Are Neutrinos Superluminal?

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Abstract

OPERA collaboration in CERN has reported that the neutrinos travelling from CERN to Gran Sasso in Italy move with a super-luminal speed. There exists also earlier evidence for the super-luminality of neutrinos: for instance, the neutrinos from SN1987A arrived for few hours earlier than photons. The standard model based on tachyonic neutrinos is formally possible but breaks causality and is unable to explain all results. TGD based explanation relies on sub-manifold geometry replacing abstract manifold geometry as the space-time geometry. The notion of many-sheeted space-time predicts this kind of effects plus many other effects for which evidence exists as various anomalies which have not taken seriously by the main stream theorists. In this article the TGD based model is discussed in some detail.

1 Introduction

The newest particle physics rumour has been that the CERN OPERA team working in Gran Sasso, Italy has reported 6.1 sigma evidence that neutrinos move with a super-luminal speed. The total travel time is measured in milliseconds and the deviation from the speed of the light is nanoseconds meaning $\Delta c/c \simeq 10^{-6}$ which is roughly 10^3 times larger than the uncertainty 4.5×10^{-9} in the measured value of the speed of light. If the result is true it means a revolution in the fundamental physics. There is now an article by OPERA collaboration [7] in arXiv so that superluminal neutrinos are not a rumour anymore. Even the finnish tabloid "Iltalehti" reacted to the news and this is really something unheard! Maybe the finding could even stimulate colloquium in physics department of Helsinki University!

The superluminal speed of neutrino has stimulated intense email debates and blog discussions. The reactions to the potential discovery depend on whether the person can imagine some explanation for the finding or not. In the latter case the reaction is denial: most physics bloggers have chosen this option for understandable reasons. What else could they do? Personally I cannot take tachyonic neutrinos seriously but I would not however choose the easy option and argue that the result is due to a bad experimentation as Lubos and Jester do. The six sigma statistics does not leave much room for objections but there could of course be some very delicate systematical error involved. Lubos wrote quite an interesting piece about possible errors of this kind and classified the possible errors to timing errors either at CERN or Italy or to errors in distance measurement.

2 Basic data

The neutrinos used are highly relativistic having average energy 17 GeV much larger than the mass scale of neutrinos of order .1 eV. The distance between CERN and Gran Sasso is roughly 750 km, which corresponds to the time of travel equal to $T = 2.4$ milliseconds. The nasty neutrinos arrived to Gran Sasso $\Delta T = 60.7 \pm 6.9$ (statistical) ± 7.4 (systematic) ns before they should have done so. This time corresponds to a distance $\Delta L = 18$ m. From this is is clear that the distance and timing measurements must be extremely accurate. The claimed distance precision is 20 cm [7].

Experimentalists tell that they have searched for al possible systematic errors that they are able to imagine. The relative deviation of neutrino speed from the speed of light is

$$\frac{c-v)}{v} = (5.1 \pm 2.9) \times 10^{-5} \ ,$$

which is much larger than the uncertainty related to the value of the speed of light. The effect does not depend on neutrino energy. 6.1 sigma result is in question so that it can be a statistical fluctuation with probability of 10^{-9} in the case that there is no systematic error.

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The result is not the first of this kind and the often proposed interpretation is that neutrinos behave like tachyons. The following is the abstract [8] of the article giving a summary about the earlier evidence that neutrinos can move faster than the speed of light.

From a mathematical point of view velocities can be larger than c. It has been shown that Lorentz transformations are easily extended in Minkowski space to address velocities beyond the speed of light. Energy and momentum conservation fixes the relation between masses and velocities larger than c, leading to the possible observation of negative mass squared particles from a standard reference frame. Current data on neutrino mass squared yield negative values, making neutrinos as possible candidates for having speed larger than c. In this paper, an original analysis of the SN1987A supernova data is proposed. It is shown that all the data measured in '87 by all the experiments are consistent with the quantistic description of neutrinos as combination of superluminal mass eigenstates. The well known enigma on the arrival times of the neutrino bursts detected at LSD, several hours earlier than at IMB, K2 and Baksan, is explained naturally. It is concluded that experimental evidence for superluminal neutrinos was recorded since the SN1987A explosion, and that data are quantitatively consistent with the introduction of tachyons in Einstein's equation.

3 TGD inspired model

This kind of effect is actually one of the basic predictions of TGD reflecting the differences between kinematics of relativities based on a view about space-time as abstract manifold and TGD in which one has sub-manifold gravitation. and emerged for more than 20 years ago. Also several Hubble constants are predicted and explanation for why the distance between Earth and Moon seems to increasing as an apparent phenomenon emerges. There are many other strange phenomena which find an explanation [5, 4, 3].

It is sub-manifold geometry which allows to fuse the good aspects of both special relativity (the existence of well-defined conserved quantities due to the isometries of imbedding space) and general relativity (geometrization of gravitation in terms of the induced metric). As an additional bonus one obtains a geometrization of the electro-weak and color interactions and of standard model quantum numbers. The choice of the imbedding space is unique. The new element is the generalization of the notion of space-time: space-time identified as a four-surface has shape as seen from the perspective of the imbedding space $M^4 \times CP_2$. The study of field equations leads among other things to the notion of many-sheeted space-time.

For many-sheeted space-time light velocity is assigned to light-like geodesic of space-time sheet rather than light-like geodesics of imbedding space $M^4 \times CP_2$. The effective velocity determined from time to travel from point A to B along different space time sheets is different and therefore also the signal velocity determined in this manner. The light-like geodesics of space-time sheet corresponds in the generic case time-like curves of the imbedding space so that the light-velocity is reduced from the maximal signal velocity. Space-time sheet is bumpy and wiggled so that the path is longer. Each space-time sheet corresponds to different light velocity as determined from the travel time. The maximal signal velocity is reached only in an ideal situation when the space-time geodesics are geodesics of Minkowski space.

Robertson-Walker cosmology imbedded as 4-surface (this is crucial!) in $M^4 \times CP_2$ [4] gives a good estimate for the light velocity in cosmological scales.

1. One can use the relationship

$$\frac{da}{dt} = g_{aa}^{-1/2}$$

   relating the curvature radius a of RW cosmology space (equal to M^4 light-cone proper time, the light-like boundary of the cone corresponds to the moment of Big Bang) and cosmic time t appearing in Robertson-Walker line element

$$ds^2 = dt^2 - a^2 d\sigma_3^2 \ .$$

2. If one believes that Einstein's equations in long scales, one obtains

$$\frac{8\pi G}{3} \times \rho = \frac{(g_{aa}^{-1} - 1)}{a^2} \quad .$$

One can solve from this equation g_{aa} and therefore get an estimate the cosmological speed of light -call it $c_\#$ as

$$c_\# = (g_{aa})^{1/2} \quad .$$

3. By plugging in the estimates

$$a \simeq t \simeq 13.8 \times Gy \ \ (\text{the actual value is around 10 Gy}) \ ,$$

$$\rho \simeq \frac{5 m_p}{m^3} \ \ (\text{5 protons per cubic meter}) \ ,$$

$$G = 6.7 \times 10^{-11} m^3 kg^{-1} s^{-2} \ ,$$

one obtains the estimate

$$c_\# = (g_{aa})^{1/2} \simeq .73 \ ,$$

What can one conclude from the estimate?

1. The result leaves a lot of room to explain various anomalies (problems with determination of Hubble constant, apparent growth of the Moon-Earth distance indicated by the measurement of distance by laser signal,....). The effective velocity can depend on the scale of space-time sheet along which the relativistic particles arrive (and thus on distance distinguishing between OPERA experiment and SN1987A), it can depend on the character of ultra relativistic particle (photon, neutrino, electron,...), etc. The effect is testable by using other relativistic particles -say electrons.

2. The energy independence of the results fits perfectly with the predictions of the model since the neutrinos are relativistic. There can be dependence on length scale: in other words distance scale and this is needed to explain SN1987A -CERN difference in $\Delta c/c$. For SN1987A neutrinos were also relativistic and travelled a distance is L=cT=168,000 light years and the neutrinos arrived about $\Delta T = 2-3$ hours earlier than photons (see this). This gives $\Delta c/c = \Delta T/T \simeq .8 - 1.2 \times 10^{-6}$ which is considerably smaller than for the recent experiment. Hence the tachyonic model fails but scale and particle dependent maximal signal velocity can explain the findings easily.

3. The space-time sheet along which particles propagate would most naturally correspond to a small deformation of a "massless extremal" ("topological light ray" [1]) assignable to the particle in question. Many-sheeted space-time could act like a spectroscope forcing each (free) particle type at its own kind of "massless extremal". The effect is predicted to be present for *any* relativistic particle. A more detailed model requires a model for the propagation of the particles having as basic building bricks wormhole throats at which the induced metric changes its signature from Minkowskian to Euclidian: the Euclidian regions have interpretation in terms of lines of generalized Feynman graphs. The presence of wormhole contact between two space-time sheets implies the presence of two wormhole throats carrying fermionic quantum numbers and the massless extremal is deformed in the regions surrounding the wormhole throat. At this stage I am not able to construct detailed model for deformed MEs carrying photons, neutrinos or some other relativistic particles.

If I were a boss at CERN, I would suggest that the experiment should be carried out for relativistic electrons whose detection would be much easier and for which one could use much shorter scale.

1. Could one use both photon and electron signal simultaneously to eliminate the need to measure precisely the distance between points A and B.

2. Can one imagine using mirrors for photons and relativistic electrons and comparing the times for $A \to B \to A$?

As a matter fact, there is an old result by electric engineer Obolensky [6] that I have mentioned earlier [2], and which states that in circuits signals seem to travel at superluminal speed. The study continues the tradition initiated by Tesla who started the study of what happens when relays are switched on or off in circuits.

1. The experimental arrangement of Obolensky suggest that that part of circuit - the base of the so called Obolensky triangle- behaves as a single coherent quantum unit in the sense that the interaction between the relays defining the ends of the base is instantaneous: the switching of the relay induces simultaneously a signal from both ends of the base.

2. There are electromagnetic signals propagating with velocities c_0 (with values $271 \pm 1.8 \times 10^6$ m/s and $278 \pm 2.2 \times 10^6$ m/s) and $c_1(200.110 \times 10^6$ m/s): these velocities are referred to as Maxwellian velocities and they are below light velocity in vacuum equal to $c = 3 \times 10^8$ m/s. c_0 and c_1 would naturally correspond to light velocities affected by the interaction of light with the charges of the circuit.

3. There is also a signal propagating with a velocity c_2 $((620 \pm 2.7) \times 10^6$ m/s), which is slightly more than twice the light velocity in vacuum. Does the identification $c_2 = c_{max}$, where c_{max} is the maximal signal velocity in $M^4 \times CP_2$, make sense? Could the light velocity c in vacuum correspond to light velocity, which has been reduced from the light velocity $c_{\#} = .73c_{max}$ in cosmic length scales due to the presence of matter to $c_{\#} = .48c_{max}$. Note that this interpretation does not require that electrons propagate with a super-luminal speed.

4. If Obolensky's findings are true and interpreted correctly, simple electric circuits might allow the study of many-sheeted space-time in garage!

If these findings survive they will provide an additional powerful empirical support for the notion of many-sheeted space-time and could be for TGD what Mickelson-Morley was for Special Relativity. It is sad that TGD predictions must still be verified via accidental experimental findings. It would be much easier to do the verification of TGD systematically. In any case, Laws of Nature do not care about science policy, and I dare hope that the mighty powerholders of particle physics are sooner or later forced to accept TGD as the most respectable known candidate for a theory unifying standard model and General Relativity.

References

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