Times of Minima and New Ephemerides for Southern Hemisphere Eclipsing Binary Stars Observed in 2015

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Abstract Observers from Australia and New Zealand used video equipment to time eclipses of short-period binary stars. The objects were typically south of –20º declination and had periods of less than a day. Many of those systems had very few observations since their discovery and some of them had not been observed for fifty or more years. We present 44 times of minima of 42 stars, provide revised ephemerides for 7 of these systems, and characterize an orbital period change for RW PsA.

1. Introduction

The development of a new technique for observing eclipsing binary stars (Pavlov and Mallama 2015) enabled observers with video equipment, typically involved in observing occultations, to participate in the observation of short-period variable stars, too. The method allows for determination of times of minima (TOMs) from observations made on a single night, based on a video record which is typically between 3 and 6 hours long. The large number of southern systems that are seldom studied makes the video technique a very useful and important addition to the work done by occultation observers in the southern hemisphere. Those taking part in this program already had the necessary video and timing equipment as well as significant experience using it.

2. Observations and analysis

The data reported here are based on observations done from February through December 2015. Video photometry was performed with the instruments listed in Table 1. The GPS-based video time inserters IOTA-VTI (Video Timers 2011) and KIWI-OSD were used to provide time information accurate to milliseconds of UTC. Eclipses were observed over a period of at least 1.5 hours on each side of the minima. Author HP used a Sloan r' photometric filter, while authors BL and SK observed without a photometric filter only targets that were above 30 degrees altitude.

The observations were recorded on computers running Windows using the OCCUREC software package (Pavlov 2014a). The photometric processing was done with the TANGRA software package (Pavlov 2014b) using aperture photometry and subtraction of the average background. The number of video measurements obtained per timing was on the order of 10,000. TOMs were derived using the Eclipsing Binary add-in for TANGRA (Mallama and Pavlov 2015b) which implements the algorithm of Kwee and van Woerden (1956).

The vast majority of the stars were contact or semi-detached systems. Most of them had a period of less than 1 day with 46% of the stars having a period of less than 0.5 day.

For many of the observed targets the predictions for the TOMs were not very accurate because of the lack of historical observations. Author HP built a software application (MINCALC) that aggregates data from a number of online resources, including the *General Catalogue of Variable Stars* (GCVS; Kholopov *et al.* 1985), the All-Sky Automated Survey Catalogues (ASAS; Pojmański 1997), the Krakow ephemeris (Kreiner 2004), and the O–C Gateway (Paschke 2015), in order to compute more accurate predictions and also provide an error estimate. Still, in several cases the minima turned out to be a few hours away

Table 1. Equipment used by the observers.

Observer	*Initials*	*AAVSO Observer Initials*	*Telescope*	*Camera*	*Timing*
Kerr	SK	KSH	50-mm Olympus Zuiko	WAT-120N+	IOTA-VTI
Loader	BL	—	250-mm Meade Schmidt-Cassegrain	WAT-910BD	KIWI-OSD
Pavlov	HP	PHRA	350-mm Meade Schmidt-Cassegrain	WAT-910BD	IOTA-VTI

The WAT-910BD video cameras were used in a TACOS-BD system (Gault et al. 2014) and the WAT-120N+ camera was used out of the box.

from the MINCALC prediction and additional observations had to be done on subsequent nights in order to obtain sufficient data for deriving a TOM.

The observed TOMs for 42 stars and their O–C values from the Krakow and GCVS ephemerides are presented in Table 2.

3. Revised ephemerides and an orbital period change

O–C diagrams for stars listed in Table 2 were evaluated in order to assess which ephemerides require an update. For each candidate star that was identified, an epoch and a period were fit to all the available TOMs by the method of least squares. Corresponding uncertainties for the new epoch and period were also computed. In cases where the earlier TOMs resulted in

Table 2. Times of minima of southern stars determined using the video technique in 2015.

Star	*Type*	*Obs.*	*Time of Minima (HJD)*	*Uncertainty*	*O–C (GCVS)*	*O–C (Krakow)*
SY Aps	II	HP	2457299.9593	0.0003	+0.0007	+0.0047
V653 Ara	I	HP	2457231.9567	0.0002	–0.0721	+0.0257
EZ Car	II	HP	2457101.0132	0.0004	+0.0343	–0.0017
PX Car	I	HP	2457108.9472	0.0001	–0.1365	+0.0006
BD Cen	II	HP	2457148.0673	0.0003	–0.2499	+0.0066
OV Cen	I	HP	2457149.9871	0.0004	+0.0176	–0.0017
V606 Cen	I	HP	2457156.0428	0.0002	+0.0303	+0.0200
V676 Cen	I	HP	2457151.0120	0.0001	+0.0698	0.0000
V689 Cen	II	HP	2457174.9407	0.0001	+0.0030	+0.0014
TW Cet	I	HP	2457230.2168	0.0002	–0.0299	–0.0014
RW CrA	I	HP	2457230.9457	0.0003	+0.0045	–0.0060
V405 CrA	I	HP	2457254.9972	0.0007	–0.0173	–0.0057
V634 CrA	II	HP	2457151.1775	0.0003	–0.0434	+0.0056
TW Cru	I	HP	2457081.1541	0.0005	+0.0659	+0.0045
AC Cru	II	HP	2457147.9210	0.0002	–0.2049	+0.0018
BF Cru	II	HP	2457099.9710	0.0004	–0.0103	+0.0117
RW Dor	II	HP	2457299.0086	0.0001	–0.0352	+0.0013
RW Dor	I	BL	2457370.9473	0.0003	–0.0333	+0.0034
CI Eri	I	HP	2457298.1954	0.0001	–0.2666	+0.0038
RV Gru	II	HP	2457157.1673	0.0001	–0.0519	–0.0004
SZ Hor	I	HP	2457267.2071	0.0007	–0.1065	–0.0078
RY Ind	I	HP	2457231.196	0.0010	+0.0008	–0.0044
FT Lup	I	BL	2457198.859	0.0002	–0.0721	–0.0046
TW Mus	II	HP	2457114.0737	0.0004	+0.0598	–0.0092
LT Pav	II	HP	2457109.2152	0.0005	+0.0671	+0.0120
MU Pav	I	HP	2457249.1956	0.0001	+0.1165	+0.0120
NP Pav	I	HP	2457255.1803	0.0002	+0.0964	+0.0097
RW PsA	I	HP	2457175.2077	0.0001	–0.0725	–0.0404
AY Pup	I	HP	2457146.9264	0.0005	–0.0766	+0.0111
DS Pup	II	HP	2457113.9639	0.0003	+0.0747	–0.0181
DS Pup	I	HP	2457158.8561	0.0001	+0.0747	–0.0181
V743 Sgr	I	HP	2457150.1689	0.0002	–0.0599	–0.0381
V902 Sgr	II	HP	2457149.1605	0.0005	–0.0612	–0.0492
V1071 Sgr	I	BL	2457224.8786	0.0004	–0.0918	+0.0083
V1647 Sgr	I	SK	2457248.9224	0.0002	–0.0491	–0.0095
V833 Sco	I	HP	2457156.2538	0.0002	–0.1214	+0.0021
RT Scl	I	HP	2457297.9961	0.0002	–0.0580	–0.0255
RS Sct	I	BL	2457272.8844	0.0005	–0.0242	+0.0064
GN TrA	I	HP	2457137.2000	0.0002	+0.0442	–0.0194
BF Vel	I	HP	2457175.9211	0.0002	–0.0505	–0.0139
EQ Vel	I	HP	2457080.9902	0.0004	–0.0179	+0.0221
EU Vel	II	HP	2457148.9619	0.0003	+0.0812	–0.0211
FM Vel	II	HP	2457081.9843	0.0003	+0.0688	+0.0203
FQ Vir	I	BL	2457184.8609	0.0001	+0.0033	–0.0001

The eclipse type indicates "I" for primary or "II" for secondary. The O–C values are given for both the General Catalogue of Variable Stars *(Kholopov et al. 1985) and the Krakow ephemerides (Kreiner 2004).*

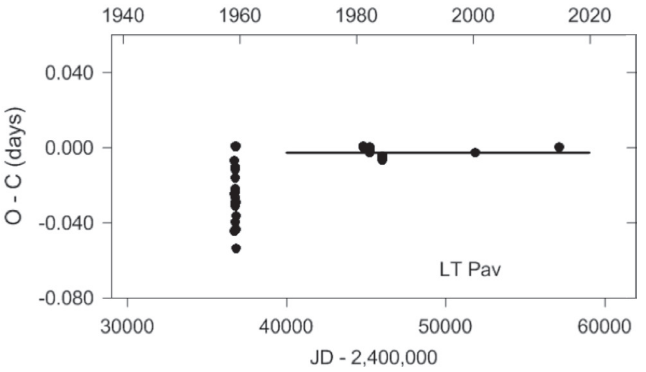

Figure 1. LT Pav. O–C residuals for the ephemeris in Table 3. The span of the best fit line indicates the range of data used in the least squares computation.

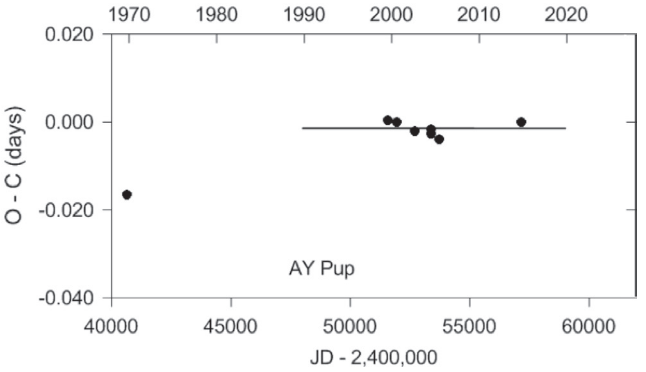

Figure 2. AY Pup. O–C residuals for the ephemeris in Table 3. The span of the best fit line indicates the range of data used in the least squares computation.

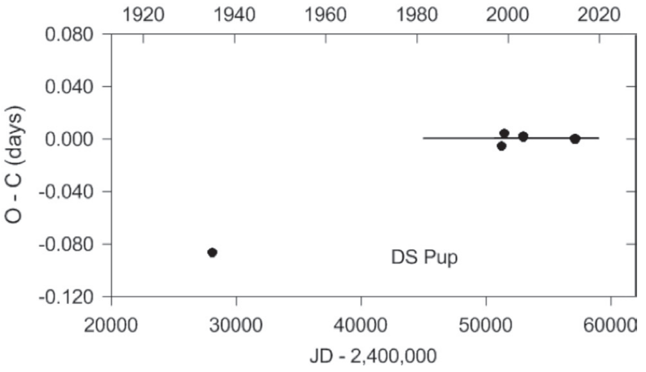

Figure 3. DS Pup. O–C residuals for the ephemeris in Table 3. The span of the best fit line indicates the range of data used in the least squares computation.

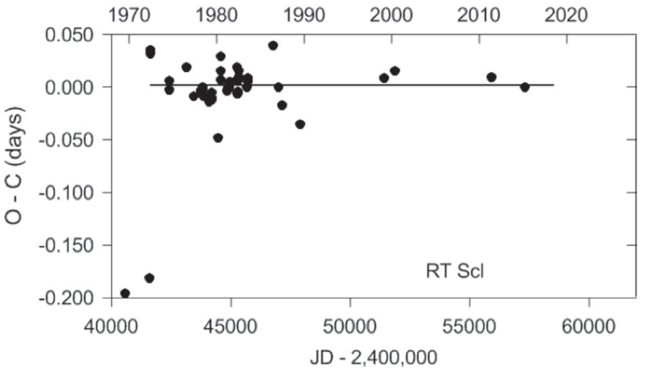

Figure 4. RT Scl. O–C residuals for the ephemeris in Table 3. The span of the best fit line indicates the range of data used in the least squares computation.

Table 3. Revised ephemeris for stars with new periods differing by more than 3.0 standard deviations from the Krakow periods.

Star	*HJD Epoch*	*Uncertainty*	*Period (d)*	*Uncertainty*	*Krakow (d)*	*Sigma*
LT Pav	2457109.4093	0.0022	0.393673633	0.000000078	0.393673300	4.2
RW PsA	2457175.2093	0.0026	0.360447226	0.000000280	0.360450200	10.6
AY Pup	2457146.9249	0.0020	0.468958832	0.000000223	0.468957900	4.2
DS Pup	2457158.8566	0.0025	0.388676139	0.000000239	0.388677700	6.5
V743 Sgr	2457150.1694	0.0025	0.276635676	0.000000081	0.276636800	13.9
V902 Sgr	2457149.1605	0.0016	0.293943837	0.000000066	0.293945670	27.8
RT Scl	2457297.9981	0.0095	0.511557652	0.000000396	0.511558840	3.0

Table 4. RW PsA.

Type: W UMa contact binary
V magnitude range: 11.05–11.76

Period after 2000: 0.360447226 ± 0.000000280 (days)
Period before 2000: 0.360450732 ± 0.000000247 (days)
Difference: –0.000003506 ± 0.000000373 (Δ days)
Difference: –0.303 ± 0.032 (Δ seconds)

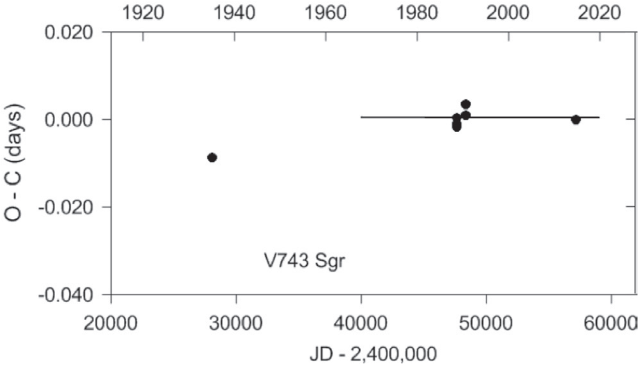

Figure 5. V743 Sgr. O–C residuals for the ephemeris in Table 3. The span of the best fit line indicates the range of data used in the least squares computation.

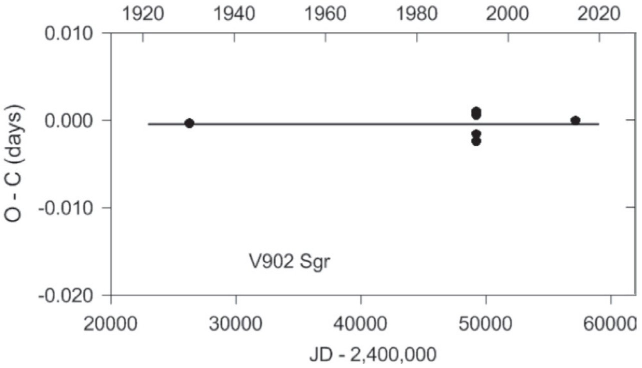

Figure 6. V902 Sgr. O–C residuals for the ephemeris in Table 3. The span of the best fit line indicates the range of data used in the least squares computation.

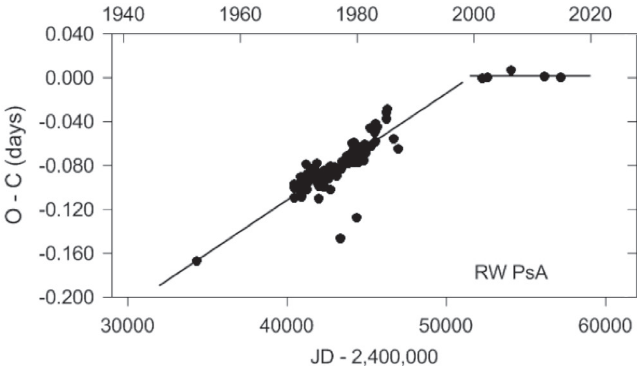

Figure 7. RW PsA O–C diagram showing the period change that occurred around year 2000. The two lines are best fits to the TOMs before and after year 2000.

large O–Cs to the best fit line, those were omitted from a second least squares solution in order to improve the fit to more recent TOMs.

The new periods which were determined for the stars LT Pav, RW PsA, DS Pup, AY Pup, RT Scl, V743 Sgr, and V902 Sgr differed by at least 3.0 standard deviations from those given on the Krakow (Kreiner 2004) web site. The new ephemerides are listed in Table 3 along with differences in standard deviations (sigma) from Krakow periods. The O–C diagrams for all of the stars listed above except RW PsA are shown in Figures 1-6. RW PsA is discussed next.

A distinct orbital period change is evident in the O–C diagram for RW PsA shown in Figure 7. The large size of this change (~0.3 second) is rather surprising considering that the period appears to have remained approximately constant for 50 years before 2000 and for the 15 years following. Information about RW PsA itself and the period change are given in Table 4.

4. Summary and conclusions

The method for timing eclipses of binary stars developed by Pavlov and Mallama (2015) has been expanded into an observing program. The first goal of this program is to obtain TOMs for short-period southern hemisphere stars which have not been regularly observed in the past. In this paper we added TOMs for 42 stars to those of the 8 stars reported on in the original paper.

The second goal of our program is to revise the ephemerides of systems when needed. We have updated the ephemerides of seven stars in this paper.

The third goal is to investigate orbital period changes for stars of particular interest. An example is V752 Cen, for which we found an abrupt period change accompanied by an anomalous and temporary dimming (Mallama and Pavlov 2015a). In the present study we characterize the large period change for RW PsA which occurred around the year 2000.

5. Acknowledgements

This research used information from the International Variable Star Index (VSX) database (Watson *et al.* 2014), operated at AAVSO, Cambridge, Massachusetts, USA.

Bob Nelson's O–C files (Nelson 2014) were used extensively in this study, especially as a source of historical TOM data.

The planning of the observations relied heavily on the meteorological forecast data provided by 7Timer (Ye 2011).

References

Gault, D., *et al.* 2014, The Watec WAT-910BD TACOS System (http://www.kuriwaobservatory.com/TACOS_BD-System.html).

Kholopov, P. N., *et al.* 1985, *General Catalogue of Variable Stars*, 4th Ed., Moscow.

Kreiner, J. M. 2004, *Acta Astron.*, **54**, 207 (http://www.as.up.krakow.pl/ephem).

Kwee, K. K., and van Woerden, H. 1956, *Bull. Astron. Inst. Netherlands*, **12**, 327.

Mallama, A., and Pavlov, H. 2015a, *J. Amer. Assoc. Var. Star Obs.*, **43**, 38.

Mallama, A., and Pavlov, H. 2015b, Eclipsing Binaries Add-in for TANGRA (http://www.hristopavlov.net/tangra3/eb.html).

Nelson, R. 2014, Eclipsing Binary O–C Files (http://www.aavso.org/bob-nelsons-o-c-files).

Paschke, A. 2015, O–C Gateway (http://var.astro.cz/ocgate).

Pavlov, H. 2014a, OCCUREC Software Package for Astronomical Video Recording (http://www.hristopavlov.net/occurec).

Pavlov, H. 2014b, TANGRA3 Software Package for Video Photometry (http://www.hristopavlov.net/tangra3).

Pavlov, H., and Mallama, A. 2015, *J. Amer. Assoc. Var. Star Obs.*, **43**, 80.

Pojmański, G. 1997, *Acta Astron.*, **47**, 467.

Video Timers. 2011, IOTA-VTI video time inserter (http://videotimers.com/home.html).

Watson, C., Henden, A. A., and Price, C. A. 2014, AAVSO International Variable Star Index VSX (Watson+, 2006–2014; http://www.aavso.org/vsx).

Ye, Q.-Z. 2011, *Publ. Astron. Soc. Pacific*, **123**, 113.