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Apsidal motion in southern eccentric eclipsing binaries: YY Sgr, V523 Sgr, V1647 Sgr, V2283 Sgr and V760 Sco*

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Abstract. Several new times of minimum light recorded with photoelectric means have been gathered for the early-type eccentric eclipsing binaries YY Sgr ($P = 2\overset{d}{.}63, e = 0.16$), V523 Sgr ($2\overset{d}{.}32, 0.16$), V1647 Sgr ($3\overset{d}{.}28, 0.41$), V2283 Sgr ($3\overset{d}{.}47, 0.49$) and V760 Sco ($1\overset{d}{.}73, 0.03$). The $O-C$ diagrams are analyzed using all reliable timings found in the literature and improved values for the elements of the apsidal motion are computed. We find more precise periods of apsidal motion of about 290, 202, 531, 528 and 38.5 years for YY Sgr, V523 Sgr V1647 Sgr, V2283 Sgr and V760 Sco, respectively. The corresponding internal structure constants log k_2 are derived and compared to their theoretical values.

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

1. Introduction

The study of apsidal motion in detached eclipsing binary systems with eccentric orbit is an important source of information on the stellar internal structure as well as for the possibility of verification of the theory of General Relativity (Claret & Giménez 1993; Claret 1997). The history of apsidal motion studies based on observations of times of minima of eclipsing binary stars is long and interesting. It began with the recognition by Dunér (1892) that there were two separate types of minima of Y Cyg with significantly different periods, and he correctly atrributed this effect to a rotating line of apsides. This massive binary is one of the best-known cases of apsidal motion among eclipsing binaries.

In this paper, we report new results for our observational project initiated in 1993 with the main purpose of monitoring eclipsing binaries with eccentric orbits. Suitable objects for this research were tabulated by Giménez (1994). In particular, the five southern-hemisphere objects analysed here, namely YY Sgr, V523 Sgr, V1647 Sgr, V2283 Sgr and V760 Sco, are well studied and early-type binaries, whose orbits have been known to be eccentric and to exhibit apsidal motion since early in this century. All these binaries have periods of less than 3.5 days. Two of them have a relatively large orbital eccentricity of more than 0.4. Moreover, all these systems triggered attention of other groups of observers during the 80ies and 90ies (Andersen & Giménez 1985; Andersen et al. 1985b; Lacy 1992, 1993a; Woodward & Koch 1989, 1992) and more than 10 years have elapsed since some of their studies.

* Based on observations collected at the South Africa Astronomical Observatory, Sutherland, South Africa

2. Observations of minimum light

In order to enlarge the number of times of minimum light, new observations for all five systems were carried out with the aim of securing at least one well-covered primary and secondary minimum for each variable.

Our new photoelectric UBV observations were obtained with the modular photometer utilizing a Hamamatsu GaAs R943-02 photomultiplier on the 0.5-m telescope at the Sutherland site of the South African Astronomical Observatory (SAAO) during two weeks in August 1999. Each observation of an eclipsing binary was accompanied by observation of a local comparison star. The photoelectric measurements were done in the UBV filters of the Johnson's photometric system with 10 seconds integration time. All observations were reduced to the Cousins E-region standard system (Menzies et al. 1989).

An additional CCD photometry of the eclipsing binary YY Sgr (Decl. $\simeq$ –19 deg) was performed at the Ondřejov observatory, Czech Republic, with 65cm reflecting telescope and CCD-camera SBIG ST-6 in July 1995 and August 1997. These measurements were done using primarily the standard Cousins R filter with typically 30 sec exposure times. Flat fields for the reduction of the CCD frames were routinely obtained from exposures of regions of the sky taken at dusk or dawn. Several comparison stars were chosen on the same frame as the variables. During the observations, no variations in the brightness of these stars exceeding the expected error of measurements (typical $\sigma \simeq 0.01$ mag) were detected. No correction was allowed for differential extinction, due to the proximity of the comparison stars to the variable and the resulting small differences in the air mass.

The new times of primary and secondary minimum and their errors were determined using the least squares fit of the data, by the bisecting cord method and the Kwee-van Woerden algorithm. Only the lower part of the eclipses was used. These 17

Table 1. New times of minimum light.

System	JD Hel.- 2400000	Error [day]	Min. type	Method Filter	Source
YY Sgr	49907.5008	0.0001	I	CCD R	Ondřejov
	49908.6160	0.0007	II	CCD R	Ondřejov
	50672.3882	0.0001	I	CCD R	Ondřejov
	50681.3952	0.0001	II	CCD R	Ondřejov
	51408.3605	0.0001	I	pe UBV	SAAO
	51417.3757	0.0002	II	pe UBV	SAAO
V523 Sgr	51421.32661	0.00005	I	pe UBV	SAAO
V1647 Sgr	48484.841	0.002	II	H	HIP
	48746.526	0.002	I	H	HIP
	51416.4009	0.0001	II	pe UBV	SAAO
V2283 Sgr	51417.42995	0.00005	I	pe UBV	SAAO
V760 Sco	47962.4342	0.0010	I	H	HIP
	48097.4483	0.0010	I	H	HIP
	48179.6753	0.0010	II	H	HIP
	48702.4140	0.0010	II	H	HIP
	51417.392:	0.010	I	pe BV	SAAO
	51418.23186	0.00005	II	pe BV	SAAO

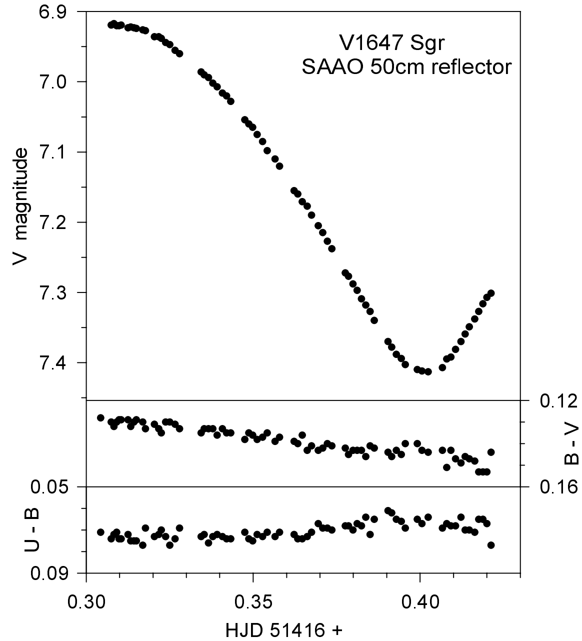

Fig. 1. A plot of the $V, B-V, U-B$ magnitudes observed during the secondary eclipse of V1647 Sgr.

times of minimum are presented in Table 1. As an example of our photoelectric measurements, Fig. 1 shows the $V, B-V$ and $U-B$ magnitudes during the secondary minimum of V1647 Sgr obtained at JD 24 51416.

3. Apsidal motion analysis

The apsidal motion in all systems was studied by means of an $O-C$ diagram analysis. We have collected all reliable times of minimum light gathered from the literature as well as from current databases of BAV and BBSAG observers.

Suitable numerical methods for the apsidal motion analysis were described by Giménez & García-Pelayo (1983) and Lacy (1992). Improved expressions for the prediction of eclipse times are also presented in Giménez & Bastero (1995). We used the method first mentioned, which is a weighted least squares iterative procedure, including terms in the eccentricity up to the fifth order. Due to the relatively large value of the orbital eccentricity of some studied systems, we used all terms in our calculation. Our formula for the prediction of the times of minimum, used for the minimization by the least-squares method, is also given in Wolf & Šarounová (1995). There are five independent variables $(T_0, P_s, e, \dot{\omega}, \omega_0)$ to be determined in this procedure. The resulting apsidal motion period U, directly given by $\dot{\omega}$ is,

$$U = 360° P_a/\dot{\omega}$$

and the relation between the sidereal and the anomalistic period, P_s and P_a, by

$$P_s = P_a\,(1 - \dot{\omega}/360°).$$

We employed the following data reduction procedure. All photoelectric times of minimum were used with a weight of 10 in our computation. The current less precise measurements were weighted with a factor of 5, while the earlier visual and photographic times of minimum were given a weight of 1 due to the large scatter in these data.

4. YY Sgr

The detached eclipsing binary YY Sgr (= HD 173140 = BD $-19°5148$ = HV 3080 = AN 38.1908 = FL 2531; α_{2000} = $18^h 44^m 36^s$, $\delta_{2000} = -19°$ 23' 23", V_{max} = 10.03 mag; Sp. B5 + B6) is a well-known early-type binary with an eccentric orbit ($e = 0.16$) and a period of about 2.63 days. This binary is a classical example of apsidal motion and its observational time span covers practically one century. It was discovered to be a variable by Cannon (Pickering 1908, 1909), the first photoelectric light-curve was obtained by Keller & Limber (1951). The history of work on this binary was summarized by Woodward & Koch (1992). Photometric orbits and apsidal motion parameters were derived by Lacy (1993b), where also the following linear light elements are given

$$\text{Pri. Min.} = \text{HJD } 24\,48059.68793 + 2\overset{d}{.}62846355 \cdot \text{E}.$$

The latest discussion of the apsidal motion is given by Lacy (1997), who arrived at an apsidal motion period of $U = 297 \pm 4$ years and eccentricity $e = 0.1575 \pm 0.0007$.

All photoelectric times of minimum light published in Woodward & Koch (1992), Lacy (1993b) as well as CCD normal minimum (HJD 24 48853.487) obtained by Paschke (1992) were incorporated in our analysis. Four new CCD times obtained at Ondřejov Observatory are given in Table 1. A total of 70 times of minimum light were used in our analysis, with 26 secondary eclipses among them. Adopting the orbital inclination, derived from the light curve solution, of $i = 88.88°$ (Lacy 1997), the apsidal motion elements can be computed. The parameters found

Table 2. Apsidal motion elements of YY Sgr, V523 Sgr, V1647 Sgr, V2283 Sgr and V760 Sco

Element	YY Sgr	V523 Sgr	V1647 Sgr	V2283 Sgr	V760 Sco
T_0 [HJD]	24 48059.5771 (3)	24 47382.5491 (2)	24 41829.2533 (5)	24 13784.1604 (8)	24 43250.8360 (2)
P_s [days]	2.6284738 (6)	2.3238131 (4)	3.2827950 (2)	3.4714208 (7)	1.7309338 (12)
P_a [days]	2.6285389 (6)	2.3238864 (4)	3.2828505 (2)	3.4714833 (7)	1.7311469 (12)
e	0.1587 (5)	0.1626 (9)	0.4142 (11)	0.488 (5)	0.0270 (5)
$\dot\omega$ [deg cycle^{-1}]	0.00892 (9)	0.01135 (7)	0.00609 (12)	0.00648 (15)	0.0443 (4)
$\dot\omega$ [deg yr^{-1}]	1.240 (12)	1.784 (11)	0.678 (13)	0.682 (16)	9.35 (8)
ω_0 [deg]	215.0 (0.3)	64.3 (0.3)	204.1 (0.2)	316.1 (0.6)	311.0 (0.5)
U [years]	290.4 (1.5)	201.8 (1.2)	531 (5)	528 (12)	38.5 (0.3)

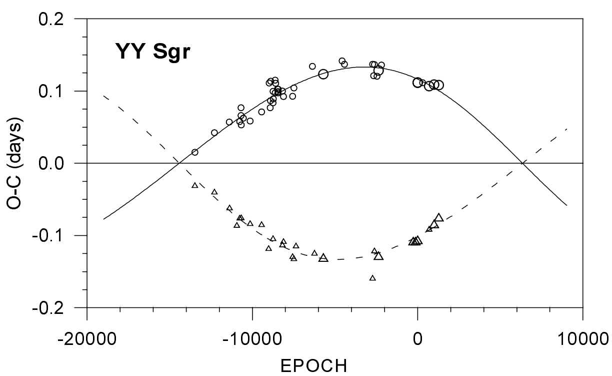

Fig. 2. $O-C$ residuals for the times of minimum of YY Sgr with respect to the linear part of the apsidal motion equation. The continuous and dashed curves represent predictions for primary and secondary eclipses, respectively. The individual primary and secondary minima are denoted by circles and triangles, respectively. Larger symbols correspond to the photoelectric measurements which were taken into calculations with higher weight.

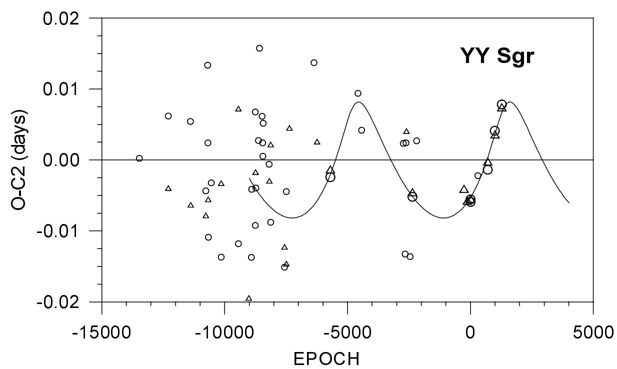

Fig. 3. $O-C_2$ diagram for the times of minimum of YY Sgr after substraction the terms of the apsidal motion. The curve represents a light-time effect for the third body orbit with a period of 44 years with and an amplitude of about 0.008 days. The individual primary and secondary minima are denoted by circles and triangles, respectively.

and their internal errors of the least squares fit (in brackets) are given in Table 2. In this table P_s denotes the sidereal period, P_a the anomalistic period, e represents the eccentricity and $\dot\omega$ is the rate of periastron advance (in degrees per cycle or in degrees per year). The zero epoch is given by T_0 and 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 are shown in Fig. 2. The non-linear predictions, corresponding to the fitted parameters, are plotted as continuous and dashed curves for primary and secondary eclipses, respectively.

Subtracting the influence of apsidal motion, the $O-C_2$ diagram on Fig. 3 can be plotted. The variation of these values are remarkable and could be caused by a light-time effect. A preliminary analysis of the third body orbit gives the following parameters

P_3 (period) $= 16195 \pm 30$ days, i.e. 44.3 years
T_0 (time of periastron) $=$ J.D. 2451675 ± 35
A (semiamplitude) $= 0.0082 \pm 0.0002$ day
e_3 (eccentricity) $= 0.44 \pm 0.03$
ω_3 (lenght of periastron) $= 62.6^\circ \pm 1.6^\circ$

These values were obtained together with the new mean linear ephemeris

$$\text{Pri. Min.} = \text{HJD } 24\,48059.5771 + 2.6284738 \cdot \text{E}, \qquad \pm 0.0003 \pm 0.0000003$$

by the least squares method. Assuming a coplanar orbit ($i_3 = 90°$) and a total mass of the eclipsing pair $M_1 + M_2 = 7.38 M_\odot$ (Lacy 1997), we can obtain a lower limit for the mass of the third component $M_{3,min}$. The value of the mass function is $f(M)$ = 0.00156 $M_\odot$, from which the minimum mass of the third body follows as 0.46 $M_\odot$. Possible third component of spectral type M0 – M1 with the bolometric magnitude about +8 mag could be practically invisible in the system with a B5 primary (M_{bol} = –1.9 mag). Therefore, new high-accuracy timings of this eclipsing binary are necessary in order to confirm the light-time effect in this system.

5. V523 Sgr

The history of observations and analysis of the eclipsing binary V523 Sgr (= HD 176754 = CoD $-29°15641$ = CPD $-29°5846$ = SAO 187605 = FL 2615; $\alpha_{2000} = 19^h 02^m 54.6^s$, $\delta_{2000} = -29°$ 08' 33.8", V_{max} = 9.57 mag; Sp. F0 + F0) now spans almost a century. It was one of the first binaries recognized to show the effects of apsidal motion in the times of its eclipses. The variability of this star was discovered by van Gent on plates taken with

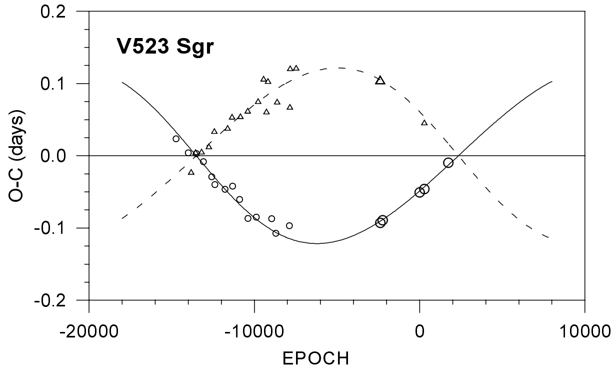

Fig. 4. $O-C$ graph for V523 Sgr. See legend for Fig. 2

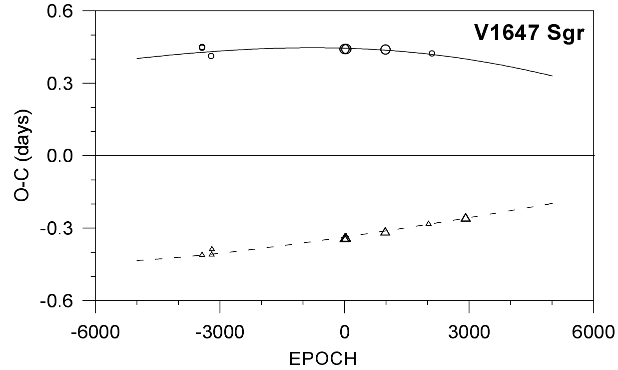

Fig. 5. $O-C$ diagram for V1647 Sgr. See legend for Fig. 2

the Franklin-Adams instrument at Johannesburg. The first photographic light-curve was obtained by Ferwerda (1934). Jones (1938) discovered an apsidal motion with the period greater than 120 years and estimated an orbital eccentricity at least 0.15. The history of this binary is described in detail in Woodward & Koch (1989), where the following linear light elements are also given.

$$\text{Pri. Min.} = \text{HJD } 24\ 41865.7240 + 2\overset{\text{d}}{.}32383724 \cdot \text{E}.$$

An extensive discussion of the apsidal motion is given by Lacy (1992, 1993a), who also derived the value for orbital eccentricity of $e = 0.1620 \pm 0.0010$ and an apsidal motion with the period of $U = 203.0 \pm 1.2$ years. No spectroscopic observations have been published for this system as far as we know. The orbital inclination was adopted to be $i = 83.1°$, following the previous results from the photometric analysis (Lacy 1993a). All times of minimum published in Woodward & Koch (1989), Lacy (1992) as well as the minimum of Grønbech (1975) were included in our analysis. A total of 39 times of minimum light were used in our analysis, with 20 secondary eclipses among them. The computed apsidal motion elements and their internal errors of the least squares fit are given in Table 2. The $O-C$ residuals for all times of minimum with respect to the linear part of the apsidal motion equation are shown in Fig. 4.

6. V1647 Sgr

The double-lined eclipsing binary V1647 Sgr (= HD 163708 = GC 24449 = SAO 209552 = CD $-36°12064$ = CPD $-36°07843$ = HIP 88069 = FL 2341; $\alpha_{2000} = 17^h 59^m 13.5^s$, $\delta_{2000} = -36°$ 56’ 20”, V_{max} = 6.9 mag; Sp. A1V) is a bright A-type binary with remarkably high orbital eccentricity ($e = 0.41$). It was discovered to be variable star by Ponsen (1956) and subsequently studied by de Kort (1955). V1647 Sgr is the primary component of the visual double star h 5000.

The complete simultaneous Strömgren four-colour photometry of V1647 Sco was obtained in 1973-74 and 1982 at ESO in Chile (Clausen et al. 1977). Spectroscopic orbital elements and absolute dimensions were determined by Andersen & Giménez (1985). They also derived an apsidal motion with the period of $U = 592.5 \pm 6.5$ yr and substantial value for orbital eccentricity of $e = 0.4130$. In that paper the following linear ephemeris were also obtained for primary and secondary eclipses, respectively:

$$\begin{aligned}\text{Pri. Min.} &= \text{HJD } 24\ 41829.69510 + 3\overset{\text{d}}{.}28279251 \cdot \text{E},\\ \text{Sec. Min.} &= \text{HJD } 24\ 41830.55561 + 3\overset{\text{d}}{.}28282227 \cdot \text{E}.\end{aligned}$$

From the Hipparcos photometry (Perryman 1997), we were able determine two additional moments of minimum light. They are given as “HIP” minima in Table 1 together with our result (Fig. 1). All photoelectric times of Ponsen (1956), Clausen et al. (1977) and Andersen & Giménez (1985) were incorporated in our calculation. A total of 17 times of minimum light were used in our analysis, with 10 secondary eclipses among them. Adopting the value of the orbital inclination ($i = 90.0°$) from the photometric analysis (Andersen & Giménez 1985), the apsidal motion can be computed. The parameters found and their internal errors of the least squares fit are given in Table 2, the corresponding $O-C$ diagram is plotted on Fig. 5.

7. V2283 Sgr

The detached eclipsing binary V2283 Sgr (= HD 321230 = CoD $-36°12180$ = CPD $-36°7977$ = HV 7498 = FL 2388; $\alpha_{2000} = 18^h 04^m 38.8^s$, $\delta_{2000} = -36°$ 54’ 52.6”, V_{max} = 10.5 mag; Sp. A0) is a photometricaly neglected binary with highly eccentric orbit ($e = 0.49$) and a period of about 3.47 days. It was discovered to be a variable by Henrietta Swope on photographic plates in MWF 187 (Swope 1936). Kooreman (1965) rediscovered this star in the region around Boss 4599 and found a remarkably high orbital eccentricity of at least 0.45. The first photoelectric observations were obtained by Swope (1974) at Siding Spring, Australia in 1965. She derived the following linear light elements

$$\begin{aligned}\text{Pri. Min.} &= \text{HJD } 24\ 38948.5043 + 3\overset{\text{d}}{.}4714231 \cdot \text{E},\\ \text{Sec. Min.} &= \text{HJD } 24\ 38946.7619 + 3\overset{\text{d}}{.}4714231 \cdot \text{E}.\end{aligned}$$

and the substantial value of $e = 0.49$ for the orbital eccentricity. Swope also found an apsidal motion with the period of $U = 570$ years. This binary has been rarely investigated since its discovery and no spectroscopic observations have been published for this system as far as we know.

All photographic and two photoelectric times of mid-eclipse of Swope (1974) and O’Connell (1974) were incorporated

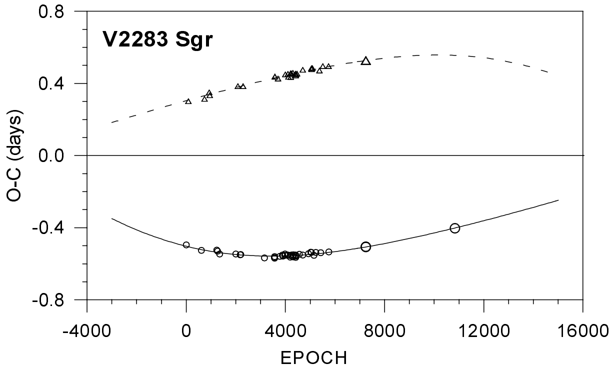

Fig. 6. $O - C$ graph for V2283 Sgr. See legend for Fig. 2

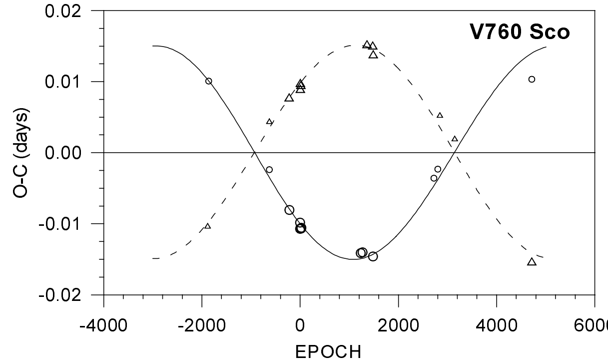

Fig. 7. $O - C$ diagram for V760 Sco. See legend for Fig. 2

in our calculation. The orbital inclination was adopted to be $i = 88.85°$, following the previous results from the photometric analysis (O'Connell 1974). A total of 72 times of minimum light were used in our analysis, with 30 secondary eclipses among them. The computed apsidal motion elements and their internal errors of the least squares fit are given in Table 2. The $O - C$ residuals for all times of minimum with respect to the linear part of the apsidal motion equation are shown in Fig. 6.

8. V760 Sco

The double-lined eclipsing binary V760 Sco (= HD 147683 = SAO 207641 = CD $-34°10981$ = CPD $-34°6506$ = HIP 80405 = BV 577 = FL 1917; $\alpha_{2000} = 16^h24^m43.7^s$, $\delta_{2000} = -34°$ 53' 37.5", V_{max} = 6.99 mag; Sp. B4V + B4V) is of seventh-magnitude and well-known binary system with equal components of spectal type B4V and a small orbital eccentricity ($e = 0.027$). It was discovered on sky patrol plates by Strohmeier et al. (1965). Apsidal motion with a short period was first discovered by van Houten (unpublished). Spectroscopically V760 Sco was investigated by Popper (1966, 1980). Very extensive photometric observations of V760 Sco, covering several seasons, were done by Danish astronomers J. Andersen and J.V. Clausen at ESO, La Silla, in Chile. The complete simultaneous Strömgren four-colour photometry of V760 Sco was obtained in 1977-78 and 1983-84 at ESO in Chile (Andersen et al. 1985a). Spectroscopic orbital elements and absolute dimensions were determined by Andersen et al. (1985b). They also derived the period of the apsidal motion $U = 40 \pm 3$ years with an uncertainty in the eccentricity $e = 0.0255 - 0.0275$. In that paper the following linear ephemeris were also obtained for primary and secondary eclipses, respectively:

$$\text{Pri. Min.} = \text{HJD } 24\,43250.8268 + 1\overset{d}{.}7309295 \cdot \text{E},$$
$$\text{Sec. Min.} = \text{HJD } 24\,43251.7098 + 1\overset{d}{.}7309383 \cdot \text{E}.$$

More than 15 years elapsed since their last observations, thus V760 Sco was also included in our photometric program. All photoelectric times of minimum presented in Andersen et al. (1985b), as well as four new times derived from the Hipparcos photometry (Perryman 1997) and our new results were incorporated in this calculation. Older photographic data of lower accuracy (Strohmeier et al., 1965; Schöffel, 1965; Bauernfeind, 1968) were not taken into account. A total of 25 photoelectric times of minimum light were used in our analysis, with 12 secondary eclipses among them. The orbital inclination was adopted to be $i = 82.2°$ based on the photometric analysis (Andersen et al. 1985b). The computed apsidal motion elements and their internal errors of the least squares fit are given in Table 2. The $O - C$ graph is shown on Fig. 7.

9. Internal structure constant

Observations of binary systems allow us to determine various stellar parameters, which can be compared to theory. One such parameter is the internal structure constant, k_2, which is related to the variation of density within the star and is an important parameter of stellar evolution models. It is best studied in binary systems with eccentric orbits that show apsidal motion. The period of rotation of the periastron in eccentric eclipsing binaries does not allow us to derive the individual internal stellar constant of the component stars. The observational average value of $k_{2,obs}$ is given by the relation

$$k_{2,obs} = \frac{1}{c_{21} + c_{22}} \frac{P_a}{U} = \frac{1}{c_{21} + c_{22}} \frac{\dot{\omega}}{360}, \qquad (1)$$

where c_{21} and c_{22} are functions of the orbital eccentricity, fractional radii, the masses of the components and the ratio between rotational velocity of the stars and Keplerian velocity (Kopal 1978).

Taking into account the value of the eccentricity and the masses of the components, one has to subtract from $\dot{\omega}$ a relativistic correction $\dot{\omega}_{rel}$ (Levi-Civita 1937; Giménez 1985)

$$\dot{\omega}_{rel} = 5.45 \times 10^{-4} \frac{1}{1 - e^2} \left(\frac{M_1 + M_2}{P} \right)^{2/3}. \qquad (2)$$

Due to the lack of spectroscopic measurements of V523 Sgr and V2283 Sgr, we adopted the approximate masses according to their spectral type (Harmanec 1988; Andersen 1991). The values of $\dot{\omega}_{rel}$ and resulting mean internal structure constants $k_{2,obs}$ are given in Table 3.

Table 3. Adopted parameters of the components and derived results.

Parameter	YY Sgr	V523 Sgr	V1647 Sgr	V2283 Sgr	V760 Sco
M_1 [$M_\odot$]	3.90	1.45	2.19	2.4	4.98
M_2 [$M_\odot$]	3.48	1.42	1.97	1.7	4.62
r_1	0.164	0.229	0.1226	0.117	0.234
r_2	0.149	0.157	0.1116	0.099	0.205
Source	Lacy (1997)	Lacy (1993a) Harmanec (1988)	Andersen & Giménez (1985)	O'Connell (1974) Harmanec (1988)	Andersen et al. (1985b)
$\dot{\omega}_{rel}$ [deg cycle^{-1}]	0.00111	0.00064	0.00077	0.00085	0.00171
$\dot{\omega}_{rel}/\dot{\omega}$ [%]	12.8	5.6	12.6	12.3	3.9
log $k_{2,obs}$	-2.280	-2.724	-2.316	-2.341	-2.183
log $k_{2,theo}$	-2.23	-2.48	-2.34	-2.40	-2.17

Table 4. Eclipsing binaries with the shortest period of apsidal motion.

System	U [years]	e	P [days]	Spectral type	Source
U Oph	21.2	0.0031	1.677	B5+B5	Kämper (1984)
GL Car	25.2	0.1457	2.422	B0.5+B1	Giménez & Clausen (1986)
V478 Cyg	26.3	0.019	2.881	O9.5V+O9.5V	Mossakovskaya & Khaliullin (1996)
DR Vul	36.3	0.095	2.251	B0V+B0.5V	Wolf et al. (1999)
NO Pup	37.2	0.1255	1.257	B8V+A7V	Giménez et al. (1986)
OX Cas	37.3	0.0415	2.489	B2V+B2V	Wolf et al. (1997)
V760 Sco	38.5	0.0265	1.731	B4V+B4V	this paper
CO Lac	43.4	0.0298	1.542	B8.5IV+B9.5V	Wolf (1994)
ζ Phe	44.2	0.0113	1.670	B6V+B8V	Giménez et al. (1986)
CW Cep	45.6	0.0293	2.730	B0.5V+B1V	Clausen & Giménez (1991)
Y Cyg	47.6	0.1458	2.996	O9.5+O9.5	Holmgren et al. (1995)

10. Conclusions

We derive updated apsidal motion elements for five southern eccentric and early-type eclipsing binaries by means of an $O-C$ diagram analysis. None of the analysed stars presented important relativistic contributions. The obtained values of the internal structure constant $k_{2,obs}$ are compared to their theoretical values $k_{2,theo}$ according to available theoretical models for the internal stellar structure along the main sequence computed by Claret & Giménez (1992) for a variety of masses and chemical compositions (Fig. 8). Except the system V523 Sgr, where the stellar parameters are estimated probably incorrectly, for all other systems, they are in good agreement.

Concerning the orbital and physical parametres, the system of YY Sgr seems to be very similar to the system RU Mon, which is another eclipsing binary with a large orbital eccentricity and an apsidal motion period of about 350 years (Wolf et al. 1999). The systems V1647 Sgr and V2283 Sgr studied in this paper are also very similar and both belong to the eclipsing binaries with the highest orbital eccentricity. Only the eclipsing system V1143 Cyg (Andersen et al. 1987) has a larger eccentricity $e = 0.540 \pm 0.003$. For V1647 Sgr we have found substantially shorter period of apsidal motion $U = 531 \pm 5$ years than previous observers.

In the case of V760 Sco, our resulting orbital eccentricity and the period of apsidal motion is in a good agreement with elements previously obtained by Andersen et al. (1985b). V760 Sco possesses the smallest known period of apsidal motion. The list of eclipsing binaries with the shortest period of apsidal motion is given in Table 4. A few more times of minimum added over the next decade will make V760 Sco one of the most

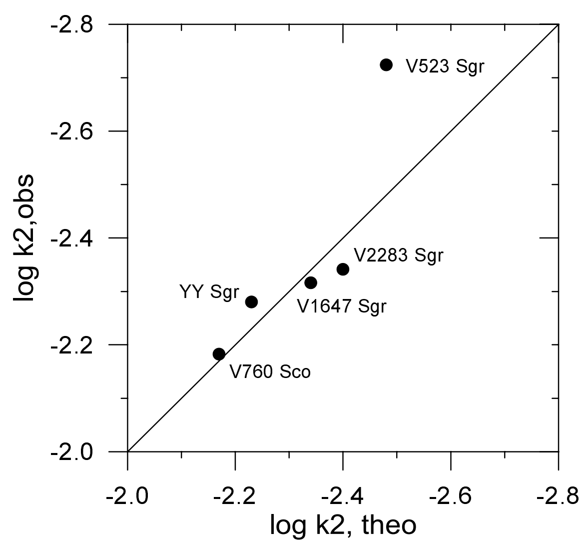

Fig. 8. Comparison between observed and theoretical average values of log k_2.

definitive systems in the observational check of stellar structure models.

More high-accuracy timing of these systems are necessary in the future to enlarge the time span for a better analysis of the apsidal motion, especially in YY Sgr, where the third body is predicted. We will attempt to obtain more precise photoelectric timings of primary and secondary eclipses in the near future. A spectroscopic orbit, allowing a precise mass determination, should be also obtained for a more thorough study of V523 Sgr and V2283 Sgr and for a more definitive determination of their orbital and physical properties.

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