PULSAR RADIO EMISSION FROM
EXPANDING CHARGE SHEETS

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Abstract. We semi-quantitatively calculate the distribution of energy in frequency and angle emitted from a sheet of charges that are moving out relativistically along dipolar magnetic field lines originating near the magnetic polar caps of a rotating neutron star. The angular distribution is conical with the angle of maximum intensity varying with frequency $\omega$ as $\omega^{-1/4}$ for $\omega \lesssim \omega_c \approx 2c/(R\theta_M^3)$, where $R\theta_M$ is the initial angular radius of the charge sheet at the surface of the star of radius $R$. At higher frequencies the width of the angular cone remains constant. The radiation is linearly polarized with the polarization vector in the plane of the line of sight and the magnetic axis. A sheet of uniform charge density and finite thickness has a frequency spectrum that varies from $\omega^{-5/2}$ to $\omega^{-4}$ for $\omega \lesssim \omega_c$ and $\omega \lesssim \omega_s$, respectively. These features are in good general agreement with the observed characteristics of the intensity, pulse shape, and frequency spectrum of the radio pulses from pulsars.

1. Introduction

This paper presents a coherent emission mechanism for the radio pulses observed from pulsars. It is generally believed that pulsars are rapidly rotating neutron stars of small dimensions and having large magnetic fields (Gold, 1968) and that the radio emission is beamed from a source that is rigidly tied to the star's rotation. These conclusions follow from the very strict periodicity, range of periods, slowing down rates, and small pulse width. The emission mechanism is, however, difficult to understand because of its high emissivity, pulse width, pulse shape, polarization, frequency spectrum, and drifting subpulses (Smith, 1970a).

Several authors (Gold, 1968; Eastland, 1968; Bertotti et al., 1969; Smith, 1970b) place the emission source far from the star in vicinity of the velocity of light cylinder, beyond which no rigid co-rotation is possible. The radiation is thought to be beamed from a localized bunch of particles rigidly rotating with the star at velocities close to the velocity of light. However, in such models there is no way of accounting for the limited widths of the pulses, nor the apparent lack of long term variation of the mean pulse structure (Manchester, 1971). Lerche (1970a, b), alternatively, has proposed that the emission is from the boundary layer where the pressure of the magnetic dipole radiation (Pacini, 1968) is balanced by the pressure of the relativistic external plasma. Although many features of pulsar emission are explained by such models, it is difficult to understand why the interpulses are not midway between the main pulses, as little asymmetry is expected so far from the star. Thus placing the radiation mechanism closer to the star may offer a simpler explanation.

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Beaming of radiation is possible, if the radiation originates from relativistic particles that are constrained to move in a preferential direction (most probably, along magnetic field lines of force). Goldreich and Julian (1969) have suggested that charges are accelerated up from the surface of a neutron star (by the induced electric field generated by the rotational motion of the star’s magnetic field) along the magnetic field lines that extend through the ‘light cylinder’. The pulse width (‘window’) is thus defined by the angular size of the open field line regions (‘polar caps’) at the surface of the star. The polarization vector of the radiation emitted from the charges as they move along the magnetic lines of force will lie in the plane of the line of sight and the magnetic polar axis, which is in excellent agreement with the observations that the position angle of the polarization vector swings through a large angle during the pulse (Radhakrishnan et al. 1969), and that the position angle variation is independent of frequency (Radhakrishnan and Cooke, 1969, and Manchester, 1970).

Radhakrishnan (1969) proposed that relativistic particles moving almost directly along magnetic field lines radiate via their accelerations associated with the curvature of these lines, in contrast with synchrotron radiation emitted by particles gyrating around field lines. Following this suggestion Komesaroff (1970) and Sturrock (1970) estimated via Fresnel zone arguments the coherence of the low frequency part of such radiation from a thin sheet of charges emitted relativistically from the region of the magnetic polar caps. However, for pitch-angles not too small the charges will radiate much more efficiently via their gyromotion around the magnetic lines than via the curvature of these lines. Also even in the absence of any curved particle trajectories, charges may radiate (though, less efficiently) via a linear acceleration along magnetic field lines due to a large electric field component parallel to the magnetic field.

In this paper we investigate, with a different approach, the coherent emission from an expanding sheet of charges ejected with relativistic velocities from the surface of a rotating neutron star. We suppose that from the magnetic polar caps many bunches of charged particles are ejected per rotation period and we further idealize each bunch of charges as a thin charge sheet. The individual charges are assumed to follow the magnetic lines of force, which is a good approximation if their pitch angles to the magnetic field are small. Although no explicit form of the accelerations experienced by the particles is specified, it is appreciated that they radiate due to their accelerated motion produced by external forces (e.g., Lorentz force, curvature of field lines, or parallel electric fields).

We do not concern ourselves with the pulse periodicity which, we assume, is caused by the rotation of the magnetic polar caps, but calculate the emission at a particular angle \( \chi \) with respect to the magnetic axis. This is a good approximation for the radiation seen by a stationary observer at an instantaneous angle \( \chi \), if the time \( \Delta t \) that the sheet radiates toward the observer is short, such that \( \Delta \chi = 2\pi \Delta t / T \ll \chi \), where \( T \) is the rotation period. Thus the observed pulse profile can be obtained from the emission intensity variation with angle \( \chi \).