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IS FASTER THAN LIGHT TRAVEL CAUSALLY POSSIBLE?

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In the conventional interpretation of Special Relativity it is said that the Principle of Causality forbids physical influences from propagating faster than light. In this paper we demonstrate that physical 'supra-luminal' speeds need not violate causality, provided that certain less stringent conditions are met; it is suggested that causality can be preserved by a Lorentz-invariant 'censor-field.' Consideration of General Relativity suggests that such a censor-field might be produced by mass-energy in a manner analogous to gravitation, perhaps derived directly from the metric tensor. Some philosophical and experimental implications are mentioned. We conclude that, despite long-standing dogma, the idea of faster-than-light travel or communication is not in conflict with either the Theory of Relativity or the Principle of Causality.

1. NAIVE ARGUMENTS AGAINST FASTER THAN LIGHT TRAVEL

Most textbooks on Special Relativity (e.g. [1, 2]) argue that it is impossible to go faster than light, giving various arguments in support of this claim; they usually point out that only physical objects or information are prohibited from propagating faster than light, whereas geometrical patterns or apparent motions are not limited in magnitude at all (cf "superluminal" radio sources [3]). The arguments used fall into two classes: arguments from causality and arguments from physical effects. In this section we shall examine and dismiss the (naive) arguments from physical effects.

"Because the mass of an object increases without limit as the velocity of light is approached it is necessary to provide an ever-increasing amount of energy to maintain its acceleration, and it would take an infinite amount of energy even just to reach the velocity of light. Therefore no object can travel faster than light."

This argument, as well as related ones using the divergence of time-rates, length-scales, etc. near light speed (e.g: [4, 5, 6]), has been demolished many times, notably by science-fiction writers (who like to be able to use fast starships in their stories). These writers usually observe that it is not necessary to go through the velocity of light in order to go faster than light ('tachyon drives,' e.g: [7]), or that it is not necessary to move through the intervening space in order to go from place to place ('hyperspace drives,' e.g: [8], and 'probability drives,' e.g: [9]).

Another argument makes use of the law of addition of linear velocities [10, 11]:

"Because any velocity, however great, when added to the velocity of light, gives only the velocity of light, it is impossible to go faster than light."

This is essentially the same as the 'light-barrier' argument. The relative velocity of two sub-luminal objects is indeed always sub-luminal, as is the relative velocity of two supra-luminal objects travelling in the same direction; whereas, the relative velocity of a sub-luminal object and a supra-luminal one is always supra-luminal. Physically this is reasonable and cannot be said to rule out FTL travel.

Another argument makes use of the Lorentz factor [10,11]:

"Since the Lorentz factor becomes imaginary for supra-luminal velocities, the results in that regime are physically meaningless. Therefore nothing can go faster than light."

This is more subtle, but nonetheless invalid. There should be no objection to the occurrence of imaginary or complex factors in mathematical expressions in physics (indeed, they occur constantly). Only actual physical measurements need have real results. However, we must emphasise that great care must be taken when trying to interpret results for the supra-luminal regime.

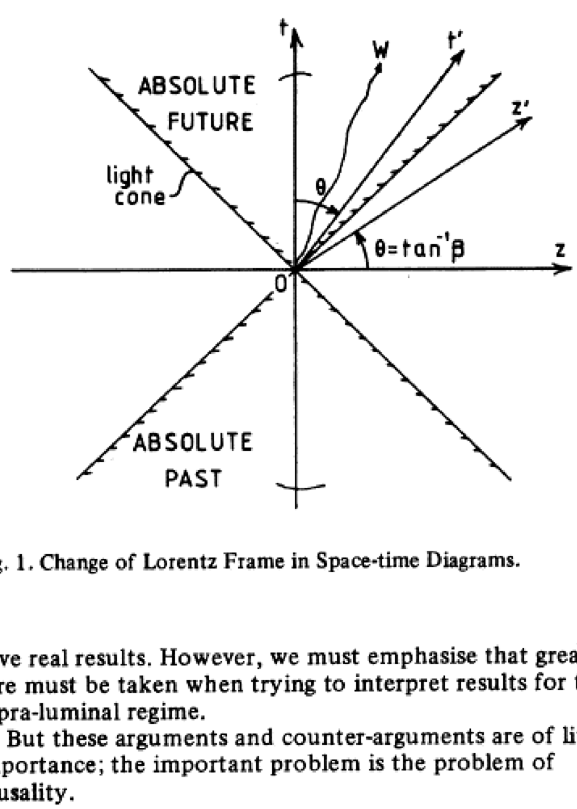

Fig. 1. Change of Lorentz Frame in Space-time Diagrams.

But these arguments and counter-arguments are of little importance; the important problem is the problem of causality.

2. THE PROBLEM OF CAUSALITY

The argument from causality makes use of the fact that travel faster than light looks like travel backwards in time for some observers. With a bit of fast footwork a traveller could return before he set out – effect preceeding cause. Since this is obviously ridiculous, it is believed that travel faster than light is impossible [6, 12]. The argument is set out in more detail below, making use of space-time diagrams [10, 11].

First of all we note that a change of Lorentz frame is accomplished by rotating the t and z axes towards each other (Fig. 1). Note that the time-like worldline OW has a positive velocity in the original frame ($dz/dt>0$), but a negative velocity in the primed frame ($dz'/dt'<0$).

Now consider a spacelike worldline viewed from two different frames (Fig. 2). Notice that OW, though apparently

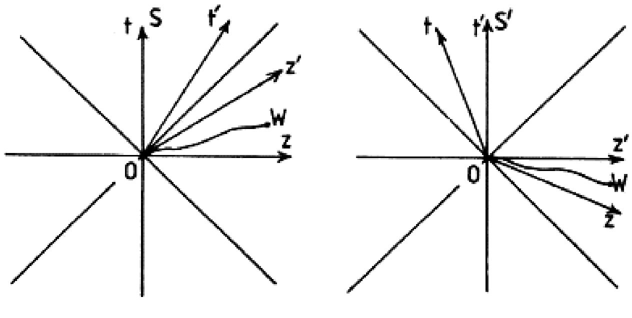

Fig. 2. A Spacelike (FTL) Worldline.

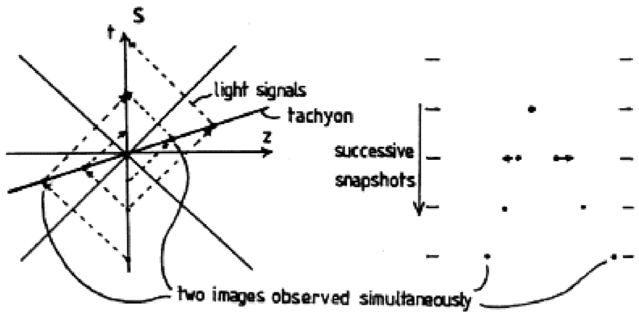

Fig. 4. Tachyon multiple imaging.

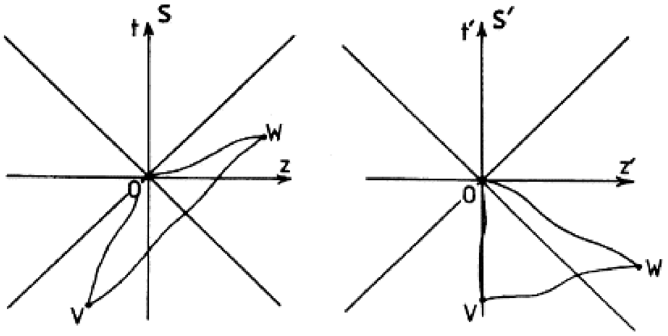

Fig. 3. Worldlines in closed Loop.

well-behaved in S, is travelling backwards in time in S'. Because we can draw a worldline that "goes back in time" we can set up a paradox.

In Fig. 3 we have a spacelike worldline OW which in S' is going backwards in time; we add a similar worldline WV, which starts at the end-point of the first and goes in the opposite direction, crossing the time axis (in S') at negative t'. The cycle is completed by the timelike path VO.

But this is absurd. For here O causes W, which causes V, which causes O itself, and so on *ad infinitum.* All observers in S and S' will agree that the traveller has gone into the absolute past of O; all observers everywhere will agree that the traveller has gone into his own absolute past on one or more legs of his journey; the traveller himself will conclude that he has followed a 'closed timelike loop.' This violates the Principle of Causality: effect could preceed cause, or be its own cause; A could equal NOT A (for example, the assertion "there is a traveller at O" could be at once both true and false). This is obviously nonsense; closed causal loops are impossible.

Since we derived this absurdity simply by assuming that spacelike worldlines (supra-luminal velocities) could actually exist, we have proved that travel faster than light is impossible. Or have we?

3. A HIDDEN ASSUMPTION

The previous section purported to show that the assumption of FTL travel automatically gives rise to causality violations. However, a hidden assumption was built into that argument, as we shall now attempt to demonstrate.

For the first leg of the journey, OW, opinions differ as to whether the traveller is going forwards or backwards in time ($\Delta t > 0$ but $\Delta t' < 0$), but all agree that W is not in the absolute past of O (as seen from any frame like S or S'); so this stage of the journey is unobjectionable, even though carried out faster than light. It is true that in some frames (such as S') observers will see things happening the "wrong way round," but this is no more than an amusing illusion, and they will have no difficulty in sorting out what really happened. So far, so good.

(The behaviour of tachyons, as observed *via* radar or emitted light, can appear very odd: Fig. 4 shows how a tachyon, moving past an observer, seems to appear out of nowhere at the point of closest approach and then move away in both directions; one image seems to go forward in time, the other backwards. If the tachyon accelerates (curved worldline) many images can be present simultaneously, "created" or "annihilated" in pairs. However, when the observer calculates the coordinates and trajectory of the images, in the usual manner, he will be able to assign the tachyon its worldline without ambiguity, and recognise the double images as optical illusions, similar to the sound images of supersonic aeroplanes. This phenomenon does not affect the validity of the space-time or Minkowski diagrams, or the nature of closed causal loops).

As soon as we try to go from W to V for the second leg of the journey we run into trouble. For the worldline WV is in the absolute past of the worldline OW, as every observer will agree. This leg violates causality, then; it is certainly impossible.

(The reader may object to the strength of the phrase "certainly impossible," which was indeed used with considerable reluctance; if so, he is invited to find a self-consistent (paradox free) description of a world in which such closed loops are allowed. It is not time travel *per se* which is forbidden, it is the returning to already visited events: "a man cannot step in the same river twice").

So the legs VO (which is timelike) and OW (which is spacelike) are causally acceptable, whereas WV is not; the symmetry between OW and WV, which we implicitly claimed above, is broken. In other words, we need not mind if the traveller goes away faster than light, so long as he doesn't try to get back too quickly!

4. SPEED LIMITS

How fast, then, can a traveller go – and which way? Consider the worldline OW in Fig. 5; it has a constant velocity $\beta_W > 1$ along the z-axis in frame S. The coordinates of W are (t_W, z_W).

The dotted arrows indicate the "speed limits" in either direction; a worldline leaving W must keep within these limits if it is not to enter the absolute past of OW. By inspection:

$$(\beta\ \max)\ \text{forwards} = -1 \tag{1}$$

$$(\beta'\ \max)\ \text{forwards} = -1 \tag{2}$$

$$(\beta\ \max)\ \text{backwards} = -z_W/t_W = -\beta_W \tag{3}$$

$$(\beta'\ \max)\ \text{backwards} = -z'_W/t'_W = -\beta'_W \tag{4}$$

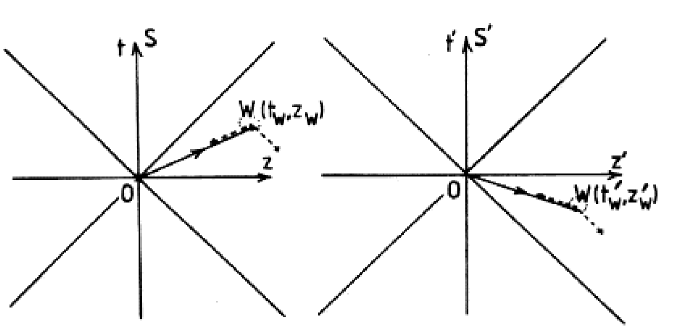

Fig. 5. Speed Limits at Event W.

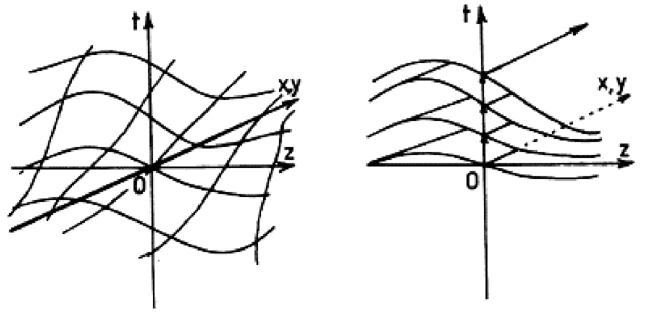

Fig. 6. The Censor-Field and its achronal Surfaces of Simultaneity.

These limits transform into any Lorentz frame by using the usual formula for the addition of velocities:

$$\beta_{sum} = (\beta_1 + \beta_2) / (1 + \beta_1\beta_2) \tag{5}$$

(Here we are dealing with a logical limit on possible speeds, the only kind of limit that can ultimately be proven; this is of philosophical interest even if the physical limits appear to be more stringent; and whatever their physical status may be, the limits derived from the Principle of Causality will be far from arbitrary).

Now clearly we cannot simply leave it up to the traveller to "obey" the speed limits; there will have to be some kind of 'censor-field' which enforces obedience to appropriate speed limits at every point in space-time, and blocks any attempt to violate causality.

A trivial example of such a censor is the scalar field of value unity ("maximum speed is everywhere c"); this is the choice that relativists usually make by default, but here we should like to find a less restrictive example.

What properties should we demand of such a censor field? It should obey the Lorentz transformations, it should supply the "correct" speed limit in all directions (so that no particle can ever travel into the absolute past for any observer, including supra-luminal ones), and it should be smoothly differentiable (with the possible exception of a few "excised" singular points). It must also be generated or built into the metric without violating the Principle of Relativity (it must not define a 'Universal Standard of Rest.' Furthermore, to be consistent with known physics, it should not forbid the propogation of 'tardyons' (sub-luminal particles) except, perhaps, under highly unusual conditions.

(It should be emphasised that the imposition of a censor field is not *ad hoc:* the Principle of Causality requires that some mathematically defineable field exist, such that closed causal loops are forbidden; what relation (if any) this 'censor-field' may have to actual physics can only be determined by experiment, but the logical limitations of causality and known physics certainly allow us to examine the requirements for a censor field without *ad hoc* invention. This is not to say that other descriptions (advanced potentials, for example – see Ref. 13 and Refs. therein) are necessarily invalid, but that such descriptions must be mathematically equivalent to, or included in, a causal field description. It must also be pointed out that such alternative descriptions have not yet in fact succeeded in changing the general belief that FTL travel is impossible).

5. A CENSOR-FIELD

Consider, as a censor-field, a sheaf of non-intersecting achronal slices through space-time, as shown in Fig. 6. An achronal slice is a surface (strictly, a hypersurface) in space-time which is everywhere spacelike (always "FTL"), but which is not necessarily a surface t=const; an example of a sheaf of achronal slices might be the surfaces $t=t_0+x/2c$.

At every point on the surface of a slice the limiting velocities are defined such that no worldline can pass through the surface. A maximally fast traveller could skate about upon the surface, but could not pass below it. In general a traveller would come up out of the surface. The achronal slice of the censor-field thus defines a (three dimensional) 'surface of simultaneity.'

It is important to realise that these surfaces of simultaneity are not in general the surfaces of constant time co-ordinates; indeed, they could only have t=const in at most one Lorentz frame. The surfaces of simultaneity are Lorentz invariant.

In moving up out of the surface one is moving forwards in time, passing irreversibly through the sheaf of achronal surfaces. Thus, if events E+ and E- occur on slices respectively above and below the slice though the origin, then O can communicate with E+ but not with E-, whereas E- can communicate with O and E+, and E- can communicate with neither.

The surfaces of simultaneity are smooth and can be defined by a unit normal vector at each point. They are allowed to undulate and change with time, but they must not intersect; at most they can approach one another infinitesimally closely.

For the normal 4-vector we use **censor** (or **c** for short), such that **c**.**c**=-1, as shown in Fig. 7. Note that **censor** does not usually *appear* to be perpendicular to the surface of simultaneity; this is because the signature of space-time is (-+++), whereas the diagram can only treat the time dimension as if it were one of space.

We have:

$$\mathbf{censor}=\text{censor}\,(t, x, y, z) \tag{6}$$

Allowable 4-velocities **v** obey the limit:

$$\mathbf{v.censor} < 0 \tag{7}$$

where the zero can be either imaginary or real, according as **v** and **censor** are, or are not, separated by the surface of null geodesics.

It is apparent that this censor-field is Lorentz invariant, since **censor** is a 4-vector, and **v.censor** an invariant scalar. It is also smoothly differentiable. It defines a local standard of rest, that is, the frame in which **c**=(1, 0, 0, 0) locally, but not a universal one, since the local rest frame can vary with time and place. Because no worldline can pass back down through the surfaces of simultaneity, but must carry on up wards, closed loops are forbidden. Thus both the Principle of Relativity and the Principle of Causality are preserved by such a field.

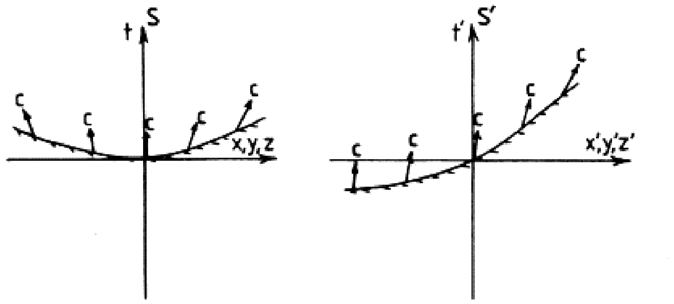

Fig. 7. The 4-vector **censor** normal to the Surfaces of Simultaneity.

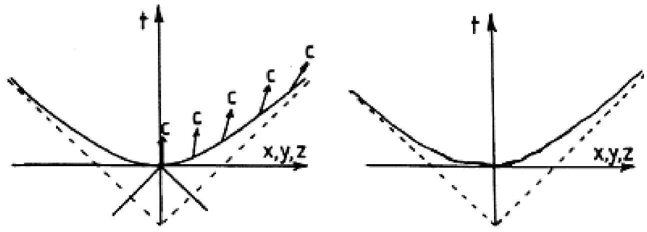

Fig. 8. A Surface of Simultaneity for the Universe with Hubble Flo\

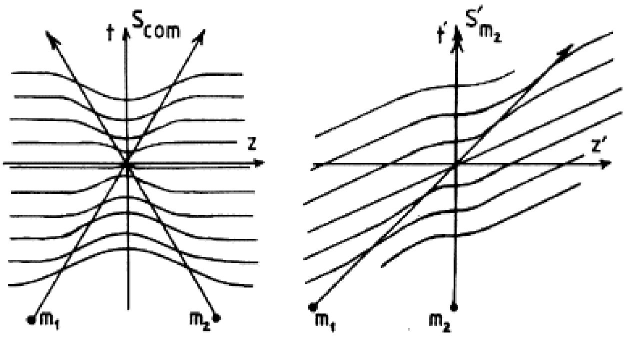

Fig. 9. The Censor-Field for two Masses in relative Motion.

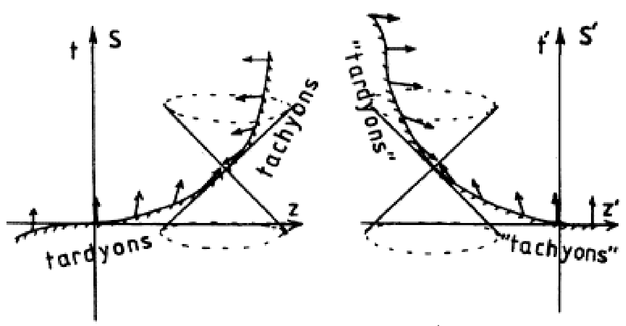

Fig. 10. The Censor-Field in Regions dominated by Tardyons and Tachyons.

6. GENERATING THE CENSOR-FIELD

In the previous section an arbitrary set of non-intersecting achronal slices was considered. It is clear, however, that the surfaces of simultaneity of the censor-field must be generated according to definite rules.

In principle, it might be, I suppose, that this field was laid down by causes "outside" space-time and is unaffacted by any event "within" space-time. This seems unlikely. We already know from General Relativity that the curvature of space-time is produced by matter, and in turn affects matter; it seems most reasonable to assume that the censor-field is bound up with the metric in a similar way.

The censor-field, we assume, is generated by material objects and radiation; that is, by mass-energy.

How might we expect this to work?

We should expect that, in a sufficiently large region of homogeneous static matter, the surfaces of simultaneity would be flat and uniformly spaced, the censor-field at rest with respect to the matter. Clearly we can expect the induced gradients of the field to be proportional to the inducing mass (at least in the weak field approximation) and to be inversely proportional to its distance (or some power thereof).

This is enough to show the qualitative form the surfaces of simultaneity must take. The trivial case of an infinite static homogeneous Universe is straightforward; the real Universe is similar, but expanding. Figure 8 shows the form of the surfaces of simultaneity for a homogeneous Universe with Hubble flow, and for a more realistic inhomogeneous one. The normal, **censor**, is simply the velocity of the Hubble flow (with small perturbations) and tends to unity slope at infinite redshift. The surfaces are also surfaces of constant proper age.

The field of two equal masses in relative motion, as viewed in two suitable frames, is shown in Fig. 9. Here each mass is sufficiently concentrated to make the local rest frame closely approximate the proper frame of each mass. Notice how the masses make a "bump" in the surfaces of simultaneity, upwards for converging masses, downwards for diverging ones.

Thus the censor-field can be seen to depend upon the distribution of mass-energy and momentum; that is, upon the stress-energy tensor that determines the structure of space-time [14].

Tardyonic (slower than light) matter seems to be predominant throughout the Universe – no tachyons (FTL particles) have yet been conclusively observed. Nevertheless, we must also consider the effects of tachyons or imaginary mass upon the censor-field. It is clear that, in a region of space dominated by tachyonic matter, the 4-vector **censor** would also be tachyonic, and the surfaces of simultaneity would become time-like (this would happen in TAUB-NUT space-time, for example). Of course, the tachyons would look at things the other way round: to them, we would be the tachyons (Fig. 10).

7. TARDYON-TACHYON SYMMETRY IN THE BIG BANG

In the conventional Big Bang theory of the origin of the Universe [15] there is difficulty in explaining its observed isotropy. The microwave background radiation shows that the expansion rate and average mass density is the same in all directions to better than ~1 part per 1000.

However, light has not yet had time to cross from one side of the sky to the other since the origin of the Big Bang; and the further back in time we consider, the less of the Universe could have been seen by any observer then.

If signals cannot propogate faster than light, then only small regions of the early Universe could have been in causal contact. At earlier and earlier epochs, smaller and smaller fractions of the Universe could have been causally connected; and at the very beginning every particle would have been causally separate from every other.

The problem is this: how could the causally unconnected regions of the Universe know how and when to expand?

Not even infinitely precise 'dead reckoning' would suffice, since quantum mechanical fluctuations would completely destroy this precision. The Universe would therefore expand in an infinitely disordered fashion, without even the topological simplicity of our own.

That is, according to conventional interpretations of Relativity and the Big Bang, our Universe cannot exist. This is a problem.

Various attempts have been made to modify the theory so as to avoid this difficulty; models in which the expansion pauses, to allow inhomogeneities to be damped out, possess some of the required properties. A recent model of this sort is the 'new inflationary Universe' [16], which is based upon considerations of Quantum Gravity and GUTS (Grand Unified field Theories): however, this model, and others like it, appear to disagree with observation.

The problem hinges upon the issue of 'Einstein Separability'; that is, whether events are causally separate when their separation is spacelike. If Einstein Separability is rejected (as it must be if signals can propagate faster than light) then the difficulty vanishes: causal connectivity can be total even at the very beginning.

A Big Bang scenario which includes tachyons and a censor-field would go something like this:

In the beginning there was a singularity, which exploded. There were equal numbers of tardyons and tachyons, all in thermal equilibrium at an extremely high temperature. The tachyons could thermalise the tardyons, and the tardyons the tachyons; across the whole Universe there was just one causally connected region. At this stage the surfaces of simultaneity would have been highly convoluted and topologically of very high connectivity. The labels "tardyon" and "tachyon" are of course merely for convenience; there would have been complete symmetry and exchangeability between them.

As the Universe cooled a process known as 'spontaneous symmetry breaking' would occur: a preponderence of one class of particle (thereafter called tardyons) would form, and most of the remaining tachyons would switch to being tardyons too. In the parlance of GUTS, a phase change from the symmetric to the asymmetric vacuum state would occur. The surfaces of simultaneity would now untangle themselves and merge into a smooth progression with the universal expansion.

With so few tachyons now left, much of the Universe would now become effectively causally disconnected; but the expansion would by now be sufficiently advanced that its isotropy and homogeneity would not be lost. Hereafter, perturbations would have only a weak effect upon the later Universe.

The scenario can then follow the standard model.

Thus the censor-field interpretation of Relativity enables us to explain some otherwise highly puzzling features of the Big Bang; this is at least an indication that we may be on the right lines: the censor-field theory "predicts" a moderately isotropic Universe, whereas Einstein Separability "predicts" a tangle. However, the evidential value of such "predictions," which are really *a posteriori* explanations, is not generally considered to be high, because other explanations of the same facts may be conceivable.

8. EINSTEIN SEPARABILITY AND REALITY

A series of experiments founded on the ideas of Einstein, Podolsky and Rosen [17] has recently brought into focus an important problem in Quantum Mechanics and Relativity, concerning the Reality of the physical world. The problem has been reviewed clearly in a Scientific American article [18]. In brief, the problem is as follows (see Fig. 11).

Quantum Mechanics predicts a strong correlation between certain kinds of distant events, a correlation which can be calculated and tested.

Local Realistic Theories predict that the correlation between distant events must be less than a certain limiting

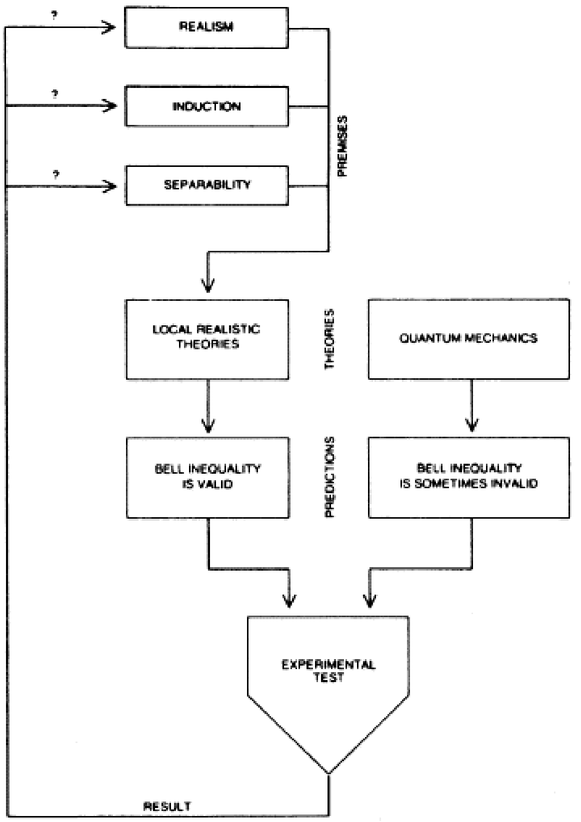

Fig. 11. Local Realistic Theories and the Bell Inequality. (Reproduced from Ref. 18, by permission).

value (the 'Bell Inequality'). Sometimes the correlation predicted by Quantum Mechanics can exceed that allowed by the Bell Inequality; and this can be tested too.

Experimental tests have shown that the Bell Inequality can be violated, just as predicted by Quantum Mechanics.

Therefore Local Realistic Theories are wrong.

Therefore at least one of the premises of the Local Realistic Theories must be incorrect.

These are the three premises that together imply the Bell Inequality:

i) The doctrine of Realism; that observed phenomena are the result of some physical reality whose existence is independent of human observation.

ii) The validity of Inductive Inference; that inductive inference is a valid mode of reasoning, so that legitimate conclusions may be drawn from consistent observations.

iii) The postulate of Einstein Separability; that no influence of any kind can propagate faster than light.

Let us consider these premises in turn.

First, Realism: this doctrine is at the root of scientific enquiry. We believe that there really is a world outside ourselves, that events have causes, that it makes sense to consider physical objects as having objective existence and properties. It is not only Science that would be trivialised without Reality, but also all other human endeavours.
I do not think that it is even possible for a man to deny reality consistently; however solipsistic his philosophy, in

his behaviour he will adhere to realism.

Second, Induction: this is even more fundamental to both Science and daily life than Realism; to all but the most sceptical of philosophers it is self-evident. Without inductive inference there could be neither science nor philosophy. In particular, the very theory of Quantum Mechanics is built upon a foundation of Realism and Induction.

Third, Einstein Separability: this has been held to be true on grounds of causality, but unlike the first two premises it has no immediate intuitive claim. In this paper we have seen that influences propagating faster than light need not violate the Principle of Causality; thus the grounds of this premise have been undercut and we need not scruple about dropping it.

In summary we might claim that Realism, Induction and Causality are intuitively true, but that Einstein Separability is merely a hypothesis to be tested, and now found wanting.

(Some readers may consider this claim excessive, preferring to deny Realism, Induction or Causality; if so, I invite them to consider which of the following seems intuitively more likely or aesthetically more pleasing:

i) It is incoherent to attempt objective description.

ii) It is incoherent to infer anything from anything.

iii) It is incoherent to talk about cause and effect.

iv) Signals can propagate faster than light).

The grave problems caused by tests of the Bell Inequality can be resolved if a censor-field interpretation of Relativity is adopted, and Einstein Separability rejected. The way is also opened to a more realistic interpretation of Quantum Mechanics, a 'statistical interpretation' as opposed to the 'Copenhagen interpretation,' as discussed in Ref. 19.

9. QUANTITATIVE ASPECTS OF THE CENSOR-FIELD

So far only qualitative aspects of the censor-field have been considered. It is not immediately obvious what the precise form of **censor** should be, nor whether the solution will be unique. It seems reasonable to consider choices like:

$$\mathbf{censor} = \Sigma(m.\mathbf{u}/r) \;/\; \Sigma(m/r) \qquad (8)$$

summed over all bodies, for which the mass and distance are proper values, evaluated in their own rest frames. The ratio (m/r) is the Newtonian potential produced by each mass, and is the same term that is used for the 'sum for inertia' when considering Mach's Principle [20].

In a parameterised post-Newtonian (PPN) approximation of General Relativity one considers a frame which becomes Lorentzian at infinity; in the notation of MTW [21] one obtains a metric:

$$g_{00} = -1+2U(1-U)+4\Phi \qquad (9)$$

$$g_{0j} = -\tfrac{7}{2}V_j - \tfrac{1}{2}W_j \qquad (10)$$

In these terms the censor-field would be given by:

$$c_j = -\tfrac{1}{2}g_{0j}/(g_{00}+1) \qquad (11)$$

When velocities and internal energies are small, this reduces to:

$$c_j = \int(\tfrac{7}{8}v_j+\tfrac{1}{8}(\mathbf{v.r})r_j/r^2).dU/U \qquad (12)$$

where U is the Newtonian potential. Notice that transverse and radial velocities have slightly different effects in this expression, corresponding to the 'dragging of inertial frames' in General Relativity.

The question of the physical means by which such a censor-field might limit the speed of particles has not been addressed. Perhaps the simplest solution might be a coordinate singularity at the limit, leading to a 180° flip on the Minkowski diagram. Alternatively we may note that, if inertial effects propogate in a Machian fashion along the surfaces of simultaneity, then as an observer approaches the limiting speed he will interact "simultaneously" with the whole Universe and the inertial "drag" tend to infinity (I am indebted to the first referee of this paper for the idea behind this suggestion).

It remains to find a generalised and completely covariant form for **censor** in the formalism of General Relativity, and to determine whether there is a natural unique solution or a range of possibilities (or whether such a field is not possible in General Relativity despite being consistent with Special Relativity).

10. MAXIMUM SPEED OF A PACKET OF ENERGY

Let us consider what the effective maximum speed of an object or packet of energy may be, assuming a censor-field in form like that of Eq. (8).

The effective 'sum for inertia' throughout the Universe is perhaps $m/r \sim 0.1$-1 ; this value depends strongly on strong field and high velocity integrals and the cosmological model chosen, and is therefore very uncertain. There is some reason to believe that for an open Universe it may even be infinite, in which case we might need to modify the fully relativistic form to give a finite integral, while retaining the weak-field or the Newtonian approximation.

The self-potential, $\sim(m/r)_{self}$, is very much less than unity for most objects: for a proton it is $\sim 10^{-40}$; for a man $\sim 10^{-25}$; and for a 10000tonne/100metre starship it would be $\sim 10^{-22}$. Thus the self-effect on the censor-field will be much less than that of the background Universe; and a moving object will produce only a slight local gradient, $\sim(m/r)_{self} \,/\, (m/r)_{universe}$, on the surfaces of simultaneity (Fig. 9).

This will prevent the object from moving back and forth on a single surface of simultaneity, its maximum speed relative to the surface being the inverse of the gradient. Thus an elementary particle might travel at up to an effective $\sim 10^{39}$c. In principle, a spaceship might fly out to the Hubble Distance (~3Gpc) and back in as little as a millisecond. If this speed is not infinite, it is certainly very fast.

This calculation has perhaps been a little naive; it is not obvious that a supraluminal object will have the same effect as a similar object at rest would have. Moreover, as pointed out in the first section, we must not assume that an object has to cross the intervening space to go from place to place.

11. IMAGINARY LORENTZ FACTORS OR THREE DIMENSIONAL TIME?

We have not yet considered how the world would appear to a supra-luminal observer. Points to consider are these;

How will he perceive our dimensions of space and time? Will they be reversed? How will he perceive the flow of time?

Will the world of tachyons appear to him like our world of tardyons? Or will certain, apparently sub-luminal, motions be forbidden?

Will he vanish from our sight? And can he ever reappear?

How can the symmetry of the Lorentz transform be maintained? And what is the meaning of the imaginary factors that arise?

It is not my intention to attempt to give a unified theory of tardyon-tachyon interactions, so little more will be done than to pose these questions for future consideration. Nevertheless, certain of the difficulties and certain possible routes for solution will be pointed out.

One can soon convince oneself that the Lorentz transform leads to the existence of imaginary "observables" for the supra-luminal regime; and no simple mathematical trick, like multiplying by i, can remove them. The difficulty is the change of signature of space-time from (-+++) for tardyons to (-+ --) for tachyons, such that two dimensions of space behave like time; even if this can be accepted, it destroys the desired symmetry between the world of tardyons and the world of tachyons.

A six-dimensional space-time would remove this difficulty, since a symmetrical arrangement of three space and three time dimensions gives a signature (---+++). Any observer will see a conventional 4-D space-time, but on going supraluminal two of his space dimensions will rotate out of his observable 4-plane, and the two previously unobservable dimensions will appear. Thus any observer is always in a space of the same signature (---+++).

In such a scheme there would no longer be two distinct regimes (tardyons and tachyons), but a total of six regimes separated by null geodesics. Going from one to another involves rotation about one or more of the six orthogonal axes. This would mean that a supraluminal observer would be unable to observe events displaced sideways from his line of flight; instead, he would see part of "hyperspace."

Whether this would imply innumerable parallel (or dissimilar) universes in the available sheafs of space-time is left for the reader to consider.

Some aspects of six-dimensional relativity are examined in Refs. 22 and 23 which develop a real six-dimensional generalised form of the Lorentz Transformations.

12. CONCLUSIONS

Let us be quite certain about what we have shown.

We have NOT shown that faster-than-light travel is possible. We have NOT developed a scientific theory of the censor-field. We have not proved the existence of such a field. We have not even considered whether faster-than-light travel would be useful; still less have we examined its practicability.

What we have done is to demolish the dogma that travel faster than light is necessarily impossible. We have shown that Special Relativity does not forbid it. We have shown that the Principle of Causality does not forbid it. We have pointed out a form of censor-field, consistent with known physics, that permits it. We have shown how such a field can solve some of the outstanding paradoxes in physics today; we have advanced this as speculative evidence of the propagation of certain signals faster than light.

We can now answer the question posed in the title of this paper:

Yes, faster-than-light travel IS causally possible.

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