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TEST THEORIES OF SPECIAL RELATIVITY, A GENERAL CRITIQUE

by

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ABSTRACT

Absolute Spacetime Theories conceived for the purpose of testing Special Relativity (SR) are reviewed. It is found that most theories proposed were in fact SR in different coordinate systems, since in general no specific SR violations were introduced. Models based on possible SR violating mechanisms are considered. Misconceptions in recently published papers are examined.

Key-words: Special relativity; Absolute spacetime; Ether theories.

1 INTRODUCTION

Since its origin, Special Relativity (SR) has been somehow under scrutiny, curiously more so in the recent decades. In fact much effort is currently directed into comparative studies between SR and absolute space-time theories.

This paper addresses mainly the formulation of absolute theories and test theories of SR in general. We have been increasingly concerned with a few misconceptions that have been finding their way into many papers in this field, and which we propose to clarify here. This is for instance the case of two recent papers[1,2] which we discuss in section 5.

Absolute theories are generally investigated[3-6] in direct comparison with SR by means of a parametrization of linear transformations connecting the coordinates of two inertial frames, in such a way as to generalize the Lorentz transformation. One may study the possibility that some SR violating phenomenon will privilege certain non SR values for the parameters, that is, one enquires into possible experimental deviations from those values dictated by SR.

Following Mansouri and Sexl[3-5] we write the generalized Lorentz transformation connecting two inertial frames, S the supposed absolute or "Ether" rest frame, and S' which has constant speed $\vec{V} = V\hat{x}$ with respect to S, in terms of a(V), b(V) and ε(V), which are arbitrary functions of V.

$$x' = b(x - Vt)$$

$$t' = at + \varepsilon x' \qquad (1)$$

$$y' = y \quad , \quad z' = z \quad , \quad c = 1$$

Very accurate measurements of the rates of time dilation[7] and length contraction[8] have confirmed practically beyond discussion the relativistic values of

$$a^{-1}(V) = b(V) = (1-V^2)^{-1/2} \equiv \gamma \ , \tag{2}$$

now a feature in most propositions of absolute theories, and which we accept in this work.

Thus, the central issue dividing SR and absolute theories concerns different procedures of clock synchronization, which may indicate different values for $\varepsilon(V)$ in eq. (1). Two particularly important values are $\varepsilon = -V$, yielding the Lorentz transformation

$$\begin{aligned} x'_E &= \gamma(x-Vt) \\ t'_E &= \gamma(t-Vx) \end{aligned} \tag{3}$$

which defines the Einstein coordinates[9], and $\varepsilon=0$ yielding the Tangherlini[10] transformation, rediscovered by Marinov[11],

$$\begin{aligned} x'_T &= \gamma(x-Vt) \\ t'_T &= \gamma^{-1} t \end{aligned} \tag{4}$$

which defines what has been called the Ives or Lorentz-Fitzgerald coordinates in previous papers[12-14]. Let us call them here the Tangherlini coordinates for uniformity with other authors.

It is convenient for future purposes to consider a special class of transformations within eq. (1), the η-Lorentz transformations,

$$x'_\eta = \gamma(x-Vt)$$
$$t'_\eta = \gamma^{-1} t - \eta V x' \qquad (5)$$

of which the Tangherlini (η=0) and Lorentz (η=1) transformations are particular cases. Note that in eqs. 3, 4, 5, the space coordinates are identical. The differences are in the time synchronizations.

It is understood that all coordinate systems given above are defined in relation to a hypothesized preferential or absolute reference system S with coordinates x and t which were prepared according to the Einstein signal method. It is postulated that in this absolute system;

(i) The propagation of light is isotropic independently of the source motion.

(ii) All methods of synchronization agree with one another.

Postulate (i) implies that the equal forth and back light speed convention has been adopted. This convention is maintained, no other being allowed, in all inertial frames whenever the light signal method is used.

The practical instalation, by an *internal* method (in the Mansouri-Sexl sense, that is, without relationship to another reference frame), of a time synchronization in any reference system S' (moving uniformly with respect to S) is necessarily based in some physical phenomenon possessing some form of invariance which favours that particular time. As a consequence of postulate (i), the instalation of Einstein's time (eq. 3) in S' can be carried out internally by the light signal method which relies upon the Lorentz invariance of the D'Alembert wave equation. Mansouri and Sexl[3] have elegantly shown that the slow transport of clocks method is equivalent to Einstein's light signal synchronization provided eq. 2 holds true.

It is clear that Einstein coordinates in S' tautologically imply the isotropy of light propagation in that frame, even if SR is not a theory of general validity. Despite the use of Einstein coordinates, there remains room for the existence of SR violations. Indeed, the implementation of non-Einstein coordinates in a reference frame S' can only be carried out *internally* (i.e. without relation to a preferential frame) if a physical phenomenon is found that breaches SR and supports some new synchronization. In the case of η-Lorentz coordinates (eq. 5), which relate to Einstein's by

$$t'_\eta = t'_E + (1-\eta)\,\vec{V}.\vec{x}' \quad ,$$

this must be some phenomenon that renders the quantities η and $\vec{V}$ observable. Given that such a phenomenon is found, and that by its means a new (non-Einstein) synchronization is installed in S', then, with respect to these new clocks, the propagation of light is nolonger isotropic in S'. It is in fact a simple exercise to work out from eq. 5 the direction dependence of the speed of light.

Such an SR violating phenomenon has not been to this date convincingly observed. Einstein coordinates are in operation in our everyday life, and this means that the absolute frame of reference remains indistinguishable from any other inertial frame.

This fact of course does not prevent proposals of tentative theories which accept the existence of a preferred (absolute) frame, and which are generally called absolute theories. They can be used as test theories of SR once they predict observable deviations from a strict SR regime. An analysis of such theories is the object of this paper.

A major source of concern, as we shall see, is the fact that absolute theories are often discussed at the level of coordinates instead of physical phenomena. Coordinate transformations cannot define an absolute theory, which must exist independently of any choice of coordinates for S', since these are only labels. In general there will be a particular transformation which is most appropriate for some theory, while other choices, leading to more cumbersome treatment, remain a matter of convention. This point has been constantly stressed by Tiomno et al. [9,12,13,15,16] who advocate the use of Einstein coordinates even in theories which violate SR principles.

Conversely, one may work out SR results in any of the coordinates implied by eq.(1), or particularly in Tangherlini coordinates. This fact led many authors to advocate the equivalence of SR and absolute test theories, as is the case of Mansouri and Sexl [3-5] whose work we analyse in section 3.

It is interesting to note that Einstein himself may have somehow originated this misleading emphasis on coordinates, by insisting on the importance of particular synchronization procedures and coordinates leading to the Lorentz transformation for SR, while later arbitrary coordinates were used by him in General Relativity (GR). Both in SR and GR, not the coordinates but real physical effects are observables of invariant meaning.

Hypothesis (test theories) have been put forward of explicit SR violating effects which could be tested experimentally. Some of these are discussed in section 4, where we exemplify how a non-Eins tein synchronization based on one such effect could be performed. But before we reach section 4, we shall carry out an analysis of the two pioneering proposals of test theories of SR, those of Robertson (section 2) and of Mansouri and Sexl (section 3), which are perhaps the most important works in this field.

Two of the most recent papers related to absolute theories are discussed in section 5, as illustrations of the perpetuation of misconceptions against which this paper intends to be an alert.

2 THE TEST THEORY OF ROBERTSON

Robertson's pioneering work[17] of 1949 is the natural starting point of our analysis. He aims to replace most of Einstein's pos tulates in the formulation of SR by observational conclusions drawn from optical experiments.

Thus, instead of a postulated equivalence of all inertial frames, he starts with a privileged one, a "rest-system" S, the only one in which light is postulated to propagate rectilinearly and isotropically with constant round trip velocity independently of the source motion. All synchronization procedures are assumed to be equivalent in S. These properties are not characteristic of SR, as they are valid for any absolute space-time theory. For all other inertial systems S' no assumption is made concerning the velocity of light or any other physical law, all to be inferred from observation and the postulates of S.

Robertson reduces his problem, that of deriving SR without most postulates of SR, to the determination of the transformation U which will relate observations made in S' to those in S. In terms of coordinates the problem is to find $(t',x',y',z') \xrightarrow{U} (t,x,y,z)$.

Einstein's light signal synchronization is then imposed *both* in S and S', thus ensuring by convention the equality of the one way to and fro velocities of light in each frame, of value $c(=1)$ in S and to be determined by observation in S'.

This synchronization, is one of the three well known ingredients in the Lorentz transformation:

(i) Fitzgerald-Lorentz length contraction

(ii) Lorentz time dilation

(iii) Einstein clock synchronization

(i) and (ii) being valid, (iii) implies c=1 also in S'.

The optical experiments of Michelson-Morley, Kennedy-Thorndike and Ives-Stilwell are invoked as exact results to prove (i) and (ii), or equivalently to prove eq.(2). This means that Robertson's general transformation eq.(1) is now restricted to the less general eq.(5) where only the synchronization parameter η remains to be determined.

However, having assumed Einstein's light signal synchronization in both the "absolute" (S) and "moving" (S') frames, Robertson has introduced by hand, as an input, Lorentz' ingredient (iii) in to his test transformation U, thereby forcefully making $\eta=1$ in eq.(5).

This led Robertson to the identification of U with the Lorentz transformation, having "replaced as far as possible Einstein's relativity postulate by facts drawn from experience". Instead, he should have found U identical to eq.(5).

Here we witness perhaps the birth moment of an apparently generalized misconception which has since then recurred in different disguises, and which is one of the main issues in this paper.

The assumption of Einstein's synchronization determines $\eta=1$, but it is clear that Robertson's proof can be repeated step by step with any other value $0 \leq \eta \leq 1$, and leads to transformations (5). To be more specific, the $a_2{}^1$ matrix element in his eq.(11) would read $\eta V a_1{}^1/c^2$. His work could then equally well be used to advocate for instance the Tangherlini transformation eq.(4), as was done later by Mansouri and Sexl (see section 3).

Thus, instead of deriving SR from basic experiments, the only physics Robertson obtained is the confirmation of the relativistic length contraction and time dilation in a more systematic approach than previously. Nothing can be inferred from his analysis about the existence or not of SR violating effects, which must be described by different laws in S and S' in Einstein coordinates, if they occur.

Notice that even if the dilation (a^{-1}) and contraction (b) parameters were not found from experience to equal γ, whatever values obtained could be used to renormalize rods and clocks so as to reobtain the Lorentz transformation and Einstein's coordinates. This way a universally invariant c=1 is recovered in S', independently of the rest of physical phenomenology, even for absolute theories.

3 THE MANSOURI-SEXL TEST THEORY

In their important series of three papers, here referred as MSI[3], MSII[4] and MSIII[5], Mansouri and Sexl aim at a systematic approach towards a test theory of SR.

Synchronization methods are divided into two categories: (i) System external methods are those in which a preferential reference frame S is singled out (the "rest" or "ether" frame), and clocks in all other reference frames S' are synchronized, directly or indirectly, with respect to those sitting in S, instantaneously at the same position. (ii) System internal synchronization methods are those established without mention to any frames other than the one in which clocks are being synchronized. The slow transport and light signal methods are examples.

The basic assumptions by Mansouri and Sexl (MS) are: (i) In any inertial system the velocity of light is independent of the motion of the source. (ii) Light signal and slow transport synchronizations agree in the absolute or rest system S. (iii) Measuring rods which agree in length in S also agree in any inertial system S', and clocks with the same period in S, also have equal periods in S'.

No synchronization in S' is previously specified and space-time coordinates in S and S' relate in principle by equation (1). Among all system external synchronization conventions or procedures, one is of special interest since it does maintain absolute simultaneity. It is the one implied by the Tangherlini coordinates of eq.(4). A recipe for preparing Tangherlini clocks is given in section 3 of MSI. It consists basically of Einstein's light signal method, plus a clock rearranging convention based on a presumedly known value of the laboratory's absolute velocity $\vec{V} = V\hat{x}$, such that Vx' is added to Einstein times in S', for clocks sitting at positions x'. Another equivalent routine is also given.

Based on this synchronization MS build their absolute test theory, and claim that it is kinematically equivalent to SR. They interpret in the light of eq.(4) the results of various experiments which are usually considered to be confirmations of SR. This program is carried out in MSII with first order (in V) tests, and in MSIII with second order tests. They conclude that all experiments analysed agree with both the Lorentz ($\eta=1$) or the $\eta=0$ transformation eq.(5), and therefore SR and their $\eta=0$ test theory are equivalent.

Our point here is that their conclusion of equivalence is again a consequence of erroneous interpretation of coordinate systems as theories.

Having adopted eq.(2) ($a^{-1} = b = \gamma$), MS were automatically restricted to SR since, as Robertson, they did not introduce any SR violating physics: space coordinates are identical in both transformations and their external method recipes for obtaining the Tangherlini synchronization are entirely consistent with SR. They are in fact Einstein's synchronization followed by some conventional rearrangement of clocks in terms of a previously known value of V. SR is preserved throughout the system external synchronization routines suggested by MS.

Therefore, their test "theory" is in fact SR in Tangherlini's coordinates, equivalence between the two coming as a trivial consequence. They could have as well obtained eq.(5).

The way out of this triviality can only be provided by system *internal* synchronization methods. No physically meaningful distinction between the Einstein and Tangherlini times is possible before some experimentally testable SR violating phenomenon is manifest that permits the synchronization of Tangherlini clocks via internal methods. This is also true for any of the η-Lorentz transformations given by eq.(5). These matters are the main subject of the next section.

Meanwhile we proceed with further comments on the MS papers. In MSII the analysis of first order experiments is carried in terms of the parameters ε, a, b of eq.(1). The synchronization parameter $\varepsilon(V)$ is set equal to its slow transport value as obtained in MSI (section 6),

$$\varepsilon_T(V) = 2\alpha V + O(V^3) \tag{6}$$

where a(V) has been expanded as

$$a(V) = 1 + \alpha V^2 + O(V^4) \quad .$$

Equation (6) is however too strong a restriction upon the different ways in which a test theory should be allowed to depart from SR. Indeed, in the MS test theory, departures of $\varepsilon(V)$ from the relativistic value of $-V$ are strictly connected, by eq. (6), with the departures of a(V) from the relativistic value γ^{-1}; this means that ε and a are not independent parameters, and the tests discussed by MSII are tests upon a only. Such unjustified restriction leads to their conclusion that "first-order tests cannot be used to distinguish between SR and ether theories".

MS do not consider the fact that $\varepsilon(V)$ (or η in eq. 5) can actually be an independent test parameter, as was detailed by Tiomno[16]. The slow transport and light signal procedures are certainly equivalent and SR abiding provided $a^{-1} = b = \gamma$, but that does not preclude the existence of other possibly inequivalent procedures. One such can be the shaft synchronization, provided the SR violation hypothesized by Marinov[18] is verified: a null synchronization parameter (ε=0) could result, that is neither of MS's ε_T or ε_L, even if $a^{-1} = b = \gamma$. Another synchronization method with similar properties has been proposed by the present authors[13] (see section 4).

Comparing the works of Robertson and of MS, we see that the first never had a complete test theory since from start Einstein's synchronization is imposed in all frames, and the results of the optical experiments are taken as leading to eq.(2) with absolute precision. All the ingredients of the Lorentz transformation are then introduced by assumptions, two of which, (i) and (ii), supported by experiments.

A considerable step forward is MS's introduction of a synchronization parameter, properly recognized as convention dependent, besides the parametrization factors a(V) and b(V) for time dilation and length contraction, thus providing us with a complete test theory of SR.

They do not however introduce any SR violations other than possible deviations of a^{-1} and b from γ. As soon as the equality $a^{-1} = b = \gamma$ is restored, their test theory colapses back to SR with a synchronization of clocks that is not Einstein's, but which can be implemented (without SR violations) only by external methods. It is then concluded that the Tangherlini time cannot be implanted internally, and that all internal methods will be equivalent to Einstein's, if $a^{-1} = b = \gamma$. To conclude otherwise, MS needed to "upgrade" the Tangherlini time from the role of mere coordinates, by devising an internal synchronization method based on some proposed hypothetical phenomenon, to be searched for experimentally, which violates SR in a way as to render observable the Tangherlini time.

It is important to mention however, that the MS analysis of tests of SR against theories which violate SR only by the departures of a^{-1} and b from γ is entirely correct. It is interesting to point out that all of the quadratic results of MSIII were reobtained in reference (16) where work was carried in Einstein coordinates, a confirmation again of the irrelevance of the coordinate system used.

4 ABSOLUTE THEORIES BUILT FROM OBSERVABLES

In the previous section we have argued that the formulation of an absolute theory must be founded on physical effects that contradict SR, rather than on a choice of coordinate transformations. The purpose of this section is to exemplify propositions of absolute theories that abide to this criterion.

Nowhere in either Robertson's work or the MS test theory has an SR violating observable been hypothesized, other than possible departures of a^{-1} and b from γ, that could be searched for in laboratories. One such observable, if time dependent, could for instance determine a non Einstein synchronization of distant clocks independently of conventions or of any prior knowledge of an absolute velocity $\vec{V}$, thereby establishing what MS have called a system internal synchronization method. Some theory other than SR should then emerge to accomodate the alleged phenomenon, and of course this theory would be at its most simple form for the study of that phenomenon when described by the time coordinates dictated by it.

One example is Marinov's hypothesis[18] of an "anti-Lorentz" twist, in principle testable in his rotating shaft apparatus, irrespective of the coordinates used. If the effect is confirmed, Marinov's two rotating wheels are two absolutely synchronized distant clocks. They could be used to establish laboratory coordinates that will relate to the absolute ones by transformations (4). The synchronization being internal, the determination of absolute $\vec{V}$ comes as a by-product by comparison with, say the light signal generated coordinates.

Tiomno et al.[9,12,13,14,16] have in the recent past considered examples of absolute theories in which the violation of SR is manifested in the free rotation of solids. Domains of physics other than rigid body rotation may remain relativistically invariant.

One such tentative model of a non relativistic rotation kinematics was called S-LET (for Strict Lorentz Ether Theory) and is described in detail in ref. 13. S-Let is built upon the hypothesis that the free rotation of a rigid body is such that equal angles are swept at equal Tangherlini time intervals. In other words, rotation is uniform if observed with Tangherlini clocks, time T, for which

$$\phi(T) = \phi_0 + \omega T \quad , \quad \omega \text{ constant.}$$

Since it is Einstein clocks which are normally in use, the equation of motion for free rotation in the Einstein time t must be worked out. This is done in ref. 13 and yields

$$\phi(t) = \phi_o + \omega t + Vv \cos(\phi_o + \omega t) \quad ,$$

where $v = \omega R$ is a tangential speed and the "absolute" $\vec{V}$ is supposed perpendicular to the rotation axis for simplicity.

It is seen that the S-LET angular velocity of free rotation of a disc as measured in Einstein coordinates oscilates around an average value ω, and therefore implies a non rigid behaviour of the disc in these coordinates. A rigid rotation in SR would imply instead,

$$\phi(t) = \phi_o + \omega t \quad .$$

In fact, the optical distance between any two points 1 and 2 in the disc,

$$L(t) = \delta t(t) = |\vec{r}_1(t) - \vec{r}_2(t + \delta t)| \quad ,$$

where δt is the $1 \rightarrow 2$ photon time of flight, can be calculated as a function of the Einstein time t. For points 1 and 2 equidistant from the center of rotation it is found to be[13], in S-LET,

$$L(t) = L_o(1 + v \cos \phi_o/2(1 - V \operatorname{sen}(\phi_o/2 + \omega t))) \quad .$$

L_o is the no rotation distance $|\vec{r}_1 - \vec{r}_2|$, and ϕ_o is the central angle associated to it. The V and t-independent correction to L_o is the Sagnac effect, also present in SR.

Thus, the S-LET hypothesis has observable consequences which can be searched for in laboratories. The time dependent fluctuation of L(t) around L_0 predicted by S-LET could be observed for instance by interferometry or by Doppler shift techniques, as discussed extensively in ref. 14. It is curious that there is no experiment to this date that conclusively disproves S-LET[14], which then remains a good test theory for SR.

A disc rotating according to S-LET (if the effect exists) would constitute another example (besides Marinov's) of a system that measures, at different points in space, a time that is inequivalent to that of Einstein, independently of conventions. In fact a freely rotating disc may be used to synchronize a non-rotating clock that sits at its center with others, a distance R appart, disposed in the vicinity of the disc's rim. This method is described in section 3.3 of ref. 13.

5 OTHER ATTEMPTS

To illustrate further our point, we have chosen to comment two recent articles which deal with absolute theories[1,2].

The first, by G. Spavieri[1], and hereafter referred to as GS, discusses the nonequivalence of Ether theories and SR. Spavieri considers the problem of internal synchronization and its connection with the parameter ε in eq.(1). We show here that most of his conclusions are wrong. GS intends to exhibit internal synchronization procedures that lead to non Einstein times.

In the first procedure, a moving rod is used to start two separate clocks at rest in S', as the rod's edge flies past them. The rod is initially at rest in S', and set parallel to the line that joins both clocks, the x' axis. It is then accelerated towards the x' axis, keeping its length always "parallel to the x' axis for S'", and reaching a uniform velocity u_y relative to S (u'_y in S') before it flies past the clocks. It is not clear whether GS considers parallel motion with respect to S or to S'. We shall consider both cases.

If parallelism is monitored in S (the absolute frame), the analysis proceeds as in GS. The rod is used to define another inertial system S" with uniform velocity u'_y in S', and uniform velocity in S given by

$$\vec{u} = u_x \hat{x} + u_y \hat{y} = V \hat{x} + u_y \hat{y} \quad .$$

As seen from S, whichever the value of η in the transformation eq. (5), the axis of S" are no longer perpendicular but open up by an angle $\Delta\phi_0 = \gamma u_x u_y$. They cannot therefore be kept both parallel to those of S, but will be arbitrarily oriented with respect to S between two extreme positions: $\hat{y}''//\hat{y}$, or $\hat{x}''//\hat{x}$.

Since the moving rod represents $\hat{x}''$, the synchronization obtained will be such that, associated to every relative orientation between the two frames, there will be a value of η ranging from the two extremes,

$$\eta = 0 \quad , \quad \text{for} \quad \hat{x}''//\hat{x}$$

and the Tangherlini time T is established, or

$$\eta = 1 \quad , \quad \text{for} \quad \hat{y}''//\hat{y}$$

and the Einstein time t is established.

GS calls this an internal synchronization method, but it is in fact external. The method needs an observer sitting in the absolute frame S, to monitor parallelisms and to pass on to those in S' (Laboratory) the value of the interception angle $(\hat{x},\hat{x}'')$, or equivalently, the value of η, so that the experimenter may know which time synchronization has been realized in S'. So, a previous knowledge of the absolute frame is necessary.

We consider now the possibility that the parallel motion of the rod with respect to $\hat{x}'$ is monitored in the laboratory S' as should be necessary for an internal synchronization. In this case the GS proposition is totally insatisfactory. The concept of parallel motion is by itself synchronization dependent, that is, un restricted motion can only be considered parallel if defined with respect to some previously established synchronization. Otherwise, how can you tell that at *one* instant of time (which time?), *two* separate moving points are equidistant from some referential axis in S'? The experimenter will need two previously synchronized clocks sitting in the x' axis to register the passing times of the rod's ends; either $t_1=t_2$ (parallel) or $t_1 \neq t_2$ (inclined).

Thus, GS's first proposition cannot be an internal method. If, however, the parallelism between rod and x' in S' is enforced by some restriction, say a track system, then necessarily the method leads to Einstein's time since no SR violating phenomenon is involved.

Like other previous authors, GS does not break SR anywhere in his proposals, and therefore no SR violating synchronizations can be extracted from them by internal methods. This is in fact a basic criterion to decide, independently of computation, whether any proposition of internal synchronization is able to yield an inequivalent time to Einstein's.

In GS's second proposition of an internal method (GS section IV, fig. 2), a rod runs along a fixed direction $\hat{x}'$, in no slide tangential contact with a rotating disk whose axis is at rest in S'. "When the rod moves with uniform constant velocity u', the disk spins with constant angular velocity ω'". GS argues that the disk can be used as a time keeper, the rod as time signal transmiter, and the apparatus as an internal synchronizer.

If this mounting is to be used as a synchronizer, a previous and independent experiment is needed to determine the physical law of rotation of the disk. Here a violation of SR could indeed exist be it S-LET[12-14] or some other law, which would reveal the nature of the time to which clocks are being synchronized with the disk and rod method. Suggestions as to how experiments to determine the physical law of free rotation of a disk should be carried out, are given in reference (14).

Before having that law experimentally established, GS's result following his equation (11) can only be written in general form,

$$\Delta t = -\ 2\gamma L_0\, \varepsilon / c^2 \quad ,$$

and his choices of ε (0 and -V) are not results but inputs. For synchronization purposes the value of ε must be set according to whichever law of rotation is found for the disk, say $\varepsilon = -V$ for SR (equal angles at equal Einstein t-intervals), $\varepsilon=0$ for S-LET (equal angles at equal Tangherlini T-intervals), or other.

Statements like "rolling without sliding assures us that the rods move with equal and opposite velocities" are coordinate dependent and can be wrong in case the coordinates used are not those that render rotation uniform. Such is for instance the case if rotation is according to S-LET (T-uniform) but Einstein t clocks are used. Then the equation of motion for some peripherical point in the rotating disk, with instantaneous tangential velocity $\vec{v}$, here assumed coplanar with $\vec{V}$, is given[13] in Einstein coordinates by (Ω is the angular velocity)

$$\frac{d\phi}{dt} = \Omega(1-\vec{V}.\vec{v}) \quad .$$

It is seen that radially opposite points, such as the two disk to rod contact points in the GS method, do not share equal and op posite tangential speeds if $\vec{V}.\vec{v} \neq 0$.

Now we come to GS's third proposed synchronization method, in the later part of his section IV (fig. 3). Here two rods of equal rest length are moving freely and parallel to the x axis in S, in opposite directions, with velocities u and $\bar{u}$. In the laboratory frame S', their velocities u' and $\bar{u}'$ are defined to be equal and opposite if the rod's leading and trailing edges cross each other at precisely the same spot, say a slash perpendicularly marked across their trajectories, and at rest in S'. Let this be the origin of the x' axis. The rods can then be used to start and synchronize two clocks that are sitting along x' at equal and opposite distances from the origin.

Prior to any calculations, it can be immediately concluded that this internal method establishes Einstein's synchronization on the clocks, since there is no room for an SR violation in its conception (other than deviations of a^{-1} and b from γ). The only physics involved here is the relative translation of solid bodies.

GS's conclusion that the method is equivalent to Einstein's is therefore right, although his reasoning to reach it lacks rigour. His basic equation (14) is correct only to order v^2, whereas equivalence should be proved with an exact result.

A simple but rigorous way of reaching the right conclusion analitically is by showing that the method implies $\eta=1$ in equation (5). This can be as follows.

From (5), with $\delta u = u-V$,

$$dx' = \gamma_v \, \delta u \, dt$$

$$dt = \gamma_v \, dt'(1+\eta V u')$$

and therefore

$$\delta u = u'\gamma_V^{-2}(1+\eta Vu')^{-1} \tag{7}$$

with an analogous equation for $\delta\bar{u}$, $\bar{u}'$.

The synchronization method implies

$$\gamma_u \delta u = \gamma_{\bar{u}}\, \delta\bar{u} \quad . \tag{8}$$

Substitution of (7) in (8), with $u' = -\bar{u}'$, implies $\eta=1$.

The GS determination of ε by means of Doppler experiments is compromised by the use of Moller's[19] formula (MSII eq. 3.1 and GS eq. 18) which has been shown[13] to have no leading term ($\sim \vec{v}.\vec{V}$) in the velocities v of emitter and absorber, for any theory with $a^{-1} = b = \gamma$. The GS determination of ε by means of the Universal Time Coordinated also lacks foundations. He does not prove that clocks can be internally synchronized to Tangherlini's time. MSI say they cannot. We say they can[13,14], provided the associated SR violating effect exists with measurable magnitude.

Closing our general critique on test theories of SR and their interpretations, we comment briefly a paper by Mac Arthur[2].

His opening discussion on the equivalence of the test theories by Robertson and MS is misleading. We quote the conclusion in his first page: "Thus, using Einstein synchronization, the MS formulation is equivalent to the Robertson formulation". We have seen in section 2 that Robertson's theory is made identical to SR because he inputs Einstein synchronization. Mac Arthur is transferring this misconception into the work of MS, thus making both test theories equivalent to each other and to SR (given that $a^{-1}=b=\gamma$). It is quite clear that MS did not follow Robertson's mistake, since they kept Tangherlini's time in their test theory.

Of more serious consequences is however the improper handling of the absolute time T when Mac Arthur writes

$$\Delta T = \Delta t \; g_0/\gamma$$

for Döppler and lifetime experiments. This equation does not relate absolute time measurements between any two inertial systems, as implied in his paper. Instead, one of the systems in question must be the absolute rest frame. It would be too much a coincidence if the "Ether" was comoving with either the laboratory or the decaying (or emitting) particle systems, or some times with one, some with the other. Tangherlini's transformation U between any two inertial systems S' and S'' need an intermediate step in S(abs.), with the consequent introduction of two absolute velocities $\vec{V}'$ and $\vec{V}''$ of both frames. Besides,

$$U(\vec{V}')\,U(\vec{V}'') \neq U(\vec{V}'+\vec{V}'') \quad ,$$

contrary to what is implied by Mac Arthur's quoted equation.

The same critique is conceptually valid for his expression for $V_\gamma - V_e$ in the velocity comparison between a high energy electron and a photon. Here however, given that both velocities ($\approx c$) are much higher than that of the laboratory translation through the "Ether" (or what is assumed of it, of course), the equation for $V_\gamma - V_e$ retains approximative validity, in as much as the absolute and laboratory frames can be thought of as coincident.

6 CONCLUSIONS

The long standing question regarding the equivalence between SR and absolute theories was reviewed critically, and it is seen that the subject has been mistreated by many of its authors, even the patriarchs in the field. There have been groundless conclusions both of equivalence and inequivalence. We hope to have contributed to clarify this question. It is our conclusion that a properly defined absolute theory must be, by construction, inequivalent to SR, since it must stand upon observable violations of SR. So far these can only be hypothetical because, to this date, no SR violations have convincingly been observed.

Admiting the validity of eq.(2), the only room left for departures from SR is necessarily connected with the nature of time. It is then only with the help of an SR violating effect that one can devise an *internal* synchronization method that will establish a time that is inequivalent to Einstein's. Examples are the Marinov shaft[18] and the S-LET disk synchronization[13].

It was certainly not our purpose here to collect misconceptions or imprecisions in the literature of Test Theories of SR. However, by showing the incorrectness of some approaches to the problem, we hope to have cleared many aspects of the subject, and revealed further how delicate it is.

Perhaps our main message is the well known but apparently little understood fact that coordinates are only labels, not physics. A rather radical example of this is the Robertson[17] and Mansouri-Sexl[3-5] treatment (although unconscious) of SR in general coordinates (eq.1), and our treatment of absolute theories[13] in Einstein coordinates.

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