Pulsar Astronomy — 2000 and Beyond
ASP Conference Series, Vol. 202, 2000
M. Kramer, N. Wex, and R. Wielebinski, eds.

On the Nature of the Geminga Pulsar

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Abstract. The model provided that Geminga is an almost aligned pulsar, which is supported by the low-frequency observations. The model explains successfully most of the peculiarities of Geminga radio emission. In the frame of the same geometry we propose a mechanism for the recently detected optical pulsation from that pulsar.

1. Introduction

The bright γ-ray source Geminga was first detected in 1992 as an X-ray pulsar and pulsed γ-rays were found from EGRET observations in the same year. Searches for pulsating radio and optical emission from Geminga were conducted for many years without success. The situation changed recently when detection of radio pulses at frequencies near 100 MHz was reported by three independent observing groups from the Pushchino Radio Astronomy Observatory (Malofeev & Malov 1997, see also references in Gil, Khechinashvili & Melikidze 1998). Vats et al. (1999) also reported about detection of the Geminga pulsar at the frequency of 103 MHz, using the Rajkot radio telescope in India. Recently Shearer et al. (1998) claimed that the optical counterpart of Geminga also pulses with a period of 237 ms.

2. The model

The natural question arises: why is the Geminga pulsar radio quiet at frequencies higher than about 100 MHz? The extremely low luminosity could be an explanation, but then one can ask why is this pulsar so different from other objects with similar values of P and $\dot{P}$ (which are quite typical: $P = 0.237$ s, $\dot{P} = 1.1 \times 10^{-14}$). Moreover, a small distance $d \simeq 0.16$ kpc should make a detection of even weak radio emission relatively easy. For instance, Malov (1998) claims that a low-intensity radio emission from a young pulsar like Geminga can be understood if it is generated near the light cylinder by the synchrotron mechanism.

We argue that this radiation is absorbed by the magnetized relativistic plasma inside the light cylinder in the region of relatively low magnetic field $B \sim 10^{3\div4}$ G. This requires that Geminga is an almost aligned rotator, so that

https://doi.org/10.1017/S025292110006019X Published online by Cambridge University Press

an observer's line of sight passes through the light cylinder at a distance of a few cylinder radii. Indeed, high signal-to-noise ($S/N \sim 10$) profiles presented by Malofeev & Malov (1997) and Vats et al. (1999) indicate that the pulsed radio emission from Geminga is distributed over the entire pulse window (360°).

The characteristic frequency of the damped waves is same for all the normal wavemodes of magnetized pair plasma and can be expressed as

$$\nu_d \approx 2.6 \times 10^7 P^{-2.5} \dot{P}_{-15}^{0.5} \gamma_p^{-1} \sin\alpha^{-1} \left(1 - \cos\theta\right)^{-1} \mathcal{R}^{-3} \quad [\mathrm{Hz}], \tag{1}$$

where θ is an angle between the magnetic field and wave vector, α is an angle between the rotation and dipole axes and $\mathcal{R}$ is a distance from the stellar surface in the units of the light cylinder radii. For the realistic parameters of the magnetospheric plasma the decrements of damping for the eigenmodes are big enough to provide absorption of all waves with frequencies higher than 100 MHz (Gil, Khechinashvili & Melikidze1998). Lyubarskii & Petrova (1998) treated thoroughly spontaneous reemission of the absorbed energy. We suggest that Geminga's optical pulsed emission is just a synchrotron radiation of the plasma particles gyrating about relatively weak magnetic field at distances of a few light cylinder radii. Defining the pitch-angle as $\psi \equiv \arctan(p_\perp/p_{||})$, we find that $\psi \approx \theta\eta^{1/2} \sim 0.1$, where $\eta = L_{\mathrm{radio}}/L_p$ is the ratio of the damped radio waves energy to the total kinetic energy of the plasma particles on which these waves are damped. In order to estimate this quantity we assume that radio luminosity of the Geminga pulsar, by what we mean the integrated radio power of Geminga as it would be in the absence of cyclotron damping on the magnetospheric plasma, can be estimated as $L_{\mathrm{radio}} \sim 3 \times 10^{27}$ erg s^{-1}. Then we obtain that the spectral density of the synchrotron radiation is $I(\nu_c) \sim 6 \times 10^{12}$ erg s^{-1} Hz^{-1}, which is a theoretically predicted value near the critical infrared frequency $\nu_c \sim 1.4 \times 10^{13}$ Hz.

Obviously, the fraction of the synchrotron optical radiation of Geminga observed on the Earth is emitted in about the same direction as the low-frequency radio waves of this pulsar. We used the feature of the dipolar field lines that all of them intersect a fixed radial line with same angle and found a geometrical place of all the points in the magnetosphere where the tangents to the field lines "look" in the same direction as a wavevector of the 100 MHz radio waves.

Acknowledgments. This paper is supported in part by the KBN grant 2 P03D 015 12. Participation of GM and DK in the Colloquium was supported by the grants from INTAS 96-0154 and Deutsche Forschungsgemeinschaft.

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https://doi.org/10.1017/S025292110006019X Published online by Cambridge University Press