TOWARDS THE ORIGIN OF RADIO PULSATIONS FROM RED DWARFS

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Several nearby flare stars observed with radio spectrometers on large telescopes (Arecibo, Effelsberg, VLA) reveal broad-band, quasi-periodical pulsations (Güdel et al,1989; Bastian et al,1990; Abada-Simon et al,1995). The most prominent pulsating events were observed from AD Leonis, a very active single dwarf M star (Gliese 388, dM3.5e, $R = 3 \times 10^{10}$ cm, $d = 4.85pc = 1.55 \times 10^{19}$ cm). The main characteristics of radio pulsations from a typical M dwarf star AD Leo are as follows:

(1) They are quasi-periodic with the period τ from less then one second to several seconds and with Q-factor $\approx 5 - 50$.

(2) Pulsations observed usually near the central frequencies 1.4 and 5.0 GHz are quite broad-band, $\Delta\nu/\nu \geq 10\%$.

(3) Circular polarization of the pulsations is high, up to $\approx 100\%$.

(4) Pulsations have high brightness temperature $T_{\rm b} \approx 10^{10}$–$10^{14}$ K which means that mechanism of radio emission should be a non-thermal coherent.

Some of radio pulsation events from dMe stars reveal no frequency drift (like pulsations in solar type IV bursts) while others have the frequency drift similar to the some extent to the drift in the type III solar radio bursts (Güdel et al, 1989). For the first type of pulsations the following mechanisms have been discussed:

(1) MHD-oscillations of a source, a magnetic flux tube (Gary et al,1982; Bastian et al,1990).

(2) Electric current oscillations in a flare loop - an equivalent LRC-circuit (Zaitsev et al, 1998).

(3) Nonlinear pulsating regimes of Electron Cyclotron Maser (ECM) and plasma radiation (Güdel et al,1989).

Stellar radio pulsations with the frequency drift can be interpreted in terms of the modulation of the electron acceleration and or injection (Gary et al,1982; Bastian et al, 1990). We have shown that the modulation mechanism is the most probably origin for stellar radio pulsations without frequency drift. Moreover, the same MHD-oscillations of a magnetic flux tube can be responsible for the modulation of particle acceleration process.

Mechanism of pulsations

We assume that non-thermal radio continuum from a red dwarf is due to the coherent (ECM or plasma) radiation of trapped electrons in stellar coronal loops. Quasi-periodic modulation of a continuum arises due to a loop magnetic field variations. Supposing radial oscillations of a loop with the period $\tau \sim r_{\rm loop}/V_{\rm A}$, we obtain for the loop radius $r_{\rm loop} \sim 10^8 - 10^9$ cm and for the ratio of electron cyclotron to electron plasma frequency $\omega_{\rm c}/\omega_{\rm p} = 0.5$ quite reasonable values for pulsation time scale $\tau \sim 0.3 - 3$ s. Here $V_A \approx 7 \times 10^8\, \omega_{\rm c}/\omega_{\rm p}$ cm s^{-1} is Alfvén velocity. A driver for loop radial pulsations can be either the fast($t < \tau$) energy release in a loop or bounce-instability of energetic particles in a loop. The bounce-instability threshold for > 10 MeV protons in a coronal loop is $\beta_{\rm p} = 4\pi n_{\rm p} M v^2/B^2 \geq 0.1$.

Pulsations can arise due to the electric current oscillations in a loop as equivalent LRC-circuit (Zaitsev et al,1998). The period of eigen-mode oscillations is $\tau_{\rm LC} = (2\pi/c)(LC)^{1/2}$. The total inductance of a slender loop can be estimated as ten loop length $L \approx 10\mathcal{L}$. The capacitance depends on the current I flowing through the cross section of a loop $C(I) \approx c^4 n M S^2/(2\pi \mathcal{L} I^2)$. Supposing cross-section area $S = 10^{18}$ cm^2 we obtain $\tau_{\rm LC} \approx 3 \times 10^{13}/I$. Taking, $\tau_{\rm LC} = \tau_{\rm pulse} \approx 2$ s, we find the value of the electric current $I \approx 1.5 \times 10^{13}$ A and thus the magnetic field in the loop: $B \approx 5$ kG. This magnetic field value exceeds or the order the photospheric field, which is highly improbable for the 1.4-5.0 GHz stellar source.

As for nonlinear mechanism (3), the maximum value of the pulsation period can be estimated as $\tau_{\rm nl} \approx 2\pi/\nu_{ei} \sim 10^{-2}$ s, where ν_{ei} is the electron-ion collisional frequency, which is too small in comparison to the observed period.

Conclusion

Hence, only a modulation of the radio source by radial MHD oscillations appear to be consistent with the observed period of the radio pulsations. It should be noted that MHD oscillations of a loop can lead also to a quasi-periodical regime of electron acceleration or electron injection into the loop. As the effective electron acceleration mechanism in coronal magnetic loops on the red dwarfs we consider acceleration in sub-Dricer ($E_D/E_{||} \sim 25 - 30$) quasi-stationary electric fields. This electric field generates due to the convective motions of photospheric plasma and gives the acceleration rate $\sim 10^{35} - 10^{36}$ el/s which is enough to supply the observed radio emission level. High polarization degree of pulsations are explained in terms of ECM (the x-mode) , if the ratio of electron cyclotron to electron plasma frequency $\omega_{\rm c}/\omega_{\rm p} > 1$ or plasma radiation at the fundamental for $\omega_{\rm c}/\omega_{\rm p} < 1$ (the o-mode). This research was partially supported by "Astronomy" program.

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