# SOUTHERN ECLIPSING BINARY MINIMA AND LIGHT ELEMENTS IN 2016

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**Abstract:** We present 110 minima estimates of 42 southern eclipsing binaries obtained 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 110 times of minima of 42 southern hemisphere eclipsing binary stars acquired in 2016 (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 17 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 second in a series, the first is Richards et al. (2016).

## 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); Canopus, http://www.minorplanetobserver.com/MPOSoftware/MPOCanopus.htm; MaxIm DL, http://www.cyanogen.com; Minima25c, now at 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). Minima25c takes the weighted mean and standard error 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 + Apogee U9 CCD | MaxIm | Muniwin | Muniwin | PERANSO |
| MB | Canon 600D & 1100D DSLRs | MaxIm | MaxIm | MaxIm | PERANSO |
| TB | 20-cm Vixen VC200L + SBIG ST-10 CCD | CCDSoft | Mira Pro 7 | AIP4Win | Minima25c |
| NB | Canon 550D | BackyardEOS | AIP4Win | AIP4Win | PERANSO |
| SL | 30-cm SCT + Atik One 6.0 CCD | MaxIm | MaxIm | Canopus | Minima25c, Canopus |
| RJ | 25 cm Newtonian + QSI-583 CCD. | MaxIm | MaxIm | MaxIm | Vstar |
| JP | 200mm SCT + Atik 383L | MaxIm | MaxIm | MaxIm | PERANSO |

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 in the original light elements is of a primary minimum. The sources of the original light elements are recorded at the end of this section. Column 6 gives the filter used: *V* is Johnson *V*, or the transformed equivalent in the case of DSLR colour sensors; *C* is Clear or unfiltered. Column 7 gives the initials of the observer.

Table 2. Minima estimates.

| ID | Type | HJD | error | Min | Filter | Obs |
|---|---|---|---|---|---|---|
| NT Aps | EB | 2457533.1106 | 0.0014 | S | V | MB |
| NT Aps | EB | 2457533.2567 | 0.0016 | P | V | MB |
| TV Aps | E: | 2457598.0013 | 0.0008 | P | V | TB |
| TV Aps | E: | 2457599.93981 | 0.00009 | P | V | TB |
| YY Aps | EA | 2457505.11131 | 0.0005 | P | V | TR |
| AO Aqr | EW | 2456816.148 | 0.003 | P | V | JP |
| AO Aqr | EW | 2456843.063 | 0.003 | P | V | JP |
| AO Aqr | EW | 2456857.2522 | 0.0003 | P | V | JP |
| AO Aqr | EW | 2456859.210 | 0.006 | P | V | JP |
| V0610 Ara | EW | 2457545.004 | 0.004 | P | V | NB |
| V0610 Ara | EW | 2457575.962 | 0.003 | P | V | NB |
| V0610 Ara | EW | 2457594.976 | 0.003 | P | V | NB |
| V0878 Ara | EW: | 2457523.162 | 0.005 | S | V | NB |
| V0878 Ara | EW: | 2457547.044 | 0.005 | S | V | NB |
| V0878 Ara | EW: | 2457577.089 | 0.004 | S | V | NB |
| V0878 Ara | EW: | 2457599.051 | 0.005 | P | V | NB |
| RR Cen | EW/KE: | 2457550.072 | 0.002 | P | V | MB |
| V0716 Cen | EB/KE | 2456018.105 | 0.003 | P | V | MB |
| V0716 Cen | EB/KE | 2456053.119 | 0.006 | S | V | MB |
| V0716 Cen | EB/KE | 2457526.080 | 0.003 | P | V | MB |
| V0716 Cen | EB/KE | 2457532.041 | 0.003 | P | V | MB |
| V0716 Cen | EB/KE | 2457538.000 | 0.002 | P | V | MB |
| V0831 Cen | ELL: | 2457539.008 | 0.003 | P | V | MB |
| V0901 Cen | EW: | 2457498.05652 | 0.0006 | S | V | TR |
| RZ Cha | EA/DM | 2457522.01880 | 0.0004 | P | V | TB |
| RZ Cha | EA/DM | 2457539.01725 | 0.0004 | P | V | TB |
| AR CMa | EA | 2457429.949 | 0.004 | P | V | SL |
| AR CMa | EA | 2457443.9385 | 0.0007 | P | V | SL |
| TU CMa | EA | 2456320.078 | 0.002 | S | V | TR |
| TU CMa | EA | 2456651.0885 | 0.0011 | P | V | TR |
| TU CMa | EA | 2456695.0724 | 0.0010 | P | V | TR |
| TU CMa | EA | 2457745.0583 | 0.0011 | P | V | TR |
| eps CrA | EW | 2457527.216 | 0.003 | P | V | NB |
| eps CrA | EW | 2457560.034 | 0.004 | S | V | NB |
| eps CrA | EW | 2457568.023 | 0.002 | P | V | NB |
| eps CrA | EW | 2457604.106 | 0.003 | P | V | NB |

| ID | Type | HJD | error | Min | Filter | Obs |
|---|---|---|---|---|---|---|
| eps CrA | EW | 2457628.944 | 0.002 | P | V | NB |
| V0711 CrA | EB | 2457598.022 | 0.003 | P | V | NB |
| CN Hyi | EW | 2457614.082 | 0.003 | S | V | MB |
| CN Hyi | EW | 2457648.058 | 0.002 | P | V | MB |
| NSV 1000 Hyi | EW | 2457690.1305 | 0.0010 | S | V | TR |
| NSV 1000 Hyi | EW | 2457712.0079 | 0.0015 | S | V | TR |
| NSV 1000 Hyi | EW | 2457712.1742 | 0.0015 | P | V | TR |
| GG Lup | EB/DM | 2456058.0909 | 0.0014 | P | V | MB |
| GG Lup | EB/DM | 2456069.1885 | 0.0013 | P | V | MB |
| GG Lup | EB/DM | 2456069.929 | 0.002 | S | V | MB |
| GG Lup | EB/DM | 2456072.888 | 0.002 | P | V | MB |
| GG Lup | EB/DM | 2456846.0179 | 0.0012 | P | V | MB |
| GG Lup | EB/DM | 2456868.958 | 0.002 | S | V | MB |
| GG Lup | EB/DM | 2457571.0633 | 0.0011 | P | V | MB |
| GG Lup | EB/DM | 2457596.9577 | 0.0012 | P | V | MB |
| QZ Lup | EA | 2457548.030 | 0.004 | P | V | NB |
| DE Mic | EW | 2457568.224 | 0.002 | P | V | NB |
| DE Mic | EW | 2457576.235 | 0.002 | S | V | NB |
| DE Mic | EW | 2457604.992 | 0.002 | S | V | NB |
| DE Mic | EW | 2457605.189 | 0.002 | P | V | NB |
| DE Mic | EW | 2457626.955 | 0.002 | P | V | NB |
| DE Mic | EW | 2457658.988 | 0.002 | P | V | NB |
| DI Mic | EW | 2457586.025 | 0.003 | S | V | TR |
| DI Mic | EW | 2457586.165 | 0.003 | P | V | TR |
| BR Mus | EW/KE: | 2457439.0754 | 0.0001 | P | V | TR |
| eta Mus | E | 2457555.010 | 0.003 | P | V | MB |
| TU Mus | EB/KE | 2456387.018 | 0.009 | P | V | RJ |
| TU Mus | EB/KE | 2457045.978 | 0.017 | P | V | RJ |
| TU Mus | EB/KE | 2457057.081 | 0.019 | P | V | RJ |
| TV Mus | EW/KW | 2457503.064 | 0.002 | P | V | TR |
| EZ Oct | EW/KW | 2457503.9750 | 0.0004 | S | V | TR |
| EZ Oct | EW/KW | 2457504.1174 | 0.0003 | P | V | TR |
| EZ Oct | EW/KW | 2457504.2607 | 0.0003 | S | V | TR |
| MW Pav | EW | 2457572.141 | 0.004 | S | V | MB |
| MW Pav | EW | 2457593.205 | 0.004 | P | V | MB |
| V0386 Pav | EW | 2457598.107 | 0.004 | S | V | MB |
| V0386 Pav | EW | 2457599.210 | 0.004 | S | V | MB |
| CT Phe | EA | 2457679.0526 | 0.0008 | P | V | SL |
| CT Phe | EA | 2457684.1039 | 0.0003 | P | V | SL |
| CT Phe | EA | 2457692.9316 | 0.0004 | P | V | SL |

| ID | Type | HJD | error | Min | Filter | Obs |
|---|---|---|---|---|---|---|
| YZ Phe | EW/KW | 2456875.1247 | 0.0013 | P | V | JP |
| YZ Phe | EW/KW | 2456878.1761 | 0.0011 | P | V | JP |
| YZ Phe | EW/KW | 2456880.2887 | 0.0015 | P | V | JP |
| CS Pup | EA | 2457403.0642 | 0.0004 | P | V | SL |
| CS Pup | EA | 2457442.9591 | 0.0007 | P | V | SL |
| CS Pup | EA | 2457474.868 | 0.0006 | P | V | SL |
| GZ Pup | EW/KW | 2457403.0963 | 0.0007 | S | V | TR |
| HI Pup | EW/KW | 2457385.1614 | 0.0006 | P | V | TR |
| UX Ret | EW | 2457403.025 | 0.002 | P | V | NB |
| CP Scl | EW | 2457686.0578 | 0.0004 | P | C | TR |
| CP Scl | EW | 2456921.987 | 0.001 | P | V | TR |
| CP Scl | EW | 2456922.145 | 0.002 | S | V | TR |
| CP Scl | EW | 2456923.085 | 0.002 | S | V | TR |
| CP Scl | EW | 2456923.242 | 0.001 | P | V | TR |
| CP Scl | EW | 2457315.002 | 0.003 | P | V | TR |
| CP Scl | EW | 2457322.997 | 0.002 | S | V | TR |
| CP Scl | EW | 2457323.155 | 0.002 | P | V | TR |
| CP Scl | EW | 2457324.095 | 0.001 | P | V | TR |
| V0883 Sco | EB/KE | 2457564.136 | 0.006 | S | V | NB |
| V0883 Sco | EB/KE | 2457579.112 | 0.006 | P | V | NB |
| V0954 Sco | EB/KE | 2457546.078 | 0.005 | P | V | NB |
| V1055 Sco | EW | 2457536.212 | 0.003 | S | V | NB |
| V1055 Sco | EW | 2457544.034 | 0.003 | P | V | NB |
| V1055 Sco | EW | 2457544.216 | 0.002 | S | V | NB |
| V1055 Sco | EW | 2457568.946 | 0.002 | S | V | NB |
| V1055 Sco | EW | 2457614.950 | 0.003 | P | V | NB |
| RS Sgr | EA/SD | 2457568.093 | 0.002 | P | V | MB |
| V0505 Sgr | EA/SD | 2457573.031 | 0.003 | S | V | MB |
| FM Vel | EW/KW | 2457425.1595 | 0.0006 | S | V | TR |
| FM Vel | EW/KW | 2457445.9997 | 0.0004 | P | V | TR |
| QX Vel | EB | 2457477.016 | 0.003 | P | V | NB |
| QX Vel | EB | 2457484.039 | 0.004 | P | V | NB |
| QX Vel | EB | 2457491.061 | 0.005 | P | V | NB |
| QX Vel | EB | 2457534.971 | 0.005 | P | V | NB |

Where four or more minima were determined for a binary, either as recorded in Table 2 or in Richards et al. (2016), we estimated light elements from them in Microsoft Excel using linear regression, as recorded in Table 3. Secondary minima were included in the light element derivations only when their *O-C* estimates and errors, calculated for the half-cycle, were the same (within error limits) as for the primaries. That is, their minima occurred at phase 0.500. Column 1 in Table 3 shows the GCVS ID of the star. Columns 2 and 3 show the heliocentric Julian date and its standard error of our zero epoch T0 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 T0 in days, the *O-C* error and its cycle count, using the original light elements. These are from the GCVS, except for the following which do not have GCVS light elements. NT Aps, CN Hyi and V386 Pav are from the AAVSO VSX (Watson et al, 2006); and V831 Cen from (Waelkens & Bartholdi 1982).

Table 3. VSS light elements of binaries derived from four or more VSS minima estimates. Starred entries use minima estimates from Richards et al. (2016) as well as from Table 2.

| ID | T0 2450000+ | T0 error | P | P error | N | Int | *O-C* | *O-C* error | Cycle |
|---|---|---|---|---|---|---|---|---|---|
| *NT Aps | 7208.1353 | 0.0005 | 0.2947616 | 0.0000006 | 4 | 326 | -0.0539 | 0.0005 | 29542 |
| AO Aqr | 6816.1484 | 0.0009 | 0.489337 | 0.000014 | 4 | 43 | 0.0604 | 0.0009 | 8005.5 |
| *V0878 Ara | 7236.934 | 0.002 | 0.770459 | 0.000006 | 6 | 364 | 0.01297 | 0.0020 | 6664 |
| *RR Cen | 6826.8896 | 0.0004 | 0.6056808 | 0.0000007 | 7 | 758 | -0.0372 | 0.0004 | 53816 |
| V0716 Cen | 6018.1033 | 0.0010 | 1.4900956 | 0.0000013 | 5 | 1520 | -0.0307 | 0.0010 | 11740 |
| *V0831 Cen | 6749.9871 | 0.0008 | 0.6425265 | 0.0000008 | 5 | 1529 | 0.012 | 0.205 | 20547 |
| TU CMa | 6651.08846 | 0.00018 | 1.1278038 | 0.0000004 | 4 | 1425 | 0.00073 | 0.0002 | 3134 |
| *eps CrA | 7527.2160 | 0.0016 | 0.591429 | 0.000008 | 6 | 344 | -0.123 | 0.003 | 30130 |
| *CN Hyi | 6869.2882 | 0.0007 | 0.4560883 | 0.0000007 | 6 | 779 | 0.0858 | 0.0007 | 18349 |
| *NSV 1000 Hyi | 6973.0472 | 0.0004 | 0.3365796 | 0.0000003 | 11 | 739 | -0.0042 | 0.0004 | 15164 |
| *DE Mic | 7249.118 | 0.003 | 0.410694 | 0.000004 | 8 | 409 | 0.001 | 0.002 | 11263 |
| *MW Pav | 7248.177 | 0.002 | 0.795000 | 0.000007 | 4 | 345 | 0.060 | 0.002 | 20611 |
| *V0386 Pav | 7281.0772 | 0.0015 | 0.551836 | 0.000005 | 4 | 320 | -0.0168 | 0.0015 | 15912 |
| *GZ Pup | 7374.1116 | 0.0002 | 0.3202612 | 0.0000005 | 6 | 384 | 0.0185 | 0.0002 | 71737.5 |
| CP Scl | 6921.9875 | 0.0006 | 0.3136572 | 0.0000006 | 9 | 765 | 0.0164 | 0.0006 | 16112 |
| V1055 Sco | 7544.0332 | 0.0008 | 0.363678 | 0.000008 | 5 | 79 | -0.0196 | 0.0008 | 24867 |
| QX Vel | 7477.0139 | 0.0017 | 0.87813 | 0.00005 | 4 | 58 | 0.0769 | 0.0017 | 10223 |

The *O-C* error is just the T0 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. No observations of primary minimum were obtained for AO Aqr. Its light elements are those for the secondary minimum. Its *O-C* values however assume that the secondary minimum is exactly at phase 0.5. Light elements for the primary minimum can be obtained by adding P/2 to the given T0 (with the same assumption). Finally, as remarked in Richards et al. (2016), the primary (deeper) minimum of GZ Pup occurs at phase 0.5 with respect to the GCVS elements.

GG Lup is omitted from this table despite having eight minima listed in Table 2. This eccentric system is thoroughly discussed in Budding, Butland & Blackford (2015) (who show its variability type is actually EA) which includes photometric data from one of us (MB). The paper uses the Hipparcos light curve (ESA 1997) as the basis for *O-C* analysis and system modelling; so new light elements and *O-C* estimates based on them are made irrelevant. However minima estimates as in Table 2 continue to be made in order to refine the authors' modelling.

# 4 Conclusions and further work

We have reported minima estimates for 42 southern eclipsing binaries. We have reported light elements (zero epochs and periods with uncertainties) for seventeen of them for which we obtained four or more minima. We have provided *O-C* values of those zero epochs, calculated from the original light elements in the literature.

In Table 3 there are cases where the *O-C* value of our T0 exceeds the *O-C* error by a large factor. But in the absence of uncertainty values for the original light elements the *O-C* error is much smaller than it should be, especially where the cycle count is large. Nevertheless in such cases a closer study of period change is indicated. Such a study requires the inclusion of other minima values (with uncertainties) that can be found in the literature, as well as more minima estimates by us in the future. These warrant separate papers and lie outside the scope of this report.

We plan to do the following future work on these stars as appropriate, as well as add 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 and (updated) light elements in further papers in this series.

# Acknowledgements

This research has made much use of the *International Variable Star Index* (VSX) database, operated at AAVSO, Cambridge, Massachusetts, USA (Watson et al. 2006); and the *General Catalogue of Variable Stars* (Samus et al. 2017). The authors would like to thank the referee for helpful comments.

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