

Proposed New Test of Spin Effects in General Relativity

R. F. O'Connell*

Department of Physics and Astronomy, Louisiana State University, Baton Rouge, Louisiana 70803-4001, USA
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The recent discovery of a double-pulsar PSR J0737-3039A/B provides an opportunity of unequivocally observing, for the first time, spin effects in general relativity. Existing efforts involve detection of the precession of the spinning body itself. However, for a close binary system, spin effects on the orbit may also be discernible. Not only do they add to the advance of the periastron (by an amount which is small compared to the conventional contribution) but they also give rise to a precession of the orbit about the spin direction. The measurement of such an effect would also give information on the moment of inertia of pulsars.

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The Hulse-Taylor binary pulsar PSR 1913 + 16 has proved to be a fascinating laboratory-in-the-sky for the investigation of general relativistic effects. However, the recent discovery of a close double-pulsar binary system [1,2] (with an orbital period about 3 times smaller and a pulsar period also smaller for the larger mass pulsar) promises an opportunity for even more exciting discoveries. Here, we consider spin effects.

Attempts to measure gravitational effects due to spin in the laboratory are futile [3]. The proposal of Schiff to investigate such effects by measuring the precession of a small gyroscope in Earth orbit is the basis of the successfully launched Gravity Probe B experiment [4]. Apart from technological and scientific challenges [5], the largest relativistic precession rates involved are less than about seven seconds of arc per year. On the other hand, with the discovery of PSR 1913 + 16 in 1975, it was immediately clear that much larger spin precession effects come into play. However, it was also obvious that the results of Schiff were no longer applicable since we are now dealing with a 2-body system. The correct required 2-body spin precession result was provided by Barker and the present author [6–8] from which it became apparent that the spin direction precesses about the orbital angular momentum direction at a rate of $1^\circ \cdot 213 \text{ yr}^{-1}$, i.e., a factor of about 6×10^5 larger than for the Earth gyroscope. However, while efforts to measure this precession have proved difficult [9,10] there is hope that observations on the new double pulsar will prove more fruitful because the calculated [6,8] spin precession rates are even larger [2], viz. $4^\circ \cdot 8 \text{ yr}^{-1}$ for *A* and $5^\circ \cdot 1 \text{ yr}^{-1}$ for *B*.

We now point out that correspondingly larger numbers arise for spin effects on the orbital motion which might prove easier to observe. Observable implications of such effects have been explored for a variety of astrophysical binary systems but no definitive results have emerged [11–16]. In particular, it would appear that the best possibility might be the effect on the gravitational radiation wave form in coalescing binary systems of compact objects

[17] but such hopes rest on the detection of gravitational radiation.

On the other hand, the double-pulsar system presents the possibility of a clean test [1,2]. The greatest effect on the orbital motion in the double-pulsar system is the periastron precession, amounting to $16^\circ \cdot 90 \text{ yr}^{-1}$. It is more important to note that, in addition to these precessions about the orbital angular momentum direction, there is also a precession of the angular momentum of the orbit itself about the spin directions [6,8] which only occurs due to spin effects. This is a reflection of the fact that the total angular momentum of the whole system remains constant (as shown explicitly in [6]) so that a precession of the spins implies a precession of the total orbital angular momentum (both effects resulting from spin-orbit interactions and, to a lesser degree spin-spin interactions). Explicit results have been written down for these quantities [6,8], which we now use to calculate the contribution from the fast 23-ms pulsar (with a mass m_1 , say) to this precession (noting that the contribution of the 2.8 -sec pulsar, with mass m_2 , may be obtained from our general formulas by the simple replacement $m_1 \leftrightarrow m_2$).

Using the notation of [6,8], the secular result for the rate of precession of the orbital angular momentum \vec{L} due to the spin $\vec{S}^{(1)}$ of m_1 may be written as

$$\frac{d\vec{L}}{dt} = A^{*(1)}(\vec{n}^{(1)} \times \vec{L}), \quad (1)$$

where

$$A^{*(1)} = \frac{GS^{(1)}(4 + 3m_2/m_1)}{2c^2 a^3 (1 - e^2)^{3/2}}, \quad (2)$$

and where $\vec{n}^{(1)}$ is a unit vector in the direction of $\vec{S}^{(1)}$, a is the semimajor axis and e is the eccentricity. Writing

$$S^{(1)} = I^{(1)}\omega^{(1)} = m_1 k_1^2 \omega^{(1)}, \quad (3)$$

where $I^{(1)}$, $\omega^{(1)}$, and k_1 are the moment of inertia, the angular rotational velocity and the radius of gyration,

respectively, of m_1 , we obtain

$$A^{*(1)} = \frac{G(4m_1 + 3m_2)\omega^{(1)}}{2c^2 a(1 - e^2)^{3/2}} \left(\frac{k_1}{a}\right)^2. \quad (4)$$

Since, from [1,2], $a = 8.79 \times 10^5$ km (which is obtained from the 2-body Kepler formula [6,7] and the measured period of orbital revolution [1,2]) and, for a neutron star, [18] $r_1 \approx 15$ km we see that $(k_1/a)^2 \approx 2.91 \times 10^{-10}$. Also [1,2] $\omega^{(1)} = 2.768 \times 10^2$ rad/sec and $(1 - e^2)^{-3/2} = 1.0117$. Thus

$$A^{*(1)} \approx 4.06''/\text{yr}. \quad (5)$$

This result for the rate of precession of the angular momentum of the orbit about the pulsar spin direction is clearly measurable over a sufficient period of time (and we note that it is more than 10^3 times larger than the ms-arc precession rates desired of the gyroscope experiment) as it is reflected in a corresponding change in the mass function which depends on observable quantities. Furthermore, it could eventually provide a way to obtain accurate information of the moment of inertia of neutron stars, particularly if both spin precession and orbital precession are observed. We note that there is also a contribution from the spin of pulsar B to the precession of \vec{L} but since its pulse period is 122 times larger than that of pulsar A , its contribution will be correspondingly smaller. Finally, we note that contributions of the same order of magnitude are present due to spin contributions to the perihelion precession (the only difference being geometric factors [6,8]) since the angular momentum and Runge-Lenz vectors precess at the same rate [6,8] but, in addition, there is also a comparable contribution from second-order spin-independent post-Newtonian effects [12,19]. However, we feel that a measurement of the precession of the orbital angular momentum is a cleaner test since any such precession is a definite signature of spin effects. The corresponding results for other gravitational theories are given in [20].

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*Email address: rfoc@phys.lsu.edu

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