The Mössbauer rotor experiment and the general theory of relativity

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Abstract

In the recent paper Eur. Phys. Jour. Plus 130, 191 (2015), the authors claim that our general relativistic analysis in Ann. Phys. 355, 360 (2015), with the additional effect due to clock synchronization, cannot explain the extra energy shift in the Mössbauer rotor experiment. In their opinion, the extra energy shift due to the clock synchronization is of order $10^{-13}$ and cannot be detected by the detectors of $\gamma$-quanta which are completely insensitive to such a very low order of energy shifts. In addition, they claim to have shown that the extra energy shift can be explained in the framework of the so-called YARK gravitational theory. They indeed claim that such a theory should replace the general theory of relativity (GTR) as the correct theory of gravity.

In this paper we show that the authors Eur. Phys. Jour. Plus 130, 191 (2015) had a misunderstanding of our theoretical analysis in Ann. Phys. 355, 360 (2015). In fact, in that paper we have shown that electromagnetic radiation launched by the central source of the apparatus is redshifted of a quantity $0.6\sqrt{v^2/c^2}$ when arriving to the detector of $\gamma$-quanta. This holds independently by the issue that the original photons are detected by the resonant absorber which, in turns, triggers the $\gamma$-quanta which arrive to the final detector. In other words, the result in Ann. Phys. 355, 360 (2015) was a purely theoretical result that is completely independent of the way the experiment is concretely realized. Now, we show that, with some clarification, the results of Ann. Phys. 355, 360 (2015) hold also
when one considers the various steps of the concrete detection. In that case, the resonant absorber detects the energy shift and the separated detector of $\gamma$-quanta merely measures the resulting intensity.

In addition, we also show that the YARK gravitational theory is in macroscopic contrast with geodesic motion and, in turn, with the weak equivalence principle (WEP). This is in contrast with another claim of the authors of Eur. Phys. Jour. Plus 130, 191 (2015), i.e. that the YARK gravitational theory arises from the WEP. Therefore, the YARK gravitational theory must be ultimately rejected. We also correct the confusion of the authors of Eur. Phys. Jour. Plus 130, 191 (2015) concerning their claims about the possibility to localize the gravitational energy and, in turn, to define a stress-energy tensor for the gravitational field. In fact, we show that these claims are still in macroscopic contrast with the WEP.

Paper dedicated to the centenary of the GTR.

1 Introduction

In [16] we gave a correct interpretation of a historical experiment by Kündig on the transverse Doppler shift in a rotating system measured with the Mössbauer effect (Mössbauer rotor experiment) [3]. The Mössbauer effect (discovered by R. Mössbauer in 1958 [14]) consists in resonant and recoil-free emission and absorption of gamma rays, without loss of energy, by atomic nuclei bound in a solid. It resulted and currently results very important for basic research in physics and chemistry. In [16] we focused on the so called Mössbauer rotor experiment. In this particular experiment, the Mössbauer effect works through an absorber orbited around a source of resonant radiation (or vice versa). The aim is to verify the relativistic time dilation for a moving resonant absorber (the source) inducing a relative energy shift between emission and absorption lines.

In a couple of recent papers [1, 2], the authors first re-analysed in [1] the data of a known experiment of Kündig on the transverse Doppler shift in a rotating system measured with the Mössbauer effect [3]. In a second stage, they carried out their own experiment on the time dilation effect in a rotating system [2]. In [1] it has been found that the original experiment by Kündig [3] contained errors in the data processing. A puzzling fact was that, after correction of the errors of Kündig, the experimental data gave the value

$$\nabla \frac{E}{E} \simeq -k \frac{v^2}{c^2},$$

(1)

where $k = 0.596 \pm 0.006$, instead of the standard relativistic prediction $k = 0.5$ due to time dilatation. The authors of [1] stressed that the deviation of the coefficient $k$ in equation (1) from 0.5 exceeds by almost 20 times the measuring error and that the revealed deviation cannot be attributed to the influence of rotor vibrations and other disturbing factors. All these potential disturbing factors have been indeed excluded by a perfect methodological trick applied by Kündig [3], i.e. a first-order Doppler modulation of the energy of $\gamma$-quanta.
on a rotor at each fixed rotation frequency. In that way, Kündig’s experiment can be considered as the most precise among other experiments of the same kind [4–8], where the experimenters measured only the count rate of detected $\gamma$-quanta as a function of rotation frequency. The authors of [1] have also shown that the experiment [8], which contains much more data than the ones in [4–7], also confirms the supposition $k > 0.5$. Motivated by their results in [1], the authors carried out their own experiment [2]. They decided to repeat neither the scheme of the Kündig experiment [3] nor the schemes of other known experiments on the subject previously mentioned above [4–8]. In that way, they got independent information on the value of $k$ in equation (1). In particular, they refrained from the first-order Doppler modulation of the energy of $\gamma$-quanta, in order to exclude the uncertainties in the realization of this method [2]. They followed the standard scheme [4–8], where the count rate of detected $\gamma$-quanta $N$ as a function of the rotation frequency $\nu$ is measured. On the other hand, differently from the experiments [4–8], they evaluated the influence of chaotic vibrations on the measured value of $k$ [2]. Their developed method involved a joint processing of the data collected for two selected resonant absorbers with the specified difference of resonant line positions in the Mössbauer spectra [2]. The result obtained in [2] is $k = 0.68 \pm 0.03$, confirming that the coefficient $k$ in equation (1) substantially exceeds 0.5. The scheme of the new Mössbauer rotor experiment is in Figure 1, while technical details on it can be found in [2].

In [16], the equivalence principle (EP), which states the equivalence between the gravitational "force" and the pseudo-force experienced by an observer in a non-inertial frame of reference (included a rotating frame of reference) has been used to re-analyse the theoretical framework of Mössbauer rotor experiments. A full geometric general relativistic treatment was developed directly in the rotating frame of reference [16]. The results have shown that previous analyses missed an important effect of clock synchronization and that the correct gen-
eral relativistic prevision gives $k \simeq \frac{3}{2}$ \[16\]. This was in perfect agreement with the new experimental results of \[2\]. In that way, the general relativistic interpretation of \[16\] showed that the new experimental results of the Mössbauer rotor experiment are a new, strong and independent proof of the correctness of Einstein’s vision of gravity. We also stress that various papers in the literature (included ref. \[4\] published in Phys. Rev. Lett.) missed the effect of clock synchronization \[11\]-\[13\], \[11\]-\[13\] with some subsequent claim of invalidity of relativity theory and/or some attempts to explain the experimental results through “exotic” effects \[11\] \[16\] \[11\] \[12\] \[13\].

In the recent paper \[17\], it is claimed that the general relativistic analysis in \[16\], with the additional effect due to clock synchronization, cannot explain the extra energy shift in the Mössbauer rotor experiment. The reason should be that the extra energy shift due to the clock synchronization is of order $10^{-13}$ and cannot be detected by the detectors of $\gamma$-quanta which are completely insensitive to such a very low order of energy shifts \[17\]. In addition, the authors of \[17\] claim to have shown that the extra energy shift can be explained in the framework of the so-called YARK gravitational theory. They also claim that such a new theory should replace the GTR as the correct theory of gravity.

In this paper we show that in \[17\] the authors had a misunderstanding of our theoretical analysis in \[16\]. In fact, in \[16\] it has been shown that electromagnetic radiation launched by the central source of the apparatus is redshifted of a quantity $0.6 \frac{v}{c}$ when arriving to the detector of $\gamma$-quanta. This holds independently by the issue that the original photons are detected by the resonant absorber which, in turns, triggers the $\gamma$-quanta which arrive to the final detector. In other words, the result in \[16\] was a purely theoretical result that is completely independent of the way the experiment is concretely realized. Now, we show that, with some clarification, our results in \[16\] hold also when we consider the various steps of the concrete detection. In that case the resonant absorber detects the energy shift and the separated detector of $\gamma$-quanta merely measures the resulting intensity.

In addition, in this paper we also show that the YARK gravitational theory is in macroscopic contrast with geodesic motion and, in turn, with the WEP. This in contrast with another claim of the authors of of \[17\], stating that the YARK gravitational theory should arise from the WEP. Therefore, the YARK gravitational theory must be ultimately rejected. We also correct the confusion in \[17\] concerning the claims about the possibility to localize the gravitational energy and, in turn, to define a stress-energy tensor for the gravitational field. In fact, we show that these claims are still in macroscopic contrast with the WEP.

2 The “gravitational” redshift

Following \[16\] \[16\] let us consider a transformation from an inertial frame, in which the space-time is Minkowskian, to a rotating frame of reference. Using cylindrical coordinates, the line element in the starting inertial frame is \[16\] \[16\]
\[ ds^2 = c^2 dt^2 - dr'^2 - r'^2 d\phi'^2 - dz'^2. \quad (2) \]

The transformation to a frame of reference \( \{ t', r', \phi', z' \} \) rotating at the uniform angular rate \( \omega \) with respect to the starting inertial frame is given by \( [9, 16] \)

\[ t = t', \quad r = r', \quad \phi = \phi' + \omega t', \quad z = z'. \quad (3) \]

Thus, eq. (2) becomes the following well-known line element (Langevin metric) in the rotating frame \( [9, 16] \)

\[ ds^2 = \left( 1 - \frac{r'^2 \omega^2}{c^2} \right) c^2 dt'^2 - 2 \omega r'^2 d\phi' dt' - dr'^2 - r'^2 d\phi'^2 - dz'^2. \quad (4) \]

The transformation (3) is both simple to grasp and highly illustrative of the general covariance of the GTR as it shows that one can work first in a "simpler" frame and then transforming to a more "complex" one \( [16, 17] \). As we consider light propagating in the radial direction \( (d\phi' = dz' = 0) \), the line element (4) reduces to \( [16] \)

\[ ds^2 = \left( 1 - \frac{r'^2 \omega^2}{c^2} \right) c^2 dt'^2 - dr'^2. \quad (5) \]

The EP permits to interpret the line element (5) in terms of a curved spacetime in presence of a static gravitational field \( [10, 15, 16] \). In that way, we obtain a purely general relativistic interpretation of the pseudo-force experienced by an observer in a rotating, non-inertial frame of reference \( [15] \). Setting the origin of the rotating frame in the source of the emitting radiation, we have a first contribution which arises from the "gravitational redshift". It can be directly computed using eq. (25.26) in \( [10] \). In the twentieth printing 1997 of \( [10] \) that equation is written as

\[ \Delta \lambda \equiv \frac{\lambda_{\text{received}} - \lambda_{\text{emitted}}}{\lambda_{\text{emitted}}} = |g_{00}(r'_1)|^{-\frac{1}{2}} - 1. \quad (6) \]

Eq. (6) represents the redshift of a photon emitted by an atom at rest in a gravitational field and received by an observer at rest at infinity. Here we use a slightly different equation with respect to eq. (25.26) in \( [10] \). In fact, here we are considering a gravitational field which increases with increasing radial coordinate \( r' \) while eq. (25.26) in \( [10] \) concerns a gravitational field which decreases with increasing radial coordinate \( [16] \). Also, we set the zero potential in \( r' = 0 \) instead of at infinity and we use the proper time instead of the wavelength \( \lambda \) \( [16] \). Thus, from eqs. (5) and (6) we get \( [16] \)

\[ z_1 \equiv \frac{\Sigma_{\text{rad}} - \Sigma_{\text{rad}}}{r} = 1 - |g_{00}(r'_1)|^{-\frac{1}{2}} = 1 - \frac{1}{\sqrt{1 \left( \frac{r'_1}{c} \right)^2 \omega^2}} = 1 - \frac{1}{\sqrt{1 - \frac{v^2}{c^2}}} \cong 1 - \frac{1}{2} \frac{v^2}{c^2}. \quad (7) \]
In eq. (7) $\nabla \tau_{10}$ is the delay of the emitted radiation, $\nabla \tau_{11}$ is the delay of the received radiation, $r'_1 \simeq c\tau$ is the radial distance between the source and the resonant absorber and $v = r'_1 \omega$ is the tangential velocity of the resonant absorber in the rest frame. Hence, we find a first contribution, say $k_1 = \frac{1}{2}$, to $k$ \[16\]. We stress again that the power of the EP enabled us to use a pure general relativistic treatment in the above discussion \[16\].

3 The missing effect: clock synchronization

Notice that we calculated the variations of proper time $\nabla \tau_{10}$ and $\nabla \tau_{11}$ in the origin of the rotating frame which is located in the source of the radiation \[16\]. But the detector of $\gamma$-quanta is moving with respect to the origin in the rotating frame and with respect to the resonant absorber, see Figure 1. Thus, the clock in the detector of $\gamma$-quanta must be synchronized with the clock in the origin. This gives a second contribution to the redshift and is exactly the point that generated confusion in our previous work \[16\]. In fact, the authors of \[17\] claimed that our analysis in \[16\] was incorrect. Let us clarify this point in an ultimate way. To compute this second contribution we use eq. (10) of \[9\] which represents the proper time increment $d\tau$ on the moving clock having radial coordinate $r'$ for values $v \ll c$

$$
d\tau = dt' \left( 1 - \frac{r'^2 \omega^2}{c^2} \right). \quad (8)
$$

Inserting the condition of null geodesics $ds = 0$ in eq. \[10\] one gets \[16\]

$$
cdt' = \frac{dr'}{\sqrt{1 - \frac{r'^2 \omega^2}{c^2}}}. \quad (9)
$$

The positive sign in the square root has been taken because the radiation is propagating in the positive $r$ direction \[16\]. Combining eqs. \[8\] and \[9\] one obtains \[16\]

$$
cd\tau = \sqrt{1 - \frac{r'^2 \omega^2}{c^2}} \, dr'. \quad (10)
$$

Eq. \[10\] is well approximated by \[16\]

$$
cd\tau \simeq \left( 1 - \frac{1}{2} \frac{r'^2 \omega^2}{c^2} + \ldots \right) \, dr', \quad (11)
$$

which permits to find the second contribution of order $\frac{v^2}{c^2}$ to the variation of proper time as \[16\]

$$
c \nabla \tau_2 = \int_0^{r'_1} \left( 1 - \frac{1}{2} \frac{r'^1_1 \omega^2}{c^2} \right) \, dr' - r'_1 = -\frac{1}{6} \frac{(r'^1_1)^3 \omega^2}{c^2} = -\frac{1}{6} \frac{r'_1 v^2}{c^2}. \quad (12)
$$
$r'_1 \simeq c\tau$ is the radial distance between the source and the resonant absorber. Thus, we get the second contribution of order $\frac{v^2}{c^2}$ to the redshift as [16] 

$$z_2 \equiv \frac{\nabla \tau_2}{\tau} = -k_2 \frac{v^2}{c^2} = -\frac{1}{6} \frac{v^2}{c^2}.$$  

(13)

Then, we obtain $k_2 = \frac{1}{6}$. Using eqs. (7) and (13), the total redshift is [16] 

$$z \equiv z_1 + z_2 = \frac{\nabla \tau_1 - \nabla \tau_2}{\tau} = - (k_1 + k_2) \frac{v^2}{c^2}$$

$$= - \left( \frac{1}{2} + \frac{1}{6} \right) \frac{v^2}{c^2} = -\frac{2}{3} \frac{v^2}{c^2} = 0.6 \frac{v^2}{c^2}.$$  

(14)

Eq. (14) is completely consistent with the result $k = 0.68 \pm 0.03$ in [2]. Let us clarify the meaning of eq. (14). It represents the total energy shift that is detected by the resonant absorber as it is measured by an observed located in the detector of $\gamma$-quanta, i.e. located where we have the final output of the measuring. This is different from the total energy shift that is detected by the resonant absorber as it is measured by an observed located in the resonant absorber, which, instead, is given by eq. (7). In fact, the two quantities should be equal only if the detector of $\gamma$-quanta should be rotating together with the resonant absorber. But the detector of $\gamma$-quanta is fixed instead. The actual detector (i.e., the receiver of electromagnetic radiation) is the resonant absorber, whose resonant line is shifted with respect to the resonant line of the source. This induces the variation of intensity of resonant gamma-quanta, passing across this absorber [2]. This intensity is measured by the detector of gamma-quanta, resting outside the rotor system [2]. The latter detector is rather a technical instrument. It allows experimentalist to judge about the shift of the lines of the source and the absorber via the measurement of resonant absorption [2]. But the key point is that the shift of the lines of the source and the absorber that is observed by an observer located in the rotating resonant absorber is different from the shift of the lines of the source and the absorber that is observed by an observer located in the fixed detector of $\gamma$-quanta. That difference is given by the additional factor $-\frac{1}{6}$ in eq. (13), which comes from clock synchronization. In other words, its theoretical absence in the works [1]-[8], [11]-[13] reflected the incorrect comparison of clock rates between a clock at the origin and one at the of $\gamma$-quanta where we have the final output of the measuring. This generated wrong claims of invalidity of relativity theory and/or some attempts to explain the experimental results through “exotic” effects [12-17] which, instead, must be rejected. Let us consider the criticism in [17] about our previous work [16]. It verbatim claims that, “as the extra energy shift due to the clock synchronization is of order $10^{-13}$ it cannot be detected by the detectors of $\gamma$-quanta which are completely insensitive to such a very low order of energy shifts”. We stress that we are still measuring the total energy shift by using the resonant absorber instead of by using the detector of $\gamma$-quanta as it has been claimed in [17]. But the key point is that such a total energy shift measured by an observer located in the fixed detector of $\gamma$-quanta is different from the one
measured by an observer located in the rotating resonant absorber. Thus, we have shown that the correct physical interpretation of a real Mössbauer rotor experiment really represent a new, independent proof of the GTR contrary to the claims in [17]. We also highlight that the appropriate reference [9] has been evoked for a discussion of the Langevin metric. This is dedicated to the use of the GTR in Global Positioning Systems (GPS), which leads to the following interesting realization [16]. The correction of $-\frac{1}{6}$ in eq. (13) is analogous to the correction that one must consider in GPS when accounting for the difference between the time measured in a frame co-rotating with the Earth geoid and the time measured in a non-rotating (locally inertial) Earth centered frame (and also the difference between the proper time of an observer at the surface of the Earth and at infinity). Indeed, if one simply considers the gravitational redshift due to the Earth’s gravitational field, but neglects the effect of the Earth’s rotation, GPS would not work [16]! The key point is that the proper time elapsing on the orbiting GPS clocks cannot be simply used to transfer time from one transmission event to another. Path-dependent effects must be indeed taken into due account, exactly like in the above discussion of clock synchronization [16]. In other words, the obtained correction $-\frac{1}{6}$ in eq. (13) is not an obscure mathematical or physical detail. It is instead a fundamental ingredient that must be taken into due account [16]. Further details on the analogy between the results of this paper and the use of the GTR in Global Positioning Systems have been highlight in [16].

4 Correct meaning of the WEP and non-viability of the YARK gravitational theory

In [17] it is claimed that, differently from the GTR, the so-called YARK (Yarman-Arik-Kolmetskii Gravitational Approach) gravitational theory [18]-[24] can explain the result of $k \approx \frac{2}{3}$ for the total energy shift of the Mössbauer rotor experiment. Actually, in the above discussion we have shown that, differently from the claims in [17], a correct physical interpretation of the GTR can explain the value of $k \approx \frac{2}{3}$. On the other hand, in this Section we show that the YARK gravitational theory is in macroscopic contrast with the WEP. Thus, it results completely non-viable.

Let us start to observe that the authors of [17] claim that, on one hand, the YARK theory is fully compatible with the WEP. On the other hand they verbatim claim that “The real space-time in a gravitation field remains flat and instead of the geodesic postulate of GTR, the laws of energy and angular momentum conservation in Minkowskian space-time are regarded as fundamental”. These two claims are in macroscopic contrast. In fact, Weinberg [25] rigorously showed that the geodesic motion is NOT a postulate of the GTR, but a rigorous consequence of the WEP. Before writing the derivation of this fundamental issue we stress its important consequence. In the absence of space-time curvature geodesic motion is given by straight lines [20]! But instead, of course, all
astrophysical observations show that the gravitational motion is not given by straight lines \[26\]. Hence, the only possibility is that space-time is curved \[26\]. In other words, the YARK’s assumption of the absence of space-time curvature should therefore indicate a macroscopic violation of the equivalence between the inertial mass and the gravitational mass \[26\]. But such an equivalence, is instead tested with the enormous precision of 1 part in \(10^{14}\) \[27, 28\]. Clearly, considering also the experiments \[29, 30, 31\] etc., it is obvious that YARK’s claim of the absence of space-time curvature is in very strong contrast with tons of data collected in more than a century. Now, let us show that the WEP implies that test masses must follow geodesic lines. Notice that in the following derivation we closely follow \[25, 26\]. Let us start supposing that no particles are accelerating in the neighborhood of a point-event with respect to a freely falling coordinate system \((X^\mu)\) \[25, 26\]. Putting \(T = X^0\) one writes down the following equation that is locally applicable in free fall \[25, 26\]

\[
\frac{d^2 X^\mu}{dT^2} = 0. \tag{15}
\]

Using the chain rule one gets \[25, 26\]

\[
\frac{dX^\mu}{dT} = \frac{dx^\nu}{dT} \frac{\partial X^\mu}{\partial x^\nu}. \tag{16}
\]

Differentiating eq. (16) with respect to \(T\) one gets \[25, 26\]

\[
\frac{d^2 X^\mu}{dT^2} = \frac{d^2 x^\nu}{dT^2} \frac{\partial X^\mu}{\partial x^\nu} + \frac{dx^\nu}{dT} \frac{dx^\alpha}{dT} \frac{\partial^2 X^\mu}{\partial x^\nu \partial x^\alpha}. \tag{17}
\]

Combining eqs. (15) and (17) one immediately gets \[25, 26\]

\[
\frac{d^2 x^\nu}{dT^2} \frac{\partial X^\mu}{\partial x^\nu} = -\frac{dx^\nu}{dT} \frac{dx^\alpha}{dT} \left[ \frac{\partial^2 X^\mu}{\partial x^\nu \partial x^\alpha} \frac{\partial X^\lambda}{\partial x^\nu} \right]. \tag{18}
\]

Multiplying both sides of eq. (18) by \(\frac{\partial x^\lambda}{\partial x^\nu}\) one gets \[25, 26\]

\[
\frac{d^2 x^\lambda}{dT^2} = -\frac{dx^\nu}{dT} \frac{dx^\alpha}{dT} \left[ \frac{\partial^2 X^\mu}{\partial x^\nu \partial x^\alpha} \frac{\partial x^\lambda}{\partial x^\nu} \right] + \frac{dx^\nu}{dT} \frac{dx^\alpha}{dT} \frac{dx^\lambda}{dT} \left[ \frac{\partial^2 X^\mu}{\partial x^\nu \partial x^\alpha} \frac{\partial X^\lambda}{\partial t} \right]. \tag{19}
\]

Setting \(t = x^0\) and using again the chain rule, \(T\) can be eliminated in favor of the coordinate time \(t\) \[25, 26\]

\[
\frac{d^2 x^\lambda}{dt^2} = -\Gamma^\lambda_{\nu\alpha} \frac{dx^\nu}{dt} \frac{dx^\alpha}{dt} + \Gamma^0_{\nu\alpha} \frac{dx^\nu}{dt} \frac{dx^\alpha}{dt} \frac{dx^\lambda}{dt}. \tag{20}
\]

Recalling that the bracketed terms involving the relationship between local coordinates \(X\) and general coordinates \(x\) are functions of the general coordinates, eq. (20) gives immediately the geodesic equation of motion using the coordinate time \(t\) as parameter \[25, 26\]

\[
\frac{d^2 x^\lambda}{dt^2} = -\Gamma^\lambda_{\nu\alpha} \frac{dx^\nu}{dt} \frac{dx^\alpha}{dt} + \Gamma^0_{\nu\alpha} \frac{dx^\nu}{dt} \frac{dx^\alpha}{dt} \frac{dx^\lambda}{dt}. \tag{21}
\]
which is equivalent to the standard geodesic equation written in terms of the scalar parameter $s$ \[25\] \[26\]

$$
\frac{d^2 x^\lambda}{ds^2} = -\Gamma^\lambda_{\nu\alpha} \frac{dx^\nu}{ds} \frac{dx^\alpha}{ds}.
$$

(22)

Clearly, based on the extreme precision on which the WEP is today tested and verified, the demonstration that we have reviewed here - i.e. that geodesic motions arise from the WEP - ultimately rules out the YARK theory. Infact, that theory is founded on the absence of curvature \[17\] - \[24\].

In addition, the authors of \[17\] claim that YARK theory permits to localize the gravitational energy. In their opinion, it should remain a non-vanishing quantity in all plausible frames of reference. This should permit to write down, explicitly, a stress-energy tensor for the gravitational field. These claims are again in macroscopic contrast with the WEP \[10\]. Another consequence of the WEP is indeed that we can always find in any given locality a reference’s frame (the local Lorentz reference’s frame) in which ALL local gravitational fields are null \[10\]. No local gravitational fields means no local gravitational energy-momentum and, in turn, no stress-energy tensor for the gravitational field \[10\].

Thus, these are other strong reasons for which the YARK theory of gravity is non-viable and must be ultimately rejected.

5 Conclusion remarks

In \[16\] we used the EP, which states the equivalence between the gravitational "force" and the pseudo-force experienced by an observer in a non-inertial frame of reference (included a rotating frame of reference), to reanalyze the theoretical framework of the Mössbauer rotor experiment directly in the rotating frame of reference. We used a general relativistic treatment. We have shown that previous analyses missed an important effect of clock synchronization and that the correct general relativistic prevision in the rotating frame gives a pre-factor $k \simeq \frac{2}{3}$ for the total energy shift of the Mössbauer rotor experiment \[16\]. This is in perfect agreement with new experimental results \[1\] - \[2\]. The effect of clock synchronization has been indeed missed in various papers in the literature \[1\] - \[8\], \[11\] - \[13\], with some subsequent claim of invalidity of the relativity theory and/or some attempts to explain the experimental results through “exotic” effects \[1\] - \[2\], \[11\] - \[13\], \[17\]. The general relativistic interpretation in \[16\] showed, instead, that the new experimental results of the Mössbauer rotor experiment are a new, strong and independent, proof of the GTR.

In the recent work \[17\], it is claimed that the general relativistic treatment in \[16\] , with the additional effect due to clock synchronization, cannot explain the extra energy shift in the Mössbauer rotor experiment. The extra energy shift due to the clock synchronization is indeed of order $10^{-13}$ and cannot be detected by the detectors of $\gamma$-quanta which are completely insensitive to such a very low order of energy shifts \[17\]. In addition, in \[17\], it is also claimed that the extra energy shift can be explained in the framework of the so-called YARK
gravitational theory [17]-[24]. In the opinion of the authors of [17]-[24] this new theory should replace the GTR as the correct theory of gravity.

In this paper we have shown that the theoretical analysis in [16] has been misunderstood by the authors of [17]. In fact, in [16] it has been shown that electromagnetic radiation launched by the central source of the apparatus is redshifted of a quantity \(0.6v^2/c^2\) when arriving to the detector of \(\gamma\)-quanta. This holds independently by the issue that the original photons are detected by the resonant absorber which, in turns, triggers the \(\gamma\)-quanta which arrive to the final detector. In other words, the result of [16] is purely theoretical and is completely independent of the way the experiment is concretely realized. In the present work we have shown that, with some clarification, the results in [16] hold also when we consider the various steps of the concrete detection. In that case, the resonant absorber detects the energy shift and the separated detector of \(\gamma\)-quanta merely measures the resulting intensity. In addition, in this paper we have also shown that the YARK gravitational theory is in macroscopic contrast with geodesic motion and, in turn, with the WEP. This is in contrast with another claim of the authors of [17] which states that the YARK gravitational theory arises from the WEP. Therefore, the YARK gravitational theory has to be ultimately rejected. We have also corrected the confusion of the authors of [17] concerning their claims about the possibility to localize the gravitational energy and, in turn, to define a stress-energy tensor for the gravitational field. In fact, we show that these claims are still in macroscopic contrast with the WEP.

Again we stress that we dedicate the results in this paper to the 100th anniversary of Albert Einstein’s presentation of the complete GTR to the Prussian Academy.

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