On the origin of pulsar-like White Dwarfs

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1 Summary

A problem posed by the existence of a strongly magnetized white dwarf rotating with the period of 33 s is discussed. The white dwarf is the degenerate component of the peculiar cataclysmic variable AE Aquarii. It is a low-mass close binary system which appears as an panchromatic flaring source. It is widely adopted that the rotation rate of the white dwarf was significantly increased in a previous epoch by accretion of material from a Keplerian disk. We show that the star in this situation could not reach the spin period of 33 s unless its magnetic field was temporally screened by the accreting material. Our scenario suggests that the mass of the white dwarf is close to $1.1\,M_{\odot}$ (Ikhsanov and Beskrovnaya 2012).

2 Peculiar properties of AE Aqr

- Regular pulsations observed in the optical, UV and X-rays suggest that the spin period of the white dwarf is $P_{\rm s} \simeq 33\,{\rm s}$.
- The white dwarf is steadily spinning down at a rate $\dot{P}_0 = (5.64 \pm 0.02) \times 10^{-14}\,{\rm s\,s^{-1}}$. The spin-down power dominates the energy budget of the system $(L_{\rm sd} \gg L_{\rm bol})$ that is typical for ejecting pulsars.
- Analyzing the observed Doppler $\rm H_{\alpha}$ tomogram it was concluded about an absence of an accretion disk in the system.
- The flaring activity of the system: on the timescale from a few minutes to an hour the luminosity of the object in the UV can change by an order of magnitude (see Fig.1). It is due to the interaction between the matter captured by the white dwarf and its rapidly spinning magnetosphere.
- Magnetic field of the white dwarf: all available indirect methods lead to the estimate of its dipole magnetic moment $\mu \simeq (1-2) \times 10^{34}\,{\rm G\,cm^3}$ (Ikhsanov 1998).
- Thus, the primary in AE Aqr is the ***very fast rotating magnetized white dwarf in the ejector state***.

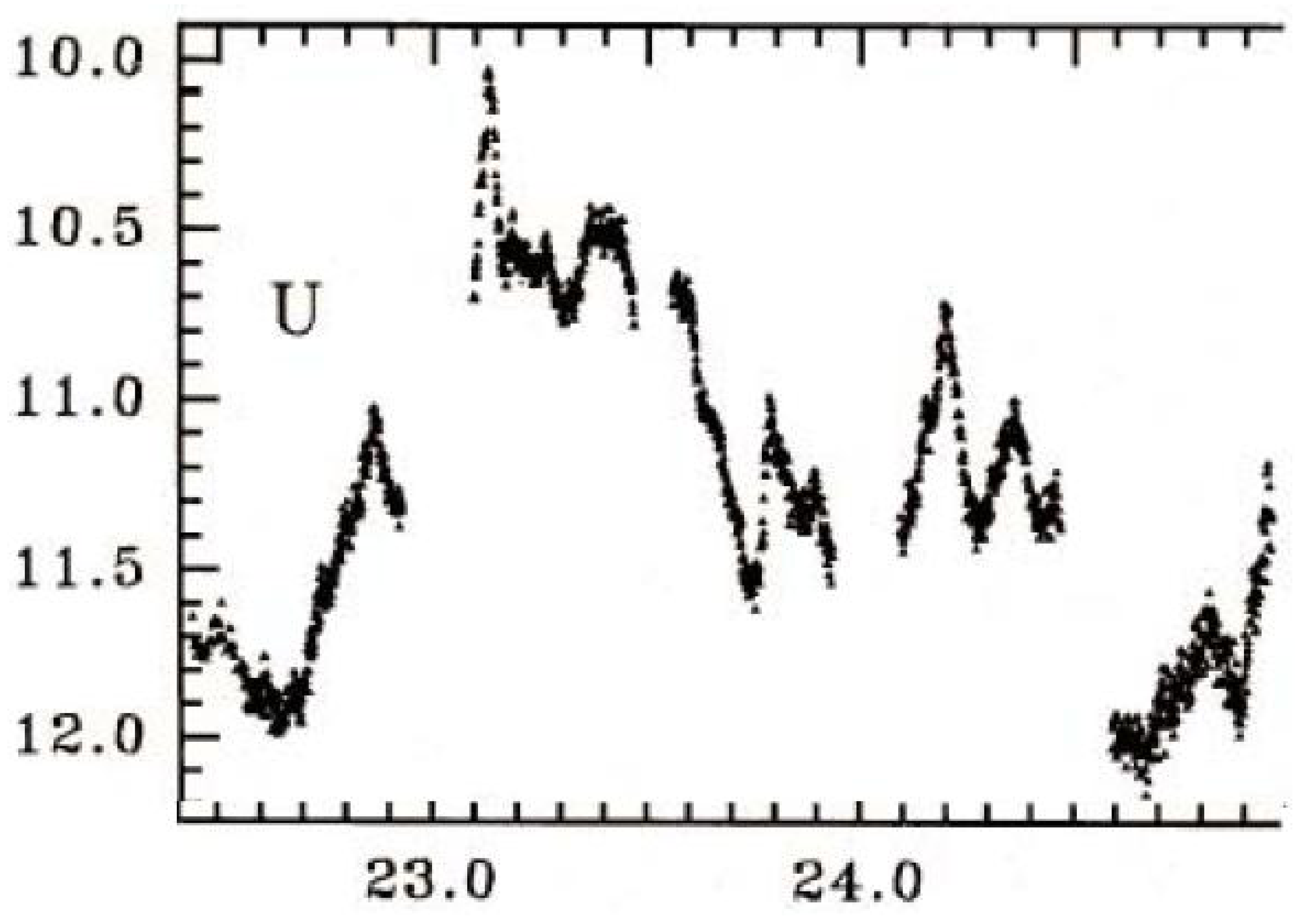

Figure 1: Flaring activity of AE Aquarii

3 The origin

- A newly formed white dwarf is presumed to rotate slowly. Its rotation rate can be, however, increased as it accretes material from a Keplerian disk. A steady spin-up can be expected if the physical conditions in the accreted material are favorable for a steady burning of hydrogen at the surface of the white dwarf. This happens if $\dot{\mathfrak{M}} > \dot{\mathfrak{M}}_{\rm cr} \sim 10^{-7}\,{\rm M_{\odot}\,yr^{-1}}$, where $\dot{\mathfrak{M}}$ is the mass accretion rate. Otherwise, the star would experience nova outbursts in which its rotational rate is effectively decelerated.

  The spin period of a white dwarf in this case tends to evolve to a so called equilibrium period

$$P_{\rm eq} \simeq 725\,\mu_{34}^{6/7}\,\dot{\mathfrak{M}}_{19}^{-3/7}\,m^{-5/7}\ {\rm s},$$

  where $\mu_{34} = \mu/10^{34}\,{\rm G\,cm^3}$, m is the mass of the white dwarf in units of $M_{\odot}$, and $\dot{\mathfrak{M}}_{19}$ is the mass accretion rate in units of $10^{19}\,{\rm g\,s^{-1}}$. Substitution of the current value of the dipole magnetic moment in this expression shows that the equilibrium period is much greater than the current value of the white dwarf spin period ($P_{\rm eq} \sim 2000\,s$). It can be explained by the possible magnetic field decrease during the spin-up epoch due to screening by the accreting material. At a final stage the magnetic field emerged from the accreted plasma due to diffusion.
- The spin period of the accreting white dwarf increases to the equilibrium period on the timescale

$$\Delta t = 1.3 \times 10^5\ I_{50} \dot{\mathfrak{M}}_{19}^{-1} m^{-2/3} P_{33}^{-4/3}\ {\rm yr},$$

  where I_{50} is the moment of inertia in the units of $10^{50}\,{\rm g\,cm^2}$ and $P_{33} = P_{\rm eq}/33\,{\rm s}$. The mass accreted onto its surface during this time is $\Delta M_{\rm a} \sim 0.03\,{\rm M_{\odot}}$.

  The maximum possible factor of magnetic field screening is limited to $(1/\sin\theta_{\rm i})^{7/2} \sim 125$, where $\theta_{\rm i} = \arcsin\left(R_{\rm wd}/R_{\rm m}^{(i)}\right)^{1/2}$ is the initial opening angle of the accretion column.

  The timescale of the magnetic field emerging after the spin-up phase is (Cumming 2002)

$$\tau_{\rm diff} \simeq 5 \times 10^7\,(\Delta M_{\rm a}/0.03\,M_{\odot})^{7/5}\ {\rm yr}.$$

- Formation of a very fast rotating, strongly magnetized white dwarf can be expected if $\tau_{\rm diff}$ is smaller than the Pointing-driven spin-down timescale. This condition is satisfied if

$$I \leq 6 \times 10^{49}\ P_{33}^{4/3} \left(\frac{M_{\rm wd}}{M_{\odot}}\right)^{2/3} \left(\frac{\Delta M_{\rm a}}{0.01\,M_{\odot}}\right)\ {\rm g\,cm^2}.$$

  According to the dependence of the moment of inertia on the white dwarf mass (Andronov and Yavorskij 1990, see Fig.2), this condition is satisfied for a pulsar-like white dwarf with the mass $\geq 1.1\,{\rm M_{\odot}}$.

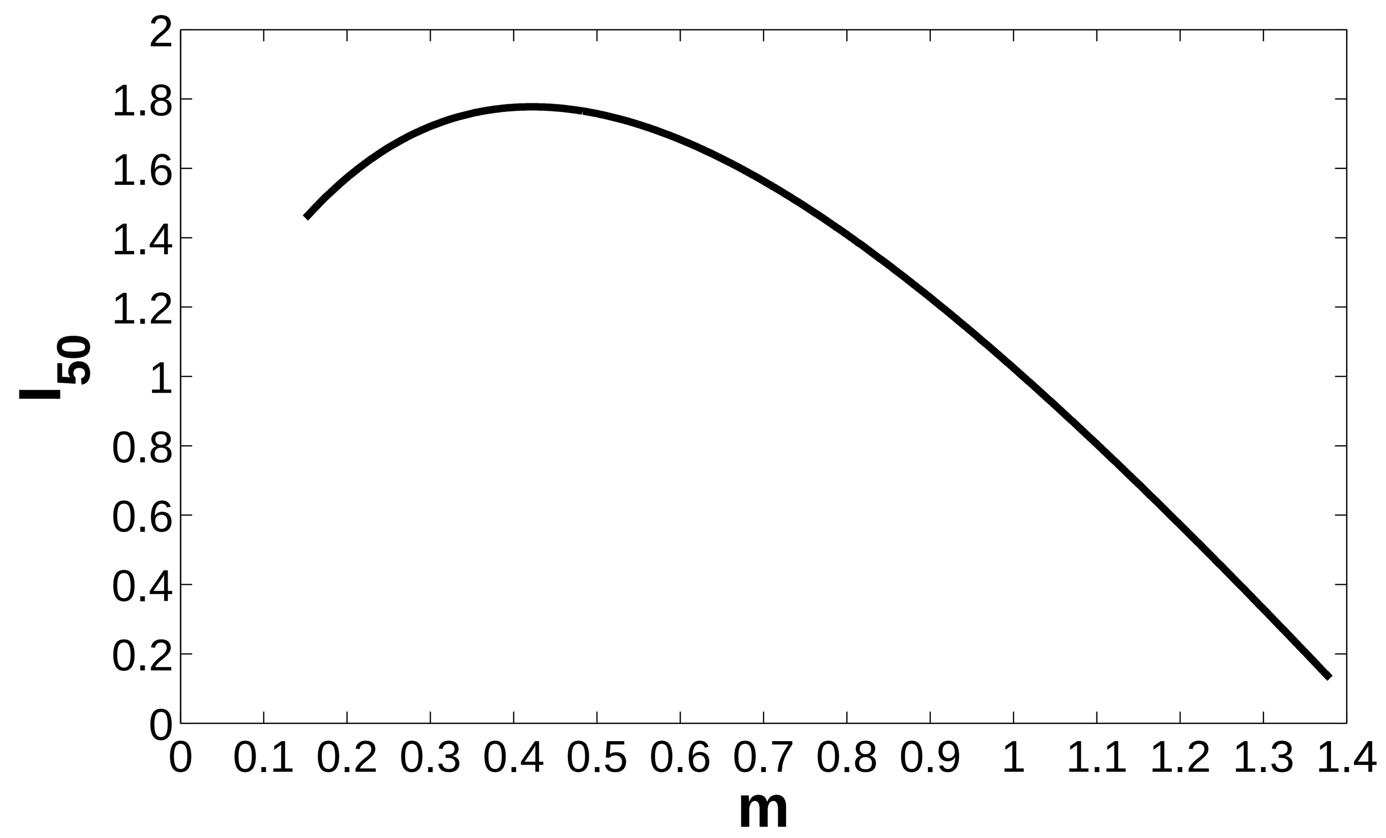

Figure 2: Dependence of the moment of inertia on the white dwarf mass ($m = M_{\rm wd}/M_{\odot}$, $I_{50} = I/10^{50}\,{\rm g\,cm^2}$)

References

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