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On the Mechanism of X-ray Emission from Radio Pulsars

I. F. Malov

Lebedev Physical Institute, Moscow, Russia

Abstract. The correlations between the luminosities of radio pulsars in various wavebands and the magnetic fields at the light cylinder suggest that the observed emission is generated in outer layers of the pulsar magnetospheres by the synchrotron mechanism. The formula for calculating the X-ray luminosity L_x of radio pulsars is derived in the framework of the synchrotron model. It is shown that L_x depends strongly on the parameter $\dot{P}P^{-3.5}$. This raises the possibility of predicting the detection of X-ray emission from more than a hundred known radio pulsars.

There are correlations between the integral radio luminosity, L_R, the bolometric optical luminosity, L_{opt} and the X-ray luminosity, L_x, of radio pulsars and their magnetic fields at the light cylinder, B_{LC}. Such relationships mean that these emissions are generated near the light cylinder and that the main radiation mechanism is synchrotron emission.

Using the solutions of the steady-state kinetic equation for the distribution function of relativistic particles (Malov & Machabeli 2002), the following formula for the total synchrotron luminosity can be written:

$$L = \frac{\sqrt{3}}{32} \frac{\pi^{7/2} e I \dot{P} \gamma_b^{3/2}}{m^{1/2} c^{3/2} P^{7/2} \gamma_p^2}, \tag{1}$$

where I is the moment of inertia of the neutron star, γ_b and γ_p are the Lorentz factors of beam particles and of the secondary plasma, respectively. We can see that L depends on the parameter $\dot{P}P^{-3.5}$. A comparison of L_x and $\dot{P}P^{-3.5}$ for 41 radio pulsars (Possenti et al. 2002) gives:

$$\log L_x = (1.32 \pm 0.10) \log \frac{\dot{P}_{-15}}{P^{7/2}} + 26.12 \pm 0.48, \tag{2}$$

with the correlation coefficient $K = 0.91 \pm 0.07$. The dependence in Equation (2) shows that our model describes the observed X-ray emission quite well. It raises the possibility of predicting the detection of X-rays from other known radio pulsars. Indeed, for the synchrotron flux we can write the following expression:

$$F = \frac{L}{4\pi d^2} = 3.34 \times 10^{-17} \frac{\dot{P}_{-15}}{P^{7/2} d_{kpc}^2}. \tag{3}$$

Here we assume that:

$$\frac{\gamma_b^{3/2}}{\gamma_p^2} = 4.37 \times 10^8. \tag{4}$$

On the other hand, the minimal X-ray flux in the range 2–10 keV is 8×10^{-16} ergs s^{-1} cm^{-2} for the sample used. This limit corresponds to the condition:

$$\frac{\dot{P}_{-15}}{P^{7/2} d_{kpc}^2} \leq 2.4. \tag{5}$$

The catalogs of Taylor et al. (1995), Manchester et al. (2001) and Morris et al. (2002) contain 114 radio pulsars satisfying this condition, and they can be registered by modern instruments. In particular, synchrotron X-ray emission should be detected from most of the known millisecond pulsars. This prediction is a crucial test that makes it possible to discriminate between the model under consideration and a model for generation of X-ray emission from these objects through thermal mechanism near the neutron star surface (Zhang & Harding 2000).

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