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SOUTHERN ECLIPSING BINARY MINIMA AND LIGHT ELEMENTS IN 2017

RICHARDS, TOM [1]; BLACKFORD, MARK[2]; BUTTERWORTH, NEIL[3]; CRAWFORD, GREG[4], JENKINS, ROBERT[5];

1. Pretty Hill Observatory, Kangaroo Ground, Vic., Australia, tomprettyhill@gmail.com
2. Congarinni Observatory, Congarinni, NSW, Australia.
3. Townsville Observatory, Mount Louisa, Qld., Australia.
4. Bagnall Beach Observatory, Corlette, NSW, Australia
5. Theta Observatory, Salisbury, SA, Australia.

Abstract: We present 101 minima estimates of 40 southern eclipsing binaries obtained in 2017 by members of the Southern Eclipsing Binary group of Variable Stars South using DSLR and CCD detectors. Where sufficient minima estimates of a target are obtained, we report the light elements derived from those minima, together with *O-C* comparisons with light elements in the literature.

1 Introduction

We present 101 times of minima of 40 southern hemisphere eclipsing binary stars acquired in 2017 (and a few earlier). These observations were acquired and analyzed by the authors who are members of the Southern Eclipsing Binary group of Variable Stars South (SEB-VSS) (http://www.variablestarssouth.org). For seven of the systems we have derived light elements and present those as well as *O-C* values for our zero epochs as calculated from the original light elements in the literature. This paper is the third in a series, following (Richards *et al*. 2016, 2017).

2 Observations and Analysis

Equipment and software used are set out in Table 1. Observer initials abbreviate the name of an author of this paper, surname last. Instrument refers to the telescope and objective diameter in cm, or to the DSLR camera used. Remaining columns refer to the software used for the purposes listed. Software references are AIP4Win (Berry & Burnell 2005); BackyardEOS (http://www.otelescope.com/store/category/2-backyardeos/); Canopus (http://www.minorplanetobserver.com/MPOSoftware/MPOCanopus.htm); MaxIm DL (http://www.cyanogen.com); Minima25e (www.variablestarssouth.org); Muniwin (http://c-munipack.sourceforge.net); PERANSO (http://www.peranso.com); and VStar (www.aavso.org/vstar-overview). All observers using PERANSO employed polynomial fitting for minima estimation; the same for Vstar. Canopus uses the Hertzsprung method (Hertzsprung 1928, described in Henden & Kaitchuck, 1982). Minima25e takes the weighted mean and standard deviation of the means of six methods: parabolic fit, tracing paper, bisectors of chords, Kwee-van Woerden (Kwee & Van Woerden 1956), Fourier fit, and sliding integrations.

Table 1. Observers, equipment and software.

Observer	Instrument	Imaging	Calibration	Photometry	Minima
TR	41 cm R-C + SBIG STXL-6303e	MaxIm	Muniwin	Muniwin	Minima25 (multiple methods)
MB (DSLR)	Canon 600D & 1100D DSLRs*	MaxIm	MaxIm	MaxIm	PERANSO (polynomial fit)
MB (CCD)	35-cm R-C + SBIG STT-3200	TheSkyX Professional	MaxIm	MaxIm	PERANSO (polynomial fit)
NB	Canon 550D	Canon EOS utility	AIP4Win	AIP4Win	PERANSO
GC	28cm SCT + SBIG STT8300	MaxIm	MaxIm	Canopus	Canopus
RJ	25 cm Newtonian + QSI-583 CCD.	MaxIm	MaxIm	MaxIm	Vstar, Minima25

*Both cameras used at prime focus of an Orion ED80T refractor; the 1100D also used with a 200mm telephoto lens.

CCD or DSLR image sets were obtained in hours-long runs. Each observer analysed their own image sets as follows:

1. Calibrated them using bias frames, dark frames and flat field frames.
2. Executed differential aperture photometric measurements on the calibrated sets.
3. Performed minima estimation on the photometric data.

3 Results

Table 2 lists the minima estimates. Columns 1 and 2 list the GCVS designation and GCVS variability type of the target stars in lexical order of constellation abbreviation, as listed in Samus et al. (2017). In some cases, more recent work may propose different variability types. Columns 3 and 4 record the heliocentric Julian dates of minima and the uncertainty (in days) as reported by the method used in the software. Column 5 lists the minimum type, primary (P) or secondary (S). We define the primary minimum as the deeper one in our observations where that can be determined, otherwise we assume the epoch recorded in the AAVSO Variable Star Index (Watson, Henden & Price, 2006) - hereafter referred to as VSX - is of a primary minimum. Column 6 gives the filter used: B and V are Johnson *B* and *V*, or the transformed equivalent in the case of DSLR colour sensors; C is clear or unfiltered. R is Cousins *R*, and i' is Sloan *i'*. Column 7 gives the initials of the observer.

Table 2. Minima estimates.

ID	Type	HJD of min	error	Min	Filter	Obs
MR Aps	EB	2457851.0402	0.0003	P	V	RJ
MR Aps	EB	2457925.998	0.004	P	V	RJ
EE Aqr	EB	2457964.1304	0.0010	P	V	MB
EE Aqr	EB	2457967.1842	0.0008	P	V	MB

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ID	Type	HJD of min	error	Min	Filter	Obs
EE Aqr	EB	2457979.147	0.002	S	V	MB
EE Aqr	EB	2458046.0782	0.0010	P	V	MB
V0610 Ara	EW	2457898.056	0.003	P	V	NB
V0610 Ara	EW	2457984.962	0.004	P	V	NB
V0454 Car	EB	2457782.1636	0.003	S	V	MB
V0454 Car	EB	2458115.0107	0.003	P	V	MB
V0901 Cen	EW	2457806.0622	0.0002	P	R	TR
V0901 Cen	EW	2457806.2377	0.0002	S	R	TR
V0901 Cen	EW	2457849.9859	0.0002	P	R	TR
V0901 Cen	EW	2457850.1643	0.0002	S	S	TR
V0711 CrA	EB	2457980.002	0.004	P	V	NB
YY Gru	EW	2458014.9844	0.0005	P	R	MB
YY Gru	EW	2458015.1315	0.0006	S	R	MB
YY Gru	EW	2458016.1550	0.0003	P	C	MB
YY Gru	EW	2458024.0565	0.0004	P	C	MB
YY Gru	EW	2458024.2035	0.0005	S	C	MB
SZ Hor	EW/KW	2458094.2075	0.0008	P	V	MB
SZ Hor	EW/KW	2458100.1459	0.0003	S	V	MB
SZ Hor	EW/KW	2458101.0831	0.0004	P	V	MB
SZ Hor	EW/KW	2458102.0209	0.0004	S	V	MB
CP Hyi	EW	2458018.081	0.003	S	V	MB
CP Hyi	EW	2458019.039	0.003	S	V	MB
CP Hyi	EW	2458019.999	0.003	S	V	MB
CP Hyi	EW	2458024.073	0.003	P	V	MB
CR Ind	EW	2457997.0743	0.0002	S	i’	TR
CR Ind	EW	2457997.2686	0.0003	P	i’	TR
CR Ind	EW	2458030.0977	0.0005	P	V	TR
CR Ind	EW	2458042.9946	0.0005	P	V	TR
CU Ind	EW	2458029.1371	0.0005	S	V	TR
CU Ind	EW	2458041.1092	0.0002	P	V	TR
FT Lup	EB/D	2457868.0092	0.0010	S	V	GC
FT Lup	EB/D	2457872.9494	0.0008	P	V	GC
FT Lup	EB/D	2457875.299	0.005	P	V	GC
FT Lup	EB/D	2457879.059	0.009	P	V	GC
FT Lup	EB/D	2457880.0003	0.0004	P	V	GC
FT Lup	EB/D	2457880.940	0.009	P	V	GC
GG Lup	EA	2457966.8771	0.0011	S	V	MB
CZ Mic	EA	2457957.9602	0.0007	P	V	GC
CZ Mic	EA	2457976.129	0.003	P	V	GC
CZ Mic	EA	2457978.1483	0.0009	P	V	GC
CZ Mic	EA	2457979.1584	0.0005	P	V	GC

ID	Type	HJD of min	error	Min	Filter	Obs
CZ Mic	EA	2457984.2054	0.0003	P	V	GC
DI Mic	EW	2457980.0832	0.0003	P	V	GC
DI Mic	EW	2457982.0883	0.0007	P	V	GC
DI Mic	EW	2457982.9461	0.0002	P	V	GC
DI Mic	EW	2457988.1076	0.0002	P	V	GC
BR Mus	EW/KE	2457810.2367	0.0013	P	R	TR
BR Mus	EW/KE	2457816.2231	0.0012	S	R	TR
BS Mus	EB/KE	2457831.2397	0.0005	S	Rc	TR
BS Mus	EB/KE	2457914.982	0.008	S	V	RJ
BS Mus	EB/KE	2457928.041	0.007	S	V	RJ
eta Mus	EA	2457936.039	0.004	P	V	MB
eta Mus	EA	2457954.003	0.004	S	V	MB
TV Mus	EW/KW	2457792.075	0.002	S	R	TR
TW Mus	EW/KW	2457841.1014	0.0002	S	R	TR
V1010 Oph	EB/KE	2457952.9182	0.0012	S	V	MB
KZ Pav	EA/SD	2455798.9647	0.0019	P	V	MB
KZ Pav	EA/SD	2455817.0139	0.0016	P	V	MB
KZ Pav	EA/SD	2456167.0440	0.0019	S	V	MB
KZ Pav	EA/SD	2457267.0027	0.0017	S	V	MB
KZ Pav	EA/SD	2457273.1769	0.0011	P	V	MB
KZ Pav	EA/SD	2457935.2434	0.0011	P	B	MB
MW Pav	EW	2457935.052	0.003	P	V	MB
AU Phe	EW	2458079.0778	0.0003	S	V	TR
BL Phe	EB	2458054.030	0.003	S	V	MB
BL Phe	EB	2458066.996	0.003	S	V	MB
CT Phe	EA	2458044.074	0.003	S	V	TR
YZ Phe	EW	2458069.9935	0.0008	S	V	TR
YZ Phe	EW	2458070.1106	0.0002	P	V	TR
XZ PsA	EW	2457961.166	0.003	S	V	MB
XZ PsA	EW	2457980.005	0.004	S	B	MB
GZ Pup	EW/KW	2458113.1199	0.0002	S	V	TR
GZ Pup	EW/KW	2458119.0455	0.0005	P	V	TR
HI Pup	EW/KW	2457816.0433	0.0006	P	R	TR
HI Pup	EW/KW	2457819.0727	0.0008	P	R	TR
UX Ret	EW	2457774.040	0.002	P	V	NB
UX Ret	EW	2458094.0786	0.0010	P	V	MB
UX Ret	EW	2458099.9602	0.0009	P	V	MB
UX Ret	EW	2458100.2046	0.0013	S	V	MB
CP Scl	EW	2458066.0568	0.0004	S	V	TR
V0883 Sco	EA	2457909.047	0.006	P	V	NB
V0883 Sco	EA	2457922.068	0.008	P	V	NB

ID	Type	HJD of min	error	Min	Filter	Obs
V1055 Sco	EW	2457924.090	0.002	P	V	NB
RS Sgr	EA/SD	2457957.0222	0.0016	P	V	MB
V0505 Sgr	EA/SD	2457952.1343	0.0010	P	V	MB
V0505 Sgr	EA/SD	2457955.0932	0.0029	S	V	MB
V4197 Sgr	EW/KE	2457956.0307	0.0015	P	V	MB
V4197 Sgr	EW/KE	2457959.9624	0.0015	S	V	MB
V4197 Sgr	EW/KE	2457963.180	0.002	P	V	MB
AQ Tuc	EW	2458098.0831	0.0007	P	V	RJ
AQ Tuc	EW	2458098.9752	0.0006	S	V	TR
DX Tuc	EW	2457982.0934	0.0018	S	V	MB
DX Tuc	EW	2457983.0355	0.0018	P	V	MB
DX Tuc	EW	2457983.2241	0.0019	S	V	MB
FM Vel	EW/KW	2457770.0879	0.0006	P	V	GC
FM Vel	EW/KW	2457804.9493	0.0015	S	V	GC
FM Vel	EW/KW	2457810.9877	0.0004	P	V	TR

Where four or more primary minima were determined for a binary, either in Table 2 or in previous papers in this series (Richards *et al* 2016, 2017) we derived light elements from them in a spreadsheet using linear regression, as recorded in Table 3. (The only exception is for V610 Ara where secondary minima were used. The reason for this is explained below.) Column 1 shows the GCVS ID of the star. Columns 2 and 3 show the heliocentric Julian date and its standard error of our zero epoch E0 derived by the regression, using the regressed value of an observed primary minimum. Columns 4 and 5 list the period and its standard error derived by the regression. Column 6 lists the number of minima estimates used in the regression, and column 7 is the interval in days over which the minima observations were obtained. Columns 8-10 record the *O-C* value of our E0 in days, the *O-C* error and its cycle count, using VSX light elements as at May 2018.

Table 3. VSS light elements of binaries with four or more VSS primary minima estimates (Secondary for V0610 Ara).

ID	E0	E0 error	P	P error	N	Int	O-C	O-C err	Cycle
MR Aps	2457159.0121	0.0004	0.5278631	0.0000004	4	766	-0.0030	0.0004	7830
V0610 Ara	2457545.0038	0.0009	0.543158	0.000002	5	439	0.0322	0.0009	9296.5
V0454 Car	2456709.0963	0.0016	0.980416	0.000002	5	1073	0.0257	0.0016	8373
YY Gru	2456962.90740	0.00004	0.29265022	0.00000008	4	1117	0.00580	0.00004	17400
FT Lup	2457872.9473	0.0006	0.47019	0.00005	5	8	-0.0843	0.0006	27253
CZ Mic	2457957.9599	0.0007	1.00943	0.00003	5	27	-0.1139	0.0007	6020
DI Mic	2457980.0820	0.0013	0.28660	0.00008	4	8	-0.0307	0.0013	17742

The *O-C* error is just the E0 error in column 3, since in no case do the original light elements include uncertainties in period or epoch. Consequently the error value is significantly too small, especially where the cycle count is large. In the case of V0610 Ara it is apparent that the GCVS epoch (2452549.548) is at phase 0.5 with respect to the VSX epoch (2452495.508). All our eclipse observations are secondaries on the VSX elements, and hence primaries on the GCVS elements. Consequently we cannot compare eclipse depths to determine which if either is measurably deeper. The only information available is the folded ASAS-3 light curve (see Figure 1) which is too noisy to identify the deeper eclipse.

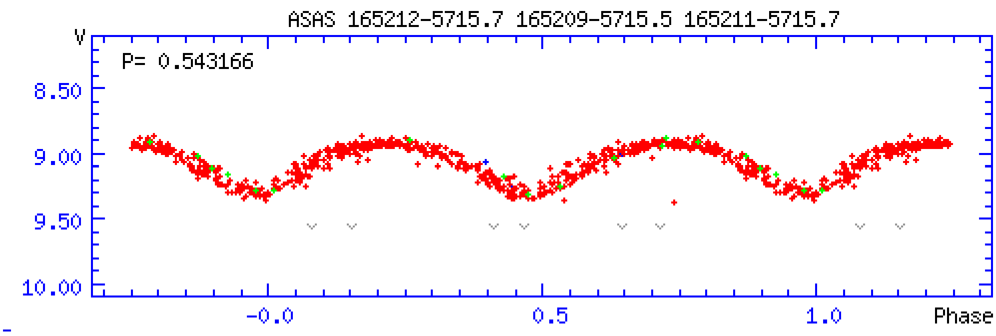

Figure 1. ASAS-3 light curve of V610 Ara.

4 Conclusions and further work

We have reported 101 minima estimates for 40 southern eclipsing binaries. We have reported light elements (zero epochs and periods with uncertainties) for seven of them for which we obtained four or more primary minima. We have provided *O-C* values of those zero epochs, calculated from the VSX light elements in the literature (except for 610 Ara, which used GCVS elements).

We are carrying out the following ongoing work on these stars as appropriate, as well as adding others to our observing list: (1) continue to monitor minima, to improve the light elements derived from our data; (2) investigate period change; (3) obtain full phased light curves in two or three bandpasses, to carry out photometric modelling of the systems. We intend to publish future minima estimates in further papers in this series.

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