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## SOME INFORMATION ABOUT THE FOUR EXPERIMENTAL SECTORS OF PHYSICS IN WHICH SUPERLUMINAL MOTIONS SEEM TO APPEAR


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# SOME INFORMATION ABOUT THE FOUR EXPERIMENTAL SECTORS OF PHYSICS IN WHICH SUPERLUMINAL MOTIONS SEEM TO APPEAR

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## Introduction

The question of Super-luminal ($V^2 > c^2$) objects or waves [tachyons: a term coined by G.Feinberg] has a long story, starting perhaps with Lucretius' *De Rerum Natura* (cf., e.g., book 4, line 201). Still in pre-relativistic times, let us recall e.g. the papers by A.Sommerfeld (quoted in refs.[1,2]). In relativistic times, our problem started to be tackled again essentially in the fifties and sixties, in particular after the papers by E.C.George Sudarshan et al., and later on by E.Recami, R.Mignani, et al. [who coined the term bradyons for slower-than-light objects, and 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). For references, one can check pages 162-178 in ref.[1], where about 600 citations are listed; pages 285-290 in ref.[3]; pages 592-597 of ref.[4] or pages 295-298 of ref.[5]; as well as the large bibliographies by V.F.Perepelitsa[6] and as the book in ref.[7]. In particular, for the causality problems one can see refs.[1,8] and references therein, while for a model theory for tachyons in two dimensions one can be addressed to refs.[1,9]. The first experiments looking for tachyons were performed by T.Alväger et al.; some citations about the early experimental quest for Superluminal objects may be found e.g. in refs.[1,10].

The subject of tachyons is presently returning after fashion, especially because of the fact that *four* different experimental sectors of physics seem to indicate the existence of Superluminal objects [it is an old use of Mignani and Recami to write Superluminal with a capital S]. We wish to put forth in the following some information (mainly, some bibliography) about the experimental results obtained in each one of those 4 different physics sectors.

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**FIRST - Negative Mass-Square Neutrinos**

Since 1971 it was known that the experimental square-mass of MUON-neutrinos resulted to be negative (with low statistical significance, but systematically). If confirmed, this would correspond (within the ordinary, naïve approach to relativistic particles) to an imaginary mass and therefore to a Superluminal speed; in a non-naïve approach[1], i.e. within a Special Relativity theory extended to include tachyons [Extended Relativity (ER)], the free tachyon "dispersion relation" becomes $E^2 - \boldsymbol{p}^2 = -m_o^2$. See e.g. E.V.Shrum & K.O.H.Ziock: Phys. Lett. B37 (1971) 114; D.C. Lu et al.: Phys. Rev. Lett. 45 (1980) 1066; G.Backenstoss et al.: Phys. Lett. B43 (1973) 539; H.B.Anderhub et al.: Phys. Lett. B114 (1982) 76; R. Abela et al.: Phys. Lett. B146 (1984) 431; B.Jeckelmann et al.: Phys. Rev. Lett. 56 (1986) 1444.

From the theoretical point of view about the above point, see E.Giannetto, G.D. Maccarrone, R.Mignani & E.Recami: Phys. Lett. B178 (1986) 115-120, and references therein; see also E.Recami: "Classical tachyons and possible applications", Rivista Nuovo Cim. 9 (1986), issue no.6, and references therein.

Recent experiments showed that also ELECTRON-neutrinos result to have negative mass-square. See e.g. R.G.H.Robertson et al.: Phys. Rev. Lett. 67 (1991) 957; A.Burrows et al.: Phys. Rev. Lett. 68 (1992) 3834; Ch.Weinheimer et al.: Phys. Lett. B300 (1993) 210; E.Holtzshuh et al.: Phys. Lett. B287 (1992) 381; H.Kawakami et al.: Phys. Lett. B256 (1991) 105, and so on. See also the reviews or comments by M.Baldo Ceolin: "Review of neutrino physics", invited talk at the "XXIII Int. Symp. on Multiparticle Dynamics (Aspen, CO; Sept.1993); E.W.Otten: Nucl. Phys. News 5 (1995) 11.

**SECOND: Galactic "Mini-Quasars", etc.** (Apparent Superluminal expansions observed inside quasars, some galaxies, and –as discovered very recently– in some galactic objects, preliminarily called "mini-quasars")

Since 1971 in many quasars (and even a few galaxies) apparent Superluminal expansions were observed ["Nature", for instance, dedicated to those observations a couple of its covers]. Such seemingly Superluminal expansions were the consequence of the experimentally measured angular separation rates, once it was taken into account the (large) distance of the sources from the Earth. From the experimental point of view, it is enough to quote the book "Superluminal Radio Sources", ed. by J.A.Zensus & S.Unwin (Cambridge Univ.Press; Cambridge, UK, 1987), and references therein.

The distance of those "Superluminal sources", however, it is not well known; or, at

least, the (large) distances usually adopted have been strongly criticized by H.Arp et al., who maintain that quasars are much nearer objects: so that all the above-mentioned data can no longer be easily used to infer (apparent) Superluminal motions. However, very recently, GALACTIC objects have been discovered, in which apparent Superluminal expansions occur; and the distance of galactic objects can be more precisely determined. From the experimental point of view, see in fact the papers by I.F.Mirabel & L.F.Rodriguez. : "A superluminal source in the Galaxy", Nature 371 (1994) 46 [with a Nature's comment, "A galactic speed record", by G.Gisler, at page 18 of the same issue]; and by S.J.Tingay et al. (20 authors): "Relativistic motion in a nearby bright X-ray source", Nature 374 (1995) 141.

From the theoretical point of view, both for quasars and "mini-quasars", see E.Recami, A.Castellino, G.D.Maccarrone & M.Rodonò: "Considerations about the apparent Superluminal expansions observed in astrophysics", Nuovo Cimento B93 (1986) 119. See also E.Recami: ref.[1], and cf. R.Mignani & E.Recami: Gen. Relat. Grav. 5 (1974) 615. In particular, let us recall that a *single* Superluminal source of light would be observed: (i) initially, in the phase of "optic boom" (analogous to the acoustic "boom" by an aircraft that travels with constant super-sonic speed) as an intense, suddenly-appearing source; (ii) later on, as a source which splits into TWO objects receding one from the other with velocity $v > 2c$ [see the quoted refs.].

**THIRD: Tunnelling photons = Evanescent waves**

It is the sector that most attracted the attention of the scientific and non-scientific *press*: it started "Scientific American" in Aug. 1993 followed by "Nature" (comment "Light faster than light?" by R.Landauer) on Oct. 21, 1993; then, "New Scientist" (editorial "Faster than Einstein" at p.3, plus article by J.Brown at p.26) in April 1995; till "Newsweek" (19 June 1995, article by S.Begley, p.44) and all the newspapers and magazines of the world (in Brazil, e.g., the "Folha de São Paulo", etc.; in Italy, e.g., "La Stampa", "La Repubblica", "Focus", "Panorama", etc.).

Evanescent waves were predicted [cf., e.g., page 158 in ref.[1], and references therein] to be faster-than-light. Even more, they consists in tunnelling photons: and it was known since long [cf. V.S.Olkhovsky & E.Recami: Phys. Reports 214 (1992) 339, and refs. therein] that tunnelling particles (wave packets) can move with Superluminal group velocities inside the barrier; therefore, due to the theoretical analogies between tunnelling particles (e.g., electrons) and tunnelling photons, it was expected since long that evanescent waves could be Superluminal. This has been actually verified in a series of already famous experiments.

The first experiments have been performed at Cologne, Germany, by Guenter Nimtz et

al., and published in 1992. Let us quote: A.Enders & G.Nimtz: J. de Physique-I 2 (1992) 1693; 3 (1993) 1089; Phys. Rev. B47 (1993) 9605; Phys. Rev. E48 (1993) 632; G.Nimtz, A.Enders & H.Spieker: J de Physique-I 4 (1994) 1; W.Heitmann & G.Nimtz: Phys. Lett. A196 (1994) 154; G.Nimtz, A.Enders & H.Spieker: "Photonic tunnelling experiments: Superluminal tunnelling", in *Wave and Particle in Light and Matter - Proceedings of the Trani Workshop, Italy, Sept.1992*, ed. by A.van der Merwe & A.Garuccio (Plenum; New York, in press); H.Aichmann and G.Nimtz: "Tunnelling of a FM-Signal: Mozart 40", submitted for pub. These are important experimental papers. Nimtz et al. made also same simulations by computer (on the basis of Maxwell eqs.), well reproducing the related experimental results, when existing: cf. H.M.Brodowsky, W.Heitmann & G.Nimtz, "Comparison of experimental microwave tunnelling data with calculations based on Maxwell's equations", in press.

Other famous experiments have been performed at Berkeley; their results appeared in 1993 in A.M.Steinberg, P.G.Kwiat & R.Y.Chiao: Phys. Rev. Lett. 71 (1993) 708, and, simultaneously, in R.Y.Chiao, P.G.Kwiat & A.M.Steinberger: Scientific American 269 (1993), issue no.2, p.38. Cf. also A.M.Steinberg et al.: Phys. Rev. A48 (1993) R867; E.L.Bolda et al.: Phys. Rev. A48 (1993) 3890.

Further experiments on Superluminal evanescent waves have been done at Florence: see e.g. A.Ranfagni, P.Fabeni, G.P.Pazzi and D.Mugnai: Phys. Rev. E48 (1993) 1453. A last experiment (as far as we know) took place at Vienna: Ch.Spielmann, R.Szipocs, A.Stingl and F.Krausz: Phys. Rev. Lett. 73 (1994) 2308.

From the *theoretical* point of view, see the above-quoted V.S.Olkhovsky & E.Recami: Phys. Reports 214 (1992) 339, and refs. therein; and V.S.Olkhovsky, E.Recami, F.Raciti & A.K.Zaichenko: J. de Physique-I 5 (1995) 1351-1365. See also pages 158 and 116-117 of the already quoted ref.[1], and D.Mugnai et al.: Phys. Lett. A209 (1995) 227-234.

## FOURTH: Superluminal motions in Electrical and Acoustical Engineering – The "X-shaped waves"

This fourth sector is perhaps the most important one.

Starting with the pioneering work by H.Bateman, it became slowly known that all the relativistic homogeneous wave equations —in a general sense: scalar, electromagnetic and spinor— admit solutions with subluminal ($v < c$) group velocities[11]. More recently, also Superluminal ($V > c$) solutions have been constructed for those homogeneous wave equations, in refs.[12] and quite independently in refs.[13]: in some cases just by applying a Superluminal Lorentz "transformation"[1,14]. It has been also shown that the same happens even in the case of acoustic waves, with the presence in this case of "sub-sonic" and "Super-sonic" solutions[15]; so that one can expect they to exist, e.g., also for seismic wave equations. More intriguingly, we may expect the same to be true in the case of

gravitational waves too.

It is interesting to remark that the Super-sonic and Super-luminal solutions forwarded in refs.[16] —some of them experimentally already realized[16]— appear to be (generally speaking) X-shaped, just as predicted in 1982 by A.O.Barut, G.D.Maccarrone & E.Recami in ref.[17]; so that now they have been preliminarily called "X-waves".

On this regard, from the theoretical point of view, let us quote pages 116-117, and pages 59 (fig.19) and 141 (fig.42), in E.Recami: ref.[1]. Even more, see the above-mentioned A.O.Barut, G.D.Maccarrone & E.Recami: "On the shape of tachyons", Nuovo Cimento A71 (1982) 509-533; where "X-shaped waves" are predicted and discussed. From the quoted papers it is also clear why the X-shaped waves keeps their form while travelling (non-diffractive waves): a property that already resulted of high interest for electrical and acoustical engineering. New experimental work is going on (e.g., by H.F.Hernandez et al. at the F.E.E.C. of Unicamp).

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