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ON THE POSSIBILITY OF A PROPULSION DRIVE CREATION THROUGH A LOCAL MANIPULATION OF SPACETIME GEOMETRY

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ABSTRACT

Since the shape of a free body's worldline is determined by the geometry of spacetime a local change of spacetime geometry will affect a body's worldline, i.e. a body's state of motion. The exploration of this possibility constitutes a radically new approach to the idea of how a body can be propelled: instead of applying a force to the body itself, the geometry of spacetime is subjected to a local manipulation which in turn results in the body's motion.

INTRODUCTION

It is the geometry of spacetime that determines the shape of a free body's worldline. If spacetime is flat, a straight worldline represents a body moving by inertia - the body is moving with a constant velocity and its motion is non-resistant. If spacetime is curved, a non-resistant (inertial) motion is represented by a geodesic worldline. In this case a body moving along a geodesic worldline (for instance, a falling body) offers no resistance to moving with acceleration with respect to a given reference frame (the Earth's surface, for example). It follows from here that if we can change the geometry of spacetime locally, we can change the shape of a body's geodesic worldline which is equivalent to making a body move without subjecting it to any force. Such a force-free motion is non-resistant no matter whether it is accelerated since the body continues to move along its geodesic worldline which has a different shape in the locally changed spacetime geometry.

The essential information concerning spacetime geometry is given by Riemann curvature tensor - if it is zero the spacetime is flat, otherwise it is curved. The nature of spacetime curvature, however, has been an unsolved puzzle in physics. In this paper an approach based on the classical electromagnetic mass theory which provides an insight into what the curvature of spacetime may mean is outlined.

One of the consequences of general relativity is that the velocity of electromagnetic signals (or simply the velocity of light) in the vicinity of massive objects is anisotropic; it is believed that this anisotropy is caused by the spacetime curvature. Using the anisotropic speed of light in the calculation of the self-force with which each non-inertial elementary charged particle (an electron, for example) acts upon itself on account of its own electric field leads to the following consequences. Due to the anisotropy of the speed of light the electric field of an electron on the Earth's surface is distorted which gives rise to a self-force originating from the interaction of the electron's charge with its distorted electric field. This self-force tries to force the electron to move downwards and coincides with what is traditionally called a gravitational force. The electric self-force is proportional to the gravitational acceleration **g** and the coefficient of proportionality is the mass "attached" to the electron's electric field which proves to be equal to the electron's mass. In such a way the electron's passive gravitational mass turns out to be purely electromagnetic in origin. This means that the only intrinsic property of an electron is its charge (and the resulting electromagnetic field). The mass of an electron is a secondary property corresponding to the energy stored in the electron's electromagnetic field. Simply put, there is no mass; there are only charges and electromagnetic fields.

The anisotropy of the speed of light is compensated if an electron is falling toward the Earth's surface with an acceleration **g**. In other words, the electron is falling in order to keep its electric field not distorted. A Coulomb (not distorted) field does not give rise to any self-force acting on the electron; that is why the motion of a falling electron is non-resistant as general relativity predicts. If an electron is prevented from falling it can no longer compensate the anisotropy of spacetime, its field distorts and as a result a self-force pulling the electron downwards arises.

Therefore the anisotropic speed of light around objects and the electromagnetic mass approach fully account for the gravitational properties of charged particles. In fact, this approach fully explains the gravitational attraction between bodies as well since the constituents of the neutron are also charged sub-particles (quarks). This is an indication that the anisotropy of spacetime (manifesting itself in the anisotropy in the propagation of electromagnetic signals) is not caused by a curvature of spacetime (since no curvature hypothesis is necessary) but itself can be interpreted as a curvature or as a gravitational field. In such a way, it turns out that Riemann curvature tensor, in fact, describes the spacetime anisotropy.

As an electron's passive gravitational mass in this approach is electromagnetic, its active gravitational mass, being equal to its passive gravitational mass, is electromagnetic too. And since it is the active gravitational mass of an electron that produces its gravitational field, i.e. the anisotropy of spacetime around the electron, it follows that the spacetime anisotropy originates from the electron's charge and electric field (since an electron possesses only charge and electric field). This means that the anisotropy of spacetime and therefore the spacetime geometry itself are locally *in principle* controllable since it is the charge and the electric field of an electron that cause the anisotropy of spacetime in its vicinity[*].

The behaviour of an electron in an accelerated reference frame is identical to that of an electron in the Earth's gravitational field (the anisotropy in the speed of light in this case is caused by the frame's accelerated motion). The electromagnetic field of an accelerated electron is distorted which results in an electromagnetic self-force acting upon the electron and resisting its accelerated motion. It is proportional to the electron's acceleration, the coefficient of proportionality being exactly its electromagnetic mass[1−10] (i.e. the mass "attached" to its electromagnetic field). In such a way, like gravitation and the passive gravitational mass, inertia and the inertial mass of an electron also turn out to be electromagnetic in nature[†]. And if we can control other electromagnetic phenomena nothing in principle prevents us from doing so to inertia and gravitation as well.

The approach followed in this paper leads to and confirms the basic results of recent publications by B. Haisch, A. Rueda and H. Puthoff[11−14] regarding the electromagnetic nature of inertia and gravitation. In their view inertia and gravitation result from interactions between the electromagnetic zero-point field and the elementary charged particles of matter. The fact that Haisch, Rueda and Puthoff's zero-point field approach and the source-field approach of this paper, which are in fact complimentary, come up with the same interpretation of inertia and gravitation can hardly be a pure coincidence.

In the sections which follow the anisotropic velocity of light in a gravitational field is calculated and it is shown that taking it into account in the calculation of the electric field of an electron in a gravitational field fully accounts for the electron's gravitational properties. The calculation of the electric potential, electric field and the self-force of a non-inertial electron is non-covariant since the physics is more transparent in this case; a covariant formulation is easily obtainable[10]. At this stage it appears that quantum mechanical treatment of the electromagnetic mass is not possible since quantum mechanics does not offer a model for the quantum object.

ANISOTROPIC VELOCITY OF LIGHT

In order to determine the expression for the anisotropic speed of light in the Earth's vicinity let us consider three points A, B and C on the x axis along the radial direction (when the origin of the Cartesian coordinates coincides with the Earth's center all coordinate axes x, y and z have radial directions). Light signals originate from point B and

[*] The controllability of spacetime geometry is a direct consequence of the fact that the sources of spacetime anisotropy (charges and electric fields), being electromagnetic phenomena themselves, are in principle controllable.

[†] What part of the mass is electromagnetic is an open question now. It is an accepted fact, however, that at least part of the mass of every charged particle is electromagnetic in origin. It has not been realized so far that an immediate consequence of this fact is that both inertia and gravitation prove to be at least partly electromagnetic as well.

reach point A lying above B at a distance r and point C situated bellow B at the same distance r. To determine the speed of light at A an C as seen from B we need the ratios of the length intervals at A, B an C. In Cartesian coordinates the interval in a gravitational field is[15]:

$$ds^2 = g_{\mu\nu}dx^\mu dx^\nu = \left(1 - \frac{2GM}{c^2R}\right)c^2dt^2 - \left(1 + \frac{2GM}{c^2R}\right)\left(dx^2 + dy^2 + dz^2\right),$$

where M is the mass of the gravitating body (in this case the Earth), R is the distance from the body's center to the point for which the interval is written, G is the gravitational constant and c is the velocity of light. Then the length interval dX_B at B in the x direction is,

$$dX_B \equiv ds_B = \sqrt{-g_{11}}dx \approx \left(1 + \frac{GM}{c^2R_B}\right)dx.$$

At A and C the length intervals dX_A and dX_C are:

$$dX_A \equiv ds_A \approx \left(1 + \frac{GM}{c^2R_A}\right)dx$$

$$dX_C \equiv ds_C \approx \left(1 + \frac{GM}{c^2R_C}\right)dx$$

Then the ratio of the lengths at A and B is:

$$\frac{dX_A}{dX_B} = \left(1 + \frac{GM}{c^2R_A}\right) / \left(1 + \frac{GM}{c^2R_B}\right) \approx \left(1 + \frac{GM}{c^2R_A} - \frac{GM}{c^2R_B}\right) \approx 1 - \frac{gr}{c^2} \qquad (1)$$

since $R_A = R_B + r$ and $GM/R_B^2 = g$, where g is the gravitational acceleration. The ratio of the lengths at C and B is analogously

$$\frac{dX_C}{dX_B} = \left(1 + \frac{GM}{c^2R_C}\right) / \left(1 + \frac{GM}{c^2R_B}\right) \approx \left(1 + \frac{GM}{c^2R_C} - \frac{GM}{c^2R_B}\right) \approx 1 + \frac{gr}{c^2} \qquad (2)$$

since $R_C = R_B - r$.

In order to calculate the speed of light at A as seen from B we are interested in seeing how much of B's proper time $d\tau_B$ (measured at B) it will take for the light to travel the distance dX_A (at A), which is the proper length of A. Two observers at A and B agree that the distance at A has the magnitude of dX_A. Using (1) we have for the speed of light at A as seen from B

$$c_A \equiv \frac{dX_A}{d\tau_B} = \frac{dX_B\left(1 - \frac{gr}{c^2}\right)}{d\tau_B} = c\left(1 - \frac{gr}{c^2}\right)$$

since the local speed of light $dX_B/d\tau_B = c$. Similarly from (2) the speed of light at C as seen from B is

$$c_C \equiv \frac{dX_C}{d\tau_B} = \frac{dX_B\left(1 + \frac{gr}{c^2}\right)}{d\tau_B} = c\left(1 + \frac{gr}{c^2}\right).$$

In vector notation the anisotropic speed of light in a gravitational field at a point at a distance r from B as seen from B is:

$$c^g = c\left(1 + \frac{\mathbf{g}\cdot\mathbf{r}}{c^2}\right)$$

The average velocity of light between the source point and the observation point is:

$$\bar{c}^g = c\left(1 + \frac{\mathbf{g}\cdot\mathbf{r}}{2c^2}\right) \qquad (3)$$

Here we consider only small distances for which $\mathbf{g}\cdot\mathbf{r}/2c^2 \ll 1$. This restriction makes it possible for the principle of equivalence to be applied and to relate results in a reference frame at rest on the Earth's surface and a reference frame moving with an acceleration $\mathbf{a} = -\mathbf{g}$.

GRAVITATIONAL ATTRACTION WITHOUT A GRAVITATIONAL FIELD

To demonstrate that the anisotropic speed of light in the Earth's vicinity fully accounts for the gravitational properties of an electron, as discussed in the introduction, let us first consider a stationary electron in a non-inertial frame N^g at rest on the Earth's surface. The electron's potential and electric field are distorted due to the anisotropic velocity of light (3). In order to calculate the force of repulsion between two charge elements de and de_1 of a non-inertial electron (at rest in N^g) we have to find the potential of a charge element de. The anisotropic speed of light (3) leads to two changes in the scalar potential (4) of an inertial charge element de:

$$d\varphi\left(r,t\right)=\frac{de}{4\pi\epsilon_o r}=\frac{\rho dV}{4\pi\epsilon_o r}, \quad (4)$$

where ρ is the charge density and dV is the volume of the charge element. First, r, determined as $r=ct$ (where t is the time it takes for an electromagnetic signal to travel from the charge element to the point at which the potential is determined), will have the form $r^g=\bar{c}^g t$ in N^g. Assuming $\mathbf{g}\cdot\mathbf{r}/2c^2 \ll 1$ we can write:

$$\left(r^g\right)^{-1}\approx r^{-1}\left(1-\frac{\mathbf{g}\cdot\mathbf{r}}{2c^2}\right). \quad (5)$$

The second change in (4) is a Liénard-Wiechert-like contribution to the scalar potential which has not been noticed up to now. It is analogous to the Liénard-Wiechert potentials resulting from an apparently larger dimension of a moving charge (in the direction of its motion) as viewed by an inertial observer I [16–19]. In N^g the electron is at rest but a volume element of it is apparently different from the actual volume element dV due to the anisotropic velocity of light (3). The anisotropic volume element (which contains the Liénard-Wiechert-like term) in N^g arises from the different average velocities of electromagnetic signals originating from the rear end and the front end of the charge element de (with respect to the observation point), and is given by[10]:

$$dV^g=dV\left(1-\frac{\mathbf{g}\cdot\mathbf{r}}{2c^2}\right) \quad (6)$$

where dV is the actual volume element (i.e. the volume element determined when the electron is at rest in an inertial reference frame). Now taking into account (5) and (6) the scalar potential of a charge element of the electron becomes

$$d\varphi^g=\frac{1}{4\pi\epsilon_0}\frac{\rho dV^g}{r^g}=\frac{1}{4\pi\epsilon_0}\frac{\rho dV}{r}\left(1-\frac{\mathbf{g}\cdot\mathbf{r}}{2c^2}\right)^2$$

or if we keep only the terms proportional to c^{-2}

$$d\varphi^g=\frac{\rho}{4\pi\epsilon_0 r}\left(1-\frac{\mathbf{g}\cdot\mathbf{r}}{c^2}\right)dV. \quad (7)$$

The potential (7) of a charge element de^g of a non-inertial electron contains a Liénard-Wiechert-like term (the expression in the brackets). The electric field of the charge element $de^g=\rho dV^g$ in N^g can be directly calculated by using only the scalar potential (7):

$$d\mathbf{E}^g=-\nabla d\varphi^g=\frac{1}{4\pi\epsilon_o}\left(\frac{\mathbf{n}}{r^2}-\frac{\mathbf{g}\cdot\mathbf{n}}{c^2 r}\mathbf{n}+\frac{1}{c^2 r}\mathbf{g}\right)\rho dV$$

and the field of the electron is

$$\mathbf{E}^g=\frac{1}{4\pi\epsilon_o}\int\left(\frac{\mathbf{n}}{r^2}-\frac{\mathbf{g}\cdot\mathbf{n}}{c^2 r}\mathbf{n}+\frac{1}{c^2 r}\mathbf{g}\right)\rho dV. \quad (8)$$

The self-force with which the electron's field interacts with another element ρdV_1^g of the electron charge is

$$\begin{aligned} d\mathbf{F}^g_{self} &= \rho dV_1^g\mathbf{E}^g \\ &= \frac{1}{4\pi\epsilon_o}\int\left(\frac{\mathbf{n}}{r^2}-\frac{\mathbf{g}\cdot\mathbf{n}}{c^2 r}\mathbf{n}+\frac{1}{c^2 r}\mathbf{g}\right) \\ &\quad \times\rho^2 dV dV_1^g. \end{aligned}$$

The resultant self-force with which the electron acts upon itself is:

$$\begin{aligned} \mathbf{F}^g_{self} &= \frac{1}{4\pi\epsilon_o}\int\int\left(\frac{\mathbf{n}}{r^2}-\frac{\mathbf{g}\cdot\mathbf{n}}{c^2 r}\mathbf{n}+\frac{1}{c^2 r}\mathbf{g}\right) \\ &\quad \times\rho^2 dV dV_1^g, \end{aligned}$$

which after taking into account the explicit form (6) of dV_1^g becomes

$$\begin{aligned} \mathbf{F}^g_{self} &= \frac{1}{4\pi\epsilon_o}\int\int\left(\frac{\mathbf{n}}{r^2}-\frac{\mathbf{g}\cdot\mathbf{n}}{c^2 r}\mathbf{n}+\frac{1}{c^2 r}\mathbf{g}\right) \\ &\quad \times\left(1-\frac{\mathbf{g}\cdot\mathbf{r}}{2c^2}\right)\rho^2 dV dV_1. \end{aligned} \quad (9)$$

Assuming a spherically symmetric distribution[1, 2] of the electron charge and following the standard procedure of calculating the self-force[20] we get:

$$\mathbf{F}^g_{self}=\frac{U}{c^2}\mathbf{g}, \quad (10)$$

where

$$U=\frac{1}{8\pi\epsilon_o}\int\int\frac{\rho^2}{r}dV dV_1$$

is the electron's electrostatic energy. As U/c^2 is the mass "attached" to the field of an electron, i.e. its electromagnetic mass, (10) obtains the form:

$$\mathbf{F}^g_{self}=m^g\mathbf{g}, \quad (11)$$

where m^g here is interpreted as the electron's passive gravitational mass. The self-force $\mathbf{F}^g_{self}$ which acts upon an electron on account of its own distorted field is directed parallel to $\mathbf{g}$ and resists its acceleration arising from the fact that the electron (at rest on the Earth's surface) is prevented from falling, i.e. from moving by inertia. This force is traditionally called a gravitational force but as we have seen $\mathbf{F}^g_{self}$ in (11) is purely electromagnetic in origin. This result explains why general relativity predicts that there is no gravitational force. The spacetime anisotropy around the Earth is sufficient to account for the force an electron on the Earth's surface is subjected to; this force, however, is not gravitational but electromagnetic.

The famous factor of 4/3 in the electromagnetic mass of the electron does not appear in (11). The reason is that in (9) we have used the correct volume element $dV_1^g = \left(1 - \frac{\mathbf{g}\cdot\mathbf{r}}{2c^2}\right) dV_1$. This apparent change of the volume element originates from the anisotropic speed of light in a non-inertial frame and taking it into account naturally removes the 4/3-factor without resorting to the Poincaré stresses (designed to explain the stability of the electron). Since its origin a century ago the electromagnetic mass theory of the electron has not been able to explain why the electron is stable (what holds its charge together). This failure has been used as evidence against regarding its entire mass as electromagnetic; it has been assumed that part of the electron mass originates from forces holding the electron charge together (known as Poincaré stresses). However, the problem of stability of the electron cannot be adequately addressed until a quantum-mechanical model of the electron structure is obtained. On the other hand, this problem can be successfully avoided in the case of the electromagnetic mass derived from the expression for the momentum of the electron's electromagnetic field[8, 9]. The stability problem does not interfere, as we have seen, with the derivation of the expression for the self-force containing the electromagnetic mass either. This hints that perhaps there is no real problem with the stability of the electron (as a future quantum mechanical model of the electron itself may find); if there were one it would inevitably emerge in the calculation of the self-force.

General relativity describes an electron falling in a gravitational field by a geodesic worldline. It implies that it moves by inertia and its Coulomb field should not be distorted which means that there should not exist any self-force acting on the electron. The electron's Coulomb field is not distorted as viewed by an inertial observer I falling with the electron. In order to obtain the electric field of an accelerated electron falling in the Earth's gravitational field ($\mathbf{a} = \mathbf{g}$) with respect to a non-inertial observer (at rest in N^g) we cannot use the Liénard-Wiechert potentials in N^g since they are valid only in an inertial reference frame (N^g is a non-inertial frame). Due to the anisotropic speed of light (3) in N^g they must include the Liénard-Wiechert-like term, contained in the potential (7):

$$\varphi^g(r,t) = \frac{e}{4\pi\epsilon_o}\frac{1}{r - \mathbf{v}\cdot\mathbf{r}/c}\left(1 - \frac{\mathbf{g}\cdot\mathbf{r}}{c^2}\right) \tag{12}$$

$$\mathbf{A}^g(r,t) = \frac{e}{4\pi\epsilon_o c^2}\frac{\mathbf{v}}{r - \mathbf{v}\cdot\mathbf{r}/c}\left(1 - \frac{\mathbf{g}\cdot\mathbf{r}}{c^2}\right). \tag{13}$$

The electric field of an electron falling in N^g (and considered instantaneously at rest[‡] in N^g) obtained from (12) and (13) is:

$$\mathbf{E} = -\nabla\varphi^g - \frac{\partial \mathbf{A}^g}{\partial t}$$

$$= \frac{e}{4\pi\epsilon_o}\left(\frac{\mathbf{n}}{r^2} + \frac{\mathbf{g}\cdot\mathbf{n}}{c^2 r}\mathbf{n} - \frac{1}{c^2 r}\mathbf{g}\right)$$

$$+\frac{e}{4\pi\epsilon_o}\left(-\frac{\mathbf{g}\cdot\mathbf{n}}{c^2 r}\mathbf{n} + \frac{1}{c^2 r}\mathbf{g}\right).$$

In such a way, the electric field of a falling electron in the reference frame N^g proves to be identical with the field of an inertial electron determined in its rest frame:

$$\mathbf{E} = \frac{e}{4\pi\epsilon_o}\frac{\mathbf{n}}{r^2}. \tag{14}$$

It follows from (14) that both an inertial observer (falling with the electron) and a non-inertial observer (at rest in N^g) detect a Coulomb field of the electron falling in N^g. In other words, while the electron is falling in the Earth's gravitational field its electric field at any instant is the Coulomb field which means that no force is acting on the electron, i.e. there is no resistance to its accelerated motion. This result sheds light on the fact that in general

[‡]The only reason for considering the instantaneous electric field is to separate the deformation of the electric field due to the Lorentz contraction from the distortion caused by the acceleration.

relativity the motion of a body falling toward a gravitating center is regarded as inertial (non-resistant) and is described by a geodesic worldline. Now we are in a position to answer the question why an electron is falling in a gravitational field and no force is causing its acceleration. As (14) shows, the only way for an electron to compensate the anisotropy in the propagation of the electromagnetic signals (responsible for the repulsion force each volume element of it is subjected to) and to keep its electric field not distorted is to fall with an acceleration $\mathbf{g}$. If the electron is prevented from falling its electric field distorts due to the anisotropic speed of light and the self-force (11) appears. It tries to force the electron to move (fall) in such a way that its field becomes the Coulomb field and as a result the self-force disappears.

We have, on the one hand, the result (14) which demonstrates that a Coulomb field is associated with a falling electron by *both* an inertial observer I (falling with the electron) and a non-inertial observer at rest in N^g. On the other hand, comparing the electric field (8) of an electron at rest in N^g(determined in N^g) and its field[19, 20] determined in I, in which the electron is instantaneously at rest (having an acceleration $\mathbf{a} = -\mathbf{g}$) shows that for both an observer in I and an observer in N^g the electron's field is equally distorted. This result reveals that there exists a unique connection between the shape of the electric field of an electron and its inertial state: if an electron is represented by a geodesic worldline (which means that it moves by inertia) its field is the Coulomb field - both an inertial observer I and a non-inertial observer N^g detect the same (Coulomb) field; if the worldline of an electron is not geodesic (meaning that the electron does not move by inertia), its electric field is deformed - both I and N^g observe the same distorted electric field. Stated another way, the inertial state of an electron is absolute and for this reason the shape of its electric field is also absolute (the same for both an inertial observer and a non-inertial observer).

CONCLUSIONS

The consequence of general relativity that the velocity of light around massive bodies is anisotropic and the classical electromagnetic mass theory reveal that gravitation is electromagnetic in origin:

(i) Due to the anisotropic speed of light the electric field of an electron on the Earth's surface is distorted which gives rise to an electric self-force trying to force the electron to move downwards. The self-force, being proportional to $\mathbf{g}$ with the coefficient of proportionality representing the mass that corresponds to the energy stored in the electron's electric field, is equal to what is traditionally called a gravitational force. In such a way, the nature of the force acting on a body on the Earth's surface is electromagnetic (since the body's constituents are all charged particles at the most fundamental level). This means that a body's passive gravitational mass is electromagnetic in origin too.

(ii) An electron is falling toward the Earth with an acceleration $\mathbf{g}$ in order to compensate the anisotropy in the propagation of electromagnetic signals (with which the different charged elements of the electron repel one another) which ensures that its electric field does not distort. The electron is not subjected to any self-force only if its electric field is the Coulomb field. If the electron is prevented from falling the compensation of the anisotropy of the speed of light is not possible any more and its electric field gets deformed which gives rise to a self-force pulling the electron downwards. This mechanism explains why all bodies fall toward the Earth with the *same* acceleration - each of their elementary charged constituents is falling with an acceleration $\mathbf{g}$ in order to prevent its electric field from being distorted.

It is believed that the anisotropy of the speed of light around a massive body is caused by the curvature of spacetime around the body (i.e. by the body's gravitational field). The spacetime curvature itself originates from the body's active gravitational mass. As we have seen, however, the mass of a body is electromagnetic in origin - this is the mass that corresponds to the energy stored in the electric fields of the body's elementary charged constituents. As there is no mass but only charges (and their fields), it follows that the anisotropy of the speed of light around a body is caused by the body's charges and their fields. In such a way, the spacetime curvature proves to be a spacetime anisotropy. And since charges and electromagnetic fields are in principle controllable, the anisotropy of spacetime and spacetime geometry itself are in principle controllable as well.

The theoretical possibility to manipulate the spacetime geometry constitutes a radically new approach to the understanding of how a body can be propelled. There is no need for any force to be applied to a body itself in order to propel it. Instead, the geometry of spacetime can be subjected to a local manipulation through the application of the sources of spacetime anisotropy - charges and electromagnetic fields. By changing the anisotropy of spacetime we are in fact changing the spacetime geometry. This in turn leads to a change of the shape of a body's geodesic worldline and ultimately to a change of a body's state of motion. In other words, a body can be propelled without being subjected to any direct force. This paper has demonstrated that this is possible at least in principle. How it can be done is the subject of ongoing work.

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