Geodetic Precession in PSR B1913+16

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**Abstract.** We review the observational evidence for geodetic precession in PSR B1913+16 and present the latest observations and results from modelling the system geometry and beam.

1. Introduction

After the discovery of PSR B1913+16 by Hulse & Taylor in 1974 (Hulse & Taylor 1975), it was immediately realized that this system represents a highly stable and accurate clock orbiting in the gravitational field of a compact star. PSR B1913+16 has indeed fulfilled all promises by finally allowing tests of theories of gravity in the strong field limit which cannot be realized in the solar system (see Weisberg, these proceedings). Indeed, no participant at this conference needs to be reminded about the role which this pulsar has played in the confirmation of the existence of gravitational waves. While these tests are based on timing observations, Damour & Ruffini (1974) pointed out very soon after the discovery of this pulsar, that by studying also its emission properties one can test another prediction made by general relativity, ie. that of geodetic precession.

In general relativity, the proper reference frame of a freely falling object suffers a precession with respect to a distant observer, called geodetic precession. In a binary pulsar system this geodetic precession leads to a relativistic spin-orbit coupling, analogous of spin-orbit coupling in atomic physics. As a consequence, the pulsar spin precesses about the total angular momentum, changing the relative orientation of the pulsar towards Earth. Due to such a change in geometry, we should also expect a change in the radio emission received from the pulsar.

The precession rate (e.g. Boerner et al. 1975) depends on the period and the eccentricity of the orbit as well as the pulsar and companion mass. As Joel Weisberg demonstrates in these proceedings, all these values can be obtained accurately from timing observations. With these we obtain a precession rate of $\Omega_p = 1.21 \, \text{deg yr}^{-1}$. Since the orbital angular momentum is much larger than the pulsar spin, the orbital spin practically represents a fixed direction in space, defined by the orbital plane of the binary system. Given the calculated precession rate, it takes 297.5 years for the pulsar spin vector to precess around it. As a result of the precession the angle between the pulsar spin axis and our line-of-sight should change with time, so that different portions of the emission
beam are observed. Consequently, one expects changes in the measured pulse shape, in particular in the profile width, as a function of time. In the extreme case, the precession may move the beam out of our line-of-sight and the pulsar may disappear from the sky until it becomes visible again.

2. Previous Studies

The pulse profiles were naturally studied closely in order to detect possible changes. Finally, Weisberg et al. (1989, hereafter WRT89), discovered a change in the relative amplitude of the two prominent profile components. While these changes can indeed be considered as the first signs of the effects of geodetic precession, a change in the component separation or profile width as expected from a cone-like pulsar beam was not detected.

Due to precession, the distance of our line-of-sight to the magnetic axis should also change with time, so that a change in the position angle (PA) swing of the linearly polarised emission component is expected. Cordes, Wasserman & Blaskiewicz (1990, hereafter CWB90) studied polarisation data to compare profiles and PA swings obtained from 1985 to 1988. CWB90 did neither detect very clear changes in the pulse shape, nor could they find any significant change in the PA swing. CWB90 pointed out, however, that the existence of a core component, which is very prominent at lower frequencies, complicates the interpretation of the polarisation data. They noted similar to WRT89 that the core may also be responsible for the change in relative component amplitude with time.

PSR B1913+16 is also monitored with the 76-m Lovell telescope and with the 100-m Effelsberg telescope. The analysis of Effelsberg profiles measured between 1994 and 1998 by Kramer (1998) revealed that the profile components were still changing their relative amplitude, consistent with the rate first determined by WRT89. Even more interesting, however, was the first detection of changes in the separation of the components. In order to model this long-expected decreasing width of the profile, two simple assumptions were made, i.e. those of a circular hollow cone-like beam and the precession rate as predicted by general relativity. Both assumptions lead to a model which has only four free parameters: the misalignment angle \( \lambda \) between the pulsar spin and the orbital angular momentum, the inclination angle between the pulsar spin axis and its magnetic axis, \( \alpha \), the radius of the emission beam, \( \rho \), and the precession phase given by the reference epoch \( T_0 \).

With the post-Keplerian parameters measured by pulsar timing, general relativity allows one to compute the value of \( \sin i \), i.e. the sine of the orbital inclination angle. For PSR B1913+16, we compute a value of \( i = 47.2^\circ \), or equivalently \( i = 180 - 47.2 = 132.8^\circ \) whereas the ambiguity cannot be resolved from timing alone. The best fit of this model therefore allows four equivalent solutions. One pair of solutions corresponds to \( i = 47.2^\circ \), the other pair to \( i = 132.8^\circ \), respectively. The remaining choice is given by the unknown relative orientation of the pulsar spin and the orbital angular momentum, i.e. as to whether the pulsar rotation is pro-grade or retro-grade. It can be argued that a retro-grade case is less likely (Kramer 1998), so that the polarisation information can be used to separate the remaining two solutions, as only one gives the correct
observe sense of PA swing. The finally obtained misalignment angle of \( \lambda = 22^{\circ}+3_{-8}^{\circ} \) obtained by Kramer (1998) is in excellent agreement with earlier simulations by Bailes (1988) who studied the effects of asymmetric supernova explosions and predicted \( \lambda \approx 20^{\circ} \) as a typical value for PSR B1913+16-like systems.

The obtained best fit also lead to the prediction that the pulsar will disappear from the sky around the year 2025! Moreover, it also implies that the component separation remains almost unchanged for about 60 yr. It is now easy to understand why WRT89 were not lucky to detect changes in the component separation. Similarly, computing the change in PA swing which had to be measured by CWB90 for a positive detection of a geometry change, produces a value which is only slightly larger than their estimated detection limit. It should also be noted that based on an emission model and the relative change in component ratio alone, Istomin (1991) also suggested a disappearance of the pulsar around 2020. The full model as presented by Kramer (1998) also predicts a reappearance around the year 2220. PSR B1913+16 will, in total, only be observable for about a third of the precession period. While this seems to affect possible detection rates of double neutron star systems and hence the detection rate of gravitational wave detectors like LIGO or GEO600, averaged over time existing numbers do not change, as discussed in more detail by Kramer (1998, 2002).

3. Recent Results and Update

In Figure 1a we show the latest measurements for the component separation as a function of time, demonstrating that the profile continues to narrow as predicted by the model. Weisberg & Taylor (2000, 2002, also these proceedings) also obtained new measurements after the Arecibo upgrade, confirming the results reported above. Thanks to the superior sensitivity of the telescope, they did not only measure the same decrease in component separation, but could also measure a general decrease in profile width at several intensity levels. Using these data they derive a geometry which is in agreement with that of Kramer.
Kramer et al. (1998), and they also obtain a map of a pulsar emission beam for the first time. Since our line-of-sight moves through the emission beam, each profile represents a slightly different cut through the beam structure. During their data analysis, Weisberg & Taylor separate the measured profiles into odd and even parts and use the width information for all intensity levels of the even profiles, combined with a mapping function, to derive a model for geometry and beam shape. The results of this mapping process are surprising as the beam seems not only to be elongated but even hour-glass shaped.

We use our data for a complementary, alternative approach. We propose to use the original profiles in order to maintain information about the features causing the profile asymmetry, namely the off-set core. We then compute profiles observable at different epochs taking full spherical geometry into account, and compare these model profiles to the observed data (see Figure 1b). While this work is still in progress, initial results suggest that the beam may indeed be slightly elongated although an hour-glass beam shape may not be necessary to explain the data. Further modelling will be necessary but it may provide us with a beam map which can then be used as input for tests of the precession rate. The observations of other precessing pulsars like PSR B1828−11 (Stairs et al. 2000) or perhaps PSR B1931+24 (Kramer et al. in prep.) may help in this process to understand the pulsar beam pattern. At the moment, the detection of effects of geodetic precession in PSR B1913+16 is a successful qualitative test of general relativity, but it may become possible to perform also a quantitative test by measuring the precession rate using our beam models.

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