The cataclysmic variable AE Aquarii: orbital variability in V band

R. Zamanov & G. Latev
Institute of Astronomy and National Astronomical Observatory, Bulgarian Academy of Sciences, Tsarigradsko Shose 72, BG-1784 Sofia, Bulgaria
rkz@astro.bas.bg glatev@astro.bas.bg

(Submitted on 28.11.2016. Accepted on 31.01.2017)

Abstract. We present 62.7 hours observations of the cataclysmic variable AE Aqr in Johnson V band. These are non-published archive electro-photometric data obtained during the time period 1993 to 1999. We construct the orbital variability in V band and obtain a Fourier fit to the double-wave quiescent light curve. The strongest flares in our data set are in phase interval 0.6 - 0.8.
The data can be downloaded from http://www.astro.bas.bg/∼rz/DATA/AEAqr.elphot.dat.

Key words: Stars: novae, cataclysmic variables – Accretion, accretion disks – white dwarfs – Stars: individual: AE Aqr

1 Introduction

AE Aqr is a bright intermediate polar cataclysmic variable ($V \approx 11 - 12.3$). In this semi-detached binary system a spotted K type dwarf (K0-K4 IV/V star) transfers material through the inner Lagrangian point L_1 toward a magnetic white dwarf (Skidmore et al. 2003, Hill et al. 2016). It has a relatively long orbital period of 9.88 hours (Robinson et al. 1991; Echevarría et al. 2008) and an extremely short rotational period of the white dwarf of only 33 s (Patterson et al. 1980). To appear in such a state, AE Aqr should be a former supersoft X-ray binary, in which the mass transfer rate in the recent past ($\approx 10^7$ yr) has been much higher than its current value (Schenker et al. 2002). The high mass transfer rate in the past is the likely reason why it is hosting one of the fastest rotating white dwarfs known. The white dwarf rapidly spins down at a rate 5.64×10^{-14} s s^{-1} (de Jager et al. 1994).

The observations obtained till now do not demonstrate clear evidence for an accretion disc. XMM-Newton observations indicate, that the plasma cannot be a product of mass accretion onto the white dwarf (Itoh et al. 2006). Neither phase-averaged gamma-ray emission nor gamma-ray variability is detected in the detailed Fermi-LAT data analysis (Li et al. 2016). Given the lack of evidence of accretion, speedy magnetic propeller (Eracleous & Horne 1996; Wynn, King & Horne 1997) and ejector (Ikhsanov, Neustroev & Beskrovnaya 2004; Ikhsanov & Beskrovnaya 2012) are supposed to operate in this star. The hydrodynamical calculations imply that the magnetic field does not prevent entirely the formation of a transient ring-like disc surrounding the magnetosphere (Isakova et al. 2016).

Here we explore the behaviour of AE Aqr in the optical V band, construct the orbital variability, and obtain a fit to the double-wave quiescent light curve.

Table 1. Electrophotometric V band observations of AE Aqr. The columns give date of observation (in format YYYYMMDD), UT-start and UT-end of the run, number of the data points in the run.

date	UT start - end hh:mm – hh:mm	N_{pts}
19930726	20:18 - 00:56	1293
19930727	21:07 - 00:50	1050
19930728	19:51 - 00:40	1411
19930917	18:04 - 22:14	1284
19930918	19:03 - 22:10	418
19940616	23:13 - 00:54	522
19940807	20:04 - 23:21	1004
19940808	19:34 - 00:02	1326
19940901	18:53 - 23:09	1318
19940902	19:17 - 23:01	1192
19950620	22:31 - 23:52	348
19950731	21:34 - 22:59	612
19950930	17:25 - 18:43	435
19980720	21:59 - 00:59	818
19980721	21:09 - 00:37	1133
19980723	20:51 - 00:27	1185
19980801	20:32 - 00:43	1312
19990810	20:01 - 23:38	1168
19990811	20:05 - 23:02	895
19990813	20:19 - 22:34	751
19990814	19:54 - 23:06	1026
19990816	20:03 - 23:15	998
19990817	19:43 - 23:12	1165

Table 2. Orbital variability of AE Aqr in V band. The columns give phase interval, median V band magnitude, standard deviation, number of the data points, average V_q, standard error of V_q, number of the data points over which V_q is calculated.

phase	median V	σ	N_{pts}	V_q	$\sigma_N(V_q)$	$N_{pts}(V_q)$
0.00 – 0.04	11.7697	0.132	889	11.8455	0.0022	445
0.04 – 0.08	11.7690	0.201	842	11.8847	0.0023	421
0.08 – 0.12	11.7564	0.221	737	11.8396	0.0023	369
0.12 – 0.16	11.7067	0.095	690	11.7596	0.0018	345
0.16 – 0.20	11.5962	0.068	562	11.6475	0.0021	279
0.20 – 0.24	11.5243	0.069	606	11.5692	0.0018	301
0.24 – 0.28	11.5194	0.093	688	11.5552	0.0015	343
0.28 – 0.32	11.5596	0.101	798	11.5982	0.0013	398
0.32 – 0.36	11.6007	0.055	967	11.6493	0.0017	484
0.36 – 0.40	11.6770	0.073	893	11.7391	0.0018	447
0.40 – 0.44	11.7455	0.105	834	11.8159	0.0024	416
0.44 – 0.48	11.7873	0.122	1125	11.8676	0.0027	563
0.48 – 0.52	11.8184	0.128	1106	11.9014	0.0031	553
0.52 – 0.56	11.8098	0.165	1098	11.8669	0.0020	550
0.56 – 0.60	11.7132	0.203	1012	11.7835	0.0021	505
0.60 – 0.64	11.6200	0.283	1035	11.6929	0.0021	517
0.64 – 0.68	11.5982	0.271	1011	11.6403	0.0012	504
0.68 – 0.72	11.5315	0.214	868	11.6074	0.0018	433
0.72 – 0.76	11.4989	0.128	1250	11.5552	0.0014	625
0.76 – 0.80	11.5283	0.196	1146	11.5711	0.0012	573
0.80 – 0.84	11.5643	0.174	1037	11.6222	0.0018	518
0.84 – 0.88	11.5739	0.155	925	11.6641	0.0027	463
0.88 – 0.92	11.6280	0.171	807	11.7136	0.0035	404
0.92 – 0.96	11.6994	0.139	873	11.7670	0.0027	436
0.96 – 1.00	11.7207	0.121	802	11.8055	0.0030	401

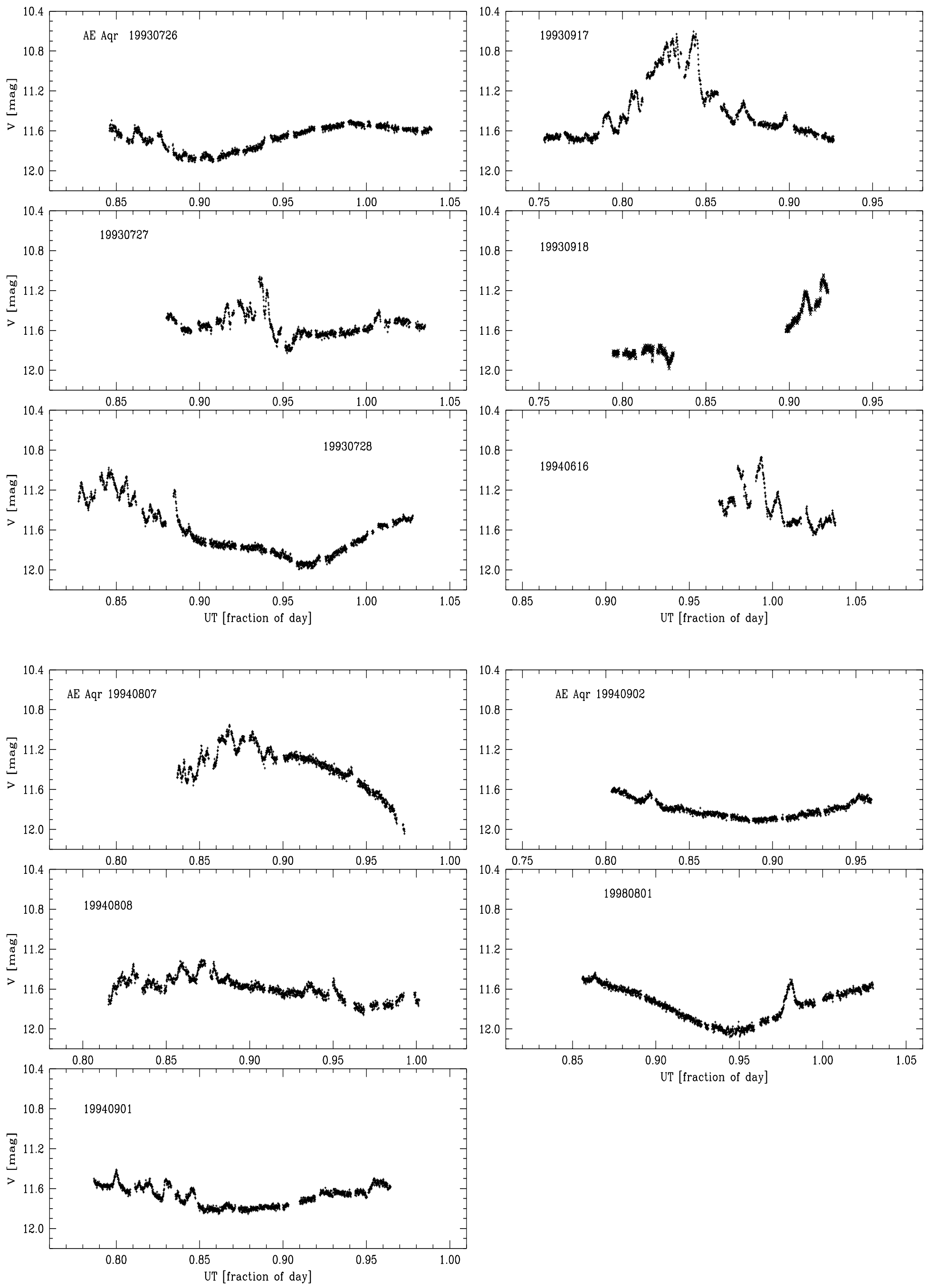

Fig. 1. V band photometry of AE Aqr.

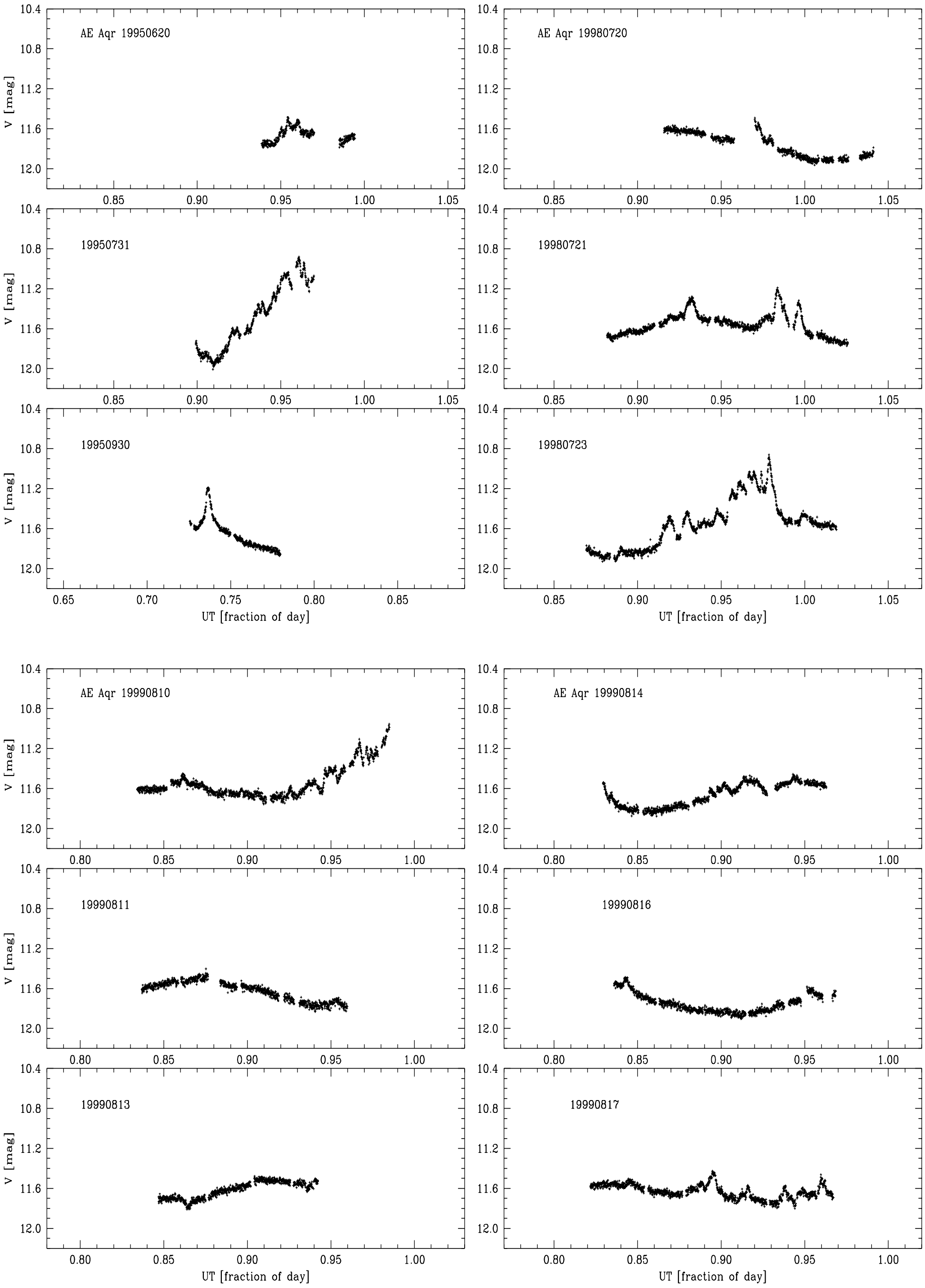

Fig. 1. Continuation.

2 Observations

The observations were performed with the 60-cm telescope of the National Astronomical Observatory Rozhen equipped with a single-channel photon counting photometer (Panov et al. 1982). For the comparison star BD-01 4018, we adopt V=10.010, B-V=0.981 magnitudes as given in AAVSO Photometric All Sky Survey (APASS) DR9 (Henden et al. 2016; Henden & Munari 2014).

The integration time was set 10 seconds for all cases. APR software (Kirov, Antov & Genkov 1991) was used for data processing. The accuracy of our V photometry was of about 0.01-0.02 mag. Journal of observations is given in Table 1. Our observations are plotted on Fig. 1. Although the observations are secured during the period 1993-1999 they have not been analyzed till now.

During 23 nights, we obtained $N_{pts} = 22601$ integrations of 10 seconds each. This is equivalent to 62.7 hours observations of AE Aqr. Adding to this the observations of the comparison star and the sky background, the total telescope time spent in making the observations is about 70 hours.

During our observations the brightness of AE Aqr varied in the range $10.60 \le V \le 12.08$, with mean V=11.61 and standard deviation of the mean 0.20 mag.

3 Orbital light curve

A distinctive peculiar property of AE Aqr is the rapid flaring of its brightness. In the optical bands AE Aqr exhibits atypical flickering consisting of large optical flares with amplitude $\lesssim 1$ magnitude in Johnson V band. The flares are superimposed on a double-wave quiescent light curve, which appears as a well defined lower envelope of the light curve when the data are folded with the orbital period (e.g. Chincarini & Walker 1974).

In Fig.2 are plotted all our data folded with the orbital period. The data are repeated over two cycles for clarity. We use the ephemeris

$$HJD = 2439030.78496 + 0.4116554800\, E, \tag{1}$$

obtained on the basis of the radial velocity curves (Echevarría et al. 2008). To define the quiescent light curve, we do the following:

- we separated the data in 25 non-overlapping bins – 0.04 in phase each;
- in each bin we calculated the median value;
- we removed the data above the median value and calculated the average value of the remaining data points;
- the quiescent light curve is shown with red squares in Fig.2.

The double-wave quiescent light curve is well defined in our data. This double-wave is due to the ellipsoidal shape of the K-type dwarf mass donor. A three-term truncated Fourier fit to the double-wave quiescent light curve gives

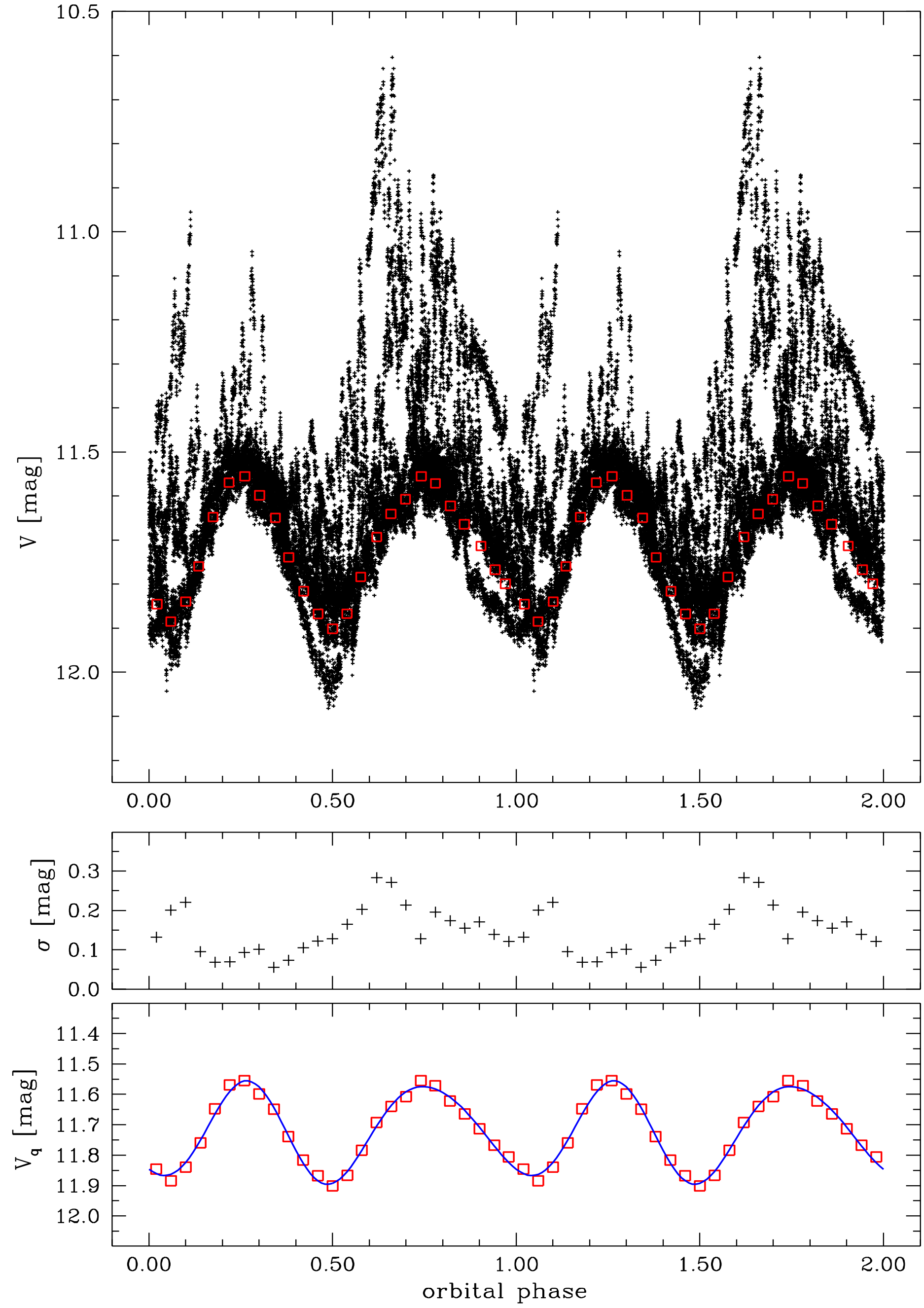

Fig. 2. Orbital variability of AE Aqr in V band. In the upper panel are plotted the observations in V band together with the calculated V_q (red squares), in the mid panel – standard deviation (σ), in lower panel – the calculated quiescent light curve V_q (red squares) and the fit given by Eq.2.

$$V_q = 11.7185 - 0.00542\cos 2\pi\phi + 0.1511\cos 4\pi\phi - 0.0177\cos 6\pi\phi + 0.0211\sin 2\pi\phi + 0.0196\sin 4\pi\phi + 0.0286\sin 6\pi\phi \quad (2)$$

where V_q is the V band magnitude of the quiescent light. The most important term in Eq.2 is $\cos 4\pi\phi$, as expected for a double-wave curve.

Average quiescent V-band curves of AE Aqr are shown in Fig.5 of van Paradijs et al. (1989). As can be seen there the averaged quiescent phase profile is variable between 1964/65, 1970 and 1985 observations. Our data taken during 1993-1998 display an orbital light curve, which is different again, however regarding the maximums of the ellipsoidal variability it is similar to that in 1964/65.

4 Discussion

The stochastic light variations on timescales of a few minutes (flickering) with amplitude of a few×0.1 magnitudes is a type of variability observed in the three main classes of binaries that contain white dwarfs accreting material from a companion mass-donor star: cataclysmic variables (CVs), supersoft X-ray binaries, and symbiotic stars (e.g. Sokoloski 2003).

A distinctive peculiar property of AE Aqr is the rapid flaring of its brightness. In the optical bands AE Aqr exhibits non-typical variability pattern consisting of large optical flares with amplitude $\lesssim 1$ magnitude in Johnson V band. The flares are visible about one third of the time and have typical rise time $200 - 400$ s (van Paradijs, van Amerongen & Kraakman, 1989; Zamanov et al. 2012). The flares are also visible in the X-rays (Mauche et al. 2012) and in sub-millimeter wavelengths (Torkelsson 2013). The flares are superimposed on a double-wave quiescent light curve. This property AE Aqr does not share with any of the known cataclysmic variables. The only system possibly similar to AE Aqr is the supersoft X-Ray source CAL 83 (Odendaal et al. 2015).

During our observations AE Aqr was active exhibiting flares about one third of the time. This is similar to what is observed in 1984-1985 (van Paradijs et al. 1989). In the upper panel of Fig. 2, it is visible that the strongest flares are observed about orbital phases 0.6-0.8. To confirm this visual impression we calculated σ for each bin. σ is plotted in the mid panel of Fig. 2. The highest values of σ are at about phases 0.6-0.7. The values of σ are higher in the phase range 0.55 - 1.05 in comparison with the phase interval 0.05-0.55. Our observations do not confirm early finding of Bruch & Grütter (1997) that probability for strong variations is higher in the first half of the orbit.

Conclusions: We report 62.7 hours ($N_{pts} = 22601$ exposures) electrophotometric observations in Johnson V band of the cataclysmic variable AE Aqr. The double-wave quiescent light curve is isolated and fitted. The Fourier fit to the quiescent light curve should provide useful input for theoretical modeling and analysis.

Acknowledgments: This work is partly supported by the Program for career development of young scientists, Bulgarian Academy of Sciences (grant DFNP-105).

References

Bruch, A., & Grutter, M. 1997, Acta Astron., 47, 307

Chincarini, G., & Walker, M. F. 1974, In: Electrography and astronomical applications; Proceedings of the Conference (A75-23926 09-89) Austin, University of Texas, p. 249

Chincarini, G., & Walker, M. F. 1981, A&A, 104, 24

de Jager, O. C., Meintjes, P. J., O'Donoghue, D., & Robinson, E. L. 1994, MNRAS, 267, 577

Echevarría, J., Smith, R. C., Costero, R., Zharikov, S., & Michel, R. 2008, MNRAS, 387, 1563

Eracleous, M., & Horne, K. 1996, ApJ, 471, 427

Henden, A. A., Templeton, M., Terrell, D., et al. 2016, VizieR Online Data Catalog, 2336,

Henden, A., & Munari, U. 2014, Contributions of the Astronomical Observatory Skalnate Pleso, 43, 518

Hill, C. A., Watson, C. A., Steeghs, D., Dhillon, V. S., & Shahbaz, T. 2016, MNRAS, 459, 1858

Ikhsanov, N. R., Neustroev, V. V., & Beskrovnaya, N. G. 2004, Astronomy Letters, 30, 675

Ikhsanov, N. R., & Beskrovnaya, N. G. 2012, Astronomy Reports, 56, 595

Isakova, P. B., Ikhsanov, N. R., Zhilkin, A. G., Bisikalo, D. V., & Beskrovnaya, N. G. 2016, Astronomy Reports, 60, 498

Itoh, K., Okada, S., Ishida, M., & Kunieda, H. 2006, ApJ, 639, 397

Kirov N. K., Antov A. P., Genkov V. V., 1991, Comptes rendus de l'Académie bulgare des Sciences, 44, 5

Li, J., Torres, D. F., Rea, N., et al. 2016, ApJ, arXiv:1608.06662

Mauche, C. W., Abada-Simon, M., Desmurs, J.-F., et al. 2012, Mem. Soc. Astron. Italiana, 83, 651

Munari, U., Henden, A., Frigo, A., et al. 2014, AJ, 148, 81

Odendaal, A., Meintjes, P. J., Charles, P. A., & Rajoelimanana, A. F. 2015, Acta Polytechnica CTU Proceedings, 2, 94

Panov, K.P., Pamukchiev, I. Ch., Christov, P. P., Petkov, D. I., Notev, P. T., Kotsev, N. G., 1982, Comptes rendus de l'Académie bulgare des Sciences, 35, No. 6, 717

Patterson, J., Branch, D., Chincarini, G., & Robinson, E. L. 1980, ApJ, 240, L133

Robinson, E. L., Shafter, A. W., & Balachandran, S. 1991, ApJ, 374, 298

Schenker, K., King, A. R., Kolb, U., Wynn, G. A., & Zhang, Z. 2002, MNRAS, 337, 1105

Skidmore, W., O'Brien, K., Horne, K., et al. 2003, MNRAS, 338, 1057

Sokoloski, J. L. 2003, Symbiotic Stars Probing Stellar Evolution, ASP Conf. 303, 202

Torkelsson, U. 2013, Feeding Compact Objects: Accretion on All Scales,IAU Symp. 290, 145

van Paradijs, J., van Amerongen, S., & Kraakman, H. 1989, A&AS, 79, 205

Wynn, G. A., King, A. R., & Horne, K. 1997, MNRAS, 286, 436

Zamanov , R. K., Latev, G. Y., Stoyanov, K. A., et al. 2012, Astronomische Nachrichten, 333, 736