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Relativistic apsidal motion in eccentric eclipsing binaries*

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ABSTRACT

Context. The study of apsidal motion in detached eclipsing binary systems is known to be an important source of information about stellar internal structure as well as the possibility of verifying of General Relativity outside the Solar System.

Aims. As part of the long-term Ondřejov and Ostrava observational projects, we aim to measure precise times of minima for eccentric eclipsing binaries, needed for the accurate determination of apsidal motion, providing a suitable test of the effects of General Relativity.

Methods. About seventy new times of minimum light recorded with photoelectric or CCD photometers were obtained for ten eccentric-orbit eclipsing binaries with significant relativistic apsidal motion. Their O–C diagrams were analysed using all reliable timings found in the literature, and new or improved elements of apsidal motion were obtained.

Results. We confirm very long periods of apsidal motion for all systems. For BF Dra and V1094 Tau, we present the first apsidal-motion solution. The relativistic effects are dominant, representing up to 100% of the total observable apsidal-motion rate in several systems. The theoretical and observed values of the internal structure constant k_2 were compared for systems with lower relativistic contribution. Using the light-time effect solution, we predict a faint third component for V1094 Tau orbiting with a short period of about 8 years.

Key words. binaries: eclipsing – stars: general – stars: fundamental parameters – relativity

1. Introduction

The apsidal motion in eccentric eclipsing binaries (hereafter EEB) is not only caused by the combined effect of the tidal distortion and rotational flattening of components. There is a subgroup amongst EEB, in which apsidal advance period is dominantly affected by the relativistic contribution. It is well known that these systems can provide additional confirmation of General Relativity outside the Solar System. A good review of apsidal-motion tests in close binaries was presented by Giménez (2007).

All EEB analysed here have properties that make them important *relativistic laboratories* for verifying General Relativity. In particular, ten northern hemisphere objects are relatively bright, eclipsing binaries with orbital periods in the range 4–15 days. Most systems are also included in the list of EEB suitable for studies of the relativistic apsidal motion (Giménez 1985, 1994) as well as in the latest catalogue of EEB (Bulut & Demircan 2007). This study is part of a series of papers on apsidal motion, where we present the results of our long-term photometric monitoring of EEB eclipses (Wolf et al. 2001, 2004, 2005). Similar studies of relativistic apsidal motion in individual binary systems were published by Giménez & Margrave (1985), Giménez et al. (1987), and Claret (1997, 1998). Regularly updated ephemeris, based on all compiled times of minima, can be found in the database of the O–C diagrams (Kreiner 2004)[1].

2. Observations of minimum light

Over the past 15 years, we have accumulated over 5000 photometric observations at selected phases during primary and secondary eclipses and derived over 70 precise times of minimum light for specific eccentric systems. This observational programme utilizes only moderately sized or small telescopes equipped with a photoelectric photometer or a CCD camera. Moreover, a large amount of observing time is needed, which is unavailable presently at large telescopes but is more practical for small amateur telescopes equipped with modern detectors.

New photoelectric or CCD photometry was obtained at several different observatories:

- Ondřejov Observatory, Czech Republic: the 0.65-m reflecting telescope with the CCD camera SBIG ST-8 or Apogee AP7 and Johnson *VR* filters.
- Hvar Observatory, Croatia: the 0.65-m Cassegrain telescope with the single-channel photoelectric photometer housing an EMI 9789 QB photomultiplier and Johnson's *UBV* filters.

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* Partly based on photoelectric observations secured at the Hvar Observatory, Faculty of Geodesy, Zagreb, Croatia, in October 2008.

[1] `http://www.as.wsp.krakow.pl/o-c/index.php3`

- Johann Pallisa Observatory and Planetarium Ostrava, Czech Republic: 0.2-m or 0.3-m telescopes with the CCD camera SBIG ST-8XME and *VRI* filters.
- Observatory Valašské Meziříčí, Czech Republic: the 0.3-m Celestron Ultima telescope with the CCD camera SBIG ST-7 and *RI* filters.
- Private observatory of LB at Pec pod Sněžkou, Czech Republic: 0.2-m Cassegrain telescope with the CCD cameras SBIG ST-8 or G2-402 and *VRI* filters.
- Private observatory of PS at Brno, Czech Republic: 0.2-m Cassegrain telescope with the CCD camera ST-7XME and Johnson-Cousins $BV(RI)_c$ filters.

CCD measurements at most observatories were flat-fielded using sky exposures taken at either dusk or dawn. Several comparison stars were chosen in the same frame as the variables. No variations in the brightness of these stars exceeding the expected error of measurements were detected (typically $\sigma \simeq 0.007$ mag in Ondřejov). The C-Munipack[2] (Motl 2007), a user-friendly software package, was used to reduce most of our CCD images. No correction for differential extinction was applied, because of the proximity of the comparison stars to the variable and the resulting negligible differences in air mass.

The new times of primary and secondary minima and their errors were generally determined by the classical Kwee-van Woerden (1956) algorithm. In some cases (*Hipparcos* data, scattered points), the light-curve fitting by polynomials of the third or fourth order and the least squares method were used. All new times are given in Table A.1. In general, only the bottom parts of the eclipses were used. All epochs in Table A.1 are calculated from the light elements given in Table 1, and the other columns are self-explanatory.

3. Apsidal motion analysis

The motion of the apsis of a binary star is a direct consequence of the finite size of its components. This effect has been known for a long time (Cowling 1938; Sterne 1939). The rate of motion of the apsis is dependent on the internal structure of each component. Determination of the characteristics of a binary thus provides an observational test of the theory of stellar structure and evolution. Moreover, there is a relativistic contribution to the periastron advance in a way similar to what occurs in the orbit of the planet Mercury.

The apsidal motion in all systems was studied by means of an O–C diagram analysis. The method described by Giménez & García-Pelayo (1983), which is a weighted least squares iterative procedure, including terms in eccentricity up to the fifth order, was slightly modified. There are in principle five independent variables ($T_0, P_s, e, \dot\omega, \omega_0$) determined in this procedure. The values of eccentricity e and the length of periastron ω_0 were fixed if known by the previous light curve or radial velocity curve solution. The periastron position ω at epoch E is defined by the linear equation

$$\omega = \omega_0 + \dot\omega\, E,$$

where $\dot\omega$ is the rate of periastron advance, and the position of periastron for the zero epoch T_0 is denoted by ω_0. The relation between the sidereal and the anomalistic period, P_s and P_a, is given by

$$P_s = P_a\,(1 - \dot\omega/360^\circ),$$

and the period of apsidal motion by

$$U = 360^\circ P_s/\dot\omega.$$

We collected all CCD and photoelectric times of minimum light available in the literature. Their weights are given directly by the inverse of the sigma squared. The earlier visual and photographic times (especially the times of the mid-exposure of a photographic plate) were not used in our calculations because of the large scatter in these data.

3.1. IT Cas

The detached and double-lined eclipsing binary IT Cassiopeiae (also GSC 3650.0959, FL 3517, $V_{\rm max} = 11\overset{\rm m}{.}2$, Sp. F5V+F5V) is a relatively well-known and frequently observed eclipsing binary with an eccentric orbit ($e = 0.08$) and orbital period of about 4 days. It was first discovered to be a spectroscopic binary by Fadeeva (Parenago 1939). Busch (1975a) obtained a photographic light curve, which was later measured photoelectricaly by Khaliullin & Kozyreva (1989). Holmgren & Wolf (1996) analysed the O–C diagram and found a relatively short period of apsidal motion $U = 404 \pm 63$ years. See also history summarized in that paper. Accurate masses and radii was determined spectroscopically by Lacy et al. (1997), who detected components of similar mass and size (see Table 3). They also excluded the previous reports of δ Scuti variations. Kozyreva & Zakharov (2001) obtained *WBVR* photoelectric measurements and determined the longer apsidal-motion period of $U = 3300 \pm 750$ years.

Apart from the minima given in Table A.1, we add numerous times of minimum obtained by several observers: Lacy et al. (1997, their Table 4, 1998, 2001), Agerer & Hübscher (2003), Diethelm (2003), Nakajima (2003)[3], Hübscher (2005), Hübscher et al. (2005), Smith & Caton (2007), and Hübscher & Walter (2007). A total of 95 times of minimum are now available, of which 51 correspond to primary eclipses and 44 to secondary eclipses (Table A.2). The computed apsidal-motion elements and their internal errors in the least squares fit (in brackets) are given in Table 1. In this table, P_s denotes the sidereal period, e represents the eccentricity, and $\dot\omega$ is the rate of periastron advance (in degrees per cycle). The zero epoch is given by T_0, and the corresponding position of the periastron is represented by ω_0.

The O–C residuals for all times of minimum with respect to the linear part of the apsidal-motion equation (O–C diagram, ephemeris curve) are shown in Fig. 1. The non-linear predictions, corresponding to the fitted parameters, are plotted as continuous and dashed curves for primary and secondary eclipses, respectively.

3.2. V459 Cas

The double-lined and detached eclipsing binary V459 Cassiopeiae (also BV 5, CSV 5894, FL 83, $V_{\rm max} = 10\overset{\rm m}{.}33$, Sp. A1V+A1V) is a known close binary system with a slightly eccentric orbit ($e = 0.024$) and a longer orbital period of about 8.5 days. It was discovered to be variable by Strohmeier (1955). The first light elements were measured by Meinunger & Wenzel (1967), who also recognized that the orbit is eccentric. Moments of photographic minima were then determined by Busch (1976ba). Precise absolute dimensions of the components of V459 Cas were derived spectroscopically by Lacy et al. (2004), who detected components of similar mass and size (see Table 3) and a period of apsidal motion $U = 6100$ yr. The

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[2] `http://c-munipack.sourceforge.net/`

[3] `http://www.ztv.ne.jp/web/K.Nakajima/light_curve.htm`

Table 1. Apsidal-motion elements for ten selected eclipsing systems.

System	T_0	P_s	e	$\dot{\omega}$	ω_0	U
	[HJD-2400000]	[days]	–	[deg cycle^{-1}]	[deg]	[10^3 years]
IT Cas	45167.4167(3)	3.8966487(2)	0.0896(4)	0.00087(7)	331.2	4.4
V459 Cas	52565.6385(4)	8.4582621(8)	0.0244(2)	0.00071(8)	240.1	11.7
V541 Cyg	44881.7927(3)	15.3378983(7)	0.4736(5)	0.00032(6)	262.7	47.1
V1143 Cyg	42213.4335(5)	7.6407418(8)	0.535(4)	0.00072(8)	47.7	10.5
V1147 Cyg	50759.4353(6)	15.2513238(5)	0.276(1)	0.00040(5)	51.6	37.6
BF Dra	47276.3384(8)	11.210980(1)	0.3898(7)	0.00056(8)	93.2	19.7
V345 Lac	50200.7695(6)	7.4919003(2)	0.4568(8)	0.00107(8)	241.2	6,9
EW Ori	44948.0037(5)	6.9368439(7)	0.068(1)	0.00057(4)	314.1	12.0
GG Ori	47814.2022(5)	6.6314924(8)	0.220(1)	0.00057(6)	122.9	11.5
V1094 Tau	49702.4468(3)	8.9885451(5)	0.2667(5)	0.00065(7)	333.8	13.6

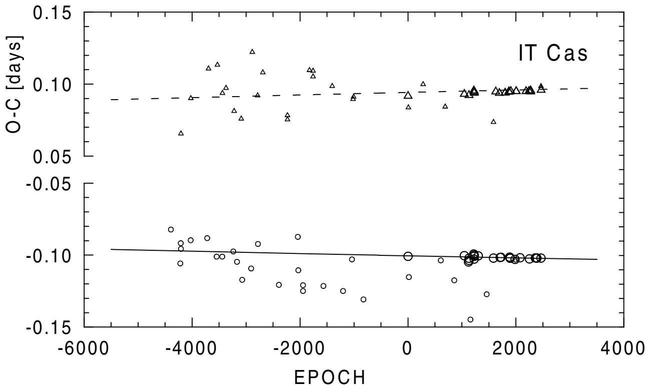

Fig. 1. The O–C diagram for the times of minimum of IT Cas. The continuous and dashed lines represent predictions for the primary and secondary eclipses, respectively. The individual primary and secondary minima are denoted by circles and triangles, respectively. Larger symbols correspond to the photoelectric or CCD measurements, which were given higher weights in the calculations.

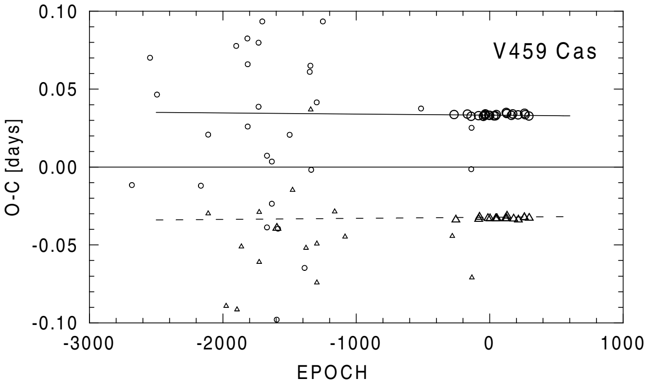

Fig. 2. O–C diagram of V459 Cas. See legend to Fig. 1.

apsidal motion in V459 Cas was later studied by Dariush et al. (2006), who confirmed the slow rate $\dot{\omega}$ = $19.^{\circ}8$ per century and found a discrepancy with the theory of stellar structure.

Since the above-mentioned papers were published, a substantial number of new times of minima have been obtained, which have allowed us to reduce the observational uncertainties. Using the *Hipparcos* photometry (ESA 1997), we were able to derive three additional times of minimum light using the light-curve profile fitting method. Besides those minima given in Table A.1, we have added numerous times of minimum obtained by Lacy et al. (2004, their Table 1), Lacy (2004), Hübscher (2005), Hübscher & Walter (2007), Sobotka (2007), and Brát et al. (2007). A total of 91 times of minimum light were found with 37 secondary eclipses among them (Table A.3). The orbital inclination was adopted to be $i = 89.^{\circ}47$, based on the photometric analysis (Lacy et al. 2004). The computed apsidal-motion parameters and their internal errors in the least squares fitting are given in Table 1, and the corresponding O–C diagram is shown in Fig. 2.

3.3. V541 Cyg

The detached eclipsing binary V541 Cygni (also SVS 1034, BD+30°3704, and FL 2814; $V_{\max} = 10.^{\rm m}35$, Sp. B9.5V+B9.5V) is also a relatively well-known eclipsing binary with a highly eccentric orbit (e = 0.48) and a long orbital period of about 15.34 days. It was discovered to be a variable star by Kulikowski (1948), photographic observations later being obtained by Karpowicz (1961) and Wachmann (1961). The very slow apsidal motion in V541 Cyg and its important relativistic contribution was studied by Wolf (1995) and Guinan et al. (1996). A review of studies of this binary can be found in Lacy (1998), where precise absolute parameters are given (see Table 3). Volkov & Khaliullin (1999) later confirmed the slow apsidal motion $\dot{\omega}$ = 0.86 ± 0.05°/100 years, obtaining good agreement with their theoretical results.

We include all times of minimum light collected in Lacy (1998, his Table 3), Volkov & Khaliullin (1999, their Table 1), and Smith & Caton (2007) as well as our new timings given in Table A.1. The orbital inclination was assumed to be $i = 89.^{\circ}88$, based on the last photometric analysis of Lacy (1998). In total, 56 minimum light times were collected in our analysis, with 30 primary eclipses among them (Table A.4). The resulting apsidal-motion parameters are given in Table 1, and the O–C diagram is shown in Fig. 3.

3.4. V1143 Cyg

The detached and double-lined eclipsing binary V1143 Cygni (also HD 185912, BD+54°2193, HR 7484, HIP 96620, and FL 2597; $V_{\max} = 5.^{\rm m}86$, Sp. F5V+F5V) is a bright and well-known binary system of high orbital eccentricity (0.54) and a rather long orbital period of 7.6 days. It was discovered to be an eclipsing binary by Snowden (1966), although it was already known to be a double-line spectroscopic binary (Harper 1919, 1935). The analysis of the radial velocity curve and

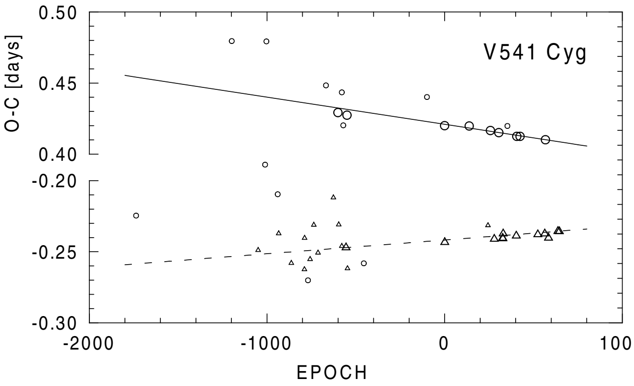

Fig. 3. O–C diagram of V541 Cyg. See legend for Fig. 1.

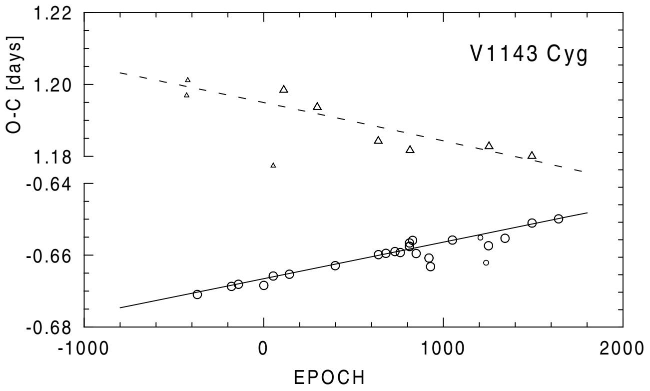

Fig. 4. O–C graph for V1143 Cyg. See legend to Fig. 1.

UBV photometry was performed by Snowden & Koch (1969). The relativistic apsidal motion in V1143 Cyg was studied by Giménez & Margrave (1985) with good agreement with theoretical results. The physical properties of the system were later carefully derived by Andersen et al. (1987). The next apsidal-motion study was presented by Burns et al. (1996), who obtained the apsidal-motion rate of $\dot{\omega} = 3\overset{\circ}{.}52/100$ yr. Finally, a light-curve analysis and apsidal-motion study was published by Dariush et al. (2005) with good agreement with results of previous investigators. The reader is also referred to the history of work on this binary described in the paper of Giménez & Margrave (1985).

New primary minimum was measured photoelectrically at Hvar Observatory, Croatia, in October 2008. The nearby comparison star HD 185978 = BD+53°2282 (Sp.F8, $V = 7\overset{\rm m}{.}88$, $B-V = 0\overset{\rm m}{.}49$, $U-B = 0\overset{\rm m}{.}07$) – used also in the previous photometric study of Burns et al. (1996) – was used during these *UBV* observations, which consisted of 10-s integrations in each filter. They were carefully reduced to the standard *UBV* system and corrected for differential extinction using the reduction program HEC 22 rel. 16.1[4]. The standard errors of these measurements were about 0.011, 0.008, and 0.006 mag in the U, B, and V filters, respectively.

Using the *Hipparcos* photometry (ESA 1997), we were able to derive one additional time of minimum light, and two revised precise CCD times of minima obtained at Pec in September 2005 are given in Table A.1. All photoelectric times of minimum light given in Giménez & Margrave (1985, their Table 1), Guinan et al. (1987), Caton & Burns (1993), Lacy & Fox (1994), Burns et al. (1996), Hegedüs et al. (1996), Dariush et al. (2001, 2003, 2005, their Tables 2 and 3) were included in this dataset. The orbital inclination $i = 87\overset{\circ}{.}3$ was taken from Dariush et al. (2004). A total of 35 times of minimum light were collected in our analysis, 10 secondary eclipses being among them (Table A.5). The computed apsidal-motion parameters are given in Table 1, and the O–C graph is shown in Fig. 4.

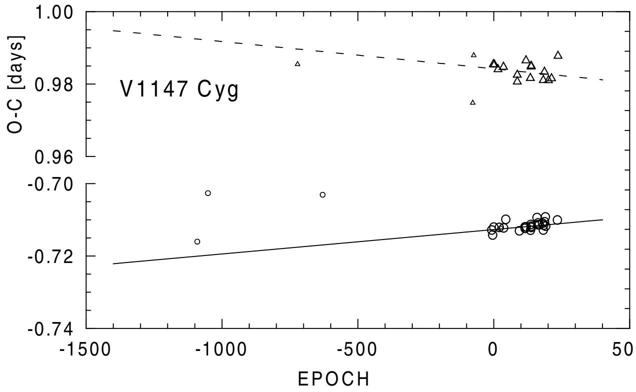

Fig. 5. O–C diagram for the times of minimum of V1147 Cyg. See legend to Fig. 1.

3.5. V1147 Cyg

The detached eclipsing binary V1147 Cygni (also HBV 423, $V_{\rm max} = 12\overset{\rm m}{.}0$, Sp. A) is a faint, poorly studied binary system with a moderate orbital eccentricity ($e \simeq 0.28$) and a long orbital period of 15.25 days. It was discovered as variable by Wachmann (1961), Chinarova (1997) later publishing a photographic light curve based on Odessa Sky Patrol photographic plates. The CCD photometry was obtained by Bloomer et al. (1998), who found the correct period. Wetterer et al. (2006) presented the photometric study and derived the slow apsidal motion of about $0\overset{\circ}{.}80$ per century.

We used all times of minima published in Wachmann (1966), Chinarova (1997), Bloomer et al. (1998), and Wetterer et al. (2006, their Table 2) as well as our new times obtained at Ondřejov and Pec observatories in our analysis. The orbital inclination was adopted to be $i = 89\overset{\circ}{.}7$, based on the photometric study of Wetterer et al. (2006). Altogether, 49 times of minimum light were collected, including 20 secondary eclipses (Table A.6). The calculated apsidal-motion parameters are given in Table 1, and the O–C diagram is shown in Fig. 5.

3.6. BF Dra

The detached and double-lined eclipsing binary BF Draconis (also BD+69°1006, HIP 92489, BV 379, $V_{\rm max} = 9\overset{\rm m}{.}83$, Sp. F8) is a poorly studied eccentric binary system with a high eccentricity ($e \simeq 0.4$) and a longer orbital period of about 11.2 days. It was discovered to be a variable star by Strohmeier et al. (1962). Döpner (1962) measured the light elements using an incorrect orbital period of 5.6 days. In his spectroscopic analysis, Imbert (1985) obtained the precise physical properties of both components and derived the correct period. Diethelm et al. (1993) obtained a photoelectric light curve and confirmed the existence of an eccentric orbit.

Using the *Hipparcos* photometry (ESA 1997), we were able to derive one additional time of secondary minimum using the light-curve profile fitting method, in addition to precise

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[4] `http://astro.troja.mff.cuni.cz/ftp/hec/HEC22/`

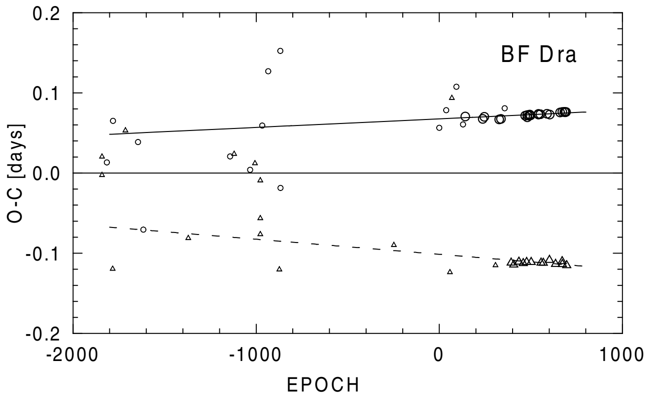

Fig. 6. O–C graph for BF Dra. See legend to Fig. 1.

CCD times obtained at Ondřejov, Ostrava and Brno observatories. Numerous precise times of minima presented in Agerer & Hübscher (1998), Caton & Smith (2005), Lacy (2006), Brát et al. (2007), Lacy (2007), as well as Smith & Caton (2007) were used in our analysis. Additional CCD photometry of BF Dra was obtained by Mr. Kamil Hornoch on Dec. 9, 2002 and Jan. 17, 2003. The observations were carried out with the 35-cm reflecting telescope and the SBIG ST-8 CCD camera at Lelekovice, Czech Republic. The star GCS 4435.426, observed also in previous photometric measurements of Diethelm et al. (1993), was targeted. Altogether 65 times of minimum light were collected in our dataset, 36 primary and 29 secondary eclipses being among them (Table A.7). The orbital inclination was assumed to be $i \simeq 90°$, because lack of a precise light curve analysis. It is known that the apsidal-motion solution is practically insensitive to relatively large changes in inclination, but strongly depends on the orbital eccentricity. The resulting apsidal-motion parameters are given in Table 1, and the O–C graph is shown in Fig. 6.

3.7. V345 Lac

The detached eclipsing binary V345 Lacertae (also GSC 3986.2900, FL 3354, $V_{\max} = 11\overset{\mathrm{m}}{.}3$, Sp. B8) is a relatively little know early-type eccentric binary with a high orbital eccentricity $e \simeq 0.45$ and a longer orbital period of about 7.5 days. It was discovered to be a variable star photographically by Miller & Wachmann (1973). The photographic light curve and new times of minimum light were later derived by Busch (1978) from the plates of Sonnenberg and Hartha Observatories. Wolf et al. (2004) presented an O–C diagram analyses and found the slow apsidal motion with a period of $U = 7000 \pm 700$ years with the substantial relativistic contribution.

Our previous times of minima given in Wolf et al. (2004, Table A.1) as well as new timings published in Caton & Smith (2005), Smith & Caton (2007), and Hübscher et al. (2008) were included. Two new additional CCD times of minimum light obtained at Ostrava observatory are given in Table A.1. A total of 72 times of minimum light were collected in our analysis, with 33 secondary eclipses among them (Table A.8). The orbital inclination was assumed to be $i = 90°$, bacause of the absence of a photometric analysis of this system to date. The computed apsidal-motion parameters are given in Table 1, and the O–C graph is shown in Fig. 7.

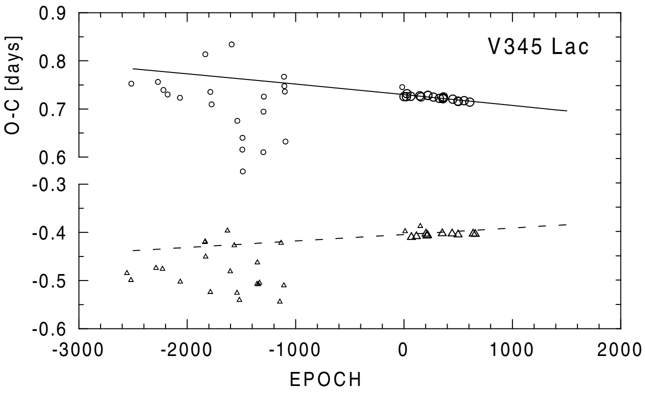

Fig. 7. O–C graph for V345 Lac. See legend to Fig. 1.

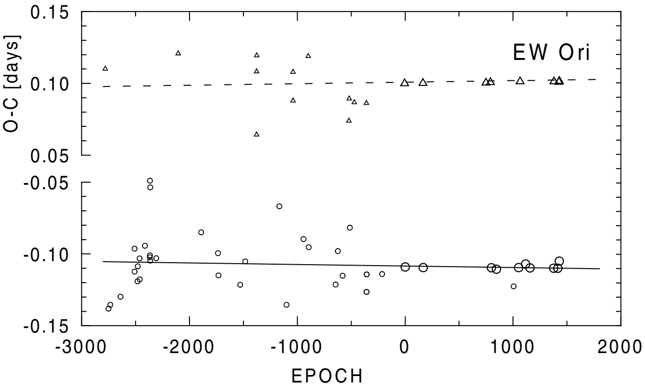

Fig. 8. O–C diagram for EW Ori. See legend to Fig. 1.

3.8. EW Ori

The detached and double-lined eclipsing binary EW Orionis (also HD 287727, BD+01°0976, HBV 421,$V_{\max} = 9\overset{\mathrm{m}}{.}9$, Sp. G0+G5) is another relatively neglected binary system with a modest eccentric orbit ($e = 0.08$) and a longer orbital period of about 7 days. It was discovered to be a variable star by Hoffmeister (1930), and later visual observations were provided by Lause (1937), Gaposchkin (1953), and Kordylewski (1962). The first photoelectric observations were obtained by Pierce (1951), and photographic moments of minima were later determined by Busch (1976b). Radial velocities and two-colour V, R photometry of EW Ori were analysed by Popper et al. (1986). The relativistic apsidal motion was studied by Wolf et al. (1997), who found a very slow apsidal motion of period $U = 160\,000 \pm 40\,000$ years.

All precise times of minima given in Wolf et al. (1997), Agerer & Hübscher (2003), and Smith & Caton (2007) as well as our new times obtained at Ondřejov and Ostrava observatories were included. A total of 65 times of minimum light were collected in our database, with 45 primary and 20 secondary eclipses among them (Table A.9). The orbital inclination was assumed to be $i = 89\overset{\circ}{.}8$, based on the photometric analysis of Popper et al. (1986). The computed apsidal-motion parameters are given in Table 1, and the O–C graph is shown in Fig. 8.

3.9. GG Ori

The detached and double-lined eclipsing binary GG Orionis (also HD 290842, $V_{\max} = 10\overset{\mathrm{m}}{.}37$, Sp. B9.5V+B9.5V) is poorly studied binary with an orbit of moderate eccentricity ($e \simeq 0.22$),

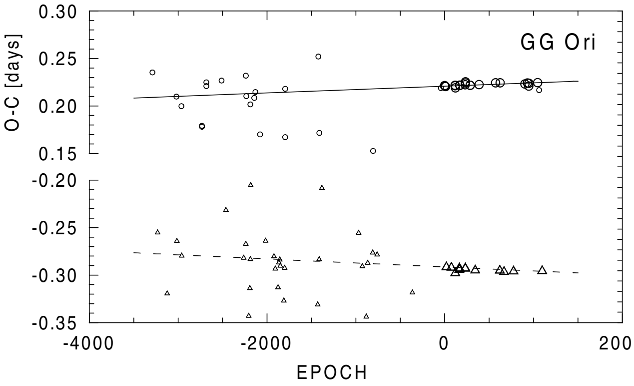

Fig. 9. O–C graph for GG Ori. See legend to Fig. 1.

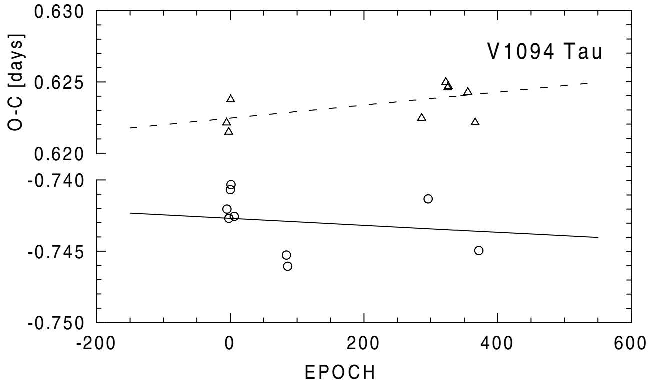

Fig. 10. O–C diagram for V1094 Tau. See legend to Fig. 1.

as a probable member of the Orion OB1 association. It was discovered to be a variable star by Hoffmeister (1934) at Sonneberg Observatory. The correct orbital period of $P = 6.631$ days was first determined by Kordylewski (1951). Numerous moments of photographic minima were determined by Busch (1975a), but the first photoelectric light curve in *UBVR* was presented later by Zakirov (1997). The absolute dimensions were derived spectroscopically in Torres et al. (2000), who obtained the precise masses given in Table 3 as well as an apsidal period of $U = 10\,470 \pm 4500$ yr (see also bibliography on GG Ori published in that paper). Additional *WBVR* photoelectric photometry was obtained by Volkov & Khaliullin (2002), who also confirmed a slow apsidal motion $0\overset{\circ}{.}046 \pm 0\overset{\circ}{.}005$ per year with a dominant relativistic contribution.

All new precise times of minima published in Zakirov (1997), Torres et al. (2000, their Table 3), Volkov & Khaliullin (2002, their Table 7), Caton & Smith (2005), Hübscher et al. (2006), Nakajima (2006)[5], Mossakovskaya (2006), as well as Hübscher & Walter (2007) were included in our analysis. In total 85 times of minimum light were collected in this dataset (Table A.10), 43 secondary eclipses being among them. The orbital inclination was assumed to be $i = 89\overset{\circ}{.}3$, based on the comprehensive study of Torres et al. (2000). The apsidal-motion parameters are given in Table 1, and the O–C graph is shown in Fig. 9.

3.10. V1094 Tau

The detached eclipsing binary V1094 Tauri (also HDE 284195, BD+21°605, DHK 41, $V_{\max} = 8\overset{\mathrm{m}}{.}96$, Sp. G0+G3) is a newly discovered binary (Kaiser 1994) with a longer orbital period ($P \simeq 9.0$ day), which is a possible member of the Hyades star cluster. With its long period of almost precisely an integer number of days, V1094 Tau is a difficult object to study with light curve photometry. Its absolute dimensions were derived spectroscopically by Griffin & Boffin (2003), where the precise value of eccentricity $e = 0.2697(18)$ and the length of periastron $\omega = 333\overset{\circ}{.}2(3)$ are in accordance with our own results.

All times of minima presented in Kaiser et al. (1995, their Table 1), Kaiser & Frey (1998, their Table 1), Lacy (2002, 2003), Hübscher (2005), and Hübscher et al. (2005) as well as our new times obtained at Ondřejov were included in the final data set (Table A.11). Only 18 times of minimum light were collected in our analysis, with 9 secondary eclipses among them. The orbital inclination was assumed to be $i = 90°$, because of absence to date of a photometric analysis of this system. The calculated apsidal-motion parameters are given in Table 1, and the O–C graph is shown in Fig. 10.

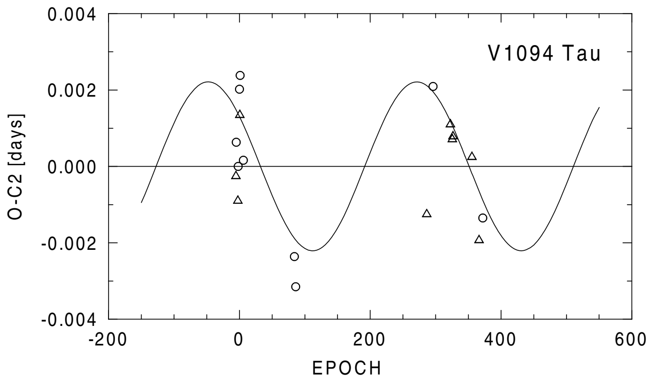

Fig. 11. O–C$_2$ residuals for the times of minimum of V1094 Tau after subtraction of apsidal motion. The sinusoidal curve represents a light-time effect for the possible third-body circular orbit with a short period of about 8 yr and an amplitude of about 4 min.

Table 2. Third-body orbit in V1094 Tau.

Parameter	Unit	Value
P_3	years	7.85 (0.81)
e_3	–	0.0 (fixed)
A	days	0.0022 (3)
$f(m_3)$	$M_\odot$	0.000 91
$M_{3,\min}$	$M_\odot$	0.17

By subtracting the slow apsidal motion in the previous O–C diagram, we also tried to ascertain the light-time effect (LITE) and the possible presence of a third body in this system. A preliminary solution of the LITE in V1094 Tau is given in Table 2, where P_3 is the orbital period of the third body, A is a semi-amplitude, and e_3 is an orbital eccentricity. Assuming a coplanar orbit ($i_3 = 90°$) and the total mass of the eclipsing pair $M_1 + M_2 = 2.11\ M_\odot$ (Griffin & Boffin 2003), we obtain a lower limit to the mass of the third component $M_{3,\min}$.

The deviations of the O–C residuals from the apsidal motion for V1094 Tau are plotted in Fig. 11. The third component may be a red dwarf of a spectral type M 7–M 8 with a bolometric magnitude of about +11.2 mag (Harmanec 1988), hardly detectable in the G0+G3 binary system.

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[5] `http://www.ztv.ne.jp/web/K.Nakajima/light_curve.htm`

Table 3. Adopted masses of the selected EEB and their classical and relativistic apsidal motion.

System	Spectral type	M_1 [$M_\odot$]	M_2 [$M_\odot$]	$\dot\omega_{\rm rel}$ [10^{-5} deg/cycle]	$\dot\omega_{\rm obs}$ [10^{-5} deg/cycle]	$\dot\omega_{\rm rel}/\dot\omega_{\rm obs}$ [%]	Source
BW Aqr	F7V	1.49(2)	1.39(2)	32	92	35	Clausen (1991)
V889 Aql*	B9.5V+A0V	2.4	2.2	25	45	78	Wolf et al. (2005)
SW CMa	A3	2.22	2.03	34	67	51	Clausen et al. (2008)
IT Cas	F6V+F6V	1.330(9)	1.328(8)	40	87	46	Lacy et al. (1997)
V459 Cas	A1V+A1V	2.02(3)	1.96(3)	33	71	46	Lacy et al. (2004)
V636 Cen	F8/G0V	1.04	0.85	32	80	40	Clausen et al. (2008)
EK Cep	A1V+G5V	2.029(23)	1.124(12)	44	93	47	Popper (1987)
V731 Cep	B8.5V+A1.5V	2.577(98)	2.017(84)	45	60	75	Bakis et al. (2008)
TV Cet*	F2V+F5V	1.39	1.27	24	30	80	Wolf et al. (2001)
V541 Cyg	B9.5V+B9.5V	2.24(9)	2.24(8)	32	32	100	Lacy (1998)
V1143 Cyg	F5V+F5V	1.391(16)	1.347(13)	39	72	54	Andersen et al. (1987)
V1147 Cyg	A2	2.15	2.01	24	40	60	Wetterer et al. (2006)
BF Dra	F8V+F8V	1.4(1)	1.4(1)	25	56	45	Imbert (1985)
RW Lac*	G5V+G7V	0.928(6)	0.870(4)	17	18	97	Lacy et al. (2005)
V345 Lac	B8V+B8V	3.0	3.0	59	107	55	Wolf et al. (2004)
RR Lyn*	A2IV+F0V	1.89(7)	1.49(5)	27	40	67	Khaliullin & Khaliullina (2002)
EW Ori	G0V+G5V	1.190(14)	1.154(14)	27	57	47	Popper et al. (1986)
GG Ori	B9.5V+B9.5V	2.342(16)	2.338(17)	45	57	79	Torres et al. (2000)
VV Pyx	A1V+A1V	2.098(18)	2.098(18)	51	138	37	Andersen et al. (1984)
V1094 Tau*	G0V+G3V	1.10(1)	1.01(1)	22	65	34	Griffin & Boffin (2003)

Note: * *possible triple system.*

4. Discussion

The observable apsidal motion in close binaries is not only due to the combined effect of tidal distortion and rotational flattening of components. An independent contribution is represented by general relativistic equations of motion. The total observable rate of apsidal motion is equal to

$$\dot\omega_{\rm obs} = \dot\omega_{\rm cl} + \dot\omega_{\rm rel}, \qquad (1)$$

where $\dot\omega_{\rm cl}$ denotes the classical or Newtonian contribution and $\dot\omega_{\rm rel}$ is the relativistic term. The relativistic contribution was first derived by Levi-Civita (1937), and later presented in Giménez (1985). The classical or Newtonian contribution is given by

$$\dot\omega_{\rm cl} = 360(c_{21}k_{21} + c_{22}k_{22}), \qquad (2)$$

where k_{2i} are the second-order internal structure constants of each component, which can be evaluated from theoretical models by numerical integration of the Radau differential equation. The c_{2i} coefficients are a known function of the mass ratio, the orbital eccentricity, and the relative radii (Kopal 1978). The values of $\dot\omega_{\rm cl}$, $\dot\omega_{\rm rel}$, and their percentage of the total apsidal rate for systems under study and several known EEB are given in Table 3. The values of $\dot\omega_{\rm obs}$ and $\dot\omega_{\rm rel}$ are compared in Fig. 12.

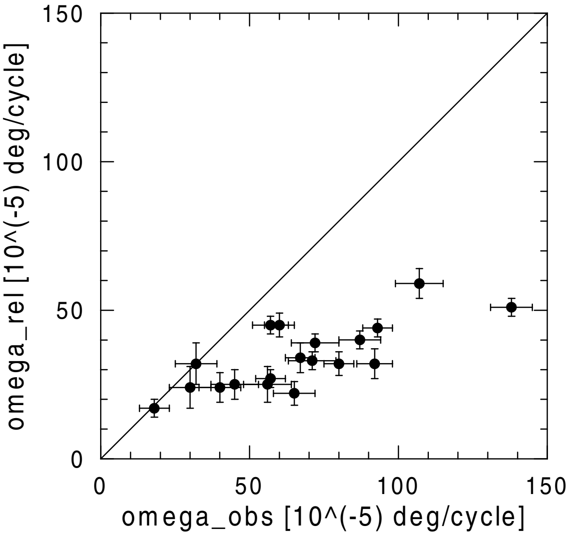

Fig. 12. A comparison between total observed and computed relativistic apsidal motion.

Before comparing the theoretical and observed k_2, we carried out a careful comparison of the theoretical and observed absolute dimensions of each system. The comparison with the absolute dimensions of some systems can be found in Claret & Willems (2002) and in Claret (1997). The absolute dimensions of the remaining systems were compared with theoretical values and we found good agreement between values for a given isochrone, as required.

The stellar models were computed for the precise observed masses. The apsidal-motion test will only be reliable if the adopted stellar models are capable of reproducing the absolute dimensions. The grids of stellar models used here are based on the code described in detail in Claret (2004). The convective core overshooting is introduced by means of an excess distance beyond the classical convective border (see also Claret 2007). This distance is defined as $d_{\rm over} = \alpha_{\rm ov} H_{\rm p}$, where $H_{\rm p}$ is the pressure scale height taken at the edge of the convective core given by Schwarzschild's criterion and $\alpha_{\rm ov} = 0.20$ is a free parameter. The tables of opacities are those taken from Iglesias & Rogers (1996), completed by the calculations by Alexander & Ferguson (1994) for lower temperatures.

The observed k_2 of the systems IT Cas, V459 Cas, V541 Cyg, RW Lac, and EW Ori show large discrepancies (and large relativistic contributions) compared with their theoretical counterparts, and the remaining systems are displayed in Fig. 13. The agreement can be considered to be good and perfectly within

Table 4. Observed and theoretical internal structure constants of selected EEB.

System	$\log k_{2,\rm obs}$	Error	$\log k_{2,\rm theo}$	Error
BW Aqr	–2.16	0.06	–2.31	0.05
IT Cas	–2.84	0.14	–2.26	0.05
V459 Cas	–2.92	0.23	–2.46	0.05
V636 Cen	–1.61	0.05	–1.65	0.05
EK Cep	–2.13	0.12	–2.13	0.05
V731 Cep	–2.35	0.48	–2.32	0.05
V541 Cyg*	–	–	–2.36	0.10
V1143 Cyg	–2.28	0.12	–2.23	0.05
RW Lac	–2.26	1.59	–1.85	0.05
EW Ori	–3.24	3.42	–1.92	0.05
GG Ori	–2.37	0.14	–2.33	0.05
VV Pyx	–2.49	0.24	–2.48	0.05

Note: * *the classical contribution is zero.*

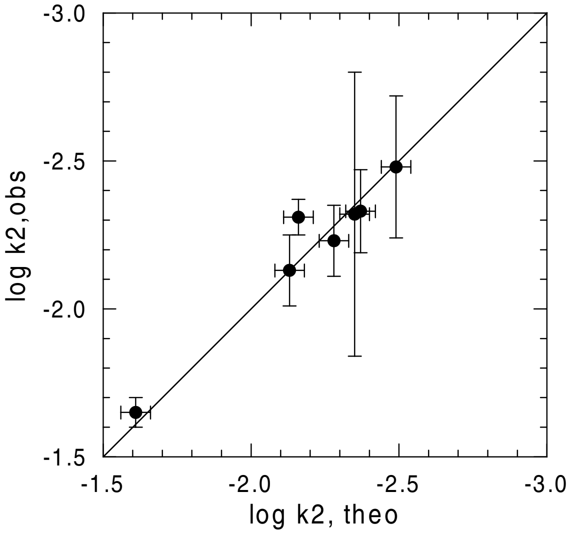

Fig. 13. A comparison between theoretical and observed internal structure constants.

the error bars, except in the case of BW Aqr. This confirms the results obtained by Claret (1997) for systems with moderate relativistic contributions and accurate absolute dimensions. However, for the 5 systems mentioned above the situation is different: the discrepancies are large, in the sense that the true stars seems to be more mass-concentrated than theoretically predicted. For V541 Cyg, when we consider only the hypothetical case of no distortional contribution, it is possible to fit the observed k_2.

When the relativistic contribution is large, the error in $\log k_{2,\rm obs}$ is also large and no significant interpretation can be derived from the comparison with the predictions of the theoretical models. Even so, some information can be extracted, such as for example, that the observed k_2 are systematically smaller than their theoretical counterparts (see Table 4). This trend that real stars seem to be more mass-concentrated than predicted by the stellar models, is well known (see for example, Claret & Giménez 1993). However, the systems investigated in that paper did not have high relativistic contributions. For systems with the high relativistic contributions, several hypotheses were proposed to explain this type of discrepancy, particularly in the case of DI Her (Claret 1998 and references): the inclination of the axes of rotation, rapid circularization of the orbit, the presence of a circumstellar cloud in the system, a third star, and the use of an alternative theory of gravitation. Concerning the alternative theory of gravitation, there are several problems in its formalism, as pointed out by Claret (1998).

An additional explanation of the large discrepancies may be related to observational aspects of the apsidal-motion rates. Indeed, the time dedicated to observe the apsidal-motion of the problematic systems is small compared to the period U. This could lead to poor results. In addition, different techniques and instruments (with different detectors and different levels of confidence) were used. The position of the longitude of periastron can also influence the measurement of the apsidal-motion rates. We refer the interested reader to the paper by Claret (1998) for a more detailed discussion of the subject. More accurate determination of the apsidal-motion rates is necessary to elucidate the reasons for these discrepancies.

5. Conclusions

The apsidal motion in eccentric eclipsing binaries has been used for decades to test evolutionary stellar models. This study provides accurate information about the relativistic apsidal motion of twenty main-sequence eclipsing binary systems (Table 3). We confirmed the long apsidal-motion periods for all systems under study reaching 50 000 years. For the systems BF Dra and V1094 Tau, the new periods of the apsidal motion have been derived. Compared to similar studies by previous authors, the database has been enlarged in time by at least 500 orbital cycles.

All of the analysed binaries contain an important relativistic contribution of up to 100% of the total apsidal-motion rate, but there is no case of an anomalously slow rate (Fig. 12). Some systems with a very high relativistic contribution (IT Cas, V459 Cas, V541 Cyg, RW Lac, and RW Ori) show large discrepancies with theoretical predictions. Moreover, our results indicate that the system V1094 Tau is probably a member of an interesting group of triple or multiple EEB (e.g., RU Mon, U Oph, YY Sgr, and DR Vul) illustrating various phenomena of celestial mechanics and meriting a regular photometric and spectroscopic monitoring. Because of the insufficient coverage of the ephemeris curve, the results for V1147 Cyg and V1094 Tau must be considered preliminary. More than 20 years has elapsed since the last similar studies of several of these binaries by Giménez & Margrave (1985) and Giménez et al. (1987). Additional observations will be needed to increase the data coverage of the apsidal motion periods as well as to derive accurate absolute dimensions and orbital parameters.

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The following internet-based resources were used in research for this paper: the SIMBAD database and the VizieR service operated at CDS, Strasbourg, France; the NASA's Astrophysics Data System Bibliographic Services; the O-C Gateway of the Czech Astronomical Society (`http://var.astro.cz/ocgate/`); the BAV and BBSAG Bulletins. We gratefully acknowledge very useful suggestions by the referee, Prof. Álvaro Giménez.

Appendix A: Tables of minima

Table A.1. New times of minimum light.

System	JD Hel.- 2 400 000	Error [day]	Epoch	Method filter	Observatory source
IT Cas	51339.6061	0.0007	1584.0	CCD	NSVS
	52448.4004	0.0003	1868.5	CCD, V	Ondřejov
	52508.60136	0.0001	1884.0	CCD, R	Ondřejov
	52982.24148	0.0001	2005.5	CCD, R	Ondřejov
	53699.22485	0.0001	2189.5	CCD, R	Ondřejov
	53913.5406	0.0003	2244.5	CCD, R	Ondřejov
	53942.56688	0.0001	2252.0	CCD, R	Ondřejov
	54026.5438	0.0003	2273.5	CCD, R	Ostrava
	54480.3049*	0.0003	2390.0	CCD, RI	Valašské Meziříčí
	54776.45024	0.0001	2466.0	CCD, R	Ostrava
	54782.49403	0.0001	2467.5	CCD, R	Ostrava
V459 Cas	50201.5104	0.002	–279.5	CCD, R	Ondřejov
	50421.4360	0.0005	–253.5	CCD, R	Ondřejov
	51381.5143	0.0005	–140.0	CCD, V	Ondřejov
	52451.41985	0.0001	–13.5	CCD, R	Ondřejov
	52506.4639	0.0002	–7.0	CCD, R	Ondřejov
	52950.45712	0.0001	45.5	CCD, R	Ondřejov
	53614.49798**	0.0004	124.0	CCD, R	Pec
	53944.3684	0.0002	163.0	CCD, R	Ondřejov
	54020.4937*	0.0002	172.0	CCD, RI	Ostrava
	54760.52605*	0.0003	259.5	CCD, VRI	Ostrava
	54815.56982	0.0004	266.0	CCD, R	Ostrava
	55052.40025	0.0001	294.0	CCD, VRI	Ostrava
	55073.48127	0.0005	296.5	CCD, R	Ostrava
V541 Cyg	52926.28338	0.0001	524.5	CCD, R	Ondřejov
	53524.46196	0.0001	563.5	CCD, R	Ondřejov
	53846.5549**	0.0007	584.5	CCD, R	Pec
	54659.46809*	0.0001	637.5	CCD, RI	Valašské Meziříčí
	54782.1712	0.0003	645.5	CCD, R	Ostrava
V1143 Cyg	48692.123	0.002	848.0	pe, H	*Hipparcos*
	53618.42104	0.0001	1492.5	CCD, R	Pec
	53620.40992	0.0001	1493.0	CCD, R	Pec
	54751.24088*	0.0002	1641.0	pe, UBV	Hvar
V1147 Cyg	52497.3742	0.002	114.0	CCD, R	Ondřejov
	52857.4777	0.0007	137.5	CCD, R	Ondřejov
	52863.4058	0.0006	138.0	CCD, R	Ondřejov
	53833.5584	0.0003	201.5	CCD, R	Pec
	54001.3235	0.0005	212.5	CCD, R	Pec
BF Dra	47920.847	0.008	57.5	pe, H	*Hipparcos*
	52416.46183	0.0001	458.5	CCD, R	Ondřejov
	52534.3595	0.0003	469.0	CCD, V	Ondřejov
	52618.2608	0.0002	476.5	CCD, R	Lelekovice
	52657.6784	0.0004	480.0	CCD, –	Ostrava
	52657.6811	0.0005	480.0	CCD, R	Lelekovice
	52859.4784	0.0004	498.0	CCD, R	Ondřejov
	52898.5355	0.0004	501.5	CCD, R	Ondřejov
	53638.4575**	0.0002	567.5	CCD, BVIR	Brno
	53868.46854	0.0001	588.0	CCD, R	Brno
	54664.4498	0.0001	659.0	CCD, R	Ostrava
	54793.192	0.001	670.5	CCD, R	Ostrava
	54804.3994	0.0008	671.5	CCD, R	Ostrava
	54810.1931*	0.0007	672.0	CCD, VRI	Ostrava
	54933.51406	0.0005	683.0	CCD, R	Ostrava
	54978.3574*	0.0008	687.0	CCD, R	Ostrava
	55073.46141	0.0005	695.5	CCD, R	Ostrava
V345 Lac	53530.5190	0.0010	2961.5	CCD, R	Ostrava
	53942.5686	0.0014	3016.5	CCD, R	Ostrava
	54976.4555	0.0005	3154.5	CCD, R	Ostrava
	55126.2929	0.0008	3174.5	CCD, RI	Valašské Meziříčí
EW Ori	52252.3908	0.0012	1053.0	CCD, R	Ondřejov
	52339.3130	0.0001	1065.5	CCD, V	Ondřejov
	54763.52786	0.0010	1415.0	CCD, VR	Ostrava
	54843.5133	0.0010	1426.5	CCD, VRI	Ostrava
	54857.38759	0.0001	1428.5	CCD, VRI	Ostrava
GG Ori	50098.4578	0.0002	344.5	CCD, R	Ondřejov
	52956.6299	0.0001	775.5	CCD, R	Ondřejov
	54001.6087**	0.0001	933.0	CCD, R	Pec
	54757.5993	0.0001	1047.0	CCD, R	Ostrava
	55098.6022	0.0005	1098.5	CCD, R	Ostrava
V1094 Tau	52278.2875	0.0002	286.5	CCD, V	Ondřejov
	52362.3148	0.0003	296.0	CCD, R	Ondřejov
	52898.49893	0.0001	355.5	CCD, R	Ondřejov

Note: * *mean value of UBV, BVRI, VR, VRI or RI measurements*; ** *presented also in OEJV No. 74.*

Table A.2. The list of minima timings of IT Cas.

JD Hel.- 2 400 000	Epoch	Weight	Source observatory
28045.46	–184.0	1	Parenago PZ5
28727.35	–9.0	1	Parenago PZ5
28762.434	0.0	1	Parenago PZ5
28776.230	3.5	1	Parenago PZ5
29483.316	185.0	1	Parenago PZ5
29493.238	187.5	1	Parenago PZ5
30675.692	491.0	1	Whitney AJ62
30763.566	513.5	1	Whitney AJ62
31353.696	665.0	1	Whitney AJ62
31402.619	677.5	1	Whitney AJ62
31762.844	770.0	1	Whitney AJ62
31772.781	772.5	1	Whitney AJ62
32033.860	839.5	1	Whitney AJ62
32557.764	974.0	1	Whitney AJ62
32610.548	987.5	1	Whitney AJ62
32822.729	1042.0	1	Whitney AJ62
33128.797	1120.5	1	Whitney AJ62
33204.588	1140.0	1	Whitney AJ62
33835.853	1302.0	1	Whitney AJ62
33919.863	1323.5	1	Whitney AJ62
34305.601	1422.5	1	Whitney AJ62
34334.641	1430.0	1	Whitney AJ62
34683.592	1519.5	1	Whitney AJ62
35838.719	1816.0	1	Whitney AJ62
36460.434	1975.5	1	Busch Hartha9
37206.476	2167.0	1	Busch Hartha9
37249.316	2178.0	1	Busch Hartha9
37588.314	2265.0	1	Busch Hartha9
38050.298	2383.5	1	Busch Hartha9
38311.373	2450.5	1	Busch Hartha9
39057.350	2642.0	1	Busch Hartha9
39702.466	2807.5	1	Busch Hartha9
40483.520	3008.0	1	Locher Orion125
41126.489	3173.0	1	Busch Hartha9
41210.460	3194.5	1	Busch Hartha9
41249.428	3204.5	1	Busch Hartha9
41960.344	3387.0	1	Busch Hartha9
45167.3158	4210.0	10	Kozyreva AL27
45173.3542	4211.5	10	Kozyreva AL27
45204.519	4219.5	1	Busch BAVMitt68
45237.441	4228.0	1	Busch BAVMitt62
46260.527	4490.5	5	Busch BAVMitt62
47540.372	4819.0	10	Diethelm BBSAG91
47850.344	4898.5	1	Busch BAVMitt68
49239.3141	5255.0	10	Kozyreva AL27
49245.3534	5256.5	10	Kozyreva AL27
49539.3517	5332.0	10	Lacy IBVS4194
49578.3208	5342.0	10	Lacy IBVS4194
49580.4645	5342.5	10	Lacy IBVS4194
49582.2160	5343.0	10	Lacy IBVS4194
49923.3716	5430.5	10	Lacy AJ114
49927.2687	5431.5	10	Lacy AJ114
49948.5032	5437.0	10	Holmgren Obs116
49952.3984	5438.0	10	Lacy AJ114
49954.5441	5438.5	10	Holmgren Obs116
49956.2972	5439.0	10	Lacy AJ114
49962.3382	5440.5	10	Lacy AJ114
50248.546	5514.0	10	Diethelm BBSAG112
50848.6032	5668.0	0	Lacy IBVS4597
51339.6061	5794.0	5	NSVS
51826.6876	5919.0	10	Lacy IBVS5067
52448.40041	6078.5	10	Ondřejov
52483.4700	6087.5	10	Monninger IBVS5484
52508.60136	6094.0	10	Ondřejov
52547.5671	6104.0	10	Diethelm IBVS5438
52555.3605	6106.0	10	Jungbluth IBVS5484
52592.5766	6115.5	10	Caton IBVS5745
52898.2647	6194.0	10	Nakajima VSOLJ42
52929.4378	6202.0	10	Poschinger IBVS5643
52982.24148	6215.5	10	Ondřejov
52982.2414	6215.5	10	Monninger IBVS5657
53699.22485	6399.5	10	Ondřejov
53913.54059	6454.5	10	Ondřejov

Table A.2. continued.

JD Hel.- 2 400 000	Epoch	Weight	Source observatory
53942.56688	6462.0	10	Ondřejov
54026.5431	6483.5	10	Ostrava
54026.5438	6483.5	10	Agerer IBVS5761
54363.4056	6570.0	10	Quester IBVS5830
54445.2352	6591.0	10	Kleidis IBVS5835
54480.30489	6600.0	10	Valašské Meziříčí
54774.7030	6675.5	10	Diethelm IBVS5871
54776.45024	6676.0	10	Ostrava
54782.49403	6677.5	10	Ostrava

Table A.3. The list of minima timings of V459 Cas.

JD Hel.- 2 400 000	Epoch	Weight	Source observatory
25321.599	0.0	1	Meinunger MVS4
29880.568	539.0	1	Meinunger MVS4
31022.515	674.0	1	Meinunger MVS4
31462.321	726.0	1	Meinunger MVS4
34253.489	1056.0	1	Meinunger MVS4
34304.372	1062.0	1	Meinunger MVS4
34710.268	1110.0	1	Meinunger MVS4
34714.447	1110.5	1	Meinunger MVS4
35691.510	1226.0	1	Meinunger MVS4
35856.253	1245.5	1	Meinunger MVS4
36245.275	1291.5	1	Meinunger MVS4
36486.560	1320.0	1	Meinunger MVS4
36541.370	1326.5	1	Meinunger MVS4
36820.533	1359.5	1	Meinunger MVS4
37205.517	1405.0	1	Meinunger MVS4
37222.377	1407.0	1	Busch Hartha10
37222.417	1407.0	1	Meinunger MVS4
37907.509	1488.0	1	Busch Hartha10
37907.550	1488.0	1	Meinunger MVS4
37945.472	1492.5	1	Meinunger MVS4
37945.504	1492.5	1	Busch Hartha10
38144.395	1516.0	1	Busch Hartha10
38440.302	1551.0	1	Busch Hartha10
38440.348	1551.0	1	Meinunger MVS4
38753.273	1588.0	1	Busch Hartha10
38753.300	1588.0	1	Meinunger MVS4
39019.572	1619.5	1	Meinunger MVS4
39057.696	1624.0	0	Meinunger MVS4
39070.326	1625.5	1	Meinunger MVS4
39070.443	1625.5	10	Wenzel MVS4
39142.337	1634.0	1	Busch Hartha10
39256.404	1647.5	1	Meinunger MVS4
39878.266	1721.0	1	Busch Hartha10
40068.542	1743.5	1	Busch Hartha10
40825.506	1833.0	1	Busch Hartha10
40859.511	1837.0	1	Busch Hartha10
40914.331	1843.5	1	Busch Hartha10
41155.504	1872.0	1	Busch Hartha10
41189.341	1876.0	1	Busch Hartha10
41210.459	1878.5	0	Busch Hartha10
41248.482	1883.0	1	Busch Hartha10
41595.314	1924.0	1	Busch Hartha10
41599.428	1924.5	1	Busch Hartha10
41599.453	1924.5	1	Busch Hartha10
41984.446	1970.0	1	Busch Hartha10
41988.428	1970.5	1	Busch Hartha10
42741.339	2059.5	1	Busch Hartha10
43392.609	2136.5	1	Locher BBSAG35
48209.6711	2706.0	10	Caton IBVS3900
50201.5104	2941.5	0	Ondřejov
50421.4360	2967.5	20	Ondřejov
50307.3162	2954.0	10	ZakirovIBVS4597
51144.6845	3053.0	10	MarcrumIBVS4737
51381.5143	3081.0	5	Ondřejov
51863.6357	3138.0	10	Lacy IBVS5067
51867.7992	3138.5	20	Lacy IBVS5067
51918.5502	3144.5	20	Lacy IBVS5067
52159.67448	3173.0	20	Lacy IBVS5251
52176.5911	3175.0	10	Lacy IBVS5251
52252.71631	3184.0	20	Lacy IBVS5357
52269.6326	3186.0	10	Lacy IBVS5357
52286.5500	3188.0	10	Lacy IBVS5357
52451.41985	3207.5	20	Ondřejov
52506.4639	3214.0	10	Ondřejov
52565.6717	3221.0	10	Nelson IBVS5371
52586.75193	3223.5	20	Lacy IBVS5357
52827.8775	3252.0	10	Lacy IBVS5487
52929.3766	3264.0	10	Jungbluth IBVS5643
52950.45712	3266.5	20	Ondřejov
52988.58525	3271.0	20	Lacy IBVS5577
52992.74846	3271.5	20	Lacy IBVS5577
53026.58164	3275.5	20	Lacy IBVS5577
53559.452	3338.5	5	Sobotka IBVS5809
53614.49798	3345.0	10	Pec
53648.33030	3349.0	10	Dariush ApSS305
53652.49302	3349.5	10	Dariush ApSS305
53669.41119	3351.5	10	Dariush ApSS305
53944.36841	3384.0	10	Ondřejov
54020.4937	3393.0	10	Agerer IBVS5761
54092.3224	3401.5	10	Agerer IBVS5761
54367.2818	3434.0	10	Agerer IBVS5830
54388.3609	3436.5	10	Agerer IBVS5830
54760.52605	3480.5	10	Ostrava
54773.2794	3482.0	10	Parimucha IBVS5898
54815.56982	3487.0	10	Ostrava
55052.40025	3515.0	10	Ostrava
55073.48127	3517.5	10	Ostrava

Table A.4. The list of minima timings of V541 Cyg.

JD Hel.- 2 400 000	Epoch	Weight	Source observatory
18240.22	–1737.0	0	Kulikovsky AC113
26507.47	–1198.0	0	Poehnitzsch AA11
28762.20	–1051.0	0	Kulikovsky PZ6
28784.42	–1049.5	1	Poehnitzsch AA11
29106.46	–1028.5	0	Poehnitzsch AA11
29375.57	–1011.0	0	Poehnitzsch AA11
29498.36	–1003.0	0	Kulikovsky PZ6
29728.47	–988.0	0	Kulikovsky PZ6
30464.54	–940.0	0	Poehnitzsch AA11
30548.29	–934.5	0	Soloviev AC70
31262.25	–888.0	0	Soloviev AC70
31637.26	–863.5	1	Soloviev AC70
32719.43	–793.0	0	Erleksova AA11
32772.26	–789.5	1	Erleksova AA11
32787.62	–788.5	1	Whitney AC114
33087.26	–769.0	0	Erleksova AA11
33210.20	–761.0	0	Lavrov AC100
33263.08	–757.5	1	Lavrov AC100
33585.20	–736.5	0	Lavrov AC100
33953.29	–712.5	1	Kurochkin AA11
35664.145	–601.0	5	Kulikowsky AA11
35732.506	–596.5	0	Kulikowsky AA11
36124.273	–571.0	1	Kulikowsky AA11
36361.344	–555.5	5	Kulikowsky AA11
36446.376	–550.0	5	Kulikowsky AA11
36499.370	–546.5	0	Kulikowsky AA11
44882.2127	0.0	10	Khaliullin ApJ299
44889.2192	0.5	10	Khaliullin ApJ299
46998.8424	138.0	10	Lines IBVS3286
48616.34	243.5	1	Diethelm BBSAG99
48839.3870	258.0	10	Diethelm BBSAG102
49168.4951	279.5	10	Agerer BAVMitt68
49560.2668	305.0	10	Lacy IBVS4194
49889.3770	326.5	10	Wolf IBVS4217
49904.7145	327.5	10	Guinan IBVS4362

Table A.4. continued.

JD Hel.- 2 400 000	Epoch	Weight	Source observatory
49935.3937	329.5	10	Lacy IBVS4597
51070.3967	403.5	10	Volkov IBVS4680
51109.3918	406.0	10	Volkov IBVS4680
52926.28338	524.5	20	Ondřejov
53524.46196	563.5	20	Ondřejov
53578.7911	567.0	10	Caton IBVS5745
53846.55486	584.5	10	Pec
54659.46809	637.5	20	Valašské Meziříčí
54782.17118	645.5	10	Ostrava

Table A.5. The list of minima timings of V1143 Cyg.

JD Hel.- 2 400 000	Epoch	Weight	Source observatory
38932.932	–429.5	1	Snowden ApJ156
38978.7807	–423.5	1	Snowden ApJ156
39385.6881	–370.0	5	Snowden ApJ156
40837.4313	–180.0	10	Batistini IBVS817
41135.4208	–141.0	10	Batistini IBVS817
42212.7651	0.0	10	Koch AJ82
42615.75	52.5	0	Koch AJ82
42617.727	53.0	5	Koch AJ82
43066.575	111.5	5	Koch AJ82
43305.3943	143.0	10	Guinan IBVS3070
44487.7482	297.5	10	Gimenez AJ90
45253.7858	398.0	10	Gimenez AJ90
47085.5910	637.5	10	Burns IBVS4363
47087.5669	638.0	10	Burns IBVS4363
47408.4784	680.0	10	Ells BAAVSS14
47790.5160	730.0	10	Ells BAAVSS15
48019.7380	760.0	10	Caton & Burns IBVS3900
48409.4175	811.0	5	Hegedus IBVS4340
48409.4176	811.0	5	Hegedus IBVS4340
48430.3590	813.5	5	Hegedus IBVS4340
48539.3118	828.0	5	Diethelm BBSAG99
48692.123	848.0	10	*Hipparcos*
49234.6144	919.0	10	Fox IBVS4009
49303.3787	928.0	5	BAA81
50235.5566	1050.0	10	Saxton BAAVSS16
51771.34410	1251.0	10	Dariush IBVS5136
51792.28645	1253.5	10	Dariush IBVS5136
52472.30445	1342.5	10	Dariush IBVS5456
52474.29443	1343.0	10	Dariush IBVS5456
53618.42104	1492.5	10	Pec
53620.40992	1493.0	10	Pec
54751.24088	1641.0	10	Hvar

Table A.6. The list of minima timings of V1147 Cyg.

JD Hel.- 2 400 000	Epoch	Weight	Source observatory
34119.52500	–1091.0	1	Wachmann Hamburg6
34952.35800	–1036.5	0	Wachmann Hamburg6
36462.34830	–937.5	0	Chinarova IBVS4455
39741.33950	–722.5	1	Chinarova IBVS4455
41150.39820	–630.0	0	Chinarova IBVS4455
50636.71190	–8.0	10	Bloomer IBVS4568
50697.71580	–4.0	10	Bloomer IBVS4568
50737.54410	–1.5	10	Bloomer IBVS4568
50758.72330	0.0	10	Bloomer IBVS4568
50798.54930	2.5	10	Bloomer IBVS4568
50996.81522	15.5	10	Wetterer PASP118
51063.74968	20.0	10	Wetterer PASP118
51140.006	25.0	1	Sato VSOLJ47
51301.84239	35.5	10	Wetterer PASP118
51307.77073	36.0	10	Wetterer PASP118
51429.7837	44.0	10	Wetterer PASP118
52079.65581	86.5	10	Wetterer PASP118
52079.65769	86.5	10	Wetterer PASP118
52192.3467	94.0	10	Frank IBVS5296
52497.37423	114.0	10	Ondřejov
52512.62516	115.0	10	Wetterer PASP118
52567.70404	118.5	10	Wetterer PASP118
52573.63089	119.0	10	Wetterer PASP118
52811.72034	134.5	10	Wetterer PASP118
52817.65115	135.0	10	Wetterer PASP118
52832.90402	136.0	10	Wetterer PASP118
52857.47746	137.5	10	Ondřejov
52857.47770	137.5	10	Ondřejov
52863.40584	138.0	10	Ondřejov
52863.40616	138.0	10	Ondřejov
53183.68637	159.0	10	Wetterer PASP118
53229.4384	162.0	10	Zejda IBVS5741
53244.69020	163.0	10	Wetterer PASP118
53305.69504	167.0	10	Wetterer PASP118
53488.7113	179.0	10	Wetterer PASP118
53534.4634	182.0	10	Frank IBVS5731
53543.78328	182.5	10	Wetterer PASP118
53549.71604	183.0	10	Wetterer PASP118
53604.79085	186.5	10	Wetterer PASP118
53610.722297	187.0	10	Wetterer PASP118
53656.4776	190.0	10	Frank IBVS5731
53671.7264	191.0	10	Nelson IBVS5672
53833.55841	201.5	10	Pec
54001.32351	212.5	10	Pec
54327.5350	234.0	10	Frank IBVS5830
54367.3615	236.5	4	Frank IBVS5830

Table A.7. The list of minima timings of BF Dra.

JD Hel.- 2 400 000	Epoch	Weight	Source observatory
26631.317	–1841.5	1	Strohmeier Bamberg14
26631.340	–1841.5	1	Strohmeier Bamberg14
26928.423	–1815.0	1	Strohmeier Bamberg14
27281.437	–1783.5	1	Strohmeier Bamberg14
27298.437	–1782.0	1	Strohmeier Bamberg14
28066.378	–1713.5	1	Strohmeier Bamberg14
28834.315	–1645.0	1	Strohmeier Bamberg14
29159.324	–1616.0	1	Strohmeier Bamberg14
31911.61	–1370.5	1	Doeppner MVS699
34473.42	–1142.0	1	Doeppner MVS699
34714.46	–1120.5	1	Doeppner MVS699
35695.40	–1033.0	1	Doeppner MVS699
35992.50	–1006.5	1	Doeppner MVS699
36317.53	–977.5	1	Doeppner MVS699
36317.550	–977.5	1	Strohmeier Bamberg14
36317.597	–977.5	1	Strohmeier Bamberg14
36435.38	–967.0	1	Doeppner MVS699
36805.41	–934.0	1	Doeppner MVS699
37169.42	–901.5	1	Doeppner MVS699
37483.428	–873.5	2	Strohmeier Bamberg14
37545.36	–868.0	1	Doeppner MVS699
37556.40	–867.0	1	Doeppner MVS699
44490.321	–248.5	1	Diethelm BBSAG50
47276.3948	0.0	1	Diethelm BBSAG88
47702.434	38.0	1	Peter BBSAG92
47920.847	57.5	1	*Hipparcos*
48044.385	68.5	0	Peter BBSAG95
48319.067	93.0	0	*Hipparcos*
48722.6155	129.0	1	Agerer BAV60
48868.368	142.0	10	Wolf BBSAG103
49933.4081	237.0	10	Ondřejov
50034.3095	246.0	5	Blaettler BBSAG111

Table A.7. continued.

JD Hel.- 2 400 000	Epoch	Weight	Source observatory
50712.3895	306.5	5	Agerer IBVS4606
50942.3958	327.0	10	Ondřejov
51054.506	337.0	2	Basel
51278.739	357.0	1	Paschke ROTSE
51676.5377	392.5	20	Ondřejov
51833.489	406.5	20	Ondřejov
52147.40	434.5	5	Diethelm BBSAG126
52416.46183	458.5	20	Ondřejov
52534.35953	469.0	20	Ondřejov
52618.2608	476.5	20	Lelekovice
52657.6784	480.0	10	Ostrava
52657.6811	480.0	10	Lelekovice
52769.7901	490.0	10	CatonSmith IBVS5595
52814.6354	494.0	10	CatonSmith IBVS5595
52859.4784	498.0	10	Ondřejov
52898.53545	501.5	20	Ondřejov
53341.55151	541.0	10	Lacy IBVS5670
53341.5523	541.0	10	Caton IBVS5745
53464.87251	552.0	10	Lacy IBVS5670
53503.9275	555.5	10	Lacy IBVS5670
53638.4591	567.5	10	Brno
53868.46854	588.0	10	Brno
54019.6359	601.5	10	Lacy IBVS5764
54036.6322	603.0	10	Lacy IBVS5764
54389.5933	634.5	10	Agerer 5830
54664.44982	659.0	20	Ostrava
54793.1920	670.5	10	Ostrava
54804.3994	671.5	10	Ostrava
54810.1931	672.0	10	Ostrava
54933.51406	683.0	10	Ostrava
54978.3574	687.0	10	Ostrava
55034.41276	692.0	10	Ostrava
55073.46141	695.5	10	Ostrava

Table A.8. The list of minima timings of V345 Lac.

JD Hel.- 2 400 000	Epoch	Weight	Source observatory
31047.243	–39.5	3	Busch Hartha13
31324.429	–2.5	3	Busch Hartha13
31344.409	0.0	3	Busch Hartha13
33062.575	229.5	3	Miller SpecVat8
33187.420	246.0	3	Miller SpecVat8
33504.595	288.5	3	Miller SpecVat8
33569.490	297.0	3	Miller SpecVat8
33861.665	336.0	3	Miller SpecVat8
34708.243	449.0	3	Miller SpecVat8
34733.240	452.5	3	Miller SpecVat8
36426.492	678.5	1	Busch Hartha13
36456.461	682.5	1	Busch Hartha13
36461.438	683.0	0	Busch Hartha13
36486.397	686.5	1	Busch Hartha13
36808.475	729.5	1	Busch Hartha13
36813.479	730.0	1	Busch Hartha13
36903.356	742.0	1	Busch Hartha13
37992.323	887.5	0	Busch Hartha13
38179.536	912.5	1	Busch Hartha13
38289.482	927.0	0	Busch Hartha13
38464.282	950.5	1	Busch Hartha13
38651.481	975.5	1	Busch Hartha13
38671.410	978.0	1	Busch Hartha13
38816.288	997.5	1	Busch Hartha13
39023.470	1025.0	1	Busch Hartha13
39038.478	1027.0	1	Busch Hartha13
39053.392	1029.0	0	Busch Hartha13
40037.501	1160.5	1	Busch Hartha13
40067.513	1164.5	1	Busch Hartha13
40127.403	1172.5	1	Busch Hartha13
40202.325	1182.5	1	Busch Hartha13
40469.401	1218.0	1	Busch Hartha13
40484.469	1220.0	1	Busch Hartha13
40514.468	1224.0	1	Busch Hartha13
41618.255	1371.5	0	Busch Hartha13
41708.280	1383.5	1	Busch Hartha13
41895.489	1408.5	1	Busch Hartha13
41900.511	1409.0	1	Busch Hartha13
41930.459	1413.0	1	Busch Hartha13
41960.415	1417.0	1	Busch Hartha13
42005.263	1423.0	1	Busch Hartha13
50081.6444	2501.0	4	Caton IBVS5595
50201.495	2517.0	20	Ondřejov
50286.53	2528.5	1	Diethelm BBSAG112
50373.8088	2540.0	10	Caton IBVS5745
50403.7826	2544.0	5	Caton IBVS5745
50673.4854	2580.0	20	Ondřejov
50713.5572	2585.5	10	Ondřejov
51065.6783	2632.5	10	Caton IBVS5595
51302.8060	2664.0	10	Caton IBVS5595
51377.7229	2674.0	10	Smith IBVS5745
51717.47874	2719.5	10	Ondřejov
51777.4102	2727.5	5	Ondřejov
51829.8544	2734.5	10	Caton IBVS5595
51849.7158	2737.0	10	Caton IBVS5595
51849.7155	2737.0	10	Caton IBVS5745
52239.29095	2789.0	20	Ondřejov
52651.3427	2844.0	10	Lelekovice
52848.7564	2870.5	10	Caton IBVS5595
52898.5748	2877.0	10	Ondřejov
52928.5439	2881.0	10	Agerer IBVS5643
52928.5459	2881.0	10	Jungbluth IBVS5643
53530.5190	2961.5	5	Ostrava
53572.8447	2967.0	10	Smith IBVS5745
53932.4522	3015.0	10	Agerer IBVS5731
53942.5686	3016.5	5	Ostrava
54359.4912	3072.0	10	Agerer IBVS5830
54749.0670	3124.0	10	VSB48Ioh
54976.4555	3154.5	10	Ostrava
55126.2929	3174.5	10	Valašské Meziříčí

Table A.9. The list of minima timings of EW Ori.

JD Hel.- 2 400 000	Epoch	Weight	Source observatory
25653.283	–272.5	1	Busch Hartha10
25864.608	–242.0	1	Busch Hartha10
25982.537	–225.0	1	Busch Hartha10
26634.606	–131.0	1	Busch Hartha10
27543.350	0.0	1	Lause AN263
27543.366	0.0	1	Lause AN263
27730.638	27.0	1	Lause AN263
27751.459	30.0	1	Lause AN263
27862.454	46.0	1	Lause AN263
27883.250	49.0	1	Lause AN263
28209.305	96.0	1	Lause AN263
28521.455	141.0	1	Lause AN263
28535.330	143.0	1	Lause AN263
28535.382	143.0	1	Kordylewski AAS5
28549.200	145.0	1	Kordylewski AAS5
28937.665	201.0	10	Pierce PrincetonContr25

Table A.9. continued.

JD Hel.- 2 400 000	Epoch	Weight	Source observatory
30349.537	404.5	1	Busch Hartha10
31823.410	617.0	1	Busch Hartha10
32912.480	774.0	1	Busch Hartha10
32940.212	778.0	1	Kordylewski AAS5
34334.511	979.0	1	Busch Hartha10
34660.559	1026.0	1	Busch Hartha10
35392.566	1131.5	1	Busch Hartha10
35392.61	1131.5	1	Busch Hartha10
35399.558	1132.5	1	Busch Hartha10
36852.640	1342.0	1	Busch Hartha10
37317.340	1409.0	1	Busch Hartha10
37730.306	1468.5	1	Busch Hartha10
37730.326	1468.5	1	Busch Hartha10
38413.407	1567.0	1	Busch Hartha10
38708.432	1609.5	1	Busch Hartha10
38739.433	1614.0	1	Busch Hartha10
40473.618	1864.0	1	Busch Hartha10
40619.315	1885.0	1	Busch Hartha10
40924.519	1929.0	1	Busch Hartha10
41330.514	1987.5	1	Busch Hartha10
41351.340	1990.5	1	Busch Hartha10
41389.321	1996.0	1	Busch Hartha10
41677.369	2037.5	1	Busch Hartha10
42454.295	2149.5	1	Busch Hartha10
42471.424	2152.0	1	Locher BBSAG21
42478.373	2153.0	1	Locher BBSAG21
43463.405	2295.0	1	Locher BBSAG35
44916.8887	2504.5	10	Popper IBVS4542
44947.8946	2509.0	10	Popper IBVS4542
46096.15233	2674.5	10	Wolf IBVS4542
46113.2839	2677.0	10	Wolf IBVS4542
50147.2694	3258.5	10	Wolf IBVS4542
50431.6804	3299.5	20	Caton IBVS5745
50497.36911	3309.0	10	Wolf IBVS4542
50823.3998	3356.0	10	Diethelm BBSAG117
52252.3908	3562.0	5	Ondřejov
52339.3130	3574.5	5	Ondřejov
52689.4144	3625.0	10	Quester IBVS5484
52973.8223	3666.0	20	Caton IBVS5745
54492.9909	3885.0	10	VSB48Ioh
54524.4188	3889.5	10	Wischnewski IBVS5874
54763.52786	3924.0	10	Ostrava
54843.5133	3935.5	10	Ostrava
54857.38759	3937.5	10	Ostrava
54860.6486	3938.0	1	Diethelm IBVS5894

Table A.10. The list of minima timings of GG Ori.

JD Hel.- 2 400 000	Epoch	Weight	Source observatory
26003.459	–1145.0	1	Hoffmeister AN253
26384.280	–1087.5	1	Hoffmeister AN253
27100.417	–979.5	1	Hoffmeister AN253
27787.305	–876.0	1	Kordylewski AAC4
27823.305	–870.5	1	Kordylewski AAC4
28165.29	–819.0	1	Kordylewski AAC4
28181.39	–816.5	1	Kordylewski AAC4
29697.143	–588.0	1	Soloviev PZ5
29697.144	–588.0	1	Nikulina AC189
30022.129	–539.0	1	Soloviev PZ5
30022.133	–539.0	1	Nikulina AC189
31156.12	–368.0	1	Cesevich
31477.29	–319.5	1	Cesevich
32816.801	–117.5	1	Nikulina BSAO25
32969.34	–94.5	1	Kordylewski AAC4
32973.154	–94.0	1	Nikulina BSAO25
33006.29	–89.0	1	Szafraniec AAC4
33181.472	–62.5	0	Nikulina AC189
33274.342	–48.5	1	Nikulina AC189
33307.53	–43.5	1	Szafraniec AAC4
33311.33	–43.0	1	Szafraniec AAC4
33334.134	–39.5	0	NikulinaAC189
33596.491	0.0	1	Szafraniec AAC5
33689.338	14.0	1	Szafraniec AAC5
34034.131	66.0	1	Nikulina AC189
34448.166	128.5	1	Nikulina AC189
35071.510	222.5	1	Szafraniec AAC5
35164.338	236.5	1	Tschuprina AC183
35376.526	268.5	1	Szafraniec AAC6
35429.604	276.5	1	Tschuprina AC183
35509.185	288.5	1	Nikulina AC189
35542.336	293.5	1	Tschuprina AC183
35807.559	333.5	1	Szafraniec AAC8
35867.277	342.5	1	Tschuprina AC183
35904.209	348.0	1	Nikulina AC189
35904.260	348.0	1	Szafraniec AAC8
38327.522	713.5	1	Busch Hartha13
38384.472	722.0	1	Busch Hartha13
38440.305	730.5	1	Busch Hartha13
38457.338	733.0	1	Busch Hartha13
38652.588	762.5	0	Busch Hartha13
41391.347	1175.5	1	Busch Hartha13
41676.466	1218.5	1	Winiarski AA24
41961.567	1261.5	0	Busch Hartha13
42074.359	1278.5	1	Busch Hartha13
42452.365	1335.5	1	Busch Hartha13
42469.372	1338.0	0	Diethelm BBSAG21
42777.306	1384.5	1	Diethelm BBSAG25
45403.337	1780.5	1	Diethelm BBSAG65
47529.267	2101.0	5	Mossakovskaya IBVS5675
47814.42361	2144.0	10	Torres AJ120
47834.31746	2147.0	10	Volkov AR46
47887.36911	2155.0	10	Zakirov AL23
47943.22611	2163.5	10	Volkov AR46
48321.2208	2220.5	10	Mossakovskaya IBVS5675
48590.30813	2261.0	10	Zakirov AL23
48590.3086	2261.0	10	Zakirov IBVS4194
48606.3690	2263.5	4	Diethelm BBSAG99
48623.4634	2266.0	10	Diethelm BBSAG99
48911.4212	2309.5	10	Zakirov IBVS4194
48911.4228	2309.5	10	Torres AJ120
48948.4090	2315.0	10	Zakirov IBVS4194
48948.4094	2315.0	10	Zakirov IBVS4194
48951.21094	2315.5	10	Zakirov AL23
49339.66777	2374.0	10	Torres AJ120
49355.7327	2376.5	10	Lacy IBVS4194
49355.73255	2376.5	10	Torres AJ120
49366.1968	2378.0	10	Zakirov IBVS4194
49366.19553	2378.0	10	Zakirov AL23
49717.6624	2431.0	10	Lacy IBVS4194
49717.66225	2431.0	10	Torres AJ120
50098.4577	2488.5	10	Ondřejov
50380.8122	2531.0	10	Caton IBVS5595
51614.27164	2717.0	10	Volkov AR46
51935.38090	2765.5	10	Volkov AR46
51952.47774	2768.0	10	Volkov AR46
52247.0597	2812.5	10	Kiyota VSOLJ39
52956.6299	2919.5	10	Ondřejov
53809.2944	3048.0	10	Monninger IBVS5731

Table A.10. continued.

JD Hel.- 2 400 000	Epoch	Weight	Source observatory
54001.6087	3077.0	10	Pec
54094.4465	3091.0	1	Schmidt IBVS5761
54101.0809	3092.0	10	Nakajima VSOLJ45
54757.59934	3191.0	10	Ostrava
54863.6952	3207.0	1	Diethelm IBVS5894
55098.6022	3242.5	10	Ostrava

Table A.11. The list of minima timings of V1094 Tau.

JD Hel.- 2 400 000	Epoch	Weight	Source observatory
49653.632	–5.5	1	Baldwin IBVS4168
49656.762	–5.0	1	Baldwin IBVS4544
49680.597	–2.5	1	Baldwin IBVS4168
49683.727	–2.0	1	Baldwin IBVS4544
49701.7061	0.0	5	Terrell IBVS4168
49707.5649	0.5	20	Kaiser IBVS4168
49710.6950	1.0	5	Kaiser IBVS4544
49755.6355	6.0	5	Kaiser IBVS4168
50456.7393	84.0	5	Frey IBVS4544
50474.7156	86.0	5	Kaiser IBVS4544
52278.2875	286.5	1	Ondřejov
52362.31480	296.0	10	Ondřejov
52601.87764	322.5	20	Lacy IBVS5357
52628.8429	325.5	5	Lacy IBVS5487
52637.83153	326.5	20	Lacy IBVS5487
52898.49893	355.5	10	Ondřejov
52997.3708	366.5	5	Jungbluth IBVS5643
53045.4406	372.0	10	Achterberg IBVS5657

References

Agerer, F., & Hübscher, J. 1998, IBVS, 4562
Agerer, F., & Hübscher, J. 2003, IBVS, 5484
Alexander, D. R., & Ferguson, J. W. 1994, ApJ, 437, 879
Andersen, J., Clausen, J. V., & Nordström, B. 1984, A&A, 134, 147
Andersen, J., García, J. M., Giménez, A., et al. 1987, A&A, 174, 107
Bakis, V., Zejda, M., Bulut, I., et al. 2008, MNRAS, 390, 399
Bloomer, R., Wetterer, C., Mumpower, A., et al. 1998, IBVS, 4568
Brát, L., Zejda, M., & Svoboda, P. 2007, OEJV, 74, 1
Bulut, I., & Demircan, O. 2007, MNRAS, 378, 179
Burns, J. F., Guinan, E. F., & Marshall, J. J. 1996, IBVS, 4363
Busch, H. 1975a, Mitt. Bruno-H.-Bürgel-Sternwarte Hartha, 9, 2
Busch, H. 1975b, Mitt. Bruno-H.-Bürgel-Sternwarte Hartha, 9, 18
Busch, H. 1976a, Mitt. Bruno-H.-Bürgel-Sternwarte Hartha, 10, 1
Busch, H. 1976b, Mitt. Bruno-H.-Bürgel-Sternwarte Hartha, 10, 11
Busch, H. 1978, Mitt. Bruno-H.-Bürgel-Sternwarte Hartha, 13, 20
Caton, D. B., & Burns, W. C. 1993, IBVS, 3900
Caton, D. B., & Smith, A. B. 2005, IBVS, 5595
Chinarova, L. 1997, IBVS, 4455
Claret, A. 1997, A&A, 327, 11
Claret, A. 1998, A&A, 330, 533
Claret, A. 2004, A&A, 424, 919
Claret, A. 2007, A&A, 475, 1019
Claret, A., & Giménez, A. 1993, A&A, 277, 487
Claret, A., & Willems, B. 2002, A&A, 388, 518
Clausen, J. V. 1991, A&A, 246, 397
Clausen, J. V., Vaz, L. P. R., García, J. M., et al. 2008, A&A, 487, 1081
Cowling, T. G. 1938, MNRAS, 98, 734
Dariush, A., Afroozeh, A., & Riazi, N. 2001, IBVS, 5136
Dariush, A., Mosleh, M., & Dariush, D. 2006, Ap&SS, 305, 85
Dariush, A., Riazi, N., & Afroozeh, A. 2005, Ap&SS, 296, 141
Dariush, A., Zabihinpoor, S. M., Bagheri, M. R., et al. 2003, IBVS, 5456
Diethelm, R. 2003, IBVS, 5438
Diethelm, R., Wolf, M., & Agerer, F. 1993, IBVS, 3867
Döppner, M. 1962, Mitt. Veränderliche Sterne No. 699
ESA 1997, The Hipparcos and Tycho Catalogues, ESA SP-1200
Gaposchkin, S. 1953, Ann. Harvard Coll. Obs., 113, 2
Giménez, A. 1985, ApJ, 297, 405
Giménez, A. 1994, Exp. Astron., 5, 91
Giménez, A. 2007, in Binary Stars as Critical Tools & Tests, ed. W. Hartkopf, E. Guinan, & P. Harmanec, Proc. IAU Symp. 240, 290
Giménez, A., & García-Pelayo, J. M. 1983, Ap&SS, 92, 203
Giménez, A., & Margrave, T. E. 1985, AJ, 90, 358
Giménez, A., Kim, C.-H., & Nha, I.-S. 1987, MNRAS, 224, 543
Griffin, R. F., & Boffin, H. M. J. 2003, Observatory, 123, 203
Guinan, E. F., Boyd, P. T., Najafi, S. I., et al. 1987, IBVS, 3070
Guinan, E. F., Maley, J. A., Marshall, J. J. 1996, IBVS, 4362
Harmanec, P. 1988, Bull. Astr. Inst. Czech. 39, 329
Harper, W. E. 1919, Publ. Dom. Astrophys. Obs. Victoria, 1, 157
Harper, W. E. 1935, Publ. Dom. Astrophys. Obs. Victoria, 6, 207
Hegedüs, T., Biró, I. B., Borkovits, T., et al. 1996, IBVS, 4340
Hoffmeister, C. 1930, Astron. Nachr., 238, 190
Hoffmeister, C. 1934, Astron. Nachr., 253, 195
Holmgren, D., & Wolf, M. 1996, Observatory, 116, 307
Hübscher, J. 2005, IBVS, 5643
Hübscher, J. & Walter, F. 2007, IBVS, 5761
Hübscher, J., Paschke, A., & Walter, F. 2005, IBVS, 5657
Hübscher, J., Paschke, A., & Walter, F. 2006, IBVS, 5731
Hübscher, J., Steinbach, H.-M., & Walter, F. 2008, IBVS, 5830
Iglesias, C. A., & Rogers, F. J. 1996, ApJ, 464, 943
Imbert, M. 1985, A&AS, 59, 357
Kaiser, D. H. 1994, IBVS, 4119
Kaiser, D. H., & Frey, G. 1998, IBVS, 4544
Kaiser, D. H., Terrell, D., Baldwin, M. E. et al. 1995, IBVS, 4168
Karpowicz, M. 1961, Acta Astron., 11, 51
Khaliullin, Kh. F., & Khaliullina, A. I. 2002, Astron. Rep., 46, 137
Khaliullin, Kh. F., & Kozyreva, V. S. 1989, Ap&SS, 155, 53
Kopal, Z. 1978, Dynamics of Close Binary Systems (Holland, Dordrecht: Reidel)
Kordylewski, K. 1951, Acta Astron. Ser. C, 4, 134
Kordylewski, K. 1962, Acta Astron. Suppl., 5, 610
Kozyreva, V. S., & Zakharov, A. I. 2001, Astron. Lett., 27, 712
Kreiner, J. M. 2004, Acta Astron., 54, 207
Kulikowski, P. G. 1948, Perem. Zvezdy, 6, 101
Kwee, K. K., & van Woerden, H. 1956, Bull. Astron. Inst. Netherlands, 12, 327
Lacy, C. H. S. 1998, AJ, 115, 801
Lacy, C. H. S. 2002, IBVS, 5357
Lacy, C. H. S. 2003, IBVS, 5487
Lacy, C. H. S. 2004, IBVS, 5577
Lacy, C. H. S. 2006, IBVS, 5670
Lacy, C. H. S. 2007, IBVS, 5764
Lacy, C. H. S., & Fox, G. W. 1994, IBVS, 4009
Lacy, C. H. S., Torres, G., Latham, D. W., et al. 1997, AJ, 114, 1206
Lacy, C. H. S., Clem, J. L., Zakirov, M., et al. 1998, IBVS, 4597
Lacy, C. H. S., Hood, B., & Straughn, A. 2001, IBVS, 5067
Lacy, C. H. S., Claret, A., & Sabby, J. A. 2004, AJ, 128, 1340
Lacy, C. H. S., Torres, G., & Claret, A., et al. 2005, AJ, 130, 2838
Lause, F. 1937, Astron. Nachr., 263, 115
Levi-Civita, T. 1937, Amer. J. Math., 59, 225
Meinunger, L., & Wenzel, W. 1967, Mitt. Veränderliche Sterne, 4, 141
Miller, W. J., & Wachmann, A. A. 1973, Ric. Astr. Specola Vaticana 8, 18
Mossakovskaja, L. V. 2006, IBVS, 5675
Motl, D. 2007, C-Munipack, http://c-munipack.sourceforge.net/
Parenago, P. P. 1939, Perem. Zvezdy, 5, 161
Pierce, N. L. 1951, Princeton Contr., 25, 93
Popper, D. M. 1987, AJ, 93, 672
Popper, D. M., Lacy, C. H., Frueh, M. L., et al. 1986, AJ, 91, 383
Smith, A. B., & Caton, D. B. 2007, IBVS, 5745
Snowden, M. S. 1966, IBVS, 217
Snowden, M. S., & Koch, R. H. 1969, ApJ, 156, 667
Sobotka, P. 2007, IBVS, 5809
Sterne, T. E. 1939, MNRAS, 99, 662
Strohmeier, W. 1955, Kleine Veröff. Remeis-Sternw. Bamberg, No. 9
Strohmeier, W., Knige, R., & Ott, H. 1962, Bamberg Veröffent. V, No. 14
Torres, G., Lacy, C. H. S., Claret, A., et al. 2000, AJ, 120, 3226
Volkov, I. M., & Khaliullin, Kh. F. 1999, IBVS, 4680
Volkov, I. M., & Khaliullin, Kh. F. 2002, Astron. Rep., 46, 747
Wachmann, A. A. 1961, Astron. Abh. Hamburger Sternw., 6, 78
Wachmann, A. A. 1966, Astron. Abh. Hamburger Sternw., 6, 281
Wetterer, Ch. J., Bloomer, R. H., & Caton, D. B. 2006, PASP, 118, 436
Wolf, M. 1995, IBVS, 4217
Wolf, M., Šarounová, L., Kozyreva, V. S., et al. 1997, IBVS, 4542
Wolf, M., Diethelm, R., & Hornoch, K. 2001, A&A, 374, 243
Wolf, M., Harmanec, P., Šarounová, L., et al. 2004, A&A, 420, 619
Wolf, M., Diethelm, R., & Zejda, M. 2005, Ap&SS, 296, 109
Zakirov, M. M. 1997, Pisma Astrophys. Zh., 23, 626