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A model for pulsar nullings

A. Kazbegi[1]**, G. Machabeli**[1]**, G. Melikidze**[1]**, and C. Shukre**[2]

[1] Abastumani Astrophysical Observatory, Al. Kazbegi ave. 2a, Tbilisi, 380060, Republic of Georgia
[2] Raman Research Institute, Bangalore, 560080, India

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Abstract. A model explaining the pulsar nulling and phase memory phenomena is developed in the frame of the plasma model for the pulsar radiation developed by the authors during the last few years. According to this model after fulfilment of the resonant conditions the pulsar radio emission is generated in definite places of the magnetosphere. In addition to waves corresponding to the pulsar radiation, very low-frequency drift waves are also generated in the magnetospheric plasma. These waves propagate transversely to the neutron star magnetic field and encircle the region of the open magnetic field lines. These waves change the curvature radius of field lines and can affect the generation of the radio waves. If the frequency of these waves is about the same as that of the star angular velocity the subpulse drift phenomena can be observed.

The particles extracted from the stellar surface form the primary beam distribution function. The particles with more energy radiate γ-quanta and produce electron-positron pairs. The positron accelerates toward the stellar surface and heats it and broaden the primary particles distribution function. This process continues until the density of the extracted particles exceeds the Goldreich–Julian density. At this time the negative potential appears screening the electric field and closing the gap. Simultaneously the peak of the primary particle distribution function moves towards the low Lorentz-factors and does not have enough energy to start the process of generation of radio emission. As a result the nulling phenomenon can be observed. Broadening of the primary particle distribution function can occur with different velocities, depending on the initial distribution function. If the typical duration of this process τ is larger than the period P of pulsar rotation ($\tau > P$) then nulling is observed. If $\tau < P$ – there is a short scale variation of radio emission.

Decrease of the peak of primary particle distribution function not only stops the radio emission but also slows down the phase velocity of low frequency drift waves. This in turn results in the subpulse drift phase memory.

Key words: instabilities – plasmas – pulsars: general

1. Introduction

It is a well-known fact that pulsars switch off, entering a 'null' state for a duration of one to several hundred periods before they begin to reemit radiowaves. Nullings are irregular and cannot be predicted accurately. For some pulsars the phase of subpulses change in a highly organized manner. This phenomenon is called a subpulse drift. There is a very interesting population of pulsars that possesses both nulling and subpulse drift. Among this population is PSR 0809+74 and is one of the most frequently studied. Unwin et al. (1978) showed that the phase of the last subpulse is "remembered" during the null. The emission restarts at the same place where it stopped. This phenomenon is called a phase memory across the null. Further studies done by Lyne & Ashworth (1983) showed that the subpulses in PSR 0809+74 still drift during nulls but at a very reduced rate. However, the pulsar PSR 1944+17 did not give any evidence for phase memory across nulls (Deich et al. 1986).

The majority of the attempts to explain this phenomenon was done in the frame of the theory of sparks (Ruderman & Sutherland 1975 (RS)). According to RS sparks discharge across the gap in certain places near the stellar surface. They are sources of plasma bunches which produce radiation. Sparks undergo $\mathbf{E_0}\times\mathbf{B_0}$ drift, here B_o is the pulsar magnetic field intensity, $\mathbf{E_0} = (\mathbf{\Omega}\times\mathbf{r})\times\mathbf{B_0}/\mathbf{c}$ is the electric field generated by the rotating, magnetized, conducting neutron star, $\mathbf{\Omega}$ – is the angular velocity, $\mathbf{r}$ – the radius-vector. Therefore information about the spark drift is preserved. Existence of a spark in the gap is connected with arrival of a γ-quantum which converts into an electron-positron pair. The charged particles are accelerated by $E_{o\|}$ in the gap. As they move along the curved magnetic field lines they produce curvature radiation. Energy of the radiation is enough to reproduce electron-positron pairs and thus develope the cascade process. At each step of the cascade process the particles which are accelerated towards the star, drift to the magnetic axis due to curvature of the magnetic field lines. According to RS the drift velocity is given by

$$v_{dr} = \frac{1}{2}\frac{ch}{R_B}, \tag{1}$$

Send offprint requests to: G. Melikidze

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where h – is the gap height, R_B – is the curvature radius. Thus in a very short period of time (130 μs for a typical pulsar with P = 1 s) the spark would diffuse over the whole polar cap. In order to avoid this problem RS suggested that downflow particles heat part of the polar cap below the place of the primary γ-quantum arrival. From the heated places $E_{o\|}$ extracts ions which create a new generation of the pairs. This patch would drift in $\mathbf{E_{o\perp}} \times \mathbf{B_o}$ field. As it was shown by Filipenko and Radhakrishnan (1982) (FR) the subpulse phase memory phenomenon cannot be explained in such a scenario. They suggested a model of plasma columns. It was supposed that the plasma column is formed around the place of a primary γ-quantum arrival. The electric field weakens in an adjacent region. Thus when the plasma leaves the column the electric field in it will be higher than that in the adjacent region. This fact increases the probability of the plasma creation in the same column. However this column undergoes the electric drift in the same manner as in the RS model. Thus, this model cannot avoid difficulties connected with the existence and broadening of the columns.

It is easy to show that a formula for the $\mathbf{E_{o\perp}} \times \mathbf{B_o}$ drift in the cylindrical coordinates is

$$V_{dr} = \Omega\left(\rho\cos\phi - z\sin\phi\right), \qquad (2)$$

here ρ – is the polar coordinate, z-axis is chosen along the magnetic moment $\mathbf{z} \parallel \boldsymbol{\mu}$, ϕ – is the inclination angle between $\boldsymbol{\Omega}$ and $\boldsymbol{\mu}$. At different heights if $\phi = 0$ the angular velocity of all sparks (columns) will be one and the same, but if $\phi \neq 0$ the drift velocity will be different . This difference leads to rapid broadening of sparks (columns). Therefore all attempts to explain subpulse drift and nulling in the frame of the spark model face insoluble difficulties. After analyzing the observational data of PSR 0826-34 Biggs et al. (1985) arrived to the same conclusion. Therefore it would be consistent to renounce the spark theory and explain the subpulse drift phenomena on the basis of plasma mechanisms as presented in Kazbegi et al. (1991) (KMM91). One of the first alternative to sparks idea was suggested in Arons (1981) where he considers a spiral wave slightly modulating the particle density explaining the presence of subpulses and their drift.

Unlike RS idea which considers that the cascade process in the gap is triggered by the background γ-quanta, many authors assume that $E_{o\|}$ field extracts electrons (Sturrock 1971; Tademaru 1973) or ions (Arons 1992 and the references therein) from the stellar surface. Despite the type of a triggering mechanism the process will lead to filling up the whole gap with plasma. To issue from this natural assumption and to use the ideas of FR and KMM91 we will explain the subpulse drift phenomena, nulling and subpulse phase memory across nulls.

2. Subpulse drift

It is assumed that the pulsar magnetosphere is filled with an electron-positron plasma flowing along the open magnetic field lines with the distribution function depicted on Fig.1 which is from Arons (1981). For the typical pulsars ($P \approx$ 1 s) the plasma is composed from the following parts: the bulk of plasma with an average Lorentz-factor $\gamma_p \simeq 3$ and the number density – $n_p \simeq 10^{16}$ cm^{-3} ; a tail on the distribution function with $\gamma_t = 10^4 \div 10^5$ and $n_t = 10^{13} \div 10^{14}$ cm^{-3}; the primary beam – characterized by Goldreich–Julian density $n_b \simeq 10^{11}$ cm^{-3} (Goldreich & Julian 1969) and Lorentz-factor $\gamma_b \simeq 10^6$ (Kazbegi et al. 1989). In such a plasma there exists two types of waves – purely transversal electromagnetic t-wave and electrostatic-electromagnetic lt-wave (Volokitin et al. 1985, Lominadze et al. 1986). Both of them have high and low-frequency branches which merge into a 'vacuum' wave ($\omega = kc$) in the case of large wave vectors $\mathbf{k}$ and frequencies ω. The spectra of the high-frequency waves are in the superluminous region (the phase velocity of waves exceeds the speed of light) and they cannot be excited. The spectra of the low-frequency modes are as follows

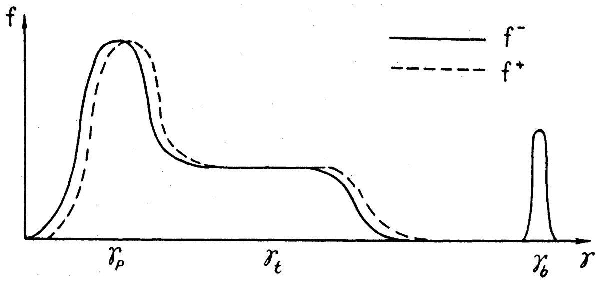

Fig. 1. The final distribution function of particles (f vs γ). The solid line describes electrons, the dashed line — positrons.

$$\omega^t = kc(1 - \delta), \qquad (3)$$

and

$$\omega_o^{lt} = k_\varphi c\left(1 - \delta - \frac{k_\perp^2 c^2}{2k_\varphi^2}\,\frac{1}{8\frac{\omega_p^2}{k_\varphi^2}\gamma_p - 1}\right). \qquad (4)$$

Here and below the cylindrical coordinate system x, r, φ has been chosen, where x-axis is directed transversely to the plane of the curved magnetic field lines, r and φ – are the radial and azimuthal coordinates; k_φ – is the component of the wave vector along the magnetic field, $k_\perp = (k_r^2 + k_x^2)^{1/2}$, $\delta = \omega_p^2/4\omega_B^2\gamma_p^3$, $\omega_p^2 = 4\pi e^2 n/m$, $\omega_B = eB/mc$, e and m – are the charge and the mass of particles, c – is the speed of light; B – is the intensity of the dipolar magnetic field. $B = B_o\left(R_o/R\right)^3$, where $R_o = 10^6$ cm is the pulsar radius and $B_o = 10^{12}$ G – the magnetic field intensity at the stellar surface (note that the particle number density changes according to the same law $n = n_o\left(R_o/R\right)^3$).

There are two main classes of the pulsar radiation mechanisms: antenna and maser. According to the first mechanism radiation is generated by particles or bunches moving along the curved magnetic field lines (see details in Gil and Snakowski 1990a,b). According to this model the generation of radiowaves originates at altitudes below 1% of the light cylinder. Though there is no strong physical evidence for existence of such bunches, this model is commonly used because of its simplicity.

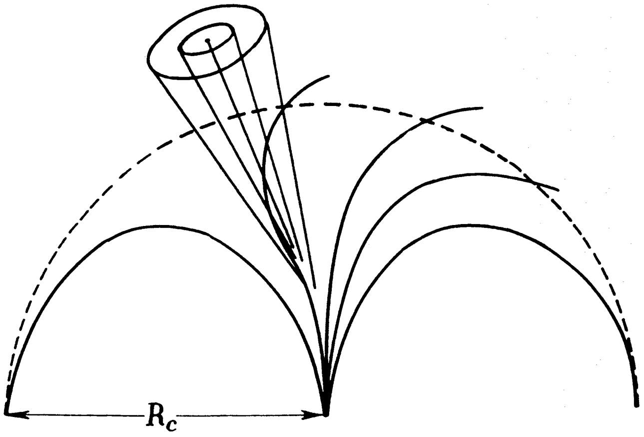

Fig. 2. The pulsar magnetosphere model and the emission cone. 1 – is the 'last' open field line; 2 – closed field line; R_c – is the radius of the light cylinder .

The waves propagating through the whole magnetosphere, should reach the regions of strong damping. This problem is common for almost all the pulsar radiation models. However, in our model the generation takes place near the edge of the opened field lines adjacent to the region of closed field lines at distance 10 - 20 % of the light cylinder from the stellar surface. The mass of particles approaching the light cylinder, increases and all the field lines bend in the direction opposite to a pulsar rotation (so called sweepback). The sweepback allows the radiation to get into a region of reduced density between the open and closed field lines (Fig. 2).

Eq. (3,4) show that at $n \to 0$, $\omega^t \to kc$ and $\omega^{lt} \to kc$, retaining their polarization properties.

The perturbations are excited either at the anomalous Doppler-effect resonance:

$$\omega - k_\varphi v_\varphi - k_x u_x = -\frac{|\omega_B|}{\gamma_{res}}, \tag{5}$$

or at Cherenkov resonance

$$\omega - k_\varphi v_\varphi - k_x u_x = 0, \tag{6}$$

here $u = v_\varphi p_\varphi c/\omega_B R_B$ – the particle drift velocity caused by the magnetic field inhomogeneity and directed along the positive direction of x-axis for the beam particles, R_B – the curvature radius, γ_{res} – the Lorentz-factor of the resonant particles, p_φ normalized φ-component (along the curved field lines) of the particle momentum. Considering that the waves are excited in small angles $\theta \equiv k_\perp/k_\varphi \ll 1$ and $v_\varphi = c\left(1 - 1/2\gamma_{res}^2 - u_x^2/2c^2\right)$ Eqs. (5) and (6) can be rewritten in the form

$$\frac{1}{2}\left(\frac{k_x}{k_\varphi} - \frac{u_x}{c}\right)^2 + \frac{1}{2}\frac{k_r^2}{k_\varphi^2} + \frac{1}{2\gamma_{res}^2} - \delta = -\frac{|\omega_B|}{\gamma_{res} k_\varphi c}, \tag{7}$$

$$\frac{1}{2}\left(\frac{k_x}{k_\varphi} - \frac{u_x}{c}\right)^2 + \frac{1}{2}\frac{k_r^2}{k_\varphi^2} + \frac{1}{2\gamma_{res}^2} - \delta = 0. \tag{8}$$

The condition (7) can be fulfilled for both the particles of the tale of the distribution function with $\gamma_{res} = \gamma_t \simeq 10^5$ and for the beam particles with $\gamma_{res} = \gamma_b \simeq 10^6$. The condition (8) can be fulfilled only at the resonance of the waves with the beam particles (the condition $\partial f_{o\parallel}/\partial p_\parallel > 0$ is necessary, here $f_{o\parallel} = \int f_o p_\perp dp_\perp$ and f_o – is the particle distribution function). For the case $\gamma_{res} = \gamma_p$ none of the resonances (7) and (8) is possible because the term $1/2\gamma_p^2$ is the largest. We believe that the t-waves generated at the anomalous Doppler-effect (resonance 7) explain 'core'-type emission, and the waves generated at the Cherenkov resonance explain the 'cone' radiation (Rankin 1983). Note that the wave generation occurs at the distance of $R \simeq 10^9$ cm (for $P \simeq 1$ s) and the frequencies get into the radio range. The observational data show that the subpulse drift is pronounced in conal single profiles (Rankin 1983; 1986). As the paper deals with the subpulse drift phenomena below we shall focus on the condition (8). The frequency of the excited waves get into the radio range; the generation of waves is possible only at the distances of the order of 10^9 cm; the growth rate is equal to

$$\Gamma = \frac{\pi}{2}\frac{\omega_b^2}{\omega}\gamma_b A \frac{\partial f}{\partial p_\varphi} \tag{9}$$

where $A = k_r^2/k_\perp^2$ for t-waves, and $A = k_x^2/k_\perp^2$ for lt-ones. The condition of the kinetic approximation is given by:

$$\frac{\Gamma}{\omega} < \left(\frac{u}{c}\right)^2 \frac{\gamma_T}{\gamma_b}, \tag{10}$$

here $u = |u_\alpha|$ and γ_T is the thermal spread of the resonant particles.

As it is shown in KMM91 besides the radio waves in the magnetosphere there can be excited the low-frequency purely transversal drift waves. These waves propagate across the magnetic field ($k_x/k_\varphi \gg 1$) with the frequency:

$$\omega = k_x u_x^b + k_\varphi c \tag{11}$$

and their growth rate is

$$\Gamma_* \simeq \sqrt{\frac{3}{2}}\left(\frac{n_b}{n_p}\right)^{\frac{1}{2}} \frac{\gamma_p^{\frac{3}{2}}}{\gamma_b^{\frac{1}{2}}} k_x u_x. \tag{12}$$

The waves take energy from the longitudinal energy of beam particles, but they are excited only if the drift motion exists.

The growth rate of the drift waves Γ_* is rather small. However the waves encircle the region of the open field lines and stay in the resonance region during the period of time which depends on the φ-component of the wave vector. The waves propagating along the magnetic field carry a small fraction of the whole energy which is defined by the ratio $k_\varphi/k_x \ll 1$. The beam particles pass part of their energy to the waves and leave the interaction region. New particles enter this region and the process is repeated. The waves leave the interaction region considerably slower than the particles. Therefore the energy accumulates in waves and its amplitude grows until the nonlinear effects begin to redistribute the energy over the different wavelength. According to KMM91 drift waves excited near the light cylinder propagate towards the star and undergo induced scattering. They reach the distances $R = 10^9$ cm (for $P = 1$ s) where due to the induced scattering the wave energy is pumped to the long-wave region and accumulates in minimum wave numbers $k_x^{min} = 10^{-8}\ \mathrm{cm}^{-1}$. Thus a balance is set between energy input into waves and output along the magnetic field lines.

Hence at the distances $R = 10^9$ cm (for $P = 1$ s) in small angles with respect to the magnetic field the radio waves are excited. At the same time and at the same altitudes the low-frequency drift waves can be generated with the frequency near to the pulsar angular velocity

$$\omega = \Omega + \Delta \tag{13}$$

(here Δ – is the difference between ω and Ω). The electric vector of this purely transversal wave is directed along the magnetic field $\mathbf{B_0}$. The Maxwell equations show that the wave magnetic field $\tilde{B}$ is directed along r-axis and $\tilde{B}_r \gg \tilde{E}_\varphi$ because $\tilde{B}_r = \tilde{E}_\varphi kc/\omega$. $\tilde{B}_r$ changes mainly the magnetic field curvature and at $k_\varphi r \gg 1$ this change is quite substantial (KMM91). The resonance (8) appears to be sensitive to the phase of the drift wave and can be fulfilled only for definite phases. If $\Delta = 0 \rightarrow$ ω exactly coincides with Ω the generation region rotates together with the magnetosphere and the subpulse is at rest. If the wave phase overtakes the magnetosphere rotation an observer detects drift in the direction of pulsar rotation. If the phase lags behind – the drift is in the opposite direction. After the period $P_3 = \Omega/\Delta$ the process repeats.

3. Nulling and phase memory phenomenon

The condition $\mathbf{E_0} \cdot \mathbf{B_0} \neq 0$ providing nonzero $E_{o\|}$ in the pulsar magnetosphere is fulfilled in a limited region called vacuum gap. Above this region $E_{o\|} \propto \exp\left(-r_\|/r_p\right)$ (RS), where r_p – is the transversal dimension of the polar cap and $r_\|$ – is the coordinate along the magnetic field. The particles extracted from the neutron star surface (Sturrock 1971; Tademaru 1973) are accelerated in the field $E_{o\|}$ up to the energies sufficient for the γ-quanta production which in their turn produce electron-positron pairs. Electrons moving along the curved field lines radiate at frequencies

$$\nu = \frac{3}{2\pi}\frac{c}{R_B}\gamma_b^3. \tag{14}$$

In order to produce electron-positron pairs the energy of the γ-quantum should exceed the value (Hardee 1979):

$$\epsilon_\gamma = 10^{10}\left(\frac{10^{12}}{B_o}\right)\left(\frac{r}{10^6}\right)\frac{2\pi}{\Omega}\quad \mathrm{eV}. \tag{15}$$

The corresponding minimum Lorentz-factor of the particles should be

$$\gamma_b^{min} = \left(\frac{2}{3}\frac{\epsilon_\gamma R_B}{\hbar c}\right)^{1/3} \approx 5 \cdot 10^6 \tag{16}$$

The electric field $E_{o\|}$ and the gap height h should be of the order of 10^7 CGSE and $10^3 \div 10^4$ cm. As the Lorentz-factors of particles reach the value $\gamma \geq \gamma_b^{min}$ the secondary particles are rapidly produced and the electric field $E_{o\|}$ is screened. Such a screening of $E_{o\|}$ by plasma can take place before particles propagate through the whole gap. Length of the gap does not exceed the polar cap size r_p (RS).

There is another point of view concerning this problem which is presented in series of papers by Arons and co-workers (Arons & Scharlemann 1979; Arons 1983; Arons 1992). In fact there is no vacuum gap in their model. Instead they suggest a pair formation front (PFF). Above the PFF the bulk of plasma is produced and the electric field is screened. In this model the alteration of the magnetic field curvature is taken into account, that leads to the particle multiplication beyond the gap (PFF). Therefore the gap height in Arons's model is constant. However in both models the energy distribution of the primary particles extracted from the stellar surface is not taken into account.

Let us assume that the energy distribution of extracted primary particles has some definite spread (it is not monoenergetic). Electrons just above the surface are free and have zero binding energy, whereas this energy for electrons of the crust is about $W \simeq 1 \div 3$ KeV (Neuhauser et al. 1987). The electrons are accelerated in the field $E_{o\|}$ up to relativistic energies maintaining their initial spread in energies $0 \leq E \leq W$. Evidently free particles reach Lorentz-factors γ_b^{min} before the pair formation front (inside the gap) and produce pairs. The pairs, that are formed by the tail of the primary particles distribution function (do not mix with the tail on the final distribution function on Fig.1) are influenced by $E_{o\|}$: positrons are accelerated towards the star achieving energies comparable with γ_b^{min}. This energy heats the stellar surface, leading to the electron thermoemission, which broadens the primary particles distribution function (the number of free electrons increases). This leads to larger number of backstreaming positrons. The process repeats and the tail of the primary particles distribution function broadens. However, as the tail grows, more and more particles produce pairs decreasing the field $E_{o\|}$. The peak of the distribution function lags behind and its Lorentz-factor can be much smaller than γ_b^{min}. For the t and lt-wave excitation determining the pulsar radio emission the condition $\partial f_{o\|}/\partial p_\| > 0$ is necessary (see Eq. (9)). From the resonance condition, the condition of kinetic approximation (the resonance width $|\omega - k_\varphi v_\varphi - k_x u_x|$ should be more than the growth rate Γ) and Eq. (9) it can be seen that the wave excitation is very sensitive to the value of γ_b. Therefore the shift of the peak of the beam distribution function implying the decrease of the γ_b by a factor even less than an order can be sufficient for stabilization of the instability, i.e., the wave generation fails and there is nulling. Note that the low-frequency drift waves are excited even with small Lorentz-factors. The condition $\partial f_{o\|}/\partial p_\| > 0$ is necessary for the drift wave excitation as well and these waves are excited on the left slope of the distribution function (corresponding to the beam). Their frequency is proportional to γ_b: $\omega = k_x u_x \equiv k_x \gamma_b c^2/\omega_B R_B$. At the decrease of γ_b ω decreases as well. Hence during the nulls the drift wave continues to propagate across the magnetic field with reduced velocity. If γ_b decreases by an order the frequency decreases by an order. At small nulls (less than $10P$) after emission restarts the subpulse shifts slightly. In the frame of the spark theory the idea that sparks slow down during nulls was first suggested in FR.

Answer to the question how long null lasts depends on the shape of the primary particles distribution function. The Poisson equation for the pulsar magnetosphere can be written as (Goldreich & Julian 1969):

$$\delta\Phi = -4\pi e(n - n_R) \tag{17}$$

where Φ – is the potential $E_{o\|} = -\nabla\Phi$, n_R – is the number density of a fictitious co-rotation charge. Evidently at the growth of the real charge density up to the values of $n > n_R$ the sign in Eq. (17) changes and the electrons will slow down (Arons, 1983).

The situation is similar to triode, when the grid has a negative potential of the same order as that of the fictitious charge. In this case the field is screened at the very surface of the star (the gap closes up). The nonstationar gap was first suggested by Sturrok (1971). The number of the extracted electrons strongly depends on the thermoemission, and consequently on number and energy of the backstreaming positrons. The number of positrons itself depends on the initial spread of the primary particles (beam) distribution function. If the initial distribution function is broad then after several events the gap closes up rapidly (we call an event a proces of an electron extraction, pair creation, a positron backstreaming and the surface heating). If we equate the energy density of positrons that have reached the surface $mc^2 n_+ \gamma_+$ with the energy density of thermoelectrons we will obtain:

$$n_{th} \simeq \gamma_+ n_+ \frac{c^2}{v_{th}^2}. \tag{18}$$

If the initial density of backstreaming positrons is high (the broad beam distribution function) then n_{th} is large enough to screen the field in the gap after several events each lasting 10^{-6} s. Thus in time of the order of 10^{-5} s the gap will be closed up and empted because the particles have initial velocities though they are not accelerated any more. The vacuum gap builds up and the process repeats. Evidently the change of the Lorentz-factors and densities on such time scales will not affect the radio emission and such pulsars will function without nulls. For the pulsars with the narrow initial beam distribution functions (almost monoenergetic) the broadening of the latter will take a long time. It can be seen from Eq. (17) that at $n_+ = 1$ cm^{-3} the density of the thermoelectrons is of the order of γ_+ and even if the whole energy of the accelerated positrons transfers to surface heating the density of thermoelectrons will be $n_{th} = 10^4 \div 10^5$ cm^{-3}. The Goldreich–Julian density is 10^{11} cm^{-3} and for $n > n_R$ we need $10^6 \div 10^7$ events. Remember that each event of surface heating takes time 10^{-6} s needed for positrons to propagate through the gap. Therefore the duration of nulls can be very high depending on the number of events enough for closing up the gap.

If the null duration is shorter than the rotation period then short time scale intensity variations should be observed. If the null duration exceeds the rotation period then the observer will not receive any emission. So we should have the actual null phase.

4. Conclusion

In our model the radio emission is generated at:

- the anomalous Doppler-effect resonance (condition (5)) for the particles of the beam or the tail of the final distribution function;
- the Cherenkov resonance for the beam particles.

The low-frequency wave which propagates across the magnetic field and encircles the magnetosphere, is generated along the radio emission. This low-frequency drift wave with the frequency $\omega \equiv k_x u_x^b = \Omega + \Delta$ changes the curvature of the magnetic field lines in the radio wave generation region. Therefore the subpulse generation region is transported together with the drift wave phase and the subpulse drift is observed.

The waves are generated in the plasma for quite a narrow range of parameters. Therefore the processes leading to the plasma formation in the gap should affect the generation process. During the particle extraction from the surface the primary beam distribution function is formed. The most energetic particles of this distribution give birth to the electron-positron pairs before the PFF. Positrons are accelerated towards the stellar surface. They heat it, cause the thermoemission of electrons and hence broaden the tale of the primary beam distribution function. This process can be repeated several times. Because of this the field $E_{o\|}$ in the gap weakens gradually each time and therefore the energy of the bulk of the beam does not obtain enough energy for the pair creation. The PFF is formed by the tale of the primary beam distribution function. This process continues until the density of the extracted particles exceeds the Goldreich–Julian density. Then negative potential appears screening the electric field and closing up the gap. The gap function is analogous to triode.

When the peak of the beam distribution function shifts towards lower Lorentz-factors the radio emission mechanisms switch off and cause nulling. The emission resumes immediately after the gap closes up.

Depending on the primary beam distribution function the process (which starts from the broadening and finishes with the closihg up of the gap) can proceed with different speed. If this process takes less time than the pulsar period, only a short time scale variability of the emission would be observed. In the opposite case we observe nulling.

The decrease of γ_b causes not only the emission disappearance but also the slowing down of the drift wave phase velocity $v_{ph} \equiv u_x^b = \gamma_b c^2/\omega_B R_B$. Hence during short nulls and at large decrease of γ_b the phase of the drift wave and the place of the pulse in the pulsar window is 'remembered'. The shorter the null the better the place is remembered. At long nulls and slight change of γ_b the phase memory does not take place. Instead of the phase memory there should be drift velocity memory, i.e., after the emission resumes the subpulse should appear near the place where it might have been in the case of no null.

One of the consequences of the theory is connected with the 'core'–type emission. The 'core' emission is generated at the anomalous Doppler-effect resonance (5) by the beam and tail particles. If the waves are excited by the tail particles then the condition $\partial f_{o\parallel}/\partial p_{\parallel} > 0$ is not necessary. Null is connected to the decreasing of the gamma-factor of the beam particles. At the same time existence of the tail is connected with the presence of the beam as well. The resonant particles of the tail can disappear. But it is not necessary. Therefore even if the waves are not excited by the beam particles they can be excited by the tail particles. That means that 'core' single profiles should be less affected by nulls than 'conal' profiles. This conclusion is in a good agreement with observations (Rankin 1986; Biggs 1992). As it follows from Biggs (1992) only 5 pulsars having the core-single profile (St) are found to null and only one of them spends 5% of its time in null as for the others they spend even less than 1%. At the same time approximately all the core-double pulsars are found to null and spend in null more than 10% of the time. We should mention that our consideration is based on the random processes and of course it describes only an average picture. If the 'core'–type emission is excited by the beam particles then the process of the quasilinear diffusion gives rise to growth of the particle transversal momenta. The latter in its turn leads to wave generation at Cherenkov resonance (6) producing 'cone'–type radiation (Kazbegi et al. 1992). Therefore the 'core' generated by beam particles is necessarily accompanied by the 'cone' emission implying that the profile is triple. Conal doubles or more complex profiles are also connected with the beam particles meaning that all profiles except 'core' singles are more or less subject of nulling. The propability of nulling for 'core' single profiles should be less than for other profiles.

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