On The OPERA Problem and Its Consequences

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Abstract: Since OPERA is a very carefully designed experiment thus the sobering importance of its result, coupled with decades of some successful tests of special relativity theory (SRT) requires certain adjustment in our usual manner of thinking, and seriously prompts us to consider alternatives which should be consistent with both. To this end, we propose an alternative model as an explanation to the observed neutrino superluminality based on the universality of the well-known rest mass energy formula, $E_0 = mc^2$, and the idea that, at superluminal level, the velocity of a particle with real mass may be simultaneously dependent on its energy ratio ε and the kinematical attainability parameter α. By raising this idea to the status of a hypothesis, we show that not only the OPERA result is very realistic but also is perfectly consistent with supernova SN1987a measurement. Consequently, SRT is not violated by the existence of superluminal particles since it is conceptually, physically and exclusively valid at subluminal level for relativistic velocities. As a direct consequence, the Minkowski space-time and Lorentz transformations are coherently extended to superluminal velocities.

Keywords: OPERA Collaboration, superluminality of μ-neutrinos, SRT, superluminal spatio-temporal transformations

1. Introduction

1.1. Lorentz Reservation about c as Limiting Velocity

We begin this introduction by the statement of Dutch theoretical physicist Hendrick Antoon Lorentz (1853-1928) one of the principal founders of (special) relativity theory. Although he clearly understood Einstein's papers, he did not ever seem to accept their conclusion regarding the velocity of light as upper limit. In his theory, Einstein asserted: "… From this we conclude that in the theory of relativity the velocity c plays the limiting part of a limiting velocity, which can neither be reached nor exceeded by real body."

Lorentz gave a lecture in 1913 wherein he remarked on how rapidly Einstein's theory had been accepted. He said: "… Finally it should be noted that the daring assertion that one can never observe velocities larger than the velocity of light contains a hypothetical restriction of what is accessible to us, a restriction which cannot be accepted without some reservation."

Actually, it seems that the Lorentz reservation is correct, because in the last years, there has been a renewed interest in superluminal velocities, due to some new experimental evidences in different sectors of physics. Those include, *e.g.*, the apparent superluminal expansion of galactic objects, the evidence for superluminal motion/propagation in electric and acoustic engineering, the superluminal tunneling of evanescent waves and photons, and Scharnhorst effect.

1.2. OPERA Collaboration

The more recently OPERA Collaboration reported [1] the experimental evidence of superluminality of μ-neutrinos. Precisely, the data reported by the OPERA/CNGS in 2011 [1], imply for the relative difference of the μ-neutrino velocity with respect to the light speed in vacuum

$$\frac{v-c}{c} = \left[2.48 \ \pm 0.28\,(\text{stat.}) \pm 0.30\,(\text{sys.})\right]\times 10^{-5} \ . \quad (1)$$

a significance of six standard deviations. This should be the most important experimental discovery in the area of fundamental physics. Since OPERA is a very carefully designed experiment hence this discovery may be interpreted as an additional confirmation of the previously observed superluminal neutrinos by MINOS Collaboration in 2007 [2] and the FERMILAB in 1979 [3]. Confronted by such a discovery, some physicists considered this experimental achievement as the end of the world because according to them, if this finding can be verified by other experiments, it would mean Einstein's SRT is wrong! This exaggerated worry shows us that these physicists have completely forgotten an important epistemological principle, which claimed that "any well-established scientific theory should have, sooner or later, its own limit of validity."

The importance of such a principle resides in the dependence of science progress continuity on this limit of validity. For instance, the limit of validity of the Galilean transformation has implied the limit of validity of classical/Newtonian mechanics, both led to the discovery of the Lorentz transformation (LT) and relativistic mechanics, respectively. Thus, the OPERA experimental discovery of the μ-neutrino superluminality should be explained as a tangible evidence of the limit of validity of LT and SRT together. This means the light speed in vacuum, $c = 299792458$m/s, is limiting speed only in the context of SRT not for all the physical theories because LT, which is the core of SRT, becomes meaningless when the relative velocity -of the inertial reference frame(s)- reaches or exceeds the light speed in vacuum, that is when $v \geq c$, Lorentz gamma factor, $\gamma = 1\big/\sqrt{1 - v^2/c^2}$, becomes imaginary or infinite.

1.3. Causality Principle

What amazes us is the false assumption that information traveling faster than c in vacuum represents a violation of causality principle! However, causality simply means that the cause of an event precedes the effect of the event. In this case, *e.g.*, a particle with real mass is emitted before it is absorbed in a detector. If the particle velocity was one million times faster than c the cause would still precede the effect, and causality principle would not be violated since, here, LT should be replaced with the superluminal spatio-temporal transformation because the particle in question was moving in superluminal space-time not in the relativistic Minkowski space-time. Therefore, in superluminal space-time, the superluminal signals do not violate the causality principle but they can shorten the luminal vacuum time span between cause and effect.

2. Energy-kinematical attainability parameter dependence on particle velocity at superluminal level

The spectacular OPERA experimental discovery with MINOS and FERMILAB neutrino experiments can additionally be viewed as a test-case of the superluminal theories, *e.g.*, the imaginary-mass of the hypothetical tachyon becomes meaningless. Motivated and inspired in a part by OPERA and MINOS neutrino experiments [1,2], which lead to the following hypothesis: "*At superluminal level, the velocity* v *of any particle with real mass should be dependent on its energy ratio* $\varepsilon = E_0 / E$ *and the kinematical attainability parameter* α*.*" This double dependence is defined as:

$$v \equiv v_\alpha(\varepsilon) = c\left(1 + \varepsilon^\alpha\right), \text{ with } \varepsilon = E_0/E \text{ and } \alpha \in /R \tag{2}$$

where v, E_0 and E are, respectively, the superluminal velocity, rest mass energy, and total kinetic energy of the particle under consideration, c is the light speed in vacuum and α is the kinematical attainability parameter (KAP) that characterizing the maximal attainable superluminal velocity by a particle with real mass. As we can easily remark it from (2), even if the superluminal velocity, v, is completely unknown, this latter may be conveniently evaluated by an appropriate KAP-estimation.

Evidently, since we have generally the energy ratio $\varepsilon = E_0 / E < 1$, or even $\varepsilon \ll 1$, therefore as a general rule, the maximal attainable velocity should be: luminal $(v = c)$ if $\alpha >> 1$, superluminal $(v > \text{c})$ if $\alpha \geq 0$ and highly superluminal $(v >> \text{c})$ if $\alpha < 0$. Furthermore, when v and ε are, *e.g.*, experimentally well known, the KAP may be expressed from (2) as follows:

$$\alpha \equiv \alpha(\beta, \varepsilon) = \ln\left(\beta - 1\right) / \ln(\varepsilon) \text{ , with } \beta = v / c \quad . \tag{3}$$

In this sense, β is defined as the superluminal rapidity, thus it is also a kinematical parameter that characterizing any particle with real mass at superluminal level.

3. The Kinematical Behaviors and the Rate of Superluminality

The OPERA, MINOS and FERMILAB results allow us to assert that, phenomenologically, in the Nature any moving particle with real mass may be evolved according to three *kinematical levels*, namely: subluminal, luminal and superluminal level. Here, we are particularly dealing with the superluminal level, which is itself may be subdivided into three levels: low, mean and high superluminal level. With such a subdivision we can investigate the kinematical behaviors (KB's) of any particle with real mass evolving at superluminal level. Thus, by KB's we mean the set of *superluminal effects* that causally occurring from the particles during their superluminal motion.

Conceptually and physically the KB's are determined by the rate of superluminality (RS), which is defined as the variation of the particle superluminal velocity, v, with respect to the (total kinetic) energy, E, of the same particle during its motion. The expression of the RS may be deduced from (2) by differentiation, and we find

$$\frac{dv}{dE} = -\alpha \varepsilon^\alpha E^{-1} c \, . \tag{4}$$

3.1. Discussion

The Eq. (4) is the expected expression of the RS that permits us to study qualitatively and quantitatively the KB's exhibited by superluminal particle. It is clear from Eq. (4), the RS either decreases or increases with energy according to the sign of KAP. Let us focus our attention on KB's, more precisely, the three main superluminal effects: the kinematical *constraint*, *flexibility* and *freedom* that occurring, respectively, at *low*, *mean* and *high* superluminal level as follows:

$$\text{KBs}:\begin{cases} \textit{constraint} \text{ if } \alpha > 0 \text{ and } (dv/dE) < 0 \\ \textit{flexibility} \text{ if } \alpha = 0 \text{ and } (dv/dE) = 0 \\ \textit{freedom} \text{ if } \alpha < 0 \text{ and } (dv/dE) > 0 \end{cases} . \quad (5)$$

Now, let us determine the numerical values of KAP for μ-neutrino according to OPERA and MINOS data. We have from; OPERA: $(\beta - 1) = 2.48 \times 10^{-5}$, $E_0 = 2\,\text{eV}$ and $E = 17\,\text{GeV}$, thus $\varepsilon = 1.176470 \times 10^{-10}$. After substitution in (3), we get

$$\alpha_{\text{OPERA}} = 4.638283 \times 10^{-1} \quad . \quad (6)$$

From MINOS, we have $(\beta - 1) = 5.10 \times 10^{-5}$, $E_0 < 50\,\text{MeV}$, $E = 3\,\text{GeV}$, here, for our purpose we adopt the value $E_0 = 2\,\text{eV}$ already used in OPERA experiment, therefore, $\varepsilon = 6.666666 \times 10^{-10}$. By substituting in Eq. (3), we find

$$\alpha_{\text{MINOS}} = 4.677841 \times 10^{-1} \ . \quad (7)$$

The value (7) is remarkably comparable to (6). This means, among other things, the value $E_0 = 2\,\text{eV}$ of the rest mass energy proposed by OPERA to μ-neutrino is a good choice.

4. Consistency of SN 1987a measurement with OPERA data

Some researchers [4-6] claimed that the OPERA result is in full contradiction with SN1987a measurement, which provided a constraint because the observed μ-neutrinos set a strict limit. The μ-neutrinos were observed to arrive some 3 hours before the first detection of optical photons [7-10] to yield a limit of

$$\frac{|v - c|}{c} < 2 \times 10^{-9} \quad . \quad (8)$$

But only for μ-neutrinos of energy $\approx 10\,\text{MeV}$. Further, it is worthwhile to recall that the SN1987a measurement is predicated on the theoretical assumption that neutrinos and photons are emitted within three hours each other.

4.1. Problematic

In principle, neutrino velocity could be a strong function of energy, which is apparently not the case when we compare OPERA result with SN1978a measurement. However, as we have already seen with OPERA and MINOS, that is, if we take seriously into account our hypothesis defined by (2), we will find that there is no any contradiction between OPERA and SN1987a, on the contrary, the OPERA experiment is more realistic since it has explicitly taken into account the μ-neutrino rest mass energy by estimating it to be $2\,\text{eV}$, which is completely neglected in/by SN1987a measurement. Now, our main aim is to show that even the observed μ-neutrinos from SN1987a should obey to our hypothesis, namely, the formula (2). To this end, it is enough to determine, according to (8), the KAP range. The determination of such α-range ensuring at the same time the correctness and the consistency of the SN1978a measurement with the OPERA result.

4.2. Determination of α -range

By adopting $(\beta - 1) < 2\times10^{-9}$ as notation for (8), and since we have from SN1987a measurement the total kinetic energy ≈ 10 MeV for the observed μ-neutrino, thus by supposing the value of 2eV as a rest mass energy for the same observed μ-neutrino, in this case, we can calculate the value of energy ratio and we find $\varepsilon = 2\times10^{-7}$. Accordingly, by fixing the range of $(\beta - 1)$ to be $[10^{-9}, 2\times10^{-9}]$ and applying the formula (3), we get the expected α-range:

$$1.298554 \leq \alpha \leq 1.343490 \ . \tag{9}$$

From this, we deduce the mean values that should be phenomenologically considered as ideal for SN1987a measurement

$$(\beta - 1)_{\text{mean}} = 1.50\times10^{-9}$$

corresponding to

$$\alpha_{\text{mean}} = 1.317204 \ . \tag{10}$$

As we can remark it, the above-deduced value of α_{mean} is very near to the arithmetic mean

$$\frac{1}{2}(\alpha_{\max} + \alpha_{\text{mean}}) = 1.321022 \ . \tag{11}$$

Again, this illustrative example reinforces the evidence of the particle velocity dependence on ε and α at superluminal level and consequently our hypothesis should be universally applicable, not only to neutrinos of any type and any energy, but also to all superluminal particles with real masses.

5. Superluminal Space-Time

Now, we are arriving at the heart of our subject. In addition to OPERA-MINO-FERMILAB experiments on superluminal neutrinos, two-dimensional modeling of the interaction with the lower ionosphere of intense electromagnetic pulses (EMP's) from lightning discharges has indicated that optical luminosities-produced at 85-95 km altitudes as result of heating by the EMP-fields [11-15] as observed

From a certain distance would appear to expand laterally at superluminal velocities, 3.10 times the light speed in vacuum, in good agreement with the original predictions. Again, this exploit reinforces the reality of superluminal motions. Consequently, the question arises naturally: what is the appropriate geometry of space-time to describe superluminal physical phenomena? In order to answer adequately the above question, we shall, firstly, postulate that, kinematically, each subluminal $(v < \mathrm{c})$, luminal $(v = \mathrm{c})$ and/or superluminal $(v > \mathrm{c})$particle with real mass has, in addition to its relative velocity v, its proper specific kinematic parameter $u(v)$, which having the physical dimensions of a constant speed defined as:

$$\begin{cases} u(v) = c, \ \text{if} \ v < c \\ u(v) > v, \ \text{if} \ v \geq c \\ u^2(-v) = u^2(v), \ \forall v \end{cases} \ . \tag{12}$$

Thus, with the help of this postulate, more precisely, the definition (12), we can undertake to establish the mathematical structure of superluminal space-time deriving from the existence of superluminal physical phenomena. The mathematical structure of superluminal space-time as *a seat* of superluminal physical phenomena is defined by the superluminal metric:

$$x'^2 + y'^2 + z'^2 - u^2(v)t'^2 = x^2 + y^2 + z^2 - u^2(v)t^2 \quad . \tag{13}$$

The velocity v in (13) may be equal to the relative velocity between the two inertial reference frames (IRF's) F and F'. Further, according to the definition (12), the superluminal metric (13) may be reduced to that of Minkowski for the case $u(v) = c$ when $v < \mathrm{c}$. The signature (+,+,+,–) into (13) implies that the geometry of superluminal space-time is not completely Euclidean, it is in fact pseudo-Euclidean because as we will see later in superluminal regime, space '*contracts*' and time '*dilates*' as in Minkowski space-time for relativistic velocities. According to the principle of relative motion: – if the inertial reference frame F' moves in straight-line at constant velocity v relative to the inertial reference frame F, then also F moves in straight-line at constant velocity $-v$ relative to F'. The superluminal metric (13) should be invariant under a certain superluminal spatio-temporal transformations during any transition from a superluminal-IRF to another. From (13), we can also define a superluminal four-vector of position as follows: relatively to the IRF F, we call superluminal four-vector of position of a superluminal event of spatio-temporal coordinates (x, y, z, t), a vector $\mathbf{R}$ of components:

$$\{x_1 = x,\ x_2 = y,\ x_3 = z,\ x_4 = i \cdot u(v)t\},\ \text{with}\ \ i = \sqrt{-1}\,.$$

6. Superluminal Spatio-Temporal Transformations

With the help of the principle of relative motion, we undertake to find the superluminal transformation (ST's) for spatio-temporal coordinates, so that the ST's should justify the principal following conditions:

a) The ST's should ensure the invariance of the superluminal metric (13) during any transition from a superluminal-IRF to another.

b) The ST's should have an algebraic structure of a linear orthogonal-orthochrone group (*i.e.*, the notion of past, present and future are preserved this automatically preserves the causality principle in all the IRF's).

In order to find these ST's let us consider two IRF's F and F', which are in relative uniform motion at superluminal velocity v such as $c < v < u(v)$. And let us assume that a superluminal event can be characterized with superluminal spatio-temporal coordinates (x, y, z, t) in F and (x', y', z', t') in F'.

To simplify the algebra let the relative superluminal velocity vector $\mathbf{v}$ of IRF's be along their common $x \mid x'$-axis with corresponding parallel planes. Also, the two origins O and O' coincide at the moment $t = t' = 0$. The supposed homogeneity and isotropy of space and uniformity of time in all superluminal IRFs require that the ST's must be linear so that the simplest form they can tike (when for example the transition operated from F to F') is:

$$\mathrm{F} \to \mathrm{F}' : \begin{cases} x' = \eta(x - vt) \\ y' = y \\ z' = z \\ t' = \lambda x + \zeta t \end{cases} . \qquad (14)$$

In order to determine the expressions of the coefficients η, λ and ζ we shall use the idea of the homogeneity and isotropy of space and uniformity of time in all superluminal IRF's, and the principal condition (a). Therefore, when (14) are substituted in left-hand side of (13), we get

$$\eta^2 (x - vt)^2 + y^2 + z^2 - u^2(v) \cdot (\lambda x + \zeta t)^2 = x^2 + y^2 + z^2 - u^2(v) t^2 . \qquad (15)$$

From which we have

$$\begin{cases} \eta^2 - \lambda^2 u^2(v) = 1 \\ \eta^2 v + \lambda \zeta u^2(v) = 0 \\ \zeta^2 u^2(v) - \eta^2 v^2 = u^2(v) \end{cases} . \qquad (16)$$

This system of three equations (16) when solved for η, λ and ζ yields

$$\eta = 1/\sqrt{1 - v^2/u^2(v)} \; ; \quad \lambda = -\left[v/u^2(v)\right]\Big/\sqrt{1 - v^2/u^2(v)} ; \quad \zeta = 1/\sqrt{1 - v^2/u^2(v)} . \qquad (17)$$

Now, by substituting (17) in (14), we obtain the expression of the expected ST and its inverse $(\mathrm{ST})^{-1}$:

$$\mathrm{F} \to \mathrm{F}' : \begin{cases} x' = \eta(x - vt) \\ y' = y \\ z' = z \\ t' = \eta\left(t - \dfrac{vx}{u^2(v)} \right) \end{cases} , \qquad (18)$$

$$\mathrm{F}' \to \mathrm{F} : \begin{cases} x = \eta(x' + vt') \\ y = y' \\ z = z' \\ t = \eta\left(t' + \dfrac{vx'}{u^2(v)} \right) \end{cases} . \qquad (19)$$

where $\quad \eta = 1/\sqrt{1 - v^2/u^2(v)} \quad$ and $\quad \begin{cases} u(v) = c, \text{ if } v < c \\ u(v) > v, \text{ if } v \ge c \\ u^2(-v) = u^2(v), \ \forall v \end{cases} .$

Furthermore, we can make sure that the ST's preserve really the invariance of superluminal (space-time) metric (13) during, *e.g*., any transition from F to F'. To this end, we have

$$\begin{aligned} x'^2 + y'^2 + z'^2 - u^2(v)t'^2 &= \eta^2 (x - vt)^2 + y^2 + z^2 - u^2(v)\cdot\eta^2 \left(t - vx/u^2(v)\right)^2 \\ &= \eta^2 \left(1 - v^2/u^2(v)\right)x^2 + y^2 + z^2 - u^2(v)\cdot\eta^2 \left(1 - v^2/u^2(v)\right)t^2 \\ &= x^2 + y^2 + z^2 - u^2(v)t^2 \end{aligned}$$

This is in good accordance with the principle of relative motion. Also, it is easy to verify that the ST's (18 and 19) which depending on the parameters v and $u(v)$ form a linear orthogonal-orthochrone group since their determinants equal to +1. The usual LT's may be recovered from (18 and 19) for the case $u(v) = c$ when $v < c$. In this sense, we can logically affirm that the principle of relativity is extended to superluminal-IRF's via ST's.

However, many scientists imitated Einstein viewpoint by claiming that "in the real physical world, the velocity greater than that of light in local vacuum have no possibility of existence." But unfortunately, the same scientists ignored one very important think: Einstein's claim in his papers [16,17] is highly contradictory simply because a deeply critical reading of Einstein's papers on special relativity theory (SRT) has already showed more conclusively that Einstein himself [16,17] used, at the same time, the subluminal and superluminal velocities in SRT. For example, in his 1905' paper [16], he wrote:*'…Taking into consideration the principle of constancy of the velocity of light we find that*

$$t_B - t_A = \frac{r_{AB}}{v - c} \qquad \text{and} \qquad t'_A - t_B = \frac{r_{AB}}{v + c},$$

where r_{AB} *denotes the length of the moving rod- measured in the stationary system…'*

It is quite clear from the above equations, that is, since in Einstein's paper $v\ (v < c)$ is the relative velocity between the two IRF's, K and K', thus $v-c$ and $v+c$ are subluminal and superluminal velocity respectively. Consequently, forbidding the existence of superluminal velocities in the real physical world is a greatest crime against Science!

In our opinion, the ST's (18, 19) are the first ones to be formulated in a practical way that, as we know, satisfy the following requirements: i) ST's are real; ii) ST's are linear; iii) ST's leave the kinematical parameter, $u(v)$, invariant; iv) ST's form an orthogonal-orthochrone group; v) ST's may be reduced to usual LT's for the case $u(v) = c$ when $v < c$.

7. Consequences of ST's

By adapting the same method used in SRT, we can arrive, after performing some differential and algebraic calculations, at the following formulae:

-The Superluminal Length Contraction

$$L = \eta^{-1} L_0 = L_0 \sqrt{1 - \beta^2} \quad . \tag{20}$$

where $\beta = v / u(v)$ and L_0 is proper length of a material object in state of relative rest in (IRF) F'.

-The Superluminal Time Dilation

$$\Delta t = \eta\, \Delta t_0 = \Delta t_0 \Big/ \sqrt{1-\beta^2} \quad . \tag{21}$$

Where Δt_0 is proper time interval measured by a clock in state of relative rest in F'.

-Superluminal Velocity Transformations

$$\mathrm{F} \to \mathrm{F}' : \begin{cases} w'_{x'} = \dfrac{w_x - v}{1 - w_x v / u^2(v)} \\[2ex] w'_{y'} = \dfrac{\eta^{-1} w_y}{1 - w_x v / u^2(v)} \\[2ex] w'_{z'} = \dfrac{\eta^{-1} w_z}{1 - w_x v / u^2(v)} \end{cases} \quad , \tag{22}$$

where $w = \sqrt{w_x^2 + w_y^2 + w_z^2}$ and $v \le w \le u(v)$.

For the very important particular case, that is, when the superluminal particle moves along the common $x \mid x'$-axis, we get the composition law for superluminal velocities

$$w = \frac{w' + v}{1 + w' v / u^2(v)} \quad . \tag{23}$$

Two main properties characterize the law (23) are especially worthy of notice. First, we can recover from (23) the well-known relativistic composition law for the case $u(v) = c$ when $v < c$ and second one, if we put $w' = u(v)$, we get

$$w = \frac{u(v) + v}{1 + v / u(v)} = u(v) .$$

Thus, the specific kinematical parameter, $u(v)$, is a superluminal invariant.

-The formulae of superluminal energy and momentum

The formulae of superluminal energy and momentum of any material particle of masse *m* moving at a superluminal velocity $\|\mathbf{v}\| = v$ equals to that of the IRF-F' relative to F are defined by the following expressions, respectively:

$$E = \eta E_0 \ ; \tag{24}$$

$$\mathbf{p} = \eta \frac{E_0}{u^2(v)} \mathbf{v} \quad . \tag{25}$$

By combining the formulae (24), (25), we get the superluminal dispersion relation

$$E^2 - u^2(v)\mathbf{p}^2 = E_0^2, \tag{26}$$

where $E_0 = mc^2$ is the particle rest mass energy.

Like before, from (24), (25) and (26), we can also recover the well-known relativistic formulae for total energy, momentum and dispersion relation for the case $u(v) = c$ when $v < c$. Therefore, with all that we can assert to have established the basic formulation for superluminal kinematics and dynamics that prepare the way to *superluminalize* the SRT.

8. Conclusion

An alternative explanation as a model has been given for the more recently observed superluminal neutrinos by OPERA experiment, which is based on the hypothesis of the dependence of particle velocity on the energy ratio ε and the kinematical attainability parameter α. From this, we have shown the realistic result of OPERA and its consistency with SN1987a measurement. SRT is not violated by the existence of superluminal particles since it is conceptually, physically and exclusively valid at subluminal level for relativistic velocities. Also, we have formulated in practical way the superluminal spatio-temporal transformations (ST's) which satisfy the following requirements: i) ST's are real; ii) ST's are linear; iii) ST's leave the kinematical parameter, $u(v)$, invariant; iv) ST's form an orthogonal-orthochrone group; v) ST's may be reduced to the Lorentz transformations.

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