X-RAY AND GAMMA-RAY RADIATION FROM THE SWITCHED-OFF RADIOPULSARS

A.I. Tsygan
A.F. Ioffe Institute of Physics and Technology,
Leningrad, USSR

It is shown that pulsars that have ceased to generate electron-positron pairs (switched-off radiopulsars) may be the sources of X-ray and γ-ray radiation. The magnetic dipole radiation from these rotating neutron stars is transformed near the "light radius" into hard radiation by the plasma that is created due to ionization of interstellar neutral hydrogen.

A radiopulsar with a period P that obeys

$$P = P_o \simeq \beta \left(\frac{B_o}{10^{12}}\right)^{8/13} (\cos\alpha)^{6/13} \qquad (1)$$

stops producing an avalanche of electron-positron pairs. Here α is the angle between the angular velocity Ω and magnetic field B_o in the avalanche region, and β is a numerical factor ~1. At $\cos\alpha \sim 1$ the period $P_o \sim \beta(B_o/10^{12})^{8/13}$ (Sturrock, 1971; Ruderman and Sutherland, 1975). For an orthogonal rotator ($\Omega \perp \mu$, μ is the magnetic moment of the star) one should put $\alpha \sim (\pi/2 - \sqrt{\Omega a/c})$ in equation (1), i.e., $P_o \sim 0.2\beta^{13/16} (B_o/10^{12})^{1/2}$, where α is the neutron star radius. Let us consider the pulsars with high radio emission factors $\eta = L_r/\dot{E} > 10^{-4}$, L_r is the radioluminosity and $\dot{E}$ the total energy loss rate. A separation of pulsars into two groups, with $\eta > 5 \times 10^{-6}$ and $\eta < 5 \times 10^{-6}$, respectively, was proposed by Vladimirsky (1981). Figure 1 shows the pulsars with $\eta > 10^{-4}$ (dots) and with $\eta < 3 \times 10^{-7}$ (crosses), according to Manchester and Taylor (1977), Smith (1977). We assume that all the pulsars displayed between the lines I and II are passing the switch-off stage and differ only by the angle between Ω and μ. The line I is quite well fitted by equation (1) with $\beta = 2$ at $\cos\alpha \sim 1$ (there should be two "switch-off lines", for $\alpha \to 0$ and $\alpha \to \pi$, which are likely to appear in figure 1). Line II corresponds to switching off pulsars with $\Omega \perp \mu$. It is probable that the avalanche generation has an oscillatory character, i.e., the plasma is being ejected with the bunches. The latter yields the high values of the parameter η.

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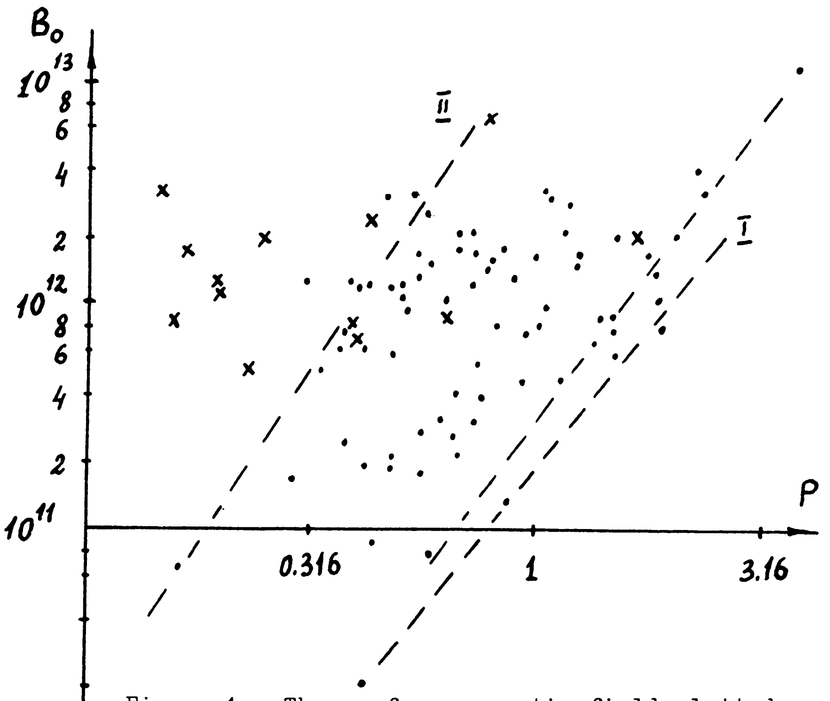

Figure 1. The surface magnetic field plotted against the period of pulsars. Dots correspond to $\eta > 10^{-4}$, crosses to $\eta < 3 \times 10^{-7}$.

Let us consider a radiopulsar in the switch-off stage ($P > P_0$) which ejects no electron-positron plasma. Magnetic dipole radiation from the rotating neutron star pushes away the interstellar plasma at a distance $\sim 10^{15}$-10^{16}cm. Interstellar neutral hydrogen is, however, captured by the neutron star gravitational field, and is then ionized by the star's thermal radiation. For a surface temperature of the star $T_s = (2\text{-}3) \times 10^4$K (the cooling time $\sim 10^6$ years (Glen and Sutherland, 1980)) the radius of photo-ionization of neutral hydrogen is given by $R = 10^8$-10^{10} cm. The cross section of neutral hydrogen capture by the star is $\sigma = \pi R^2(1+2GM/RV_\infty^2)$, $V_\infty \sim 10^7$cm s^{-1} being the star's velocity relative to the neutral hydrogen. The hydrogen number density in the ionized region equals $n(R) = n_\infty V_{ff}(R)/4V_\infty$, where $V_{ff}(R) = \sqrt{2GM/R}$ and n_∞ is the number density of neutral hydrogen. In the quasistatic zone, within the "light radius" sphere ($r_L = c/\Omega$), the electromagnetic field accelerates some fraction of the charged particles towards the neutron star (Tsygan, 1980). They produce two "hot spots" with radii $R_0 = a\sqrt{\Omega a/c}$ at the bottom of the "open" magnetic field lines on the surface of the neutron star. While cooling down to a temperature $T_s < 2 \times 10^4$K, the neutral hydrogen will be ionized in the vicinity of the "light radius" by X-ray radiation from the "hot spots". At $P = 0.5$-1.5s and $n_\infty = 0.1$cm^{-3} the temperature of the "spots" is $T \sim 10^6$K and their luminosity is 2×10^{27}-10^{29} erg s^{-1}.

At the "light radius" the electric field component along the magnetic field equals $E_{\parallel} \sim 0.5 B_o \, (\Omega a/c)^3$, and accelerates electrons along the magnetic field up to a γ-factor given by $\gamma = eE_{\parallel}\Gamma_L/mc^2$ or $\gamma = (3E_{\parallel}\Gamma_L^2/2e)^{1/4}$ if the radiative losses are significant (Ferrari and Trussoni, 1974). For a switched-off pulsar with $\Omega \perp \mu$, $B_o = 10^{12}$G and P = 0.5s (P P_o according to equation (1)) electrons are accelerated up to $\gamma = 2.8 \times 10^7$ and emit quanta (curvature radiation) of energy $\hbar\omega \sim \hbar c\gamma^3/2\Gamma_L = \hbar\Omega\gamma^3/2 = 1.4 \times 10^{-4}$ erg (70 Mev). In this case the γ and X-ray ($\hbar\omega \sim 100$ Kev) luminosities are about $L_\gamma = 2.5 \times 10^{31}$ erg s^{-1} and $L_x = 4 \times 10^{27}$ erg s^{-1}, respectively.

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