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The Radius Estimation of Double Pulsar PSR J0737-3039A

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Abstract. We investigate the radius of the recycled pulsar in double pulsar PSR J0737-3039. In the standard accretion spin-up model, the recycled pulsar spin up continues until arriving at a minimum spin period, or so-called "equilibrium period", which is related to stellar magnetic field, accretion rate, mass and radius. If present spin period is much longer than that at birth, the spin-down age can give the realistic true age estimation for normal pulsar J0737-3039B. Base on the above conditions, we estimate the radius of millisecond pulsar (MSP) J0737-3039A by assuming its true age is same as the spin-down age of its companion J0737-3039B. We obtained that the radius of J0737-3039A ranges approximately from 5 to 27 km.

Keywords. Pulsar, characteristic age, true age, equilibrium period

1. Introduction and Evolutionary Track of PSR J0737-3039

In the standard model for binary pulsar formation (Bhattacharya & Heuvel 1991), the two neutron stars (NSs) are formed from massive binary system, where the more massive star (primary) initially undergoes a supernova explosion to form a NS. The spin period of the first NS decays with the magnetic dipole emission, while the secondary less massive star evolves. During the evolution of the secondary, the accretion disk is formed around the first born NS, and it accretes matter from the disk and acquires the angular momentum that spins it up to the short period (Alpar *et al.* 1982) which is called equilibrium period. If the secondary is massive (e.g. 10 solar masses) enough to explode as a supernova, and the binary system survives with NSs: a short-period recycled pulsar J0737-3039A from the primary and a "normal" pulsar J0737-3039B from the secondary. J0737-3039A has the typical period P_A (22.7ms), magnetic field $B_A(6 \times 10^9 G)$, period derivative $\dot{P}_A(1.7 \times 10^{-18} ss^{-1})$ of a millisecond pulsar, while the 2.77s period J0737-3039B, has the basic properties of a relatively young, normal pulsar, having a magnetic field B_B of $2 \times 10^{12} G$, a period derivative $\dot{P}_B$ of $0.88 \times 10^{-15} ss^{-1}$ (Lyne *et al.* 2006). At present, there is no method so far to directly measure the radius of NS (Miller 2002). In this paper, we present a method to estimate the radius of recycled pulsar in double pulsar PSR J0737-3039.

2. Result and Discussion

In the double pulsar systerm PSR J0737-3039 (Lyne *et al.* 2004), the age of the "normal" pulsar J0737-3039B can be conveniently approximated by its characteristic age, since its present spin period is much longer than the usual spin period at birth. By exploiting the period and period derivative, we obtain the spin-down age of the normal pulsar J0737-3039B which is essentially the same as the true age of recycled pulsar J0737-3039A. Thus, we can constrain the recycled pulsar equilibrium period (Tauris *et al.* 2012) when it ended its spin-up there, which is more influenced by the accretion rate, and less infected by the stellar mass and radius (Haensel *et al.* (2007)).

Most systems may accrete 0.01-0.2$M_\odot$ at the end of the accretion phase (Zhang & Kojima 2006). If a NS accretes a small amount of mass from its companion (e.g. $\sim 0.001M_\odot - 0.01M_\odot$), a recycled pulsar with mildly weak field and short spin period ($B \sim 10^{10}$ G, $P \sim 50$ ms) (Kramer *et al.* 2006) will be formed. If the accreted mass is greater than $0.2M_\odot$, the NS magnetic field may arrive at a bottom value of about $10^8 - 10^9$ G and its spin period may reach a minimum of about a few milliseconds (Wang *et al.* 2011). In this system, for the recycled pulsar J3037-3039A, whose period is shorter than 50 ms, which means it had accreted the mass more than $0.01M_\odot$. By the present parameters, the difference between the two pulsars masses is about $0.1M_\odot$, assuming all the difference to be accreted from the progenitor of J0737-3039B, then we can limit the max accreted mass is about $0.1M_\odot$. Therefore, we select the range of accreted mass as 0.01-0.1$M_\odot$. The accretion age can be approximated by the main sequence age of J0737-3039B, which is about 10^7yr. so we can obtain the range of accretion rate as $\dot{M} \sim 0.1 - 1\dot{M}_{Edd}$. Thus, with the recycled pulsar equilibrium period and the range of accreted rate, the radius of the recycled pulsar is estimated at the range of $\sim$ 5 - 27 km.

Moreover, Lattimer and Prakash (2004) have given a conclusion that,"for a star of mass M and radius R, a upper limit to the NS spin frequency is the mass-shedding limit, at which the velocity of the stellar surface equals that an orbiting particle suspended just above the surface."

$$\nu_k \leqslant 1045(\mathrm{Hz})(\frac{M}{M_\odot})^{1/2}(\frac{10km}{R})^{3/2}, \tag{2.1}$$

for J0739-3039A, $\nu_k = 1/P_{eq}$, we can obtain that the upper limit to the NS radius is 80.31 km, which is too large to be a constraint of NS.

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