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

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ABSTRACT

Radial-velocity measurements and sine-curve fits to the orbital radial velocity variations are presented for ten close binary systems: EG Cep, V1191 Cyg, V1003 Her, BD+7°3142, V357 Peg, V407 Peg, V1123 Tau, V1128 Tau, HH UMa, and PY Vir. While most of the studied eclipsing systems are contact binaries, EG Cep is a detached or a semi-detached double-lined binary and V1003 Her is a close binary of an uncertain type seen at a very low inclination angle. We discovered two previously unknown triple systems, BD+7°3142 and PY Vir, both with late spectral-type (K2V) binaries. Of interest is the low-mass ratio ($q = 0.106$) close binary V1191 Cyg showing an extremely fast period increase; the system has a very short period for its spectral type and shows a W-type light curve, a feature rather unexpected for such a low mass-ratio system.

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

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1. INTRODUCTION

This paper is a continuation of the series of papers (Papers I – XII) of radial-velocity studies of close binary stars and presents data for the twelfth group of ten close binary stars observed at the David Dunlap Observatory. For full references to the previous papers, see the last paper by Pribulla et al. (2007, Paper XII); for technical details and conventions, for preliminary estimates of uncertainties, and for a description of the broadening functions (BFs) technique, see the interim summary paper Rucinski (2002a, Paper VII). The DDO studies use the efficient program of Pych (2004) for removal of cosmic rays from 2-D images.

All data used in the present paper were obtained using the broadening functions extracted from the region of the Mg I triplet at 5184 Å, as in most of the previous papers. In August 2005, a new 2160 lines/mm grating was acquired to replace the previously most frequently used 1800 lines/mm grating which after many years of use lost its efficiency. The new grating markedly improved quality of the observed spectra and of the resulting BFs. Of the reported results, the older grating was used for 1997 observations of V357 Peg, V1123 Tau and V1128 Tau (this star was also briefly observed in 2003); all three stars were later re-observed using the new grating. The radial velocity (hereafter RV) observations reported in this paper have been collected between October 1997 and August 2007. The ranges of dates for individual systems can be found in Table 1. A few additional, low quality spectra of PY Vir, not listed in Table 1, were taken on February 19, 2008.

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 phase. For this paper, we selected mostly targets from among fainter Hipparcos discoveries. None of the present targets has a spectroscopic orbit published. V1003 Her and PY Vir have only relatively poor, ground-based photometric data while V1191 Cyg is a rather neglected but – as we describe – a very interesting contact binary.

The radial velocities for the short period binaries reported in this paper were determined by fitting the double rotational profiles, as explained in Pribulla et al. (2006). Similarly as in our previous papers dealing with multiple systems (here the cases of BD+7°3142 and PY Vir), RV's for the eclipsing pair were obtained after removal of the slowly rotating components (Pribulla et al. 2007).

As in other papers of this series, whenever possible, we estimate spectral types of the program stars using new classification spectra centered at 4200 Å or 4400 Å. 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 of Bessell (1979). In this paper we also made use of infrared colors determined from 2μ All Sky Survey (Skrutskie et al. 2006, 2MASS). Especially useful is the $J - K$ color index, which is monotonically rising from the early spectral types to about M0V (Cox 2000). This infrared color is affected relatively less by the interstellar absorption than $B-V$. Parallaxes cited throughout the paper were adopted from the new reduction of the Hipparcos data (van Leeuwen 2007) which supersede the original reductions (ESA 1997).

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 of their preliminary sine-curve solutions in Table 2. Radial velocities and the corresponding spectroscopic orbits for all ten systems are shown in phase diagrams in Figures 1 – 3. The measured RV's are listed in Table 1. Only data with full weights were used to compute the orbits; we discarded poorer observations. Table 2 contains also our new spectral classifications of the program objects. Section 2 of the paper contains summaries of previous studies for individual systems and comments on the new data. Examples of BFs 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 the primary 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. The reference ephemerides were taken from various sources: For V1003 Her, we doubled the Hipparcos period and shifted the instant of the maximum by $0.25P$; for BD+7°3142, we took it from the ASAS[2] survey (Pojmanski 2002); for V407 Peg, from Maciejewski et al. (2002) and for PY Vir, from Wils & Dworak (2003). For the rest of the systems, the ephemerides given in the on-line version of "An Atlas O-C diagrams of eclipsing binary stars"[3] (Kreiner 2004) were adopted. Because the on-line ephemerides are frequently updated, we give those used for the computation of the $O-C$ residuals in the comments to Table 2 (the status as of December 2007). 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. EG Cep

The variability of EG Cep was discovered by Strohmeier (1958). Photoelectric light curves and their solutions have been presented by several investigators; for references see Erdem et al. (2005). The system shows a β Lyrae-type light curve with minima about 1.0 and 0.3 mag deep. Etzel & Olson (1993) determined the projected rotational velocity of the primary as 146 ± 20 km s^{-1}. A photometric analysis of the system was performed by Kaluzny & Semeniuk (1984) who used

[2]http://archive.princeton.edu/∼asas/

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

a grid search to find the mass ratio $q_{ph} = 0.45 - 0.50$ and a semi-detached configuration for the system. Chochol et al. (1998) discussed the long-term period change in the system and also arrived at the semi-detached configuration with the less massive component filling its Roche lobe and the mass ratio $q_{ph} = 0.47$. The new analysis of Erdem et al. (2005) led to a similar mass ratio. No spectroscopic orbit of the system has been published so far.

In view of discrepancies between the spectroscopic and photometric mass ratios previously noted in our DDO series, it is surprising, but also encouraging, that all photometric investigations have led to a mass ratio close to our spectroscopic value, $q_{sp} = 0.464(5)$. This is in spite of the semi-detached configuration which has weaker photometric constraints than the contact configuration in the light curve solution. The agreement must result from the high orbital inclination angle, $\approx 86°$ (Chochol et al. 1998) and the presence of the total eclipses.

The intrinsic color of the system was estimated at about $(B-V)_0 = 0.197$ (Kaluzny & Semeniuk 1984) indicating the spectral type of the primary component of A7. The Tycho-2 color index $B - V = 0.24$ is consistent with our A7V classification and requires a slight reddening. The $J - K = 0.19(4)$ color indicates the A9V – F2V spectral type which may reflect the stronger contribution of the secondary component. EG Cep was not included into the Hipparcos astrometric measurements.

2.2. V1191 Cyg

The contact binary V1191 Cyg (GSC 3159-1512, $V_{max} = 10.82$, $V_{min} = 11.15$) was detected by Mayer (1965) while observing the nearby star V1187 Cyg. Since then the system was rather neglected with the only thorough photometric analysis of Pribulla et al. (2005), who found that the orbital period of the system increases at a record rapid (for contact binaries) rate of $\Delta P/P = 2.12\ 10^{-6}$ year^{-1}. The system is totally eclipsing so the geometric elements derived through a light curve solution, $i = 80.4°$, $q = 0.094$ and $f = 0.46$ were well defined in the solution of Pribulla et al. (2005). The deeper minimum is flat, hence the system was classified as a W-type contact binary. The authors determined $(B - V) = 0.62$ (uncorrected for the interstellar absorption). No spectroscopic study of the system has been published yet.

We found V1191 Cyg to be a rather difficult spectroscopic target due to its relative faintness, the short orbital period of $P = 0.3134$ days and the weakness of the Mg I triplet lines. As a solution, we took 129 spectra evenly covering all phases; the extracted BFs were subsequently smoothed in the phase domain (the phase step of 0.02) in the way described before in Rucinski et al. (2005).

The spectroscopic lower conjunction of the more massive component occurs during the primary minimum, hence V1191 Cyg is a W-type system. The spectroscopic mass ratio, $q_{sp} = 0.107 \pm 0.005$ is consistent with the photometric determination. The system is, however, very unusual: (1) It is of a rather late spectral type for such a small mass ratio; (2) Its mass ratio is unusually small for a W-type system; (3) The orbital period is short for the mid-F spectral type implying smaller, more compact components than for typical solar-type contact binaries. The 2MASS color, $J-K = 0.318$, corresponds to the F6V spectral type which is exactly what we see in the classification spectra. The Tycho-2 color, $B-V = 0.39 \pm 0.10$ is too uncertain to draw any firm conclusions.

2.3. V1003 Her

The variability of this system was found by the Hipparcos satellite. It is described there as a periodic variable of an unspecified variability type with the period $P = 0.246661$ days. Later Duerbeck (1997), suggested that it is a contact binary with the orbital period twice the original Hipparcos value. Analysis of photometric observations of the binary is complicated by the rather low amplitude, $\Delta V = 0.09$. In the ASAS-3 survey Pojmanski (2002), the system appears with an undefined variability type and the best period of 21.846 days; however, the same observations, when phased with the double of the Hipparcos period, show a light curve with the minima of similar depths, a feature which is typical for contact binaries. Rather noisy observations can be found in the NSVS database (NSVS 11074663, http://skydot.lanl.gov/nsvs/nsvs.php). Except for those fragmentary observations, no other photometric or spectroscopic observations of V1003 Her are available.

Our spectroscopic observations show that V1003 Her is indeed a close binary, most likely of the W UMa type, but – because of the very small photometric amplitude – a full description and classification of the system is impossible at this point and would require a high-precision photometry. The projected total mass of the system, $(M_1 + M_2)\sin^3 i = 0.672 \pm 0.009$ $M_\odot$, the low photometric amplitude, the early spectral type (A7) and the absence of any third light, all indicate a very low inclination angle. The Hipparcos parallax, $\pi = 4.64 \pm 1.66$ mas is of limited use because of its low relative accuracy. Our spectral type estimate, A7V, is consistent with the 2MASS infrared color, $J-K = 0.234$, but the Tycho-2 color index $B-V = 0.38$ indicates a substantial reddening in the direction to V1003 Her, $E(B-V) \approx 0.19$.

2.4. BD+7°3142 (Her)

Variability of BD+7°3142 was detected during the analysis of the ASAS data (Pojmanski 2002). It was classified as an eclipsing binary with the following ephemeris: $HJD = 2\,452\,383.92 + 0.275277 \times E$ for the primary minima. No photometric or spectroscopic observations of the system have been published yet. Simultaneous photometry during our spectroscopic observations has led to determination of one light minimum at $HJD = 2\,454\,188.8663(1)$, which occurred at the phase 0.8366 of the ASAS prediction. Our spectroscopic conjunction agrees with this newly observed minimum.

The spectroscopic observations show BD+7°3142 as a triple system with a third component stationary in radial velocities. The light contribution of the third component is $L_3/(L_1+L_2) = 0.50$

at the brightness maximum of the eclipsing pair; its signature is narrow with $V \sin i \leq 15$ km s^{-1}, which is close to the resolution of our spectroscopy. After approximating the third peak by a Gaussian and its removal from the BFs, we obtained well-defined BFs of the eclipsing pair. The radial velocity of the third component, $RV_3 = -69.2 \pm 1.4$ km s^{-1} was found to be close to the center of mass velocity of the eclipsing pair, $V_0 = -64.1 \pm 0.8$ km s^{-1}, hence the third component appears to be a physical member of the system. The small difference of velocities is, very probably, a result of a slow mutual revolution. The system is not listed in the WDS catalogue as a previously recognized visual double (Mason et al. 2001).

The parallax of the system is unknown, but its absolute visual magnitude can be estimated using calibration of Rucinski & Duerbeck (1997) and the K2 spectral type ($(B-V)_0 = 0.74$) at $M_V = 4.84$. A correction of the maximum visual magnitude of the combined system, $V = 9.89$, for the contribution of the third component, results in $V_{12} = 10.33$ and then the distance $d = 97$ pc.

By combining the proper motion of BD+7°3142 adopted from the Tycho-2 catalogue (Høg et al. 2000) with the systemic radial velocity and the estimated distance, one obtains a large space velocity of 88 km s^{-1}. The 2MASS color of BD+7°3142, $J - K = 0.591$, and the Tycho-2 $B - V = 0.92$ agree with our spectral type of K2V and is consistent with the very short period of the system.

2.5. V357 Peg

The variability of V357 Peg (HD222994) was discovered during the Hipparcos mission. The system was correctly classified as a contact binary. The first photometry of V357 Peg, published by Yasarsoy et al. (2000), shows a typical W UMa-type light curve. The photometric amplitude is about 0.48 mag so the eclipses cannot be far from total (assuming our $q_{sp} = 0.40$). No photometric or spectroscopic study of the system has been published yet in spite of a fairly large brightness of $V_{max} = 9.06$.

Our spectroscopic observations show that V357 Peg is a contact binary of the A type with the mass ratio of $q = 0.401$ which is moderately large for this type. The total projected mass of the system $(M_1 + M_2) \sin^3 i = 2.112\, M_\odot$ is probably not far from the true total mass. Our spectra taken in August and September 2005 showed a dark photospheric spot on the secondary component which became visible just after the secondary minimum (Fig. 5). In addition to the main series of observations in 2005, V357 Peg had been shortly observed in 1997. These observations do not show any indication of the photospheric spots. All radial velocities are listed in Table 1, but the 1997 data were not used in orbital solution given in Table 2 to avoid any influence of the possibly imprecisely-known or variable period. An orbit based on the 1997 data ($V_0 = -10.8$ km s^{-1}, $K_1 = 93.8$ km s^{-1}, $K_2 = 234.1$ km s^{-1}, $T_0 = 2,450,748.7496(12)$ for the spectroscopic conjunction) is consistent with the 2005 results.

The trigonometric parallax of the system, $\pi = 6.00 \pm 1.56$ mas, is too imprecise to determine reliably its absolute magnitude. Our estimate of the spectral type, F2V, agrees with both, the 2MASS color, $J-K=0.178$, and the Tycho-2 color, $B-V=0.33$.

2.6. V407 Peg

V407 Peg (BD+14°5016; $V_{max}=9.28$) was found to be a variable during the Semi-Automatic Variability Search program at the Piwnice Observatory close to Toruń, Poland (Maciejewski et al. 2002). The authors presented a moderate-precision BV photometry and the first ephemeris for the primary minima $HJD = 2\,452\,558.1703 + 0.636889 \times E$. The light curve of V407 Peg was that of a contact binary.

Later Maciejewski & Ligeza (2004) published 13 radial-velocity determinations based on spectra taken at the David Dunlap Observatory and processed using the BF formalism. Unfortunately, about a half of the available spectra were taken close to the orbital conjunctions making the derived spectroscopic elements ($V_0 = 22.1 \pm 5.9$ km s^{-1}, $K_1 = 54.7 \pm 3.8$ km s^{-1} and $K_2 = 233.9 \pm 5.6$ km s^{-1}) rather uncertain and in fact very different from our orbit which is based on 63 spectra. The most substantial difference is in the 8.7% larger sum of the semi-amplitudes resulting in the 29% larger total (projected) mass.

The star was not included in the Hipparcos mission. Its $J-K$ color in the 2MASS catalogue (Skrutskie et al. 2006) is 0.181 corresponding to the F1 spectral type, which is consistent with the $(B-V)=0.35$ determined by Maciejewski et al. (2002). Our spectral classification is F0V.

2.7. V1123 Tau

The variability of V1123 Tau (visual double WDS 03350+1743) was discovered during the Hipparcos satellite mission. In the Hipparcos Variable Stars Annex, the star is classified as a β Lyrae eclipsing binary with the ephemeris for the primary minimum: $HJD = 2\,458\,500.3570 + 0.399957 \times E$. The binary is accompanied by a fainter companion ($\rho = 4.3''$, $\theta = 136°$ and $\Delta V = 1.77$). The large error of the Hipparcos trigonometric parallax, $\pi = 6.82 \pm 3.03$ mas, suggests that it was most likely corrupted by the presence of the visual companion.

Özdarcan et al. (2006) published the first ground-based photometry of the system. Based on the observed color of the system, $(B-V)=0.684$, the authors estimated the spectral type to be G6V which is much later than our direct classification of G0V. The rather red color and the wavelength-dependent depths of the minima were very probably a result of the neglected contribution of the late-type companion which was almost certainly entering the diaphragm of the photoelectric photometer. The third light of the visual companion appears to have caused the amplitudes of the system to be color-dependent: while in the U filter the full amplitude of the light curve was 0.413 mag, it was only 0.352 mag in the R filter.

The light of the visual companion was partially entering the spectrograph slit during periods of the poor seeing; it was however marginally visible in the extracted BFs with the relative contribution not larger than typically 0.02 – 0.03. Its radial velocity, $V_3 = 29$ km s^{-1} was constant during our observing run and was fairly close to the center-of-mass velocity of eclipsing pair, $V_0 = 25.2 \pm 0.6$ km s^{-1}.

In addition to the recent observations reported here (September 2005 – March 2007), V1123 Tau was also observed in 2002 using the older CCD chip (see previous papers of this series) and the 1800 lines/mm grating. The resulting radial velocities, listed in Table 1, were not used in orbital solution given in Table 2 due to the long interval between the two datasets. The orbit based on the 2002 data ($V_0 = 24.6$ km s^{-1}, $K_1 = 69.3$ km s^{-1}, $K_2 = 258.2$ km s^{-1}, $T_0 = 2,452,558.4581(8)$ for the spectroscopic conjunction) is consistent with the results from the new, better-defined data.

The lower conjunction of the more massive component corresponds to the time of the secondary minimum as given in the on-line database of ephemerides of eclipsing binary stars (see http://www.as.ap.krakow.pl/ephem/ and Kreiner, 2004); therefore V1123 Tau is W-type contact binary.

2.8. V1128 Tau

V1128 Tau (visual double WDS 03495+1255) is another Hipparcos discovery. Originally it was classified as a β Lyrae eclipsing binary with the 0.3043732 days orbital period. The eclipsing pair forms a relatively wide visual double with BD+12°511B, separated by 14 arcsec. The visual companion at the position angle $\theta = 196°$ was not entering our spectrograph slit which is permanently oriented in the E-W direction. The high-precision photometry of Tas et al. (2003) showed that the system is a totally eclipsing contact binary, with the totality lasting about 16 minutes. A subsequent light curve modeling led to $q_{ph} = 0.48$ and the high orbital inclination angle of $i = 85$ degrees. The light curve asymmetry, with the maximum following the primary minimum being brighter, was interpreted in terms of a cool spot on the cooler component.

Our spectroscopic mass ratio, $q_{sp} = 0.534(6)$, is in a reasonable but not perfect consistency with the photometric estimate. However, we could not see any evidence of dark photospheric spots on either of the components in our BFs. The lower conjunction of the more massive component coincides with the deeper eclipse so that V1128 Tau is definitely a W-type contact binary.

In addition to our recent observations reported here (December 2005 – March 2007), V1128 Tau had been shortly observed in 1997 and in 2003 using the old CCD detector and the 1800 lines/mm grating. The resulting radial velocities, listed in Table 1, were not used in orbital solution given in Table 2. The corresponding orbit ($V_0 = -14.5$ km s^{-1}, $K_1 = 127.1$ km s^{-1}, $K_2 = 243.4$ km s^{-1}, $T_0 = 2,451,119.0927(5)$ for the spectroscopic conjunction) is consistent with the results from the new data.

The presence of the visual companion to the contact binary makes the Hipparcos parallax, $\pi = 1.71 \pm 6.27$ mas, rather uncertain (see Pribulla & Rucinski (2006)). There is a disparity between $J - K = 0.454$, as determined from the 2MASS survey, implying a spectral type later than G6V and our spectral type estimate, F8V; this disparity is probably caused by the late-type companion.

2.9. HH UMa

The photometric variability of HH UMa was discovered by the Hipparcos mission where it was classified as a periodic variable with $P = 0.187747$ days. On the basis of the color–period relation, Duerbeck (1997) concluded that it is very probably a genuine contact binary with twice the Hipparcos period. The ground-based observations of Pribulla et al. (2003) supported the contact binary nature of HH UMa; they also gave an improved ephemeris: $HJD = 2\,452\,368.3979 + 0.3754937 \times E$. Due to the partial eclipses, the mass ratio could not be reliably determined and was estimated as $q_{ph} \approx 0.35 - 0.45$.

Our spectroscopy definitely shows a contact-binary nature of HH UMa and gives $q_{sp} = 0.295(3)$. The low projected total mass, $(M_1 + M_2)\sin^3 i = 0.826 M_\odot$, together with low amplitude of the light curve, 0.17 mag, support the low inclination angle, as found in the photometric analysis.

The trigonometric parallax of the system, $\pi = 4.50 \pm 1.78$ mas, is too imprecise to draw any conclusions on its absolute magnitude. The 2MASS color of the system, $J - K = 0.572$, agrees fairly well with our estimate of the spectral type, F5V. The Tycho-2 $B - V = 0.50$ corresponds to the F7V spectral type.

2.10. PY Vir

PY Vir (GSC 4961-667) was found on Stardial images to be a variable of the W UMa type (Wils & Dworak 2003). The system is also known as an X-ray source (1RXS J131032.4-040934). No photometric or spectroscopic analysis of PY Vir has been published yet. A minimum observed photometrically in parallel with the spectroscopic observations ($HJD = 2\,554\,201.7944$) was used for a preliminary improvement of the ephemeris used for phasing of our spectroscopy.

The broadening functions of PY Vir based on the 2007 observations show the presence of a third component with a constant radial velocity, $V_3 = -32.9 \pm 4.1$ km s^{-1}; this velocity is rather different from the systemic velocity of the contact binary, $V_0 = -14.66$ km s^{-1}. A few additional, low quality spectra of PY Vir taken in poor-weather conditions on February 19, 2008 (not listed in Table 1) give $V_3 = -23.3 \pm 3.7$ km s^{-1} (at the mean HJD = 2 454 515.883) so that we have an indication of a change in V_3. The velocities of the close binary from these additional observations are not precise enough to see if the motion of the third component is reflected in systemic radial velocity of the eclipsing pair. The third component may be a binary itself; otherwise, the velocity changes may result from its low mass and a relatively fast orbital motion in a tight triple system. We consider the latter possibility as a relatively probable and more exciting one, but its verification would require observations over several seasons.

PY Vir has not been known to be a multiple system; it is also not listed in the WDS catalogue. A lunar occultation of the system in July 1984 did not reveal presence of any visual companion (Evans et al. 1985), hence the separation of components is probably very small. Moreover, the light contribution of the third component is fairly small, only about $L_3/(L_1 + L_2) = 0.08$, at the maximum light of the eclipsing pair.

The 2MASS color of the system, $J - K = 0.572$, indicates the K2V spectral type, which is consistent with our spectral classification. The orbital period of the system, 0.311 days, is rather long for such a late spectral type (it would be more consistent with late F) so that the system may be close but detached. The shape of the broadening function (see Figure 4) with a gap between the two peaks is not inconsistent with this possibility. The Tycho-2 $(B - V)$ color is rather uncertain to draw any conclusions, $B - V = 0.80 \pm 0.06$.

3. SUMMARY

With the new ten short-period binaries, this paper brings the number of the systems studied at the David Dunlap Observatory to 120. Almost all systems of this group have been rather neglected and little has been known about them.

The highlights of this series are: (1) the triple systems BD+7°3142 and PY Vir, both with short-period, late spectral-type (K2V) binaries; (2) both of the above are interesting: BD+7°3142 is a high space-velocity system while PY Vir maybe a very close, but detached binary; (3) the spotted contact binary, V1128 Tau, with a large spot on the secondary component, (4) V1191 Cyg, the unusual, W-type contact binary with the small mass ratio of 0.107 and a relatively short-period, observed during the rapid mass-transfer stage. V1191 Cyg has an unexpectedly short orbital period for its F6V spectral type implying smaller components than for typical solar-composition, solar-age contact binaries; this may be an indication of its old population characteristics, similar to those of binaries in globular clusters (Rucinski 2000). None of the systems had been observed spectroscopically before (except for the measurements of the rotational velocity of the EG Cep primary component (Etzel & Olson 1993)).

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Captions to figures:

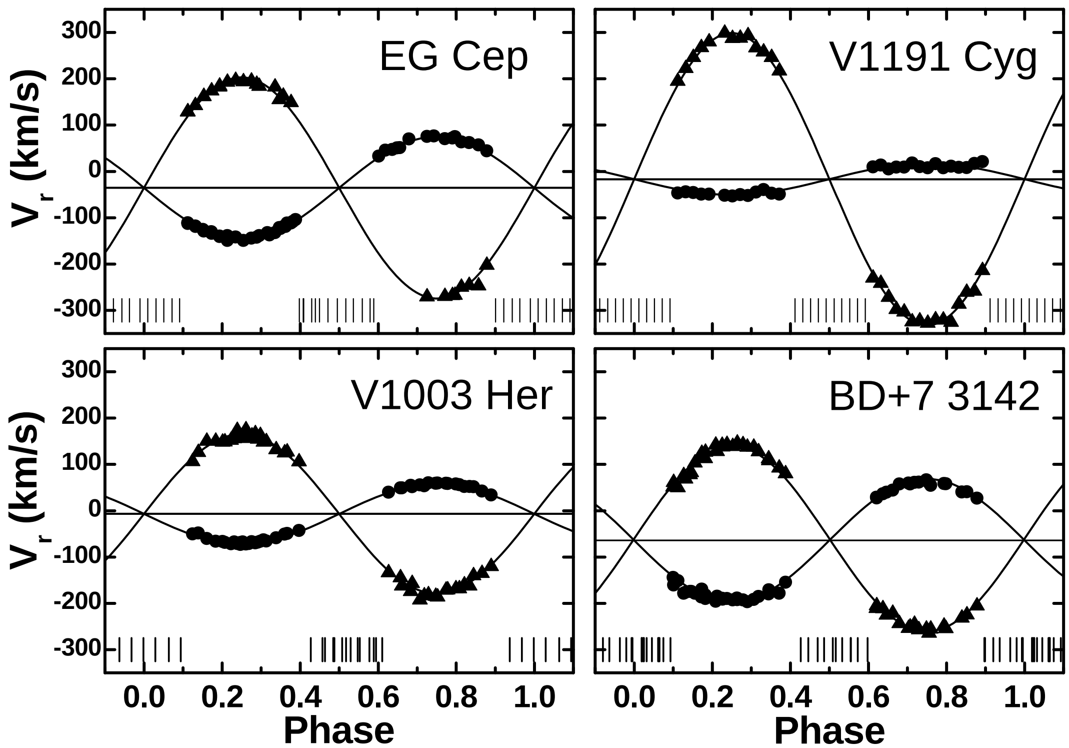
Fig. 1.— Radial velocities of the systems EG Cep, V1191 Cyg, V1003 Her and BD+7°3142 (in Hercules) are plotted in individual panels versus the orbital phases. The lines give the respective circular-orbit (sine-curve) fits to the RV's. EG Cep is very probably a detached or semi-detached binary, V1003 Her is close binary of uncertain type while V1191 Cyg and BD+7°3142 are contact binaries. BD+7°3142 is member of triple system with a relatively bright third component. 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 spectral line blending.

Fig. 2.— The same as for Figure 1, but for V357 Peg, V407 Peg, V1123 Tau, and V1128 Tau. All four systems are contact binaries. V1123 Tau and V1128 Tau are members of relatively wide visual binaries.

Fig. 3.— The same as for Figures 1 and 2, for the two remaining systems HH UMa, and PY Vir. Both are typical contact binaries.

Fig. 4.— The broadening functions (BFs) for all ten systems of this group, selected for phases close to 0.25 or 0.75. The phases are marked by numbers in individual panels. The third star features in the BFs of the contact binaries BD+7°3142 and PY Vir are strong and clearly visible. All panels have the same horizontal range, -500 to $+500$ km s^{-1}.

Fig. 5.— The broadening functions (BFs) of V357 Peg determined from observations between August 25 and September 6, 2005. The original BFs were binned into 0.02 phase intervals and smoothed by convolution with a Gaussian profile ($\sigma = 0.02$ in phase). The dark feature drifting through the secondary component profile is very probably a large photospheric spot. Its signature appears to be variable, especially around the phase 0.75 implying that the spot may have changed its position during the two weeks of our observations.



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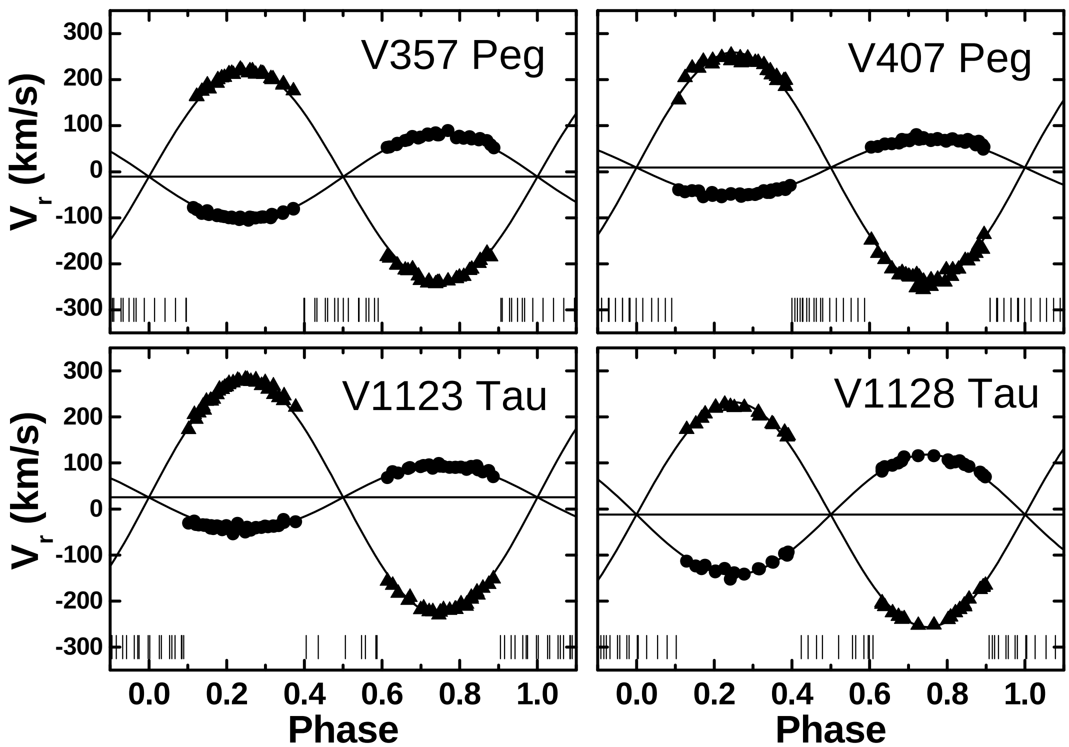
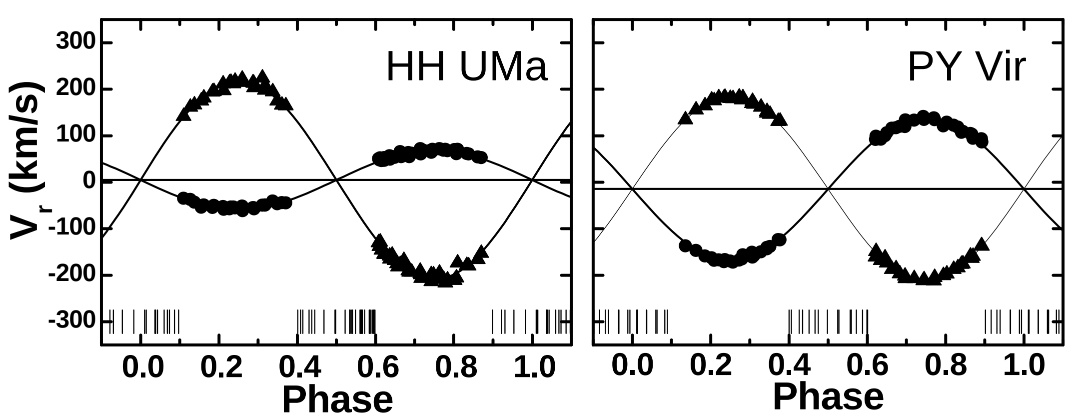


Fig. 2.— The same as for Figure 1, but for V357 Peg, V407 Peg, V1123 Tau, and V1128 Tau. All four systems are contact binaries. V1123 Tau and V1128 Tau are members of relatively wide visual binaries.



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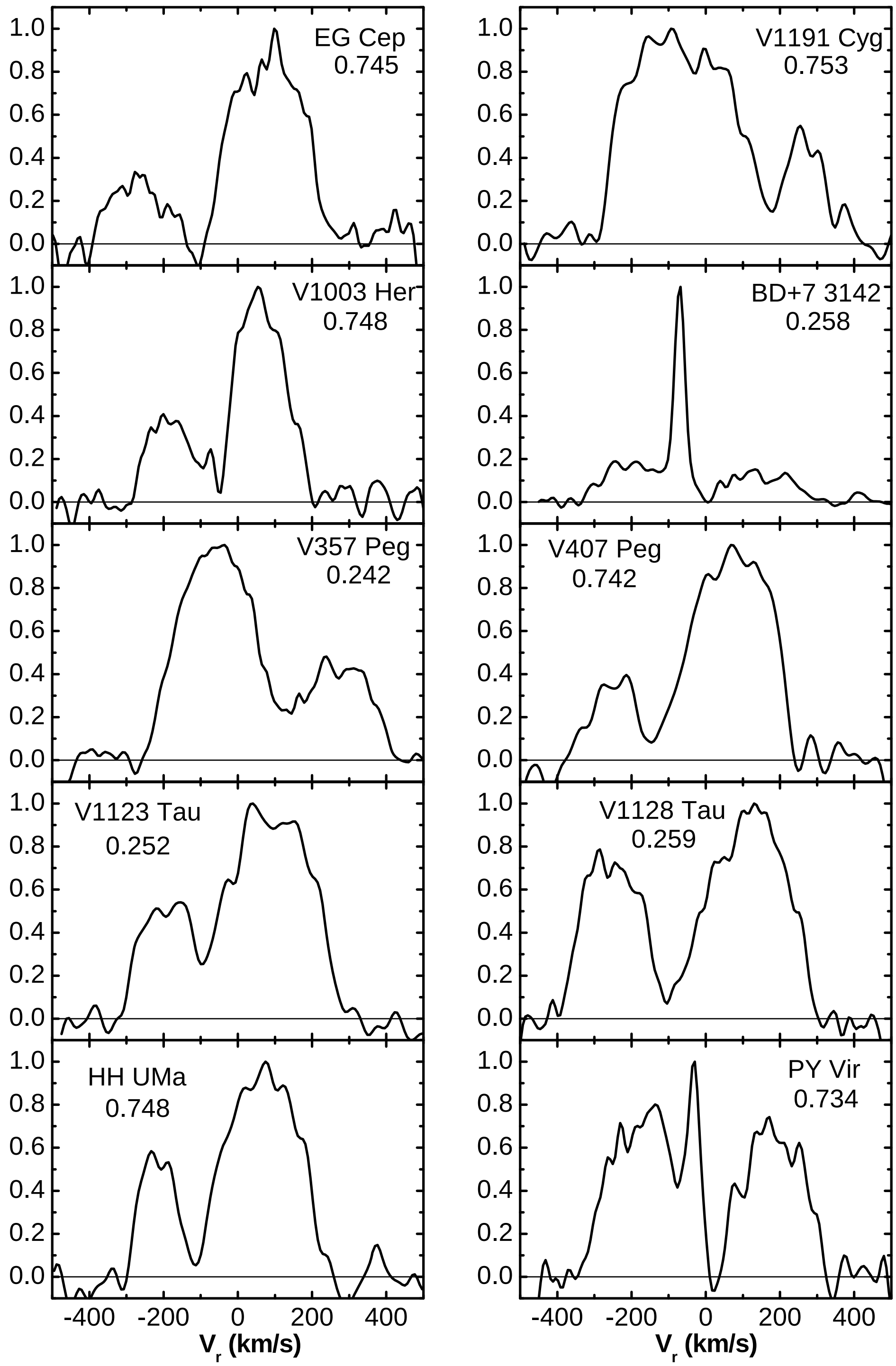

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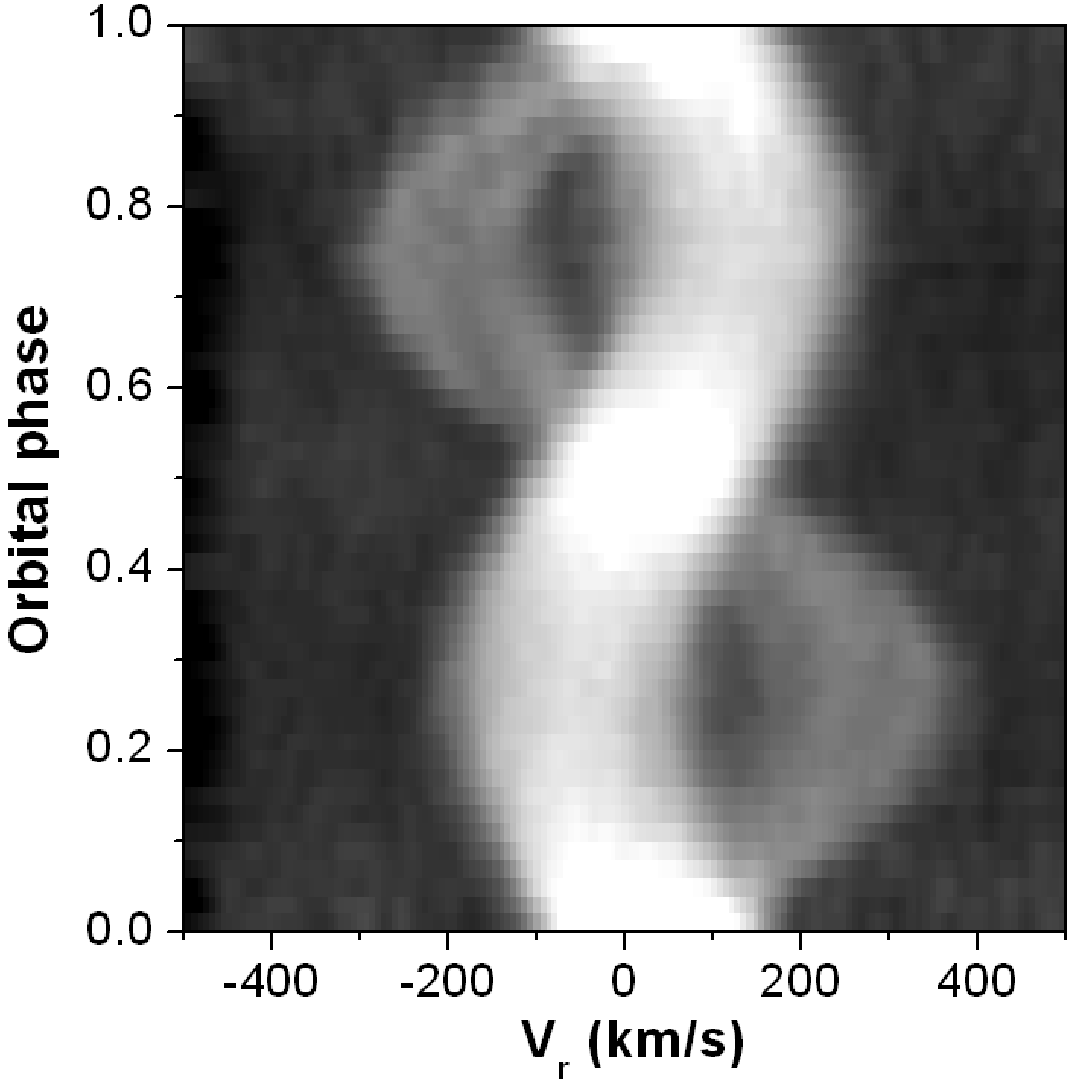

Fig. 5.— The broadening functions (BFs) of V357 Peg determined from observations between August 25 and September 6, 2005. The original BFs were binned into 0.02 phase intervals and smoothed by convolution with a Gaussian profile (σ = 0.02 in phase). The dark feature drifting through the secondary component profile is very probably a large photospheric spot. Its signature appears to be variable, especially around the phase 0.75 implying that the spot may have changed its position during the two weeks of our observations.

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
54251.6402	−139.75	1.00	190.61	1.00	0.2919
54251.6582	−134.70	1.00	183.19	0.00	0.3250
54251.6736	−120.90	1.00	162.99	0.00	0.3533
54251.6902	−106.37	1.00	167.77	0.00	0.3837
54251.7059	0.00	0.00	0.00	0.00	0.4126
54251.7222	0.00	0.00	0.00	0.00	0.4425
54251.8037	0.00	0.00	0.00	0.00	0.5921
54251.8199	48.14	1.00	−211.99	0.00	0.6218
54251.8363	53.42	1.00	−258.35	0.00	0.6520
54251.8527	72.41	1.00	−254.16	0.00	0.6820

Note. — The table gives the RV's V_i for observations described in the paper. The first 10 rows of the table for the first program star, EG Cep, 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. Zero weight are assigned to observations of marginally visible peaks of the secondary component (mainly in case of EG Cep). 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. For V1191 Cyg, where we used phase-smoothed BFs heliocentric Julian dates are omitted.

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
EG Cep	EB	HD194089	−35.61(0.74)	110.67(1.02)	3.41	54304.3114(8)	0.54462228	0.464(5)
	A7V	BD+76°790		238.72(1.30)	8.67	+0.0010 [+3,312.0]	2.407(27)	
V1191 Cyg	EW(W)		−16.82(0.94)	33.68(1.52)	6.28	52500.4104(8)	0.3133867	0.107(5)
	F6V			315.52(1.52)	8.16	+0.0030 [+0.5]	1.383(22)	
V1003 Her	EW?	HD343341	−6.92(0.61)	64.07(0.94)	2.92	54286.5955(9)	0.493322	0.373(6)
	A7V	BD+21°3589		171.91(0.94)	7.66	−0.0082 [+11,729]	0.672(9)	
BD+07°3142	EW?		−64.08(0.79)	132.56(1.27)	7.82	54212.8136(4)	0.2752770	0.662(8)
	K2V			200.16(1.44)	8.83	−0.0018 [+87]	1.050(14)	
V357 Peg	EW(A)	HD222994	−10.84(0.54)	93.78(0.86)	4.07	53730.6697(6)	0.5784514	0.401(4)
	F2V	BD+24°4828		234.08(0.87)	7.19	+0.0024 [+2,127]	2.112(18)	
V407 Peg	EW(A)	BD+14°5016	9.06(0.70)	63.92(1.12)	4.59	54049.7666(8)	0.636889	0.256(6)
	F0V			250.02(1.16)	10.22	+0.0023 [+2,342]	2.042(25)	
V1123 Tau	EW(W)	BD+17°579	25.32(0.54)	71.08(0.84)	5.42	53791.0975(4)	0.3999496(8)	0.279(4)
	G0V	HIP 16706		254.71(0.84)	6.41	+0.0004 [+3,380.5]	1.433(13)	
V1128 Tau	EW(W)	BD+12°511	−12.27(0.76)	130.48(1.27)	5.75	53864.7026(4)	0.3053707(7)	0.534(6)
	F8V	HIP 17878		244.19(1.28)	7.68	−0.0007 [+4,468.5]	1.664(18)	
HH UMa	EW(A)	BD+36°2149	4.92(0.44)	63.06(0.69)	3.74	54,070.1229(4)	0.3754889(9)	0.295(3)
	F5V	HIP 54165		213.84(0.75)	6.17	−0.0017 [+4,181]	0.826(7)	
PY Vir	EW(W)		−14.51(0.45)	152.78(0.77)	4.92	54,193.2347(3)	0.311251	0.773(5)
	K1/2V	BD-03°3419		197.58(0.77)	4.65	−0.0149 [+7,364.5]	1.387(10)	

Note. — The spectral types given in column 2 relate to the combined spectral type of all components in a system; they are given in parentheses if taken from the literature, otherwise 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:
EG Cep: 52500.5214 + 0.54462228
V1191 Cyg: 52500.2507 + 0.3133874
V1003 Her: 48500.43 + 0.493322
BD+7°3142: 54188.8663 + 0.275277
V357 Peg: 52500.3022 + 0.5784509
V407 Peg: 52558.1703 + 0.636889
V1123 Tau: 52500.2670 + 0.3999474
V1128 Tau: 52500.1463 + 0.3053725
HH UMa: 52500.1967 + 0.3754910
PY Vir: 51901.0416 + 0.311251