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SUB- AND SUPERLUMINAL VELOCITIES IN SPACE WITH VECTOR TIME

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Is the hypothesis of superluminal speeds at variance with the experiment?

Let us consider the Lorentz transformation of a time interval Δt between two events separated by a space interval; Δx:

$$\Delta t' = (\Delta t - \Delta x\dot{u}/c^2)\gamma = \Delta t(1 - uv/c^2)\gamma < 0 \tag{1}$$

if the product of the moving body speed $V = \Delta x/\Delta t$ and the relative velocity of the reference frame u exceeds the unity: , $uv/c^2 > 1$ (the factor $\gamma = \sqrt{(1 - u^2/c^2)}$ and u can be smaller than c). Such a possibility to turn back the time flow by considering the sequence of events from a moving body leads to the difficulties of two types:

- Acausal phenomena contradicting our ideas on the time order of events appear when, for example, a bullet flies not from a hunter's gun to a target-crow but, on the contrary, the crow emits the bullet and the latter gets precisely into the gun barrel.
- Using superluminal signals one can change the Past. In particular, an effect can destroy its cause: e. g. by a faster-then-light signal we can prevent our birth or to kill oneself in a cradle and than the fact of our existence becomes an unexplicable puzzle.

At present there are two main viewpoints on this difficulty. Some authors (e.g. E. Recami, see his review [1]) consider the phenomena with time turnings as really observable but seeming, illusory events where one can always find a genuine cause, just as we do when the roaring sound runs down a flown supersonic jet. However, such way one cannot explain or forbid the suicide in the cradle since it does not seem but can be done really by a faster-then-light ray.

Another point of view shared by the majority of physicists (see the review [2] where more detail bibliography can be found) considers the difficulties as a prof of an obvious contradictoriness of the superluminal hypothesis and generally rejects the existence of superluminal signals carrying the energy and information. Though we also shared the latter opinion, it seems, nevertheless, insufficiently grounded. Indeed, as it was mentioned above, the time turning occurs, even if events are observed from a subluminal reference frame (e.g., from a customary bicycle!), the existence of bodies with $v > c$ assumes the possibility to use them as superluminal reference frames (i.e with $u > c$) consistent generalization of Lorentz transformation for which in four-dimensional space-time , as it has been proved in paper [3], is impossible [1]. The set of the equalities (1) is obviously true up to the last relation when it is assumed $uv > 1$. In four-dimensional space-time $\mathbf{x} = (x_1, x_2, x_3, ct)^T$ such an assumption, as it was shown in paper [3], turns at once the Lorentz group into an equivalent group of linear transformations $x'_\mu = \Lambda(v)_{\mu\nu}x^\nu$ $Det\Lambda = \pm 1$. A successive use of several sub- and superluminal Lorentz transformations results in some symmetries which do not exist un our world. — in a space dilation $\mathbf{x} \to \lambda\mathbf{x}$, in the time inversion $t \to -t$ etc. It means that the relations (1) at $uv > 1$ are notreliable and the conclusions based on them are doubtful.

True, no superluminal phenomena carrying energy have been observed yet. However, these results are relate to the region of the phenomena described by the known physics and one cannot exclude the existence of some inaccessible today regions of events, outside the known ones, with principally new laws where information can be carried with a faster-then-light speed without any violation of relativity and causality. One must also take into account that superluminal objects appear in various string models, in theories with high-order Lagrangians, by supersymmetrical

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[1] One should note that such a difficulty is present in any theory with non-local interaction. For example, in a field theory with form-factor where space- and time-like points get into the interaction term $\int \phi(x_1)\phi(x_2)A(x_3)d^4x_1x_2x_3$ quite equivalently the reference frames tied to these points can be both types —a sub- and a superluminal one .A formal relativistic invariant form of equations by himself doesn't yet provide the complete Lorentz invariance of the theory.

generalizations etc., and one may suspect that this fact is not only a disappointing theoretical failing but is a reflection of some reality [2].

To answer the question about existence of the faster-then-light motions one must go into regions of unstudied phenomena where one can develop a consistent theory of relativity with velocities $v > c$.

Multitime velocity

In this respect a interesting possibilities are provided by the theory of multidimensional time. Taking into account the becoming apparent tendency of a symmetrization of physical theory with respect to the space and time co-ordinates, we assume that our world has the six-dimensional space-time structure

$$\hat{\mathbf{x}} = (\mathbf{x}, \hat{t})^T = (x_1, x_2, x_3, t_1, t_2, t_3)^T \tag{2}$$

(In what follows the tree-dimensional vectors in x- and t-subspaces will be denoted, respectively, by bold symbols and by a "hat", six-dimensional vectors will be marked, accordingly, by bold symbols with a hat).

The six-dimensional velocity vector is defined now as

$$\hat{\mathbf{v}} = \frac{\mathbf{d}\hat{\mathbf{x}}}{\mathbf{d}\hat{\tau}} = (\hat{\tau}\hat{\nabla})\hat{\mathbf{x}} = \tau_{\mathbf{i}}\frac{\partial\hat{\mathbf{x}}}{\partial \mathbf{t_i}} = \frac{\mathbf{d}\hat{\mathbf{x}}}{\mathbf{dt}} = (\mathbf{v}, \mathbf{c}\hat{\tau})^{\mathbf{T}}, \tag{3}$$

where $\hat{\nabla} = (\partial/\partial t_1, \partial/\partial t_2, \partial/\partial t_3)$ and the unity vector $\hat{\tau} = d\hat{t}/dt$ with proper time t along the considered time trajectory.

If we notice that a differential of the squared length in the six-dimensional space-time

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[2] In paper [4] the superluminal solutions for Maxwell equations were discovered. Such solutions can be interpreted as ones describing "phase phenomena" which do not carry any information, like a catch of sunbeams in a mirror. If we suppose that these solutions describe a transportation of energy, then superluminal co-ordinate frames can be tied with bundles of such rays and the mentioned above difficulties appear. The discovered solutions can describe information caring signals in a space-time with the dimensionalities $N > 3 \bigoplus 1$

$$ds^2 = c^2(d\hat{t})^2 - (d\mathbf{x})^2 = c^2(dt)^2\,[1 - c^{-2}(d\mathbf{x}/dt)^2] = dt^2c^2/\gamma^2, \tag{4}$$

where $\gamma = [1 - (v/c)^2]^{1/2}$, then the velocity vector can be written in the covariant form

$$\hat{\mathbf{u}} = d\hat{\mathbf{x}}/ds = (\gamma/c)d\hat{\mathbf{x}}/dt = \gamma\hat{\mathbf{v}}/c. \tag{5}$$

As in the customary onetime case the scalar product

$$\hat{\mathbf{u}}^2 = \gamma^2\hat{\mathbf{v}}^2/c^2 = \gamma^2(c^2\hat{\tau}^2 - \mathbf{v}^2/c^2) = 1 \tag{6}$$

and a light wave front always has a spherical form:

$$\sum_i(\Delta x_i^2 - c^2\Delta t_i^2) = \Delta t^2\sum_i(v_i^2 - c^2\tau_i^2) = \Delta t^2(v^2 - c^2) = 0, \tag{7}$$

i. e. in any direction of the x-subspace the body speed does not exceed the light velocity. Nevertheless, in multitime world we can observe faster-then-light speeds of bodies.

Superluminal velocities

It is very important to emphasize that the body speed $\mathbf{v}$ is defined with respect to an increment Δt along the body time trajectory $\hat{t}$. If it is unknown and an observer uses instead of Δt his own proper time $\Delta t_p = \Delta t\cos\theta$ where θ is the angle between the body and observer's time trajectories, then the "speed" $\mathbf{v_p} \equiv \Delta\mathbf{x}/\Delta t_p = \mathbf{v}/\cos\theta$ defined in this way may turn out to be larger than the light velocity. In this case the considered body behaves, from the observer's viewpoint, like a tachyon. For example, if $\theta \simeq \pi/2$, it passes any finite distance practically instantaneously and "grows old" straight away. However, as it was shown in the papers [5]-[7], Lorentz transformations depend on $\mathbf{v}$ but not on $\mathbf{v_p}$, therefore, in the multitemporal world no accausal effects can be observed by transformations to moving reference frames in contrary to the true tachyons which transfer information in the new frame, as it is judged by the observer, backwards in time (if the relations (1) are correct [2]).

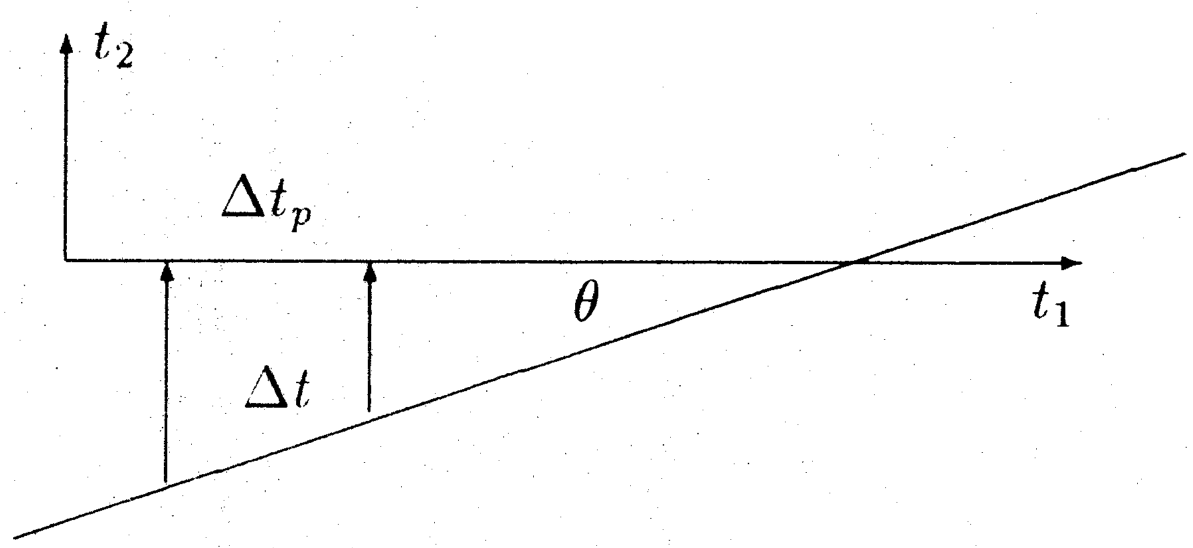

Fig.1. *An observer moves along the axis t_1. From his viewpoint the speed of the body can surpass the light velocity.*

Superluminal velocities can also be observed in a more general case when the observer's time trajectory is, like a body, inclined with respect to the axis t_1.

At the same time one should take into account that, as the onetime world with parallel trajectories $\hat{r}(t)$ is a particular case of the multitime world, the proved in paper cite1 forbidding theorem on superluminal generalization of Lorentz transformations is also valid.

A discovery of any superluminal motions in experiment would be a serious indication on multidimensionality of world time. As it is known, faster-than-light objects are indeed observed by astronomers. Though up to now they succeeded in interpreting suchphenomena within the limits of onetime notions as optical illusions(see, e.g. [8, 9] where there are more detailed references), one can not exclude that among such "superluminal objects" there are bodies moving along the distinct time directions.We need more experimental information to identify such a possibility.

However, one must bear in mind that creation of an objects moving along time trajectories different from ours is possible only in exceptional cases when the known energy conservation law is vanished — in some cosmic cataclismuses where new types of gravitation and electromagnetic waves can be produced or in very small space and time intervals (see Fig. 2). [10]- [12] [3].

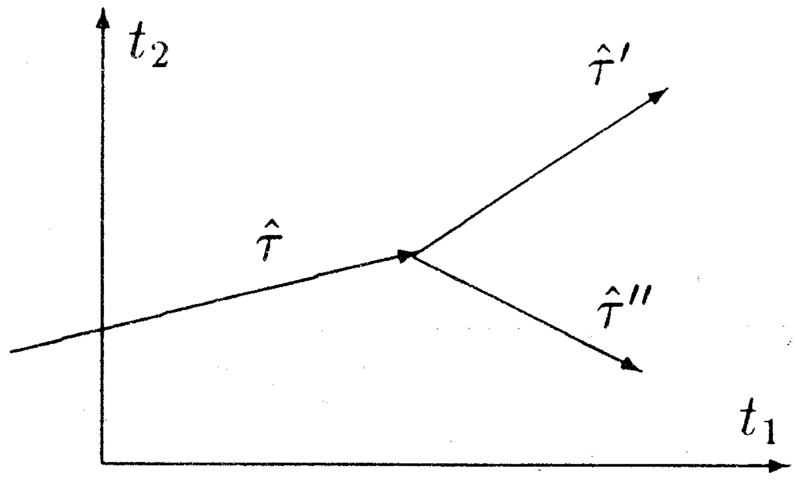

Fig. 2. *The creation of a component with the energy* $\hat{E}' = \hat{\tau}' E \geq 0$ *is accompanied, without fail, by the creation of a compensating, moving back in time component with the energy* $\hat{E}'' = \hat{\tau}'' E \leq 0$. *(The energy vector is parallel to the time vector:* $\hat{E} = E\hat{\tau}$*).*

Now let us consider interesting peculiarities of the signal spreading in the multitime world which can be used for an experimental determination of the time dimensionality.

Detection of signals

As a simple example illustrating the peculiarities of the detection of signals in a multitime world, Cole and Starr considered a case when owing

[3]In paper[10] it was proposed to detect gravitation waves evolving along time trajectories different from the our observing the correlations of gravitation detector oscillations in two perpendicular directions. Another possibility to discover a motion along a distinct time trajectories can be based on the fact that the new components of the electromagnetic field created in the multitime world have a longitudinal polarization and can be detected when the transversal components are excluded by any absorber.

to the force of some circumstances a splitting of time trajectories of a luminous body motionless in x-subspace and the observer occurs suddenly (Fig.3) [13]. In the considered by these authors variant of theory symmetrical with respect to every possible time directions, the light source losing little by little its lustre (displacing into infrared region) remains visible some time after the moment of the splitting. However, if the time-reverse motions are forbidden (as it is indeed observed in Nature), we come to quite a different conclusion. Particularly, if the observer's time trajectory coincides with the axis t_1, the luminous body gets invisible in a moment because it occurs at once in the future with respect to the detector. The body can remain visible for some time after the splitting only if the observer's trajectory has some inclination with respect to the t_1 axis.

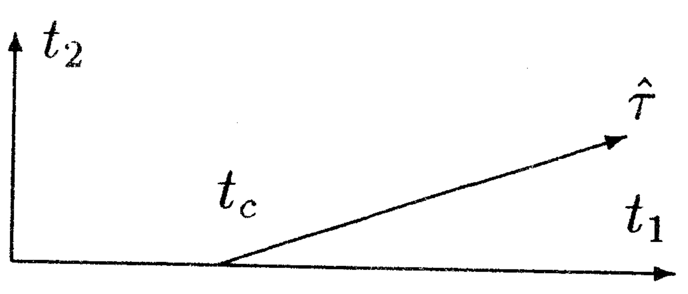

Fig.3. *At a moment t_o a splitting of time trajectories of an observer and a luminous body $\hat{\tau}$ occurs. After that ($t_1 > t_o$) the body gets invisible.*

One can see from Fig.4 where a more complicated case is considered that the duration of observable luminescence when the emitted light spreads in the plane (t_1, t_2) from the past to the future

$$T \equiv (t_f - t_c) = (t_f - t_p) - R/c =$$

$$\frac{R}{c}\left(\frac{\sin(\varphi+\theta)}{\sin\varphi} - 1\right) \qquad (8)$$

Here t_c is the time of the splitting, t_p is the observer's proper time when the light signal trajectory becomes parallel to the axis t_1. At $t > t_f$ the time light signal propagates backward in time t_2. R is a constant distance between the light source and the detector and φ is the angle between $\hat{t}$ and $\hat{\tau}$. By θ the inclination of observer's trajectory with respect to the axis t_1 is denoted.

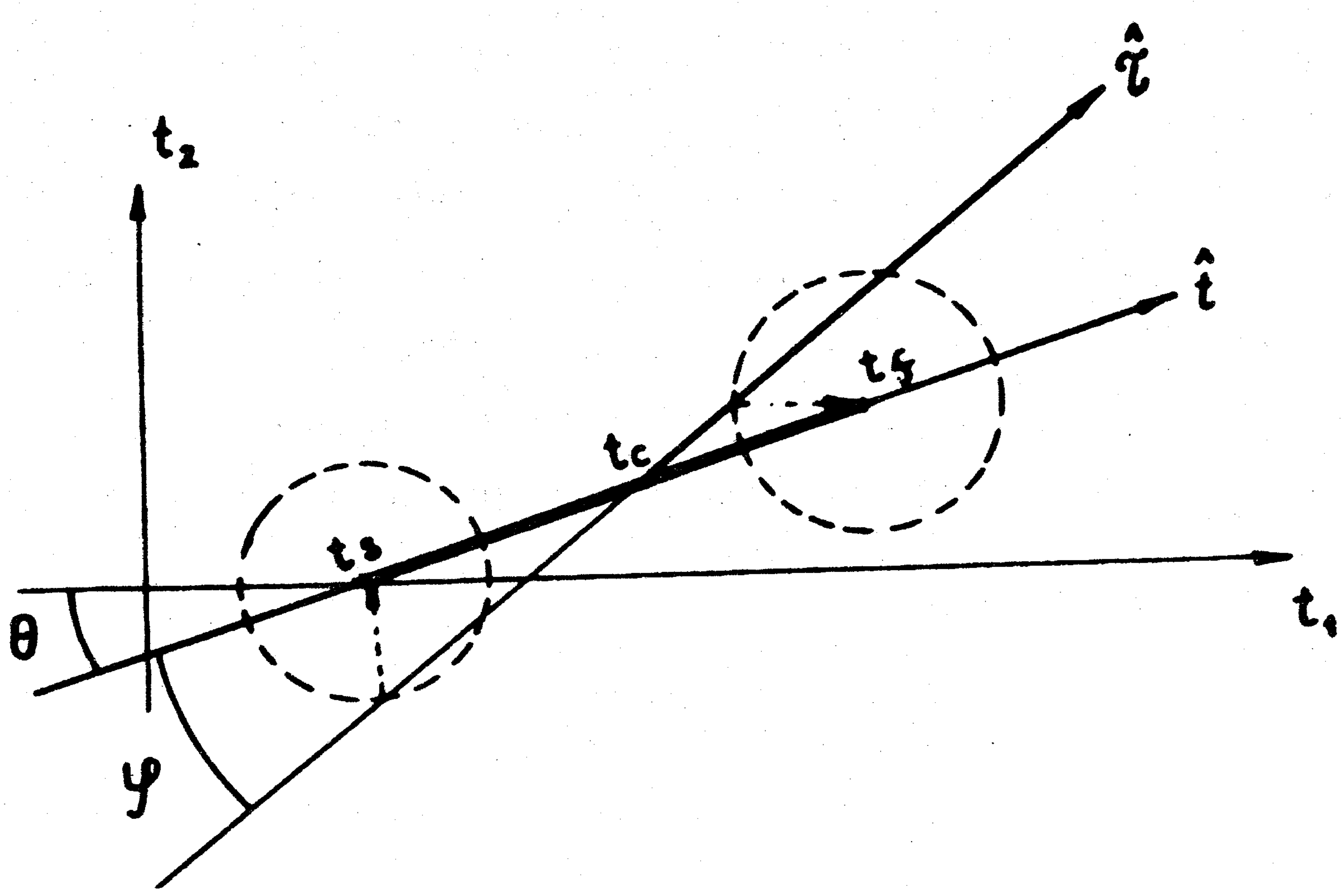

Fig. 4. *At an observer's proper time t_c the luminous body time trajectory $\hat{\tau}$ is splitted off from the observer's trajectory $\hat{t}$. The luminescence is seen in the interval $t_s \div t_f$. Light spheres $(\hat{t}-\hat{\tau})^2 = (R/c)^2$ from which at different times t the observer can receive signals are dotted. The dotted lines with arrow show the trajectories of the first and last visible signals.*

If the time trajectory of a luminous body *intersects* the observer's trajectory (at the moment $t = t_c$, see Fig. 4), the detector holds fixed the luminescence in an interval from t_s when it fixes the ray emitted at right angle to the axis t_1 up to the moment of the last visible signal arrival t_f. For $t < t_s$ the body is too remote in the past and the connection to it is possible only with the help of subluminal signals ($v < c$). The rays emitted at $t > t_f$ can not be observed by vertue of the causality principle. So, the duration of the visible luminescence expressed throughout the observer's proper time

$$T \equiv t_f - t_s = (t_f - t_c) + (t_c - t_s) =$$

$$\frac{R}{c}\frac{\sin(\varphi + \theta)}{\sin\varphi}[1 + \cot(\varphi + \theta)] \quad (9)$$

As in the model considered by Cole and Starr [13, 14] the value of T is significant only for remote cosmic objects. For example, if $R = 1$ m and $\varphi = \theta = 1', 1^o, 40^o$, it is equal, respectively, to $2.10^{-5}, 4.10^{-7}, 10^{-8}$ c. In a multitime world a great number of invisible time displaced bodies around any observer can be present. In this respect such a world looks like a hypothetical world of tachyon theories where there are also plenty of nonabsorbable objects [15]. One can think at an intersection of t-trajectories of the bodies between which a space distance is smaller than their dimensions must result in dramatic body destruction. As such phenomena are not observed in a surrounding us part of universe, it proves that the time flow is single-directed in this region. A duration of the visible luminescence of *a moving* in x-subspace light source depends on a value and a direction of its velocity, however qualitatively the picture remains the same as in the above considered static case. Particularly, if the observer's t-trajectory coincides with axis t_1 and the light source moves in x-subspace with zero impact parameter (a head-in-head collision), then the luminescence becomes visible from a moment

$$t_s = \frac{R_s}{c}\tan\varphi = \left(\frac{R_c}{c} + \beta t_s\right)\tan\varphi, \quad (10)$$

where $R_s = R(t_s)$ is the distance of the luminous body from the detector at the moment t_s, R_c is the respective distance at the moment when their t-trajectories intersect $(t = 0)$, φ is the angle between these trajectories (Fig. 5A), $\beta = v/c$ is the relative velocity of the luminous body and the observer. Solving this equation we obtain

$$t_s = \frac{R_c/c}{\tan\varphi - \beta}. \qquad (11)$$

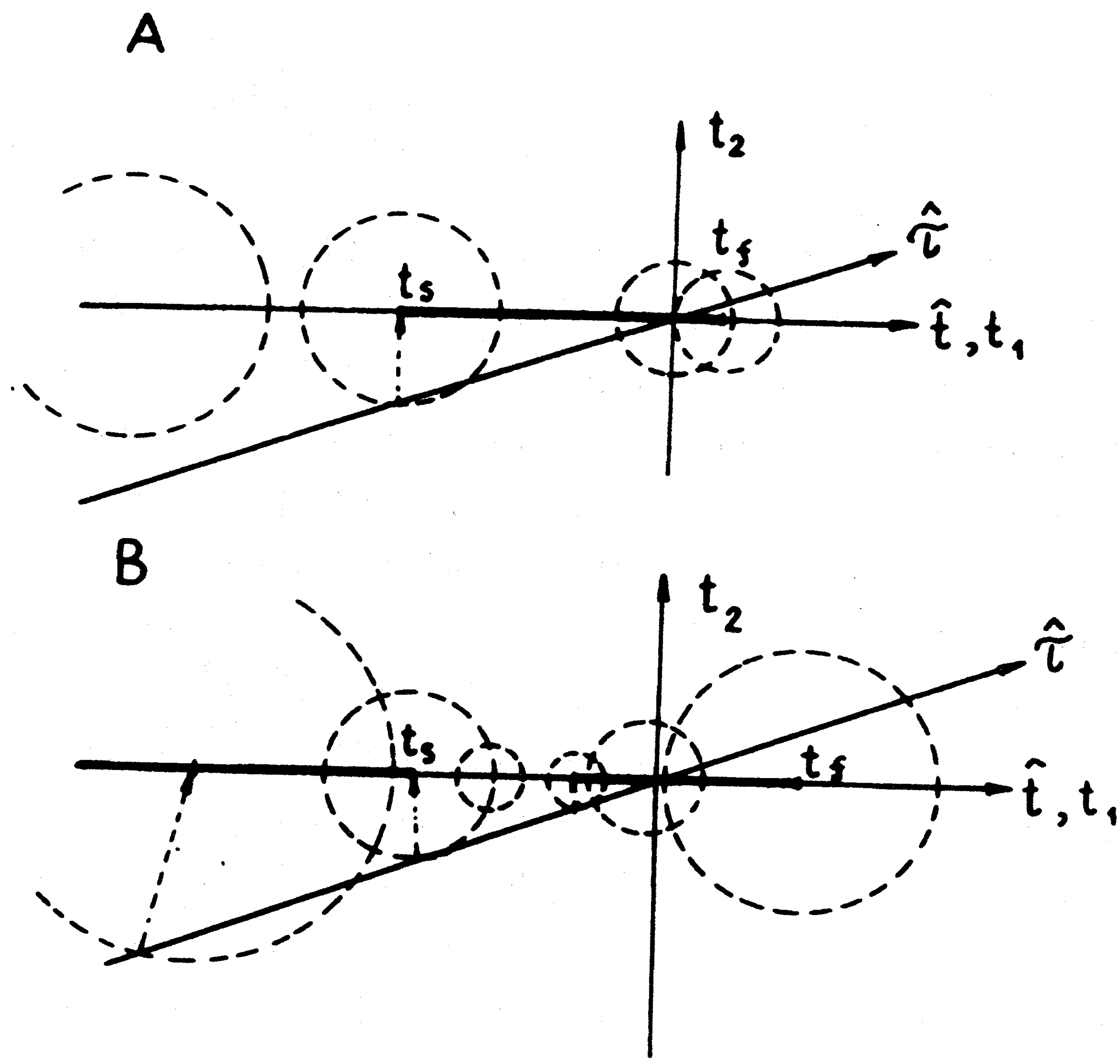

Fig. 5. *The bold tracks of the axis t_1 are the intervals of visible luminescence of a moving light source. The moment of time trajectories intersection is chosen as $t = 0$. The observer's light spheres are dotted. In case A the luminous body with velocity $\beta < \tan\varphi$ comes at time $t = 0$ near to the observer. In case B the luminous body with large velocity $\beta > \tan\varphi$ moves at $t = 0$ from the observer.*

If at $t = 0$, the source and the detector draw together and the velocity β is small ($\beta < \tan\varphi$, Fig.2A), then the luminescence is seen in an interval from t_s up to $t_f = R_c/c$:

$$T = \frac{R_c}{c}[1 + 1/(\tan\varphi + \beta)]. \tag{12}$$

By increasing the velocity ($\beta \geq \tan\varphi$) the time interval stretches over all the left half-axis from $t_s = -\infty$ up to t_f. In the case when at the moment $t = 0$ the light source moves off from the detector and its velocity $\beta < \tan\varphi$ the luminescence is observed, as before, in the interval from t_s up to t_f. However, by $\beta \geq \tan\varphi$ (Fig. 5B) one more interval of the visible luminescence beginning at $t_s = -\infty$ springs up.

The asymmetry of the cases of approaching and moving off light source is stipulated by the detector asymmetry with respect to signals from the past and the future.

Conclusion

In the limits of the usually used superluminal generalizations of Lorentz transformations the hypothesis of faster-then-light velocities brings inadmissible paradoxes. However, this conclusion is doubtful since all the used generalizations are contradictory, and we cannot be fully confident that the basic relations (1) are correct. One cannot exclude that cuts of the reality exist where events developing with faster-then-light velocities and carrying the energy can be observed. Is this statement right or wrong — it is now the question for experiment. The theories are purposed, e.g. multitime generalizations, which permit the superlight processes without any violation of causality and relativity.

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Барашенков В.С., Юрьев М.З. E2-2000-1
До- и сверхсветовые скорости
в пространстве с векторным временем

В рамках известной релятивистской теории гипотеза сверхсветовых скоростей позволяет воздействовать на прошлое, что приводит к акузальным парадоксам. Мы хотели бы подчеркнуть, что этот вывод основан на противоречивом продолжении известных лоренцевских преобразований за световой барьер. Поскольку никаких других запретов для переносящих энергию и информацию сверхсветовых сигналов сегодня не имеется, ответ на вопрос, существуют такие сигналы или нет, может дать лишь эксперимент или какая-то более общая теория. В качестве таковой рассматривается теория с векторным временем, допускающая некоторые сверхсветовые явления, не противоречащие принципам относительности и причинности. Распространение сигналов во многовременном мире имеет характерные особенности, которые могут быть использованы для экспериментального определения размерности нашего времени.

Работа выполнена в Лаборатории вычислительной техники и автоматизации ОИЯИ.

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Barashenkov V.S., Yuriev M.Z. E2-2000-1
Sub- and Superluminal Velocities in Space with Vector Time

Within the bounds of the known relativistic theory the hypothesis of superluminal velosities allows one to influence the Past what leads to acausal paradoxes. We should like to stress, however, that this conclusion is based on the contradictory continuation of the customary Lorentz transformations after the light barrier. Since at present no other prohibitions for faster-than-light signals carrying the energy and information are unknown, the answer on the question does exist such signals or not cannot be obtained only from an experiment or from a more general theory. As such a generalization of a theory with vector time is considered which allows one some superluminal phenomena compatible with the principles of relativity and causality. Spreading of signals in the multitime world is characterized by some peculiarities which can be used for an experimental determination of the time dimensionality of our world.

The investigation has been performed at the Laboratory of Computing Techniques and Automation, JINR.

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