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On the nature of optical emission from radio pulsars

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There are more than one thousand known radio pulsars, but only 9 of them have detected optical emission (Caraveo 1999). A part of optical emission can be caused by thermal radiation from the hot surface of the neutron star. We shall try to describe the non-thermal component (Kurt et al. 1980) on the base of the synchrotron mechanism, using one-dimensional distribution function of emitting electrons.

One of the possible reasons of observed pulsar emission is the cyclotron instability developed in an anisotropic plasma (Sagdeev & Shafranov 1960). To generate transversal (t) waves with the spectrum

$$\omega_t = k\,c(1-\delta), \tag{1}$$

$$\delta = \frac{\omega_p^2}{4\omega_B^2\gamma_p^3}, \qquad \omega_p^2 = \frac{4\pi n_p e^2}{m}, \qquad \omega_B = \frac{eB}{mc}. \tag{2}$$

the condition of the cyclotron resonance (Kazbegi et al. 1992)

$$\frac{k_\perp^2}{2k_\parallel^2} + \frac{1}{2\gamma_r^2} - \frac{k_\perp u_\perp}{k_\parallel c} - \delta = \pm\frac{\omega_B}{\gamma_r k_\parallel c} \tag{3}$$

must be fulfilled. Here $k_\parallel^2 + k_\perp^2 = k^2$, γ_r is the Lorentz-factor of resonance particles, $u_1 = \frac{cV_\parallel\gamma}{\rho\omega_B}$ is the drift velocity of particles, ρ is the curvature radius of field lines.

Plus in this equation corresponds to the excitation of waves, minus to their absorption. Both these processes lead to a redistribution of particles due to the quasilinear diffusion.

The equation (3) can be written approximately as

$$\delta = \frac{\omega_B}{\omega\gamma_r}. \tag{4}$$

and we have the next estimate of the level of the wave excitation

$$\frac{r}{R_*} = \left(2\cdot 10^{39}\frac{\gamma_p^4 P B_{12}^2}{\gamma_b^2\omega}\right)^{1/6} \tag{5}$$

If we put $\gamma_p \sim 10$ and $\gamma_b \sim 10^6$ then waves are excited near the light cylinder with $r_{LC} = \frac{cP}{2\pi}$.

The kinetic equation for the distribution function of beam particles can be written in this case as

$$\frac{1}{mc\gamma_b^2\psi}\frac{d}{d\psi}(\psi G_{\perp} f^{\circ}) = \frac{1}{m^2c^2\gamma_b^2}\frac{1}{\psi}\frac{d}{d\psi}\left(\psi D_{\perp\perp}\frac{df^{\circ}}{d\psi}\right), \tag{6}$$

This equation has the solution

$$\chi(\psi) = Ce^{\int \frac{G_{\perp} mc\gamma_b}{D_{\perp\perp}} d\psi} = CE^{-A\psi^2}, \qquad A = \frac{2m^2c^4\gamma_b^2\left(\frac{\omega_B}{\omega_p}\right)^2}{\pi e^2 \rho |E(k)|^2 \gamma_p} \tag{7}$$

where

$$G_{\perp} = -\frac{mc^2}{\rho}\gamma_r\psi,\ G_{\|} = \frac{mc^2}{\rho}\gamma_r\psi^2,\ D_{\perp\perp} \approx \frac{\pi e^2\omega_p^2}{4c\omega_B^2}\gamma_p |E(k)|^2_{k=k},\ |E(k)|^2 \approx \frac{12\pi m^2 c^7 \gamma_b n_b}{e^2 r \omega_B^3} \tag{8}$$

The mean value of pitch-angle is

$$\bar{\psi} = \left[\frac{24\pi^2 m^4 c^6 \rho (r/R_*)^9}{e^5 B_s^3 P^2 r}\right]^{1/2} \tag{9}$$

For PSR 0656+14 with $r/r_{LC} = 0.5$ $\bar{\psi} = 3.6 \cdot 10^{-4}$ in the rest plasma frame.

$$\psi_H \approx \frac{\bar{\psi}}{2\gamma_p}, = 1.8 \cdot 10^{-5} \tag{10}$$

in the observer's frame for $\gamma_p = 10$. If $\gamma_b = 10^5$ the frequency of the maximum in the synchrotron spectrum (Epstein 1973)

$$\nu_m = a(\gamma\psi)\frac{eB}{2\pi mc\gamma\psi^2}, \tag{11}$$

is of 10^{15} Hz for PSR 0656+14. The intensity decreases slowly after the maximum to the higher frequencies. Such behaviour is in an agreement with the observed optical spectrum of PSR0656+14 in the frequency range from $3 \cdot 10^{14}$ Hz to $8.9 \cdot 10^{14}$ Hz.

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