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Peculiarities in emission of radio loud and radio quiet gamma pulsars and gamma quiet radio pulsars

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Comparison of three pulsar samples-radio pulsars (R), gamma pulsars (γ) and pulsars with emission in both ranges ($\gamma + R$) has been carried out. It was shown that magnetic fields at the light cylinder are two orders of magnitude higher in gamma pulsars ($\langle \log B_{lc} \rangle$ = 3.60–3.95 G) when compared with radio pulsars ($\langle \log B_{lc} \rangle$ = 1.75 G). Losses of rotation energy in these objects differ much more ($\log dE/dt$ = 35.37–35.53 and 32.60, correspondingly). Gamma pulsars form two groups separated in space. The conclusion is made that generation of gamma emission takes place at the light cylinder and can be caused by the synchrotron mechanism.

Keywords: Pulsars, magnetic fields, gamma-rays

1 Introduction

More than 2500 radio pulsars are currently known [1]. These objects radiate mainly in the radio range, but gamma emission is detected in approximately 150 pulsars [2]. It is interesting to elucidate some possible differences in parameters of objects in these two groups. We will carry out the comparison of some characteristics describing gamma loud ($\gamma + R$) and gamma quiet (R) radio pulsars and then search for differences in parameters of radio loud ($\gamma + R$) and radio quiet gamma pulsars (γ). For the analysis we will use pulsar periods, their derivatives, losses of rotation energy, luminosities, magnetic fields at the surface of neutron stars and near the light cylinders. We will consider isolated neutron stars only and exclude from the analysis pulsars in globular clusters and binary systems, since their observed characteristics can be distorted by an influence of other nearby stars.

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2 Distributions of the parameters

Figure 1 shows that only one millisecond pulsar emits gamma rays without radio emission. Other millisecond pulsars from our sample radiate radio and gamma emission simultaneously.

Magnetic fields near the light cylinders (Fig. 4) for gamma pulsars are two orders higher than fields of gamma quiet radio pulsars. This probably means that gamma radiation is generated at the periphery of magnetosphere.

Gamma pulsars lose their rotation energy (Fig. 5) three orders of magnitude faster on average than normal radio pulsars. However their distribution of dE/dt is nearly uniform, i.e. there is gamma radiation from objects with rather small values of dE/dt.

So, we can conclude that high values of B_{lc} and dE/dt are necessary conditions for generation of gamma rays in pulsars. They give the possibility to choose objects from catalogs which can be gamma ray emitters.

Distribution of radio luminosities at 1400 MHz

$$R_{lum} = S_{1400} d^2 \quad (\mathrm{mJy\,kpc^2}) \tag{1}$$

for normal pulsars (Fig. 6) can be described by Gaussian. However $\gamma + R$ pulsars show the bimodal distribution. The analysis reveals the Gaussian distribution for S_{1400} but bimodal one for distances to pulsars. This means that there are two groups of gamma pulsars separated in space. One population is located 0.2–0.6 kpc from the Earth and is probably in the Orion Arm. The other is located at distances of 2–18 kpc from the Sun.

As we conclude gamma emission is generated near the light cylinder. In this region pitch angles of relativistic electrons are formed [3] and the synchrotron mechanism is switched on.

The power of the synchrotron emission

$$p_s = \frac{2e^4 B^2 \gamma^2 \sin^2 \psi}{3m^2 c^3} \tag{2}$$

grows with increasing magnetic field, and we can expect that the gamma luminosity depends on the magnetic field at the light cylinder. Such a dependence is observed indeed (Fig. 8). Here e is the charge of electron, γ its Lorentz-factor, ψ pitch angle, m the mass of electron, c speed of light.

Pierbattista with coauthors [4] compared the observed distributions of gamma pulsars in the frames of different models: polar cap, slot gap and outer gap. They have shown that only the last two models can be used for the description of the observations.

Our results show that the best model for the explanation of the known data is the outer gap model with two emitting regions (Fig. 9). Indeed the Goldreich–Julian density [5]

$$n = -\frac{\vec{\Omega}\vec{B}}{2\pi ce}, \tag{3}$$

where Ω is the angular velocity of rotation, is equal to zero if

$$\vec{\Omega}\vec{B} = 0. \tag{4}$$

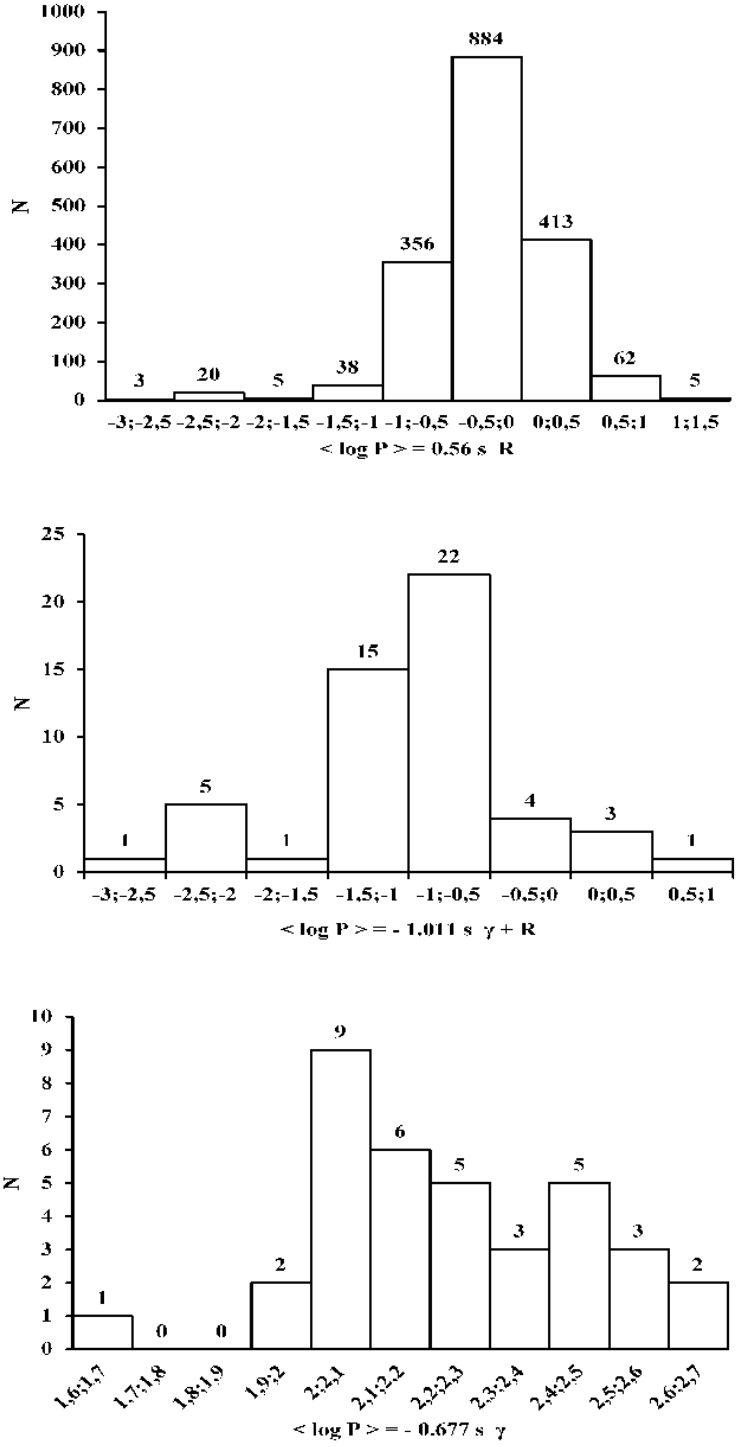


Figure 1 Distributions of pulsars periods for three groups of pulsars.

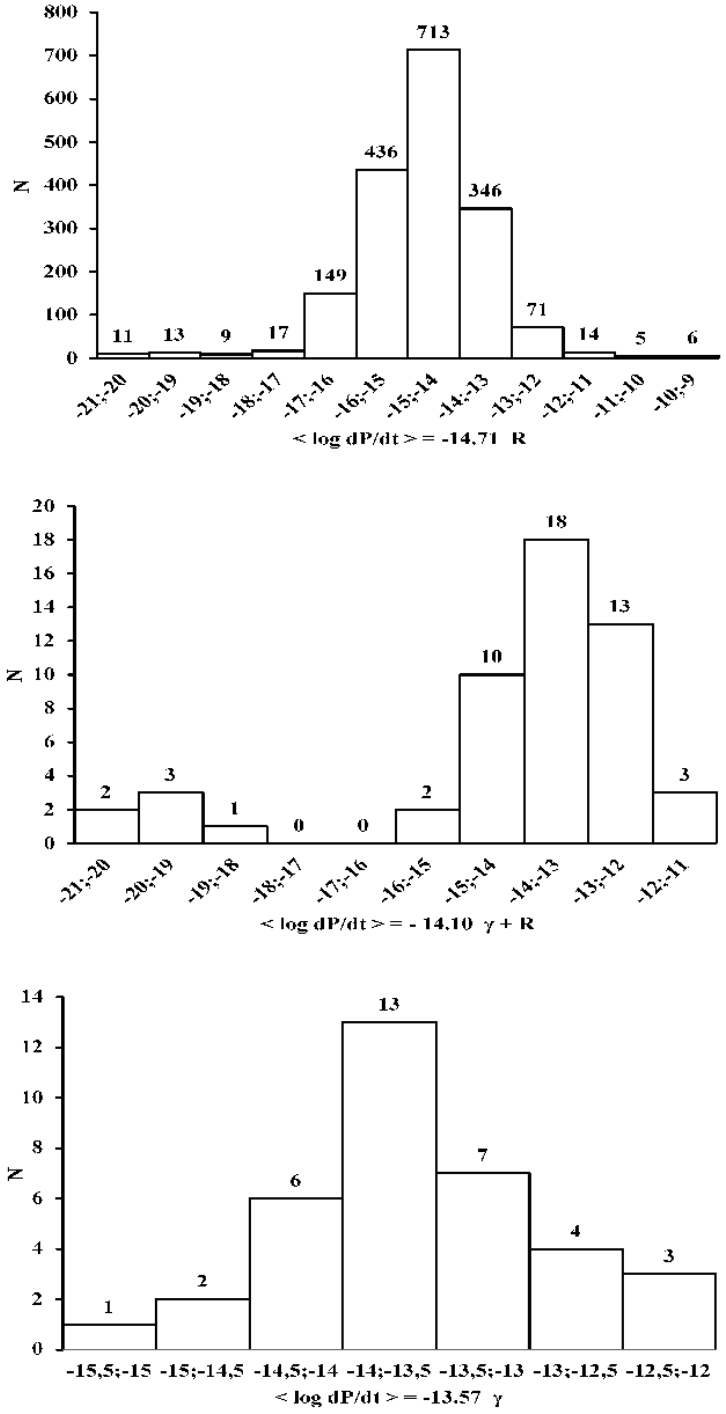


Figure 2 Distributions of period derivatives.

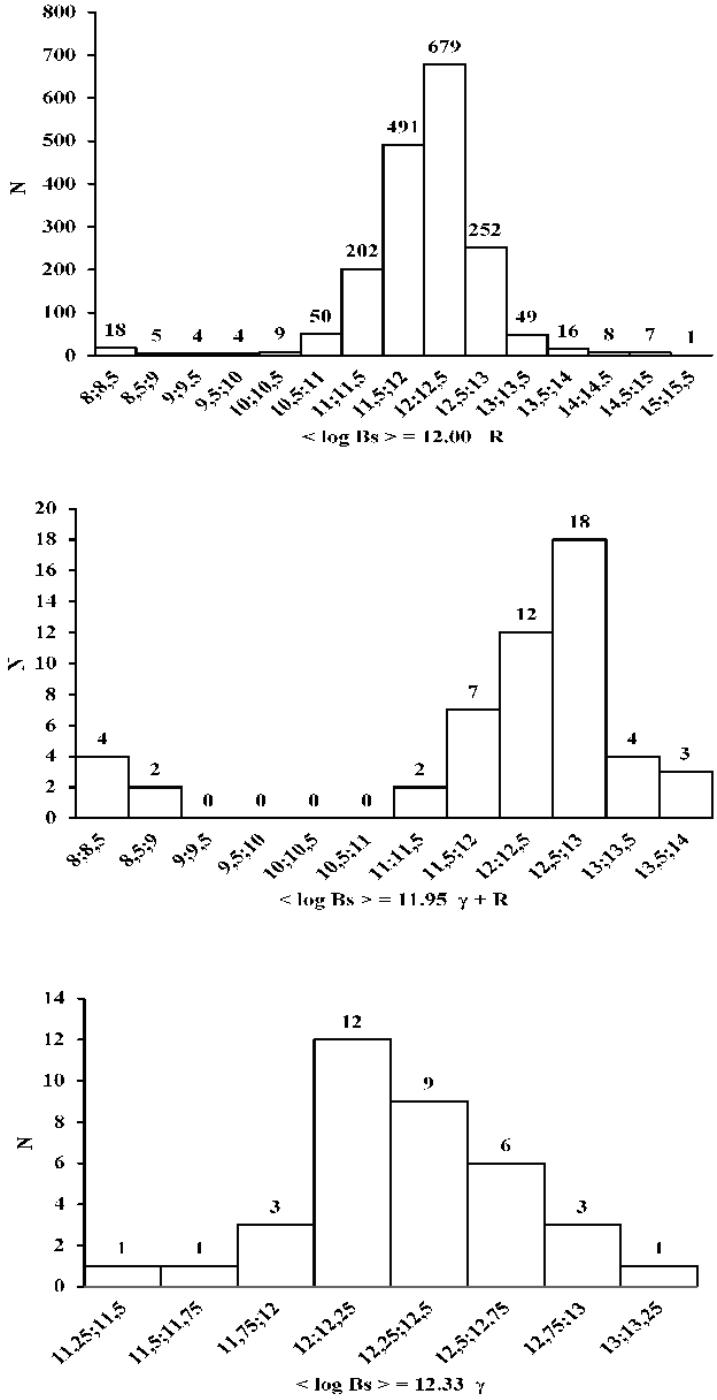


Figure 3 Distributions of magnetic inductions (G) at the surface.

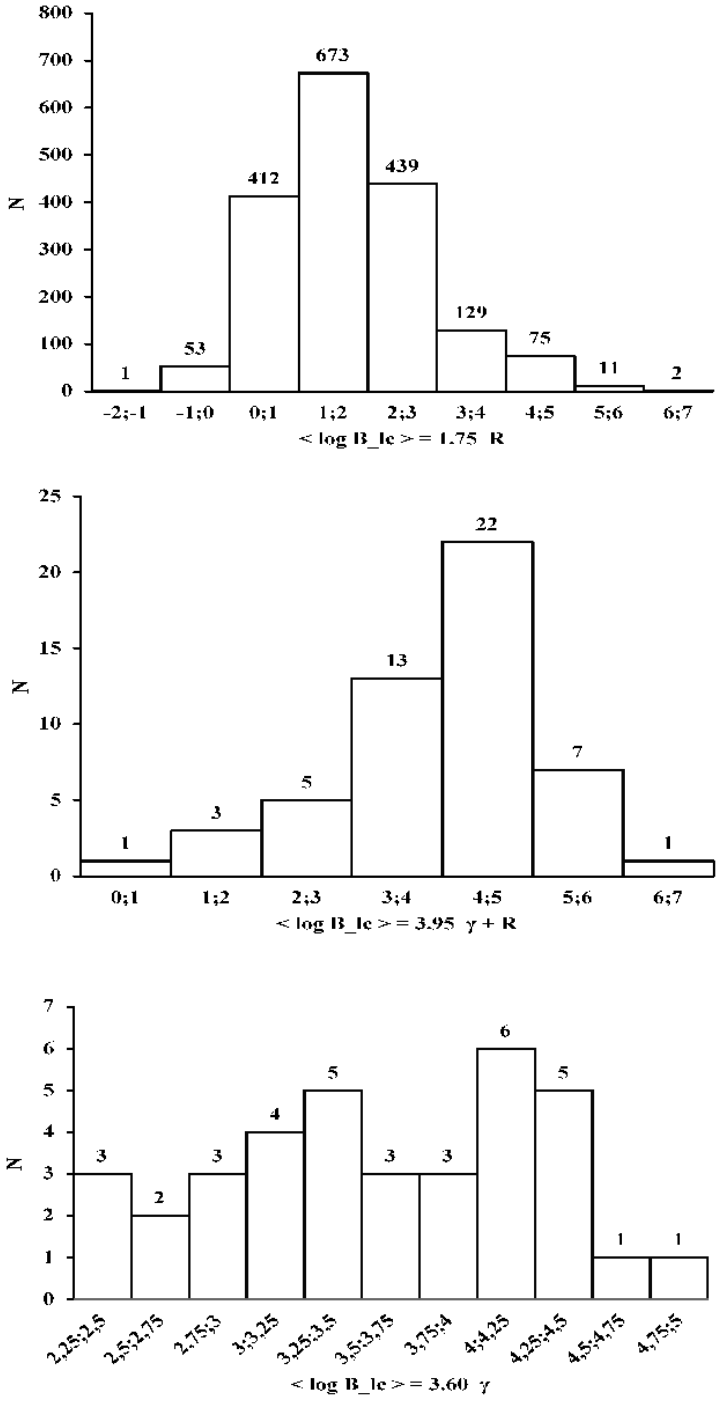


Figure 4 Distributions of magnetic inductions (G) at the light cylinder.

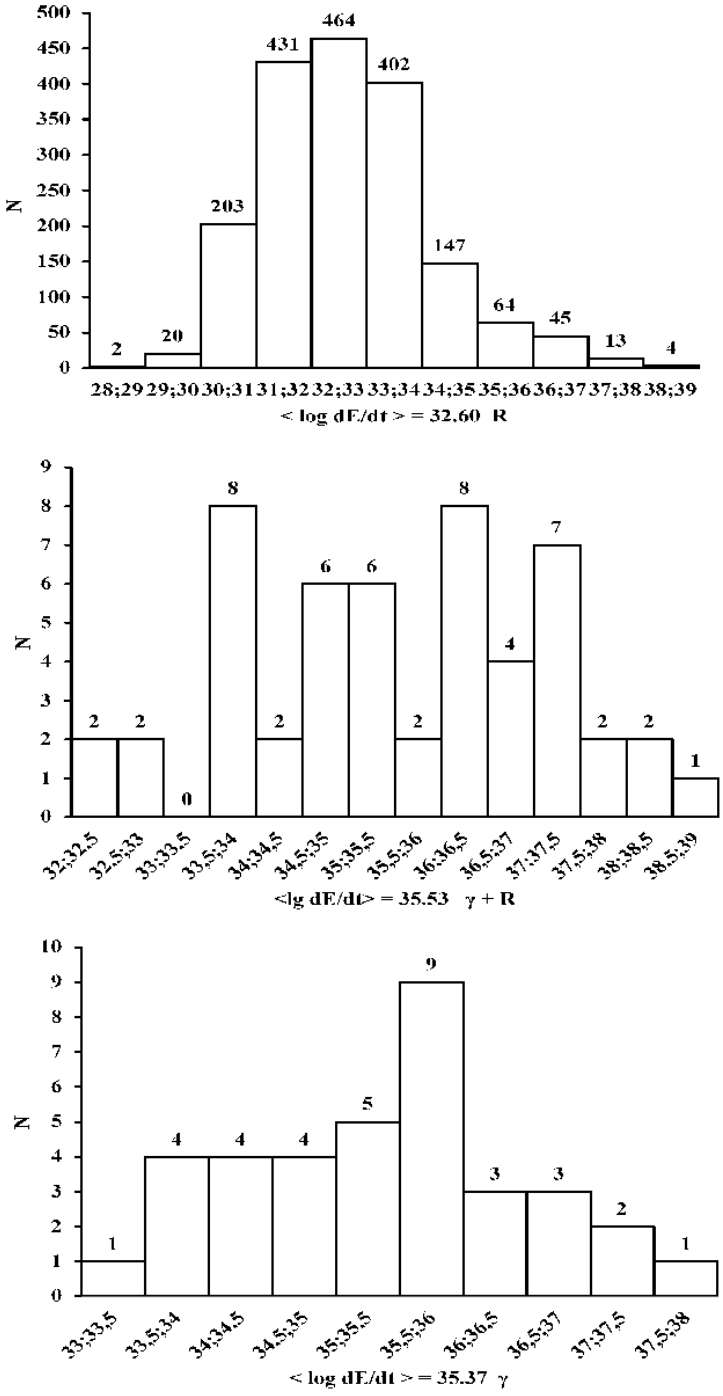


Figure 5 Distributions of rates of rotation energy losses (erg/s).

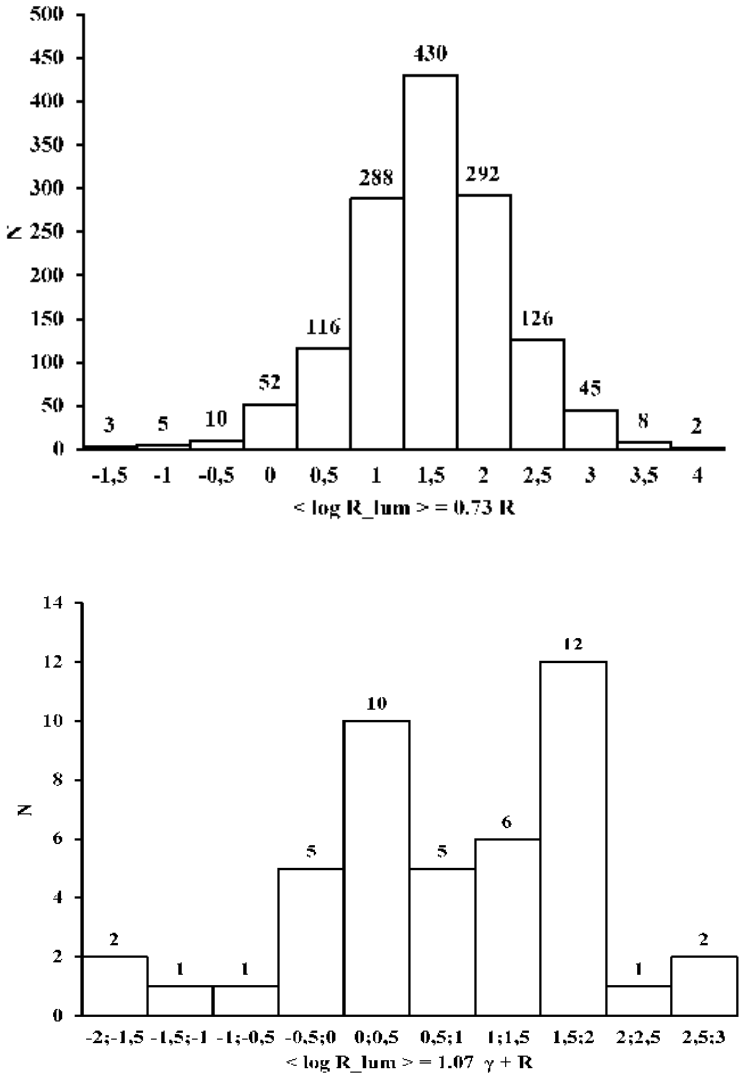


Figure 6 Distributions of radio luminosities at 1400 MHz.

For the dipole magnetic field this condition leads to the equation:

$$9(1+\tan^2\beta)\cos^2 2\theta + 6\cos 2\theta + 1 - 9\tan^2\beta = 0, \tag{5}$$

where β is the angle between the magnetic moment and the rotation axis, θ angle between the magnetic moment and the direction to the given point at the line of force. For $\beta = 45°$, we obtain $\theta_1 = 74°$ and $\theta_2 = 29°$ (Fig. 9).

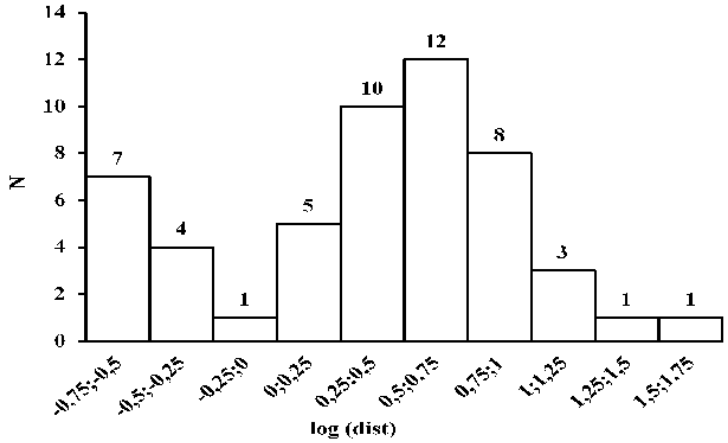


Figure 7 Distribution of distances (kpc) for gamma pulsars.

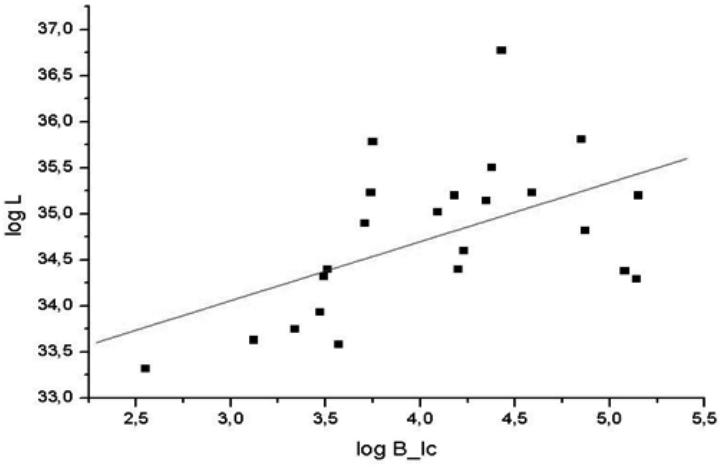


Figure 8 Relationship between gamma luminosities and magnetic inductions at the light cylinder.

3 Conclusions

1. Magnetic fields near the light cylinder for gamma pulsars are two orders of magnitude higher than fields of gamma quiet radio pulsars. Gamma pulsars lose their rotation energy three orders faster on an average than normal radio pulsars. These results give the possibility to predict the existence of gamma rays from objects with high values of B_{lc} and dE/dt.
2. There are two groups of gamma pulsars separated in space. One population is located 0.2–0.6 kpc from the Earth and is probably in the Orion Arm. The other is located at distances of 2–18 kpc from the Sun.

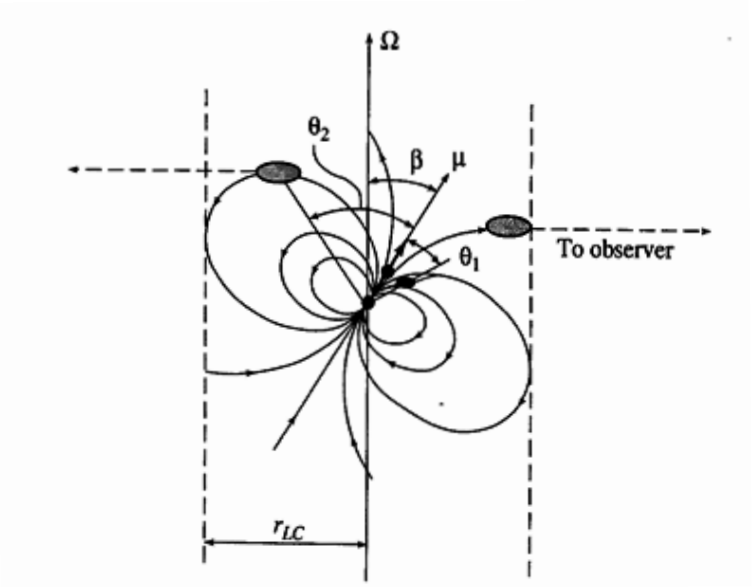


Figure 9 Two emitting regions in outer gap model.

3. The best model for the explanation of known data is the outer gap model with two emitting regions.
4. Generation of gamma emission takes place at the light cylinder and can be caused by the synchrotron mechanism.

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