RADIAL VELOCITY STUDIES OF SOUTHERN CLOSE BINARY STARS. I. WINTER SYSTEMS

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ABSTRACT

Radial velocity measurements and sine-curve fits to the orbital velocity variations are presented for nine contact binaries: V1464 Aql, V759 Cen, DE Oct, MW Pav, BQ Phe, EL Aqr, SX Crv, VZ Lib, and GR Vir. For the first five of these, our observations are the first available radial velocity data. For the three remaining radial velocity variables, CE Hyi is a known visual binary, while CL Cet and V1084 Sco are suspected to be multiple systems in which the contact binary is spectrally dominated by its companion (which itself is a binary in V1084 Sco). Five additional variable stars, V872 Ara, BD Cap, HIP 69300, BX Ind, and V388 Pav, are of unknown type, but most are pulsating stars; we give their mean radial velocities and \( V \sin i \).

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

Online material: machine-readable tables

1. INTRODUCTION

The origins of this paper are related to those of the series of radial velocity studies of short-period binaries currently conducted at the David Dunlap Observatory (DDO papers 1–10; Lu & Rucinski 1999 [DDO 1]; Rucinski 2002 [DDO 7]; Rucinski & Lu 1999 [DDO 2]; Rucinski et al. 2000 [DDO 3], 2001 [DDO 5], 2002 [DDO 6], 2003 [DDO 8], 2005 [DDO 10]; Lu et al. 2001 [DDO 4]; Pych et al. 2004 [DDO 9]). Both authors realized in the 1990s that, with availability of good Hipparcos parallaxes (Perryman 1997), the limiting factor in gathering spatial velocities of contact binaries would be radial velocities (RVs). While the DDO studies have since succeeded in obtaining RV data for now over 100 northern binary stars, for many reasons the data presented in this paper are so far the only effort for southern binary stars. We present these results because the chances of continuation of these observations are basically nil: the telescope has been retired, and the remaining ESO telescopes are assigned for more technically demanding tasks.

The observations reported in this paper were collected on four nights, 1998 August 8–11. To optimize the returns from such a short survey, the 17 targets were selected to be a mixture of contact binaries possibly offering reasonable orbital solutions with a selection of variable stars suspected to be contact binaries (Duerbeck 1997, hereafter HDH). The next paper will contain similar results for spring southern targets.

In this paper we attempt to stay close to the format of the DDO series. In particular, we use the same data-extraction procedures through the broadening function (BF) approach, as described in the DDO interim summary paper (DDO 7). Of 17 stars discussed in this paper, four contact binaries (EL Aqr, SX Crv, VZ Lib, and GR Vir) have been observed in the meantime during the DDO program resulting in good RV orbits; we include these systems here to report the southern observations as a check of consistency. The remaining stars have been observed by us for RV variations for the first time. We have derived the RVs in the same way as described in the DDO papers; see the DDO 7 paper for a discussion of the BF technique used in the derivation of the RV orbit parameters: the amplitudes, \( K_1 \), the center-of-mass velocity, \( V_0 \), and the time-of-primary-eclipse epoch, \( T_0 \). The primary radial velocity standard used to determine the BFs, as well as to find radial velocities, was 6 Cet (F5 V), assumed to have the velocity of +14.9 km s\(^{-1}\) (Nordstrom et al. 2004). This was the only sufficiently well-observed standard that could be used as the BF template, but it appeared to serve well for the whole range of spectral types from mid-A to mid-G; the disparity of the spectral types manifested itself mostly in the BF intensities that would not normalize to unity as expected for perfect spectral matches.

We describe our results in the context of the existing photometric data from the literature and the Hipparcos project. We also use the mean \((B-V)\) color indexes taken from the Tycho-2 catalog (Hög et al. 2000) and the photometric estimates of the spectral types using the relations published by Bessell (1979). The spectral types are taken uniformly from the five volumes of the Michigan Catalogue of HD Stars (Houk & Crowley 1975; Houk 1978, 1982; Houk & Smith-Moore 1988; Houk & Swift 1999; hereafter HDH). Because of the high incidence of companions to contact binary stars (Pribulla & Rucinski 2006), we checked all stars for possible membership in visual systems using the Washington Double Star Catalog (WDS).\(^2\) DE Oct and CE Hyi have been identified as members of already-known visual binaries. VZ Lib is a previously recognized (DDO 4) spectroscopic triple system.

The observations were carried out with the ESO 1.52 m telescope at ESO La Silla, equipped with a Boller & Chivens Cassegrain spectrograph. Holographic grating No. 32 (2400 lines mm\(^{-1}\)) was used in combination with Loral CCD No. 39 (2048 \( \times \) 2048 pixels). The slit width was set to 220 \( \mu m \). The BFs were extracted from the wavelength region of 401.6–499.8 nm. Thus, compared with the DDO results based on the Mg I triplet at 518.4 nm, with

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1 Based on data obtained at the European Southern Observatory.

2 See http://ad.usno.navy.mil/wds.
of our spectra for V1464 Aql indeed supports an early F spectral type.

2.2. EL Aqr

EL Aqr (HIP 117317) was the subject of a previous DDO study (DDO 5) in which the orbital coverage was good, but the reported final elements had a larger scatter than for most of the DDO systems, probably because of typically large zenith distances and a relative faintness of the system at $V_{\text{max}} = 10.35$. The $B - V$ given in DDO 5 was incorrect; the value of $B - V = 0.47$ better agrees with the DDO spectral type of F3 V, but still suggests some amount of interstellar reddening. The spectral type is not available in HDH. For more information about the system, please consult DDO 5.

Our 15 observations are concentrated in the first half of the orbit. They confirm the DDO results, but the $K_2$ semiamplitude is significantly smaller. This may be an indication of an insufficient spectral resolution, although the peaks in the BFs are quite well separated (Fig. 1). The primary eclipse prediction of $T_0$ from the DDO observations served the new observations well and was adopted here without a change.

2.3. V759 Cen

The bright contact binary V759 Cen (HIP 69256, HD 123732) was discovered by Bond (1970). In spite of its brightness of $V_{\text{max}} \approx 7.45$, it has not been much observed since then, with only sporadic photometric observations for eclipse timing. The color $b - y = 0.39$, the spectral type F8 (Bond 1970) or G0 V (HDH), and the period of 0.394 days suggest a typical contact binary.

The binary was observed six times within our program, and these were its first RV observations. The phase distribution of the observations was far from optimal, so the orbital elements must be treated as preliminary. As can be seen in Figure 1, the spectral resolution was insufficient for this binary, which is probably visible at a low inclination angle.

The Cracow database4 consulted in 2006 April provided an ephemeris used for our observations, as given in Table 3. Our bootstrap-estimated errors are very large because of the insufficient number of observations. The mass ratio is probably close to $q \approx 0.2$.

2.4. SX Crv

The very interesting and important contact binary SX Crv (HIP 61825, HD 110139), with the currently smallest known mass ratio of $q \approx 0.07$ (DDO 5), was observed eight times. The BFs show the faint peak of the secondary component quite well, although the DDO 5 elements are definitely better established, as

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3 See http://www.eso.org/projects/esomidas.

4 See http://www.as.ap.krakow.pl/ephem/.
they were based on 49 best observations selected from 96 available ones. As may be expected for a lower spectral resolution, the current observations give a smaller \( K_2 \), but the center-of-mass velocity also appears to be different; the latter effect may be due to the uneven phase distribution of the observations.

For more information about SX Crv, please consult DDO 5. Note the incorrect value of \( B - V \) in that paper, which should be 0.44. The HDH spectral type is F3–5 V (HDH), agrees with that found in DDO 5.

In DDO 4, a continuous change of the RV of the companion in four seasons was noted. The current observations with the mean value \( V_3 = -36.7 \pm 2.9 \) at JD 2,451,034 (see Table 2 for individual observations) confirm the \( V_3 \) variability within the combined span of 4 yr very well. The “kink” in \( V_3 \) visible in Figure 5 in DDO 4 is apparently real, so the orbital period of the triple system is probably quite short, of the order of a few years. It may be necessary to look for systematic changes in the center-of-mass data for the binary VZ Lib itself to confirm its motion. The fact that no obvious changes of \( V_3 \) have been noted so far suggests that the third component is probably much less massive than the binary.

2.6. DE Oct

DE Oct (HIP 100187, HD 191803) was observed spectroscopically for the first time within this program. D97 had suggested that this is a contact binary with an orbital period twice as long as the Hipparcos discovery period, \( 2P = 0.5555922 \) days. With this period, their three observations cannot properly define an orbit, and no estimates of element uncertainties could be determined. However, we can exclude applicability to our observations of the Hipparcos conjunction time at \( T_0 = 2,448,500.157 \); the new value of \( T_0 \) is given in Table 3. The BF s are poorly resolved, so the measured velocities, particularly of the secondary component, are very tentative.

2.7. MW Pav

MW Pav (HIP 102508, HD 197070) was observed by our program for the first time and was the best observed star of this series, with 18 observations defining a good RV orbit. The spectral signatures are well separated in the BF s, although one must take into account the warning signs from the other binaries that might be systematically underestimated at the available resolution. We assumed the value of the period from the Hipparcos results.

MW Pav is a well-known southern contact binary with \( V_{\text{max}} = 8.80, B - V = 0.33 \) (Tycho-2), spectral type F3 IV–V (HDH), and a relatively long orbital period of 0.795 days. It was discovered by Eggen (1968) and initially designated as BV 894. A light curve solution was presented by Lapasset (1980). The secondary eclipse seemed to be total, so evaluation of the mass ratio appeared to be possible. However, \( q_{\text{obs}} = 0.122 \pm 0.003 \) disagrees with our spectroscopic determination, \( q_{\text{sp}} = 0.228 \pm 0.008 \), even if we consider the possibility of a probable systematic underestimate of \( K_2 \) by (at most) 10%. Our spectroscopic observation should permit a combined solution of the parameters of this binary.

2.8. BQ Phe

BQ Phe (HIP 2005, HD 2145) was suggested by D97 to be a contact binary with a period 2 times longer than that given by the Hipparcos discovery observations, \( 2P = 0.437 \) days. We confirm that BQ Phe is a contact binary, but with only four observations our orbital solution is indicative rather than definitive, and the formal errors are very large. We assumed both the \( T_0 \) and the double Hipparcos period (see Table 3).

The star was a bit faint for this program, \( V_{\text{max}} = 10.4 \). Its spectral type, F3–5 V (HDH), agrees with \( B - V = 0.51 \) (Tycho-2).

2.9. GR Vir

GR Vir (HIP 72138) was analyzed for RV variations in DDO 2, in which a good orbital solution was presented. With only five
new observations we can only say that we fully confirm the DDO 2 solution. We assumed both the \( T_0 \) and the period from the DDO 2 results.

For more information about GR Vir, please consult DDO 2. As for other systems observed before, we see that our value of \( K_2 \) is slightly lower than that observed at DDO.

3. POSSIBLE BINARY MEMBERS OF MULTIPLE SYSTEMS

3.1. CL Cet

CL Cet (HIP 2274, HD 2554) was suggested in D97 to be a contact binary with a period 2 times longer than the *Hipparcos*
Fig. 2.—Orbital solutions for the nine contact systems discussed in §2. Observations of lower quality are marked by open symbols. Dashes at the bottom mark orbital phases when signatures of the components were unresolved. The sine-curve solutions based on DDO data are shown by dashed lines. Note that the present solutions give systematically smaller values of $K_2$. V1464 Aql is the only single-lined binary in this group of stars.
discovery result, $2P = 0.6216$ days. The star has $V_{\text{max}} = 9.9$ and a Tycho-2 color index $B - V = 0.313$; the latter agrees with the spectral type of F2 V (HDH).

Our spectroscopic observations do not have sufficient resolution to analyze apparent changes in the single-peaked, wide BF (Fig. 3). It is possible that the binary signature is masked by a relatively rapidly rotating companion with $V \sin i = 135 \pm 8$ km s$^{-1}$. The single peak in the BF has a velocity $V = -18.9 \pm 1.2$ km s$^{-1}$. However, a significant shift by 10 km s$^{-1}$ from the average was observed for the last of our four observations. The case for a complex blending of three components in this system is the weakest one among the three cases discussed here; the star may be in fact a pulsating one.

Fig. 3.—The first three panels show BFs for the multiple systems discussed in § 3, while the next five panels show the respective functions for RV variables of mostly unknown type, as discussed in § 4. Note that the strengths or intensities of the BFs have different vertical scales for different stars. This is because the BFs depend not only on the geometric (rotational) broadening but also on how well spectral types of the template and of the program star match. For a perfect fit, the integral of the BF should give unity. The $y$-axis units correspond to the BF sampling at 12.5 km s$^{-1}$ per point.

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3.2. CE Hyi

CE Hyi (HIP 7682, HD 10270) is another case suggested to be a contact binary by D97. Again, the orbital period suggested was $2P = 0.4408$ days.

The star is known as the visual double star WDS 01389-5835 (HU 1553), with an angular separation of 1$^\circ.9$ at a position angle of 10$^\circ$ and a small magnitude difference of only 0.24. Our three observations show very clearly that the spectrum is dominated by a slowly rotating companion, while the close, low-inclination contact binary is visible only in the base of the combined BF profile. Hipparcos and Tycho photometry of individual components shows that it is the fainter star (B) that is the photometric variable and thus the contact binary.
The comparable light contribution of both components to the combined spectrum is visible in the BF, where the sharp-lined star shows the peak with \( V \sin i \) that is immeasurably low, below the spectral resolution of our observations, while the contact binary light is distributed in the velocity domain within \( \pm 200 \text{ km s}^{-1} \) (Fig. 3). The RV of the slowly rotating companion is \( V_1^{3} = 9.00 \pm 0.33 \text{ km s}^{-1} \).

The observed \( V_{\text{max}} \approx 8.3 \) is for the combined light of both visual components. The Tycho-2 catalog gives \( V_A = 9.08, V_B = 9.29, \) and \( (B-V)_A = 0.333, (B-V)_B = 0.497 \), respectively. The SIMBAD database gives \( B - V = 0.49 \) and F5 V for CE Hyi. The spectral type is from HDH.

3.3. \textit{V1084 Sco}

V1084 Sco (HIP 86294, HD 159705) was suggested by D97 to be a contact binary with a period twice the \textit{Hipparcos} period, \( 2P = 0.3003 \) days. We have only three observations that show that the system is a complex one. It appears to be a quadruple system consisting of a detached binary giving two sharp peaks in the BF (see Fig. 3) and a slightly fainter contact binary responsible for the short-period photometric variability. The contact binary, because of the stronger line broadening, is just barely detectable at the base of the BF. The radial velocities of the sharp-line binary components (designated as “3” and “4” in Table 2) varied during the 3 days of observations between \( -19 \) and \( -31 \text{ km s}^{-1} \) for the stronger component and \( +77 \) and \( +83 \text{ km s}^{-1} \) for the fainter component. Thus, the detached binary must also be relatively compact, but our observations were insufficient to determine any parameters of the RV orbit. The star was included in the major RV survey of Nordstrom et al. (2004), where it appears with the average RV of \( +21.3 \text{ km s}^{-1} \).

This star is a very interesting object for further studies, particularly if the mutual period of revolution of the two binary stars turns out to be short enough to be observable within a reasonable time interval. The star is relatively bright, \( V_{\text{max}} = 9.0 \), while the color and the spectral type given in SIMBAD are late, \( B - V = 0.76 \) and G6 V (HDH). The Tycho-2 catalog is in agreement, with \( B - V = 0.73 \).

4. RADIAL VELOCITY VARIABLES OF UNKNOWN TYPE

4.1. \textit{V872 Ara}

This star, at that time identified as HIP 81650 (HD 149989), was suspected in D97 to be a contact binary with an orbital period of 0.8532 days. Very little can be said on the basis of its light variations, which are very small (0.02 mag). Three observations obtained here show a wide, rotationally broadened profile with the average \( V \sin i = 142 \pm 6 \text{ km s}^{-1} \). The mean velocity is constant at \( +42.1 \pm 2.4 \text{ km s}^{-1} \), but the variation between \( +37 \) and \( +45 \text{ km s}^{-1} \) is larger than the measurement error of about \( \pm 1.2 \text{ km s}^{-1} \), so some small variability may be present.

Our results are fully consistent with the recent study of de Cat et al. (2006), which explains the variability of V872 Ara by \( \gamma \) Dor–type pulsations with the originally suggested period of 0.42658 days. The measured value of \( V \sin i = 134 \pm 3 \text{ km s}^{-1} \) is consistent within the combined errors with our estimate. We refer the reader to the paper of de Cat et al. (2006) for more information on this star. The spectral type is A8/F0 V (HDH).

4.2. \textit{BD Cap}

BD Cap (HIP 99365, HD 191301) was suggested by D97 to be a contact binary with the period twice as long as the one given by the \textit{Hipparcos} project, \( 2P = 0.3204 \) days. Our three spectra show a very broad BF with \( V \sin i = 133 \pm 10 \text{ km s}^{-1} \). The mean velocity is practically constant at \( -9.7 \pm 1.0 \text{ km s}^{-1} \). We cannot say more about this star except we note that it was included in the catalog of suspected and confirmed \( \delta \) Scuti pulsating stars (Rodriguez et al. 2000), as well as in the survey of spatial velocities of nearby stars (Nordstrom et al. 2004). The spectral type is A9 III (HDH).

4.3. \textit{HIP 69300 (Anonymous Centauri Star)}

HIP 69300 (HD 123720) was another suggestion of D97 to be a contact binary. Our two observations substantially differ in RV of the star, \( -94.6 \) and \( -25.9 \text{ km s}^{-1} \), but the broadening profile has the same \( V \sin i = 116 \pm 7 \text{ km s}^{-1} \). The star does not have an entry in the General Catalog of Variable Stars,\(^5\) and no variable star name has been assigned to it yet, but it is definitely a RV variable. The spectral type is A4 V (HDH).

4.4. \textit{BX Ind}

BX Ind (HIP 108741, HD 208999), another candidate of D97, appears to be a slowly rotating star. Our seven observations all show a BF peak consistent with no rotation. Some small RV changes within \( -32 \) and \( -20 \text{ km s}^{-1} \) appear to be present, with a mean value \( -27.6 \pm 1.7 \text{ km s}^{-1} \). This is definitely not a close binary star. It is listed in the Catalog of \( \delta \) Scuti stars of Rodriguez et al. (2000). The spectral type is F2 V (HDH).

4.5. \textit{V388 Pav}

We have only two observations of V388 Pav (HIP 103803, HD 199434), another candidate of D97. The RV may be constant at the mean of \( +5.6 \pm 1.2 \text{ km s}^{-1} \), while the BF's indicate a mild broadening of \( V \sin i = 45 \pm 7 \text{ km s}^{-1} \). It is not a close binary star. It is listed in the Catalog of \( \delta \) Scuti stars of Rodriguez et al. (2000). The spectral type is F5 II (HDH).

5. SUMMARY

This program of RV measurements of known and suspected southern contact binary stars was performed to fill the growing disparity in the available RV data for northern and southern hemispheres. With only four successive nights, the program could not achieve the same goals as the current David Dunlap Observatory (DDO) survey. Still, some useful results have been obtained for 17 targets of the fall southern sky.

We have confirmed the suggestion of D97 that V1464 Aql, DE Oct, and BQ Phe are contact binaries and obtained the first preliminary orbital data for these systems; V1464 Aql is a single-lined binary, while the rest are double-lined systems. We obtained the first RV orbital data for the well-known southern systems V759 Cen and MW Pav. We confirmed the DDO results for the double-lined binaries EL Agr, SX Crv, VZ Lib, and GR Vir, but we noticed that in all these systems the secondary star semi-amplitude \( K_2 \) is a few percent smaller than observed at DDO, which may be a result of the lower spectral resolution.

Three systems could not be analyzed because of the presence of companions. In the case of CE Hyi, a visual companion had been known, but we see spectral signatures of a binary companion in V1084 Sco (so the system is a quadruple one) and suspect the presence of a companion in CL Cet. We are not able to say much about other variables suggested in D97 (V872 Ara, BD Cap, HIP 69300, BX Ind, and V388 Pav), but most appear to be pulsating stars and have been included in catalogs of such objects; we give their mean radial velocities and \( V \sin i \).

\(^5\) See http://www.sai.msu.su/groups/cluster/gcvs; the most recent electronic version is 4.2.
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