First analysis of eight Algol-type binaries: EI Aur, XY Dra, BP Dra, DD Her, VX Lac, WX Lib, RZ Lyn, and TY Tri

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Abstract

The available photometry from the online databases were used for the first light curve analysis of eight eclipsing binary systems EI Aur, XY Dra, BP Dra, DD Her, VX Lac, WX Lib, RZ Lyn, and TY Tri. All these stars are of Algol-type, having the detached components and the orbital periods from 0.92 to 6.8 days. For the systems EI Aur and BP Dra the large amount of the third light was detected during the light curve solution. Moreover, 468 new times of minima for these binaries were derived, trying to identify the period variations. For the systems XY Dra and VX Lac the third bodies were detected with the periods 17.7, and 49.3 yr, respectively.

Key words: stars: binaries: eclipsing, stars: fundamental parameters
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1 Introduction

The role of eclipsing binaries in nowadays astrophysics is undisputable. We use the eclipsing binary systems (hereafter EB) for the most accurate determination of the stellar masses, radii, as distance indicators, or as classical celestial mechanics laboratories. We can test the stellar structure models even outside of our Galaxy, see e.g. Ribas (2004). Additionally, also the hidden components can be studied via the dedicated observations of particular binaries as well as the dynamical effects in such multiple systems (Rappaport et al., 2013). Due to all of these reasons the photometric monitoring and analysis of the light
curves of selected eclipsing binaries still presents a fruitful contribution to the stellar astrophysics.

On the other hand, the available photometry for many interesting eclipsing binaries exists, but some of these EBs were still not analysed yet. Hence, we decided to use mainly the Super WASP photometry (Pollacco et al., 2006) for a light curve analysis and derivation of new minima times for such systems, which were not studied before and their light curve solution is missing.

2 Analysis

The selection criteria for the binaries included in our study were the following. Only such binaries with known orbital periods were chosen, having no light curve solution published up to date, have enough data points for the analysis and also have several published times of minima. The last point was checked via an online archive of minima times observations, a so-called O–C gateway (Paschke & Bráť, 2006). Due to the very good time coverage provided by the Super WASP survey we used this database for the whole analysis of the light curve. The other databases such as NSVS (Woźniak et al., 2004), ASAS (Pojmanski, 2002), CRTS (Drake et al., 2009), or OMC (Mas-Hesse et al., 2004) were used only for deriving the times of minima for a subsequent period analysis. All of the studied systems are the northern-hemisphere stars of moderate brightness (10 mag < V < 15 mag) and with the orbital periods ranging from 0.9 to 6.8 days.

For analysing the light curves we used the PHOEBE program (Prša & Zwitter, 2005), which is based on the algorithm by Wilson & Devinney (1971). Having sometimes rather limited information about the stars, some of the parameters have to be fixed for the light curve (hereafter LC) solution. At first, the ”Detached binary” mode (in Wilson & Devinney mode 2) was assumed for computing. The value of the mass ratio q was set to 1. The limb-darkening coefficients were interpolated from van Hamme’s tables (see van Hamme 1993), and the linear cosine law was used. The values of the gravity brightening and bolometric albedo coefficients were set at their suggested values for convective or radiative atmospheres (see Lucy, 1968). Therefore, the quantities which could be directly calculated from the LC are the following: the relative luminosities $L_i$, the temperature of the secondary $T_2$, the inclination $i$, and the Kopal’s modified potentials $\Omega_1$ and $\Omega_2$. The synchronicity parameters $F_1$ and $F_2$ were also fixed at values of 1. The value of the third light $L_3$ was also computed if a non-negligible value resulted from the fitting process. And finally, the linear ephemerides were calculated using the available minima times for a

1 http://var.astro.cz/ocgate/
Table 1
The light-curve parameters as derived from our analysis.

| Parameter | EI Aur | XY Dra | BP Dra | DD Her |
|-----------|--------|--------|--------|--------|
| $JD_0 - 2400000$ | 54050.6460 ± 0.0019 | 54597.5551 ± 0.0160 | 54659.5430 ± 0.0013 | 53165.3571 ± 0.0152 |
| $P$ [d] | 1.2266930 ± 0.0000013 | 2.3152311 ± 0.0000342 | 0.9868693 ± 0.0000003 | 5.6433970 ± 0.0000061 |
| $i$ [deg] | 87.67 ± 0.59 | 89.76 ± 0.40 | 86.97 ± 0.52 | 79.61 ± 0.35 |
| $T_1$ [K] | 6000 (fixed) | 6500 (fixed) | 6000 (fixed) | 8800 (fixed) |
| $T_2$ [K] | 6044 ± 38 | 4343 ± 34 | 5429 ± 41 | 4985 ± 50 |
| $\Omega_1$ | 4.847 ± 0.059 | 5.942 ± 0.039 | 5.312 ± 0.052 | 5.354 ± 0.022 |
| $\Omega_2$ | 5.181 ± 0.072 | 4.619 ± 0.020 | 6.216 ± 0.063 | 10.671 ± 0.021 |
| $L_1$ [%] | 38.3 ± 0.5 | 83.7 ± 0.8 | 45.3 ± 0.9 | 93.7 ± 0.8 |
| $L_2$ [%] | 32.9 ± 0.7 | 16.3 ± 0.5 | 18.5 ± 0.8 | 6.3 ± 0.6 |
| $L_3$ [%] | 28.8 ± 0.7 | 0.0 ± 0.0 | 36.2 ± 0.4 | 0.0 ± 0.0 |

With the final LC analysis, we also derived many times of minima for a particular system, using a method as presented in [Zasche et al. (2014)]. The template of the LC was used to fit the photometric data from the Super WASP as well as from other surveys. This set of minima times was then combined with the already published minima mostly taken from the $O-C$ gateway ([Paschke & Bráč 2006]).

3 The individual systems

3.1 EI Aur

The system EI Aur (also GSC 02392-00102) was discovered by [Hoffmeister (1936)], who also classified the star as an Algol-type. Its orbital period is of about 1.2 days, but there were no light curve or any spectroscopic analysis performed. We can only roughly estimate its type from the color indices, hence we fixed the primary temperature at a value of 6000 K for the whole fitting process.

The Super WASP photometry revealed that it is a detached system, having both minima of roughly equal depths. Therefore, the PHOEBE code was used to these data and the LC fit is presented in Fig. 1 while the LC parameters are given in Table 1. As one can see, the secondary component has almost the same temperature as the primary, hence there is still a doubt which of the minima is the primary one. Another interesting finding is the fact that relatively large contribution of the third light was detected in the LC solution. This would naturally explain why both the minima have only so shallow depths.

One can ask whether the third body detected in the LC solution is somehow gravitationally bounded with the eclipsing pair or is it just a coincidence as a so-called optical binary. We also derived the times of minima from the Super
Fig. 1. Light curve analysis of EI Aur, based on the Super WASP photometry.

Fig. 2. O-C diagram of times of minima derived from available photometry for EI Aur. The black points stand for the primary minima, while the open circles stand for the secondary ones. The larger the symbol, the higher the weight.

WASP photometry and plotted them together with the already published ones in Fig. 2. As one can see, there is no obvious variation in the times of minima. The data coverage is still rather poor, but even this diagram can be used to set some tighter limits for the parameters of the proposed additional body in the system.

3.2 XY Dra

Eclipsing binary called XY Dra (also AN 391.1929) was discovered as a variable by Wolf (1929). Since then no detailed analysis of this star was carried out, only a few minima times were published, mostly in the last 20 years. Its spectral type is not known, hence we fixed the primary temperature at a value of 6500 K in agreement with the photometric indices as published in different databases.
Fig. 3. Light curve analysis of XY Dra, based on the Super WASP photometry.

Fig. 4. O-C diagram of times of minima derived from available photometry for XY Dra. The solid curve represents the final fit (see the text for details).

The light curve solution was carried out in the same way as for the previous system, resulting in light curve parameters given in Table 1 while the fit is presented in Fig. 3. As one can see, the primary component is very dominant star in the system and no third light was detected. On the other hand, there still remains an open question whether the data points located in the center of the primary eclipse are real or not. One possible explanation is that there is a total eclipse (as assumed in our fit), or the second explanation could be that we just reached a limit for the Super WASP photometry of about 15.5 mag and the real eclipse is much deeper. Only further dedicated observations of the primary eclipse would reveal its true nature.

Moreover, we also derived the times of minima from the Super WASP photometry and combined them with the already published more precise data from the "O-C gateway". The result of our fitting is presented in Fig. 4. We used a so-called light-travel-time effect for describing the variation in the $O-C$ diagram. This method was described elsewhere, e.g. Irwin (1959) or Mayer (1990), using a set of five orbital parameters for description of the third body
orbit around the eclipsing binary itself. With this assumption we found that the variation with period of about 17.7 yr, eccentricity 0.59 and a semiamplitude of 0.0095 days is probably caused by a third body of such a small mass that its light contribution to the total light of the system would be negligible. This would be a reason why no third light was detected in the LC solution as presented in Table 1.

3.3 BP Dra

The star BP Dra (also GSC 04231-01877) was discovered by Gessner (1966). It has the orbital period shorter than one day, of about 0.99 days, which makes it rather hard to observe for the minima timings. This is maybe a reason why only so little information is known about this star. Lacking enough data, we have to fix the primary temperature at a value of 6000 K in agreement with the color indices (Skrutskie et al. 2006 and Pickles & Depagne 2010).

The LC solution was found and the parameters are given in Table 1 while the plot with the final fit is presented in Fig. 5. As one can see, both eclipses are rather shallow and the scatter of the observations is quite large. However, this is due to the fact that there was detected also a non-negligible amount of the third light in the LC solution. We can only speculate about its origin and classify the system as a potential triple.

Collecting all available Super WASP photometry we also derived about 50 new minima timings. These data are plotted together with the ones from 1960’s and indicate that there is obviously no period change during these fifty years. Only a more detailed analysis would reveal the third-body hypothesis as a plausible or implausible.
Another system in our sample of stars is DD Her (also TYC 2103-352-1), discovered as a variable by Hoffmeister (1929). It has relatively longer period of about 5.6 days, however it is also a system lacking of any detailed analysis. Due to its spectral classification as A2, we used the primary temperature of 8800 K for the whole LC fitting process.

The Super WASP photometry used for the LC analysis yielded a LC solution given in Table 1 while the LC fit is plotted in Fig. 7. As one can see, the primary star is absolutely dominant in the system and no third light was detected. Due to its deep and well-covered eclipses we derived only the primary minima for a period analysis and the $O-C$ diagram (plotted in Fig. 8). Also the ASAS and NSVS photometry was used for deriving two minima times. The older observations suffer from large scatter and are almost useless for any analysis. More recent data points show no variation.
The system VX Lac (also TYC 3214-1295-1) is probably the most studied star in our sample of binaries. Cannon (1934) derived its spectral type as F0, and since then no other more recent classification was carried out. The system was also included into the study of eclipsing binaries with period changes and third bodies by Zasche et al. (2008), who discovered a variation of about 68 yr and 0.02 days semiamplitude.

We collected the Super WASP photometry for a LC solution and analysed the system using the PHOEBE program. The primary temperature was set to 7228 K using the F0 spectral classification and also the Tycho-2 data from Ammons et al. (2006). The result is plotted in Fig. 9 and the LC parameters are given in Table 2. As one can see, the primary is the dominant component in the system. No third light was detected, which sets some constraints on the third-body hypothesis as resulted from the period analysis. There was also found that either of the stars is probably slightly physically variable, because in the outside-eclipse region there were seen some period-to-period deviations, which cause a slightly larger scatter of the data near quadratures.

The analysis of period was performed on the already published data as well as our new derived times of minima from the Super WASP and NSVS photometry. Our updated solution as presented in Fig. 10 represents only a slight correction of the already published one by Zasche et al. (2008). New values of period, eccentricity and semiamplitude are: 49.3 yr, 0.239, and 0.0144 days, respectively. However, even such a result is able to explain a non-detection of the third light in the LC solution. The potential third body is probably so small (hence has so low luminosity) that it cannot be detected in the LC solution.
Fig. 9. Light curve analysis of VX Lac, based on the Super WASP photometry.

Fig. 10. O-C diagram of times of minima for VX Lac. The solid line represents the final fit, while the dash-dotted line stands for the quadratic ephemerides term.

Table 2
The light-curve parameters as derived from our analysis.

| Parameter | VX Lac      | WX Lib      | HZ Lyn      | TY Tri      |
|-----------|-------------|-------------|-------------|-------------|
| JD0–2400000 | 49908.9074 ± 0.0012 | 54564.5560 ± 0.0007 | 45347.3639 ± 0.0056 | 35778.5110 ± 0.0658 |
| P [d]      | 1.07449709 ± 0.0000014 | 0.9200078 ± 0.000003 | 1.1469092 ± 0.000007 | 6.7620349 ± 0.0000381 |
| i [deg]    | 86.84 ± 0.25 | 85.05 ± 0.17 | 76.03 ± 0.36 | 89.94 ± 0.27 |
| T1 [K]     | 7228 (fixed) | 5200 (fixed) | 8690 (fixed) | 5720 (fixed) |
| T2 [K]     | 4486 ± 0.36  | 5053 ± 0.27  | 6119 ± 0.62  | 5487 ± 0.40  |
| Ω1         | 4.589 ± 0.019 | 4.808 ± 0.021 | 3.961 ± 0.025 | 8.871 ± 0.032 |
| Ω2         | 5.021 ± 0.018 | 5.728 ± 0.029 | 4.295 ± 0.046 | 12.906 ± 0.041 |
| L1 [%]     | 94.1 ± 0.9 | 64.3 ± 1.0 | 83.8 ± 0.8 | 74.0 ± 0.7 |
| L2 [%]     | 5.9 ± 0.8 | 35.5 ± 0.9 | 13.4 ± 0.7 | 26.0 ± 0.3 |
| L3 [%]     | 0.0 ± 0.0 | 0.2 ± 0.4 | 2.8 ± 0.4 | 0.0 ± 0.0 |

3.6 WX Lib

The star WX Lib is relatively seldom studied system. It is the southernmost star in our sample, hence it was also observed by the ASAS survey. It is also the star with the shortest orbital period in our sample, of about 0.92 days
Due to lacking relevant information about the system, we fixed the primary temperature to the value of 5200 K in agreement with the photometric indices found in various databases. The LC shows two rather similar and relatively deep eclipses. The LC solution (see Fig. 11 and Table 2) reveals that both stars are somehow similar, with the primary slightly dominating. The value of the third light remains negligible.

The period variation was studied using the Super WASP as well as the ASAS, CRTS, and OMC photometric data. Because of only very poor coverage of the time interval since its discovery to the nowadays time we are not able to identify any period variation in this time interval.
Fig. 13. Light curve analysis of RZ Lyn, based on the Super WASP photometry.

Fig. 14. O-C diagram of times of minima for RZ Lyn.

3.7 RZ Lyn

RZ Lyn (also GSC 02995-00972) is another rather neglected eclipsing binary, briefly studied by [Huth (1953)], who classified it as a β Lyrae type star and giving its correct orbital period of about 1.147 days. Its spectral of A2 type was given by [Goetz (1961)]. Since then only several publications with the times of minima were published.

We carried out an analysis of the LC of this system, using the Super WASP photometry. The results given in Table 2 and the plot in Fig. 13 show that the system contains one larger component and slightly smaller secondary revolving on mildly inclined orbit. The amount of the third light is rather negligible.

For the period analysis we collected the already published data from the O–C gateway and combined them with our derived minima times from the Super WASP and NSVS photometry. As one can see from our Fig. 14 the system obviously undergoes a mass transfer between the components. Such an effect
is displayed in the $O - C$ diagram as quadratic ephemerides, here in our case the rate is of about $-5.904 \cdot 10^{-10}$ days.

### 3.8 TY Tri

The eclipsing binary TY Tri (also TYC 2312-190-1) was discovered as a variable by Weber (1963). No detailed analysis was carried out for this star, only several publications with the times of minima were published during the last decades. For the light curve analysis we fixed the primary temperate at a value of 5720 K, in agreement with Pickles & Depagne (2010) and Ammons et al. (2006).

The LC analysis revealed (see Fig. 15 and Table 2) that here we deal with the most detached system in our sample of stars, but still moving on circular orbit. We see the system almost exactly edge-on. The third light was not detected. The LC solution was used for deriving the minima times (both from the Super...
WASP as well as from the NSVS photometry. The final plot is given in Fig. 16, where we were not able to detect any period variation over the time span of more than 50 years.

4 Discussion and conclusions

The very first LC solution for eight Algol-type eclipsing binaries (based on the Super WASP photometry) led to several interesting results:

- The Super WASP survey served as a unique source of photometric data suitable for the LC analysis of many eclipsing binaries never studied before.
- The effects of the second order, like the third light, are also detectable in these data.
- For two of the systems (EI Aur, and BP Dra) the amount of the third light is so large that these cannot easily be considered as pure binaries in any future more detailed study.
- The method of using the light curve templates for deriving the times of minima provides reliable and sufficiently precise minima suitable for a period analysis.
- For RZ Lyn we found a steady period decrease (probably due to mass transfer), while for two other systems (XY Dra and VX Lac) there were detected the third-body period modulations with their respective periods of 18, and 49 years, respectively.

All of the presented systems were never been studied before concerning their light curves, hence we can consider this study as a good starting point for any other future investigators. Especially, a special focus should be take to these systems, where a larger fraction of the third light was detected and these systems, where a third body variation in the \( O - C \) diagram was detected.

5 Acknowledgments

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References

Ammons, S. M., Robinson, S. E., Strader, J., et al. 2006, ApJ, 638, 1004
Cannon, A. J. 1934, BHarO, 897, 12
Drake, A. J., Djorgovski, S. G., Mahabal, A., et al. 2009, ApJ, 696, 870
Gessner, H. 1966, VeSon, 7, 61
Goetz, W. 1961, MitVS, 569, 1
Hoffmeister, C. 1929, AN, 236, 233
Hoffmeister, C. 1936, AN, 259, 37
Huth, H. 1953, AN, 281, 183
Irwin, J. B. 1959, AJ, 64, 149
Lucy, L. B. 1968, ApJ, 151, 1123
Mas-Hesse, J. M., Giménez, A., Domingo, A., et al. & the OMC team 2004, 5th INTEGRAL Workshop on the INTEGRAL Universe, 552, 729
Mayer, P. 1990, BAICz, 41, 231
Paschke, A., & Brát, L. 2006, OEJV, 23, 13
Pickles, A., & Depagne, É. 2010, PASP, 122, 1437
Pojmanski, G. 2002, AcA, 52, 397
Pollacco, D. L., et al. 2006, PASP, 118, 1407
Prša, A., Zwitter, T. 2005, ApJ, 628, 42
Rappaport, S., Deck, K., Levine, A., et al. 2013, ApJ, 768, 33
Ribas, I. 2004, NewAR, 48, 731
Skrutskie, M. F., Cutri, R. M., Stiening, R., et al. 2006, AJ, 131, 1163
van Hamme, W. 1993, AJ, 106, 2096
Weber, R. 1963, IBVS, 21, 1
Wilson, R. E., Devinney, E. J. 1971, ApJ, 166, 605
Wolf, M. 1929, AN, 236, 245
Woźniak, P. R., Vestrund, W. T., Akerlof, C. W., et al. 2004, AJ, 127, 2436
Zasche, P., Liakos, A., Wolf, M., & Niarchos, P. 2008, NewA, 13, 405
Zasche, P., Wolf, M., Vraštil, J., et al. 2014, A&A, 572, A71
| Star   | HJD   | Error  | Type  | Filter | Source |
|--------|-------|--------|-------|--------|--------|
| EI Aur | 5320.7943 | 0.0028 | Prim  | W      | Super WASP |
| EI Aur | 5324.6394 | 0.0044 | Sec    | W      | Super WASP |
| EI Aur | 5325.6625 | 0.0024 | Prim  | W      | Super WASP |
| EI Aur | 5326.6413 | 0.0039 | Sec    | W      | Super WASP |
| EI Aur | 5326.6085 | 0.0040 | Prim  | W      | Super WASP |
| EI Aur | 5326.7284 | 0.0022 | Sec    | W      | Super WASP |
| EI Aur | 5327.5947 | 0.0024 | Prim  | W      | Super WASP |
| EI Aur | 5327.5849 | 0.0014 | Sec    | W      | Super WASP |
| EI Aur | 5327.6982 | 0.0045 | Prim  | W      | Super WASP |
| EI Aur | 5402.8389 | 0.0046 | Sec    | W      | Super WASP |
| EI Aur | 5403.6734 | 0.0015 | Prim  | W      | Super WASP |
| EI Aur | 5403.6369 | 0.0016 | Sec    | W      | Super WASP |
| EI Aur | 5405.6116 | 0.0057 | Prim  | W      | Super WASP |
| EI Aur | 5405.7851 | 0.0057 | Prim  | W      | Super WASP |
| EI Aur | 5406.9913 | 0.0014 | Sec    | W      | Super WASP |
| EI Aur | 5408.4484 | 0.0031 | Sec    | W      | Super WASP |
| EI Aur | 5409.6580 | 0.0064 | Sec    | W      | Super WASP |
| EI Aur | 5411.0594 | 0.0080 | Sec    | W      | Super WASP |
| EI Aur | 5412.0522 | 0.0062 | Prim  | W      | Super WASP |
| EI Aur | 5415.6558 | 0.0012 | Prim  | W      | Super WASP |
| EI Aur | 5416.5845 | 0.0097 | Sec    | W      | Super WASP |
| EI Aur | 5417.5851 | 0.0053 | Prim  | W      | Super WASP |
| EI Aur | 5419.7417 | 0.0045 | Sec    | W      | Super WASP |
| EI Aur | 5421.5865 | 0.0062 | Sec    | W      | Super WASP |
| EI Aur | 5423.3533 | 0.0033 | Sec    | W      | Super WASP |
| EI Aur | 5423.3533 | 0.0033 | Sec    | W      | Super WASP |
| EI Aur | 5424.3409 | 0.0062 | Sec    | W      | Super WASP |
| EI Aur | 5425.6920 | 0.0013 | Prim  | W      | Super WASP |
| EI Aur | 5426.2026 | 0.0050 | Sec    | W      | Super WASP |
| EI Aur | 5427.4696 | 0.0014 | Prim  | W      | Super WASP |
| EI Aur | 5428.7638 | 0.0015 | Prim  | W      | Super WASP |
| EI Aur | 5430.5761 | 0.0058 | Sec    | W      | Super WASP |
| EI Aur | 5430.6308 | 0.0015 | Prim  | W      | Super WASP |
| EI Aur | 5431.5435 | 0.0024 | Prim  | W      | Super WASP |
| EI Aur | 5431.6715 | 0.0009 | Prim  | W      | Super WASP |
| EI Aur | 5432.5774 | 0.0018 | Prim  | W      | Super WASP |
| EI Aur | 5434.6707 | 0.0032 | Prim  | W      | Super WASP |
| EI Aur | 5436.7905 | 0.0048 | Prim  | W      | Super WASP |
| EI Aur | 5437.4199 | 0.0024 | Prim  | W      | Super WASP |
| EI Aur | 5437.4199 | 0.0024 | Prim  | W      | Super WASP |
| EI Aur | 5438.4663 | 0.0040 | Prim  | W      | Super WASP |
| EI Aur | 5439.6079 | 0.0014 | Prim  | W      | Super WASP |
| EI Aur | 5440.6522 | 0.0063 | Sec    | W      | Super WASP |
| EI Aur | 5441.0681 | 0.0030 | Prim  | W      | Super WASP |
| EI Aur | 5441.6079 | 0.0055 | Prim  | W      | Super WASP |
| EI Aur | 5442.6954 | 0.0048 | Prim  | W      | Super WASP |
| EI Aur | 5443.6429 | 0.0028 | Prim  | W      | Super WASP |
| EI Aur | 5443.6900 | 0.0035 | Prim  | W      | Super WASP |
| EI Aur | 5444.6593 | 0.0021 | Prim  | W      | Super WASP |
| EI Aur | 5445.5363 | 0.0015 | Prim  | W      | Super WASP |
| EI Aur | 5446.5769 | 0.0008 | Prim  | W      | Super WASP |
| EI Aur | 5446.7561 | 0.0030 | Prim  | W      | Super WASP |
| EI Aur | 5447.6141 | 0.0024 | Prim  | W      | Super WASP |
| EI Aur | 5448.6774 | 0.0078 | Prim  | W      | Super WASP |
| EI Aur | 5449.6065 | 0.0045 | Prim  | W      | Super WASP |
| EI Aur | 5450.2563 | 0.0016 | Prim  | W      | Super WASP |
| EI Aur | 5451.1155 | 0.0078 | Prim  | W      | Super WASP |
| EI Aur | 5452.0375 | 0.0008 | Prim  | W      | Super WASP |
| EI Aur | 5453.4009 | 0.0014 | Prim  | W      | Super WASP |
| EI Aur | 5456.7067 | 0.0071 | Prim  | W      | Super WASP |
| EI Aur | 5457.6386 | 0.0049 | Prim  | W      | Super WASP |
| EI Aur | 5458.6677 | 0.0008 | Prim  | W      | Super WASP |
| EI Aur | 5459.7588 | 0.0057 | Prim  | W      | Super WASP |
| EI Aur | 5460.6385 | 0.0062 | Prim  | W      | Super WASP |
| EI Aur | 5461.6315 | 0.0020 | Prim  | W      | Super WASP |
| EI Aur | 5462.6153 | 0.0028 | Prim  | W      | Super WASP |
| EI Aur | 5463.6985 | 0.0040 | Prim  | W      | Super WASP |
| EI Aur | 5464.7786 | 0.0040 | Prim  | W      | Super WASP |
### Table 4
New heliocentric minima times for the studied systems - cont.1

| Star     | HJD   | Error | Type   | Filter | Source     |
|----------|-------|-------|--------|--------|------------|
| VX Lac   | 53146.18754 | 0.00124 | Prim   | W Super WASP | WX Lib |
| VX Lac   | 53126.35783 | 0.00283 | Prim   | W Super WASP | WX Lib  |
| VX Lac   | 53144.32122 | 0.00109 | Prim   | W Super WASP | WX Lib  |
| VX Lac   | 53126.59039 | 0.00137 | Prim   | W Super WASP | WX Lib  |
| VX Lac   | 53150.21535 | 0.00010 | Prim   | W Super WASP | WX Lib  |
| VX Lac   | 53126.36364 | 0.00030 | Prim   | W Super WASP | WX Lib  |
| VX Lac   | 5427.66978 | 0.00015 | Prim   | W Super WASP | WX Lib  |
| VX Lac   | 5428.65478 | 0.00074 | Prim   | W Super WASP | WX Lib  |
| VX Lac   | 53124.52475 | 0.00061 | Prim   | W Super WASP | WX Lib  |
| VX Lac   | 53150.30804 | 0.00020 | Prim   | W Super WASP | WX Lib  |
| VX Lac   | 53152.75332 | 0.00219 | Prim   | W Super WASP | WX Lib  |
| VX Lac   | 5426.31027 | 0.00080 | Prim   | W Super WASP | WX Lib  |
| VX Lac   | 53140.04312 | 0.00095 | Prim   | W Super WASP | WX Lib  |
| VX Lac   | 53126.97678 | 0.00036 | Prim   | W Super WASP | WX Lib  |
| VX Lac   | 5426.75754 | 0.00042 | Prim   | W Super WASP | WX Lib  |
| VX Lac   | 53168.64857 | 0.00172 | Prim   | W Super WASP | WX Lib  |
| VX Lac   | 53166.72988 | 0.00154 | Prim   | W Super WASP | WX Lib  |
| VX Lac   | 53175.33499 | 0.00186 | Prim   | W Super WASP | WX Lib  |
| VX Lac   | 53194.69325 | 0.00021 | Prim   | W Super WASP | WX Lib  |
| VX Lac   | 5424.71004 | 0.00146 | Prim   | W Super WASP | WX Lib  |
| VX Lac   | 53195.67481 | 0.00018 | Prim   | W Super WASP | WX Lib  |
| VX Lac   | 53196.84747 | 0.00111 | Prim   | W Super WASP | WX Lib  |
| VX Lac   | 53197.52162 | 0.00018 | Prim   | W Super WASP | WX Lib  |
| VX Lac   | 5423.54345 | 0.00018 | Prim   | W Super WASP | WX Lib  |
| VX Lac   | 5424.37046 | 0.00018 | Prim   | W Super WASP | WX Lib  |
| VX Lac   | 53197.07080 | 0.00087 | Prim   | W Super WASP | WX Lib  |
| VX Lac   | 5425.76780 | 0.00036 | Prim   | W Super WASP | WX Lib  |
| VX Lac   | 5143.97547 | 0.00148 | Prim   | W Super WASP | WX Lib  |
| VX Lac   | 5426.31015 | 0.00163 | Prim   | W Super WASP | WX Lib  |
| VX Lac   | 53197.04413 | 0.00315 | Prim   | W Super WASP | WX Lib  |
| VX Lac   | 5426.37508 | 0.00178 | Prim   | W Super WASP | WX Lib  |
| VX Lac   | 5431.53992 | 0.00017 | Prim   | W Super WASP | WX Lib  |
| VX Lac   | 5436.73412 | 0.00137 | Prim   | W Super WASP | WX Lib  |
| VX Lac   | 5439.67807 | 0.00017 | Prim   | W Super WASP | WX Lib  |
| VX Lac   | 5440.24107 | 0.00018 | Prim   | W Super WASP | WX Lib  |
| VX Lac   | 5455.10178 | 0.00018 | Prim   | W Super WASP | WX Lib  |
| VX Lac   | 5460.43706 | 0.00018 | Prim   | W Super WASP | WX Lib  |
| VX Lac   | 5460.50459 | 0.00018 | Prim   | W Super WASP | WX Lib  |
| VX Lac   | 5463.33415 | 0.00018 | Prim   | W Super WASP | WX Lib  |
| VX Lac   | 5433.36859 | 0.00018 | Prim   | W Super WASP | WX Lib  |
| VX Lac   | 5436.37798 | 0.00018 | Prim   | W Super WASP | WX Lib  |
| VX Lac   | 5437.84697 | 0.00018 | Prim   | W Super WASP | WX Lib  |
| VX Lac   | 5438.37798 | 0.00018 | Prim   | W Super WASP | WX Lib  |
| VX Lac   | 5445.30829 | 0.00018 | Prim   | W Super WASP | WX Lib  |
| VX Lac   | 5454.10163 | 0.00018 | Prim   | W Super WASP | WX Lib  |
| VX Lac   | 5456.76791 | 0.00018 | Prim   | W Super WASP | WX Lib  |
| VX Lac   | 5443.41257 | 0.00018 | Prim   | W Super WASP | WX Lib  |
| VX Lac   | 5446.73739 | 0.00018 | Prim   | W Super WASP | WX Lib  |
| VX Lac   | 5450.78234 | 0.00018 | Prim   | W Super WASP | WX Lib  |
| VX Lac   | 5451.95561 | 0.00018 | Prim   | W Super WASP | WX Lib  |
| VX Lac   | 5452.15718 | 0.00018 | Prim   | W Super WASP | WX Lib  |
| VX Lac   | 5452.54345 | 0.00018 | Prim   | W Super WASP | WX Lib  |
| VX Lac   | 5453.21075 | 0.00018 | Prim   | W Super WASP | WX Lib  |
| VX Lac   | 5453.15630 | 0.00018 | Prim   | W Super WASP | WX Lib  |
| VX Lac   | 5453.62650 | 0.00018 | Prim   | W Super WASP | WX Lib  |
| VX Lac   | 5455.39912 | 0.00018 | Prim   | W Super WASP | WX Lib  |
| VX Lac   | 5456.33415 | 0.00018 | Prim   | W Super WASP | WX Lib  |
| VX Lac   | 5458.50459 | 0.00018 | Prim   | W Super WASP | WX Lib  |
| VX Lac   | 5459.48015 | 0.00018 | Prim   | W Super WASP | WX Lib  |
| VX Lac   | 5460.50459 | 0.00018 | Prim   | W Super WASP | WX Lib  |
| VX Lac   | 5463.36859 | 0.00018 | Prim   | W Super WASP | WX Lib  |
| VX Lac   | 5466.37798 | 0.00018 | Prim   | W Super WASP | WX Lib  |
| VX Lac   | 5467.84697 | 0.00018 | Prim   | W Super WASP | WX Lib  |
| VX Lac   | 5468.37798 | 0.00018 | Prim   | W Super WASP | WX Lib  |
| VX Lac   | 5470.30829 | 0.00018 | Prim   | W Super WASP | WX Lib  |
| VX Lac   | 5473.85561 | 0.00018 | Prim   | W Super WASP | WX Lib  |
| VX Lac   | 5474.30829 | 0.00018 | Prim   | W Super WASP | WX Lib  |
| VX Lac   | 5475.15718 | 0.00018 | Prim   | W Super WASP | WX Lib  |
| VX Lac   | 5476.54345 | 0.00018 | Prim   | W Super WASP | WX Lib  |
| VX Lac   | 5477.33415 | 0.00018 | Prim   | W Super WASP | WX Lib  |
| Star     | HJD   | Error  | Type | Filter | Source |
|----------|-------|--------|------|--------|--------|
| WX Lib  | 54073.4895 | 0.00168 | Sec  | WASP   |        |
| WX Lib  | 54015.0568 | 0.00158 | Prim | CRTS   |        |
| WX Lib  | 54321.4867 | 0.00228 | Prim | WASP   |        |
| WX Lib  | 54022.2307 | 0.00474 | Prim | CRTS   |        |
| WX Lib  | 54021.2260 | 0.00180 | Prim | CRTS   |        |
| WX Lib  | 54073.1420 | 0.00157 | Sec  | CRTS   |        |
| WX Lib  | 54073.2712 | 0.07346 | Sec  | CRTS   |        |
| WX Lib  | 54063.9726 | 0.00578 | Sec  | CRTS   |        |
| WX Lib  | 54041.6772 | 0.00611 | Sec  | CRTS   |        |
| WX Lib  | 54201.6815 | 0.00380 | Sec  | CRTS   |        |
| WX Lib  | 54210.1624 | 0.01775 | Prim | CRTS   |        |
| WX Lib  | 54235.6976 | 0.00181 | Prim | CRTS   |        |
| WX Lib  | 54237.2867 | 0.00071 | Prim | CRTS   |        |
| WX Lib  | 54246.0160 | 0.00380 | Prim | CRTS   |        |
| WX Lib  | 54244.0224 | 0.00071 | Prim | CRTS   |        |
| WX Lib  | 54501.9586 | 0.02533 | Prim | CRTS   |        |
| WX Lib  | 54661.9609 | 0.00346 | Sec  | CRTS   |        |
| WX Lib  | 55743.0760 | 0.00240 | Sec  | CRTS   |        |
| WX Lib  | 55629.3706 | 0.00551 | Prim | CRTS   |        |
| WX Lib  | 57453.6769 | 0.00339 | Prim | OMIC   |        |
| WX Lib  | 57174.3520 | 0.00125 | Sec  | OMIC   |        |
| WX Lib  | 57655.3913 | 0.00687 | Prim | OMIC   |        |
| WX Lib  | 57174.8807 | 0.00347 | Sec  | OMIC   |        |
| WX Lib  | 57709.3978 | 0.00131 | Prim | OMIC   |        |
| WX Lib  | 56519.7808 | 0.00123 | Prim | OMIC   |        |
| WX Lib  | 56248.3938 | 0.00075 | Prim | OMIC   |        |
| WX Lib  | 55679.6172 | 0.00022 | Prim | OMIC   |        |
| WX Lib  | 55908.3126 | 0.00224 | Sec  | OMIC   |        |
| WX Lib  | 55962.3967 | 0.00045 | Prim | OMIC   |        |
| WX Lib  | 56010.6760 | 0.00011 | Sec  | OMIC   |        |
| WX Lib  | 53811.2464 | 0.00146 | Prim | Super WASP |        |
| WX Lib  | 53932.5965 | 0.00572 | Prim | Super WASP |        |
| WX Lib  | 54877.3166 | 0.00036 | Prim | Super WASP |        |
| WX Lib  | 54894.2923 | 0.00265 | Prim | Super WASP |        |
| WX Lib  | 54856.6366 | 0.00551 | Prim | Super WASP |        |
| WX Lib  | 54926.0277 | 0.00642 | Prim | Super WASP |        |
| WX Lib  | 54994.4521 | 0.00317 | Prim | Super WASP |        |
| WX Lib  | 54994.4521 | 0.00016 | Prim | Super WASP |        |
| WX Lib  | 54994.4521 | 0.00047 | Prim | Super WASP |        |
| WX Lib  | 55494.2899 | 0.00070 | Prim | Super WASP |        |
| WX Lib  | 55494.2899 | 0.00014 | Prim | Super WASP |        |
| WX Lib  | 55494.2899 | 0.00036 | Prim | Super WASP |        |
| WX Lib  | 55494.2899 | 0.00020 | Prim | Super WASP |        |
| WX Lib  | 55494.2899 | 0.00055 | Prim | Super WASP |        |
| WX Lib  | 55494.2899 | 0.00070 | Prim | Super WASP |        |
| WX Lib  | 55494.2899 | 0.00012 | Prim | Super WASP |        |
| WX Lib  | 55494.2899 | 0.00047 | Prim | Super WASP |        |
| WX Lib  | 55494.2899 | 0.00014 | Prim | Super WASP |        |
| WX Lib  | 55494.2899 | 0.00036 | Prim | Super WASP |        |
| WX Lib  | 55494.2899 | 0.00020 | Prim | Super WASP |        |
| WX Lib  | 55494.2899 | 0.00055 | Prim | Super WASP |        |
| WX Lib  | 55494.2899 | 0.00070 | Prim | Super WASP |        |
| WX Lib  | 55494.2899 | 0.00012 | Prim | Super WASP |        |
| WX Lib  | 55494.2899 | 0.00047 | Prim | Super WASP |        |
| WX Lib  | 55494.2899 | 0.00014 | Prim | Super WASP |        |
| WX Lib  | 55494.2899 | 0.00036 | Prim | Super WASP |        |
| WX Lib  | 55494.2899 | 0.00020 | Prim | Super WASP |        |
| WX Lib  | 55494.2899 | 0.00055 | Prim | Super WASP |        |
| WX Lib  | 55494.2899 | 0.00070 | Prim | Super WASP |        |
| WX Lib  | 55494.2899 | 0.00012 | Prim | Super WASP |        |
| WX Lib  | 55494.2899 | 0.00047 | Prim | Super WASP |        |
| WX Lib  | 55494.2899 | 0.00014 | Prim | Super WASP |        |
| WX Lib  | 55494.2899 | 0.00036 | Prim | Super WASP |        |
| WX Lib  | 55494.2899 | 0.00020 | Prim | Super WASP |        |

Table 5: New heliocentric minima times for the studied systems - cont.