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Relativistic energy and mass originate from homogeneity of space and time and from quantum vacuum energy density

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Abstract: In a previous paper we have shown it is possible to build alternative versions of Special Theory of Relativity only considering homogeneity of space, of time and Relative Principle without invoking the postulate of invariance of light velocity in all the inertial frames. Within these alternatives, space and time transformations different than the Lorentz ones like, in particular, the Selleri inertial transformations, are possible. This has many important consequences as, for example, the need for the distinction between physical time as duration of change in space and mathematical time as a parameter quantifying this change as well as the anisotropy of one-way velocity of light. These results require a reformulation and a new understanding of relativistic energy and mass. In this paper we'll firstly show that, using only classical laws of Newtonian mechanics, classical electrodynamics and fundamental physical principles of homogeneity of space and time without referring to Theory of Relativity at all, it is possible to derive the correct form of fundamental equation $E_0 = mc^2$, the relativistic energy and momentum of a free particle in a preferred inertial frame. This makes relativistic energy and mass to assume a realistic physical meaning and an unambiguous definition only when referred to this preferred inertial frame identified by inertial transformations. This special universal meaning of energy, not recognized by standard Theory of Relativity, in which relativistic energy can assume different and independent values in all the possible infinite inertial frames, appears to be related to the fundamental invariance properties of space itself on which inertial transformations are based. In order to explain the origin of relativistic energy and mass, a novel physical model, also coherent with experimental results, has been then proposed. According to our model, mass could be considered as a conventional view of more fundamental properties of space emerging from a quantum vacuum, ruled by the Planck metric, in which the most fundamental physical entity is represented by energy density. In this picture relativistic mass and energy are coherently expressed as a measure of the diminished energy density of quantum vacuum.

Keywords: Special Theory of Relativity, Homogeneity of Space and Time, Invariance, Preferred Inertial Frame, Relativistic Mass, Relativistic Energy, Quantum Vacuum, Energy Density

1. Introduction

It has been shown that it is possible, considering only homogeneity of empty space and time and the Relativity Principle (RP), to build "alternative" versions of Special Theory of Relativity (STR), without assuming the invariance of light velocity in vacuum [1].

The latter, in fact, has a "special" electrodynamics origin because it describes a specific property of light arising from Maxwell equations and it is not required by the internal consistence of STR itself.

This result is also related to the non – measurability of the velocity of light, independently of conventions concerning the synchronization of distant clocks [2]. Poincare already expressed this concept in 1989 writing: "The simultaneity of two events should be fixed in such a way that the natural laws become as simple as possible. In other words all these rules, all these definitions are only the result of an implicit convention" [3]. This synchronization is then substantially conventional and is not necessarily related to true properties of physical reality [2,4] as known to Einstein itself [5].

The Lorentz Transformations (LT) realize a complete equivalence between an inertial frame S_0, initially supposed to be stationary and in which the one - way velocity of light is assumed to be invariant, and all the other infinite possible inertial systems S in relative motion, in which LT leave the one way velocity of light equal to c in all directions ("Einstein synchronization"). The system S_0 then loses its "particularity" and becomes equivalent to any other inertial frame in the Universe. Nevertheless, the alternatives synchronization methods give rise to different space and time transformations, of which LT only represent a special case. As we have shown [1], the set of the possible space and time transformations includes a subset of Lorentz like transformations characterized by a generic invariant velocity $\Lambda \neq c$ and the so – called "inertial transformations" (IT), found by Selleri [6] that we'll consider in the following discussion. The IT, in fact, are particularly interesting because they are able to reproduce all the main experimental evidence of standard STR, like the Michelson - Morley experiment, but without many of the paradoxes and difficulties of STR, like, for example the lack of the complete explanation of the Sagnac effect. The IT, including the LT as special case, have very important consequences on the most crucial features of STR as, for example, the true meaning of the physical time [1] and inertial frames, as well as the concept of simultaneity, energy and mass. Considering two inertial frames S_0 and S, respectively specified by the space and time coordinates (x_0, y_0, z_0, t_0) and (x, y, z, t), in motion with relative velocity v along the $x_0 = x$ axis, the IT are defined by the following equations

$$\begin{aligned} x &= (x_0 - \beta c t_0)\big/\sqrt{1-\beta^2} \\ y &= y_0 \\ z &= z_0 \\ t &= \sqrt{1-\beta^2}\, t_0 \end{aligned} \tag{1}$$

where $\beta = v/c$ and c is the invariant one – way velocity of light measured in S_0 [6].

One of the most interesting features of (1) is the absence of space components in the time transformation, causing, as already pointed out [1], the metric interval $(\Delta s)^2$ not to be invariant in all the inertial frames. This results in $X_4 \neq ict$, due to the particular method of synchronization adopted, and implies a new meaning of physical time [1].

The IT (1) gives, in particular, two other novel features [7]: the definition of absolute synchronization (namely two events taking place in different points of the system S but at the same time t are considered to be simultaneous also in the system S' and vice versa) and the existence of a "preferred" inertial frame S_0. The latter is called "preferred" because it is that in which the first synchronization of clocks is made according to the Einstein method, and where the speed of light is isotropic and equal to c, while, in the moving frame S it is given by

$$c'(\theta) = c/(1 + \beta\cos\theta) \tag{2}$$

where c' and θ respectively are the speed of light and the polar angle in the system S.

The anisotropy of light velocity and the existence of a preferred inertial frame provided by inertial transformations imply a reformulation and a deeper understanding of the concepts of relativistic energy and mass.

In fact, it must be stressed that, even in the "commonly" accepted picture of theoretical physics, the fundamental equation $E = mc^2$ between the energy and mass of a free relativistic particle can be achieved through several different procedures (as, for example, the consideration of the Newtonian limit $p = mv$, the use of less fundamental equation $p = Ev/c^2$ the study of elastic collision process and so on) some of which are exclusively based on classical newtonian mechanics and electrodynamics without invoking relativistic concepts at all as well as the light velocity invariance principle in all the inertial frames.

This suggests that energy could be considered a sort of fundamental "substance" of the Universe (being conserved and entering all the dynamical processes) and mass a "localized" form of energy, so appearing to be an only convenient definition of a more fundamental view [8,9].

Nevertheless the "standard" STR, although based in its dynamical part, on the fundamental equation $E = mc^2$, de facto denies this "special" role to energy, since every inertial observer assigns to a given massive body or particle a different speed and, consequently, a different total energy given, as known, by the expression

$$E_{tot} = mc^2\big/\sqrt{1 - v^2/c^2} \tag{3}$$

where m is the "rest" mass of the body and v its speed with respect the considered inertial frame.

This critical question arises because, in the in the currently accepted picture of STR based on LT, the equation (3) holds in any generic inertial frame $S, S', S'', S''', \ldots$ provided that speeds $v, v', v'', v''', \ldots$ are respectively referred to $S, S', S'', S''', \ldots$. This means that all the corresponding values $E, E', E'', E''', \ldots$ are equally valid or, in other words, that there is no well defined energy value for the particle. This energetic "relativism" is a consequence of LT symmetry and there is no way to avoid it in the standard STR.

The only way to overcame this conclusion, recovering a realistic and objective meaning and a coherent definition of relativistic energy and mass, explaining their deepest nature, in the same time accomplishing the agreement with the consolidated experimental results, is to introduce the inequality of inertial frames and a new model of physical space.

In this paper we'll show how relativistic energy and mass can be properly and realistic defined considering only the universal postulates of space and time homogeneity, in turn reflecting the invariance of a physical system with respect space and time translations, without considering the light velocity invariance postulate, through the introduction of a novel model of physical space.

In particular, the use of IT has allowed us to identify a preferred inertial frame S_0 in which relativistic energy assumes a more fundamental value; in this picture also the relativistic mass assume a "absolute" meaning as the energy of a particle at rest in S_0.

Mass can be then interpreted as the manifestation of the energy associated to the space itself through the space and time translational invariance in the "preferred" inertial frame, defined by IT.

This suggests the introduction of a novel model of a quantum vacuum (QV), determining the properties of physical space, ruled by the Planck metric (so called because it makes use, to define the most fundamental structure of QV, of Planck mass and length only), in which the ultimate physical entity is represented by its energy density, whose diminishing originates rest mass and relativistic energy of particles and radiation.

2. On the Equivalence of Energy and Mass and the Relativistic Energy in the Preferred Inertial Frame

It can be shown that (3) can be considered as having a universal validity and it is not a distinguishing result of STR and gives the correct expression of total energy of a moving massive particle only in a preferred inertial frame defined by IT. Einstein itself formulated his famous equation in the second of his 1905 paper [5], without using purely relativistic arguments, in the form

$$\Delta E_0 = \Delta mc^2 \tag{4}$$

through a "gedanken experiment". He considered a body at rest with rest energy E_0, in a given inertial system, emitting two equal light pulses in opposite directions.

If this process is analyzed in a slowly (with respect to light speed) moving frame by means of fundamental conservation laws only, we easily arrive to (4) that, for this reason, con be considered as universal and, as Einstein wrote: "a measure of its (the body) energy content".

The basic reasoning supporting (4) can be outlined as follows. We consider a box provided, at its two opposite sides A and B, with two light emitter / absorber instruments able to completely adsorb or emit a photon in a definite direction. If the transmitter A emits a light pulse at $t = 0$ in the direction of absorber B, the box recoils in the opposite direction.

The momentum conservation, in the direction of light pulse, implies that

$$p_{box} + p_{light} = 0 \tag{5}$$

where p_{box} and p_{light} respectively are the quantity of motions of box and light pulse. From the classical laws of mechanics we know that:

$$p_{box} = m_{box} v_{box} \tag{6}$$

and

$$p_{light} = E/c \tag{7}$$

where E is the light pulse energy and c the light speed in S_0.

Equation (7) immediately follows from classical electrodynamics considering the radiation pressure of an electromagnetic wave on a given surface. Substituting (6) and (7) in (5) we have

$$v_{box} = -E/m_{box}c \tag{8}$$

i.e. the box recoils with velocity v_{box} in the opposite direction of the light pulse.

If L is the box length in the direction of light pulse emission, neglecting higher order terms, the light pulse will arrive at absorber B at time

$$t = L/c \tag{9}$$

meanwhile the box has moved in the opposite direction by an amount

$$x = v_{box} t = EL/m_{box}c^2 \tag{10}$$

supposing that we can associate to light pulse a mass m we can integrate (5) by time obtaining

$$m_{box} X_{box} - mL = 0 \tag{11}$$

where X_{box} is the displacement of the box's center of mass in the considered time interval. Using (10) in (11) we finally have the Einstein's equation

$$E = mc^2 \tag{12}$$

Actually the (12) can be derived in many other different ways, some of which are not free of authentic criticisms of Einstein's reasoning, starting from the classical laws and the classical relativity principle, even without considering STR [10,11,12].

In any case, just the assessment that all these approaches lead to the same result represented by (12) can be considered as the proof of its universal validity.

Nevertheless, some remarks must be expressed about the correct form and meaning of (12). In fact, in the standard formulation of STR [8], and often in the other approaches leading to (12), the mass of a particle is defined in terms of its total energy E and momentum $\vec{p}$ by the fundamental equation

$$m^2 = \left(E^2/c^2\right)^2 - \left(\vec{p}/c\right)^2 \tag{13}$$

in which energy and momentum are related by the other fundamental equation

$$\vec{p} = \vec{u}E\Big/c^2 \tag{14}$$

When $\vec{u}=0$, we have $\vec{p}=0$ and $E=E_0$ in (13) with

$$E_0 = mc^2 \tag{15}$$

where E_0 is the rest energy and m is the ordinary mass, the same as in the Newtonian mechanics [8]. The latter consideration arises from the true nature of mass that must be an invariant quantity not depending on velocity, namely a four scalar in the standard STR, in order to obtain the correct non - relativistic limit of Newtonian mechanics [8].

The equation of relativistic energy in the same inertial frame S_0 in which (15) holds can be obtained by simply using non - relativistic Newtonian mechanics.

We start from considering the non – relativistic classic equation relating the differential increase of kinetic energy due to work done by an external force $\vec{F}$ for a displacement $d\vec{s}$

$$dE = \vec{F}\cdot d\vec{s} = \left(dp/dt\right)ds = u_0 dp \tag{16}$$

where u_0 is the velocity component along the direction defined by $d\vec{s}$.

Now, considering (7) and assigning to photon the mass given by (12) [13], we can write, using the classic relation $p_0 = mu_0$,

$$u_0/c = cp_0/E \tag{17}$$

Equations (16) and (17) lead to the differential equation

$$EdE = c^2 p_0 dp_0 \tag{18}$$

whose solution is

$$E^2 = c^2 p_0^2 + C \tag{19}$$

where C is an integration constant having the dimension of a squared energy. So we can put $C \equiv E_0^2$, obtaining

$$E^2 - c^2 p_0^2 = E_0^2 \tag{20}$$

that can be rewritten, using (17), as

$$E = E_0\Big/\sqrt{1-{u_0}^2/c^2} \tag{21}$$

As showed above, in the system S_0 when $u_0 = 0$ we must have $E = E_0 = mc^2$ so the (21) becomes the known expression of relativistic energy given by (3). From (21) we get, using (17), the equation of momentum of the particle

$$\vec{p}_0 = m\vec{u}_0\Big/\sqrt{1-u_0^2/c^2} \tag{22}$$

It is important to observe that (21) and (22) are identical to the corresponding equations derived in the standard STR, using light velocity invariance postulate and LT.

From the above discussion we can conclude that the mass – energy equivalence and the interpretation of the momentum as quantity of motion, as in Newtonian physics, leads, without using relativistic concepts, to the correct expressions of relativistic energy, mass and momentum in the preferred inertial frame defined as the inertial system in which homogeneity of space and time, Relativity principle, as well as the Maxwell equations hold [1,6].

This system is also that in which the first clocks synchronization is made [1,6] and (21) and (22) are invariant under LT as well (although it has been derived without using them).

In the next section we'll see the situation is very different in the others possible inertial frames in relative motion with respect the preferred one previously determined and that (21) and (22) must be modified in order to consider the effect of their motion.

3. Relativistic Energy and Mass Arising from Fundamental Invariance Properties of Space

Once we have obtained, using universal principles only, the expressions of energy, mass and momentum of a free particle in the preferred inertial frame S_0, we are ready to derive, invoking the same principles, their correspondent equations in a generic inertial frame S in relative motion with respect the preferred system S_0.

We first consider the inverse of IT (1) given by [7]

$$\begin{cases} x_0 = \sqrt{1-\beta^2}\left[x + vt/\left(1-\beta^2\right)\right] \\ y_0 = y \\ z_0 = z \\ t_0 = t\Big/\sqrt{1-\beta^2} \end{cases} \tag{23}$$

where, as usual, $\beta = v/c$, v being the module of relative velocity $\vec{v} = v\vec{i}$ of S with respect to S_0. The (23) written in differential form are

$$\begin{cases} dx_0 = \sqrt{1-\beta^2}\left[dx + vdt/\left(1-\beta^2\right)\right] \\ dy_0 = dy \\ dz_0 = dz \\ dt_0 = dt/\sqrt{1-\beta^2} \end{cases} \tag{24}$$

from which, recalling the definition of velocity, we can get the inertial transformation rules of velocities

$$\begin{cases} u_{0,x} = \left(1-\beta^2\right)u_x + v \\ u_{0,y} = \sqrt{\left(1-\beta^2\right)}u_y \\ u_{0,z} = \sqrt{\left(1-\beta^2\right)}u_z \end{cases} \tag{25}$$

where $\vec{u}_0 = \left(u_{0,x}, u_{0,y}, u_{0,z}\right)$ is the particle velocity in the system S_0, $\vec{u}_0 = \left(u_{0,x}, u_{0,y}, u_{0,z}\right)$ that in the system S.

The system (25) can be rewritten, in vector form, as

$$\vec{u}_0 = \gamma\vec{u} + \left[1 + \left(\gamma^2 - \gamma\right)\vec{u}\cdot\vec{v}/v^2\right]\vec{v} \tag{26}$$

that simply follows from (25), using $\vec{v} = v\vec{i}$.

By scalar multiplying (26) by $\vec{v}/c^2$ and subtracting side by side from 1 we can easily get

$$1 - \vec{u}_0\cdot\vec{v}/c^2 = R^2\left(1 - \vec{u}\cdot\vec{v}/c^2\right) \tag{27}$$

similarly, multiplying (27) by $\vec{u}_0/c^2$ and substituting in the right side the (25) we have

$$\sqrt{1 - u_0^2/c^2} = R\left[\left(1 - \vec{u}\cdot\vec{v}/c^2\right)^2 - u^2/c^2\right]^{1/2} \tag{28}$$

Now we consider the (25) multiplied by m together with the identity $mc^2 = mc^2$

$$\begin{cases} u_{0,x} = \left(1-\beta^2\right)u_x + v \\ u_{0,y} = \sqrt{\left(1-\beta^2\right)}u_y \\ u_{0,z} = \sqrt{\left(1-\beta^2\right)}u_z \\ mc^2 = mc^2 \end{cases} \tag{29}$$

and divide the (29) by (28), obtaining

$$\begin{cases} u_{0,x}\Big/\sqrt{1-u_0^2/c^2} = \left(R^2u_x + v\right)\Big/R\left[\left(1-\vec{u}\cdot\vec{v}/c^2\right)^2 - u^2/c^2\right]^{1/2} \\ u_{0,y}\Big/\sqrt{1-u_0^2/c^2} = u_y\Big/\left[\left(1-\vec{u}\cdot\vec{v}/c^2\right)^2 - u^2/c^2\right]^{1/2} \\ u_{0,z}\Big/\sqrt{1-u_0^2/c^2} = u_z\Big/\left[\left(1-\vec{u}\cdot\vec{v}/c^2\right)^2 - u^2/c^2\right]^{1/2} \\ mc^2\Big/\sqrt{1-u_0^2/c^2} = mc^2\Big/\left[\left(1-\vec{u}\cdot\vec{v}/c^2\right)^2 - u^2/c^2\right]^{1/2} \end{cases} \tag{30}$$

At the first member of (30) we can recognize the expressions of momentum and energy in the system S_0 given by (21) and (22): this allows us to identify, in a similar fashion, the correspondent transformed quantities in S at the second members of (30) and write

$$\begin{cases} p_{0,x} = R\left(p_x + vE/c^2R^2\right) \\ p_{0,y} = p_y \\ p_{0,z} = p_z \\ E_0 = E/R \end{cases} \tag{31}$$

where

$$E = mc^2\Big/\sqrt{\left(1 - \vec{u}\cdot\vec{v}/c^2\right)^2 - u^2/c^2} \tag{32}$$

and

$$\vec{p} = m\vec{u}\Big/\sqrt{\left(1 - \vec{u}\cdot\vec{v}/c^2\right)^2 - u^2/c^2} \tag{33}$$

The (32) and (33) represent the energy and momentum of the particle expressed in the moving inertial frame S and are generally different from the corresponding expressions in the preferred system S_0. We note that only if $\vec{u}\cdot\vec{v} = 0$ they respectively coincide with (21) and (22), with (21) that gives, in this case, the proper value of total energy of particle.

It must be stressed the important result represented by (21) - (22) and (31) - (32) for the subsequent development of our model: they contain, as particular case (namely, when we refer to the preferred inertial frame S_0) the results of the standard formulation of STR. Nevertheless they are obtained considering only the universal principles of space and time homogeneity, without using the light velocity invariance (in all the inertial frames) and, above all, adopting the IT (1) in which time and space are "separated" in the time transformation that not contains space components.

This leads to the very important conclusion that relativistic energy and mass could be considered as the results of deeper and more fundamental invariance properties of a 3D space in which time is a mathematical parameter giving the duration of the physical states of a system [1].

4. Relativistic Energy and Mass as the Result of the Diminished Energy Density of Quantum Vacuum

As shown in the previous section, when described in the preferred inertial frame S_0, a free particle is characterized by relativistic energy given by (21) and its mass can be considered as a convenient definition of energy itself, in turn related to space and time homogeneity of the 3D physical space.

Mass is then ultimately a manifestation of energy of empty space or, more precisely, of QV.

In order to explain such connection, we'll assume a model of a physical quantum vacuum consisting of a granular structure of the universal space ruled by a Planckian metric somehow similar to that proposed, for example, in many versions of loop quantum gravity [14], but conceptually different, because based on the conception of a physical 3D space composed by minimal energetic packets having the size of Planck volumes. This allows us to define its most elementary structure in terms of fundamental physical constants only,

Within this model, according to our previous results [1], time exists only as mathematical parameter, characterizing the numerical ordering of the occurring of physical states and the crucial role is played by energy density, viewed as the most fundamental entity also originating mass.

In a fixed volume of physical space, a given isolate system has a total energy we can express as

$$E_{QV} + E_{em} + E_M = D \tag{34}$$

where E_{QV} is the quantum vacuum energy, E_{em} is the electromagnetic energy in the form of radiation, E_M is the relativistic energy in the form of matter given by (21) and D is a constant.

This can be rewritten in a more general form, independent on the volume, in terms of density, also assuming that energy tends to a uniform distribution

$$\rho_{QV} + \rho_{em} + \rho_M = d \tag{35}$$

where ρ_{QV} is the quantum vacuum energy density, ρ_{em} the electromagnetic energy density, ρ_M is the relativistic energy density in the volume V and d is a constant energy density.

According to the Planck metric, quantum vacuum energy density, in the absence of matter and radiating electromagnetic fields, can be written as

$$\rho_{QV} = m_P c^2 / l_P^3 \tag{36}$$

where m_P is the Planck mass and l_P the Planck length. The value of ρ_{QV} can be considered as the maximum possible value of quantum vacuum energy density, representing the volumetric energy density averaged on all the frequency possible modes within the visible size of the universe.

The quantum vacuum energy density is usually considered as the source of the so-called dark energy and, consequently, of the cosmological constant in General Relativity. Dark energy, in turns, is supposed to represent the bridge between Quantum Mechanics and General Relativity and its role is crucial for the elaboration of an eventual Theory of Everything. Nevertheless, the above correspondence between ρ_{QV} and dark energy poses some questions.

The most noticeable one is represented by the numerical value given by (36) we can obtain substituting in (36) the known expressions for m_P and l_P namely

$$\rho_{QV} = \sqrt{c^{14}/\hbar^2 G^4} \cong 10^{97}\, kg \cdot m^{-3} \tag{37}$$

in disagreement with the value deriving from the currently available experimental evidences

$$\rho_{DE} \cong 10^{-26}\, kg \cdot m^{-3} \tag{38}$$

this poses the so – called "cosmological constant problem".

In order to solve this question Santos [15] has recently proposed the consideration of quantum vacuum fluctuations through the introduction of an energy density operator $\hat{\rho}(\vec{r},t)$ of the quantum field. This operator square has a non zero expectation value when applied to quantum vacuum

$$\langle vac | \hat{\rho}^2 | vac \rangle \neq 0 \tag{39}$$

due to the fluctuations of quantum vacuum itself, possibly associated, according to the what suggested by Zeldovich [16] to dark energy density ρ_{DE} in turns related to the gravitational energy of quantum vacuum as due to the presence of a particle of mass m such as

$$\rho_{DE} \cdot c^2 \sim G m^6 c^4 / \hbar^4 = G m^2 / \lambda^4 , \quad \lambda \equiv \hbar / mc \tag{40}$$

In addition, the interpretation of mass as the results of an electromagnetic quantum vacuum energy density has been also proposed by Rueda and Hairsch [17] in whom model the inertial mass m_i of a given particle is given by

$$m_i = m_g = V_0 / c^2 \int \eta(\omega) \hbar \omega^3 / 2\pi^2 c^3 \, d\omega \tag{41}$$

where V_0 is the proper volume of the object, ω is the characteristic frequency of the e.m mode and $\eta(\omega)$ is a sort of coupling function representing the relative strength of the interaction between the zero – point field and the massive object. In this picture a mass m expels from the space volume V_0 associated with it a quantity of energy equal to its rest energy $E_0 = m_i c^2$.

The above pictures both agree with our model but the latter has the advantage that it is obtained only considering universal invariance of 3D space without any further assumptions, especially as regard as the particular nature of energy density of quantum vacuum involved.

According to the above results we can then consider that every particle is made out of electromagnetic energy of quantum vacuum and so it consists of diminishing energy density of an ideal quantum vacuum. For massless particle, the diminishing of energy density corresponding to the "creation" of a particle of energy $E = \hbar\omega$ is

$$\rho'_{QV,E} = \left(m_P c^2 - \hbar\omega\right)\Big/ l_P^3 \quad (42)$$

where $\rho'_{QV,E}$ is the quantum vacuum energy density after the "expulsion" of the massless particle. For a massive particle of rest mass m we have

$$\rho'_{QV,m} = \rho_{QV} - mc^2/V \quad (43)$$

where V is the proper volume of the considered body and the energy density variation is considered to be concentrated in the body center of mass.

According to (42) and (43), particles are made out of quantum vacuum energy "stuff", substantially made of electromagnetic field modes.

From (43) it immediately follows that mass can be expressed as a result of the difference of energy density of an "electromagnetic" quantum vacuum

$$m = \left(\rho_{QV,m} - \rho'_{QV}\right)V\Big/c^2 \quad (44)$$

or, equivalently

$$m = \Delta E_{QV}\Big/c^2 \quad (45)$$

having defined $\Delta E_{QV} = \left(\rho_{QV,m} - \rho'_{QV}\right)V$, and that energy of which particles are made out, comes from quantum vacuum. Our picture furthermore gives a physical coherent and non-contradictory interpretation of the proper meaning of relativistic energy and mass of a free particle characterized, in the commonly accepted formulation of STR, by very deep ontological and operative issues as discussed above [18].

This as obvious as underestimated question, apart its fundamental ontological importance in relation to the meaning of physical reality, could imply serious difficulties, for example, when considering physical process characterized by energetic thresholds.

The proposed model, based on the inertial transformations, overcomes this problem assuming the relativistic energy equation (21) to be valid only when referred to the "preferred" inertial system S_0, in which it is directly related to ΔE_{QV}, so giving a "preferred" scale, relative to S_0, for the energy calculation.

Equation (43) can be generalized to a moving particle assuming not only rest energy $E = mc^2$ but also relativistic total energy of the particle in the preferred inertial frame S_0, is related to quantum vacuum energy density by the equation

$$\rho'_{QV} = \rho_{QV} - E_{rel}/V \quad (46)$$

where E_{rel} is given by (21).
Substituting (21) in (46) we get

$$\Delta\rho_{QV}\left(S_0\right) = mc^2\Big/V\sqrt{1-u_0^2/c^2} \quad (47)$$

meaning that a relativistic massive particle in motion with respect the preferred inertial system S_0 gets its own additional energy from quantum vacuum so further decreasing the energy density of the latter (see fig. 1). In the inertial frame S we have

$$\Delta\rho_{QV}\left(S\right) = mc^2\Big/V\sqrt{\left(1-\vec{u}\cdot\vec{v}/c^2\right)^2 - u^2/c^2} \quad (48)$$

showing that the diminishing of QV energy density measured in the generic inertial frame S differs from that measured in the preferred system S_0 with the latter giving the "realistic" value of $\Delta\rho_{QV}$. We also note a very interesting consequence of (48) namely

$$\Delta\rho_{QV}\left(S\right) > \Delta\rho_{QV}\left(S_0\right) \quad (49)$$

since $\vec{u}\cdot\vec{v} < c^2$. This means the QV energy density diminishing "required" in any given inertial frame S is greater than its corresponding value in the preferred system S_0, so suggesting a simple and interesting explanation of the origin of a possible QV inertia, already proposed in some models of QV [17].

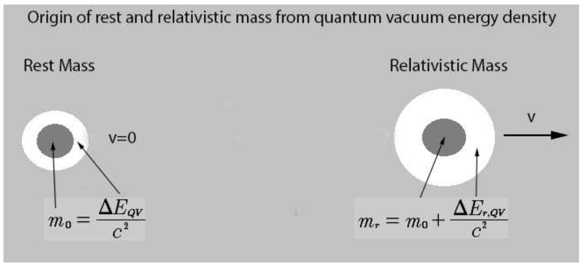

__Figure 1.__ Schematic representation of rest and relativistic mass due to QV energy density diminishing.

5. Conclusions

In this paper we have proposed a new derivation of relativistic energy and mass of a free particle only based on fundamental physical postulates of homogeneity of space and time and a novel interpretation of their origin in terms of quantum vacuum energy density.

As we have shown in a previous work [1] different class of space and time transformations, even different from the Lorentz ones, whose form depend on the synchronization method adopted for the definition of simultaneity, can be used to construct a STR coherent with the fundamental postulates of homogeneity of space and time and Relativity Principle, in which the speed of light is not generally invariant in all the different inertial frames. Among these classes a very important role is played by the inertial transformations found by Selleri, in which time transformation doesn't contain space, providing the existence of a preferred inertial frame in which the first synchronization of events is realized and the one – way velocity of light is invariant.

The IT, in fact, are able to reproduce all the main experimental evidence of standard STR but without many of the paradoxes and difficulties of STR, like, for example the lack of a complete understanding of the Sagnac effect. The consideration of inertial transformations and the equation $E_0 = mc^2$ (that can be derived also without using standard STR), give us the expression (21) of relativistic energy in the preferred frame S_0 as function of rest mass and relative speed, whose expression is formally identical that commonly used within the standard STR that is fully compliant with the LT.

Nevertheless, the meaning of this relation in the two cases is deeply different. In the standard approach, in fact, the energy – mass relation is valid for every couple of inertial system in relative motion that result completely equivalent, due to the Einstein's relative synchronization procedure.

On the contrary, in our model the (21) is valid when referred to the "special" inertial frame S_0 (in which the one way invariance of light velocity holds) and only here the particle at rest has exclusively the rest energy $E_0 = mc^2$ (since in every other inertial frame S in relative motion it is given by (32)). The possibility to define a preferred inertial frame (in the above sense) should not to be confused with the introduction of an absolute system of reference but it means we can choose, among the infinite possible and initially equivalent frames, a system where we perform the first synchronization which, from that moment on, will became the preferred one.

This important result has two deep consequences: the first one is that it fixes a sort of "preferred" scale of energy respect to which we must evaluate all the dynamical process; the second one is that the rest mass assumes a very special meaning being interpretable as the energy associated, through translational invariance, to the 3D physical space itself.

The latter statement is used as the starting point for the introduction of novel model of quantum vacuum, ruled by a Planck metric, whose most elementary physical entity is represented by energy density.

In such quantum vacuum mass naturally arises from energy density diminishing with respect the maximum possible value ρ_{QV} expressed in terms of Planck's mass and length only.

The proposed model furthermore conceptually explains, in natural way and through fundamental principles only, the origin and the behavior of relativistic energy of a particle as, in particular, its increase with the particle velocity viewed as the more and more diminishing of the energy density of quantum vacuum transferred to particle, during its motion, by QV.

In this way, the motion of a given free particle, specified by its mass and velocity as regards a given inertial frame, is necessarily associated with a well defined variation of QV energy density whose value in the preferred system is unique. This further suggests the role of QV energy density as the most fundamental physical entity in all the dynamical process of the Universe when expressed in the preferred inertial frame as defined above.

Another interesting feature of our model concerns its ability to explain the quantum vacuum inertia hypothesis as well as its fully compatibility with the picture of an electromagnetic vacuum, like that proposed by Hirsch and Rueda, although it results more general than the latter because of the absence of any particular starting hypothesis about the QV energy density nature.

In this regard, an interesting perspective would be to extend the approach of the quantum vacuum energy density introduced in this paper also to the treatment of strong interactions, weak interactions as well as to the contributions linked to grand unification field theories outside the Standard Model.

Although it is still in a preliminary development phase, the proposed model of quantum vacuum could represent a very important starting point to explain some fundamental questions of modern physics as, first of all the true origin of gravity and dark matter, all these aspects being currently under active consideration.

Moreover, as it will be discussed in a forthcoming paper, the concept of mass resulting from the proposed model should be able to answer the question of what gives mass to the Higgs boson itself, since within Higgs theory mass appears a result of a dynamics between a given particle or massive body and the quantum vacuum in which a particle or a massive body exists.

A question to be deepened concerns the role of the invariant velocity previously founded [1] and its effect on (47) and (48). To this aim the model proposed above could be able also to quantitatively relate the maximum velocity of a massive body to the quantum vacuum energy diminishing. This aspect has deep and important consequences on the theoretical foundation of superluminal signals (SSL) as we'll show in a forthcoming paper.

Nevertheless, further researches and developments are necessary and currently in progress firstly as regards the formulation of a complete dynamical model of quantum vacuum energy density, explaining, for example, how and under what conditions, the quantum vacuum undergoes energy density diminishing as well as the origin of gravitational mass and its relationship with space curvature in this new model of quantum vacuum.

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