**Pulse emission mechanisms**

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**Abstract.** High-energy and radio emission mechanisms for pulsars are reviewed. The source region for high energy emission remains uncertain. Two preferred radio emission mechanism are identified. Some difficulties may be resolved by appealing to nonstationary pair creation distributed widely in height.

1. **Introduction**

Collectively, pulsars emit over essentially the entire electromagnetic spectrum. However, most pulsars are observed only in a relatively narrow range, ~100 MHz–~10 GHz. The basic properties determined for most pulsars are the period, $P$, and the period derivative, $\dot{P}$, which determine the magnetic field, $B \propto (P \dot{P})^{1/2}$, the characteristic age $P/2 \dot{P}$ and the spin-down power $\propto \dot{P}/P^3$. Also available for most pulsars are the integrated pulse profile, the position angle of the linear polarization, which determines the inclination angle between the magnetic and rotational axes, and the dispersion measure, which provides an estimate of the distance to the pulsar. Based on the location in the $P$–$\dot{P}$ plane, pulsars are classified as young ($< 10^5$ yr), old, recycled (or millisecond), or magnetar. It is remarkable that despite the large ranges in $P$, $B$, the variations in pulse profile between classes are similar to those within classes. This suggests that the radio emission mechanism cannot be sensitive to either $P$ or $B$. The source of the radio emission appears to be between inner and outer gaps, seemingly far from these sites where parallel electric fields are thought to accelerate primary particles and trigger pair cascades. Only a small fraction of radio pulsars are also observed at high energies, in the X-ray and gamma-ray ranges, which emissions should provide a direct signature of particle acceleration and pair creation. However, there remains a major uncertainty in the location of the source region, with both inner-gap and outer-gap models considered viable.

High-energy emission mechanism are summarized in section 2 and radio emission mechanisms are summarized in section 3. The identification of source regions is discussed in section 4.

2. **High-energy emission mechanisms**

The high-energy emission mechanisms that need to be considered for pulsars are synchrotron emission, curvature emission and inverse Compton emission (IC),
all of which are relatively well known. A less familiar, resonant form of IC emission (RIC) is important.

A preliminary point is that in a relativistic quantum treatment, the energy of an electron has discrete values \( \varepsilon_n = (m^2c^4 + p^2c^2 + 2neBc^2\hbar)^{1/2} \) where \( p_z \) is the component of the momentum along the field lines, and \( n = 0, 1, \ldots \) is the Landau quantum number. In a pulsar the lifetime of the excited states is very short, and all electrons quickly relax to their ground state, \( n = 0 \).

Synchrotron emission occurs only if highly relativistic pairs are created with \( n \gg 1 \), corresponding to \( \gamma \sin \alpha \gg 1 \), \( \gamma = \varepsilon_n/\gamma mc^2 \), \( \alpha \) = pitch angle. The emission is strongly concentrated around an angle \( \theta = \alpha \), with a broad frequency spectrum peaked at \( \omega \approx \omega_B \gamma^2 \sin \theta \), where \( \omega_B = eB/m \) is the cyclotron frequency. The power radiated is \( (\varepsilon^2 \omega_B^2/6\pi \varepsilon_0 c) \gamma^4 \sin^2 \theta \), and the radiation is highly linearly polarized, \( \sim 70\% \), in the direction perpendicular to the projection of the magnetic field on the plane of the sky. For a power-law energy spectrum of radiating particles, \( N(\gamma) \propto \gamma^{-q} \), the intensity spectrum is a power law, \( I(\omega) \propto \omega^{-(\gamma+1)/2} \).

Curvature emission by an individual electron with Lorentz factor \( \gamma \gg 1 \) moving along \( (n = 0) \) a magnetic field line with radius of curvature \( R_c \) is strongly concentrated around \( \theta = 0 \), with a broad frequency spectrum peaked at \( \omega \approx \omega_c \gamma^2 \), \( \omega_c = c/R_c \). The power radiated is \( (\varepsilon^2 \omega_c^2/6\pi \varepsilon_0 c) \gamma^4 \), and the radiation is highly linearly polarized in the direction perpendicular to the plane containing the curved magnetic field line. For a power-law energy spectrum of radiating particles the intensity spectrum is a power law with index \(-(a+2)/3\).

IC emission is actually Thomson scattering by highly relativistic electrons. An initial photon with frequency \( \omega_0 \) is scattered into a final photon with frequency \( \omega \sim \omega_0 \gamma^2 \) propagating nearly along the direction of the initial electron. The power radiated is \( \approx \sigma_T cW_0 \gamma^2 \), where \( \sigma_T = (8\pi/e)(c^2/4\pi \varepsilon_0 mc^2)^2 \) is the Thomson cross section and \( W_0 \) is the energy density in the initial photons. The polarization has no characteristic value in general, and the spectrum is synchrotron-like. Relativistic quantum effects sharply reduce the cross section, from the Thomson to the Klein-Nishina value, for \( \omega_0 \gg mc^2/\gamma \).

RIC emission is Thomson scattering by highly relativistic electrons in a magnetic field such that the wave frequency, \( \omega_0 \), is near the relativistic cyclotron frequency, \( \omega_0 \approx \omega_B/\gamma \). When this condition is satisfied, the Thomson cross section is greatly enhanced, by a factor \( \sim \omega_0^2/(\omega_0^2 - \omega_B^2/\gamma^2) \) (Canuto, Lodenquai & Ruderman 1971) dependent on the polarization of the photon (Melrose & Sy 1972). The maximum enhancement factor is \( \sim \omega_B^2/I^2 \), where \( I \) is the width of the cyclotron resonance. RIC involves scattering in which the initial and final state of the electron is \( n = 0 \) and the (virtual) intermediate state is \( n = 1 \). The relevant \( I \) is the inverse lifetime of the first excited state (Herold 1979), which is \( I = e^2\omega_B^4/3\pi \varepsilon_0 mc^2 \gamma \). The importance of RIC in high-energy emission from pulsars was emphasized by Daugherty & Harding (1989) and Dermer (1990).

3. Models for high-energy emission

There are both inner-gap and outer-gap models for the high-energy emission, and there is no clear consensus on which type of model is to be preferred.

High-energy emission should provide a signature of acceleration and pair production in inner-gap models, provided a small fraction of high-energy pho-