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On the origin and parameters of the pulsar-like white dwarf in AE Aquarii

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Abstract. The rapid braking on the white dwarf in the close binary AE Aqr can be explained in terms of the canonical pulsar mechanism provided the magnetic moment of the star $\mu \sim 1.5 \times 10^{34}\,\mathrm{G\,cm^3}$. The scenario for the origin of the fast rotating ($P_s = 33\,\mathrm{s}$), magnetized white dwarf, which is based on the magnetic field amplification in differentially rotating stars, is presented.

1. Introduction

The close binary system AE Aqr contains one of the most rapidly spinning magnetic white dwarfs: $P_s = 33\,\mathrm{s}$. The mean spindown rate of the white dwarf is $\dot{P} = 5.64 \times 10^{-14}\,\mathrm{s\,s^{-1}}$, which implies a spindown power $L_{sd} \sim 10^{34}\,\mathrm{erg\,s^{-1}}$ to be in excess of the UV and X-ray luminosities of AE Aqr by a factor of 100 and even the bolometrical luminosity of the system. The average surface temperature of the white dwarf is $T_{int} \sim (10000 \div 16000)\,\mathrm{K}$, while the temperature in the magnetic pole regions is $T_{max} \simeq 26000\,\mathrm{K}$. The X-ray spectrum of AE Aqr is soft and due to some properties (e.g. the power law with $\alpha \approx -2$ and $L_x/L_{sd} \sim 10^{-3}$) it is rather similar to the X-rays detected in the ROSAT energy range from canonical radio pulsars. Finally, the detection of the optical circularly polarized radiation from AE Aqr with the average value of $0.06 \pm 0.01\%$ implies the magnetic field in excess of $10^6\,\mathrm{G}$. These properties argue against models that consider the white dwarf in AE Aqr as an accretion powered source (see Ikhsanov 1998, and references therein).

2. Pulsar versus Propeller

There are two possible explanations for the rapid spindown of the white dwarf: (i) the strong interaction between the fast rotating magnetosphere of the white dwarf and the matter inflowing from the normal component (the 'magnetic propeller' model), or/and (ii) the pulsar-like spindown due to the magneto-dipole waves generation and particle acceleration.

If the spindown power of the white dwarf is converted *predominantly* to the kinetic energy of the outflowing non-relativistic matter, the rate of mass exchange in AE Aqr should be $\dot{M}_{in} \gtrsim \dot{M}_{out} = L_{sd}/V_{out}^2 \simeq 7 \times 10^{18}\,\mathrm{g\,s^{-1}}$ that is much higher than the mass-exchange rate evaluated from various observations.

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Within the *pulsar-like spindown* approach the magnetic moment of the white dwarf can be estimated as follows:

$$\mu \simeq 2 \times 10^{34} \sin^{-1}\beta \, L_{34}^{1/2} \, P^2 \text{ G cm}^3,$$

where L_{34} is the spindown power expressed in units of 10^{34} erg s^{-1} and P is expressed in units of 33 s. The observed stream-fed mass-exchange picture is realized if the mass-exchange rate between the system components is $\dot{M} \sim (0.5 \div 5) \times 10^{17}$ g s^{-1}. The average velocity of matter outflowing from the system is

$$V_{\rm out} \simeq 5 \times 10^7 \text{ cm s}^{-1} \varepsilon_{0.37}^{-1/2} \, \dot{M}_{16.5}^{1/7} \, \mu_{34.2}^{-2/7} \, M_{0.8} \, ,$$

and the efficiency of the propeller action of the white dwarf: $L_{\rm st}/L_{\rm sd} \sim 10^{-2}$ (see for discussion Ikhsanov 1998).

3. Possible history of AE Aqr

In the frame of the pulsar-like approach the magnetic field of the white dwarf is strong enough to prevent accretion with the rate $\lesssim 10^{-4.3} M_{\odot}$ yr^{-1} onto its surface, so the traditional accretion-driven spin up mechanism cannot be applied to this system without additional assumptions. This problem can be avoided within a scenario in which AE Aqr in a previous epoch was almost an ordinary member of DQ Her subclass of Cataclysmic Variables (CVs), i.e. a binary system in which the normal companion transfers material to the moderately magnetized white dwarf via a Keplerian accretion disk. The magnetic field strength of the white dwarf in a previous epoch was about of 10^4 G. The white dwarf slowly spun up by accretion and became unstable to the gravitational wave mechanism as its period decreased below the critical value $P_{\rm cr} \sim 20$ s. During this period the rotation of the white dwarf was essentially differential causing the winding-up of the magnetic field up to $B_{\phi} \sim$ a few $\times\, 10^8$ G. The field has been amplified on a time scale of a month and floated up from the white dwarf interior due to bouyancy instability. As a result, the surface dipole magnetic field of the white dwarf increased up to ~ 50 MG, i.e its present value. The later spindown of the white dwarf (presently observed) can be explained in terms of the canonical pulsar mechanism, and mass transfer between the components operates according to the propeller mechanism with the efficiency $\sim 10^{-2}$ (see for a detailed discussion Ikhsanov 1999).

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