

Transition Radiation in a Relativistic Electron-positron Plasma

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Abstract

Transition radiation in a relativistic electron-positron plasma is investigated, when electron or positron beams pass through the local density inhomogeneity produced by the ponderomotive force due to nonlinear spiky Alfvén solitons in the pulsar magnetosphere.

Transition radiation is a quite general radiation process, which occurs when a point charge moves with a constant velocity in the inhomogeneous or nonstational medium.

Recently, several problems of the theory of transition radiation were reviewed by Ginzburg and Tsytovich, connected with the nonlinear media such as plasma.

In a plasma there often appears the density inhomogeneity produced by the ponderomotive force due to nonlinear collective modes; Langmuir soliton, Alfvén soliton etc. In the astrophysical plasma, the energy density of low frequency magnetohydrodynamic (MHD) waves such as Alfvén waves is thought to be quite large compared with the electrostatic wave energy density. Therefore the density inhomogeneity produced by nonlinear MHD waves may play an important role for the transition radiation.

The nonlinear behaviour of Alfvén waves in an electron-positron plasma was investigated, stimulated by the theoretical models of pulsar magnetosphere. It has been shown that there appears the spiky Alfvén soliton associated with the local density hump.

In the present letter, we investigate the process of transition radiation due to the density hump produced by the spiky Alfvén soliton in the electron-positron plasma.

The permittivity $\hat{\epsilon}$ for electromagnetic waves propagating along the magnetic field in the electron-positron plasma is given by,

$$\hat{\epsilon} = 1 - \left(\frac{kc}{\omega}\right)^2 - \frac{2\omega_p^2}{\omega^2 - \omega_c^2}, \quad \dots\dots\dots(1)$$

where $\omega_p^2 = 4\pi n_0^2 e^2 / \rho$, $\omega_c = en_0 B_0 / \rho c$, and

$$\rho = (P + \epsilon) / c^2.$$

The total energy W emitted by a relativistic particle ($\epsilon \gg mc^2$) is given by,

$$W \approx \frac{e^2 \omega_p}{24c} \frac{\epsilon}{mc^2} \left(\frac{\delta n}{n_0}\right)^2, \quad \dots\dots\dots(2)$$

where the density jump δn across the boundary is determined from the difference of the permittivity.

$$|\hat{\varepsilon}_2 - \hat{\varepsilon}_1|^2 = (\delta\hat{\varepsilon})^2 \left(\frac{\delta n}{n_0}\right)^2.$$

On the other hand, the density hump due to the spiky Alfvén soliton is given by,⁵⁾

$$\frac{\delta n}{n_0} = -\frac{|B|^2}{16\pi\rho c^2(1 - \bar{V}_A^2/c^2)}, \dots\dots\dots(3)$$

where B is the amplitude of Alfvén wave, and \bar{V}_A is the Alfvén wave velocity;

$$\bar{V}_A = c(1 + 2\omega_p^2/\omega_c^2)^{-\frac{1}{2}}.$$

The characteristic width Δ of the spiky soliton is also given by

$$\Delta \approx \frac{\sqrt{8\pi\rho_0 c \bar{V}_A}}{B} \left(\frac{\bar{V}_A}{c}\right) \left(1 - \frac{\bar{V}_A^2}{c^2}\right)^{\frac{1}{2}} \left\{ \frac{\bar{V}_A}{c} - \left(1 - \frac{\bar{V}_A^2}{c^2}\right)^2 \right\}^{-\frac{1}{2}}. \dots\dots\dots(4)$$

If we consider the situation that electron or positron beams with the velocity, $V_b \approx c$ pass through the density hump of the Alfvén spiky soliton, we can estimate the total energy W_T emitted by the transition radiation as

$$W_T = \frac{V_b}{\Delta} N_b^2 W \quad [\text{erg/sec}], \dots\dots\dots(5)$$

where N_b is the total beam number contributed to the radiation process. By making use of eqs. (2), (3) and (4), we obtain

$$W_T = \frac{N_b^2 \omega_p^2}{24} \left(\frac{\varepsilon^5}{mc^2}\right) \frac{B^5}{\sqrt{8\pi\rho c \bar{V}_A}} \left(\frac{\omega_c}{\bar{V}_A}\right) \left(1 - \frac{\bar{V}_A^2}{c^2}\right)^{-\frac{5}{2}} \left\{ \frac{\bar{V}_A}{c} - \left(1 - \frac{\bar{V}_A^2}{c^2}\right)^2 \right\}^{\frac{1}{2}} (16\pi\rho c^2)^{-2} \dots\dots\dots(6)$$

[erg/sec],

In the strong magnetic field region such as pulsar magnetosphere, the Alfvén velocity \bar{V}_A becomes comparable to the light velocity c. So the total energy W_T can be enhanced near the pulsar. Recently, a generation mechanism of Alfvén waves in the electron-positron plasma was proposed by Mikhailovskii.⁷⁾

The transition radiation mentioned here may be important in the theory of pulsar radio emission.

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