is sent from the clock in the direction of rotation around the perimeter of the disc to the clock and back. Let the time t_1' at the start of the transmission be $t_1' = 0$. Let the time of arrival of the signal at the clock after going around once in the direction of rotation be t_2' and the time of return of the signal at the clock after going around once in the opposite direction be t_3'. Then from equations (12) and (13), these times are given by

$$t_1' = 0 \tag{16}$$

$$t_2' = \frac{2\pi R}{c}(1 + \frac{v}{c}) \tag{17}$$

$$t_3' = \frac{2\pi R}{c}(1 + \frac{v}{c}) + \frac{2\pi R}{c}(1 - \frac{v}{c}) = \frac{4\pi R}{c} \tag{18}$$

For the clock to be Einstein-synchronized with itself, the time t_2' must be adjusted such that

$$t_2' = \frac{t_1' + t_3'}{2} = \frac{2\pi R}{c} \tag{19}$$

This as Weber pointed out is in conflict with the actual reading of the clock which is $t_2' = \frac{2\pi R}{c}(1 + \frac{v}{c})$. This unphysical prediction of a discontinuity in time on a rotating disc arising from Einstein synchronization has been appropriately described by Klauber (2002) as "bizarre" and that it amounts to a clock being out of synchronization with itself! Weber "solved" the problem by restricting all measurements to small regions along open paths on the rotating disc, prohibiting any consideration of closed paths. This proposal by Weber is an attempt to avoid the time discontinuity and is of course untenable as such a restriction is artificial and not a practical reality in the physical world.

Unfortunately, despite recognizing the failure of the Einstein synchronization method, Kassner embraced the resulting unphysical time discontinuity and introduced the strange concept of a "time gap" that can be manipulated in order to deal with the discontinuity. Thus regarding the frame on the rotating disc he stated, "the speed of light is c everywhere except at the point on the circle where we put the time gap. The position of this point is arbitrary but there must inevitably be such a point." Kassner then concluded that he obtained what he considered to be a valid explanation of the Sagnac effect within special relativity using Einstein synchronization. However an adjustable "time gap" based on an unphysical time discontinuity is a theoretical construct that has no basis in reality and must be rejected.

It turns out that the failure of Einstein synchronization demonstrated above for the synchronization of clocks in a rotating frame is well known to GPS engineers who discovered that they cannot synchronize GPS clocks fixed on the rotating Earth using Einstein synchronization. The CCIR reports of 1990 and 1997 contain the correct algorithm based on equation (11) that is necessary for the accurate synchronization of the GPS clocks at different points on the Earth (Ashby, 2003). It shows that synchronization of such clocks requires a non-trivial adjustment of Einstein synchronization referred to as a "Sagnac correction" (Ashby, 2003) [note 1]. This combination corresponds to using asymmetrical light speeds on the Earth as demonstrated by Selleri (2010) and Gift (2013) which are completely consistent with the anisotropic light speeds (3) and (4) in a rotating frame determined by Kassner. In light of this experimental verification of accurate clock synchronization in the GPS and the consequent falsification of Einstein synchronization in a rotating frame, Kassner's claim of a resolution of Selleri's paradox based on Einstein synchronization and the phantom idea of a time gap resulting in "forward and backward speeds of light are c everywhere except at the position of the time gap" is baseless and completely unjustified.

3. Kassner's Second Approach

The discussion in section 2 above revealed the inadequacy of Kassner's "time gap" method of resolving Selleri' paradox within the framework of special relativity and the failure of Einstein synchronization on a rotating disc. Kassner himself expressed "a certain uneasiness" with the asymmetry associated with "the minor nuisance of the time gap, the crossing of which has to be avoided." As a result he described a second method to the resolution of the paradox. He stated, "The crucial point is that we are not obliged to use Einstein synchronization. After all, the time gap arising with this approach is awkward. It may be avoided by a different synchronization of clocks along the circle $r = R$." Thus Kassner's alternative approach was to abandon Einstein synchronization altogether and choose "an alternative synchronization" on the grounds that "the preference for a particular synchronization is one of human decision, not one of nature". Is there really freedom to select an "alternative synchronization" as Kassner suggested?

In addressing this question we first note the IEEE 1588 Standard for a Precision Clock Synchronization Protocol for Networked Measurement and Control Systems which defines synchronized clocks for real-world systems in the following manner (IEEE-1588, 2008): "Two clocks are synchronized to a specified uncertainty if they have the same epoch and measurements of any time interval by both clocks differ by no more than the specified uncertainty. The timestamps generated by two synchronized clocks for the same event will differ by no more than the specified uncertainty." In other words in the practical world clocks are synchronized if they indicate the same time for the same event and this is the one logical and practically meaningful definition of synchronized clocks. We will refer to such clocks as "properly synchronized" clocks. This proper synchronization may be realized using suitable clock adjustment procedures. Unfortunately some authors apply certain clock adjustment procedures that result in modes of clock operation that do not correspond to properly synchronized clocks but which they nevertheless refer to as clock synchronization. Such procedures should instead be referred to as "clock de-synchronization" since they do not result in properly synchronized clocks. Therefore the ability to choose an "alternative synchronization" should be constrained by the requirement that the resulting clocks must be properly synchronized. Such a consideration undermines Kassner's contention that there is freedom to select an "alternative synchronization" independent of the resulting clock operating mode.

The main problem though is that one-way light speeds determined using clocks adjusted based on "alternative synchronization" will show a dependence on these different schemes since differently adjusted clocks will measure different time intervals for the same light signal transmission. In fact virtually any speed, including c, can be obtained by suitably "de-synchronizing" the measuring clocks and Will (1992) referred to the resulting speed as "apparent" speed, thereby emphasizing its fictitious nature. He pointed out that "a particularly perverse choice of [de-] synchronization can make the apparent speed…infinite"! It is therefore clear that these "apparent" speeds are completely artificial and bear no relation to physical reality. Clock synchronization, however this is accomplished, must result in clocks that indicate the same time for the same event and this is exactly the synchronization mode that exists in the very accurate and extremely successful GPS. For this system it has been established that the use of an "alternative synchronization" algorithm that does not result in "proper synchronization" would produce serious timing and navigational errors, which will render the system inoperable (Ashby, 2002). As mentioned previously, the method that is used on an ongoing basis to produce "proper synchronization" in the GPS clocks is Einstein synchronization with a "Sagnac correction". Selleri treated with this issue in his consideration of the Sagnac Effect (Selleri, 2010) and showed that similar to the situation in the GPS "it is not true that the synchronization procedure can be chosen freely" as Kassner contended and many researchers seem to believe. No such freedom exists and the only acceptable "alternative synchronizations" are those that produce properly synchronized clocks. As Selleri has noted "the usually adopted convention leads to an unacceptable discontinuity in the physical theory."

Considering now the specific "alternative synchronization" chosen by Kassner to resolve Selleri's paradox, the basis of this proposal is the elimination of the "time gap" or time discontinuity previously encountered. He accomplished this by advancing the Einstein synchronized clocks on the rotating disc by vx'/c^2 such that $t' \to t' + vx'/c^2$. The effect of this is the adjustment of the time component of the associated Lorentz transformations given by

$$t'_L = t/\gamma - vx'/c^2 \tag{20a}$$

$$x' = \gamma(x - vt), y' = y, z' = z \tag{20b}$$

thereby incorporating what Kassner refers to as "gapless synchronization" giving transformations

$$t'_S = t/\gamma \tag{21a}$$

$$x' = \gamma(x - vt), y' = y, z' = z \tag{21b}$$

where $\gamma = 1/\sqrt{1-v^2/c^2}$ and subscripts are used on the time variable for identification purposes. Using these transformations (21) which exhibit the characteristic of absolute simultaneity, Kassner calculated light speed in the rotating frame corresponding to light speed measurement using the "gapless synchronized" clocks on the rotating disc. The result is light speeds given in (3) and (4) previously calculated by Kassner which represent the local light speeds everywhere on the rim of the rotating disc. He then stated "This is the situation envisioned by Selleri, the velocity of light being homogeneous along the entire circle but different in the forward and backward directions" an apparent acceptance of Selleri's position.

Thus while the "Einstein synchronization" involving one-way light speed isotropy failed to provide a valid description of the Sagnac effect, Kassner's "gapless synchronization" represented by transformations (21) succeeded, maintaining Selleri's paradox in the process. But the transformations (21) are not an invention by Kassner as the paper implies by its lack of any citation regarding their origin. Remarkably these are the Inertial transformations that were advanced by Selleri as replacements for the Lorentz transformations especially in view of the contradiction with light speed isotropy presented by Selleri's paradox. These transformations were first considered by Tangherlini but in recognition of Selleri's considerable contribution to their development we refer to them as the Selleri transformations. They are summarized in Selleri's papers containing the paradox (Selleri, 1997, 2010) which were cited by Kassner and therefore his failure to even mention the presence of these transformations in Selleri's work is disturbing!

In the penultimate part of his challenge to Selleri's paradox and its undermining effect on special relativity, Kassner claimed equivalence of the troubled Lorentz transformations with the successful Selleri transformations he has embraced on the basis that

$$t'_L = t'_S - vx'/c^2 \tag{22}$$

This claim of equivalence is manifestly false since equation (22) is nothing more than a statement of a mathematical relation between the temporal components of the two transformations. The fact that the Lorentz time component can be obtained from the Selleri time component by subtracting the quantity vx'/c^2 does not make the two transformations equivalent. A more direct indication that the two transformations are not equivalent is the fact that they make different light speed predictions. With $dx/dt = c$, the Selleri transformations predict light speed $dx'/dt'_S = \gamma^2(c-v)$ in the moving frame where the γ^2 factor arises because of length contraction and time dilation experienced by the rulers and clocks used in the measurements (Levy, 2003). This light speed accords with (3) on the rotating disc and more significantly (in the approximate form $dx'/dt'_S \approx (c-v), v << c$) has been detected in the West-East direction using properly synchronized GPS clocks fixed on the surface of the Earth where $v << c$ (Gift, 2010, 2012, 2013; Marmet, 2000; Kelly, 2005). The Lorentz transformations on the other hand predict light speed $dx'/dt'_L = c$ which of course is consistent with the requirement of the postulate of light speed invariance of special relativity but is different from the anisotropic light speed derived from the Selleri transformations and confirmed on the rotating Earth.

Kassner concluded that the solution to Selleri's paradox is recognizing light speed anisotropy in the limiting inertial system as argued by Selleri (1997, 2010) and that "All one has to be aware of is that the one-way speed of light is synchronization dependent and therefore a difference from c does not constitute a problem." Contrary to Kassner however, since as we have shown the synchronization procedure is not open to free selection (Selleri, 2010), a light speed difference from c does constitute a problem for special relativity. This is particularly so as it has been demonstrated that light travels faster West than East relative to the surface of the rotating Earth (Gift, 2010, 2012, 2013; Marmet, 2000; Kelly, 2005) contrary to the light speed invariance requirement of special relativity. Based on measurements using the properly synchronized clocks of the GPS, this light speed anisotropy is now an objective fact validated by observational experience in the real-world time measurement of light travelling in a rotating frame.

4. Response to Reviewer Comments

This commentary was first submitted to the American Journal of Physics where Kassner's paper was published. The expectation was that Kassner would be given an opportunity to respond and assuming there were no obvious technical errors in my paper that both items would be published in the journal. This would be in the spirit of free and open debate on an important issue as is often entertained by this journal in which different points of view are presented. Unfortunately the journal rejected the paper on the basis of negative reports from two reviewers without giving me an opportunity to respond.

The first reviewer was quite dismissive, contending that my paper "is without substantial value" and arguing incorrectly as Kassner did that "we can choose any synchronization procedure, as long as we understand the basic relativistic physics involved, such as on a rotating disk." The report did not adequately address my points

of objection to this idea of free choice of synchronization nor the several other issues detailed above. It was scant and superficial and in my view should not have been accepted by the editor.

The second reviewer seemed to have given much more serious consideration to the paper as his report in small type extended to five pages. He surprisingly started by attempting to excuse Kassner's failure to cite Selleri's work as containing equations (21) by suggesting, "A reason, why Kassner did not cite anyone in giving these equations, may have been that he knew they were not due to Selleri but did not know who had actually used them first." This explanation is however without merit since even though Selleri was not himself the inventor, these equations published in Kassner's paper as resolving Selleri's paradox were advanced by Selleri in his papers as satisfying and not resolving the paradox. He also proposed them as replacements for the Lorentz transformations and therefore Kassner had a duty to indicate this in his paper.

The reviewer then addressed my objections to Kassner's first approach by embarking on what he referred to as an "excursion into general relativity" from whence he invoked an approach to justify Kassner's unphysical "time gap" technique introduced in his attempt to validate Einstein synchronization in a rotating frame. He stated "there is no reason to believe that the remedy that is known to work in general relativity would not work in special relativity, which, after all, is but a subset of general relativity." He went on, "To consider this "untenable" and "artificial" may be an expression of personal taste but hardly a scientific objection. The gap is about as unphysical as the gap of twenty-four hours between clocks on the two sides of the international date line." He concluded that "Gift's criticism of Kassner's first approach is unfounded." In response to this, my claim that the method is "untenable" and "artificial" is not an expression of personal taste but is actually an objection based on science; a discontinuity in time is unscientific since it is unreal and the invocation of supporting ideas from elsewhere does not make it real. It belongs strictly to Baggot's world of "fairy-tale physics" (Baggott, 2013) that unfortunately has crippled the scientific enterprise for the past 25 years in its search for truth about nature and its processes. The reviewer's comparison with the International Date Line is also misplaced since Kassner's "time gap" technique is a theoretical construct in which crossing the time gap is strictly prohibited lest the principle of light speed constancy be violated, whereas the international dateline is a functional (though imaginary) time boundary the crossing of which goes on continuously. The reviewer did not address my observational evidence from the GPS that in a rotating frame, Einstein synchronization really does not work and requires the "Sagnac correction" if clocks are to be properly synchronized.

Following this the reviewer turned his attention to my treatment of Kassner's second approach, the basis of which is freedom to select an "alternative synchronization". His position like that of Kassner is that "there are infinitely many ways to set up synchronicity" even though he later qualified this with "synchronization is conventional, within limits." He also dismissed my definition of "properly synchronized clocks" as "useless" but appears to use it in context when he concluded "There is more than one way to "properly synchronize" clocks." Apart from these inconsistencies, he entered into an extensive discourse in support of the idea that "synchronization is conventional" and therefore can be freely chosen. As I indicated I disagree with this synchronization freedom and have argued that the only acceptable clock synchronization mode is "proper synchronization" where the clocks tell the same time for the same event. This view is firmly supported by the fact that this "proper synchronization" is utilized in the GPS where any other synchronization mode would result in timing and navigational errors. The reviewer, as occurred previously, did not treat with this real-world physical observation. His repeated failure to consider robust and relevant experimental data from the GPS with no stated reason is unscientific. Instead he seemed satisfied to remain mired in unphysical ideas and theoretical considerations and to simply ignore real experimental data, perhaps because reality is antithetical to his case. He made a few gratuitous remarks in his review and closed with the suggestion that Selleri would have been capable of accepting conventionality of synchronization in more general settings such as rotating frames. On the basis of my reading of Selleri's papers and written communications with him, I disagree completely.

My view then is that these two reviewers (particularly the second) set out with the single goal of defending Kassner's thesis, rather than objectively addressing the counter arguments advanced in my paper as neither considered the critical experimental data available from the GPS which I presented. The first reviewer closed his superficial review declaring "Selleri's "paradox"…has now been thoroughly resolved by Kassner and others. There is no need to revisit it." The other speculated by way of special pleading that "Selleri himself would probably have accepted the resolution of the paradox offered in Kassner's paper." Both are wrong since the east-west light speed variation contained in the paradox is now an incontrovertible experimental fact (Gift, 2010, 2012, 2013; Marmet, 2000; Kelly, 2005).

But in the current scheme of things this seems to make little difference. The stakes are simply too high for science's mainstream to allow any challenge to an accepted paradigm and my paper countering Kassner's

attempt to delegitimize Selleri's relativity-destroying paradox had no chance in a system where there is no opportunity to reply. As Max Planck observed, "A new scientific truth does not triumph by convincing its opponents and making them see the light, but rather because its opponents eventually die, and a new generation grows up that is familiar with it." However efforts to change this must continue and the availability of journals such as Applied Physics Research and Physics Essays where challenges to orthodoxy are part of the normal discourse gives hope.

5. Conclusion

Selleri's paradox which demonstrates light speed anisotropy in an inertial system stands in stark contrast to the one-way light speed constancy requirement of special relativity theory. Kassner recognized that a robust and convincing rebuttal is required if this 100 year old theory which is now accepted science is to survive in the face of this paradox. In an effort to provide one he presented detailed but ultimately unsuccessful arguments, the core idea of which is the incorrect notion that a clock synchronization procedure may be freely adopted.

He first tried to circumvent Selleri's argument by utilizing "Einstein synchronization" in a rotating frame. This he argued results in forward and backward light speeds of c and hence $q \equiv \frac{c_+}{c_-} = 1$ almost everywhere on the rim of a rotating disc. This method however failed because it introduces an unphysical "time gap" or time discontinuity where the light speed is not equal to *c*. Moreover GPS technology has long established that "Einstein synchronization" applied in a rotating system leads to error unless the "Sagnac correction" is introduced.

Kassner then replaced the unworkable "Einstein synchronization" by his "gapless synchronization" involving transformations extensively developed by Selleri. These transformations effectively account for the Sagnac effect but also preserve rather than resolve Selleri's construction $q \equiv \frac{c_+}{c_-} = \frac{c - \omega R}{c + \omega R} \neq 1$. Kassner addressed this problem by asserting that this construction "fails to demonstrate a flaw in relativity, because there is some liberty in the choice of synchronization" even claiming that this synchronization liberty "is well-known to the relativity community." We have however shown that despite its wide acceptance no such synchronization liberty exists since artificial light speeds unconnected to the real world would result. The GPS is an example of a real-world system whose operation requires proper clock synchronization and any other synchronization mode would result in timing and navigational errors. The success of this system is sufficient to destroy the idea that there is freedom to choose a synchronization procedure, an idea that was also discounted by Selleri (1997, 2010). We also pointed out that the one-way light speed asymmetry predicted by the Selleri transformations, contained in Selleri's construction and accepted by Kassner as existing on the rotating disc, has been experimentally confirmed on the surface of the rotating Earth using the properly synchronized clocks of the GPS (Gift, 2010, 2012, 2013; Marmet, 2000; Kelly, 2005).

Thus both of Kassner's attempts to resolve Selleri's paradox have failed despite his claims to the contrary. His assertion that "it simply corresponds to the adoption of a synchronization procedure different from Einstein's" is wrong and the paradox stands. Unfortunately in his unsuccessful efforts to negate the paradox Kassner, a seasoned member of the community of relativists has done a grave disservice to Selleri by not properly citing his considerable and invaluable work regarding the Selleri transformations which Kassner utilized in his paper. He has however unwittingly demonstrated the validity of the Selleri construction (1) which he set out to delegitimize and inadvertently highlighted the real problem it presents for special relativity and the Lorentz transformations. By his introduction of Selleri's transformations in explaining the Sagnac effect, he has added further authenticity to these transformations which Selleri proposed as replacements for the Lorentz transformations.

Kassner claimed that the two (Lorentz and Selleri) transformations are equivalent but they are not. He may have been induced into this erroneous proposition by the fact that both transformations are members of the set of "equivalent" transformations derived by Selleri (1997, 2004b, 2010) which contains all possible space-time transformations that connect two inertial frames under a set of reasonable assumptions. As Selleri has indicated, the transformations are "equivalent" in the sense that they have the same space transformations but have time transformations that differ by a clock synchronization parameter e_1 given by

$$t' = t / \gamma + e_1 (x - vt) \tag{22}$$

The Lorentz transformations of special relativity correspond to $e_1 = -v\gamma/c^2$ while the Selleri transformations correspond to $e_1 = 0$. Though these transformations make the same predictions for a broad range of phenomena including Michelson-Morley, Romer and Doppler despite the synchronization difference (Selleri, 2004b), as indicated before they predict different light speeds

$$c(S') = \frac{c}{1+\beta+ce_1\sqrt{1-\beta^2}} \tag{23}$$

where $\beta = v/c$ (Selleri, 2004b). The "particularly perverse choice" of synchronization mentioned by Will (1992) corresponds to $e_1 = -\gamma(1+\beta)/c$ in light speed equation (23) which yields an "apparent" light speed that is infinite $c(S') \to \infty$ and obviously absurd! Therefore clock synchronization is not open to free choice, the transformations in Selleri's "universal" set are not equivalent and only one member of the set can be correct. That member of course is the one whose light speed prediction agrees with observation. This turns out to be the Selleri transformations corresponding to $e_1 = 0$ which predict light speed $c(S') = \frac{c}{1+\beta} \approx c - v, v \ll c$, the light speed detected on the surface of the rotating Earth using accurate GPS technology (Gift, 2010, 2012, 2013; Marmet, 2000; Kelly, 2005).

Selleri in his papers (Selleri, 2010, 2004b) and in his recent book (Selleri, 2011) showed in several different ways that $e_1 = 0$ thereby identifying the Selleri transformations as being correct and this value of the parameter has been independently confirmed using light speed analysis (Gift, 2009, 2013). In view of the several points raised in this commentary including the rigorously established method of GPS clock synchronization and especially the incontrovertible GPS data confirming light speed anisotropy in a rotating frame, we conclude that the Selleri transformations corresponding to $e_1 = 0$ constitute the member of the set of "equivalent" transformations that best represents the physical world. We believe therefore that these transformations should be given serious consideration by the scientific community, which appears now to be in critical need of a new direction (Smolin, 2006; Wolchover, 2012; Lykken & Spiropulu, 2014).

Note

Note 1. We fully accept the correctness of the GPS clock synchronization algorithm given in Ashby (2003) but do not accept the interpretation that it physically involves light travel at speed c between fixed points around the rotating disc and a "Sagnac correction" because of the rotation of the disc. Instead we have shown that the rigorously tested and confirmed synchronization algorithm is based on anisotropic light speeds with no "Sagnac correction" and this has been thoroughly discussed and demonstrated in Gift (2013). In this regard Selleri (2010) has stated, "We see that the mystery of the "Sagnac correction" of Earth physics is fully eliminated by adopting the [Selleri] transformations. The procedure which we can suggest to experimentalists is to avoid using a wrong velocity of light [c] and correcting the result with an *ad hoc* term, but rather to use from the beginning the velocity of light [$c_+ = \frac{c}{1+v/c}$] of the [Selleri] transformations."

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