

## Superluminal signals and causality

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ABSTRACT. Transformations of space and time depending on a synchronisation parameter,  $e_1$ , generalize the Lorentz transformations which are reobtained for a particular  $e_1 \neq 0$ . No fundamental experiment of relativity depends on the choice of  $e_1$ , but if accelerations are considered only  $e_1 = 0$  remains possible. Electromagnetic superluminal signals (SLS) have recently been detected in several experiments. The causal paradoxes generated by SLS in the theory of relativity are shown to be naturally solved if the SLS propagate in a Lorentz ether at rest in a privileged inertial system  $S_0$ . This conclusion is compatible with all the experimental evidence.

### 1. The inertial transformations of space and time

In this first section previous results are reviewed which provide the basis of a sound theoretical treatment of superluminal signals (SLS). According to Poincaré [1], Reichenbach [2], Jammer [3] and Mansouri and Sexl [4] the clock synchronisation in inertial systems is conventional and the choice based on the invariance of the one way velocity of light made in the TSR was only based on simplicity. In [5] we showed that a suitable parameter  $e_1$  can be introduced to allow for different synchronisations in the transformations of the space and time variables. The TSR is obtained for a particular nonzero

value of  $e_1$ . It was also found, however, that the choice  $e_1 = 0$  is the only one allowing for a treatment of accelerations rationally connected with the physics of inertial systems. These results are reviewed in the present section.

Given the inertial frames  $S_0$  and  $S$  one can set up Cartesian coordinates and make the following standard assumptions:

- (i) Space is homogeneous and isotropic and time homogeneous, at least if judged by observers at rest in  $S_0$  ;
- (ii) In the system  $S_0$  the velocity of light is " $c$ " in all directions, so that clocks can be synchronised and one way velocities can be measured in  $S_0$ ;
- (iii) The origin of  $S$ , observed from  $S_0$ , is seen to move with velocity  $v < c$  parallel to the  $+x_0$  axis, that is according to the equation  $x_0 = v t_0$  ;
- (iv) The axes of  $S$  and  $S_0$  coincide for  $t = t_0 = 0$  ;

The system  $S_0$  turns out to have a privileged status in all theories satisfying these assumptions, with the exception of the TSR. Two further assumptions based on direct experimental evidence can be added:

- (v) The two way velocity of light is the same in all directions and in all inertial systems [6];
- (vi) Clock retardation takes place with the usual velocity dependent factor when clocks move with respect to  $S_0$  [7-10].

These conditions were shown [5] to imply for the transformations of the space and time variables from  $S_0$  to  $S$ ;

$$\left\{ \begin{array}{l} x = \frac{x_0 - v t_0}{R} \\ y = y_0 \quad ; \quad z = z_0 \\ t = R t_0 + e_1(x_0 - v t_0) \end{array} \right. \quad (1.1)$$

where

$$R = \sqrt{1 - v^2/c^2} \quad (1.2)$$

Using (v) and eq.s (1.1), the one way velocity of light relative to the moving system  $S$  for light propagating at an angle  $\theta$  from the velocity  $\vec{v}$  of  $S$  relative to  $S_0$  is [11]:

$$c_1(\theta) = \frac{c}{1 + \Gamma \cos \theta} \quad (1.3)$$

with

$$\Gamma = \frac{v}{c^2} + e_1 R \quad (1.4)$$

while, of course, the two way velocity of light relative to  $S$  is  $c$  in all directions.

The inverse transformations of (1.1) are

$$\left\{ \begin{array}{l} x_0 = (R - e_1 v)x + \frac{v t}{R} \\ y_0 = y \quad ; \quad z_0 = z \\ t_0 = \frac{t - R e_1 x}{R} \end{array} \right. \quad (1.5)$$

Theories with different  $e_1$ 's imply the existence of a privileged inertial system,  $S_0$ . Thus, if one such theory describes correctly the physical reality a particular inertial system has to exist in which time is truly physical. This should be the system in which the Lorentz ether is at rest. The TSR is a particular case given by

$$e_1 = -\frac{v}{c^2 R} \quad (1.6)$$

giving  $\Gamma = 0$  and  $c_1(\theta) = c$  and reducing (1.1) and (1.5) to their Lorentz form.

The transformations (1.1) in differential form are

$$\left\{ \begin{array}{l} dx = \frac{dx_0 - v dt_0}{R} \\ dy = dy_0 \quad ; \quad dz = dz_0 \\ dt = R dt_0 + e_1(dx_0 - v dt_0) \end{array} \right. \quad (1.7)$$

If a pointlike structure moves with velocities  $\bar{u}_0$  and  $\bar{u}$  relative to  $S_0$  and  $S$ , respectively, the velocity components are naturally given by

$$\begin{aligned} u_{0x} &= \frac{dx_0}{dt_0} \quad ; \quad u_{0y} = \frac{dy_0}{dt_0} \quad ; \quad u_{0z} = \frac{dz_0}{dt_0} \\ u_x &= \frac{dx}{dt} \quad ; \quad u_y = \frac{dy}{dt} \quad ; \quad u_z = \frac{dz}{dt} \end{aligned}$$

Dividing the first three equations (1.7) by the fourth one the transformations of velocities are obtained:

$$\left\{ \begin{array}{l} u_x = \frac{u_{0x} - v}{R[R + e_1(u_{0x} - v)]} \\ u_y = \frac{u_{0y}}{R + e_1(u_{0x} - v)} \quad ; \quad u_z = \frac{u_{0z}}{R + e_1(u_{0x} - v)} \end{array} \right. \quad (1.8)$$

For velocities parallel to the  $x$  axis eq.s (1.8) reduce to

$$u = \frac{u_0 - v}{R[R + e_1(u_0 - v)]} \quad (1.9)$$

The transformations (1.1)-(1.5), and (1.7)-(1.9) contain only a free parameter,

$e_1$ , the coefficient of  $x$  in the transformation of time, which can be fixed by choosing a clock synchronisation method. Different choices of  $e_1$  imply different theories of space and time which are empirically equivalent to a very large extent. Michelson type experiments, Doppler effect, aberration, occultations of Jupiter satellites, radar ranging of planets and elementary particle kinematics were shown to be insensitive to the choice of  $e_1$  [5].

Accelerations modify the conceptual situation to the point that  $e_1 = 0$  becomes unavoidable [11]. Three cases have been investigated :

1. **The accelerating spaceships.** In the isotropic system  $S_0$  clocks have been synchronised with the Einstein method, by using light signals. Two identical spaceships **A** and **B** initially at rest on the  $x_0$  axis of  $S_0$  have internal clocks synchronised with those of  $S_0$ . At time  $t_0 = 0$  the spaceships start accelerating in the direction  $+x_0$ , and they do so in exactly the same way, so that they have the same velocity  $v(t_0)$  at every time  $t_0$  of  $S_0$ . At time  $\bar{t}_0$  they reach a preestablished velocity  $v = v(\bar{t}_0)$  and their acceleration ends. For  $t_0 \geq \bar{t}_0$  the spaceships are at rest in a different inertial system  $S$  (which they concretely determine) in motion with velocity  $v$  with respect to  $S_0$ . The relationship between the coordinates of  $S_0$  and  $S$  is given by the transformations (1) with  $e_1 = 0$  (not by the Lorentz transformations), because the delay between the times marked by clocks on board of **A** and **B** and those in  $S_0$  does not depend on position: since **A** and **B** had at every time exactly the same velocity, their clocks accumulated exactly the same delay with respect to  $S_0$ . Therefore two events simultaneous in  $S_0$ , taking place in points of space near which **A** and **B** are passing, must be simultaneous also for the travelers in **A** and **B**, and thus also in the rest system of the spaceships,  $S$ . This is clearly a situation of absolute simultaneity which cannot be accounted for if the Lorentz transformations are applied, but is obtained from (1) with  $e_1 = 0$  (“inertial transformations”).

Not only the absolute simultaneity arises spontaneously in  $S$ , but it provides the only reasonable description of the physical reality. To see this, suppose that in **A** and **B** there are two passengers who are homozygous twins. Naturally nothing can stop them from resynchronising their clocks, once the acceleration has ceased. However, if they do so, they discover to

have different biological ages at the same time of  $S$ , as they cannot resynchronise their bodies! Everything is regular, instead, if they do not modify the times shown by their clocks.

2. **The rotating disk.** The propagation of light along the rim of a circular rotating disk requires, in any reasonable theory, a velocity of light locally identical (in any point  $P$  on the rim) with the velocity of light relative to the inertial system instantaneously endowed with the same velocity as  $P$ . Unfortunately this condition is not satisfied in the standard relativistic approach. Given that all possible points  $P$  are physically symmetrical, for the proof one needs only consider the velocity of light for a complete tour around the disk, with no reference to any synchronisation procedure. It has been shown that for calculating correctly, on the disk, the fundamental time delay between light pulses propagating in opposite directions around the disk, one must use the velocity of light given by eq. (1.3) with  $e_1 = 0$  [12]. The same result allows one to explain the Sagnac effect which up to now received only unsatisfactory theoretical treatments [13]. In this way a clear improvement has been made over the relativistic theory which contains a discontinuity between the rims of slowly rotating large disks and the locally comoving inertial systems.

3. **The gravitational potential of the sun.** A longstanding problem of satellite physics is that all clocks in the earth centered inertial frame (including GPS satellite clocks) seem to be insensitive to the variations of the gravitational potential of the sun. A recent paper by Ron Hatch [14] has eliminated the puzzle by showing that on the earth orbit there is a precise equality between the consequences of the solar potential and those of the extraterm needed to convert the transformations with  $e_1 = 0$  into the Lorentz transformations. In other words, all problems disappear if instead of using the Lorentz transformations from the sun centered inertial system to the earth centered locally comoving inertial system (as it is usually done in satellite physics) one uses the  $e_1 = 0$  (“inertial”) transformations. Notice that also in the present case accelerations have a role as earth on its orbit continuously modifies the comoving inertial system.

The adoption of  $e_1 = 0$  in (1.1)-(1.5) gives rise to the “inertial transformations” in which the transformation of time becomes simply

$t = R t_0$ . This implies absolute simultaneity: two events taking place in different points of  $S_0$  but at the same  $t_0$  are judged to be simultaneous also in  $S$  (and *viceversa*). The existence of absolute simultaneity does not imply that time is absolute, as the velocity dependent factor in the transformation of time gives rise to clock retardation phenomena. A clock at rest in  $S$  is seen from  $S_0$  to run slower, but a clock at rest in  $S_0$  is seen from  $S$  to run faster so that both observers agree that motion relative to  $S_0$  slows the pace of clocks. The difference with respect to TSR does not contradict any experiment because a clock at rest in  $S_0$  has to be compared with clocks at rest in different points of  $S$ , and the result depends on the way the latter clocks were synchronised.

Absolute length contraction can also be deduced from (1.1)-(1.5) with  $e_1 = 0$ . A rod at rest in  $S$  is seen from  $S_0$  to be shorter, but a rod at rest in  $S_0$  is seen from  $S$  to be longer so that both observers agree that motion relative to  $S_0$  leads to contraction. The discrepancy with the TSR is due again to different synchronisation of clocks: the length of a moving rod can only be obtained by marking the simultaneous positions of its end points, and therefore depends on the very definition of simultaneity of events.

With  $e_1 = 0$  the one way speed of light retains the form (1.3), but now  $\Gamma = v / c$ . In  $S_0$  one has  $v = 0 \rightarrow \Gamma = 0$ ; thus  $c_1(\theta) = c$ , the velocity of light is isotropical in  $S_0$ . In this theory the inertial system  $S_0$  is not only privileged, but also very much physically active. Clocks slow down and rods shorten, but only if they move with respect to  $S_0$ . Light propagates in the simplest way only in  $S_0$ . These special properties can be understood by assuming the presence of a physical medium at rest in  $S_0$  which generates them causally. It can only be the Lorentz ether, of course, which acts as a support of all electromagnetic perturbations.

## 2. The evidence for superluminal signals

Two independent developments make the existence of superluminal signals (SLS) possible. Theoreticians have shown that solutions of Maxwell's equations exist representing electromagnetic waves propagating with

arbitrarily large group velocities [15], an unexpected result. Experimentally, evidence of signals propagating with velocity larger than  $c$  has been found in different areas:

1. Astrophysics. If quasars are taken to be at redshift distances (*Big Bang* model), then superluminal motions up to  $45 c$  have been observed [16]. But of course Arp showed that redshift quasar distances are unreliable [17]. However, even within the Milky Way (where distances are well established) there is evidence of something moving with superluminal velocity [18].
2. Tunnelling photons. Ever since 1992 it was shown in Cologne [19] that tunnelling photonic wave packets can move with superluminal group velocities inside the barrier, result confirmed by experiments carried out in Berkeley [20].
3. Microwave pulses. Microwave signals have been observed to propagate in open air with a velocity of about  $2 c$  [21]. The effect was present when the detector was displaced laterally with respect to a launcher 90 cm away and was attributed to evanescent waves which go to zero over typical distances of a few wavelengths.
4. X-shaped waves. Bessel pulses of electromagnetic waves with an X-shaped structure were predicted theoretically and observed experimentally [22, 23]. Their superluminal velocity is  $c / \cos \theta$ , where  $\theta$  is the cone angle of the Bessel beam.

In the present paper we will explore the point of view, consistent with experiments, that all superluminal signals are electromagnetic waves. From such a point of view light, but no massive particle, can be superluminal. Some simple theoretical considerations can guide us. Consider the complex function

$$\Phi(x, y, z, t) = \frac{a}{\sqrt{[b - ic(x - ut)]^2 + (u^2 - c^2)(y^2 + z^2)}} \quad (2.1)$$

where  $a$  and  $b$  are constants,  $c$  is the usual “velocity of light” parameter, and

$$u > c \quad (2.2)$$

is any given superluminal velocity. Obviously the function (2.1) is a structure propagating along the  $x$  axis with velocity  $u$ . With a direct calculation it can



propagating along the  $x$  axis with velocity  $u$ . With a direct calculation it can be confirmed that  $\Phi$  is a solution of the well known d'Alembert equation [24]

$$\nabla^2 \Phi(x, y, z, t) - \frac{1}{c^2} \frac{\partial^2 \Phi(x, y, z, t)}{\partial t^2} = 0 \quad (2.3)$$

**Proof:** Setting

$$R = \sqrt{[b - ic(x - ut)]^2 + (u^2 - c^2)(y^2 + z^2)} \quad (2.4)$$

one has  $\Phi = a/R$  and one can easily calculate the second derivatives:

$$\left\{ \begin{array}{l} \frac{1}{a} \frac{\partial^2 \Phi}{\partial x^2} = \frac{c^2}{R^3} - \frac{3c^2}{R^5} [b - ic(x - ut)]^2 \\ \frac{1}{a} \frac{\partial^2 \Phi}{\partial y^2} = -\frac{u^2 - c^2}{R^3} + 3(u^2 - c^2)^2 \frac{y^2}{R^5} \\ \frac{1}{a} \frac{\partial^2 \Phi}{\partial z^2} = -\frac{u^2 - c^2}{R^3} + 3(u^2 - c^2)^2 \frac{z^2}{R^5} \\ \frac{1}{a} \frac{\partial^2 \Phi}{\partial t^2} = \frac{c^2 u^2}{R^3} - \frac{3c^2 u^2}{R^5} [b - ic(x - ut)]^2 \end{array} \right. \quad (2.5)$$

From these equations one gets:

$$\frac{1}{a} \left[ \frac{\partial^2 \Phi}{\partial x^2} - \frac{1}{c^2} \frac{\partial^2 \Phi}{\partial t^2} \right] = -\frac{u^2 - c^2}{R^3} + 3(u^2 - c^2)^2 \frac{[b - ic(x - ut)]^2}{R^5} \quad (2.6)$$

and

$$\frac{1}{a} \left[ \frac{\partial^2 \Phi}{\partial y^2} + \frac{\partial^2 \Phi}{\partial z^2} \right] = -2 \frac{u^2 - c^2}{R^3} + 3(u^2 - c^2)^2 \frac{y^2 + z^2}{R^5} \quad (2.7)$$

whence, remembering (2.4):

$$\frac{1}{a} \left[ \frac{\partial^2 \Phi}{\partial x^2} + \frac{\partial^2 \Phi}{\partial y^2} + \frac{\partial^2 \Phi}{\partial z^2} - \frac{1}{c^2} \frac{\partial^2 \Phi}{\partial t^2} \right] = 0 \quad (2.8)$$

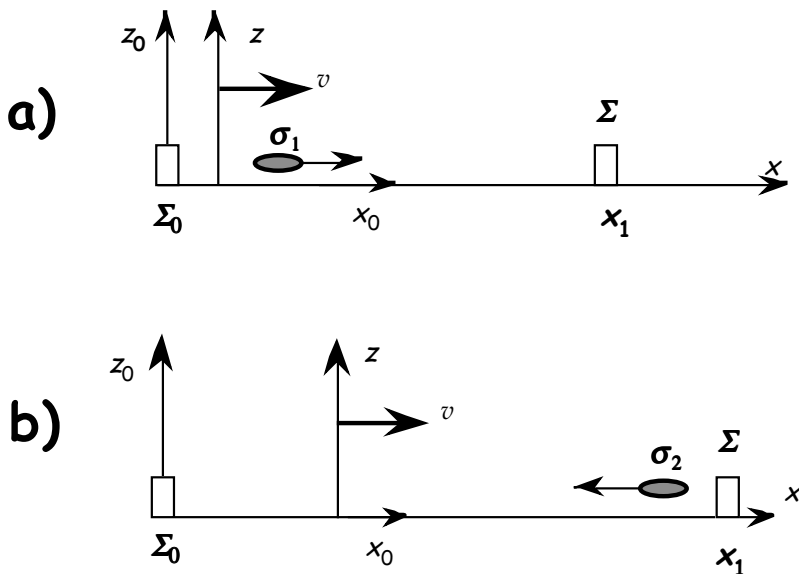
The d'Alembert equation is satisfied!

This result provides a theoretical scheme for the SLS. As it is well known, in deducing the d'Alembert equation for electric and magnetic fields from Maxwell's equations the charge and current densities disappear, indicating independence of field propagation on source motion. Such an independence applies also to the superluminal solutions. Thus they can naturally be interpreted as oscillations of a medium.

After stressing that superluminal signal velocities exist, their compatibility with the TSR was discussed by Nimtz and Haibel [25] and by Garrison et al. [26] who could offer no general solution of the well known causal paradox (also called "Tolman paradox"). The solution advocated by Recami [27] is based on his "reinterpretation rule": a superluminal particle appearing to propagate forward in time is actually an antiparticle going from the future towards the past. This solution is not acceptable, as shown by some counterexamples [28].

### 3. The causal paradox can be avoided

We will now discuss the exchange of SLS which gives rise to the typical causal paradox in the TSR. Only  $e_1 < 0$  in (1.1) ("retarded simultaneity") is considered, but we checked that  $e_1 > 0$  can be treated in a similar way leading to the same conclusions. The choice  $e_1 = 0$  remains preferable also for SLS (it avoids the causal paradox), but we will show that the logical roots of the paradox for all theories of the set (TSR included) lie in the requirement that a superluminal propagation may overtake clocks showing a decreasing physical time.



**Figure 1** a) The superluminal signal  $\sigma_1$  emitted by  $\Sigma_0$  in the origin of the system  $S_0$  propagates along  $+x_0$  until absorbed by a device  $\Sigma$  at rest in the point  $x_1 > 0$  of the system  $S$ ; b) immediately after absorbing  $\sigma_1$ ,  $\Sigma$  emits a new superluminal signal  $\sigma_2$  which propagates along the  $-x$  axis until it is absorbed by  $\Sigma_0$ . The process is represented from the point of view of the observers in  $S_0$ .

Suppose a localised superluminal signal  $\sigma_1$ , emitted by a device  $\Sigma_0$  at rest in the origin of  $S_0$  at time  $t_0 = t = 0$  (see Fig. 1), propagates along  $+x_0$  according to

$$x_0 = u_0 t_0 \tag{3.1}$$

with  $u_0 > c$ . Its position  $x$ , seen from  $S$ , is given by the first Eq. (1.1) becoming  $x = (u_0 - v)t_0 / R$ . A device  $\Sigma$  in point  $x_1 > 0$  is reached at time  $t_{01}$  given by

$$t_{01} = \frac{R}{u_0 - v} x_1 \tag{3.2}$$

At this time the signal has a position in  $S_0$  given by

$$x_{01} = \frac{u_0 R}{u_0 - v} x_1 \quad (3.3)$$

When  $x_1$  is reached the clock at rest in  $S$  near  $x_1$  marks  $t_1 = R t_{01} + e_1 (x_{01} - v t_{01})$ , as given by the fourth eq. (1.1). Owing to (3.2) and (3.3) it becomes

$$t_1 = R \left[ \frac{R}{u_0 - v} + e_1 \right] x_1 \quad (3.4)$$

Notice that at a critical superluminal velocity  $\tilde{u}_0$  given by

$$\tilde{u}_0 = v - \frac{R}{e_1} \quad (3.5)$$

one has  $t_1 = 0$ . Using (1.6), (3.5) gives the relativistic value  $\tilde{u}_0 = c^2/v$  as a particular case. Since  $x_1$  could be any point, if  $\sigma_1$  propagates with constant velocity  $\tilde{u}_0$  it will always pass near clocks of  $S$  showing time  $t=0$ . Furthermore, if  $u_0 > \tilde{u}_0$ ,  $\sigma_1$  will pass near clocks showing a decreasing time. This is no causal paradox, but only an artifact of the conventional synchronisation of clocks in  $S$ .

At the time  $t_1$  of  $S$  a second signal  $\sigma_2$  leaves point  $x_1$  propagating along the  $-x$  axis with the superluminal velocity  $w$  relative to  $S$ . Its equation is

$$x = x_1 - w(t - t_1) \quad (3.6)$$

with  $t \geq t_1$  and  $w > 0$ . The problem is to find the time at which  $\sigma_2$  reaches the device  $\Sigma_0$  in the origin of  $S_0$  which sent out the first signal. We see from Eq. (1.5) that the origin of  $S_0$  ( $x_0 = 0$ ) satisfies in  $S$  the equation

$$x = -\frac{v}{R(R - e_1 v)} t \quad (3.7)$$

Obviously,  $\sigma_2$  has to be faster than the origin of  $S_0$ , if it has to reach it. Therefore

$$w > \frac{v}{R(R - e_1 v)} \quad (3.8)$$

The overlapping of the propagations described by (3.6) and (3.7) will take place at a time  $t_2$  of  $S$  for which the positions coincide:

$$-\frac{v}{R(R - e_1 v)} t_2 = x_1 - w(t_2 - t_1)$$

whence, using (3.4)

$$t_2 = \frac{(R - v e_1) \left[ (1 + w R e_1)(u_0 - v) + w R^2 \right]}{w R (R - v e_1) - v} \frac{R x_1}{u_0 - v} \quad (3.9)$$

The point  $x_2$  in  $S$  of overlapping is obtained by inserting (3.9) in (3.7), and is

$$x_2 = -\frac{(1 + w R e_1)(u_0 - v) + w R^2}{w R (R - v e_1) - v} \frac{v x_1}{u_0 - v} \quad (3.10)$$

The time  $t_{02}$  of  $S_0$  at which the pointlike event (3.9)-(3.10) takes place can be calculated using the inverse transformations (1.5):  $t_{02} = (t_2 - R e_1 x_2) / R$ , whence

$$t_{02} = \frac{(1 + w R e_1)(u_0 - v) + w R^2}{w R (R - v e_1) - v} \frac{R x_1}{u_0 - v} \quad (3.11)$$

Also in the present case one could consider a critical velocity of  $\sigma_2$ ,  $\tilde{w}$ , at which the  $S_0$  time does not increase, so that  $t_{02} = t_{01}$ . Equating (3.11) and (3.2) one gets

$$\tilde{w} = -\frac{1}{R e_1} \quad (3.12)$$

Notice that  $\tilde{w} > 0$ , due to  $e_1 < 0$ . Furthermore, using (1.6), eq. (3.12) gives again the relativistic value  $\tilde{w} = c^2 / v$ . There is however a profound difference between  $\tilde{u}_0$  and  $\tilde{w}$ , since the superluminal signal  $\sigma_2$  with velocity  $\tilde{w}$  would pass near clocks of  $S_0$  showing a constant *physical* time. Furthermore, for all  $w > \tilde{w}$ ,  $\sigma_2$  would “see” time running backwards. But the time  $t_0$ , which is not conventional but real, cannot run backwards and we must impose the “arrow of time” condition

$$w \leq -\frac{1}{R e_1} \quad (3.13)$$

ensuring that time will always run in the right direction in  $S_0$ .

One can easily show that

$$\frac{\partial t_{02}}{\partial w} = \frac{-R^2 u_0}{[w R (R - v e_1) - v]^2} \frac{R x_1}{u_0 - v} \quad (3.14)$$

which is negative because  $u_0 > c > v$ , so that  $t_{02}$  is a decreasing function of  $w$ . Substitution of the maximum acceptable value (3.13) in  $t_{02}$  leads to

$$t_{02}^{\min} = \frac{R x_1}{u_0 - v} \quad (3.15)$$

which is positive. Thus if the arrow of time condition (3.13) is satisfied the second superluminal signal comes back to the origin of  $S_0$  at  $t_{02} > 0$ , that is in the future of the time  $t_0 = 0$  at which the first signal left it. The causal paradox is solved.

If, instead, we had set no limit on  $w$ , allowing the product of superluminal velocities  $u_0 w$  to grow faster than anything else in (3.11), we would have obtained

$$t_{02} \approx \frac{e_1 R x_1}{R - v e_1} \quad (3.16)$$

which is negative due to  $e_1 < 0$ . Therefore the arrow of time condition (3.13) is truly fundamental for overcoming the causal paradox.

Finally, notice that if  $e_1 = 0$  we obtain from (3.11) the following expression

$$t_{02} = \frac{w R^2 - v + u_0}{w R^2 - v} \frac{R x_1}{u_0 - v} \quad (3.17)$$

which is positive since  $w R^2 - v > 0$  [from eq. (3.8) with  $e_1 = 0$ ] and  $u_0 > v$ . In this case no extra condition is needed, consistently with the fact that eq. (3.13) for  $e_1 \rightarrow 0+$  becomes  $w < +\infty$ . Furthermore the SLS would not see time running backwards in any inertial system, as  $e_1 = 0$  in (3.5) leads to  $\tilde{u}_0 = \infty$ , which is the same as saying that for all finite velocities time is seen to run in the same way.

#### 4. Conclusion

In the equivalent transformations (1.1) there is a fundamental difference between the inertial systems  $S_0$  and  $S$ . In the former system clock synchronisation is dictated by a physical condition, the (assumed) isotropy of the propagation of light relative to  $S_0$ . In the latter system, instead, clock synchronisation is considered a free choice based on observer convenience. The theory of special relativity made the simplest choice by postulating the invariance of the one way velocity of light and applying the same synchronisation procedure in all inertial frames. However, simplicity in one respect can give rise to complication in another, as it happens with SLS which are excluded in the TSR, owing to the causal paradoxes. In the present paper we proposed an alternative approach based on the indication contained in the equivalent transformations (1.1). The one way velocity of light is isotropical only in  $S_0$  for almost all values of  $e_1$  (the only exception is the TSR). The Einstein synchronisation procedure has to be implemented in  $S_0$  in all cases and once this is done clocks at rest in  $S_0$  measure the true physical time. This indicates that  $S_0$  is the privileged system in which the Lorentz luminiferous ether is at rest. It is natural to assume that electromagnetic perturbations (including SLS) are vibrations of this medium. From such a point of view it is impossible that a SLS may pass near  $S_0$  clocks showing a decreasing time, because any signal takes a finite positive physical time to cover a finite distance. The roots of the causal paradoxes are thus seen to lie in the symmetrical treatment of inertial systems. In other words, in the XXth century people have believed too much in the principle of relativity. Assuming that SLS propagate in a Lorentz medium at rest in  $S_0$  excludes negative velocities relative to  $S_0$  and thus limits the velocities relative to other inertial systems to such values that, when transformed to  $S_0$ , they are non negative. In this way causal paradoxes disappear.

But there is more. Given two generators of SLS, such as  $\Sigma_0$  and  $\Sigma$  of Fig. 1, we consider them identical if, when placed in the same inertial system side by side, they can generate at the same time two SLS (e.g., two X-shaped pulses) which arrive simultaneously in a detector placed at any distance in

front of them. After checking their identity, we can place  $\Sigma_0$  and  $\Sigma$  at rest in the inertial system  $S$ , facing one another at some distance, and use them to carry out an experiment. That the pulses emitted by  $\Sigma_0$  and  $\Sigma$  have the same velocity in  $S_0$  remains true, even if one moves parallel and the other one antiparallel to the velocity of its generator, since they propagate in the Lorentz ether independently of source velocities. We could show that it then becomes possible to measure the absolute velocity of the laboratory in which a suitable experiment with such  $\Sigma_0$  and  $\Sigma$  is carried out [29].

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