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Equation of state and pulsar death line

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Abstract. In this proceeding, we are going to introduce our recent work about the dependence of pulsar death line on the equation of state (Zhou *et al.* 2017). The results show that the equation of state affects the location of the pulsar death line in the $P - \dot{P}$ diagram. We offer another point of view to understand the pulsar death line and multiple observational facts would help us to reveal the nature of pulsars.

Keywords. stars: neutron,equation of state,(stars:) pulsars: general

1. Introduction

The radio pulsar death line is defined by setting the potential drop across the accelerator, ΔV, equal to the maximum one ($\Delta V = \Phi_{\rm max}$), which is a line in the $P - \dot{P}$ diagram and separates the pulsars that can support pair production in their inner magnetosphere from those that cannot. The maximum potential drop is written as (Ruderman & Sutherland 1975): $\Phi_{\rm max} \approx \frac{B_{\rm p} R^3 \Omega^2}{2c^2}$, where R is the radius of the pulsar, Ω its angular velocity, c is the speed of light and $B_{\rm p} = \frac{1}{\sin\alpha}\left(\frac{3Ic^3 P\dot{P}}{2\pi^2 R^6}\right)^{1/2}$ is the polar magnetic field strength at the pulsar surface (Shapiro & Teukolsky 1983).

Most of previous works are mainly focused on the configurations of the surface magnetic field or the models for pair acceleration. The potential drop ΔV, across an accelerator gap, is model dependent. Different particle acceleration models will change ΔV considerably and alter the death lines. The pulsar death line is also related to the moment of inertia of neutron star (NS), which is determined by the equation of state (EoS). By setting a constant potential drop $\Delta V = 10^{12} V$, we only need to consider the dependence of the pulsar death line on the EoS. With the development of observational equipment, the number of new radio pulsars is increased and other classes of NSs have been identified, including magnetars, X-ray dim isolated neutron stars (XDINS), central compact objects (CCOs) and Rotating Radio Transients (RRATs) (e.g., Kaspi 2010; Kaspi & Kramer 2016). Some of these new sources have precise measurements of P and $\dot{P}$, but they lie below the traditional pulsar death line(in Figure 1 of Zhou *et al.* 2017).

In the following section, we are going to introduce the properties of death lines affected by EoSs. Observational constraints on EoSs are also considered.

2. Dependence of Pulsar Death Line on the Equation of State

For comparison, we specified the mass of NS, as $0.2\mathrm{M}_\odot, 0.5\mathrm{M}_\odot, 1.0\mathrm{M}_\odot, 1.4\mathrm{M}_\odot$ and $2.0\mathrm{M}_\odot$. The corresponding radii and moments of inertia are obtained by employing different EoSs. The smallest mass of NSs with typical nuclear matter EoSs are named bsk21, wwf1, and h4, sustained to be $0.2\mathrm{M}_\odot$ (Zhou *et al.* 2017). For the strange stars (SSs), the radius increases with increasing mass. The smallest mass can be determined by the radius measurements. Assuming the thermal emission of CCOs or XDINSs comes from the whole surface, we could set the smallest radius of the SSs at 4km (details about the smallest radius measurement can be found in Zhou *et al.* 2017). The corresponding masses and moments of inertia are obtained by employing the EoS named pMIT, CDDM1 and CDDM2. The details are shown in Table 1 of Zhou *et al.* (2017).

In Figure 4 and Figure 5 of Zhou *et al.* (2017), we plot the pulsar death lines for different masses of NSs and SSs with constant potential drop ($\Delta V = 10^{12}$V). From top to bottom, the mass of the corresponding pulsar death line increases. For the same mass of NSs or SSs, death lines with different EoSs show no obvious diversity with each other. The region of death lines of SS spreads wider than NS. The death lines of NSs and SSs do not have obvious difference while the mass is larger than $1.0\mathrm{M}_{\odot}$. Meanwhile, most of the sources are above the death lines. In Figure 4 of Zhou *et al.* (2017), the long period (8.5s) pulsar PSR J2144-3933 is located beyond the death line, but closest to the death lines for $2.0\mathrm{M}_{\odot}$. PSR J2144-3933 just crosses the death lines with $2.0\mathrm{M}_{\odot}$ in Figure 5 of Zhou *et al.* (2017). The obvious distinctions of the pulsar death line are for the smallest mass of NS and SS.

For the smallest mass, most of magnetars and XDINSs are above the death lines of neutron stars, and some of them are close to the death lines (Figure 4 of Zhou *et al.* 2017). All of the XDINSs are below or across the death lines of SS (Figure 5 of Zhou *et al.* 2017), which agrees with the observational facts that XDINSs do not have detected radio emission until now. All of the radio-loud magnetars are above the death lines, and some of the radio-quiet magnetars are below the death lines. For the CCOs, in the NS case (Figure 4 of Zhou *et al.* 2017), all of them are above the death lines. And in the case of SS (Figure 5 of Zhou *et al.* 2017), they are near or below the death lines. RRATs are located around the normal pulsars, dispersed on both side of the death lines. All of the intermittent pulsars are above the death lines for both NSs and SSs. Moreover, Figure 4 and Figure 5 of Zhou *et al.* (2017) show that the death lines of SS spread larger areas than that of NS. Particularly, the location of pulsar death lines with the smallest mass of SS is much higher than others. Comparing with Figure 4 of Zhou *et al.* (2017), the distribution of sources, such as magnetars, XDINSs, CCOs, RRATs, is much more different for the death line with the smallest mass of SS.

3. Results

EoSs affect the location of the pulsar death line in the $P-\dot{P}$ diagram. More discussions, details and references are shown in Zhou *et al.* (2017). In this work, we offer a another point of view to understand the pulsar death line and multiple observational facts would help us to reveal the nature of pulsars. Moreover, the results show that CCO would be small mass strange stars; RRAT might be old pulsars on the verge of death; PSR J2144-3933 would be a large mass pulsar, which would be larger than $2.0M_{\odot}$.

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