Exploration

Gravitational Bending of Starlight: Does the Factor 2 Vindicate Einstein?

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Abstract

As currently understood, the predictions of Newtonian and Einsteinian gravitation on the issue of the gravitational bending of starlight differ by a *watershed factor* "2" and this factor has been used to post Einsteinian gravitation as the superior gravitational model. The pioneering May 29, 1919, total eclipse observational measurements led by Sir Arthur S. Eddington heralded Einsteinian gravitation as the new superior model of gravitation by confirming this factor "2" which is assumed to be a prerogative prediction of Einsteinian gravitation. Subsequent eclipse observational measurements in the years (1922 – 1973) have reasonably agreed with the Eddington team. However, apart from the most precise quasar observational measurements made using the latest technologies of Very Large Baseline Array (VLBA), the factor "2" as measured in total eclipse observations is not exactly reproduced with the same hairs-breath accuracy as in the case of the VLBA measurements. Our result unequivocally demonstrates that if one where to preserve the identity of the inertia and gravitational mass of the photon in their calculations in the framework of Newtonian gravitation, the Newtonian gravitational paradigm can be brought into complete tandem with both the VLBA and eclipse observational measurements. Given the present result, the dominance of the Einsteinian gravitational paradigm since the Eddington measurement, and, the centrality and importance of this factor "2" in posting the Einsteinian paradigm as the superior model, this letter brings the reader to ponder and rethink the position of this factor "2" *vis-a-vis* its importance in overthrowing Newtonian gravitation as first assumed by the Eddington team.

Keywords: mass: inertial mass, gravitational – light: gravitational bending – principle of equivalence.

1 Introduction

The Year 2015 AD marks the first centenary of Albert Einstein (1879−1955)'s General Theory of Relativity (GTR) first published on Thursday November 25, 1915 (Einstein 1916). Right at its inspection, the GTR succeeded in explaining the peculiar perihelion precession of the planet Mercury which at the time had become a problem that boggled the then celestial mechanicians since about 1843 when the renowned French astronomer, Urbain Le Verrier (1811 – 1877), brought this problem to light, namely, that there exists an unaccounted for $43.1 \pm 0.5''$ per century of the precession of the perihelion of the planet Mercury. In an unprecedented manner, the GTR explained this with a hairs-breath accuracy, thereby giving the nascent theory the much needed impetus. Apart from this, the GTR predicted that starlight barely grazing the Solar limb must suffer a very tiny – *albeit* significant and measurable; gravitational deflection of about $1.75''$ from its otherwise straight path.

Rather generously, history has indelibly recorded that on the occasion of the historic total Solar Eclipse of May 29, 1919, the then Secretary of the Royal Astronomical Society of London, Sir Arthur Eddington (1882 – 1944), successfully led a British expedition to *Sobral* in Brazil and *Principe* (Gulf of Guinea)

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in West Africa to measure this predicted $1.75''$ gravitational deflection of starlight and their result was announced at an history Joint Meeting of the Royal Society of London on Thursday November 6, 1919.

This pioneering result of the Eddington-led expedition – almost instantaneously – emerged to become one of the single-most important scientific touchstone measurements of the 20^{th} century for this result arcanely led to the international acceptance of the GTR. On this eventful day of the announcement of the Eddington result, Newtonian gravitation is said to have been overthrown. Despite the GTR's unprecedented success after success with every experiment to which it has been submitted to (*cf.* Will 2006, 2009, 2014, 2015), it is not only important, but very important that we genuinely and frankly answer the question as to whether or not Newtonian gravitation actually failed the gravitational bending of starlight experiment? The bare truth is that – Newtonian gravitation did not fail this test. Shortly, we will show why.

2 Traditional Newtonian Approach

It is well known in Newtonian gravitational theory that the differential equation of motion of a test body of gravitational mass $\mathrm{m_g}$ around a gravitating body of gravitational mass $\mathcal{M}_\mathrm{g}$ is given by:

$$\frac{d^2u}{d\varphi^2} + u = -\frac{F(u)/\mathrm{m}_i}{u^2 J^2}. \tag{2.1}$$

where $(u = 1/r)$: r is radial distance of the test body from the center of mass of the massive central gravitating body and m_i is the inertial mass of the test body, J is the test body's specific orbital angular momentum, φ is its angular displacement, and $F(u)$ is the radially dependent gravitational force acting on the test body. The Newtonian gravitational force is such that $[F(u) = -G\mathcal{M}_\mathrm{g}\mathrm{m_g}u^2]$ where G is Newton's universal constant of gravitation. As is commonly the case: assuming the equity of the inertial and gravitational mass *i.e.* $(\mathrm{m}_i = \mathrm{m_g})$, it follows that (2.1) will reduce to the well known equation, namely:

$$\frac{d^2u}{d\varphi^2} + u = \frac{G\mathcal{M}_\mathrm{g}}{J^2}. \tag{2.2}$$

Further, as is well known, the solution to (2.2) is $[u = (1 + e\cos\varphi)/l]$, where e is the eccentricity of the orbit and $[l = (1 + e)\mathcal{R}_\mathrm{min}]$ is the semi-lectus rectum of the orbit and $\mathcal{R}_\mathrm{min}$ is the closest distance the orbiting test body will ever come close to the central massive body. Substituting $[u = (1+e\cos\varphi)/l]$ into (2.2), one obtains the well known result, namely that $(J^2 = G\mathcal{M}_\mathrm{g}l)$.

Now, treating a photon as ordinary matter [as did *von* Soldner J. G. (1804), Einstein (1911)], its orbital angular momentum (as it grazes the limb of a gravitating object of radius $\mathcal{R}_\mathrm{min}$) is such that $(J = c\mathcal{R}_\mathrm{min})$, the meaning of which is that $(e = c^2\mathcal{R}_\mathrm{min}/G\mathcal{M}_\mathrm{g} - 1)$, and to first order approximation, we have $(e \simeq c^2\mathcal{R}_\mathrm{min}/G\mathcal{M}_\mathrm{g})$ since for hyperbolic orbits $(c^2\mathcal{R}_\mathrm{min}/G\mathcal{M}_\mathrm{g} \ggg 1)$. The gravitational deflection angle δ is related to e by the formula $(\delta \sim 1/e)$. It follows from this, that the Newtonian gravitational deflection angle δ_N will be such that:

$$\delta_N = \frac{2G\mathcal{M}_\mathrm{g}}{c^2\mathcal{R}_\mathrm{min}}. \tag{2.3}$$

Substituting the relevant values for the Sun, one obtains the famous Newtonian Solar gravitational bending of starlight value of $0.87''$ (*von* Soldner J. G. 1804, Einstein 1911).

3 Novel Newtonian Approach

Now, *behold*! If we do not cancel the factor $\mathrm{m_g}/\mathrm{m}_i$ in (2.1), that is, we do not make the traditional assumption that $(\mathrm{m}_i = \mathrm{m_g} :\Rightarrow \mathrm{m}_i/\mathrm{m_g} \equiv 1)$, but now decide to set this say to $2\gamma_\mathrm{g}$, that is to say:

$$\frac{\mathrm{m_g}}{\mathrm{m}_i} = 2\gamma_{\mathrm{g}}, \tag{3.1}$$

where γ_{g} is to be taken as a measure of the gravitational to inertial mass ratio of the test particle in a gravitational field; then, instead of (2.2), we will now obtain:

$$\frac{d^2u}{d\varphi^2} + u = \frac{2\gamma_{\mathrm{g}} G\mathcal{M}_{\mathrm{g}}}{J^2}. \tag{3.2}$$

The factor "2" in the equation $(\mathrm{m_g}/\mathrm{m}_i = 2\gamma_{\mathrm{g}})$ has been inserted so that when $(\gamma_{\mathrm{g}} = 1)$, the theory coincides with the Einsteinian value of $1.75''$; in this way, just as in the paper by Merat (1974), γ_{g} becomes a measure of the deviation of the measured deflection δ from the Einsteinian value of $1.75''$. Certainly, the solution to equation (3.2) is the same as before *i.e.* $[u = (1 + e\cos\varphi)/l]$, *albeit*, with the important difference that now $(J^2 \neq G\mathcal{M}_{\mathrm{g}} l)$, but $(J^2 = 2\gamma_{\mathrm{g}} G\mathcal{M}_{\mathrm{g}} l)$, and this leads to an interestingly different gravitational deflection angle $\delta_{\gamma_{\mathrm{g}}}$ which is such that:

$$\delta_{\gamma_{\mathrm{g}}} = \frac{4\gamma_{\mathrm{g}} G\mathcal{M}_{\mathrm{g}}}{c^2\mathcal{R}_{\mathrm{star}}}. \tag{3.3}$$

With the attainment of (3.3), insofar as answering the question of "*whether or not Newtonian gravitation actually failed the gravitational bending of starlight experiment*", we are done – for, this result (3.3) provides us with profound answers – because, any deviation from the Einsteinian value can now be attributed to γ_{g}. Surely, there appears to be no escape from this rather simplistic, bare and trivial result for what (3.3) is telling us is that from a purely Newtonian gravitational standpoint, the gravitational bending of starlight measurements are to be interpreted as a measure of γ_{g} *i.e.*, the ratio of the amount of gravitational to inertial mass of photons and nothing else. Even those results that lie in the peripheries far from the $1.75''$ Einsteinian prediction, these have a meaning and are not to be discarded as has traditionally been the case in measurements of this nature (see *e.g.* Almassi 2009, 's critic on this issue).

4 Analysis

Table (1) shows thirteen measurements (in eight eclipses) so far carried out by humankind on the gravitational bending of starlight and from this table it is seen that it is already forty three years since the last attempt on a total eclipse measurement of the gravitational bending of starlight. The value of γ_{g} for these thirteen measurements can be read-off the table. The GTR predicts that $(\gamma_{\mathrm{g}} \equiv 1)$. Inspection of Table (1) shows that γ_{g} varies slightly – *i.e.*, there is a 45% in standard deviation. Usually, the excuse given for having such significantly high deviation on the value of γ_{g} is that these measurements are difficult to carry out. It is only in VLBA measurements (*cf.* Fomalont & Sramek 1976, Robertson et al. 1991, Lebach et al. 1995, Shapiro et al. 2004) that one obtains a γ-value that is so close to unity. The reason perhaps for abandoning total eclipse measurements of the gravitational bending of starlight may have come after the first convincing measurements from VLBA measurement where made.

Actually, the prevalent thinking is that VLBA methods are the best way to measure γ_{g} as starlight measurements during eclipses are not only difficult, but marred by inherent and intrinsic systematic errors. If this is true and is the actual case in reality, then, in the light of the present findings, there may be need to make very accurate measurements of the gravitational bending of light using the traditional methods of total solar eclipse because it probably is difficult to dismiss these measurements on the grounds of level difficulty because the VLBA measurements with their γ-value nearly equal to unity as required, this may mean that this value is almost equal to unity for radio waves and the reason it varies when using white light may be that this value is different for white light and varies markedly.

The eclipse observers sought to obtain values of γ_{g} that are close to unity and after the seemingly impressive VLBA measurements, their thinking may have been altered to the viewpoint that VLBA measurements where the best way to confirm the GTR's predictions on the gravitational being of starlight.

Table 1: **Eclipse Measurements of the Gravitational Deflection of Starlight (1919 – 1973):** Column (1) gives the number of the observation in the table. Column (2) and (3) gives the date and location of execution of the eclipse observations. Column (4) gives the actual measurements made, while column (5) and (6) gives the γ-factor. Column (7) gives the deviation of the measurement from Einstein's expected 1.75″ Solar deflection. Lastly, column (8) gives the number of stars observed for the particular observational run.

	Date	Location	Measurement δ_D (arcsec)	γ-Factor	Deviation (%)	Number of Stars
(1)	May 29, 1919.	Sorbal	1.98 ± 0.16^a	1.14 ± 0.07	$+13.10 \pm 0.80$	7
(2)		Principe	1.61 ± 0.40^a	0.90 ± 0.20	-8.00 ± 2.00	5
(3)	Sept. 21, 1922.	Australia	1.77 ± 0.40^b	1.00 ± 0.20	$+1.10 \pm 0.30$	$11 - 14$
(4)			1.80 ± 0.40^c	1.00 ± 0.20	$+2.90 \pm 0.60$	18
(5)			1.72 ± 0.15^d	1.00 ± 0.10	-1.70 ± 0.10	$62 - 85$
(6)			1.82 ± 0.20^d	1.10 ± 0.10	$+4.00 \pm 0.40$	145
(7)	May 9, 1929.	Sumatra	2.24 ± 0.10^e	1.29 ± 0.06	$+28.00 \pm 1.00$	$17 - 18$
(8)	June 19, 1936.	USSR	2.73 ± 0.31^f	1.60 ± 0.20	$+56.00 \pm 6.00$	$16 - 29$
(9)		Japan	1.70 ± 0.40^g	1.00 ± 0.20	-2.90 ± 0.70	$4 - 7$
(10)	May 20, 1947.	Brazil	2.01 ± 0.27^h	1.20 ± 0.20	$+15.00 \pm 2.00$	51
(11)	Feb. 25, 1952.	Sudan	1.71 ± 0.10^i	0.98 ± 0.06	-2.30 ± 0.10	$9 - 11$
(12)	Oct. 2, 1959.	Sahara	2.17 ± 0.34^j	1.20 ± 0.20	$+24.00 \pm 4.00$	11
(13)	June 30, 1973.	Mauritania	1.66 ± 0.19^k	1.00 ± 0.10	$+5.10 \pm 0.60$	39
	Weighted Mean	$\longmapsto$	$\mathbf{1.92 \pm 0.05}$	$\mathbf{1.10 \pm 0.50}$	$\langle \mathbf{S} \rangle = \mathbf{13.00 \pm 2.00}$	**395 − 440**

References: [a]Dyson et al. (1920); [b]Dodwell & Davidson (1924); [c]Chant & Young (1924); [d]Campbell & Trumpler (1923); [e]Freundlich et al. (1929, 1931, 1933); [f]Mikhailov (1940, 1949); [g]Matukuma (1941); [h]*van* Biesbroeck (1949); [i]*van* Biesbroeck (1953); [j]Schmeidler (1963); [k]Jones (1976)

As already said above – given that the present calculation fully allows Newtonian gravitation to give equal claim to be in complete agreement with the total eclipse measurements of the gravitational bending of starlight, there is need to find another platform where the GTR can claim superiority over Newtonian gravitation. There are two things Newtonian gravitation can say about these measurements and these are:

1. Yes, photons do have a non-zero gravitational charge since observations give ($\gamma_g \neq 0$).
2. The gravitational to inertia mass ratio of photons seems to be different for different photons since γ_g appears to vary markedly from one measurement to the other.

As pointed out in Nyambuya & Simango (2014), a variable γ-value may, at a *prima facie* level of analysis appear to violate Einstein's seemingly sacrosanct *Equivalence Principle*. In the subsequent section, we argue otherwise by presenting the same argument of Nyambuya & Simango (2014).

5 Status of Einstein's Principle of Equivalence

A variable γ-value may, at a *prima facie* level of analysis appear to violate Einstein (1907)'s seemingly sacrosanct *Equivalence Principle* (EP), and is well known, a violation of the PE has far reaching implications on how we must take our present most trusted paradigm of gravitation – the GTR; for, at the very heart and nimbus of Einstein's GTR is the EP. Interwoven and intertwine in Einstein's EP are three separate principles (see *e.g.* Will 2006, 2009, 2014, 2015): that is, (1) the *Weak Equivalence Principle* (WEP), and (2) the principles of *Local Lorentz Invariance* (LLI) and (3) *Local Position Invariance* (LPI).

More explicitly:

1. **WEP:** Test bodies fall with the same acceleration independently of their internal structure or composition. This is the WEP first set into motion by Galileo's famous experiment at the Learning Tower *of* Pisa in Italy.

2. **LLI:** The outcome of any local non-gravitational experiment is independent of the velocity and acceleration of the freely-falling reference system in which it is performed. This is the Local Lorentz Invariance principle.

3. **LPI:** The outcome of any local non-gravitational experiment is independent of where and when in the Universe it is performed. This is the Local Position Invariance.

Now, for as long as all material bodies have the same value of $\gamma_{\rm g}$ at a given point (r, θ, φ) in a gravitational field, they will fall at the same rate, thus, Galileo's famous law (WEP) of falling bodies derived from his experiments at the Learning Tower of Pisa in Italy, will hold exactly leading to the same conclusion everywhere in the Universe. The ideas (which are to be briefly discussed in the next section) that we are currently working on in-order to find a theory that can explain the variability of γ, these ideas suggest that $\gamma_{\rm g} = \gamma_{\rm g}(r)$ [or more generally $\gamma_{\rm g} = \gamma_{\rm g}(r, \theta, \varphi)$], so all material bodies have the same value of $\gamma_{\rm g}$ at a given point in a gravitational field, thus, in the local neighbour of a freely falling cabin in a gravitational field, the LLI and the LPI principles will hold exactly. For an observer in a closed freely falling cabin, they will not be able to distinguish whether they are in a gravitational field or they are experiencing an inertia generated acceleration. They will however be able to tell that their closed freely falling cabin is undergoing an acceleration by measuring the deflection of light rays of different wavelength.

In Nyambuya & Simango (2014), we did argue that the observed scatter in the gravitational bending of starlight points to a violation of the WEP and that this violation did not entail a violation in the LLI and LPI. Given the violation of the WEP, the question naturally arises: *Does this mean that Einstein's EP does not hold any longer?* Further: *Does this mean that Einstein's GTR is not correct?* As pointed out in Nyambuya & Simango (2014), we strongly believe that Einstein's GTR requires the survival of only the LLI and the LPI principles. These two principles *i.e.* the LLI and the LPI principles should be sufficient to uphold the Principle of Relativity. In its depth and breath, the EP's ultimate endeavour is to uphold the LLI and the LPI principles, that is:

> *...for as long as the outcome of any local non-gravitational experiment is independent of the velocity and acceleration of the freely-falling reference system in which it is performed ...*

Einstein's GTR is safe. Actually, in-order to in-cooperate the new development, there is a way out. Einstein's bare GTR will have to be transformed into a conformal theory of gravitation much akin to Weyl (1918, 1927*a*,*b*)'s conformal theory of gravitation *i.e.*, in Riemann geometry, the metric $g_{\mu\nu}$ will have to be transformed into $2\gamma_{\rm g} g_{\mu\nu}$: $g_{\mu\nu} \longmapsto 2\gamma_{\rm g} g_{\mu\nu}$, so that the line element of spacetime ds now becomes:

$$ds^2 = 2\gamma_{\rm g} g_{\mu\nu} dx^\mu dx^\nu, \tag{5.1}$$

where x^μ is the four position in spacetime. Under such a setting, $\gamma_{\rm g}$ is now a scalar field and the line element *via* the metric, couples to the test particle's gravitational to inertial mass ratio. The geodesic equation in such kind of a spacetime is:

$$\frac{d^2x^\lambda}{ds^2} - 2\gamma_{\rm g} \left(\Gamma^\lambda_{\mu\nu} + {\rm W}^\lambda_{\mu\nu}\right) \frac{dx^\mu}{ds}\frac{dx^\nu}{ds} = 0, \tag{5.2}$$

where $\Gamma^\lambda_{\mu\nu}$ is the usual Christophel three symbol in Riemann geometry and:

$${\rm W}^\lambda_{\mu\nu} = \frac{1}{2}\left(\delta^\lambda_\nu \partial_\mu + \delta^\lambda_\mu \partial_\nu - g_{\mu\nu}\partial^\lambda\right) \ln \gamma_{\rm g}, \tag{5.3}$$

is the corresponding *Weyl* conformal affine connection. To first order approximation, in the weak field approximation where the *Weyl* conformal affine connection $\mathrm{W}^{\lambda}_{\mu\nu} \sim 0$, equation (5.2) reproduces the usual equations of motions. Obviously, there is need for more work than has been conducted here in-order to get these ideas on a firm pedestal. However, we have something different in mind. We are currently working on a much more ambitious goal that tries to tie all the forces of the world into one unified, consistent and coherent mathematical structure where all these issues are solved by a single unifying principle. For a glimpse at this work, we direct the reading to Nyambuya (2014, and references therein).

6 Plausible Cause of the Scatter

What could be the cause of the scatter in the gravitational bending of starlight measurements? As already said, it is predominately and largely believed that the scatter is as a result of the level difficulty in the measurements themselves. However, in our on-going investigations into an alternative theory of gravitation presented in the readings Nyambuya (2010, 2015*a*), it appears an answer as to *why the scatter in the gravitational bending of starlight measurements* may very well be in-sight. The theory presented in Nyambuya (2010, 2015*a*), we have coined it the Azimuthally Symmetric Theory of Gravitation (ASTG-model).

The ASTG-model results from the azimuthal solution of the well accepted Poisson-Laplace equation ($\boldsymbol{\nabla}^2\Phi = 4\pi G\varrho$) where (Φ, ϱ) are the gravitational potential and the mass density respectively. That is to say, traditionally, the gravitational potential is assumed to be a central field *i.e.* $\Phi = \Phi(r)$. In the ASTG-model, we considered the solution $\Phi = \Phi(r, \theta)$ of the Poisson-Laplace equation ($\boldsymbol{\nabla}^2\Phi = 4\pi G\varrho$) and the hypothesis therein, is that the θ-dependence comes about due to the spin of the gravitating body. In an affort to seek credence for the ASTG-model, the ASTG-model has been applied to the problem of the perihelion precision of the Solar planetary orbits (Nyambuya 2010, 2015*a*) and to the problem of the secular recession Earth-Moon system (Nyambuya et al. 2015). Apart from the perihelion precision of the Solar planetary orbits and the secular recession Earth-Moon system, we have applied (in the up-coming reading Nyambuya 2015*c*) it [the ASTG-model] to the Flyby Anomaly Problem (FAP) (see *e.g.* Antreasian & Guinn 1998, Anderson et al. 2007, 2008, Iorio 2009, Turyshev & Toth 2009, Iorio 2014, 2015).

Naturally, from within the confines of the ASTG-model, where (as in the present reading) the general assumption is made that ($\mathrm{m_g} \neq \mathrm{m}_i$); our findings are that the FAP finds a solution which requires that the γ-values for the spacecrafts in the gravitational field must vary as:

$$\gamma_{\mathrm{g}} = \left(\frac{\gamma\mathcal{R}_{\mathrm{min}}}{r}\right)^{\sin\theta}, \tag{6.1}$$

where $(\mathcal{R}_{\mathrm{min}}, r)$ has the same meaning as in the present and γ is what we call the natural gravitational to inertia mass ratio of the test particle and this is the value of gravitational to inertia mass ratio in a region free from any form of gravitation. The angle θ is the angle between the line joining the point joining the perigee point and the centre of mass of the central massive body and the spin axis of the spinning gravitating body. There is nothing prohibiting us from extending the relation (6.1) to photons.

So doing, that is applying this relation (6.1) in the case of starlight barely grazing the Solar limb, we will have ($\delta_{\gamma_{\mathrm{g}}} = 1''.75\gamma^{\sin\theta}$), so that equation (3.3) will now be given by:

$$\delta_{\gamma_{\mathrm{g}}}(r, \theta) = \frac{4\gamma^{\sin\theta} G\mathcal{M}_{\mathrm{g}}}{c^2\mathcal{R}_{\mathrm{star}}}\left(\frac{\mathcal{R}_{\mathrm{star}}}{r}\right), \tag{6.2}$$

and in the case of starlight barely grazing the Solar limb, we have $\left[\delta_{\gamma_{\mathrm{g}}}(\theta) = 1.75''\gamma^{\sin\theta}\right]$ and at any point (r, θ) away from the Solar rim, we will have $\left[\delta_{\gamma_{\mathrm{g}}}(r, \theta) = 1.75''\gamma^{\sin\theta}\left(\mathcal{R}_{\odot}/r\right)\right]$. What this all means is that the scatter in the 13 measurements made in the gravitational bending of starlight measurements made from 1919 to 1973 [as presented in Table (1)], this may very well be a result of the inclination θ

of the starlight's orbital plane relative to the Solar spin axis. As is well known and as already pointed out earlier, the use of starlight to confirm this GTR prediction of the gravitational bending of light is no-longer a viable option in the face of the Very Large Baseline Interferometer (VLBI) technology (*cf.* Will 2006, 2009, 2014, 2015).

In a private communication with Clifford M. Will (2015), VLBI-measurements have provided the most precise measurements of the deflection in measurements involving well over 500 quasars and radio sources distributed over the entire sky. Further he [Clifford M. Will (2015)] says that the overwhelming majority of the quasars are scattered around the Sun, the meaning of which is that the radio-waves from these quasars actually never come close to the the Solar rim, the meaning of which is that they the effects of these electromagnetic waves interfering with the activities (*e.g.* Solar plasma) of the Sun thereby leading to possible suspicion that the scatter may be due to this interference – this is ruled out. The deflections are much smaller (on the scale of milli-arcseconds rather than arcseconds), but VLBI-measurements are impressively so precise that they can measure the deflections extremely accurately. Furthermore, VBLA-measurements are done at multiple wavelengths so as to take care of any residual plasma effect.

Given the impressive accuracy of the VLBI-measurements, we naturally began to wonder why is it that these exists a marked and significant scatter in the gravitational bending of starlight measurements. So as to confirm the well known position is to why this is so, as presented above, we decided in an email private communication to ask Professor Clifford M. Will[2] (8/May/2015), a well known expect in the field. Of this observed scatter in the gravitational bending of starlight measurements, he said that '*the main reason for the scatter of measurements using optical light is that making such observations during solar eclipses is extremely difficult, and the results are plagued with systematic errors.*"

While Professor Clifford M. Will's position is correct in-accordance with prevalent and present wisdom – if confirmed – the findings from our up-coming studies (Nyambuya 2015*c*) suggest otherwise, that, this scatter may very well be a result of the inclination θ of the starlight's orbital plane relative to the of the Solar spin axis. With this in mind, the question naturally will arise: *Why is it that this scatter is only observed exclusively in measurements that use starlight rather than quasar radio-waves?* It may be that for radio-waves ($\gamma \simeq 1$) while for while light γ may be significantly different from unity. To answers these and other questions pertaining the scatter and the implied spatial variation of $\gamma_{\rm g}$, we now plan a separate study to investigate this matter. Certainly, it is quite interesting to note that a study of the FAP is directly leading us to a seemingly disconnected field of scientific endeavour such as the gravitational bending of electromagnetic radiation. In addition to this, the present findings thereof, appear to us to hold the latent and potent seed that may unlock deeper secrets about the way the gravitational phenomenon actually works.

7 General Discussion

Given the thesis presented herein, there certainly is need for a reanalysis of the past measurements and possibly fresh now dedicated missions for future measurements using starlight during Solar eclipses. That said: despite a modern reanalysis by Harvey (1979) whose final result is in favour of the 1919 measurement, physicists (*e.g.* Professor Stephen W. Hawking 1988) and historians of science (*cf.* Almassi 2009) have cast doubt on the soundness of the Eddington measurement by claiming that this measurement of 1919 may not have been sufficiently accurate to discern between the Einsteinian and Newtonian theories of gravity (*cf.* Earman & Glymour 1980), our point here is not on the accuracy of this measurement or on any subsequent measurements thereof, but on a matter of principle that this measurement alone or any that preceded it, all of them combined including the very accurate and impressive VLBA measurements (without other different measurements in favor of the GTR) – these gravitational bending of starlight measurements alone – they are, in light of the present arguments, all not able to discern which of the two theories (Einsteinian and Newtonian gravitation) is superior to the other.

[2]Professor Clifford M. Will of McDonnell Center for the Space Sciences, Washington University, United States of America.

The notion that the May 29, 1919 total solar eclipse measurement (Dyson et al. 1920) was not the decisive measurement it has been purported to have been (*e.g.* by Ellis et al. 2009, Ellis 2010, Will 2006, 2009, 2014, 2015, *etc*), this according to Kennefick (2009) has two forms, the first of which is common among physicists since at least the 1970*s* is that, the May 29, 1919 observationalists were simply lucky to obtain a measurement reasonably close to one of the two predictions, thus making this measurement not to constitute a really viable test of the two theories in the dock. The second form (according to Kennefick 2009) which is common among philosophers and historians of science but beginning to find a popular audience, originates in a reading by philosophers Earman & Glymour (1980). According to Kennefick (2009), these philosophers (Earman & Glymour 1980) specifically charge Sir Eddington and his team with throwing out data that appeared to support Sir Isaac Newton rather than Professor Einstein [*e.g.* Dyson et al. (1920) discarded their $0.98''$ measurement on the grounds it was inaccurate].

Further according to Kennefick (2009), some modern critics have charged that such action – as discarding the $0.98''$ measurement; was not justifiable on scientific grounds and was more likely motivated by Sir Eddington's theoretical and political bias. For example, Sir Eddington was as well known enthusiastic proponent of the GTR and is said to have been anxious to make a gesture toward reconciliation between the United Kingdom (UK) and Germany in the aftermath of the so-called World War I by verifying the theory of one of Germany's leading men of science – Professor Albert Einstein, who, like Sir Eddington himself, was a pacifist (Kennefick 2009). Thus – according to Kennefick (2009), the 1919 eclipse is sometimes given as a prime example of experimenters fitting their data to the expected result and this has come to be known as the *Predictor Effect*. However, one can successfully defend Sir Eddington by stating that – not only do subsequent measurements agree with the 1919 result, but that a reanalysis by Harvey (1979) agrees in general with the conclusion of the Eddington team.

Kennefick (2009) further contends that probably the most famous illustration of Eddingtons alleged bias in favour of Einstein's theory is a story narrated in Chandrasekhar (1976), a story that Sir Eddington himself subsequently repeated, a story which Professor Dyson, in explaining the experiment to Professor Cottingham before departure, told a clockmaker that there were three theoretically plausible results: (1) no deflection; (2) half deflection, which would show that light had mass, and vindicate Newton; and (3) full deflection, which would vindicate Einstein. On gathering that the greater the deflection the more theoretically exciting and novel the result, Kennefick (2009) say that Professor Cottingham asked what would happen if they obtained twice the Einstein deflection. "Then," replied Professor Dyson, "Eddington will go mad, and you will have to come home alone."

As already said, the issue here is not about the correctness of the Eddington measurement but the apparent variation of γ. If it turns out that $(\gamma = 1)$ for total solar eclipse gravitational bending of starlight measurements, then, for photons we must have $(\mathrm{m_g}/\mathrm{m}_i = 2)$. Therefore, if we assume the correctness of the present thesis, then, one can safely say that the gravitational bending of starlight results are no longer an indicator of the superiority of Einsteinian gravitation over Newtonian gravitation. With his as given, one may say that the unprecedented correct prediction of the precession of the perihelion of the planet Mercury's orbit keeps Einsteinian gravitation a foot ahead. On this, as already said in §(6), we have shown (in Nyambuya 2010, 2015*b*) that this result – of the perihelion of the planet Mercury, can *in-principle* be explained within the framework of Newtonian gravitation by invoking the ASTG-model.

That is to say, traditionally, the Newtonian gravitational field is assumed to the a central force, it only has a radial dependence *i.e.* $\Phi = \Phi(r)$. However, one can argue (as done in Nyambuya 2010, 2015*b*) that the spin of a gravitating object can be included in Newtonian gravitation by considering the azimuthal solution of the Poisson-Laplace equation *i.e.* $\Phi = \Phi(r, \theta)$. Despite having a number of free parameters that are to be fixed using observational data, the resulting theory [from the solutions $\Phi = \Phi(r, \theta)$] can *in-principle* explain the Mercurial perihelion precession. Therefore – *in-principle* – Newtonian gravitational theory can explain the gravitational bending of starlight and the Mercurial perihelion precession. Certainly, this leaves us with the task of thinking a little deeper about Newtonian and Einsteinian gravitational theories.

In-closing, allow us to say that, as we celebrate the centenary of the GTR, it is important that we seriously and non-dogmatically introspect the GTR and consider the possibility of improving this theory in areas that it has failed to naturally account for – such as the Flyby anomalies (Antreasian & Guinn 1998, Anderson et al. 2007), the Pioneer anomaly (Anderson et al. 1998, 2002), the secular recession of the Earth-Moon system (Standish 2005, Krasinsky & Brumberg 2004) and that of the Moon from the Earth (Williams et al. 2004, 2014), dark-matter (Zwicky 1933*a*,*b*, Rubin et al. 1985) to mention but a few such areas. Such an introspection will – amongst others – require us to search for subtle shortcomings in the GTR, shortcomings as those revealed *e.g.* by a variable γ as suggested herein.

8 Conclusion

Assuming the correctness and acceptability of the ideas propagated herein, we hereby make the following conclusion:

1. Yes, photons do have a non-zero gravitational charge since observations give ($\gamma_{\rm g} \neq 0$).

2. The gravitational charge ($m_{\rm g}$) to inertia mass (m_i) of photons seems to be different for different photons since $\gamma_{\rm g}$ appears to vary markedly from one measurement to the other.

9 Recommendations

Assuming the correctness and acceptability of the ideas propagated herein, we hereby make the following recommendations:

1. In-order to verify whether or not $\gamma_{\rm g}$ varies markedly (with a 45% standard deviation) as suggested by the total solar eclipse gravitational bending of starlight measurements made so far *i.e.* measurements from $1919 - 1973$, there is need to conduct anew highly accurate measurements of the same nature and these measurements must preferably measure as many stars as is possible.

2. If $\gamma_{\rm g}$ varies from one starlight to the next as suggested herein, then, the deflection of starlight for a given star must be evaluated separately and if possible a histogram be constructed so as to evaluate the nature of the distribution of these deflections. If the distribution if the deflections is Gaussian, a case can be made that this division is of a random statistical nature. But if it is not Gaussian, this would point to a fundamental systematic variation of $\gamma_{\rm g}$. If the GTR is correct, then $\gamma_{\rm g}$ must be very close to unity and the resulting distribution of the measurements of $\gamma_{\rm g}$ must be Gaussian; and, if GTR is not correct on this matter, then $\gamma_{\rm g}$ will vary significantly and the resulting distribution of the measurements of $\gamma_{\rm g}$ will certainly not be Gaussian.

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