Does the Velocity of Light Depend on the Source Movement?

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Data from spacecrafts tracking exhibit many anomalies that suggest the dependence of the speed of electromagnetic radiation with the motion of its source. This dependence is different from that predicted from emission theories that long ago have been demonstrated to be wrong. By relating the velocity of light and the corresponding Doppler effect with the velocity of the source at the time of detection, instead of the time of emission, it is possible to explain quantitatively and qualitatively the spacecraft anomalies. Also, a formulation of electromagnetism compatible with this conception is possible (and also compatible with the known electromagnetic phenomena). Under this theory the influence of the velocity of the source in the speed of light is somewhat subtle in many practical situations and probably went unnoticed (i.e. below the detection limit) in other measurements.

1 Introduction

In these lines I intend to show that there exists consistent evidence pointing to the need of revision and further study of what seem at present a settled issue, namely the independence of the speed of electromagnetic radiation on the motion of its source.

The main point in the evidence is the range disagreement during the Earth flyby of the spacecraft NEAR in 1998. Its range was measured near the point of closest approach using two radar stations, Millstone and Altair, of the Space Surveillance Network, and compared with the trajectory obtained from the Deep Space Network [1]. As for the range, the two measurements should match within a meter-level accuracy (the resolution is 5 m for Millstone and 25 m for Altair), but actual data showed a difference that varies linearly with time (with different slopes for the two radar stations) up to a maximum difference of about 1 km, i.e. more than 100 times larger than the accuracy of the equipment used (see figure 10 of [1]). Further, when NEAR crossed the orbits of Global Positioning System (GPS) satellites, orbital radius 26,600 km, the measured range difference was 650 m, that is, a time difference of 2 μs. Is it reasonable that any standard GPS receiver performs better than the Deep Space Network or the Space Surveillance Network?

There has not been a complete explanation for the range discrepancy. It is very difficult to find any physical reason that may produce this anomaly, for any physical disturbance of the path of the spacecraft should manifest equally in the Deep Space Network and the Space Surveillance Network data. Guruprasad [2] proposed an explanation that points to a time lag in the Deep Space Network signals proportional to the range, but the model is, at best, within 10% of the measured data (i.e. larger than the instrumental error) and, more important, it fails to explain an important feature, that is, the different slope for the two radars. If we assume that systems are working properly, then the measured range difference (time lag) could be due to different propagation time of the employed signals.

Additional points in the evidence come from anomalies related to the tracking of spacecrafts, present in both Doppler and ranging data. The Pioneer anomaly [3] and the flyby anomaly [4] refer to small residuals of the differences between measured and modeled Doppler frequencies of the radio signals emitted by the spacecrafts. Although these residuals are very small (less than 1 Hz on GHz signals) the problem is that they follow a non-random pattern, indicating failures of the model. According to the temporal variation of those residuals the Pioneer anomaly exhibits a main term, an annual term, a diurnal term and a term that appears during planetary encounters. It should be clarified that a few years ago an explanation of the Pioneer anomaly was published [5]. However, it is a very specific solution that applies only to the main term of the Pioneer spacecraft anomaly, but left unresolved many other anomalies, including those of the spaceships Cassini, Ulysses and Galileo; the annual term; the diurnal term; the increases of the anomaly during planetary encounters; the flyby anomaly; and the possible link between all them (it is hard to think that there are so many different causes for the mentioned anomalies). For all this, I believe that the issue can not be closed as it stands.

2 Range disagreement

As a matter of fact, the range difference between the Space Surveillance Network and the Deep Space Network, δR, is perfectly fitted with

$$\delta R\,(t) = -\frac{\mathbf{R}\,(t)\cdot\mathbf{v}\,(t)}{c}\,, \qquad (1)$$

where $\mathbf{R}\,(t)$ is a vector range pointing from the spacecraft to the radar, $\mathbf{v}\,(t)$ the spacecraft velocity relative to the radar, and c the speed of light. Figure 1 shows this fit and its comparison with measured data. The orbital and measured data were taken from [1]. Although the exact location of the radar stations are unknown to the author (approximate values are: Millstone 42.6° N 71.43° W, and Altair 9.18° N 167.42° E), the fit is statistically significant for both radar stations ($p < 10^{-3}$) including the first outliers points. It reproduces the (almost) linear dependence with time during the measured interval, and the two different slopes for Millstone and Altair stations due to their different locations.

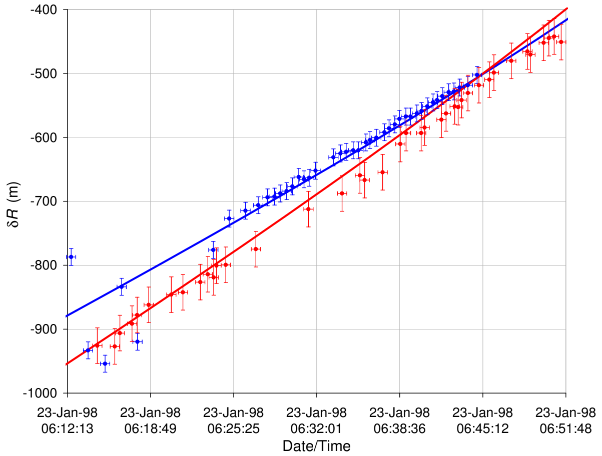

Fig. 1: Range disagreement between the Space Surveillance Network and the Deep Space Network, for 1998 NEAR flyby (Millstone blue points, upper trace, and Altair red points, lower trace). Also the fit (1) is plotted (full lines, Millstone in blue and Altair in red). For Millstone, the error bars refer to the uncertainties in the extraction of the data from figure 10 of [1], rather than to its tracking error (5 m), while for Altair, the accuracy is 25 m.

Since range measurements are based on time-of-flight techniques, the validity of (1) means that the electromagnetic waves (microwave) of the Deep Space Network and the Space Surveillance Network travel at different speeds. Specifically, in the radar frame of reference, if the Space Surveillance Network waves travel at c, then the Deep Space Network waves travel at c plus the projection of the spacecraft velocity in the direction of the beam, in sharp contrast with the Second Postulate of the Special Relativity Theory.

In view of the above result one may ask what is established, at present, about the relation of the speed of electromagnetic radiation (light for short) to the motion of the source. In order to elaborate this point the following questions are of relevance:

1. Are there *simultaneous* measurements of the speed of light from different moving macroscopic sources (not moving images) with different velocities?;
2. Since ballistic (emission) theories are ruled out (see, for example, DeSitter [6,7], Brecher [8] and Alväger et al [9]), how else could the speed of light depend on the source movement?;
3. How is it possible that there is a first order difference in v/c in spacecraft range measurements, while at the same time there are many experiments on time dilation that are consistent with Special Relativity Theory to second order in v/c (see, for example, [10])?;
4. If the velocity of light depend on the velocity of the source, why has this not been observed in other phenomena in the past?

In answer to the previous questions, so far as the author is aware, there is no known experimental work that simultaneously measures the speed of light from two different sources (not images), or that simultaneously measures the speed of light and that of its source. For example, in the work by Alväger et al, [9] the speed of light is measured at a later time (≈ 200 ns) than the emission time, and there is no measurement of the speed of the source at the time of the *detection* of the light.

Note that measurements involving moving images produce different results from those produced by mobile sources. For example, under Special Relativity Theory, a moving source is affected by time dilation while a moving image is not. Therefore, to ensure the independence of the speed of light from its source movement, it is essential to have two sources with different movements.

Although controversial and beyond the scope of the this note, time dilatation phenomena may be of different physical origin from first order terms, as it may be inferred from the work of Schrödinger [11]. Thus, measurements of time dilatation phenomena in accordance with Special Relativity Theory, does not necessarily imply the independence of the speed of light with the movement of the source.

The experiments mentioned above [6–9] only rule out ballistic theories in which radiation maintains the speed of the source at the time of *emission*, but do not rule out other ideas, like Faraday's 1846 [12].

3 Faraday's ray vibrations

In order to remove the ether, Faraday introduced the concept of vibrating rays [12], in which an electric charge is conceived as a center of force with attached "rays" that extend to infinity. The rays move with their center, but without rotating. According to this view, the phenomenon of electromagnetic radiation corresponds to the vibration of these "rays", that propagates at speed c relative to the rays (and the center). That is, the radiation remains linked to the source even after emitted. Today we could describe the interaction as a kind of entanglement between the charge and the photon. A framework for the electromagnetic phenomena according to Faraday's ideas was developed. It was called "Vibrating Rays Theory" [13] in reference to Faraday's "vibrating rays".

Under Faraday's idea, the velocity of radiation at a given epoch will be equal to c plus the velocity of the source at the *same* epoch, in contrast with ballistic theories in which the emitted light retains the speed of the source at the *emission* epoch. In this sense the radiation is always linked to the charge at every time after the emission. Consequently, the measured Doppler Effect corresponds to the speed of the source at the time of *reception*, as well.

Further, a difference between active and passive reflection is expected, since the latter is still related to the original source according to Vibrating Rays Theory. The Deep Space Network works with the so called active reflection (the spacecraft re-emits in real time a signal in phase with the received signal from Earth), while the Space Surveillance Network works with passive radar reflection. In consequence, the down-link signal from the approaching spacecraft will propagate faster that the reflected one. Using the available orbital data [1] we found that, under Vibrating Rays Theory, the theoretical time-of-flight difference between active and passive reflection gives exactly the same range disagreement as (1), see Part 6 of [13].

4 Pioneer anomaly

The Pioneer anomaly refers to the fact that the received Doppler frequency differs from the modeled one by a blue shift that varies almost linearly with time, and whose derivative is

$$\frac{d(\Delta f)}{dt} \approx -6 \times 10^{-9}\ \mathrm{Hz/s}, \tag{2}$$

where Δf is the frequency difference between the measured and the modeled values.

In the case of a source with variable speed, the main difference in Doppler (to first order) between Vibrating Rays Theory and Special Relativity Theory, is that Special Relativity Theory relates to the speed of the source at the time of *emission*, while Vibrating Rays Theory relates to the speed of the source at the time of *reception*. Precisely, this difference seems to be present in the spacecraft anomalies.

If Vibrating Rays Theory is valid, it automatically invalidates all calculations and data analysis of spacecraft tracking which are based on Special Relativity Theory. So, it is not easy to make a direct comparison between the expected results from Special Relativity Theory and Vibrating Rays Theory. However, to see whether or not the main features predicted by Vibrating Rays Theory are present in the measurements, we can evaluate the residual by simulating a measured Doppler signal assuming that light propagates in accordance to Vibrating Rays Theory but analyzed according to Special Relativity Theory.

Calling t_2 the emission time of the downlink signal from the spacecraft toward Earth and t_3 the reception time at Earth, the first order difference of the Doppler shift between Vibrating Rays Theory and Special Relativity Theory is (see [13] Part 4)

$$\Delta f = f_{VRT} - f_{SRT} \approx f_0 \hat{\mathbf{r}} \cdot \frac{\mathbf{v}_2 - \mathbf{v}_3}{c}, \tag{3}$$

where $\mathbf{v}_2$ and $\mathbf{v}_3$ represent the velocities of the spacecraft at the corresponding epoch, $\hat{\mathbf{r}}$ is the unit vector from the spaceship to the antenna, and f_0 the proper frequency of the signal. That is, the velocity used in the Special Relativity Theory formula is that at the time of *emission* while according to Vibrating Rays Theory is that corresponding at the time of *reception*.

Since the spacecraft slows down as it moves away, then $\hat{\mathbf{r}} \cdot (\mathbf{v}_2 - \mathbf{v}_3) > 0$, therefore the difference corresponds to a small blue shift mounted over the large red shift, as it has been observed in the Pioneer anomaly. It should be noted that this difference appears because of the active reflection produced by the on-board transmitter. In case of a passive reflection (for example, by means of a mirror) the above difference vanishes.

4.1 Main term

An estimate of the order of magnitude of 3 is obtained by using that the variation of the velocity of the spacecraft between the time of emission and reception is approximately

$$\mathbf{v}_2 - \mathbf{v}_3 \approx \mathbf{a}\,(t_2 - t_3), \tag{4}$$

where $\mathbf{a}$ is a mean acceleration during the down-link interval. An estimate for the duration of the down-link is simply

$$t_3 - t_2 \approx \frac{r}{c}, \tag{5}$$

where r is a mean position of the spaceship between t_2 and t_3, therefore

$$\Delta f \approx -f_0 \frac{\mathbf{r} \cdot \mathbf{a}}{c^2}.$$

Since

$$\mathbf{a} = -\frac{GM}{r^2}\hat{\mathbf{r}},$$

where G is the gravitational constant, and M the mass of the Sun, then, the time derivative becomes

$$\frac{d\,(\Delta f)}{dt} \approx f_0 \frac{\mathbf{v} \cdot \mathbf{a}}{c^2}. \tag{6}$$

If the difference (6) is interpreted as an anomalous acceleration we get

$$a_a \approx \frac{v}{c}\,a, \tag{7}$$

that is, the so-called anomalous acceleration is v/c times the actual acceleration of the spacecraft.

Using data from HORIZONS Web-Interface [14] for the spacecraft ephemeris, some characteristic value for a_a can be obtained. Consider the anomalous acceleration detected at the shortest distance of the Cassini spacecraft during solar conjunction in June, 2002. The spacecraft was at a distance of 7.42 AU moving at a speed of 5.76 km/s. The anomalous acceleration given by (7) is $a_a \approx 2\times10^{-9}$ m/s^2 of the same order of the measured one ($\approx 2.7\times10^{-9}$ m/s^2). Also, the closest distance at which the Pioneer anomaly has been detected was about 20 AU. the anomalous acceleration predicted by (7) at that distance is $a_a \approx 7.3 \times 10^{-10}$ m/s^2 of the same order as the measured one.

The "anomaly" given by (7) decreases in time in a way that has not been observed. Note, however, that according to Markwardt [15] the expected frequency at the receiver includes an additional Doppler effect caused by small effective path length changes, given by

$$\Delta f_{path} = -\frac{2f_0}{c}\frac{dl}{dt}, \tag{8}$$

where dl/dt is the rate of change of effective photon trajectory path length along the line of sight. This is a first order effect that can partially hide the difference between Special Relativity Theory and Vibrating Rays Theory. Therefore, a more careful analysis should take into account the additional contribution of (8) in (7).

Further, other first order effects may appear, for example, by a slight rotation of the orbital plane. Due to spacecraft maneuvers or random perturbations the orbital parameters are obtained by periodically fitting the measurements with theoretical orbits. Therefore there is no straightforward way to weight the importance of these fittings in (7). In other words, data acquisition and analysis may hide part of the Vibrating Rays Theory signature.

4.2 Annual term

Apart from the residual referred to in the preceding paragraph there is also an annual term. According to Anderson et al [16] the problem is due to modeling errors of the parameters that determine the spacecraft orientation with respect to the reference system. Anyway, Levy et al [17] claim that errors such as errors in the Earth ephemeris, the orientation of the Earth spin axis or the stations coordinates are strongly constrained by other observational methods and it seems difficult to modify them sufficiently to explain the periodic anomaly.

The advantage of studying the annual term over the main term, is that the former is less sensitive to the first order correction mentioned above, and, for the case of Pioneer, also to the thermal propulsion correction [5]. Clearly, the Earth orbital position does not modify those terms.

As before, the annual term is explained by the difference between the velocity of the spacecraft at the time of emission and that at the moment of detection, which depends on whether the spaceship is in opposition or in conjunction relative to the Sun. When the spacecraft is in conjunction, light takes longer to get back to Earth than in opposition. The time difference between emission and reception will be increased by the time the light takes in crossing the Earth orbit. Specifically, taking into account the delay due to the position of Earth in its orbit, in opposition equation (5) should be written as

$$t_3 - t_2 \approx \frac{r + R_{orb}}{c}, \tag{9}$$

while in conjunction it would be

$$t_3 - t_2 \approx \frac{r - R_{orb}}{c}, \tag{10}$$

where R_{orb} is the mean orbital radius of Earth.

Therefore, an estimate of the magnitude of the amplitude of the annual term is

$$\Delta f \approx f_0 \frac{aR_{orb}}{c^2}. \tag{11}$$

For the case of Pioneer 10 at 40 AU we get

$$\Delta f \approx 14 \text{ mHz}, \tag{12}$$

and at 69 AU

$$\Delta f \approx 4.8 \text{ mHz}, \tag{13}$$

in good agreement with the observed values.

Using data from HORIZONS Web-Interface [14] a more complete analysis of the time variation of Δf has be performed. The residual (that is, simulated Doppler using Vibrating Rays Theory but interpreted under Special Relativity Theory) during 12 years time span is plotted in figure 2. Also the dumped sine best fit of the 50 days average measured by Turyshev et al [18] is plotted showing an excellent agreement between measurements and Vibrating Rays Theory prediction. The negative peaks (i.e., maximum anomalous acceleration) occur during conjunction when the Earth is further apart from the spacecraft, and positive peaks during opposition. Also, the amplitude is larger at the beginning of the plotted interval and decreases with time, as it was observed [4, 18].

5 Flyby anomaly

Like the Pioneer anomaly, the Earth flyby anomaly can be associated to a modeling problem, in the sense that relativistic Doppler includes terms that are absent in the measured signals. The empirical equation of the flyby anomaly is given by Anderson et al [4], which, notably, can be derived using Vibrating Rays Theory, as is done in Part 6 of [13].

Consider the case of NEAR tracked by 3 antennas located in USA, Spain, and Australia (a full description of the tracking system is found in a series of monographs of the Jet Propulsion Laboratory [19]). The receiving antenna was chosen as that having a minimum angle between the spacecraft and the local zenith.

Using available orbital data, a simulated Doppler signal has been calculated using Vibrating Rays Theory. Thus, the simulated residual is obtained by subtracting the theoretical Special Relativity Theory Doppler, from the Vibrating Rays Theory calculation. We observed, however, that the term that contains the velocity of the antennas, that is

$$d = \frac{\gamma_{u_3}}{\gamma_{u_1}} \frac{1 - \hat{\mathbf{r}}_{23} \cdot \mathbf{u}_3/c}{1 - \hat{\mathbf{r}}_{12} \cdot \mathbf{u}_1/c}, \tag{14}$$

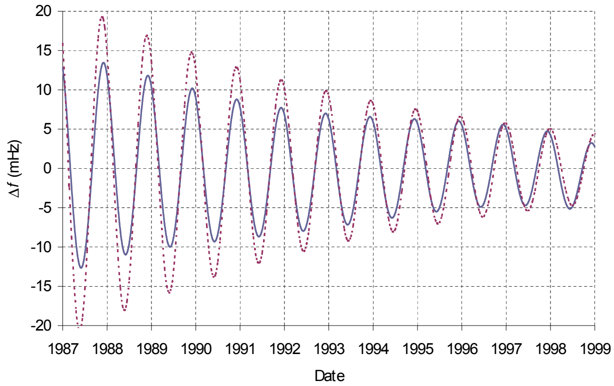

Fig. 2: Annual variation of the frequency difference between Vibrating Rays Theory and Special Relativity Theory (full line) and anomalous dumped sine best fit of the 50 days average measured by Turyshev et al [18] (dashed line), for Pioneer 10 from January 1987 to January 1999.

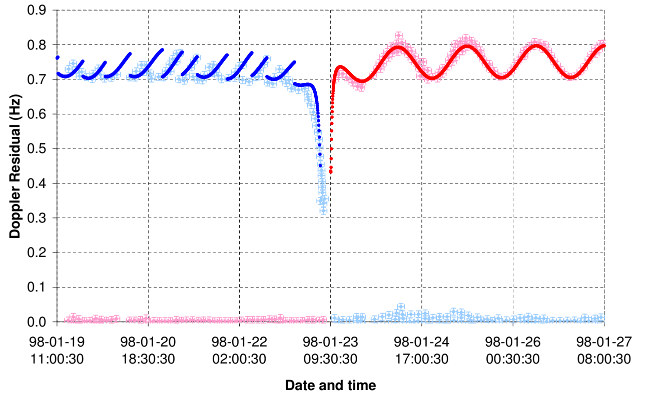

Fig. 3: Fitting the pre- (right half, in red) and post-encounter (left half, in blue) X-band Doppler data residual, for the NEAR flyby under an ideal hyperbolic orbit. Solid lines simulated according to Vibrating Rays Theory. Crosses, actual data extracted from reference [4].

is not enough to completely remove the first order (in u/c) Earth signature ($\mathbf{u}$ is the velocity of the antenna, 1 refers to the emission epoch and 3 to the reception epoch, as in [13] Part 4).

This is so because the velocity of the antennas is not uniform and the evaluation of the emission time is different for Vibrating Rays Theory and Special Relativity Theory. Then, a small first order term remains. Anyway, since orbital parameters are obtained by periodically fitting the measurements to theoretical orbits, thus a similar procedure is needed for Vibrating Rays Theory. Curiously, by doing so, the first order term is removed. The only difference between orbits adjusted by Special Relativity Theory and Vibrating Rays Theory is a slight rotation of the orbit plane, as mentioned above. Note that in the case of range disagreement (discussed above) two different orbital adjustment would be needed by the Deep Space Network and the Space Surveillance Network due to the different propagation speed. In consequence, it will be impossible to fit a simultaneous measurement, as it seems to happen with the range disagreement.

The final result shows that each antenna produces a sinusoidal residual with a phase shift at the moment of maximum approach. Therefore, if we fit the data with the pre-encounter sinusoid a post-encounter residual remains and vice versa.

In figure 3 are simultaneously plotted the result of fitting the residual by pre-encounter data (right half in red, corresponding to figure 2a of [4]) and by post-encounter data (left half in blue, corresponding to figure 2b of [4]).

Note that the simulated plots are remarkably similar to the reported ones, including the amplitude and phase (i.e., minima and maxima) of the corresponding antenna. The fitting of post-encounter data (blue) can be improved by appropriately setting the exact switching times of the antennas (which are unknown to the author). The flyby Doppler residual exhibits a clean signature of the Vibrating Rays Theory.

6 Conclusions

In this work I have presented observational evidence favoring a dependence of the speed of light on that of the source, in the manner implied in Faraday's ideas of "vibrating rays".

It is remarkable and very suggestive that, as derived from Faraday's thoughts, simply by relating the velocity of light and the corresponding Doppler effect with the velocity of the source at the time of detection, is enough to quantitatively and qualitatively explain a variety of spacecraft anomalies.

Also, it is worth mentioning that a formulation of electromagnetism compatible with Faraday's conception is possible, as shown in [13] Part 8, which is also compatible with the known electromagnetic phenomena. The most remarkable fact of this new formalism is the simultaneous presence of instantaneous (static terms) and delayed (radiative terms) interactions (i.e., local and nonlocal phenomena in the same interaction).

Finally, under Vibrating Rays Theory the manifestation of the movement of the source in the speed of light is more subtle than the naive $c + kv$ hypothesis (k is a constant, $0 \leq k \leq 1$) usually used to test their dependence [8]. Thus, it is also of fundamental importance the fact that, from the experimental point of view, it is very difficult to detect differences between Vibrating Rays Theory and Special Relativity Theory, as discussed in [13], which is also manifest in the smallness of the measured anomalies, and in the non clear manifestation of the effect in usual experiments and observations. For example, it produces a negligible effect on satellite positioning systems, see Part 7 of [13].

I am aware of how counterintuitive these conceptions are to the modern scientist, but also believe that, given the above evidence, a conscientious experimental research is needed to settle the question of the dependence of the speed of light on that of its source as predicted by Vibrating Rays Theory, and that has been observed during the 1998 NEAR flyby. As a closure, I recall Fox's words regarding the possibility of conducting an experiment on the propagation of light relative to the motion of the source: "*Nevertheless if one balances the overwhelming odds against such an experiment yielding anything new against the overwhelming importance of the point to be tested, he may conclude that the experiment should be performed*" [20].

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Editorial Comment

This paper plays an importance in the understanding of the physical observable velocity of light that differs from the world-invariant in the General Theory of Relativity.

Defining physical observable quantities in the General Theory of Relativity is not a trivial problem. This is because we are looking at objects in a four-dimensional space-time, and we have to determine which components of these four-dimensional tensor quantities are physically observable. A complete mathematical theory for calculating physically observable quantities in the four-dimensional space (space-time) of General Relativity was introduced in 1944 by Abraham Zelmanov, and is known as the *theory of chronometric invariants*[*]. Landau and Lifshitz in §84 of their *The Classical Theory of Fields* also introduced physically observable time and observable three-dimensional intervals similar to Zelmanov. But they limited themselves only to this particular case, while only Zelmanov arrived at the versatile mathematical theory. A compendium of Zelmanov's theory of physical observable quantities can also be found in the books[†].

In short, physically observable are the projections of four-dimensional quantities onto the time line and the three-dimensional spatial section of the observer, which can be non-uniform, deformed, curved and rotating. These projections are calculated through the special projecting operators which take all the aforementioned factors into account. In particular, the physical observable velocity of light differs from the world-invariant, and is depended on the gravitational potential and the rotation velocity of the observer's space. In ultimate physical conditions, as is shown in Chapter 5 of *Particles Here and Beyond the Mirror*[†], the observable velocity of light can even become zero, that is verified by the frozen light experiment (Lene Hau, 2001).

Even more. In a physical space (space-time metric) wherein is a shift at one of the spatial directions (that means a spatial anisotropy), the observable velocity of light is depended on the signal source's velocity at this preferred direction. We drafted such a space-time metric in the last decade.

Einstein's postulates have now only a historical meaning. Once Einstein moved his theory on the mathematical basis of Riemannian geometry, he found that all the postulates are the manifestations of geometry of Riemannian spaces. It is as well true about the world-invariant of the velocity of light. In a space, which is free of gravitation, is uniform, non-deformed, and non-rotating, the physical observable velocity of light coincides with the world-invariant. However in a real physical space it does not.

For this reason the experimental compendium and the analysis presented in Bilbao's paper will maybe give a new fresh stream in search for the further theoretical predictions of the General Theory of Relativity.

Dmitri Rabounski, Editor-in-Chief
Larissa Borissova, Assoc. Editor

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