On radio emission of anomalous pulsars

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ABSTRACT

We estimated earlier angles between rotation axes and magnetic moments of neutron stars in a number of anomalous X-ray pulsars. It was shown that these angles were small and we could use the drift model to describe such objects. The peculiar feature of their magnetospheres is the larger size comparing with orthogonal rotators. In this case the conditions are fulfilled for generation of transverse waves due to the cyclotron instability. Spectra of generated emission are expected to be very steep (their spectral indices must be $\alpha > 3$). This prediction is in a good agreement with observed values of spectral indices for radio emission of AXPs ($\alpha > 2$). Large magnetospheres give the possibility to form sufficient pitch-angles of relativistic electrons and generate the synchrotron radiation. Maximum of this radiation is in the microwave range. Such a mechanism gives rather high flux densities at frequencies of order of tenths GHz and can explain the observed growth of radiation intensities of AXPs in this range.

MAGNETIC FIELDS OF PULSARS

SGR 0418+5729 B = 6.2 x 10^12 G

SWIFT J1822.3-1606 B ~2 x10^13 G

3XMM J185246.6+003317 B < 4.1x10^13 G

↓

Magnetic field with B > Bcr = 4.43 x 10^13 G is not necessary condition for AXPs and SGRs

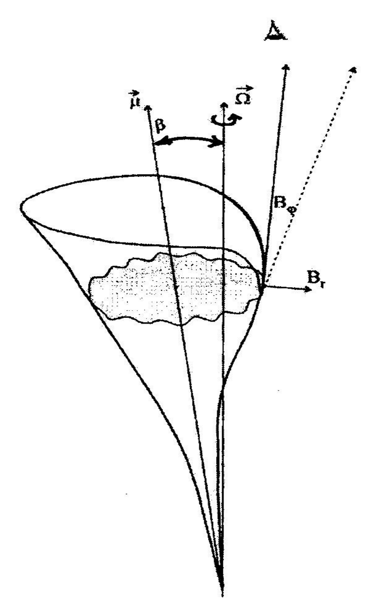
There are about 20 radio pulsars with B > Bcr

↓

Magnetic field with B > Bcr is not sufficient condition for AXPs and SGRs.

We must suppose magnetic fields in AXPs and SGRs two orders higher than dipolar ones or use alternative models, for example, accretion or drift model. Here we discuss the last one

Drift model



μ – magnetic moment,
Ω – rotation axis

Radio emission has been observed in 5 AXPs :
1E 2259+586 [1], XTE J1810-197 [2], 1E 1547-5408 [3], 4U 0142+61[4] and PSR J1622-4950 [5].

1E2259+586	spectral index	$\alpha > 2.5$
AXP 4U0142+61		$\alpha > 2.7$
AXP XTE J1810-197		$\alpha = 2.2$

AXP 1622-4950

$$\beta = 15.6 \text{ deg}$$

In the drift model

$P_{rot} = 0.32$ sec, $\log B_s = 12.53$

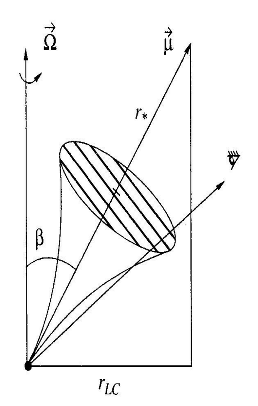


Fig.1. Model of the magnetosphere considered.

$$r_* = \frac{r_{LC}}{\sin\beta},$$

where

$$r_{LC} = \frac{cP}{2\pi}$$

the radius of the light cylinder

$$\delta = \frac{1}{4}\,\frac{\omega_p^2}{\gamma_p^3\,\omega_B^2}$$

$$\delta > \frac{1}{2} + \frac{1}{\gamma_r^2}\left(\frac{k_x}{2} - \frac{u_x}{k_\varphi c}\right)^2 + \frac{k_r^2}{2k_\varphi^2}$$

$$\omega = \frac{4\gamma_p^3\,\omega_B^2}{\gamma_r\,\omega_p^2}$$

$$r/R_* = \left(\frac{e^2 B_s^2 P \gamma_p^4}{2\pi^2 m^2 c^2 \gamma_b^2 \nu}\right)^{1/6} = 1.42\; 10^3 \left(P B_{12}^2/\nu_8\right)^{1/6}$$

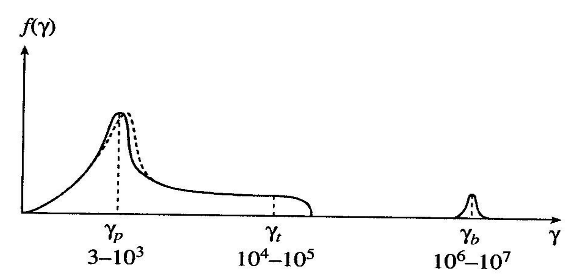


Fig.2. Distribution function of electrons and positrons (dash line) in pulsar magnetospheres

$$r/R_* = 1.76\; 10^3/\nu_8^{1/6}$$

$$\Gamma = \frac{\pi\,\omega_{pres}^2}{\omega\,\gamma_T}$$

$$\Gamma_{ct} = \frac{2\pi e B_s \gamma_b (R^*/r)^3}{m c P \nu \gamma_T \gamma_t}$$

For $\gamma_b = 10^7$, $\gamma_t = 10^5$, $\gamma_T = 100$

$$\Gamma_{ct} = 1.17\; 10^{13}\,(R^*/r)^3\,\nu_8^{-1}$$

$$\tau_{ct} = \int \Gamma_{ct}\, dr/c$$

$$\tau_{ct} = 1.17\; 10^{13}\,\nu_8^{-1} \int dx/x^3,$$

where $x = r/R^*$

For AXP 1622-4950, if $R^* = 10^6$ cm, $r_{LC} = 1.53\; 10^9$ cm.

Supposing that radiation is generated between

$x_1 = 1.76\; 10^3$ and $x_2 = 3\, r_{LC} = 4.59\; 10^3$, we obtain

$$\tau_{ct} = 13.5\,\nu_8^{-1}$$

This means that the radiation at lower frequencies is generated higher in the magnetosphere. If the number density of the radiating electrons decreases as $n \propto r^{-3}$ as in a dipole field, and the intensity increases proportional to the wave amplitude, then we obtain a ratio for the intensities at 100 MHz and 1 GHz of the order of 10^4, which corresponds to a spectral index $\alpha = 3.8$. The spectra of the three AXPs considered above are indeed very steep ($\alpha > 2.2$). These sources were successfully detected at 100 MHz, but were not seen at frequencies of the order of 1 GHz.

Synchrotron radiation

Pitch angles of radiating particles are equal to [6]:

$$\Psi_0 = \left(\frac{3\pi^3 m^5 c^7 \gamma_b^3}{4 e^6 B_s^4 P^3 \gamma_p^4 \gamma_r^2}\right)^{1/4} (r/R^*)^3$$

Using values of the parameters and fundamental constants we obtain:

$$\Psi_0 = 3{,}73\; 10^{-12}\,(r/R_*)^3$$

We have used $\gamma_p = 8.5$ for the secondary plasma, $\gamma_r = 5\; 10^4$ for resonanse particles, $\gamma_b = 10^7$ for the primary beam.

For $x_1 = 1.76\; 10^3$ and $x_2 = 4.59\; 10^3$

$$\Psi_0 = 0.025 - 0.446 \text{ rad.}$$

$$\nu_{max} = \frac{0{,}87\,\omega_B\,\gamma^2 \sin\Psi_0}{4\pi}$$

frequency of the maximum in the synchrotron spectrum.

For PSR J1622-4950

$$\nu_{max} = 4.14\; 10^{18}\,(R^*/r)^3\,\gamma^2 \sin\Psi_0$$

For used parameters

$$\nu_{max} = (1.52 - 1.85)10^7\,\gamma^2 \text{ Hz}$$

There are electrons with different values of γ (Fig.2). For $\gamma = 100$ maximum in the synchrotron spectrum corresponds to frequency $\nu_{max} \sim 150 - 200$ GHz . If the distribution of emitting electrons is monoenergetic intensity of radiation depends on frequency as $\nu^{1/3}$.

So, it can be expected that flux density at frequencies of order of dozens GHz increases with increasing of frequency (Fig.3).

Indeed XTE J1810-197 shows increasing of flux densities near 10 GHz (Fig.4) [7], and in 1E 1547-5408 the similar increasing is observed at frequensies higher than 20 GHz [8].

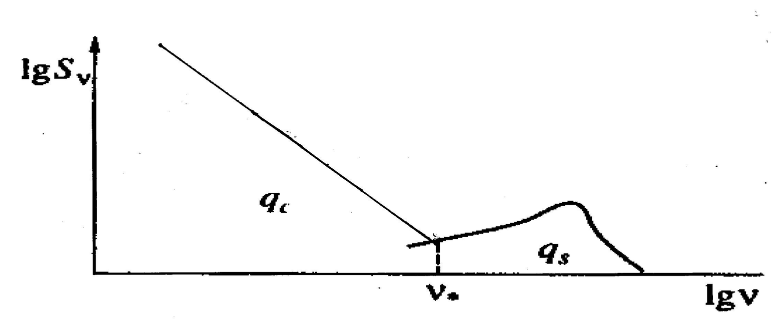


Fig.3.Expected spectrum of AXP. Here q_c is the power of waves generated due to cyclotron instability, q_s is the power of synchrotron emission.

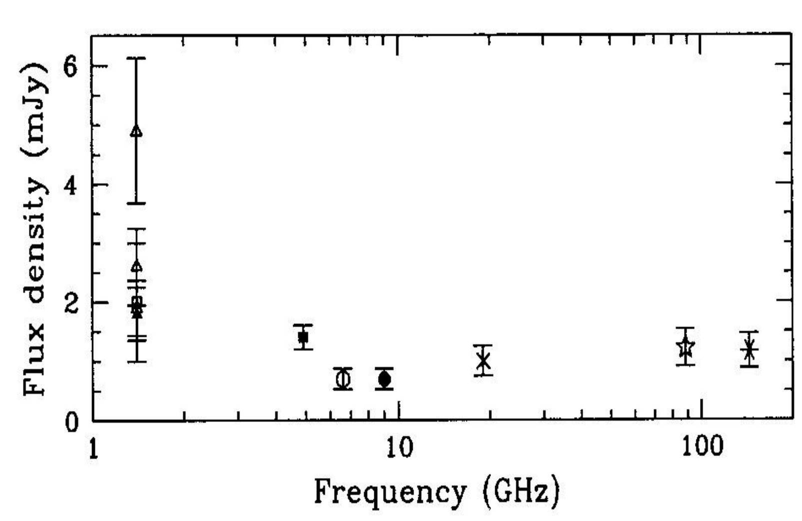


Fig..4. PSR 1810-157

CONCLUSIONS

1.Polarization parameters of known AXPs show that these objects are nearly aligned rotators and we can describe them by the drift model.

2. Radii of magnetospheres in such sourses are 1 / Sin β times larger than in orthogonal rotators.

3. In these sourses conditions are realized for generation of transverse waves due to the cyclotron instability. The expected spectrum of such waves must be very steep (its spectral index $\alpha > 3$). This mechanism can explain the observed radio spectra of known AXPs ($\alpha > 2$).

4. Sufficient pitch angles has appeared in relativistic electrons at large distancies in aligned magnetospheres. This leads to generation of synchrotron emission with the maximum in the microwave range. Such mechanism can explain the observed increasing of flux densities in AXPs at high frequencies.

REFERENCES

1.V.M.Malofeev, O.I.Malov, D.A.Teplykh et al. Astron. Rep., V.49, P. 242 (2005).

2. J.P.Halpern, E.V.Gotthelf, R.H.Becker et al. Astrophys. J., V.632, P.L29 (2005).

3. F.Camilo, S.M.Ransom, J.P.Halpern, J.Reynolds. Astrophys. J., V.666, P.l93 (2007).

4. V.M.Malofeev, D.A.Teplykh, O.I.Malov. Astron. Rep., V.54, P. 995 (2010).

5. L.Levin, M.Bales, S. Bates et al. Astrophys. J. (Letters), V.721, P.L33 (2010).

6. I.F.Malov, G.Z.Machabeli. Astron. Rep., V.46, P. 684 (2002).

7. F.Camilo, S.M.Ransom, J.Penalver et al. Astrophys. J., V.669, P.561 (2007).

8. F.Camilo, J. Reynolds, S. Johnston et al. Astrophys. J., V. 679, P. 681 (2008).