The necessity for “dark energy”, a fourth spatial dimension, and a partial time-reversal in General Relativity

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Abstract: It is shown that 100-year-old ideas on the energy of the gravity field collide with the principle of local conservation of energy. A scrutiny of the Schwarzschild metric, carried out with a different method than that applied by E. Schrödinger but completed with a similar result, re-confirms that the gravity field holds no energy, with that recognition being tacitly acknowledged by Misner, Thorne and Wheeler in 1973. Given that it does not hold any energy, it cannot be qualified as a force-field. Given that it is not a force-field, it must be capable of being completely transformed away even in the rigid reference-frame of a distant observer outside of the field. Contrary to what (early) Einstein believed, this can (and must) be achieved by the concept of “flowing spaces” that was introduced by elder Einstein himself in 1952. It is shown that this concept leads to empirical consequences. Moreover, the energy of the gravity field is necessarily replaced by an inexhaustible “dark energy”, which flows into any massive object (including Newton’s apple) whenever it is gathering speed in free fall. Thereby Schrödinger’s vision of “new foundations” of the energy conservation principle (as a consequence of the gravity field holding no energy) is coming true. Because of the absence of any gravitational field lines that originate from that energy, the (main) seat of this “dark energy” cannot be in three-dimensional space. The free *rise* of a test body in the gravity field can, along these lines, only be accounted for by an outward flow of space, which, in turn, can only be the result of a partial time-reversal.

1) The quest for a determination of the energy density of the gravity field

a) Einstein’s field equation of General Relativity (see its formulation by A. Einstein, “The Meaning of Relativity”, Princeton University Press, 5th edition 1956, therein: “The General Theory”, p. 84, Equation 96), that is,
(1)

$$G^{\mu\nu} = R^{\mu\nu} - \frac{1}{2}g^{\mu\nu}R = 8\pi G\ T^{\mu\nu}$$

presupposes the vanishing of the covariant divergence of the “ordinary” energy-momentum tensor **T** that comprises energy and momentum of ordinary matter **M** (but not of matter or momentum ascribed to a gravitational field).

Proof: The covariant divergence of the middle part of the equation is zero by mathematical necessity. Consequently, the covariant divergence of the right part of the equation, too, must vanish.

In mathematical terms (as an expression of the vanishing of the covariant divergence of the energy-momentum tensor **T**, see A. Einstein, "The foundation of the general theory of relativity", translated from "Die Grundlage der allgemeinen Relativitätstheorie", Annalen der Physik, Vol. 354 – 1916 – , pp. 769, in: A. Einstein/H.A. Lorentz/ H. Minkowski/,"The Principle of Relativity", Dover Publ. 1952, § 18, Equation 57 and 57a, p. 151):
(2)

$$0 = \frac{\delta T_{\sigma}^{\alpha}}{\delta x_{\alpha}} + \Gamma_{\sigma\beta}\, T_{\beta}^{\alpha} = \frac{\delta T_{\sigma}^{\alpha}}{\delta x_{\alpha}} + \frac{1}{2}\,\frac{\delta g^{\mu\nu}}{\delta x_{\sigma}}\, T_{\mu\nu}$$

One is getting a deeper understanding of (2) by imagining a test body that, from the perspective of a far-away observer, is "gathering speed" in a gravity field. In such a case, **T** is of a kind that makes (2) an expression of a geodesic along which the test body is coasting (W. Pauli, Theory of Relativity, Dover Publ. 1981, Section 54, p. 158). Apparently (see below), kinetic energy is generated at the expense of the energy of the gravity field, and the principle of energy conservation is apparently observed (see A. Einstein, op. cit, after Equation 57: "*Physically, the occurrence of the second term on the left-hand side shows that laws of conservation of momentum and energy do not apply in the strict sense for matter alone, or else that they apply only when the g are constant, i.e. when the field intensities of gravitation vanish. This second term is an expression for momentum, and for energy, as transferred per unit of volume and time from the gravitational field to matter.*"; see also A. Einstein, "The Meaning of Relativity", Princeton University Press, 5th edition 1956, therein: The General Theory, p. 83: *"It must be remembered that besides the energy density of the matter there must also be given an energy density of the gravitational field, so that there can be no talk of principles of conservation of energy and momentum alone.*").

From (2), one can derive (see A. Einstein, "The foundation of the general theory of relativity", § 17, Equation 56, p. 150; A. Einstein, "*Der Energiesatz in der allgemeinen Relativitätstheorie*", Sitzungsberichte der Preußischen Akademie der Wissenschaften, 1918, Vol. 1, pp. 448-459):
(3)

$$0 = \frac{\delta (T_{\mu}^{\sigma} + t_{\mu}^{\sigma})}{\delta x_{\sigma}}$$

The term **t** is a function that depends on the change in the components of the metric tensor **g**. According to Einstein, it is an expression of the density of "momenergy" ascribed to the gravitational field. An integral which is founded on (3), that is
(4)

$$\int_V (T_i^4 + t_i^4)\, dx^1 dx^2 dx^3 = const$$

has (under certain restrictions) the same value in any reference frame (see W. Pauli, Theory of Relativity, Dover Publ. 1981, Section 61, Equation 447, p. 176; A. Einstein, "*Der Energiesatz in der allgemeinen Relativitätstheorie*", Sitzungsberichte der Preußischen Akademie der Wissenschaften, 1918, Vol. 1, pp. 448-459, Equation. 25). That is to say: The sum of all "momenergies" of bodies and gravitational fields is not only constant over time, but is also the same in any frame of reference. In Special Relativity, the "momenergy" of a body has the same magnitude in any frame of reference, and is equal to the mass of the body in its own rest frame. In General Relativity, the sum of the "momenergies" of bodies and gravitational fields apparently replaces the "momenergies" of the bodies alone.

Quite astonishingly, the energy-momentum density **t** of the gravitational field, and hence also its ordinary energy density, can be made to locally vanish by means of an appropriate choice of "flat" coordinates [see W. Pauli, Theory of Relativity, Dover Publ. 1981, Section 61 , p. 176: "*Since these quantities do not depend on the derivatives of the g higher than the first, we can conclude immediately that they can be made to vanish at an arbitrarily prescribed world point for a suitable choice of the coordinate system (geodesic reference system).*"].

Even more: One- and the same observer arrives at completely different results for **t** and hence for the energy density of the gravitational field, depending on which coordinate system he is using (see H. Bauer, "Über die Energiekomponenten des Gravitationsfeldes", Physikalische Zeitschrift, Vol. 19 – 1918 – , pp.163-165: "*As a concluding remark, we may state that the 'energy components' t have nothing to do with the existence of a gravitational field, but depend on the choice of coordinates only...*"). Einstein and Pauli drew the following conclusion from this (W. Pauli, Theory of Relativity, Dover Publ. 1981, Section 61, p. 177):

"*According to this, one cannot asign any physical meaning to the values of the t themselves, i.e. it is impossible to carry out a localization of energy and momentum in a gravitational field in a generally covariant and physically satisfactory way.* "

Hence, no definite, time- and space-dependent value can be attributed to the local energy density of the gravitational field.

This stance of Einstein's presents a sharp contrast to the long-standing and still popular assertion according to which the energy density of the gravitational field is proportional to the negative square of the local intensity of the gravitational field. That assertion has been backed by the following argument: Since General Relativity can be expected to be almost indistinguishable from Newton's physics when it comes to objects like the solar system, and since Newtonian physics has been understood as equalling the negative potential energy and the energy of the gravitational field, one might be inclined to assume that the energy density near gravitating masses has to be negative also in General Relativity. See *W. Pauli* (Theory of Relativity, Dover Publ. 1981, Section 61, p. 176):

"*In the earlier field theories of gravitation already, it was the sign of the energy density of the gravitational field which had led to difficulties. In spite of these difficulties it would, on physical gounds, be hard to abandon the requirement that an analogue to the energy- and momentum-integrals of Newtonian theory should exist.*"

This led *T. Levi-Civita* and *H.A. Lorentz* to the belief that the sum of positive energy of matter and (postulated) negative energy of the gravitational field is always zero in a closed system.

Einstein rejected this assertion categorically [see his paper: "Über Gravitationswellen", Sitzungsberichte der königlich preußischen Akademie der Wissenschaften, Jahrgang 1918, Halbband 1, S. 154-167 [167]], because it would then be possible "*for a material system to vanish into nothing without leaving a trace*."

Moreover, one cannot but acknowledge that **t** is spatially and temporally indeterminate. Given this fact, the energy density of the gravitational field, which, in the rest frame of the postulated gravitational field energy, is nothing else but **t**, cannot be equal to the negative square of the clearly determinate gravitational field intensity.

Despite the impossibility of giving the energy density and the momentum density of the gravity field a definite value at a certain place and time, equation (3) is meaningful to Pauli and Einstein, since that equation appears to make it possible to (see Pauli, Theory of Relativity, Dover Publ. 1981, Section 61, p. 177) "*calculate the change in the material energy of a closed system in a simple fashion*.". For Pauli and Einstein, the principle of conservation of energy is observed in General Relativity by means of equations (3) and (4). Einstein put it the following way (A. Einstein, "Der Energiesatz in der allgemeinen Relativitätstheorie", aaO, S. 452):

"*Contrary to our present thinking habits, we thus arrive at attributing more reality value to an integral than to its differentials*."

b) But such a reasoning can be convincing only in case the principle of conservation of energy (and also the principle of conservation of momentum) is not understood as a *local* principle. Otherwise, that is, if one does understand the energy principle as a local one (saying that energy can never simply appear or disappear at some location, but can only flow into that location or out of it), then the two equations (3) and (4) – given that the local energy density is indeterminate in any frame of reference – are not sufficient to guarantee the principle of energy conservation in General Relativity.

This insufficiency surfaces in an obvious manner in Einstein's short paper "Notiz zu E. Schrödingers Arbeit 'Die Energiekomponenten des Gravitationsfeldes' " (Physikalische Zeitschrift, Vol. 19 – 1918 – , pp. 115/116):

"*There can well be gravitational fields without tensions and without energy density*."

When a test body is "gathering speed" in a gravitational field, energy has to flow into the test body from its immediate surroundings. This is similar to the case of an electric charge set into accelerated motion by an electric field (which, for this reason, can be said to be a "force field"), where the energy-flow (from the adjacent electric field into the accelerating charge) is made "visible" by the Poynting vector. Presuming (for a short while only) that no energy reservoir other than the gravitational field is available (!), energy has to flow from the gravity field into the test body. Then, however, the gravitational field cannot have zero energy density at this location.

c) To put it the other way round: If the gravity field is void of energy, it cannot be a force field.. Otherwise the principle of local conservation of energy would be violated.

2) The absence of any heavy mass (and hence of any energy density) of a gravitational field

a) If a gravity field were in possession of energy, it would have to have heavy mass [see A. Einstein, "The foundation of the general theory of relativity", translated from "Die Grundlage der allgemeinen Relativitätstheorie", Annalen der Physik, Vol. 354 – 1916 – , pp. 769, in: A. Einstein/H.A. Lorentz/ H. Minkowski/,"The Principle of Relativity", Dover Publ. 1952, § 16, p. 148: "*For if we consider a complete system (e.g. the solar system), the total mass of the system, and therefore its total gravitating action as well, will depend on the total energy of the system, and therefore on the ponderable energy together with the gravitational energy*."].

One can, however, show that the gravity field does not have any heavy mass or any energy. On the one hand, the lack of any energy or mass of the gravity field becomes obvious for logical reasons already, as the concept of an energy of the gravity fields leads to contradictions:

--Given that the gravitational "force" is spatially determinate (which is beyond doubt), and assuming (for a while) that the energy of the gravity field is a cause of this determinate "force", the energy of the gravity field, too, must be spatially determinate. It has to have a minimum energy density – and must insofar have a determinate energy – , enough to "feed" the increase in kinetic energy of a freely falling test object that is gathering speed.

– Presuming that **t** denotes the energy density of the gravitational field, the energy density of the gravitational field is locally indeterminate.

But the energy of the gravitational field cannot be determinate and indeterminate at the same time.

b) On the other hand, the absence of any energy of the gravity field follows from the Schwarzschild-equation (as a solution of Einstein's field equation for a non-rotating, spherical mass and its surroundings). According to the Schwarzschild-equation, the intensity of the gravitational "force" is inversely proportional to the square of the distance **r** (=circumference of a circle, divided by 2 pi) from the central spherical body, and directly proportional to its ordinary mass **M**, exactly the same as in Newton's law of gravitation.

Proof: If, in the formula for a **r**-geodesic, that is
(5)

$$\frac{d^2R}{d\tau^2} + \Gamma^1_{\mu\nu}\frac{dx^\mu}{d\tau}\frac{dx^\nu}{d\tau} = \frac{d^2r}{d\tau^2} + \Gamma^r_{\mu\nu}\frac{dx^\mu}{d\tau}\frac{dx^\nu}{d\tau} = 0$$

$d^2x^1/d\tau^2$ is exchanged for **$d^2r/d\tau^2$**, and if the Christoffel symbol, that is
(6)

$$\Gamma^{p}_{\mu\nu} = \frac{g^{pn}}{2}\left(\frac{\delta g_{n\mu}}{\delta x^{\nu}} + \frac{\delta g_{n\nu}}{\delta x^{\mu}} - \frac{\delta g_{\mu\nu}}{\delta x^{n}}\right)$$

is written in full detail on the basis of the Schwarzschild metric, that is, on the basis of the tensor
(7)

$$g_{\mu\nu} = \begin{matrix} 1-\frac{2GM}{c^2r} & 0 & 0 & 0 \\ 0 & -[c^2(1-\frac{2GM}{c^2r})]^{-1} & 0 & 0 \\ 0 & 0 & -\frac{r^2}{c^2} & 0 \\ 0 & 0 & 0 & -\sin^2\theta \end{matrix}$$

we get:
(8)

$$\frac{d^2R}{d\tau^2}\frac{d\tau^2}{dt^2}\frac{1}{r(1-r_s/r)} = -\frac{c^2r_s}{2r^3} - \frac{r_s}{2(1-r_s/r)^2r^3}\frac{dr^2}{dt^2} - \frac{d\varphi^2}{dt^2}$$

R stands for the radial distance measured by laying meter sticks end to end; **r** stands for the circumference of a circle around the spherical mass, divided by **2 pi**.

Since, according to the Schwarzschild metric, **dtau²/dt²** times **$(1-r_s/r)^{-1}$** equals unity if **tau** is the time of a (at least momentarily) stationary observer in the gravity field, and since with respect to a stationary object both **dr/dt** and **dphi/dt** are zero, we get for this situation from (8):
(9)

$$\frac{d^2R}{d\tau^2} = -\frac{c^2r_s}{2r^2} = -\frac{MG}{r^2}$$

or:
(10)

$$\frac{d^2R}{dt^2} = -\frac{c^2r_s}{2r^2}\left(1-\frac{r_s}{r}\right)$$

(10) is identical with the result obtained by Droste in 1917 (J. Droste, "The field of a single center in Einstein's theory of gravitation and the motion of a particle in that field", Proceedings of the Royal Netherlands Academy of Science, Vol 19 I, 1917, pp. 197-215, especially page 203). **M** is the ordinary mass of the spherical body, **G** is Newton's gravitational constant.

For a momentarily stationary observer in the gravity field, the gravitational acceleration $d^2R/dtau^2$, that is, the gravitational "force" per unit mass of a test body, is, according to (9), directly proportional to the mass **M** of the gravitating body (and does not differ from the acceleration yielded by Newton's law of gravitation). For if one doubles the ordinary density and hence the ordinary mass of the gravitating body, one doubles the gravitational "force".

If a heavy mass of the gravitational field appeared in the Schwarzschild-equation in a hidden manner and thus co-determined the intensity of the gravitational "force", and if one regarded the energy of the gravity field as being proportional to the positive or negative square of the intensity of the gravity field, a direct proportionality between the ordinary mass **M** and the gravitational "force" (as given by equation 9) would be unexplainable because of that quadratic relationship.

On top of this, (9) proves that the local gravitational "force", that is the "force" felt by a stationary observer in the field, is the same function of **r** as it is according to Newton's law of gravitation. field lines (outside of the central body) is the same expression of the local gravitational "force", that is of the "force" felt by a stationary local observer, as it is according to Newton's law of gravitation. Then the density of gravitional field lines, too, is the same expression of the local gravitational "force" as it is according to Newton's law of gravitation. Consequently, the gravitational field lines are divergenceless according to (9). This, too, shows: The gravity field that exists in empty space does not exhibit a heavy mass. Even more: There is no additional mass (=energy) at all – that would sit inside or outside of the central body – besides the ordinary gravitating mass.

Note that the absence of any mass or energy of the gravitational field occurs despite the fact that the components of the metric tensor **g** shown in (7) are not all zero or unity.

From this follows (recapitulated): According to the Schwarzschild-equation and hence according to General Relativity, heavy mass only exists in the form of ordinary mass **M**, not in the form of mass of the gravitational field. Hence, according to Special Relativity and its principle of equivalence of mass and energy, the gravitational field cannot have any energy.

Such a result is tacitly – though not explitly – acknowledged by C.W. Misner, K.S. Thorne, J.A. Wheeler in their famous standard textbook on gravitation (Gravitation, 1973, Chapter 20.4: Why the energy of the gravitational field cannot be localized, p. 467):

"*Not one of these properties does 'local gravitational energy-momentum' possess. There is no unique formula for it, but a multitude of quite distinct formulas. The two cited are only two among an infinity. Moreover, 'local gravitational energy-momentum' has no weight. It does not curve space. It does not serve as a source term on the righthand side of Einstein's field equations*."

With the local gravitational energy-momentum having no weight, and given the equivalence of heavy mass and energy, the gravitational field has no energy.

c) This recognition was anticipated by E. Schrödinger ("Die Energiekomponenten des Gravitationsfeldes", Physikalische Zeitschrift, Vol. 19 – 1918 –, pp. 4-7). Schrödinger combined (3) and the Schwarzschild-solution. He thereby achieved the following result (op. cit., pp. 6/7):

"*As mentioned above in an anticipating manner, it follows ... that **t** vanishes everywhere (outside of the gravitating sphere) identically in all four coordinates within the chosen frame of reference. 3. This result appears to me under all circumstances of massive importance for our idea of the physical nature of the gravitational field. For we either have to dispense with qualifying **t** – defined by (2) – as energy components of the gravitational field; thereby, however, the importance of the 'conservation principles' (see A. Einstein I.c) would collapse, and the task would arise to secure this integral part of the foundations in a new way. – If, instead, we hold on to the terms (2), then our calcucation teaches us that real gravity fields do exist (i.e., fields that cannot be 'transformed away'), with vanishing energy components, or, more precisely, energy components that can be 'transformed away'*; ..."

The latter of the two alternatives has to be dismissed: If there were real gravity fields, that is, gravity fields that cannot be "transformed away", these fields would, as real force-fields, have to have energy (and would, because of the equivalence of mass and energy, have to act as a source of gravitational field lines).

The only possible solution presents itself as follows: All gravitional fields can, without exception, be "transformed away", and have, as a consequence thereof, no energy. Hence, the term **t** does *not* stand for the energy components of the gravitational field.

3) The total absence of a real gravitational force and the indispensabiliy of the idea of flowing spaces in General Relativity

a) According to the solution of Einstein's field equation for spherical masses found by Schwarzschild (and by Droste only a short time thereafter), namely (**tau** stands for the proper time of an observer who is sitting in the gravity field, **t** idenotes the time of an observer who is at rest far away from the gravitating mass, **G** is Newton's gravitational constant, **c** is the speed of light, **r** denotes the "distance" between an observer and the center of the spherical, gravitating mass, with this distance **r** being circumference of a circle, divided by 2 pi; **theta** and **phi** are angles in the system of polar coordinates that are used)
(11)

$$d\tau^2 = g_{\mu\nu} dx^{\mu} dx^{\nu} = \left(1 - \frac{2GM}{c^2 r}\right) dt^2 - \frac{1}{c^2\left(1 - \frac{2GM}{c^2 r}\right)} dr^2 - \frac{r^2}{c^2}\left(d\theta^2 + \sin^2\theta \; d\varphi^2\right)$$

there is no gravitational force; instead, new space volume elements are steadily popping up in space out of nothing, so that space is permanently flowing towards the surface of the spherical mass, in order to disappear somewhere in its interior. The velocity of a volume element of space is increasing while the volume element is approaching the surface of the spherical body. Objects floating in space take part in that accelerated flow.

a) This description is justified already by the fact that it is only thereby that all gravity fields are capable of being "transformed away" (without the introduction of flowing or streaming space, spherically symmetrical gravitational forces can undoubtedly be transformed away only locally, but not ubiquitously). This capability, in turn, is indispensable for explaining the absence of energy of gravitational fields.

b) In addition, the above description is justified by the fact that Einstein's field equation can be summarized as follows (according to J.A. Wheeler): Masses in space tell space how to curve, and the curvature of space (not gravitational force) tells masses how to move. But the curvature of space can result in motions of masses only if volumes of space *move* in the reference frame of an observer.

An illustration of the flow of space volume is provided by a modification of the Schwarzschild-metric, namely by replacing $\mathbf{2MG/c^2r}$ with $\mathbf{H^2R^2/c^2}$, so that the metric can be applied to an expanding de-Sitter-universe characterized by a Hubble-constant **H** (=escape velocity, divided by distance) which is constant both in space and in time. (The replacement is achieved by setting all components of the tensor **T** appearing in Einstein's field equation equal to zero, and by setting Einstein's additional term on its left side, that is the summand that contains the cosmological constant **lambda** as a coefficient, no longer equal to zero, but giving **lambda** a positive numerical value.)

Then we get (**tau** is the proper time of a second observer far away from Earth and the Milky Way, **t** is the time of a first observer who sits on Earth, **R** is the distance between the two observers, measured as circumference of a circle around Earth, divided by 2 **pi**):
(12)

$$d\tau^2 = \left(1 - \frac{H^2R^2}{c^2}\right) dt^2 - \frac{1}{c^2\left(1 - \frac{H^2R^2}{c^2}\right)} dR^2 - \frac{R^2}{c^2}(d\theta^2 + \sin^2\theta \; d\varphi^2)$$

All points in space whose distance from the first observer is large enough are escaping toward the cosmic event horizon on straight lines. No force is exerted on objects, for instance, galaxies, that sit at those points in space. Instead, the accelerated motion is brought about by a steady expansion of space, that is, by a permanent popping up of space volume elements between the galaxies [see A. Einstein, Relativity – The Special and the General Theory, Bonanza Books 1961, Appendix IV, p. 134: *"Namely, the original field equations admit a solution in which the 'world radius' depends on time (expanding space)*."].

With regard to gravitational field of the spherical mass, the situation is just alike. Different from the expanding universe, though, the emerging space volume elements do not drift toward the cosmic event horizon, but to the surface of the spherical mass (or, if the spherical mass constitutes a Black Hole, to the Schwarzschild-horizon) (see H. Reichenbach, The Philosophy of Space and Time, Dover Publ. 1958, § 36, Fig. 41, p. 226), in order to disappear into nothingness in the interior of the spherical mass. Note that according to the Schwarzschild-equation, stationary, radially oriented meter sticks and stationary clocks in gravity fields behave exactly like meter sticks and clocks in Special Relativity do in case they are moving (on straight lines) at a velocity that is equal in amount to the escape velocity at the considered location in the gravity field. The straight and unaccelerated motion in Special Relativity is substituted by the flow of space (at a velocity that depends on radial distance) in General Relativity.

4) Empirical consequences of space that flows or streams

a) Thereby the gravitational force is completely and ubiquitously"transformed away" in the rigid reference frame of a far-away observer. The complete absence of any gravitational force is made evident especially when looking at electric charge that is falling in a gravity field. No electromagnetic radiation is generated. For a co-falling observer, the electrostatic field of a point charge stays spherical (otherwise the famous observer in a falling elevator cabin could, contrary to the principle of equivalence of heavy and inert mass, tell by means of a simple observation, namely by determining the shape of the electrostatic field of a charge, whether he is falling in a gravity field, or whether he is far away from heavy masses, instead). If the electrostatic field stays spherical-symmetrical for a co-falling observer, electromagnetic radiation is generated neither in the rest frame of the falling observer, nor – and that is of great importance -- in the rest frame of a far-away observer who is stationary with respect to the gravitating mass.

b) In comparison, things are very different when an electric charge is "falling" in an external *electric* field.(in the absence of gravity), i.e., if the charge is accelerated by the electric field. Then electromagnetic radiation is generated which is felt by the far-away observer, and for the co-falling observer the shape of the electrostatic field of the charge is distorted and no longer spherical-symmetrical.

This difference between the two scenarios provides justification for claiming that it is not only the charge, but also the surrounding space volume itself that, in case of a spherical symmetry of the electrostatic field, is in accelerated motion in a rigid freference frame of a distant observer.

c) It was Einstein himself who, a few years prior to his death, mentioned the possibility of moving space volumes (A. Einstein, Relativity – The Special and the General Theory, Bonanza Books 1961, Appendix V – supplemented in 1952 by Einstein –, pp. 138, 139):

"*When a smaller box is situated, relatively at rest, inside the hollow space of a larger box S, then the hollow space of s is a part of the hollow space of S , and the same 'space', which contains both of them, belongs to each of the boxes. When s is in motion with respect to S, however, the concept is less simple. One is then inclined to think that s encloses always the same space, but a variable part of the space S. It then becomes necessary to to apportion to* *each box its particular space, not thought of as bounded, and to assume that these two spaces are in motion with respect to each other.*

Before one has become aware of this complication, space appears as an unbounded medium or container in which material objects swim around. But it must now be remembered that that there is an infinite number of spaces, which are in motion with respect to each other. The concept of space as something existing objectively and independent of things belongs to pre-scientific thought, but not so the idea of the existence of an infinite number of spaces in motion relatively to each other. This latter idea is indeed logically unavoidable, but is far from having played a considerable role even in scientific thought."

5) The indispensability of "dark energy" in General Relativity

a) If it is taken for granted that the sum of kinetic and potential energy of a system of gravitating bodies is constant over time, and if it is also taken for granted that the gravitational field cannot have or give off any energy, it follows that an increase in the total kinetic energy of a system goes along with an appropriate decrease in some "dark energy" (and not in energy of a gravitational field). One should note that the seat of potential energy of a test body is never in the test body itself; when the potential is realized, energy disappears elsewhere, e.g. in the interior of some field.

General Relativity thus cannot dispense of a "dark energy reserve" for the description of everyday phenomena in nature. The seat of that "dark energy" cannot be found in three-dimensional space. Otherwise that energy would contribute to the curvature of space and hence to the intensity of the gravitational "force". Instead, one cannot do without the assumption of a fourth spatial dimension. It is in that fourth direction where the bulk of all "dark energy" must be located.

Thereby Schrödinger's vision (cited above) of "new foundations" of the energy conservation principle – that are required as soon as one is realizing that the gravity field is void of energy – is coming true.

b) Of course, in order to solve the task of quantifying the amount of energy absorbed or given off by the reserve of "dark energy", one is free to act as if the gravity field were in possession of a non-vanishing energy whose density is proportional to the negative square of the gravitational intensity in space. Nevertheless, one should always be aware of the fact that during a Helmholtz-contraction of a hollow gravitating sphere (by which, in theory, an infinite amount of mechanical work can be gained according to Newtonian physics), the field-free (!) space in the interior does not, contrary to common belief, possess a gravitational field with an infinite energy density [as regards the common belief, see only Brian Greene, "The Hidden Reality, Parallel Universes and the Deep Laws of the Cosmos", 2011, Note 9 to pages 65-70 – Chapter 3 – , p. 381: "*The gravitational field can supply the particles with such positive energy because gravity can draw down its own energy reserve, which becomes arbitrarily negative in the process: the closer the particles approach each other, the more negative the gravitational energy becomes (equivalently, the more positive the energy you'd* *need to inject to overcome the force of gravity and separate the particles once again). Gravity is thus like a bank that has a bottomless credit line and so can lend endless amounts of money; the gravitational field can supply endless amounts of energy because its own energy can become ever more negative. And that's the energy source that inflationary expansion taps*."; see also Alex Vilenkin, Many Worlds in One – The Search for Other Universes, 2006, Part I 1, pp. 11/12: "*So the energy of the inflating chunk must also have grown by a collossal factor, while energy conservation requires that it should remain constant. The paradox disappears if one remembers to include the contribution to the energy due to gravity. It has long been known that gravitational energy is always negative. This fact did not appear very important, but now it suddenly aquired a cosmic significance. As the positive energy of matter grows, it is balanced by the growing negative gravitational energy. The total energy remains constant, as demanded by the conservation law*."]. At that location, space is rather in communication with an inexhaustable reserve of 'dark energy'. Unfortunatey, no method of tapping this reserve in cyclic processes for technical purposes has been found so far.

c) The cosmological constant **lambda**, which has been correctly regarded as an expression of "dark energy", stands for nothing but that small fraction of "dark energy" which is not located in the direction of a fourth spatial dimension. In other words: The spatial position vector of this small part of "dark energy" points in the three familar spatial directions only, whereas the fourth component of this position vector is (practically) zero.

6) Free radial fall and free radial rise viewed by General Relativity; big and small "arrow of time"

a) For a distant observer who uses a rigid coordinate system (frame of reference), a test body which is falling at (**r**-dependent) escape velocity in a gravity field of a heavy mass is hence stationary relative to a flowing space volume element that surrounds the test body (while the test body is *not* stationary relative to the rigid system of coordinates the distant observer is using).

A test body freely falling at a velocity less than the **r**-dependent escape velocity does not change its velocity relative to the moving space volume element by which it is surrounded.

A test body sitting on the surface of the gravitating, spherical mass is not experiencing a downward "force" of gravity, but is experiencing upward intermolecular, repulsive forces from the surface on which it is sitting. These upward , intermolecular forces (that are counteracted by the inertia of the test body) do not manage, though, to set the test body in motion with respect to the surface of the sperical mass, but they do manage to set the test body in accelerated motion relative to a space volume element that is passing by.

b) But what if the test body is radially *rising* in free motion in the gravity field at (**r**-dependent) escape velocity? In that case, gravity in the reference frame of the distant observer can only be "transformed away" by assuming the existence of space volume elements that do not flow *towards* the gravitating mass, but *move away* from this mass (thereby reducing their velocity, which is always equal to the **r**-dependent escape velocity).

c) How can space flow towards the gravitating mass and also move away from it? One should recall that Einstein mentioned (in 1952) the possibility of numerous, different velocities of space volumes as “logically unavoidable”, without, however, providing examples. If one assumes that space volume elements are flowing toward the gravitating mass even when there is no test body in the gravity field, one is compelled to rate the rising motion of space volume elements as being a result of a partial time reversal. There is no other way of transforming the gravitational force away. The “transforming away” of the gravitational force, in turn, is indispensable for “depriving” the gravitatonial field of its energy (which is does not have according to the Schwarzschild metric).

A partial time reversal, that is, the encounter of a “big arrow of time” with a much smaller one, is known in principle. The existence of anti-matter and also of hole conduction in semiconductors can be described in this fashion. However, so far only phenomena that occur on the *microscopic* scale have been candidates for representing “small arrows of time”. This limitation is no longer justified. As a consequence, the concept of a definite, uniform direction of time as something intrinsic to the macroscopic objects is rigorously destroyed.

d) Since gravitation is not a force and since the gravitational field has no energy (quite different from an electric or magnetic field), it is hardly conceivable that, on the level of quantum mechanics, gravitation is put into effect by particles, that is by gravitons.

Moreover, given that gravitation and the expansion of space are manifestations of one and the same phenomenon, gravitons, if they existed, would have to play a decisive role in the expansion of the universe as well. Conversely: If, as is generally believed, gravitons do not play a decisive role in the expansion of the universe, they do not play a role in ordinary gravitation (Newton’s apple) either.

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