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Rotational Evolution of the Magnetic White Dwarfs in Intermediate Polars

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ABSTRACT
We provide the results of the long-term multicolour photometric monitoring of selected intermediate polars MU Cam, V405 Aur, FO Aqr, EX Hya, V1323 Her, V2306 Cyg, obtained at different observatories. We analysed variability of the spin period of the white dwarf using our observations and previously published spin maxima timings. We found that some of these stars show spin-up, some show spin-down, sometimes we see no spin period variability and sometimes we may see more complicated changes of the spin periods. For some binary systems we studied also orbital period variations.

Keywords: cataclysmic variables – close binaries – white dwarfs – period variability

1 INTRODUCTION

Intermediate polars, often called DQ Her star, are interacting binary systems with strong magnetic fields (Patterson, 1994; Warner, 1997; Hellier, 2001). Gravity of the white dwarf leads to the gravitational capture of the part of the substance of the secondary component

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near the inner Lagrange points. Due to the Coriolis force, plasma flux deviates from the center line and forms an accretion disk around a white dwarf. A strong magnetic field destroys the inner part of the disk and leads to the formation of two accretion columns, which are one of the brightest sources of radiation in a wide spectral range from x-ray to infrared. The cyclotron radiation is characterized by the presence of polarization. The matter forms a shock wave heats up and settles on the surface of the white dwarf. Rare outbursts are possible (e.g. DO Dra (Andronov et al., 2008)). Intermediate polars were often classified as nova-like stars with relatively small changes in average per night light.

Usually intermediate polars show two kinds of optical variability which are caused by different physical processes. The orbital period is usually 3–7 hours. The spin variability is caused by the rotation of the white dwarf with one or two accretion columns with the period range from few to dozens of minutes. So, the light curve is a superposition of two different periodic variations and some aperiodic processes like flickering, outbursts, changes from high to low luminosity state etc. But, in case of V1323 Her we may see no orbital variability, suggesting a low orbit inclination (Andronov et al., 2011) and in case of V709 Cas we may see no spin variability because the object is faint, spin period is very short and time resolution is not sufficient (Hric et al., 2014).

Some of selected intermediate polars exhibit a statistically significant dependence of the color index on the spin phase, indicating a variable distribution of energy in the spectrum and necessity of multicolour observations rather than mono-filter or unfiltered ones. During our monitoring we obtained mainly time series with alternatively changing V and R color filters.

2 DATA PROCESSING

The CCD frames were processed using C-MuniPack software. In some cases (too few stars in the field, not enough to match frames automatically) we used the program Winfits written by V. P. Goranskij. The final time series were obtained using the program MCV (Andronov and Baklanov, 2004) taking into account multiple comparison stars (Kim et al., 2004), the same software was used for periodogram analysis. For our objects we analysed all available photometric data, including long CCD series published in AAVSO database.

To determine extrema timings we used trigonometric polynomial approximation. We choose 2-periodic variability model for smoothing

$$m(t) = m_0 - r_1 \cos\big(\omega_1 (t - T_{01})\big) - r_2 \cos\big(\omega_2 (t - T_{02})\big)\,, \tag{1}$$

where $m(t)$ – is the smoothed value of brightness at time t, m_0 – average brightness on theoretical curve (generally different from the sample mean (Andronov, 2003), $\omega_j = 2\pi/P_j$, r_j – semi-amplitude, T_{0j} is the epoch for maxima of brightness of photometric wave with number j and period P_j. We calculated only one moment per set of observations (i.e. per night) because the accuracy estimate is much better then for individual extrema. This method is optimal for approximation of observations of intermediate polars and is often used in case of spin + orbital variability, e.g. EX Hya (Andronov and Breus, 2013), MU Cam (Kim et al., 2005). For objects that show variability with one period we used regular trigonometric polynomial approximation. This way we determined spin maxima and orbital minima timings.

To study period variations we used O-C analysis. Generally we calculated two O-C diagrams: for spin maxima and for orbital minima timings. Along with moments determined using our own data we used all published ones. Contrary to a classical representation of the "O-C diagram" as a dependence of the timings from an ephemeris, i.e.

$$O - C = T - (T_0 + P \cdot E) \tag{2}$$

on the cycle number E, we have used phases instead, i.e. $\phi = (O - C)/P$. For a correct ephemeris, the phases should be concentrated near the zero value. For some objects we detected cycle miscounts caused by gaps in regular observations and not enough-precisely determined values of the periods. After correction of it, we smoothed O-C diagram with a polynomial with statistically-optimal degree. Using coefficients of these polynomials after many years of monitoring, it is possible to determine the value of the period more precisely and (in some cases) detect second derivatives of the period, e.g. acceleration of the spin period of the white dwarf. Sometimes the period increase was turned to a period decrease (FO Aqr). These changes may be interpreted by a model of precession of a rapidly rotating white dwarf (Andronov 2005), which predicts chaotic variability of the spin period at time scales of decades.

3 MU CAMELOPARDALIS

The X-Ray source 1RXS J062518.2+733433 was classified as an Intermediate polar (Araujo-Betancor et al., 2003; Staude et al., 2003). Later, results of 7 nights of CCD-photometry obtained using 1.8m telescope in Korea were published (Kim et al., 2005): ephemeris of the orbital minima

$$\mathrm{BJD} = 2453023.6159(42) + 0.1966431(33) \cdot (E - 1735) \tag{3}$$

and improved ephemeris for spin maxima

$$\mathrm{BJD} = 2452893.78477(10) + 0.01374116815(17) \cdot (E - 15382)\,. \tag{4}$$

Hereafter in brackets we provide a statistical error estimate in units of a last digit.

After this publication, photometric monitoring of the system was continued in Korea (Chungbuk National University Observatory), Slovakia (Astronomical observatory and planetarium in Hlohovec and Vihorlat observatory in Kolonica, 2007–2014) and Poland (Jagiellonian university observatory, Krakow, 2013–2014). First we determined the value of orbital period of the system $0^{\mathrm{d}}.1968538 \pm 0.0000013$ and spin period $0^{\mathrm{d}}.01374$ which were close to published earlier values. By now we collected more then 300 spin maxima timings. We used two-periodic trigonometric polynomial fit. Dependence of phase on time is presented on the Fig. 1

As we see significant trends and phase shifts, we suggested period variability hypothesis. Taking into account results obtained for other intermediate polars, where phase variability was detected on the timescale of years or decades, this dependence should be smooth so we corrected cycle numbers for MU Cam and found parabolic dependence:

$$T(E) = 2454085.50721(14) + 0.0137409414(13) \cdot E - 1.520(13) \cdot 10^{-12} \cdot E^2\,. \tag{5}$$

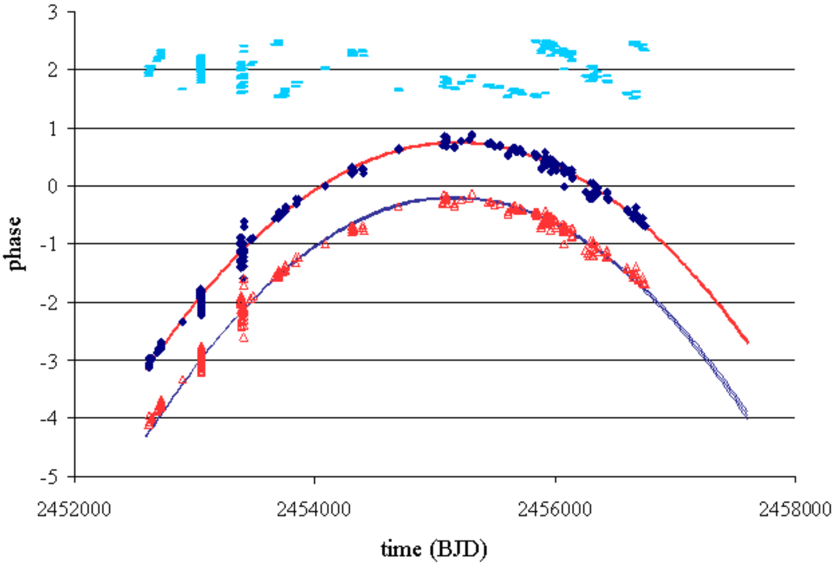

Figure 1. Dependence of phase of MU Cam spin maxima on time. Cycle count for constant period model (*top*) and variable period model (*middle and bottom*). Weighted (*red*) and non-weighted (*blue*) polynomial approximation are presented with corresponding error corridors.

The Q coefficient is 114 times higher of it's error estimate and is statistically significant. So we may see the decrease of the spin period of the white dwarf (the spin-up of the white dwarf). The characteristic time of the spin-up is $\tau = 170 \pm 1.5$ thousand years. If we will take into account individual error estimates of maxima timings (i.e. weighted polynomial fit) we got slightly different parameters:

$$T(E) = 2454085.50766(25) + 0.0137409545(16) \cdot E - 1.635(23) \cdot 10^{-12} \cdot E^2 . \qquad (6)$$

Here the Q coefficient is only 70 times higher of it's error estimate but still is statistically significant. The characteristic time of the spin-up is $\tau = 158.1 \pm 2.2$ thousand years. This value is 30 times smaller then 4.71 million years observed for the intermediate polar EX Hya (Andronov and Breus, 2013), but only 2 times smaller then 290 thousand years for BG CMi (Kim et al., 2004)

4 V405 AURIGAE

The intermediate polar V405 Aur was discovered as an optical counterpart of the soft ROSAT source 1RXS J055800.7+535358 (Haberl et al., 1994). The soft X-Ray flux was changing with a period of 272.74 s, which was supposed to be a spin period of the white dwarf. The presence of optical pulsations at a period of 272.785 ± 0.003 s was reported (Ashoka et al., 1995).

Later two independent announcements (Allan et al., 1995; Skillman, 1996) were made that the spin period of the white dwarf in V405 Aur is twice longer (545.45 s). It was justified by detection of circular polarization with a period of $P = 0.006301 \pm 0.000055$ d (544.4 ± 4.8) s and semi-amplitude of 1.80 ± 0.16 percent (Shakhovskoj and Kolesnikov, 1997).

The O-C analysis of the maxima timings obtained in 1994–2007 and second-order polynomial fit to the timings were published (Piirola et al., 2008):

$$T_{\max} = \mathrm{HJD} \sim 2449681.46389(5) + 0.0063131474(4)E + 4(4) \cdot 10^{-16} E^2 \,. \tag{7}$$

The quadratic term is formally positive (corresponding to a period increase) it is not statistically significant.

We analysed photometric CCD observations obtained using different telescopes in Slovakia (Kolonica and Hlohovec), Hungary (Baja), Ukraine (Crimea), USA (Arkansas Tech University Observatory) and got 93 spin maxima timings (Breus et al., 2013). The O-C diagram for historical timings (Piirola et al., 2008), maxima timings published later and our own ones was analysed. Contrary to a suggestion of Piirola et al., the points for the recent years show a distinct period decrease. We considered 4 models of period variations, the most probable were the 3-rd order weighted fit to the phases of maxima:

$$\begin{aligned} T_{\max} = \mathrm{HJD}\, 2452867.07807(2) + 0.006313147760(131) \cdot (E - E_0) - \\ - 502(237) \times 10^{-18} (E - E_0)^2 - 239(80) \times 10^{-23} (E - E_0)^3 \,. \end{aligned} \tag{8}$$

It corresponds to all observations better then quadratic one and fits most recent observations showing a negative trend (see Fig. 2). Also we checked a hypothesis of periodic change of O-C. We calculated the periodogram using the approximation combining a 1-st order trigonometric and a 1-st order algebraic polynomials. The maximum peak at the periodogram corresponds to a period of $2268^{\mathrm{d}} = 6.2$ yr. The corresponding fit is

$$\begin{aligned} \phi = -0.00049(219) + 0.0000002(14) \times (T - 2452881) + \\ + 0.0315(32) \cos\big(2\pi \cdot (T - 2452389)/2268\big) \,. \end{aligned} \tag{9}$$

As these periodic variations are statistically significant (at a level of semi-amplitude of 9.7σ), we suggested a third body orbiting the inner binary system with a period of ≈ 6.2 yr, with a distance of the center of masses to the binary of $(5.15 \pm 0.53) \times 10^9$ meters). The corresponding mass function is $F(M) \approx 0.09\, M_\odot$, so a third body may be a low-mass red dwarf (Breus et al., 2013). But, the latest observations show us continuation of period decrease, thus we should confirm it by new observations and return to the 3-rd order polynomial fit.

5 FO AQUARII

The intermediate polar FO Aqr is known for many years. Observations were obtained in Slovakia (Vihorlat Astronomical Observatory) and Hungary (Baja Astronomical Observatory). Periodogram analysis revealed that the photometric period of the system is

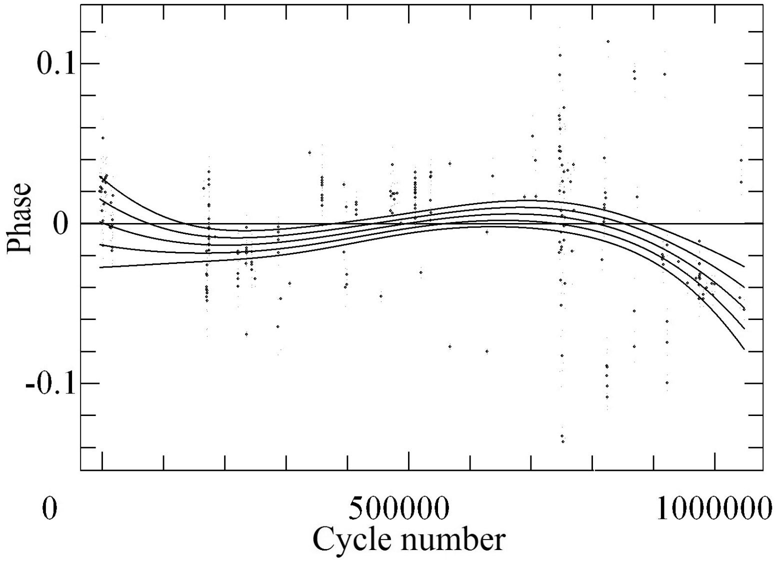

Figure 2. Dependence of phases of maxima timings of V405 Aur on cycle number of the spin period: *circles* – original observations, *line* – an approximation using 3-rd order polynomial fit with corresponding $\pm 1\sigma$ and $\pm 2\sigma$ error corridors.

$0^{d}.014312(5)$ that was a daily alias of the spin period of the white dwarf published before. So we concluded that the period during our observations was $0^{d}.014521(3)$ with an initial epoch for the maximum brightness of 2455068.72430(36) (Breus et al., 2012). The previous published values of the spin period were $0^{d}.01451905$ (Patterson et al., 1998) and $0^{d}.01451718$ (Williams, 2003) so, the spin period is significantly shorter than earlier.

We collected spin maxima timings for more then 30 years and carried out the O-C analysis (see Fig. 3). At the beginning the observations were regular and no cycle miscount was done. Later on, there was a gap for almost 6 years after which we have started our own monitoring. So, we have 2 branches on the O-C diagram, which are separated with a gap and there is no published timings or time series which could help in filling this gap with points to restore the correct cycle numbering. This shows a very high importance of regular studies of such short period objects. Opposite to other objects, period variations of FO Aqr are complicated. From 1981 to 1987, the white dwarf showed a spin-down, then it changed to a spin-up.

6 EX HYDRAE

The intermediate polar EX Hya is another "old" variable star, according to the SAO/NASA Astrophysics Data System (ADS) the first publication on it was in 1957. We observed this object using remotely-controlled telescopes TOA150 (15cm) and BigMak (35cm) at the Tzec Maun observatories (`http://tzecmaun.org/`) in 2010–2011. For the O-C analysis we used as moments of maxima of our own and published patrol observations, as published moments. In total we used 452 moment of maxima, that cover 49 years.

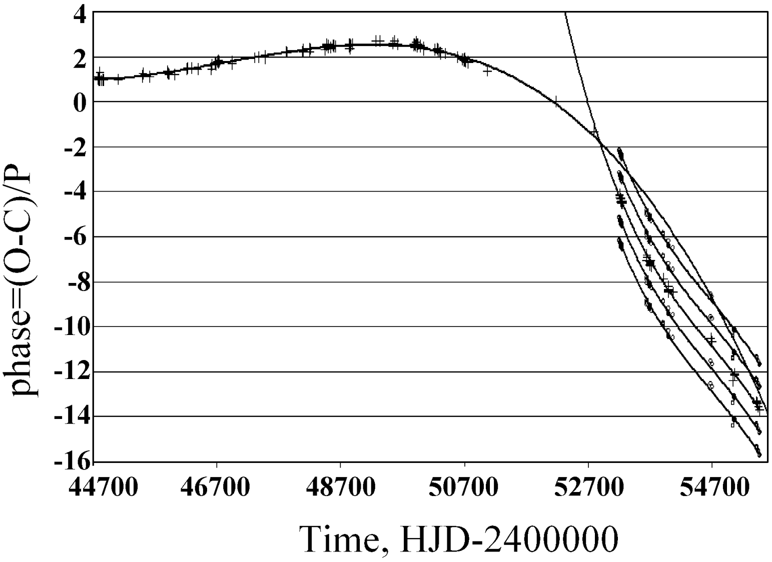

Figure 3. Dependence of phase of FO Aqr spin maxima on time with 2 branches – based on own and compiled observations. Best fit 3-rd order polynomials are shown for different cycle difference between the branches.

As a result of previous analysis (Mauche et al., 2009) the ephemeris was published:

$$T(E) = 2437699.8917(6) + 0.046546484(9) \cdot E - \\ - 7.3(4) \times 10^{-13} \cdot E^2 + 2.2(6) \times 10^{-19} \cdot E^3 \,. \quad (10)$$

Authors suggested the presence of a statistically significant cubic coefficient Q_3. Using the program MCV we determined the statistically optimal degree of the polynomial for O-C approximation and it was equal to two. So, analysed timings do not confirm the assumption of the presence of a statistically significant cubic term in ephemeris by Mauche (Mauche et al., 2009). O-C diagram and it's $\pm 1\sigma$ and $\pm 2\sigma$ error corridors are shown on Fig. 4.

We obtained the ephemeris for spin maxima

$$T_{\max} = 2437699.89079(59) + 0.0465464808(69) \cdot E - 6.3(2) \times 10^{-13} \cdot E^2 \,. \quad (11)$$

The Q coefficient corresponds to the characteristic time of the spin-up of $\tau = 4.67(14) \times 10^6$ years.

7 V1323 HERCULIS

The intermediate polar V1323 Her (previously known as RXS J180340.0+401214) was regularly observed in Slovakia (Kolonica and Hlohovec) and Korea (Chungbuk National University Observatory). The light curve shows that the orbital variability is almost absent,

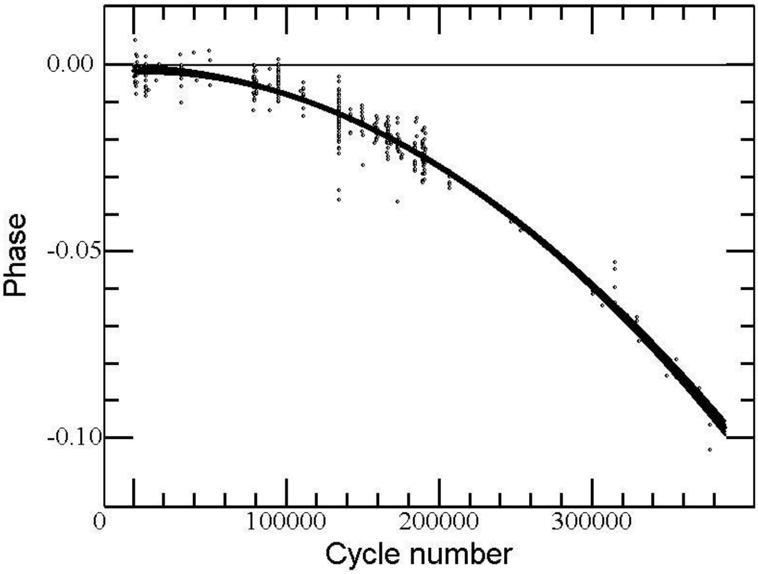

Figure 4. O-C diagram for spin maxima of the EX Hya, calculated for the values of the initial epoch $T_0 = 2437699.8920$ (Vogt et al., 1980) and the period $P_0 = 0^d.046546484$ (Mauche et al., 2009).

no eclipses were found, suggesting a low orbit inclination (less then 70 degrees). The photometric wave is originated due to a spin rotation of the white dwarf, during which the viewing conditions of the accretion columns are continuously changing. So the variability seems to be due to the geometric conditions (changing of the angle between stream and beam of view in the rotation), rather than for the physical ones (instability of the accretion column – that really is present, but not periodic). One hump shape at the phase light curve argues for a high inclination of the magnetic axis in this system, so we see mainly an upper accretion column.

From periodogram analysis of our first observations in 2007 we obtained the value of the spin period of 1520.4509 ± 0.0022 seconds (25.34 minutes). It had 30 times better accuracy then published earlier value because of more time series obtained during longer time interval were used. Later on, the O-C analysis (see Fig. 5) showed the necessity of improvement of this value. However, due to a published epoch of minimum instead of maximum (Teichgraeber et al., 2007), previous attempt to fit all timings (Andronov et al., 2011) were not successive. So, we determined a new linear ephemeris for the spin maxima:

$$T_{\max} = 2454604.04449(14) + 0.017596986(3) \cdot E\,. \tag{12}$$

We checked quadratic polynomial approximation. The coefficient $Q = (9 \pm 5) \times 10^{-14}$ formally corresponds to characteristic time scale of period variations of $\tau = (4.6 \pm 2.5) \times 10^6$ years, but the parameter is equal to 1.9 of its error estimate and thus is not statistically significant (Andronov et al., 2012). So, we conclude that contrary to other intermediate polars, no spin period variations were detected in V1323 Her.

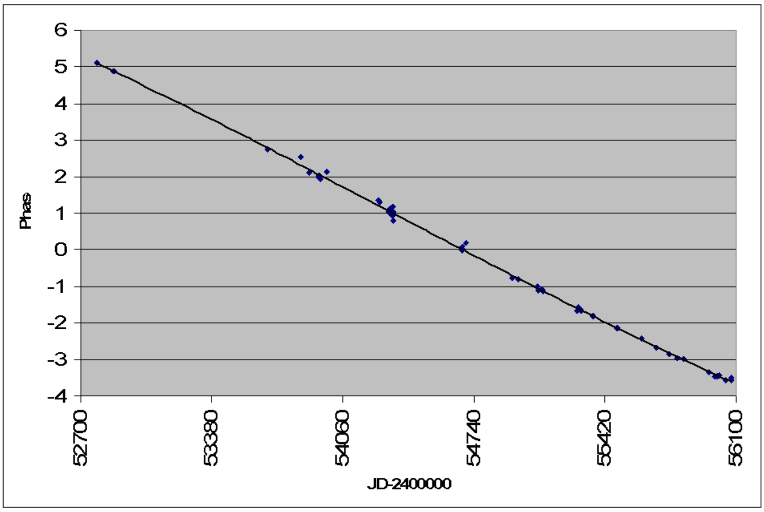

Figure 5. O-C diagram of the V1323 Her for the spin maxima timings.

8 V2306 CYG

The pulsating X-ray source 1WGAJ1958.2+3232 was discovered using ROSAT observations (Israel et al., 1998). From the spectroscopy and photometry an orbital period of 4 h 36 m and the pulsation period of 733 s were found (Zharikov et al., 2001). Later on, orbital period 5.387 h was reported (Norton et al., 2002), corresponding to the −1 day alias of the previous value (Zharikov et al., 2001). Just after it, Zharikov et al. repeated the analysis using own photometric and spectroscopic data along with the data by A. Norton and confirmed their previously found orbital period of 4 h 35 m (Zharikov et al., 2002). The star was named as V2306 Cyg in 2003. For V2306 Cyg, we obtained large dataset with the timespan of 4 years mainly in Hlohovec and Krakow observatories, between 2010 and 2014. Additionally, we analysed all 14 CCD time series from the AAVSO data archive. Extrema timings were determined. Unfortunately, short timespan and high error estimates does not allow us to find spin period variations. We used linear fit to the O-C which shows that the spin period is $0^d.008487557(9)$ instead of $0^d.00848$ At the same time, periodogram analysis shows different peaks, including the published values of the orbital period and it's aliases, and many of these peaks are even higher. We built O-C diagram for the orbital minima timings (see Fig. 6) and found a few cycles per year miscount, which gave us the linear trend on the O-C. So, we can conclude that the correct orbital period may be 0.2232685(24) days or 0.181545(3) days, which are daily aliases of each other and are close to (Norton et al., 2002; Zharikov et al., 2002)respectively.

9 CONCLUSIONS

Period variations are frequently observed in intermediate polars and are typically detectable at a time scale of decades. Some objects do not show a statistically significant period change (e.g. V1323 Her (Andronov et al., 2012) and V2306 Cyg), some show a period

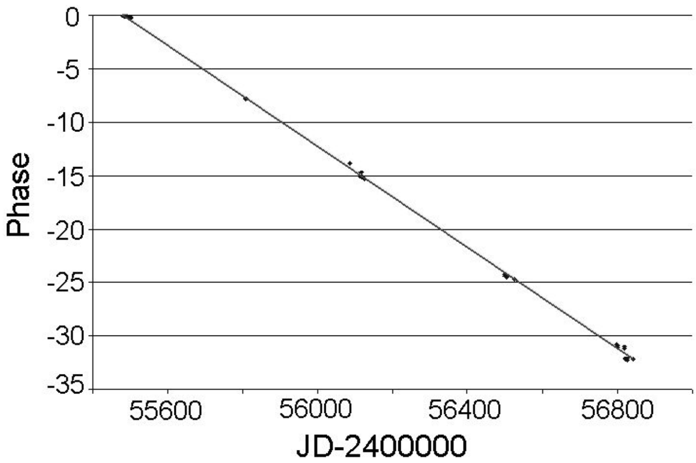

Figure 6. O-C diagram of the V2306 Cyg orbital minima timings.

decrease (e.g. MU Cam, EX Hya (Andronov and Breus, 2013), V405 Aur (Breus et al., 2013), BG CMi (Kim et al., 2004)), some show more complicated spin period variations (e.g. FO Aqr (Breus et al., 2012)). From theoretical expectations, the spin periods of the white dwarf should be equal to some equilibrium value, which is equal to period of "Kepler" rotation of the inner accretion disk at a distance of the magnetospheric radius (Warner, 1997; Hellier, 2001). Period variations may be caused by changes of the accretion rate due to modulation of the mass transfer caused by magnetic activity of the red secondary (Andronov and Shakun, 1990) fluctuations of the orbital separation (Andronov and Chinarova, 2002), or precession of the magnetic white dwarf (which will be present either with constant, or variable accretion rate), (Andronov, 2005). At time scales of decades, one may see only a part of the curve of cyclic variations. Thus apparently the "O-C" diagram may be not a "wave", but a square (for smaller time intervals) or cubic parabola (for larger intervals).

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REFERENCES

Allan, A., Horne, K. and Hilditch, R. W. (1995), RX J0558+53, *IAU Circ.*, **6154**, p. 2.

Andronov, I. L. (2003), Multiperiodic versus noise variations: mathematical methods, in C. Sterken, editor, *Interplay of Periodic, Cyclic and Stochastic Variability in Selected Areas of the H-R Diagram*, volume 292 of *Astronomical Society of the Pacific Conference Series*, p. 391.

Andronov, I. L. (2005), Spin-Up and Spin-Down of Magnetic White Dwarfs in Cataclysmic Variables: Theory vs Long-Term Monitoring, in D. Koester and S. Moehler, editors, *14th European Workshop on White Dwarfs*, volume 334 of *Astronomical Society of the Pacific Conference Series*, p. 447.

Andronov, I. L. and Baklanov, A. v. (2004), *Astron. School Reports*, **5**, p. 264.

Andronov, I. L. and Breus, V. V. (2013), Variability of the Rotation Period of the White Dwarf in the Magnetic Cataclysmic Binary System EX Hya, *Astrophysics*, **56**, pp. 518–530, arXiv: `1308.1805`.

Andronov, I. L., Breus, V. V. and Zola, S. (2012), Determination of Characteristics of Newly Discovered Eclipsing Binary 2MASS J18024395 +4003309 = Vsx J180243.9+400331, *Odessa Astronomical Publications*, **25**, p. 150, arXiv: `1212.6741`.

Andronov, I. L. and Chinarova, L. L. (2002), Third component in cataclysmic variables: Additional mechanism for accretion rate changes?, in B. T. Gänsicke, K. Beuermann and K. Reinsch, editors, *The Physics of Cataclysmic Variables and Related Objects*, volume 261 of *Astronomical Society of the Pacific Conference Series*, p. 47.

Andronov, I. L., Chinarova, L. L., Han, W., Kim, Y. and Yoon, J.-N. (2008), Multiple timescales in cataclysmic binaries. The low-field magnetic dwarf nova DO Draconis, *Astronomy and Astrophysics*, **486**, pp. 855–865, arXiv: `0806.1995`.

Andronov, I. L., Kim, Y. K., Yoon, J.-N., Breus, V. V., Smecker-Hane, T. A., Chinarova, L. L. and Han, W. (2011), Two-Color CCD Photometry of the Intermediate Polar 1RXS J180340.0+401214, *Journal of Korean Astronomical Society*, **44**, pp. 89–96.

Andronov, I. L. and Shakun, L. I. (1990), Alternating cycle durations in dwarf novae, *apss*, **169**, pp. 237–240.

Araujo-Betancor, S., Gänsicke, B. T., Hagen, H.-J., Rodriguez-Gil, P. and Engels, D. (2003), 1RXS J062518.2+733433: A new intermediate polar, *Astronomy and Astrophysics*, **406**, pp. 213–219, arXiv: `astro-ph/0305270`.

Ashoka, B. N., Marar, T. M. K., Seetha, S., Kasturirangan, K. and Bhattacharyya, J. C. (1995), Detection of optical pulsations from RX J0558.0+5353., *Astronomy and Astrophysics*, **297**, p. L83.

Breus, V. V., Andronov, I. L., Dubovsky, P., Kolesnikov, S. V., Zhuzhulina, E. A., Hegedus, T., Beringer, P., Petrik, K., Robertson, J. W., Ryabov, A. V., Kudzej, I. and Shakhovskoy, N. M. (2013), Variability of the Spin Period of the White Dwarf in the Intermediate Polar V405 Aur: Low-Mass Third Body or Precession?, *Journal of Physical Studies*, **17**, iD: 3902.

Breus, V. V., Andronov, I. L., Hegedus, T., Dubovsky, P. A. and Kudzej, I. (2012), Two-period variability of the intermediate polar FO Aqr, *Advances in Astronomy and Space Physics*, **2**, pp. 9–10.

Haberl, F., Throstensen, J. R., Motch, C., Schwarzenberg-Czerny, A., Pakull, M., Shambrook, A. and Pietsch, W. (1994), Discovery of the new intermediate polar RX J0558.0+5353, *Astronomy and Astrophysics*, **291**, pp. 171–180.

Hellier, C. (2001), *Cataclysmic Variable Stars*, Springer.

Hric, L., Breus, V., Katysheva, N. A., Shugarov, S. Y. and Dubovský, P. (2014), The new period of the intermediate polar v709 cas, *Astronom. Nachr.*, **335**(4), pp. 362–366, ISSN 1521-3994, URL `http://dx.doi.org/10.1002/asna.201312044`.

Israel, G. L., Angelini, L., Campana, S., Giommi, P., Stella, L. and White, N. E. (1998), The discovery of 12-min X-ray pulsations from 1WGA J1958.2+3232, *Monthly Notices Roy. Astronom. Soc.*, **298**, pp. 502–506, arXiv: `astro-ph/9802119`.

Kim, Y., Andronov, I. L. and Jeon, Y.-B. (2004), CCD Photometry Using Multiple Comparison Stars, *Journal of Astronomy and Space Sciences*, **21**, pp. 191–200.

Kim, Y.-G., Andronov, I. L., Park, S.-S., Chinarova, L. L., Baklanov, A. V. and Jeon, Y.-B. (2005), Two-Color VR CCD Photometry of the Intermediate Polar 1RXS J062518.2+733433, *Journal of Astronomy and Space Sciences*, **22**, pp. 197–210.

Mauche, C. W., Brickhouse, N. S., Hoogerwerf, R., Luna, G. J. M., Mukai, K. and Sterken, C. (2009), Updated spin ephemeris for the cataclysmic variable EX Hydrae, *Information Bulletin on Variable Stars*, **5876**, p. 1, arXiv: `0902.1977`.

Norton, A. J., Quaintrell, H., Katajainen, S., Lehto, H. J., Mukai, K. and Negueruela, I. (2002), Pulsations and orbital modulation of the intermediate polar 1WGA J1958.2+3232, *Astronomy and Astrophysics*, **384**, pp. 195–205, arXiv: `astro-ph/0201088`.

Patterson, J. (1994), The DQ Herculis stars, *Publications of the Astronomical Society of the Pacific*, **106**, pp. 209–238.

Patterson, J., Kemp, J., Richman, H. R., Skillman, D. R., Vanmunster, T., Jensen, L., Buckley, D. A. H., O'Donoghue, D. and Kramer, R. (1998), Rapid Oscillations in Cataclysmic Variables. XIV. Orbital and Spin Ephemerides of FO Aquarii, *Publications of the Astronomical Society of the Pacific*, **110**, pp. 415–419.

Piirola, V., Vornanen, T., Berdyugin, A. and Coyne, S. J., G. V. (2008), V405 Aurigae: A High Magnetic Field Intermediate Polar, *Astrophys. J.*, **684**, pp. 558–568, arXiv: `0805.4289`.

Shakhovskoj, N. M. and Kolesnikov, S. V. (1997), RX J0558.0+5353, *IAU Circ.*, **6760**, p. 2.

Skillman, D. R. (1996), Photometry of the New DQ HER Star, RX J0558.0+5353, *Publications of the Astronomical Society of the Pacific*, **108**, p. 130.

Staude, A., Schwope, A. D., Krumpe, M., Hambaryan, V. and Schwarz, R. (2003), 1RXS J062518.2+733433: A bright, soft intermediate polar, *Astronomy and Astrophysics*, **406**, pp. 253–257, arXiv: `astro-ph/0304323`.

Teichgraeber, C., Wood, M. A., Patterson, J., Monard, B., Rea, R. and Kemp, J. (2007), Updates on Two New Cataclysmic Variable Systems: 1RXS J173021.5-055933 and 1RXS J180340.0+401214, *Journal of the Southeastern Association for Research in Astronomy*, **1**, pp. 24–27.

Vogt, N., Krzeminski, W. and Sterken, C. (1980), Periodic and secular variations in the lightcurve of dwarf nova EX Hydrae, *Astronomy and Astrophysics*, **85**, pp. 106–112.

Warner, B. (1997), Book review: Cataclysmic variables stars, *Irish Astronomical Journal*, **24**, p. 85.

Williams, G. (2003), CCD Photometry of the Intermediate Polars FO Aquarii and AO Piscium, *Publications of the Astronomical Society of the Pacific*, **115**, pp. 618–625.

Zharikov, S. V., Tovmassian, G. H. and Echevarría, J. (2002), On the orbital period of the Intermediate Polar 1WGA J1958.2+3232, *Astronom. and Astrophys. Lett.*, **390**, pp. L23–L26, arXiv: `astro-ph/0206303`.

Zharikov, S. V., Tovmassian, G. H., Echevarría, J. and Cárdenas, A. A. (2001), The orbital period of intermediate polar 1WGA J1958.2+3232, *Astronomy and Astrophysics*, **366**, pp. 834–839, arXiv: `astro-ph/0009049`.