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A Coherent ICS Model for Radio Pulsars

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Abstract. A coherent Inverse Compton Scattering Model (ICS) model for radio pulsars is proposed. Based on this model, we have calculated simulated pulses with full polarization and find that they closely resemble observational results. It is argued that the circular polarization intensity of radio pulsar's emission might be the result of coherent superposition of a emission bunch.

1. Introduction

It has long been emphasized that the polarization observations and their interpretations are very important for understanding the magnetosphere structure and radiation mechanisms of pulsars(Radhakrishnan et al., 1969, Manchester 1971, Rankin 1983, Lyne & Manchester 1988).

Although polarization observations of radio pulsars have provided plentiful data for us to understand the pulsars, there are many observational facts for which theoretical models do not give a good explanation, such as the position angle jumps (for example, see Stinebring et. al. 1984a, b) and circular polarization.

We choose inverse Compton scattering process as a mechanism for pulsar radio emission (Qiao 1996, Qiao & Lin 1997). A coherent ICS model is proposed in this paper, which is mainly focused on the polarization properties of radio pulsars. Although the radiation of a single electron is totally linearly polarized because of the strong magnetic field near the pulsar's surface, we could still get considerable circular polarization intensity if we consider the coherent addition of radiation of many electrons or positrons near the pulsar's polar cap region. This circularly polarized emission by coherent superposition may be a good candidate for producing the circular polarization observed in pulsar's radio emission beams.

2. The polarization of ICS in strong magnetic fields

There are two ways to get the polarization information of Compton radiation in strong magnetic fields:

- Calculating the electric field of scattered wave by classical electrodynamics (CED). The coherent superposition of the scattered waves can then be easily obtained (for example, see Xu & Qiao 1997b).

- Computing the scattered wave intensity in different polarization modes using the Quantum Electrodynamics (QED) results for the cross sections. The coherent quantum state expression must then be used to get the coherent superposition of the scattered waves.

Generally, the second way gives exact results, but the calculation is complicated. The CED methods gives a good approximation for low frequency scattered waves.

Xu & Qiao (1997a) have calculated the polarization characteristics of Compton radiation in strong magnetic fields, and found that:

1. At the low frequency limit, the scattered photon is totally linearly polarized with position angle of 0^o, which means the electric field is in the plane of the in-coming photon and the magnetic field;

2. As the frequency of out-going photon becomes higher, the scattered photon will be elliptically polarized, and the position angle of the scattered photon will be 90^o (the electric field is perpendicular to the plane of out-going photon and the magnetic field) when the resonant scattering takes place.

Although the radiation of a single electron is totally linearly polarized in case of radio pulsars, we could still get significant circular polarization intensity if we consider the coherent process. For two linearly polarized plane electromagnetic waves which have same wave vectors $\mathbf{k}$, with the electric amplitudes $\mathbf{E}_1 = \mathbf{E}_2 = \mathbf{E}$, the angle between $\mathbf{E}_1$ and $\mathbf{E}_2$ to be κ, and the phase difference between them fixed to be $\delta = \varphi_2 - \varphi_1$, then the percentage of circular polarization intensity can be calculated as

$$\frac{V}{I} = \frac{\sin\kappa \sin\delta}{1 + \cos\kappa \cos\delta}.$$

So, $|\sin\kappa|$ and $|\sin\delta|$ should not be small to get significant circular polarization intensity. If one of κ and δ is zero, then the total circular polarization intensity will also be zero. If $\kappa = \delta = \frac{\pi}{2}$, then the composite emission will be totally circular polarized.

3. The Model

Following the RS inner gap model of Ruderman & Sutherland (1975), Qiao and Lin (1997) presented a model for the radio emission of pulsars, and they have shown that this ICS process can produce the emission beams (core and cone) naturally, which is consistent with the observations.

Considering the coherent superposition of emission from many electrons, we could discuss the polarization properties of the model. In Fig.1, we give a sketch picture for the region near the pulsar's polar cap. The emission from region near the polar gap is only considered in this paper, which is possibly corresponding to the observational core component. The low frequency wave from a sparking point S propagates to a point A, where it is scattered by some high-energy particles with Lorentz factor $\gamma \simeq 100$. The radiation of scattered waves from a bunch of electrons is superposed coherently. The maximum observational emission region along the line of sight corresponds to a spatial extent of 240 m for typical pulsar values. As the spatial extent of emission region is nearly perpendicular to the observational direction, the Lorentz shrink has not be included, and the spatial extent along the observational direction is smaller than 1 m, so the emission from many electrons can be coherent. We assume the width of a electron bunch is 40 m, and discuss six bunches of electron in our simulation (Xu & Qiao 1997b).

In the simulated six pulses for the six bunches, sign reverses of circulars polarization and 'S' shapes of position angle are clear. If we incoherently sum the Stokes parameters for radiation from the six bunches, we could get another pulse profile, where depolarization of both linear and circular polarization occurs, and the position angle curve is not that for the six bunches but similar to the polarization observations for PSR 2303+30 at 430 MHz (Gil 1992).

4. Conclusion & Discussion

Using a coherent ICS model for radio pulsars, we have simulated the profiles of the total intensity I, linear polarization intensity L, position angle χ and circular polarization V.

As the radiation region moves away from the neutron star surface for a fixed spatial extent of electron bunch, the angle between the vectors of electric fields scattered from many electrons becomes smaller , and so the circular polarization intensity V is also smaller. Circular polarization have a tendency to exist in the core components of pulsar radio emission, which has long been noted (Rankin 1993) in observations.

Many factors, which could be important, have not been included in this paper, such as the distribution of the Lorentz factor γ, the reduction of γ as particles flow away, the rotation of neutron star. A paper considering this factors is being prepared in our research group, where the calculated results might be more similar to observations.

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Fig.1 The geometry near the polar cap region in the coherent ICS model.