Radial Velocity Studies of Close Binary Stars. XII[1]

Theodor Pribulla

Astronomical Institute, Slovak Academy of Sciences
059 60 Tatranská Lomnica, Slovakia

pribulla@ta3.sk

Slavek M. Rucinski, George Conidis, Heide DeBond, J.R. Thomson

David Dunlap Observatory, University of Toronto
P.O. Box 360, Richmond Hill, Ontario, Canada L4C 4Y6

(rucinski,conidis,debond,jthomson)@astro.utoronto.ca

Kosmas Gazeas

Department of Astrophysics, Astronomy, and Mechanics
National and Kapodistrian University of Athens, 157 84 Zographou, Athens, Greece

kgaze@skiathos.physics.auth.gr

Waldemar Ogłoza

Mt. Suhora Observatory of the Pedagogical University
ul. Podchorażych 2, 30–084 Cracow, Poland

ogloza@ap.krakow.pl

ABSTRACT

Radial-velocity measurements and sine-curve fits to the orbital radial velocity variations are presented for ten close binary systems: OO Aql, CC Com, V345 Gem, XY Leo, AM Leo, V1010 Oph, V2612 Oph, XX Sex, W UMa, and XY UMa. Most of these binaries have been observed spectroscopically before, but our data are of higher quality and consistency than in the previous studies.

While most of the studied eclipsing pairs are contact binaries, V1010 Oph is probably a detached or semi-detached double-lined binary and XY UMa is a detached, chromospherically active system whose broadening functions clearly show well defined and localized dark spots on the primary component. A particularly interesting case is XY Leo, which is a member of visually unresolved quadruple

system composed of a contact binary and a detached, non-eclipsing, active binary with 0.805 days orbital period. V345 Gem and AM Leo are known members of visual binaries. We found faint visual companions at about 2–3 arcsec from XX Sex and XY UMa.

Subject headings: stars: close binaries - stars: eclipsing binaries – stars: variable stars

1.   INTRODUCTION

This paper is a continuation of a series of papers (Papers I – VI and VIII – XI) of radial-velocity studies of close binary stars and presents data for the eleventh group of ten close binary stars observed at the David Dunlap Observatory. For full references to the previous papers, see Pribulla et al. (2006, Paper XI); for technical details and conventions, presentation of the broadening functions approach and for preliminary estimates of uncertainties, see the interim summary paper Rucinski (2002a, Paper VII). The recent DDO studies use the very efficient program of Pych (2004) for removal of cosmic rays from 2-D images.

While most of the data used in this paper were determined using the broadening functions (from now on called BF's) extracted – as in the previous papers – from the region of the Mg I triplet at 5184 Å, we also used a few observations of XY UMa from a region centered at 6290 Å. This experimental setup, which included telluric features, was used (i) because of concerns about flexure effects in our spectrograph and (ii) to improve visibility of the late-type secondary component in this binary. The experiment provided a good check on the stability of our radial-velocity system and – to a large extent – alleviated our concerns. We found also that the stellar lines around 6290 Å and 6400 Å were generally too weak to replace the 5184 Å feature for routine stellar BF determinations. The BF's for XY UMa extracted from the 6290 Å were more noisy than those from the 5184 Å spectral region and the detection of the secondary component was not improved.

In August 2005, a new grating with 2160 l/mm was acquired to replace the previously most frequently used 1800 l/mm grating which after many years of use lost its efficiency. This markedly improved quality of the observed spectra and of the resulting BFs. The older grating was used only for 2005 observations of V1010 Oph and XY UMa.

---

[1]Based on the data obtained at the David Dunlap Observatory, University of Toronto.

The radial velocity (hereafter RV) observations reported in this paper have been collected between April 2005 and April 2006. The ranges of dates for individual systems can be found in Table 1. Selection of the targets in our program remains quasi-random: At a given time, we observe a few dozen close binary systems with periods usually shorter than one day, brighter than 10 – 11 magnitude and with declinations $> -20°$; we publish the results in groups of ten systems as soon as reasonable orbital elements are obtained from measurements evenly distributed in orbital phases. In this paper we re-observed several relatively bright systems (V1010 Oph, W UMa, XY Leo) to ascertain possible systemic velocity changes which could indicate presence of a third body in the system. Similarly as in our previous papers dealing with spectroscopically multiple systems (here the cases of XY Leo and V345 Gem), RV's for the eclipsing pair were obtained from BF's with the third-star sharp peaks removed first, as described most recently in Pribulla et al. (2006).

As in other papers of this series, whenever possible, we estimate spectral types of the program stars using our classification spectra. These are compared with the mean $(B - V)$ color indices usually taken from the Tycho-2 catalog (Høg et al. 2000) and the photometric estimates of the spectral types using the relations published by Bessell (1979).

This paper is structured in a way similar to that of previous papers, in that most of the data for the observed binaries are in two tables consisting of the RV measurements in Table 1 and the sine-curve orbital solutions in Table 2. The RV's and the corresponding spectroscopic orbits for all ten systems are shown in phase diagrams in Figures 1 to 3. The RV's are fitted without proximity effects taken into acoount. This results in systematic deviations of the fits close to the eclipses. A further improvement of the orbits can be obtained by simultaneous fitting of the RV's and photometry taking into account the proximity effects end eclipses, but it has not been attempted in this paper. The measured RV's are listed in Table 1 together with weights, determined from $1/\sigma^2$, as based on individual determinations of centroid velocities. This weighting scheme, which accounts for differences in the *relative* quality of observations, markedly improves the overall quality of the orbital solutions. However, these errors – resulting from non-linear least-squares fitting – tend to stay at a level of a few 0.1 km s^{-1} and therefore under-estimate the real uncertainties. In turn, the errors of the unit weight, as given by the fit (Table 2, column ϵ_i), combine the errors of the individual RV's with all systematic deviations (proximity effects, flexures of the spectrograph, mismatch of template spectral types, etc.) and thus over-estimate the measurement uncertainties.

Table 2 contains also our new spectral classifications of the program objects. Section 2 of the paper contains brief summaries of previous studies for individual systems and comments on the new data. Examples of BF's of individual systems extracted from spectra observed close to quadratures are shown in Fig. 4.

The data in Table 2 are organized in the same manner as in the previous papers of this series. In addition to the parameters of spectroscopic orbits, the table provides information about the relation between the spectroscopically observed upper conjunction of the more massive component T_0 (not necessarily identified with the primary, i.e. deeper eclipse) and the recent photometric determinations of the primary minimum in the form of the $O - C$ deviations for the number of elapsed periods E. For XX Sex, the reference ephemeris was taken from Wils & Dvorak (2003); for the rest of the systems, the ephemeris given in the on-line version of "An Atlas O-C diagrams of eclipsing binary stars"[2] (Kreiner 2004) were adopted. Because the on-line time-of-eclipse data are frequently updated, we give those used for the computation of the $O - C$ residuals below Table 2 (status as of May 2006). The deeper eclipse in W-type contact binary systems corresponds to the lower conjunction of the more massive component; in such cases the epoch in Table 2 is a half-integer number.

2. RESULTS FOR INDIVIDUAL SYSTEMS

2.1. OO Aql

This bright ($V_{max} = 9.50$) contact binary is quite unusual in that it has a mass ratio close to unity in spite of being an A-type system. It also shows a discrepancy between the spectral type and the color index. While Roman (1956) assigned the G5V spectral type to the system, Hill et al. (1975) found the K0 type based on the classification spectra. The observed color indices $(B - V) = 0.76$ (Eggen 1967) and $(b - y) = 0.46$ (Rucinski & Kaluzny 1981) indicate a late spectral type of G8 to K0, but as pointed by Eggen (1967), the reddening in this galactic direction is very patchy and may reach $E_{B-V} \simeq 0.15$. Our classification spectra give discordant estimates: While the G-band (4300 Å) gives about F9V, the hydrogen lines are weak indicating a late G type perhaps G8V.

In spite of its relatively high brightness, the system was not observed by the Hipparcos satellite so no direct measure of the distance is available. Using Rucinski & Duerbeck (1997) calibration and assuming a wide range of spectral types of F8V to G8V, we obtain a range of absolute magnitudes of $M_V = 3.06$ (F8V) to $M_V = 3.66$ (G8V), corresponding to minimum distances (no reddening) of 194 and 147 pc, respectively. The reddening of $E_{B-V} = 0.15$ would increase these estimates to 208 and 158 pc, respectively.

Mochnacki (1981) suggested that OO Aql may be considered as a prototype of a sub-group of contact binaries with components recently evolved into contact after a considerable

---

[2]http://www.as.wsp.krakow.pl/ephem/

angular momentum loss in the pre-contact stage. The view that the system represents a rare, transitional phase in the evolution of contact binaries was later shared by Hrivnak (1989) who presented a consistent, combined radial-velocity and light-curve solution, and showed that the orbital inclination of the system is close to 90°. A sine-curve approximation to the radial velocities obtained with the cross-correlation method led to a spectroscopic orbit with $V_0 = -46.4 \pm 0.9$ km s^{-1}, $K_1 = 147.3 \pm 1.4$ km s^{-1}, and $K_2 = 178.5 \pm 112.0$ km s^{-1}. This resulted in a large mass ratio of $q = 0.825 \pm 0.012$, which – with the proximity effects included – raised to $q = 0.843 \pm 0.008$. This value is very close the one obtained from our new spectroscopic orbit, $q = 0.846 \pm 0.007$.

The center-of-mass velocities of Hrivnak (1989) and the present result differ by about 7 km s^{-1}. In the view of typical differences found for contact binaries from analyses of different authors (Pribulla & Rucinski 2006), we regard this as manifestation of a systematic effect which could be caused by differences in radial-velocity standard systems or/and differences in methods used for radial-velocities determination (cross-correlation or broadening functions, combined with the RV determination via centroids, Gaussians or rotational profiles).

We see the OO Aql system practically edge-on, so the true masses are very close to the projected ones. With $(M_1 + M_2)\sin^3 i = 1.954 \pm 0.019 M_\odot$ and the new mass ratio, we obtain $M_1 = 1.058 \pm 0.011 M_\odot$ and $M_2 = 0.895 \pm 0.009 M_\odot$. The mass of the primary component corresponds to the main sequence spectral type G1V (the secondary component would be G6V, if not in contact). Thus, the primary spectral type, as estimated from its mass, is close to the hot end of the two extremes in the direct estimates, F8V and G8V. The distinctly red color of the system, $(B - V) = 0.76$, would then imply a surprisingly large reddening of $E_{B-V} \simeq 0.2$.

2.2. CC Com

CC Com is a totally eclipsing contact binary at the extreme short-period end of the currently available period distribution. With its period of only 0.22068 days, it has been a record holder for a long time until a contact binary with the 0.215 day period was found in 47 Tuc by Weldrake et al. (2004). Because of its extreme properties, it has been a subject of several photometric studies (e.g., Rucinski (1976); Linnell & Olson (1989)) and of two spectroscopic studies (Rucinski et al. 1977; McLean & Hilditch 1983).

Using an old, now totally obsolete technique of measuring individual metallic lines in image-tube, 4m-telescope spectra, Rucinski et al. (1977) determined relatively reasonable spectroscopic parameters: $V_0 = -10.2 \pm 5.4$ km s^{-1}, $K_1 = 122.0 \pm 5.5$ km s^{-1}, $K_2 =$

235.9 ± 4.8 km s^{-1} confirming the photometric mass ratio found from the timing of the eclipse inner contacts (Rucinski 1976). The broadening functions do not show any trace of a third component, hence we regard a 7.3 km s^{-1} difference between systemic velocities of Rucinski et al. (1977) and present paper as resulting from systematic errors. A spectroscopic orbit of McLean & Hilditch (1983), based on a few rather poor measurements, while agreeing with the above, has been of a limited use.

A new determination of radial velocities was a real challenge for our 2m-class telescope due to the relatively low apparent brightness ($V_{max} = 11.0$), red color and the very short period of the system. Even with relatively long exposures of 500s (2.6% of the orbital period) the spectra were very noisy. Moreover, with the K5V spectral type, the system is relatively faint at the Mg I triplet. We solved these difficulties by re-observing the quadrature segments of the orbit several times with the total number of 134 spectra. As expected, individual BF's were poor so we sorted them in the phase domain and then used temporal smoothing with a $\sigma = 0.02$ Gaussian filter with the subsequent re-binning to a step of 0.02 in phase. Consequently, Table 1 gives radial velocities in equidistant phases with the mean values of the HJD time equal to the average time of the contributing observations. Our new spectroscopic elements are within the errors of those determined by Rucinski et al. (1977). Total minimum mass of the system, $(M_1 + M_2)\sin^3 i = 1.088 \pm 0.014 M_\odot$, is expected to be close to the true value because the orbit of the system is seen practically edge-on.

2.3.   V345 Gem

The photometric variability of V345 Gem was discovered by the Hipparcos satellite (ESA 1997), where it was catalogued as a periodic variable with a period of 0.1373890 days. Later, Duerbeck (1997) classified the system as a pulsating variable on the basis of the period-color relation. V345 Gem was subsequently included in the GCVS (Kazarovets et al. 1999) as a δ Scuti variable. Finally, a high-precision photometry of Gomez-Forrellad et al. (2003) (with both components of the visual pair within the photometric aperture – see below) showed that system is very probably a contact binary with twice the period (0.274778 days) and a photometric variation amplitude of 0.07 mag. These authors determined the first reliable ephemeris $Min.I = BJD\,2448362.7224(10) + 0.2747736(2) \times E$ by doubling of the Hipparcos period.

V345 Gem is the member of visual binary WDS 07385+3343 (Mason et al. 2001) consisting of components with magnitudes $V_1 = 8.08$ and $V_2 = 9.35$, separated by 3.1 arcsec and at present positioned practically perpendicular to our spectrograph slit. Kazarovets et al. (1999) commented that the photometric variability of V345 Gem might be due to the fainter

component. In fact, it was the early spectral type of the dominant component (F0) which resulted in an incorrect classification of the star as a pulsating variable by Duerbeck (1997).

By mistake, our spectroscopic observations of V345 Gem were first focused on the primary component of the visual pair. After some time it became obvious that the primary component is a single, slowly-rotating star and that the contact binary has to be identified with the fainter companion. The presence of the bright companion remained still obvious in the spectra of the close binary because – due to the relatively poor seeing at the DDO site of typically 1–4 arcsec – the spectra of the fainter component were always contaminated by the visual companion. Although the companion spectral signature could be removed by fitting three Gaussian profiles to the extracted BF's, some persistent features most likely caused by the different level and slope of the continua in both stars did remain. In spite of these difficulties, the resulting spectroscopic orbit of the contact pair is of a good quality with the minimum mass of $(M_1 + M_2) \sin^3 i = 1.054 \pm 0.013 M_\odot$, which is rather high for its orbital period of 0.275 days and the mass ratio of $q = 0.143$. After a correction for the third light of the brighter visual companion, the photometric amplitude of the contact pair is about 0.33 mag, which implies a high inclination angle so that the total mass is probably close to the above minimum-mass estimate.

The recent secondary minimum ($HJD2, 453, 731.9423$, Nelson (2006)) coincides in phase with the upper spectroscopic conjunction of the more massive component. Hence, V345 Gem is a contact binary of the W sub-type.

The Hipparcos trigonometric parallax $\pi = 8.61 \pm 1.77$ mas may be affected by the visual binary character of the wide pair. If we take F7V spectral type, estimated for the fainter component of the visual pair from our classification spectra and the corresponding $(B - V)_0 = 0.50$, the absolute magnitude calibration of Rucinski & Duerbeck (1997) gives $M_V = 4.12$ which is very close to the absolute magnitude $M_V = 4.03$ determined from the parallax and the visual magnitude.

The radial velocity of the visual companion, $V_3 = -1.68 \pm 0.15$ km s^{-1}, determined from strongly contaminated spectra of the binary, $L_3/(L_1 + L_2) > 0.10$, is close to the center of mass velocity of the contact binary, $V_0 = 0.03 \pm 0.68$ km s^{-1}; however, this value may be affected by the asymmetric distribution of the third light across the spectrograph slit. A similar value, $V_3 = -2.55 \pm 0.73$ km s^{-1}, was found from the 44 spectra of the third star which were observed by mistake, but were well centered on the spectrograph slit. No RV variations of the brighter visual component have been found. This confirms the physical bond of the visual pair and indicates that the orbital motion in the visual orbit is very slow. Radial velocities of the bright visual component of V345 Gem are available in 3.

2.4. XY Leo

The bright contact binary XY Leo is a member of a quadruple system with an active binary and a contact binary on 20-year period mutual orbit (Barden 1987). The system has a long history of being recognized as somewhat unusual and abnormally bright in the X-rays (Cruddace & Dupree 1984) and the chromospheric Mg II emission (Rucinski 1985).

The multiple nature of the system had been first indicated by the periodic changes of the orbital period of XY Leo; the light-time effect interpretation and the expected nature of the third body was extensively discussed by Gehlich et al. (1972). The authors deduced the minimum mass for the third body to be about 1 $M_\odot$. Struve & Zebergs (1959) obtained the first spectroscopic orbit for the contact binary and noted strong Ca II H and K emissions, which were considered to originate on the more massive component. Finally, Barden (1987) found the companion spectroscopically as a BY Dra-type binary of a mid-M spectral type with its own short orbital period of 0.805 days. The lines of this component were seen as narrow absorption features in the red spectra, relatively easy to measure compared with the spectral lines of the contact binary. The light contributions of the third and fourth components at H_α were found to be 7.5% and 2.5% of the total light, respectively. The orbits of both systems are not coplanar: While the inclination of the eclipsing pair is about 66°, the M-star binary orbit is seen at a 31°angle (Barden 1987). Unfortunately, the outer 20-year period orbit has not been resolved visually nor astrometrically yet, although in the Hipparcos catalogue it is suspected to be an astrometric double (the "S" flag in the H61 field).

Our new observations (February to April 2006) were obtained almost exactly one whole 20-year period of the outer orbit after the spectroscopy of Barden (1987). Hence we cannot provide any new insight into the outer orbit. The systemic (center of mass) velocity of the contact pair is expected to have changed due to mutual revolution by ±6.23 km s^{-1} according to the most recent light-time effect (hereafter LITE) solution (Pribulla & Rucinski 2006). An evenly distributed spectroscopic coverage of the 20-year orbit would enable to unambiguously determine masses of all four components in the system, the same way as it was done for VW LMi (Pribulla et al. 2006).

In the non-Keplerian solution (with proximity effects included) of Barden (1987), $K_1 = 124.1 \pm 2.8$ km s^{-1} is significantly smaller than our value of 144.65 km s^{-1}. It is interesting to note that Hrivnak et al. (1984) obtained an even smaller K_1 than Barden (1987), only 108 ± 2 km s^{-1}. This systematic effect is probably due to the previous use of the cross-correlation technique and thus inadequate resolution leading to a stronger influence of the third component which is always close to the center-of mass velocity of the close binary. As a result, our mass ratio for the contact pair is relatively large compared with the previous

results, $q = 0.729(7)$.

At 5184 Å, the light contribution of the fourth component (the secondary of the M-dwarf pair) is only about 1–2% so that this component is not seen in our spectra; therefore, we could determine only a single-line orbit for the second pair (Table 4 and Fig. 5). The parameters, $V_0 = -39.67 \pm 0.27$ km s^{-1}, $K_3 = 46.44 \pm 0.38$ km s^{-1}, are practically identical with those for the solution of Barden (1987). The light contribution of the third component estimated from the triple-Gaussian fits to our BF's around the quadratures of the contact binary is about $L_3/(L_1+L_2) = 0.13$, which is much higher than that found in the photometric analysis of Yakut et al. (2003). We note that because of the different spectral continuum normalization levels for slowly and rapidly rotating components in spectroscopically multiple systems, the spectroscopic estimates tend to overestimate this ratio.

2.5.   AM Leo

The contact binary AM Leo is the brighter component of the visual double star ADS 8024 (WDS J11022+0954) with the separation of 11.5 arcsec. The position angle of the fainter companion is 270°, i.e. along our spectrograph slit, so the light of both components entered the spectrograph and was recorded simultaneously. The radial velocity of the visual companion, $V_3 = -11.08 \pm 0.97$ km s^{-1}, was found to be stable and close to the systemic velocity of the eclipsing binary. Due to the relatively high brightness of the eclipsing pair, it was a subject of numerous photometric investigations (for references see Hiller et al. (2004); Albayrak et al. (2005)). Hiller et al. (2004) analyzed the light curves of the system and found $q = 0.398$ and the inclination angle $i = 86°$. While AM Leo was included in the Hipparcos mission, the presence of the visual companion significantly deteriorated its trigonometric parallax determination leading to its large uncertainty, $\pi = 13.03 \pm 3.64$ mass.

The only spectroscopic orbit was presented by Hrivnak (1993) who performed a preliminary solution neglecting proximity effects and finding the mass ratio of $q = 0.45$ with $M_1 + M_2 = 2.00\,M_\odot$. Our solution with $q = 0.459(4)$ is consistent with the above determination. The system is seen almost edge-on, so that the minimum mass derived by us, $M_1 + M_2 = 1.882 \pm 0.018\,M_\odot$, is close to the true total mass of the system.

The recent period study of AM Leo Albayrak et al. (2005) shows possible cyclic period variations interpreted by the authors as a result of a LITE caused by an invisible third component with the minimum mass of $0.18 M_\odot$. The authors estimated that this hypothetical body would be about 7 magnitudes (i.e., more than 600 times) fainter than the contact binary. This component, if it really exists, cannot be identified with the known visual companion

on the wide astrometric orbit. As expected, with the 7 mag. difference, we do not see any persistent feature close to the systemic velocity which could be interpreted as being caused by a faint nearby companion. In fact, in the DDO averaged spectra (D'Angelo et al. 2006), the brightness difference detection limit is about 5.2 magnitudes.

2.6. V1010 Oph

V1010 Oph is a bright ($V_{max} = 6.20$) early spectral type (A3V) short-period, almost-contact, semi-detached eclipsing binary. Its variability was discovered by Strohmeier et al. (1964). The published spectroscopic studies of the system (Guinan & Koch 1977; Margoni et al. 1981; Worek et al. 1988) found V1010 Oph to be a SB1 system with $K_1 \simeq 100$ km s^{-1}. Margoni et al. (1981) observations led to a significant orbital eccentricity of 0.23 ± 0.03 which is highly unexpected for such a close binary and indicated a problem in the analysis. Later observations of Worek et al. (1988) gave a small eccentricity of $e = 0.02 \pm 0.02$ which is consistent with zero due to the biased character of the eccentricity estimates (it cannot be negative). While the previous velocity semi-amplitudes were consistent, the center of mass velocity was discordant, with $V_0 = -15 \pm 3$ km s^{-1} determined by Margoni et al. (1981) and $V_0 = -41 \pm 1.5$ km s^{-1} determined by Guinan & Koch (1977). The photometric analysis of Leung & Wilson (1977), based on the assumption of the Roche model, showed that (i) the primary eclipse is a transit, (ii) the eclipses are total and (iii) the system is in marginal contact.

Our BF's of V1010 Oph (Fig. 4) clearly show the secondary component orbiting with a large semi-amplitude (see Table 2). The well determined mass ratio of $q_{sp} = 0.465 \pm 0.003$ is in agreement with the photometric determination $q_{ph} = 0.4891 \pm 0.0016$ of Leung & Wilson (1977). Note, that this statement is a qualified one because very frequently we see large discordances between q_{sp} and q_{ph} and even in this case the error of q_{ph} must have been strongly under-estimated. As expected, we do not see any indications of a non-zero eccentricity. It is interesting to note that all radial-velocity determinations from 2005 (plotted as open symbols in Fig. 2) give a much smaller systemic velocity for the system, by $\Delta V_0 \simeq -30$ km s^{-1}, possibly indicating that the eclipsing pair orbits around a common center of gravity with a third star in the system. The system was included into the Hipparcos mission with the resulting parallax of 13.47 ± 0.83 mas, so the system has a very well determined distance.

2.7.   V2612 Oph

The variability of V2612 Oph (= NSV 10892 in the General Catalog of Variable Stars) was first suspected by Hiltner (1958). The author gave $V = 9.50$, $B - V = 0.60$ and $U - B = 0.07$. V-band photometry of Koppelman et al. (2002) showed that it is a contact binary. The authors determined a preliminary ephemeris for the primary minimum: $Min.I = HJD2,452,454.7107 + 0.375296 \times E$. Their light curve is asymmetric with the maximum following the primary minimum brighter by about 0.03 mag. New minima of V2612 Oph observed by Tas et al. (2004), gave a large $(O - C)$ shift indicating a slightly longer orbital period. Therefore in our spectroscopic solution, we optimized both T_0 and P leading to P = 0.375307(3).

Yang et al. (2005) analyzed the light curve of Koppelman et al. (2002) and found the following parameters $q = 0.323 \pm 0.002$, $i = 65.7 \pm 0.3$ and $f = 0.23 \pm 0.04$. Our mass ratio $q = 0.286$ is not consistent with the photometric estimate, as frequently observed for partially eclipsing system with over-interpreted light curve analyses. T_0 in the ephemeris of Koppelman et al. (2002) coincides with upper conjunction of the less massive component so the system is clearly of the W subtype. The projected total mass of the system, $(M_1 + M_2) \sin^3 i = 1.279 \pm 0.011\, M_\odot$, is consistent with our spectral type estimate, F7V, for a moderately low value of the orbital inclination.

V2612 Oph is located in the outskirts of the intermediate age galactic cluster NGC 6633. The star was included in the four color photometry of NGC 6633 by Schmidt (1976) who found $(b - y) = 0.382$ and determined a large value for the interstellar reddening of $E(b - y) = 0.472$, which is inconsistent with the average cluster reddening of $E(b - y) = 0.124 \pm 0.017$. Similarly to Hiltner (1958), the author did not accept the membership of the star in NGC 6633.

V2612 Oph was not observed by Hipparcos satellite, and its trigonometric parallax is unknown so the cluster membership cannot be reliably verified. Using the Rucinski & Duerbeck (1997) absolute magnitude calibration assuming F7V spectral type, we obtain $M_V = 3.52$. With the distance modulus of NGC 6633 of $V - M_V = 7.71$ mag (Kharchenko et al. 2005) the system should be as faint as $V_{max} = 11.26$. Hence, it seems that V2612 Oph is in front of the cluster, although this is entirely inconsistent with the supposedly very large $E(b - y)$ reddening value.

The proper motion of V2612 Oph, $\mu_\alpha \cos \delta = 57.2 \pm 2.1$ mas/year and $\mu_\delta = 23.3 \pm 2.1$ mas/year (Høg et al. 2000), does not correspond to the mean NGC 6633 motion of $\mu_\alpha \cos \delta = 0.10$ mas/year and $\mu_\delta = -2.0$ mas/year (Kharchenko et al. 2005). On the other hand, the center of mass velocity of V2612 Oph, $V_0 = -25.59 \pm 0.44$ km s^{-1} is close to mean radial

velocity of the cluster of $V_R = -25.43$ km s^{-1}, as given by Kharchenko et al. (2005). Recently, high precision photometry of the cluster performed by Hidas et al. (2005) has led to detection of several variable stars in NGC 6633. In particular, a W UMa variable V7 with a similar period of $P = 0.38673$ days, at $V_{max} = 12.8$, is over 3 magnitudes fainter than V2612 Oph. Hence we reject the membership of V2612 Oph to NGC 6633.

2.8.   XX Sex

The photometric variability of XX Sex (HD 89027) was found on the Stardial images (Wils & Dvorak 2003). The authors determined an approximate ephemeris for the primary minima $Min.I = HJD2452314.79 + 0.54011 \times E$. The ASAS-3 light curve shows that XX Sex is a totally eclipsing system with rather different depths of the minima. The orbital period in ASAS is slightly improved to 0.540111 days. No high-precision photometry of XX Sex has been published yet.

Our independent spectral type estimate of F3V is slightly later than F0, as given in Simbad Astronomical database. XX Sex was not included in the Hipparcos mission, hence its trigonometric parallax is unknown. During our spectroscopic observations we noted a faint visual companion to XX Sex separated by about 3 arcsec in the NW direction.

The upper spectroscopic conjunction of the more massive component observed by us coincides in phase with the deeper minimum in the ASAS-3 photometry indicating that the system is of the A-type. This is further supported by the low mass ratio determined by us, $q = 0.100 \pm 0.002$ and by the relatively long orbital period. For such a small mass ratio, eclipses remain total for a wide range of inclinations down to as low as 70°. This is actually indicated by the relatively small projected total mass of $(M_1 + M_2)\sin^3 i = 1.153 \pm 0.026 \, M_\odot$ for the spectral type of F3V.

In the analysis of the broadening functions we noted that while the peak of the secondary component is usually well defined around the second quadrature (phase 0.75), where it was sufficiently separated from the primary-component peak, its profile is flat and poorly defined around the first quadrature. These unexplained shape variations in the secondary component signature resulted in rejection of four RV determinations for this component.

2.9.   W UMa

The prototype contact binary W UMa has been intensively observed since its discovery in 1903 (Muller & Kempf 1903). The contact binary is the brighter ($\Delta m = 4.4$) component

of the visual pair ADS 7494 (WDS J09438+5557) with the separation of 6.4 arcsec. The physical association of the components has not been yet demonstrated. The Hipparcos Catalogue lists W UMa as a suspected astrometric binary with "S" flag in the H61 field.

Apart from numerous photometric observations and studies (Linnell 1991), the system was observed several times spectroscopically (McLean 1981; Rucinski et al. 1993). The spectroscopic elements of the system are still poorly known with large differences in the center of mass velocity ranging from $V_0 = 0$ km s^{-1} (Binnendijk 1967) to $V_0 = -43$ km s^{-1} (Popper 1950); it is unclear if these differences can be explained by very different and slowly improving methods of radial velocity determinations for contact binaries. In addition, W UMa shows unexplained, irregular orbital period changes which probably indicate simultaneous action of several mass and angular-momentum transfer processes within the contact system.

Our new spectroscopic orbit is based on 36 high-precision RV measurements extracted from very-well defined BF's (see Fig. 4). The resulting parameters (Table 2) clearly supersede all previous determinations. The spectroscopic elements are well within previous determinations uncertainties, as given in the last two studies (McLean 1981; Rucinski et al. 1993). During our observations covering 16 days we didn't observe any center-of-mass velocity changes.

The trigonometric parallax of the system, $\pi = 20.17 \pm 1.05$, is very well defined. The absolute visual magnitude determined from the period-color-luminosity relation of Rucinski & Duerbeck (1997), $M_V = 3.86$, is rather severely inconsistent with the magnitude found from the parallax, $M_V = 4.82 \pm 0.11$. To obtain a reasonable accord, a substantial amount of reddening ($A_V = 0.96$) or a much later spectral type – perhaps as late as K1V – would be required; both explanations are equally unlikely. This major discrepancy is entirely unexplained and puzzling for such a well observed contact binary.

2.10. XY UMa

XY UMa is a highly chromospherically active system with an exceptionally short orbital period for a detached binary of only 0.479 days. The photometric variability of XY UMa was first noted by Geyer et al. (1955). The binary has been the subject to extensive photometric studies; for references see Pribulla et al. (2001). The spectroscopic orbit of the primary component was first obtained by the CCF technique by Rainger et al. (1991). To detect and measure the RV's for the secondary, Pojmanski (1998) applied a sophisticated modeling of the near-infrared spectra in the region of the Ca II infra-red triplet. This led to the following parameters $V_0 = -10.5 \pm 1.0$ km s^{-1}, $K_1 = 122.5 \pm 1.0$ km s^{-1}, $K_2 = 202 \pm 6$ km s^{-1}. The

chromospheric emission filling the H_β and H_α lines was later studied by Özeren et al. (2001).

The system was suspected to be a member of a multiple system (Pribulla et al. 2001) with the third-body orbital period of about 30 years. The H61 field of the Hipparcos Catalog contains flag "S" (as described in the catalog, "suspected non-single"), i.e., a plausible astrometric orbital solution for XY UMa was found. While our BF's do not show any trace of the third component, we noted during the current observations a faint ($\Delta m \approx 3$ mag) visual companion in the NW direction about 2–3 arcsec from XY UMa. A spectrum of the companion taken on March 24, 2006 indicates that it may be a binary system, although contamination by the light of XY UMa is not excluded.

Our new spectroscopic observations consist of two runs: In the spring of 2005, we observed spectra centered at 6290 Å, in a spectral window which included a telluric molecular feature (later removed in the BF extraction), while in the spring of 2006 we used the standard setup around Mg I 5184 Å triplet. Neither of the runs revealed any obvious signatures of the secondary component so, at first, we treated the orbit as that of a single-lined binary (SB1). An orbit based only on the 2006 observations, $V_0 = -7.68 \pm 0.24$ km s^{-1} and $K_1 = 124.74 \pm 0.28$ km s^{-1} utilized 61 spectra (excluding spectra obtained within ± 0.09 in phase around the primary eclipse). When we arranged the spectra in phase and smoothed them in the phase domain, a faint feature of the secondary component became visible (Fig. 6). Its semi-amplitude was about $K_2 \simeq 178$ km s^{-1}, which is markedly smaller than 202 km s^{-1}, found by Pojmanski (1998). The discrepancy may be caused by the dominance of the reflection effect at 5184 Å so that the effective line center on the secondary is shifted towards its irradiated hemisphere. We note that our BF's are very well defined for the primary component. They clearly show a dark, relatively small and well localized spot visible around the second quadrature which migrates through the stellar profile following the stellar rotation of the primary component. A weaker similar spot was recorded around the first quadrature in some of the spectra.

The Hipparcos parallax of the system, 15.09 ± 1.48 mas, and the maximum visual magnitude $V = 9.62$ give the absolute visual magnitude $M_V = 5.51 \pm 0.22$ corresponding to a single G8V main-sequence star. The light contribution of the secondary companion is just a few percent in the V passband.

The spectral type of XY UMa was estimated by analyzing average spectrum of the system. The best template to fit the average spectrum was found to be K0V (the next available templates were G8V and K4V). This template was the best even for individual spectra observed during the eclipses. The published spectral types of the components are G3V + K4-5V (Pribulla et al. 2001), which appear to be much too early.

3. SUMMARY

With the new ten short-period binaries, this paper brings the number of the systems studied at the David Dunlap Observatory to one hundred and ten. The systems presented in this paper include (1) the quadruple system XY Leo consisting of a contact binary and a BY Dra-type close binary consisting of two M-type dwarfs, (2) the very close, detached, chromospherically active system XY UMa, (3) V1010 Oph which is probably a detached or semi-detached SB2 system. The remaining seven SB2 binaries are all contact ones: OO Aql, CC Com, V345 Gem, AM Leo, V2612 Oph, XX Sex and W UMa. Six systems of this group were observed spectroscopically before: OO Aql, CC Com, XY Leo, AM Leo, W UMa, and XY UMa, but our new data are of higher quality than in any of the previous studies.

Companions to the close binaries appear to be present in V345 Gem, XY Leo, AM Leo, XX Sex and XY UMa, but all have been recognized as such before except for XX Sex and XY UMa where the faint companions are new detections. The case for the physical association of the visual companion to W UMa still remains open.

We point out that the red color of OO Aql is unexplained, unless it is very heavily reddened. We also note a large discrepancy in the absolute magnitude of W UMa between the predicted by the simple period–color–luminosity calibration and the one derived from the parallax.

REFERENCES

Albayrak, B., Selam, S.O., Ak, T., Elmasli, A., Özavci, I. 2005, Astron. Nachr., 326, 122

Barden, S.C. 1987, ApJ, 317, 333

Bessell, M.S. 1979, PASP, 91, 589

Binnendijk, L.A. 1967, Publ. Dominion Astrophys. Obs., 13, No. 3

Cruddace, R. G. & Dupree, A. K. 1984, ApJ, 277, 263

D'Angelo, C., Kerkwijk, M.H., Rucinski, S.M. 2006, AJ, 132, 650

Duerbeck, H.W. 1997, Inf. Bull. Variable Stars., No. 4513

Eggen, O.J. 1967, MemRAS, 70, 111

European Space Agency. 1997. The Hipparcos and Tycho Catalogues (ESA SP-1200)(Noordwijk: ESA) (HIP)

Gehlich, U.K., Prölss, J., Wehmeyer, R. 1972, A&A, 18, 477

Geyer, E.H., Kippenhahn, R., Strohmeier, W. 1955, Kleine Veroff. Remeis Sternwarte Bamberg, No. 9

Gomez-Forrellad, J.M., Vidal-Sainz, J., Sanchez-Bajo, F., Garcia-Melendo, E. 1997, Inf. Bull. Var. Stars, 5387

Guinan, E.F., Koch, R.H. 1977, PASP, 89, 74

Hidas, M.G., Ashley, M.C.B., Webb, J.K., Irwin, M., Phillips, A., Toyozumi, H., Derekas, A., Christiansen, J.L., Nutto, C., Crothers, S. 2005, MNRAS, 360, 703

Hill, G., Hilditch, R.W., Younger, F., Fisher, W.A. 1975, Mem. RAS, 79, 131

Hiller, M.E., Osborn, W., Terrell, D. 2004, PASP, 116, 337

Hiltner, W.A., Iriarte, B., Johnson, H.L. 1958, ApJ, 127, 539

Høg, E., Kuzmin, A, Bastian, U., Fabricius, C., Kuimov, K., Lindegren, L., Makarov, V.V., Roesser, S. 1998, A&A, 335, L65–L68

Høg, E., Fabricius, C., Makarov, V.V., Urban, S., Corbin, T., Wycoff, G., Bastian, U., Schwekendiek, P., & Wicenec, A. 2000, A&A, 355L, 27

Hrivnak, B.J., Milone, E.F., Hill, G., Fisher, W.A. 1984, ApJ, 285, 683

Hrivnak, B.J. 1989, ApJ, 340, 458

Hrivnak, B.J. 1993, in ASP Conf. Series, New Frontiers in Binary Star Research, J.C. Leung & I.S. Nha (eds.), p.269

Kazarovets, A. V., Samus, N. N., Durlevich, O. V., Frolov, M. S., Antipin, S. V., Kireeva, N. N., Pastukhova, E. N. 1999, Inf. Bull. Var. Stars, 4659

Kharchenko, N.V., Piskunov, A.E., Röser, S., Schilbach, E., Scholz, R.D. 2005, A&A, 438, 1163

Koppelman, M.D., West, D., Price, A. 2002, Inf. Bull. Variable Stars, No. 5327

Kreiner, J.M. 2004, Acta Astron., 54, 207

Leung, K.C., Wilson, R.E. 1977, ApJ, 211, 853

Linnell, A.P., Olson, E.C. 1989, ApJ, 343, 909

Linnell, A.P. 1991, ApJ, 374, 307

Margoni, R., Stagni, R., Illes-Almar, E. 1981, Ap&SS, 79, 159

Mason, B.D., Wycoff, G.L., Hartkopf, W.I., Douglass, G.G., & Worley, C.E. 2001, AJ, 122, 3466 (WDS)

McLean, B.J. 1981, MNRAS, 195, 931

McLean, B.J., & Hilditch, R.W. 1983, MNRAS, 203, 1

Mochnacki, S. W. 1981, AJ, 245, 650

Muller, G., Kempf, P. 1903, ApJ, 17, 201

Nelson, R.H. 2006, Inf. Bull. Variable Stars, No. 5672

Özeren, F.F., Gunn, A.G., Doyle, J.G., Jevremovic, D. 2001, A&A, 366, 202

Pojmanski, G. 1998, Acta Astron., 48, 711

Popper, D.M. 1950, PASP, 62, 115

Pribulla, T., Chochol, D., Heckert, P.A., Errico, L., Vittone, A.A., Parimucha, Š., Teodorani, M. 2001, A&A, 371, 997

Pribulla, T., Rucinski, S.M. 2006, AJ, 131, 2986

Pribulla, T., Rucinski, S.M., Lu, W., Mochnacki, S.W., Conidis, G., DeBond, H., Thomson, J.R., Pych, W., Blake, R.M., Ogloza, W., Siwak, M. 2006, AJ, in press (Paper XI)

Pych, W. 2004, PASP, 116, 148

Rainger, P.P., Hilditch, R.W., Edwin, R.P. 1991, MNRAS, 248, 168

Roman, N.G. 1956, ApJ, 123, 247

Rucinski, S.M. 1976, PASP, 88, 777

Rucinski, S.M. 1985, MNRAS, 215, 615

Rucinski, S.M. 2002a, AJ, 124, 1746 (Paper VII)

Rucinski, S.M., & Duerbeck, H.W. 1997, PASP, 109, 1340

Rucinski, S.M., Kaluzny, J. 1981, Acta Astron., 31, 409

Rucinski, S.M., Whelan, J.A.J., Worden, S.P. 1977, Publ. Astron. Soc. Pacific, 89, 684

Rucinski, S. M., Lu, W.-X., & Shi, J. 1993, AJ, 106, 1174

Schmidt, E.G. 1976, PASP, 88, 63

Ströhmeier, W., Knigge, R., Ott, J. 1964, Inf. Bull. Variable Star, No. 74

Struve, O., Zebergs, V. 1959, ApJ, 130, 137

Tas, G., Sipahi, E., Dal, H.A., Goker, U.D., Tigrak, E., Yigen, S., Ozdarcan, O., Topcu, A.T., Gungor, C., Celik, S., Evren, S. 2004, Inf. Bull. Variable Stars, No. 5548

Weldrake, D.T.F., Sackett, P.D., Bridges, T.J., Freeman, K.C. 2004, AJ, 128, 736

Wils, P., Dvorak, S.W. 2003, Inf. Bull. Variable Stars, No. 5425

Worek, T.F., Zizka, E.R., King, M.W. 1988, PASP, 100, 371

Yakut, K., Ibanoglu, C., Kalomeni, B., Degirmenci, O.L. 2003, A&A, 401, 1095

Yang, Y.G., Qian, S.B., Koppelman, M.D. 2005, Chin. J. Astron. Astrophys., 5, 137

Captions to figures:

Fig. 1.— Radial velocities of the systems OO Aql, CC Com, V345 Gem and XY Leo are plotted in individual panels versus the orbital phases. The lines give the respective circular-orbit (sine-curve) fits to the RV's. While all four systems are contact binaries, V345 Gem and XY Leo are members of multiple systems. The circles and triangles in this and the next two figures correspond to components with velocities V_1 and V_2, as listed in Table 1, respectively. The component eclipsed at the minimum corresponding to T_0 (as given in Table 2) is the one which shows negative velocities for the phase interval $0.0 - 0.5$ and which is the more massive one. Short marks in the lower parts of the panels show phases of available observations which were not used in the solutions because of the excessive spectral line blending.
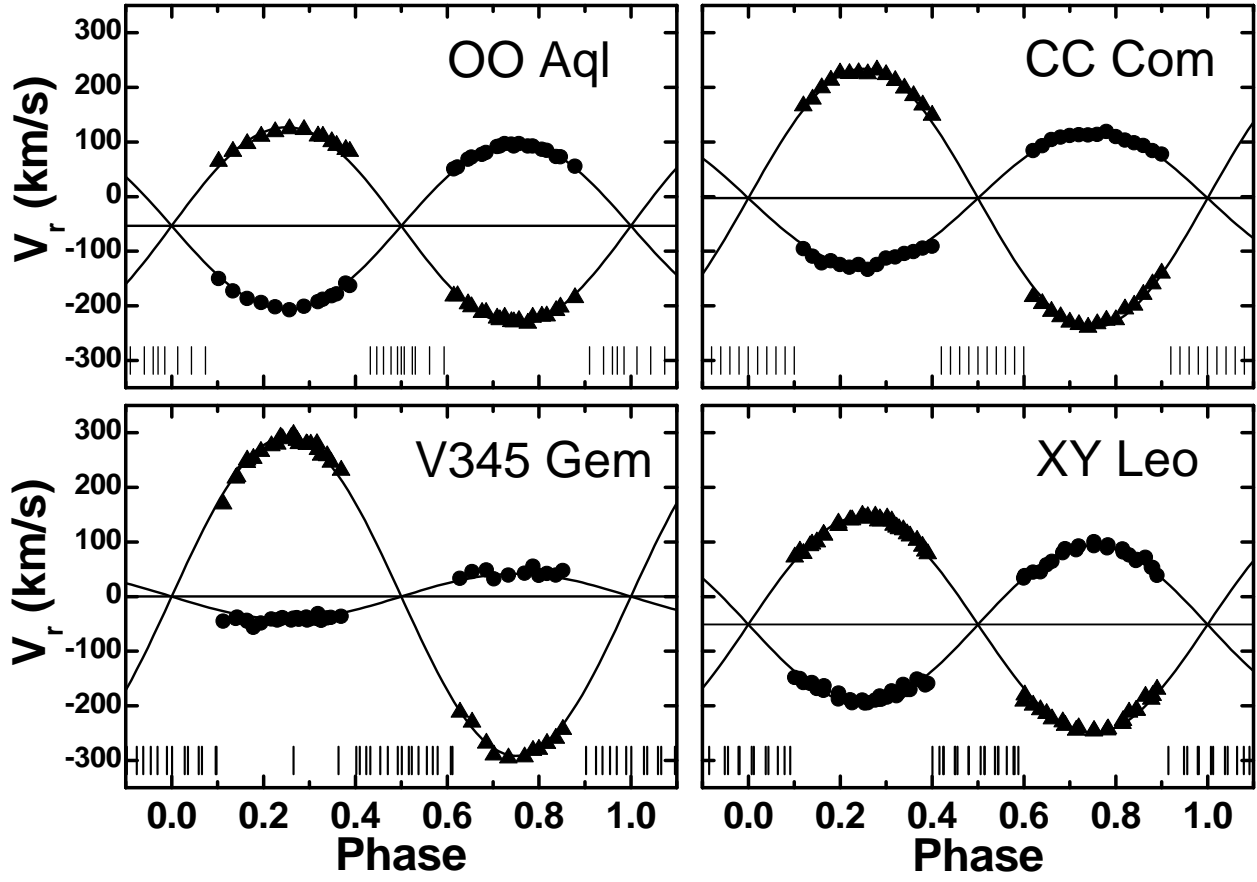
Fig. 2.— The same as for Figure 1, but for AM Leo, V1010 Oph, V2612 Oph, and XX Sex. While V1010 Oph is double-lined detached or semi-detached binary, AM Leo, V2612 Oph, and XX Sex are contact binaries. Open symbols correspond to the observations not used for the spectroscopic orbit determination.
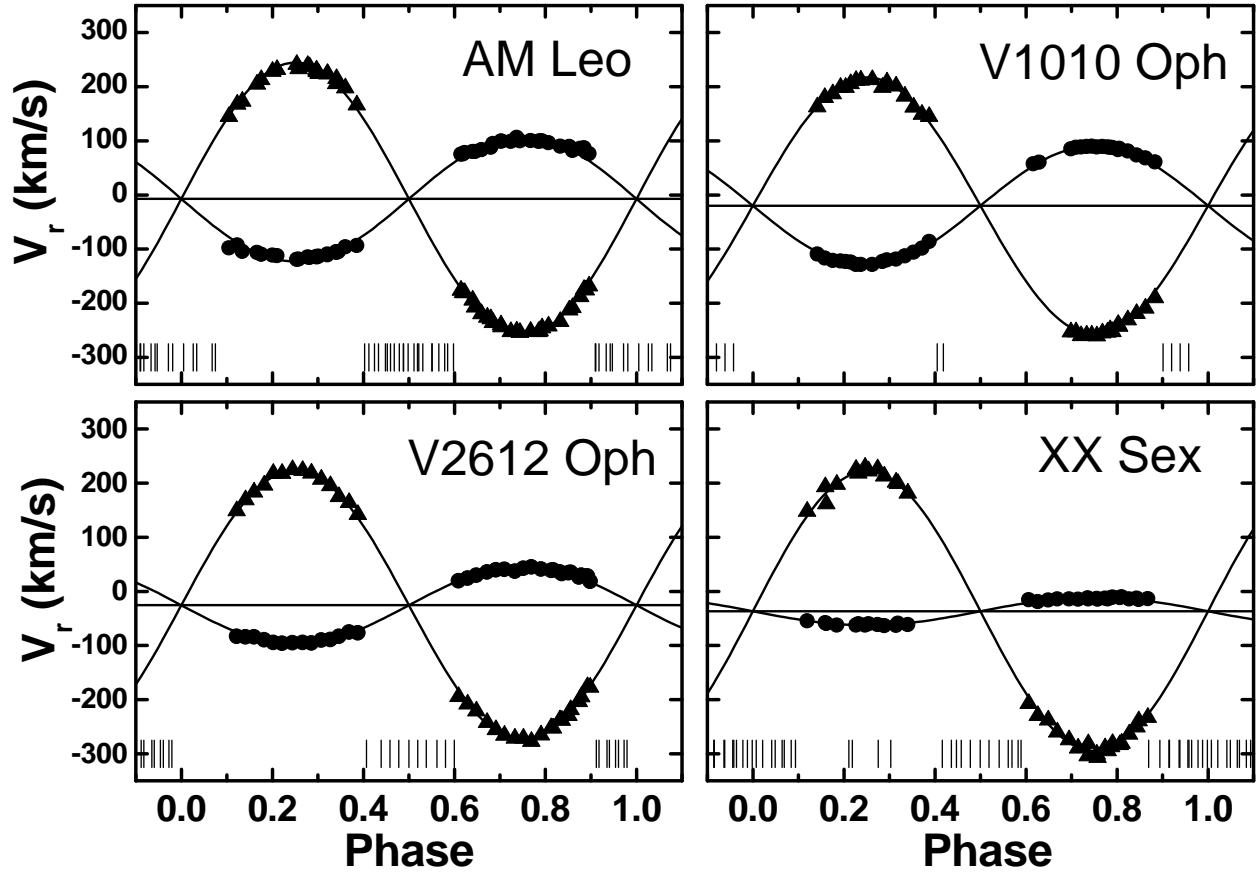
Fig. 3.— The same as for Figures 1 and 2, but for the two remaining systems W UMa, and XY UMa. While W UMa is the prototype contact binary, XY UMa is a very close, but detached binary.
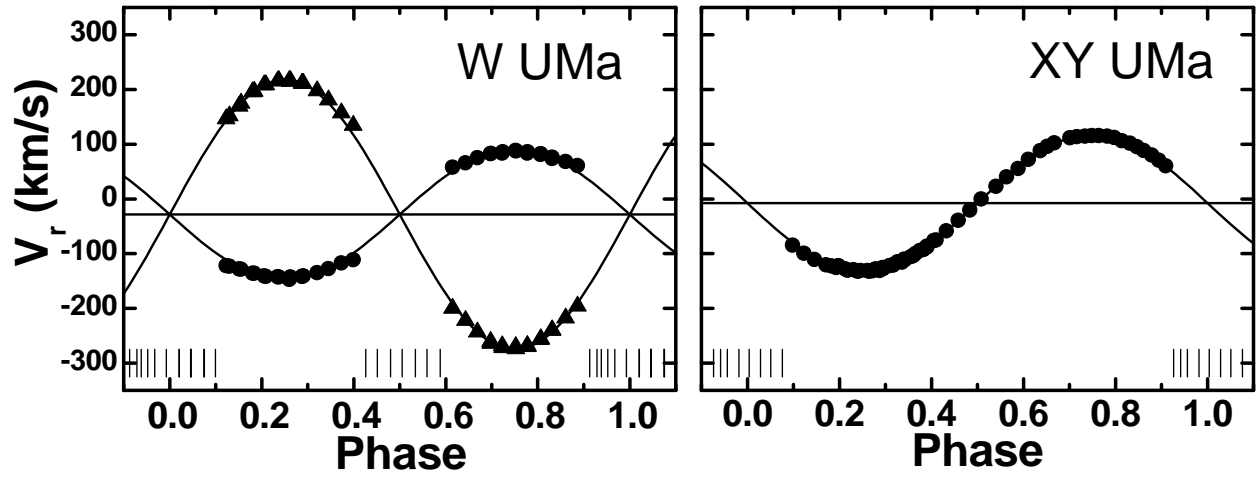
Fig. 4.— The broadening functions (BF's) for all ten systems of this group, selected for phases close to 0.25 or 0.75. The phases are given by numbers in individual panels. XY Leo is quadruple system composed of the contact eclipsing binary and of the detached, non-eclipsing, close binary with the orbital period $P \approx 0.805$ days and with only one component visible as a relatively sharp peak in the BF (its orbit is shown in Fig 5). The third star feature in the BF of the contact binary V345 Gem is also clearly visible. All panels have the same horizontal range, -500 to $+500$ km s^{-1}.
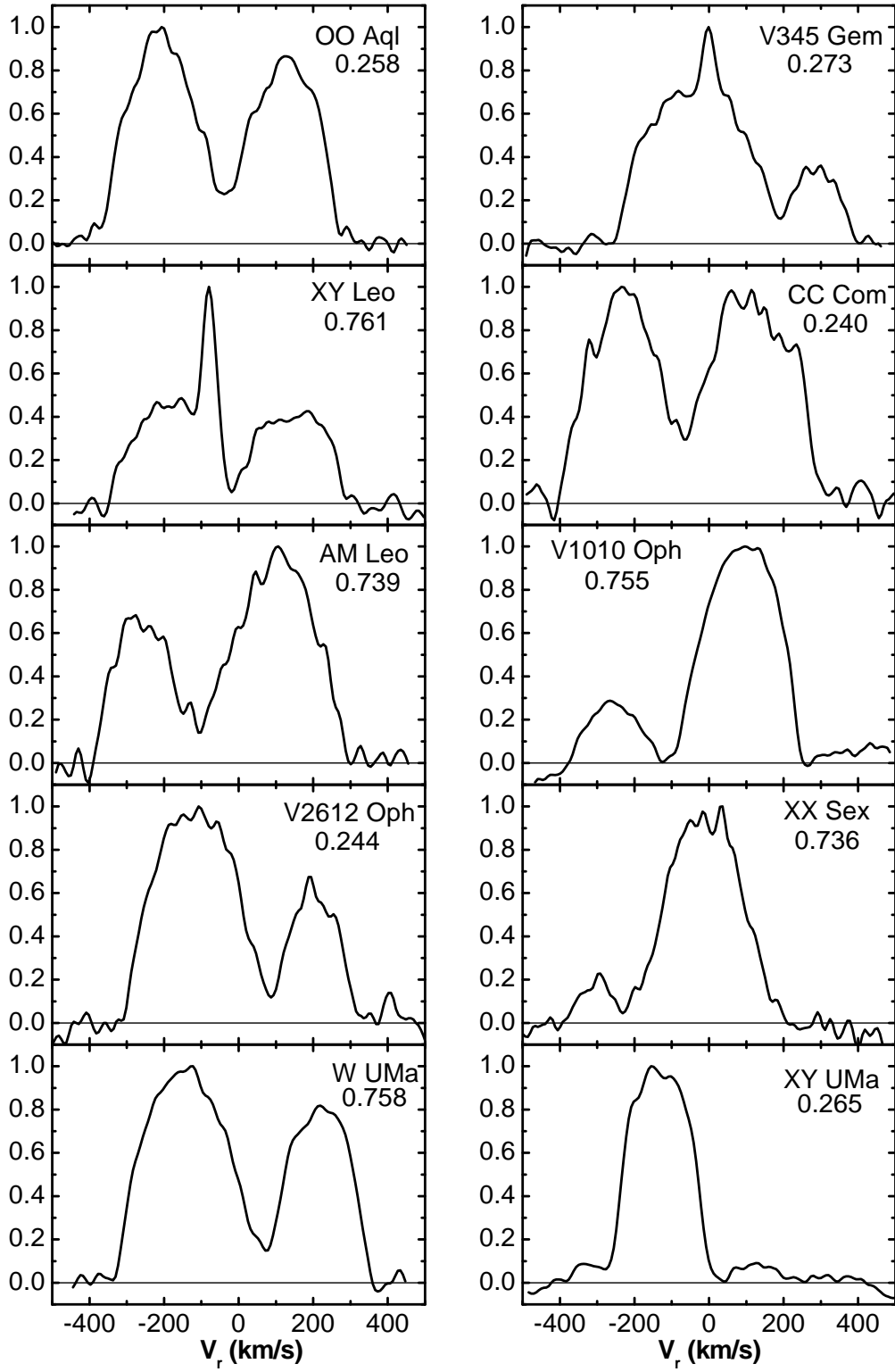
Fig. 5.— The radial velocities of the third component of XY Leo and the corresponding fit to its orbital motion with the period of 0.805 days.
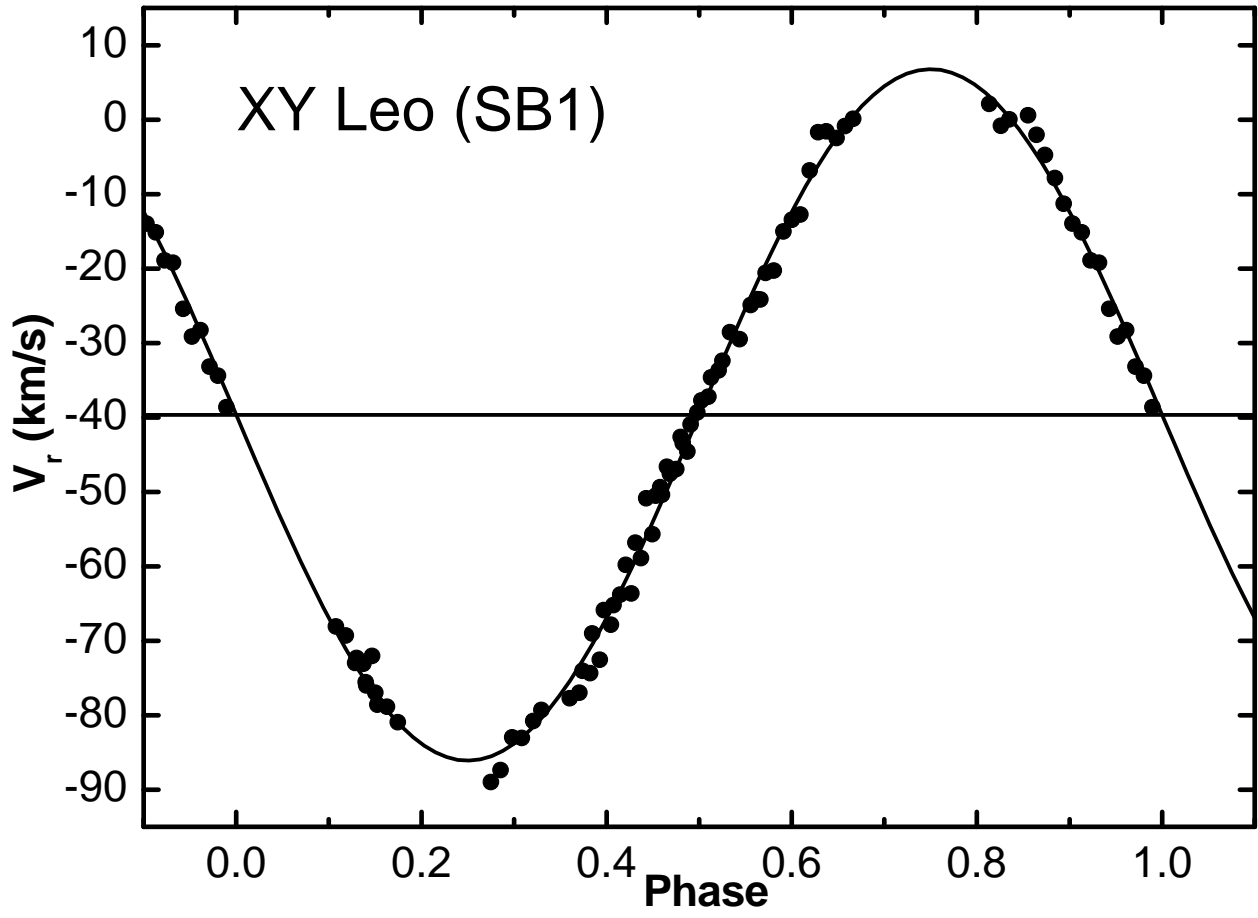
Fig. 6.— A gray-scale plot of the phase-domain averaged broadening functions of XY UMa showing faint features of the secondary companion, best visible after the secondary minimum. During the primary eclipse the secondary component is clearly visible as a moving dark feature within the primary component profile. Note also the dark spots on the primary best visible in phases 0.7 0.8. An orbit of the secondary component, as observed in our spectral window at 5184 Å, is plotted by a solid line.
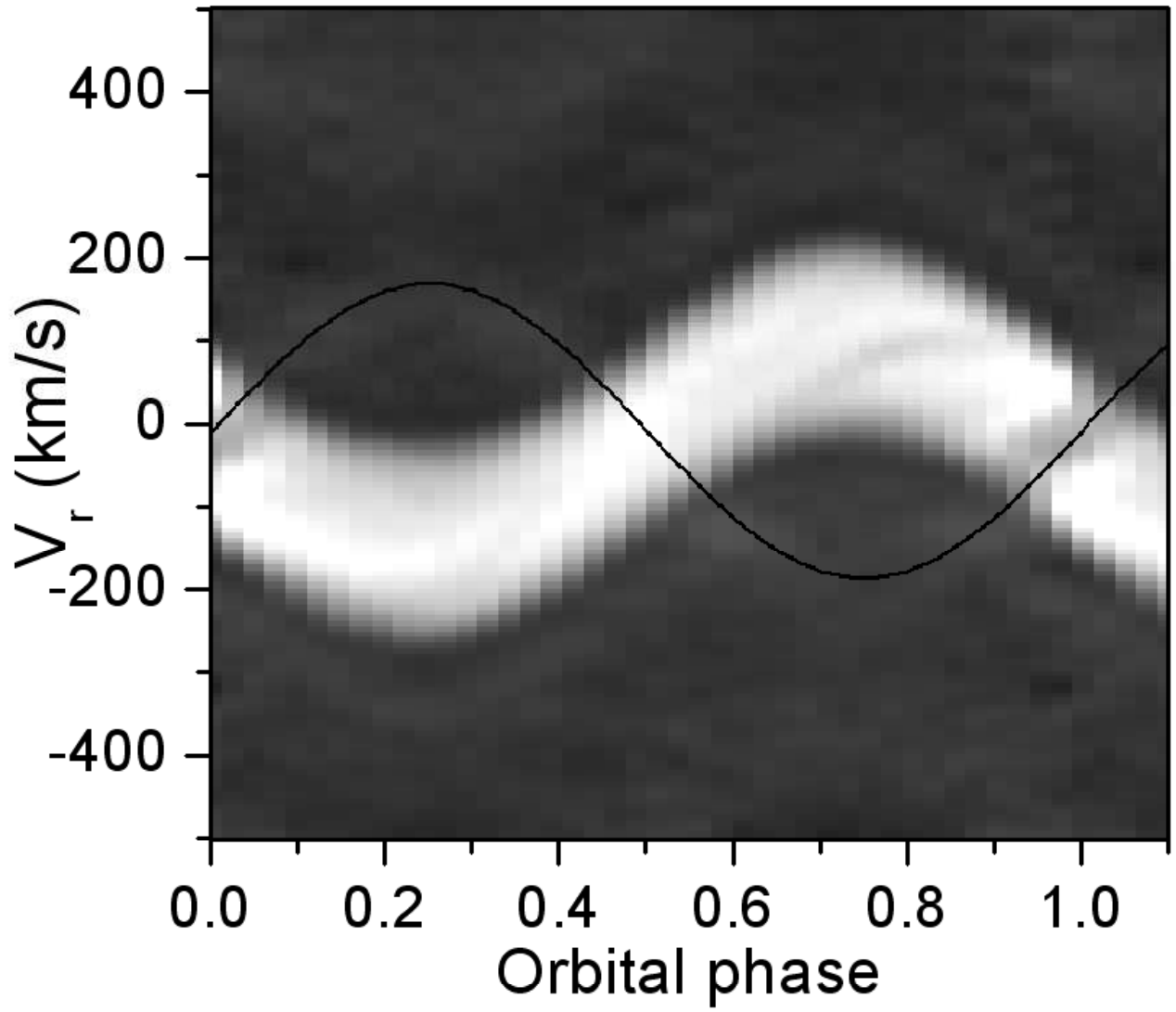
Table 1.   DDO radial velocity observations (the full table is available only in electronic form

HJD–2,400,000	V_1 [km s^{-1}]	W_1	V_2 [km s^{-1}]	W_2	Phase
53590.6265	0.00	0.00	0.00	0.00	0.4984
53590.6421	0.00	0.00	0.00	0.00	0.5292
53590.6578	0.00	0.00	0.00	0.00	0.5602
53590.6738	0.00	0.00	0.00	0.00	0.5917
53590.6893	53.83	2.65	−181.89	1.05	0.6223
53590.7049	72.29	5.60	−201.81	0.73	0.6531
53590.7208	80.82	0.54	−212.17	0.45	0.6845
53590.7362	92.63	0.74	−225.73	0.46	0.7149
53590.7516	92.74	0.69	−229.77	0.34	0.7453
53590.7669	92.44	0.65	−232.10	0.30	0.7754

Note. — The table gives the RV's V_i and associated weights W_i for observations described in the paper. The first 10 rows of the table for the first program star, OO Aql, are shown. Observations leading to entirely inseparable broadening function peaks are given zero weight; these observations may be eventually used in more extensive modeling of broadening functions. The RV's designated as V_1 correspond to the more massive component; it was always the component eclipsed during the minimum at the epoch T_0 (this not always corresponds to the deeper minimum and photometric phase 0.0). The phases correspond to T_0 and periods given in Table 2.

Table 2.   Spectroscopic orbital elements

Name	Type Sp. type	Other names	V_0	K_1 K_2	ϵ_1 ϵ_2	$T_0 - 2,400,000$ $(O-C)$(d) [E]	P (days) $(M_1 + M_2)\sin^3 i$	q
OO Aql	EW(A) F9V	HD 187183 BD+08 4224	−53.71(0.61)	153.03(0.93) 180.81(1.14)	4.08 7.35	53,606.0845(6) +0.0008 [+2,182]	0.5067932 1.954(19)	0.846(7)
CC Com	EW(W) K4/5	GSC 1986-2106	−2.89(0.74)	124.83(1.34) 237.00(1.09)	5.72 5.54	53,822.2339(3) −0.0004[+5,990.5]	0.2206860 1.083(12)	0.527(6)
V345 Gem	EW(W) F7V	HD 60987 HIP 37197	+0.03(0.68)	41.54(0.96) 291.75(1.26)	5.31 6.90	53,802.8329(3) +0.0505[+4,740.5]	0.2747690 1.054(13)	0.142(3)
XY Leo	EW(W) (K0V)	HIP 49136 BD+18 2307	−51.24(0.64)	144.65(1.10) 198.41(1.11)	6.95 6.92	53,812.1951(3) +0.0022[+4,618.5]	0.2840978 1.188(12)	0.729(7)
AM Leo	EW(W) F5V	HIP 53937 BD+10 2234	−7.25(0.62)	115.56(0.97) 251.98(1.17)	6.49	53,787.5742(12) +0.0003[+3,519.5]	0.3657989 1.882(18)	0.459(4)
V1010 Oph	EB(SB2) A7V	HD 151676 HIP 82339	−19.92(0.38)	110.46(0.45) 237.33(1.44)	2.68 6.48	53,825.7086(19) +0.0009 [+2,004]	0.6614168 2.883(30)	0.465(3)
V2612 Oph	EW(W) F7V	HD 170451 BD+6 3809	−25.59(0.44)	71.33(0.66) 249.09(0.89)	3.66 4.04	53,846.9204(3) +0.0492 [+3,709.5]	0.375307(3) 1.279(11)	0.286(3)
XX Sex	EW(W) F3V	HD 89027 BD-05 3027	−36.75(0.39)	25.80(0.45) 258.51(1.54)	2.28 7.78	53,824.4139(9) +0.0164 [+2,795]	0.540110 1.286(20)	0.100(2)
W UMa	EW(W) F5V	HD 83950 HIP 47727	−28.40(0.48)	119.21(0.68) 246.30(0.87)	4.90 3.40	53,804.8472(3) −0.0006[+3,910.5]	0.33363487 1.688(12)	0.484(3)
XY UMa	EB(SB2:) K0V	HD 237786 HIP 44998	−7.68(0.24)	124.74(0.28)	1.67	53,821.6344(2) +0.0000 [+2,759]	0.4789961	

Note. — The spectral types given in the second column relate to the combined spectral type of all components in the system; they are given in parentheses if taken from the literature, otherwise they are new. The convention of naming the binary components in the table is that the more massive star is marked by the subscript "1", so that the mass ratio is defined to be always $q \leq 1$. The standard errors of the circular solutions in the table are expressed in units of last decimal places quoted; they are given in parentheses after each value. The center-of-mass velocities (V_0), the velocity amplitudes (K_i) and the standard unit-weight errors of the solutions (ϵ) are all expressed in km s^{-1}. The spectroscopically determined moments of primary or secondary minima are given by T_0; the corresponding $(O-C)$ deviations (in days) have been calculated from the available prediction on primary minimum, as given in the text, using the assumed periods and the number of epochs given by [E]. The values of $(M_1 + M_2)\sin^3 i$ are in the solar mass units.

Ephemerides (HJD$_{min}$ − 2,400,000 + period in days) used for the computation of the $(O-C)$ residuals:

OO Aql: 52500.2610 + 0.5067932; CC Com: 52500.2158 + 0.22068583;

V345 Gem: 52500.24 + 0.274769; XY Leo: 52500.0872 + 0.2840978;

AM Leo: 52500.1452 + 0.3657989; V1010 Oph: 52500.231 + 0.661414;

V2612 Oph: 52454.7107 + 0.375296; XX Sex: 52314.79 + 0.54011;

W UMa: 52500.1693 + 0.3336347; XY UMa: 52500.0844 + 0.4789960.

Table 3.   Radial velocity observations (the full table is available only in electronic form) of visual companion to V345 Gem and third component in XY Leo. The radial velocities of V345 Gem until HJD $2,453,785$ were derived from spectra where the single, dominant component was centered on the spectrograph slit. After HJD $2,453,788$ the spectrograph slit was centered on the fainter eclipsing binary and the radial velocities were determined by Gaussian profile fitting to the BFs with the light contamination $L_3/(L_1 + L_2) > 0.10$.

HJD–2,400,000	V_3 [km s^{-1}]
53780.81180	-0.884
53780.82239	-0.987
53780.82978	-0.787
53781.79724	-1.586
53781.80200	-1.760
53781.81979	-1.672
53781.82691	-1.783
53785.51372	-2.312
53785.52096	-2.789
53785.52816	-3.365

Note. — The table gives the RV's for the visual companion to V345 Gem. The typical 10 rows of the table are shown

Table 4.   Spectroscopic orbital elements of the circular orbit of the second non-eclipsing SB1 binary in the quadruple system XY Leo

Parameter		error
P_{34} [days]	0.80476	0.00003
e_{34}	0.00	–
ω [rad]	1.5708	–
T_0 [HJD]	2,453,814.5286	0.0008
V_0 [km s^{-1}]	−39.67	0.27
K_3 [km s^{-1}]	46.44	0.38
$a_3 \sin i$ [R$_\odot$]	0.738	0.006
$f(m)$ [M$_\odot$]	0.0084	0.0002

Note. — The table gives spectroscopic elements of the second binary in XY Leo: orbital period (P_{34}), eccentricity (e_{34}), longitude of the periastron passage (ω), time of the periastron passage (T_0), systemic velocity (V_0), semi-amplitude of the RV changes (K_3), semi-major axis of the relative orbit ($a_3 \sin i$), mass-function ($f(m)$). The elements were obtained assuming circular orbit.