THE PERIOD ANALYSIS OF V418 AQL, SU BOO, RV CVn, CR CAS, GV CYG, V432 PER, AND BD+42 2782

P. ZASCHE1, M. WOLF1, R. UHLAŘ, AND H. KUČÁKOVÁ1,3

1 Astronomical Institute, Charles University in Prague, Faculty of Mathematics and Physics, CZ-180 00 Praha 8, V Holešovičkách 2, Czech Republic
2 Private Observatory, Pohoří 71, CZ-254 01 Jílově u Prahy, Czech Republic
3 Johann Palisa Observatory and Planetarium, Technical University Ostrava, CZ-708 33 Ostrava, Czech Republic

ABSTRACT

The minimum timings of eclipsing binaries V418 Aql, SU Boo, RV CVn, CR Cas, GV Cyg, V432 Per, and BD+42 2782 were collected and analyzed. Their long-term behavior was studied via period analysis, revealing a periodic term in eclipse times. We derived 576 new times of minimum. Hence, to describe the periodic variation, a third-body hypothesis was proposed and the resulting orbital periods are as follows: 70, 7.4, 53, 37, 27, 53, and 18 yr, respectively. For the system V432 Per an additional 9.5 yr variation was also found. The predicted minimum masses of these distant bodies were calculated and their detectability discussed. The light curves of SU Boo and RV CVn were analyzed using the PHOEBE program, resulting in physical parameters of the components. New variable stars in the field of V418 Aql were discovered.

Key words: binaries; eclipsing – stars: fundamental parameters – stars: individual (V418 Aql, SU Boo, RV CVn, CR Cas, GV Cyg, V432 Per, BD+42 2782)

Online-only material: color figures, machine-readable and VO table

1. INTRODUCTION

After more than a century of intensive study of eclipsing binaries (hereafter EBs), these objects still represent the best method to derive the masses, radii, and luminosities of the stars. Moreover, discovering additional components in these systems is also rather straightforward using the precise times of minimum and analyzing the period variation of the eclipsing pair, a so-called light–time effect (hereafter LITE; Irwin 1959; Mayer 1990).

The period analysis method, despite its classical nature and many decades of usage (about 250 such systems are known nowadays; see, e.g., Zakirov 2010), still provides us with an efficient method of discovering the hidden components in eclipsing systems. Its main advantage is its ease of use because huge data sets of eclipse times exist. The other benefit is that this method is able to reveal the hidden components that are otherwise hardly detectable: the short-periodic ones can be easily detected via spectroscopy, while the long-period ones are visual or interferometric doubles. Hence, the period gap in between can be harvested via period analysis in these systems—it is adequately sensitive to relatively low masses, independent of luminosities of the third bodies, and also only mildly dependent on the orbit orientations (only the body orbiting perpendicular to the EB orbit cannot be detected). Finally, its usefulness with huge photometric databases was also shown (e.g., by Rappaport et al. 2013).

2. METHODS

For a brief reminder of the method of period analysis using the LITE hypothesis,

\[ \tau = \frac{A}{\sqrt{1 - e^2}} \cos \frac{\omega}{2} \left[ \frac{(1 - e^2) \cdot \sin(v + \omega)}{1 + e \cos v} + e \sin \omega \right] \]

is the light–time orbit delay as the body moves around a common barycenter (see, e.g., Mayer 1990 for an explanation of the individual parameters). This delay is periodically changing with respect to the current orbital phase, hence the times of minimum for a particular system are being observed earlier and later than predicted from the linear ephemerides. For some of the systems the quadratic term in ephemerides was also used. Hence another parameter of a rate of period change \( q \) was introduced. This continuous period change is often attributed to the mass transfer between the close eclipsing components. Mass transfer is slowly moving the barycenter of the double and hence also the period of the pair itself. Using a hypothesis of conservative mass transfer (i.e., no mass loss from the system), the well-known equation introduced, e.g., by Hilditch (2001) can be used to compute the estimated rate of mass transfer:

\[ \frac{1}{P} \frac{dP}{dt} = \frac{3}{M_1 M_2} \frac{dM_1}{dt} \]

where \( M_i \) are the masses of the primary and secondary components, respectively.

There are still many eclipsing systems lacking a detailed period analysis despite the fact that their observations exist in various databases. For example, the automatic photometric projects (like ASAS (Pojmanski 2002), Super WASP (Pollacco et al. 2006), “Pi of the sky” (Burdon et al. 2005), NSVS (Woźniak 2004), OMC (Mas-Hesse et al. 2004), and others) monitor the sky continuously, and the data are publicly available. These data points can be used either for deriving the times of minimum, or for the complete light curve (hereafter LC) analysis. For our study we have chosen several rather neglected eclipsing binaries on the northern sky for their availability from our observatories.

3. NEW PHOTOMETRIC OBSERVATIONS

New observations were mostly obtained at Ondřejov Observatory in the Czech Republic, using the 65 cm reflector equipped with the MI G2–3200 CCD camera. The standard \( R \) photometric filter was used, while the exposing times were chosen according to the brightness of the target (usually 10–90 s). The only exception was the star BD+42 2782, which is too bright for this telescope, and hence was observed by one of the authors (R.U.)
with small 34 mm and 200 mm telescopes at a private observatory in Jílové u Prahy in the Czech Republic. The observations were obtained using the standard R filter, without any filter. All of the observations were routinely reduced in a standard way, using dark frames and flat fields. The resulting photometry was used for deriving the times of minimum for a particular system. The standard Kwee–van Woerden procedure (Kwee & van Woerden 1956) was used for deriving the times of minimum. Finally, the heliocentric correction was applied to the data points. All of the data points used for the analysis are stored in Table 4 below. All of these times of minimum are heliocentric (HJD). The accuracy of particular minima are also given in the tables, for our newly derived ones as well as for the already published ones (if available).

4. THE INDIVIDUAL SYSTEMS UNDER ANALYSIS

In the present analysis we included only the systems that satisfy all of the following criteria.
1. A northern-sky eclipsing binary in the range of 9–15 mag and an orbital period of up to 3 days.
2. The times-of-minimum data set is sufficiently large for a period analysis.
3. The variation in the O – C diagram shows periodic variation and at least one period of such variation is covered recently.
4. The system was not studied before, or a new solution significantly differs from the published one.
5. At least a few new minimum time observations were obtained by the authors during the last few years.

Using these criteria, seven systems were found to be suitable for the analysis.

4.1. V418 Aql

V418 Aql (=AN 115.1930, V = 11.6 mag) was discovered as a variable star by Guthnick & Schneller (1939), who also correctly classified the star as an Algol type. However, since then only a few studies on this star were published, and no detailed photometric or spectroscopic study was performed. The spectral type was classified as F8III (Halbedel 1984), but based on only fair quality spectrograms. Later, Locher (1987b) published his finding on the duration of the total primary eclipse of about 2 hr, which is only a bit longer than that derived from our new observations (1h43m). Moreover, the system V418 Aql comprises two components; see the Washington Double Star Catalogue (Mason et al. 2001). The secondary component is about 17” distant.

We collected all available times of minimum of V418 Aql; see Table 4. For deriving new times of minimum we also used the publicly available photometry obtained for the ASAS survey (Pojmanski 2002), NSVS survey, and the OMC camera on board the INTEGRAL satellite. Two new minima were also observed during the last year by the authors. The data were analyzed applying the LITE hypothesis. See Figure 1 for the final results; the parameters of the LITE orbit are given in Table 1. In this table we present all the fitted parameters from the LITE hypothesis together with their respective errors. However, it is necessary to emphasize that these errors are only formal errors as resulting from the fitting procedure (for the estimation of errors from the covariance matrix, see, e.g., Press et al. 1986). Hence, these mathematical errors can sometimes be two to five times lower than more reliable physical uncertainties of the individual parameters. As one can see, the periodic variation is clearly visible, its period is about 70 yr, and the periastron passage will occur in upcoming years. Hence, new observations would be very welcome.

One can argue that the whole analysis and our solution is based on one crucial point only, the one near the last periastron in 1944. However, this is not true. We tried to perform a similar analysis using only the data after 1950, and using only the quadratic term in ephemerides with no LITE variation. But this approach did not lead to a better result due to the fact that the curvature of the points is not symmetric for a parabola and some of the points significantly deviate.

From the LITE hypothesis, we know that the mass function of the third hidden body is about 0.2 $M_\odot$, hence one can speculate about its nature. Using the easiest assumption about the coplanarity of both orbits (and using the total mass of the

| Parameter | V418 Aql | SU Boo | RV CVn | CR Cas | GV Cyg | BD +42 2782 |
|-----------|----------|--------|--------|--------|--------|------------|
| JD0       | 2451276.4853 (106) | 2453142.5733 (18) | 2444374.6415 (16) | 2440529.0619 (96) | 2450283.4500 (45) | 2444423.3372 (19) |
| $P$ (days) | 2.23490129 (168) | 1.56125039 (20) | 0.2696736 (3) | 2.84019694 (262) | 0.99066628 (56) | 0.37015161 (9) |
| $P_1$ (day) | 255484.4 (953.1) | 2709.1 (24.8) | 19397.8 (852.3) | 13553.0 (789.6) | 9847.1 (442.9) | 6470.60 (67.49) |
| $r_0$ (yr) | 69.95 (2.61) | 7.42 (0.07) | 53.1 (2.3) | 37.1 (2.2) | 27.0 (1.2) | 17.7 (0.2) |
| $\Delta$ (day) | 0.0453 (96) | 0.0076 (5) | 0.0074 (9) | 0.0451 (32) | 0.0079 (8) | 0.0099 (5) |
| $T_0$ | 2430626.6 (760.0) | 2453523.1 (892.0) | 2490833.6 (133.6) | 2453523.1 (892.0) | 2453523.1 (892.0) | 2453523.1 (892.0) |
| $\omega$ (deg) | 27.9 (15.8) | 131.5 (31.9) | 131.5 (31.9) | 131.5 (31.9) | 131.5 (31.9) | 131.5 (31.9) |
| $e$ | 0.658 (0.305) | 0.000 (0.001) | 0.013 (0.014) | 0.000 (0.001) | 0.000 (0.001) | 0.054 (0.090) |
| $q$ ($10^{-10}$ d) | 1.695 (0.001) | 0.024 (0.001) | 24.04 (0.01) | 0.693 (0.003) | 0.004 (0.001) | 0.016 (0.001) |

$J_{\text{rest}} = 0.184 (56)$, $K = 0.045 (0.002)$, $M = 0.001 (0.001)$, $P = 0.347 (0.015)$, $M = 0.004 (0.001)$, $M = 0.016 (0.001)$.

Figure 1. Period analysis of V418 Aql. The individual times of minimum are plotted as dots; the bigger the symbol, the larger the weight, while the continuous curve represents the final fit. See the text for details.

(A color version of this figure is available in the online journal.)
We found a minimal mass of the third body of about $1.1 \, M_{\odot}$. Such a component should be easily detectable in the light curve solution and should also be visible in the spectra of the system. A new detailed analysis is hence needed. Finally, this third component is different than the one observed visually; hence, we are dealing with at least a quadruple stellar system.

One can also ask whether such a picture of the system is self-consistent with the individual luminosities. Using a spectral type of F8III as derived by Halbedel (1984), its absolute bolometric magnitude is about 3 mag brighter than normal main sequence F8 stars (see, e.g., Cox 2000). About the same spectral type was also derived using the photometric indices ($V - K$) and ($J - H$) of V418 Aql observed by the Two Micron Sky Survey (2MASS) (Skrutskie et al. 2006). According to our observations, the primary minimum is about 2.36 mag deep, while the secondary about 0.04 mag only. Hence, the primary giant component contributes about 90% of the total luminosity of the system and is the absolutely dominant source. This is also the reason that the observed combined spectral type F8III is mainly the spectral type of the primary component. We tried to find out the individual properties of the three components in the system from our (poorly covered) light curve. We found that the secondary is probably a subgiant with a spectral type of about M1IV. Hence, the total mass of the eclipsing binary is about $1.2 + 0.4 = 1.6 \, M_{\odot}$.

From the fitting procedure we also derived that the value of the third light is about 4% of the total light. The light contribution of the third body with a mass of $1.1 \, M_{\odot}$ (i.e., about G5V spectral type) as derived from the LITE analysis is about 3.5%, which is in excellent agreement.

Moreover, during the observations of V418 Aql we discovered several new variable stars in the field. See Figure 2 for the identification chart and position of the new variables near V418 Aql. Our two nights of observations are plotted for each of these stars. The brightest one (designated as VAR 01) is the star GSC 0048604545 ($=2MASS \, 19364467 +0352167$, R.A. 19h36m44s70, decl. +03°52′16″). It is a rapidly pulsating star, probably of δ Scuti type. Its variations are about 0.07 mag in the $R$ filter, while the period of pulsations is about 1.5 hr. The second star (VAR 02) is 2MASS 19362870 +0359267 (R.A. 19h36m28s73, decl. +03°59′27″), but its type is unknown, having an amplitude of at least 0.35 mag. The two other new variables (VAR 03 $=2MASS \, 19370740 +0351051$, R.A. 19h37m07s40, decl. +03°51′05″17 and VAR 04 $=2MASS \, 19360258 +0351466$, R.A. 19h36m02s58, decl. +03°51′46″64) are rather faint, but their variations are still visible in the data; see Figure 2.

### 4.2. SU Boo

Another star in our sample is SU Boo ($=\text{AN} \, 78.1914$, $V = 11.9$ mag). It was discovered as a variable by Beljawsky (1914), while later Broglia (1960) performed the first analysis of its light curve. It is a classical Algol-type binary with deep primary and shallow secondary minima, its orbital period is about 1.5 days, and its spectral type was derived to be A3V/A4V type.
(Hill et al. 1975). The inclination of the system is about 81.5° according to Broglia (1960); however, Mardirossian et al. (1980) later published the value $i = 86.3°$. Therefore, such a large discrepancy is noteworthy and a new LC analysis would be useful.

We collected all available times of minimum published since its discovery. These are given in Table 4, including our six new measurements. Most of the data points used for the analysis were derived using the WASP (Pollacco et al. 2006) photometry, the NSVS photometry (Woźniak 2004), and two from the CRTS data (Drake et al. 2009). The resulting $O-C$ diagram is plotted in Figure 3, where the periodic variation is clearly visible, covering several cycles. We used the same approach as for V418 Aql and the LITE hypothesis to analyze the period variations. The parameters of the LITE fit are in Table 1. The period of LITE variation is about 7.4 yr, which makes this system even more interesting. Moreover, we also detected a slow steady increase in the period of the eclipsing pair (see the blue dash–dotted line in Figure 3), probably caused by a mass transfer between the close components. If we use Equation (2), we can estimate its rate to be about $2 \times 10^{-7} M_\odot$ yr$^{-1}$, which is quite a realistic value for a conservative mass transfer in an eclipsing binary.

We used the WASP data for the LC analysis. Despite having no spectroscopy and radial velocities (RVs), some of the parameters have to be fixed or only estimated. At first, the ephemerides were fixed according to the period analysis. Secondly, the albedo and gravity darkening values were kept fixed at their suggested values for stars with radiative envelopes (i.e., $A_1 = 1$, $g_1 = 1$, $i = 1, 2$). The temperature of the primary component was kept fixed at a value of $T_1 = 8450$ K, in agreement with its spectral type (Harmanec 1988). We used the program PHOEBE, ver. 0.31a (Prša & Zwitter 2005), which is based on the Wilson–Devinney algorithm (Wilson & Devinney 1971) and its later modifications. For the whole computation process the eccentricity was fixed at zero. The limb-darkening coefficients were automatically interpolated from the van Hamme tables (van Hamme 1993).

During the fitting process, we found why there was such a large discrepancy between the two inclination angles previously published. Starting with equal components ($q = 1$), the inclination results in $i = 81.5°$, while if we fit the mass ratio, it decreases and hence the inclination increases. We get the smallest possible chi-square value when the value of $q = 0.85$ and the inclination is about $i = 83.2°$. Moreover, the solution presented by Broglia (1960) is doubtful because of $q > 1$, which is rather improbable. For our final solution see Figure 4 and the parameters of the light curve given in Table 2. As one can see, the primary component dominates the system luminosity and also the mass.

The resulting mass function of the predicted third body (see Table 1) yields a minimal mass of such component of about $1 M_\odot$ (with the assumption that the orbits are coplanar and the masses of the eclipsing components are 1.95 and 1.66 $M_\odot$). It is noteworthy that no additional third light was detected in the LC solution. Assuming a normal main sequence star, then such a component should contribute about 3% to the total light, which probably should be detectable. More precise observations are needed. However, one can also speculate about an underluminous or even binary nature of the third star. From the estimated luminosities of all components, the photometric distance to the system was derived to be about 1.5 kpc.

### 4.3. RV CVn

RV CVn ($=$AN 4.1921, $V = 14.9$ mag) is another seldom investigated eclipsing binary system. It is a W UMa-type star, discovered as a variable by Larink (1921). Its spectral type was derived as F8, according to Schilt (1927). In the latter paper, Schilt stated that the star is of W UMa type, but no reliable LC solution was given. Moreover, there was a discussion about its membership to the cluster NGC 5272 ($=$M 3), which seems nowadays rather improbable. Another paper by Hoffmann (1981) also presented only the light curves, but no LC solution to the data. Since then, many new observations of times of

![Figure 3](https://example.com/figure3.png)

**Figure 3.** Period analysis of SU Boo. The open circles stand for the secondary, while the filled dots for the primary minima. The blue dash–dotted line represents the quadratic term in ephemerides.

(A color version of this figure is available in the online journal.)

![Figure 4](https://example.com/figure4.png)

**Figure 4.** Light curve of SU Boo from the WASP survey and our final fit.

(A color version of this figure is available in the online journal.)

| Parameter | SU Boo | RV CVn |
|-----------|--------|--------|
| $T_1$ (K) | 8450 (fixed) | 6100 (fixed) |
| $T_2$ (K) | 5090 | 5564 |
| $i$ (deg) | 83.18 (fixed) | 84.75 |
| $\Omega_1$ | 5.075 (fixed) | 3.039 |
| $\Omega_2$ | 5.717 (fixed) | 0.00 (fixed) |
| $L_1$ (%) | 94.5 | 50.1 |
| $L_2$ (%) | 5.5 |
| $r_1/a$ | 0.239 |
| $r_2/a$ | 0.184 |
| $q = M_2/M_1$ | 0.852 |
| $e$ | 0.00 |
| $F_1 = F_2$ | 1.00 |
| $A_1 = A_2$ | 1.00 |
| $g_1 = g_2$ | 1.00 |

The Parameters of the Light Curves of SU Boo and RV CVn as Derived from the Analysis

| Parameter | SU Boo | RV CVn |
|-----------|--------|--------|
| $T_1$ (K) | 8450 (fixed) | 6100 (fixed) |
| $T_2$ (K) | 5090 | 5564 |
| $i$ (deg) | 83.18 (fixed) | 84.75 |
| $\Omega_1$ | 5.075 (fixed) | 3.039 |
| $\Omega_2$ | 5.717 (fixed) | 0.00 (fixed) |
| $L_1$ (%) | 94.5 | 50.1 |
| $L_2$ (%) | 5.5 |
| $r_1/a$ | 0.239 |
| $r_2/a$ | 0.184 |
| $q = M_2/M_1$ | 0.852 |
| $e$ | 0.00 |
| $F_1 = F_2$ | 1.00 |
| $A_1 = A_2$ | 1.00 |
| $g_1 = g_2$ | 1.00 |

| Parameter | Value | Error | Value | Error |
|-----------|-------|-------|-------|-------|
| $T_1$ (K) | 8450 (fixed) | 6100 (fixed) |
| $T_2$ (K) | 5090 | 5564 |
| $i$ (deg) | 83.18 (fixed) | 84.75 |
| $\Omega_1$ | 5.075 (fixed) | 3.039 |
| $\Omega_2$ | 5.717 (fixed) | 0.00 (fixed) |
| $L_1$ (%) | 94.5 | 50.1 |
| $L_2$ (%) | 5.5 |
| $r_1/a$ | 0.239 |
| $r_2/a$ | 0.184 |
| $q = M_2/M_1$ | 0.852 |
| $e$ | 0.00 |
| $F_1 = F_2$ | 1.00 |
| $A_1 = A_2$ | 1.00 |
| $g_1 = g_2$ | 1.00 |
minimum have been published; however, no reliable LC solution was available until now.

Hence, we collected all the minimum observations for a period analysis as well as the data obtained within the WASP survey project for the LC analysis. For the LC analysis, we used an approach similar to that used for SU Boo: the primary temperature was fixed at a value of 6100 K (i.e., spectral type F8), and a circular orbit. The relevant light curve quantities are given in Table 2. As one can see, both components are similar to each other; the LC fit is plotted in Figure 5. The contact configuration of the system is obvious, as is usual for these types of compact W UMa-type systems.

The set of times of minimum is rather huge nowadays: 153 new minima were derived from the WASP photometry, 6 new ones from the LINEAR data (Sesar et al. 2011), and 10 from the CRTS survey. Eight new observations were obtained by the authors. All of the minima used are given in Table 2. As one can see, both components are similar to each other; the LC fit is plotted in Figure 5. The contact configuration of the system is obvious, as is usual for these types of compact W UMa-type systems.

The periodic variation is clearly visible, despite a rather large scatter of the older visual or photographic observations (we believe all published data are trustworthy due to rather deep eclipses, so all of them were used for the analysis). Hence, we followed the same procedure as for the previous systems, and the LITE hypothesis was used. The resulting fit is plotted in Figure 6, while its parameters are written in Table 1. Besides the 52 yr LITE variation we also detected a steady period increase (i.e., fitting also the quadratic term in ephemerides). Therefore, if such a body orbits on a coplanar orbit with the eclipsing pair, then its light contribution to the total luminosity of the binary should be negligible. This is also the result of our LC analysis, where no additional third light was found. Also, the interferometric detection is inapplicable because of its low luminosity.

4.4. CR Cas

The system CR Cas (=AN 450.1934, V = 11.70 mag) was discovered to be a variable star by Nielsen (1935). Later (Guthnick & Schneller 1939), it was classified as an Algol type with an orbital period of about 1.42 days, half of the correct value. Its spectral type according to the SIMBAD database is K8, which is definitely wrong. The precise UBV photometry outside of eclipse published by Lacy (1992) was used to derive the unreddened index \( (B - V)_0 = -0.27 \text{mag} \). Almost the same value of \( (B - V)_0 \) was derived using the Strömgren magnitudes by Clement & Fabregat (1998; following the method described in Harmanec & Božič 2001). This \( (B - V)_0 \) index corresponds to a spectral type of B0.5V–B1V (Popper 1980). Later, Popper (1996) gives a type of B. The most detailed analysis of the star was published by Clement & Fabregat (1998). They obtained the \( uvby \) photometry and the consequent analysis yielded that the components are probably of B0.5V and B1V spectral types, but located away from the Sun (more than 3.5 kpc, the reddening of the system is \( E(b - y) = 0.621 \)). Moreover, our observations show that the system has total eclipses (lasting about 45 minutes).

We collected all available published times of minimum for the period analysis. Moreover, 14 new minima were derived from the NSVS and OMC photometry, and a few other minima were observed by the authors. All of these data are stored in Table 4. The same period analysis was used as in the previous cases, yielding a set of LITE parameters given in Table 1. As one can see from Figure 7, the periodic variation is clearly visible nowadays, even despite a rather large scatter in the older visual observations. Moreover, we also detected a rather rapid period increase (i.e., fitting also the quadratic term in ephemerides). Clement & Fabregat (1998) speculated about the emission-type secondary component, which probably should be connected with the rapid mass transfer between the components. From our analysis we found about \( 3 \times 10^{-6} M_\odot \text{yr}^{-1} \), which is the largest mass transfer in our sample. Nevertheless, as noted, e.g., by Hilditch (2001), such a value is still possible on a thermal timescale in binaries. On the other hand, without the detailed spectroscopic analysis, this is still only a hypothesis.

From the third-body fit, we can also derive the mass function \( f(m_3) = 0.347 \pm 0.015 M_\odot \), from which we find the minimum mass of the third body to be about 6.6 \( M_\odot \). Hence, we can...
speculate about its detectability in the LC solution performed by Clement & Fabregat (1998). The third light fraction resulted in more than 6% of the total light, which should be detectable. However, the authors did not test the presence of additional light in their LC solution. We can also compute the predicted angular separation of the third component assuming the coplanar orbits and using the photometric distance as derived by Clement & Fabregat (1998). This resulted in about $a = 9.4\,\text{mas}$, which is within the capabilities of modern stellar interferometers; however, its low luminosity makes it probably undetectable with current facilities.

4.5. GV Cyg

The system GV Cyg (=AN 354.1929, $V = 13.2\,\text{mag}$) is the least studied system in our sample. It is an Algol-type eclipsing binary with an orbital period of about 0.99 day. It was discovered as a variable by Hoffmeister (1930). The first brief analysis and the LC of the system were published by Ahnert et al. (1941), which revealed a rather deep primary eclipse of about 2 mag, and probably a rather shallow secondary. The updated ephemerides were presented by Wood & Forbes (1963), while its spectral type was estimated to be about A5 by Brancewicz & Dworak (1980). However, no detailed LC and RV analyses exist and the papers published during the last two decades only contain new times of minimum observations.

Hence, we collected all available minimum timings, as well as a few of our new observations, for a period analysis. Our complete data set consists of more than 70 observations spanning over 80 yr. All of the data points are stored in Table 4. As one can see from Figure 8, the periodic variation is clearly visible, especially with the more precise observations obtained during the last two decades.

The LITE hypothesis applied to the data points led to the parameters presented in Table 1. The period of the LITE variation is about 27 yr, while the amplitude is about 11 minutes. Using the very rough parameters of the system as published by Budding et al. (2004), we can calculate the predicted minimal mass of the third component. This resulted in about $0.3\,M_\odot$ (hence an M dwarf), which should contribute only a negligible and hardly detectable portion to the total luminosity. Only a detailed spectral analysis would detect such a body in the system via spectral disentangling. The quadratic term in ephemerides shows some indication of a slow mass transfer between the eclipsing components; the smallest in our sample is only about $9 \times 10^{-7}\,M_\odot\,\text{yr}^{-1}$.

4.6. V432 Per

The system V432 Per (=GSC 02856-01647 = TYC 2856-1647-1, $V=11.2\,\text{mag}$) is probably the most often studied system in our sample. It is relatively bright, with a short orbital period (about 0.4 day), deep minima (about 0.7 mag), and high declination, which all make it an ideal target for observers from the northern hemisphere. Its first photoelectric light curves in BV filters were published by Agerer (1992); later, Yang & Liu (2002) published the first LC solution of the system, revealing its asymmetric shape (‘O’Connell effect) and contact W UMa-type configuration. More recently, Lee et al. (2008) published their photometric study of the star, where they presented spectral types for the primary and secondary components of G4 and G8–9. Moreover, they also found a periodic modulation of minimum timings, which led to a period of about 35 yr, which could be caused by a hidden M-type component. Finally, the most recent paper on the star by Odell et al. (2009), which benefits from a few spectral observations, more or less affirms the results published by Lee et al. (2008).

Since its discovery, about 200 times of minimum have been published. Despite the fact that the set of minima is quite large and several studies on period changes were published, we still believe that its true nature is different than the already published one. The problem with the interpretation of the $O - C$ diagram is that if we collect all available times of minimum and use the LITE hypothesis as presented in published papers, there still remains an unexplainable variation in the residuals. Hence, we believe that one has to use two LITE terms to describe the data in detail.

Therefore, we applied a double LITE hypothesis; hence, twelve parameters were fitted in total. The list of all available data found in the literature is given in Table 4, while our results are written in Table 3. The final fit is presented in Figure 9, where both LITE terms are plotted to the available data points. Despite a rather large scatter of the older visual and photographic minima, the most recent data obtained during the last decade clearly shows the additional variation superimposed on the third-body LITE orbit. However, such an approach is nothing novel: the double periodic LITE hypothesis was used for several eclipsing systems; see, e.g., Borkovits & Hegedüs (1996).

We can only speculate about the nature of these variations. Lee et al. (2008) find that the period modulation is most probably caused by the third body orbiting around the EB pair, and the third light contribution found in the LC solution originates from

![Figure 8. Period analysis of GV Cyg.](image_url)
has to be lower than the detected \( l_3 \) in the LC solution presented by Lee et al. (2008); however, disentangling their individual contributions is impossible. Moreover, using the distance to the system as presented in Lee et al. (2008), we can compute the predicted angular separation of the third and fourth body in the system for a prospective interferometric detection. For the third body we found a separation of about 68 mas, and for the fourth body about 23 mas. The hope of finding these bodies is diminished due to rather low brightness of the system. Hence, spectroscopic detection via disentangling currently seems to be the best method to solve this problem.

4.7. BD +42 2782

BD +42 2782 (\( = \)TYC 3080-1410-1, \( V = 9.5 \) mag) is the brightest star in our sample, and also the system studied in the most detailed analysis. It was discovered as a variable by Sokolovsky & Antipin (2005). A detailed LC and RV analysis of the star was performed by Lu et al. (2007). They derived that the system is in contact, its curve is of W UMa-type, and it has a cool spot on the primary component, which is surprisingly underluminous. Its spectrum is probably about F5 and its distance was derived to be about 124 pc. Moreover, there is also a visual component about 3\(^\prime\).5 distant, which contributes about 6.5\% to the total light of the system.

Despite having a huge set of photometric observations from the WASP survey covering the whole LC, we decided not to perform the LC analysis due to a more detailed LC+RV analysis published by Lu et al. (2007) based on precise observations obtained in two filters. However, the WASP data were used for the minimum time derivation, and hence the collection of minima (see Table 4) is rather large. Moreover, we also derived new minima from the discovery paper by Sokolovsky & Antipin (2005), from Tycho (Perryman et al. 1997), from NSVS, and from our recent observations. However, we find two major problems. At first the amplitude of photometric variations is about 0.25 mag, while the precision of individual photometric observations published by Sokolovsky & Antipin (2005) is 0.01 mag. We find a similar problem with the data sampling (it is the sparse photometry; two subsequent data points are separated by more than 24 minutes, which is about 1/20 of the orbital period). All of these make the scatter of the older observations rather large.

As one can see from Figure 10, the periodic variation is currently pretty well covered. Applying the LITE hypothesis to the data, we get the parameters given in Table 1. There are only two cycles covered by the observations; however, the variation is evident, mainly during the last two decades. One can ask how reliable the fit presented in Figure 10 is, but the lack of other
observations prevents us from doing more analysis. The period of LITE was derived relatively well, but the amplitude should be a bit different because of poor coverage near both periastron passages.

From the LITE hypothesis we find that the predicted minimal mass of the third body should be about 0.5 \( M_\odot \), which should be detectable in the LC solution. However, dealing with the visual component and also this predicted third one, we cannot disentangle the third light into the contributions from the individual components. Hence, we also deal with a quadruple system. Using the distance to the system as derived by Lu et al. (2007), we can also estimate the predicted angular separation of the third component from the eclipsing pair. This value resulted in about \( a = 78 \pm 10 \) mas, which should be easily detectable with current stellar interferometers. However, there arises a problem with its luminosity. It should be more than 3 mag fainter than the eclipsing pair (which itself is rather faint for interferometry), so its detection is right on the limit of current technique.

5. CONCLUSION

We performed a period analysis of times of minimum for seven rather seldom investigated eclipsing systems, where a third component orbiting around the EB pair was suggested as a realistic hypothesis. For some of these systems, the periods are adequately short for the third body to be discovered via spectroscopic monitoring during several seasons. For others, the third light contribution to the total light in the LC solution was discussed as a more promising technique of detection. We also discussed the possibility of interferometric detection of the additional components, but this was mostly ruled out due to their low luminosities. Moreover, for the prediction of angular separation of the third components, the distance of the systems from the Sun is needed, which is still unavailable for some of the systems.

The most interesting system in our sample is probably CR Cas, being the most distant and also the most massive system in our sample. Moreover, besides a proposed third body orbiting around the EB pair with period of about 37 yr, we derived a rather rapid mass transfer between the eclipsing components. Hence, the system might be in an interesting evolutionary stage. Another noteworthy system is also SU Boo, having the shortest third body period in our sample, only about 7.4 yr, and also significant mass transfer.

One can also ask whether such periodic variation is presented in a specific kind of EB, or if it is a quite common phenomenon. Most of the early-type stars are multiples (e.g., Chini et al. 2012), hence the LITE should also be detected for many of them. Usually, there is a problem with an insufficient data set for such an analysis. On the other hand, there are many EBs observed for decades, where no period variation was detected. Such systems are, e.g., AA And, AE Cyg, ER Vul, and many others. For a catalog of available \( O - C \) diagrams of EBs, see Paschke & Brášt (2006) or Kreiner et al. (2001).

The benefit of such period analyses for the stellar multiplicity studies in general is undisputed. There exist a few hundred LITE systems, and their period variation is still being monitored. Hence, on longer timescales one can still hope to find some dynamical effects due to third bodies. All of our systems are certainly stable (from the ratio of periods), but generally the orbits of both inner and outer bodies are not stable and are subject to long-term precession, which can be studied in the future.

We acknowledge the anonymous referee for useful comments and suggestions that significantly improved the paper. This work is based on data from the OMC Archive at LAEFF, pre-processed by ISDC. We thank the ASAS, WASP, NSVS, CRTS, and LINEAR teams for making all of the observations easily and publicly accessible. We would like to thank Ms. Lenka Kotková, Mr. Kamil Hornoch, and Mr. Dalibor Hanžl for obtaining some of the photometric observations. This work was supported by the Czech Science Foundation grant No. P209/10/0715, by the grant UNCE 12 of the Charles University in Prague, and by the research program MSM0021620860 of the Czech Ministry of Education. This research has made use of the SIMBAD database, operated at CDS, Strasbourg, France, and of NASA’s Astrophysics Data System Bibliographic Services.

REFERENCES

Agerer, F. 1992, IBVS, 3797, 1
Agerer, F., Dahm, M., & Hübischer, J. 1999, IBVS, 4712, 1
Agerer, F., & Hübischer, J. 1995, IBVS, 4222, 1
Agerer, F., & Hübischer, J. 2002, IBVS, 5296, 1
Agerer, F., & Hübischer, J. 2003, IBVS, 5484, 1
Ahnert, P., van Schewick, H., & Hoffmeister, C. 1941, KVeBB, 6, 4
Bakis, V., Bakis, H., Erdem, A., et al. 2003a, IBVS, 5464, 1
Bakis, V., Tuyuz, M., Zeyda, M., et al. 2003b, IBVS, 5399, 1
Beljawsky, S. 1914, AN, 198, 371
Blätter, R. 2001, BBSAG, 126, 1
Borkovits, T., & Hegedűs, T. 1996, A&AS, 120, 63
Borkovits, T., van Cauteren, P., Lampens, P., et al. 2008, IBVS, 5835, 1
Borovička, J. 1995, CoBrn, 31, 1
Brancewicz, H. K., & Dworak, T. Z. 1980, AcA, 30, 501
Brášt, L., Trnka, J., Lehký, M., et al. 2009, OEJV, 107, 1
Brášt, L., Zeyda, M., & Svoboda, P. 2007, OEJV, 74, 1
Brejlař, T. 1987, CIBAA, 66, 35
Brejlař, T. 1992, CIBAA, 73, 1
Broglia, P. 1960, MmSAI, 31, 107
Budding, E., Erdem, A., Çelik, C., et al. 2004, A&A, 417, 263
Burd, A., Cwiok, M., Czyrkowski, H., et al. 2005, NewA, 10, 409
Busch, H., Häußler, K., & Splügterber, E. 1979, VeSon, 9, 125
Busch, H., & Häußler, K. 1986, VeSon, 10, 210
Chini, R., Hoffmeister, V. H., Nasserri, A., Stahl, O., & Zinnecker, H. 2012, MNRAS, 424, 1925
Clement, R., & Fabregat, J. 1998, A&AS, 128, 139
Cox, A. N. (ed.) 2000, in Allen’s Astrophysical Quantities (4th ed.; New York: Springer)
Csizmadia, S., Klagyivik, P., Borkovits, T., et al. 2006, IBVS, 5736, 1
Dahm, M. 1994, BAVSR, 43, 104
Diethelm, R. 1996, BBSAG, 112, 1
Diethelm, R. 1998a, BBSAG, 116, 1
Diethelm, R. 1998b, BBSAG, 118, 1
Diethelm, R. 2001a, BBSAG, 124, 1
Diethelm, R. 2001b, BBSAG, 125, 1
Diethelm, R. 2001c, IBVS, 5027, 1
Diethelm, R. 2009a, IBVS, 5871, 1
Diethelm, R. 2009b, IBVS, 5894, 1
Diethelm, R. 2010, IBVS, 5920, 1
Diethelm, R. 2011a, IBVS, 5960, 1
Diethelm, R. 2011b, IBVS, 5992, 1
Diethelm, R. 2012a, IBVS, 6011, 1
Diethelm, R. 2012b, IBVS, 6029, 1
Diethelm, R. 2013, IBVS, 6063, 1
Dogru, S. S., Donmez, A., Tuyuz, M., et al. 2007, IBVS, 5746, 1
Drake, A. J., Djorgovski, S. G., Mahabal, A., et al. 2009, ApJ, 696, 870
Dvorak, S. W. 2010, IBVS, 5938, 1
Gessner, H. 1966, VeSon, 7, 84
Gokay, G., Demircan, Y., Terzioglu, Z., et al. 2010, IBVS, 5922, 1
Graff, K. 1923, Ibid, 217, 310
Gokay, G., Demircan, Y., Terzioglu, Z., et al. 2010, IBVS, 5922, 1
Gessner, H. 1966, VeSon, 10, 210
Gurol, B., Derman, E., Muyesseroglu, Z., et al. 2007, IBVS, 5791, 1
Graff, K. 1923, Ibid, 217, 310
Gokay, G., Demircan, Y., Terzioglu, Z., et al. 2010, IBVS, 5922, 1
Gessner, H. 1966, VeSon, 7, 84
Go"ok, G., Demircan, Y., Terzioglu, Z., et al. 2010, IBVS, 5922, 1
Graff, K. 1923, Ibid, 217, 310
Gurol, B., Derman, E., Muyesseroglu, Z., et al. 2007, IBVS, 5791, 1
Guthnick, P., & Schnellner, H. 1939, AN, 268, 165
Halbedel, E. M. 1984, PASP, 96, 98
Harmance, P. 1988, BAICs, 39, 329
Harmance, P., & Boč, H. 2001, A&A, 369, 1140
Häussler, K. 1973, MiHar, 15, 6
