A NEW LOOK AT THE CLASSIFICATION OF PULSARS

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Abstract

It is shown that pulsars with long periods differ systematically from those with short periods. We conclude that generation of emission in the second group occurs in a very thin layer (near the light cylinder). Relativistic effects may be significant here. Some properties of core emission can be explained by Melrose's mechanism.

1. Most specialists on pulsars now try to describe all observable peculiarities of these objects in the framework of some single model. However, the parameter differences are so large that there have been many attempts to classify them since their discovery. Purely mathematical methods used to search for groups in catalogues also show that the observed population of pulsars is inhomogeneous (Fracassini, Pasinetti, and Rafaelli 1986). The problem of constructing some analogue to the Hertzsprung-Russell diagram in stellar astronomy is very important and demands an extensive review of all the current classification schemes. Here we shall say only a few words about the possible types of pulsars and the mechanisms of their radiation.

2. Observations conducted over more than 20 years show that the characteristics of pulsars with short and long periods differ systematically. Let us remind ourselves of some of these differences.

The profiles of pulsars with short periods are simple in many cases while complex profiles are observed in long-period pulsars. The most detailed classification scheme based on the properties of profiles was worked out by Rankin (1983) who concluded that the observations could not all be described within the framework of a single radiation mechanism.

Malov (1987) pointed out several differences between pulsars with long and short periods.

i) The relationship between equivalent width W and period P has a different form for pulsars with $P \geq 1\,\mathrm{s}$

$$W(\mathrm{ms}) = A_1 P^{1/2}(\mathrm{s}) \tag{1}$$

and for objects with $P \leq 0.3\,\mathrm{s}$

$$W(\mathrm{ms}) = A_2 P(\mathrm{s}) \tag{2}$$

where A_1 and A_2 are constants.

ii) The average magnitude $\overline{\Delta\Psi}$ of the change of polarization position angle through the integrated pulse and its dispersion are larger for pulsars with long periods

$$\overline{\Delta\Psi} = 35^\circ \pm 15^\circ,\ P < 0.7\,\mathrm{s}\ (N = 18),$$

$$\overline{\Delta\Psi} = 90^\circ \pm 50^\circ,\ P \geq 0.7\,\mathrm{s}\ (N = 20)$$

iii) The rms arrival-time residuals are

$$\overline{\sigma_1} = 8.5\,\mathrm{ms},\ P < 0.7\,\mathrm{s}\ (N = 18),$$

$$\overline{\sigma_2} = 1.2\,\mathrm{ms},\ P \geq 0.7\,\mathrm{s}\ (N = 14)$$

iv) There are no interpulses in pulsars with $P \geq$ 1,s. Interpulses are observed only in sources with short periods, and the shorter the period, the higher on average the interpulse intensity.

v) Spectral details (maxima or high-frequency cutoffs) are not detected in pulsars with short periods.

All these peculiarities can be explained if the generation of emission in pulsars with long periods occurs at distances $r \ll r_{\mathrm{LC}} = cP/2\pi$ as in the framework of the traditional hollow-cone model, and emission of short-period pulsars has its origin in the neighborhood of the light cylinder ($r \sim r_{\mathrm{LC}}$) where other mechanisms can play a role.

3. From the absence of frequency-dependent time delays (excluding interstellar dispersion and scattering) in PSR 1937+21 Cordes and Stinebring (1984) came to the conclusion that "all emission from 0.3 to 1.4 GHz arises from the same altitude to within ±2 km" and "emission radii ≈ light cylinder radius."

Non-dependence of subpulse width on frequency and the invariability of the integrated profile through 40 octaves in PSR 0531+21 show that the generation of emission occurs in this pulsar in a rather compact region near the light cylinder (Smith 1977).

The quantity

$$X = (\zeta - \beta)/\theta, \tag{3}$$

where β and ζ are the angles between the rotation axis, the magnetic field and the line of sight, respectively, and θ is the angular radius of emission cone, is independent on frequency for pulsars with short periods (Malov 1991). For a dipolar field

($\zeta - \beta$ = constant) this means that θ does not depend on frequency, *i.e.* emission is generated in a very thin region of the magnetosphere.

Different types of plasma instabilities develop at distances from the neutron star $\sim 10^8$–10^9 cm, that is, near the light cylinder in pulsars with small magnetospheres (*i.e.* short periods) (Usov 1987b, Kazbegi *et al.* 1988).

All these arguments show that the observed radiation in short-period pulsars is emitted within some compact volume in the neighborhood of the light cylinder.

4. Does the curvature-radiation mechanism operate here or is another mechanism at work? Evaluations show (Smith 1977) that the intensity of cyclotron radiation is much higher than that of curvature radiation near the light cylinder. Therefore if the pitch-angles of electrons are not equal to zero, they must emit observable cyclotron (or synchrotron) radiation. The power increases with increasing magnetic field B, and if this mechanism operates we must observe a positive correlation between the luminosity of the pulsar L and the magnetic field in the generation region.

In fact there is a noticeable correlation (the correlation coefficient is 0.66 ± 0.19) between $\log L$ and $\log B_{\rm LC}$ (figure 1) for 18 pulsars with $P < 0.2$ s. We suggest that the structure of the magnetic field is dipolar and its value near the light cylinder is

$$B_{\rm LC} = (R/r_{\rm LC})^3 = (8\pi^3 R^3 B_s/c^3 P^3) \qquad (6)$$

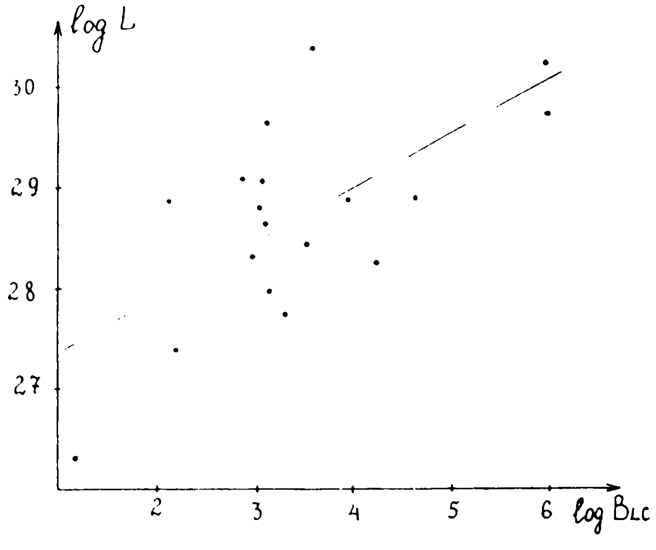

Figure 1 The relationship between $\log L$ (erg/s) and $\log B_{\rm LC}$ (G). The straight line was calculated by the least squares method: $\log L = 26.82 \pm 0.57 + (0.55 \pm 0.26) \log B_{\rm LC}$.

Data for these pulsars were published by Manchester and Taylor (1981), Ashworth *et al.* (1983), Artyuch *et al.* (1984), and Boriakoff *et al.* (1983).

The power of curvature radiation

$$dE/dt = 2e^2 c\gamma^4/3\rho^2 \qquad (7)$$

does not depend on B, and there is no correlation between L and $B_{\rm LC}$ for 87 pulsars with $P > 1$ s (Malov 1985).

In a number of classification schemes authors attach importance to the origin of pulsars (Deng, Huang, and Xia 1987, Vladimirsky 1989). We believe that the conditions of birth do not decide the location or mechanism of emission. In fact, two pulsars with quite different origin and age but both with $P < 0.1$ s (PSR 0531+21 and 1937+21) are surprisingly similar in their observable characteristics.

5. Our scheme can describe $\mathbf{S_d}$, **D** and some $\mathbf{S_t}$ pulsars (by Rankin's classification). As for the core emission in **T**, **M** and other $\mathbf{S_t}$ pulsars, we need a mechanism for accelerating charges along the axis of the cone of open field lines. Melrose (1978) put forward such a mechanism. Variable electric fields cause an acceleration of electrons near the surface of a neutron star, and they emit radiation in the frequency range

$$c\gamma^3/\rho \ll \omega \leq 2\omega_p \gamma^2 \qquad (7)$$

This mechanism can work near the center of the cone only, where ρ is very large and the curvature radiation is extremely weak. The Melrose spectrum is rather steep; in fact, for $\gamma = 10$ (such a Lorentz-factor is optimum for the operation of the mechanism) and $\omega_p = 10^8\,{\rm s}^{-1}$ the limit frequency is 3 GHz. Such a phenomenon is observed in the central components of complex profiles. The large fluctuations of intensity of these components can easily be explained by small variations in n_e and γ. Both the Melrose and curvature radiation mechanisms can function at the same level of the magnetosphere but at different distances from the axis of the cone of open field lines.

6. In conclusion, the generation of emission in pulsars with short periods near the light cylinder demands a detailed study of the physical processes in this region of the magnetosphere. Inequalities $\Omega r/c \ll 1$ and $\varepsilon_p/\varepsilon_B = (8\pi\gamma n m c^2/B^2) \ll 1$, which are used in many models and theories, are inapplicable here. It is quite probable that relativistic effects are important throughout the magnetospheres of pulsars with $P \sim 1$ ms ($r_{\rm LC} < 10R$).