ISSUE ON MEASURING THE LIGHT SPEED IN VACUUM

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Abstract. Based on the proposed differential equations of the interaction of the electric signal with the gravitational field, the observed phenomena are known as the gravitational lens and the Shapiro effect are investigated. The deflection of a light ray in the field of the Sun is simulated. It is shown that a moving photon undergoes in the gravitational field not only a transverse action, which causes a curvature of the trajectory but also a longitudinal one, implementing the acceleration-braking processes. As a result, the instability of the speed of light in a vacuum was revealed.
Key words: Differential equations; gravitational lens; the light signal in gravity; speed of light in vacuum; quasi-constant.

1. Introduction

From ancient times people are concerned with methods of measuring the speed of light *c*. It is assumed that gravity and gravitational waves also propagate at the speed of light [1, 2]. Experiments to determine the speed of light have fulfilled G. Galileo. He has concluded that the light speed is much higher than the capabilities of the current measurement methods. Traditional methods of determination of the light speed are based on measuring the time of the light passing a certain way. An example of such measurements is the independent determination of the frequency and wavelength of a particular radiation. Historically correct estimation of light-speed was performed by O. Roemer, 1675 by observations of Jupiter's moons. Next studies have been carried out one after another until the 20th century until the 17th conference of the Main Commission of Measures and Weights (MCMW) put an end to it. The results of the research are summarized in Table 1, where the light speed is given in km/s.

Studies of the light speed by the scientists

1675	Roemer and Huygens	220000
1729	Bradley	301000
1849	Fizo	315000
1862	Foucault	298000±500
1907	Rose and Dorsey	299710±30
1926	Michelson	299726±4
1950	Essen and Gordon-Smith	299792±3
1958	Fromom	299792±0,1
1972	Evanson et al.	299792,4562±0,0011
1983	17th MCMW	*ñ* = 299792,458

The principle for the further development of physics was not the numerical value of speed, but experimental confirmation that the speed of light is finite. In addition, it is limited from above, as required by the Lorentz factor in special relativity (SR)

$$\gamma = \frac{1}{\sqrt{1 - v^2 / c^2}}, \qquad (1)$$

where *v* is the current speed.

In general relativity (GR) in gravitationally curved space or accelerated reference frames, the local speed of light is also constant and equal to *c*. However, some theories suggest that the speed of light may change over time [3, 4]. Moreover, there are convincing observable phenomena that confirm the aforementioned. Among them is the phenomenon of the gravitational lens and the Shapiro effect.

A gravitational lens is a massive body (star, planet), or system of bodies (galaxy, cluster of galaxies), which distorts the direction of propagation of electromagnetic radiation by its gravitational field, just as a normal lens distorts a ray of light. Among the observed cosmic effects of this phenomenon are known as Einstein's rings and cross, named after him for his contribution to GR. Einstein's rings are a type of gravitational lens that occurs when the observer is in line with the gravitational field source and the light source behind it. Einstein's cross is an image of a quasar distorted by a gravitational lens, located along the axis of view of the galaxy 2W2237 + 030. This quadrupled image forms a perfect cross with a lens galaxy in the center.

The Shapiro effect [5] is a known effect of the gravitational delay of the signal, which includes observations of the supernova SN1987A, which exploded in 1987 at 50000 pcs from the Sun. As a result, the flow of photons and neutrinos was recorded, but the photons appeared at 4.7 h. later than expected.

Based on the above, we have to admit that it is too early to put an end to the speed of *c* in Table 1. The metrological problem of measuring the speed of propagation of electromagnetic and gravitational fields is just entering a new round of study, but no longer as constants, but at least as quasi-constants. In support of this, let us recall that the first who questioned the constancy of velocity *c* was perhaps the main creator of the new physics H. Poincare.

2. Disadvantages

In GR, the effect of the interaction of the electromagnetic signal with the gravitational field is computed without proceeding from the differential equations of motion, and traditionally – by searching for a convenient approximating algebraic expression of these observations, as in the case of calculating the precession of the Mercury trajectory [6, 7]. Thus, Shapiro offers the expression of the gravitational delay of the light signal Δt in the form of:

$$\Delta t = -R_g \log(1 - \mathbf{r}_0 \cdot \mathbf{x}_0), \quad (2)$$

where R_g is the gravitational radius of the gravitating body (2.9); $\mathbf{r}_0, \mathbf{v}_0$ are unit vectors directed from the observer to the source and the gravitational mass. This time delay corresponds to the deformation of space at $\Delta x = c\Delta t$, and

$$R_g = \frac{2GM}{c^2}. \quad (3)$$

The question is, isn't it more natural to assume that c = *v*ar and leave alone long-suffering both time and space?

3. The Goal of the Work

To explain the phenomenon of the gravitational lens and the Shapiro effect based on differential equations of motion of celestial bodies. To simulate the mentioned phenomena in dynamics. To present the simulation results graphically and to analyze them.

4. Simulation of the Dynamics of the Interaction of a Light Signal with a Gravitational Field in Vacuum

If we study the phenomenon of the interaction of the gravitational and electromagnetic fields meticulously in theory, then some controversial issues arise. The first of them is the concept of mass of energy carriers. We consider it to appear by the formula $m = E/c^2$. And once it is present, it must enter not only into gravitational processes but also into inertial ones. Why inertial, because of the speed of light c = const? But no, if we agreed with the interaction itself, it not only distorts the trajectory of movement but inevitably determines the acceleration and braking action! This is where the shocking problem arises – the principle of the constancy of the speed of light in a vacuum.

This problem cannot be solved at the desk, therefore we concede a little in the scanty neighborhood of light speed (c = 299792458 ms^{-1}) its constancy, otherwise, the fact of the existence of a gravitational lens and the effect of gravitational signal delay lose their physical meaning.

With such an agreement, we get the opportunity to use proposed by us the differential equations of motion of celestial bodies in 3D space [8, 9]. To construct adequate equations of motion, it suffices to apply Newton's adopted law in the case of mutually movable interacting masses [8].

$$\mathbf{F} = G\frac{mM}{r^2}\left(1 + \frac{v^2}{c^2} + 2\frac{v}{c}\mathbf{r}_0 \cdot \mathbf{v}_0\right)\mathbf{r}_0, \quad (4)$$

where $\mathbf{F}$ is the vector of gravity between the masses m (moving) and M (gravitating); r is the distance between the centers of mass; G is the gravitational constant; $\mathbf{r}_0$, $\mathbf{v}_0$ is the unit vectors of trajectory and mutual instantaneous velocity v.

The equations of moving mass are obvious:

$$\mathbf{F} = m\frac{d\mathbf{v}}{dt}; \qquad \frac{d\mathbf{r}}{dt} = \mathbf{v}, \quad (5)$$

where **v, r** are velocity and distance vectors, but they need to be explained because they are light velocities. The functional dependence $m = m(v)$ is one of the annoying misunderstandings in physics, far from mathematics, and incorrect physical interpretation. It is a dependence on the speed of interaction of the masses, not the masses themselves! This crystallizes in the process of taking into account the finite velocity of field propagation.

The balance of forces (4), (5) in Cartesian coordinates is following [8, 9]:

$$\begin{aligned}
\frac{dv_x}{dt} &= -\frac{GMr_x}{r^3}\left(1 + \frac{v^2}{c^2} + 2\frac{r_x v_x + r_y v_y + r_z v_z}{cr}\right);\\
\frac{dv_y}{dt} &= -\frac{GMr_y}{r^3}\left(1 + \frac{v^2}{c^2} + 2\frac{r_x v_x + r_y v_y + r_z v_z}{cr}\right);\\
\frac{dv_z}{dt} &= -\frac{GMr_z}{r^3}\left(1 + \frac{v^2}{c^2} + 2\frac{r_x v_x + r_y v_y + r_z v_z}{cr}\right);\\
\frac{dr_x}{dt} &= v_x; \quad \frac{dr_y}{dt} = v_y; \quad \frac{dr_z}{dt} = v_z;\\
r &= \sqrt{r_x^2 + r_y^2 + r_z^2}; \quad v = \sqrt{v_x^2 + v_y^2 + v_z^2}.
\end{aligned} \quad (6)$$

where **v, r** are vectors of velocity and distance (in projections); M is gravitational mass; G is the gravitational constant.

If to carry out within the limits of the accepted compromise adaptation (6) to the solving of the set task in 2D space, we receive:

$$\frac{dv_x}{dt} = -2\frac{GM\,r_x}{r^3}\left(1+\frac{r_x v_x + r_y v_y}{rv}\right); \quad \frac{dr_x}{dt} = v_x;$$
$$\frac{dv_y}{dt} = -2\frac{GM\,r_y}{r^3}\left(1+\frac{r_x v_x + r_y v_y}{rv}\right); \quad \frac{dr_y}{dt} = v_y. \tag{7}$$

Based on (7), we simulate the curvature of the trajectory of the electromagnetic signal under the action of the gravitational field of the star. At the same time, we will discuss the contradiction of the obtained results in terms of observations.

Example 1. We simulate the correction of the trajectory of the light beam in the gravitational field of the Sun at the maximum convergence to $0.5\cdot 10^8$ m with its calculated surface. The results of numerical integration of equations (7) are shown in Fig. 1 and Fig. 2 at constant parameters $GM = 13{,}27128\cdot 10^{19}\ \text{m}^3\text{s}^{-2}$, corresponding to the Sun and the initial conditions:

$$r_x(0) = -12.0\cdot 10^8;\ r_y(0) = 7.5\cdot 10^8;\ v_x(0) = c;\ v_y(0) = 0.$$

Fig. 1 demonstrates the curvature of the trajectory of the light beam at the gravitational field of the Sun. Analysis of numerical data of the computer simulation showed that the beam in the time field of capture 12 s deviated by a very negligible angle – 0.857503" of the angular arc.

In calculations based on classical equations (under the action of Newton's force only), this angle turned out to be much smaller than 0.468197" of the angular arc, and when gravitomagnetic force (analog of the Lorentz force in a magnetic field) was involved [10–13], slightly increased to 0.936394" angular arc. Calculations performed by different methods only power the presence of the physical effect, confirmed by field observations.

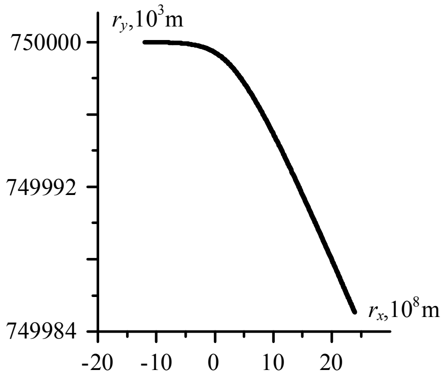

Fig. 1. The curvature of the trajectory of the light signal c(t), which flies around the Sun at a distance of 750000 km from its center

The further course of thought is chained to the time dependence of the signal propagation velocity (Fig. 2). It is its course and is a fundamental problem of theoretical physics – is the speed of light constant [12]?

The positive answer to this question is not only known but also endowed with the face of holiness. While in the current consideration, under the action of the Sun's gravity at the stage of the approach to the luminary, the obtained speed exceeds c by 213 ms^{-1} (299792671); and at the stage of increasing the distance, this speed diminishes from *c* by 1616 ms^{-1} (299790842). It is for the sake of this important information, the duration of the transitional process has been increased from 12 s to 25 s.

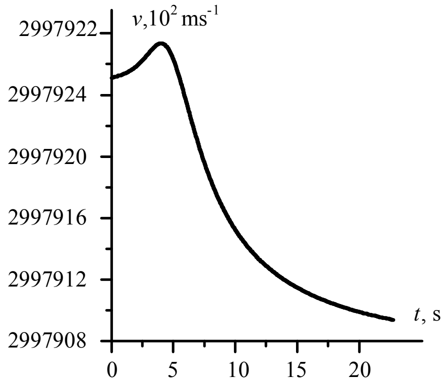

Fig. 2. The time dependence of the speed of the gravitational signal c=c (t), in the transition process, which corresponds to Fig. 1

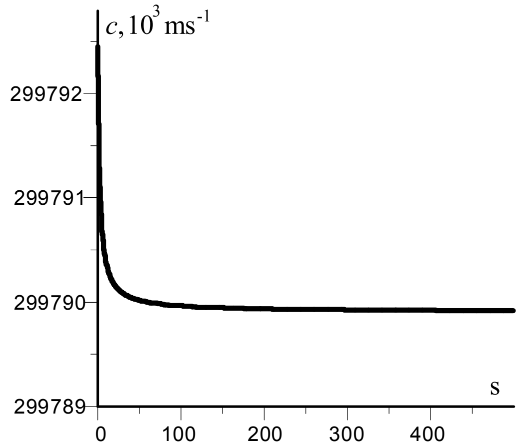

Fig. 3. The speed of light sunlight c = c (t) on a straight trajectory from the Sun to the Earth

Based on the dependence $c = c(t)$, obtained by the fundamental laws of physics, *can be safely transposed the light speed in vacuum c as a physical constant into a quasi-constant*, especially since this phenomenon is confirmed by observations.

The results of the simulation of the Shapiro effect are shown in Fig.3, as the time dependence of the speed of light along a rectilinear trajectory from the Sun to the Earth. This task is much simpler than the previous one since can be solved in 1D space. So, the differential equations of motion (5) acquire the simplest form [8]:

$$\frac{dv}{dt} = \frac{GM}{(R_g + h)^2}\left(1 - \frac{v}{c}\right)^2; \quad \frac{dh}{dt} = -v; \quad \frac{v_0 \le v \le c;}{h_0 \ge h \ge 0,} \quad (6)$$

here v_0, h_0 are the initial conditions.

Example 2. We simulate the trajectory of a photon from the Sun to the Earth.

The velocity characteristic of the sunbeam (Fig. 3), obtained as a result of integrating equations (6) for the value GM = $13{,}27128 \cdot 10^{19}$ and the initial conditions: $v_0 = c$; $h_0 = 6934 \cdot 10^8$. The signal lost 2542 ms^{-1} speed during the flight, and a third of this loss occurs in the first second. Time delay in equation (2) is 0.004 s. If only Newton's force is considered in the computation, this delay is quadrupled by 0.001 s. By the way, formula (7) is not applicable here.

J. Franson from the University of Maryland (USA), a supporter of the variable speed of light in a vacuum in the direction of its diminishing, substantiates the phenomenon from a quantum position [3]. Franson's argument is based on observations from the supernova SN 1987A, discussed above. He believes that photons can be slowed down due to the polarization of the vacuum: the photon spontaneously splits into a positron and an electron and then recombines into a photon. At this moment, a gravitational differential can appear between the particles, which can have a slight energy effect on them and delay the motion of the photon somewhat. On a long journey of 168 thousand light-years, such minor delays may well lead to a delay in 4.7 hours.

The main thing is that the results of observations fix the reality of the problem.

5. Conclusion

The simulation illustrates that the moving photon in the gravitational field enters not only into the transverse interaction, which causes the trajectory curvature but also into the longitudinal one, which leads to the acceleration-braking processes. The latter predetermines the fluctuations in the speed of light in a vacuum in the scanty range of values of c. Therefore, arises a new metrological problem of measuring the speed of light in a vacuum no longer as a constant, but as a function of time. Shortly, here not at all, there is no way to fulfill it without a close combination of experimental, theoretical, and simulation efforts.

6. Conflict of interest

The author claims that there are no possible financial or other conflicts over the work.

7. Gratitude

The author is grateful to prof. Svyatoslav Yatsyshyn for advice in presenting the manuscript to publishing.

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