ON NATURE OF THE HIGH FREQUENCY CUTOFF IN PULSAR RADIO SPECTRA

IGOR F. MALOV AND VALERII M. MALOFEEV
Radio Astronomy Department, Lebedev Physical Institute

Abstract

Using values of the frequencies ν_c for the high-frequency cutoffs of 31 pulsars obtained by other authors, we confirmed the relationship (obtained by us earlier) between ν_c and the period of pulsar P. The plot $\nu_c(\chi)$ was drawn where χ is the relative angular distance between the line of sight and the center of the radiation cone. It is shown that pulsars with long periods cluster in the lower left corner of this diagram. Some geometrical and physical reasons causing high-frequency cutoffs are analyzed. The results can be explained by a model of thin plasma sheets. The interaction of these sheets causes generation of Langmuir waves at distances $\sim 10^8$ cm from the center of the neutron star. Pulsars without high-frequency cutoffs can be described by a model in which ν_c is very near the frequency of maximum in the spectra of these pulsars.

One of the main features of average pulsar spectra is the high frequency cutoff. The corresponding frequency ν_c is known now for 31 pulsars (table 1) (Kuz'min *et al.* 1986, Izvekova *et al.* 1990). New data confirm our relationship between ν_c and the pulsar period P (Malov and Malofeev 1981). The modern form of this relationship is

$$\log \nu_c \text{ (GHz)} = 0.4 \pm 0.1 - (0.5 \pm 0.2) \log P \text{ (sec)} \quad (1)$$

The correlation coefficient between $\log \nu_c$ and $\log P$ is equal to (-0.6 ± 0.2). Figure 1 shows the plot $\nu_c(\chi)$. $\chi = (\xi - \beta)/\theta_c$ is the relative distance of the line of sight from the center of the emission cone. This quantity was determined from the system of equations (Malov 1990)

$$\tan\beta = C \sin\xi / (1 + C\cos\xi),$$
$$\cos\theta_c = \cos\beta\cos\xi + D\sin\beta\sin\xi, \quad (2)$$
$$\xi - \beta = \chi\theta_c$$

where we have used the definitions

$$C = (d\psi/d\phi)_{\max},$$
$$D = \cos(W_{10}/2), \quad (3)$$
$$\theta_c = \sqrt{(r/r_{LC})} = \sqrt{(2\pi r/cP)}$$

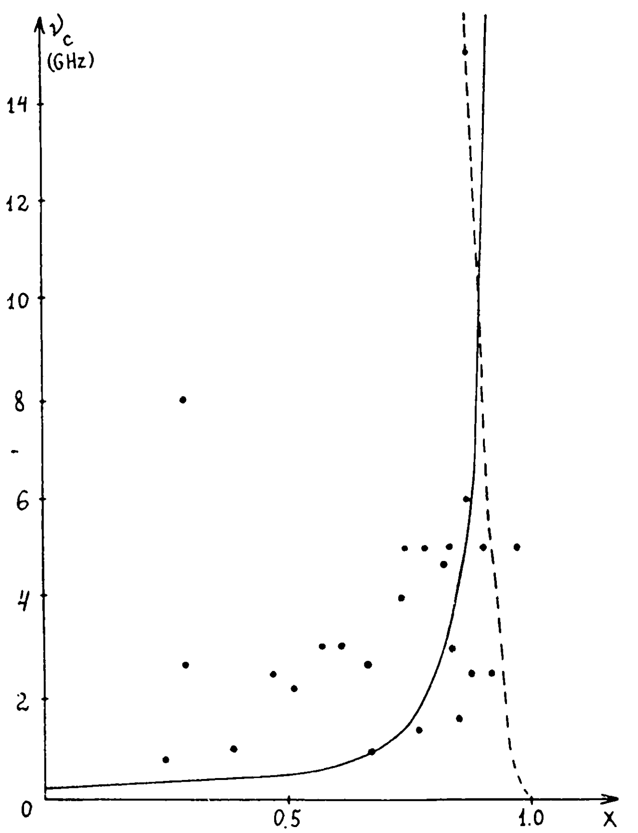

Figure 1

The high-frequency cutoff may be caused by two effects: i) a geometrical effect—the line of sight moves (with higher frequency) out of the emission cone, ii) a physical effect—weak emission of particles or low efficiency of amplification of radiation at $\nu \geq \nu_c$. In the case i) pulsars with two component profiles should have ν_c higher than pulsars with simple profiles, and the profile should become simple for $\nu \geq \nu_c$. However observations show the opposite picture. Two component profiles keep their forms at $\nu \geq \nu_c$. Moreover for such pulsars $\overline{\nu_c} = 2.8$ GHz (23 objects), and for pulsars with simple profiles $\overline{\nu_c} = 5.2$ GHz (8 sources). This effect may operate only in two pulsars: PSR 0540+23 and PSR 1612+07.

Physical reasons may be of two classes: 1) weak emission of individual particles at frequencies higher than ν_c and 2) weak amplification of the radiation.

https://doi.org/10.1017/S0002731600154988 Published online by Cambridge University Press

Table 1

PSR	ν_c (GHz)	χ
0031−07	5	0.86
0320+39	(0.6)	–
0329+54	8	0.29
0355+54	5	0.74
0525+21	(2.7)	0.29
0540+23	6	0.87
0628−28	4	0.73
0809+74	4.7	0.83
0823+26	3	0.61
0834+06	2.5	0.47
0950+08	5	0.78
1133+16	1.4	0.78
1426−66	1	0.68
1508+55	2.7	0.66
1612+07	1.4	–
1857−26	(3)	0.84
1859+03	(2.5)	0.88
1919+21	1.5	–
1929+10	5	0.97
1933+16	5	0.90
1944+17	(1.6)	0.85
1952+29	5	0.83
2016+28	2.5	0.92
2021+51	15	0.87
2045−16	0.8	0.25
2111+46	2.6	–
2154+40	2.2	0.51
2224+65	1.7	–
2310+42	2.5	–
2324+60	(3)	0.57
2327−20	1	0.39

Emission generated in the region of the exponential turnover of the curvature-radiation spectrum may be an example of reason 1) (*cf.* figure 2). If the energy of radiating particles decreases to the edges of the emission cone, we can obtain the dotted line of figure 1 by using known formulæ

$$\nu_{cr} = 3c\gamma^3/4\pi\rho,\ \rho \approx 4r/3\theta \qquad (4)$$

Comparison with the observations shows that this mechanism may explain the right-hand part of the diagram $\nu_c(\chi)$ only.

2) The observed radio emission of pulsars is connected in almost all models of pulsars with plasma instabilities causing inhomogeneities of plasma density and amplification of radiation at frequencies corresponding to fixed levels in the magnetosphere. Any instability is characterized by some increment Γ. Let us suppose that amplification is sufficient if

$$\tau = \int_{r_0}^{r} \Gamma\, dr/c \geq 3 \qquad (5)$$

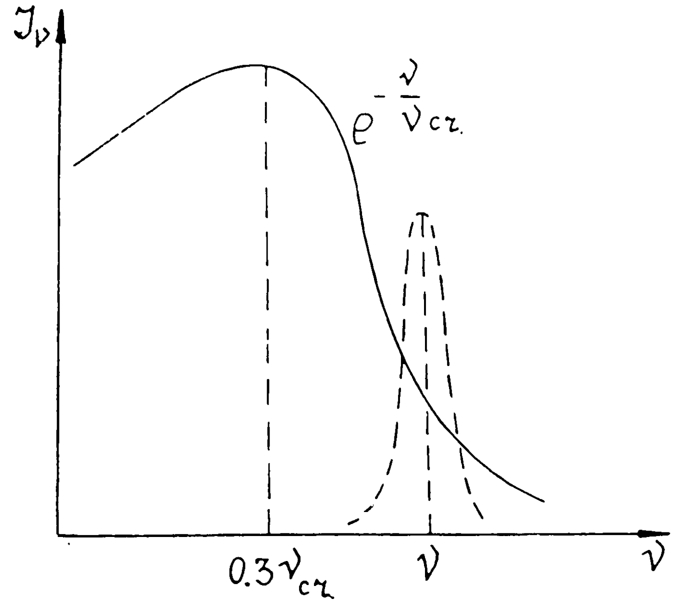

Figure 2

Here r_0 is the initial level of the development of the given plasma instability. The opposite inequality means a sharp decrease of emission intensity, *i.e.*, a high-frequency cutoff.

We shall illustrate this mechanism in the framework of the Usov (1987) model, which deals with plasma sheets moving away from the surface of neutron star. Usov supposed that electrons in a sheet had a Lorentz-factor distribution spreading from γ_{min} to γ_{max}, and the distance between two neighboring sheets was equal to the radius of the neutron star $R = 10^6$ cm. Then particles with $\gamma = \gamma_{max}$ overtaking those from the previous sheet with $\gamma = \gamma_{min}$ (at a distance $R\gamma^2_{min}$) play the role of the beam and induce in the surrounding plasma Langmuir oscillations with the increment

$$\Gamma_L \approx \left(\frac{n_b}{n_p}\right)^{1/3} \left(\frac{\omega_p}{\gamma_b}\right),\ \omega_p = \sqrt{4\pi n_p e^2/\gamma_p m} \qquad (6)$$

If $\gamma = \gamma_{max} = 10^3$, $\gamma_p = \gamma_{min} = 10$, $B = 10^{12}$ G, and $P = 1$ s, then a in the formula

$$n_b = Ba/Pce \qquad (7)$$

is equal to 10^4, and γ_p and γ_b decrease to the edges of the emission cone. The dependence $\nu_c(\chi)$ has the form of the unbroken line in figure 1. This dependence is in good agreement with observational data and corresponds qualitatively to an increase of ν_c with a decrease of P.

Curvature radiation becomes ineffective near the axis of the emission cone. Here Melrose's (1978) mechanism may be significant, giving radiation at frequencies higher than ν_{cr} due to acceleration of charges in a variable electric field. Using formulæ from Melrose's paper

https://doi.org/10.1017/S0002731600154988 Published online by Cambridge University Press

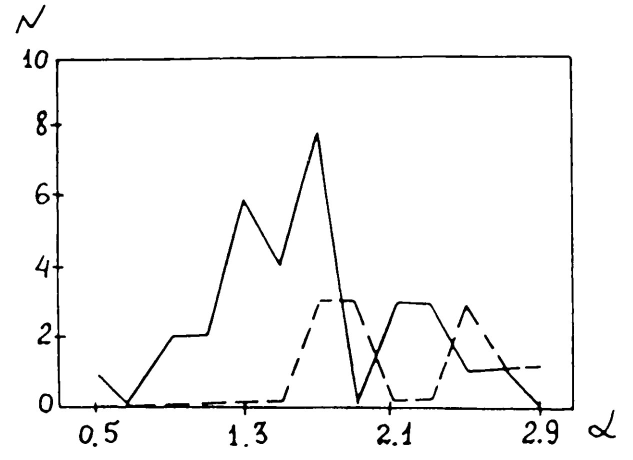

Figure 3

$$\tau \approx 2\omega_p \rho / c\gamma^5, \qquad \omega_c \leq 3\omega_p \gamma^2/2 \tag{8}$$

for $\gamma = 10$ and $P = 1$ s we obtain

$$\nu_c(\text{GHz}) = 1.2\chi \tag{9}$$

This relationship operates for small values of χ ($\chi \leq 0.2$). In this case $\nu_c \leq 200$ MHz, which is very close to the frequency of the maximum in the pulsar spectrum and the linear part of the spectrum is absent. It is very difficult to detect the "high-frequency" cutoff in this spectrum. These pulsars must have steeper spectra at frequencies higher than the frequency of maximum ν_{max}. Probably we observe this effect: Figure 3 shows two histograms of distributions of spectral indices for pulsars with observable cutoffs (solid line) and without those (dotted line).

Several pulsars in the table give "core emission" only (according to the classification of Rankin 1983). For these pulsars the method for determining χ [system (2)] may be wrong, and in fact values of χ may be small for them.

https://doi.org/10.1017/S0002731600154988 Published online by Cambridge University Press