Pulsar frequency and pulsar tilted axis explained as geodesic precession effects

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The hypothesis is presented that pulsar-time is geodesic precession rotation time, in both the causal sense and the quantitative sense (T-pulsar exactly equals T-geodesic). The causal sense implies the hypothesis that, in the outer crust of the neutron star, the curvature of the metric favors alignment of elementary particle magnetic moments along the geodesic precession. A consequence of this hypothesis is the partial decoupling of pulsar time and orbital rotation time. For a "canonical" neutron star, with 1.4 solar mass and a radius of 10 km, this implies that T-orbit equals approximately one fifth of T-pulsar. The pulsar time as being geodesic precession time explains the extreme stability of pulsar frequencies, despite strong magnetic turbulences. It also quite naturally explains the tilted axis of the neutron stars magnetic moment relative to its orbital axis. The hypothesis is formulated within the environment of the Ehlers-Pirani-Schild Weyl Space Free Fall Grid approach as developed in two previous papers, but it should be theory independent and thus be derivable in GR-Schwarzschild as well.

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CONTENTS

I. RELATIVISTIC REDSHIFTS AND NEUTRON STARS

I start with a few quotes. The first is about the lighthouse pulsar model.

> *Radio pulsars are conceived as rapidly rotating highly magnetized neutron stars and the pulsations are a consequence of the so called "lighthouse effect" in which rotating beamed emission sweeps our line of sight. (Ekşi, 2016)*

The second is about the environment at the surface of a neutron star.

> *Neutron stars represent the most relativistic stellar surfaces accessible to observatio. (Pechenick et al., 1983)*

The model used in astronomy still is the Schwarzschild metric, usually in its Parametrized Post Kepler or PPK extension.

> *The metric outside the star is taken to be the Schwarzschild metric with mass M and radial coordinate r. [...] The observer is taken to be stationary at $r = r_0$ where $r_0 \to \infty$. Since neutron stars are "slowly rotating" from the point of view of general relativity, we assume the brightness of the rotating star to have the value it would have at that instant if the star were stationary; we do not use the Kerr metric and we neglect the "dragging of inertial frames". (Pechenick et al., 1983)*

This allows me to apply the EPS-FFG approach of my previous two papers (de Haas, 2014, 2017).

Neutron star facts can be found in the literature. The pulsar frequency, actually the pulsation time, of neutron stars varies from 10 seconds to about 1 milliseconds. The neutron star mass distribution is about $1.3 - 1.6 M_{\odot}$. The "canonical" neutron star has values of mass $M_{ns} \simeq 1.4 M_{\odot}$, radius $R_{ns} \simeq 10\ km$ and pulsation time of $T_{ns} \simeq 1\ s$. As a result, a canonical neutron star has a surface Newtonian potential field strength of $GM/c^2R \simeq 0.2$ (Damour and Taylor, 1992; Lattimer and Prakash, 2007; Kaspi, 2010; Kiziltan et al., 2013; Özel and Freire, 2016). It has an equatorial surface velocity of $v_{orb} \simeq 10^5\ m/s$. These value determines the gravitatinal redshift. On a "canonical" neutron stars surface, the gravitational redshift by far overweights the kinematic redshift.

In standard Neutron Star Astronomy, the γ-factor, the "Einstein delay," γ, gives the relativistic redshift on the surface of the star, combining the effect of gravity and of velocity(Damour and Taylor, 1992; Özel and Freire, 2016). Binary neutron stars make it possible to measure the mass of these stars. The mass of isolated neutron stars cannot be measured directly (Özel and Freire, 2016). Neutron stars that spin moderately fast aren't easily described in spacetime by the Schwarzschild metric (Özel and Freire, 2016).

The General Relativity Schwarzschild gravitational redshift at the surface of a neutron star is given by (Zwicky, 1939; DeDeo and Psaltis, 2003; Bauböck et al., 2015; Ekşi, 2016)

$$z = |-g_{tt}(R)|^{-1/2} - 1 = \left(1 - \frac{2GM}{Rc^2}\right)^{-1/2} - 1 \tag{1}$$

In (Zhao, 2013), using $G = 1$ and $c = 1$, this was given as:

$$z = \frac{1}{\sqrt{1 - \frac{2M}{r}}} - 1 \tag{2}$$

In (Lindblom, 1984), measurements gave $0.1 < z < 0.3$, consistent with the redshifts computed for neutron stars in the $1.2 - 1.4\ M_{\odot}$ range. The model used in the calculations is GR-Schwarzschild.

> *In this analysis one assumes that general relativity correctly describes the gravitational interaction at neutron star densities. One also assumes that the stars are nonrotating, spherical, and composed of fluid matter (that is, matter having isotropic stresses). (Lindblom, 1984)*

In (Cottam et al., 2002), an extreme case with $z = 0.35$ was reported.

In the FFG approach of (de Haas, 2017) one has for the gravitational redshift

$$\frac{\nu_{ns}}{\nu_0} = \frac{\gamma_{ns}}{\gamma_0} = \frac{1 - \frac{\Phi_{ns}}{c^2}}{1 - \frac{\Phi_0}{c^2}} = 1 - \frac{\Phi_{ns}}{c^2} = \gamma_{ns}, \tag{3}$$

so also

$$z = \frac{\nu_{ns} - \nu_0}{\nu_0} = \gamma_{ns} - 1 = \frac{GM_{ns}}{R_{ns}c^2} \simeq 0.2 \tag{4}$$

for a standard or "canonical" neutron star with $M_{ns} = 1.4M_\odot$ and $R_{ns} = 10km$. But the total redshift in the FFG approach includes the kinematic part of Special Relativity. This is determined by the total relativistic Lorentz boost on the equator, as seen from the Free Fall Grid perspective, $z = \gamma_{ns} - 1 = \gamma_{escape}\gamma_{orbital} - 1$, and this can be significantly higher for milliseconds pulsars, reaching values of $z \simeq 0.3$. This is directly related to the high orbital velocity on millisecond neutron stars, implying a non-negligible orbital Lorentz boost relative to the escape velocity Lorentz boost.

II. GEODESIC PRECESSION OF BINARY NEUTRON STARS

Neutron star binaries are of special interest for astronomers and for gravitational theorists.

> *With their strong gravitational fields and rapid motions, DNS [Double Neutron Stars] binaries exhibit large relativistic effects. General relativity and other theories of gravity can be tested when a number of relativistic corrections, the so-called post-Keplerian (hereafter PK) parameters, to the classical Keplerian descriptions can be measured. (Lyne et al., 2004)*

Double pulsar PSR J0737-3039, individually known as PSR J0737-3039A and PSR J0737-3039B, has been a laboratory for relativistic gravity (Lyne et al., 2004). This binary pulsar system has allowed astronomers to measure the occurring geodesic or de Sitter precession of neutron star B.

> *Because of the curvature of space-time near massive objects, the spin axes of both pulsars will precess about the total angular momentum vector, changing the orientation of the pulsars as seen from Earth. With the measured system parameters (Table 1), general relativity predicts periods of such geodetic precession of only 75 years for A and 71 years for B. (Lyne et al., 2004)*

A precaution is at place regarding the previous statement. The geodesic precession has been calculated using the PPK extension of the GR-Schwarzschild approach (Barker and O'Connell, 1975). This derivation is considerably more complicated than the original by de

Sitter, Schouten and Fokker or the later one by Schiff (de Haas, 2014). The complication is due to the fact that a binary system isn't a pure Schwarzschild metric and that for two reasons. First it isn't circular but elliptic. And second, non of the two stars is in or close to the center of mass CM because their masses are comparable.

In (de Haas, 2014), the hyperbolic Minkowsk-EEP (Einstein Equivalence Principle) and EPS Free Fall Grid calculus of the geodesic precession resulted in the geodesic precession as a gravitational Thomas precession formula:

$$\Omega_G = (\gamma_{esc}\gamma_{orb} - 1)\Omega_{orbital}. \tag{5}$$

The first thing that has to be noticed is that the factor $(\gamma_{esc}\gamma_{orb} - 1)$ relating the geodesic precession to the orbital rotation is exactly the same as the total relativistic redshift factor z in the relativistic redshift EPS-FFG approach of (de Haas, 2017).

Before I will apply this formula for the geodesic precession to isolated neutron stars, I will test it on a binary system, PSR J0737-3039, for which the geodesic precession for the companion B has actually been measured (Breton et al., 2008). The reported measured precession time was, when given in years instead of degrees per year, $T_G = 75^{+10}_{-10}\ years$ which was compared to the calculated Parametrized Post Kepler precession time of $T_G = 70\ years$. In the following I will apply the FFG approach to this system, with Eqn. (5) rewriten as

$$T_G = \frac{T_{orb}}{(\gamma_{esc}\gamma_{orb} - 1)}. \tag{6}$$

The basic facts for the binary system PSR J0737-3039 are given in the following table.

Property (Lyne et al., 2004)	**PSR J0737-3039A**	**PSR J0737-3039B**
Pulse period P (ms)	22.70	2773
Orbital period Pb (hours)	2.454	2.454
Gravitational redshift parameter (ms)	0.385	-
Stellar mass ($M_\odot$)	1.338	1.250
Mass ratio $R = m_A/m_B$	1.069	1.069
Typical distance A-B (m)	$9 \cdot 10^8$	$9 \cdot 10^8$

The distance from B to the center of mass CM, B-CM thus can be estimated as

$$R_{orb,B} = \frac{m_a}{m_a + m_b} 9 \cdot 10^8\ m = 4.653 \cdot 10^8\ m. \tag{7}$$

From this, one can calculate the orbital velocity as

$$v_{orb,B} = \frac{2\pi R_{orb,B}}{T_{orb}} = 3.31\ m/s. \tag{8}$$

Together with the escape Lorentz boost factor $\gamma_{esc} = 1 - \Phi/c^2 = 1 + 2.18 \cdot 10^{-6}$ which leads to a Lorentz boost factor $\gamma_{orb} = 1 + 6.084 \cdot 10^{-7}$ and to a geodesic precession factor of

$$\gamma_G - 1 = \gamma_{esc}\gamma_{orb} - 1 = 2.794 \cdot 10^{-6}, \tag{9}$$

which gives a precession time $T_G = T_{orb}/(\gamma_G - 1) = 100 years$.

In this model I assumed the center of mass (CM) of the binary system to be the FFG, which clearly is incorrect because close to the binary system, the CP geodesics will dynamically deviate from the radial lattice towards the CM. Another model could take PSR J0737-3039A as the center of the FFG and thus as the center of mass. Then the orbital radius of B would be $9 \cdot 10^8\ m$. Repetition of the above calculus would then lead to a precession time $T_G = T_{orb}/(\gamma_G - 1) = 65\ years$. But this model is also incorrect due to the dynamic fluctuation of the CP geodesics, actually causing them to case to be CP geodesics and to erase the possibility of a FFG approach. The CM model underestimates the orbital radius of B and the model in which A is the center of mass overestimates the radius of B, from the FFG perspective.

Averaging the two models would lead to a radius of $6.83 \cdot 10^8\ m$ and to a precession time of $T_G = T_{orb}/(\gamma_G - 1) = 80\ years$. The end result in the FFG approximation, the extension of the model beyond its exact form, could be given as a precession time of $T_G = 80^{+20}_{-15}\ years$. This can be compared to the measured precession time as $T_G = 75^{+10}_{-10}\ years$ and to the more exact Parametrized Post Kepler precession time of $T_G = 70\ years$, see (Breton et al., 2008). I can conclude that the FFG has troubles to handle binary systems, but that with some basic modeling around the problem an average and a range can be produced that nicely overlap the measured and the PPK values and range.

As a test of the pragmatic Minkowski-EEP FFG approach relative to the geodesic precession time of PSR J0737-3039B in the binary system PSR J0737-3039, my approach stands up to the challenge. It is also clear that the FFG approach has severe limitations, because it cannot exactly handle a binary system. A such, it is a preliminary approach towards relativistic gravity, intended to provide more conceptual anchor points for further metric research. This FFG limitation mimics the GR-Schwarzschild metric limitations, being the metric around a central static mass in an empty Universe. The PPK model is a successful approach to pragmatically handle the limitations of the Schwarzschild metric, to extend its experimental reach.

The test of the FFG approach towards geodesic precession has withstand the test of the extreme case of a neutron star binary system. The following statement can therefore be regarded as outdated.

> *While relativistic spin precession is well studied theoretically in general relativity (GR), the same is not true of alternative theories of gravity and hence, quantitative predictions of deviations from GR spin precession do not yet exist. (Breton et al., 2008)*

It has to be noted that the FFG approach, as being a Minkowski-EEP based method, should be perceived as gravity 1.5 relative to Newton's theory of gravity as gravity 1.0 and Einstein's General Relativity as gravity 2.0. The goal of the FFG approach to gravity is to produce conceptual anchor points to assist a fully metric theory of gravity. The primary reason for a Minkowski-EEP approach to gravity is that Quantum Mechanics is formulated in the Minkowski metric environment and resists unification with General Relativity. The move from the Minkowski metric Standard Model to a Minkowski-EEP theory of gravity should be easier than the direct move from the Minkowski metric SM to GR.

III. PULSAR FREQUENCY AND PULSAR TILTED AXIS AS GEODESIC PRECESSION EFFECTS

As I already pointed out, the FFG redshift time dilation factor is the same as the FFG geodesic precession factor. One has for the geodesic precession time

$$T_G = \frac{T_{orb}}{\gamma_{esc}\gamma_{orb} - 1}. \tag{10}$$

In the case of canonical neutron stars one has $\gamma_{esc}\gamma_{orb} \simeq \gamma_{esc}$, giving

$$T_G \simeq \frac{T_{orb}}{\gamma_{esc} - 1} \simeq \frac{T_{orb}}{0.2}. \tag{11}$$

Now, the escape velocity is a very stable quantity of neutron stars and the orbital velocity of neutron stars is also highly stable. Thus, the precession time of a neutron star also is very stable and for canonical neutron stars about one fifth of the orbital time, so clearly in the same order of magnitude. This geodesic precession must have an axis that is tilted relative to the orbital axis of the particles in the outer crust of the neutron star because it has to precess around that axis. Already in two occasions, the FFG approach produced the same results, within the experimental limits, as the GR-Schwarzschild and its PPK extension. The first was the Gravity Probe B and the second the binary pulsar system PSR J0737-3039. It should be expected that GR-Schwarzschild experts can reproduce the above geodesic precession rate on the surface of a "canonical" neutron star.

Neutron stars as being magnetic pulsars with a extremely stable periodicity of the same order in magnitude as the geodesic precession time and a magnetic moment axis tilted relative to the rotational axis, leads to the natural hypothesis that being a pulsar is a geodesic effect and that the pulsar time equals the geodesic time.

The first consequence would be a rotational time five times faster than the pulsar time for "canonical" neutron stars,

$$T_{orb} \simeq 0.2 T_G = \frac{1}{5} T_{pulsar}. \tag{12}$$

This will probably be a minor issue because that rotation time hasn't been measured independent of the pulsar time, it has been assumed from the beginning that the magnetic moment was fixed to the inertial moment and never that the first was precessing around the second.

For this hypothesis, geodesic precession leads to the pulsar effect, it is necessary to assume some metronome-like effect of the elementary particle magnetic momenta relative to the geodesic precession. Somehow it is energetically less stressful for the individual magnetic momenta to align to the geodesic precession axis.

The advantage of the geodesic precession pulsar hypothesis would be that the dynamic turbulence of the magnetic fields wouldn't be able to affect the long term periodicity of the pulsar effect.

From the perspective of Ockhams razor blade, the geodesic precession is theoretically undeniable, the pulsar phenomenon is an experimental fact beyond any doubt, the easiest hypothesis being the first as causally related to the second.

For millisecond pulsars, the orbital Lorentz boost is significant and the geodesic precession gives

$$T_G = \frac{T_{orb}}{\gamma_{esc}\gamma_{orb} - 1} \simeq \frac{T_{orb}}{0.3}. \tag{13}$$

and

$$T_{orb} \simeq 0.3 T_G \simeq \frac{1}{3} T_{pulsar}. \tag{14}$$

It can also be calculated that for an equatorial orbital velocity of $0.8c$, we have

$$T_{orb} \simeq T_G \simeq T_{pulsar}, \tag{15}$$

and the axis would be locked on to each other. It seems unlikely that such neutron stars exist. Besides that, with sufficiently high orbital velocities, the pulsar magnetic alignment should be much more dynamic than with "canonical" neutron stars, because the geodesic precession would then depend on the latitude as well. This should be observable in millisecond pulsars.

An interesting question is if the rotation time of neutron stars could be measured directly, independent of metric effects as relativistic redshift and geodesic precession/pulsar time. Such a measurement would directly verify/falsify the hypothesis of this paper.

REFERENCES

Barker, B. M. and R. F. O'Connell (1975, Jul). Gravitational two-body problem with arbitrary masses, spins, and quadrupole moments. *Phys. Rev. D 12*, 329–335.

Bauböck, M., F. Özel, D. Psaltis, and S. M. Morsink (2015). Rotational corrections to neutron-star radius measurements from thermal spectra. *The Astrophysical Journal 799*(1), 22.

Breton, R. P., V. M. Kaspi, M. Kramer, M. A. McLaughlin, M. Lyutikov, S. M. Ransom, I. H. Stairs, R. D. Ferdman, F. Camilo, and A. Possenti (2008). Relativistic spin precession in the double pulsar. *Science 321*(5885), 104–107.

Cottam, J., F. Paerels, and M. Mendez (2002). Gravitationally redshifted absorption lines in the x-ray burst spectra of a neutron star. *Nature 420*(6911), 5154.

Damour, T. and J. H. Taylor (1992, Mar). Strong-field tests of relativistic gravity and binary pulsars. *Phys. Rev. D 45*, 1840–1868.

de Haas, E. P. J. (2014). The geodetic precession as a 3d schouten precession and a gravitational thomas precession. *Canadian Journal of Physics 92*(10), 1082–1093. Vixra: 1310.0099.

de Haas, E. P. J. (2017). Using a syntonized free fall grid of atomic clocks in ehlers-pirani-schild weyl space to derive second order in ϕ/c^2 relativistic gnss redshift terms. Vixra: 1710.0165.

DeDeo, S. and D. Psaltis (2003, Apr). Towards new tests of strong-field gravity with measurements of surface atomic line redshifts from neutron stars. *Phys. Rev. Lett. 90*, 141101.

Ekşi, K. Y. (2016). Neutron stars: compact objects with relativistic gravity. *Turk.J.Phys. 40*(2), 127–138. ArXiv:1511.04305 [astro-ph.HE].

Kaspi, V. M. (2010). Grand unification of neutron stars. *Proceedings of the National Academy of Sciences 107*(16), 7147–7152.

Kiziltan, B., A. Kottas, M. De Yoreo, and S. E. Thorsett (2013). The neutron star mass distribution. *The Astrophysical Journal 778*(1), 66.

Lattimer, J. M. and M. Prakash (2007). Neutron star observations: Prognosis for equation of state constraints. *Physics Reports 442*(1), 109 – 165. The Hans Bethe Centennial Volume 1906-2006.

Lindblom, L. (1984). Limits on the gravitational redshift from neutron stars. *The Astrophysical Journal 278*, 364368.

Lyne, A. G., M. Burgay, M. Kramer, A. Possenti, R. Manchester, F. Camilo, M. A. McLaughlin, D. R. Lorimer, N. D'Amico, B. C. Joshi, J. Reynolds, and P. C. C. Freire (2004). A double-pulsar system: A rare laboratory for relativistic gravity and plasma physics. *Science 303*(5661), 1153–1157.

Özel, F. and P. Freire (2016). Masses, radii, and the equation of state of neutron stars. *Annual Review of Astronomy and Astrophysics 54*(1), 401–440.

Pechenick, K. R., C. Ftaclas, and J. M. Cohen (1983, nov). Hot spots on neutron stars - the near-field gravitational lens. *Astrophysical Journal 274*, 846–857.

Zhao, X.-F. (2013). The surface gravitational redshift of the neutron star psr j1614-2230. *Acta Physika Polonga B 44*(2), 211–219.

Zwicky, F. (1939, Apr). On the theory and observation of highly collapsed stars. *Phys. Rev. 55*, 726–743.