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ASTRONOMY AND ASTROPHYSICS

Spectroscopic Investigation of the Peculiar Binary V 389 Cyg

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Summary. 60 spectrograms have been obtained at the Hoher List Observatory for an investigation of the peculiar spectroscopic binary V 389 Cyg. The spectrum of the single-line binary shows enhanced Si II lines so that the star can be classified as a silicon B 9p star. The period found earlier by Young (1921) and Guthnick (1938) is improved to 3.313168 ± 0.000008 days. New orbital elements are derived. The unusually large scatter around the radial velocity curve can be attributed to a variable center-of-mass velocity resulting from a revolution about a third unseen component with the period of 154.09 ± 0.02 days. The elements of the long-period orbit are determined.

Additional peculiarities which seem to be present in Guthnick's spectroscopic data and which have been interpreted by him as δ Cephei-like variability have not been recognized in our data.

Key words: spectroscopic binary — triple system — Ap star

Introduction

The peculiar variable V 389 Cyg (HD 201433, $\alpha = 21^h\, 04^m\!.4$, $\delta = 29°48'$ (1900), B 9 V), component *A* of the visual quadruple system ADS 14682, has unique properties in several respects. First announced to have a variable radial velocity by Plaskett and Young (1919), Young (1921) found a periodic solution for the radial velocity changes. He concluded that the star was a spectroscopic binary and presented the first set of orbital elements. However, the scatter of the radial velocities about the computed radial velocity curve (RV curve) was much larger than expected from spectra of this quality. Since no spectroscopic explanation for this behaviour could be offered, a search for a photometric one seemed reasonable. In fact, a photoelectric investigation by Guthnick and Bottlinger (1922) revealed a variability of about 0.2 mag. However, spectroscopic and photometric studies by Guthnick (1938, 1939, 1942) could not explain the strange findings of Young, but revealed several additional puzzles:

1. The RV scatter had the same order of magnitude than that of Young's measurements. The period was slightly improved to $P = 3^d\!.3132$.

2. The light variations could be best represented by one of the two different periods $P_1 = 1^d\!.12912$ or $P_2 = 1^d\!.19328$, which obviously are not commensurable with the orbital period, but are interrelated by $1/P_1 - 1/P_2 = 1/21.0000$, as pointed out by Hoffleit (1977). The oscillations with the period P_1 had an amplitude of $0^m\!.19$, those with period P_2 $0^m\!.05$. Both oscillations were alternatively present in the observations, interrupted by periods of irregular variations or constant brightness. The most challenging fact, however, was that each of the two oscillations reappeared at the correct (unshifted) phase, as if it had not been interrupted at all. Therefore both oscillations could be described by the above periods and only two initial epochs.

3. Considering the residuals of the radial velocities from the mean RV curve, which had been obtained during the action of one of the photometric oscillations, a superposed RV oscillation with an amplitude of ± 8 km s^{-1} and period equal to the current photometric period, either P_1 or P_2, seemed to be present. Further, since the maximum of this secondary RV oscillation coincided nearly with the minimum light and vice versa, a δ Cephei-like behaviour was suggested.

Because of these strange properties of this most peculiar star, we found it worthwhile to gather new spectroscopic observations.

Observations and Reductions

The observations have been obtained with the Cassegrain spectrograph attached to the 106 cm telescope of the Hoher List Observatory. Between 1975 and 1977 a total of 60 spectrograms of V 389 Cyg at the reciprocal linear dispersion of 29 Å mm^{-1} were made. The spectra

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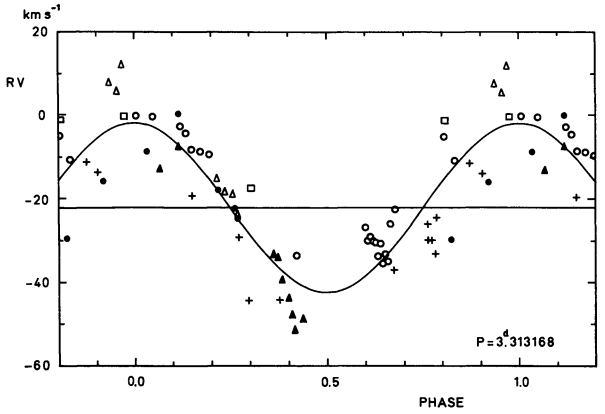

Fig. 1. RV curve of V 389 Cyg based on present observations
+ JD 2442672–728 △ JD 2443103–104
● JD 2442874–968 □ JD 2443123, 253, 258
▲ JD 2443067–068 ○ JD 2443410–426

Table 1. Lines in the spectrum of V 389 Cyg measured for radial velocity determinations

No.	Ion	Multipl.	λ_{Lab}(Å)
1	Mg II	4	4481.228
2	He I	14	4471.507
3	Hγ	1	4340.468
4	Si II	3	4130.893
5	Si II	3	4128.067
6	Hδ	1	4101.737
7	Ca II (K)	1	3933.664
8	H8	2	3889.051
9	Si II	1	3862.595
10	Si II	1	3856.017
11	Si II	1	3853.664

were exposed on Kodak IIa-O and widened to about 0.3 mm. The 3″.5 visual component ($\Delta m = 2^{m}.1$) was 2″.5 off the slit. For a better discrimination between the expected measuring error and intrinsic stellar RV variations it was important to take at least sometimes a larger number of plates per night. The RV system of the spectrograph was continuously controlled by observations of standard stars.

Before starting the measurements at the oscilloscope-type Abbe comparator of the Hoher List Observatory, we undertook a careful selection of suitable spectral lines. We found a useful set of 11 spectral lines listed in Table 1. With few exceptions this set was suitable for measurements in all spectra.

Results and Discussion

V 389 Cyg was classified by Cowley et al. (1969) as B 9 V. Indeed, our spectra show great similarity between V 389 Cyg and the MK B 9 standard α Del. But the stars differ in two respects: The lines of V 389 Cyg are considerably sharper and its Si II doublet at λλ 4128, 4131 and the triplet at λλ 3854, 3856, 3863 are enhanced. Both facts indicate a silicon Ap characteristic which, however, has to be confirmed by quantitative spectrophotometric measurements.

After a study of the individual spectral lines in each of the spectra we found that within the error no systematic deviations of single lines or groups of lines from the average over all lines were present. In particular, we could not find any statistically significant systematic deviations between the radial velocities derived from the Ca II K line, the Mg II λ 4481 line, the peculiar Si II lines and the other lines of a normal B 9-type spectrum.

Table 2. Radial velocities of V 389 Cyg

Plate	JD(Hel) -2400000	φ_1	RV	Internal error	φ_2	O-C
			km/s	km/s		km/s
C 3718	42672.3962	0.8719	-11.4	± 2.4	0.2251	- 1.0
C 3720	42672.4968	0.9022	-13.8	1.9	0.2258	- 5.9
C 3723	42673.3127	0.1485	-19.4	4.0	0.2311	- 7.1
C 3725	42675.3433	0.7614	-26.0	2.6	0.2443	- 3.1
C 3727	42675.4165	0.7835	-24.4	1.4	0.2447	- 4.3
C 3735	42678.3639	0.6731	-37.1	± 2.8	0.2639	- 3.5
C 3737	42680.3445	0.2709	-29.4	3.0	0.2767	- 2.5
C 3738	42685.3153	0.7712	-29.9	1.7	0.3090	- 8.3
C 3739	42687.3157	0.3749	-44.1	1.2	0.3220	- 5.6
C 3740	42690.3683	0.2963	-44.4	3.2	0.3418	-14.3
C 3751	42728.3514	0.7606	-29.9	± 1.7	0.5883	- 6.9
C 3752	42728.417	0.7804	-33.1	2.6	0.5887	-12.6
C 3836	42874.6458	0.9160	-16.1	1.8	0.5377	- 9.1
C 3844	42877.641	0.8200	-29.8	2.0	0.5571	-14.1
C 3855	42881.6476	0.0293	- 8.8	2.9	0.5831	- 4.2
C 3913	42898.4917	0.1133	0.0	± 4.2	0.6924	+ 9.1
C 4168	42968.4100	0.2164	-18.1	2.3	0.1462	2.0
C 4172	42968.5552	0.2603	-22.3	2.6	0.1471	3.3
C 4173	42968.5774	0.2670	-24.5	2.5	0.1473	1.9
C 4315	43067.3010	0.0643	-12.9	2.0	0.7880	- 7.1
C 4320	43067.4587	0.1119	- 7.5	± 2.0	0.7890	+ 1.5
C 4326	43068.2788	0.3594	-33.4	2.6	0.7943	3.6
C 4328	43068.3121	0.3695	-33.9	2.7	0.7945	4.1
C 4330	43068.3559	0.3827	-39.3	1.7	0.7948	- 0.1
C 4332	43068.4121	0.3996	-43.8	2.0	0.7952	- 3.3
C 4333	43068.4371	0.4072	-47.5	± 2.2	0.7953	- 6.4
C 4334	43068.4621	0.4147	-51.3	2.9	0.7955	- 9.7
C 4336	43068.5337	0.4364	-48.4	3.5	0.7960	- 5.6
C 4374	43103.3076	0.9320	+ 7.8	2.0	0.0216	+13.8
C 4376	43103.3736	0.9519	5.6	1.8	0.0221	10.7
C 4377	43103.4174	0.9652	12.0	± 2.1	0.0224	+16.7
C 4385	43104.2340	0.2116	-15.2	3.0	0.0277	4.3
C 4387	43104.3049	0.2330	-18.4	2.5	0.0281	3.8
C 4389	43104.3771	0.2548	-18.8	2.1	0.0286	6.1
C 4390	43104.4208	0.2680	-23.8	4.4	0.0289	2.8
C 4414	43123.3133	0.9702	- 0.3	± 2.3	0.1515	+ 4.3
C 4544	43253.6223	0.3009	-17.5	1.6	0.9971	13.1
C 4557	43258.6011	0.8036	- 1.3	3.9	0.0295	16.4
C 4608	43410.3216	0.5967	-26.8	2.1	0.0141	14.0
C 4609	43410.3653	0.6099	-29.2	2.9	0.0144	10.6
C 4610	43410.4084	0.6229	-30.6	± 2.8	0.0146	+ 8.1
C 4611	43410.4514	0.6359	-30.7	1.4	0.0149	6.8
C 4612	43410.4945	0.6489	-33.3	1.9	0.0152	2.9
C 4613	43410.5375	0.6619	-26.2	2.9	0.0155	8.7
C 4614	43410.5813	0.6751	-22.5	0.9	0.0158	10.9
C 4615	43414.3097	0.8005	- 5.3	± 1.9	0.0400	+12.7
C 4617	43414.4041	0.8289	-10.9	2.3	0.0406	3.8
C 4618	43418.2886	0.0014	- 0.3	1.9	0.0658	3.9
C 4619	43418.4317	0.0446	- 0.6	1.9	0.0667	4.4
C 4620	43420.2870	0.6046	-29.8	1.9	0.0787	10.4
C 4621	43420.3294	0.6174	-30.3	± 1.7	0.0790	+ 8.9
C 4622	43420.3718	0.6301	-33.8	1.6	0.0793	4.2
C 4623	43420.4141	0.6429	-35.5	2.2	0.0796	1.3
C 4624	43420.4565	0.6557	-35.1	3.6	0.0798	0.4
C 4626	43425.3021	0.1182	- 2.8	1.3	0.1113	6.7
C 4627	43425.3475	0.1319	- 4.6	± 3.1	0.1116	+ 6.1
C 4628	43425.3930	0.1457	- 8.5	1.8	0.1119	3.6
C 4629	43425.4708	0.1692	- 8.9	1.6	0.1124	5.6
C 4630	43425.5458	0.1918	- 9.6	2.4	0.1129	7.5
C 4636	43426.2985	0.4190	-33.7	2.0	0.1178	8.1

φ_1 are the phases of the 3.31 days orbit

φ_2 are the phases of the 154 days orbit

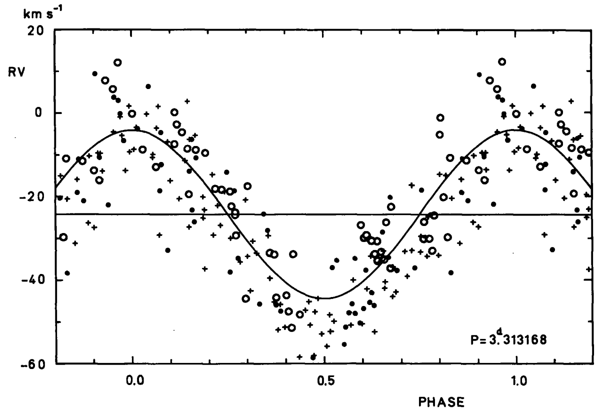

Fig. 2. RV curve of V 389 Cyg based on observations of Young (1921), Guthnick (1938, 1939, 1942) and this paper (● Young, + Guthnick, ○ this paper)

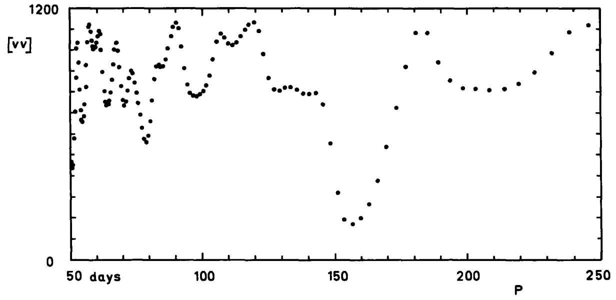

Fig. 3. Periodogram of the velocity residuals; $[vv]$ means the sum of the squared errors resulting from sine fits

Our measured radial velocities together with the internal errors are listed in columns 4 and 5 of Table 2.

By a search for periodic solutions, we confirmed the period found by Young (1921) and Guthnick (1938) and by combining Young's data with ours we improved it to 3.313168 ± 0.000008 days. With this period we derived new orbital elements, given in Table 3. The plot of our radial velocities and the computed RV curve based on the corresponding orbital elements are shown in Figure 1. The phases and $(O-C)$-values are listed in Table 2, columns 3 and 7. It is quite obvious that the overall scatter of our data about the mean curve is of the same order of magnitude as found earlier, namely $\sigma = \pm 7.6$ km s^{-1} (s.d.). For comparison see Table 3, last line, and the presentation of all published observations including the present ones in Figure 2.

Since our observations are fortunately grouped in more or less compact time intervals, the interpretation of these different groups may be reasonable: First we find that the scatter of the observations within each of these groups, which are distinguished by different symbols in Figure 1, is drastically reduced. At the same time some systematic effects may now be recognized. Both can best be seen in the group of observations between JD 2443410 and JD 2443426, which may be regarded as the most homogeneous one, since it contains a large number of observations distributed only over 16 nights but nicely over all phases (open circles in Fig. 1). Nearly all observations within this group have a positive excess from the mean RV curve, suggesting that the center-of-mass velocity (γ-velocity) may be variable on a longer time scale. Moreover, this homogeneous group of observations gives us an indication of what RV scatter may be expected, if we could remove the possible systematic effects. If we assume an excess γ-velocity of $+4.6$ km s^{-1} the standard deviation of the RV measurements is reduced to ± 3.6 km s^{-1}. This value is actually even smaller than that expected for measurements of a

Table 3. Orbital elements of V 389 Cyg (assumed $e=0$) with the period $P = 3^d.313168 \pm 0^d.000008$

Element		Young 1918–1921	Guthnick 1936–1940	GS 1975–1977	Young + GS
K	km s^{-1}	19.7	21.1	20.2	20.1 ± 1.2
γ	km s^{-1}	− 26.8	− 28.9	− 22.1	− 24.3 ± 0.8
T_0	JD(Hel)	22522.14	22522.14	42669.51	42669.51 ± 0.19
$f(m)$	$10^{-3} M_\odot$	2.63	3.23	2.83	2.79 ± 0.29
$a_1 \sin i$	10^5 km	8.98	9.61	9.20	9.16 ± 0.55
σ	km s^{-1}	± 9.3	± 7.2	± 7.6	± 8.7

Data from Young (1921)
Guthnick (1938, 1939, 1942)
GS, this paper, Table 2

B 9-type star at 29 Å mm^{-1}. We may further conclude that, at least during these last observations, possible superposed RV changes on a small time scale are not present.

These qualitative considerations encouraged us to look for a periodic representation of the supposed variable γ-velocity. For this we combined the residuals from the mean RV curve for all our measurements into 17 normal points according to time intervals not exceeding 7 days. After weighting these normal points on the basis of the number of single measurements contributing to them, we tried to represent them by a sine fit with variable period, yielding the periodogram shown in Figure 3. As can clearly seen from the figure the weighted normal points can be described by a period of about 156 days. In the next step we tried to find the period also in the observations of Young and Guthnick. Therefore weighted normal points for all observations were formed (Table 4). The attempt to represent these again by a sine fit yielded indeed a periodic solution improving the former period to $P = 154.09 \pm 0.02$ days. (This result, by the

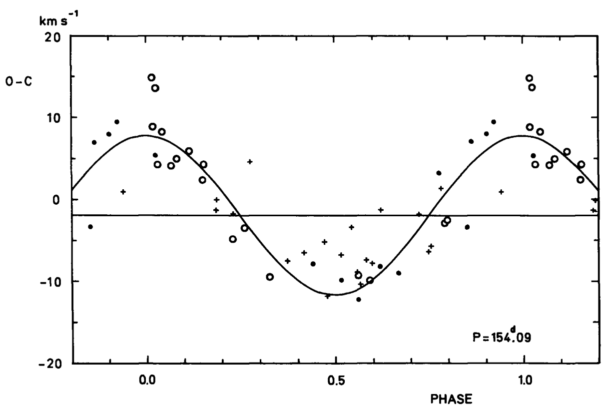

Fig. 4. RV curve of the long-period orbit of V 389 Cyg based on the normal points of the velocity residuals with weight equal or larger 1 (same symbols as in Fig. 2)

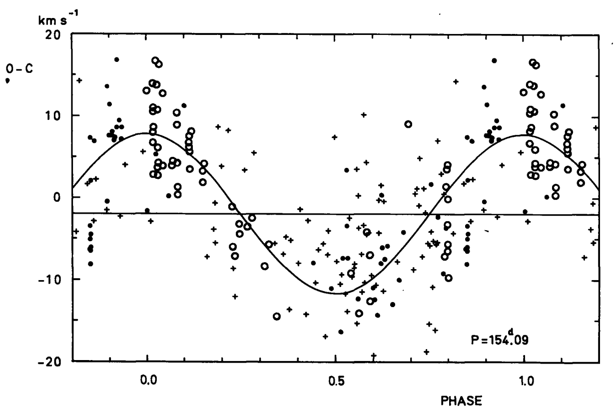

Fig. 5. RV curve of the long-period orbit of V 389 Cyg giving all individual velocity residuals (same symbols as in Fig. 2)

Table 5. Elements of the long-period orbit of V 389 Cyg (assumed $e=0$)

Element		Data from 1921/22 and 1975/77
P	days	154.09 ± 0.02
T_0	JD (Hel)	2442638 ± 11
K	km s^{-1}	9.7 ± 0.6
$\Delta\gamma$	km s^{-1}	−2.0 ± 0.5
$f(m)$	$10^{-3}\ M_\odot$	14.6 ± 2.0
$a_1 \sin i$	10^6 km	20.6 ± 1.3
σ	km s^{-1}	±3.0

Table 4. Normal points NP of the residuals of the short-period orbit of V 389 Cyg (isolated single measurements unweighted)

No.	JD(Hel) −2400000	φ	NP (km/s)	w
1	21763.96	0.5354	+ 3.4	-
2	21777.94	0.6261	- 8.0	-
3	21786.91	0.6843	-25.2	-
4	21836.79	0.0080	- 1.6	-
5	22153.90	0.0660	+ 0.2	-
6	22520.89	0.4476	- 7.8	1
7	22523.30	0.5217	- 9.8	3
8	22538.93	0.5647	-12.2	1
9	22547.99	0.6235	- 8.1	3
10	22555.47	0.6721	- 9.0	2
11	22572.29	0.7812	+ 3.3	2
12	22610.76	0.0309	+ 5.4	1
13	22891.85	0.8551	- 3.3	4
14	22893.72	0.8672	+ 7.0	1
15	22899.80	0.9067	+ 8.0	3
16	22903.06	0.9278	+ 9.5	3
17	28410.55	0.6698	- 7.7	-
18	28422.98	0.7505	- 6.4	2
19	28427.85	0.7821	+ 1.3	2
20	28433.41	0.8182	- 4.1	-
21	28441.34	0.8697	+ 2.4	-
22	28452.39	0.9414	+ 1.0	1
23	28798.39	0.1868	- 1.3	1
24	28805.43	0.2325	- 1.8	1
25	28812.36	0.2775	+ 4.6	1
26	28827.78	0.3776	- 7.5	2
27	28834.28	0.4197	- 6.5	2
28	28839.28	0.4522	-10.2	-
29	28853.60	0.5451	- 3.4	1
30	28859.75	0.5850	- 7.4	1
31	28865.72	0.6238	- 1.3	1
32	29151.89	0.4809	-11.8	1
33	29157.55	0.5177	- 6.7	2
34	29164.34	0.5617	- 8.8	2
35	29170.35	0.6007	- 7.8	2
36	29175.42	0.6336	- 0.3	-
37	29196.27	0.7690	-15.9	-
38	29205.26	0.8273	+14.4	-
39	29216.24	0.8985	- 1.4	-
40	29231.26	0.9960	+ 5.7	-
41	29234.32	0.0159	- 2.7	-
42	29473.66	0.5691	-10.4	2
43	29481.38	0.6192	- 0.2	-
44	29497.41	0.7233	- 1.8	2
45	29502.58	0.7568	- 5.7	2
46	29516.43	0.8467	+ 1.9	-
47	29877.35	0.1890	- 0.1	1
48	29884.31	0.2341	- 8.4	-
49	29901.30	0.3444	- 5.5	-
50	29921.27	0.4740	- 5.1	1
51	29935.25	0.5647	- 3.6	-
52	29945.29	0.6299	-11.3	-
53	29962.31	0.7403	+ 1.3	-
54	29981.25	0.8632	- 2.7	-
55	42672.74	0.2274	- 4.7	1
56	42677.37	0.2574	- 3.4	2
57	42687.67	0.3243	- 9.4	1
58	42728.38	0.5885	- 9.8	1
59	42877.98	0.5593	- 9.1	1
60	42898.49	0.6924	+ 9.1	-
61	42968.51	0.1468	+ 2.4	1
62	43067.38	0.7885	- 2.8	1
63	43068.40	0.7951	- 2.5	3
64	43103.36	0.0220	+13.7	1
65	43104.33	0.0283	+ 4.3	2
66	43123.31	0.1514	+ 4.3	1
67	43256.11	0.0133	+14.8	1
68	43410.45	0.0149	+ 8.9	3
69	43414.36	0.0403	+ 8.3	1
70	43418.36	0.0662	+ 4.2	1
71	43420.37	0.0793	+ 5.0	2
72	43425.41	0.1120	+ 5.9	2
73	43426.30	0.1178	+ 8.1	-

way, nicely confirms a recent note by Bolton (1977), who suspected that a longer period of the order of 150 days or 110 days or 270 days may be present in his yet unpublished spectroscopic observations between 1971 and 1974).

Concluding that we have detected the orbital motion of the spectroscopic binary V 389 Cyg around an unseen third companion, we determined the elements of this larger system as listed in Table 5. The mean RV curve based on these elements together with the normal points of all residuals are shown in Figure 4, the phases are listed in Table 4. Due to the scatter of the observations about the mean curve we did not find it reasonable to try solution for $e \neq 0$.

For a discussion of the true second order residuals we have plotted in Figure 5 *all* the residuals of the observations of Young, Guthnick and the present paper. The scatter of our residuals (open circles) about the mean curve proves to be ± 5.4 km s^{-1}. Because this is only a little bit larger than that to be expected from the mean internal error of our measurements of ± 2.3 km s^{-1}, namely two times this value, a third order variability of the radial velocities cannot be established. Assuming a similar internal error to be present in the measurements of Young, the scatter of his residuals (filled circles) about the mean curve is also not considerably larger than normal. On the other hand, the scatter of the residuals of the observations of Guthnick (crosses), which are distributed more or less uniformely over the quite long time interval between 1936 and 1940 is probably too large. Therefore, the existence of a third companion alone may not yet be a sufficient explanation. Thus we have to search for an additional physical effect, which is able to explain these superposed "activities" (if real!) appearing in Guthnick's observations. For this we refer to the conclusions of Guthnick himself, who found a certain correlation between small amplitude RV changes and one of the short-period photometric oscillations, which is in action in that very moment—suggesting a kind of δ-Cephei behaviour. Since these pecularities seem not to be present in our new measurements, we are not able to confirm or to disprove this finding. Because of the complete absence of any superposed short-period RV changes in our observations between JD 2443410 and JD 2443426, we can only say that the occurence of these pecularities must be strongly time dependent.

Without being able to support the idea by our observations, we alternatively would like to point out another possible interpretation of Guthnick's results, namely that at least part of the photometric and spectroscopic pecularities may be due to the Ap nature of the main component of V 389 Cyg, which was completely unsuspected at the time of Guthnick.

Conclusions

In combination with previous observations of Young (1921) and Guthnick (1938, 1939, 1942) our new spectroscopic observations of V 389 Cyg revealed this object to be a triple system consisting of a single-line spectroscopic binary with an orbital period of 3.313168 days revolving in 154.09 days about a third unseen component. Assuming the visual multiple system ADS 14682 to be real, our result would make them a sixtuple system. In the observations of Guthnick additional superposed RV variations may be present. Because of the absence of these anomalies in our observations, we cannot explain his results. Therefore we only can refer to Guthnick who proposed (for possibly both components of the spectroscopic binary) short-period pulsational instabilities. Alternatively, we suggested that some observed pecularities may also be due to the Ap star nature of the main component of the system. Since actually 4 stars (the above discussed triple system and the 3″.5 distant visual component) are contributing to the brightness of V 389 Cyg, we finally like to recommend further investigators to be very careful with the interpretation of its photometric behaviour.

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