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The influence of inclination angle on polar cap heating of J0901-4046 radiopulsar

D. Barsukov, I. Morozov, and A. Popov

Ioffe Institute, Saint-Petersburg, 194021 Russia

Abstract. The influence of inclination angle to electron-positron pairs production in inner gap and polar cap heating by reverse positron current in case of J0901-4046 radiopulsar is considered. It is shown that J0901-4046 pulsar “work” may be explained by the presence of a highly curved small scale surface magnetic field without the substantial increasing of its dipolar magnetic field at inclination angle values $\chi \lesssim 30°$.

Keywords: pulsars: general, individual (J0901-4046)

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1 Introduction

The pulsar J0901-4046 is the slowest known pulsar among normal rotating-powered radiopulsar (Caleb et al. 2022). Its rotation period is $P = 75.89$ s, $\dot{P} = 2.25 \cdot 10^{-13}$. According to the "standard" magnetic field estimation (Manchester et al. 2005), it corresponds to the induction $B_{\rm dip} = 2.6 \cdot 10^{14}$ G of the magnetic dipolar field on star surface at the magnetic pole (Caleb et al. 2022). Its spin-down age is $\tau = P/(2\,\dot{P}) \approx 5.3 \cdot 10^6$ years, its spin-down luminosity is $\dot{E} \approx 2.0 \cdot 10^{28}$ erg s^{-1} (Caleb et al. 2022). The distance to the pulsar may be estimated by using dispersion measure DM as $D \approx 328$ pc or as $D \approx 467$ pc (Caleb et al. 2022). This pulsar has been considered in many papers, see, for example, Sob'yanin 2023; Beskin & Istomin 2022. Although, the value of its inclination angle χ, which is the angle between the dipolar magnetic momentum $\mathbf{m}$ of radiopulsar and the angular rotation velocity $\mathbf{\Omega}$ of neutron star, is not very well known at present. The detailed analysis of its radio radiation properties has been made in Sob'yanin (2023) and gives the value $\chi \approx 10^\circ$ so this pulsar is close to being aligned. Also, the pulsar was assumed to be close to aligned in Barsukov et al. (2023). However, in the paper Beskin & Istomin (2022) it is assumed that this pulsar is close to orthogonal $\chi \approx 90^\circ$. The attempt to estimate inclination angle χ by its radio pulse width $W_{50} \approx 296 - 299$ ms (Caleb et al. 2022) gives us the values $\chi \approx 11^\circ$ if we use minimal pulse width estimation $W_{\rm min} \approx 2.45^\circ \cdot (P/1{\rm s})^{-1/2}$ taken from Rankin (1990), $\chi \approx 50^\circ$ or $\chi \approx 90^\circ$ when using estimations $W_{\rm min}$ taken from Malov & Nikitina (2011). It is worth to note that its impact parameter $\beta \lesssim 0.2^\circ$ (Caleb et al. 2022), where β is an angle between magnetic momentum $\mathbf{m}$ and the line of sight. Hence, the estimation of inclination angle χ by pulse width seems to be very close to its real value. Due to these uncertainties of inclination angle value, in this paper, we consider the influence of inclination angle on electron-positron pairs production and polar cap heating by the reverse positron current in the framework of the J0901-4046 pulsar model considered in Barsukov et al. (2023) (see also Kantor & Tsygan 2003).

2 Results

In this paper, we use the same model as Barsukov et al. (2023). Following Barsukov et al. (2023) we assume the presence of the small scale magnetic field component on the surface of the star with induction $\mathbf{B}_{\rm sc}$ and space scale $\ell \approx r_{\rm ns}/20$, where $r_{\rm ns}$ is neutron star radius. The geometry of field near by inner gap is shown in Fig. 1 (see Kantor & Tsygan 2003 for details). The calculations of electron-positron production and reverse positron current are made in the same way as in Barsukov et al. (2023). In order to roughly estimate the influence of a possible positronium annihilation, we

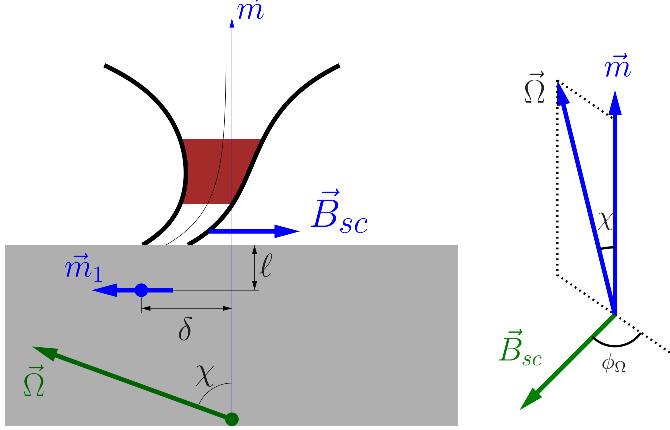

Fig. 1. The sketch of used geometry of magnetic field near by the inner gap, which is shown by the red area. Neutron star crust is shown by the gray area.

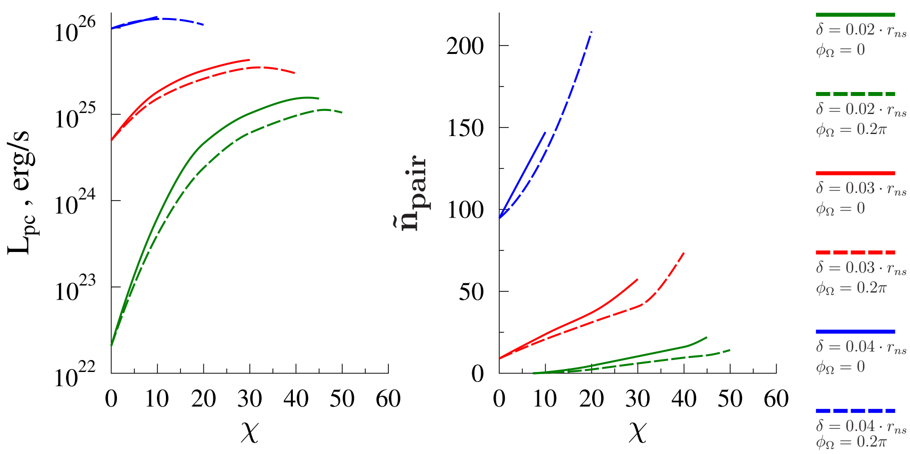

Fig. 2. The dependence of polar cap heating $L_{\rm pc}$ on inclination angle χ for some small scale field configuration is shown in the left graph. The same, but in case of the number density of produced unbounded positrons $\tilde{n}_{\rm pair}$ in units $(\Omega B)/(2\pi ce)$ is shown in the right graph. In both cases angle χ is in degrees.

assume that $(1-f)$ part of positronium immediately decays after its production and f part of positronium does not decay at all. Temperature of neutron star surface is assumed to be equal to $T_{\rm surf} = 3 \cdot 10^5$ K (Barsukov et al. 2023). The dependence of polar cap luminosity $L_{\rm pc}$ due to the reverse positron heating and unbound pairs multiplicity $\tilde{n}_{\rm pair}$ in case of $B_{\rm sc} = 0.7 \cdot B_{\rm dip}$ and $f = 0.3$ (Barsukov et al. 2023) is shown in Fig. 2. You can see from Fig. 2 that the J0901-4046 pulsar "work" may be explained in the framework of model Barsukov et al. (2023) at inclination angles $\chi \lesssim 30°$. So if the pulsar has larger inclination angle value $\chi \sim 60-90°$ it is necessary to give preference to other models, for example, to the model considered in Beskin & Istomin (2022) in the case of nearby orthogonal pulsar $\chi \approx 90°$.

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References

Barsukov D., Morozov I., and Popov A., 2023, Astronomy Letters, 49, p. 806
Beskin V. and Istomin A., 2022, Monthly Notices of the Royal Astronomical Society, 516, p. 5084
Caleb M., Heywood I., Rajwade K., et al., 2022, Nature Astronomy, 6, p. 828
Kantor E. and Tsygan A., 2003, Astronomy Reports, 47, p. 613
Malov I. and Nikitina E., 2011, Astronomy Reports, 55, p. 878
Manchester R., Hobbs G., Teoh A., et al., 2005, The Astronomical Journal, 129, p. 1993
Rankin J., 1990, Astrophysical Journal, 352, p. 247
Sob'yanin D., 2023, Physical Review D, 107, id. L081301.