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Superluminal Motions? A Bird's-Eye View of the Experimental Situation[1]

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In this article, after a theoretical introduction and a sketch of some related long-standing predictions, a bird's-eye view is presented—with the help of nine figures—of the various experimental sectors of physics in which Superluminal motions seem to appear (thus contributing support to those past predictions). In particular, a panorama is presented of the experiments with evanescent waves and/or tunnelling photons, and with the "localized Superluminal solutions" to the Maxwell equations (like the so-called X-shaped beams). The present review is brief, but is followed by a large enough bibliography to allow the interested reader deepening the preferred topic.

1. INTRODUCTION

The question of Superluminal ($V^2 > c^2$) objects or waves,[3] has a long story, starting perhaps in 50 B.C. with Lucretius' *De Rerum Natura* (cf., e.g., book 4, line 201: [≪ Quone vides *citius* debere et longius ire/Multiplexque loci spatium transcurrere eodem/Tempore *quo Solis* pervolgant *lumina* coelum? ≫]). Still in pre-relativistic times, one meets various related works, from those by J. J. Thomson to the papers by the great A. Sommerfeld. With Special Relativity, however, since 1905 the conviction spread over that the speed c of light in vacuum was the *upper* limit of any possible speed. For instance, R. C. Tolman in 1917 believed to have shown by his "paradox" that the existence of particles endowed with speeds larger than

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[3] It is an old use of ours to write Superluminal with a capital S.

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c would have allowed sending information into the past. Such a conviction blocked for more than half a century—aside from an isolated paper (1922) by the Italian mathematician G. Somigliana—any research about Superluminal speeds. Our problem started to be tackled again essentially in the fifties and sixties, in particular after the papers[1] by E. C. George Sudarshan *et al.*, and later on[2] by E. Recami, R. Mignani, *et al.* [who rendered the expressions subluminal and Superluminal of popular use by their works at the beginning of the seventies], as well as by H. C. Corben and others (to confine ourselves to the *theoretical* researches). The first experiments looking for tachyons were performed by T. Alväger *et al.*

Superluminal objects were called tachyons, T, by G. Feinberg, from the Greek word $\tau\alpha\chi\acute{\upsilon}\varsigma$, quick, and this induced us in 1970 to coin the term bradyon, B, for ordinary subluminal ($v^2 < c^2$) objects, from the Greek word $\beta\rho\alpha\delta\acute{\upsilon}\varsigma$, slow. Finally, objects travelling exactly at the speed of light are called "luxons."

In recent years, terms as "tachyon" and "superluminal" fell unhappily into the (cunning, rather than crazy) hands of pranotherapists and mere cheats, who started squeezing money out of simple-minded people; for instance by selling plasters (!) that should cure various illnesses by "emitting tachyons"... We are dealing with them here, however, since at least four different experimental sectors of physics seem to indicate the actual existence of Superluminal motions, thus confirming some long-standing theoretical predictions.[3] So much so that even the *N.Y. Times* commented on May 30, 2000, upon two of such experiments, imitated the next day (and again at the end of the next July) by nearly all the world press. In this rapid informative paper, after a sketchy theoretical introduction, we set forth a reasoned outline of the experimental state of the art: brief, but accompanied by a bibliography sufficient in some cases to provide the interested readers with coherent, adequate information; and without forgetting to call attention—at least in the two sectors more in fashion today—to some other worthy experiments.

2. SPECIAL AND EXTENDED RELATIVITY

Let us premise that special relativity (SR), abundantly verified by experience, can be built on two simple, natural Postulates: (1) that the laws (of electromagnetism and mechanics) be valid not only for a particular observer, but for the whole class of the "inertial" observers: (2) that space and time be homogeneous and space be moreover isotropic. From these Postulates one can theoretically *infer* that one, and only one, *invariant* speed exists: and experience tells us such a speed to be that, c, of light in vacuum; in fact, light possesses the peculiar feature of presenting always the same speed in vacuum, even when we run towards or away from it. It is just that feature, of being invariant, that makes quite exceptional the speed c: no bradyons, and no tachyons, can enjoy the same property!

Another (known) consequence of our Postulates is that the total energy of an ordinary particle increases when its speed v increases, tending to infinity when v tends to c. Therefore, infinite forces would be needed for a bradyon to reach the speed c. This fact generated the popular opinion that speed c can be neither achieved nor overcome. However, as speed c photons exist which are born live and die always at the speed of light (without any need of accelerating from rest to the light speed), so particles can exist—tachyons[4]—always endowed with speeds V larger than c (see Fig. 1). This circumstance has been picturesquely illustrated by George Sudarshan (1972) with reference to an imaginary demographer studying the population patterns of the Indian subcontinent: ≪ Suppose a demographer calmly asserts that there are no people North of the Himalayas, since none could climb over the mountain ranges! That would be an absurd conclusion. People of central Asia are born there and live there: they did not have to be born in India and cross the mountain range. So with faster-than-light particles ≫. Let us add that, still starting from the above two postulates (besides a third postulate, even more obvious), the theory of relativity can be generalized[3, 4] in such a way to accommodate also Superluminal objects; such an extension is largely due to the Italian school, by a series of works performed mainly in the sixties–seventies. Also within the "Extended Relativity"[3] the speed c, besides being invariant, is a limiting velocity: but every limiting value has two sides, and one can a priori approach it both from the left and from the right.

Actually, the ordinary formulation of SR is restricted too much. For instance, *even leaving tachyons aside*, it can be easily so widened as to include *antimatter*.[5] Then, one finds space-time to be a priori populated

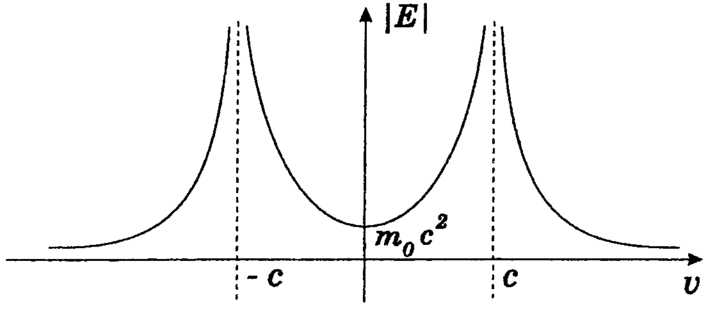

Fig. 1. Energy of a free object as a function of its speed.[2–4]

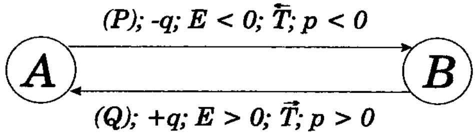

Fig. 2. Depicting the "switching rule" (or reinterpretation principle) by Stueckelberg–Feynman–Sudarshan–Recami:(3–5) Q will appear as the antiparticle of P. See the text.

by normal particles P (which travel forward in time carrying positive energy), *and* by dual particles Q "which travel backwards in time carrying negative energy." The latter shall appear to us as *antiparticles*, i.e., as particles—regularly travelling forward in time with positive energy, but—with all their "additive" charges (e.g., the electric charge) reversed in sign!: see Fig. 2. To clarify this point, let us recall that we, macroscopic observers, have to move in time along a single, well-defined direction, to such an extent that we *cannot* even see a motion backwards in time…; and every object like Q, travelling backwards in time (with negative energy), will be *necessarily* reinterpreted by us as an anti-object, with opposite charges but travelling forward in time (with positive energy).(3–5)

But let us forget about antimatter and go back to tachyons. A strong objection against their existence is based on the opinion that by tachyons it would be possible to send signals into the past, owing to the fact that a tachyon T which, say, appears to a first observer O as emitted by A and absorbed by B, can appear to a second observer O' as a tachyon T′ which travels backwards in time with negative energy. However, by applying (as it is obligatory to do) the same "reinterpretation rule" or switching procedure seen above, T′ will appear to the new observer O' just as an antitachyon $\bar{\mathrm{T}}$ emitted by B and absorbed by A, and therefore travelling forward in time, even if in the contrary *space* direction. In such a way, every travel towards the past, and every negative energy, disappear.

Starting from this observation, it is possible to solve(5) the so-called causal paradoxes associated with Superluminal motions: paradoxes which result to be the more instructive and amusing, the more sophisticated they are; but that cannot be re-examined here (some of them having been proposed by R. C. Tolman, J. Bell, F. A. E. Pirani, J. D. Edmonds and others).(6, 3) Let us only mention here the following. The reinterpretation principle, according to which, in simple words, signals are carried only by objects which appear to be endowed with positive energy, does eliminate any information transfer backwards in time; but this has a price: The one of abandoning the ingrained conviction that the judgement about what is cause and what is effect be independent of the observer. In fact, in the case examined above, the first observer O considers the event at A to be the cause of the event at B. By contrast, the second observer O' will consider the event at B as causing the event at A. All the observers will however see the cause to happen *before* its effect.

Taking new objects or entities into consideration always forces us to a criticism of our prejudices. If we require the phenomena to obey the *law* of (retarded) causality with respect to all the observers, then we cannot demand also the *description* "details" of the phenomena to be invariant: namely, we cannot demand in that case also the invariance of the "cause" and "effect" labels.[6, 2] To illustrate the nature of our difficulties in accepting that, e.g., the parts of cause and effect depend on the observer, let us cite an analogous situation that does not imply present-day prejudices: ≪ For ancient Egyptians, who knew only the Nile and its tributaries, which all flow South to North, the meaning of the word "south" coincided with the one of "upstream," and the meaning of the word "north" coincided with the one of "downstream." When Egyptians discovered the Euphrates, which unfortunately happens to flow North to South, they passed through such a crisis that it is mentioned in the stele of Tuthmosis I, which tells us about *that inverted water that goes downstream* (*i.e.*, *towards the North*) *in going upstream* ≫ (Csonka, 1970).

The last century theoretical physics led us in a natural way to suppose the existence of various types of objects: magnetic monopoles, quarks, strings, tachyons, besides black-holes: and various sectors of physics could not go on without them, even if the existence of none of them is certain (also because attention has not yet been paid to some links existing among them: e.g., a Superluminal electric charge is expected to behave as a magnetic monopole; and a black-hole a priori can be the source of tachyonic matter). According to Democritus of Abdera, everything that was thinkable without meeting contradictions had to exist somewhere in the unlimited universe. This point of view—which was given by M. Gell-Mann the name of "totalitarian principle"—was later on expressed (T. H. White) in the humorous form "Anything not forbidden is compulsory." Applying it to tachyons, Sudarshan was led to claim that if tachyons exist, they must be found; if they do not exist, we must be able to say clearly why.

3. THE EXPERIMENTAL STATE OF THE ART

Extended Relativity can allow a better understanding of many aspects also of *ordinary* relativistic physics, even if tachyons would not exist in our cosmos as asymptotically free objects. As already said, we are dealing with them, however, since their topic is presently returning into fashion, especially because of the fact that at least three or four different experimental sectors of physics seem to suggest the possible existence of faster-than-light motions. We wish to put forth in the following some information (mainly bibliographical) about the experimental results obtained in each one of those different physics sectors.

(A) *Neutrinos*. First: A long series of experiments, started in 1971, seems to show that the square m_0^2 of the mass m_0 of muon-neutrinos, and more recently of electron-neutrinos too, is negative; which, if confirmed, would mean that (when using a naïve language, commonly adopted) such neutrinos possess an "imaginary mass" and are therefore tachyonic, or mainly tachyonic.[7, 3] [In Extended Relativity, the dispersion relation for a free tachyon becomes $E^2 - \mathbf{p}^2 = -m_0^2$, and there is *no* need therefore of imaginary masses...].

(B) *Galactic micro-quasars*. Second: As to the *apparent* Superluminal expansions observed in the core of quasars[8] and, recently, in the so-called galactic microquasars,[9] we shall not deal here with that problem, too far from the other topics of this paper: without mentioning that for those astronomical observations *there exist orthodox interpretations, based on Ref. 10, that are accepted by the majority of astrophysicists*. For a theoretical discussion, see Ref. 11. Here, let us mention only that simple geometrical considerations in Minkowski space show that a *single* Superluminal light source would appear:[11, 3] (i) initially, in the "optical boom" phase (analogous to the acoustic "boom" produced by a plane travelling with constant supersonic speed), as an intense source which suddenly comes into view; and that (ii) afterwards seem to split into TWO objects receding one from the other with speed $V > 2c$.

(C) *Evanescent waves and "tunnelling photons."* Third: Within quantum mechanics (and precisely in the *tunnelling* processes), it had been shown that the tunnelling time—firstly evaluated as a simple "phase time" and later on calculated through the analysis of the wavepacket behaviour—does not depend on the barrier width in the case of opaque barriers ("Hartman effect").[12] This implies Superluminal and arbitrarily large (group) velocities V inside long enough barriers: see Fig. 3. Experiments that may verify this prediction by, say, electrons are difficult. Luckily enough, however, the Schroedinger equation in the presence of a potential barrier is mathematically identical to the Helmholtz equation for an electromagnetic wave propagating, e.g., down a metallic waveguide along the x-axis: and a barrier height U bigger than the electron energy E corresponds (for a given wave frequency) to a waveguide of transverse size lower than a cut-off value. A segment of "undersized" guide does therefore behave as a barrier for the wave (photonic barrier).[13] The wave assumes therein —like an electron inside a quantum barrier—an imaginary momentum or

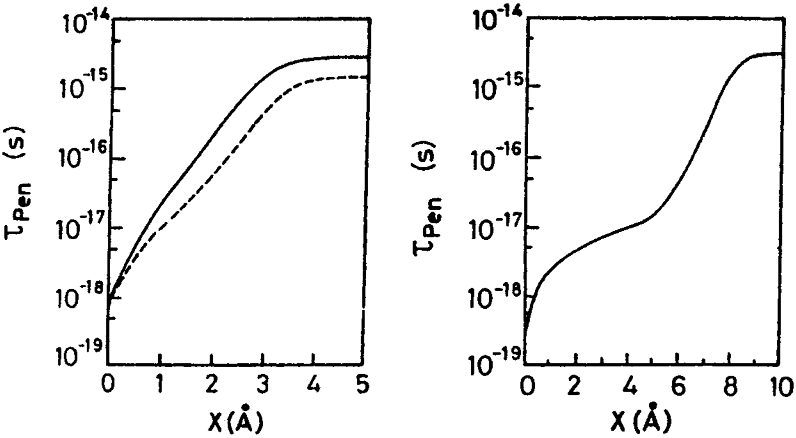

Fig. 3. Behaviour of the average "penetration time" (in seconds) spent by a tunnelling wavepacket, as a function of the penetration depth (in angstroms) down a potential barrier (from Olkhovsky *et al.*, Ref. 12). According to the predictions of quantum mechanics, the wavepacket speed inside the barrier increases in an unlimited way for opaque barriers; and the total tunnelling time does *not* depend on the barrier width[12].

wave-number and gets, as a consequence, exponentially damped along x. In other words, it becomes an *evanescent* wave (going back to normal propagation, even if with reduced amplitude, when the narrowing ends and the guide returns to its initial transverse size). Thus, a tunnelling experiment can be simulated[13] by having recourse to evanescent waves (for which the concept of group velocity can be properly extended[14]). The fact that evanescent waves travel with Superluminal speeds has been actually *verified* in a series of famous experiments (cf. Fig. 4).

Namely, various experiments, performed since 1992 onwards by G. Nimtz at Cologne,[15] by R. Chiao's and A. Steinberg's group at Berkeley,[16] by A. Ranfagni and colleagues at Florence,[17] and by others at Vienna, Orsay, Rennes,[17] verified that "tunnelling photons" travel with Superluminal group velocities. Such experiments raised a great deal of interest,[18] also within the non-specialized press, and were reported by Scientific American, Nature, New Scientist, and even Newsweek, etc. Let us add that also Extended Relativity had predicted[19] evanescent waves to be endowed with faster-than-c speeds; the whole matter appears to be therefore theoretically selfconsistent. The debate in the current literature does not refer to the experimental results (which can be correctly reproduced by numerical elaborations[20, 21] based on Maxwell equations only), but rather to the question whether they allow, or do not allow, sending signals or information with Superluminal speed.[21, 14]

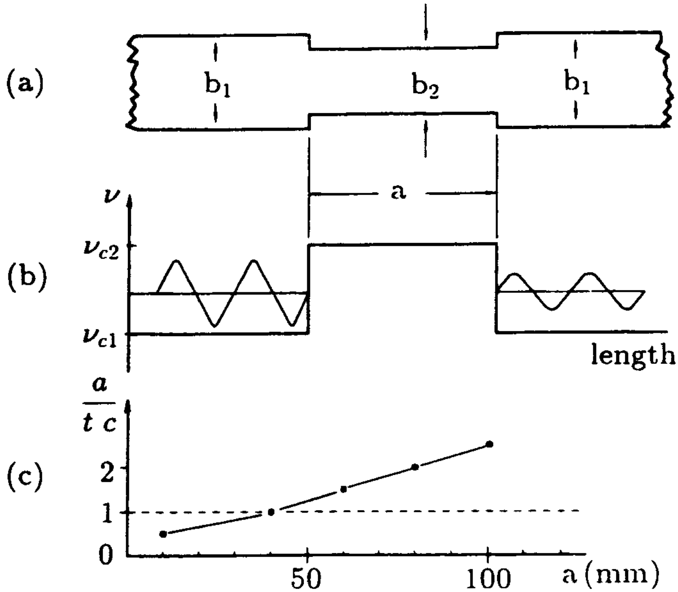

Fig. 4. Simulation of tunnelling by experiments with evanescent classical waves (see the text), which were predicted to be Superluminal also on the basis of Extended Relativity.[3, 4] The figure shows one of the measurement results in Ref. 15; that is, the average beam speed while crossing the evanescent region (= segment of undersized waveguide, or "barrier") as a function of its length. As theoretically predicted,[19, 12] such an average speed exceeds c for long enough "barriers."

Let us emphasize that the *most interesting* experiment of this series is the one with two "barriers" (e.g., with two segments of undersized waveguide separated by a piece of normal-sized waveguide: Fig. 5). For suitable frequency bands—i.e., for "tunnelling" far from resonances—, it was found that the total crossing time does not depend on the length of the intermediate (normal) guide: namely, that the beam speed along it is infinite.[22] This agrees with what predicted by Quantum Mechanics for the non-resonant tunnelling through two successive opaque barriers (the tunnelling

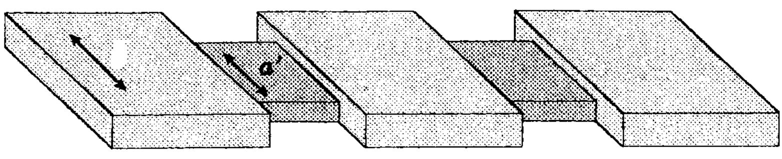

Fig. 5. The very interesting experiment along a metallic waveguide with TWO barriers (undersized guide segments), i.e., with two evanescence regions.[22] See the text.

phase time, which depends on the entering energy, has been shown by us to be *independent* of the distance between the two barriers[23]). Such an important experiment could and should be repeated, taking advantage also of the circumstance that quite interesting evanescence regions can be easily constructed in the most varied manners, like by different "photonic band-gap materials" or gratings (it being possible to use from multilayer dielectric mirrors or semiconductors, to photonic crystals…)

We cannot skip a further topic—which, being delicate, should not appear in a brief review like this one—since the last experimental contribution to it (performed at Princeton by J. Wang *et al.* and published in Nature on 7.20.00) is one of the two articles mentioned by the N.Y.Times and commented at the end of July, 2000, by the whole world press. Even if in Extended Relativity all the ordinary causal paradoxes seem to be solvable,[3,6] nevertheless one has to bear in mind that (whenever it is met an object, $\mathcal{O}$, travelling with Superluminal speed) one may have to deal with negative contributions to the tunnelling times:[24] and this should not be regarded as unphysical. In fact, whenever an "object" (particle, electromagnetic pulse,…) $\mathcal{O}$ *overcomes* the infinite speed[3,6] with respect to a certain observer, it will afterwards appear to the same observer as the "*anti*-object" $\overline{\mathcal{O}}$ travelling in the opposite *space* direction.[3,6] For instance, when going on from the lab to a frame $\mathcal{F}$ moving in the *same* direction as the particles or waves entering the barrier region, the object $\mathcal{O}$ penetrating through the final part of the barrier (with almost infinite speed,[12,21,23] like in Fig. 3) will appear in the frame $\mathcal{F}$ as an anti-object $\overline{\mathcal{O}}$ crossing that portion of the barrier *in the opposite space-direction*.[3,6] In the new frame $\mathcal{F}$, therefore, such anti-object $\overline{\mathcal{O}}$ would yield a *negative* contribution to the tunnelling time: which could even result, in total, to be negative. For any clarifications, see Refs. 18. What we want to stress here is that the appearance of such negative times is predicted by Relativity itself, on the basis of the ordinary postulates.[3,6,24,12,21] (In the case of a non-polarized beam, the wave anti-packet coincides with the initial wave packet; if a photon is however endowed with helicity $\lambda = +1$, the anti-photon will bear the opposite helicity $\lambda = -1$). From the theoretical point of view, besides Refs. 24, 12, 21, 6, and 3, see Refs. 25. On the (quite interesting!) experimental side, see papers,[26] the last one having already been mentioned above.

Let us *add* here that, via quantum interference effects in three-level atomic systems, it is possible to obtain dielectrics with refraction indices very rapidly varying as a function of frequency, with almost complete absence of light absorption (i.e., with quantum induced transparency).[27] The group velocity of a light pulse propagating in such a medium can decrease to very low values, either positive or negatives, with *no* pulse distortion. It is known that experiments were performed both in atomic samples at room temperature, and in Bose–Einstein condensates, which showed the possibility of reducing the speed of light to a few meters per second. Similar, but negative group velocities, implying a propagation with Superluminal speeds thousands of time higher than the previously mentioned ones, have been recently predicted, in the presence of such an "electromagnetically induced transparency," for light moving in a rubidium condensate,[28] while the corresponding experiments are being done at the Florence European laboratory "LENS."

Finally, let us emphasize that faster-than-c propagation of light pulses can be (and was, in same cases) observed also by taking advantage of anomalous dispersion near an absorbing line, or nonlinear and linear gain lines, or nondispersive dielectric media, or inverted two-level media, as well as of some parametric processes in nonlinear optics (cf. G. Kurizki *et al.*)

(D) *Superluminal Localized Solutions* (*SLS*) *to the wave equations. The* "*X-shaped waves.*" The fourth sector (to leave aside the others) is not less important. It came into fashion again, when some groups of capable scholars in engineering (for sociological reasons, most physicists had abandoned the field) rediscovered by a series of clever works that any wave equation—to fix the ideas, let us think of the electromagnetic case—admit also solutions as much sub-luminal as Super-luminal (besides the ordinary waves endowed with speed c/n). Let us recall that, starting with the pioneering work by H. Bateman, it had slowly become known that all homogeneous wave equations (in a general sense: scalar, electromagnetic, spinorial,...) admit wavelet-type solutions with sub-luminal velocities.[29] Subsequently, also Superluminal solutions started to be written down, in Refs. 30 and, independently, in Refs. 31 (in one case just by the mere application of a Superluminal Lorentz "transformation"[3, 32]).

A quite important feature of some new solutions of these (which attracted much attention of the engineering colleagues) is that they propagate as localized, non-dispersive pulses: namely, according to the Courant and Hilbert's[29] terminology, as "undistorted progressive waves." It is easy to realize the practical importance, for instance, of a radio transmission carried out by localized beams, independently of their being sub- or Super-luminal. But non-dispersive wave packets can be of use also in theoretical physics for a reasonable representation of elementary particles.[33]

Within Extended Relativity since 1980 it had been found[34] that—whilst the simplest subluminal object conceivable is a small sphere, or a point as its limit—the simplest Superluminal objects results by contrast to be (see Refs. 34, and Figs. 6 and 7) an "X-shaped" wave, or a double cone as its limit, which moreover travels without deforming—i.e., rigidly—in a homogeneous medium.[3] It is worth noticing that the most interesting

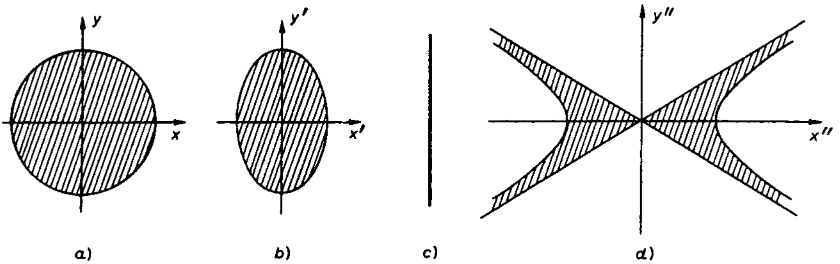

Fig. 6. An intrinsically spherical (or pointlike, at the limit) object appears in the vacuum as an ellipsoid contracted along the motion direction when endowed with a speed $v < c$. By contrast, if endowed with a speed $V > c$ (even if the c-speed barrier cannot be crossed, neither from the left nor from the right), it would appear[34] no longer as a particle, but rather as an "X-shaped" wave[34] travelling rigidly (namely, as occupying the region delimited by a double cone and a two-sheeted hyperboloid—or as a double cone, at the limit—, moving Superluminally and without distortion in the vacuum, or in a homogeneous medium).

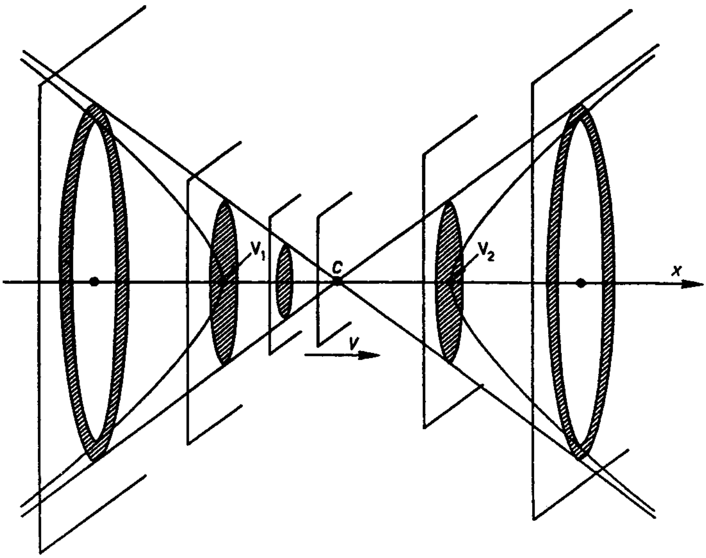

Fig. 7. Here we show the intersections of an "X-shaped wave"[34] with planes orthogonal to its motion line, according to Extended Relativity.[2–4] The examination of this figure suggests how to construct a simple dynamic antenna for generating such localized Superluminal waves (an antenna which was in fact adopted, independently, by Lu *et al.*[36] for the production of such non-dispersive beams).

localized solutions happened to be just the Superluminal ones, and with a shape of that kind. Even more, since from Maxwell equations under simple hypotheses one goes on to the usual *scalar* wave equation for each electric or magnetic field component, one can expect the same solutions to exist also in the field of acoustic waves, and of seismic waves (and perhaps of gravitational waves too). Actually, such beams (as suitable superpositions of Bessel beams) were mathematically constructed for the first time by Lu *et al.*,[35] *in acoustics*: and were then called "X-waves" or rather X-shaped waves.

It is more important for us that the X-shaped waves have been in effect produced in experiments both with acoustic and with electromagnetic waves; that is, X-beams were produced that, in their medium, travel undistorted with a speed larger than sound, in the first case, and than light, in the second case. In acoustics, the first experiment was performed by Lu *et al.* themselves[36] in 1992, at the Mayo Clinic (and their papers received the 1992 IEEE first award). In the electromagnetic case, certainly more "intriguing," Superluminal localized X-shaped solutions were first mathematically constructed (cf., e.g., Fig. 8) in Refs. 37, and later on experimentally produced by Saari *et al.*[38] in 1997 at Tartu by visible light (Fig. 9), and recently by Mugnai, Ranfagni and Ruggeri at Florence by microwaves[39]

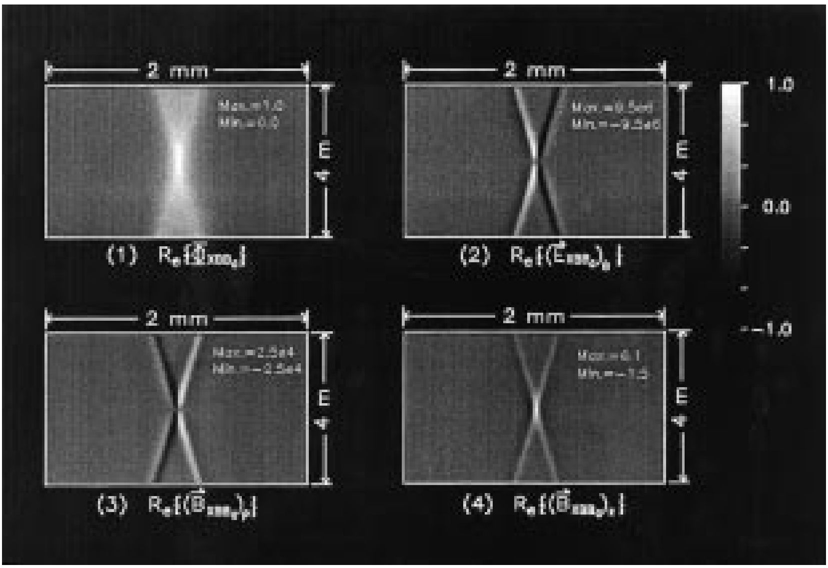

Fig. 8. Theoretical prediction of the Superluminal localized "X-shaped" waves for the electromagnetic case (from Lu, Greenleaf and Recami,[37] and Recami[37]).

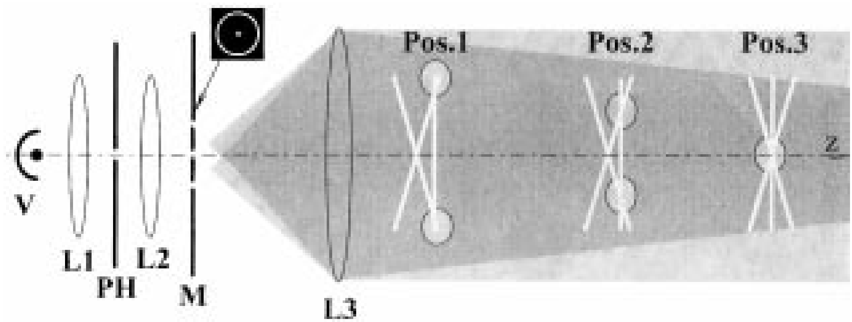

Fig. 9. Scheme of the experiment by Saari *et al.*, who announced (PRL of 24 Nov. 1997) the production in optics of the beams depicted in Fig. 8: In this figure one can see what shown by the experiment, i.e., that the Superluminal "X-shaped" waves run after and catch up with the plane waves (the latter regularly travelling with speed c). An analogous experiment has been performed with microwaves at Florence by Mugnai, Ranfagni and Ruggeri (PRL of 22 May 2000).

(paper appeared in the Phys. Rev. Lett. of May 22, 2000, which the national and international press referred to). Further experimental activity is in progress, for instance, at Pirelli Cables, in Milan (by adopting as a source a pulsed laser) and at the FEEC of Unicamp, Campinas, S.P.; while in the theoretical sector the activity is even more intense, in order to build up—for example—new analogous solutions with finite total energy or more suitable for high frequencies, on one hand, and localized solutions Superluminally propagating even along a normal waveguide,[40] on the other hand.

Let us eventually touch the problem of producing an X-shaped Superluminal wave like the one in Fig. 7, but truncated—of course—in space and in time (by the use of a finite, *dynamic* antenna, radiating for a finite time): in such a situation, the wave will keep its localization and Superluminality only along a certain "depth of field," decaying abruptly afterwards.[35, 37] We can become convinced about the possibility of realizing it, by imaging the simple ideal case of a negligibly sized Superluminal source S endowed with speed $V > c$ in vacuum and emitting electromagnetic waves W (each one travelling with the invariant speed c). The electromagnetic waves will result to be internally tangent to an enveloping cone C having S as its vertex, and as its axis the propagation line x of the source.[3] This is analogous to what happens for a plane that moves in the air with constant supersonic speed. The waves W interfere negatively inside the cone C, and constructively only on its surface. We can place a plane detector orthogonally to x, and record magnitude and direction of the W waves that hit on it, as (cylindrically symmetric) functions of position, and of time. It will be enough, then, to replace the plane detector with a plane antenna which *emits*—instead of recording—exactly the same (axially symmetric) space-time pattern of waves W, for constructing a cone-shaped electromagnetic wave C that will propagate with the Superluminal speed V (of course, without a source any longer at its vertex): even if each wave W travels with the invariant speed c. For further details, see the first of Refs. 37. Here let us only add that such localized Superluminal beams appear to keep their good properties only as long as they are fed by the waves arriving (with speed c) from the dynamic antenna: Taking account of the time needed for fostering such Superluminal pulses (i.e., for the arrival of the speed-c feeding waves coming from the antenna), one concludes that these localized Superluminal beams are probably unable to transmit *information* faster than c. However, they have *nothing* to do with the illusory "scissors effect," since they certainly carry energy-momentum Superluminally along their field depth (for instance, they can get two detectors at a distance L to click after a time *smaller* than L/c).

As we mentioned above, the existence of all these X-shaped Superluminal (or "Super-sonic") beams seem to constitute at the moment, together, e.g., with the Superluminality of evanescent waves, one of the best confirmations of Extended Relativity. It is curious than one of the first applications of such X-waves (that takes advantage of their propagation without deformation) is in progress in the field of medicine, and precisely of ultrasound scanners.(41) A few years ago only, the hypothesis that "tachyons" could be used to obtain directly 3-dimensional ultrasound scans would have arisen the scepticism of any physicist, this author included.

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