Abstract

We report the detection of a long-term change in the integrated pulse profile of the relativistic binary pulsar B1534+12. The rate of change over 2.5 years is consistent with that expected from geodetic precession of the pulsar’s spin axis in the gravitational field of the companion neutron star.

I Introduction

The curvature of space-time around a massive star results in precession of the spin axis of an orbiting gyroscope or, equivalently, a rotating companion star. The magnitude of this “geodetic” precession, the larger of two relativistic effects, is calculable in any metric theory of gravity and generally depends on the masses of the two stars and the nature of the orbit. For the double neutron-star system PSR B1534+12, General Relativity predicts a geodetic precession rate for the pulsar’s spin axis of 0.5 deg yr⁻¹, a prediction based on component star mass measurements made through the dependence of other strong-field relativistic effects on those same masses (Damour & Taylor 1992, and references therein). As a result, detection and measurement of pulsar precession in a relativistic system promise a new and stringent self-consistency test of General Relativity, or any other relativistic theory of gravity, in the strong-field regime.

As a neutron star’s magnetosphere sweeps through the line of sight, variation of the radiated beam’s polarization angle with rotational phase establishes the angle that the magnetic axis makes with the line of sight at closest approach, the “impact parameter” (Radhakrishnan & Cooke 1969). For relativistic binary pulsars, changes in this viewing geometry are the most promising means of detecting precession of the pulsar spin axis, which would reveal itself in evolving pulse intensity and polarization profiles. A long-term change in the intensity profile of PSR B1913+16, the original relativistic binary pulsar, has in fact been observed at a rate consistent with geodetic precession (Weisberg, Romani & Taylor 1989); the constancy of the polarization profile over the same epoch, however, is surprising (Cordes, Wasserman & Blaskiewicz 1990).
The opening angle of the cone traced out by the precessing spin axis, i.e., the misalignment between the pulsar's spin and orbital angular momentum vectors, ultimately determines whether the effects of pulsar precession are detectable. For PSR B1534+12, pulse polarization measurements (Arzoumanian et al. 1996) constrain this misalignment to be small, but likely non-zero. Here, we report the detection of a long-term, monotonic change in the pulsar's intensity profile, evidence for precession of the pulsar spin axis.

II Observations and Results

We examined the pulse shape of PSR B1534+12 using a large number of intensity profiles collected during dual-frequency (430 MHz and 1400 MHz) timing observations made at biweekly intervals between October 1990 and January 1994 with the Arecibo radiotelescope (see Arzoumanian 1995 for details). Low-noise integrated profiles were formed from the single-epoch observations by combining them into thirteen 100 day averages.

Figure 1 plots 1400 MHz integrated profiles for B1534+12 at three epochs. Each profile is averaged over all orbital phases and normalized to unit peak intensity. The dotted and dashed lines represent low-noise profiles from two early 100 day groupings, and the highest-quality late-epoch profile is plotted with a solid line. The increasing relative intensity of the "off-pulse" emission with time is clear. Figure 2 depicts the same trend in a different manner: intensity contours are plotted versus pulse phase and date for averaged profiles from each of the thirteen intervals.
III Discussion

The stability of average pulse shapes over long periods of time has been quantitatively studied for a number of pulsars (Blaskiewicz 1991). Excepting the "moding" phenomenon (the switching, at irregular intervals, between two or three distinct emission patterns) and the relativistic binaries B1534+12 and B1913+16, the pulse waveforms of only three objects (all isolated) are known to evolve: PSRs B2217+47 (Suleymanova & Shitov 1994), B0833−45 and B1642−03 (Blaskiewicz 1991). These authors have proposed models invoking free precession to explain the profile changes they observe; since the models depend on changes in the internal structure of the neutron stars, it seems unlikely that they would apply to either B1913+16 or B1534+12, which are at least two orders of magnitude older, and therefore cooler and less active, than the others. No compelling explanation for long-term changes in pulse shape other than precession has ever been advanced, and while other effects cannot be ruled out, the observed profile shape evolution of PSR B1534+12 is evidence for spin-orbit precession of the pulsar spin axis.
If the shape change at 1400 MHz is assumed to be due to precession, we can estimate the angular displacement of the pulsar's spin axis. We assume that the central component of the main pulse is circularly symmetric, and note that the observed change can be simply described as a gradual decrease in the intensity of the main pulse relative to the other profile components. The difference in impact parameter between early and late epochs is then roughly the phase on the main pulse of the early profile at which the peak intensity of the late profile is reached. Scaling the average 1400 MHz profiles at MJDs 48376 and 49276 (Fig. 1) by the peak intensity of the interpulse, we find that the main pulse has dropped to 66% of its original intensity. This level is reached on the early-epoch profile at 3.3 phase bins from the peak, both preceding and following it, a value obtained by simple-mindedly interpolating between bins \((360°/1024 \text{ bins} = 0°35/\text{bin})\). The implied angular displacement of approximately 1°2 is clearly consistent with geodetic precession of the spin axis over 2.5 years.

No evolution of the 430 MHz pulse profile similar to that at the higher frequency is observed. The lack of a clear shape change does not necessarily rule out precession. The central component of the main pulse is twice as wide at 430 MHz as it is at 1400 MHz—the larger width at the lower frequency may be masking changes at the level observed in the high-frequency profile. More importantly, the low-frequency data is known to suffer from systematic effects, such as scintillation slopes (Arzoumanian 1995; Stairs et al. 1998), which would tend to smear profile features in pulse phase.

References


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