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NUCLEI, PARTICLES, FIELDS, GRAVITATION, AND ASTROPHYSICS

Correlation of Pulsar Radio Emission Spectrum with Peculiarities of Particle Acceleration in a Polar Gap

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Abstract—The analytical expression for the frequency of radio emission intensity maximum in pulsars with free electron emission from the stellar surface has been found. Peculiarities of the electron acceleration in a polar gap are considered. The correlation between the high-frequency cutoff and low-frequency turnover in the radio emission spectrum of pulsars known from observations has been explained.

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1. INTRODUCTION

The studies carried out at the Pushchino Radio Astronomy Observatory, the Astro Space Center of the Lebedev Physical Institute of the Russian Academy of Sciences (ASC LPI RAS), have revealed a high-frequency cutoff in the spectrum for a number of pulsars forming a sample of 46 fairly powerful objects [1–4] at a frequency dependent on the pulsar period P [4]:

$$\tilde{\nu}_{cf} = 1.4 \times 10^9\ \text{Hz}\sqrt{\frac{1\ \text{s}}{P}}. \qquad (1a)$$

The explanation of this phenomenon that we proposed previously in [5–7] associates the cutoff with the change of radio emission mechanism. The emission of electrons through their longitudinal acceleration in the inner gap over the polar cap responsible for the radio emission in our model ceases at frequencies

$$\tilde{\nu}_{cf} = \sqrt{2} \times 10^9\ \text{Hz}\sqrt{\frac{B}{2 \times 10^{12}\ \text{G}}\frac{1\ \text{s}}{P}}, \qquad (1b)$$

where B is the magnetic field strength on the pulsar surface. Significantly, the accelerating field in the gap increases (linearly) from zero on the stellar surface (see below). In such a field, the acceleration of an electron emitted from the pulsar surface also increases from zero and passes through its maximum in the range of subrelativistic electron velocities. As the speed of light is approached, the electron acceleration decreases and this emission mechanism switches off. In a narrow cone of directions along the magnetic field line, it is replaced by a relativistic emission mechanism [8–10].

As follows from observations, for some of the pulsars from the Pushchino sample with the spectrum cutoff, the high-frequency cutoff correlates with the low-frequency turnover. More specifically, according to Malofeev and Malov [4], the following correlation exists for this subsample containing 32 pulsars with known positions of both frequencies:

$$\tilde{\nu}_{tr} = 0.1\tilde{\nu}_{cf}. \qquad (2)$$

Here, $\tilde{\nu}_{tr}$ (tr from turnover) denotes the frequency at which the radio emission intensity reaches its maximum and the spectrum turnover to lower frequencies begins. For many astrophysical objects, including extragalactic sources, the turnover frequency is determined by the dissipative mechanisms or specific plasma dispersion [11]. In the case of pulsars of interest to us, these mechanisms cannot take place. At the same time, Eq. (2) suggests that the same acceleration mechanism that leads to the high-frequency cutoff should be responsible for the low-frequency turnover. We will show that this is actually the case.

2. ELECTRON ACCELERATION NEAR THE PULSAR SURFACE

A vacuum gap under the magnetosphere of open field lines was introduced by Ruderman and Sutherland [2]. A strong accelerating electric field almost instantaneously imparts relativistic velocities to the electrons, including those torn out from the stellar surface by autoelectronic emission, bringing their gamma-factors to very high values, $\Gamma \sim 10^7$. A momentary burst of acceleration resembling the δ-function in time, after its expansion in a Fourier integral, leads to a flat spectrum—a step with a cutoff frequency of the order of the inverse acceleration time. This frequency falls into the X-ray range and, accordingly, a negligible part of the emitted energy is accounted for by the radio frequencies. Therefore, other mechanisms of radio emission in the magnetosphere, in particular, the plasma mechanisms, have been developed. The cases of two-stream instabilities [13], which arise in a