Unabridged Response to "The Mössbauer rotor experiment and the general theory of relativity" by C. Corda: General relativity cannot supply a satisfactory answer to the extra time dilation in ultracentrifuge Mössbauer experiments

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Abstract

A neoteric refitting of general theory of relativity (GTR) by C. Corda – under the strain to supply an answer to the extra time dilation, contradicting the known classical prediction, measured in ultracentrifuge rotor setups via Mössbauer spectroscopy – demands our reply. According to Corda, decades of science somehow pertinaciously misperceived how to properly apply GTR to make a correct prediction for the actual outcome of Mössbauer rotor experiments, and that – somehow without any detrimental corollary to more than half a century of physics which used to affirm stereotypical laboratory findings along this line as validation of GTR – he straightaway succeeded at devising a "*new, strong and independent proof of the correctness of Einstein's vision of gravity*" in the face of recent incontrovertible data (including our disclosure of Walter Kündig's rectified 1963 figures) that contradict GTR's classical prediction with respect to the thus-far overlooked additional time dilation at the edge of ultracentrifuge rotors. We show herein that the outstretched attempt by Corda to reinterpret recent Mössbauer experiments in a rotating system as a "*new, strong and independent proof of the correctness of Einstein's vision of gravity*" (Ann. Phys. 368 (2016) 258), just like his previous attempt (Ann. Phys. 355 (2015) 360) that we had answered before (A.L. Kholmetskii et al., Ann. Phys. 363 (2015) 556), is erroneous, and thus, inadmissible. In addition, we demonstrate that Corda's perfunctory criticism of Yarman-Arik-Kholmetskii gravitation theory (in short YARK) is based on the application of ill-posed and specious logic; thus rendering the entirety of his claims against YARK as unfounded and invalid. We wish to emphasize the principal importance of future repetitions of the Mössbauer experiments in question (especially by trying out various other possible configurations on the placement of the source, absorber, and detector), which are sensitive enough to allow a thorough distinction to be made between the predictions of general theory of relativity and YARK theory with regard to the relative energy shift between emission and absorption lines of resonant spectra. We finally discuss further perspectives in the implementation of such experiments with improved precision that can lead to a better understanding as to which theory of gravitation comes closer to explaining reality.

Keywords: Mössbauer effect, Rotating systems, Time dilation effect, General theory of relativity, YARK theory, Yarman's Approach

1. Introduction

In a series of papers that we published during the past decade with respect to Mössbauer experiments in a rotating system [1-5], it has been experimentally shown that the relative energy shift $\Delta E/E$ between the source of resonant radiation (situated at the center of the rotating system) and the resonant absorber (located on the rotor rim) is described by the relationship

$$\Delta E/E=-ku^2/c^2, \quad (1)$$

where u is the tangential velocity of the absorber, c the velocity of light in vacuum, and k some coefficient, which – contrary to what had been classically predicted – turns out to be substantially larger than 1/2.

It cannot be stressed enough that the equality k=1/2 had been predicted by general theory of relativity (GTR) on account of the special relativistic time dilation effect delineated by the tangential displacement of the rotating absorber, where the "clock hypothesis" by Einstein (*i.e.*, the non-reliance of the time rate of any clock on its acceleration [6]) was straightly adopted. Hence, the revealed inequality k>1/2 indicates the presence of some additional energy shift (next to the usual time dilation effect arising from tangential displacement alone) between the emitted and absorbed resonant radiation, whose origin must be – and in our previous work, which we will recall below, had already successfully been – disclosed.

In particular, via our team's retrospective re-analysis of the 1963 rotor experiment by Kündig [7], where his published results claiming k=1/2 within 1% of experimental measurement accuracy were discovered to contain critical errors that needed to be rectified, we revealed that

$$k=0.596\pm0.006 \text{ [1]}. \quad (2)$$

Similarly, our own recent measurements controversially led to

$$k=0.66\pm0.03 \text{ [2, 3]}, \quad (3)$$

$$k=0.69\pm0.02 \text{ [4, 5]}. \quad (4)$$

Such being the case, determination of the physical meaning behind the extra-energy shift uncovered by the above experimental results (2)-(4) explicitly indicates a topical problem.

In 2015, when confronted with our clarification of these findings under Yarman-Arik-Kholmetskii (in short YARK) theory, Corda claimed in [8] that our results (3), (4) still find a perfect explanation within the framework of GTR – while, astoundingly (or rather, preposterously), decades of science so far used to hold (and still widely holds) in stark contrast that, GTR coincides with (and therefore has already been confirmed by) a stereotypically reported/rounded down k=1/2 too.

At which point, we may understandably be excused for asking, on what grounds can a fundamentally accepted modern scientific theory – in what is conceivably the only instance in the history of science – be custom-tailored under peer-review according to *confirmation bias* (and somehow without any damaging consequence to more than half a century of established practice and understanding) so as to agree with whichever forthcoming scenario that happens to contradict, and therefore challenge, its previously maintained unique position?

Specifically, Corda purports to notice that earlier analyses of Mössbauer rotor experiments "*missed an important effect of clock synchronization between a spinning source and detector of gamma-quanta located outside the rotor system, where the detector moves with respect to the origin of a rotating frame*". Thus, according to this author, the detector must – with regard to a "correct" determination of the relative energy shift between emission and absorption lines – be synchronized with a clock located at the center of the rotor that he argues shall yield an additional contribution to the energy shift next to the classical energy shift between the lines of the source and absorber.

Based on his derivation along such a line of reasoning, Corda advocated an additional contribution to the relative energy shift [8]

$$(\Delta E/E)_{\text{sync}}=-u^2/6c^2 \qquad (5)$$

due to the claimed synchronization effect.

Customarily, though, the relative energy shift between the lines of the resonant source and the resonant absorber had since many decades been given by the standard expression for the time dilation effect:

$$(\Delta E/E)_{\text{source-absorber}}=-u^2/2c^2. \qquad (6)$$

Upon this, Corda contends that the total relative energy shift measured in Mössbauer experiments in a rotating system must be furnished as the sum of the components (5) and (6); *i.e.*,

$$\left(\frac{\Delta E}{E}\right)_{total}=\left(\frac{\Delta E}{E}\right)_{source-absorber}+\left(\frac{\Delta E}{E}\right)_{sync}=-\frac{u^2}{2c^2}-\frac{u^2}{6c^2}=-\frac{2u^2}{3c^2}, \qquad (7)$$

which, at first glance, might give the impression to be in agreement with the results of the latest measurements (3), (4). However, in our preceding comment [9] with regard to such a calculation setup, we had already pointed out that the summation of the two components of relative energy shift (5) and (6) is definitely inadmissible; and insisting in doing so reflects a crucial misconception by said author of the established methodology pertaining to Mössbauer measurements.

As is well-known, in transmission Mössbauer spectroscopy (which is the case for Mössbauer rotor experiments under consideration), the detector of γ-quanta measures the *intensity* of resonant γ-radiation emitted by the source after they pass through the absorber, which varies with the change of a relative shift of resonant lines *between* the source and the absorber. Having thus measured the intensity with a sufficiently high statistical certainty, one can calculate the shift of resonant lines if their shapes are known beforehand. Thus, the detector herein is used solely as a *counter*, but not as a *spectrometer* of resonant γ-quanta; wherefore, such a detector shall be totally insensitive to the energy shift (5) that would emerge between the source and the detector – which, at u=200… 300 m/s, has the order of magnitude 10^{-12}… 10^{-13}. It quite obviously is an unrealistic level to bother with for ordinary detectors of γ-quanta.

As a result, it is clear that only the relative energy shift (6) between the source and the absorber would sensibly affect the measurement in Mössbauer rotor experiments; so much so that, the origin of the inequality k>1/2 remains altogether unexplained by Corda's unusual implementation of GTR to the problem at hand.

Despite all this, said author published a subsequent paper [10], where he continues to insist that his original analysis [8] is the "ultimately" correct one. In section 2, we elucidate how the endorsement of some far-fetched argumentations by Corda in favor of his GTR-motivated interpretation of Mössbauer rotor experiments only continues to highlight the fallacy of his approach, and that the only measurable value to really speak of is the relative energy shift between resonant lines of the source and the absorber.

Additionally, in the mentioned paper [10], Corda tries to attack our gravitation theory christened YARK (as abbreviated from the initials of the co-authors of this manuscript). We show in section 2 that he strives at this in a flawed manner, *i.e.*, based on the application of ill-posed and specious logic; thus, rendering the entirety of his claims against YARK as unfounded and invalid. In section 3, we discuss further perspectives for prospective ultracentrifuge Mössbauer experiments. Finally, we conclude in section 4.

2. Neoteric attempt by C. Corda at re-interpreting Mössbauer rotor experiments in complaisance to general theory of relativity

In the mentioned ref. [10], the author claims the present co-authors have misunderstood his analysis [8]; although this time, *for a change,* he explicitly admits that the detector does indeed work as a counter of resonant γ-quanta – and is, therefore, intrinsically insensitive to the energy shift (5). However, at this stage, Corda proffers a wholly redeeming interpretation to the energy shift (7): According to him, eq. (7) "*...represents the total energy shift that is detected by the resonant absorber as it is measured by an observe*(r)~~*d*~~ *located in the detector of γ-quanta, i.e. located where we have the final output of the measuring...*". After painting such a vague outline, he further writes: *"...We stress that we are still measuring the total energy shift by using the resonant absorber instead of using the detector of γ-quanta as it was claimed in [11]* (the present ref. [9]). *But the key point is that such a total energy shift measured by an observer located in the fixed detector of γ-quanta is different from the one measured by an observer located in the rotating resonant absorber...".* However, Corda's bizarre assertion is inconsistent from the relativistic viewpoint (even more so by virtue of his failing to individually address other plausible Mössbauer setups with variations on the placement of the source, absorber, and detector), and immediately leads to a causal contradiction.

In order to show this, we emphasize that the result of a measurement in Mössbauer rotor experiments is the number of pulses N (*i.e.*, the number of detected resonant γ-quanta passing through a resonant absorber) during a fixed time interval T at the given tangential velocity u for the absorber.

According to Corda, one introduces for consideration an observer co-rotating with the absorber (the frame K′), and a laboratory observer K attached to the detector placed outside. It then follows that a strong causal requirement is the equality

$$N' = N,$$

which simply means, the indication of a counter of the pulses connected with the output of the detector represents an absolute fact; *i.e.*, it is *the same* for *any* observer (including the introduced observers in the frames K and K′). Therefore, the average number of counts $\overline{N} = \int_0^T I(t)dt$ obtained via the averaging of the indications of the counter after multiple successive measurements in the frame K would be equal to the average number of counts $\overline{N}' = \int_0^{T'} I(t')dt'$ as seen in the frame K′. (Here, $I(t)$ and $I'(t')$ are intensities of resonant radiation passing through the resonant absorbers in the frames K and K′ respectively – where the remaining designations are obvious). Consequently, the intensities $I(t)$ and $I'(t')$ may differ from each other due only to the difference of dt and dt' (*i.e.*, the time dilation effect between the frames K and K′). For the Mössbauer rotor experiments in question, the latter (as we have already mentioned) has a typical difference of the order 10^{-12}… 10^{-13} for either rotating or resting observers; so that, the admissible range of relative difference between $I(t)$ and $I'(t')$ entails the same order of magnitude – and is totally negligible.

Further, according to Corda, the intensity $I'(t')$ in the frame K′ corresponds to the relative energy shift between the source and the absorber as given by eq. (6); whereas, the intensity $I(t)$ in the frame K corresponds to the relative energy shift between the source and the absorber according to eq. (7).

We now look carefully at the resonant absorber, and suppose that it is characterized by a single resonant line with the maximum absorption of 50 % (which is a realistic value for a "thick" absorber highly enriched with the resonant ^{57}Fe isotope). We may further suppose that the energy shifts (6) and (7) at the given u correspond to the points of the Mössbauer spectrum on a slope of the resonant line, where resonant absorption would change approximately linearly with the change of energy shift. In such a case, the relative difference between $I(t)$ and $I'(t')$ has a typical value of about 5 %. Hence, being contingent upon a suitable measurement time T – *e.g.*, when the statistical uncertainty in the determination of a number of counts is much smaller than the indicated difference of 5 % between $I(t)$ and $I'(t')$ – the observers in their respective K and K′ frames would, according to Corda's rationale, *always* see *different* indications of the counters N and N' respectively. This, however, is complete nonsense; just like, in fact, the contrived attempt by Corda [8, 10] to atypically and furtively reinterpret ultracentrifuge Mössbauer experiments in emphatic partiality to GTR with the sole aim of "discrediting" YARK theory.

We recapitulate that only the relative energy shift between the emitted resonant radiation of a source and the absorbed radiation by a resonant absorber is subject to realistical measurement in this kind of laboratory setups. If (or rather, since) the inequality k>1/2 in eq. (1) – as manifested by the experimental results (2)-(4) – actually does take place, then one should recognize that the Mössbauer rotor experiments of concern cannot in the least be adequately explained, come what may, under either the GTR-based classical formulation or the "patch solution" concocted by Corda.

Contrastingly, we would like to inform the readers that the equality k=2/3, with respect to the energy shift between emission and absorption lines, had been recently derived in full accordance with the experimental results (3) and (4) by the present authors under the framework of the novel Yarman-Arik-Kholmetskii gravitation theory (*e.g.*, [11-17]), which originates from the earlier "Yarman's approach" of the second co-author (*e.g.*, [18-21]). Details on the derivation of the k=2/3 result essentially pertain to a natural symbiosis of YARK theory with quantum mechanics, and can be found in ref. [15].

The reaction displayed by Corda against the remarkably successful results of YARK was well expected. In the same ref. [10], Corda tries to "discredit" YARK so as to bring an end (in his opinion) to the entire discussion on the physical interpretation of the additional time dilation measurement in Mössbauer rotor experiments under consideration. To that end, he wants to implicate YARK as being based on the weak equivalence principle (WEP). Already, this is not correct by any means; for the primary basis of YARK is the conservation of energy throughout gravitational interaction (although, the WEP conjecture also happens to be fulfilled thoroughly besides).

Corda then continues to cite our paper [15], where we notice the following statement with respect to YARK theory: "*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-like space-time are regarded as fundamental*". Thus, in Corda's opinion, the latter premise is "*in a macroscopic contrast with WEP*", because this principle implies geodesic motion [22]. Whereupon, Corda jumps to the flawed conclusion that geodesic motion is given by straight lines in the absence of space-time curvature in YARK theory. Therefore, in his opinion [10], our approach "*…is in very strong contrast with tons of data collected in more than a century*".

Furthermore, Corda advocates one of the peremptory consequences of WEP as being the impossibility to localize gravitational energy. To that effect, he again refers to Weinberg's book [22]. Based on it, Corda extrapolates YARK's contradistinctive assertion about the possibility to localize gravitational energy and define the energy-momentum tensor for a gravitational field [15] to be in "*macroscopic contrast with WEP*".

However, the criticism levied against YARK by this author represents a typical manifestation of ill-posed, and thus misleading, logic, because cited results had been derived beforehand under the approach of GTR, and are now being invalidly extended over to an altogether incompatible alternative theoretical framework. Needless to say, this is totally unacceptable, since YARK theory drastically differs from GTR both in its conceptual content and intrinsic structure.

An outline of the core aspects of YARK theory, which is essentially based on the energy conservation law for any realistically ponderable gravitational interaction scenario, can be found in the Appendix of this manuscript. Therein, we mention that space-time in YARK is characterized by a Minkowskian-like metric, where the Christoffel symbols are equal to zero, and the diagonal metric coefficients are multiplied by a conformal factor that explicitly depends on the "static gravitational binding energy E_B" of a test particle as it traverses a gravitational environment – *i.e.*, the energy to be furnished in order to bring the test particle of concern quasistatically from an infinite distance away to a given point within the scrutinized celestial system.

This conditionality distinguishes YARK from the centennial gravitation theory of G. Nordström in principle, where the Minkowskian-like metric is also derived for the latter, but with an altogether different physical meaning of the conformal factor associated with it [23]; making Nordström's theory ultimately incompatible with experimental outcomes. In contrast, YARK theory and GTR do, in point of fact, converge to the same end results in the limit of a weak gravitational field; insofar as allowing us to fully explain the well-established experimental and observational findings of the past century such as gravitational redshift [20], gravitational lensing as well as related Shapiro Delay [24], and precession of the perihelion of Mercurial planets [20, 25], *etc.*. Moreover, modern cosmological data also find their non-contradictory explanations under the framework of YARK – and all that in full conformance with quantum mechanics; whereupon, we address the interested reader to the concomitant references [12, 16, 17] as well as the Appendix.

Now we are ready to consider eqs. (15)-(22) of ref. [10] (*i.e.*, the derivation of geodesic motion from WEP); which, in Corda's imagination, should serve to "disprove" YARK theory.

However, said derivation is exclusively restricted to the domain of a purely metric theory, whereas YARK theory combines both metric and dynamical approaches. In particular, in the case of YARK, the derivatives $\partial X^{\mu}/\partial x^{\nu}$ at, for example, μ, ν=1, 2, 3 already do not depend explicitly on spatial coordinates, but only on the static gravitational binding energy E_B (here X^{μ} stands for the spatial coordinates in a local frame pertaining to the test particle, and x^{μ} denotes the spatial coordinates of a distant frame). Hence, the second spatial derivative $\partial^2 X^{\mu}/\partial x^{\nu}\partial x^{\alpha}$ contains the spatial derivative of E_B, which, in turn, is proportional to the force experienced by the particle in a given gravitational field. As a result, instead of the geodesic motion in a curved space-time, we obtain (omitting at this time the details of derivation) a dynamical equation of motion for a test particle in a flat space-time governed by the force resulting from the spatial variation of E_B.

Therefore, it is easy to demonstrate that Corda's presumption that particles always move along straight lines in YARK theory is wholly unsubstantiated.

We further need to stress how the alleged impossibility to localize gravitational energy – as derived in ref. [22] on the basis of WEP, and as stipulated by Corda in [10] – is again strictly applicable only to metric theories, as is the case with GTR; and thus, cannot justifiably be extended over to YARK theory – since YARK is built upon an altogether different framework instead of a specific metric approach.

Moreover, localization of gravitational energy directly stems from the fact that YARK theory is equatable, by default, to a non-degenerate Lagrangian [15, 17], where the energy-momentum tensor for the gravitational field in YARK is defined in the common way.

As a corollary of our preceding elementary confutation, none of Corda's claims that were posed in ref. [10] against YARK theory are correct. Even more than that, the outcomes (3), (4) of modern Mössbauer rotor experiments [2-5] – let alone our previous re-analysis and rectification of Kündig's results (2) as disclosed in ref. [1] – remain altogether unexplained by Corda. Under these circumstances, further repetition of these experiments with enhanced techniques and increased precision – in addition to trying out various other possible configurations on the placement of the source, absorber, and detector – is of utmost importance. All the more so, since ultracentrifuge Mössbauer experiments are sensitive enough to allow a thorough distinction to be made between the predictions of general theory of relativity and YARK theory with regard to the relative energy shift between emission and absorption lines of resonant spectra at different rates of revolution.

3. Prospective Mössbauer experiments in a rotating system: Further perspectives

Past and present realizations of Mössbauer rotor experiments allow us to classify accumulated empirical experience into three categories characterized by markedly different technical approaches (where, in our particular case, we imply the positioning of a radioactive source at the center of the rotational axis, and an absorber on the rotor rim):

- measurement of the count rate of resonant γ-quanta passing through a rotating resonant absorber versus the latter's tangential velocity (*e.g.*, [26-30]);
- measurement of the shape and position, on the energy scale, of the resonant line of the absorber via the linear Doppler modulation of resonant radiation of the source at each fixed value of the absorber's tangential velocity (Kündig experiment [7]);
- measurement of the count rate of resonant γ-quanta passing through two different rotating absorbers (picked one at a time) with the specified energy shift of their resonant lines versus their tangential velocity [2-5].

The methods indicated above with respect to past and present realizations of Mössbauer rotor experiments differ from each other in terms of their sensitivity to chaotic mechanical vibrations in a rotor system; which can, in general, affect the measured count rate of the detector via the broadening of the resonant line of the absorber. Since these vibrations do not influence the area and position of the resonant line on the energy scale, they instead result in the broadening of the line that reduces the value of the resonant effect and upsets the detector's count rate. What is worse, the level of vibrations in the rotor system intensifies with the increase of rotational frequency; so much so that, variation of the count rate due to vibrations is mixed with the variation of the count rate of the detector on account of the relative energy shift between emission and absorption lines – insofar as leading to the corresponding distortions in the determination of the coefficient k in eq. (1).

However, in a series of experiments conducted in the early 1960s [26-30], this fact was totally ignored; which makes the obtained results unreliable to a critical extent. We remind the scientific community that all these experiments reported the value k as being near 1/2 within the precision of measurement – and hence, in full conformance with the classical prediction of GTR.

The 1963 experiment by Kündig [7] should be accorded separate attention, since he was the only one who applied a first order Doppler modulation of the energy of γ-quanta on a rotor; measuring, thusly, the shape and position of the resonant line on the energy scale versus the rotational frequency. Seeing as the chaotic nature of vibrations in suchlike rotor systems do not ordinarily affect the position of a resonant line on the energy scale, Kündig – via the accumulation of Mössbauer spectra at each fixed rotational frequency, along with the determination of the position of the resonant line on the energy scale – achieved a *direct measurement* of the energy shift of this line as a function of the rotational frequency of the rotor, as though it was freed from the influence of mechanical juddering.

Even so, serious misprocessing of his experimental raw data appears to have incentivized Kündig to publish egregiously inaccurate results, as revealed after a careful investigation by our team. The result k=0.503±0.005 that Kündig reported had to be rectified upon a retrospective re-analysis by our team about half a century after the date of his publication; revealing eq. (2) after the elimination of computational errors that he had unfortunately committed [1].

Be that as it may, the scheme of Kündig's experiment still leaves one with doubts with regard to the validity of the obtained result; especially by reason of the presence of non-avoidable and difficult-to-estimate instrumental factors that might have otherwise further shifted the corrected value of k in eq. (2). One such factor is the finite length of the piezotransducer applied by Kündig (about 1 mm); where its edges must inevitably have experienced the different centrifugal forces (corresponding to a centrifugal acceleration of up to 10^4 m/s^2), which could have altered the piezoelectric constant with the variation of the rotational frequency. Although Kündig judged this factor to be negligible, he did not present a convincing proof for it [7]. In contrast, according to our own estimation, the variation of the piezoelectric constant should have decreased the value of the measured coefficient k in eq. (1) by up to 10 % in comparison with its true value.

Thus, we have to conclude that the actual outcome of Kündig's experiment should yield a re-evaluated value of k as lying between 0.60 and 0.66 due to the presence of such systematic errors.

An effective way to eliminate a systematic error in the evaluation of the coefficient k in experiments of the type carried out by Kündig is to apply an independent method for the measurement of the relative linear velocity between the oscillating source and the absorber via employing laser interferometry. However, a practical realization of this method (which, in fact, is often used in ordinary Mössbauer spectroscopy; see, *e.g.*, [31]) may not be so simple from a technical viewpoint – especially when the laser system has to be mounted on a spinning rotor. On the other hand, this method will definitely allow us to obtain an unbiased estimate of the coefficient k in eq. (1) without involving a complicated data processing procedure.

Finally, one more approach that we actualized in our experiments [2-5] is similar in its technical side to the old approach exploited in historical Mössbauer rotor experiments [26-30]. In contrast to these experiments, however, we did evaluate the influence of vibrations on the measured value of k. For this purpose, we applied a method which involved the joint processing of data collected from two select resonant absorbers (picked one at a time) with the specified energy shift of resonant lines. The idea behind this method hinges on the aforementioned fact that rotor vibrations broaden a given resonant line, but do not influence the total area and position of this line on the energy scale. Hence, one can easily understand how – for two resonant lines shifted on the energy scale, say, at their linewidth – the equal broadening of these lines due to mechanical vibration essentially induces different variations of the detector's count-rate for each absorber. By comparing the data obtained with either absorber in the rotor experiment, one can land at the required information concerning the level of vibrations, and separate their contribution from the energy shift between emission and absorption lines. This allows us to reach an estimate of k even when facing an appreciable level of vibrations in the rotor system; although, with a larger measurement uncertainty than that, one could infer the direct measurement algorithm applied in Kündig-type experiments. The details of suggested algorithm and data processing procedure can be found in refs. [2-5].

Notwithstanding, we cannot be all the way certain that the algorithm just described above provides an unbiased estimate of the coefficient k; because we assumed – in the determination of the broadening of the resonant line on account of vibrations in the rotor system (which is a necessary step in the data processing procedure [2, 5]) – that such a line keeps its Lorentzian shape in the presence of vibrations. However, this assumption is legitimate only in the case where the broadening of the resonant line due to vibrations is substantially smaller than its proper linewidth. Since, in the mentioned experiments, the opposite case was effectual (*i.e.*, the broadening of lines was up to 2.5-3 times at the upper limit of tangential velocity), a systematic measurement error in the evaluation of the coefficient *k* could emerge. In this respect, a repetition of Mössbauer rotor experiments based on the method [2-5] with an improved rotor system that permits a low level of vibrations would seem a fundamental requisite.

Apart from the comparably simple realization of suchlike experiments from a technical viewpoint (particularly in juxtaposition to experiments of the Kündig type entailing the involvement of laser interferometry for a strict control of the velocity of the source of oscillation), two principal points would make future experiments along this line very promising:

- a decrease in the level of vibrations of the rotor system by at least twice in comparison with the experiments [4, 5] shall – according to our estimations – allow us to achieve the decrease of measurement uncertainty of statistical origin by at least 4-5 times as compared to the results (3), (4).
- when the broadening of the resonant line due to rotor vibrations is smaller than the proper linewidth of the line, one can reliably adopt its Lorentzian form up to the highest rotational frequency, and practically eliminate any possible component of systematic error in the evaluation of the coefficient *k* (which may have contaminated previous evaluations (3), (4) in some measure). As a result, one can expect to obtain an unbiased estimate of the coefficient *k* in eq. (1) – with the total measurement uncertainly (both of statistical and systematic origin) being less than 1 %.

Just as importantly, other plausible Mössbauer setups with variations on the placement of the source, absorber, and detector should allow a thorough distinction to be made between the predictions of general theory of relativity and YARK theory with regard to the relative energy shift between emission and absorption lines of resonant spectra. Such an undertaking would lead to a better understanding as to which theory of gravitation comes closer to explaining reality.

Finally, we may mention a recent suggestion brought to our attention in [32], to perform Mössbauer experiments involving a rotating system with synchrotron radiation. However, in such experiments, rotor vibrations directly affect the shape of the resonant line; which, as shown by the authors of ref. [32], can substantially distort information about the energy shift – even in the case of a high-quality rotor – between emission and absorption lines. In contrast, in the case of ordinary Mössbauer spectroscopy, where both a source and a resonant absorber are *rigidly* fixed on a rotor as considered above, any distortion in the Mössbauer spectrum would be determined by *relative* vibrations between the source and the absorber; which, in any practical situation, turn out to be much smaller than the vibrations of the rotor itself. In this respect, we are sure that ordinary Mössbauer spectroscopy remains the most promising tool for measurement of a relative energy shift between emission and absorption lines in a rotating system at high periodicities.

4. Conclusion

Following our earlier publication [9], we have unambiguously demonstrated herein that, a newfangled attempt by Corda [10] to explain, on the basis of GTR, the origin of the extra energy shift in Mössbauer rotor experiments (next to the classical relativistic time dilation effect arising from tangential displacement alone) still constitutes a fallacy, and only serves to expose said author's inability to grasp the technical side of such experiments as well as his failure to understand the general methodology of Mössbauer spectroscopy.

We also revealed herein the flawed character of Corda's criticism against Yarman-Arik-Kholmetskii (YARK) theory of gravity. In particular, we have shown that our gravitation theory possesses its own intrinsic logical structure that Corda overlooked or ignored in his analysis; thus, rendering his peremptory claims against YARK and in favor of GTR as entirely unfounded and invalid. YARK does, in point of fact, converge with GTR's predictions in the limit of weak gravitational fields, insofar as fully accounting for well-established centennial observations given as proof of the validity of GTR; with the contradistinction that YARK – unlike GTR and in full conformity with quantum mechanics – allows the localization of gravitational energy in any realistically ponderable interaction scenario. Due to the limited allowance of this manuscript, we have referred to our relevant papers published elsewhere for further details **[**15-17**]**, but nevertheless included an Appendix below to elucidate YARK theory's unique features in contrast to GTR.

Finally, we have emphasized the crucial role Mössbauer rotor experiments would play for an in-depth study of the origin of the extra-energy shift (next to the usual relativistic dilation of time) between emission and absorption lines at high rates of revolution; which, at the moment, remains explained under neither the classical, nor Corda's suggested neoteric, framework of GTR. This is all the more so, since other plausible Mössbauer setups with variations on the placement of the source, absorber, and detector should allow a thorough distinction to be made between the predictions of general theory of relativity and YARK theory of gravity.

Discussions on further perspectives in the implementation of such experiments with improved precision can lead to a better understanding as to which theory of gravitation comes closer to explaining reality.

5. APPENDIX: General theory of relativity versus Yarman-Arik-Kholmetskii (YARK) gravitation theory

During the past years, the co-authors of this manuscript developed the novel Yarman-Arik-Kholmetskii gravitation theory (or YARK for short) (*e.g.*, [11-17]), which originates from the core Yarman's approach appertaining to any ponderable gravitational interaction scenario (see, *e.g.*, [18-21]). We hereby present a brief synopsis of the basic ideas underlying YARK theory.

The root postulate of Yarman's approach states that, the primary effect of gravity is the variation of the rest mass of the interacting objects, and the magnitude of such variation is governed by the energy conservation law [18-20] embodying the mass and energy equivalence of special theory of relativity (STR).

Thus, according to this postulate, the proper mass $m_{0\infty}$ of any object – *e.g.*, when it had initially been measured at an infinitely far away distance from all other masses – will be altered by the "gravitational environment" to the extent that, the total relativistic energy E of the object can be described by the relationship [18-20]

$$E = \gamma m_{0\infty} c^2 \left(1 - E_B / m_{0\infty} c^2\right), \tag{8}$$

where γ is the Lorentz factor associated with the motion of the object at hand, and E_B is what we deem the "*static gravitational binding energy*" – *i.e.*, the energy to be furnished in order to bring the object quasistatically from an infinite distance away to where it would conceivably hang at rest in the gravitational medium; all the while assuming – for simplicity sake at this point, but without any loss of generality – that gravity is generated by an extremely massive stationary source which is immensely heavier compared to $m_{0\infty}$.

Yarman's approach postulate (8) provides us with the ability to describe any gravitational interaction at a phenomenological level (just like, in fact, any other theory of gravity). It also betokens that gravitational energy is localized inside the interacting particles rather than being distributed across outer space. As we will see below, this approach lends itself very effectively to the description of gravity in a comparably simple mathematical language.

Bear in mind that, the static gravitational binding energy E_B of the given object – which sits at rest at a certain distance to the ponderable host mass – is, conversely, the energy one has to supply in order to carry it from its initial location to infinitely far away, aside from being proportional to the rest mass of the object $m_{0\infty}$. Therefore, the mass of the object term is dropped out from the final equation of motion at any rate; which makes postulate (8) fully compatible with WEP. (We feel the need to reiterate that, WEP was never a starting point of YARK, but just happens to be an end result of it.)

Thus, particles with different rest masses shall indeed acquire the same acceleration in a given gravitational medium. We would moreover like to point out that, the *equivalence* of gravitational and inertial masses (in the meaning elaborated above) always allows us to choose a reference frame wherein the local geometry becomes pseudo-Euclidean by intrinsic design [11]. Nevertheless, a particle in such a frame of reference continues to "*experience*", so to say, the presence of gravity due just to the difference of its rest mass from what it would have been in the total absence of gravitation. As we will momentarily see below, this allows us to apply a non-degenerate Lagrangian to the description of gravitational interaction.

As shown previously by Yarman, the *variation of the rest mass* of a given particle that exhibits the radial coordinate $\boldsymbol{r}_{\mathrm{m}}\{x_{\mathrm{m}}, y_{\mathrm{m}}, z_{\mathrm{m}}\}$ at the considered time moment t induces a corresponding *change* of its *temporal and spatial units*; and it so happens owing to the intrinsic quantum mechanical relationship between the quantities "mass-energy-frequency".

The change of temporal and spatial units associated with the given object are notated respectively as $dT_{empty\ space}$ and $d\boldsymbol{L}_{empty\ space}$ in their frame of rest – indicating, thus, a hypothetical *"original measurement"* of said particle's properties in totally empty space and at rest [11, 21].

These quantities – were they embedded in a gravitational environment – become dT and $d\mathbf{L}$ when assessed by a resting distant observer outside the interacting system, which then turn out to be a function of the static gravitational binding energy; *i.e.*,

$$dT = \frac{dT_{empty\ space}}{1 - E_B / m_{0\infty} c^2}, \quad d\mathbf{L} = \frac{d\boldsymbol{L}_{empty\ space}}{1 - E_B / m_{0\infty} c^2}. \qquad (9), (10)$$

We like to stress that, because the static gravitational binding energy in YARK is proportional to $m_{0\infty}$, the expressions above do not actually necessitate the original mass of the object $m_{0\infty}$ to be weighed at an infinite distance (viz., free of any field of interaction) – since, this term evidently cancels out in the fraction of the denominator in the above-given relationships.

The change of time and scale units (9), (10) brings about the following set of relationships – as measured by either a local observer or a distant observer remaining at rest with respect to each other – between temporal and spatial intervals:

$$dt = dt_0\left(1 - E_B(\boldsymbol{r}_m)/m_{0\infty}c^2\right),\ dx = dx_0\left(1 - E_B(\boldsymbol{r}_m)/m_{0\infty}c^2\right),$$
$$dy = dy_0\left(1 - E_B(\boldsymbol{r}_m)/m_{0\infty}c^2\right),\ dz = dz_0\left(1 - E_B(\boldsymbol{r}_m)/m_{0\infty}c^2\right). \qquad (11)$$

Here, the subscript "$_0$" designates the corresponding quantities measured far away from any gravitational influence, and $\boldsymbol{r}_m$ stands for the location coordinate the object in question occupies at the considered time moment. These relationships signify a warp of geometry in the distant frame as compared with the ideal situation in empty space, and subsequently alter the metric coefficients as follows:

$$g_{00} = \left(1 - E_B(\boldsymbol{r}_m)/m_{0\infty}c^2\right)^2,\ g_{11} = g_{22} = g_{33} = -\left(1 - E_B(\boldsymbol{r}_m)/m_{0\infty}c^2\right)^2, \text{ and all others } g_{\alpha\neq\beta} = 0 \quad (12)$$

(where α, β = 0, 1, 2, 3).

Thus, the space-time interval for a distant observer acquires the form

$$ds^2 = c^2 g_{00}dt^2 + g_{11}dx^2 + g_{22}dy^2 + g_{11}dz^2 = \left(1 - E_B(\boldsymbol{r}_m)/m_{0\infty}c^2\right)^2\left(c^2dt^2 - dl^2\right), \quad (13)$$

where $dl^2 = dx^2 + dy^2 + dz^2$.

Eq. (13) manifests a Minkowskian-like metric, where the Christoffel symbols are equal to zero, and the diagonal metric coefficients {1, -1, -1, -1} are multiplied by the factor $\left(1 - E_B(\boldsymbol{r}_m)/m_{0\infty}c^2\right)^2$; with the latter explicitly depending on the spatial coordinate of the particle of concern, and implicitly depending on time for a moving particle.

At this point, we would like to emphasize the innate harmonization of YARK with STR at the very outset; which, in dynamical cases, implies that $\boldsymbol{r}_m$ represents the retarded distance between a test particle and a source of gravity.

We can now derive the keystone equations of YARK using the minimization of action in the metric (13). One may henceforth define the action for a client object in the common way:

$$S = -m_{0\infty}c\int ds\,. \quad (14)$$

Using expression (13) for the ds of the particle moving with velocity $\boldsymbol{v} = d\boldsymbol{l}/dt$, we obtain

$$S = -m_{0\infty}c^2\int\left(1 - E_B(\boldsymbol{r}_m)/m_{0\infty}c^2\right)dt\sqrt{1 - v^2/c^2}\,. \quad (15)$$

Next, we are going to take into account the aforementioned fact that, $E_B(r_l)$ is proportional to $m_{0\infty}c^2$. It thence becomes convenient to present $E_B(\boldsymbol{r}_m)$ in terms of [20]

$$E_B(\boldsymbol{r}_m) = \left(1 - e^{-\alpha(\boldsymbol{r}_m)}\right)m_{0\infty}c^2, \quad (16)$$

where α is some function of $\boldsymbol{r}_m$. As a result, Eq. (15) takes the form

$$S = -m_{0\infty}c^2\int e^{-\alpha(\boldsymbol{r}_m)}\sqrt{1 - v^2/c^2}\,dt.$$

Thus, we arrive at the Lagrangian corresponding to Yarman's approach:

$$L = -m_{0\infty}e^{-\alpha(\boldsymbol{r}_m)}c^2\sqrt{1 - v^2/c^2}\,. \quad (17)$$

Using this Lagrangian, we can determine the force, energy, and momentum of a particle traversing any gravitational medium. First, we find the force:

$$\boldsymbol{F} = \frac{\partial L}{\partial \mathbf{r}} = m_{0\infty}e^{-\alpha}c^2\sqrt{1 - v^2/c^2}\,\frac{\partial \alpha}{\partial \mathbf{r}}, \quad (18)$$

where $\alpha = \alpha(\mathbf{r})$.

In order to determine this latter function explicitly, we demand that $\alpha \to 0$, in the course of $r \to \infty$. Furthermore, for a particle at rest in the limit $r \to \infty$, we should be able to acquire the Newtonian force in a radially symmetric gravitational field.

One can right away see that, these requirements are thoroughly implemented within the frame of

$$\alpha(r) = GM/rc^2\,, \quad (19)$$

where M is the mass of the source of gravity in the conceived system, and G the known gravitational constant.

Substituting Eq. (19) into Eq. (18), we derive for a radially symmetric case

$$\boldsymbol{F} = -G\frac{m_{0\infty}e^{-\alpha}M\boldsymbol{r}}{\gamma r^3}. \qquad (20)$$

At this juncture, it is important to accentuate the fact that, the velocity $\boldsymbol{v}$ of any client object is the same for both the local observer and the distant observer sitting at rest in relation to one another in the case of the metric manifested by eq. (13) under the framework of YARK. The reason is simply because, lengths and periods of time vary in a gravitational environment by the same fractional amount as assessed by a remote observer; which entails that, the ratio of length per period of time does not change from one reference frame to another when gauged from the outside. Correspondingly, light velocity c will be an invariant value for either set of local observers and distant observers in YARK.

Therefore, in the case of the metric (13), $\boldsymbol{v}$=$\boldsymbol{v}_0$; and the Lorentz coefficient $\gamma = 1\big/\sqrt{1-v^2/c^2}$ for a local observer equals to the Lorentz coefficient γ_0 for a distant observer.

Next, we determine the momentum of a particle traversing the gravitational medium of the source mass:

$$\boldsymbol{p} = \frac{\partial L}{\partial \boldsymbol{v}} = \gamma m_{0\infty}e^{-\alpha}\boldsymbol{v}\,, \qquad (21)$$

and then the energy of said particle:

$$E = \boldsymbol{p}\cdot\boldsymbol{v} - L = \gamma m_{0\infty}e^{-\alpha}v^2 + \frac{m_{0\infty}e^{-\alpha}c^2}{\gamma} = \gamma m_{0\infty}e^{-\alpha}c^2\left(\frac{v^2}{c^2} + \left(1-\frac{v^2}{c^2}\right)\right) = \gamma m_{0\infty}e^{-\alpha}c^2\,. \qquad (22)$$

The reader should nevertheless be heedful of the fact that, Yarman had arrived at eqs. (20)-(22) in his previous publications [18-21] directly via eqs. (8)-(10) (*i.e.*, the law of energy conservation embodying the mass and energy equivalence of STR). Regardless, the derivation of the expressions, as presented above, for force, energy, and momentum via the minimization of action (14) in the metric (13) endorses their general character and validity for both the weak and strong gravitational fields. Whatever the case, the law of energy conservation is attributed the highest priority in Yarman's approach.

Furthermore, it is straightforward to see the similarity of eq. (22) with the total relativistic energy obtained under the framework of GTR in the limit of a weak gravitational field [33]:

$$m_\gamma c^2 = \gamma m_{0\infty}c^2\sqrt{1-2\alpha}\ , \qquad (23)$$

where the velocity is measured by a local observer.

Comparing eqs. (22) and (23), we see that the terms describing the effect of gravity in these equations coincide with each other up to the accuracy of c^{-3} (*i.e.*, $e^{-\alpha} \approx (1-\alpha) \approx \sqrt{1-2\alpha}$); where we have taken into account the fact that α itself contains c^{-2}, and where both equations yield Newton's equation of motion as a first order approximation.

Hence, YARK theory and GTR do, in point of fact, converge in the limit of a weak gravitational field on the basis of just a single equation of motion at the heart of YARK theory [20].

For making a suitable comparison, the reader should recognize that YARK is not a purely metric theory like GTR, and it is not a purely dynamical theory like, for example, classical electrodynamics; but subsumes features from both categories.

YARK's amalgamation of metric and dynamic traits can be better visualized when we consider, for instance, an infinitesimal spatial displacement of a test particle traversing a gravitational environment. Such a sequence of events would induce, in general, a change in the static gravitational binding energy E_B of the system that commensurately affects the client object's rest mass – no matter how tiny this may be – and ergo, subsequently alters the diagonal metric coefficients (12). The link between metric and dynamic relationships is thus established through the venue where, a variation of metric versus an infinitesimal displacement is *sensed*, in a manner of speaking, by the particle as the gravitational force.

Thus, in diametrical opposition to Corda's claims, YARK is a thoroughly self-consistent theory with its own intrinsic logic for having been based uniquely on the law of energy conservation in full concordance with STR. This is true to such an extent, that YARK's predictions amazingly converge with the centennial confirmations of GTR in the limit of a weak gravitational field. Such being the case, it is worth emphasizing how YARK theory has already reached exceptional milestones since the past few years in satisfactorily accounting for modern astrophysics and laboratory observations that continue to pose problems under the framework of GTR. These are:

- derivation of the alternating sign for the accelerated expansion of the Universe, which is naturally arrived at by YARK without the need to invoke "dark energy" [11];
- analytical derivation of the Hubble constant [11];
- elimination of the information paradox for "black holes" of the YARK type [16];
- explanation (despite being set aside for the moment to make do at a qualitative level) as to why galaxies get shaped mostly as disks, while stars coagulate as ellipsoids [11];
- wave-particle dualistic justification for the substantial dissimilarity between the gravitational deflection of low-energy and high-energy photons [15], which was recently established by preliminary experiments at Deutsches Elektronen-Synchrotron (DESY) when Compton scattering of laser beams on ultra-relativistic electrons were analyzed [34].

At this point, the reader should also take notice of our currently evaluated submission [35] on how we used YARK theory to adequately explain the GW150914 and GW151226 signals as reported by LIGO Scientific Collaboration [36, 37], and without the need to espouse GTR's hypothesis for gravitational waves.

Finally, with respect to recent Mössbauer rotor experiments [2-5], we recapitulate the extraordinary coincidence of YARK's unique calculation (k=2/3) with the measured relative energy shift between emitted and absorbed resonant radiation (3), (4) – whereas, currently available GTR-based formulations demonstrably fail to explain this result.

While we still prefer not to jump to any definitive conclusions in favor of YARK theory at this stage, it is nevertheless fundamentally important to emphasize how Mössbauer experiments in a rotating system hold exceptional significance for modern physics of space-time; especially given that they can be repeated at the laboratory scale with increased measurement precision at any time, so as to let scientists clearly discern which theory of gravitation can describe reality more accurately.

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