Astron. & Astrophys. 37, 179–182 (1974)

Research Note

Definitive Orbital Elements and Apparent Metal Deficiency for the Spectroscopic Binary 16 Piscium

Giusa Cayrel de Strobel
Département d'Astrophysique Fondamentale, Observatoire de Paris-Meudon

M. Fracassini and L. E. Pasinetti
Osservatorio Astronomico di Milano-Merate

Received September 2, 1974

Summary. A new set of preliminary and definitive orbital elements has been computed for the spectroscopic binary 16 Piscium (HD 221950) recently discovered by Cayrel de Strobel (1968). Some other twenty six spectra have been added to the thirteen ones formerly adopted by Cayrel de Strobel, in calculating the preliminary orbital elements of this star.

Key words: spectroscopic binary

The spectroscopic binary 16 Piscium (HR 8954, HD 221950) was discovered by Cayrel de Strobel (1968) at the coudé focus of the 193 cm telescope of Haute Provence Observatory on the occasion of a research program for chemical abundance determination of F stars.

By means of thirteen spectra, taken in the years 1967–1968 at the coudé spectrograph of the 193 cm telescope (reciprocal dispersion 9.7 Å/mm) of the Haute Provence Observatory, preliminary set of orbital elements were obtained.

In the present work twenty six spectra taken in the years 1968–1970 at the Haute Provence Observatory have been added. Fourteen taken with the coudé spectrograph of the 193 cm telescope (reciprocal dispersion 9.7 Å/mm) and twelve taken with the coudé spectrograph of the 152 cm telescope (reciprocal dispersion 12.4 Å/mm). Of these spectra the fourteen 9.7 Å/mm spectra were measured by Cayrel de Strobel with a Zeiss comparator, the twelve 12.4 Å/mm spectra by Fracassini and Pasinetti with the Koristka comparator of Merate Observatory. In addition, eleven spectra among those measured by Cayrel de Strobel have been remeasured by Fracassini and Pasinetti. The twenty six new spectra have been measured by eye-estimate in the same way as used in the paper of Cayrel de Strobel (1968).

In Table 1, we have listed all the observational data and the derived radial velocities (from 1967 to 1970) for 16 Piscium.

Looking at the values of the radial velocities and of the respective probable errors one can ascertain that:
1) all the measures may be considered of equal accuracy;
2) no systematic correction seems to be necessary for the two spectrographs employed. This fact is more evident in Fig. 1 where we have plotted all the observed radial velocities referred to the same phase (the origin of the phases is T_0, the time of periastron passage).

By means of the graphical method of Lehmann-Filhès we have derived the set of preliminary elements, independently for each component, averaged for the common elements, reported in Table 2.

For the computation of the period we have adopted the method proposed by Lafler and Kinman (1965) adapted to the Univac 1106 computer of the University of Milano. The value of P reported here is the average of the values $P_{\rm I} = 45\overset{d}{.}42$ and $P_{\rm II} = 45\overset{d}{.}48$ obtained independently for each component.

Finally, using the method of Lehmann-Filhès (1894) for the differential corrections of the elements, adapted to the Univac 1106 computer of the University of Milano, we have obtained by successive iterations the three sets of orbital elements (averaged from the results obtained independently from each component) reported in Table 2. An inspection of the row of the sums of the squared residuals $[rr]$ deduced from each differential system shows that the 2nd iteration represents the best fitting. Therefore, we have assumed this set of orbital elements as the definitive one. If one compares the preliminary results of Cayrel de Strobel (1968) to the pre-

Table 1. Radial velocities for the two components of 16 Piscium

1 Plate	2 Date	3 J.D.	4 Phase	5 R.V. (*I*)-p.e.	6 R.V. (*II*)-p.e.	7 r. to the Sun	8 N. of lines
W 3918	15–10–'67	2439779.4347	0.0425	+15.49±2.62	+85.45±3.50	−14.02	12
W 3933	16–10–'67	780.4208	0.0642	9.21 4.38	94.53 5.39	−14.45	25
W 3944	17–10–'67	781.3403	0.0844	7.92 5.23	97.62 6.11	−14.70	7
W 3945	17–10–'67	781.4208	0.0862	3.61 5.65	91.07 6.58	−14.51	9
W 3949	18–10–'67	782.4132	0.1080	4.25 2.40	89.90 5.61	−15.34	26
W 3957	19–10–'67	783.5306	0.1326	18.16 3.50	93.85 7.03	−16.05	28
W 3965	20–10–'67	784.3854	0.1514	10.65 3.70	91.63 4.98	−16.17	28
W 3976	21–10–'67	785.5382	0.1768	15.00 3.77	87.32 5.69	−16.95	9
W 3986	26–10–'67	790.3297	0.2822	27.01 2.60	72.86 3.33	−18.60	27
W 4045	20–12–'67	845.3611	1.4929	48.08 2.91	48.08 2.91	−30.37	20
W 4054	8– 1–'68	864.2694	1.9089	77.41 2.46	18.43 2.55	−28.06	12
W 4056	9– 1–'68	865.2597	1.9307	66.31 5.27	24.08 4.03	−27.85	19
W 4096	18– 1–'68	874.2778	2.1290	9.16 3.25	92.41 4.90	−25.66	27
W 4552	29–10–'68	2440159.2875	8.3993	49.43 4.58	49.43 4.58	−20.01	58
W 4555	30–10–'68	160.2993	8.4215	46.44 2.75	46.44 2.75	−20.43	37
W 4565	5–11–'68	166.2549	8.5525	62.75 4.49	32.71 5.42	−22.54	17
W 4582	6–11–'68	167.2660	8.5748	62.24 7.68	32.36 7.68	−22.91	36
W 4605	7–11–'68	168.2674	8.5968	65.80 3.46	27.64 4.50	−23.27	24
W 4611	9–11–'68	170.4743	8.6454	72.68 4.07	22.47 4.60	−24.37	26
W 4624	11–11–'68	172.3903	8.6875	77.34 5.10	18.99 4.45	−24.81	40
W 4640	12–11–'68	173.2847	8.7072	80.69 5.80	17.89 4.86	−24.88	43
W 4919	19– 8–'69	453.4708	14.8713	84.90 3.49	15.42 2.89	+13.68	39
W 4923	20– 8–'69	454.6194	14.8966	79.79 3.91	23.44 5.79	+12.87	34
W 4925	21– 8–'69	455.5847	14.9178	78.62 4.74	21.87 4.30	+12.50	39
W 4928	22– 8–'69	456.6014	14.9402	65.03 2.91	28.47 3.33	+12.00	28
W 4930	24– 8–'69	457.5472	14.9610	49.55 2.22	49.55 2.22	+11.68	40
W 4932	25– 8–'69	458.5521	14.9831	47.35 2.88	47.35 2.88	+11.21	34
W 3957	20–10–'67	2439783.5306	0.1326	+10.08±4.69	95.25±6.51	−16.05	24
W 3965	20–10–'67	784.3854	0.1514	10.61 5.04	93.27 5.87	−16.17	20
W 3986	26–10–'67	790.3299	0.2822	26.67 3.44	76.62 2.96	−18.60	21
W 4096	18– 1–'68	874.2778	2.1290	2.65 5.06	90.63 6.10	−25.66	17
W 4624	11–11–'68	2440172.3903	8.6875	75.75 4.40	14.70 4.05	−24.81	17
W 4919	19– 8–'69	453.4708	14.8713	82.52 3.86	10.77 4.50	+13.68	16
W 4923	21– 8–'69	454.6194	14.8966	83.21 3.60	19.52 2.82	+12.87	17
W 4925	22– 8–'69	455.5847	14.9178	75.46 3.73	21.90 5.47	+12.50	16
W 4928	23– 8–'69	456.6014	14.9402	68.04 4.39	33.09 5.42	+12.00	17
W 4930	24– 8–'69	457.5473	14.9610	59.90 8.70	41.73 7.62	+11.68	17–9
W 4932	25– 8–'69	458.5521	14.9831	49.31 3.52	49.31 3.52	+11.21	17
W 5272	20– 9–'70	850.4341	23.6045	69.75 3.70	29.13 4.52	− 2.59	16
GB 399	21– 9–'70	851.3084	23.6237	68.95 4.62	25.77 5.37	− 2.15	17
GB 400	21– 9–'70	851.3333	23.6243	72.58 4.16	29.20 4.98	− 2.14	17
GB 401	22– 9–'70	851.5375	23.6288	73.41 5.42	26.32 5.47	− 2.03	17
GB 402	22– 9–'70	851.5598	23.6293	75.56 4.87	25.56 5.07	− 2.02	17
GB 405	22– 9–'70	852.4195	23.6482	73.66 5.23	24.01 5.71	− 3.58	17
GB 406	23– 9–'70	853.4250	23.6703	77.57 3.77	21.18 4.50	− 3.07	16
GB 407	25– 9–'70	854.5639	23.6953	79.51 7.95	23.78 4.35	− 3.50	15
GB 408	25– 9–'70	855.4764	23.7154	79.34 3.90	16.75 4.83	− 3.98	17
GB 409	26– 9–'70	856.3111	23.7338	81.45 6.02	16.55 6.19	− 4.39	17
GB 410	27– 9–'70	856.5577	23.7392	84.16 5.71	17.05 4.57	− 4.51	17
GB 632	15–11–'70	906.3007	24.8336	86.15 5.76	10.14 4.20	−26.84	17

Explication of the columns: 1 Plate number; 2 date; 3 Julian day; 4 phase referred to $T_0 = 2439777.5031$; 5 radial velocity and probable error for the Component I; 6 radial velocity and probable error for the Component II; 7 reduction to the Sun; 8 number of measured lines in the plate.
Upper group of measures, W 3918 – W 4932: made by Cayrel de Strobel.
Lower group of measures, W 3957 – GB 632: made by Fracassini and Pasinetti.

sent definitive results (Table 2, Column 3) one finds satisfactory agreement, taking into account the fact that the 1968 results were based on only two observing runs, four months apart from each other.

One can remark that the probable errors of T_0 and P are considerable. In Fig. 1 we can also notice that the computed curve of radial velocity (dotted curve) of Component II (diffuse spectral lines) deviates systema-

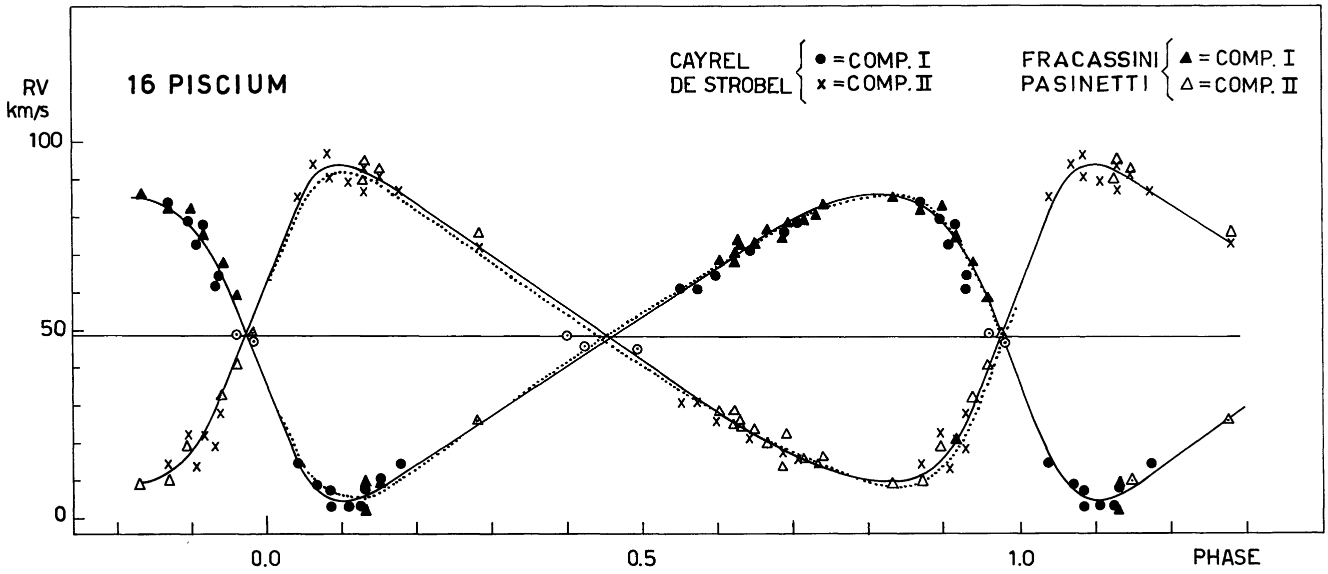

Fig. 1. Radial velocity for the two components of the binary system 16 Piscium. ●, ×, measures by Cayrel de Strobel for Companions I and II; ▲, △, measures by Fracassini and Pasinetti for Companions I and II; ——— curves drawn by hand for the computation of preliminary elements; ········· curves computed from definitive elements

Table 2

Preliminary elements	1st Iteration	2nd Iteration p.e.	3rd Iteration
$T_0 = $ J.D. 2439777.5031	777.512	777.367 $\pm$ 0.295	777.392
$P = 45.45$ days	45.456	45.461 $\pm$ 0.014	45.459
$\gamma = 48.4$ km/s	48.43	48.43 $\pm$ 0.38	48.43
$K_{\mathrm{I}} = 40.3$ km/s	39.95	40.10 $\pm$ 0.53	40.10
$K_{\mathrm{II}} = 42.0$ km/s	41.66	41.52 $\pm$ 0.52	41.62
$e = 0.37$	0.372	0.370 $\pm$ 0.015	0.372
$\omega_{\mathrm{I}} = 103^\circ$	$103\overset{\circ}{.}00$	$103\overset{\circ}{.}00$ $\pm$ 0.05	$102\overset{\circ}{.}98$
$\omega_{\mathrm{II}} = 283^\circ$	$283\overset{\circ}{.}12$	$283\overset{\circ}{.}23$ $\pm$ 0.04	$283\overset{\circ}{.}33$
$a_{\mathrm{I}} \sin i = 23.29 \times 10^6$ km $= 0.156$ AU	—	$23.29 \times 10^6 = 0.156$ AU	—
$a_{\mathrm{II}} \sin i = 24.50 \times 10^6$ km $= 0.164$ AU	—	$24.11 \times 10^6 = 0.162$ AU	—
$m_{\mathrm{I}}/m_{\mathrm{II}} = 1.04$	—	1.035	—
$(m_{\mathrm{I}} + m_{\mathrm{II}}) \sin^3 i = 3.57\, M_\odot$	—	$3.49\, M_\odot$	—
$[rr]$	339.21	336.86	338.62

Preliminary and definitive orbital elements for the spectroscopic binary HD 221950 (16 Piscium): First column, preliminary elements; second column, first correction to the elements by least squares solution of the differential correction system; third column, second correction (definitive elements) and probable errors; fourth column, third correction; last row, sum of squared residuals for the differential system.

tically from the observed curve (solid curve drawn by hand) at the maximum and minimum. This fact seems to indicate that some peculiar phenomena could have distorted the "normal" curve of 16 Piscium. In our opinion, these peculiar phenomena could be similar to those observed by Struve (1944) in the eclipsing binary system SX Cassiopeiae A6III–G6III, $P = 36\overset{\mathrm{d}}{.}6$; (streams of gas) and by Popper (1964) in the eclipsing binary system KU Cyg F4p–K5III, $P = 38\overset{\mathrm{d}}{.}4$; (gaseous ring).

Unfortunately, 16 Piscium is not an eclipsing binary system; nevertheless, we have attempted to point out these peculiar phenomena comparing the distribution of the radial velocities of the hydrogen lines H_β, H_γ, H_δ, with the curves of radial velocities computed from the Fe lines (definitive orbital elements). In Fig. 2, in spite of random scattering, the systematic and large scattering of the open circles (H_β line) from the computed curves is fairly evident.

As is well known (Popper, 1964), the extended envelopes about one or both components of a binary system produce departures from the Keplerian velocity curves which causes the range of the observed velocities to be greater than the range of the true orbital velocities. In particular, this effect is evident in the H_β line around both conjunctions. Further, from Fig. 2, one can see that the departures of the H_β velocities are symmetric with respect to the velocity γ of the system. This fact seems to indicate that the peculiar phenomena (streams of gas or gaseous ring) are associated with one or both components (Popper, 1964; p. 163). Hence, if our interpretation of these peculiarities of the system 16 Piscium is correct and not produced by improperly

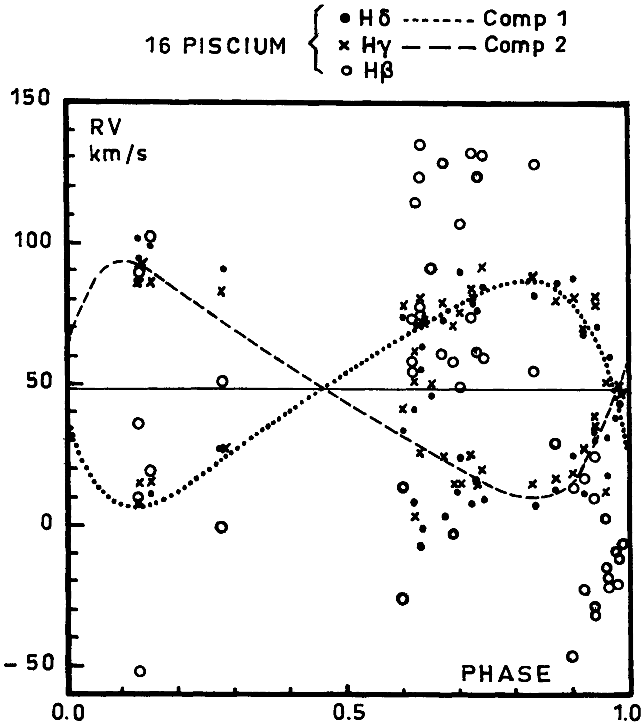

Fig. 2. Radial velocity curves of the binary system 16 Piscium. ...... Companion I from definitive orbital elements (Fe lines); --- Companion II from definitive orbital elements (Fe lines); ○, radial velocities measured from hydrogen line H_β; ×, radial velocities measured from hydrogen line H_γ; ●, radial velocities measured from hydrogen line H_δ

resolved hydrogen lines, these phenomena according to Struve, lower the meaning of the differential corrections of preliminary elements.

Cayrel de Strobel (1968) has pointed out that the position of 16 Piscium in Strömgren's diagram, m_1 versus $b-y$, shows a metal deficiency with regard to the Hyades. This fact could indicate that the material of which the system were formed had a different metal content from that of the Sun.

Alternatively, as it is now clear that the star is a binary, it could be the result of a contribution of gaseous streams (Struve, 1944; Popper, 1964) between the two components to the u color. Indeed the two components of 16 Piscium, having the same mass, and apparently similar brightness, should have similar normal colors.

Further observations will help in deciding if 16 Piscium is actually metal poor star or if the m_1 anomaly is more likely explainable by an additional gaseous ultra-violet emission.

Acknowledgements. Dr. Fiamma Arienti for her kind and intelligent help in the programmation of the routine of differential corrections for the 1106 Univac computer of the University of Milano.
The referees for useful advices.

References

Cayrel de Strobel, G. 1968, *Astrophys. Letter* **1**, 173
Lafler, J., Kinman, T. D. 1965, *Astrophys. J. Suppl.* **100**, 216
Lehmann-Filhès, R. 1894, *Astron. Nachrichten* **136**, 17
Popper, D. M. 1964, *Astrophys. J.* **139**, 143
Struve, O. 1944, *Astrophys. J.* **99**, 89

G. Cayrel de Strobel
Dèpartement d'Astrophysique Fondamentale
Observatoire de Paris-Meudon
F-92190 Meudon, France

M. Fracassini
L. E. Pasinetti
Osservatorio Astronomico di Milano-Merate
Via Brera N. 28
I-20121 Milano, Italia