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RADIAL VELOCITY STUDIES OF CLOSE BINARY STARS. VI.[1]

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ABSTRACT

Radial velocity measurements and sine-curve fits to the orbital velocity variations are presented for the sixth set of 10 close binary systems: SV Cam, EE Cet, KR Com, V410 Cyg, GM Dra, V972 Her, ET Leo, FS Leo, V2388 Oph, and II UMa. All systems except FS Leo are double-lined spectroscopic binaries. The type of FS Leo is unknown, while SV Cam is a close, detached binary; all remaining systems are contact binaries. Eight binaries (all except SV Cam and V401 Cyg) are the recent photometric discoveries of the *Hipparcos* satellite project. Five systems, EE Cet, KR Com, V401 Cyg, V2388 Oph, and II UMa, are members of visual/spectroscopic triple systems. We were able to observe EE Cet separately from its companion, but in the remaining four triple systems we could separate the spectral components only through the use of the broadening-function approach. Several of the studied systems are prime candidates for combined light and radial velocity synthesis solutions.

Key words: binaries: close — binaries: eclipsing — stars: variables: other

On-line material: machine-readable table

1. INTRODUCTION

This paper is a continuation of the radial velocity studies of close binary stars by Lu & Rucinski (1999, Paper I), Rucinski & Lu (1999, Paper II), Rucinski et al. (2000, Paper III), Lu et al. (2001, Paper IV), and Rucinski et al. (2001, Paper V). The main goals and motivations are described in these papers. A companion paper (Rucinski 2002, Paper VII) describes the technical details and methods of data reductions, as well as the resulting measurement uncertainties, based on data in the six previous papers.

This paper is structured in the same way as Papers I–V in that most of the data for the observed binaries are in two tables consisting of the radial velocity measurements (Table 1) and their sine-curve solutions (Table 2). Section 2 of the paper contains brief summaries of previous studies for individual systems. Figures 1–3 show the data and the radial velocity solutions.

The observations reported in this paper have been collected between 1997 October and 2001 June; the ranges of dates for individual systems can be found in Table 1. All systems discussed in this paper except SV Cen have been observed for radial velocity variations for the first time. We have derived the radial velocities in the same way as described in previous papers. See Paper IV and Paper VII for discussion of the broadening-function approach used in the derivation of the radial velocity orbit parameters: the amplitudes K_i, the center-of-mass velocity V_0, and the time-of-eclipse epoch T_0.

The data in Table 2 are organized in the same manner as in previous papers. In addition to the parameters of spectroscopic orbits the table provides information about the relation between the spectroscopically observed epoch of the primary-eclipse T_0 and the recent photometric determinations in the form of the $O-C$ deviations for the number of elapsed periods E. It also contains our new spectral classifications of the program objects.

For further technical details and conventions used in the paper, please refer to Papers I–V and VII of this series.

2. RESULTS FOR INDIVIDUAL SYSTEMS

2.1. *SV Cam*

SV Cam is a short-period, detached binary system. It has been the subject of numerous photometric and four spectroscopic studies. In two first spectroscopic investigations, Hiltner (1953) and Rainger et al. (1991), the system was observed as a single-lined spectroscopic binary (SB1). The secondary component was subsequently detected by Pojmanski (1998), who used a spectral resolution 3 times lower than ours. Oezeren et al. (2001) observed the system at a relatively high spectral resolution but chose to adopt the spectroscopic results of Pojmanski (1998), concentrating on the details of line-profile changes in relation to the known, high activity of this short-period RS CVn type system.

Our double-lined (SB2) spectroscopic orbit is very well defined, with small errors in the orbital parameters. We note that determinations of the radial velocity semiamplitude of the primary component, K_1, agree well in the four existing

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TABLE 1

DDO Observations of the Sixth Group of 10 Close Binary Systems

HJD −2,400,000	Phase	V_1	ΔV_1	V_2	ΔV_2
SV Cam:					
50730.6143	0.3832	−88.4	2.3	117.2	−1.0
50750.6585	0.1804	−122.5	−3.0	150.8	−12.4
50751.6033	0.7735	108.9	−2.5	−186.8	10.4
50751.8944	0.2643	−134.3	−3.8	189.1	8.8
50764.5407	0.5877	55.9	1.3	−123.2	−14.5
50764.5533	0.6089	66.8	−1.1	−135.0	−5.7
50756.6032	0.2040	−129.2	−3.3	165.6	−7.5
50756.6399	0.2659	−136.1	−5.7	179.1	−1.0
50756.6546	0.2907	−128.2	−1.2	174.7	−0.2
50756.6710	0.3183	−120.1	−0.2	164.9	1.1

Notes.—Table 1 is presented in its entirety in the electronic edition of the Astronomical Journal. A portion is shown here for guidance regarding its form and content. Velocities are expressed in kilometers per second. The deviations ΔV_i are relative to the simple sine-curve fits to the radial velocity data. Observations leading to entirely unseparable broadening- and correlation-function peaks are marked by ellipses; these observations may be eventually used in more extensive modeling of broadening functions. The radial velocities designated as V_1 correspond to the component eclipsed during the primary minimum at the epoch given as T_0 in Table 2.

solutions. Starting with Hiltner (1953) (as reanalyzed by Rainger et al. 1991), Rainger et al. (1991), Pojmanski (1998), and the current studies, the results have been (in kilometers per second) 121.7 ± 1.9, 122.3 ± 1.5, 118.5 ± 2.0, and 121.86 ± 0.76. The results of Pojmanski (1998) differ the most but are still within the errors of the solutions. The center-of-mass velocity V_0 seems to show a secular progression, although the data of Pojmanski (1998) deviate from the trend. In the same order as before the values are -16.2 ± 1.4, -11.2 ± 1.2, -13.7 ± 1.5, and -9.13 ± 0.78 km s^{-1}. Noting that the observations were made in 1947, 1988, 1993, and 1997, the trend may be related to the motion about the third body, with a period of about 65–75 yr and a semiamplitude of about 2 km s^{-1} (Rainger et al. 1991).

The results of Pojmanski (1998), although the first to reveal the motion of the secondary component, show deviations described above and, even more importantly, differ rather substantially from our results in the value of K_2 (211.5 ± 5.5 vs. our 190.17 ± 1.73 km s^{-1}). Possibly the discrepancies are due to the rather complex reduction scheme of the previous study, which involved the successive removal of the two spectral signatures from individual spectra. This was entirely unnecessary in our case because the broadening functions (BFs) that we analyzed were very well defined and radial velocities of both components could be measured with great ease. Figure 4 shows one of the BFs for SV Cam in comparison with other systems analyzed in this paper. On the basis of the widths of the individual signatures in the BFs, and taking into consideration the instrumental broadening, we estimate the apparent rotation velocity of the components, $V_1 \sin i = 122 \pm 10$ km s^{-1} and $V_2 \sin i = 85 \pm 8$ km s^{-1}. Patkos & Hempelman (1994) found that the orbit of SV Cam is oriented exactly edge-on, $i \simeq 90°$, so that these are our estimates of the equatorial rotational velocities. We note that Pojmanski (1998) esti-

TABLE 2

Spectroscopic Orbital Elements of the Sixth Set of 10 Close Binary Systems

Name (1)	Type Sp. Type (2)	Other Names (3)	V_0 (4)	K_1 K_2 (5)	ϵ_1 ϵ_2 (6)	$T_0 - 2{,}400{,}000$ $(O-C)$(d) [E] (7)	P (days) $(M_1+M_2)\sin^3 i$ (8)	q (9)
SV Cam.....................	EA/RS	HD 44982	−9.13 (0.78)	121.86 (0.76)	3.10	50,792.6597 (11)	0.593073	0.641 (7)
	G2 V	HIP 32015		190.17 (1.73)	7.79	+0.0012 [0]	1.871 (45)	
EE Cet	EW/W	HD 17613	+1.60 (0.93)	84.05 (1.24)	5.43	51,818.8005 (7)	0.379917	0.315 (5)
ADS 2163 (S)	F8 V	HIP 13199		266.92 (1.54)	8.32	+0.0315 [8735]	1.706 (41)	
KR Com	EW/A	HD 115955	−7.86 (0.38)	19.18 (0.34)	1.85	52,001.4365 (4)	0.407968	0.091 (2)
ADS 8863A...............	G0 IV	HIP 65069		211.07 (0.80)	4.45	+0.0430 [8582]	0.517 (8)	
V401 Cyg	EW/A	BD +30°3592	+25.53 (2.14)	72.23 (2.43)	9.74	51,630.9481 (35)	0.582714	0.290 (11)
	F0 V	HIP 95816		249.13 (4.53)	26.87	−0.0047 [−192]	2.008 (130)	
GM Dra....................	EW/W	HD 238677	+9.12 (1.63)	46.69 (1.74)	10.45	51,350.3418 (13)	0.338741	0.180 (7)
	F5 V	HIP 84837		258.72 (2.66)	13.69	−0.0058 [−1181]	1.002 (42)	
V972 Her	EW/W	HD 164078	+3.98 (0.46)	25.95 (0.36)	2.34	51,349.1808 (16)	0.443094	0.167 (3)
	F4 V	HIP 87958		155.65 (1.00)	5.51	+0.0224 [6430]	0.276 (6)	
ET Leo......................	EW/W	HD 91386	+21.46 (0.78)	59.08 (0.80)	4.36	51,990.9912 (13)	0.346503	0.342 (5)
	G8 V	HIP 51677		172.95 (1.20)	7.30	+0.0021 [10075]	0.450 (12)	
FS Leo	EB?	BD +15°2335	−30.75 (0.64)	53.60 (0.74)	3.62	51,660.2706 (14)	0.456971	
	F2 V	HIP 55952				−0.0349 [6915]		
V2388 Oph................	EW/A	HD 163151	−25.88 (0.52)	44.62 (0.48)	3.36	51,569.7076 (12)	0.802298	0.186 (2)
Fin 381A...................	F3 V	HIP 87655		240.22 (0.98)	7.59	−0.0108 [2093]	1.926 (30)	
II UMa	EW/A	HD 109247	−8.02 (1.10)	43.16 (0.86)	5.46	51,221.6579 (44)	0.825220	0.172 (4)
ADS 8594A...............	F5 III	HIP 61237		250.96 (2.74)	18.64	−0.0007 [3298]	2.180 (80)	

Notes.—The spectral types given in column (2) are all new and relate to the combined spectral type of all components in a system. The convention of naming the binary components is that the subscript 1 designates the component which is more massive 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. For example, the last table entry for the mass ratio q, 0.172 (4), should be interpreted as $q = 0.172 \pm 0.004$. 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 kilometers per second. The spectroscopically determined moments of primary minima are given by T_0; the corresponding $O - C$ deviations (in days) have been calculated from the most recent available ephemerides, 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.

[a] SV Cam: T_0 has been advanced from the published time to the time of observations.

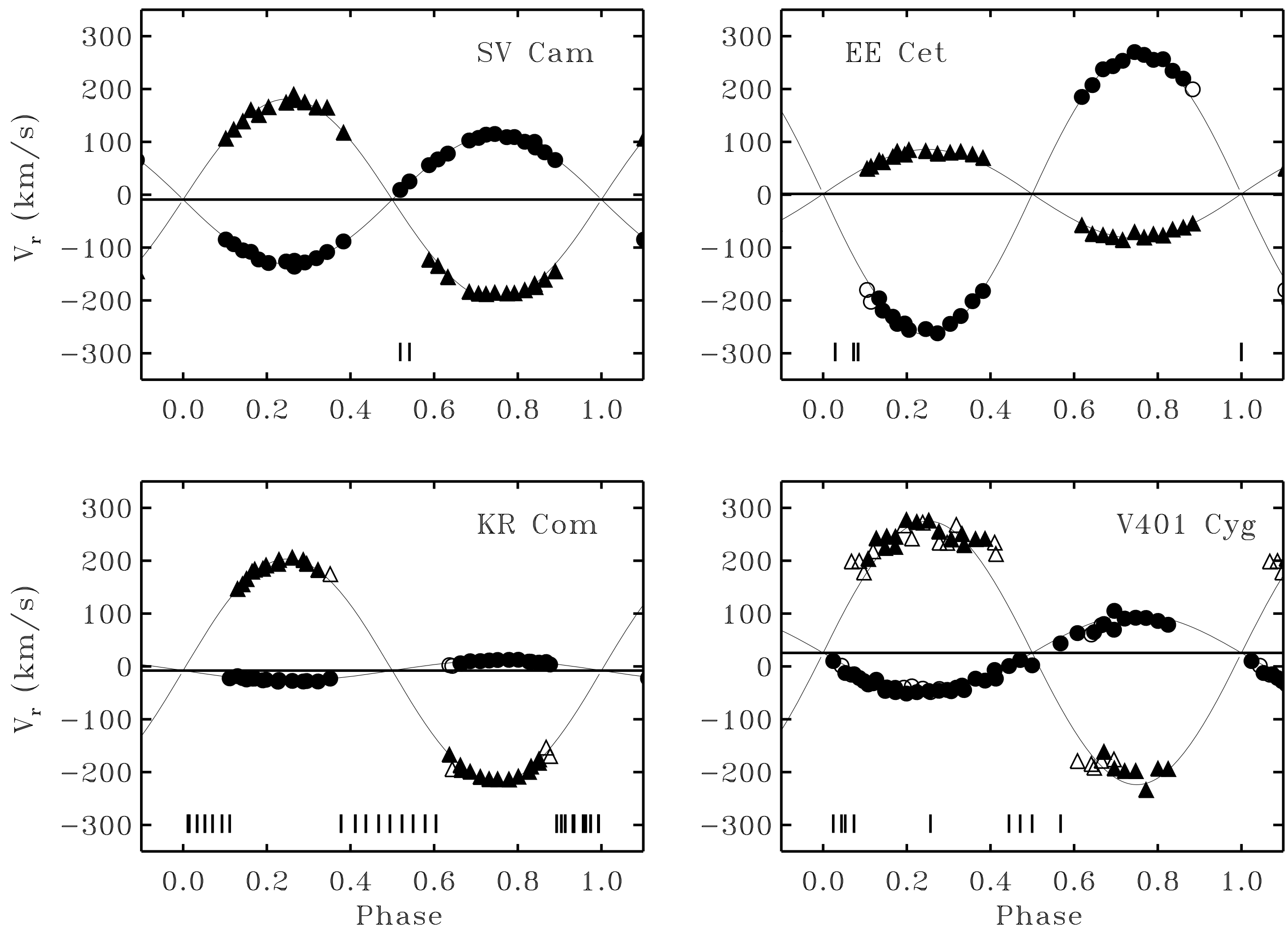

FIG. 1.—Radial velocities of the systems SV Cam, EE Cet, KR Com, and V401 Cyg are plotted in individual panels vs. orbital phases. The lines give the respective circular-orbit (sine-curve) fits to the radial velocities. SV Cam is a close, detached binary. KR Com and V401 Cyg are A-type contact systems, while EE Cet is a W-type contact system. EE Cet, KR Com, and V401 Cyg are members of triple systems although the companion of EE Cet could be excluded by the spectrograph slit. The circles and triangles in this and the next two figures correspond, respectively, to components eclipsed at the minimum corresponding to T0 (as given in Table 2) or half a period later, while open symbols indicate observations contributing half-weight data in the solutions. Short marks in the lower parts of the panels show phases of available observations which were not used in the solutions because of the blending of lines. All panels have the same vertical ranges, -350 to $+350$ km s^{-1}.

mated $V_1 \sin i = 105$ km s^{-1}, while a solar-size star in the orbital synchronism would have $V \sin i \simeq 90$ km s^{-1}.

The total mass, $(M_1 + M_2) \sin i = 1.871 \pm 0.045\ M_\odot$, and the mass ratio, $q = 0.641 \pm 0.007$, lead to the masses 1.14 and 0.73 $M_\odot$, which are somewhat large for the combined spectral type that we estimated as G2 V but would agree with the estimate of Pojmanski (1998) of F8 V. The estimated value of $V_1 \sin i$ would also suggest a primary larger than the Sun. The mean color index from the Tycho-2 catalog (Hog et al. 2000, hereafter TYC2), $B-V = 0.62$, is in agreement with our spectral type. We should note that our low-dispersion classification, as well as the TYC2 color index, relate to the combined photometric properties of the system.

The ephemeris that we used was that of the photometric study of Pribulla et al. (2001), which covered the time range actually slightly after our observations and gave a perfect agreement for the time of eclipses. Since the published T_0 was already shifted from the actual time of observations, we recalculated the published moment to our T_0 so that no whole cycles appear in the phase count in Table 2. We also used the orbital period from the same study simplifying it to the six decimal places, 0.593073 days, which was entirely sufficient for the duration of our observations. We note that the orbital period cited in the *Hipparcos* Catalogue (ESA 1997, HIP) was slightly different, 0.593075 days, while Pojmanski (1998) used 0.593071 days.

With a good *Hipparcos* parallax, $p = 11.77 \pm 1.07$ mas (HIP), and well-determined tangential motions, $\mu_\alpha \cos\delta = 41.5 \pm 1.1$ mas yr^{-1} and $\mu_\delta = -150.9 \pm 1.1$ mas yr^{-1} (TYC2), the system of SV Cam appears to be one of the best currently characterized close binary systems on the lower main sequence. Of note is the relatively large spatial motion of 64 km s^{-1}, mostly the result of the large tangential motion; the systemic radial velocity is moderate, $V_0 = -9.13 \pm 0.78$ km s^{-1}.

2.2. *EE Cet*

Variability of the combined light of the visual binary ADS 2163 was discovered by the *Hipparcos* satellite mission (ESA 1997). The light curve was relatively sparsely covered, showing variation of about 0.23 mag. On the basis of an observation that the southern component rotates too rap-

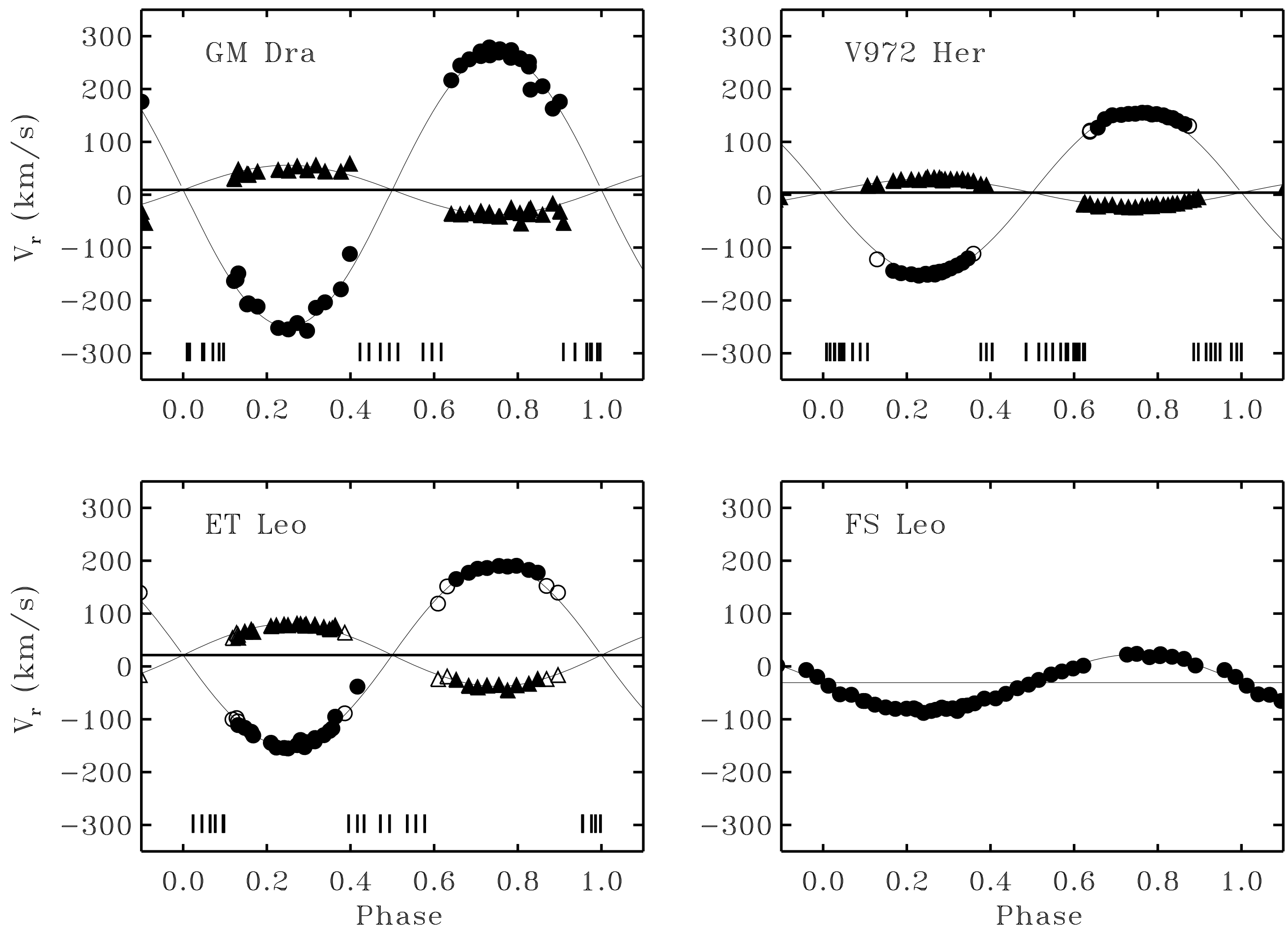

FIG. 2.—Same as Fig. 1, but with the radial velocity orbits for the systems GM Dra, V972 Her, ET Leo, and FS Leo. All systems, except FS Leo (which is a single-line binary of unknown type), are W-type contact systems.

idly for the technique used by Nordstrom et al. (1997) to measure its radial velocity, this component was our prime candidate for being the source of the variability observed by *Hipparcos*. We could observe this star without contamination by the northern companion, which is separated by 5″6. We found that the southern component is a contact binary system, and we assume that it should carry the variable-star name EE Cet. It appears to be a contact system of the W type, i.e., with the less massive component eclipsed during the primary eclipse; however, it is the more massive, slightly cooler component that gives a better defined signature in the BF, probably because of its larger radiating area. In phasing our observations, we used the HIP prediction for times of eclipses.

We caution that there exists certain confusion in the literature as to which component of ADS 2163 should be called A, and which B. On average the southern component, which we identify here with EE Cet, is the fainter of the two, and this agrees with the naming of the stars in the HIP catalog, where the visual binary appears under CCDM J02499+0856. However, in the ADS catalog the names are actually reversed and in SIMBAD it is the northern, brighter component that carries the name of EE Cet. Lampens et al. (2001) published photometric data for one epoch and gave $V(A) = 9.47$ and $V(B) = 9.83$, identifying the southern component as fainter. To complicate things even further, we found that the northern component of ADS 2163 is also a close binary system showing radial velocity variations; this component may very well be a variable star. However, currently we have insufficient radial velocity data to analyze this binary system; we hope to be able to provide such data in one of the subsequent papers of this series. We only note that Nordstrom et al. (1997) gave its radial velocity, $V_0 = +2.26 \pm 0.04$ km s^{-1}, which is similar to the center-of-mass velocity of EE Cet, $V_0 = +1.60 \pm 0.93$ km s^{-1}.

The radial velocity solution for EE Cet is very well defined. However, because of the lack of reliable *Hipparcos* parallax (it is actually listed as negative), we cannot derive the absolute magnitude of the binary. Once the two components of the visual binary are photometrically separated and parallaxes for both components determined, this quadruple system may turn out to be one of the most interesting among bright stars of the sky.

2.3. *KR Com*

KR Com is another *Hipparcos* satellite photometric discovery. In phasing our observations, we used the HIP prediction for times of minima. The shallow eclipses are of almost identical depth of only about 0.06 mag so there is no obvious reason for the EB classification, which has been

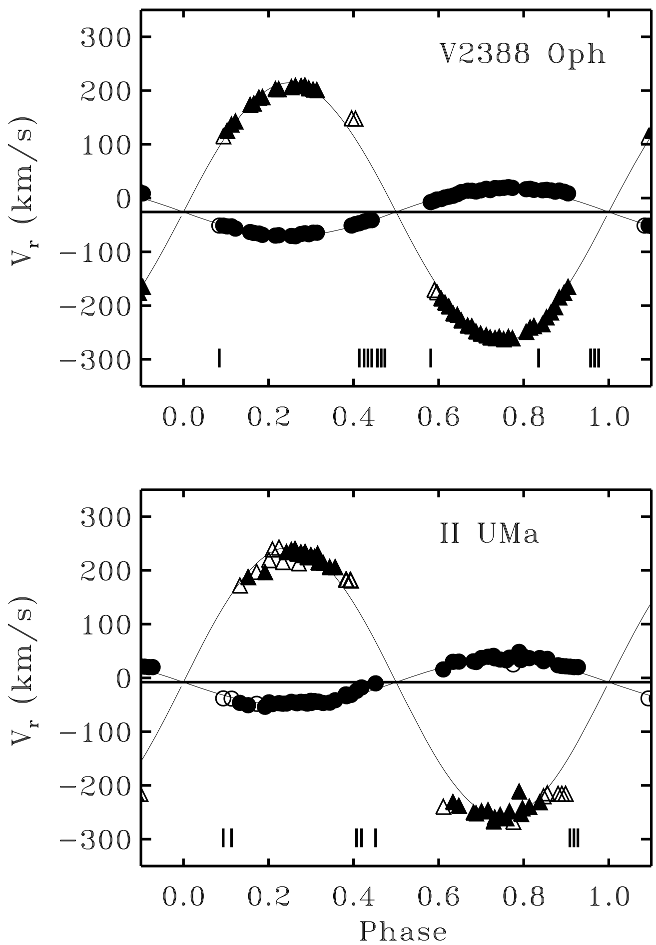

FIG. 3.—Same as for Fig. 1, but for the systems V2388 Oph and II UMa. They are quite similar A-type contact systems with relatively long periods of slightly over 0.8 days, both being members of very close triple systems.

used in the HIP catalog; the system is a contact binary and would normally be designated as EW.

The star had been known as a very close visual system of very small mean separation of only 0\".12. In the HIP catalog it appears as CCDM J13203+1746, with the magnitude difference of components of 0.60 mag; it is also known as ADS 8863. The visual binary was a subject of numerous speckle interferometry investigations. While these observations are of lesser relevance in the context of this paper, we note that the close binary shows rather large radial velocity variations, so that its small photometric variation may be partly due to "dilution" of the close-binary variability signal in the combined light of the visual system. Our BF indicates that the brighter component is the contact system, while the fainter component is a slowly rotating star, as can be seen in Figure 4. The brightness of the visual companion is large, $L_3/(L_1 + L_2) = 0.56 \pm 0.04$ (at light maxima of the close binary), which confirms the previous magnitude-difference estimates.

Our radial velocity orbit is very well defined, mostly as a result of the brightness of the system at $V_{\rm max} = 7.14$. We could very well isolate the signature of the third, slowly rotating star, as one can see in Figure 4. Allowing for the contribution of the visual companion, and with the *Hipparcos* parallax of $p = 13.07 \pm 0.87$ mas, one obtains $M_V^{\rm tot} = 2.72 \pm 0.15$ and thus $M_V^{\rm EW} = 3.20$, while the RD97 calibration predicts $M_V^{\rm EW}({\rm cal}) = 3.42$. The latter is obtained using the color TYC2 index, $B-V = 0.52$, which suggests a spectral type of about F8; our direct classification is G0 IV, although the spectral type and the luminosity class relate to the combined properties of the triple system. The average radial velocity of the third component, $\langle V_3 \rangle = -3.59 \pm 0.12$ km s^{-1} (the error of a single observation is 0.93 km s^{-1}), is significantly different from the center-of-mass velocity of the binary, $V_0 = -7.86 \pm 0.38$ km s^{-1}.

KR Com has one of the smallest mass ratios known among contact binaries, $q = 0.091 \pm 0.002$. The total minimum mass, $(M_1 + M_2) \sin^3 i = 0.517 \pm 0.008$ $M_\odot$, indicates that the orbit is rather strongly inclined to the line of sight, which is another reason for the small photometric amplitude. As is normally observed, the small mass ratio is associated with the A-type characteristics of the contact system, i.e., the deeper eclipse corresponds to the more massive star being eclipsed by the less massive companion.

2.4. *V401 Cyg*

Together with SV Cam this binary is one of two in this paper that had not been discovered by the *Hipparcos* mission. In fact it was discovered by Hoffmeister (1929) and since then was sporadically observed, mostly for eclipse timing. Photometrically the binary appears to be a rather typical contact system with relatively large light variation of about 0.55 mag. Herczeg (1993) pointed out that the orbital period of the system is lengthening. Wolf et al. (2000) conducted a light-curve analysis and found the best-fitting photometric mass ratio, $q_{\rm ph} \simeq 0.3$. To some extent to our surprise (because we see so many cases of $q_{\rm ph} \neq q_{\rm sp}$), we found $q = 0.290 \pm 0.011$.

Our radial velocity orbit was based on the assumed period of 0.582714 days, as in the HIP catalog. For the initial time of the primary minimum, we used the data in Nelson (2001), obtained during the span of our observations. The agreement is very good (see Table 2), given the somewhat larger error of our T_0 for this star when compared with other binaries. The main reason for the larger error was the relative faintness of this binary ($V_{\rm max} \simeq 10.5$) and the fact that we discovered a third "light" in the system. The spectral signature of the third star (which may, but does not have to be, physically associated with the binary) can be seen in the BF in Figure 4 as a small feature projecting onto the prominent signature of the primary component. Similar noise fluctuations are common in BFs of faint stars, but this one is always present, at the same radial velocity at all orbital phases. By integrating the amount of light in this additional feature, we could estimate that, at the light maximum of the binary, $L_3/(L_1 + L_2) = 0.03 \pm 0.01$. Because the third-light contribution is so small, we neglected it in our measurement. However, it may have slightly affected the amplitude of the primary component K_1 because of the facts that (1) the radial velocities of primary component are, by necessity, always close to V_0 and (2) the third component appears to have a very small radial velocity relative to the binary system.

2.5. *GM Dra*

GM Dra was discovered photometrically by the *Hipparcos* satellite as a 9th magnitude contact binary with a fairly large variation of about 0.27 mag. The system was observed

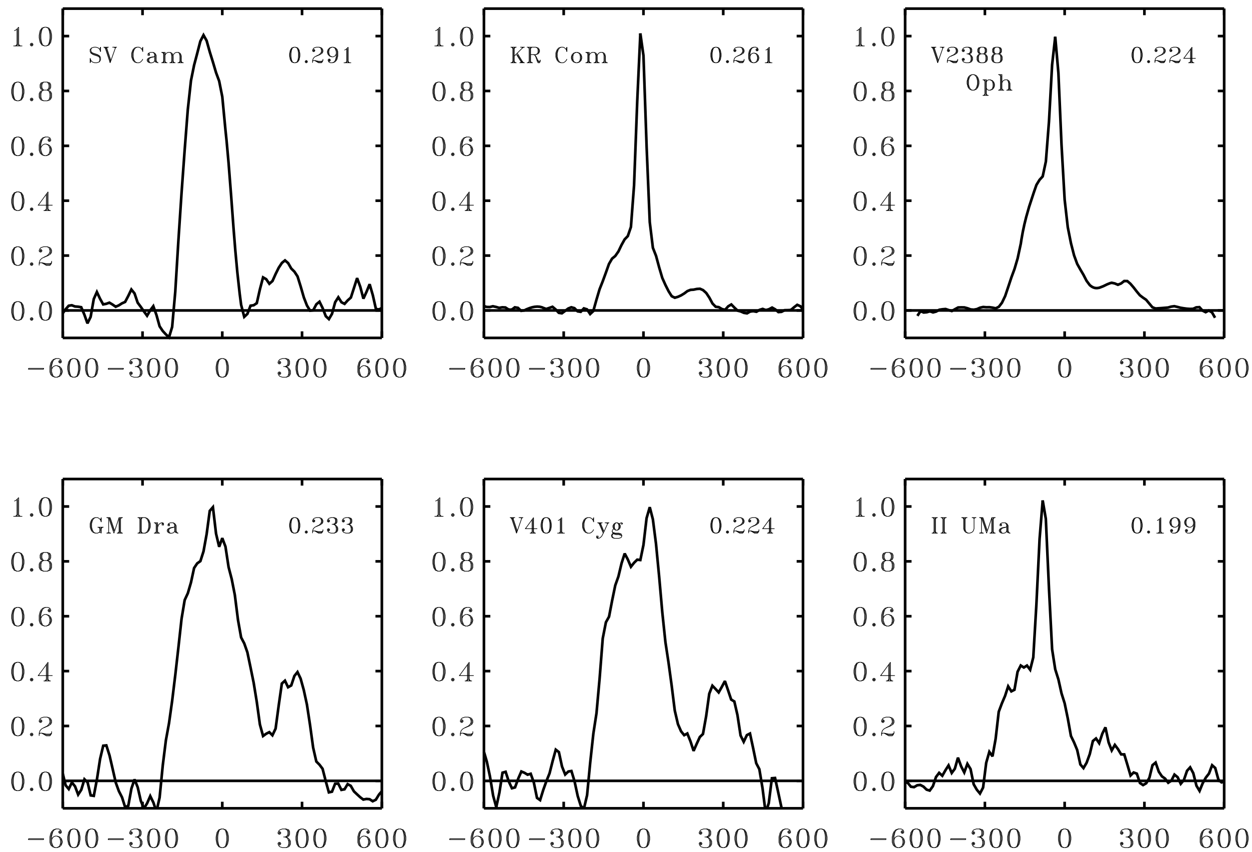

FIG. 4.—Broadening functions for six close binary systems of this series. The two leftmost panels show the BFs for rather typical cases of a detached binary SV Cam and the contact binary GM Dra, both 9 mag objects. The spectroscopic triple systems are shown in the four center and right panels: The contact binary components result in broad BFs while the third body produces a narrow feature between the two broad components. Note the exceptionally well-defined BFs for the bright, 6 mag systems KR Com and V2388 Oph. All cases shown here illustrate orientations of components close to the orbital phase 0.25. The small third-body feature in the BF for V401 Cyg could be taken for a small error fluctuation if not for its persistence throughout all the phases.

photometrically by Çiçek et al. (2001), 1 year after our observations. The authors gave a recent moment of the light minimum and improved the value of the orbital period.

Our radial velocity orbit is quite well defined (Fig. 2). GM Dra is a rather uncomplicated contact system of the W type, i.e., with the smaller star eclipsed during the deeper minimum (although the difference in the depth of the eclipses is very small). The spectral type F5 V and the color index $B-V=0.48$ agree. The absolute magnitude derived from the HIP parallax, $p=10.16\pm0.88$ mas and $V_{\max}=8.65$, is $M_V=3.68\pm0.20$, which is in perfect agreement with the calibration of Rucinski & Duerbeck (1997, hereafter RD97), $M_V(\text{cal})=3.66$.

2.6. *V972 Her*

V972 Her is another *Hipparcos* photometric discovery. The light variation is small, about 0.08 mag, indicating a small orbital inclination or "dilution" of light in a triple system. The HIP light curve is very well defined and suggests a perfect contact system (EW). It is not clear why the system was given there a classification EB, which would suggest unequally deep minima.

Our radial velocity orbit is very well defined, mostly thanks to the large brightness of the system, $V_{\max}=6.62$. With the relatively large HIP parallax (the largest in this group of binaries), $p=16.25\pm0.61$ mas and thus $M_V=2.67\pm0.09$, the system is the nearest contact binary in this group of 10 binary systems. The RD97 calibration with $B-V=0.39$ (which agrees with our spectral type F4 V) gives $M_V(\text{cal})=2.87$, which is in marginal agreement with the directly determined M_V. The very small value of $(M_1+M_2)\sin^3 i=0.276\pm0.006\ M_{\odot}$ confirms the expectation of a very small orbital inclination angle.

Our initial T_0 was based on the time determined by Keskin et al. (2000), which was obtained in the middle of our spectroscopic run, but gives a rather large $O-C=+0.0224$ days. We have no explanation for this discrepancy because our T_0 is nominally accurate to 0.0016 days. The binary is a contact system of the W type with the less massive component eclipsed at the deeper minimum; however, the difference in depth is very small.

2.7. *ET Leo*

The photometric variability of the star was discovered by the *Hipparcos* mission. The period assigned there was equal to one half of the true orbital period. Instead of the exact double of the HIP period, we used the value given by Gomez–Forrellad et al. (1999) of 0.346503 days. Their initial epoch T_0 (obtained 3 years before our observations) and the new period predict the moment of the deeper eclipse which agrees well with our determination (see Table 2).

Our spectral type, G8 V, appears to be late relative to the TYC2 color index $B-V = 0.61$. The parallax is large, $p = 13.90 \pm 1.44$ mas, but apparent magnitude is only moderate, $V_{\max} = 9.48$, indicating that the system is intrinsically rather faint: $M_V = 5.20 \pm 0.24$. The RD97 calibration, utilizing the $B-V$ index as above, predicts $M_V(\mathrm{cal}) = 4.01$; an agreement in M_V would require a color index as large as $B-V \simeq 1.0$. This discrepancy between the spectral type and the color index remains to be explained.

ET Leo must be observed at a relatively low orbital inclination angle. This would explain the small photometric variability of only 0.06 mag, as well as the small radial velocity amplitudes leading to $(M_1 + M_2)\sin^3 i = 0.450 \pm 0.012\ M_\odot$.

2.8. *FS Leo*

The photometric variability of FS Leo was discovered by the *Hipparcos* mission. In spite of our efforts we have not been able to find any spectral signatures of the secondary component in the system, so that this is a single-lined binary (SB1); it is the only such system in this group of ten binary systems. The radial velocity of the only visible component is very well defined. For the initial phasing of our observations we used the original HIP prediction which gave a time deviation $O-C = -0.035$ days.

Our spectral type is F2 V and the photometric data derived from the HIP and TYC databases give $V_{\max} = 8.94$ and $B-V = 0.26$, the latter suggesting a slightly earlier spectral type around F0. The HIP parallax, $p = 6.12 \pm 1.41$, leads to $M_V = 2.87 \pm 0.51$. At this point we are unable to classify the system, but it is unlikely that this is a contact system. Of interest is the large spatial velocity of the system of 70 km s^{-1}, which results mostly from the large tangential motion: 71.3 ± 1.1 and -38.7 ± 1.1 mas yr^{-1} in both coordinates (TYC2).

2.9. *V2388 Oph*

This bright, 6th magnitude, very close visual binary (Fin 381, CCDM J17542+1108) has been the subject of many speckle interferometry investigations. The study of Soederhjelm (1999) resulted in the following set of the parameters: the separation, $a = 0\farcs088$, the magnitude difference between components, $\Delta m = 1.80$ mag, the mean HIP magnitude for the primary $H_p = 6.45$, the orbital period, $P = 8.9$ yr. Δm derived in this study was much larger than in several previous speckle interferometry investigations which usually suggested a number around 0.2 mag. We note that our entirely independent derivation based on the BFs gives $L_3/(L_1 + L2) = 0.20 \pm 0.02$, hence $\Delta m = 1.75 \pm 0.02$ mag, confirming the result of Soederhjelm (1999).

Rodriguez et al. (1998) discovered variability of the star, apparently independently of the HIP discovery. They classified it as a W UMa type system with a relatively long orbital period of 0.802 days. Newer photometry of Yakut & Ibanoglu (2000) (used for T_0 in Table 2) confirmed that the HIP times-of-minima prediction; in fact, the HIP ephemeris gives a slightly smaller $O-C$ for the time of the primary eclipse. The *ubvy* photometric data agree with the previous spectral type of F5 Vn, assuming no interstellar reddening. We would tend to give the star a slightly earlier spectral type, F3 V. The HIP light curve is very well defined and has a shape typical for a contact system, with eclipses 0.30 and 0.25 mag deep. The relatively large HIP parallax, $p = 14.72 \pm 0.81$, and $V_{\max} = 6.13$, gives $M_V = 1.97 \pm 0.13$ for the whole triple system hence $M_V^{\mathrm{EW}} \simeq 2.17$, while the RD97 calibration predicts $M_V(\mathrm{cal}) = 1.78$ for the W UMa type binary, assuming $(B-V)_0 = 0.41$ from TYC2. The system appears to be one of the most luminous among currently known contact binaries. This may explain the imperfect agreement in M_V at the high-luminosity end, where the RD97 calibration becomes highly uncertain.

As for other triple-lined systems, we measured the radial velocities of the binary after removing the third-body signature from the BF first and then by analyzing the remaining contact-binary BF. The radial velocity orbit of the close binary is very well defined (Fig. 3) and describes a typical A-type contact system with moderately small mass ratio, $q = 0.186 \pm 0.002$. The minimum mass, $(M_1 + M_2)\sin^3 i = 1.93 \pm 0.03\ M_\odot$, when related to the spectral type of about F3–F5, suggests a rather large orbital inclination angle, $i \simeq 90°$. Thus, in spite of the necessity of dealing with a complicated BF (Fig. 4), the radial velocity parameters for V2388 Oph are very well defined.

The radial velocity measurements for the third component show some residual dependence on the phase of the close binary, which may indicate some "cross-talk" in the measurements; we illustrate a similar but larger effect in the case of the next system, II UMa. The semiamplitude of the variations which correlate with the binary phase is about 2.5 km s^{-1}, which leads to a slightly elevated error per a single-observation of 1.50 km s^{-1}; for a single sharp-line star we could expect an error at the level of 1.2–1.3 km s^{-1} or less. The mean radial velocity of the third component, $\langle V_3 \rangle = -30.64 \pm 0.20$ km s^{-1}, is significantly different from the center-of-mass velocity for the binary, $V_0 = -25.88 \pm 0.52$ km s^{-1}, which may result from the motion on the 8.9 yr orbit.

2.10. *II UMa*

The photometric variability of the star was discovered by the *Hipparcos* satellite. The HIP prediction on the time of eclipse served very well for phasing of our observations. The star is a known, close visual binary, designated as ADS 8594 or CCDM J12329+5448, with the separation of component of $0\farcs87$ and difference in brightness 1.64 mag.

The BFs (see Fig. 4) show a well-defined signature of the third component with the relative brightness, $L_3/(L_1 + L_2) = 0.17 \pm 0.01$, implying $\Delta m = 1.92 \pm 0.01$ mag. The triple-star characteristics of the star were handled by us in the same way as for the previously described star, V2388 Oph. Again we see some unwelcome cross-talk in the radial velocities V_3, as shown in the plot versus the close-binary phase in Figure 5. This case is a bit more extreme than for V2388 Oph, with the error per single observation of 2.86 km s^{-1} in place of the expected 1.2–1.3 km s^{-1} or less. We do not have a ready explanation for the coupling between the velocities and why the scatter appears to be increased only within the first half of the orbit. The dependence of V_3 on the binary-system phase has been observed in some triple stars in our program, but we usually have no simple explanation for its occurrence. However, we are not very concerned about its presence because our goal is the radial velocity orbit of the close binary system, which is in fact very well defined (see Fig. 3). The average velocity of the third component, $\langle V_3 \rangle = -16.02 \pm 0.37$ km s^{-1}, can be com-

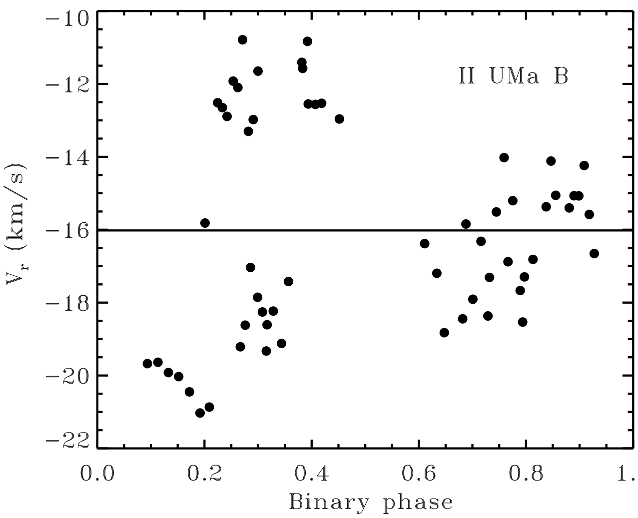

FIG. 5.—Radial velocities of the companion of II UMa plotted vs. the orbital phase of the close binary. In principle, there should be no relation between the two quantities, and thus we see here some sort of a "cross-talk." We have no explanation for the systematic trend in the deviations and, in particular, why the spread was larger for phases in the first half of the binary orbit. A similar but smaller effect has been observed for V2388 Oph.

pared with the center-of-mass velocity of the close binary, $V_0 = -8.02 \pm 1.10$ km s^{-1}.

The binary is a long-period ($P = 0.825$ days) contact system of the A-type. Our spectral type suggests elevated luminosity, F5 III, but classification of strongly broadened spectra of contact binaries is not easy, especially when combined with the spectrum of the third component. However, a high luminosity would agree with the relatively large size of the system implied by the long orbital period. The system is quite distant, because its HIP parallax is $p = 5.04 \pm 1.81$ mas. With the observed $V_{\rm max} = 8.14$ for the whole system, $M_V = 1.65 \pm 0.8$. Using $L_3/(L_1 + L2) = 0.17 \pm 0.01$, the absolute magnitude of the close binary is $M_V^{\rm EW} = 1.82$, which agrees rather well with the RD97 calibration predicting $M_V({\rm cal}) = 1.70$ for the assumed TYC2 color index $B-V = 0.40$.

3. SUMMARY

The paper presents radial velocity data and orbital solutions for the sixth group of 10 close binary systems, which we observed at the David Dunlap Observatory. Only the detached, short-period system SV Cam was observed spectroscopically before. All systems except FS Leo are double-lined (SB2) binaries with visible spectral lines of both components, and all, with the additional exception of SV Cam, are contact binaries.

Although our selection of our targets is quite unsystematic and is driven only by brightness above the limit of about 11 mag and the shortness of the orbital period (less than 1 day), we continue to see very interesting objects among the bright, photometrically discovered binaries. Eight of the systems are new photometric discoveries of the *Hipparcos* project. The magnitude-limited nature of the HIP survey has led to an emphasis on relatively luminous, massive, early-type (middle-A to early-F) contact systems. Because the *Hipparcos* mission discovered mostly small photometric amplitude systems, which were overlooked in previous whole-sky surveys, we tend to observe systems somewhat preselected in that they either have low orbital inclinations, such as V972 Her or ET Leo, or are members of triple systems, such as KR Com, V401 Cyg, V2388 Oph, and II UMa. In the latter case, while radial velocity amplitudes are large, the diminished photometric variation is due to the "dilution" of the variability signal in the combined light of the triple system. In addition to these four triple systems we also observed separately a component in a wider visual binary, EE Cet; the other component of this system appears to be radial velocity variable whose properties remain to be studied.

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