PHOTOMETRY AND SPECTROSCOPY OF THE VERY CLOSE EARLY TYPE BINARY SV CENTAURI[1]

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ABSTRACT

New high-quality observations of this unusual early type contact binary are presented. BVRI photometry of SV Cen provides a precise moment of minimum in March 1990. From high-resolution profiles of the He I line at 492.1 nm a new, improved set of orbital parameters was derived. Intrinsic line profile variability was not detected in either component and both photometry and spectroscopy. Low-noise spectra of the region around He II λ 468.6 nm showed no feature at any orbital phase, therefore, not giving a clue on the location of the source of a far-UV flux excess previously inferred from *IUE* observations. Since, for technical reasons, simultaneous EUV spectrophotometry with the *Voyager* spacecraft was lost, the temperature of this possible ultrahot spot could not be further constrained.

1. INTRODUCTION

SV Centauri (= HD 102552 = CoD $-$ 59°3950 = CPD $-$ 59°3809) is a close binary system consisting of two B-type components in a tight 1.66-day orbit, apparently undergoing a very rapid orbital evolution. The period change is very large, indicating a timescale for orbital evolution shorter than 10^5 yr, and shows superposed irregularities (Paczynski 1971; Rucinski 1976; Herczeg & Drechsel 1985). Synthesis solutions of the light curve—which is characterized by deep eclipses and very strongly curved maxima—suggest very deep contact (Rucinski 1976; Wilson & Starr 1976). In fact, SV Cen seems to be the contact system with the strongest known degree of overcontact. However, this may be misleading, as the *IUE* observations indicate the presence of a very hot (10^5 K) but small ($<1\%$ of the binary's projected area) source (Drechsel *et al.* 1982) for which there is no space in a normal contact model.

A more easily acceptable explanation of such a source could be found in a semidetached model as an impact-heated accretion region on the accreting star. This would then nicely agree with the tremendous mass transfer implied by the large period change (since the mass ratio is close to unity, it may be as high as a few times $10^{-4}\,\mathscr{M}_\odot$/yr). It could also explain the large difference in spectral type between the components (Drechsel *et al.* on the basis of colors guessed them to be B 1V and B 6.5III), in spite of their very similar masses. The system would then be a semidetached and very close one, caught in the short stage when the components are very near to each other, just before the reversal of the mass ratio. The massive accretion flow taking place between the components would simulate good thermal contact. Unfortunately, Drechsel *et al.* could not determine the location of the hot source. If it really were situated somewhere between the two stars, it should be eclipsed during both light minima.

There exist alternative explanations of the rapid period change in SV Cen: Drechsel *et al.* (1982), using the *IUE*, observed clear indications of wind condensations or circumbinary shells expanding radially from the system; they explain these ejections as related to the mass- and angular-momentum loss through the outer Lagrangian point L_2.

The present paper describes observations which have been made as the ground support part of a far-UV spectrophotometry program with the *Voyager* spacecraft in February 1990. That program explicitly aimed at obtaining phase coverage of the hot spot, and at detecting resonance lines from the circumstellar matter in the spectral region between 90 and 150 nm. However, for technical reasons, the whole one week-long data string was not captured by the Deep Space Network antennae. Subsequently, the two *Voyager* spacecrafts have been reoriented in such a way that SV Cen falls into the dead zones of both. In spite of this bad luck with the far-UV data, the observations in the optical range turned out to be interesting and useful in themselves.

The next section gives the new *BVRI* photometry of the system, which was meant as a check on timing of minima. Section 3 describes observations of the He line at 492.1 nm, which were used to improve the orbital parameters of the system. In the last section, the results are briefly summarized and discussed.

2. PHOTOMETRY

BVRI photometry of SV Cen was performed during several nights between 1990 March 23–April 3 with the 61 cm telescope of the University of Toronto at Las Campanas. A CCD system with a 512×512 pixel Ford chip was used in a differential photometry mode. SV Cen and the comparison star, HD 102503, were placed in opposite corners of the field. Three consecutive short (2–15 s) exposures each were obtained through the four Kron–Cousins filters. All frames were analyzed by extracting aperture data for SV Cen, the main comparison star, and a few control sources in the field.

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The data have an accuracy of about 0.01 mag, entirely adequate for the moment of minimum determination (for a recent, densely covered curve, see Kviz 1988). Since we were only interested in timing of minima, the instrumental magnitude differences, Δb, Δv, Δr, and Δi (listed in Table 1) have not been converted into standard colors in order to avoid interpolation in time. But if desired, the following transformation coefficients can be used: $\Delta(B-V) = 1.044 \times \Delta(b-v)$, $\Delta V = \Delta v + 0.138 \times (B-V)$, $\Delta(V-R) = 1.227 \times \Delta(v-r)$, $\Delta I = 1.086 \times \Delta i$. HD 102503 (B 3III: $V = 7.93$, $(B-V) = 0.06$ or 0.08) served as a comparison star for most of the previous photometric programs (Drechsel *et al.* 1982; Pfleiderer & Pfleiderer 1985; Kviz 1988), but its *UBV* data are somewhat discrepant, especially in the $(U-B)$ index; *R* and *I* magnitudes are entirely unavailable.

Since the observations, as listed in Table 1, were not numerous and frequent enough to determine moments of individual minima, we constructed a preliminary light curve using phases computed with the adopted period of 1.6585 days. Then, these instrumental, differential light curves in four colors (Fig. 1) were subjected to a minimum-finding routine, similar to that described by Matthews *et al.* (1991). The time of minimum obtained that way is

$$\mathrm{JD_{hel}}\,(\mathrm{pri}) = 2\,447\,973.2238 \pm 0.0008,$$

where the rms error results from independent determinations in each of the four colors and with widths of minima varied between ± 0.02 and ± 0.05 in phase. Because of the

TABLE 1. Instrumental differential magnitudes SV Cen—HD 102503.

JD (hel) −2 447 900	b	JD (hel) −2 447 900	v	JD (hel) −2 447 900	r	JD (hel) −2 447 900	i
73.5644	0.759	73.5610	0.781	73.5683	0.791	73.5731	0.825
73.6483	0.709	73.6432	0.734	73.6516	0.746	73.6544	0.776
73.7040	0.713	73.7001	0.732	73.7093	0.753	73.7127	0.778
73.8123	0.822	73.8094	0.837	73.8070	0.848	73.8016	0.859
73.8613	0.919	73.8585	0.915	73.8550	0.935	73.8518	0.941
74.5207	0.825	74.5177	0.821	74.5257	0.850	74.5294	0.867
74.5728	0.885	74.5615	0.874	74.5650	0.887	74.5687	0.894
74.6550	1.050	74.6517	1.033	74.6578	1.026	74.6613	0.985
75.5650	1.026	75.5618	1.020	75.5686	1.049	75.5710	1.067
75.6208	1.192	75.6172	1.188	75.6253	1.233	75.6146	1.200
75.6974	1.469	75.6944	1.475	75.7004	1.496	75.7030	1.520
75.7652	1.368	75.7621	1.386	75.7680	1.387	75.7705	1.389
75.8145	1.199	75.8114	1.232	75.8181	1.215	75.8204	1.243
75.8535	1.101	75.8510	1.111	75.8562	1.114	75.8585	1.131
76.5043	1.922	76.5016	1.870	76.5069	1.899	76.5094	1.891
76.5692	1.988	76.5661	1.972	76.5718	1.925	76.5742	1.906
76.6312	1.516	76.6287	1.521	76.6340	1.512	76.6363	1.499
76.6989	1.182	76.6965	1.193	76.7016	1.196	76.7039	1.198
76.7665	0.953	76.7637	0.985	76.7691	0.989	76.7717	0.994
76.8264	0.842	76.8239	0.859	76.8290	0.883	76.8317	0.889
76.8664	0.776	76.8639	0.797	76.8692	0.810	76.8716	0.839
77.5080	1.096	77.5056	1.117	77.5108	1.124	77.5130	1.139
77.5792	0.936	77.5759	0.950	77.5817	0.949	77.5841	0.982
77.6466	0.828	77.6440	0.850	77.6492	0.854	77.6516	0.879
77.7026	0.789	77.7001	0.803	77.7051	0.812	77.7076	0.826
77.7613	0.770	77.7589	0.783	77.7638	0.799	77.7663	0.824
77.8275	0.794	77.8250	0.804	77.8301	0.831	77.8324	0.840
77.8789	0.838	77.8763	0.851	77.8814	0.867	77.8836	0.891
78.5050	0.792	78.5026	0.789	78.5076	0.804	78.5099	0.831
78.8583	0.970	78.8559	0.964	78.8608	0.991	78.8631	1.017
79.6992	1.212	79.6966	1.204	79.7023	1.205	79.7056	1.237
79.7680	1.529	79.7650	1.482	79.7713	1.535	79.7737	1.576
81.5131	2.083	81.5107	2.023	81.5159	2.053	81.5182	2.006
81.5883	1.605	81.5859	1.633	81.5931	1.587	81.5955	1.566
83.7164	0.781	83.7140	0.746	83.7190	0.804	83.7212	0.830
84.6902	1.307	84.6877	1.280	84.6959	1.311	84.6990	1.330

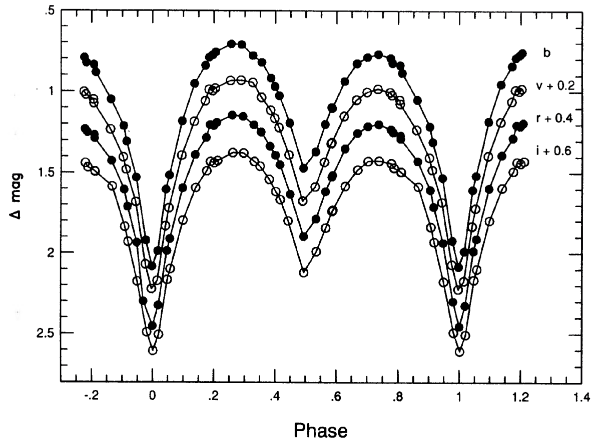

FIG. 1. The instrumental, differential light curves of SV Cen relative to HD 102503. Because the colors of both stars are very similar, the light curves have been shifted vertically, as indicated in the right margin of the figure.

grouping of filter observations and a noticeable asymmetry of the minima, this error may underestimate the actual uncertainty in the moment of the primary minimum. The moment of the secondary minimum derived in the same way is

$$\mathrm{JD}_{\mathrm{hel}}\,(\mathrm{sec}) = 2\,447\,972.3712 \pm 0.0010.$$

This corresponds to phase 0.486. The system of phases used for the analysis of the spectroscopic observations (next section) is based on the above determination.

As expected, the moment of the primary minimum is considerably different from predictions based on the existing ephemerides. As was shown by Herczeg & Drechsel (1985), the rate of the period change is not constant in SV Cen. The referee of this paper, Dr. H. Drechsel, very kindly provided a new ephemeris resulting from a combination of the Drechsel and Herczeg data with the new moment of the primary minimum

$$\mathrm{JD}_{\mathrm{hel}}\,(\mathrm{pri}) = 2\,443\,332.9756(18) + 1.658\,531\,8(45)E - 4.1(2)\times 10^{-8}E^2,$$

with the standard deviation of 0.0039 day. The numbers in parentheses represent the errors of coefficients expressed in units of least significant decimal places. It should be noted that the quadratic term corresponds to an *e*-folding time of the orbital period change of 55 000 yr.

The new light curve shows the same sense of the O'Connell effect as before (Drechsel *et al.* 1982), with the maximum after the deeper minimum being somewhat higher than the second maximum.

3. SPECTROSCOPY

Spectroscopic observations of SV Cen were made in five consecutive nights on 1990 March 21–25. The CAT 1.4 m telescope of the European Southern Observatory and the Coudé Echelle Spectrograph (CES) were used under remote control from ESO Headquarters in Garching. The so-called Short Camera gave a resolving power of about 6×10^4. A thinned, back illuminated RCA CCD with 1024 pixels along the dispersion direction served as the detector, giving a sampling rate of about 2 pixels per resolution element. Two 40 Å long spectral windows centered on He I 492.1 nm and He II 468.6 nm were observed alternately, for exposure times of 30–40 min each. The reduction followed standard procedures (debiasing, flatfielding, wavelength calibration, one-dimensional extraction) and was performed with IRAF. A few simultaneously obtained spectra of the very sharp-lined B2.5IV-star HR 4472 served as a check on the reduction procedures used with SV Cen. They were particularly important for removing the residual curvature of the flatfield divided He I spectra of SV Cen because around quadrature, the strongly rotationally broadened lines of the two stars filled a very major part of the observed spectral window (Fig. 2).

Among a total of about 50 spectra, 32 were of the He I λ 492.1 nm. They were used for a new determination of SV Cen's orbital parameters. Given the relative faintness of the star, the S/N of the spectra is rather satisfactory with values between 50 and 150 (per pixel). However, because of the rotational shallowness of the line profiles, it was impossible to extract the radial velocity information without further processing. We could not deconvolve the line shape for the broadening function using the profiles of the slowly rotating

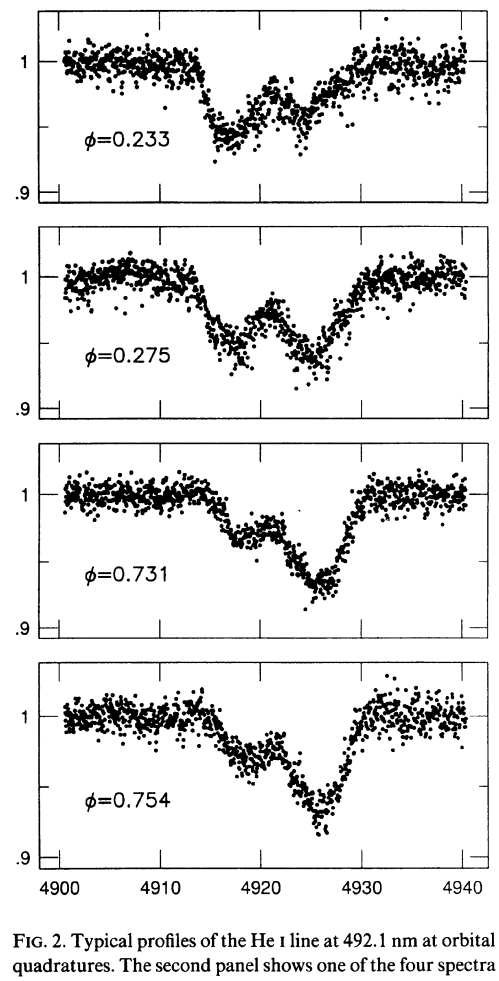

FIG. 2. Typical profiles of the He I line at 492.1 nm at orbital quadratures. The second panel shows one of the four spectra where the component produced by the more massive star (here seen shifted towards longer wavelengths) is abnormally strong (see Sec. 3). It is not clear whether this is a genuine effect, e.g., due to gas streams, or some deficiency of the reduction process.

star HR 4472 because of the presence of additional weak features on both sides of the main line. For that reason, all spectra were cross-correlated with a narrow Gaussian mimicking a narrow stellar-line profile using the program VCROSS of Hill (1982). The parameters of the Gaussian were chosen such as to yield a FWHM of 0.8 Å and a depth equal to 30% of the continuum. Figure 3 shows the computed correlation functions arranged by orbital phase for the velocity range -500 to $+500$ km/s. The radial velocities derived from them are compiled in Table 2.

The radial-velocity solution was obtained with the program RVORBIT (Hill 1991) using 25 spectra in which the lines of the stars were well separated. This number is significantly higher than for previous solutions, which are only based on 6 spectra (Irwin & Landolt 1972) and 14 spectra (Drechsel *et al.* 1982), respectively. This solution is presented graphically in Fig. 4 and, in tabular form, in Table 3. A circular solution with identical γ velocities for both stars was found to adequately represent the orbital velocities. (Separate solutions gave γ velocities offset by $+5.3$ km/s and -5.0 km/s from the average for the more and the less massive component, respectively.) In view of the uncertainty about the geometrical model of the system, no corrections for line shifts were applied, which in rotationally broadened lines might occur because of geometrical distortions and/or inhomogeneous surface brightness distributions. This simplification should be legitimate for early type stars where in

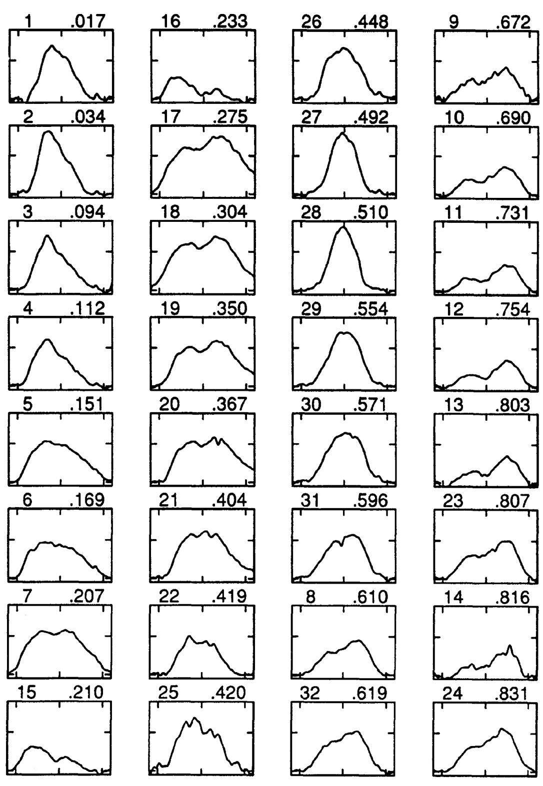

FIG. 3. Cross-correlations of the He I 492.1 nm line with a Gaussian mimicking a narrow stellar profile. The numbers give the spectrum number (Table 2) and the photometric phase. The plots are arranged by increasing phase. The ticks on the x axis are at -500, 0, and 500 km/s.

integral-light observations the relatively strong gravity darkening gives higher weight to the center of the stellar disk. In spite of the strong rotational broadening, the solution is quite well defined and the O − C residuals are relatively moderate (Table 2, Fig. 4).

The less massive, hotter star (No. 2 in the tables) consistently gave the stronger component of the line. The exception are four consecutive spectra (numbered 17–20; cf. Table 2 and Figs. 3 and 4) within the phase interval 0.275–0.45, where the line originating from the more massive component seemed to be stronger. Over this range of phases, the radial velocities of this star consistently deviated from the circular solution. We do not know whether this is a real effect (gas streams?) or rather an artifact of our reduction process. We present one of these spectra in the second panel of Fig. 2, together with three spectra which do not show any abnormal behavior of the line.

The radial-velocity curve solution is detailed in Table 3. It is compared there with the best existent solution of Drechsel *et al.* (1982). It should be kept in mind that our solution is based on only one line and that differences in amplitudes and γ-velocity values are not uncommon in early type stars. We found the radial-velocity amplitude of the more massive, cooler component (star No. 1, the "primary" here) somewhat smaller than before. This leads to a slightly larger mass disparity of the components; the mass ratio is 1.41. The systemic velocity γ is also somewhat less negative. Because of the reduction in the velocity amplitude of the primary star, the values of $\mathscr{M}_i \sin i$ are slightly smaller than determined by Drechsel *et al.* Irrespective of the actual geometry, the eclipses are so deep that the orbital inclination must be very close to $i \simeq 90°$, so that the values of $\mathscr{M}_i \sin i$ should well represent the actual masses.

It is perhaps appropriate to stress at this point that in spite of the reasonably good determination of the individual masses of components, we still know very little about the system of SV Cen. The spectral classification is apparently impossible for so broadened spectra so that we cannot say anything about consistency of masses and spectral types. Popper 1966 says about the spectral type: "B 8... very difficult"; Irwin & Landolt 1972, on the other hand, describe the spectrum as: "certainly earlier than B 5, and has been classified by Bond as B 3, which is in reasonable agreement with the color indices". The often quoted spectral types B 1V and B 6.5III were arrived at by Drechsel *et al.* (1982) on the basis of color indices only. The same uncertainty applies to the geometry of the system: the contact model (Rucinski 1976; Wilson & Starr 1976) relates sizes of stars to their masses in an obvious way: the hotter component, giving stronger lines (component No. 2), must be the smaller one. In the semidetached configuration, this component would also be smaller, but its size would not be identical to its Roche lobe dimensions. The more massive, cooler primary in both cases would have the diameter similar to or larger than its Roche lobe, i.e., about 5.9 $R_\odot$. This is well above the dimensions of a B 6.5 main sequence star (if this is indeed the correct spectral type of the primary), confirming its evolved state and lending credence to the scenario of the mass transfer from the primary to the secondary.

The observations of He II λ 468.6 were carried out in an attempt to constrain the location of the putative ultrahot spot (cf. Introduction). However, at no phase did the region observed around this line show any spectral feature, either in emission or in absorption. Because the line of sight is very

TABLE 2. Radial velocities for SV Cen.

No.	JD (hel) 2447900+	Phase	V_1 (km/s)	$(O-C)$	V_2 (km/s)	$(O-C)$
1	71.5933	0.017	*	*	*	*
2	71.6218	0.034	*	*	*	*
3	71.7210	0.094	73	−15	−178	−21
4	71.7500	0.112	92	−12	−189	−10
5	71.8157	0.151	138	3	−208	15
6	71.8449	0.169	146	0	−221	17
7	71.9089	0.207	137	−25	−248	14
8	72.6092	0.610	−138	8	180	6
9	72.6788	0.672	−151	23	223	9
10	72.7096	0.690	−212	−29	215	−11
11	72.7770	0.731	−202	−8	226	−16
12	72.8158	0.754	−175	20	235	-9
13	72.8965	0.803	−164	22	242	12
14	72.9183	0.816	−170	10	226	4
15	73.5712	0.210	114	−49	−280	−17
16	73.6102	0.233	158	−10	−302	−33
17	73.6799	0.275	199	33	−278	−10
18	73.7270	0.304	189	31	−235	21
19	73.8041	0.350	171	37	−211	10
20	73.8327	0.367	160	39	−200	4
21	73.8939	0.404	80	−10	−205	−46
22	73.9184	0.419	79	4	−185	−46
23	74.5614	0.807	−174	10	224	−4
24	74.6012	0.831	−165	8	197	−15
25	75.5781	0.420	131	56	−143	−5
26	75.6246	0.448	*	*	*	*
27	75.6981	0.492	*	*	*	*
28	75.6274	0.510	*	*	*	*
29	75.7997	0.554	*	*	*	*
30	75.8285	0.571	*	*	*	*
31	75.8696	0.596	−118	−2	144	12
32	75.9087	0.619	−148	−11	156	-6

* Not used in the orbital solution owing to blending.

close to the orbital plane, the possibility of obscuration effects limits interpretations of this null result.

4. SUMMARY

We have presented new photometry and spectroscopy of the close early-type binary SV Cen, which seems to be in an interesting and very active phase of its evolutionary mass exchange process. A new minimum time confirms the very rapid period change and yields an improved ephemeris for the moments of primary minima. The characteristic time of the period change is only of order 5.5×10^4 yr, so that a system like SV Cen should be very rare indeed.

The new photometric observations confirm the existence and sense of the O'Connell effect with higher maximum after the primary minimum. It should be noted that this was also the phase range where we found some peculiarities in the spectral line profiles, a coincidence which may shed some light on the subject of gas streams and mass accretion phenomena in the SV Cen system.

Formally, the new radial velocity solution which was obtained from high-resolution line profiles should be better defined than any of the previous determinations. On the other hand, it suffers from an uncertainty associated with being based on only one spectral line. The components of SV Cen appear to differ slightly more in mass than previously thought. Nevertheless, a discrepancy between photometric spectral types and spectroscopic masses remains.

Neither in the photometry nor in the spectroscopy do we find evidence of intrinsic variability, but our detection limits are not very strong, only 1%–2% of the continuum flux. Small photometric variability was previously seen by Pfei-

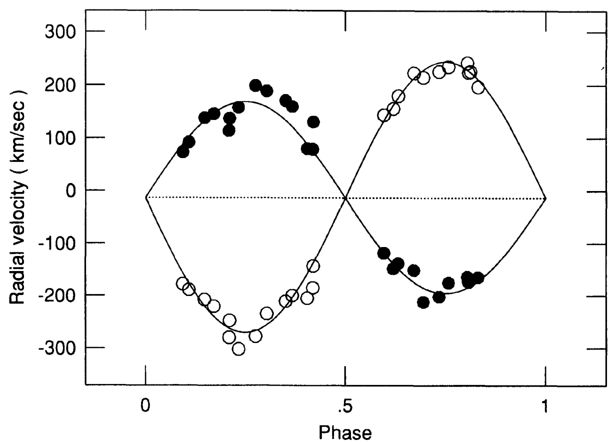

FIG. 4. Observed radial velocities and computed solution for SV Cen. Note the systematic deviation of velocities of the more massive component (filled circles) in four spectra between phases 0.275 and 0.45.

derer & Pfeiderer (1985) and Kviz (1988), but it was confined to the deepest parts of minima. This lack of obvious intrinsic variability is still worth pointing out because of the ubiquity of variability among B-type stars, which seems to peak around spectral type B 2 (Smith 1981; Smith & Penrod 1984; Baade 1987). On the other hand, Waelkens & Rufener (1984), who specifically searched for β Cephei stars in binaries, did not find evidence of any intrinsic variability among binaries with orbital periods less than about 4 days. Therefore, SV Cen might be another example of reduced pulsational activity in close binaries.

The primary goal of the original observing program had been to clarify the nature and location of a small but very hot UV source in the system. The UV Spectrometer onboard the *Voyager* spacecraft would have permitted observations at

TABLE 3. Radial velocity solution for SV Cen [compared with that of Drechsel *et al.* (1982)].

Parameter	Value	*rms* error	Drechsel *et al.*	*rms* error	unit
γ	-13.4	3.5	-27.7	6.3	km/s
K_1	182.1	4.9	205.2	7.1	km/s
K_2	257.4	5.8	255.6	7.3	km/s
rms_1 single obs.	24.6				km/s
rms_2 single obs.	19.0				km/s
$q = M_1/M_2$	1.414	0.049	1.25	0.05	
$M_1 \sin^3 i$	8.56	0.35	9.5		$M_\odot$
$M_2 \sin^3 i$	6.05	0.26	7.6		$M_\odot$
$a_1 \sin i$	5.97	0.16	6.8		$R_\odot$
$a_2 \sin i$	8.44	0.19	8.5		$R_\odot$

significantly shorter wavelengths than is possible with *IUE*, which had given the first hint of such a source. However, because the *Voyager* data were lost, improved limits on the temperature of such a source could not be derived. Since no EUV eclipses could be observed and no line emission due to He II 468.6 was detected at any orbital phase, the location of this hot spot remains entirely unconstrained.

In spite of the unfortunate fate of the observations with the Ultraviolet Spectrometer on board the *Voyager* spacecraft, we would like to thank the UVS team, Drs. Tim Carone, Jay Holberg, and Ron Polidan for their dedicated efforts to organize these observations. The cross-correlation analysis using RVCROSS was done by remote login to the computers of the Dominion Astrophysical Observatory, Victoria. We are indebted to Dr. Graham Hill for permission to use his programs. Special thanks are due to Dr. H. Drechsel who, acting as a referee, contributed very important comments and suggestions leading to improvement of the paper. The research of W. X. L., A. U., and S. M. R. was supported by an operating grant from the Natural Sciences and Engineering Research Council of Canada to S. M. R.

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