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Inner core wobble and free core nutation of pulsar PSR B1828-11

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Abstract

PSR B1828-11 has long-term, highly periodic and correlated variations in pulse shape and a slow-down rate with period variations of approximately 1000, 500 and 250 days [Stairs, I.H., Lyne, A.G., Shemar, S.L. Evidence for free precession in a pulsar. Nature 406, 484–486, 2000]. There are three potential explanations of pulses time-of-arrival from a pulsar. These are related to the interior of the neutron star, planetary bodies, free precession and nutation. We use the Hamiltonian canonical method of Getino (1995) for analyzing the dynamically symmetric pulsar PSR B1828-11, consisting of a rigid crust, elliptical liquid outer core and solid inner core. Using the theory of differential rotation of a pulsar, we investigate the dependence on Chandler wobble period, inner core wobble, retrograde free core nutation and prograde free inner core nutation from ellipticity of the inner crystal core, outer liquid core and total pulsar.

Keywords: PSR B1828-11; Differential rotation; Inner core wobble; Free core nutation; Chandler wobble

1. Introduction

Observation of pulsars is a powerful source of information for research of dynamics and the internal structure of neutron stars. It is known that innate feature of pulsar radiation is high stability of time-of-arrival (TOA) of pulses, and therefore the analysis of the TOA fluctuations can be a reflection of subtle effects of neutron star dynamics. A small number of neutron stars also exhibit long-term cyclical, but not precisely oscillatory, variations in their spin (Sedrakian et al., 1999 and references there). For example, the Crab pulsar has very systematic phase residuals with peak-to-peak range of order ±10 ms and characteristic cycle duration of about 20 months (Lyne and Graham-Smith, 1998). Observation of Vela pulsar's glitch in 1988 showed suppressing of oscillatory phase residuals with a period of order 25 days (Alpar et al., 1990); evidence for oscillations (Tkachenko oscillation) in the frequency derivative of the pulsar both before and after the glitch with a period of about 25 days was also reported (McCulloch et al., 1988). The long-term variations (correlation times $\sim$100 days) in the pulse shape of the Vela pulsar has been found in data spanning for approximately 4 years (Cordes, 1993). The analysis of the pulse shape of PSR 1642–03 has shown evidence for cyclical pulse shape variations with a period of about 1000 days (Cordes, 1993).

The accreting X-ray pulsar Her X-1 has well-known variations with a period of about 35 days, which appears and disappears; observed variations in pulse shape over the cycle propose that they are related to periodic variations in the rotation of the neutron star (Shakura et al., 1998). In 2000, Stairs, Lyne and Shemar reported about their discovery of long-term, highly-periodic and correlated variations of pulse shape and the rate of slow-down of the pulsar PSR B1828–11 (Table 1) with period variations approximately 1000, 500, 250 and 167 days, which may be a result of the spin axis caused by an asymmetry in the shape of the pulsar. The long-periodic precession phenomenon was also detected for a few pulsars: PSR 2217+47, PSR 0531+21, PSR B0833–45, PSR B1828–11, PSR B1642–03 (Suleymanova and Shitov, 1994; Kitiashvili, 2004).

Soon after the discovery of radio pulsars, it was suggested that long-term variations in their spin could result

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