射电脉冲星的偏振特性与逆康普顿散射 (ICS) 模型

徐仁新[1]　乔国俊[1]　韩金林[2]

(1 北京大学天文学系　北京　100871)

(2 中国科学院北京天文台　北京　100012)

摘　　要

大量射电脉冲星的偏振观测 —— 包括线偏振和圆偏振，个别脉冲的垂直偏振模式，累积脉冲的消偏振现象等 —— 为辐射区的物理状态和辐射过程提供了非常确切的观测事实。但现有理论对众多观测事实尚无法给出完整的说明。综述了脉冲星的偏振观测特征，并利用逆康普顿散射模型对这些特性进行了解释。

关 键 词　脉冲星 — 偏振 — 辐射机制

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Polarization Properties of Radio Pulsars in the Inverse Compton Scattering(ICS) Model

Xu Renxin[1]　Qiao Guojun[1]　Han Jinlin[2]

(1 Department of Astronomy, Peking University, Beijing 100871)

(2 Beijing Astronomical Observatory, Chinese Academy of Sciences, Beijing 100012)

Abstract

Polarization observations of radio pulsars, such as linear and circular polarization, polarization position angle jumps of individual and integrated pulses, can be used to get abundant information, which is very important to understanding the physical processes in the emission regions. In this paper, some basic properties of polarization observations of radio pulsars and their theoretical explanation in the Inverse Compton Scattering (ICS) model are briefly reviewed.

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Key words Pulsars—Polarization—Radiation mechanism

1 Basic Observational Facts

Generally, pulsar radio emission is found to be highly linearly polarized over all longitudes of profiles, sometimes as high as up to 100%. The position angle sweep is in an "S" shape, which can be well understood within the rotating vector model[1]. However, depolarization and position angle jumps are often found in the integrated profiles of some pulsars. One of the difficulties to understanding pulsar polarization observations is the polarization position angle jumps in mean (or integrated) pulses as well as in individual pulses[2]. For mean pulses, it is generally found that position angles would have discontinuities about 90° at some longitudes, where the linear polarization intensities are almost zero (totally depolarized). For individual pulses, the position angles would be dispersed or have two 90° separated distributions at some observational longitude bins, where the linear polarization fraction is remarkably small.

Pulsar radio emission has also significant part of circular polarization, the percentage of which could sometimes be as high as 60%. Radhakrishnan and Rankin[3] identified two types of circular polarization: "anti-symmetric", for which there is a sense change near the center of the pulse profile, and "symmetric", for which the same hand of circular polarization is observed across the profile. However, based on all the available polarization data published, Han *et al*[4]. present a systematic study of the circular polarization in the integrated pulses, and find no general correlation between the sense-change of circular polarization and the sense of the linear polarization sweep, but only that the sense of circular polarization is correlated with the sense of the linear polarization variation in conal double profiles. They also point out that circular polarization is not restricted to the core components.

It is a common conception that the individual pulses have higher linear and circular polarization fraction than the integrated ones, since the superposition of single pulsars tends to decrease the total polarization of mean pulses. The position angles of individual pulses are generally not the same as those of integrated ones, and the adding of such individual pulses should thus conduce to linear depolarization in the integrated pulses. It is found that there are some position angles "jumps" in individual pulses, but not in integrated pulses. Also the senses of the circular polarization of individual pulses could not be the same as those of integrated ones.

2 Theoretical Aspects in the ICS Model

The basic idea of the model can be found in Qiao & Lin[5] and Xu *et al*[6]. In the model, low frequency electromagnetic waves are supposed to be produced near the star surface due to the violent breakdown of RS type vacuum gap[7]. The waves are assumed to propagate freely in pulsar magnetospheres and are inverse-Compton-scattered by the secondary particles produced in gap sparking processes. The up-scattered photons are in the radio band, i.e., the observed radio emission. With the simple dipole field, the incident angle of the ICS decreases first, and then starts to increase above a critical height. The Lorentz factor of the secondary particles, however, keeps decreasing due to various energy loss mechanisms (mainly the ICS with the thermal photons near the surface). The combination of the above two effects naturally results in the feature that on a given field line, the emission has the same frequency at three heights, corresponding to one core and two conal emission components.

The polarization features of scattered emission by a single relativistic electron in the strong magnetic field were calculated from the Stokes parameters of scattering emission[6]. For the radio band in the ICS model, the scattered photons are completely linearly polarized, and its polarization position angle is in the co-plane of the out-going photon direction and the magnetic field. However the inverse Compton scattering of a bunch of particles out-flowing in pulsar magnetosphere should be coherent. Such coherence can produce significant circular polarization in beamed radio emission[6].

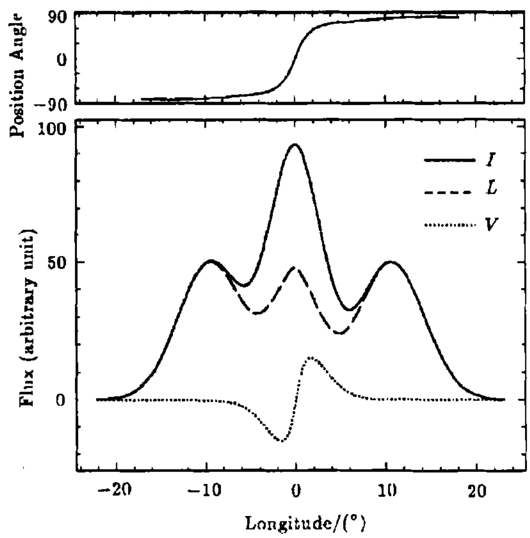

Fig.1　A simulated integrated pulse profile in the ICS model[6]

The normalized impact angle is chosen to be 0.3

The coherent inverse Compton Scattering process in pulsar magnetosphere has been simulated. An observer can only see a small part of an emission beam radiated by a particle bunch, which is called as "transient beam". (1) In the ICS model, at a given frequency the transient beam consists of three parts (core, inner and outer cones), each of them is called "mini-beam", and their polarization feature is quite different. (2) Circular polarization is very strong (even up to 100%) in the core mini-beam and on the other hand it is much less in the inner cone mini-beam. (3) If the line of sight sweeps across the center of a core (or inner conal) mini-beam, the circular polarization will experience a central sense reversal, or else it will be dominated by one sense, either the left hand or the right hand according to its traversing line relative to the mini-beam. (4) There are diverse values of the position angles at a given longitude of transient "sub-pulses" around the projection of the magnetic field. The variation range of position angles is larger for core emission, but smaller for conal beam. (5) Stronger circular polarization should be observed in sub-pulses with higher time resolution according to our model.

Fig.1 shows a typical integrated polarization profile calculated by summing up incoherently the Stokes parameters of the scattered waves from the particle bunches, the scattered emission of which can be seen at a given observational longitude. It is found that the integrated profiles are highly linear polarized in general, and their polarization angles follow nice S-shape, which well represents the rotating vector model. One important result is the anti-symmetric circular polarization in the central or core components. As we mentioned above, circular polarization can be up to 100% on some parts of core mini-beam (sub-pulses), but depolarization occurs in the process of incoherent summation of circular polarization of opposite senses. This also produces a substantial amount of un-polarized emission. For the linearly polarized emission, position angles of transient sub-pulses should vary, causing further depolarization. However, in the conal components, circular polarization is insignificant, mainly because it is originally weak in the mini-beam. Since there is negligible variation of position angles of sub-pulse, almost no linear depolarization presents, and therefore, the conal components are always highly linearly polarized.

Considering the retardation effect due to relative phase shift between pulsar beam components, we find that such shift could cause further depolarization and may result in position angle jump(s) in integrated profiles[8]. Further study of this kind of shift in the ICS model indicates that the emission beams of pulsars with small rotation periods do not have circular cross sections even if the emission regions are symmetric with respect to the magnetic axes, if we take into account the toroidal velocity due to rotation[9].

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