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Centrifugal Acceleration in Pulsar Magnetosphere

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Abstract. We present a relativistic model of pulsar radio emission by plasma accelerated along the rotating magnetic field lines projected on to a 2D plane perpendicular to the rotation axis. We have derived the expression for the trajectory of a particle, and estimated the spectrum of radio emission by the plasma bunches. We used the parameters given in the paper by Peyman and Gangadhara (2002). Further the analytical expressions for the Stokes parameters are obtained, and compared their values with the observed profiles. The one sense of circular polarization, observed in many pulsars, can be explained in the light of our model.

1. Introduction

It is important to understand the charged particle dynamics in the pulsar magnetosphere to unravel the radiation mechanism of pulsars. The particles are constrained to move strictly along the field lines, owing to the super-strong magnetic field that the gyration of the particles are almost suppressed. The equation of motion for a charged particle moving along the rotating field line is given by Gangadhara (1996). Here we extend this work to obtain an analytical expression for particle trajectory and Stokes parameters. The pulsar rotation effects such as aberration and retardation can create asymmetric pulse profiles

2. Dynamics of a Charged Particle

The equation of motion of a charged particle along a rotating magnetic field line is given by (Gangadhara 1996)

$$\frac{d}{dt}\left(m\frac{dr}{dt}\right) = m\Omega^{*2}r, \qquad \gamma = \left(1 - \frac{\dot{r}^2}{c^2} - \frac{r^2\Omega^{*2}}{c^2}\right)^{-1/2} \tag{1}$$

where $m = m_0\gamma$ is the relativistic electron mass, m_0 is the rest mass, c is the speed of light, γ is the Lorentz factor, $\Omega^* = \Omega\sqrt{1 - b^2/r^2}$ is the effective angular velocity of the particle, and $b = d_0 \cos\theta_0$. We have solved this equation and obtained the analytical solution:

$$r = \frac{c\sqrt{1+D^2}}{\Omega} cn(\lambda - \Omega t), \tag{2}$$

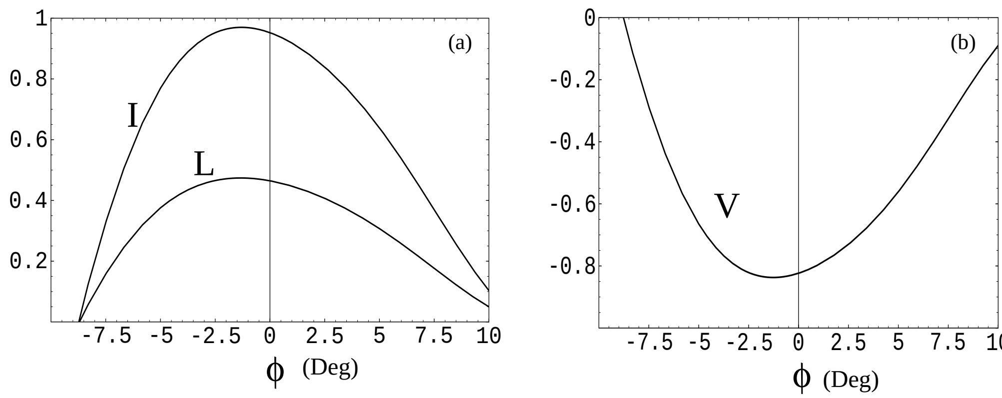

Figure 1. (a) Intensity and linear polarization vs rotation phase ϕ for the radiation emitted by particles accelerated along the rotating magnetic field lines, and (b) Circular polarization of the emitted radiation.

where $\mathrm{cn}(\lambda - \Omega \mathrm{t})$ is the Jacobian Elliptical cosine function (Abramowitz & Stegun),

$$D = \frac{\Omega d_0 \cos\theta_0}{c}, \quad \lambda = \int_0^{\phi_0} \frac{d\zeta}{\sqrt{1 - k^2 \sin\zeta^2}}, \quad \phi_0 = \arccos\left(\frac{r_0 \Omega}{c}\right),$$

r_o the initial particle injection point, d_o the distance between magnetic pole and rotation axis in the projected 2D plane, θ_o the initial injection angle with respect to meridional plane, Ω the angular velocity of the pulsar, k is an integration constant, ζ is a dummy variable, θ is the angle that the line of sight makes with the 2D plane. Using the expression for the 'r' an approximate value for ρ, the radius of curvature of the particle in the lab frame, is found out to be $\rho \approx \sqrt{1 + D^2}\ r_L/2$ where r_L is the light cylinder radius.

For a pulsar with period of 1 s, we estimated the components of the electric field of radiation and hence the Stokes parameters. In Fig. 1a, we have plotted the intensity I, linear polarization L, and in Fig. 1b circular polarization V is plotted. Due to aberration-retardation phase shift the profile is asymmetric about the center ($\phi = 0$) of the profile. It also shows that leading part of the profile is stronger than trailing part. Since line of sight stays above or below the plane of particle trajectory, circular polarization becomes one sense, as observed in many pulsars.

References

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