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The unique magnetic cataclysmic variable V1432 Aql (*Research Note*)

Third type of minima and synchronization⋆

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ABSTRACT

Results of a CCD study of the variability of the unique magnetic cataclysmic variable V1432 Aql from the Astronomical Observatory of Mallorca are presented. The "multi-comparison star" method had been applied for better accuracy estimates. The linear ephemeris based on 76 timings of orbital eclipses for 1993–2004 is $\mathrm{HJD_{min}} = 2\,451\,492.09876(14) + 0.140235812(12)\cdot E$. For the wide minima due to the spin variability, the quadratic ephemeris $\mathrm{HJD_{spin}} = 2\,449\,638.327427(74) + 0.14062831(23)\cdot E - 7.81(11)\times 10^{-10}E^2$ was determined. The rate of the spin-up of the white dwarf corresponds to the synchronization time-scale determined to be (96.7 ± 1.5) years, in an agreement with theoretical model of the accretion torque. A third type of minima was detected that occur with the spin period. It was interpreted as indicating presence of the second accretion column. For adopted values of mass $M_1 = 0.9\ M_\odot$ and $M_2 = 0.3\ M_\odot$, the estimated accretion rate is $\sim 7\times 10^{-10}\ M_\odot$/yr. Further multi-colour monitoring is needed to study of late stages of the "spin-orbital" synchronization and periodic changes of the accretion geometry caused by "idling" of the white dwarf.

Key words. novae, cataclysmic variables – stars: rotation – stars: variables: general – white dwarfs – stars: magnetic fields

1. Introduction

V1432 Aql (RX J1940.1-1025) belongs to a unique subclass of variable stars called "asynchronous polars", in which the spin period $P_{\rm spin}$ and orbital period $P_{\rm orb}$ of the magnetic white dwarf differ by a few per cent (cf. Warner 1996; Hellier 2001). Four such objects are known, namely the prototype of this type V1500 Cyg, BY Cam, CD Ind and V1432 Aql (Ritter & Kolb 2005).

Rosen et al. (1993) identified the variable ROSAT X-ray source RX J1940.1-1025 with an optical counterpart V1432 Aql. Strong He II emission lines at λ4686 and λ5411 in combination with X-ray radiation allowed investigators to classify the object as a magnetic cataclysmic variable (Patterson et al. 1995). Light variations in the optical range show both the period of 12 150 s and cycle-to-cycle variability. Spectroscopic studies show periodic changes of radial velocity of the emission lines (Staubert et al. 1993) with a period of 12 120.3 s. This difference in periods allowed them to classify the object as an asynchronous polar. Staubert et al. (2003) detected variation of the spin period of the white dwarf.

These stars are excellent laboratories to study multi-component processes of accretion in the presence of a strong magnetic field, as well as the structure and evolution of gravimagnetic rotators. Because of asynchronism of the rotation of the white dwarf with respect to the orbital motion, such objects can show switching of the magnetic poles onto which the accretion of matter takes place (cf. Mason et al. 1998). In asynchronous polars, beat periods are usually observed between the basic periods $P_{\rm spin}$ and $P_{\rm orb}$ and their harmonics. This partially is caused by switching of accretion from the vicinities of one magnetic pole of the white dwarf to another one.

In these objects, the synchronization of the spin and orbital periods takes place over a characteristic time of hundreds of years (Schmidt & Stockman 2001), in an excellent agreement with theoretical models (cf. Andronov 1987; Campbell 1997). Such a synchronization timescale is variable, as one may see e.g. from the extensive study of V1500 Cyg since its nova outburst in 1975 (Pavlenko & Shugarov 2005). Because the synchronization time-scale is much smaller than the interval between the nova outbursts (cf. Warner 1995), these objects evolve to classical polars, the synchronisation of which is regularly broken by a nova outburst.

V1432 Aql is unique in this sub-type. Contrary to the other 3 systems (BY Cam, V1500 Cyg and CD Ind), the rotation period of the white dwarf exceeds the orbital period. Moreover, this object is the only one among the four objects for which eclipses and self-eclipses of the accretion column are observed (Patterson et al. 1995).

An extensive photometric campaign by Patterson et al. (1995) allowed to determine a beat period between $P_{\rm spin}$ and $P_{\rm orb}$, equal to $\sim 50^{\rm d}$. Mukai et al. (2003) studied the X-ray variability as the function of phase of this beat period.

⋆ Tables 3 and 4 are only available in electronic form at http://www.edpsciences.org

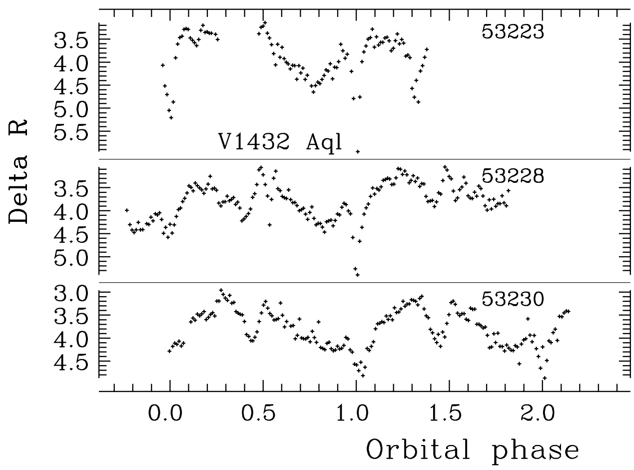

Fig. 1. Examples of nightly light curves plotted vs orbital phase with respect to the comparison star ($R = 11\overset{\rm m}{.}02$). To show cycle-to-cycle variability, the points are not repeated. An orbital dip occurs at phase 0, the spin minimum drifts from phase 0.77 to 0.9 (for these nights, which are close in phase of the beat period). The numbers are the last 5 digits of the integer Julian date.

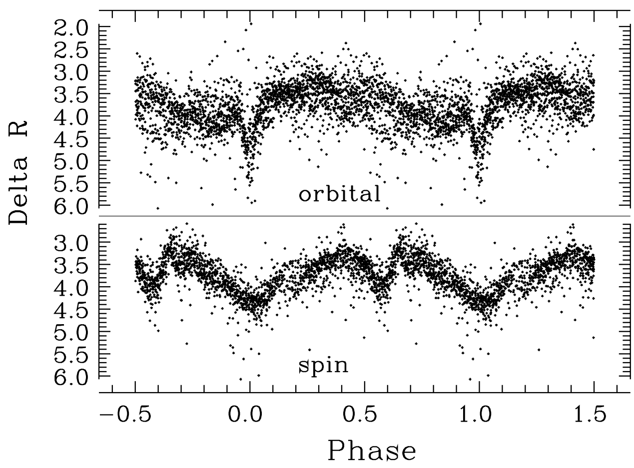

Fig. 2. Phase light curves with respect to the comparison star: *top*: for all data, using the ephemeris (1) for the orbital period, *bottom*: for the data outside the phases of the orbital "dip", using the ephemeris (3) for the spin period. The "spin 2" – type minimum preceeds the previously known "spin 1" – type minimum by $(0.43 \pm 0.001)P_{\rm spin}$.

2. Observations and analysis

The observations were obtained in the Astronomical Observatory of Mallorca (OAM) using the Meade 14″ telescope with the CCD camera SBIG ST-1001E. Over 16 nights, 4024 CCD images in alternatively changing VR filters were obtained. The photometry was made using the program WinFITS (Goranskij, private communication). For improvement of accuracy, we used the method of "artificial" (or "mean weighted") star (Andronov & Baklanov 2004; Kim et al. 2004). The main comparison star is "C" of Patterson et al. (1995), for which we determined $V = 11\overset{\rm m}{.}95 \pm 0\overset{\rm m}{.}03$ and $R = 11\overset{\rm m}{.}02 \pm 0\overset{\rm m}{.}02$ by linking to the standard near WZ Sge (Henden 2001) and applying a small color correction to the instrumental V system (Andronov et al. 2006). The magnitudes are expressed as the instrumental differences between the variable star and the comparison star.

Table 1. Heliocentric timings t of orbital eclipses and their error estimates $\sigma[t]$.

Filter	$t - 2\,453\,200$ σ	Filter	$t - 2\,453\,200$ σ
V	13.63413 0.00004	R	13.63633 0.00001
V	14.47376 0.00070	R	14.47416 0.00004
V	14.61397 0.00101	R	14.61584 0.00090
V	15.59621 0.00033	R	15.59620 0.00116
V	18.54012 0.00002	R	23.45064 0.00005
V	20.50842 0.00078	R	23.58958 0.00002
V	23.45080 0.00004	R	24.57328 0.00303
V	23.59149 0.00161	R	27.37633 0.00108
V	24.57230 0.00076	R	28.35738 0.00021
V	27.37817 0.00072	R	28.49851 0.00001
V	28.35707 0.00045	R	29.47859 0.00724
V	28.49873 0.00005	R	30.46258 0.00091
V	29.33766 0.00037	R	30.60227 0.00059
V	29.47896 0.00061	R	31.44184 0.00082
V	30.46475 0.00087	R	31.58690 0.00010
V	30.60380 0.00148		

The most prominent feature of the light curve is a deep narrow minimum, which is often called a "dip", and is explained by an eclipse by a secondary star (Patterson et al. 1995) near the orbital phase zero. There are also wide and narrow minima, occuring every rotation (spin) period of the white dwarf. We will refer to them as "type 1 and 2".

The second type of these minima, despite being seen in published light curves, is separately introduced in the present work. The minima of all three types were identified in the individual light curves separately for the filters V and R. The minima timings were determined using the method of "asymptotic parabolae" (program "Asymp" by Marsakova & Andronov (1996) and program "OL" by Andronov 2003), which is especially effective for generally asymmetric light curves.

3. Orbital period

In addition to our 31 timings of orbital eclipses (Table 1), we have used 45 moments published by Patterson et al. (1995) and Staubert et al. (2003) (76 moments in all). The orbital ephemeris has been corrected:

$$\mathrm{HJD_{min}} = 2\,451\,492.09876(14) + 0.140235812(12) \cdot E. \qquad (1)$$

The orbital phase curve are presented in Fig. 3. The most prominent feature is the "dip", which occurs near the orbital phase zero, which is superimposed on a slightly asymmetric photometric wave. There is a large contribution to the scatter of the physical variability of the shape of the light curve.

4. Spin period of the white dwarf

The characteristics of both types of "spin" minima are presented in Table 2. The Tables 3 and 4 of individual data points in V and R are available electronically. Using the program OL (Andronov 2003), the ephemerides were obtained from the least squares fits. The value of $P_{\rm spin} = 0\overset{\rm d}{.}140585(30)$ was determined as a weighted mean of two values for wide and narrow minima, as the difference between the two values is within the corresponding error estimates. The initial epoch for the wide "spin-1"-type minima is 2 453 223.8359(13). The second "narrow spin minimum" precedes the "wide spin minimum" by $(0.43 \pm 0.01)P_{\rm spin}$, arguing for an asymmetry in the location of both accretion regions.

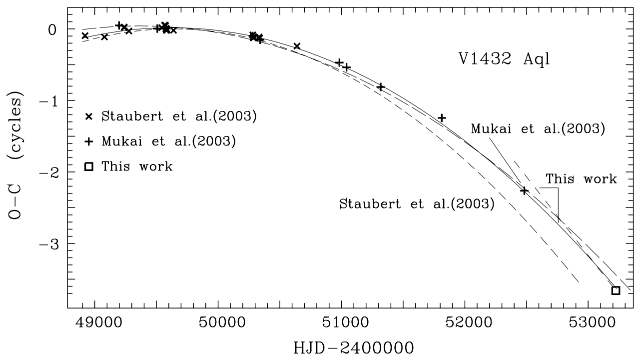

Fig. 3. O–C diagram for the spin minima according to the linear ephemeris (8) by Staubert et al. (2003). The captions mark corresponding parabolic and linear fits.

Table 2. Heliocentric timings of minima t of types "spin-1" (left) and "spin-2" (right) and their error estimates $\sigma[t]$.

Filter	$t - 2\,453\,200$	$\sigma[t]$	Filter	$t - 2\,453\,200$	$\sigma[t]$
R	13.57592	0.00088	*R*	17.45399	0.00001
R	14.56002	0.00057	*R*	18.57460	0.00065
R	15.54276	0.00119	*V*	24.47805	0.00257
R	16.51804	0.00001	*R*	26.44568	0.00075
V	17.50671	0.00349	*V*	27.44568	0.00008
V	19.62190	0.00307	*V*	28.41663	0.00385
R	23.55650	0.00113	*R*	28.55832	0.00001
V	24.54139	0.00180	*R*	29.39733	0.00001
R	26.50980	0.00001	*V*	29.53877	0.00134
V	27.47784	0.00303	*R*	30.38345	0.00050
V	28.47246	0.00124	*R*	30.52329	0.00013
R	29.46275	0.00051	*R*	31.36602	0.00039
R	30.44833	0.00175	*R*	31.50848	0.00069
V	30.57848	0.00199			
R	31.43427	0.00148			
R	31.56738	0.00086			

With "idlings" of the white dwarf with respect to the secondary, accretion takes place along different magnetic field lines (cf. Geckeler & Staubert 1997). This should cause phase shifts varying with beat phase. For the case of two-column accretion in the intermediate polar RXS J062518+733433, Kim et al. (2005) discovered variability of the spin phases with orbital phase. For switching accretion from one pole to another in the asynchronous polar BY Cam, the phases show a "tooth-like" curve with abrupt changes by 0.5 (Silber et al. 1997). For V1432 Aql, our observations span $18^{\rm d} = 0.3 P_{\rm beat}$, so one cannot obtain firm conclusions on the periodicity of phases, even though such a character of variability may not be excluded.

The difference of the shapes of both minima, related to the rotation of the white dwarf, can be explained by a difference in characteristics of two accretion columns, as well as of their orientations. Examples of the model light curves of inclined columns above the surface of the white dwarf are presented e.g. by Andronov (1986).

5. Synchronization of the white dwarf

This period value $P_{\rm spin}$ differs from that published previously by Staubert et al. (2003) or Mukai et al. (2003). For an initial ephemeris, we used the linear part of the elements published by Staubert et al. (2003):

$$\mathrm{BJD}_{\rm spin1} = 2\,449\,638.32497(93) + 0.14062845(26) \cdot E. \quad (2)$$

The significant difference in the period values may be explained if the period decreases during the decade of studies of V1432 Aql. The spin-up of the white dwarf in this system was originally discovered by Geckeler & Staubert (1997). Using the quadratic ephemeris by Staubert et al. (2003), the extrapolated value of the period at the epoch of our observations is equal to $P_{\rm spin} = 0\overset{\rm d}{.}140582(50)$, in agreement with our results. However, the error estimate for one season is relatively large, thus for a study of period change with better accuracy, an O–C analysis was applied.

Contrary to the "classical" style of the "O–C" diagram, where the residuals from the ephemeris are plotted versus the cycle numbers, in Fig. 3 the phase versus time is plotted.

For the analysis, we used one published minimum from Staubert et al. (2003), 26 from Mukai et al. (2003) and 19 from Patterson et al. (1995). For our observations, we used a "seasonal mean" value of 16 points (with a corresponding weight) of the "wide spin" minima. The best quadratic ephemeris

$$\mathrm{HJD}_{\rm spin} = 2\,449\,638.327427(74) + 0.14062831(23) \cdot E$$
$$-7.81(11) \times 10^{-10} \cdot E^2. \quad (3)$$

The corresponding synchronization time-scale is

$$\tau = (P_{\rm spin} - P_{\rm orb})/({\rm d}P_{\rm spin}/{\rm d}t) = 96.7 \pm 1.5 \text{ yr}. \quad (4)$$

A decrease of $|\dot{P}|$ in another synchronizing polar V1500 Cyg was detected by Pavlenko & Shugarov (2005). However, the present data show no evidence for a statistically significant variation of $\dot{P}_{\rm spin}$.

6. Estimate of the accretion rate

To estimate the accretion rate from the observed value of $\dot{P}$ (Lamb et al. 1973; Campbell 1997), we have adopted the values of the the masses of the secondary $M_2 = 0.3\ M_\odot$ (from the statistical relationship $M_2(P_{\rm orb})$ by Echevarria (1983)) and of the white dwarf $M_1 = 0.9\ M_\odot$ with a relative accuracy of 10 per cent (Singh et al. 2004). Having no direct estimate of the magnetospheric radius, we estimated it as a distance to the "hot spot" in the model of Warner & Peters (1972). It was defined as the radius of the circular orbit at which the net angular momentum is the same as for the mass leaving the inner Lagrangian point. The moment of inertia of the white dwarf was determined using the computations of Andronov & Yavorskij (1990) based on commonly used models of Nauenberg (1972) for "zero-temperature" white dwarfs. The possible temperature correction to the radius of the white dwarf is expected to be much smaller than that of a dozen per cent for the mass itself. The moment of inertia for $M_1 = 0.9\ M_\odot$ is equal to $I = 1.23 \times 10^{50}$g cm^2, so $\dot{M} = 6.6 \times 10^{-10}\ M_\odot$/yr. Assuming the error corridor $\pm 0.08\ M_\odot$ (Singh et al. 2004) for the mass, the relative error of $\dot{M}$ reaches ~20%. For the estimate $M_1 = 1.2\ M_\odot$ (Rana et al. 2005), $\dot{M} = 2.5 \times 10^{-10}\ M_\odot$/yr.

Using Eq. (2) from Staubert et al. (2003) we estimated $\dot{M} = 3.8 \times 10^{-9}\ M_\odot$/yr. This value is larger by a factor of 3.1 than that obtained using the distance of the hot spot for the same mass $M_1 = 0.6\ M_\odot$, as adopted Staubert et al. (2003). The estimates based on statistical relations $\dot{M}(P_{\rm orb})$ by Tutukov & Yungelson (1979) and Patterson (1984) are $\dot{M} = 5.1 \times 10^{-9}\ M_\odot$/yr and $\dot{M} = 3 \times 10^{-10}\ M_\odot$/yr, respectively. In summary, based on these different estimates, the mass transfer rate in V1432 Aql is of the order of several $10^{-10}\ M_\odot$/yr.

7. Conclusions

- The ephemerids for the orbital and spin minima were corrected.
- Third type of minimum were detected, which was interpreted by presence of the simultaneously accreting second accretion column.
- The rate of the spin-up of the white dwarf corresponds to the synchronization time-scale of (96.7 ± 1.5) years, in an agreement with theoretical models of the accretion torque.

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