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Asynchronous polars as a laboratory for study of magnetic field structure of accreting white dwarfs

E.P. Pavlenko*

Crimean Astrophysical Observatory, Russian Academy of Sciences, Nauchny, Bakhchisaray, 298409, Crimea, Russia

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Brief information on the magnetic white dwarfs in cataclysmic binary systems is given. The most recent achievements in the study of magnetic field structure of some asynchronous polars, in particular, V1500 Cyg = Nova Cygni 1975, are presented.

Keywords: Variable stars: general stars: cataclysmic variables – stars: magnetic field

1 Introduction

Not long ago magnetism was regarded as a rare phenomenon among white dwarfs. Babcock (1947) first detected a magnetic field in 78 Vir. Blackett (1947) suggested that some white dwarfs should exhibit magnetic fields of up to 10^7–10^8 G. A first isolated magnetic white dwarf Grw+70°8247 was discovered by Kemp et al. only in 1970 on the basis of its strong circular polarisation. Over the next 40 years the number of known magnetic white dwarfs with fields in the range 2–1000 MG increased up to ∼600 in 2015 (Ferrario et al. 2015). The first accreting magnetic white dwarf among the cataclysmic binary stars (polars) was discovered in the known cataclysmic variable (CV) AM Her due to the emission of soft X-rays, detected by SAS-3 (Hearn et al. 1976) and ∼9% circular polarisation at the 3.09 h binary orbital period (Tapia 1977).

The origin and evolution of magnetic fields of white dwarfs are the as yet unsolved part of our understanding of stellar evolution partially because of unknown magnetic field configuration. It is assumed that progenitors of magnetic white dwarfs are Ap/Bp stars (Kawka and Vennes 2004 and references therein). Wendell et al. (1987) estimated that the dipole field decreases by two times over 10^{10} years, that confirms its possible fossil nature. Contrary to a common opinion that a higher order magnetic field decays faster than the dipole field, Muslimov et al. (1995) suggested that the magnetic field may be more complicated than the dipole one due to the Hall effect. They pointed out that new observational data could encourage theoretical analyses of

*Email: eppavlenko@gmail.com

the role of the Hall effect to understand how the higher order multipoles could survive in magnetic white dwarfs. Indeed, later several cases of the very complex magnetic field topologies became known (see Ferrario et al. 2015 for review). Also Cumming (2002) considered the role of accretion in the magnetic field structure change in such systems.

2 Synchronous and asynchronous polars

Polars and "intermediate polars" belong to the category of cataclysmic variable stars. In such systems the late-type star filling in its Roche lobe loses matter onto the poles of the magnetic white dwarf without forming an accretion disk. Polars are synchronous systems, i.e., the systems, where the white dwarf and the orbit are synchronous due to the interaction of the magnetic field of the white dwarf with the donor star (Campbell 1985; King and Whitehurst 1991). Polars comprise about 20–25% of all known CVs (Ferrario et al. 2015). Polars have typically surface magnetic field strengths $B = 10^7$–10^8 G while "intermediate polars" have $B = 10^6$–10^7 G.

There is a small group of confirmed asynchronous polars, namely V1432 Aql = RX J19402-1025, V1500 Cyg, BY Cam and CD Ind, where the asynchronism is ∼1% (Patterson et al. 1995; Geckeler, Staubert 1997; Stockman et al. 1988; Pavlenko, Pelt 1991; Silber et al. 1992; Schwope et al. 1997). Several candidates for asynchronous polars are also known as Paloma or RX J0524+42 (Campbell, Schwope 1999); V4633 Sgr (Lipkin, Leibowitz 2008); Swift J2319.4+2619 (Shafter et al. 2008) and IGR J19552+0044 (Tovmassian et al. 2017).

Asynchronous polars are an excellent laboratory for the study of the magnetic field structure of a white dwarf. Contrary to synchronous polars with fixed orientation of the magnetic field with respect to the accretion stream, in asynchronous polars this orientation will change with the phase of the synodic (or spin-orbital beat) period that is $P_{\rm beat}^{-1} = P_{\rm spin}^{-1} - P_{\rm orb}^{-1}$, where $P_{\rm beat}$, $P_{\rm spin}$ and $P_{\rm orb}$ are the beat, spin and orbital periods correspondingly. Studying the geometry of accretion in a rotating magnetic field of the white dwarf, we can determine its structure. BY Cam was a first asynchronous polar, for which most of the observational evidence of a complex magnetic field such as "dipole + quadrupole" was found. Yet Piirola (1994), using N. Shakhovskoy's polarimetric observations made on the 2.6-m Shajn telescope of CrAO, suggested a complex magnetic field for BY Cam. A multipole magnetic field model of an aligned dipole plus quadrupole field model was suggested by Wu and Mason (1996); Mason et al. (1998), Schwarz et al. (2005). Pavlenko (2006), Pavlenko et al. (2007a,b), for the data of BY Cam in a low accretion stage, found additional evidences of switching between a dipole spot and an equatorial one. MHD calculations around the beat cycle also demonstrated the main effects of pole switching in the case of a complex magnetic field structure (Zhilkin et al. 2012). For the new findings in BY Cam accretion geometry over the last years, see the paper of Babina et al. (also published in this volume).

3 Case of asynchronous polar V1500 Cyg

V1500 Cyg is a unique system among the asynchronous polars. It was one of the brightest novae of the 20th century (Honda 1975; Warner 2006) with an amplitude of eruption about 19^m. It is assumed that in the past V1500 Cyg was a synchronized polar (Stockman et al. 1988) and the nova explosion in 1975 disrupted the spin-orbital synchronism. The strong irradiation of the secondary by the hot WD (so-called the "reflection effect") still dominates the total radiation of this system (Pavlenko et al. 2018). That is why it was difficult to extract an optical radiation from the accretion columns of the V1500 Cyg white dwarf over many years.

Kaluzny and Chlebowski (1988) first reported on the possibility of the two-pole accretion in V1500 Cyg from spectral observations obtained in 1987 with MMT. Recently Harrison and Campbell (2017) obtained phase-resolved optical spectroscopy with 3.5-meter telescope of the Apache Point Observatory. They revealed that there are discrete cyclotron humps from two different strength magnetic poles.

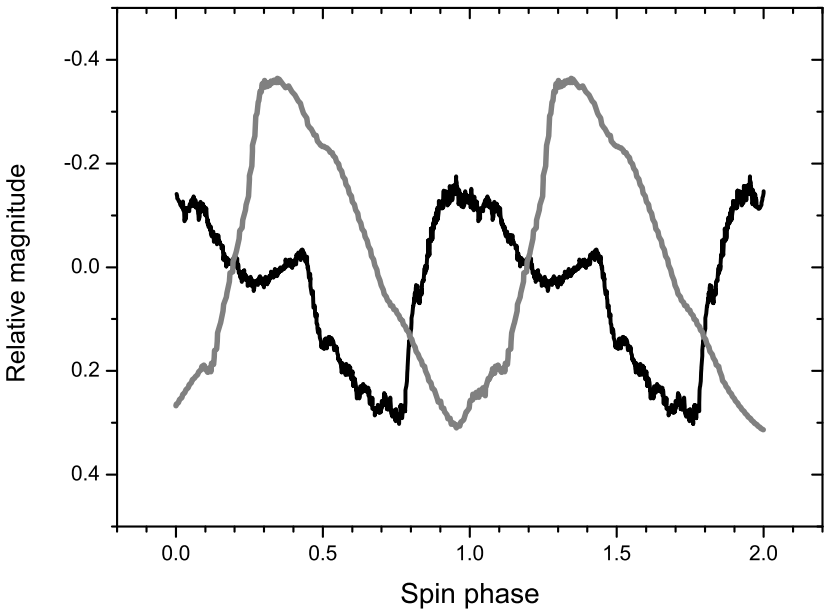


Figure 1 An example of "spin" smoothed light curves for the two groups of the V1500 Cyg data for 2015 after subtraction of the orbital modulation, caused by the reflection and ellipsoidal effects. The light curves were constructed on the basis of original data available online in Pavlenko et al. (2018). 1) for the $P_{\rm beat}$ phases 0.5–1.0 (black line) and 2) for the $P_{\rm beat}$ phases = 0.0–0.5 (grey line). The first group involves the data of seven nights of observations that have mean beat phases of 0.46, 0.46, 0.53, 0.54, 0.56, 0.58 and 0.72, while the second one involves the data of two nights at the beat phases of 0.01 and 0.12. The phases were calculated according to the ephemeris given in Pavlenko et al. (2018).

The first attempt to search for the optical radiation from accretion columns was done on the basis of photometric data obtained in 2000, 2001 and 2003 (Pavlenko 2003). After the removal of the orbital wave caused by the reflection effect, the

result was a 0.13734 d period that only roughly coincided with the expected spin period. However because the residual variability was additionally contaminated by the ellipsoidal modulation of the secondary component in a field of high-mass white dwarf, this potential spin period could not be exact. The contribution of ellipsoidal modulation was first extracted from the photometric data obtained ∼40 years after Nova eruption (Pavlenko et al. 2018), when the brightness of V1500 Cyg varied between $V = 19^m$ and $V = 21^m$. A similar two-humped profile of the residuals after removing the modulation that was produced by "reflection effect" was obtained somewhat earlier by Harrison and Campbell (2016), but they wrongly identified this as a radiation from accretion columns of white dwarf and concluded that V1500 Cyg was already synchronized.

After the correct removal of both the "reflection" and "ellipsoidal" modulation, Pavlenko et al. (2018) detected the signal at 0.137613-d that is likely to be the spin period, and found that profiles of the 2015 spin light curves of V1500 Cyg are similar to those of BY Cam in a high accretion state. Similar to BY Cam, for V1500 Cyg pole switching was detected. The mean spin light curves for the synodic phases separated by half of the 9.6-d synodic cycle are given in Fig. 1. These curves demonstrate the pole-switching of the accretion flow. They show that accretion occurs onto wide accretion zones that could be produced by a magnetic field that is more complex than the dipole one.

Conclusion

The recent observations of asynchronous polars showed that the magnetic field structure of the white dwarfs in the cataclysmic variable stars may be more complex than a simple dipole-like structure. The long-term monitoring of asynchronous polars will help in understanding this problem. We could expect that in a hundred years or so when V1500 Cyg according to the theoretical prediction of Pryalnik (1986) and identifications from observations (Pavlenko et al. 2018) finally returns to its historical quiescence, the accretion zones will become more narrow (by analogy with BY Cam in a low accretion stage) and the magnetic field structure will become more clear.

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